TRANSACTIONS

OF THE

Institution of Engineers and Shipbuilders

IN SCOTLAND

(INCORPORATED).

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FORTY-NINTH SESSION, 1905-1906.

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1857-59 WILLIAM JOHN MACQUORN RANKINE, C.E., LL.D., F.R.SS.L. & E., Professor of Civil Engineering and Mechanics, Glasgow University.

1859-61 WALTER MONTGOMERIE NEILSON, Hyde Park Locomotive Works, Glasgow.

1861-63 WILLIAM JOHNSTONE, C.E., Resident Engineer, Glasgow South-Western Railway, Glasgow.

1863-65 JAMES ROBERT NAPIER, Engineer and Shipbuilder, Glasgow.

1865-67 JAMES GRAY LAWRIE, Engineer and Shipbuilder, Glasgow.

1867-69 JAMES MORRIS GALE, C.E., Engineer, Glasgow Corporation Water Works.

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1870-72 DAVID ROWAN, Marine Engineer, Glasgow.

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1889-91 EBENEZER KEMP, Marine Engineer, Glasgow.

1891-93 ROBERT DUNDAS, C.E., Resident Engineer, Southern Division, Caledonian Railway, Glasgow.

1893-95 JOHN INGLIS, LL.D., Engineer and Shipbuilder, Glasgow.

1895-97 SIR WILLIAM ARROL, LL.D., M.P., Engineer and Bridge Builder, Glasgow.

1897-99 GEORGE RUSSELL, Mechanical Engineer, Motherwell.

1899-01 ROBERT CAIRD, LL.D., F.R.S.E., Shipbuilder, Greenock.

1901-03 WILLIAM FOULIS, Engineer, Glasgow Corporation Gas Works.

1902-04 ARCHIBALD DENNY, Shipbuilder, Dumbarton.

Elected
2nd May, 1905, JAMES GILCHRIST, Marine Engineer, Glasgow.

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PAPERS READ.

Errata.

Page 376, line 13 from top, *for* advantages *read* disadvantages.

Page 388, line 9 from foot, *instead of* when he (Mr Goodrich) said that "one should not make little of the bridge that carried one over," *read* when he (Mr Goodrich) quoted Mr Jones to the effect that "one should not make, etc.

PLATES.

PREMIUMS AWARDED

FOR

PAPERS READ DURING SESSION 1904-1905.

PREMIUMS OF BOOKS.

1 —To Dr. J. BRUHN, for his paper on "Methods of Estimating the Strength of Ships."

2.—To Mr A. MELENCOVICH, for his paper on "Multiple Steam Turbines."

ADVERTISEMENT.

The responsibility of the statements and opinions given in the following Papers and Discussions rests with the individual authors; the Institution, as a body, merely places them on record.

MEMORANDUM OF ASSOCIATION

OF THE

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

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1. The Name of the Association is "THE INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND."

2. The Registered Office of the Association will be situate in Scotland.

3 The Objects for which the Association is established are :—

(1.) The Incorporation of the present Institution of Engineers and Shipbuilders in Scotland, under the 30th and 31st Victoria, cap. cxxxi., and

(2.) To facilitate the exchange of information and ideas amongst its Members, to place on record the results of experience elicited in discussion, and to promote the advancement of science and practice in Engineering and Shipbuilding.

(3.) The doing all such other lawful things as are incidental or conducive to the attainments of the above objects.

4. The Income and Property of the Association, whencesoever derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly by way of dividend, bonus, or otherwise howsoever, by way of profit, to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them.

Provided that nothing herein shall prevent the payment in good faith of remuneration to any Officers or Servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association.

5. The fourth paragraph of this Memorandum is a condition on which a Licence is granted by the Board of Trade to the Association, in pursuance of Section 23 of the "Companies Act, 1867." For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which may be duly observed by the Association.

6. If the Association acts in contravention of the fourth paragraph of this Memorandum, or of any such further Conditions, the liability of every Member of the Council of the Association, and also of every Member who has received any such dividend, bonus, or other profit as aforesaid, shall be unlimited.

7. Every Member of the Association undertakes to contribute to the Assets of the Association – in the event of the same being wound up during the time that he is a Member, or within one year afterwards, for payment of the Debts and Liabilities of the Association, contracted before the time at which he ceases to be a Member, and of the Costs, Charges, and Expenses of winding up the same, and for the adjustment of the rights of the Contributaries among themselves—such amount as may be required, not exceeding Ten Pounds, or, in case of his liability becoming unlimited, such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

WE. the several persons whose names and addresses are subscribed, are desirous of being formed into an Association in pursuance of this Memorandum of Association :—

Names, Addresses, and Description of Subscribers—

DAVID ROWAN, 217 Elliot Street, Glasgow, Engineer.
W. J. MACQUORN RANKINE, C.E., LL.D., &c., 59 St. Vincent St., Glasgow.
M. R. COSTELLOE, 26 Granville Street, Glasgow, Measuring Surveyor.
BENJAMIN CONNOR, 17 Scott Street, Garnethill, Engineer.
JAMES DEAS, 16 Robertson Street, Glasgow, Civil Engineer.
JAMES M. GALE, 23 Miller Street, Glasgow, Civil Engineer.
W. MONTGOMERIE NEILSON, C.E., Hyde Park Locomotive Works, Glasgow

Dated the Twelfth day of July, Eighteen Hundred and Seventy-One.

ROBERT ROSS, of Glasgow, Solicitor, Witness to the above signatures.

NOTE.—By Special Resolution passed on 2nd October, 1902, and confirmed on 20th October, 1902, the Articles of Association dated 12th July, 1871, as modified and altered in 1873 and 1880, were annulled, and the following Articles of Association (with the exception of Articles Nos. 23, 25, and 27) were substituted, and they were registered with the Registrar of Joint Stock Companies on 28th October, 1902.

By Special Resolution passed on 20th March, 1906, and confirmed on 17th April, 1906, the Articles Nos. 23, 25, and 27 of the Articles registered on 28th October, 1902, were cancelled, and the Articles Nos. 23, 25, and 27 below were substituted. This Resolution was lodged with the Registrar of Joint Stock Companies on 28th April, 1906.

ARTICLES OF ASSOCIATION

OF THE

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

SECTION I.—PRELIMINARY

1. For the purpose of registration, the number of Members of the Institution is declared unlimited.

2. These Articles shall be construed with reference to the provisions of the Companies Acts, 1862 to 1900; and terms used in these Articles shall be taken as having the same respective meanings as they have when used in those Acts.

Objects of the Institution.

3. The Objects of the Institution are those set forth in the Memorandum of Association.

SECTION II.—CONSTITUTION.

Constitution.

4. The Institution shall consist of Members, Associate Members, Associates, Students, and Honorary Members.

Who may be Members.

5. Candidates for admission as Members shall be persons not under 25 years of age, who have been educated as Engineers or Shipbuilders and have occupied a responsible position in connection with the Practice or Science of Engineering or Shipbuilding.

Who may be Associate Members.

6. Candidates for admission as Associate Members shall be persons not under 22 years of age, who have

been educated as Engineers or Shipbuilders and are engaged in the Practice or Science of Engineering or Shipbuilding.

Who may be Associates.

7. Candidates for admission as Associates shall be such persons, not included in the classes enumerated in the two preceding Articles, who, not being under 25 years of age, are considered by the Council eligible on account of their scientific attainments, or are considered by the Council qualified by knowledge bearing on Engineering Science or Practice.

Who may be Students.

8. Candidates for admission as Students shall be persons not under 18 years of age who are engaged in study or employment with a view to qualifying themselves as Engineers or Shipbuilders. Before attaining the age of 25 years they must apply for election as Members or Associate Members if they desire to remain connected with the Institution. They may not continue to be Students after attaining the age of 25 years.

Who may be Hon. Members.

9. Honorary Members shall be such distinguished persons as the Council shall recommend and the Institution shall appoint. The number of Honorary Members shall not exceed Twelve.

Members, etc., under former Articles of Association.

10. All persons whose names shall on 30th April, 1902, be on the Roll of the Institution under the former Articles of Association as Members, Associates, or Honorary Members, and whose Subscriptions are not more than two years in arrear at that date, shall become Members, Associates and Honorary Members respectively within the meaning of these Articles, and that without procedure of any kind on the part of such persons.

Graduates under former Articles of Association.

11. All persons whose names shall on 30th April, 1902, be on the Roll of the Institution under the former Articles of Association as Graduates, and whose Subscriptions are not more than two years in arrear at that date, shall be considered and treated as Students within the meaning of these Articles, and shall have the privileges, and be subject to the regulations affecting Students;

and, notwithstanding the terms of Article 8 hereof, such Graduates as are over 25 years of age shall be allowed to remain as Students for one year from and after 30th April, 1902, but no longer.

12. The abbreviated distinctive titles for indicating the connection with the Institution shall be the following, viz.—For Members, M.I.E.S.; for Associate Members, A.M.I.E.S.; for Associates, A.I.E.S.; for Students, S.I.E.S.; and for Honorary Members, HON. M.I.E.S. **Abbreviated Titles of Members, etc.**

13. Every Candidate for admission as a Member, Associate Member, Associate or Student of the Institution, shall obtain the recommendation of at least three Members, such recommendation and the relative undertaking by the candidate being according to Form A contained in the Appendix. Such recommendation and undertaking shall be lodged with the Secretary, and the Council shall consider the same at their first Meeting thereafter, and if they approve the recommendation shall be mentioned in the notice calling the next general meeting of the Institution; and then, unless a ballot be demanded by at least five persons entitled to vote, the Candidate shall be declared elected. If a ballot be taken he shall be admitted if three-fifths of the votes are favourable; Members only being entitled to vote. The proposal for transferring any person from the Class of Students to the Classes of Associate Members or Members, or from the Class of Associate Members to the Class of Members, shall be according to Form B contained in the Appendix, and this form shall be subscribed by at least three Members and delivered to the Secretary for the consideration of the Council who shall, if they think fit, make the proposed transfer. **Candidates, how recommended and elected.**

14. The granting of Honorary Membership to any person may be proposed at any Council meeting, and, if the Council, after consideration at their next meeting, approve of the proposal, intimation thereof shall be given by the Secretary in the circular calling the next general meeting of the Institution. At that **Honorary Members, how elected.**

meeting unless a ballot be demanded by at least five persons entitled to vote, the person proposed shall be declared elected. If a ballot be taken then the person proposed shall be admitted if four-fifths of the votes are favourable; Members only being entitled to vote.

Members, &c. formally admitted.

15. Every person duly elected or admitted as a Member, Associate Member, Associate, Student, or Honorary Member, shall be notified in writing of his election or admission by the Secretary. At the first meeting of the Institution held thereafter at which he is present, he shall be introduced according to the ensuing form, viz. —The President or the Chairman of the Meeting, addressing him by name, shall say: "As President (or Chairman of this meeting) of the Institution of Engineers and Shipbuilders in Scotland, I introduce you as a Member (or Associate Member or Associate or Student or Honorary Member as the case may be). Thereafter the new Member, Associate Member, Associate, Student or Honorary Member shall sign the Roll of Members, etc., to be kept by the Secretary, and on making payment of any fees or subscriptions due he shall be entitled to receive a diploma. The diploma shall be signed by the President and the Secretary.

Diploma.

Rejected candidates not to be noticed in minutes—wish of Honorary Members to be obtained before being balloted for.

16. If any person proposed for admission into the Institution be not approved by the Council, or be rejected on being balloted for, no notice shall be taken of the proposal in the Minutes of the General Meetings, and such person shall not be proposed again for admission until after the expiry of one year from the date of such disapproval or rejection. Before the meeting of Council for considering any proposal to grant Honorary Membership it shall be ascertained from any person proposed to be made an Honorary Member, whether he will accept the honour, no notice being taken of the proposal in the Minutes unless he is elected.

SECTION III.—MANAGEMENT AND OFFICE-BEARERS.

17. The Direction and Management of the affairs of the Institution shall be confided to a Council, which shall consist of a President, six Vice-Presidents, and eighteen Councillors. Of the eighteen Councillors, not more than three may be Associates, the remainder being Members. Five Members of Council shall constitute a Quorum. **Council, Management by.** **Constitution of Council – Five a Quorum.**

18. Members only shall be eligible for election as President. The President shall preside over all meetings of the Institution and Council at which he is present, and shall regulate and keep order in the proceedings. The President shall hold office for one year only, but shall be eligible for re-election at the expiry of the year. **Who may be President.**

19. Members only shall be eligible for election as Vice-Presidents. In the absence of the President, the Vice-Presidents in rotation shall preside at meetings of the Council and Institution. The Vice-Presidents shall hold office for three years. **Who may be Vice-Presidents.**

20. In case of the absence of the President and all the Vice-Presidents, the meeting may elect any one of the Council, or any Member, to preside. In all cases the Chairman of any meeting shall have a Deliberative Vote and a Casting Vote. **Chairman to have casting vote.**

21. Members and Associates only shall be eligible for election as Ordinary Members of Council, and shall hold office for three years, and not more than three Associates shall hold office in the Council at any one time. **Who may be Councillors.**

22. Past Presidents of the Institution shall be *ex officio* Honorary Members of Council.

23. The Office-Bearers in office at 30th April, 1902, shall continue in office till the First General Meeting of the Institution in October, 1902, when a new Council shall be elected in terms of these Articles. Such Office- **First Council.**

Bearers shall be eligible for election for the new Council. Of the new Council, two Vice-Presidents shall retire in October of each of the years, 1903, 1904, and 1905, their places being filled by election, and the persons elected shall hold office until the expiry of the terms of office. Similarly of the new Council, six Councillors (being five Members and one Associate) shall retire in October, 1903, and a like number in October, 1904, and the remainder in October, 1905, their places being filled by election at these dates respectively, and their successors retiring at the expiry of the terms of office, and so on thereafter from year to year. The Vice-Presidents to retire in October, 1903, and 1904, shall be determined by lot among the six Vice-Presidents first elected, and the Members of Council to retire in October, 1903 and 1904 shall be determined by lot among the Members of the Council first elected. The Vice-Presidents and the Ordinary Members of Council who fall to retire at the dates mentioned, or who fall to retire at any time on the expiry of their term of office, shall not be eligible for re-election in the same capacity, nor shall a retiring Vice-President be eligible for election as a Member of Council until one year has elapsed from the date of retiral.

Retiral of Members of Council.

Office-Bearers to to be elected by Ballot.

24. The Members of Council shall be elected by ballot at the Annual General Meeting, such meeting being the last Ordinary Meeting held in each month of April, but the new Office-Bearers elected at this meeting shall not enter office until 1st October following. In the election of President, Vice-Presidents, and Ordinary Members of Council from the Class of Associates, all Members, Associate Members, and Associates shall be entitled to vote. In the election of the other Members of Council only Members and Associate Members shall be entitled to vote.

Lists for Election.

25. In March of each year the Council shall meet and prepare a list of names for the election of Council for the ensuing year. This list shall be submitted to the

Members at the Monthly Meeting preceding the Annual Meeting, and the Members present may by motion, duly seconded, propose any additional names for any of the offices.

Ballot Lists to be sent to Members.

26. Fourteen days before the General Meeting in April of each year the list as proposed by the Council for the election of Members and others to fill the vacancies in the Council for the ensuing year, with such additions as may have been made thereto under Article 25, shall be printed and sent to all Members, and Associate Members, and the list shall serve as a ballot paper. A similar list shall be printed and sent to all Associates containing the names of those for whom they are entitled to vote. Those persons entitled to vote may vote for as many names on the list as there are vacancies to be filled. In the event of any ballot paper not containing names equal to the number of vacancies to be filled such ballot paper shall be treated as a spoiled paper.

The ballot papers may be sent by post or otherwise to the Secretary so as to reach him before the day and hour named for the Annual General Meeting, or they may be presented personally by those entitled to vote, at the opening of the Meeting.

Vacancies occurring during the Session to be filled up by the Council.

27. A vacancy occurring during any Session in consequence of the resignation or death of any Office-Bearer (except the President) shall be filled up by the Council, until the next Annual General Meeting for electing Office-Bearers. Any vacancy in the office of President shall be filled up at the next General Meeting of the Institution. A person elected to fill a vacancy shall hold office for the period unexpired of the term of office of the Office-Bearer resigning or dying or being removed from office, and he shall not be eligible for re-election.

Section IV.—POWERS AND DUTIES OF COUNCIL.

Meetings of Council.

28. The Council shall meet as often as the business of the Institution requires, and during each Session—that is from October till April—the Council shall meet at least once a month.

Committees.

29. The Council may delegate any of their powers to Committees consisting of such Members of the Council as they think fit, and they may appoint Committees to report to them upon special subjects. In particular, they shall appoint a Finance Committee to superintend the finances of the Institution, a Library Committee to superintend Library arrangements, and a Papers Committee to arrange for papers being submitted at meetings of the Institution. The Minutes of all Committees shall not take effect until approved by the Council. The President shall be *ex officio* a member of all Committees.

Honorary Treasurer.

The Convener of the Finance Committee shall be styled Honorary Treasurer. He shall be elected by the Council from their number, and notwithstanding the provision for retiral in Article 23, he shall be entitled to retain the office of Honorary Treasurer for three years from the date of his appointment.

Bye-Laws, etc.

30. The Council may make Bye-Laws and Regulations for carrying on the business of the Institution, and from time to time, alter, amend, repeal, vary, or add to the same; but any Bye-Law or Regulation, or any alteration or amendment thereon, or addition thereto, shall only come into force after the same has been confirmed at a General Meeting of the Institution, and no Bye-Law or Regulation shall be made under the foregoing which would amount to such an addition to or alteration of these Articles as would only be legally made by a Special Resolution passed and confirmed in accordance with Sections 50 and 51 of the Companies Act, 1862. The Council shall

Investments

be entitled to invest the Funds of the Institution as they think fit, on such security, heritable or moveable, as to them shall seem proper, and may alter or vary the investments from time to time. The Council may purchase or sell property, heritable or moveable, for the use of the Institution, and may borrow money on the security of the property of the Institution, subject to confirmation by the Institution at an Extraordinary Meeting called for the purpose. **Council may purchase or sell.** **Borrowing.**

31. The Council shall appoint a Secretary and a Treasurer, and any other official or servant required to carry on the work of the Institution, and the appointments made by the Council shall be on such terms and conditions as the Council may think fit. **Officials to be appointed.**

32. All questions in or before the Council shall be decided by vote, and such vote shall be taken by a show of hands or by ballot; but at the desire of any four Members present the determination of any subject shall be postponed till the next meeting of Council. **Votes at Council Meetings.**

SECTION V.—SECRETARY AND TREASURER.

33. Subject to regulation by the Council, the Secretary (who may also act as Treasurer) shall conduct the correspondence of the Institution; attend all Meetings of the Institution, of the Council, and of Committees; take Minutes of the proceedings of such Meetings, and enter them in the proper books provided for the purpose; read at all Meetings of the Institution and Council respectively the Minute of the preceding Meeting, and all communications received by him or ordered to be read; superintend the publication of such papers as the Council may direct; take charge of the Library; issue notices of Meetings; issue Diplomas; keep the Roll and Registers; and perform whatever other duties are indicated in the Regulations of the Institution as appertaining to his department or set forth in the terms of his appointment. **Duties of Secretary.**

34. Subject to regulation by the Council, the duties of the Treasurer shall be to take charge of the property **Duties of Treasurer.**

of the Institution (excepting books, papers, drawings, models, and specimens of materials, which shall be in the charge of the Secretary); to receive all payments and subscriptions due to the Institution; to direct the collection of subscriptions; to pay into one of the Glasgow Banks, in the joint names of the President, Honorary Treasurer, and himself, the cash in his hands whenever it shall amount to Ten Pounds; to pay all sums due by the Institution, but not without an order signed by two Members of the Finance Committee, and to keep an account of all his intromissions in the General Cash Book of the Institution, which shall upon all occasions be open to inspection of the Finance Committee, and which shall be balanced annually, as at 30th September. The Treasurer shall prepare an Annual Statement of the Funds of the Institution, and of the receipts and payments of each financial year, which shall be audited by the Auditor aftermentioned, and this Statement of the Funds and an Inventory of all the property possessed by the Institution, and a List of the Members, Associate Members, Associates, and Students, whose subscriptions are in arrear, shall be submitted to the First Meeting of the Council, in October.

Annual Report. 35. An Annual report upon the affairs of the Institution shall be drawn up under the direction of the Council at a meeting to be held not less than ten days before the General Meeting of the Institution in October. This report shall embody reports from the representatives elected by the Council to various official bodies.

SECTION VI.—AUDIT OF ACCOUNTS.

Auditor and duties. 36. An Auditor, who must be a Chartered Accountant of at least five years standing, shall be appointed by the Council at their meeting preceding the last General Meeting of each Session, to examine the accounts and books of the Treasurer, and the Annual Financial Statement or Statements of the Funds, and that Statement along with the Audit and Annual Report, shall be printed in the notice calling the First General Meeting of the Institution in October, and shall be read at that meeting.

SECTION VII.—MEETINGS AND PROCEEDINGS OF THE INSTITUTION.

Ordinary General Meetings every four weeks during the Session.

37. The Institution shall hold ordinary meetings for reading papers, and for discussing matters connected with the objects of the Institution; and such meetings shall take place regularly, at least once in every four weeks during each Session; and may be adjourned from time to time. The Sessions shall commence in October, and continue until the month of April next following, inclusive. No business shall be transacted at any Meeting, unless 25 Members shall be present.

At the General Meeting in April of each year for the election of Office-Bearers, the order of business shall be :—

(1) Minutes of last meeting.

(2) To read and consider the reports of the Council and Treasurer.

(3) The meeting shall nominate two Scrutineers who shall be members, and shall hand to them the ballot-box containing the voting papers for the new Office-Bearers.

(4) The Scrutineers shall receive all ballot papers which may have reached the Secretary, and all others which may be presented at the Meeting. The Scrutineers shall then retire and verify the lists and count the votes, and shall, before the close of the meeting, report to the Chairman the names which have obtained the greatest number of votes subject to the conditions of the ballot. The Chairman shall then read the list presented by the Scrutineers, and shall declare the gentlemen named in the list to be duly elected, provided always that the list does

not contain more names than there are vacancies to be filled.

Ordinary Meetings—order of business.

38. At every ordinary meeting of the Institution, the Secretary shall first read the minutes of the preceding meeting, which, on approval, shall then be signed by the Chairman of the meeting at which the minutes are read and approved. The Secretary shall next read any notices which may have to be brought before the meeting; after which any Candidates for admission may, if necessary, be balloted for, and any new Members shall be admitted. Any business of the Institution shall then be disposed of, after which notices of motion may be given. The paper or papers for the evening shall then be read and discussed. Each Member shall have the privilege of introducing one friend to the General Meetings, whose name must be written in the Visitors' Book together with that of the Member introducing him; but if the introducing Member be unable to attend the Meeting he may send with the visitor a card signed by him addressed to the Secretary. During such portions of any of these Meetings as may be devoted to any business connected with the management of the Institution, visitors may be requested by the Chairman to withdraw.

Nature of papers to be read.

39. All papers read at the meetings of the Institution must be connected with the Science or Practice of Engineering or Shipbuilding, and must be accepted by the Papers' Committee before being read.

***Proceedings* to be published.**

40. The papers read, and the discussions held during each Session, or such portion of them as the Council shall select, shall be printed and published forthwith.

Explanatory notes after reading of papers may be published.

41. Explanatory notes communicated after the reading or discussing of papers may be printed in the *Transactions*, if the Council see fit.

Copyright of papers shall be the property of the Institution.

42. The copyright of any paper read at a meeting of the Institution, with its illustrations, shall be the exclusive property of the Institution, unless the publication thereof by the Institution is delayed beyond the commencement

of the Session immediately following that during which it is read; in which case the copyright shall revert to the author of the paper. The Council shall have power, however, to make any arrangement they think proper with an author on first accepting his paper.

43. The printed *Transactions* of each Session of the Institution shall be distributed gratuitously, as soon as ready, to those who shall have been Members, Associate Members, Associates, or Honorary Members of the Institution during such Session, and they shall be sold to the public at such prices as the Council shall fix. Authors of papers shall be entitled to thirty separate copies of their papers, with the discussions, as printed in the *Transactions*. **Members, &c., to receive copies of *Transactions*—Authors 30 copies of their papers.**

44. Extraordinary or Special Meetings may be called by the Council when they consider it proper or necessary, and must be called by them on receipt of a requisition from any 25 Members, specifying the business to be brought before such meeting. **Special Meeting may be called by the Council, or on requisition by 25 Members.**

45. Any question which, in the opinion of the President or the Chairman of the meeting of Council and Institution, is of a personal nature, shall be decided by ballot; all other questions shall be decided by a show of hands, or by any convenient system of open voting. **Voting.** In all cases, not hereinbefore provided for, only Members, Associate Members, and Associates, shall be entitled to vote. Every Member, Associate Member, and Associate, shall have one vote only, which must be given personally. **Who may Vote.**

SECTION VIII.—SUBSCRIPTIONS OF MEMBERS AND OTHERS.

46. Each Member shall, on election, pay an entrance fee of £1, and for the current and for each Session thereafter an annual Subscription of £2. **Annual Subscription payable.**

Each Associate Member shall, on election, pay an entrance fee of £1, and for the current Session and each of the two following Sessions an Annual Subscription of £1, and thereafter an Annual Subscription of £1 10s.

Each Associate shall, on election, pay an entrance fee of £1, and for the current Session and each Session thereafter an Annual Subscription of £1 10s.

Each Student shall pay an Annual Subscription of Ten Shillings, but no entrance fee.

In the case of Members, Associate Members, Associates, and Students, elected during March and April no subscription shall be payable for the current Session.

47. Honorary Members shall be liable for no contribution or subscription or entrance fee.

48. The Liability of any Member or Associate for future Annual Subscriptions may be commuted by the following payments, viz., in the case of a Member, by the payment of £25; and in the case of an Associate, by the payment of £20 and, in the event of such payment being made by a Member or Associate on his admission to the Institution, the same shall be in full of Entry Money as well as future Annual Subscriptions.

49. All persons transferred, in terms of Articles 10 and 11, to the Roll of Members, Associates, or Students, to be kept under these Articles, shall not be liable to pay any entrance fee, but for the Session, 1902-3, and thereafter they shall be liable for the Annual Subscription applicable to the Class to which they are transferred. All persons who, as Members or Associates under the former Articles of Association, had commuted their Annual Subscriptions by a capital payment to the Institution shall not be liable for any subscription, notwithstanding the terms of this Article.

When Annual Subscriptions due.

50. Annual Subscriptions shall become due on the first day of October in each year, and must be paid before 1st January following.

Members, etc., not entitled to vote if in arrear.

51. No Member or Associate Member or Associate, whose subscription is in arrear, shall be entitled to vote at any meeting of the Institution nor to receive copies

of papers or proceedings while the subscription remains unpaid.

52. Any Member, Associate Member. Associate or Student, whose subscription is more than three months in arrear shall be notified by the Secretary. Should his subscription become six months in arrear he shall be again notified by the Secretary and all his rights in connection with the Institution shall be suspended. Should his subscription become one year in arrear he shall be removed from the roll of the Institution unless the Council may deem it expedient to extend the time for payment.

Members, etc., retiring from the Institution.

53. Any Member, Associate Member, Associate, or Student retiring from the Institution, shall continue to be liable for annual subscriptions until he shall have given formal notice of his retirement to the Secretary. Contributions payable by Members, Associate Members, Associates or Students, shall be debts due to the Institution, and may be recovered by the Treasurer.

Remission of Subscription in certain cases.

54. In the case of any Member or Associate who has been long distinguished in his professional career, but who, from ill health, advanced age, or other sufficient cause, does not continue to carry on a lucrative practice, the Council, if they think fit, may remit the annual subscription of such Member or Associate, and they may remit any arrears due by him. Any such case must be considered and reported upon to the Council by a Committee appointed by the Council for the purpose.

Council may refuse to receive subscriptions in certain cases.

55. The Council may refuse to continue to receive the subscription of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall, in the opinion of the Council, have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution, and may remove his name from the Register, and he shall thereupon cease to be a Member, Associate Member, Associate or Student (as the case may be) of the Institution.

SECTION IX.—GENERAL POWERS AND PROVISIONS.

Powers of Institution in General Meeting.

56. Any Extraordinary or Special Meeting of the Institution, duly called, shall have power, by a majority in number of the persons present thereat entitled to vote, from time to time, to review the decisions or determinations of the Council; to remove Members of Council; to expel Members, Associate Members, Associates, Students, or Honorary Members, from the Institution, and to expunge their names from the Roll; and to delegate to the Council all such further powers as may be considered necessary for efficiently performing the business of the Institution. At any Extraordinary or Special Meeting 50 Members shall be a quorum.

To delegate powers to Council.

Common Seal.

57. The Institution shall have a common seal, which will be under the charge of such of the Office-Bearers as the Council may appoint, and all instruments bearing the seal shall be countersigned as the Council shall direct.

SECTION X.—NOTICES.

Notices.

58. Notices requiring to be served by the Institution upon its Members, Associate Members, Associates, Students, or Honorary Life Members, may be served either personally, or by leaving the same, or by sending them through the post; and notices so posted shall be deemed to have been duly served. No Members, Associate Members, Associates, Students, or Honorary Life Members, who have not a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to any such.

Inducize of Notices.

59. Notices for any General or Extraordinary or Special Meeting of the Institution must be given by the Secretary to all Members, Associate Members, Associates, or Honorary Life Members, at least four days before such meeting. Notices of any adjourned meeting shall be given at least two days before the

adjourned meeting is held. Such notices shall specify the nature of the business to be transacted and no other business shall be transacted at that Meeting.

60. Notices for any meeting of Council must be given by the Secretary at least four days before such meeting. Notices for the meetings of Committees shall be given as the Council shall direct. **Notices.**

61. In computing the *induciæ* of any notice the day on which the same is delivered shall be reckoned as an entire day **Computation of Induciæ.**

APPENDIX.

FORM A.

Form of Recommendation and Undertaking.

A. B.............. of................being upwards of........ years of age and being desirious of belonging to the Institution of Engineers and Shipbuilders in Scotland, I recommend him from personal knowledge as in every respect worthy of that distinction because (here specify distinctly the qualifications of the Candidate according to the spirit of Articles 5, 6, 7, and 8).

On the above grounds I beg leave to propose him to the Council as a proper person to belong to the Institution.

..............................*Member.*

Dated this............*day of*............19

We, the undersigned, from personal knowledge, concur in the above recommendation.

..................................*Member.*

..................................*Member.*

I, the said A B., do hereby promise that in the event of my election I will abide by the Rules and Regulations of the Institution, and that I will promote the objects of the Institution as far as may be in my power.

....

Form B.

Form for Transfer from one Class to another.

A. B...............of.................having been a...........of the Institution of Engineers and Shipbuilders in Scotland for.................years, and being desirous of becoming a..........................of the Institution, we, from personal knowledge, recommend him as in every respect worthy of being elected a.............. of the Institution.

.... *Member.*

................................*Member*

...............................*Member.*

I, the said A. B., do hereby promise that in the event of my election I will abide by the Rules and Regulations of the Institution, and that I will promote the objects of the Institution as far as may be in my power.

....

The Council having considered the above recommendation and undertaking approve of the same.

....*President (or Chairman).*

Dated this.........day of.............19

BYE-LAWS.

MEDALS AND PREMIUMS.

1. Each of the two Medals founded by subscription, for the best paper in the Marine and Railway Engineering Departments respectively, shall be awarded by the vote of a General Meeting, not oftener than once in each Session. Marine and Railway Engineering Medals.

2. The Council shall have power to offer annually a Medal for the best paper on any subject not comprehended by the Marine and Railway Engineering Medals. Such additional medal to be called the Institution Medal, and to be paid for out of the Funds of the Institution, until a Special Fund be obtained. This medal also shall be awarded by the vote of a General Meeting. Institution Medal.

3. If it shall be the opinion of the Council that a paper of sufficient merit has not been read in a particular department during any Session, the Medal shall not be given in that department; and, in the case of the Marine and Railway Engineering Medals, the interest arising from the particular Fund shall be added to the principal. When Medals may not be awarded.

4. If the Person to whom a Medal may be awarded shall express a wish to receive a Bronze Medal, accompanied with the extra value in Books, in lieu of the ordinary Gold Medal, the award shall be made in that form. The Council may recommend premiums of Books in lieu of, or in addition to, the Gold Medals. The value of such premiums of Books to be determined by the Council. Medals and Books may be awarded.

MANAGEMENT OF THE LIBRARY.

5. The Council, at their first Meeting each Session, shall appoint eight of their number to form a Library Appointment of Library Committee.

Committee, one of the eight to be Honorary Librarian and Convener of the Committee. Three Members of the Committee shall form a quorum.

Secretary shall have charge of Library.

6. The Secretary of the Institution shall have charge of the Library, and shall also act as Secretary of the Library Committee.

Powers of Library Committee.

7. The Library Committee, subject to the sanction of the Council, shall expend in Books and Library expenses the sums placed at their disposal, and, subject to the approval of the Council, may make Bye-Laws for the management of the Library, and appoint Assistants. The sum of £30 or thereby shall be expended annually out of the funds of the Institution, in the purchase of Books for the Library, in addition to the ordinary expenditure in binding, &c.

Duties of Library Committee and Annual Report.

8. The Library Committee shall annually make an examination of the property in connection with the Library, and report to the Council, detailing the state of the Library affairs.

LIBRARY BYE-LAWS AS TO USE OF BOOKS.

When Library is to be open.

9. Except during Holidays and Saturdays, the Library shall be open each lawful day from 1st May till 30th September inclusive, from 9.30 a.m. till 5 p.m. On Saturdays the Library shall be open from 9.30 a.m. till 1 p.m. On the 1st October and thereafter throughout the Winter Session the Library shall be open each lawful day from 9.30 a.m. till 8 p.m., except on Meeting nights of the Institution and Royal Philosophical Society, when it shall be closed at 10 p.m. The Library shall be closed for the Summer Holidays from the 11th July till 31st July inclusive.

Who may borrow books.

10. Books shall not be lent to any persons except Members, Associate Members, Associates, Students or Honorary Members of the Institution; but a person entitled to borrow books may send a messenger with a signed order.

11. The books marked with an asterisk in the Catalogue shall be kept for consultation in the Library only, and shall not be lent. Books for Consultation only.

12. The Librarian and Assistant Librarian shall take their instructions from the Secretary of the Institution. They shall keep an Accession Book, in which shall be entered the particulars of all books purchased for or donated to the Library. Librarian to keep Accession Book.

13. The Librarian, or Assistant Librarian, shall keep a Register, in which he shall enter the titles of the book or books lent, the date of lending, the name of the borrower, and the date of the return of the book or books to the Library. Register of books lent kept.

14. The borrower of the book or books, or, in his absence, the bearer of his order, shall sign his name to the entry of such borrowing in the Librarian's Register. Borrower to sign for books.

15. The Librarian, or Assistant Librarian, shall sign his initials to the date of the return of the book or books. Librarian to certify return of books.

16. The borrower shall be responsible for the safe return of the book, and if it be damaged or lost he shall make good such damage or loss. Should books be returned in a damaged condition, the Librarian, or Assistant Librarian, shall immediately make an entry of the fact in the Register, and report the same to the Library Committee without delay; and he shall give notice in writing of such entry, and report to the person from whom he last received the book, within three clear days of the receipt of the book, exclusive of the day of receiving the book and the day of giving such notice. Books damaged to be entered in Register. Intimation to Library Committee, and notice to last borrower.

17. No person shall be entitled to borrow, or have in his possession at one time, more than two complete works belonging to the Library, or two volumes of any periodical. Number of books which may be borrowed at one time.

18. No person being six months in arrears with his subscription to the Institution shall be at liberty to use the Library or Reading Room. Persons in Arrears of Subscription not to have use of Library.

Time books may be obtained. 19. No borrower shall have the right to retain a book longer than thirteen clear days, exclusive of the days of borrowing and returning; and written notice shall be sent to the borrower one day after the time has expired. In no case shall any book be kept longer than twenty clear days.

Lots to be drawn when two may apply for the same book. 20. In the event of two or more persons applying for the same book at the same time, the applicants shall draw lots for priority.

Introduction of friends to Reading Room. 21. Each Member shall be entitled to introduce a friend to the Reading Room, whose name shall be written in the Visitors' Book, together with that of the Member introducing him.

Annual scrutiny of books. 22. All books belonging to the Library shall be called in for inspection, and the lending out of books shall be suspended in each year for one week, being the last seven clear days of March; and all Members shall be required, by an intimation to be inserted in the notice calling the preceding meeting of the Institution, to return all books in their hands to the Library on or before the day next preceding the period before mentioned.

NOTE.—The Library and Reading Room are open to Members, Associate Members, Associates, and Students; and the Library of the Philosophical Society is open for consultation.

WILLIAM BROWN, *Convener.*	E. HALL-BROWN.
WM. M. ALSTON.	WILLIAM MELVILLE.
PROF. A. BARR, D.Sc.	JOHN STEVEN.
W. A. CHAMEN.	JOHN WARD.
	EDWARD H. PARKER, *Secretary.*

21*st April*, 1903.

INSTITUTION

OF

ENGINEERS AND SHIPBUILDERS

IN SCOTLAND

(INCORPORATED).

FORTY-NINTH SESSION—1905-1906.

INSTALLATION OF THE PRESIDENT.

24th October, 1905.

MR JOHN WARD, Vice-President, said he regretted that continued illness prevented their late President, Mr Archibald Denny, from being present that evening and introducing to them his successor, Mr James Gilchrist. Since noon of the previous day he (Mr Ward) had travelled a good many hundred miles in order to be present that evening, to join them in wishing for their friend and new President a very helpful, happy, and prosperous term of office. Mr Denny was about to leave for Egypt in search of health, and he had been requested to tell the Members how very real and lasting was the regret Mr Denny felt at his inability to fill the Chair. They all knew what it was at some time or other to be laid aside, perhaps for a week, or a month, or even longer, but when the months slipped into years, as they had done in their late President's case, it became very hard to bear. Had Mr Denny been able to fill the Chair he would have justified the hopes they had regarding him when they gave him that honour. It was hoped his sojourn abroad would bring him renewed health, and should this be so, he could be counted upon to do his utmost in the days to come to help the work of the Intitution, of which they were all so proud. Illness was not a desirable thing, but one effect was to link closer together those who took up the work when the leader or chief fell out of the ranks for the time being. Mr Denny had asked Mr Gilchrist, when he felt ill-health coming upon him, to act for him as Chairman of the Council, and during that time Mr Gilchrist had fulfilled the duties attached to that office faithfully and well. It had been a good apprenticeship for the honour which had now come to him—an honour which he was quite sure Mr Gilchrist valued very highly. Mr Gilchrist was the unanimous choice of the Members, and they believed he would fully justify by deeds their faith in him. There was no need for him to formally present Mr Gilchrist to the Members. Those who knew him longest esteemed him highest. He had grown grey in the profession, and ranked to-day as an outstanding captain of industry of engineering and shipbuilding. From the experience garnered in the past years, Mr Gilchrist should prove a very faithful help and strength to the Institution and its Members. Without further words, he had very much pleasure, indeed, in introducing Mr Gilchrist as their President, and again wishing for him, in their name, a most happy and prosperous term of office.

The PRESIDENT took the Chair amid continuous applause, and said he was not quite sure how to express his thanks for the extremely kind manner in which they had received the remarks which had been made by his good friend Mr Ward. Those remarks had been more than kind, and he could only hope that during his term of office he would so conduct himself as to give satisfaction to the Members. If he could manage that he would do well. He thanked the Members very much for the kind appreciation of the remarks which Mr Ward had made, and to Mr Ward for the more than kind way in which he had said them.

PRESIDENT'S ADDRESS.

GENTLEMEN,—On taking the chair for the first time as your President, I have to thank you for the great honour you have conferred upon me; but I approach the duties with fear and trembling and a deep sense of my own unworthiness, especially when I look back upon the long list of presidents who have preceded me, men who were in the front rank of their profession, and distinguished by their high scientific attainments—and although many of them have passed away, their works remain as a valuable legacy. When I think of what these men have been to the Institution, and compare their work with my best efforts, I fear I shall come far short of your expectations. Fortunately, I have exceptionally able colleagues as members of my Council, who are deeply interested in the welfare of the Institution, and upon whose help I can confidently rely.

For the last two years the Institution has been deprived of its President, owing to severe and long continued illness. In April 1904, when arrangements were being made for the annual election, Mr Denny had so far improved in health that he anticipated being able to take up the duties of President in October. Consequently, he was unanimously re-elected, but when the opening of the Session arrived he was not sufficiently strong to take up the duties. Mr Ward (our good friend and Vice-President) occupied the chair, and in his opening remarks said that Mr Denny was then improving, and that complete recovery would come in due time. Naturally, everyone was buoyed up with the hope of his return to the Presidential chair; but, unfortunately, last Session slipped past, and still he was not. Mr Denny has suffered much bodily pain, and I am sure that the disappointment at the non-fulfilment of his cherished hope to carry on the work of the Institution as he intended, has given him a deal of mental anxiety, which very probably may have retarded his recovery. I understand that, although not yet restored to his usual health, he is making satisfactory progress. He has all the sympathy and best wishes of the Members, and I fervently hope that, ere long, he will again be able to attend the general meetings.

The Institution is now entering on the forty-ninth Session, and it is pleasant to know that it is still progressing, not only in respect to memberssbip, but also in the matter of finance. The large influx of Members to the Institution has given the Council a great deal of concern, owing to the present premises being too small for their accommodation. These buildings are held conjointly, one-half each, by the Royal Philosophical Society and the Institution of Engineers and Shipbuilders in Scotland, and were formally opened in 1880. At that time they were considered large enough for all the purposes of both Institutions, but as the membership of both Societies has greatly increased, your Council considered that a separation of the two bodies was expedient, and that either one or the other should take over the existing premises. Accordingly, during the last two years many meetings have taken place between representatives of the Royal Philosophical Society and of the Institution, with the view of coming to some amicable arrangement. It was ultimately decided to offer the Royal Philosophical Society a certain sum for its interests, or that it should accept the same amount for the Institution's rights. The Councils of the two Societies agreed upon the latter course, and it now rests with the Members of each body to ratify the action of their respective Councils. The agreement, which has been signed by both Councils, is that the Philosophical Society pays the Institution £4,000 for its half share of the property, and that the Institution shall occupy the premises as tenants for two years at a rental of £100, plus £120 for services rendered, making in all £220 per annum. As already stated, this agreement, however, requires the confirmation of the Members of both bodies, and for this purpose, special or extraordinary meetings will be called. At present, it would be rather premature for me to say anything further. The Council of the Institution has appointed a small committee of gentlemen, experts in land and property, who are looking out for a site suitable for its requirements, and soon, such a scheme as will recommend itself to all, will be placed before you. I may say, however, that the Council are desirous of erecting a building, commodious within, handsomely designed, and one worthy of the Institution, and which will also be a lasting ornament to the greatest engineering and shipbuilding city in the world.

In connection with the proposed removal, it may be interesting to place on record the number of Members on the roll at the dates of previous removals. The Institution was founded in 1857, and meetings were held in Anderson's University, 204 George Street, Glasgow, the first President being Professor W. J. Macquorn Rankine, C.E., whose works on civil and mechanical engineering are known throughout the world:—

Session, 1857-58.

Members, ...	118
Associates, ...	1
Graduates, ...	8
	127

In 1868, during the Presidency of the late Mr J. M. Gale, the place of meeting was removed to the Corporation Buildings, Dalhousie Street:—

Session, 1868-69.

Members,...	313
Associates, ...	49
Graduates, ...	14
	376

An increase of 249.

Then, again, in 1880, when the late Mr J. L. K. Jameson, of the famous firm of Randolph, Elder & Co., was President, the present buildings were opened :—

Session, 1880-81.

Members, ...	378
Associates, ...	35
Graduates, ...	128
	541

A further increase of 165.

At the close of last Session, the numbers were as follows :—

Session, 1904-05.

Members, ...	1031
Associate Members, ...	127
Associates, ...	91
Students, ...	202
	1451

An increase of 901 during the occupation of these buildings.

From such a large membership, changes in the roll must be expected, and I regret to say that during the past year, death has removed from our midst ten Members :—James Foster, James Gray, E. Hunt, David M'Call, John F. Miller, Edmund Mott, William Robertson, G. L. Watson, John J. Wilson, and John Young; one Associate Member—George Anderson; and one Associate—James Napier; of whom you will find special mention in the Obituary of last Session's Transactions.

Since the last volume was printed, two more of our old members have passed away, Mr Thomas M. Welsh, the engineering partner of Messrs A. & J. Inglis, Ltd., who died on 25th September, 1905, aged 70 years; Mr Welsh joined the Institution in 1869. On the same day, Mr James Anderson, of Messrs Lees, Anderson & Co., died, aged 59 years; Mr Anderson joined as a Graduate in 1874, and became a Member in 1880. The Institution has also lost The

Right Hon. Lord Inverclyde, an Associate. He died on 8th October, aged 44 years. Although his lordship only joined the Institution in 1904, it, in common with the community of Glasgow, mourns his loss, for the Council hoped, and he had promised, that he would take a deep interest in the welfare of the Institution, but it was not to be.

With your permission, I should like to allude to some of the papers which have been read during the past two Sessions. During 1903 and 1904, ten papers were read, and last Session nine, embracing such subjects as Superheated Steam, Valve Gears, Marine Propellers, Properties of Radium, Mercury Vapour Lamp, Uses of the Integraph for Ship Calculations, Railway Crossings, Motor Cars, The Smoke Problem, Repairing Engines at Sea, Transmission of Power by Ropes, Steam Turbines, Estimating Strength of Ships, Compounding Locomotives, Gyroscopic Action of Steam Turbines, and Gyrostats and Gyrostatic Action. These papers, covering a large variety of subjects, were extremely interesting and instructive, several of them bringing forth lively discussions, which were carried on in the friendliest spirit. The authors well deserve, as they have already received, the thanks of the Institution.

Many people not associated with the Institution are under the erroneous impression that because the word "engineers" is coupled with shipbuilders in the name of the Institution, that it only allows marine engineers to enter its ranks. I would request every one to correct this error on every possible occasion. It will be seen that the list of Members contains the names of marine, land, locomotive, mining, hydraulic, sanitary, gas, and electric engineers, also a large number of civil engineers; consequently, the word "engineers," as used by the Institution, is of the most comprehensive character. Having, therefore, such a large field to draw upon, the Council desires the hearty co-operation of every Member in endeavouring to add to the roll, practical and scientific men from each of the aforementioned branches of engineering.

Of the value of such an Institution as this there can be no doubt. Those who are engaged in designing and construction work, of whatever kind, have the advantage of bringing their ideas and their difficulties before their professional brethren where they can be discussed, and anything unsound fully criticised. It is only by attending meetings of this kind, and by reading the transactions of similar societies (many of which may be found in the Library), that the engineer is enabled to keep himself informed of the progress of science and the development of manufactures. With respect to progress, much has been accomplished during the last few years. Steamers have increased enormously in size and power, and the introduction of the twin and triple screws have enabled the enginner to apply power on board ship hitherto undreamed of. Consequently the speed of vessels both in the navy and mercantile marine has been greatly increased. The adoption of larger vessels has necessitated the remodelling and enlargement of shipyards and engine works, the condemnation of old and obsolete tools, and the substitution of new and "up-to-date" plant, driven by electricity instead of steam.

Steam turbines are now being largely introduced instead of the triple and quadruple reciprocating engines on board ship, and the results obtained have been somewhat phenomenal. At present, the results are known only to a favoured few. Speed has been well announced, but reliable information regarding initial cost, upkeep, and coal consumption has not yet been given. To Messrs William Denny & Bros., Dumbarton, belong the credit of introducing turbines into the mercantile marine. They have spent much time, labour, and expense in bringing turbine-driven ships to their present efficiency. All honour is due to Mr Parsons for his indomitable perseverance in perfecting his invention; but without the valuable aid of Messrs Denny the turbine would not have created such a sensation among marine engineers and shipowners. Quite recently Mr William Gray read a most interesting and valuable paper, before the Institution of Naval

Architects, on "A Comparison of the Performances of Turbines and Reciprocating Engines in the Midland Railway Company's Steamers." These vessels were built for the Irish and Isle of Man services; two were equipped with turbines, and two with reciprocating engines. In that paper, Mr Gray showed that the best results, so far as speed is concerned, were obtained by the turbines, that the vibration always present with the reciprocating engine is entirely done away with, that the difference in weight is considerably in favour of turbines, and that the saving in coal by their use is from 8 to 9 per cent. Mr Gray also says—"The difference in the initial cost of the turbines is not great, being 1½ per cent. of the total cost of hull and machinery." That statement I think, requires some explanation, as my firm offered recently for a steamer having four-cylinder triple-expansion twin-screw engines of 4,800 I.H.P., with an alternative offer for propulsion by turbines. Messrs Parsons' offer was 63·7 per cent. higher than the cost of reciprocating engines, 44 per cent. higher for total machinery, and 19 per cent. higher for total cost of hull and machinery.

Shipowners and marine engineers are looking forward with very great interest to the performances of the two large Cunard steamers, "Caronia" and "Carmania." These vessels, I am informed, are of exactly the same dimensions, are built from the same model, and have the same kind of boilers fitted—the first-named being propelled by reciprocating twin-screw engines, whilst the latter has three propellers driven by turbines. As both ships will be driven across the Atlantic on the same station, accurate and reliable results of the most valuable nature will be obtained. The two large turbine vessels already running on the North Atlantic have done good work, and are greatly favoured by passengers owing to the absence of vibration, but it is rumoured that the coal bill is much heavier than was anticipated. To-night Mr Edward M. Speakman will deliver a paper on the "Determination of the Principal Dimensions of the Steam Turbine, with Special Reference to Marine Work," from which some light may be thrown on the darkness surrounding this subject.

Since the general adoption of electricity for lighting purposes, many schemes have been devised for the use of this as yet unknown power. Cranes, lathes, planing machines, drilling machines, punching machines, shearing machines, and in short, all kinds of plant, for shipbuilding, bridgebuilding, coal and rock cutting, or for engineering establishments are now driven by electric power. The conversion of the old steam plant to the new electric plant has called forth the best efforts of electrical experts, and so far they have every reason to be proud of their achievements. The citizens of Glasgow, as well as the inhabitants of many other cities, also thank them, for without their aid the splendid systems of tramways would not exist.

Air compressors for pneumatic plant are now coming well to the front. Most of the large shipbuilding, bridgebuilding, and boilermaking firms are now using compressed air for boring, riveting, and caulking, with marked success, and the various makers of air compressors are experiencing a healthy competition as to who shall command the market. Undoubtedly, the work accomplished by pneumatic tools is of a very high order, but, unfortunately, up to the present time the upkeep of such plant is so great that no economy (except in time) has resulted. I know that this statement may be questioned, but from my own experience and that of several of my friends, the fact remains, particularly in regard to caulking, the economy of time saved being swallowed up by the cost of the upkeep of the tools. Many engineers of marked ability are at present "steeping their brains" as to the best manner of rectifying these objections, and I am confident that their united efforts will ultimately be crowned with success, notwithstanding that the subject involves many difficulties, practical and theoretical.

Locomotive builders have also been advancing with the times, and have made giant strides, not so much on any great alteration in design as in excellence of workmanship and efficiency; and the rapidity with which they now construct locomotives is really nothing short of wonderful.

Machine tool makers during the last few years have been continually designing and making tools necessary for the various requirements of their clients, with marked success. The speed now attained in cutting material, and the accuracy with which it can be finished has enabled the engineer not only to produce more work in a given time, but better work. To machine tool makers, manufacturing engineers of all kinds owe a deep debt of gratitude, for without their help the great output and the smooth-working machinery of the present day could not have been accomplished.

Gas engines have now been largely adopted on land, many firms having fitted up special gas producing plant for power purposes, whilst others use the ordinary illuminating gas of the district. This latter plan, being much more expensive, is only adopted where small power is required. This carries out the prophetic statement of our deceased and highly esteemed friend —Mr Foulis—who in his presidential address said—"There can be no doubt that for stationary engines the gas engine will come more and more into use, supplanting steam engines and resulting in a great economy of fuel and a purer atmosphere." Some of the largest firms now use gas engines with producer gas for driving dynamos which supply electricity, both for motive power and for lighting, and I am informed that one firm has not a steam boiler on its premises. Gas engines with gas producers are now being made for use on board ship instead of steam boilers and steam engines. An installation is now being made in Manchester, for the Admiralty, of 500 B.H.P., and thoroughly practical and searching experiments may be expected from such critics as the scientific staff of that body. Messrs. Beardmore & Co. are also making gas engines to be placed in an existing Glasgow steamer, and so great is their belief in its efficiency that, unless the new installation proves more economical in every respect than the old engines, the new machinery is to be taken out and the old engines replaced. I hope that Messrs. Beardmore will not be called upon to do such disagreeable work, but that the anticipated results will be attained. Hitherto, much trouble and inconvenience has been caused by the tarry residuals from bituminous coal clogging up the valves and passages, but ere long efficient purifiers may be made which will overcome this difficulty, for to use anthracite or dear coal makes the system very expensive.

The Extraordinary Meetings which were held at the close of the last Session, relative to the requirements of the Board of Trade, as to the training, experience, and efficiency of young engineers before being eligible for a second-class certificate of competency, were not so well attended as the Council expected, consequently the discussion was confined to few speakers. The subject is one of vital importance to the prosperity of the mercantile marine, as no steamer should be allowed to go to sea without a thoroughly efficient staff in the engine room; especially in these days, when there are so many auxiliary machines on board ship, such as centrifugal engines, separate feed, bilge, and ballast pumps, electric, hydraulic, and refrigerating engines, also feed-heaters, evaporators, distillers, grease extractors, &c., all of which require special attention, and unless the engineer understands the mechanism and the nature of the work to be done by each machine, want of efficiency is bound to result, and the expectation of the shipowner greatly disappointed. This subject has been consigned to the care of the representatives of the Institution on the Consultative Committee of the Board of Trade, and they, along with their colleagues from the Institution of Naval Architects and the North East Coast Institution of Engineers and Shipbuilders, will no doubt bring such evidence before the Board of Trade as will enable that body to come to such a settlement regarding this subject as will be satisfactory to all concerned.

In all institutions like this, there are always "grumblers"—people dissatisfied because everything is done differently from what they would do. Strangely enough, these are the people who do nothing, except complain, and to all such I say—Amend your ways. The commonest complaint is one regarding the nature of the papers read; they are either too scientific, or else very uninteresting. But, gentlemen, the remedy is in your own hands—correct it at once. The members of the Committee on Papers deserve the highest praise and thanks for the time they spend in reading and selecting papers worthy of being put before the Institution, whilst the contents of the Transactions, year after year, speak for the excellence of their selection.

I have already referred to the various industries represented by the Members of the Institution. From these Members there ought to be no difficulty in getting papers representative of their work.

Last Session, an innovation was introduced in the form of a Smoking Concert. Many Members considered that the ordinary meetings in the lecture hall, once a month, were cold and formal, and gave no opportunity of association one with another—that, in short, the friendly feeling and brotherly kindness which should be characteristic of such an Institution was conspicuously absent. To rectify this, it was decided to hold a Smoking Concert in the Grosvenor Restaurant on the 3rd of March. Mr John Ward presided, and the attendance was highly satisfactory, about 300 being present. The programme was an excellent one, thoroughly enjoyed, and there was ample evidence that the success of such meetings was assured. On the evening of Friday, the 13th of this month, another such entertainment took place, over which I had the honour to preside. There was a much larger attendance than on the former occasion—400 being present, and all agreed that such social gatherings, where Members could be introduced to each other and freely indulge in friendly conversation, were conducive in many ways to the welfare of the Institution, and ought to be regularly continued. In furtherance of this good object, the Council has arranged to hold a Conversazione and Dance in the St. Andrew's Halls on Friday, the 10th November. Former meetings of this kind have been well patronized and highly successful, and it is earnestly hoped that the coming one may be the most successful of all.

The Graduates' Section, or, as it is now named, the Students' Section, has always been to me of special interest. I became a Graduate in 1866, and, when in 1874 the Association of Assistant Engineers, of which Association I was then President, amalgamated with the Graduates' Section, I was chosen as the first President of that Section. It is, therefore, very gratifying to me to be able to state that our Students' Section is being carried on with greater success than ever under the Presidency of Mr E. Hall-Brown, who has been unremitting in his efforts to raise the standard of the meetings. Last Session seven meetings were held, and the papers read were of high merit, extremely interesting, and such as brought forth lively discussions. From the Report of the Council, which you have now in your hands, you will observe that 43 students were elected during the year, whilst 12 students were transferred to the class of Associate Members, and 11 to the class of Members. These transfers are necessary and expedient, as it is on the Students that the future greatness of the Institution depends. The young engineer of the present day has indeed many advantages which his forefathers had no opportunity of enjoying, and as brain power and intelligence must be dominating features in the industrial warfare of the future, it is absolutely necessary that he must train his faculties.

The Universities and Technical Colleges of this country have now been splendidly equipped for teaching the science of engineering, and up-to-date machinery has been annexed to them for imparting technical instruction. Much diversity of opinion exists regarding the proper period for the training of students attending such classes. Some say that it should be immediately after leaving school, whilst others affirm that a more perfect knowledge of the theory of mechanics can be grasped after an apprenticeship and when some knowledge of practical work has been gained. At whatever time, either before or after an apprenticeship, it is now compulsory for success, that every young man must have a good theoretical training, for, as I have already said, brain power and not handiwork is the necessity of the age. Dr. Caird, in his opening address, said—"It is the opinion of the great majority of engineers in this country that it is only by a systematic training in scientific and technical subjects, as well as in business methods and in workshop management, that we can hold our own against the vigorous, skilfully directed, and amply subsidised attacks of our foreign rivals," and what Dr. Caird said about foreign rivals, is equally applicable to the vigorous efforts which we all make to produce work cheaper than our own immediate neighbours. This rivalry is in many cases to be deplored, although it is unquestionably stimulating, and such Institutions as this, where ideas are freely expressed and discussed, must in a great measure level costs of production and minimise rivalry. In an address recently delivered by Mr Henry R. Towne, to the students of Purdue University, he said—"The true function of the engineer is, or should be, not only to determine how physical problems may be solved, but also how they may be solved most economically. The engineer is, by the nature of his vocation, an economist. His function is not only to design, but also so to design as to ensure the best economical result. He who designs an unsafe structure or an inoperative machine, is a bad engineer; he who designs them so that they are safe and operative, but needlessly expensive, is a poor engineer, and, it may be remarked, usually earns poor pay; he who designs good work, which can be exacted at fair cost, is a sound and usually successful engineer; he who does the best work at lowest cost sooner or later stands at the top of his profession, and usually has the reward which this implies." A man with a sound theoretical knowledge is undoubtedly a good man, so is one with a good deal of practical and administrative ability, but what is wanted is men having both these capacities, coupled with energy, zeal, uprightness, and straightforwardness, in all their actions.

In conclusion, I might say that employers should train young men to the best of their ability, and there their responsibility ends.

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Mr D. C. Hamilton.

The after career of young men depends entirely on their own exertions, but I earnestly entreat all the Students, to so conduct themselves, that the honour and dignity of this Institution may be maintained and recognised as one of the great Technical Societies of Great Britain.

Vote of Thanks.

Mr D. C. Hamilton (Member of Council) moved a vote of thanks to the President for his able Address, which was both interesting and instructive. Some present would, no doubt, have liked to criticise and discuss it, but he supposed that that was out of the question. The President had mentioned the Graduates' Section, and had told them that he was the first President of that Section. He (Mr Hamilton) was a graduate at the time when Mr Gilchrist was President of the Section, and he was not only the first President, but he was the best. He (Mr Hamilton) was sure that they all wished him to turn out the best President of the Institution also.

The vote of thanks was carried by acclamation.

THE DETERMINATION OF THE PRINCIPAL DIMENSIONS OF THE STEAM TURBINE WITH SPECIAL REFERENCE TO MARINE WORK.

By Mr. E. M. Speakman (Associate Member).

SEE PLATES I., II., III., IV., AND. V.

Read 24th October, 1905.

In designing any turbine installation, the first and most essential step is to estimate the highest suitable speed of rotation in order that the turbine may be made as small as possible for any given efficiency. While there is now no great difficulty in accurately determining the proportions of turbines and propellers to ensure certain results, with ample confidence to enable a stiff guarantee to be made both for speed and economy, the principal dimensions involve considerable calculation, and much attention must be devoted to the efficiency of propulsion if the best results are to be obtained.

Knowledge of propulsive efficiency, and all its component values for various classes of work, is essential for calculating propeller dimensions, and thereby arriving at the highest revolutions attainable, for it is only when the rotary speed is settled that the best compromise of turbine dimensions, chiefly in the matter of blading arrangements, can be determined.

Turbine efficiency and propeller efficiency must be considered separately and also together, because it may be found that the use of revolutions somewhat below the maximum obtainable will increase the combined efficiency, while on the other hand, to obtain certain advantages in weight and space, this efficiency may be slightly sacrificed at the highest speed, and it is necessary to know the effect of such modifications on the design and performance. Roughly, the weight of the turbines will vary inversely as the square of the revolutions, while the economy of the turbine will remain almost constant if designed for the same internal conditions; the efficiency of the propeller will be slightly improved as the revolutions decrease and the diameter is made greater.

In electrical work the design of generators almost invariably admits of very convenient speeds, but, in marine work, the size of propeller necessary to avoid cavitation imposes a much lower limit, with which the size of the turbine is greatly increased. The minimum size of propeller required to avoid this phenomenon (and its attendant inefficiency due to increased slip and consequent loss of thrust at the higher powers), *must* be calculated at the beginning of any design, as it is almost impossible to assume certain revolutions, and later on to design a propeller to suit.

Cavitation is partly the result of attempting to obtain too much work per square foot of blade area, and partly of excessive peripheral speeds. It has been found, by bitter experience occasionally, that there is a narrow limit to the tensional pressure possible on the water, per unit of projected area, beyond which the propeller efficiency drops very rapidly. This pressure is approximately from 10 to 12 lbs. per square inch at a depth of twelve inches below the surface, and to reduce the total thrust to this, sufficient blade area must be provided, which, in conjunction with certain practical proportions, necessitates a certain size of propeller, thereby limiting the revolutions.

Friction and slip constitute the normal losses in all propellers, and augmented resistance must also be taken into account. This latter loss, however, is materially reduced with the smaller diameters of propeller found in turbine work. Comparing the "Manxman" with the "Ulster"—a Holyhead mail boat of similar speed and power—the total disc area of the twin propellers of the latter is 226 square feet (for two 12 feet diameter propellers), while that of the "Manxman" is only about 80 square feet. If the thrust deduction is proportional to the absolute area of the disturbance of the stream lines at the stern, the effect on the "Ulster" will be far greater than on the "Manxman," but this action is to some extent affected by the intensity over the disturbing area which again is modified by the proximity of the propellers to the side of the vessel, this being less in turbine work. The disc area in H.M.S. "Velox" is less than half that of the propellers in ordinary destroyers of the same power and speed. Cavitation is a preventable loss, and its presence on many vessels with insufficient blade area may be deduced from the falling off of the thrust curve and the rapid rise in the slip curve above a certain speed.

From the analysis of numerous trials it appears that the pressure per square inch of projected area, when reduced to twelve inches immersion of tip, due to the effective thrust, is approximately 1 lb. for every 1000 feet per minute of circumferential velocity of blade tips. For a screw of a given pitch ratio, working at its maximum efficiency, this velocity should be proportional to the designed speed of the ship, and at full speed the pressures seem to have hitherto been about 5 lbs. per square inch for slow cargo vessels, from 6 to 7 lbs. for ocean going mail steamers, and from 7·5 to 8·5 for cross-channel steamers; in cruisers and battleships they vary from 8 to 10·5 lbs. in some recent notable instances, and in torpedo craft from 9 to 11 lbs. At about 9 lbs., rather less possibly, the lowest suitable limit is reached for turbine screws; from 10 to 11 lbs. may be more usual in fast vessels, and though even from 12 to 14 lbs. has been known, pressures over about 11 lbs. always seem to be accompanied by low efficiencies. In large ocean going vessels, which may be delayed by head winds and seas, a much lower designing pressure should be used, but, in destroyers, as suggested above, something may be sacrificed at the maximum speed to obtain other advantages. The above pressure is worked out as mean pressure, as there exists no method of determining the local intensity per square inch, though the tendency of the distribution may be assumed in some cases. The only published results are in Barnaby's papers on the trials of H.M.S. "Daring," but they are very inconclusive in many ways. Fig. 1 is submitted with much diffidence, merely as an illustration of the values of this limiting pressure.

The maximum peripheral speed of tip ever used, I think, was 12,400 feet per minute in H.M.S. "Viper;" in H.M.S. "Velox" it is about 11,650, and in the "Londonderry" about 11,760, but many vessels have been below 9000, which is quite normal for ordinary destroyer practice.

The pitch ratio for turbine propellers has been purposely made considerably finer than usual. Thus, the pitch ratio for the "Emerald" was about 0·6; in channel steamers and cruisers of from 18 to 25 knots, it has varied from 0·8 to 1·0, and in torpedo craft from 1·0, in H.M.S. "Velox" to 1·35 in H.M.S. "Viper," and 1·6 in H.M.S. "Cobra"; the latter vessels having 1, 2, and 3 screws per shaft respectively driven by identical turbines, the approximate revolutions at full speed being 900, 1200, and 1050, for 27, 36, and 31 knots respectively on trial.

The percentage of slip has varied from 28 per cent. in H.M.S. "Viper," down to about 14 per cent. in the "Viking"—channel steamers usually having about from 17 to 24 per cent. For large ocean going vessels, about 16 to 20 per cent. may be used with due regard to other considerations of propeller efficiency. The section of the blades should be carefully designed in order to try to obtain a shape that will enable as high a mean pressure as possible to be adopted. Recent experiments in the model tank at Washington, D.C.,* seem to show that a symmetrical section, as shewn in Fig. 2, will materially increase the pressure at which cavitation commences, and also demonstrate that in fine-pitch high speed screws the back of the blade should receive almost as much attention as the face. This, as the author is well aware, is no new idea, but there have been repeated indications, especially in the trials of ordinary torpedo boat destroyers, that while the gain may not be great, it is sufficient to merit attention. Mr.

* See D. W. Taylor's paper, American Soc. N.A., 1904.

Parsons has advocated a 10 per cent. reduction of pitch at the blade tip in order to avoid excessive local thrust, which might induce early cavitation, but there seems to be no advantage from departing from a true screw. The tendency of late years, in reciprocating engine practice, has been to increase the ratio of projected to disc area from the ·2 of Froude's classic screw, and the ·22 to ·26 of naval practice, to about ·33; destroyer practice is included between this and ·37, or even ·4, at which point turbine practice may be said to commence. In this, even from ·5 to ·56 has been used, but beyond, about ·58 blade interference becomes excessive, and to obtain greater area a larger diameter must be used.

The best form of blade is still undetermined. In the photo of the stern of the "Lorena," Fig. 3, will be seen the usual shape adopted, and experience seems to show that this almost circular shape, with the area disposed symmetrically on each side of the centre line, and with the generating line of the screw at right angles to the axis, gives as good results as any form.

I find that the following formula will give the diameter of a turbine propeller with considerable accuracy when the effective thrust along the shaft is known, and this must be calculated in any case if the steam balance of the turbine is to be good:—

$$\text{Diameter of propeller in feet} = \sqrt{\frac{\text{Effective Thrust in lbs.}}{\text{Coefficient}}} = \frac{\sqrt{T}}{C}.$$

This coefficient has been deduced from the limiting pressure per square inch, and the ratio of projected to disc area, and is given in diagram form, in Fig. 4, where the full coefficient 400 – 900 is given in the left hand scale, and values of C or $\sqrt{\text{Coefficient}}$ appear in the right hand margin. The square root is only extracted for simplicity whereby such coefficients as 30 are obtained for H.M.S. "Viper"; while for the "Manxman," that for the centre screw is 26·4, and for the wing screws about 28·75. For large ocean going vessels with lower designing pressures these values will be rather less, perhaps about 22.

The following table gives a few propeller dimensions and the corresponding coefficients, which the Author trusts will be of use in designing high speed screws.

TABLE I.—PROPELLER DIMENSIONS.

VESSEL.	TYPE.	No. of Screws.	Diameter.	Pitch.	Pitch Ratio.	Speed of Tip.	C (Approximate).
			Ft. In.	Ft. In.		Feet per min.	
Turbinia, ...	Experimental	9 3	1 6 2 4	2 0 2 4	1·33 1·0	10,860 —	28 * 31·3 *
Viper, ...	T. B. D.	8	3 4	4 0 ford. 4 6 aft.	1·2 1·35	12,350	30·1
Amethyst, ...	3rd Class Cruiser	3 { 1 2	6 6	6 6 5 10	1·0 ·898	9,200 10,000	30·8
Manxman, ...	Cross Channel Steamer	3 { 1 2	6 2 5 7	5 7 5 0	·906 ·896	10,270 10,760	26·4 28 75
Londonderry, ...	,,	3 { 1 2	5 0	4 6	·9	10,550 11,810	30·8
Dieppe, ...	,,	3	5 3	4 6	·857	10,100 10,400	29
Carmania, ...	Atlantic Mail	3	14 0	13 0	·928	8,125	21
Victorian, ...	Intermediate	3†	9 6	8 6	·895	8,050	21·1

* These C values are calculated from the same effective thrust in each case.
† Original propellers, four-bladed.

Compared with above values of C, reciprocating engine practice gives such figures as:—R. M. S. "Lucania," 16·5; H. M. S. "Diadem" class, 17·5; H. M. S. "Exmouth" class 19·0, and standard 30-knot destroyers of 6100 H.P., 20·8; all of which have much lower ratios of projected to disc area, and therefore a larger diameter and smaller C for a given power. Regarding these figures, it must be understood that C is an approximation only, and owing to the difficulty of obtaining the actual power in each shaft in every case, cannot be considered as absolutely accurate. Probably, however, the error involved is under 2 per cent. It seems likely, to some at present undeterminable extent but within narrow limits for each class of vessel, that the propeller efficiency is proportional to the coefficient C, and this seems to be borne out by the trials of the "Manxman" and the "Londonderry."

Effective thrust is a somewhat subtle subject, and our knowledge of propulsive efficiency is by no means what it ought to be. These considerations will undoubtedly be brought into far greater prominence in the near future, and it is by no means improbable that the Admiralty or certain private owners will require some definite standard in this, just as coal or steam consumption is regulated at present. The more propeller efficiency is studied and understood the greater will be the improvement in the design of turbine installations for marine work; the turbine itself is a comparatively secondary consideration, and while at present propeller dimensions for turbine steamers can be quite as closely determined as those for ordinary work, the exact proportions must necessarily largely remain subject to modification from actual experience.

While a general tendency has been very noticeable towards increasing the propeller diameter and reducing the revolutions, there will of course be some point, at present undetermined, at which the triple screws used in turbine work will be distinctly less efficient than ordinary twin screws. Very largely, this is the case at present with triple screws driven by piston engines, on account of excessive thrust deduction and interference, but probably before this point is reached the weight of the turbines will have prevented its adoption.

Having obtained the diameter of the propeller and the revolutions possible, the design of the turbine can then be undertaken, but for this no formulæ exist at present, such as are met with in reciprocating engine practice.

Restricting attention to the design of the Parsons type of turbine, a few notes on the action of the steam among the blades may be of interest. Expanding through a definite range of temperature and pressure, steam exerts the same energy, whether it issues from a suitable orifice or expands against a receding piston. Two transformations of energy take place in the steam turbine—first, from thermal to kinetic energy; secondly, from kinetic energy to useful work. The latter alone presents an analogy to the hydraulic turbine, the radical difference between the two lying in the low density of steam compared with water, and the wide variation of its volume under different temperatures and pressures.

Fig. 5 gives a sectional elevation of a marine turbine blading arrangement, and though this is only for an H.P. cylinder the principle is exactly the same throughout. The expansion, which is approximately adiabatic is carried out in this annular chamber from A to B, which essentially resembles a simple divergent steam nozzle, but with this difference, that whereas in a nozzle the heat energy of the working steam is expended upon itself in producing high velocities, in Parsons' turbine the total expansion is subdivided into a number of steps, in each of which a certain dynamic relationship between jet and vane is maintained. The expansion of steam at any one stage is typical of its working throughout the turbine. Each stage consists of a ring of stationary blades which give direction and velocity to the steam, and a ring of moving blades that immediately convert the energy of velocity into useful torque. The total torque on the shaft is due to the impulse of steam entering the moving blades and to reaction as it leaves them, this process being repeated throughout the turbine.

Leakage past the revolving portion of the spindle at D is almost entirely prevented by the ingenious form of frictionless packing, shown on a larger scale in Fig. 6. The fine clearances and the sudden increase of section have the effect of alternately wire-drawing and expanding the steam, so that at successive grooves it becomes increasingly difficult for the steam to leak past the fine clearances. In the astern turbines, a radial form of packing, depending on fine tip clearances, must be adopted owing to the difference in expansion between spindle and cylinder. Numerous varieties of these forms of packing exist, some of them being extremely efficient in their action.

The laws governing the best theoretical velocity of steam and blades are similar to those for water turbines, but in practice some modification is necessary, and the best ratio of blade speed and steam speed is still a matter of opinion. The ideal condition for impulse turbines occurs when the peripheral velocity of the buckets is one-half that of the jet, or in reaction turbines, when it is equal to it.

Parsons' turbines, however, have been built with Vt, Fig. 7, varying from ·25 to ·85 of Vs, where Vt represents blade velocity at mean diameter, and Vs the steam speed due to expansion across the row in question. A very usual ratio in electrical work for large units has been $\frac{Vt}{Vs} = 0{\cdot}6$, but this involves a greater number of rows than is possible in marine work, and the ratio must be reduced. These ratios need very careful calculation. The steam consumption must be accurately known in order to proportion them correctly throughout the turbine, and the necessity, (which is inevitable with the present form of caulking piece,) of having the same area of openings in so many rows while the steam volume increases so rapidly, adds to the difficulty of close calculation. The potential energy of the steam, corresponding to the "head" in water turbines, can easily be calculated for given pressure differences.

$$\text{B. Th. U.} \times 778 = \text{Energy in foot lbs. per lb. of steam} = e.$$

$$Vs = 8\sqrt{e} = 223\sqrt{\text{B. Th. U.}}$$

For a given blade velocity, it is obvious, then, that the speed ratio between jet and vane must affect the number of stages, and the greater the ratio of V_t to V_s the greater will be the required number of rows, that is, to obtain the required V_s at each stage a smaller pressure drop per row is necessary, or *vice versa*.

The best blading arrangement, scientifically and commercially, is the result of much theory and practice. The mean diameter is an arbitary dimension capable of wide variation without affecting the efficiency, provided that the number of rows is correct; it is found by assuming, from experience, a blade velocity, whence—

$$\text{Mean diameter in inches} = \frac{\text{Blade velocity in feet per sec.} \times 228}{\text{R. p. M.}}.$$

To arrive at the corresponding number of rows, the revolutions being given, the ratio of V_t to V_s must be settled, from which the steam speed can be obtained; it is a convenient assumption at the beginning of any design to consider the turbine as parallel throughout and of constant efficiency, and to design on this basis. The number of rows N on one diameter can be found by working out the B. Th. U's. necessary to give a certain steam speed at each row, see Fig. 8; the available energy divided by the energy it is desired to abstract at each row will give the number of rows required. This result may be arrived at by various ways, but the principle involved is the same in each case. Numerous empirical coefficients for approximating steam speeds and the corresponding number of rows are obtainable from experience, and are similar in use and value to the Admiralty coefficient, that is, while they represent a crude method of doing something that should be done more scientifically, they are very simple and capable of rapid handling. Being, however, based on long and costly experiments, much reticence is observed regarding their publication. Varying, of course, with the steam pressure and vacuum, the number of rows on one diameter would involve an excessive length of turbine and also inconvenient blade heights. It is, therefore, usual to divide the rotor into three or more stages, which has the advantage of shortening the turbine and reducing the number of rows. If n = the fraction of power developed in the first cylinder or barrel, $\frac{N}{n}$ = number of rows in the first barrel, and with the alteration of diameter and increase of blade velocity in the succeeding stages, the number of rows on other barrels are so altered as to keep, for equal powers and efficiencies :—

$$(\text{Blade velocity})^2 \times \text{No. of rows} = \text{Constant.}$$

The vane speeds adopted in practice vary considerably; for some time 100 feet per second was regarded as a standard for the first row, and I think the Westinghouse Co. at Pittsburg was first to make a radical departure in this and adopt far higher speeds. The maximum vane speed used for Parsons' blading is, as far as I am aware, about 375 feet per second in the low pressure blades, and 170 in the high pressure blades of electrical turbines; the lowest speeds used are in marine work, and are only about one-third of these. To some extent blade speed is governed by blade height; the speed should be so modified that this may be at least three per cent. of the mean diameter to reduce the proportion of clearance losses. Leakage over the tips of the blades is perhaps not so detrimental on account of actual leakage loss as in its superheating effect on steam between the row past which it leaks and the last row, because this reheating effect upsets calculations regarding openings by increasing the steam volume, and thereby affects the fluid efficiency. This leakage over the tips must be taken into account in designing reaction turbines. Temperature and diameter influence the clearance, and the stiffer the cylinder is to resist distortion due to heat the less it may be made. A clearance diagram based on measurements off a large number of machines is given in Fig. 9.

In Table II., the vane speeds adopted in various classes of work are given, and the reduction in peripheral speed on account of the propeller reducing the revolutions, and the necessary proportion of blade height modifying the diameter may be clearly

TABLE II.—MARINE WORK.

TYPE OF VESSEL.	Peripheral Vane Speed		Mean Ratio of $V_t - V_s$.	Number of Shafts.
	H.P.	L.P.		
High speed mail steamers	70- 80	110-130	·45-·5	4
Intermediate do.	80- 90	110-135	·47-·5	3 or 4
Channel Steamers	90-105	120-150	·37-·47	3
Battleships and large cruisers	85-100	115-135	·48-·52	4
Small cruisers ...	105-120	130-160	·47-·5	3 or 4
Torpedo craft	110-130	160-210	·47-·51	3 or 4

ELECTRICAL WORK.

Normal Output of Turbine.	Peripheral Vane Speed		No. of Rows.	Revs. per Minute.
	1st Expansion.	Last Expansion		
5000 K.W.	135	330	70	750
3500 K.W.	138	280	75	1200
2500 K.W.	125	300	84	1360
1500 K.W.	125	360	72	1500
1000 K.W.	125	250	80	1800
750 K.W.	125	260	77	2000
500 K.W.	120	285	60	3000
250 K.W.	100	210	72	3000
75 K.W.	100	200	48	4000

seen. To this combined action is due the fact that only in the faster classes of vessels, or in those small types in which some propulsive efficiency can be sacrificed, is the turbine applicable. In slow cargo steamers, though the revolutions may be high enough, the power required is not sufficient to enable a reasonable blade height to be adopted, and it is this consideration, viz., proportion of leakage over blade tips—that curtails the wider adoption of this type of turbine. For the same low peripheral blade speed, other types of turbine are unsuitable on account of the impossibility of reducing the steam velocity sufficiently without abnormal weight and inefficiency.

The smallest size of marine turbine is usually larger than the average electrical turbine as far as power is concerned, and therefore does not meet with the same commercial considerations as the smaller sizes of the latter type. These are not designed for the same internal efficiency as the larger machines, chiefly on account of manufacturing cost, and they do not attain anything like the same efficiency compared with the Rankine cycle.

Speaking in reply to the discussion on his paper to the Institution of Naval Architects in 1903, Mr. Parsons said that, "for all practical purposes, while the steam is traversing each set (of blades) as shown, it behaves like an incompressible fluid, just like water would do, as the expansion is very small at each set. The frictional losses and the eddy-making losses would be practically identical within small limits with what they would be with water, and the actual forces would be in proportion to the density of the medium. . . . In the turbine blades themselves, the efficiency is between 70 and 80 per cent."

Using this hydraulic analogy enables one to calculate the number of stages required in a different manner: the "equivalent head," due to the steam pressure, may be found, together with that at each row necessary to give the required velocity, from which both the number of stages and the coefficient of expansion at each stage may be worked out.

In the early marine designs, such as the "Queen Alexandra" and

H.M.S. "Amethyst," the turbine drums were all made of the same diameter, and the higher speed necessary on the L.P.'s was got by running at considerably higher revolutions than on the H.P. shaft; but, following up the increase in propeller efficiency found to be due to the use of larger screws the speed for each shaft is now more nearly equal, while the wing drums are made larger in diameter. The vagaries of the following wake, however, necessitate slightly different propeller dimensions on each shaft, or else slightly different revolutions with the same screws; and it is noticeable that in a triple-screw arrangement, the centre screw being right-handed and the wing screws revolving outwards, that the starboard propeller is influenced by the centre one, and almost invariably revolves at a lower speed. In a four-shaft design, due to the varying wake values at different speeds, and possibly, also, to some unequal distribution of power, the outer screws run slower at low speeds, and faster at high speeds than the two inner shafts, but exact data as to this, and the possibility of allowing for it in the design, are still wanting.

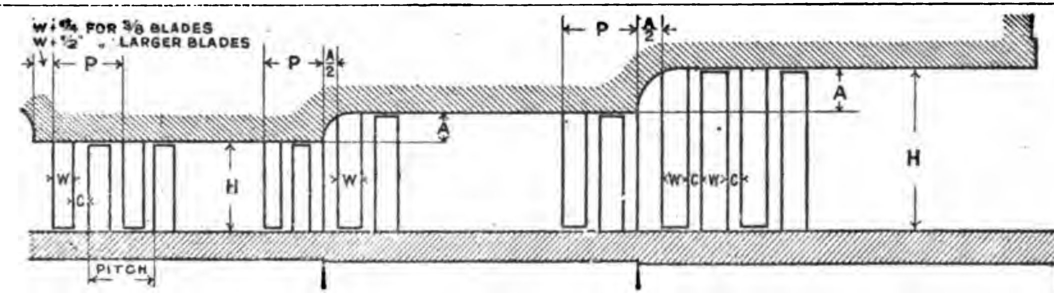
In all types of turbines—Parsons', Rateau's, Curtis', &c.—a certain ratio must be maintained between the blade velocity and steam velocity, and as steam acquires very high velocities by expansion, the blade velocity must be maintained either by the revolutions or by large diameters, or both. As the weight inincreases very rapidly with the diameter, and extraordinarily so with the reduction in rotative speed, it is preferable to increase, if possible, the revolutions or the number of stages rather than the diameter, and especially should this be done in cases where, as in the Rateau or Zoelly types, the weight increases more rapidly in inverse proportion to the R.P.M. and the diameter than it does with other types. To increase the revolutions, it may be necessary to increase the number of shafts and propellers, thus reducing the power per shaft and the effective thrust through each screw. Increasing the diameter of the turbine adds largely to the constructional difficulties, especially of the cylinder.

Having obtained the number of rows and the diameter, the blading arrangement can be worked out in detail. The height of blade depends on the volume of the steam and the speed at which it is to flow, and also on the ratio of the area of exit openings between the blades to that of the annulus between spindle and cylinder, which is about one-third in normal blades. The necessary clear area to pass the steam being equal to volume ÷ velocity, and knowing this annular factor, say 3, for a ratio of one-third (or 2 for ½, etc.), then

$$\text{Height of blade in inches} = \frac{\text{Clear area in square inches} \times 3.}{\text{Mean circumference in inches.}}$$

The ratio of blade height to mean diameter should not be less than 3 per cent. or more than 15 per cent., because in the former the leakage will be excessive, and in the latter the bending moment on the blade becomes too great, and the radial divergence of the blades too much. The width of blade, the shape of section adopted, and the circumferential pitch, are standard considerations, and affect the factor 3 given above. It is not proposed to enlarge upon them in this paper. It may, however, be remarked that for $\frac{Vt}{Vs}$ greater than ·6 the usual shape of Parsons' section, as shown in Fig. 5, should be modified to a somewhat different form of blade, with a sharper entrance edge. This section is not to be recommended, as, owing to the necessity of strengthening the blade sufficiently, the metal must be placed nearer the exit edge, thus increasing the angle between the face and the back of the exit edge of the blades, and giving, in fact, an inferior shape of opening compared with that obtainable with a blade section adapted to ratios under ·6. If, for the present, it is sufficient to use the blade sections and packing pieces similar to those now adopted so generally, in Table III. can be found a list of widths for a given height, and the axial spacing of the rows. While this must be kept down to reduce the length of drum, it must be sufficient to allow for some play in overhauling; and sufficient clearance can be allowed here without affecting the economy. The openings

TABLE III.—STANDARD BLADING DIMENSIONS.



Height (H)...	1″	2″	3″	4″	6″	8″	10″	12″	15″	18″	21″	24″	30″
Width (W)...	$\frac{3}{8}$″	$\frac{3}{8}$″	$\frac{3}{8}$″	$\frac{1}{2}$″	$\frac{1}{2}$″	$\frac{5}{8}$″	$\frac{5}{8}$″	$\frac{3}{4}$″	$\frac{3}{4}$″	1″	1″	$1\frac{1}{8}$″	$1\frac{1}{4}$″
Pitch (P)...	$1\frac{1}{8}$″	$1\frac{1}{8}$″	$1\frac{1}{4}$″	$1\frac{5}{8}$″	$1\frac{3}{4}$″	$2\frac{1}{8}$″	$2\frac{1}{4}$″	$2\frac{1}{2}$″	$2\frac{5}{8}$″	$3\frac{1}{8}$″	$3\frac{1}{4}$″	$3\frac{5}{8}$″	4″
Axial clearance (C) ..	$\frac{3}{16}$″	$\frac{3}{16}$″	$\frac{1}{4}$″	$\frac{5}{16}$″	$\frac{3}{8}$″	$\frac{7}{16}$″	$\frac{1}{2}$″	$\frac{1}{2}$″	$\frac{9}{16}$″	$\frac{9}{16}$″	$\frac{5}{8}$″	$\frac{11}{16}$″	$\frac{3}{4}$″
Section Number													
Spindle Packing Piece No.													
Cylinder, do.													

Note.—While the above represents general practice, it is obvious that such a table is largely arbitrary between the blades to allow of the passage of the steam are very important, and must be carefully designed. The actual volume of the steam—not the volume per lb., as found in tables, or the volume due to adiabatic expansion, but the exact volume per lb. at any point along the turbine—must be determined, in order to arrive at the desired adjustment of velocities. It is extremely doubtful whether the present blading arrangements give the best results; greater accuracy of calculation and consequently improved pressure distribution and efficiency seem likely to follow the use of a more mechanical blading construction.

Fig. 10 shows the percentage error involved in using either the dry volume, or that due to adiabatic expansion, compared with the correct volume corresponding to the actual expansion in a large turbine using dry saturated steam at the first row of blades and 27 inches vacuum. Attention must be paid to the effect of approximately adiabatic expansion and the consequent moisture in the steam.

For manufacturing convenience, as well as to allow for the expansion of the steam, the blade heights are stepped up, but no rule exists for this; the blades might be of one, or of sixty-four heights, provided the blade openings are correct. It is, however, convenient to step them, as in Fig. 5, say, in 8 steps of 8 each, or 4 of 16—even 9 of 7 would do—and so avoid any great variation from the annular area factor 3 as shown above. To obtain heights and areas, it is best to plot off graphically, volumes, steam speeds, and clear areas required. The use of standard blade heights will then enable the number of stages and rows per stage to be determined: wide differences can be made in any arrangement without materially affecting the economy. The best arrangement is largely a matter of convenience and experience.

The material of which blades are usually made is a mixture of cheap brass containing about 16 parts of copper and 3 parts of tin. Alloys containing zinc are extremely unreliable for high temperatures, but blades containing about 98 per cent. of copper have been found very satisfactory for use with high superheats. More recently a material containing about 80 per cent. of copper and 20 per cent. of nickel has been adopted, and this is undoubtedly the best blading material existing. Steel blading, drawn in the same way as the usual brass section, has been used in the United States with fairly good results. The process of drawing turbine blades gives an extremely tough skin to the metal used, not only increasing the tensile strength, but greatly decreasing the chances of erosion.

It seems probable that the usual caulking piece now adopted will be discarded in favour of a machine-divided strip into which the blades may be fitted, and instead of the slotting, wiring, lacing, and soldering process at the tip, a similarly machine-divided shroud will be used, giving a far stronger construction, and enabling finer clearances and better workmanship to be obtained; at the same time considerably reducing the cost of manufacture, and the risk of blade stripping.

The chief causes of the latter may be set down to bad workmanship in fixing the blades, defective blade material, excessive cylinder distortion (this is probably the most fruitful cause, and is a serious one, being due to bad design), whipping of turbine spindles (which is also due to bad design, or bad balancing), wear of bearings (which is very remote), and the introduction of extraneous substances such as water or grit. In fact, blade stripping may be said to generally occur from preventable causes. Small vibrations of very high frequency occasionally set up an action in certain rows of responsive length that fatigues the blade material and causes the loss of blades without any fouling at all.*

Due to the action of the steam, an end thrust occurs in the direction of the propeller, which is advantageously used in partially balancing the propeller thrust, thereby reducing the size

* The writer had experience of this early in 1905 when a 5000 k.w. turbine, under test in one of the large New York power stations, shed several rows of blades. This difficulty has also occurred in Europe, and can be circumvented by an alteration in the position of the lacing strip.

of thrust block necessary. A margin must be allowed here, and the propeller thrust is not entirely balanced by the pressure on the annulus between the dummy-ring diameter D, and the spindle C, Fig. 5, plus the end pressure on the blades. For the diameter D to give the required annulus, as well as that of the propeller, the effective thrust must be carefully calculated; and experience shows that there is a drop in steam pressure varying from 10 to 15 lbs. per square inch between the pipe inlet to the H.P. receiver and the first row of blades, which should be considered in designing this balancing area. The number of rows of dummy packing used varies according to the designer's judgment very largely, and may be modified according to the pressure and the clearance allowed—say a 7-1000th to a 15-1000th of an inch in electrical work, and rather more in marine work.

The dimensions of the astern turbine are arrived at in the same manner as those of the ahead, the efficiency being largely sacrificed on account of weight and space, generally, the mean diameter is made practically the same as that of the H.P. drum.

To a large extent, the inferior manœuvring capabilities of the earlier turbine steamers were due to insufficient astern power.

It may be remembered that in a marine turbine the spindle is in compression and the cylinder in tension when working. In electrical turbines where the end thrust must be eliminated by the use of balancing pistons, the spindle is in tension and the cylinder is balanced. The shafts between the turbine bearings and the drum must be made amply stiff enough, as well as strong enough, for any sag in the spindle will destroy the clearance. As will be seen from Fig. 11, the stresses due to centrifugal force are very low in the Parsons' turbine, and except in occasional L.P. barrels do not exceed about 7,500 lbs. per square inch, while at the H.P. end they are usually under 2,000.

The pressure on the bearings in a turbine is only due to the weight of the spindle, plus the negligible addition in marine work of that due to any gyroscopic action; it may be taken as from 80 to 90 lbs. per square inch as long as the rubbing velocity does not exceed 30 feet per second. If it does, the pressure must be reduced so that the product of pressure × velocity does not exceed 2500-2700. In land work, 50 lbs. × 50 feet is very common. The friction heat of the bearings added to that due to conduction through the pedestals necessitates the use of large oil coolers, and in the case of very high temperatures, of special kinds of oil. If possible, the bearing temperature should not exceed from 140 degrees to 150 degrees F., though the writer has known of 190 degrees F. being used without trouble. In marine turbines this temperature is usually much lower. Rigid bearings are used for marine spindles, not the flexible type adopted in land work.

Space does not permit of more than passing reference to cylinders; but it would be difficult to exaggerate the importance of very careful design in this connection. Cylinders, with heavy flanges on the centre line, distort in a very curious fashion when heated with their axes horizontal, and measurements taken off a hot cylinder on a surface plate with micrometer gauges reveal some very remarkable facts. When working, the temperature along the cylinder falls possibly from 400 degrees to 100 degrees F. in a distance of 6 or 8 feet, and, unlike the reciprocating engine, this remains constant; the radial expansion is consequently more at one end than the other; while at any point along the turbine the tendency is to expand less at the flanges than at the top and bottom. For this reason ample clearance must be allowed; exactly what this will be when spindle and cylinder are hot is hard to say, but it seems most likely that the total clearance area will differ but little from what it is when cold.

The longitudinal expansion when hot is often very marked, and in all turbines necessitates provision for the resultant movement at one end. In marine work the after end of the cylinder is secured to the vessel, the engine seating also performing the function of a thrust-block seat, while the forward end slides forward, taking with it the entire shafting. The thrust block is at the forward end of the cylinder, and also performs the duties of an adjustment block for setting the longitudinal clearances, to do which generally necessitates uncoupling the shafting abaft the turbine.

The difference in expansion between the cylinder and spindle, from the thrust block to the dummy ring, may be the cause of serious difficulties in large marine turbines, unless the closest attention is paid to this feature in the design; and "warming up" with these large cylinders needs possibly even more care than is essential with large piston engines.

On shipboard, the turbine cylinders are practically under one's feet, and the radiation from them is very unpleasant, especially if there is any leakage from the glands. To all who are responsible for the lagging of cylinders and the system of ventilation in turbine engine rooms I would call attention to the possibility of their having to stand a watch of from 4 to 6 hours on the top of the H.P. cylinder, such as in the case in H.M.S. "Eden" or H.M.S. "Amethyst," the heat in the latter vessel being almost unbearable. With reciprocating engines, one stands on a comparatively cool lower platform with the cylinders overhead, and with some chance of the hot gases rising clear, but in naval turbine work, under a low deck, this point has not met with adequate attention.

In the course of operation, more especially in marine work where no superheaters are used, there is a distinct tendency for the turbine to be supplied with wet steam, the effect of which on the economy is very marked. Experiments that have been made, show that the percentage increase in consumption is about twice that of the moisture in the steam. For instance, with 2 per cent. of moisture in the steam at the first row, the consumption is increased about 4 per cent.

A considerable amount of data on the performance of turbines compared with reciprocating engines for marine work, is now available. The Admiralty has had tested both cruisers and torpedo-boat destroyers, exactly similar but for their engines and propellers, and trials of the Midland Railway Company's steamers and other cross-channel boats have corroborated the results regarding economy obtained from the naval vessels. In Fig. 12 is given the steam consumption per unit of power of H.M.S. "Amethyst"* compared with that of several recent warships, and it is noticeable that only below from 55 to 60 per cent. of their full speed does the consumption of the turbine exceed that of the piston engines. Very seldom do vessels steam below these speeds. Cruisers carrying relief crews to the China or Australian stations usually proceed at about 60 per cent. of full speed, and in the Atlantic manœuvres of 1903 nearly 80 per cent. of full speed was maintained by the large fleets, whilst the Japanese battleships built in England made their first voyage to Japan at about 54 per cent. of their full speed; at which ratio the consumption per I.H.P. of both the "Hindustan" and "Dominion," representing very recent battleship construction by eminent builders, is materially in excess of that of the first installation of warship turbines (not including the destroyers). The total consumption of H.M.S.'s "Amethyst" and "Topaze" plotted on a base of power is given in Fig, 13, while Fig. 14 shows that for the Midland Railway boats.† The progressive trials of H.M.S. "Amethyst" are shown in Fig. 15, and, in view of the results obtained from these various vessels, the wholesale adoption of turbine machinery in the Royal Navy is not surprising.

It is probable that the adoption of cruising turbines will be discontinued before long, and this view seems to be corroborated by the consumption trials of the Midland Railway steamers. Down to 60 per cent. of her full speed, the "Manxman" required less water than the highly efficient "Antrim," and with a different blading arrangement in the

* Since the above-mentioned results were obtained, the steam piping has been altered so as to permit the auxiliary exhaust steam to pass through the main L.P. turbines when desired. This arrangement considerably decreases the consumption at low speeds, bringing the "Amethyst's" consumption below that of her sister ships down to ten knots, or about 45 per cent. of full speed.

† Fig. 14 is compiled from the results given in Mr Gray's paper to the Institution of Naval Architects, July 1905.

main turbines, such a result should be equalled, if not improved on, in war vessels. The additional complication involved with two cruising turbines and their accompanying leakage and receiver losses, together with a considerable increase in weight and space occupied, largely modifies any advantages obtainable in the way of reduced consumption at lower powers. An improved (and easily obtainable) design of main turbine blading should give a better result at the highest powers, practically the same at intermediate powers (as in the case of H.M.S. "Amethyst," from fourteen to twenty knots), and only slightly inferior at speeds below fourteen knots, while it will undoubtedly admit of greater ease of handling and be much simpler. In a triple-shaft arrangement the unequal distribution of power on the wing shafts, due to the use of cruising turbines, is a distinct disadvantage; the fluctuation in rotative speed, due to shutting off the H.P. cruising turbine, may be seen from the trials of H.M.S. "Amethyst."

One of the L.P. rotors of the Allan Line steamer "Victorian," is illustrated by Fig. 16. This rotor is 8 feet in diameter, and carries 80 rows of blades, varying successively from 1½ inches to 7 inches in length.

Fig. 17 shows the complete blade rings of a Willan's turbine, the machine divided construction of which, coupled with the strong form of shrouding adopted, presents such great advantages over the present unmechanical system that its universal adoption may be expected in the near future.

In conclusion, the writer would remark that it is impossible in the scope of a paper such as this, to touch more than lightly on a subject which is of such vast importance. Many of the points dealt with above, such as cavitation, blading, cylinder design, etc., would require a volume to describe. While turbines perhaps are still in their infancy, they are already largely supplanting the reciprocating engine in many types of vessel. The next few years will undoubtedly show as great an improvement as has taken place since the advent of the "King Edward" barely five years ago, the more especially as the subject will, henceforward, be engaging the attention of all engineers instead of a few specialists, and that this improvement will more than justify the policy of the Admiralty and of the Cunard Company is already certain.

It should be a matter of some satisfaction to the members of this Institution that the present status of the marine turbine, if not absolutely due to the Clyde alone, is at any rate entirely a product of Great Britain.

Discussion.

Mr E. G. Izod (Rugby), speaking as an ex-marine engineer, said he thought it was very evident that the turbine was the only engine of the future for marine work, though no doubt progress would be so rapid that it was probable that the design of a marine turbine installation of ten years hence would very materially differ from that adopted at the present day. Mr Speakman and himself had worked together on the turbine question, and he could assure the Members of the Institution that Mr Speakman had very closely studied the problems relating to propellers and turbines with a view to obtaining better efficiencies in the propulsion of large and small vessels, and he quite thought that the information contained in the paper, which they had just listened to, would make those interested take a deeper and more careful view of this, one of the most important changes in the annals of marine engineering. He quite agreed with Mr Speakman's remarks that no information was forthcoming from those who had been building turbines; and while, no doubt, the reticence displayed was justifiable from the point of view that such experimental work was a commercial asset they did not wish to part with, yet one could not help feeling that such reticence was perhaps impairing the chance Britons had of making their turbines, as their reciprocating engines were, second to none in the world. However, he hoped that the extraordinary keeness now displayed by marine engine builders in this new class of work would result in the success which they undoubtedly deserved. Mr Speakman had called attention to the

	REMARKS.
	each shaft.
...	
...	d for experimental trials.
& Co.	ng Naval Manœuvres in 1901. Trials made in 1900.
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& Co.	s, 7½", 11", and 16" × 9" stroke.§ 400 R.P.M. Launched 2/1902.
& White	
c. Hawthorn, }	
Co.	ift.")
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ay Co.	[illegible] being replaced by turbines.

Appendix.—May 1, 1906.

The following list gives the vessels, with turbine machinery, fitted and under construction (but not included in Table IV.).—

With Parsons' Turbines:—

		Knots.	H.P.
(*a.*)	2 Vessels for Great Central Railway Co., ...	18·5	6,500
,,	1 Vessel for Glasgow & South-Western Railway Co., "Atlanta,"	18·0	1,600
,,	1 Vessel for Caledonian Steam Packet Co., "Duchess of Argyll,"	20·0	3,500
,,	1 Vessel for General Steam Navigation Co., "Kingfisher,"	20·0	4,500
,,	1 Vessel for British India S.N. Co., "Rewa,"	—	—
(*c.*)	2 Vessels for New York & Boston S.S. Co., ...	20·0	10,000
,,	1 Vessel for Eastern S.S. Co., Boston, Mass.,	20·0	5,000
,,	1 Vessel for New England Navigation Co., ...	18·0	7,000
(*b.*)	6 Torpedo boat destroyers, G132-137, for Imperial German Navy, similar to S125, ...	—	—
,,	1 Cruiser, "Lubeck" type, for Imperial German Navy, ...	—	—
(*c.*)	1 Battleship (projected) for U.S. Navy, "Delaware,"	—	—

With Curtis' Turbines:—

(*c.*)	1 Vessel for Southern Pacific S. S. Co., s.s. "Creole," ... ... (415′-8″ × 53′ 0″ × 25′-0″ draught; 10,160 tons displacement; revolutions 250).	16·0	8,000
(*b.*)	1 Cruiser "Lubeck" type, for Imperial German Navy (projected), ...	—	—

With Zoelly Turbines:—

(*b.*)	1 Vessel for Baltic trade, built by Messrs. Howaldt, ...	13·0	1,000
,,	1 Vessel similar to s.s. "Kaiser,"	20·0	6,000

Two small experimental vessels have also been built:—

(*a.*) 1 by Messrs. Yarrow, similar to s.s. "Caroline," fitted with Fullagar turbines.

(*b.*) 1 by Vulcan Co. 60′-0″ × 9′-0″, fitted with Schultz turbines.

Note.—(*a*) Built in England; (*b*) in Germany; (*c*) in United States.

In addition to the above, numerous vessels are under consideration for the Government and leading private companies of France, Germany, Japan, and elsewhere.

Mr E. G. Izod.

sample ring of blading exhibited during the evening, and, speaking as a member of the firm which made its blading on this principle, he would like to point out that there were many advantages which accrued from the use of separately built-up machine-divided blade rings; as for instance, correct spacing of blades, correct angles and openings, increased facility for handling the blading and completing the necessary blading work before the rotor and casing were finished. One of the features of the system was the channel shrouding which gave extraordinary stiffness to the blade rings, and had the added advantage that if contact did take place between the revolving and fixed elements, no harm was done, as it was practically impossible to disturb the blading even under the severest conditions known at the present time—a factor of great importance in a marine turbine where absolute breakdown of any portion of the propulsive agent was to be avoided. He would, however, point out that this shrouding made a virtue of necessity, that was, it reduced the effect of contact to a negligible item; this, in his opinion, was hardly the way to tackle turbine problems, and he would advise most exhaustive tests being made on cylinder distortion with a view to annuling the cause, and hence the effect would disappear, he hoped, nearly entirely. The finer the clearance the better the steam consumption, but there were other ways of improving the efficiency of turbines just as important as reduction of clearances, which were too often neglected; for instance, the frictional losses in the blading were a most important item, and could be considerably reduced by a proper attention to blading materials and construction. He ventured to submit a small chart, Fig. 18, which showed where the most important losses occurred, and these losses, if considered carefully, could be minimized considerably. Concerning the actual blading strip itself, this could be improved considerably, and it was hoped that figures would be given later which would explain more fully how a great saving in friction losses was obtained. There was another vitally important matter to be considered in the manufacture of turbine machinery if it was to reach the excellence of the present marine reciprocating engine,

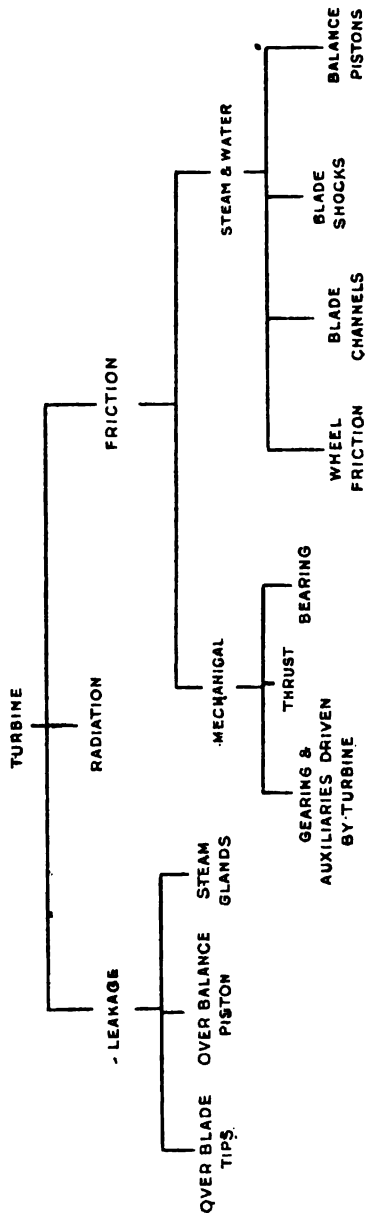
TURBINE
LEAKAGE
RADIATION
FRICTION
OVER BLADE TIPS
OVER BALANCE PISTON
STEAM GLANDS
MECHANICAL
STEAM & WATER
GEARING & AUXILIARIES DRIVEN BY TURBINE
THRUST
BEARING
WHEEL FRICTION
BLADE CHANNELS
BLADE SHOCKS
BALANCE PISTONS

Fig. 18.

hich was that men and methods would have to be revised and lapted to this special class of work; turbine manufacture to be success called for a much finer degree of accuracy and much ore careful workmanship than was accustomed to be met with the manfacture of big reciprocating machinery; and while he as confident that designers and workmen would rise to the ccasion, it was impossible to give too much attention to this, one the most important factors making for the ultimate success of e marine steam turbine. There was an all-prevailing thirst for formation on turbine design, but it must not be forgotten that e design was only the preliminary canter, as there were innumerble intricacies to be attended to in the manufacture and steaming hich were, if anything, more important than the actual design. He sincerely hoped a good discussion would be the result of Mr Speakman's valuable paper, and the great interest taken in steam urbines by the Members would, he felt sure, result in an exchange of opinions invaluable to the records of the Institution.

Mr John Ward (Vice-President) said it was a coincidence that most of the Members who could speak with weight and authority on the subject were at the present moment (together with the Members of the late Turbine Commission) guests of the builders and owners of the largest, and probably the most successful, turbine steamer yet built, viz., the "Carmania." Her official trial had commenced on the Clyde that morning, and would continue until she arrived at Liverpool. It was an open secret that the trials of the steamer on the Clyde during the past week had fulfilled in every way the highest expectations of all connected with her. That was a matter of great gladness to every Member of the Institution, but he also felt that it carried with it a tinge of sadness and regret, that the late Lord Inverclyde—the talented chief of the Cunard Company, who had such faith in the possibilities of turbine machinery, that he agreed to have it fitted in the "Carmania," and so judge it on its merits in Atlantic running — had not lived to see the trials which were just concluded and had been so successful. The paper contributed

Mr John Ward.

by Mr Speakman would, he was sure, prove of much value to the Institution. The Author showed a thorough acquaintance with turbine construction, and many of the deductions he made from that knowledge and from the data regarding ships' performances, which he had collected, were of much interest. Speaking of the turbine vessels built by Messrs William Denny & Bros., much of the data given by Mr Speakman could only be in the nature of an approximation, as none of it had been published by them, or others, as far as he knew. He did not, therefore, touch on the accuracy of the figures given, but there was one point which had not been taken up in the paper, and it was the question of power measurement in turbine vessels. While it was not easy to indicate turbines in the ordinary sense of the word, it was possible to determine the shaft horse power, namely, the power delivered to the propellers. The ability to do this, of course, gave them the power required to drive the vessel, and also the turbine efficiency, provided the steam consumed by the turbines was accurately measured. In addition to this, if one was provided with an experimental tank, extremely interesting results in screw problems could be obtained. For instance, were the effective horse power of a vessel known, then by means of such an instrument as the torsion meter, now before them, and shown by the joint-patentee (Mr Charles Johnson), the nett horse power delivered to the propellers could be ascertained, which was usually called the shaft horse power; and if the augmentation of resistance produced by the propellers were known—which could also be determined in the tank—a measure was at once had of the total screw efficiency. When his firm began to build turbine vessels, the need of such an instrument was at once apparent, and the question was gone into by their late President, Mr Archibald Denny, and a member of the Leven Shipyard Electrical Staff (Mr Charles Johnson). After a great expenditure of time and trouble, the many difficulties in the way were successfully overcome, and a practical and reliable instrument designed, and used with complete success on the turbine vessels built by his firm. To obtain the torsion, a suitable length of shaft was chosen for the measurement, and discs were fitted at each end. On each of these discs a permanent magnent was secured radially, with a sharp edge at the periphery of the disc, lying with the edge parallel to the shaft. Essentially there was a single coil inductor set beneath one of the magnets, and a series of coils beneath the other magnet. These were arranged circumferentially, and lay very closely together, so that the sharp edge of the magnet passed directly opposite each separate coil in turn. When the shaft was at rest, and without torsion, the magnet at one end was placed above its coil, and the magnet at the other end was brought exactly above the first of its series of coils. As soon as the shaft was revolved with the transmission of power, a torsion was put upon it. When the first magnet reached its single coil, it was apparent that the other magnet would no longer be above the first coil of its series, but above some other coil farther round the the circumference. The recording box of the torsion meter was designed to ascertain which coil was the one directly beneath the magnet at that time, and hence knowing the spacing of the coils, the amount of torsion at the radius of their centres was ascertained. To obtain this information, the currents induced in the coils at each end were balanced, that was to say, when each magnet was above a coil the currents induced were adjusted by resistances, so as to exactly neutralise one another. A telephone receiver differentially wound was so connected that, the separate currents from the inductors at either end of the shaft were made to act simultaneously upon the diaphragm of the receiver. There would only be one position where that neutralisation took place perfectly. For all other positions a "tick" would be heard at every revolution of the shaft. By making contact with each coil of the series successively, it was easily discovered which was the particular coil where the neutralisation took place, there being no "tick" for that position. This selection of coil was made by passing a switch over a series of studs, each stud connected to one of the series of coils, and each stud therefore representing a fixed amount of torsion, namely, the

Mr John Ward.

distance between adjacent coils of the series. A direct reading from the scale round the studs would give the amount of displacement of the magnets relatively to one another, and therefore the amount of torsion. The foregoing was a description of the torsion meter in its simplest form. In practice it was usual to supply six single coils at one end of the shaft, and a series of coils at the other, the distance between the single coils being rather less than the whole space occupied by the series of coils. This was done to give greater range of measurement to the instrument. In effect this arrangement multiplied the amplitude of measurement of the simple form about five-fold. The apparatus upon the table was fitted for three shafts, and, as would be seen, had two circles of studs for each shaft, one for the single coils and the other for the series of coils. There was provided a row of studs at the top of the box; these were connected to resistances, and were for balancing the currents induced by the two permanent magnets, which were not necessarily of exactly the same magnetic intensity. A feature of this induction method was that there was no actual touching of the fixed and revolving parts, and therefore no error introduced by the wearing away of surface. It could be left in position for any length of time, and was always ready for use. The recording box might be placed in any convenient position in the ship where comparative quietness could be obtained to take the observations; the connecting cables being led to it from the inductors. He thought no apology was required for making this digression, as Mr Speakman had pointed out how important it was that one should know the inter-relation between the turbines and the propellers. He placed a high value upon Mr Speakman's paper, which would prove of service to Members and a valuable acquisition to the Transactions.

Mr Alex. Craig (Member), said he had read Mr Speakman's paper with very great interest indeed and he had noted several points upon which he would like to ask Mr Speakman a few simple questions. With respect to the question of pressure per square inch of projected area of propellers, the Author stated that

Mr Alex. Craig.

pressures of from 12 to 14 lbs. had been known, but he was under the impression that in some torpedo boat destroyers the pressure reached as high as from 15 to 16 lbs. If this really were the case—What percentage of slip of propeller might be expected under the circumstances? With regard to the adoption of turbines for tramp steamers, that would come, but in the meantime the most valuable information which Mr Speakman, or any other expert, could put before them was in connection with channel steamers and destroyers. With regard to the ratio of projected area to disc area, the highest mentioned by Mr Speakman was ·58, but he knew that in some cases that figure had been exceeded. He had taken great interest in the turbine steamer "Victorian," to which the Author had referred in Table I., where it was stated that the propeller had a diameter of 9 feet 6 inches. To him the propeller looked smaller than that, and he was certainly surprised to see that some material had evidently been removed from the tips of the blades. The original propellers were four-bladed, and he understood that they were being replaced with others of three blades about 8 feet 10 inches in diameter. He would like to ask Mr Speakman what he thought about that change? Referring to Fig. 7, the Author said that "Parsons' turbines, however, have been built with Vt, varying from ·25 to ·85 of Vs." He would like to know what the ratio was in channel steamers, and how this effected the economy of the turbine. In the formula (Blade velocity)^2 × No. of rows = Constant, it was not quite clear what that constant really was, and the Author, in his reply, might perhaps be able to state how it was used in turbine design. Coming to the blades of the turbine, Mr Speakman seemed to think lightly of the principle on which the blades were fixed in the Parsons turbine. He (Mr Craig) had seen a few Parsons' turbines, and certainly to his mind the fixing of the blades seemed a weak point. The arrangement of blades exhibited on the table was a very excellent substitute for the method used by Mr Parsons. The fixing of the blades was pretty much controlled by the weight of the hammer and the strength of the

Mr Alex. Craig.
engineer's arm, but with this new method the variance of pitch of blades appeared to have been eliminated. From what he had seen of the Parsons turbine blades in position, they seemed not to be so regularly spaced as those in the Willans' ring on the table. The action turbine was the turbine that he was practically wedded to, and he would like to ask Mr Speakman if he thought that there was any possibility of the action turbine being used economically for driving steamships? It had certainly one advantage, in that superheated steam could be used. He did not know whether superheaated steam had been used for Parsons' marine turbines, but he looked to Mr Speakman for this information. The stripping of blades would be a very serious matter if such occurred in mid-ocean, and from what Mr Speakman had said it was very apt to occur. But he gave no instance of such a thing having taken place, and many like himself would like to hear of the results of such stripping, and the best way to obviate the same. The Author referred to turbines for generating electricity and marine turbines, and said that the former were not designed for the same internal efficiency. What did the Author mean by this internal efficiency? In Table III, he noticed that the widths of turbine blades varied from ⅝ of an inch up to 1¼ of an inch, and he had been lead to believe that for lengths of 21, 24, or 30 inches their widths should be greater. It would be seen from the diagram above Table III. that there was a clearance at blade tips which extended for the full length of the space traversed by the steam without any opposition whatever. This clearance seemed to him to correspond with a leak in a main steam pipe, involving an irrecoverable loss. The retardation of the steam in its passage through the turbine by the wire lacing of the blades was also another loss which he thought might be obviated by a better mechanical device. In discussing matters of this nature, it was better to have reliable figures—he did not mean to say approximate figures—but figures upon which an engineer could rely. He desired to thank Mr Speakman for having submitted such a meritorious paper.

Mr J. R. Jack (Member) remarked that Mr Speakman's paper

Mr J. R. Jack.

really concerned the engineer more than the naval architect, but as they had to work together it was of interest to them both. In taking up the question, Mr Speakman hit the nail on the head at the very beginning, where he said that the turbine efficiency and the propeller efficiency must be considered separately and together. The propeller of a turbine driven boat was nearly always too small, because if a big propeller were fitted a larger turbine would be necessary than the engineer could afford weight for. The same difficulty obtained, though on a smaller scale, in motor boats, and he thought the motor boat might be looked to for a solution of that problem. In such small craft, the propellers could be altered cheaply and experiments readily carried out. It appeared to him that the motor boat seldom gave a high efficiency, because the revolutions were kept down in order that the propeller might be large enough to have *some* efficiency; with the result that neither motor nor propeller reached their maximum efficiency, each having made a sacrifice to help the other, and so it was exactly on a par with the turbine vessel. Although he was afraid his engineering friends would scoff at the suggestion, he thought the time had arrived when the question of gearing should be considered. In the early days of screw propulsion, gearing was adopted, as the engines could not run fast enough for the propeller. Direct driving followed, and he felt that with the present style of motor or turbine it might be advisable to introduce gearing. He had experimented with gearing in a small way with a motor boat, and the results had surprised him. He tried a small petrol engine geared down two to one by a chain drive, with the result that the motor was able to run at its maximum revolutions. The propellers running at a reasonable speed could be of a reasonable diameter, and a ratio of effective horse power to brake horse power could be obtained almost as high as the best of the turbine boats that were mentioned in the paper. Of course it was one thing to work gearing with a boat 25 feet long, and quite another matter with a ship 600 feet in length; but he thought there was a possibility of screw gearing being adopted somewhat on the lines

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of that used in the Lanchester motor car. It would run for thousands of miles without showing appreciable wear, and such a gear might give the de Laval turbine a chance of being applied to marine propulsion. Another advantage of using a large propeller was in starting and reversing the vessel. With the small propeller, that was a weak point in a turbine ship, and a large propeller would get over the defect. Tank models helped largely in investigations, but they had their limitations. The principal limitation was atmospheric pressure. A model propeller placed a foot below the surface had an atmospheric pressure equivalent to nearly 30 feet of water on the top of it, and a propeller 30 feet in diameter had only its own diameter above it. That difference was so serious that it shifted the cavitation point out of scale altogether. To get over this difficulty, an experimental tank would have to be arranged with self-recording instruments, the air being so rarefied that during experiment it would bear the same relation to the model as the atmosphere did to the full-sized ship. There was another difficulty with the present type of turbine vessels. They had almost invariably three shafts. Now for river or cross-channel steamers that did not matter, but with large passenger and cargo vessels having such an arrangement the designer had a grievance. The bottom of the ship abaft the machinery space was monopolised by these shafts, and the result was that the centre of gravity of the cargo spaces was very far forward, which, of course, could not be helped. The common centre of gravity of the ship, when loaded, was much further forward than when light, and therefore inevitably there was a big difference of trim between these conditions. A vessel only devoted to cargo might be designed with a quarter deck or a long poop or something of that kind, but cargo steamers driven by turbines were not yet in evidence—if ever they would be. Usually the upper part of a turbine vessel was monopolised by passenger space, and the objectionable feature could not be got over. If the centre shaft could be got rid of, a tunnel as in an ordinary twin screw steamer might be arranged. There was another shipbuilding point referred to by the Author regarding the defective ventilation of turbine rooms, and he knew that a great number of vessels suffered from that. It was a fault that was not altogether incurable, and it was largely due to the nervousness of the turbine maker with regard to stripping of blades and possible break down. A turbine was long (unfortunately, it usually worked out rather longer than the ordinary engine), and it was liable to the disease of stripping, when it had to be taken out to be sent back to the maker; in consequence, the air casing had to be made large enough to let the turbine out. If the makers of turbines could guarantee that the turbines would not require to be unshipped for repairs, the shipbuilders could divide the air casing into two portions, with one portion over the after end of the turbine room and the other over the fore end, and so have a complete circulation of air through the space. It was pretty much the same with regard to ships' galleys, which in some ships were very hot places. Some of them, indeed, were worse than any naval turbine room; in fact, it was almost impossible to live in them, but with this system of ventilation the galley nowadays was no worse than any other part of the ship. As to a comparison between ordinary screw steamers and turbine vessels, it was almost impossible to get data on which to work, because a comparison which was true to-day was not so to-morrow. The best published comparison was that respecting the Midland Railway Company's steamers, which furnished an excellent contrast between the "Antrim" and the "Londonderry." That had been drawn up with every care to avoid undue favour to the turbine, and still the turbine showed a sensible advance on the reciprocating engines, taken at the time. But to-day that comparison was of little value. The "Antrim" was an exceedingly fine vessel, and if she had to be repeated to-day he doubted if either her designers or builders could improve upon her from the standpoint of speed, but with the "Londonderry" it was quite different. Coming from the 22 knots of the "Londonderry" to the 23 knots of the "Manxman," there was an increase of boiler pressure of from 150 to 200 lbs. The turbines were designed to utilise all the steam

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produced by the boilers, whereas in the "Londonderry" they were designed to work best with the single-ended boilers shut down. In order to carry the extra weight, the "Manxman" had had her beam increased one foot. To-day a "Londonderry" could be easily built to reach the speed of the "Manxman" without any of these increases, and in fact in the case of the "Invicta" it had been done on even smaller dimensions. He had looked through the paper in vain for one thing, and that was any reference to the gas turbine. The steam turbine had given the engineer a lighter motor—there was no doubt about that—its introduction had got rid of a great deal of the vibration, if not all, but the weight and trouble of the boilers still remained. He was sorry to add to the number of questions which Mr Speakman had to answer, but he would like to know if Mr Speakman did not think that if the gas turbine did not come pretty soon it would have a hard fight with the reciprocating gas engine for marine propulsion?

Mr W. H. Riddlesworth, M.Sc. (Associate Member), said it was with feelings of more than ordinary diffidence that he rose to address the meeting after the very eloquent opening by Mr Ward. He would like to offer a few critical remarks on this interesting paper, but before doing so he would like to pay tribute to the skill with which Mr Speakman had collected the tables and data on matters which were certainly not very easily got at. The first part of the paper was devoted to the relation of propeller and motor, and the intimate inter-relation of these had formed the subject of many essays and attempts at elucidation, whilst the attempts at overcoming the difficulties had produced almost as many wonderful devices as the search for the elusive perpetual motion machine. The particular troubles incident to high rotational speed had often been made patent to those who had tried to obtain light weight machinery or small dimensions of propeller. The steam turbine was essentially a high speed motor, and it was only by a compromise between almost irreconcilables that any satisfactory propelling apparatus could be made. To that problem the first part of the paper was devoted, and it was assumed as a working basis that the desirable thing was to make the revolutions as great as was consistent with a reasonable propeller efficiency. That was a point which required some proof, as it was quite conceivable that some lower speed at which the propeller efficiency might be greater would pay in spite of the probably increased dimensions and weight of the turbines. The Author's first step in the solution of this part of the programme was to obtain the minimum diameter of the propeller, and this he did without reference either to pitch or revolutions, both of which must obviously have no inconsiderable influence on the dimensions of the propeller. He would suggest that a somewhat similar formula to that on page 21 might safely be used to give the minimum projected blade area, but that in this present form the Author's formula was incomplete and apt to be misleading. It was probable for ships which had to make fair weather passages and for which a high trial trip record (in smooth water) was the desideratum, that the pressure should be pushed to the point at which cavitaton was imminent, but for ships that had to keep time in all weathers the pressure allowed should be kept down something like in the ratio of the smooth water resistance to the augmented resistance due to bad weather, etc. On page 24 the Author said, "Having obtained the diameter of the propeller and the revolutions possible, the design of the turbine can then be undertaken, but for this no formulæ exist at present, such as are met with in reciprocating engine practice." He had tried to show that the diameter obtained by the formula on page 21 ought rather to be regarded as an indication of the minimum projected area, whence of course, assuming a surface ratio, diameter could be obtained, but he nowhere saw any method of determining revolutions unless he was to infer it from the allowable speed of blade tips. The relation between axial thrust and circumferential speed of blade was by no means a simple one, as might be seen from the Author's Fig. 1, which might be accepted for the present purpose. Hence any calculation of revolutions from these two elements alone must be of somewhat doubtful value. Accepting the thesis

Mr W. H. Riddlesworth, M.Sc.
that the revolutions must be kept as great as practicable, he would suggest that the propeller should be designed on the ordinary lines if possible by a method involving all the elements of the propeller; that was revolutions, diameter, pitch ratio, and surface ratio, etc. That might have to be done for a series of revolutions, and one ought to be able then to see what sacrifice of efficiency would be necessary in any particular case in order to keep the thrust pressure on the blades below the predetermined maximum. The maximum revolutions could also be determined, and the problem solved generally. Even then, the solution or solutions of the propeller problem would not be as definite as might be wished, for it was well known that many cases have arisen in which the best information had been read as a basis for determining propeller dimensions, and yet vast improvements have been made by changes of propeller which had apparently not been foreseen in the original solution. The case of the cruisers of the "Drake" class would at once occur to many. Assuming the dimensions of the propeller fixed, then the next consideration was of the turbine problem. He did not propose to deal with that at any great length, but he must call the Author's attention to the looseness with which he had explained his method of finding the velocity of flow of steam. That was, he thought, best explained as that velocity which implied that the added kinetic energy of the fluid was equal to the work done in expanding, in whatever way it did expand—adiabatic or otherwise—from the initial pressure to the final pressure in the passage under consideration. In Fig. 19, if a pound of steam at $p_1 v_1$ passed through

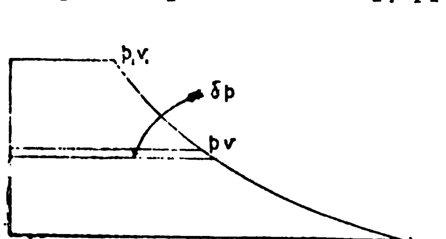

Fig. 19.

the turbine and expanded to $p_2 v_2$, then at any particular stage in the turbine, if the pressure was $p v$ for a small drop in pressure, such as from row to row, the work $= v \, \delta p$, and the velocity was such that $\frac{V_s^2}{2g} = - v \, \delta p$, the initial velocity being neglected, or with an initial velocity V_i $\frac{V_s^2 - V_i^2}{2g} = - v \delta p$. In a paper read before the Institution last session, Mr Melencovich gave a very elegant method of finding the successive pressures, and hence the drop in pressure from row to row when the work was equally divided amongst any number of rows of blades. It might be noted that the Author's use of "8" as the value of $\sqrt{2g}$ in his formula was capable of a refinement which was surely well worth making. Even a common 10-inch slide rule showed a very considerable difference between the accepted value of $\sqrt{2g}$ and 8. In connection with the relation of the blade velocity and the steam velocity, it was worthy of note that the two cases quoted at the middle of page 25 were only correct when the angle between direction of motion of the impinging or issuing jet and the blade was zero; for all other cases, a relation depending on this angle held good. Of course, in a combination impulse-reaction turbine the relation of these velocities was empirical to a certain extent. In conclusion, he would point out the futility of elaborate theoretical investigations of the necessary blade heights, etc., when it was impracticable to approximate to these dimensions, and the blades had to be made of constant size for very considerable portions of the length of the turbine, although by suitably grading the packing pieces much might be done to make the openings of approximate sizes; and until a method of building turbines was evolved which allowed each row of blades to be made of the proper size, all turbine dimensions must of necessity depend on a number of empirical rules which would naturally be guarded with the greatest jealousy by the fortunate possessors of sufficient experience to enable them to devise such rules. One line of progress, it seemed to him, lay in the direction of abolishing

Mr W. H. Riddlesworth, M.Sc.
steps in the size of the various rows of blades, and another was in the adoption of a more mechanical construction of the blades and passages, one example of which was shown by a very enthusiastic advocate at the last meeting.

Mr JOHN REIKIE (Member) considered Mr Speakman's paper one of very great interest to every engineer. Although the Author had framed it with special reference to marine work, the question of economy in steam consumption was of vital importance to all engineers, and any remarks bearing on that question might lead to still greater economy than that now attained in general practice. As a locomotive engineer—in which branch of engineering it was at present impracticable to make use of the steam turbine – he did not agree with Mr. Izod that this type of engine was the only one for future marine work. For marine practice, although the turbine might at present have a great advantage over that of the slow-speed triple-expansion reciprocating engine with respect to high rotative shaft speed and steady running, still the introduction of a high-speed reciprocating engine in combination with a high steam pressure of 500 lbs. and upwards, and designed so as to make use of steam superheated to a high degree, would not only place it on an equal footing with the turbine as regarded high rotative speed and eliminating vibration, but it would enable it to reach a very much lower consumption of steam than that possible with the turbine as now designed. Regarding economy in steam consumption, his opinion was that if the maximum efficiency were to be attained with every engine designed, it became necessary to have a standard in the quality of steam generated in the boiler, equally as much as for material used in making the engine. So far as he could judge, steam of the highest pressure carried in boilers was accepted by many engineers as being the best in quality. That appeared to him to be a mistaken idea; the measure of quality in steam should be temperature, not pressure, so that every engine should compete on equal terms in economy in steam consumption, independent of the pressure carried in the boiler. On page 36 the Author, when referring to the cylinder of the

Mr John Beikie.

turbine, mentioned a temperature of 400 degrees as a maximum, although that temperature did not admit of the best quality of steam being used in the cylinders, still it would be found by a reference to Fig. 12, that the consumption of steam was as low as 13½ lbs. per I.H.P. He would like to ask the Author if the steam used in the cylinders of the engines of the other vessels shown in the same table was of the same temperature, for if not it might go a long way to explain the difference in steam consumption. As to the introduction of a standard quality of steam, experiments only would bring to light what the temperature should be to form that standard. So far, he had found no difficulty from using a temperature as high as 900 degrees F. in cylinders; this, however, might be as much above the average required to bring about the best results, as 400 degrees F. was too low. Experiments on the Continent with a 300 H.P. engine had proved that with a temperature of about 540 degrees F., the consumption of steam per I.H.P. was brought down to 9·9 lbs. What could be accomplished with one engine should be within the reach of all engineers; a universal reduction of steam consumption was surely a goal all interested in the search for economy should endeavour to reach. If the steam turbine could not compete with the reciprocating engine under such exacting conditions, he had no doubt it could be designed to do so. He was not quite sure if Mr Izod had not already in view the early introduction of very highly superheated steam, for he remarked that the turbine of ten years hence might differ materially from that of the present day.

Mr James Hamilton (Member) remarked that some observations made by Mr Jack had suggested to him that he might say a word or two which might be useful in connection with cavitation and the figures for the pressure per unit of projected area of propeller. He had for a long time thought that blade interference had more to do with inefficiency of propellers than cavitation, and he had taken the trouble to plot down the path traced by each blade of a propeller, and it was very surprising to see, when allowances for the advance of the screw, the slip, and

Mr James Hamilton.

the wake were made, what a very small layer of water each blade had to work upon with fast speed vessels, such as were under discussion, and it was worse when the ship did not travel fast like the screw. That had been confirmed in a small yacht fitted with a motor, which he owned, and he was surprised to find that in making a distance of about 13 nautical miles, after one of the blades of the propeller had been thrown off, she went about as fast with the one blade as with the two blades. It was not very good for the shaft, but he did not think it suffered. The point was that there was a great deal less blade interference, and there was very little difference between the speed with the two blades and the speed with the one blade. Of course the engine was running about 1,000 revolutions in the one case, and about 750, or the normal speed, in the other case, the propeller going at half the speed of the engine in each case, connection being by a chain belt and pulleys. Those investigating propeller problems should consider the question of blade interference. It was perhaps easy to calculate the pressure on the disc, but in what way could an analysis be made to show that after reaching 11 or 12 lbs. per square inch the efficiency fell off? Although the adoption of such a pressure might be a convenient way of ensuring that the propellers were not made too small, the falling off in efficiency might be equally a question of blade interference and not a matter of cavitation at all.

Mr James Anderson (Associate Member) said that Mr Speakman had stated that the tensional pressure of propeller blades was approximately from 10 to 12 lbs. per square inch at a depth of 12 inches below the surface, and he desired to know if the indicated horse power used in the thrust formula, got from model experiments, was calculated from the steam consumption or from a torsion meter? He considered the formula at the foot of page 25 somewhat indefinite, and he could not make out what "8" was.

Mr John Alexander (Member) asked the Author if he would tell the Institution what the present method of grouping the turbines was in a vessel running at cruising speed? In electrical work the power of the steam turbine was generally governed by altering the period of the blasts of steam admitted to the turbine, and he would like to know if this method was used in vessels with turbines running at reduced speeds?

Mr R. T. NAPIER (Member) observed that the use of triple propellers came up in connection with the application of the steam turbine to marine purposes. Those who had experience with twin screw steamers knew that the slip was much greater than with single screws, and he asked, if it was not a business secret, whether it was customary to make the centre propeller, where three were used, of less pitch than the wing propellers. If this was not done at present, he was prepared to learn some day that power was being lost. Another matter was the time required for the construction of large steam turbines. The number of blades on a single rotor amounted to hundreds of thousands, and the number that could be fixed in a working day was limited. He asked if it was not the case that for engines of large power those of the turbine type required longer time to construct than did multicylinder engines.

Mr ROBERT ROYDS, B.Sc. (Member) observed that Mr Speakman had said that the greater the ratio of Vt to Vs, the greater would be the required number of rows of blades. It appeared to him that, the number of rows required depended on the amount of useful work that could be given to the turbine by the steam per row of blades. He would like to know what particular law Mr Speakman adopted when he calculated the volume for actual expansion, whether it was with 70 per cent. efficiency or 80 per cent., or some intermediate value?

Correspondence.

Mr B. M. NEILSON (Manchester) felt that Mr Speakman's paper was full of useful information, much of which, he believed, had not been published before. Mr Speakman had referred to the leakage over the tips of the blades in Parsons' turbine. The

Mr R. M. Neilson.
effect which that leakage had on the efficiency of a turbine, was a question which had been generally passed over without comment, by writers of papers on steam turbines. That was probably due to the fact that it was difficult to tell how much loss was due to this cause. Mr Speakman suggested that that leakage was perhaps not so detrimental on account of actual leakage loss as in its heating effect, because the heating of the steam increased its volume, and thus upset calculations regarding dimensions. It was, of course, impossible in designing a turbine to calculate exactly what the heating effect due to leakage over the tips of the blades would be; but it was quite possible, he believed, to calculate the heating effect with sufficient exactness to enable the turbine dimensions to be determined without great error due to that cause. The changes of volume of the steam caused by friction and by the transference of heat to the metal parts were, in his opinion, much more difficult to ascertain beforehand than the change of volume due to the heating effect of leakage past the tips of blades. While the difficulty due to this change of volume, produced by leakage past the tips of blades, was, in his opinion, not serious, he believed that the direct loss due to this leakage might be, and in some cases was very serious. A certain amount of heat energy of the steam was at every stage converted into kinetic energy. With the kinetic energy so acquired, some of the steam—sometimes a large percentage—leaked past the tips of the blades, and a great part of its kinetic energy was converted back into heat. It might be thought at first sight that this energy was not lost: it was only converted into another form. As a matter of fact, however, *much* of it was lost as far as ultimately getting useful work out of it was concerned. This would be obvious on a little consideration. He did not need to give the proof here, but the loss was on the same lines as that which would occur if the heat produced by friction in the turbine bearings were used to generate steam to drive the turbine. The leakage past the tips of the blades was, in his opinion, an important loss in turbines of the Parsons type. The percentage leakage was usually greater at the high pressure

end of the turbine, but the thermo-dynamic loss for a given weight of leaking steam was here least. Fig. 9, showing the tip clearances, was very interesting, but its value would, he thought, be much more added to if the heights of the blades were also given. He presumed that the overall diameter was measured from tip to tip of the rotating blades, and was not the outside diameter of the fixed casing. A little more explanation of Fig. 10 would also be useful. Mr Speakman gave a formula, which depended on the effective thrust, for finding the diameter of a propeller. In order to use that formula as the Author intended, it was necessary to know what assumptions he had made in obtaining the effective thrust. On page 30, it was stated that "the higher speed necessary on the L.P's was got by running at considerably higher revolutions than on the H.P. shaft." Why "necessary"? In referring to the material of which turbine blades were made, Mr Speakman said the alloy contained 16 per cent. of copper and 3 per cent. of tin. It would be interesting to know what the remaining 81 per cent. was?

Mr HENRY L. S. NICOL (Southampton) stated that having had a considerable experience in turbine work, both in designing and running turbines from 200 K.W. to 5500 K.W., and being at present with Messrs. Thornycroft, directing their turbine work for torpedo-boat destroyers, he felt much indebted to the Author for his very able and valuable paper. One had only to study the subject a little to find the many difficulties which had to be overcome before the final design could be attempted. The Author had, as one might say, laid the foundation stone. Of the many papers which had been read before the various Institutions, perhaps never had the subject been so openly treated, and he hoped the formulæ given in this paper might be fully considered and bear a future weight in turbine design. From a practical point of view, he would like to bring forward three important points, namely:—(1) Distortion through cylinder design, (2) balancing, and (3) end thrust. With regard to distortion, he had met with it in several turbines, and in one special case, an 1800 K.W. machine on test (after being balanced, and all other preliminaries attended to) commenced to tip so badly that the test had to be abandoned. That was due to the distortion of the cylinder, and it had to be overcome by "relining up" the spindle and increasing the blade-tip clearance between the cylinder blades. That was done by fixing and driving a narrow emery wheel, to an arrangement on the boring bar, keeping the bar out of its true centre, thus increasing the spindle blade-tip clearance where actually required, and treating the cylinder blade-tips in the same way. Although he approved of superheated steam, naturally such high temperatures caused more distortion, which, he was afraid, would never be totally overcome, as it took place in various directions. In his experience, the most effectual way to overcome distortion had been to increase the number of radial ribs or webs. As to balancing, that was also a very important point, and he had recourse to the knife edge, which should have plenty of bearing surface to ensure easy rolling, and to prevent marking heavy spindles. Then, finally running the spindle in its bearings, either by a motor, apart from the turbine, or by steam in its cylinder. The provisions for fixing balance weights, the number, and easy access to same, were points in design of great advantage. The end thrust, the Author said, could be calculated, and great care was necessary in the calculation. The figures could only help to decrease excessive end thrust, the final end thrust being acquired by careful measurement and regauging at the blades.

Mr John Ward (Vice-President) considered it incorrect to say that the torsion meter was not a dynamometer. It might be pointed out that the torsion meter was greatly superior to that kind of dynamometer which absorbed the power to be measured, in that it measured the power transmitted by a shaft while it was doing useful work. Every kind of dynamometer must of course be calibrated. In the case of the torsion meter, the shaft formed an essential part of the whole dynamometric apparatus. It was the spring which had to be calibrated, and this could easily be done before it was placed on the vessel, or, alternatively, it would be found fairly accurate to use the following formula for ordinary solid steel shafts :—

$$W R = \frac{140 \times (d)^4 \times \theta}{L.}$$

Where W R = Foot pounds turning moment.
d = Diameter in inches of shaft.
θ = Angular deflection in degrees. } Between the discs
L = Length in feet of shaft. } of the meter.

Mr William Gray (Member) stated that the figures which Mr Speakman quoted from his paper, read at the Institution of Naval Architects in July last, were based on observations made at the speed trials of the respective vessels, and they were not approximate. He (Mr Gray) did not say they were absolute figures, they were given in the paper as comparative with the word "comparative" italicised. The "Manxman" had one foot more beam to give her increased stability as she was built for the Isle of Man passenger traffic, and the whole of the shade deck was available for passengers as compared with a portion at the forward end in the other vessels. The increase in beam had no connection with the larger turbines.

Mr John H. Macalpine (Member), after reading Mr Speakman's paper repeatedly with interest and profit, thought there were quite a number of points which the Members of the Institution would like the Author to amplify. Some of these he would touch upon in the following remarks. The co-ordinate subjects of propulsive efficiency and propeller thrust were frequently referred to. But while on page 23 effective thrust was referred to as a somewhat subtle subject, at quite a number of places the true value of the propulsive efficiency or thrust was supposed to be known, or to be calculable with considerable accuracy for the various classes of work, when determining the proper dimensions of the propeller and the turbine. In referring to Table I., the value of C was stated to be probably within 2 per cent. of the truth. As C was proportional, in any case, to the

Mr John H. Macalpine

square root of the effective thrust, the value of this thrust would then be true within 4 per cent. It was hardly to be supposed that anything like such a close approximation could be arrived at except by a most careful experiment on the actual ship or on a model. In the latter case, when passing from the model results to those of the ship, with a propeller under a pressure of 8 or 10 lbs. per square inch of blade area, the margin of possible error was considerable; for while the full size propeller was near the limit at which it would work without cavitation, the intensity of pressure on the small model propeller, at the corresponding speed, was quite light, and it was not to be expected that the action of the water in the two cases would be entirely similar. If the full size propeller produced cavitation, the action would be very dissimilar. This was a question that would repay careful experimental research. To predict, in a proposed design of ship and propeller, the value of the effective thrust within 4 per cent. seemed to him practically impossible, and in the design, both of the propeller and turbine, much larger errors would have to be allowed for. But the question of propulsive efficiency was one to which Mr Speakman had evidently given extended study, and he felt sure that he could add much of interest to what was popularly known on the subject, and give interesting data on which his conclusions were based. In Table I. the approximate value of C was given as 30·8. From the equation—

$$\text{Diameter of propeller in feet} = \frac{\sqrt{T}}{C}$$

$$C^2 = \frac{\pi}{4} \times \text{Effective thrust per square foot of disc area.}$$

From this, for the "Amethyst," effective thrust per square inch of disc area—

$$= \frac{30{\cdot}8^2 \times 4}{\pi \times 144} = 8{\cdot}4 \text{ lbs.,} \quad \dots \quad \dots \quad \dots \quad \text{A.}$$

In *Engineering* of November 18th, 1904, would be found the following data for the "Amethyst":—

14,000 I.H.P. (This must be estimated).

Propellers.		Diameter.	Pitch.	Revolutions per minute.
Centre, ...	...	6′ – 8″	6·56′	449·4
Starboard,	...	6′ – 8″	5·75′	484
Port, ...	...	6′ – 8″	5·75′	499

From which—

Travel of propellers per minute.

Centre,	... ...	6·56 × 449·4	= 2948
Starboard,	... ...	5·75 × 484	= 2783
Port, ...	... ...	5·75 × 490	= 2869
		3)	8600
Mean, ...	...		2867

From this the *indicated* thrust approximately—

$$= \frac{14,000 \times 33,000}{2867} = 161,000 \text{ lbs.}$$

The total disc area = 34·9 × 3 × 144 square inches. Therefore, the pressure per square inch for 100 per cent. propulsive efficiency—

$$= \frac{161,000}{34 \cdot 9 \times 3 \times 144} = 10 \cdot 7 \text{ lbs.}$$

Equation A gave the effective thrust per square inch from Mr Speakman's figures, from which the propulsive coefficient was—

$$\frac{8 \cdot 4 \times 100}{10 \cdot 7} = 78 \cdot 5.$$

There must be some serious discrepancy between the data used in the paper and that given by *Engineering*, as it seemed hardly likely, with propellers working under such high pressure, that the propulsive coefficient was much if any above 50. The sentence, "It seems likely, to some at present undeterminable extent but within narrow limits for each class of vessel, that the propeller efficiency is proportional to the coefficient C, and this seems to be borne out by the trials of the 'Manxman' and the 'Londonderry,'" he found very obscure, and would like Mr Speakman to explain it more fully. As C was proportional to the intensity of disc pressure, it seemed to him that its relation to the efficiency of the propeller must be quite complex, involving a number of other variables, and

Mr John H. Macalpine.

following a law very different from the simple one stated. No doubt Mr Speakman's conclusion that where there was danger of cavitation there was no advantage of departing from a true screw, was founded on good data; but it seemed obvious that with a true screw the pressure at the tip must be a good deal more intense than at the root of the blade. This might be a positive advantage for low-pressure screws, but surely must be a disadvantage when the pressure was near the allowable limit. This seemed to be borne out by the experience of the writer with some torpedo-boat propellers. In one set, the variation of pitch was such as to make one expect great irregularity of pressure and consequent bad performance at high speeds. These were replaced by propellers which had a diminished pitch towards the tip. In the first, the dreakdown of efficiency occurred long before the maximum speed was attained, and in the second, there was no indication of breakdown, though the contract speed was exceeded by fully 1½ knots. The fining of pitch towards the tip, giving diminished slip and more edgewise movement through the water, must increase the peripheral speed which could be used without producing cavitation. With regard to the turbine, also, he was sure Mr Speakman could readily add much of very great interest. He suggested that Mr Speakman should give an appendix containing the full calculations for a particular case, giving both the rough calculations on which one would make the preliminary determination of blading and the more exact calculations of fall of pressure, efficiency, etc., with notes at the various steps showing what was deduced from theory and what from experience and judgment. Perhaps this was asking too much, but it would compress a large amount of information into a concise and easily used form. All who had had to do with turbine calculations must know that the theory was very imperfect, and experience counted for a great deal. So far, those who had had most experience, especially with marine turbines, were exceedingly niggardly in what they had put on record, and Mr Speakman would render a distinct service by boldly breaking this reserve. There was much which one would like to see discussed further. For instance, it was stated that "the best ratio of blade speed to steam speed was a matter of opinion." Was it not the case that $V_t/V_s = \cdot 6$, as used frequently in electrical work, had been found to be the best, but that this ratio must be reduced in marine work partly, as Mr Speakman stated, to keep down the number of rows of blades; but still more, at some sacrifice of efficiency, to accommodate the fast moving turbine to the slow moving propeller? A few lines would have made clear the origin of the important formula for equal powers and efficiencies—

$$(\text{Blade velocity})^2 \times \text{No. of rows} = \text{Constant.}$$

For if $V_t/V_s =$ constant, the flow (neglecting secondary losses) would remain similar for the different values of V_s; and the loss of head in passing each row would be proportional to V_s^2 or V_t^2. The similarity of flow also showed that the steam, on passing one set of blades, was deprived of energy in proportion to V_s^2; hence, for equal powers, the larger V_s^2 or V_t^2, the smaller, proportionally, was the number of rows required. Also, the total loss of head would remain constant. It seemed probable that the eddying and other losses would not greatly alter this constancy of efficiency. The tabulation of the value of the constant of this formula in a few typical cases would be very valuable. He thought Mr Speakman had not stated the real difficulty which prevented the turbine being adopted in slow ships. The propeller must be large enough to drive the ship against a head wind and sea, or to keep it off a lee shore. This, together with any allowable pitch ratio, would bring the revolutions so low that the turbine could not be thought of. Fig. 10 showed the expansion line of the steam lying between that for saturation and the adiabatic line, as of course it should, since, due to imperfect efficiency arising from frictional and leakage losses, etc., less energy was extracted from the steam between the two definite temperatures than would be were the expansion exactly adiabatic. Thus the actual expansion curve, such as that given in Fig. 10, would not be quite the same for all turbines. It would be of interest if the Author set down exactly the assumptions made in this particular case. It was obviously a point of considerable importance in the determination of blade openings and the intelligent design of the turbine.

Prof. A. Jamieson (Member) stated that Mr John Ward had showed and explained the construction and action of the very interesting and ingenious Denny-Johnson torsion meter which his firm had used; but he neither gave the full particulars concerning the percentage accuracy of the results derived from it, nor referred to the reliance that could be placed upon these particulars. Further, members would feel greatly indebted to Mr Ward if he would give them details of the necessary preliminary tests of shafts in the works, for angle of twist produced by different torques, upon different sizes and qualities of shafts. It would also be interesting to know how closely the results arrived at by use of the formula Mr. Ward gave, agreed with the results obtained from the torsion meter, since he (Prof. Jamieson) had failed to prove that the constant 140, used in Mr Ward's formula, agreed with the constants given by various authors, as shown by the accompanying remarks. The formula given by Mr Ward for the turning moment of a screw-propeller shaft was as follows:—

$$\text{W R} = \frac{140 \times (d)^4 \times \theta}{\text{L}}$$

Where W R = Foot-pounds turning moment.
d = Diameter in inches of shaft.
θ = Angular deflection in degrees. } Between the discs
L = Length in feet of shaft. } of the meter.

It, however, did not agree with the formula deduced from Seaton, Bauer, Ewing, and Jamieson's rules for the torsional moment of resistance of circular solid shafts, which all closely agreed with each other, viz.:—The turning or twisting moment

$$\text{T.M.} = \frac{\text{C}\pi d^4 \theta}{32\,\text{L}} = \frac{\text{C}\,d^4 \theta}{10{\cdot}2\,\text{L}} = \frac{515\,d^4 \theta}{\text{L}} \text{ inch-tons.}$$

Where C = modulus of rigidity, was taken as 5250 tons per square inch.

d = diameter of shaft in inches.

θ = the total angle of torsion or twist in circular measure.

L = length of shaft in inches between the two fixed points.

Whereas, in Mr Ward's formula—

$$\text{T.M.} = \frac{140 \times d^4 \times \theta}{\text{L}} \text{ foot-pounds.} \quad \left\{ \text{But } \theta \text{ in degs. was equal to } \theta \cdot \frac{180}{\pi} \text{ in circular measure.} \right.$$

$$\text{Hence, T.M.} = \frac{140 \times d^4 \times \theta \times 180 \times 7 \times 12}{\text{L} \times 12 \times 22 \times 2240} = \frac{3{\cdot}6 \times d^4 \times \theta}{\text{L}} \text{ inch-tons,}$$

when— d = diameter of shaft in inches.

θ = the total angle of torsion in circular measure.

L = length of shaft in inches between the discs.

Would Mr Ward kindly explain wherein this great, apparent difference occurred between the numerical constants 3·6 from his formula, and 515 as derived from the other authorities mentioned above? It might be as well to state that Bauer and Ewing used a value for the modulus of rigidity, C = 5250 tons per square inch. Also, they used a shearing stress in the case of steady motion, f_s = 13,500 lbs. per square inch with steel; whilst, with wrought iron, f_s = 9000 lbs. per square inch, which might be taken as safe values for the stresses in shafting.

Mr Robert Johnson (Associate Member) considered that the results so far achieved reflected the greatest credit on those responsible for the introduction of the steam turbine for marine propulsion, but it was a matter for regret that more had not been made public both with regard to the performance of the machinery and to the method of design. The advantages claimed for the turbine might be considered under four heads:—1, absence of vibration; 2, reduction in space occupied; 3, reduction in weight, and 4, increased economy. As to the first, it was a temptation to

Mr Robert Johnson.

think that this point had been overestimated. So much had been said about it, and the subject had been forced into so much prominence that one was led to believe that the bogey of vibration had been set up for the express purpose of being knocked down again. His own practical experience with turbines certainly did not confirm the assertion that less space was occupied, *i.e.*, less length of ship (the important matter in the case), since in all cases with which he had been brought into direct contact, the fore and aft length of engine room would easily have sufficed for reciprocating engines of the same power. In certain classes of vessels where the speed of rotation of the machinery was high, everything was sacrificed to obtain lightness. Saving of weight was certainly an important matter, but from experience so far gathered with turbine machinery of the largest description, any material reduction in weight would not be consistent with durability and reasonable propeller efficiency, and the natural tendency at present was to make the turbine more substantial. It was upon this question of economy that the marine turbine must stand or fall. Unless the turbine could shew itself *cæteris paribus* superior in economy when employed for propulsion, it could never supersede the piston engine for the ordinary purposes of commerce. And it was curious that those who knew the facts and who appeared to be most directly interested in the matter maintained a discreet silence on this point. The case of H.M.S. "Amethyst" was perhaps a striking exception, but it must be remembered that extraordinary methods were adopted to secure efficiency and the ship carried no fewer than seven turbines, three only of which were required for full speed. This involved a degree of complication and an amount of expense, which could not be seriously entertained as a permanent condition. As to the contention raised with regard to reversing, viz.—that a turbine propelled ship could be brought to rest in the same distance as was required for a ship with ordinary engines—it was exceedingly difficult to believe that the astern turbines would take effect on the ship as quickly as piston engines, in view of the fact, inseparable from all turbines, that of necessity the starting torque was small. Mention was made in the paper of cases in which the blades of turbines had been stripped. This appeared to be a not altogether infrequent occurrence and would be a very serious matter especially if it happened in mid-Atlantic. Blade stripping might arise through the very small radial clearance permissible, if so, then a hot bearing would almost of necessity be followed by the loss of many blades. It was a matter for regret that Mr Speakman had not been able to enter into the question of design more fully, but nevertheless the paper formed a substantial addition to the literature of the subject. It would be of great interest if the Author could supplement the information already given by stating what the angles of entrance and exit respectively, of the standard blade section, really were. Mr Speakman said—"The actual volume of the steam—not the volume per lb., as found in tables, or the volume due to adiabatic expansion, but the exact volume per lb. at any point along the turbine, etc." He was quite at a loss to know what this meant, as the only volume the steam could have per lb. was the volume as per tables, the suitable table of course being used. Was it possible that Mr Speakman meant the volume of steam, per lb. of *mixture*, at any point, etc.?

Mr John Ward (Vice-President)—The formula which he had placed on record was based on actual tests of solid round steel shafting as fitted to all the steamers built by his firm. Tests had also been made with steel, iron, and brass rods of 18 inches in length and $\frac{3}{8}$ of an inch in diameter, which gave for k values of 134, 132, and 57 respectively. The lengths of ships' shafting tested varied from 14 feet to 78 feet, and the diameters from $4\frac{3}{8}$ inches to $7\frac{3}{4}$ inches. Altogether, 46 tests had been made, of which five were early experimental, in 1901; 37 were made on actual shafting for turbine steamers, and four on actual shafting of reciprocating marine engines. All the tests were outwith the ships, and in all cases the uniformity of the scale of torsional deflection had been proved by measuring the effect of five or six loads. The error involved by refraining from testing a particular shafting, and taking $k = 140$, would not probably be

Mr John Ward.
very serious. The true value of *k* could, however, be easily found (and the error thus avoided) by making the actual tests on each piece of shafting to which the torsion meter was to be applied. In view of the extensive practical tests and the remarkable consistency of all the results of power measurements which had been obtained from turbine steamers built by his firm, and some fitted with reciprocating engines, it did not seem necessary to comment on the calculations Prof. Jamieson had been

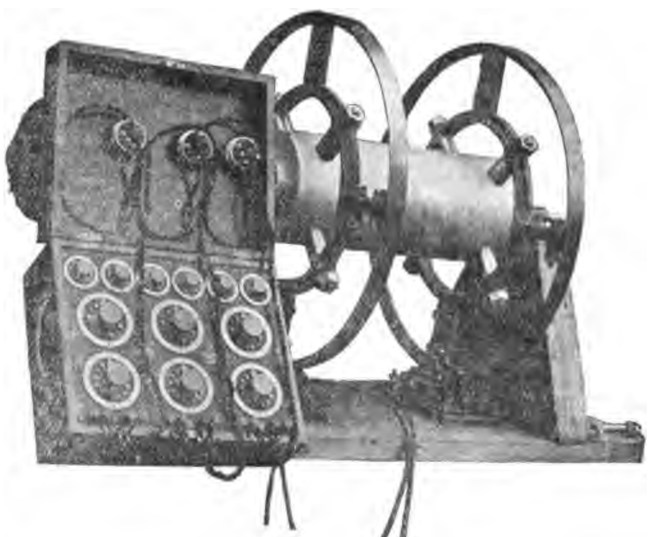

Fig. 20.

good enough to send him, beyond pointing out the error into which he (Prof. Jamieson) had fallen in stating the same in the Transactions. It was open to Prof. Jamieson or any one else to make actual tests. At the request of Mr Speakman he had much pleasure in supplying an illustration of the Denny-Johnson torsion meter, Fig. 20.

Mr W. J. Goudie, B.Sc. (Member), thought that Professor Jamieson had made a slip in his calculation when deducing the "torque" equation, given on page 69. It was hardly possible that such a descrepancy between the constants, as shown by Professor Jamieson, could be due to any error in Mr Ward's formula, as he presumed the figure 140 was the average of a large number of experiments on actual shafts. On looking into the matter, he found that Mr Ward's expression was exactly the same as that which could be derived from first principles when the value of C = 5250 tons per square inch, or 11,760,000 lbs. per square inch was taken for the rigidity modulus. This would be evident from the following calculation:—It could easily be shown if a portion of a shaft A B, of diameter *d* inches and length *l* inches, had the plane *b* twisted relatively to the plane *a*, Fig. 21, by a

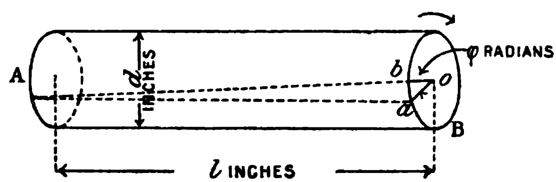

Fig. 21.

torque T, so that any radial in the plane *b* was deflected from O*a* to O*b* through an angle of ϕ radians, that, $\phi = \frac{32\,T\,l}{\pi\,C d^4}$, and the torque $T = \frac{\pi\,C d^4 \phi}{32\,l}$ inch-lbs., C being the rigidity modulus in lbs. per square inch. In the notation given by Mr Ward, the length L was in feet, and the angular deflection θ in degrees, so that, in the above expression, $l = 12\,L$, and $\phi = \frac{\theta}{57 \cdot 3}$. When these were substituted, and the left-hand side further divided by 12, to bring the torque to foot-lbs., it became—

$$T = \frac{3 \cdot 1416 \times C d^4\,\theta}{12 \times 32 \times 12\,L \times 57 \cdot 3} = \frac{C d^4\,\theta}{84{,}046\,L} \text{ foot-lbs};$$

and when 11,760,000 was substituted for C, the expression took the final form—

$$T = \frac{140\,d^4\,\theta}{L}, \text{ as given by Mr Ward.}$$

Mr W. J. Goudie.

If, as suggested by Professor Jamieson, Mr Ward could favour the Members with particulars of a series of tests on shafts of various diameters, it would be instructive to note the values of the rigidity modulus for steel derived from these full-sized members, instead of from small specimens of the materials. The modulus could be easily ascertained in each case by multiplying the constant by 84,046.

Prof. A. JAMIESON felt pleased that his reference to the torsion meter had elicited such practical information, as well as the fact, that the formula, as stated by Mr Ward, had been based upon results from full-sized shafts. Further, that the previously accepted constant for the modulus of rigidity of steel shafts, where C = 5250 tons per square inch, had been confirmed by the large number of experiments carried out by Mr Ward's firm. It was, however, unusual to issue a formula with the numerator and denominator in different units, *e.g.*, where *d* was in inches and L in feet, as corrected by Mr Goudie. Consequently, the fundamental formula as deduced by him (Prof. Jamieson) for the torque,

$$\text{T. M.} = \frac{515\, d^4\, \theta}{\text{L}} \text{ inch-tons}$$

was correct, and agreed closely with the results taken from actual practice, as stated by Mr Ward.

Mr SPEAKMAN, in reply to the discussion and correspondence, said that he had first to thank the many gentlemen who had contributed thereto, and especially Messrs William Denny & Bros., Dumbarton, who had given the Members such an excellent opportunity of making themselves better acquainted with the Denny-Johnson torsion meter. He would endeavour, as far as possible, to answer the speakers individually, but in some cases one reply would suffice for more than one critic. He was greatly indebted to Messrs Willans & Robinson for the loan of the sample ring of machine-divided blading, to which he had referred in the paper, and which was a magnificent sample of refined commercial workmanship. It was more than this, of course; it was essentially a practical solution of the hitherto weakest feature of the multiple reaction turbine. The "disease of blade stripping," quoted by Mr Jack, was a very great difficulty, and the cases in which it had occurred were very numerous; as the blading represented such a large proportion of the cost of the turbine—perhaps one-fifth to one-sixth—such an improvement, representing as it did a much cheaper and infinitely more reliable system, must affect turbine design to an enormous extent. His friend, Mr Izod, who had been so largely responsible for the success of this invention, had given a diagram to illustrate his remarks, in which he summarized the losses that occurred in the turbine, though he gave no analytical values, which he might easily have done. The principal losses were due to leakage and friction, though the percentage of each varied considerably in different types of turbine. With the shrouded blading, the somewhat excessive clearance necessary to prevent any chance of the blade tips coming into contact with the cylinder, which almost inevitably caused stripping, was reduced to a minimum, as the effect of contact was negligible. What these clearances were could be seen from Fig. 9, and as Mr Craig also drew attention to the saving possible, he thought the following figures would cast some light upon the subject. Taking, for instance, the low-pressure turbine, shown in Fig. 16. The drum was 93 inches in diameter, and the height of the first ten rows of blades $1\frac{3}{8}$ of an inch. From Fig. 9 it would be seen that the tip clearance amounted to about ·080—ten-thousandths of an inch per foot of diameter was a good rule—and as there were two tips to a pair, the effective area through the blades was only that represented in Fig 22. The actual clear area through a row of normal blades was only one-third of the annular area, and with these dimensions would amount to

$$\frac{94{\cdot}375'' \times 3{\cdot}1416 \times 1{\cdot}215''}{3} = 120 \text{ square inches} = a.$$

The clearance area was $94{\cdot}375'' \times 3{\cdot}1416 \times 0{\cdot}160'' = 47$ square

Mr E. M. Speakman.

inches = *b*, and the ratio of *b* to *a* was 39·2 per cent.* Obviously, with a shroud, this tip leakage could be almost prevented—the actual clearances being only about one-eighth of those necessary for a blade. A great many similar points cropped up in

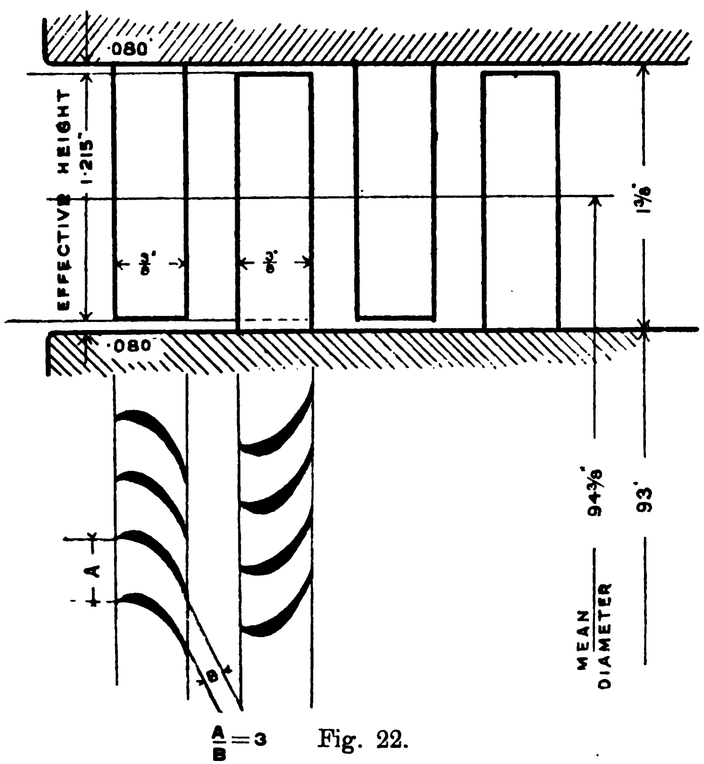

Fig. 22.

the design of blading. In the dummy packing, for instance, a clearance of ·055 of an inch on a 90-inch labyrynth diameter meant a clear leakage area of 14·3 square inches, corresponding to a 4½-inch

* This, of course, was only over the first stage—but the clearance loss in the analytical work-diagram might be calculated in the same way. Needless to say, it would be somewhat less.

pipe. Regarding Mr Izod's remarks on friction, he did not feel able, owing to lack of space, at present to give the actual figures regarding the saving obtainable by the use of smooth blades, but anyone who cared to put the ordinary brass blade under a microscope, and compare its surface with that of a copper nickel blade, would certainly be enlightened as to the possibilities of improvement in blading material. Mr Ward stated that the data given in Table IV., referring more especially to the vessels built by Messrs. Denny, was only approximate, and he fully realised that, the more so as Mr Parsons himself, in separate publications, had given different dimensions for the same vessel. If any objections were made to this table, it was perfectly open to the builders of the vessels to supply the actual figures, but the table was, he believed, substantially correct. It was, however, an obviously unintentional error for Mr Ward to say that some of this data had not been published either by his firm or others, in proof of which he would refer him to Mr Parsons' papers to the Institution of Civil Engineers and to the Institution of Naval Architects, as well as to Mr Gray's paper. Some of it had likewise been taken from a pamphlet entitled, "Extracts from the *Dumbarton Herald* regarding Turbine Steamers, built at Dumbarton by William Denny & Bros.," and sent to him by that firm. This tallied with Mr Parsons' own publications. With regard to the torsion meter shown, he was very grateful to Mr Ward for adding a feature of such material interest at the present time to the discussion on the paper. If the idea of shaft horse-power measurement were not entirely new, at anyrate the ingenious method of obtaining readings was, and the machine had the merit of great simplicity. Based on the principle that even the strongest shaft would assume a twist under the influence of torque, and that the arc of torsion would be proportional thereto, there were several other meters of the same kind available, and he was sorry that Mr Ward had confined himself to a description of the instrument—which had appeared in *Engineering* some time before—rather than giving some idea of the results that could be obtained from it in order that comparisons

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might be made with other types. Apparently, with this meter, it was only possible to obtain occasional readings on engines of practically constant torque, such as turbines or electric motors, and it was therefore at a great disadvantage compared with such a torsion indicator as Dr. Föttinger's, of the Stettiner Maschinenbau A. G. Vulcan, from which continuous diagrammatic records of the effective torque of any marine engine could be obtained. The torsional vibrations of shafting were very important—they accounted for many fundamental differences between ordinary steam engines and marine engines, and, incidentally, vibration had frequently resulted in blade stripping. These vibrations were due to the periodic fluctuation in propeller resistance, and, in the case of ordinary engines especially, of the varying tangential force acting on the cranks. The latter force, due to the steam acting on the turbine blades, was practically constant, and did not affect the readings off turbine shafts to any extent, of course, but the variable nature of the propeller resistance did so very considerably, by setting up torsional oscillations, the action of which affected the effective torque and also the propeller thrust, and could only be determined by some continuous method of measurement. This formed the essential feature of Dr. Föttinger's method, and naturally necessitated greater complication; but, until the true effect of these torsional oscillations was known, it appeared that the great potentialities of continuous, and therefore more accurate, measurement more than justified this method. It might be remarked, in passing, that practically all the published data on this subject was of German origin, for in Germany the question of the B.H.P. of ordinary marine engines had received very careful attention during the last eight years. In the case of the "Kaiser Wilhelm II.," the Vulcan Company had obtained an efficiency of ·94 per cent. on service, and if such a result was obtainable with piston engines and twin screws, it was not surprising that the North German Lloyd Co., whose large steamers stood so high in point of propulsive efficiency, should have adhered to this type of engine instead of adopting the turbine. The subject of accurate

power measurement in turbine vessels was very interesting, but it was also necessary to investigate the effective power in ordinary vessels as well, if any reasonable comparisons were to be made. This had been done most exhaustively, and the results liberally published by Dr. Föttinger, whose work on the subject was unexcelled, but as far as turbine vessels were concerned "those who knew the facts (to quote Mr Johnson) and appeared most directly interested in the subject, maintained a discreet silence." Power measurement led up to economy, and in turbine steamers this involved the most careful consideration, not only of the turbine and of the propeller, but of their combined efficiency, for unless it could be shown that this was at least practically equal to that of ordinary engines, to adopt turbines might be a very doubtful expedient. This last was certainly not the view that he would take, but shipowners frequently did, and in view of the attempted suppression of data, especially on the subject of design, this silence was significant. In answer to Mr Craig, it was very likely that pressures of 15 and 16 lbs. per square inch of projected area had been reached in turbine work, but it simply involved a sacrifice of propeller efficiency in order to get a suitable turbine, and the same applied to the higher ratios of projected to disc area. With blades of circular form in the projected view, such as were shown in Fig. 3, a ratio of 0·6 was about the highest obtainable, but if the propeller blades were broadened at the tip so as to bring this ratio even higher—and the necessity for this was already apparent—it would be necessary to thicken up the root of the blades considerably. It had been proved very conclusively in the United States experimental tank what sacrifice of screw efficiency was involved by this, and as the turbine efficiency would remain constant to a large extent, it was only too probable that increasing the area ratio would, as Mr Hamilton remarked, entail a further drop in propeller efficiency due to blade interference. In fact, as Mr Barnaby predicted soon after the trials of the "Daring," it might be necessary in future, as speeds and powers increased, to put up with reduced propulsive efficiencies. In remarking on the possibilities of action

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turbines in marine work, Mr Craig had opened up a very imporant aspect of the turbine question. Mr Izod had not given analytical values in his diagram of losses, but they were entirely changed by the adoption of action turbines in which friction was the chief loss as opposed to leakage in the Parsons type, and it might eventually be shown that for low-speed work, where the ratio of blade height to mean diameter was very small in this machine, that action turbines would prove more successful. It might interest the Members to know that Herr Zoelly, from whose electrical turbines the Continental syndicate were obtaining such remarkably good results, had achieved considerable success in the application of his type of turbine to a 13-knot tramp steamer, built by Messrs Howaldt, of Kiel. This installation, made by the Escher Wyss Co., of Zurich, was of 1,000 B.H.P. With two turbines driving twin screws, the steam consumption was only 14 lbs. per H.P., a result that was materially better than most published tests on other types, excepting the case of H.M.S. "Amethyst." Apart from its applicability to slow-speed work, this multiple-stage action turbine was specially suitable for marine work, as it allowed of almost any superheat being used. Temperatures, in fact, like those quoted by Mr Riekie became both feasible and advantageous, and some development in this line might certainly be expected before long. Hitherto, with the Parsons marine turbine, depending on clearances like it did—fine, as far as the chance of stripping was concerned; large, as compared with the effective opening—superheat had not been used, but with the action turbine much larger clearances were possible without loss of efficiency. Mr C. G. Curtis had placed a twin-screw arrangement of his own type of turbine in an 8,000 H.P. 16-knot cargo steamer for the Southern Pacific Co., and in a scout cruiser for the U.S. Government; while the A. E. G. Co., of Berlin, his German licensees, had also done so in the "Kaiser," of the Hamburg-American Line, from which remarkably good results had been obtained. These three installations all consisted of separate and independent turbines, one on each shaft, both being complete in themselves and both reversible.

The reduction in complication by the use of two instead of three shafts was very great, and the superior efficiency of twin over triple screws would, he thought, before long, cause some modification in marine turbine practice. This agreed with Mr Jack's criticism of turbine-driven cargo steamers—that the third shaft was very much in the way. Mr Jack had also referred to the gas turbine, and the possibility of its competing with the gas engine for marine work. While he doubted the probabilities of this for a long time to come, he (the Author) certainly thought, that for low-power and slow-speed cargo vessels, that the gas engine would be adopted before any steam turbine; history would probably repeat itself if the gas turbine ever did come, but the enormous practical difficulties in the way necessitated for the solution of the gas turbine problems a stroke of far greater genius than was ever required for steam turbine work. In answer to Mr Royds, the volume for actual expansion was taken with 70 per cent. efficiency in the case given in Fig. 10; this diagram was inserted to show the necessity of very carefully investigating the question of openings between the blades—in other words, of blade heights, as standard sections were necessary, but perhaps it would have been more correct to say volume of steam per lb. of mixture. He failed to appreciate Mr Riddlesworth's reasoning when he stated that elaborate investigations of these openings were unnecessary in view of the considerable difference in volume shown by the curves; possibly it followed from his hypercritical anxiety for the use of 8·022 instead of 8 for the $\sqrt{64{\cdot}37}$. His friend, Mr Macalpine, had asked for more information regarding the calculation of dimensions. The formula quoted (Blade Velocity)^2 × No. of Rows, gave a rapid and easily handled approximation of the diameter and number of rows when the revolutions were determined. The suitable blade speeds were given in Table II., and the value of the constant, or rather coefficient, might be taken as about 1,500,000 for marine work—say, perhaps, 1,400,000 to 1,600,000, while for land work it was rather higher, being about 1,600,000 to 1,700,000. The blade heights were simply calculated

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from the total volume, the desired steam speed, which was from two to three times the blade velocity, and ratio of exit opening between the blades to the annular area. He entirely disagreed with him about the imperfection of the theory of design, as it was much simpler than that of a reciprocating engine, but a good design had got to be worked out in a properly scientific manner. The determination of dimensions and the possibility of forecasting results in strict conformity with the designed and desired efficiency compared with the Rankine cycle, could be done with great accuracy, though not by the simple method of accepting someone else's empirical rules. He certainly maintained that the most suitable ratio of steam speed to blade speed had yet to be determined. Equally good—almost record results in fact—had been obtained with wide differences, but there were so many variables to be considered that it was hard to lay down definite rules; mechanical possibilities and the question of manufacturing costs entered into consideration so much. In answer to Mr Neilson, a higher vane speed was "necessary"—possibly "advisable" was a better word—at the L.P. end to avoid the unwieldy and unmechanical blade heights that would be necessary if there were no increase of speed. The volume of steam, as Mr Neilson knew, increased very rapidly at the L.P. end, and to get the clear area for this to flow through could be done in various ways, but to increase the diameter, and consequently the vane speed, and the steam speed too, was one of the simplest. It was with this in view, as well as the leakage question, on which he fully agreed with Mr Neilson, that he had stated in the paper that the blade heights bore a certain ratio to the mean diameter—about 3 to 15 per cent.; above 15 per cent. the blades were apt to bend at the root. Mr Neilson, and also Mr Macalpine, had referred to the propeller diameter formula which he had given. It was based on the cavitation theory—or rather fact, as it had since become with the high speed screws now used—the first step being to obtain the actual effective thrust necessary, for which resistance data from tank trials, including the wake and augmented thrust values, was

of such assistance. Failing this, Mr Barnaby's formula for effective thrust might be used. Experience showed what the limit of pressure was per square inch of projected blade area, due to this effective thrust, for various classes of vessel, and consequently the projected blade area in square feet became (as was given by Mr Barnaby):—

$$\frac{\text{Effective thrust in lbs.}}{\text{Pressure per square inch} \times 144} = \left\{ \begin{array}{l} \text{Projected blade area in} \\ \text{square feet.} \end{array} \right.$$

His (the Author's) formula went a good deal further, he believed, because by inserting values of the pressure, and of the ratio of projected to disc area, one could arrive at the disc area for the effective thrust. It then needed little or no extra trouble to insert the ratio of diameter to disc area, whence by means of a diagram which gave the coefficient that he had called C, the propeller diameter could easily be found for a given pressure and area ratio when once the effective thrust was known. The "Invicta," referred to during the discussion, showed, it was said, a considerable improvement over the "Londonderry" on smaller dimensions; her propellers were rather larger in diameter and probably more efficient, and might be expected to have a "C" value of, say, 27·6, compared with the "Londonderry's" 30·5. The diagram was only drawn out up to a ·6 ratio of areas, but anyone who cared to pursue the subject could easily extend it. With reference to the points brought up by Prof. Jamieson and Mr Goudie as to the modulus of rigidity, it might be of interest to record the fact that this figure —5,250 tons per square inch—had been corroborated by experiments on an assortment of steel shafts made by various companies, which were carried out at the Royal Mechanical Testing Station at Charlottenburg, for Messrs Blohm & Voss, a few years ago, when Mr Frahm was commencing his experiments on the torsional stresses in shafting. This figure, again, was practically identical with that found from actual experiments made last year on the 6½-inch shafting of the turbine cruiser, "Lubeck," of the Imperial German Navy; in this case, the average of the four shafts calibrated, showed a shear modulus of 11,774,160 lbs. per square inch, making

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k = 140·09. Mr Johnson had referred to the advantages claimed for the turbine. As far as reduction of space was concerned, those who claimed this seldom or never added that occupied by at least one extra shaft tunnel, but in most cases some overhead space had been saved. As to absence of vibration from main engines, this had certainly been proved in a great many vessels, but propeller vibration still remained, and he agreed with him that too much was made of this claim. For instance, in the "Carmania," the vibration—slight as it was—was noticeable just where it was not wanted, viz., in the berths. It was almost impossible to say, by placing one's hand on the turbine cylinders, whether the rotor was revolving or not, but no excellence of the turbine could overcome the vibration due to a very rapidly revolving centre propeller passing the stern post, or to the inevitable fluctuation of propeller resistance. As far as the "Carmania" was concerned, he could assure Mr Johnson that while the vibration was enormously reduced, compared with the "Lucania" or the "Deutschland," it represented no improvement whatever on the "Baltic" or the "America," in his opinion. What a passenger cared about was personal comfort rather than pallograph records; he did not feel the vibration if he were walking on deck, and if well enough to spend his time in the smoking room, he did not care much if he did feel it; but where it was desirable to reduce it was in the rooms, and this was just where it was most noticeable in the "Carmania." While he certainly preferred the slower and scarcely noticeable throb of the "Baltic's" engines, compared with the rapid and intermittent tremour due to the "Carmania's" screws, it was only fair to say that the testimony of lady passengers who had used both vessels was that they noticed considerably less vibration in the "Carmania" than in the "Caronia." A good deal depended on how the ship was built. Again, where weight was concerned, the saving was important in warships and channel steamers, where considerable reductions had been obtained; but in vessels like the "Carmania," in which, on a rough day, half-way out, five or six hundred tons of water ballast might be let in: What advantage was there in saving a few pounds per horse power on the main engines only, unless the auxiliaries and the boilers were effected as well as the adoption of turbines? Saving in weight in Atlantic steamers was of comparatively small moment. Regarding the shape of the standard blade section, the general exit angles were from 20 to 25 degrees, but they varied somewhat with the width of the blade and the shape of the section. At the low-pressure end the exit angle was increased to allow a greater opening in proportion to the annular area. There were an enormous number of standard sections in use by various firms; and just at present there was a tendency to alter the shape somewhat in order to obtain greater strength at the root to resist bending. He might be permitted to refer to the "Carmania," in which he had crossed to New York on the maiden trip, returning in her on her third voyage. Almost exceptionally rough weather prevailed on the first two complete trips, but it was remarkably calm on the third. The universal testimony of every engineer who had visited the turbine room, either *en route* or at either end, was to the magnificent success which had attended the skill and thoroughness which the staff of Messrs John Brown & Co. had lavished on the vessel and her machinery. The engine room was spacious and cool, in spite of a large overhead saving of space that had been devoted to second-class accommodation, while every detail showed with what thoroughness and care the design had been investigated and carried out. It was not surprising that the vessel, as Mr Ward said, should have fulfilled the highest expectations of all connected with her in every way. He gave a summary of the speeds for the successive voyages on the following page. In spite of very heavy weather, the average of the longest distance run in one day worked out at 18·16 knots. One very noticeable feature was the absence of racing in rough weather, compared with that noticeable with ordinary propellers; though the revolutions rose slightly as the screws approached the surface, the effect was not felt on deck at all. In conclusion, he wished to again thank the Members

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	VOYAGE.					
	1.		2.		3.	
	Out.	Home.	Out.	Home.	Out.	Home.
Left Liverpool, ...	Dec. 2	—	Dec. 30	—	Jan. 27	—
Left New York, ...	—	Dec. 16	—	Jan. 13	—	Feb. 10
Total distance run—knots* ...	2,780	2,807	2,780	2,808	2,889	2,932
	d. h. m.	d. h. m.	d. h. m.	d. h. m.	d. h. m.	d. h. m.
Total time, ...	7 9 31°†	7 0 40	6 20 34	7 19 ·05†	6 17 42	6 23 09
Speed—knots,...	15·64	16·66	16·89	15·00	17·87	17·51
Longest distance run in one day—knots, ...	457	420	446	417	457	420

* From Daunt's Rock Lightship to Sandy Hook Lightship.

° Vessel lay to on account of weather for several hours.

† Very rough passages.

for the way in which they had received the paper. The subject of steam turbines was one of engrossing interest at the present time, and it was therefore a source of much pleasure to himself to have been able to submit a paper on the subject to the Institution of Engineers and Shipbuilders in Scotland, of which so many of the leading Members had contributed to the present status and success of the marine steam turbine.

The PRESIDENT said that every Member was deeply indebted to Mr Speakman for bringing this most interesting subject before the Institution. He was curious to know as much as possible about turbines, and he had learned a great deal from Mr Speakman's paper. He proposed that the Institution should award Mr Speakman a hearty vote of thanks for his paper.

The vote of thanks was heartily accorded.

THE EVOLUTION AND PROSPECTS OF THE ELASTIC FLUID TURBINE.

By Mr R. M. NEILSON (Manchester).

SEE PLATES VI., VII., VIII., AND IX.

Read 19th December, 1905.

THE efficiency of large steam turbines built for driving electric generators has been brought so high during the last few years that there is little chance of the present records for low steam consumption being lowered in the near future to any great extent.

The elastic fluid turbine is, however, in the Author's opinion, by no means so perfect or so adaptable as it may reasonably be hoped that it will be in the near future.

With regard to the propulsion of ships by steam turbines, wonderful progress has been made during the last ten years, but there is still room for improvement in the steam turbine screw propeller combination, especially with respect to vessels which have to steam at widely varying speeds and with respect to small slow vessels. There is also room for improvement as regards reversing.

For many purposes the speeds of rotation, which it has been found necessary to give to steam turbines, especially those of small power, has been a serious objection to their use.

Moreover, the serious falling off in the efficiency of turbines when run with a poor vacuum, and the still greater drop in their efficiency when run non-condensing has in many cases prevented their adoption.

Steam although a convenient, is not the only possible elastic fluid for a turbine; and the much greater ranges of temperature with the same range of pressure obtainable by the employment of other fluids instead of or in conjunction with steam deserve serious consideration.

It is neither desirable nor likely that engineers will rest content with the success already attained, but will strive, by improved constructions of turbines and cycles of working, to allow a still greater percentage of the heat units obtainable from burning coal or other suitable fuel to be converted into useful work, and will further strive to adopt the elastic fluid turbine to work effectively under conditions at present unfavourable to it.

An immense amount of time, money, ingenuity and patient work have been expended on matters relating to elastic fluid turbines; and quite a large proportion has been spent on inventions intended to be of a revolutionary nature. Much of the time would have been saved or expended more usefully had there been a greater knowledge (1) of what had already been tried by others, and (2) of the most hopeful lines on which to work and the utmost possibilities obtainable from certain treatments of the fluid and certain working cycles.

It is of course impossible to give in this paper anything like a full account of what has already been done with elastic fluid turbines; but it was thought that a brief historical sketch would be both interesting and instructive. This is consequently presented; and following it are some notes and suggestions on possible lines of progress and difficulties to be overcome, which it is hoped will be of some use or will, at least, induce a good discussion.

It will never be known for certain when an elastic fluid was first employed to rotate a machine deserving the name of a turbine. Hero, the Egyptian philosopher, is usually honoured by having his name placed first in the history of the steam turbine. The nature of his rotating steam globe is well known, but it is not certain that he was the first to use it or even that he did any research work at all in the matter. The point is, however, of little consequence.

Windmills (which come under the heading of turbines when the latter word is used in its broad sense) were probably used in very early times, but with these the present paper will not deal.

As regards turbines actuated by elastic fluids other than air, there were undoubtedly attempts made to usefully employ such in the seventeenth, if not in the sixteenth, century. Branca, an Italian architect in 1629, described an engine in which a jet of steam was projected against vanes carried on the periphery of a horizontal wheel, which was consequently caused to rotate and to do useful work in pounding drugs. An engine of substantially the same nature was used by a Jesuit named Kircher in 1642.

In 1694, a model motor car is said to have been exhibited to the Emperor Cang Hi of China by Grimaldi and Periera. Grimalidi was a Jesuit who had great mechanical ability. The car in question is said to have carried a brazen vessel containing a coal fire. This generated steam from water contained in a vessel situated over the fire. The steam was directed on to vanes arranged like those of a windmill, and the shaft carrying the vanes actuated the driving axle of the car.

In 1784 a patent was granted to Wolfgang de Kempelen for obtaining and transmitting motive power. Fig. 1 shows the turbine proposed by Kempelen. A is the boiler provided with a safety valve B. C is a turncock controlling the admission of steam to the pipe E, which conducts it to the cylinder D, which, in turn, is secured to a vertical tube situated within and concentric with the pipe E. This cylinder D has a small hole at each end, the holes facing opposite directions. One hole can be seen in the drawing. The escape of steam from these holes causes the cylinder to rotate about the axis of the tube E. The inventor states that "having accomplished this first moving power which constitutes the principle of the machine, any kind of machine or engine may very easily be put into motion by it by means of a handle, crown-wheel pinion, or other connection adapted to it, as is done with respect to a double pump by the eccentric trunion K."*

* Specification of British Patent No. 1426, of 1784. The drawing is reproduced from "The Steam Turbine," by R. M. Neilson, by kind permission of the Publishers, Messrs, Longmans & Co.

About the same time James Watt patented a turbine in which steam was employed to force water out of a vessel adapted to rotate about a vertical axis. The vessel had two chambers, and the steam was admitted alternately to these, the steam exhausting from one chamber while it was entering the other. The escape of the water from the chambers, under the action of the steam, rotated the vessel.* About the time that Watt received his letters patent for this invention, he commenced to get on well with his reciprocating engine, which hitherto had caused him much disappointment by the slow progress he was able to make with it. The turbine idea seems, therefore, to have been dropped soon after its conception. †

In 1823 Samuel Brown, whose name is famous in the history of the gas engine, suggested that gas should be burned in a chamber so as to heat the air contained therein and drive out some of it, and then that the partial vacuum produced by the cooling of the air in the chamber should draw up water which could afterwards be discharged into the buckets of an overshot water-wheel. The water-wheel could be used to drive machinery.

In 1837 Sir James Caleb Anderson, Bart., proposed to convey the steam exhausting from the cylinder of a reciprocating engine to a rotary engine of the Hero type, which rotated in a chamber connected to a condenser. The turbine spindle drove on to the crank shaft which was connected to the reciprocating piston.‡

In the same year John Hardman and William Gilman § both proposed to convey steam to nozzles mounted on a rotating wheel and cause this steam escaping from the nozzles to act so as to rotate another wheel in the opposite direction. Both inventors

* For a fuller description, see Specification of British Patent No. 1432, of 1784, or "The Steam Turbine," by R. M. Neilson, Longmans & Co. Third Edition, p. 10.

† This turbine of Watt's must not be confounded with his rotary piston engine, which was conceived at an earlier date.

‡ British Patent 7407, of 1837.

§ British Patents 7308 and 7417, of 1837.

proposed to connect the two wheels together by gearing, Gilman by bevel wheels, and Hardman by an internally toothed wheel, and an externally toothed wheel connected by a pinion.

Gilman also proposed to expand the steam in stages and employ several turbine wheels in series, each in a separate chamber, a scheme which has been successfully developed in recent years by many turbine engineers, notable M. Rateau in his multi-cellular turbine. Fig. 2 shows Gilman's multi-stage turbine. The steam enters each wheel at the centre and quits it at the circumference.

In 1838 Matthew Heath described an engine of the Hero type with diverging nozzles.* The reason he gave for employing diverging nozzles was that the "power of movement" to be obtained by "expanding the steam" (as he said) might not be lost. The invention was not that of Heath himself but of "a certain foreigner residing abroad." Heath may have known that better results could be obtained by using diverging nozzles; but it is to be inferred that he did not fully understand their effect. It is interesting, however, to find at this date a description of a diverging nozzle although it was not called by that name. The Author has come across no previous record of diverging nozzles having been proposed for an elastic fluid turbine.

Heath proposed to furnish the stuffing boxes of his turbine spindle with "pounded amianthus instead of common hemp which would catch fire from the rapidity of the rotary movement in spite of oil cisterns."

Heath also proposed to blow steam into a furnace and to convey away the mixture of steam and products of combustion for use in an engine. He did not, however, mention in the specification of his patent if he intended to use this mixture in the Hero type of engine.

About 1840, James Pilbrow of Tottenham, Middlesex, seems to have devoted considerable time to the steam turbine idea. Pilbrow made experiments with steam jets and made calculations from the results of these experiments. His data and his treatment of the

*British Patent 7554, of 1838.

subject were not such as to give him accurate results as to the velocity of steam jets; but he found out at any rate that, with a large drop of pressure, a very high velocity could be obtained, and that with a single wheel very high vane speeds were consequently called for.

In order to work economically with a lower vane speed, Pilbrow proposed to arrange two or more wheels in series. Figs. 3 and 4 show an arrangement of two wheels in series proposed by Pilbrow. The vanes are arranged on the peripheries of the wheels, and overlap each other. Fig. 5 shows the vanes of two such wheels in section, the steam nozzle also being shown. Pilbrow seems to have tackled the steam turbine problem in a fairly scientific manner. It is doubtful, however, if he understood the necessity of expanding the steam in a divergent nozzle in order to obtain the best results with single stage expansion. The balance of probability is that Pilbrow did not have this knowledge, and without it his turbines could never be a success.

Robert Wilson, of Greenock, was granted letters patent in 1848* for improvements relating to rotatory engines. His specification describes several designs of steam turbine in which the steam passes in series through several sets of moving buckets. Fig. 6 shows Wilson's design for an outward flow steam turbine. The steam is intended to pass from the centre outwards through the six sets of buckets, of which the second, fourth, and sixth are carried by a disc keyed on a shaft which rotates in a clock-wise direction, while the first, third, and fifth are attached to a disc which is either stationary or rotates in a counter-clock-wise direction. Wilson intended his turbines to be powerful machines. One of them is shown in his specification drawings as being over 9 feet in diameter.

In 1850, William Francis Fernihough, of London, proposed to mix the products of combustion from a furnace with steam or water spray, and to use the mixture to propel a turbine.† Fig. 7 shows an apparatus proposed by Fernihough. A is a furnace

* British Patent No. 12026, of 1848.

chamber made of plate iron lined with fire clay and provided with fire bars B, on which fuel is burnt. Combustion takes place under pressure, air being forced by a blower through the pipe E. Water is forced in the form of a spray from the nozzle or rose H, and, falling upon the fire clay bars G, kept hot by the combustion of the fuel, is vapourised The combined steam and products of combustion, mixed with small particles of unconsumed fuel, pass through the nozzle I into the chamber K, and act to rotate the vanes L L, which are formed integrally with the spindle M. The rotation of the spindle M can, by means of a belt or belts P, be made to drive machinery.

An engine of the Hero type is said to have been employed at the printing establishment of Messrs Chambers, of Edinburgh, previous to 1852.* The Author has not, however, been able to get any particulars of this engine.

A wheel 11½ feet in diameter, provided with vanes on its circumference and driven by steam jets at 500 revolutions per minute, is said to have been tried at the Surrey Docks prior to 1852. It fell into disuse, however, owing to its steam consumption being greater for an equal duty than that of a piston engine.† The Author has been unable to get any particulars of this engine, although Mr J. S. Gaskell very kindly put himself to considerable trouble to try to get information about it.

In 1853, the French mining engineer, Tournaire, pointed out very clearly some of the requisites of a successful steam turbine. He proposed to expand the steam in stages to avoid excessive velocity, and to employ helicoidal gearing in connection with turbine shafts rotating at high speeds.

In Bourne's Treatise on the Steam Engine, fifth edition, 1861, occurs the following passage:—‡

* British Patent No. 13281, of 1850.

† "Steam and Locomotion," by John Sewell, published by John Weale, London, in 1852, pp. 224 and 237.

‡ A Treatise on the Steam Engine by John Bourne, Published by Longmans, Fifth edition, 1861, page 397.

"Steam of a high temperature will, therefore, be more economical in its use than steam of a lower temperature, and surcharged steam being much hotter than common steam is consequently more advantageous. After all, however, the temperatures which it is possible to use with any kind of steam in an engine, are too low to render any very important measure of economy possible by their instrumentality. We are, therefore, driven to consider the applicability of other agents, the most suitable of which appears to be the air, and this brings us back to the point from whence we started at the commencement of the present chapter. Small measures of improvement are worth very little consideration when great and important steps of progress are apparently within our reach, and to us it appears quite clear that the products of combustion may be employed to produce motive power, not through the instrumentality of a cylinder and piston, but rather by means of a turbine or an instrument like a smoke jack or Barker's mill and which may be made to work in water or some other liquid. In this way high temperatures may be dealt with, and it is only by employing very high temperatures that any great step of improvement is to be attained."

The specification of a patent granted to M. P. W. Boulton in 1864 * contains some interesting suggestions regarding turbines actuated by hot gases. The patentee seems to have appreciated that a difficulty in driving a turbine wheel by products of combustion lay in the high velocity that would have to be given to the wheel to obtain a good efficiency. He proposes three methods of overcoming this difficulty :—

(1) To cause a high velocity gas jet by an injector action to suck in a supply of air, thus obtaining a large body of fluid at a low velocity instead of a small body at a high velocity.

(2) To employ several turbine wheels arranged in series, each one utilising a portion of the velocity of the gas jet.

* British Patent No. 1636, of 1864.

(3) To employ the hot gases to exert pressure on a liquid, and so force the liquid to drive a hydraulic turbine.

Fig. 8 is a reproduction of the patentee's drawing illustrating the first method. The nozzle A is supplied with hot gases travelling at a high velocity, and induces a current of air in the tube B; and the combined gases induce a further current of air in the tube C. The whole of the fluid, travelling at a moderate velocity, then acts on the turbine D.

The second method is not illustrated. Fig. 9 illustrates the third method. The gaseous products of combustion (or other gas or gases) are forced through the passage H into the chamber A, and drive liquid (at present in the chamber A) through the valve B into the passage C, which leads to the turbine. The liquid leaving the turbine passes into the tank F. When sufficient gas has been admitted to the chamber A, the supply is cut off by a valve and the gas allowed to expand. When a sufficient quantity of liquid has been forced out of the chamber A, a valve in the passage K is opened, the pressure in the chamber A falls, and liquid enters by the valve L and displaces the gas. The cycle of operations is then repeated. It is stated that the valves may be operated by the motion of the liquid, and that two or more vessels A may be employed, so as to give a more constant supply of liquid to the turbine. D is an air vessel arranged on the passage C.

Boulton proposed to mix steam or water with the products of combustion in order to reduce the temperature of these. Fig. 10 shows an apparatus proposed by him for utilising some of the heat of combustion of a gas for generating steam and obtaining a mixture of steam and products of combustion. An inflammable gas is burned in the chamber A, which is enclosed in the chamber B containing water. The products of combustion proceed down the passages C C and enter the water. The gas, in passing through fine holes in the plates or gauze D, gets broken up, and rises in "fine streams" through the water, thus heating the water and generating steam. Heat for generating steam is also presumably obtained from the sides of the passages C C. The baffle plates E E are provided to cause the gas to take a zig-zag course.

The specification of a patent granted to John Morrison Hunter, of Morristown, N.J., U.S.A., in 1868,* contains a description of a flying machine proposed to be propelled through the air by means of propellers actuated by gas jets. Pilbrow had previously proposed to rotate a propeller by steam jets. Hunter proposed to employ gaseous products of combustion, the fuel employed being preferably American natural oil. Fig. 11 is a section of Hunter's proposed vapouriser, and Fig. 12 is an end view. The oil is poured into the funnel M and admitted to the vapourising tubes L through two valves arranged in series, one only being opened at a time. A section of a tube is shown in Fig. 13. The oil is first passed along the crescent-shaped upper part, and then back by the larger section. Products of combustion from a furnace passes through between the tubes and heats them.

Fig. 14 shows the preferred form of nozzle. One of these nozzles is arranged on each propeller blade. The vapour is led to the chamber A by the tube B, and then passes through the holes C C, and escapes between the inner surface of the cone D and the outer surface of the cap E, which can be adjusted to regulate the supply of vapour. Air is caught in the cone F by the backward rotation of the nozzle, and mixes with the vapour at the exit of the nozzle. Ignition at the moment of exit was proposed to be accomplished by an electric spark or by means of spongy platinum. The products of combustion from the furnace are led to each nozzle by the annular passage G and pipe H. An .nduced draught from the fire is thus obtained.

In 1869-70, John Bourne proposed† to produce carbon monoxide by the incomplete combustion of coal dust with air, and to afterwards complete the combustion by additional air and inject steam or water into the resultant hot gases, which could then, he stated, be employed to drive a turbine. The actuating fluid could, if desired, be diluted by mixture with additional air before use in the

* British Patent No. 2680, of 1868.

† British Patents Nos. 3705, of 1869, and 1859, of 1870.

turbine. The apparatus for producing the motor power fluid is explained at great length in the specifications of Bourne's patents, and many forms of apparatus are described and illustrated. There is no drawing or description of a turbine. Bourne intended to employ very high pressures. He states, for example, in one place that he prefers the pressure of the water injected among the hot products of combustion to be about 1,000 lbs. per square inch.

Mr Parsons, in a paper recently read before the Institution of Civil Engineers, mentions the use of steam turbines "in the sixties and seventies" to drive the assisted draught fans on some of the Holyhead-Kingstown mail steamers.

James Anderson, in a provisional specification with an application for a patent in 1871,* makes suggestions regarding gas turbines, although no details of construction are given. Anderson states that the object of his invention is to secure increased economy and advantage in producing currents, or otherwise developing motive power by means of heat, and that the invention consists mainly in igniting a mixture of combustible gas and air in a continuous manner in a chamber or channel near a nozzle or orifice through which the gases of greatly increased volume, due to the combustion, issue in the form of a jet. The inventor states that "the gases resulting from the combustion, and issuing from the ignition or combination chamber or channel, or a current of mixed gas and air produced by a jet action of the gases, is led into a reaction turbine, so as to thereby impart rotation to machinery. Or, again, the ignition or combination chamber may be the hollow arms or body of the turbine itself. The ignition or combination chamber or channel is to be lined with fireclay or other suitable refractory and non-conducting material to retain heat sufficient for insuring the continuous ignition or combustion of the gas, and to prevent loss of heat. The combustible gas and the air are led to the ignition or combination chamber under a suitable pressure by

* Application for British Patent No. 2326, of 1871.

separate pipes, or they may be led to it in a mixed state by one pipe; but in this latter case a diaphragm of porous material must be interposed at the inlet into the ignition chamber to prevent the ignition from extending back along the supply pipe. There may, of course, be two or more nozzles, orifices, or outlets to one ignition chamber."

In 1877, a patent was granted for an invention communicated by Joseph Wertheim, of Frankfort-on-Main, Germany, for "obtaining and applying motor power." * Fig. 15 is an elevation of Wertheim's engine, and Fig. 16 is a vertical section of part of it. A is a chamber into which air and gas are admitted and in which they are exploded, the pressure of explosion driving water down the pipe T, so as to drive the turbine wheel situated within the casing C. When the water is flowing down the pipe T, the valve G is open and the valve Q is closed, so that the water is directed along the passage X and acts on the lower vanes of the turbine wheel. The flow of water continues up the pipe H into the reservoir D, which is provided with an air chamber E. An excess of pressure then ensues in the reservoir D over that in the explosion chamber A, and, the valve G being now closed and the valve Q open, water flows down the pipe H and through the passage Z, acting on the upper turbine vanes. The water rises up the pipe T and expels the products of combustion from the explosion chamber, thus completing the cycle.

About 1882, Dr Gustav de Laval invented a turbine on the principle of Hero's engine. Figs. 17 and 18 show the nozzle N and the S-shaped flyer F which were employed. This turbine seems to have been intended chiefly for the direct driving of milk separators; and milk separators so driven are, the author believes, now at work. Dr de Laval does not seem to have thought of the divergent nozzle till a later date.

In 1884, the Hon. C. A. Parsons applied for a patent † for

* British Patent No. 3444, of 1876.

† British Patent No. 6735, of 1884.

"Improvements in Rotary Motors actuated by Elastic Fluid Pressure,* and applicable also as Pumps." The specification of this patent is exceedingly interesting, and has probably been more read than any other British patent specification. Four editions have been sold out by the Patent Office. A particularly interesting part of the specification is the following passage, which has reference to turbines actuated by gaseous products of combustion:—

"Motors, according to my invention, are applicable to a variety of purposes, and if such an apparatus be driven, it becomes a pump and can be used for actuating a fluid column or producing pressure in a fluid. Such a fluid pressure producer can be combined with a multiple motor, according to my invention, to obtain motive power from fuel or combustible gases of any kind. For this purpose I employ the pressure producer to force air or combustible gases into a furnace into which there may or may not be introduced other fuel (liquid or solid). From the furnace, the products of combustion can be led in a heated state to the multiple motor which they will actuate. Conveniently, the pressure producer and multiple motor can be mounted on the same shaft, the former to be driven by the latter; but I do not confine myself to this arrangement of parts. In some cases I employ water or other fluid to cool the blades, either by conduction of heat through their roots or by other suitable arrangement to effect their protection."

The early Parsons steam turbine, as described in this specification and as first made, was generally speaking the same as the modern Parsons turbine. Many improvements have been made since then, but the first Parsons turbine constructed in 1885 was a practical and satisfactory machine. It was of the double-flow type, the steam entering at the centre and exhausting at both ends. It ran at 18,000 revolutions per minute, and was in use for many years.

* The expression—actuated by fluid pressure—was unfortunate. It has remained in use, and has led to much misconception as to the action of turbines, which, of course, are operated by the kinetic energy of the fluid, and not directly by the pressure.

In the list of distinguished and talented engineers to whom credit is due for developing the steam turbine idea, and securing for the steam turbine its present extensive use, the Hon. C. A. Parsons easily takes first place. The more one considers the subject of the evolution of the elastic fluid turbine, and the more one views each step of progress in the light of the knowledge existing at the time, the more one appreciates the value of the work done by Parsons.

In 1889, Dr de Laval applied for a British Patent* for a steam turbine wheel combined with a divergent nozzle for converting the heat energy of the steam into kinetic energy, and directing the steam into the turbine buckets. Two views of the wheel and nozzle, taken from the patent specification, are given in Figs. 19 and 20. The nozzle is substantially the same as the de Laval nozzle now used, but differs in two details—(1) The neck A is angular instead of being rounded; (2) the approach B to the neck is longer than is now employed.†

Another British Patent of Dr de Laval's, of the same year,‡ has reference to the flexible support of bodies rotating with higher angular velocities. Several devices are described for giving flexibility, including the one now adopted in de Laval turbines—making the shaft sufficiently slender to be flexible within the limits required. These two features—the diverging nozzle and the flexible shaft—are the essential features of the modern de Laval turbine.

Mr Alexander Morton, of this city, did a considerable amount of experimental work on the flow of fluids through nozzles of different forms from a higher to a lower pressure, and several steam turbines were made and run by him during the years 1884 to 1893. Mr Morton read several papers before Glasgow societies

* No. 7143, of 1889.

† A section of a modern de Laval nozzle was illustrated in a paper read before this Institution by Mr. Konrad Andersson in 1902.

‡ No. 12509, of 1889.

on the results of his experiments, including a paper before this Institution in December, 1893, on Rotatory and Reaction Engines.

Figs. 21 and 22 illustrate a steam turbine of Morton's of about 16 B.H.P., which was employed in driving a Schielé fan at the works of Messrs Campbell, Smart & Co., Old Dumbarton Road, Glasgow. The right hand part of Fig. 21 is a side elevation of the engine, and the left hand part a vertical axial section. The right and left hand sides of Fig. 22 are cross sections on the lines of L L and R R respectively of Fig. 21, looking respectively to the left and to the right.

The cylindrical casing A encloses three chambers, of which the left hand one and half of the centre one are shown in section in Fig. 21. The casing is built up of two parts, of which the plane of division is indicated by P P. The divisions between the chambers, of which one C is shown, are cast in one piece with the respective parts of the casing, and are flat. The end covers K K are dished. In each chamber is a duplex wheel composed of three circular steel plates, of which the centre one N is flat, while the others O O are dished. These three plates are connected together at the ircircumference by the brass rings S S_1. The centre plate is attached to the nave M, which is mounted on a conical part of the shaft D. Nozzles are formed in the brass rings S S_1, those in the ring S being outward flow, and those in the ring S_1 being inward flow, as shown in Fig, 22, where the outward flow nozzles are indicated by the letters U U and the inward flow nozzles by the letters V V.

Steam is admitted to the first wheel by way of the conduit T and the annular space W around the shaft. The steam passes outwards between the plates O and N of the first wheel, and quits the wheel and enters the chamber X by way of the nozzles U, in which it expands and gains velocity, the change of momentum acting to rotate the wheel.

The steam then passes back from the Chamber X to the interior of the wheel by way of the nozzles V, in which it again expands, and the reactive force is again employed to rotate the wheel. The steam passes inwards towards the shaft, and proceeds to the second wheel by way of an annular passage between the bearing Y and the interior of the partition C. The steam proceeds through the second and third wheels in the same manner. The nozzles through the ring S of the first wheel measure $\frac{1}{32}$ of an inch by $\frac{1}{2}$ an inch. The other nozzles are progressively greater, till the last set are nearly $\frac{3}{16}$ of an inch by 1 inch. The vanes E and F are provided for the purpose of re-directing the steam after leaving the nozzles. The vanes F are carried by the non-rotating conical plates H, of which there is one for each wheel.

The means for balancing the axial pressure on the first wheel is shown in Fig. 21. Z is an annular chamber which is kept at the same pressure as exists in the second compartment of the wheel by means of the tubes L. This chamber is proportioned so as to give the necessary balancing effect.

This turbine was tested at various speeds up to rather over 1,000 revolutions per minute. It was found to be the most efficient at the higher speeds, and another turbine was consequently designed to run with a greater angular velocity.

This second turbine had only one chamber. Fig. 23 is a vertical section of the machine. There are two wheels, each formed of dished plates connected together by rings containing nozzles. The first wheel through which the steam passes outwardly has four dished plates B, C, K, L, and three rings 1, 2, 3. The second wheel through which the steam passes inwardly has three dished plates M, N, P, and two rings 4, 5. The nozzles formed in the rings are very much the same as those of the previously constructed turbine. Fig. 24 shows the (outward flow) nozzles of the outermost ring of the first wheel, and Fig. 25 shows the (inward flow) nozzles of the outer ring of the second wheel. Vanes E are formed on the casing A to arrest the rotation of the steam issuing from the nozzles in the ring 3, and vanes F, F^1, F^2, F^3 carried by dished plates H are provided at the exit ends of the other nozzles to redirect the steam. Ring 1 of the first wheel is $9\frac{1}{2}$ inches, ring 2 is $12\frac{1}{4}$ inches, and ring 3 is 15 inches in diameter. The two rings of the second wheel are respectively 15 inches and $12\frac{1}{2}$ inches in diameter. Ring 1 (of the first wheel) has eight nozzles, each $\frac{1}{32}$ of an inch by $\frac{1}{2}$ an inch. Ring 5 (of the last wheel) has ten nozzles, each $\frac{1}{8}$ of an inch by 1 inch.

The two wheels are mounted on the same shaft which runs at 4,000 revolutions per minute, ordinary oil cups and wicks being used for lubrication. The steam enters the casing by the duct R, and leaves it by the duct S.

The engine was tested by Professor Barr and Mr H. A. Mavor, of this city, and, with steam at 78 lbs. per square inch above the atmosphere and a vacuum of 20 inches, was found to consume 87 lbs. of steam per B. H. P.-hour when developing 10·16 brake horse power.

These two turbines of Morton's were found to run satisfactorily and give little trouble. Their high steam consumption was, however, against them.

In 1894, M. Rateau began the construction of a single-wheel steam turbine; and Rateau turbines of this type were built at St. Etienne and at Paris during the years 1895 and 1896. The best design of single-disc Rateau turbine had a wheel like a Pelton water-wheel. Several of these turbines are said to be still running.

The Rateau multi-cellular turbine seems to have been schemed out by M. Rateau about 1897, and one of these machines, of about 900 H.P. was commenced by Messrs Sautter, Harle & Cie., in 1898. A Rateau multi-cellular turbine of 1,000 H. P. was to have been exhibited at the Paris International Exhibition in 1900, but was not ready in time; and it was not until about 1901 that the Rateau multi-cellular turbine had really passed over the preliminary experimental stage.

About 1895-6, Mr C. G. Curtis, of New York, started experimenting on a type of steam turbine differing considerably from either the Parsons or the de Laval, the only two turbines which had then been made on anything other than an experimental scale. Mr Curtis' object was to obtain satisfactory results with fewer parts than the Parsons type of turbine required, and yet to get sufficiently low speeds of rotation to avoid the use of gearing. About 1900, the General Electric Company of America undertook to build Curtis machines for service. A 600 kilowatt unit was then built, and was put into operation at Schenectady towards the end of 1901. This machine had a horizontal shaft. Shortly after this, work was commenced on a 5,000 kilowatt unit for the Chicago Edison Co., and a 500 kilowatt unit for the Newport (R. I.) power station of the Massachusetts Electric Companies. These machines had vertical shafts.

The Riedler-Stumpf and the Zoelly turbines have been placed on the market at a still later date.

Although there are at present being constructed, and sold in large quantities, turbines which differ among themselves very considerably, there is a visible tendency of the different types to approach each other.

The history of the Curtis turbine appears to show a gradual approach towards greater similarity to the Rateau.

The Zoelly turbine, which very closely resembles the Rateau, but is of later date, has a less number of stages and higher vane speed, thus approaching more nearly to the Curtis.

The British Westinghouse Electric and Manufacturing Co., Ltd., have recently altered their design of Parsons' turbine and provided nozzles and what they call "impulse" blades, which deal with the first part of the expansion of steam. The initial treatment of the steam very closely resembles that adopted in the Curtis turbine. The length of the turbine is much shortened by this device.

The Brush Electrical Engineering Coy., Ltd., have recently shortened their standard designs of turbines.

The Stumpf turbine was made first with one wheel, but there is now a design having two wheels.

The Maison Bréguet, who manufacture the de Laval turbine in Paris, are said to be experimenting with multiple-wheel turbines.

The present tendency seems, therefore, for the different types to come closer together.

The success of the steam turbine during the last few years has caused much attention to be given to the question of the employment of hot gaseous products of combustion to drive a turbine. To one who has not considered the question deeply, it appears natural to think that, as steam turbines have been built to successfully compete with reciprocating steam engines, it ought to be possible to build a gas turbine to successfully compete with reciprocating gas engines. It will be useful to consider here the relative advantages and disadvantages of reciprocating and turbine steam engines, and to try to see how far these will apply to reciprocating and turbine gas engines.

In a reciprocating steam engine the frictional losses are generally small — wonderfully small in some cases; but it suffers, however, from two great losses. One of these is that the expansion cannot be carried to the condenser pressure, and the other is that more steam is consumed than is represented on the indicator diagram. The first loss is very well understood; but practical considerations prevent one from reducing it. The volume of steam increases so rapidly with loss of heat at low pressures that, to expand the steam in a cylinder in a manner approaching the isentropic to a good vacuum would require a cylinder of unpracticable size. For example, if steam at 200 lbs. pressure absolute were expanded isentropically to a pressure of 0·6 lbs. absolute (28·8 inches of mercury when the barometer is at 30), 25·5 per cent. of the steam would be condensed; and the volume of 1 lb. of the steam and water would be over 400 cubic feet. It would require a cylinder 6½ feet in diameter by 12 feet stroke to contain this single lb. Even to expand the steam to a much poorer vacuum would require a cylinder of unpracticable size for the power. A turbine on the other hand can, without any practical difficulty and without the necessity for huge dimensions, be made to expand the steam almost to the pressure in the condenser.

The other great loss with reciprocating steam engines is, as aforesaid, that more steam is actually consumed than is accounted for by an indicator diagram. Strictly speaking, this is a proof of the loss rather than the loss itself. The causes of the loss are probably initial condensation and leakage past valves; but how much of the loss should be attributed to initial condensation, and how much to leakage past valves, is a question about which there is much difference of opinion; but that a waste of steam does occur has been proved beyond doubt.

These two great losses are incurred by reciprocating steam engines, while steam turbines are practically free from them. But the efficiency of steam turbines is only about the same as that of reciprocating steam engines. Therefore, turbines must be subjected to losses from which reciprocating engines are exempt, or to which reciprocating engines are subjected to a less extent. These losses may be understood by turbine builders, but they have not received from engineers in general an amount of attention proportional to their importance. The losses are due to friction and eddies. In a reciprocating engine there is friction between the moving metallic parts. This friction accounts for the difference between the I.H.P. and the B.H.P., and is in its important features well understood.

In a steam turbine running well there ought to be very little friction of this nature. There are, however, fluid frictional losses and eddy losses which depend upon the type of turbine and the dimensions and speeds of rotation of the rotating parts. For similar wheels, the moment of frictional drag or the speed-reducing torque produced by the rotation of the wheel in steam of a given pressure and dryness fraction (or superheat) varies approximately at least as the fifth power of the diameter and the square of the angular velocity or revolutions per minute. The useful work taken per second or per minute from the turbine by this drag is therefore proportional to the fifth power of the diameter of the wheel and the cube of the angular velocity. From this it can easily be deduced that it is better, as far as this loss of work is concerned, to obtain the requisite vane speed with a small wheel and a high angular velocity than with a large wheel having a relatively small angular velocity. There are usually, however considerations which limit the angular velocity and thus cause a much greater absorption of energy from the turbine spindle than would otherwise be the case.

There is also friction in the passage of the steam through the moving buckets of a turbine and through the nozzles or guiding passages, which reduces the velocity of the steam, and therefore reduces the amount of mechanical work obtainable from it. The loss in any case presumably depends greatly on the velocity of the steam.*

Kinetic energy is obtained by the expansion of the steam in one or more stages, and there is always some of this energy which is not given up to the rotating parts of the turbine, but acts to produce eddies. The percentage kinetic energy which thus goes to eddies depends upon the type of turbine, the vane and steam velocities, the angles of the buckets, etc.

The kinetic energy given up by the steam or by the rotating parts of the turbine in friction and eddies is (except for a possible small loss by eddies at exhaust) converted back into heat, some of which escapes; but the greater part as a rule is given back to the steam. It is important to consider what real loss a turbine suffers through friction and eddies.

An entropy temperature diagram for steam is shown in Fig. 26. A B represents the heating of the feed water, B C the generation of steam, C D the isentropic expansion of the steam, and D A the isothermal condensation of the remaining uncondensed steam back to feed water at the original temperature.

The efficiency of any heat engine working on the cycle shown is represented by the ratio of the area A B C D to the area F A B C E, the latter area representing the total heat supplied to the engine, and the former area the portion of this which can be converted into mechanical work.

If a steam turbine, working in conjunction with a steam genera-

*The friction in different types of turbine is compared in a paper read by the Author before the Manchester Association of Engineers, January 14th, 1905.

tor and with a condenser, could work on the cycle shown by the diagram (which has been called the Rankine cycle), then the thermal efficiency would be represented by the ratio of the area A B C D to the area F A B C E.

In steam turbines some of the mechanical energy represented by the area A B C D is absorbed by friction (eddies are included in the term friction). Heat is produced by the friction, and this heat is employed in whole or in part in adding to the heat energy of the steam. Generally, by far the greater part of the friction-produced heat must go to increase the heat energy of the steam. In a turbine of the Parsons type this heat energy is added to the steam gradually and, presumably, with fair regularity during the expansion of the steam. In other types of turbine the supply of heat from this source may be less regular. Let C H represent the expansion of the steam while being continually supplied with friction-produced heat; C H has been drawn straight, but there is no reason why it should be a straight line—it may be concave to either side. The total heat given to the steam by friction is then represented by the area E C H K. Of this the part represented by the area D C H is converted into mechanical work, and the part represented by the area E D H K is rejected to the condenser. The total mechanical work is then represented by the area A B C H. The work done against friction must come from that part of the heat energy of the steam which has been converted into mechanical work. Therefore, before the net amount of useful mechanical work obtainable from the steam can be ascertained, an amount equal to or greater than the area E C H K must be deducted from the area A B C H. Let only an equal amount be deducted, that is, suppose that all the friction-produced heat is given to the steam. If the line M N be drawn so that the area N M C D equals the area E D H K, then the area N M C H equals the area E C H K. The area A B M N then represents the net mechanical energy of the steam which is or can be usefully employed. The line N M has, of course, no significance as regards its position or inclination or curvature. It is only drawn to cut off an area of a given size, and it is usually convenient to draw it straight and vertical. It will be evident from the diagram that friction must always cause a net loss of mechanical work. It will also be evident that the ratio of the net loss to the work done against friction, *i.e.*, the ratio of the area N M C D to the area E C H K depends upon when the friction occurs. The net loss is greater or less, according as the friction occurs at a later or earlier period in the expansion.

Fig. 27 is a similar diagram for steam which is superheated. This diagram requires little explanation. The line C Q represents the superheating of the steam at constant pressure (before admission to the turbine). W X is drawn to cut off an area X W C Q V equal to the area R V S T, so that the area A B W X represents the net useful mechanical work obtainable.

This frictional and eddy loss is so great with steam turbines as to lower their practical efficiency to approximately the same as that of reciprocating steam engines of equal power. Now this frictional and eddy loss may be expected to occur whenever the heat energy of an elastic fluid is converted into mechanical work by means of a turbine. Therefore it must be counted upon in a gas turbine, and it will handicap the gas turbine as compared with the reciprocating gas engine. The gas turbine will be further handicapped owing to frictional and eddy losses during compression.

It will therefore be obvious that, unless the gas turbine wastes less energy than the reciprocating gas engine in other ways, it will have a much lower efficiency. It ought to waste less energy than the reciprocating gas engine does in the friction between relatively moving metallic parts. In a reciprocating gas engine, the friction of the piston, crank shaft, crank pin, skew gearing, cams, &c., is usually a large fraction of the total I.H.P. of the engine. The gas turbine ought also to waste less energy at exhaust, because it ought to be able to expand the gas down to approximately the pressure of the atmosphere, whereas reciprocating gas engines usually stop the expansion very far short of this. Otto cycle engines stop the expansion when a volume is reached equal to the volume before compression. The pressure at exhaust must, therefore, in Otto engines be very much above atmospheric if the efficiency is good.

The relative losses which will be incurred by gas turbines and reciprocating engines by heat transferred to metal surfaces and radiated or conducted away will depend upon the nature of the turbine used. In a reciprocating gas engine, a large amount of heat passes from the gas through the walls of the cylinder into the water in the jacket. If gas, at the same high temperature as exists in the cylinder of a reciprocating explosion gas engine just after the explosion, were admitted to a turbine of the Parsons type, the blades would have to be water cooled (it is questionable if this would save them, but admit it for the sake of argument.), and a much larger amount of heat would pass to the jacket water than is the case with a reciprocating gas engine If, however, divergent nozzles were employed to convert the heat energy of the gas into kinetic energy before the gas was admitted to the casing in which the turbine wheel or drum rotated, the heat losses in the turbine would be much reduced. The nozzles would, of course, have to be made of or lined with refractory material, and in certain cases at least would have to be water cooled in addition. The heat transferred by the gas to the nozzles would be appreciable, but still probably not very great. It would probably be advisable to make the nozzles larger for the power than in the case of steam turbines, and employ fewer of them, thus reducing the cooling surface per square inch of section at the throat.

Steam can be expanded very satisfactorily in divergent nozzles, even with very large ratios of expansion, for example, from 200 lbs. per square inch absolute to 1 lb. per square inch absolute, which is a ratio of 200. No experimental data of much value are, however, to be obtained regarding the corresponding expansion of hot air or the hot gaseous products of combustion obtained from the combustion of a hydro-carbon in air; and, until such experiments are made and the results published, one will be very much in the dark as to what help may be expected from the divergent nozzle in enabling successful gas turbines to be obtained.

When an elastic fluid is passed through a nozzle or orifice from a higher to a lower pressure, the heat energy corresponding to the drop of pressure is converted into kinetic energy. In order that the kinetic energy may be in a form in which it can be utilised to the best advantage to produce mechanical work, it is necessary that the velocities of the particles should be arranged in some methodical manner—it would not do if the particles were moving all in different directions, and all with different magnitudes of velocity. For turbine work it is desirable that the particles should all leave the nozzle with the same velocity, both as regards magnitude and as regards direction, so as to produce a homogeneous stream of constant section, or, as it is sometimes called, though rather paradoxically, a "solid stream of fluid." With steam, a close approximation to this effect can be obtained by adopting a suitable nozzle. The design of the nozzle depends upon the initial condition of the steam and the final pressure. After the heat energy of an elastic fluid has been converted into kinetic energy in a nozzle, some of the kinetic energy so obtained is converted back into heat owing to friction. There is a loss due to this double conversion, which loss has already been dealt with. With steam expanding in a suitable nozzle, the loss appears to be slight. Without experiment, however, it cannot be said that the loss would be equally small with other elastic fluids. Experiment in this direction is much needed.

It has also been proposed to mix steam or water with the hot products of combustion in order to reduce their temperature, thus obtaining a large mass of fluid at a moderate velocity instead of a small mass at a very high velocity. This proposal has much to be said in its favour, and several experimentists seem to have adopted it. It is as well, however, to take care lest its value is not overrated.

If the gas and fuel are compressed before combustion to a high pressure, and the Brayton or Otto cycle followed except as regards the mixture with the water or the steam, a fairly high ideal efficiency is the result. The ratio of negative work to gross work is, however, high—much higher than one might at first be led to suppose.*

If no compression is adopted and the fuel and air burnt at, or exploded from, atmospheric pressure, there is approximately no negative work; but the efficiency is not high for a gas engine.

The products of complete combustion of a hydrocarbon with oxygen are steam and carbon dioxide of which the steam is condensible. If more steam is added, the proportion of condensible matter is increased. It will, therefore, be possible by the aid of a condenser and air pump to work the turbine condensing. The air pump will, however, require to be large. A reciprocating air pump would probably be out of the question. A rotary air pump might do.

The compression losses in a gas turbine are so important that a good deal of space can be justifiably devoted to them. In a gas engine, compression of the air and fuel before ignition is necessary for efficiency; and generally it may be said that the greater the compression, the greater the thermal efficiency. Now compression means negative work—it means that some of the mechanical work which has been obtained from the heat energy of the fluid never leaves the engine, but has to be expended in pumping. Let the terms gross work, negative work, and net work be used. The gross work is the total mechanical work performed by the fluid. It is represented in the pressure-volume diagram of an explosion engine by the area A B C D E F, Fig. 28. The negative work is represented by the area A B C F.† The net work

*See paper read by the author before the Inst. of Mechanical Engineers, Oct. 21st, 1904.

†In the negative work has been included not only the work of compression, but also the work done in delivering the charge in a compressed state. This is the true negative work if the compression is performed in a separate chamber from that in which expansion takes place. It is not strictly true in the ordinary Otto engine in which there is no delivery of the compressed charge. With a turbine, the compressed charge would have to be delivered after compression, and the negative work has been defined accordingly. If the work of delivering the compressed charge is included in the negative work, then an equal amount of work, representing the work done in entering the combustion chamber must be included in the gross work. This has been done. Otherwise the gross work would have to be represented only by the area F H C D E and the negative work by the area H C F.

is the difference between the gross work and the negative work and it is represented by the area C D E F. It is this net work which engineers usually wish to obtain when they take an indicator diagram of an engine. Therefore, they measure only the area, C D E F, given on the indicator card. In an ideal engine, one is concerned, as regards the efficiency, only with the ratio of the net work to the heat supplied to the engine. With engines which are not ideal (and, of course, no engine is) the ratio between the negative work and the gross work is very important. Especially is this the case if the efficiency of compression is low. To show this forcibly consider an extreme case. Suppose that the ratio of negative work to gross work in an ideal engine is 0·5; or in simpler language, suppose that the pump requires half the gross power of the machine, there being no friction. If now the machine is not ideal, and if the mechanical efficiency of the pump is only $\frac{2}{3}$, and that of the motor only $\frac{3}{4}$, no useful work whatever will be got out of the machine—all the work will be absorbed by the frictional and other losses. For, if the power of the motor proper, including that spent on friction is 100, the pump will require 50, and as its efficiency is $\frac{2}{3}$ it will take 75. This is exactly what the motor will give out after deducting friction. There will, therefore, be no power whatever obtainable from the machine for doing external work.

Even if the mechanical efficiency of the motor were increased from 75 per cent. to 85 per cent., or the mechanical efficiency of the pump increased from 67 per cent. to 77 per cent., the work got out of the machine would amount to only $\frac{10}{50}$, or 20 per cent. of that obtainable from the ideal machine, the addition to the efficiency of the pump having in this case the same effect as the addition to the efficiency of the motor proper, although the work done by the pump is much less than the work done by the motor.

Let E represent the efficiency of the motor proper, and e the efficiency of the pump. Let n represent the ratio of negative work to gross work, which would exist in an ideal engine, that is an engine in which E and e were both unity. Let W_1 represent the work which would be got out of the ideal machine, and W the work that can be got out of the actual machine—

$$\text{Then } W = W_1 \left(E - \frac{n}{e}\right).$$

If n is a very small fraction, e is of comparatively little importance; if n is large—say from 0·3 to 0·5—e is of very great importance.

Turbine compressors do not seem to be efficient, with the possible exception of those used for small ratios of compression. It is desirable, therefore, in a gas turbine, to be able to work with a small value of n. Unfortunately, a small value of n means, as a rule, a small value of W_1 for a given quantity of heat energy supplied to the engine. This was discussed somewhat fully in a paper, read by the Author before the Institution of Mechanical Engineers, in October, 1904, to which paper reference can be made by those interested. An efficient gas turbine, which is a turbine both as regards the motor and the pump, seems therefore to depend on the obtaining of an efficient turbine compressor. If someone could produce a turbine compressor, or any other form of rotary pistonless compressor, which could compress air isentropically from atmospheric temperature and pressure to a pressure of 300 lbs. per square inch, with an efficiency of 90 per cent., the road to a successful and economical gas turbine would be very much clearer than it is now.

The preliminary experimental stage of the gas turbine has not yet been passed, and it cannot at present be said whether or not it ever will. If satisfactory information were obtained from experiment on the following four points then it could be said whether or not there was any reasonable chance of success in the near future :—

1. Losses in pneumatic compression to high pressures—
   (*a*) With reciprocating compressors.
   (*b*) With rotary compressors.
   (*c*) With a combination of reciprocating and rotary compressors.

2. Expansion of hot gases in divergent nozzles.
3. Tranference of heat from gases to metals at high temperatures—especially at very high velocities.
4. Oxidation of turbine blades, when exposed to the action of air, steam, carbon dioxide, &c., at high temperatures.

Until thorough experiments have been made on these four points and the results published, the chances of success of the gas turbine will be very much shrouded in darkness. It is to be hoped that this information will be forthcoming before long; and it will then probably be known whether it is worth while expending money and brain energy on the gas turbine problem, or whether it would be better to divert finances and energy to more remunerative channels.

Whether or not turbines actuated by hot products of combustion will ever come into extensive use, the Author is certain that turbines actuated by some elastic fluid will form a very large per centage of the prime movers employed during the next 50 years. This prophecy is made with a good knowledge of the success that has been achieved with gas producers and large reciprocating gas engines—and with a belief that the advantages of steam turbines have often been overrated—and it is not made from any special feeling of attachment to turbines, but from a careful weighing of the advantages and disadvantages of reciprocating and turbine motors.

Although information on the four points mentioned above is very badly wanted, it is possible without this information to effect improvements on turbines actuated by an elastic fluid, composed wholly or largely of steam generated in a boiler. A few suggestions as to the lines on which progress may possibly be made are now offered.

1. Where condensing cannot be employed, the steam may be superheated by mixing with it hot products of combustion obtained by burning coal gas, natural gas, or producer gas. No great improvement in efficiency need be expected by this scheme over what is now obtained with superheated steam in non-condensing

turbines, but the initial cost and depreciation in the case of a gas producer will probably be less than in the case of a superheater of the ordinary externally-fired tube type; and the cost of fuel for producing a given thermal value of actuating elastic fluid may also be reduced.

2. With steam turbines employed for the propulsion of steamships it is common practice to provide one high pressure turbine to drive on to a central shaft, and a pair of low pressure turbines each driving on to a wing shaft. Reversing turbines are placed in the L. P. turbine casings. It is suggested that it might be advantageous to construct the H.P. turbine with a single stage of expansion, and to arrange for steam being passed through it in a reverse direction when it is desired to stop quickly or go astern, in addition to passing steam through the usual reversing turbines in the L.P. casings. The advantage in quick stopping and reversing would be that, not only would an increased aggregate reversing torque probably be obtained, but, what is more important, there would be three propellers acting to stop the vessel instead of only two. It seems a great pity when in turbine steamships a considerable aggregate propeller area has been obtained at a sacrifice of weight, cost, and turbine efficiency that, one-third—and in some cases one-half—of the total propeller area should be out of action at a time when it may be most urgently required—say, to avoid a collision in a fog.

In a single-stage H.P. turbine the error in areas, due to passing the steam in a reverse direction through the turbine, would not be very objectionable, seeing that the turbine when reversing would be passing only about one-third of the steam it passed when going ahead, and the expansion of the steam would take place wholly in the nozzles before the first moving buckets were reached, and would be independent of the areas through the moving and fixed buckets. A branch pipe would have to be arranged to take live steam to the exhaust end of the H.P. turbine, where a reversing set of nozzles would have to be provided. These would be small matters. Conduits would have to convey the exhaust steam from the H.P. casing to the condenser for use when reversing. These, although of considerable sectional area, would be short, as the steam could reach the condensers by way of the exhaust end of the L.P. casings. Valves controlling the passage of steam through these conduits would be required, and a considerable amount of force might be required to open these valves quickly. If a reversing engine were employed, however, the requisite force would be easily obtained.

3. There seems to be no insuperable obstacle to the use of gearing in the driving of the propeller shaft or shafts of small vessels. A direct drive is, of course, preferable mechanically, but a direct drive in a small vessel of low or moderate speed means an expensive and not very economical turbine, and a propeller having a smaller projected area and a higher speed of rotation than is generally desirable. The use of gearing would allow of a small high-speed turbine being employed in conjunction with a propeller or propellers of ample projected area rotating at a speed not excessively high. The employment of gearing in vessels driven by turbines would be considerably different from the employment of gearing in vessels driven by reciprocating engines. In the case of turbines the high speed of rotation of the turbine spindle would allow of the employment of fine teeth and small tooth pressures; and the uniformity of turning effort of the turbine and the great kinetic energy of its rotating parts would tend to promote smooth running even if the propeller occasionally left the water.

4. Condensing arrangements are open to improvement. Steam turbines benefit much by a good vacuum, but the cost of condensing plant and condensing water are sometimes very great. In marine steam turbines the question of cost of condensing water disappears, but another important factor is introduced in the shape of weight of condensing plant.

Mr Parsons has lately increased the vacuum in the condensers employed with some of his turbines, by introducing what he terms a vacuum augmenter. This consists of a steam jet propelling device placed between the main condenser and an auxiliary condenser. This device produces a considerably lower pressure in the main condenser than exists at the suction side of the air pump. Further developments on the lines inaugurated by Mr Parsons may not unreasonably be expected. The subject which is of a somewhat complex nature deserves very careful consideration.

Discussion.

Mr W. H. RIDDLESWORTH, M.Sc, (Associate Member), asked what Mr Neilson meant by a single-stage turbine, as such an expression seemed somewhat indefinite? In connection with the marine steam turbine the Author suggested the use of a high pressure turbine of a single-stage type, so that by arranging suitable nozzles on the discharge side it could be reversed. If by a single-stage turbine, one with a single row of moving blades was understood, then the speed of rotation would be of necessity high and the desirable (for marine purposes) low speed of rotation would be sacrificed to the idea of obtaining more astern power.

Prof. A. JAMIESON (Member) complimented Mr Neilson upon his interesting history of steam turbines, and upon the clear way in which he had stated the prospects of gas turbines as well as the necessity for experiments before any decided opinion regarding their probable success could be arrived at. Prof. Jamieson doubted the propriety of Mr Neilson's substitution of the term isentropic for that of adiabatic expansion in the example he gave. Did Mr Neilson accept the definition, "that adiabatic expansion meant doing work without gain or loss of heat," and, "that isentropic expansion meant doing work without change of entropy"? Further, did he consider that entropy meant simply the ratio of the heat taken up or rejected during a small change in a working fluid to its absolute temperature, or, $d\,\phi = d\,\mathrm{H}/\tau$? If so, would Mr Neilson, in his reply to the discussion, kindly furnish proofs from reliable tests, with actual turbines, to substantiate his preference for isentropic as distinct from adiabatic expansion. Mr Parsons, n his paper on "The Steam Turbine and its application to the

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Propulsion of Vessels," read at the Summer Meeting of the Institution of Naval Architects, June 26, 1903, gave the consumption of steam in his turbine as 15·8 lbs. per K.W.-hour or about 9·8 lbs. per I.H.P.-hour, when using steam at 142 lbs. per square inch (by gauge?) delivered to his turbine at 250° C. or 514° F., a superheat of 152° F. Whereas, in the combined paper read by Mr Parsons and Mr Stoney before "The Institution of Civil Engineers," London, last month, the Authors' lowest consumption of steam was given as 14·74 lbs. per K.W.-hour for a 3000 K.W. turbine, using steam at 138 lbs. per square inch (by gauge?) and 586° F. or a superheat of 235° F., with a 27-inch vacuum. Now, using the same estimated combined efficiency of 83 per cent. for dynamo and turbine as in the previous case, and 1 K.W.-hour as 1·34 H.P.-hour, then—

1·34 (H.P.-hour) : 1 (H.P.-hour) : : 14·74 lbs. : x lbs.
100 per cent. : 83 per cent.
$\therefore x = 9 \cdot 13$ lbs. steam per I.H.P.-hour.

This is an improvement of 6·8 per cent. in the economy of steam over the previous case, and 27 per cent. gain upon the results obtained by Messrs Lindley, Schröter, and Weber in their tests of a 1000 K.W. Parsons Steam Turbo-Alternator for the City of Elberfeld, in 1900, when they got 20·15 lbs. steam consumption per K.W.-hour with ordinary steam of 150 lbs. pressure per square inch and a 27-inch vacuum. This showed a very great improvement in the economy of steam with a larger turbine, greater superheat but practically the same vacuum, although an increase from 27 to 28 inches vacuum was known to produce an economy of 4½ per cent. in the steam used by the turbine alone. The following questions naturally arose from the above data and from other published results—(1) Were the pounds of steam required to work the air and circulating pumps and the vacuum augmenter included? (2) When turbines and reciprocating engines of the same power were compared, did Mr Neilson consider that the estimated I.H.P. of the former could be fairly ranged alongside the actual indicated H.P. derived from the latter, more especially when the steam used for air and circulating and feed pumps were all taken into account in complete trials of reciprocating marine and land engines? (3) These two questions naturally evoked another. What reliance could be placed upon the percentage exactitude of torsion-meters or dynamometers for estimating the shaft horse power of marine and land turbines? Mr Parsons now claimed, that steam travelled at a moderate velocity through his turbine and flowed through each ring of blades approximately as an incompressible fluid. But, when viewed over the whole range of the turbine, the expansion of the steam was governed by the usual adiabatic laws of steam, and from 70 to 80 per cent. of its energy was transformed into useful mechanical work. This most assuredly meant that the efficiency was from 70 to 80 per cent., or, that from 70 to 80 per cent. of the heat energy of the steam which passed through his turbine re-appeared as useful work in the turbine shaft, and was there available for driving dynamos or screw propellers or any other suitable appliance to which his turbine might be coupled. Now, take his best published results, for a 3000 K.W. turbine driving a dynamo, which used only 14·74 lbs. of steam per K.W.-hour, as supplied to it at 138 lbs. pressure per square inch (by gauge?) but superheated to 235° F. and with only a 27-inch vacuum. No record was given of the efficiency of the dynamo, but it would be perfectly fair to assume that, it gave 92 per cent. as the ratio of the K.W. got out, to the K.W. spent on its shaft to drive it; and, that 1 K.W. was equal to 1·34 H.P. If a lower dynamo efficiency were assumed at full load, then the turbine would appear to be still more efficient, since it would show a still less consumption of steam per B.H.P. or per shaft horse power than the following proportion. But well-designed and constructed dynamos of 3000 K.W. output at full load, gave as a rule quite 92 per cent. electro-mechanical efficiency in the sense here applied to the case in question—

Hence, as, 1·34 H.P. : 1 H.P. :: 14·74 lbs. steam : x lbs. steam.
100 % : 92 %
$\therefore x$ = 10·12 lbs. of steam per B.H.P.-hour.

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The method of calculating the heat required per minute by The Institution of Civil Engineers' Standard of Comparison per H.P. might have been adopted, but its formula for an engine using superheated steam was*—"The B.Th. U. per minute per H.P. for the Standard Engine of Comparison, with superheated steam" =

$$\frac{42.4\left\{L_a + T_a - T_e + 0{\cdot}48(T_{as} - T_a)\right\}}{(T_a - T_e)\left(1 + \frac{L_a}{T_a}\right) + 0{\cdot}48(T_{as} - T_a) - T_e\left(\text{hyp.log.}\frac{T_a}{T_e} + 0{\cdot}48\,\text{hyp.log}\,\frac{T_{as}}{T_a}\right)}$$

Where T_a is absolute temperature of saturated steam at stop-valve pressure.

,, T_{as} ,, ,, ,, of superheated steam at stop-valve.

,, T_e ,, ,, ,, in exhaust.

,, L_a ,, latent heat of steam at temperature T_a.

,, 0·48 ,, the specific heat of superheated steam.

This appeared a rather formidable and complex formula to tackle and one might naturally question the correctness of the final result arrived at? Whereas, the following was a much simpler expression which he submitted for critical examination, as he believed that it included all the requisite factors of the Institution of Civil Engineers' formula, when used in conjunction with the temperature entropy or heat energy chart as herewith applied—

$$\text{B.H.P. Efficiency, } \eta = \frac{\text{Work got out at turbine shaft}}{\text{Heat energy used by turbine}}.$$

Or,

$$\eta = \frac{\text{Heat units equivalent to one B.H.P.}}{(\text{Heat put in per lb.} - \text{heat rejected at exhaust per lb.}) \times \text{lbs. steam per B.H.P.-minute.}}$$

$$\therefore \quad \eta = \frac{33{,}000 \text{ foot lbs. per minute}}{J\,(H - h)\,W_s \text{ foot per lbs. minute}}.$$

* See Minutes of Proceedings, Inst. C.E., Vols. CXXXV., p. 294, and CL., p. 218, *et seq.* for 1902-03.

Where, J = Joule's equivalent (778 foot lbs. of work per B.Th.U.)
,, H = Heat units per lb. of steam supplied per minute to turbine at stop-valve.
,, h = Heat units per lb. of exhaust (wet) steam per minute.
,, W_s = Weight of steam passed into turbine per minute per B.H.P.
33,000 = Number of foot lbs. of work per minnte per B.H.P. or shaft-horse power.

By gauge, 138 lbs. steam pressure = (138 + 15) or 153 lbs. absolute. From any good table on the properties of saturated steam, it could be seen that each pound weight of such steam contained 1191·68 B. Th. U. Further, each lb. of this steam was superheated to 235 degrees F., therefore the additional heat units per lb. due to this superheat was—

B.Th.U. of superheat = Weight of steam × degrees rise × specific heat of steam.
Or, B.Th.U. ,, = 1 × 235° F. × ·48.
,, ,, = 112·8.
$\therefore$ H = (1191·68 + 112·8) = 1304·48 B. Th. U.

From the accompanying $\tau\phi$ or temperature entropy diagram, Fig. 29, which he had drawn to scale for the turbine in question, as well as from calculations and from good entropy tables, he found that, with superheated steam admitted to the turbine, as previously stated, the condition of the exhaust was wet steam of 85 per cent. dryness fraction. In other words 15 per cent. had become condensed, and was at a 27-inch vacuum, or gave 1½ lbs. absolute back pressure at a temperature of 114 degrees F. (or 82 degrees above 32 degrees F.) Consequently—

	Dry saturated steam.		Dry saturated steam.		Dry saturated steam. B.Th.U. per lb.		Dry saturated steam. B.Th.U. for ·85 lb.
As,	1 lb.	:	·85 lbs.	::	1117·3	:	949·7

	Liquified steam.		Liquified steam.		Liquified steam. B.Th.U. per lb.		Liquified steam. B.Th.U. for ·15 lb.
And as,	1 lb.	:	·15 lbs.	::	82	:	12·3

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Hence, the total heat per lb. of wet exhaust steam was—

$$(949{\cdot}7 + 12{\cdot}3) \text{ B. Th. U., or, } h = 962 \text{ B. Th. U.}$$

The weight of steam used per hour per B.H.P. was found to be 10·12 lbs., or, $W_s = 10{\cdot}12/60$ lbs. per minute. By substituting for the symbols the previously ascertained values in the equation—

$$\eta = \frac{33{,}000}{J\,(H - h)\,W_s}.$$

Then,
$$\eta = \frac{33{,}000}{778\,(1304{\cdot}48 - 962)\,\dfrac{10{\cdot}12}{60}} = {\cdot}74,$$

Or, the efficiency of that particular turbine was 74 per cent. by this formula and calculation. Mr Parsons was to be congratulated upon this high efficiency; but, observe, that no steam was reckoned herein, for production of the vacuum, and as might be the case — for instance, at the Westinghouse Company's plant at Yoker—for the engine to work the exciter dynamo to produce the field magnetism for the alternating current dynamo. Would 5 per cent. additional steam be a fair allowance per B.H.P.-hour for the whole of the auxiliary plant, when the cooling water had to be forced through the condenser tubes at such a great velocity to produce such a high vacuum as was desired for the efficient working of steam turbines? All those interested in the highly speculative question of gas turbines would do well to study most carefully, not only Mr Neilson's excellent and instructive suggestions, but also Mr Dugald Clerk's Presidential Lecture to The Junior Institution of Engineers on "The Problem of the Gas Turbine," delivered on 3rd November, 1905. Mr Clerk said, "Only one gas turbine had really rotated within his own direct knowledge . . . with a total brake-horse power equal to that evolved by two blue-bottle flies!"

Mr JOHN RIEKIE (Member) said that Mr Neilson's paper on the turbine was very interesting both from a historical and a practical point of view. The Author dealt in a very clear manner, not only with the losses brought about by frictional eddies which took place in this type of engine, but also with the acknowledged losses due to cylinder condensation and leakage past slide valves which occurred in the reciprocating engine. He had had no practical experience with the turbine engine and could therefore offer no suggestion as to the possibility of minimising the losses from frictional eddies. He had had, however, an extensive experience with the reciprocating type of engine and could testify to the practicability of making a very substantial reduction in its present losses. Mr Neilson stated that practical considerations prevented one from designing a reciprocating engine so that the steam could be carried down to the condenser pressure. On that point he did not quite agree with him and believed that the ratio of high to low pressure cylinder area could be so arranged that the number of expansions could be considerably increased without increasing the area of the low pressure cylinder. Moreover, even from the use of higher steam pressures and from the use of steam of high superheat it would still be practicable to expand the steam down to atmospheric pressure before final exhaust took place. The waste of steam due to cylinder condensation could be reduced to a minimum by superheating it to 700 degrees or even 800 degrees F. The excessive waste from valve leakage could be overcome by abolishing the use of all forms of slide valves and using tappet valves only. The proposed cylinder ratio referred to had been successfully tried on engines. The use of highly superheated steam, ranging from 700 degrees to 800 degrees F., with tappet valves, was in daily use on steam motor cars. It only remained for the combination to be tried on an engine, no matter whether large or small, to demonstrate that a turbine engine of equal power, as now designed, could not live in competition with it. Mr Neilson also alluded to the use of gearing to assist the turbine engine, but it was needless to point out that gearing which was a source of loss was not required with the reciprocating engine.

Mr. W. B. Sayers.

Mr W. B. Sayers (Member) remarked that he had been experimenting for the last 18 months on a method of driving turbines by means of a heavier liquid driven by steam and also by gas explosion, but having said so much he was not at liberty to enter further on that subject. He had had to stop his experiments in the meantime for financial reasons, but recently he had been giving attention to a turbine to be driven by an elastic fluid, and he would like to say a few words about such turbines. He had placed on the blackboard a few figures which represented some elementary considerations. Before he spoke about these he would say that Mr Neilson described rather minutely the turbine invented by Mr Morton. Criticising that design, with the view of seeing what might be the cause, or causes, of too low an efficiency to be of practical value, he noticed one point in particular, and that was that the nozzles, which were represented by little narrow slits through the rims, in Figs. 24 and 25, seemed to be of wrong form. They were divergent nozzles, whereas they ought to be convergent nozzles. Another point about Morton's turbine was that there were a number of discs, one inside of the other, and these were rotated at a high velocity in the dense steam, the density diminishing, of course, towards the exhaust end, but there would be considerable friction between these discs and the steam. To go a little further on the question of convergent and divergent nozzles, he noticed the statement by Mr Neilson that the different types of turbines showed a tendency to draw towards one another. He supposed he referred to the fact that Westinghouse used divergent nozzles on Parsons' blades; Curtis used divergent nozzles on blades which were somewhat like Parsons'; de Laval and Stumpf, on the other hand, used convergent-divergent nozzles; but Stumpf, instead of using steam only once on the turbine wheel as did de Laval, provided guides to catch the steam off the buckets, and returned it through them a second time, or directed it into another set of buckets. Now, if one considered the essential thing that happened in any turbine, he would find that the steam had to expand as it passed on through the turbine in order to give up its energy. In de Laval's turbine it expanded down to its lowest pressure right away, appearing at the discharge end of the nozzle as kinetic energy, and there was simply one velocity stage, or two velocity stages, or more. The matter was much more complicated in the Parsons or Curtis form of turbine. What he wanted to elucidate—he was striving himself to get a clear mental picture of what happened—was just how much of the several possible actions took place, and what sort of attention ought to be given to them. Referring now to the question of convergent and divergent nozzles, Rateau, in his book "On the Flow of Steam," showed that the proper form of nozzle depended upon the ratio $\frac{P^1}{P}$. where P was the pressure at the inlet, and P^1 the pressure at the outlet end. If the ratio $\frac{P^1}{P}$ were greater than 0·58, the nozzle should be convergent, but if less than this value, the nozzle should first converge to a "throat" (the sectional area of which determined the quantity of steam which would pass with a given initial pressure) and afterwards diverge, Fig. 30. Further, with a given initial pressure, the pressure and velocity at the discharge ends of the nozzle depended upon the ratio of the areas of the inlet and discharge ends of the nozzle, and was independent of the pressure in the exhaust chamber so long as the latter did not exceed the pressure corresponding to the area of the discharge by more than a definite amount. That amount was the pressure equivalent to the kinetic energy of the steam, and was equal to V^2m. The point to grasp was the vital importance in elastic fluid turbine design of the correct proportioning of the nozzles or passage ways between blades, etc., to correspond with the law of flow of the expanding fluid. So much had been said, and rightly as regards the importance of good vacuum, that the above might, at first sight, seem contradictory to experience, but unless the passage ways or nozzles have an area of not less than that corresponding to the back pressure in the exhaust, reduction of this pressure would have no appreciable effect in increasing the

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velocity of flow of the steam in the turbine. The effect of reducing the pressure in the exhaust, if the area of the discharge ends of the passage ways or nozzles were too small, was that the steam on entering the exhaust chamber being freed from lateral constraint expanded in a direction at right angles to the direction of flow, deflecting and accelerating the flying particles uselessly. In other words, there was no appreciable increase of expansion and consequent acceleration due to lowering the exhaust pressure until the exhaust chamber was actually reached, unless the area of the discharge ends of the passage ways or nozzles was sufficiently great. All this became clear when once one realized the fundamental conception of the pressure of the elastic fluid being balanced only against the inertia of its own mass, and entirely absorbed in producing acceleration of its own particles, instead of being balanced against another resisting body, the resistance of which depended partly upon the back pressure, as in a piston engine. In a multiple stage turbine the steam was being retarded while passing through each set of moving blades, and was accelerated by its own expansion and redirected while passing through the fixed guides. Or, if there were only "velocity" stages, then the steam would be retarded when passing through each set of moving blades, and would be redirected when passing through each set of guides. This was only a very partial statement of the laws affecting the flow of steam through turbines. Parsons' turbine required, for the most advantageous condition, convergent nozzles or passage ways, and on inspection, Fig. 32, it would be seen that the fixed and moving blades in a Parsons turbine form between them converging passage ways. On the other hand, turbines using one or more "velocity stages" would generally have a greater drop of pressure between the two ends of the nozzles than was represented by $\frac{P^1}{P} = 0{\cdot}58$, and nozzles or passage ways should therefore be convergent-divergent. Referring again to Mr Morton's turbine, Fig. 23, as there were five stages, it was clear that the ratio of the pressures across any one stage would

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always be greater than 0·58, and consequently the nozzles should have been convergent, instead of divergent, as shown in the figure. It did not necessarily follow, of course, that the correcting of this point would have lifted the turbine from failure to success. The general design was probably hopeless, but if the turbine had been provided with three or four times the number of passages or nozzles, and other parts modified to pass a greater quantity of steam and develop a larger power, it would probably have come much nearer success. Passing now to the consideration of the problem of designing a turbine of the Parsons type. If, in Fig. 31, A represented the area taken at right angles to the axis of the annulus, in which a gang of rings of blades of the same length were fixed, then expansion of the steam occurred during its passage from one end to the other of this annulus, and therefore a greater volume must pass at the outlet end of this annulus than at the inlet. This was possible in three different ways, and in combinations of two or all of these three ways:—

1. By acceleration occurring during the flow along the annulus so that the velocity was greater at the exit end than at the inlet.

2. By the effective area being made to increase towards the outlet end by reducing the thickness of the blades.

3. By the effective area being made to increase toward the outlet end by reduction of the amplitude of curvature of the blades, thus reducing the obliquity of flow of the steam round the cylinder, Fig. 33.

Note.—In practice 2 and 3 went together, one involved the other. Examination of these three points showed that when a number of rows of blades were made identical, as they were in practice, for convenience in manufacture, expansion of the steam passing through such uniform rows of blades must be accompanied by acceleration of the flow of steam, because 2 and 3 both required non-uniformity of the blades. It therefore appeared that the ratio

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$\frac{Vt}{Vs}$ referred to in Mr Speakman's recent paper (where V*t* was the mean speed of the turbine blades and V*s* the steam speed) could not be constant through a succession of uniform rows of blades. Next it appeared that if the increased area of the annulus A, corresponding to the increase in volume of the steam due to expansion, were obtained entirely by thinning of the blades towards the outlet end, the ratio $\frac{Vt}{Vs}$ might be kept approximately constant. Again, if increase of area were obtained by reduction of the obliquity of flow, $\frac{Vt}{Vs}$ could not remain constant, for consideration of Mr Speakman's velocity diagrams, Plate II., showed that the relative velocities of steam and bladesfor a given blade speed was directly connected with the angle of obliquity of the flow. The magnitude of the effect of varying the angle of obliquity of flow was great, being proportional to the cosine of the angle of obliquity to the axis. Referring to Fig. 31, if the first row of blades deflected the steam stream to an angle of 68 degrees with the axis, the effective area of the annulus A to the flow of steam would be A cos 68 degrees or 0·37 of the area of the annulus A taken at right angles to the axis. If succeeding rows of blades deflected the steam to diminishing angles of obliquity until the last row deflected it to 30 degrees only, the effective area would have increased from 0·37 A to 0·86 A, or, the increase of effective area would be $\frac{0{\cdot}86}{0{\cdot}37}$ = as 2·3 to 1. He was endeavouring to give the mental picture which he had in his own mind, of the conditions of the problem of design in a Parsons turbine and also of the action of the steam stream through the blades, and to make this more complete he would say that if the turbine shaft were fixed so as to prevent it from revolving, the steam would take an undulating or zig-zag course through the turbine, and if the fixed and moving blades were identical the undulations would be equally above and below a line parallel with the axis. When the turbine was allowed to revolve the effect of the motion of the blades was to tend to straighten out or diminish the amplitude of the undulations on one side only of the axial line, that was those caused by the moving blades, with the result that as the speed increased the stream fell more and more away from parallelism and took a helical course around the drum, Figs. 33 and 34. From published drawings of Rateau's turbine, it would be seen that convergent nozzles were used, and also that there were a considerable number of discs which revolved in separate cells filled with steam starting at high density and diminishing towards the exhaust. It would be interesting to have definite information about the efficiency of Rateau turbines, and especially to know what percentage of the losses was due to the friction of the discs in the dense fluid. He did not know whether there were any figures available as to the efficiency of this turbine as compared with Parsons' turbine. It followed, he thought, from the considerations he had put forward, that they might have the steam accelerating as it passed through the buckets, and consequently, that in addition to "pressure" and "velocity" stages there might be "acceleration" stages, but this last was a stage or condition to be avoided.

Mr Edwin Griffith (Member) said the remarks made about the velocity of steam through one stage of a Parsons turbine by Mr Sayers were quite in order, and, as those who dealt with the Parsons' turbine knew, the last stage of that turbine had blades set at a different angle towards the exhaust end. Strictly speaking, the blades in every stage ought to be changed in angle, but the difference in efficiency did not justify the practical objections involved. At the exhaust end, where the volume increased very rapidly, it would be necessary to have the blades of an abnormal length to give the proper volume with the normal angling. With reference to the Rateau turbine, there was some published information on that point. Mr Yarrow had tried a torpedo boat with the Rateau turbine and another with the Parsons turbine, and he thought the results of the trials had been published; at any rate, Mr Yarrow had told him that the results were practically the same in both

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cases. The amount of coal used was about the same, and so was the speed. Reference was made in the paper to the astern power, and it was suggested that the H.P. might be made a single stage turbine with provision for passing the steam in the opposite direction. It seemed to him that that would involve a reduction of the power of the H.P. shaft very considerably in going ahead, and if the centre turbine was single stage the bulk of the expansion would need to take place on the wing turbines, so that there would be an equal ratio of power between the three shafts, to meet which it would be necessary to reduce the centre screw, probably to an undesirable small dimension. For that reason he did not think very highly of the suggestion. Some of the other means adopted to get additional astern power were more practical, such as increasing the power of the astern turbines on the two wing shafts, which had been done in almost every recent installation. The Admiralty were adopting astern turbines on every shaft, and meeting the trouble in that way. He thought it might be worth trying another type of turbine for working astern in conjunction with a Parsons turbine for working ahead—some type that did not take up so much fore and aft space. He did not think the Rateau turbine was such a long turbine as the Parsons, and the Curtis turbine was shorter still.

Mr Sayers—Was it not the case that the Curtis turbine had a higher speed in proportion to its shortness?

Mr Griffith was not familiar enough with the Curtis turbine to answer that question definitely; it depended upon the number of stages. There did not seem to be any inherent reason why it should not have a greater number of stages than at present, and when used for the astern power it would not be a very serious thing to put up with a loss of efficiency as was done with Parsons' astern turbines. He suggested that those who were using Parsons' turbine for ahead work might learn something of the other types by using them for astern work. Mr Neilson had said that the turbine was inherently irreversible. The Parsons turbine was inherently irreversible, but the turbine, as such, was not necessarily so. As a matter of fact, some years ago, he himself had experimented with a turbine that was reversible. He reversed it when going 3,000 or 4,000 revolutions ahead to practically the same speed astern in about six seconds, and that reversibility was obtained without sacrificing the ahead efficiency at all, so that he did not agree with such a sweeping statement as that the turbine was inherently irreversible. He thought that turbine experts might direct their attention towards obtaining a satisfactory reversible turbine. The one he referred to was perfectly satisfactory in that respect. He would not advise Mr Neilson to put any money on the idea of geared shafts. Even if the proposal was reasonable he would not get marine engineers to listen to him. Mr Neilson also said, "In marine steam turbines the cost of condensing water disappears, but another important factor is introduced in the shape of weight of condensing plant." He did not think the weight of condensing plant was an important factor considering its great efficiency value in turbine installations. There need not be in condensing plant any appreciable addition in weight if it were made efficient. It was getting to be well known that the condensing plant was most inefficient on board ship in reciprocating practice, and he knew, as a matter of fact, that in the Durham College engine at Newcastle, a new type of condenser had been tried, and that a much better vacuum obtained with less than half the usual cooling surface ratio. Prof. Weighton was now preparing a paper giving a full account of his experiments, and all those who had been connected with turbine work were thoroughly aware of the low efficiency of the average condensing plant on board ship. The importance of it in turbine work had directed a great deal of attention to the subject, and the addition in weight that might be involevd with an efficient plant, was of small consequence, compared with the saving in coal with turbine machinery. He thought the Members of the Institution were highly indebted to Mr Neilson for bringing his valuable paper to their notice.

Correspondence.

Professor ROBERT H. SMITH considered that the history of the steam turbine had been very completely and ably dealt with in W. Gentsch's "Dampfturbinen," 1905; and that in addition to the splendid 1905 edition of Dr. A. Stodola's "Die Dampfturbinen," there had also been more recently published an excellent treatise by W. H. Eyermann also entitled "Die Damfpturbinen," and dated 1906. The approximation now taking place among the designs of several firms of builders and mentioned by Mr. Neilson was very interesting. For some time he had been convinced of the desirability of lessening the number of stages from that found at the end of the scale. He had been told of a new theory by Prof. Banki, of Buda-Pesth, which fixed a definite number of stages as the most economical number for each prescribed combination of peripheral speed and horse power. It must evidently consist in a minimum balancing of frictional losses and exhaust kinetic energy losses. Mr Neilson did not mention leakage as one source of loss in turbines, but in most forms its amount must be very considerable. The kinetic energy of the steam that leaked through the clearance between wheel and casing must be wholly lost. Mr Neilson's law of friction and eddy loss in turbines might be more simple, and therefore more easily intelligibly expressed by saying that the driving force so lost was proportional to the square of the product of diameter by linear speed. It seemed questionable whether any large proportion of the eddy kinetic energy was reconverted into heat within the limits of the working parts of the turbine, and what was so reconverted must in some material ratio go into the iron and not go to reheating the steam. As to the gas turbine discussion, in his opinion the greatest difficulty lay in the burning of the guides and blades, or their distortion through overheating. The attempt to avoid this difficulty by expansion-cooling before the gas reached the blades meant, of course, restriction to an extremely small number of stages. He believed it very possible to use a fluid compounded of a mixture of burnt gas and steam, and he had made experiments in that direction. A portion of the heat of combustion was first used in heating and evaporating water into steam, and then the burnt gases were further cooled by mixture with the steam while the steam was superheated. By regulating the proportion of steam and burnt gas, one could get any desired combination of pressure and temperature above the temperature of saturated steam. The combustion of gas or oil fuel went on steadily, of course under full pressure, without deviation from the most efficient conditions of combustion. The objection was the large proportion of the negative work in compressing the air needed for combustion to the full working pressure.

Mr. F. J. Rowan (Member) having been prevented from attending the last meeting of the Institution, wished to say that he had read Mr Neilson's paper with much interest, and thought that the historical and descriptive portions left little to be desired, except with regard to the first, in which, seeing that the Author subsequently gave much prominence to the gas turbine question, he thought that he might with advantage have enlarged that part by including in it some account of the various designs of gas turbines which had been proposed. Several of these were very ingenious, and it would not be easy to find a better way of illustrating the practical difficulties inherent to the gas turbine problem than by giving a description of the plans of inventors and the investigations of those who had dealt with the theory of the subject. Amongst the inventors were Crossley and Atkinson; Heinrich Zoelly, of Zurich; René Armengaud and Charles Lemale, of Paris; Franz Windhausen, jun., of Berlin; and Thomas G. Saxton, of Lexington, Ky.; and amongst the investigations which had been published, Mr Neilson's paper to the Institution of Mechanical Engineers (in their October, 1904, Transactions), took a prominent place, and there were those of Alfred Barbezat, in the Revue d' Electricité; R. Barkow and K. Schreber, in Zeitschr. Elektrotechn., of Vienna; Dr. C. E. Lucke, of Columbia University, and Prof. Sidney A. Reeve. Dr. Lucke's experiments on the expansion of hot gases in nozzles were a commencement of

Mr F. J. Rowan.

the line of investigation desired by Mr Neilson, although they dealt with gases of comparatively low temperature; and Mr T. E. Stanton had made some research into the influence of velocity on the transference of heat from gases to metals. With regard to the idea thrown out by Mr Neilson that with steam added to the products of combustion, a condenser and air-pump could be used, would not the size of air-pump and the power required to drive it, render this method impracticable? It had been proposed to utilize the heat of such waste gases in heating feed-water and air for combustion, and he (Mr Rowan) understood that experiments with a gas turbine so arranged were in progress.

Mr NEILSON, in reply to Mr Riddlesworth's query as to the meaning of a single-stage turbine, stated that, the expression did not indicate a turbine in which there was only one ring of blades, but a turbine in which the expansion of steam took place all at one step. There might be one or more rings of moving blades. In Curtis' turbines as many as four rings of moving blades had, he believed, been arranged in one stage, the steam being redirected from one to another by means of fixed blades. In a H.P. single-stage marine steam turbine either three or four rings of moving blades might be employed according to the diameter which could be given to the H.P. casing; and a sufficiently low propeller speed could be obtained. Such a high pressure turbine would have certain disadvantages compared with a high pressure turbine of the Parsons type, but would also have advantages over the latter. Mr Griffith objected to the use of a single-stage H.P. turbine on the ground that this would mean a reduction of ahead power on the central shaft, but he (Mr Neilson) did not think that such a reduction was a necessary consequence. The single-stage H.P. turbine could be made of any desired power. The power would have to be determined by considerations of propeller efficiency and accommodation on board ship. The turbine should have a large diameter for the power if the nature of the ship and the engine-room arrangements allowed of this. Mr Griffith referred to the Admiralty adopting astern turbines on every shaft. If by this was meant the placing of H.P. reversing turbines on the H.P. shafts, and L.P. reversing turbines on the L.P. shafts (as reported in an engineering journal), the device had several objections. In the first place the length of the H.P. turbine casings would be increased, thus calling for more fore and aft space, which, as Mr Griffith stated, was an objection. In the second place the H.P. reversing turbines would cause an appreciable drag when the vessel was going ahead, as they would be rotating in wet steam at a considerable pressure. In the third place the initial reversing torque (which was usually of much more importance than the normal power when steaming astern) would be reduced by compounding the reversing turbines unless these were made very large. All the reversing turbines should, he considered, take boiler steam and exhaust into the condenser. By using one single-stage H.P. turbine and two L.P. Parsons' turbines, a high initial reversing torque could be obtained on all three shafts; and the fore and aft space required by the turbines would be small. There would also be no more drag caused by the reversing turbines when the vessel was going ahead than with the present arrangement. Mr Griffith referred to Prof. Weighton's experiments on condensers. He (Mr Neilson) was acquainted with some of the results obtained by Prof. Weighton, and looked forward with great interest to perusing in full Prof. Weighton's paper, which, he understood, was to be read at an early date before the Institution of Naval Architects. There was no doubt that Prof. Weighton's experiments would have a most important effect on condensing plant designed both for land purposes and for turbine propelled vessels, especially warships. Although the weight of a condenser on a turbine ship might be small compared with the benefit to be desired from it, still the weight ought to be taken into account in considering what degree of vacuum should be employed. If, by special design, the weight of condensers for a given effect could be reduced, this would obviously affect the degree of vacuum to which it was desirable to work, especially in a warship. Prof. Jamieson referred to the meaning of the words "adiabatic" and "isentropic." He (Mr Neilson) had used the

Mr Neilson.
word "isentropic" because there was no doubt as to its meaning, which was that given by Prof. Jamieson. The meaning of "adiabatic" was doubtful, different meanings having been applied to it by different writers.* He did not consider that turbines and reciprocating engines could be fairly and satisfactorily compared except as regards their B.H.P. or E.H.P. when driving electric generators. Concerning the consumption of steam by the auxiliary plant, this was a very big question, and he was afraid could not be fully gone into on the present occasion. He might state now, however, that the steam consumption of the auxiliaries varied very greatly with the degree of vacuum for which the plant was designed; and with high vacua the temperature of cooling water and the design of the condenser had an immense effect on the power required to work the auxiliaries. Prof. Robert H. Smith's remarks were always interesting. Regarding loss due to leakage in turbines, he (the Author) had not dealt with this loss independently of other losses. The loss due to leakage in a turbine of the Parsons type was almost wholly due to the eddies produced by the leaking steam. But for these eddy losses the leakage would be of little consequence. If the kinetic energy of the steam leaking past one ring of moving blades could be usefully employed, in whole, by the next ring of moving blades, there would of course be no loss due to leakage. As a matter of fact, however, the leaking steam produced eddies. Eddies were also produced by other causes, and he dealt with the eddy loss as a whole. He should have liked to have heard more of the experiments which Prof. Smith had conducted on turbines using a mixture of burnt gas and steam. Mr Riekie alluded to the expansion of steam in a reciprocating engine down to the condenser pressure. No matter what ratio was adopted between the cylinders of a reciprocating engine, if the steam was expanded down to the condenser pressure, the low pressure cylinder would have to be large enough to contain the steam which passed through the stop valve for every stroke of the engine. With a low condenser pressure the volume of this steam

* See discussion in the *Engineer*, December, 1905.

would be so great as to necessitate a quite impracticable bulk for the low pressure cylinder. He quite agreed that there would be no difficulty in expanding steam in a reciprocating engine down to atmospheric pressure, even if a high degree of superheat were adopted, but the expansion to a pressure corresponding to a good vacuum was a very different matter. He quite agreed with Mr Sayers with respect to the importance of the correct proportioning of the nozzles and passage ways between the blades of elastic fluid turbines. Sometimes, however, the correct proportions had to be slightly deviated from for practical considerations, and this could often be done with very little loss of efficiency. Mr F. J. Rowan referred to the researches and experiments of several engineers at home and abroad on the gas turbine question. He (Mr Neilson) had considered that his paper would have been too long if he satisfactorily described recently proposed forms of gas turbines. Mr Rowan's list of names and articles were useful for reference. With respect to Dr. Lucke's experiments referred to by Mr Rowan, these were interesting to physicists, but he did not think that they threw much light on the gas turbine problem, and it would be a mistake to form conclusions relating to gas turbine possibilities on the results of these experiments. Regarding his suggestion of using a condenser and air pump, with a mixtue of steam and products of combustion, he threw out the idea as an arrangement mechanically possible. Whether or not it would ever be commercially desirable, was at present an open question.

The President moved a vote of thanks to Mr Neilson for his excellent paper.

The vote of thanks was enthusiastically accorded.

THE APPLICATION OF CALCULATING CHARTS TO SLIDE-VALVE DESIGN.

By Mr William J. Goudie, B.Sc. (Member).

SEE PLATES X., XI., AND XII.

Read 19th December, 1905.

In getting out the design particulars for a marine engine slide-valve, the valve diagrams most commonly employed are probably the Zeuner and the Bilgram, as their construction, unlike that for the so-called "harmonic" diagram, or the valve ellipse, involves the use only of straight lines and circles.

Despite this fact, however, they still possess the drawback, that in either case the result of the modification of any of the variable elements of the problem cannot be ascertained, unless the diagram is either partly or wholly redrawn. It has often occurred to me that, the time and labour involved in this tentative process might be much reduced by the substitution of one or more calculating charts for the valve diagram, and as the outcome of the idea, I have designed the charts which form the subject of this paper.

The elements which enter into the various problems relating to simple slide-valve design, may, for the present purpose, be classified into three groups, as follows:—

Group I.—This contains the elements, cylinder diameter, stroke, revolutions, steam or exhaust velocity, port length or circumference, and port opening or width. Of these, either the port opening or width is usually the unknown quantity.

Group II.—This contains the elements affecting the steam distribution at the outside edges of the valve, viz., valve travel, port opening, lead, outside lap, cut-off, and connecting-rod ratio. Of these, the valve travel and the outside lap are usually the unknown quantities.

Group III.—This contains the elements affecting the steam distribution at the inside edges of the valve, viz., valve travel, angular or linear advance, inside lap, compression and release, and connecting-rod ratio. Of these, either the inside lap or compression, or release, may be the unknown quantity.

In order to deal with every possible case involving the foregoing, I have designed a chart to handle each group of elements. Strictly speaking, Chart No. 1 is of a preliminary character; Charts Nos. 2 and 3 being the calculative substitutes for the valve diagram. The purpose of this paper is, first, to indicate the basis on which each chart has been constructed to meet the requirements of the case, and then to illustrate, by a number of numerical examples, how the charts may be applied, to obtain as closely approximate results in practice, as can be got by the longer and more laborious geometrical constructions.

Taking *Group I.*:—

Let D = Cylinder diameter in inches,
L = Stroke in feet,
N = Revolutions per minute,
V = Steam or exhaust velocity in feet per minute,
S = Mean piston speed in feet per minute,
λ = Port length in circumference in inches,
W = Port opening or width in inches,
a = Port area in square inches.

Then—

$$\left(\frac{\pi}{4} D^2\right) (2 L N) = (W \lambda) V, \text{ that is—}$$

$$\left(\frac{\pi}{4} D^2\right) S = aV = K.$$

On Chart No. 1, the left hand and right hand diagrams show the graphical interpretations of the corresponding sides of this identity. On a piston speed base are plotted values of the revolutions for a series of values of the stroke; and on the same piston speed base are plotted values of K for a series of values of the cylinder diameter. Similiarly, on a port area base are plotted values of K for a series of values of the steam velocity, and on the same area base are plotted values of the port opening or width, for a series of values of the port length or circumference. The ordinate scale, for values of K, which, however, does not appear on the chart, is the analogue of the sign of equality in the identity, and links the diagrams together. From this explanation, the rule appended for the direct use of the chart will be readily understood. The piston speed is first ascertained from the given revolutions and the stroke; the value of K is then obained from the determined piston speed and the given cylinder diameter; the port area is then obtained from the determined value of K and the given steam velocity; and finally the port width, or opening, is obtained from the determined port area and the given port length. The rule for direct use of the Chart may, therefore, be stated as follows:—

CHART, No. 1.

Rule I.

(*a*) From the revolution scale follow the horizontal to the stroke curve.

(*b*) Follow the vertical from the stroke curve to the cylinder diameter curve.

(*c*) Follow the horizontal from the cylinder diameter curve to the steam velocity curve.

(*d*) Follow the vertical from the velocity curve to the port length or circumference curve.

(*e*) Follow the horizontal from the port length curve to the port opening or width scale, and read the result.

For those who may wish to avoid operation (*a*) and use the piston speed direct, a scale of piston speed has been added at the top of the chart. Also, since it is advisable to know the port area, and as the calculation for it is exactly the same as that for the steam or exhaust-pipe diameter, scales for these values have been added at the bottom and the top, so that at the end of operation (*c*), by following the vertical from the velocity curve to either the lower or the upper scale, either the port area or the steam or exhaust-pipe diameter can at once be ascertained.

Altogether, it will be seen that this chart shows at a glance the interdependent relations between nine elements more or less directly connected with the design of the valve. The accuracy of the results obtainable is limited only by the size of the chart. The sets of curves, the velocity curves in particular, are not as complete as they might be made, owing to the restriction imposed by the size of the Volume of the Transactions; but even with this limitation, as will be seen from the numerical examples at the end of the paper, it is possible to get quite reliable figures for preliminary design purposes. The scales used throughout are logarithmic, as any attempt to plot the curves to uniform scales would result, with the working limits adopted, in a chart of unwieldy proportions, possessing the common defect of the crowding of each set of curves near the origin. When the log scales are substituted, each series of curves consists of parallel straight lines, inclined at 45 degrees to either axis, so that it is only necessary to obtain one point on each curve, and draw a line through it with the aid of the 45-degree set square.

Turning now to *Groups II.* and *III.*, there are, doubtless, several ways in which the different elements may be graphically combined; but the production of a chart, on which they can be handled without a considerable amount of preliminary or intermediate calculation, is not quite such a simple matter as that of Chart, No. 1.

The following methods of construction have been adopted here, by means of which, all calculation, except that of a simple addition or subtraction, is avoided; the operation on Chart, No. 2, is continuous from start to finish, while on Chart, No. 3, there is only one break in the continuity of the operation when the disturbing element of inside lap is involved. Taking *Group II.*, and referring to Fig. 1, Plate IX., Let—

L_0 = Outside lap,

α = Lap angle,
l = Lead,
β = Lead angle, so that—
A = $(L_0 + l)$ = linear advance,
$\theta = (\alpha + \beta)$ = angular advance,
W = port opening,
R = length of crank,
r = eccentricity, or half the valve travel, and
X_1 = piston travel to cut-off, when the connecting rod is infinite,
x = fraction of stroke to cut-off = $\frac{X_1}{2R}$.

When the crank is in the dead centre position OP, the eccentric is at Od, and the steam edge of the valve is at a, the port being open by the amount of lead. Steam is admitted to the cylinder while the valve edge moves from a to b and back from b to c, and during this period the eccentric and crank each rotate through an angle ϕ, finally occupying positions Od_1 and OP_1, when the valve closure to steam admission takes place. The error in the valve motion, due to the obliquity effect of the eccentric rod, is here neglected, as in the case of the valve diagram, since it is usually too small to appreciably affect results.

Here, obviously, $\phi = \left\{180 - (2\alpha + \beta)\right\}$ and hence the angle P_1OM_1, which the crank makes with the line of stroke at cut-off, is

$$\delta = (180 - \phi)$$
$$= (2\alpha + \beta).$$

Referring to Fig. 2, let P_1OM_1 be bisected by the line OQ, then the angle $QOM_1 = \frac{\delta}{2} = \left(\alpha + \frac{\beta}{2}\right)$; and

$$fg = r \operatorname{Sin}\left(\alpha + \frac{\beta}{2}\right) \quad \ldots \quad (1)$$

$$L_0 = r \operatorname{Sin} \alpha \quad \ldots \quad (2)$$

$$(L_0 + l) = r \operatorname{Sin}(\alpha + \beta) \quad \ldots \quad (3)$$

Adding (2) and (3), $2L_0 + l = r\left\{\operatorname{Sin}\alpha + \operatorname{Sin}(\alpha + \beta)\right\}$

$$= r\, 2 \operatorname{Sin}\left(\alpha + \frac{\beta}{2}\right) \operatorname{Cos}\frac{\beta}{2} \quad \ldots \quad (4)$$

Dividing (4) by (1) $\frac{2 L_0 + l}{fg} = 2 \cos \frac{\beta}{2}$.

But since $\frac{\beta}{2}$ is a very small angle, $\cos \frac{\beta}{2} \doteq 1$, hence—

$$fg = \left(L_0 + \frac{l}{2}\right), \text{ and}$$

$$\frac{L_0 + \frac{l}{2}}{r} = \sin \frac{\delta}{2} = \sqrt{\frac{1 - \cos \delta}{2}}. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

$$\cos \delta = \frac{h}{R} = \frac{X - R}{R} = \left(\frac{X}{R} - 1\right) = (2x - 1)$$

hence substituting in (5)—

$$\frac{L_0 + \frac{l}{2}}{r} = \sqrt{\frac{1 - (2x - 1)}{2}},$$

$$\text{and } L_0 = r \sqrt{(1 - x)} - \frac{l}{2}$$

In a new design the port opening is given, and the lap is required. Since $L = (r - W)$, then—

$$(r - W) = r \sqrt{(1 - x)} - \frac{l}{2},$$

$$\text{and } (2W - l) = 2r\left\{1 - \sqrt{1 - x}\right\} = K_1$$

The left-hand portion of Chart No. 2 gives the graphical interpretation of this identity. On a port opening (vertical) base are plotted values of K_1 for a series of values of lead, and on a cut-off base are plotted corresponding values of K_1 for a series of values of valve travel. This portion of the chart gives the same solution as the Bilgram diagram when the connecting rod is infinite, viz., given the lead, port opening, and cut-off, the necessary valve travel and lap can be determined. From the nature of the right hand side of the identity, a readable diagram cannot be obtained when uniform scales are used, and logarithmic scales have again been adopted. Their use, on the other hand, introduces the crowding defect in the lead curves, and can be seen at the lower corner of the diagram. A compromise has to be made between extreme conditions, and the relative dimensions of the scales used have been arrived at by the eliminating process of trial and error.

The cut-off with an infinite rod being ascertained, correction has to be made for the finite rod used in ordinary practice.

The error due to the obliquity of the rod can be calculated from the expression—

$$\pm \frac{R \operatorname{Sin}^2 \delta}{8n},$$

where, $$n = \frac{\text{connecting rod}}{\text{stroke.}}$$

A proof of this will be found in Zeuner's standard work on "Valve Gears," or in Cotterill's "Applied Mechanics," so that it need not be enlarged upon here.

This value has to be added to the piston travel on the down, and subtracted from it on the up stroke. The corrected value divided by 2 R gives the necessary fractional value x. A quicker and simpler way, however, is to obtain values of x directly by construction from a large-scale diagram. For the right-hand portion of the chart these values of cut-off, obtained by construction for a finite rod, are plotted on the (vertical) base of cut-off with infinite rod, for a series of values of the connecting-rod ratio. A combination of logarithmic and uniform scales is employed here, in order to make one diagram serve for both top and bottom readings, and to get in readable sets of ratio curves. To prevent confusion, only five curves are plotted in each set. Intermediate values of the ratios can be easily got by interpolation.

The direct method of the use of this Chart is either to find the travel from the lead, port opening, and cut-off, and then to subtract the port opening from half the travel and obtain the lap; or, as is usually done in the case of the Zeuner diagram, from the lead, cut-off, and an assured travel, to determine the port opening and lap. When the leads are equal at top and bottom, the laps are equal, since $A = (L_0 + l)$ is a constant. If, however, as is generally the case, the bottom lead is in excess of the top lead, the bottom port opening will be greater than the top one by an amount equal to the difference between the leads, and in the operation to ascertain the cut-off on the bottom side, the value to be used for the bottom port opening = {top port opening + (bott. lead − top lead)}

From the foregoing the following rules may be formulated.

CHART No. 2.

Rule II.

Given: Port opening, lead, cut-off, and connecting-rod ratio.

To find: Valve travel and outside lap.

(*a*) Follow the cut-off vertical to the connecting-rod ratio curve, and note the horizontal from this curve.

(*b*) Follow the port opening horizontal to the lead curve.

(*c*) Follow the vertical from the lead curve till it cuts the observed horizontal, and read the valve travel at the point of intersection.

(*d*) Subtract the port opening from half the travel and obtain the outside lap.

Rule III.

Given: Travel, lead, cut-off, and connecting-rod ratio.

To find: Port opening and outside lap.

(*a*) Follow the cut-off vertical to the connecting-rod ratio curve.

(*b*) Follow the horizontal from the ratio curve to the travel curve.

(*c*) Follow the vertical from the travel curve to the lead curve.

(*d*) Follow the horizontal from the lead curve to the port opening scale and read the result.

(*e*) Subtract the port opening from half the travel and obtain the outside lap.

Rule IV.

Given: Top and bottom leads, top port opening, and valve travel.

To find: Cut-off top and bottom, and mean cut-off.

(*a*) Follow the top port-opening horizontal to the top lead curve

(b) Follow the vertical from the lead curve to the travel curve.

(c) Follow the horizontal from the travel curve to the ratio curve for the top end, and read the top cut-off on the upper scale. Next subtract the top from the bottom lead, and add the value to the top port-opening. With this as bottom port-opening repeat the operations using the bottom lead and ratio curves, and read the bottom cut-off on the lower scale. Average these values for the mean cut-off.

These three rules will be found sufficient for the handling of any of the problems, connected with the steam edge of the valve, which are likely to arise in the initial stages of a design.

Finally, taking *Group III.*, when there is no inside lap the location of the piston position at release and compression is a comparatively simple matter, as will be seen by referring to Fig. 3. As already shown on Fig. 1, when the crank is at the cut-off position OP_1 and the eccentric at Od_1, the crank angle $\delta = (180 - \phi) = (2\alpha + \beta)$. If OP_2 is the crank position at release, and Od_2 the corresponding position of the eccentric, then $P_1OP_2 = d_1Od_2 = \alpha$, the lap angle, since both cranks must describe this angle, while the valve edge moves from position c to k, before the valve is again in its central position. At release, then, the angle the crank makes with the line of stroke is $\gamma = (\delta - \alpha) = (2\alpha + \beta - \alpha) = (\alpha + \beta) = \theta$ the angle of advance. Obviously the same reasoning holds for the location of the crank position OP_3 at compression, so that when the linear advance has been determined from Chart No. 2 the piston positions at release and compression are determinate. With an infinite connecting rod the fraction of the stroke corresponding to the crank angle $\gamma = \theta = \text{Sin}^{-1}\frac{A}{r}$ is easily ascertained either from the expression $X_2 = X_3 = R(1 - \text{Cos}\,\theta)$ by calculation, or from a table of values such as is given in Zeuner's standard work, or directly by construction.

On the left hand diagram of Chart No. 3, the above conditions have been graphically embodied by plotting on a valve-travel base the values of $\text{Sin}^{-1}\frac{A}{r}$ for a series of values of the linear advance A. The correction for the connecting-rod obliquity is made as in the previous case by plotting in the right-hand diagram, on the (vertical) base of $\text{Sin}^{-1}\frac{A}{r}$ with infinite rod, the corrected cut-off values with finite rod, for a series of values of connecting-rod ratio. When, therefore, there is no inside lap, after the constant element of linear advance has been determined from Chart No. 2, the release and compression points are ascertained by following the valve travel vertical to the linear advance curve, then following the horizontal to the ratio curves and the verticals from these to the corresponding scales for top and bottom release and compression. As in the case of Chart No. 2, a combination of logarithmic and uniform scales has again been adopted to get in a readable set of ratio curves. As the obliquity error rapidly decreases towards the ends of the stroke, it is somewhat difficult to accomplish this object satisfactorily.

In marine engine practice, there is almost always positive inside lap at the bottom and negative inside lap at the top edge of the valve, and a modification of the Chart is necessary, in order to take account of both these elements. Referring to Fig. 4, if the valve has a positive inside lap $= L_1$, then the eccentric and crank must describe a further angle ω, while the inner edge of the valve moves from the central position k to the position m, where release takes place. The position of the crank and eccentric at release will therefore be OP_4 and Od_3 and the crank angle $\gamma_4 = (\gamma - \omega)$. By similar reasoning, it can be shown that at compression the crank angle (in the fourth quadrant) is $= \gamma_5 = (\gamma + \omega)$. It will also be obvious that when the inside lap is negative, this order will simply be reversed—that is, $\gamma_5 = (\gamma + \omega)$ is the crank angle at release, and $\gamma_4 = (\gamma - \omega)$ is the crank angle at compression. Put generally, then, the crank angle γ for $\begin{Bmatrix}\text{release}\\\text{compression}\end{Bmatrix} = (\theta \mp \omega)$, with positive inside lap; and γ for $\begin{Bmatrix}\text{release}\\\text{compression}\end{Bmatrix} = (\theta \pm \omega)$, with negative inside lap. The upper and lower signs correspond respectively to the release and compression. All that is necessary, therefore, to take account of the inside lap is to determine the inside lap angle ω, add or subtract it from $\theta = \text{Sin}^{-1}\frac{A}{r}$ determined from the travel and linear advance, follow the horizontal from this increased or diminished value of the crank angle to the ratio curves, and complete the operation as before. The arcs qs and qt do not differ sensibly in value from the inside lap L_1; hence ω (radians) $= \frac{L_1}{r}$ and ω (degrees) $= 57{\cdot}3\,\frac{L_1}{r}$. For the determination of ω, values of ω, calculated from this expression, have been plotted on the valve-travel base for a series of values of inside lap. In order to avoid the objectionable feature of having the $\text{Sin}^{-1}\frac{A}{r}$ and ω scales on the same axis, the venue of this latter scale has been changed to the upper part of the diagram, through the medium of the diagonal line AB. As it is not usually the custom, when designing a valve, to measure the angular values, and as it is conducive to conciseness in the statement of the working rules, the value of crank angle with inside lap has been termed simply Result I; that of the lap angle, Result II; and the corrected value of crank angle, Result III. In the light of the above explanation, the working rules for Chart, No. 3, will be readily understood.

Chart No. 3.

Rule V.

Given: No inside lap.

To find: Release and compression.

(*a*) Follow the travel vertical to the linear advance curve.

(*b*) Follow the horizontal to both sets of connecting-rod ratio curves.

(*c*) Follow the verticals from the ratio curves and read (top release or bottom compression) on the upper scale; (bottom release or top compression) on the lower scale.

Rule VI.

Given: Positive inside lap.

To find: Release and compression.

(*a*) Follow the travel vertical to the linear-advance curve, and the horizontal to Scale I., and read Result I.

(*b*) Follow the travel vertical to the inside-lap curve, then the horizontal to the diagonal line A B, then the vertical to Scale II., and read Result II.

(*c*) For { Release take, Result III. = (I. − II.)
Compression take, Result III. = (I. + II.)

From Value III. on Scale I., follow the horizontal to the ratio curves, then follow the verticals from these curves, and read the results on the corresponding scales.

Rule VII.

Given: Negative inside lap.

To find: Release and compression.

Perform operations (*a*), (*b*), and (*c*), as in Rule VI., but under—

(*c*) For { Release take Result III. = (I. + II.)
Compression take Result III. = (I. − II.)

Rule VIII.

Given: Top or bottom compression.

To find: Inside laps.

(*a*) Follow the travel vertical to the linear-advance curve, and read Result I. on Scale I.

(*b*) Follow the compression vertical to the corresponding ratio curve, and the horizontal to Scale I., and read Result III.

(*c*) II. = (III. − I.), and if negative, the inside lap is negative.

(*d*) From Value II. on Scale II. follow the vertical to A B, and the horizontal to the travel vertical, and read the value of the inside lap at their point of intersection.

This rule is equally applicable where top or botton release is given instead of compression; and if the difference (III. − I.) under (*c*) is positive the inside lap is negative.

NUMERICAL EXAMPLES TO ILLUSTRATE THE APPLICATION OF THE CHARTS.

Example (1) The H.P. cylinder of a triple-expansion engine is 23 inches in diameter by 42 inches stroke; the revolutions are 75 per per minute. The piston valve is to be 11½ inches in diameter, with an approximate circumference of 36 inches.

Determine, the diameter of the main steam pipe for a steam velocity of 8000 feet per minute; the port width for an exhaust velocity of 5000 feet per minute; and the top port opening for a steam velocity of 7800 feet per minute, assuming that 35 per cent. of the gross port area is taken up by the ribs in the liner.

To find the main steam pipe diameter, apply *Rule I.*, Chart No. 1—

(*a*) Follow the 75 horizontal to the 42 stroke curve.

(*b*) Follow the vertical from the 42 stroke curve to the 23 cylinder-diameter curve.

(*c*) Follow the horizontal from the cylinder-diameter curve to the 8000 velocity curve.

(*d*) Follow the vertical from the velocity-curve to the upper scale, and read steam pipe diameter $= 5\frac{7}{8}$, say 6 inches.

In the case of the port width opening, the net values will be 65 per cent. of the gross or actual widths.

(*c*) Follow the horizontal from the 23 cylinder-diameter curve to the 7800 and 5000 velocity curves.

(*d*) Follow the verticals from the velocity curves to the 36-inch circumference curve.

(*e*) Follow the horizontals from the circumference curve to port width scale, and read ·65 port width $= 1\frac{7}{32} = 1{\cdot}218$ inch; and ·65 port opening $= \frac{25}{32} = {\cdot}7812$ inch. Then the gross port width $= \frac{1{\cdot}218}{{\cdot}65} = 1{\cdot}94$, say 2 inches, and the gross top port opening $= \frac{{\cdot}7812}{{\cdot}65} = 1{\cdot}2$, say $1\frac{3}{16}$ inch.

Example (2) For the above named engine the mean H.P. cut-off is to be about ·63. Taking top lead $=\frac{1}{8}$ inch, bottom lead $=\frac{5}{16}$ inch, determine the valve travel and the outside laps. Also determine the steam velocity through the bottom port and the mean of the steam velocities. The connecting rod is 7 feet between centres.

Here the connecting-rod ratio is 2. As in the case of the valve diagram, assume provisionally that the top cut-off is about ·67.

Apply *Rule II.*, Chart No. 2, to find valve travel and top outside lap.

(*a*) Follow the ·67 top cut-off vertical to the 2 ratio-curve for top end, and note the horizontal from this curve.

(*b*) Follow the $1\frac{3}{16}$ top port opening horizontal to the $\frac{1}{8}$ top lead-curve.

(*c*) Follow the vertical from the lead curve to the observed horizontal, and read at the point of intersection, valve travel = 6 inches.

(*d*) Top outside lap $= (3 - 1\frac{3}{16}) = 1\frac{13}{16}$ inch.

The linear advance $A = (1\frac{13}{16} + \frac{1}{8}) = 1\frac{15}{16}$ inch.

The difference between the leads is $(\frac{5}{16} - \frac{1}{8}) = \frac{3}{16}$ inch, hence the gross bottom port opening $= 1\frac{3}{8}$ inch, and the bottom outside lap $= (1\frac{15}{16} - \frac{5}{16}) = 1\frac{5}{8}$ inch.

Next apply *Rule IV.* to find the bottom cut-off :—

(*a*) Follow the $1\frac{3}{8}$ bottom port-opening horizontal to the $\frac{5}{16}$ bottom lead-curve.

(*b*) Follow the vertical from the lead curve to the 6-inch travel curve.

(*c*) Follow the horizontal from the travel curve to the 2 ratio curve for the bottom end.

(*d*) Follow the vertical from the ratio curve to the lower scale, and read bottom cut-off = ·59, then the mean cut-off

$$=\frac{\cdot 67 + \cdot 59}{2} = \cdot 63 \text{ (as required).}$$

Finally to determine the steam velocity through the bottom steam port refer again to Chart No. 1.

Here the gross port opening is $1\frac{3}{8}$ inch and the net opening $\cdot 65 \times 1\cdot 375 = \cdot 8937 = \frac{29}{32}$ inch.

(*a*) Follow the $\frac{29}{32}$ port opening horizontal to the 36 circumference curve, and note the vertical from this curve.

(*b*) Follow the 75 revolution horizontal to the 42 stroke curve.

(*c*) Follow the vertical from the stroke curve to the 23 cylinder-diameter curve.

(*d*) Follow the horizontal from the diameter curve to the observed vertical, and read at their point of intersection the approximate steam velocity = 6600 feet per minute, then the mean of the steam velocities, top and bottom,

$$= \frac{7800 + 6600}{2} = 7200 \text{ feet per minute.}$$

Example (3) For the above named engine, determine the necessary top and bottom inside laps to give compression at about ·887 stroke. Also ascertain the corresponding points of release.

Apply *Rule VIII.*, Chart No. 3, to find the top inside lap. Here the linear advance $= 1\frac{15}{16}$ inch.

(*a*) Follow the 6-inch travel vertical to the $1\frac{15}{16}$ linear-advance curve, and on Scale I read Result I = 40.

(*b*) Follow from the lower scale, the ·887 compression vertical to the 2 ratio curve for top compression, then the horizontal to Scale I, and read Result III = 35·3.

(*c*) II = (III − I) = (35·3 − 40) = − 4·7, and the top inside lap is negative.

(*d*) Follow the 4·7 vertical from Scale II to AB, then the horizontal to the 6-inch travel vertical, and at their point of intersection read top inside lap = − $\frac{1}{4}$ inch.

Next to find the bottom inside lap.

(*b*) Follow from the upper scale, the ·887 compression vertical to the 2 ratio curve for bottom compression, then the horizontal to Scale I, and read Result III = 44·7.

(*c*) II = (III − I) = (44·7 − 40) = 4·7. The bottom inside lap is therefore positive and also $\frac{1}{4}$ inch.

Rules VI. and *VII.* might be applied here to ascertain the points of release; but since the laps are the same it will be evident that the release top and bottom is also approximately ·887.

Example (4) Each L.P, cylinder of the four-crank triple-engines of a battleship is 66 inches in diameter by 48 inches stroke, Each steam port is $62\frac{1}{2}$ inches by $3\frac{1}{2}$ inches. Assuming provisionally a travel of 9 inches for the double-ported slide-valve, top lead = $\frac{5}{8}$ inch and the bottom lead = $\frac{7}{8}$ inch, what will be the mean cut-off with top outside lap = 2 inches and bottom outside lap = $1\frac{3}{4}$ inch?

The connecting rod is 9 feet between centres.

Apply *Rule IV.*, Chart No. 2, to find top cut-off—

(*a*) Follow the $2\frac{1}{2}$ top port-opening horizontal to the $\frac{5}{8}$ top lead curve.

(*b*) Follow the vertical from the lead curve to the 9-inch travel curve.

(*c*) Follow the horizontal from the travel curve to the 2 ratio curve for the top end.

(*d*) Follow the vertical from the ratio curve to the upper scale and read the top cut-off = ·784.

Next to find the bottom cut-off—

(*a*) Follow the $2\frac{3}{4}$ bottom port-opening horizontal to the $\frac{7}{8}$ bottom lead curve.

(*b*) Follow the vertical from the lead curve to the 9-inch travel curve.

(*c*) Follow the horizontal from the travel curve to the 2 ratio curve for the bottom end.

(*d*) Follow the vertical from the ratio curve to the lower scale and read bottom cut-off = ·716, then the mean cut-off

$$= \frac{(\cdot 784 + \cdot 716)}{2} = \cdot 75.$$

Example (5) If for the four-crank engine the top inside lap = $-\frac{3}{16}$ inch, and the bottom inside lap = 0, what will be the corresponding top and bottom release and compression values?

Apply *Rule VII.*, Chart No. 3, to find release and compression. Here the linear advance = $2\frac{5}{8}$ inches.

(*a*) Follow the 9-inch travel vertical to the $2\frac{5}{8}$ linear-advance curve, and the horizontal to Scale I, and read Result I = 35·7.

(*b*) Follow the 9-inch travel vertical to the $\frac{3}{16}$-inch top inside-lap curve, then the horizontal to A B and the vertical to Scale II, and read Result II = 2·3.

(*c*) For top release III = (I + II) = (35·7 + 2·3) = 38. For top compression III = (I - II) = (35·7 - 2·3) = 33·4.

Follow the 38 horizontal from Scale I. to the 2 ratio curve for top release and the vertical to the upper scale and read top release = ·918.

Follow the 33·4 horizontal from Scale I, to the 2 ratio curve for top compression, and the vertical to the lower scale and read top compression = ·902.

Next apply *Rule V.* to find the bottom release and compression.

(*a*) Follow the 9-inch travel vertical to the $2\frac{5}{8}$ inches linear-advance curve.

(*b*) Follow the horizontal from the linear-advance curve to both sets of ratio curves.

(*c*) Follow the vertical from the 2 ratio curve for bottom release to the lower scale and read bottom release = ·885. Follow the vertical from the 2 ratio curve for bottom compression to the upper scale and read the bottom compression = ·928.

Example (6) Each L.P. cylinder of the four-crank engine exhausts to the condenser through a pipe $24\frac{1}{2}$ inches in diameter. What will be the velocity of exhaust to the condenser; and also the mean of the steam and exhaust velocities through the ports when the speed of the engine is 120 revolutions per minute?

Referring again to Chart No. 1. To find the velocity of exhaust to the condenser.

(*a*) Follow the 120 revolution horizontal to the 48 stroke curve.

(*b*) Follow the vertical from the stroke curve to the 66 cylinder-diameter curve and note the horizontal from the curve.

(*c*) Follow the vertical from the 24½ diameter on the upper scale to the observed horizontal and read, at their point of intersection, the approximate exhaust velocity to the condenser = 7000 feet per minute.

To find the mean of the steam velocities and the exhaust velocity through the ports.

Since the mean port opening = 2⅝ inches, and port width = 3½ inches, and the valve is double ported, the effective values are, mean port opening = 5¼ inches, and port width = 7 inches.

(*a*) Follow the 5¼-inch port opening horizontal to the 62½-inch (interpolated) port length curve.

(*b*) Follow the vertical from the port length curve to the previously observed horizontal, and at their point of intersection read the mean of the steam velocities = 10,000 feet per minute.

Again, repeat operations (*c*) and (*d*), using the 7-inch port width value, and read the exhaust velocity through the full port = 7500 feet per minute (approx.).

These results can also be obtained by calculating the port area, starting from the port area scale, and repeating operation (*d*).

These numerical examples should suffice to indicate that, results approximate enough for all practical purposes can be obtained from the Charts, with a minimum of calculation, and in much less time than it would take to obtain them from a valve diagram. At first sight the working rules may appear cumbersome; but in reality the operations they describe can be rapidly carried out if the charts are pinned on a drawing board and a T-square and a set-square used to locate the intersections of the lines and curves.

The figures obtained, in the examples, show that on Chart No. 1 port openings can be got to the nearest $\frac{1}{32}$ inch; pipe diameters from 3½ inches to 20 inches to the nearest ⅛ inch; while steam velocities can be got, with fair accuracy, to the nearest 100 feet per minute.

On Charts, Nos. 2 and 3, port openings can be got to the nearest

$\frac{1}{32}$ inch; leads and inside laps to the nearest $\frac{1}{16}$ inch direct, or to $\frac{1}{32}$ inch by interpolation; valve travels to the nearest $\frac{1}{4}$ inch direct, or $\frac{1}{8}$ inch by interpolation; while the values of cut-off, release, and compression, can be got correct to the second decimal, and with careful operation, with fair accuracy, to the third decimal place.

Discussion.

Mr R. T. NAPIER (Member) said that he had listened to the paper with great interest, for, in earlier years, he made a special study of valve gears, and was familiar with Zeuner's diagram. Rather to his disappointment, however, no opportunity of designing a valve arrangement in its entirety had fallen to his lot. He concluded that the Author intended the curves to give a close approximation to the values for port-opening, lap, etc., and did not aim at superseding the valve diagram as drawn down in regular form. He (Mr Napier) owned, to a sentimental regret, that the designing of valve gears, the job which he well remembered looking upon as the best job that the drawing office could offer, should be reduced to a matter of measuring values off a curve; although, with the adoption of standard types of engine, valve gears could hardly escape being standardised also.

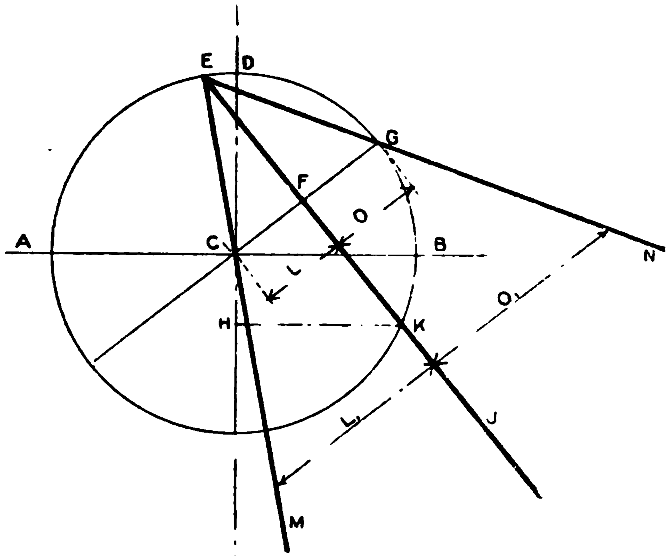
Mr JAMES ANDREWS (Member) expressed regret that Mr Goudie's paper had induced such a meagre discussion, as it dealt with a very important subject to the engine designer, and one upon which much might be said. On looking over the Charts one could scarcely fail to be impressed with the enormous amount of thought and careful calculation which must have been expended on them to bring them into their present form, and after putting the Charts to a few tests, from known data, he felt sure there could be no question but that they gave all the information which was said to be obtainable. In the comparatively short time which he had been able to devote to them he thought that there was just a question as to whether that information was presented in the best possible form, because he rather thought that the Author had endeavoured to combine too much information in one sheet.

Taking No. 1 Chart, for example, one commenced from revolutions per minute, followed the horizontal line to the length of the stroke, then the vertical piston-speed line was followed to the cylinder diameter, from thence along to a horizontal line to the speed of steam line, and from that point along the vertical lines to the port area, and steam and exhaust-pipe diameters; or again, the vertical and horizontal lines might be followed to obtain the length and width of port on their respective scales. Now, while this operation would be very simple to Mr Goudie, who had devoted much time to the construction of this Chart, it would be a very difficult one to the average draughtsman who had few opportunities of designing valves, with perhaps long intervals of time between them. The result of each stage was useful information recorded, and from his point of view he would prefer the Chart to be sub-divided into more than one diagram, because, he found from the short experience he had had of it, that in the multiplicity of lines, cross references, and scales, that one was liable to make mistakes. It was true that a board and squares would facilitate the operation, but those requisites were not always at hand, many, too, would prefer to keep their transactions with the various rules intact, and in any case he thought that the liability to err was still, more or less, present. He would submit that it was just as essential in a chart as it was in the case of speaking or writing, to convey the information in such a way, not merely that it would be understood, but that it could not be misunderstood. Now, take for example a separate chart or diagram giving revolutions, stroke of engine, and piston speed, the required information would be read off easily, accurately, and with more confidence by a junior draughtsman, who was perhaps drawing a valve twice or three times in a twelve month, and he would record the result before proceeding to the next stage. No doubt Mr Goudie would think this method too simple, but he (Mr Andrews) was speaking more on behalf of the draughtsman who was not designing a valve every day, who was most liable to err and who would derive an equal, if not a greater benefit from Mr Goudie's system.

Mr James Andrews.

Regarding Chart No. 2 it would be observed that the amount of lead was given in fractions of an inch. Now while that method was very useful to the man who was setting the valve on the engine, it did not strike him (Mr Andrews) as being very intelligible to the draughtsman who wished to use lead to the best advantage, and he thought it preferable that the amount of lead should be stated in degrees of angle of crank, in advance of the dead centre or end of piston stroke. Lead was a very arbitrary factor to deal with; there was no hard and fast rule about it. Some engineers had the notion that $\frac{1}{16}$, $\frac{1}{8}$, or $\frac{3}{16}$ of an inch of lead was the only choice admissible, but he had given valves as much as an inch and a quarter of lead. which was beyond the limit of the Chart, without injuriously affecting the steam distribution at that point while greatly improving it at another. In fact the amount of lead should be varied to suit the circumstances in each case, and this could be most intelligently done in degrees of angle, because it was not affected by the length of valve travel. A 12-inch valve travel might appear to have an abnormally large amount of lead in fractions of an inch, while in fact it was under the normal in degrees of angle as compared with the smaller valve travels. Varying the lead within certain limits was often a great convenience in varying the percentage of release or compression by reason of the eccentric being turned one way or another, and that was a relation which could not be so easily followed on the Chart as on the Zeuner diagram. It was also useful to manipulate the lead to obtain the required port opening without interfering with the valve travel. In his (Mr Andrews) experience he could not recollect having seen an engine with too much lead, although it was sometimes credited with causing an engine to knock, but it would generally be found that the knock would disappear by linking up the gear, notwithstanding that the lead had been increased. During the last twenty years, he (Mr Andrews) had been accustomed to using a comparatively simple modification of the Zeuner diagram for obtaining the preliminary information for a valve design. It would

Fig. 5.



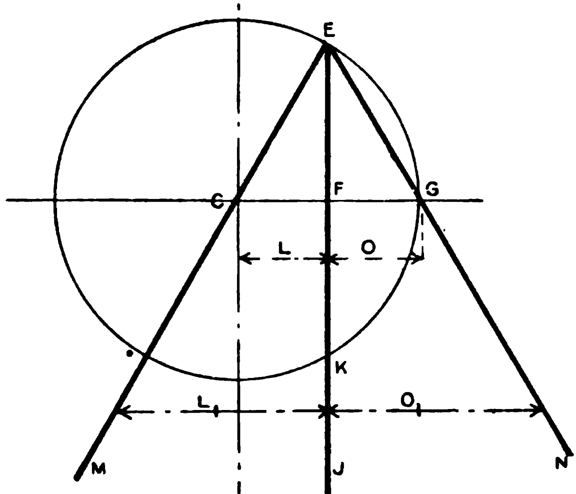


Fig. 6.

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be easily understood by reference to Fig. 5. The circle A D B was drawn ten units or ten inches in diameter to any scale. The length D H was then set off as the percentage of cut-off relative to the stroke A B, so that the crank would be at K with an infinite connecting rod. The angle of lead, E C D, having being marked off to give 5, 10, or 15 degrees as required, then draw the lines E M through C, E J through K, E N through G, and C G at right angles to E J. Now any length O or O_1 parallel to C G measured to give the necessary steam opening would have the steam lap L or L_1 in the same straight line, and of course the sum of L plus O was half the valve travel. For convenience of measuring he preferred to turn the diagram round as in Fig. 6, so as to measure with the rule or scale on a horizontal line. This would be recognised as the Zeuner diagram extended, so that it was applicable to any engine having the same percentage of cut-off and angle of lead, and since most engineers had a standard practice, probably one such diagram would serve for every new design. The diagram might also be drawn for a definite connecting rod, but having designed hundreds of valves with it, he found the simple diagram as shown to be near enough for all practical purposes in a preliminary design, leaving the exhaust edges till the final valve setting was required. He was sure Mr Goudie's Charts would be very useful to those who were designing valves often. They embraced a considerable amount of information which must have given him a great deal of study, but as he (Mr Andrews) had said, he felt that in the hands of a junior draughtsman it would have been better to have had the Charts subdivided.

Correspondence.

Mr J. F. Douglas (Southampton) considered that Mr Goudie's Charts showed a great deal of ingenuity, a vast amount of labour, patient calculation, and neatness in design. He heartily congratulated him on the results, and his efforts to still further reduce the time spent in getting out the necessary data for this important work. In these days of high pressure, slide rules, and calculating charts

Mr J. F. Douglas.

had become almost a necessity in the drawing office, and any means to expedite or readily check intricate calculations or graphic methods of arriving at results, were readily welcomed. Like all such efforts to minimise labour, one had still to draw on experience for piston speed, calculations for cut-offs and mean pressures, and the requisite leads needed consideration. With these arranged, the process for fixing the other points in slide-valve design by these Charts was much simpler than by the old time Zeuner diagram. A comparatively short acquaintance with the Charts reduced one's labour to a matter of minutes instead of hours. He had not only run over the examples given by Mr Goudie, but had taken some data of his own, drawn by the methods mentioned by the Author, and in each case had found very close agreement. He hoped Mr Goudie would give a supplementary paper and continue his investigations for a curve which would give values for valve travel, etc., when the gear was linked up or out, as the method for attaining this was at present somewhat involved.

Mr Goudie, in reply, expressed his regret that so few Members had taken part in the discussion. He was afraid that among engineers there was a feeling of distrust in the use of the calculating chart, which it did not merit. To those who took the trouble to study the simple principles underlying the construction of such a chart, its operation was as equally simple and reliable as that of its mechanical equivalent—the compound slide rule; and he hoped that if the paper did nothing else, it would help to stimulate an interest in this somewhat neglected branch of graphics. He desired to thank those who had taken part in the discussion for their favourable comments on the Charts. Mr Napier "concluded that the Author intended the curves to give a close approximation to the values for port-opening, lap, etc., and did not aim at superseding the valve diagram, drawn down in more regular form." This was just the end he (Mr Goudie) had in view, as he had indicated, though perhaps not quite clearly on page 140, when he attacked the problem on its graphical side. It was just as essential that the valve diagram should be filed away with the

Mr Goudie.

rest of the engine drawings as the drawing of the valve gear to which it was related; and he had no intention of advocating the abandonment of the diagram in favour of tabulated results obtained from the Charts. He had aimed at the production of a combination of curves from which, for given design conditions, the exact value of each unknown element necessary for the construction of the diagram could be obtained in a few minutes, without any geometrical trial and error process. Once the proper values of cut-off, lap, lead, etc., were thus ascertained, the draughtsman had simply to take his instruments and embody the data in diagram form right away. It would be found by those who took the trouble to study Charts Nos. 2 and 3, that, in addition to the fulfilment of this primary condition, they afforded the means for the rapid analysis of the effect of varying any particular element of a design. In the case of the valve diagram, a separate construction was necessary for each variation, whereas, with the Charts, the effects of such variation could usually be at once ascertained by inspection. The operation was much quicker, and there was not the confusion of lines which inevitably resulted on the Zeuner diagram when it was used for this purpose. He had been at considerable pains to design these Charts, so that the results obtained would be identical with those given by the Zeuner construction; and he was pleased to note that Mr Douglas and Mr Andrews, who had put them to the test against diagram values, had found them satisfactory in this respect. Mr Andrews took exception to the compounding of the diagrams on Chart No. 1, on the ground that the junior draughtsman would probably find a difficulty in operating it. He (Mr Goudie) could quite understand the feeling of uncertainty of anyone, unaccustomed to chart manipulation, on a first trial of this Chart; but he did not think that this initial trouble justified the dismemberment of the Chart as suggested by Mr Andrews. The "junior," he thought, would at the outset find just as much trouble when started on some line of work to which he was unaccustomed, but nobody would dream of altering the designs to save him the trouble of thinking out his difficulties. The difficulty in this case was, however, more apparent than real; and he thought that Mr Andrews, and others who were of the same opinion regarding this Chart, would see that this was the case, if they adopted the following simple expedient. Let them take an example, and, beginning at the revolution scale, convert the horizontal and vertical lines of operation into heavy dotted lines standing out in distinct relief from the others. On each line mark one or two directional arrow-heads, showing the route from one set of curves to the next, between the revolution and port-opening scales. These lines and arrow-heads would serve as guides to the eye for any subsequent calculation. The port area and pipe diameters were of a secondary character, and should not be mixed up with the calculation. For their estimation a second example should be lined in, quite independently of the other one. He might go into this secondary aspect of chart construction raised by Mr Andrews, in detail, and deal with the various combinations which might be adopted, and further demonstrate the fact that, although at first sight apparently simpler for the operator, the graphical manipulation of six elements in a series of separate charts, involved more liability to error and time and labour than the co-related set he had submitted. As he had already pointed out in the paper, this Chart was really subsidiary to the others, and on that account he did not think it justified an extension of his reply. Mr Andrews took exception to the linear lead, and advocated angle of lead instead, while, at the same time, he admitted that the linear value was "very useful to the man who was setting the valve on the engine." He (Mr Goudie) would be inclined to go further, and say that it was a necessity for the erector, if he was to embody the designers ideas properly in the engine. He did not see therefore why the draughtsman should mix up angular and linear values when getting out his diagram, as in every case he had to ascertain the values of linear lead and linear advance for shop purposes. He thought this was a generally accepted fact; and for one designer who used angular values there were pro-

Mr Goudie.

bably ten who used linear ones directly in their constructions. Referring to Mr Andrews' diagram, Fig. 5, and taking for illustration C D as the actual eccentricity or half-travel of the valve, he thought that, from the constructional point of view it was easier and handier to draw in the lead circle with D as centre, and then draw E K J tangent to it in the ordinary way thus obtaining the point E, than to set off a small lead angle D E C with a protractor or scale of chords. Mr Andrews' diagram, however, was drawn with C D as a standard radius and not as the absolute or actual eccentricity for any given case, and of course under this condition it was necessary to use the angular lead value, which was proportional to the ratio between the linear lead and the actual eccentricity to be considered. The diagram really represented the initial stage of the Zeuner construction, adapted, through the medium of the auxiliary construction line E N, for the determination of the ratio $\frac{\text{port-opening}}{\text{outside lap}}$ with varying travel, constant lead, and constant cut-off. It was slightly more elastic than the parent diagram, but it still necessitated the redrawal of the construction lines for every alteration of cut-off and lead angle, and it did not reveal the disturbance of the setting due to the finite connecting rod. Mr Andrews stated that, after long experience, he had found this diagram sufficiently good for preliminary design purposes; but he thought Mr Andrews would, as a rule, require to do a little final trial and error work when he drew out his complete Zeuner. This brought the discussion back to the initial trial and error conditions which he had set himself to eliminate, by endeavouring, in chart form, to take account of every variable of the problem, except that of the eccentric rod obliquity which was always neglected in practice. Mr Andrews thought that the variations of compression and release, due to alteration of the lead angle, or, what was the same thing the angle of advance θ, could not be as readily followed on Chart No. 3 as on the Zeuner diagram. He (Mr Goudie) had shown in the paper that the crank angle at compression or release was $\gamma = (\theta \pm \omega)$, and that the values on Scales I. and II. were really values of θ and ω in degrees, so he thought that any one who had mastered the principle of the combination would find no difficulty in making an equally quick estimate from Chart No. 3, either by using the angular or linear alteration of the lead. With regard to the manipulation of the lead to get a given port opening with a fixed travel, he thought that, for this purpose, Chart No. 2 rather scored over the geometrical method. This was one of the many analytical operations for which the Charts could be used. By following the cut-off vertical to the connecting-rod ratio-curve, then the horizontal to the fixed travel curve, then the vertical from this travel curve, across the sixteen lead curves, sixteen values of port-opening, and corresponding outside laps were at once determined by simple inspection. How long would it take to get this information by construction from a diagram? Mr Douglas' remarks were more complimentary than critical, and he did not think he could add much more in the way of comment than he had already done, except to touch on the interesting point Mr Douglas had raised regarding the application of the chart method to an analysis of the Stephenson link motion. Since he read the paper he had acted on the suggestion thrown out, and by a judicious "method of approximation" had evolved two equations which could be embodied in chart form. The first of these dealt with the alteration of linear lead due to any degree of "linking in" between "full" and "mid" gear; and the second dealt with the corresponding variations of valve travel, on the assumption that there was no slotting action of the block in the link. He had constructed two charts in skeleton, but had been forced to lay the matter aside in the meantime, and was not in a position to judge whether or not such a combination would be of any practical value in the drawing office. The subject was difficult, and demanded more time and study than he was able to devote to it at present. He hoped in the light of what had been said that although the discussion had been meagre, those Members who were frequently dealing with valve design would give the Charts

Mr Goudie.

a good trial, and if they did so he was sure that they would find, as Mr Andrews remarked, that they were "very useful" for preliminary design or analytical purposes. There was just one point which had not been raised, but to which his attention had been directed privately, that was the size of the Charts, Nos. 2 and 3, in the transactions, which had been reduced to about half the size of the original. He had found by actual trial that the operation of these Charts was much easier on the larger size, due to the wider spacing of the curves, and he would suggest that those who wished to make the most of the combinations, should get the Charts enlarged, say from two to three times the size of the lithographed ones, and adopt the following colour distinctions. Draw the heavy lines in black, the light lines in blue, and the dotted lines in red. He had done this in other cases and found that it greatly facilitated the operation of the Charts. The enlargement could be easily and quickly done by means of a pair of proportional dividers, or by simply transferring lengths on the edge of a slip of paper.

On the motion of the President, Mr Goudie was awarded a vote of thanks for his paper.

THE FRAHM SPEED INDICATOR

By Mr W. C. Martin (Member).

SEE PLATE XIII.

19th December, 1905.

Mr W. C. Martin exhibited the Frahm speed and frequency indicator, and explained its action. The instrument, he said, which had been adopted by the Corporation of Glasgow, was not only a speed indicator, but it also indicated the frequency of alternating electric currents. The invention was due to Mr Hermann Frahm, and was based on the employment of the principle of resonance, which was the property that elastic bodies posssessed of being set in vibration if subjected to rhythmic impulses, the frequency of which corresponded with the natural period of vibration of the bodies themselves. The instrument was the result of Mr Frahm's experiments on the torsional vibrations in propeller shafts. The inventor did not cease his investigations when he found a means of suppressing the dangers of resonance, but went forward and employed the same principle for measuring speeds, and his experiments had resulted in the discovery of the present form of speed indicator. The fundamental part of the indicator consisted of a spring of the best watch spring steel Fig. 1, the dimensions for ordinary purposes being from $1\frac{1}{2}$ to 2 inches in length, $\frac{1}{8}$ of an inch wide, and $\frac{1}{100}$ of an inch thick. These sizes permitted of a convenient adjustment of the apparatus, and were sufficient for most practical purposes. They might be varied in accordance with any special application. These springs were set in a slit, cut in a small rectangular shoe, to which they were firmly pinned and soldered. At its upper end, each spring was bent over at right angles for about $\frac{1}{8}$ of an inch, and the head thus formed was covered with white enamel so as to render it easily visible. In the angle, which the head made with the stem of the spring, was placed a small drop of solder. The number of vibrations that such a spring would make, depended primarily on the length of the vibrating part and the weight of the head, as it was made of a material as uniform as possible in quality and thickness, so that any desired period between the limits of 35 and 100 vibrations per second could be obtained. By the employment of thinner and longer or shorter and thicker springs, the range of measurement could be extended either up or down, so that in most cases a sufficiently long scale for normal measurements could be obtained.

A range of 25 springs, attuned to various periods, and spaced 1. mm. apart, was illustrated by Figs. 2 and 3. Similar combs could be arranged to contain 100 or more units as required. Mr Martin showed an experiment made with an ordinary gyroscope, Fig. 4, by placing a small comb of springs on one of the pivot screws. In all rapidly running machines, where the number of revolutions per minute was a thousand and over, the instrument might be directly attached to the machine, and for steam turbines it was now being employed generally, as the method had proved most advantageous. Another method for the production of vibrations was to employ a tappet wheel or cam. Such a cam was fixed on the shaft, the speed of which it was desired to measure, and worked against a lever which was thereby caused to vibrate. The vibrations could be transmitted to one of the combs by placing it directly on the other end of the lever, or it might be connected with the lever by means of a rod, wire, or string, Figs. 6, 7, and 8. Should it be necessary to measure the speed of a machine at greater distances, it would be better to employ electrical transmission. If it were desired to measure the speed of a machine which did not furnish alternating currents, one must use a special alternating current generator, and a generator of the simplest form consisted of a toothed disc of soft iron, which rotated close to the pole pieces of a permanent magnet on which were wound two small coils, as shown in Fig. 8. The revolving armature might be fixed direct to the shaft, the revolutions of which it was desired to measure, or the driving power might be transmitted from the shaft to the revolving inductor by means of a small belt.

The indications of the apparatus did not vary in the least with the lapse of time, even in the case of apparatus which had been worked continuously for nearly four years. Single springs had during that period made more than one thousand million vibrations, but they had not experienced any detrimental change, and still possessed their original natural period. The number of vibrations per second was not in the least influenced by the manner in which the impulses were set up, nor by the amount of movement of the cam, nor by the nature of the electrical transmission. In the latter case the degree of accuracy of the indications was not affected by the variation in the resistance of the conducting wires, nor the voltage of the magneto-generator. In fact, the accuracy depended solely on the frequency of the impulses.

From the description of the apparatus, it would be obvious that the electrically actuated vibrator might be conveniently used for ascertaining the frequency of alternating current machinery, or the interruptions of a continuous current circuit, and determining the number of revolutions per minute of any shaft. Fig. 5 illustrated the apparatus used for electrically registering the speed of any number of machines from a convenient centre.

The President moved a vote of thanks to Mr Martin for his exhibition of the Frahm Speed Indicator, and said machines were run now at such a pace that it was difficult to count the revolutions. This was a most ingenious instrument, it appeared well adapted for high speed indications, and there was very little about it liable to be become defective, which spoke very much in its favour.

The vote of thanks was carried by acclamation.

THE SCREW PROPELLER CONTROVERSY.

By Mr. James Howden (Member).

SEE PLATE XIV.

Read 23rd January, 1906.

The following introductory remarks explain the circumstances which have led me to bring this subject before this Institution at the present time.

In November, 1895, Dr. Caird read a paper here on "Propeller Diagrams," the curves of which he explained he had constructed from the diagrams given in a paper read by Mr R. E. Froude before the Institution of Naval Architects in 1886, on "The Determination of the Most Suitable Dimensions of Screw Propellers." Dr. Caird said this paper "marked an epoch in the investigation of the properties and behaviour of the Screw Propeller," and characterised Mr Froude's work in this paper as "beyond praise."

In the discussion of Dr. Caird's paper in the following month, I took exception to Dr. Caird's estimate of the value of Mr Froude's investigation of the action of the propeller and his conclusions thereon. The reasons I gave for my dissent from Dr Caird's estimate of Mr Froude's work were, that the formulæ on which his diagrams and curves representing values of thrust, efficiency, etc., were constructed, were incompetent to fulfil the purposes aimed at; the treatment of the subject, as a whole, being based on erroneous conceptions of the real action of the screw in propelling, and of the quantities of water put in motion under given conditions of diameter, pitch, and slip.

As an example of the incompetent character of Mr Froude's formulæ, given in the fifth proposition of his 1886 paper, from which both his and Dr. Caird's diagrams were made up, I showed its application to a case where two screws, tried in the same ship, gave equal speeds with the same revolutions and power of engines, these screws differing only in diameter and shape of blades. A proper formula applied to these two cases should, therefore, have shown the thrust ordinates equal; but Mr Froude's formula, when applied to these two cases, showed a difference in results of nearly 45 per cent., thus proving its incompetency in a very marked degree.

As an example of the erroneous conceptions of the screw's action, which give rise to such formula and diagrams as those of Mr Froude, I called attention to the theory of the screw propeller, as given by Professor Rankine in his paper "On the Mechanical Principles of the Action of Propellers," published in the Transactions of the Institution of Naval Architects for 1865, which I had previously fully proved to be erroneous. I also referred to the mistaken views of Dr W. Froude, as given in his paper "On the Elementary Relation between Pitch, Slip and Propulsive Efficiency," read before the same Institution in 1878, in which, among other incorrect views, it was enunciated, "that instead of its being correct to regard a large slip as a proof of waste of power, the opposite conclusion is the true one. To assert that a screw works with unusually little slip is to give a proof that it is working with a large waste of power."

Of both Prof. Rankine's theory and Dr. Froude's conclusions on the effect of slip—for the latter did not formulate any definite theory of the propeller's action, but apparently accepted in general Prof. Rankine's views—I had given illustrations with geometrical and quantitative proofs of the erroneous conclusions held by those eminent men at the discussion of Dr. Caird's paper in December, 1895. These illustrations were taken chiefly from my paper, read in 1890 before the Institution of Naval Architects. The vital errors of Prof. Rankine's theory I had, however, previously demonstrated in two papers, read before this Institution in 1878 and 1879 respectively.

In the following month, January 1896, I attended the adjourned discussion expecting to hear Dr. Caird's reply to my criticism. On entering the hall a few minutes after eight o'clock, I found Dr. Caird addressing the meeting, but heard no reference, after I entered, to my remarks on his paper.

I happened to be away from Glasgow in February, and missed seeing the Transactions issued that month, which contained the report of the January meeting and Dr. Caird's remarks.

Being much engaged at that time, I soon forgot the matter, and it was only when looking over the Transactions of 1895-6 for some other purpose, four or five years after these were published, that I came upon a lengthy criticism, by Dr. Caird, of my remarks on his paper on "Propeller Diagrams," which I had failed to hear, or see, in 1896. This criticism, to my surprise, contained statements of a character so depreciatory and incorrect, that my failing to challenge them, would, in my opinion, have been inexcusable.

A severe illness, however, soon after I lighted on Dr. Caird's remarks, prevented me from dealing with the matter at that time as I intended, and although, since then, I have more than once begun preparations for a reply, it is only now that I have been able to put it into the form of this paper.

The statements of Dr. Caird, as given in the Transactions for 1895-6, which have led to the writing of this paper, are as follows:—

"Mr Howden's remarks fall naturally into three categories. The first was a brief and not unsympathetic, if somewhat inaccurate account of the paper he was criticising. The second was a concrete example which was intended to prove the fallacy of Froude's 5th proposition; the third was in the form of copious quotations from previous papers of his own. He proposed to take up Mr Howden's third category first."

"*Of Mr Howden's attack on Froude and on Rankine, the most complete and conclusive refutation was to be found in the discussions which followed the papers to which Mr Howden referred. He would particularly direct the attention of any one interested to Mr*

Froude's remarks on Mr. Howden's 1890 paper, read before the Institution of Naval Architects. It would be a work of mere supererogation to add anything to these remarks."

These unqualified assertions of Dr. Caird, unsupported by one word of proof, that my papers on the screw propeller were, in the discussions which followed their reading, so completely and conclusively refuted as to make any further remarks by him a mere work of supererogation, are, I believe, unique in the records of the discussions of this Institution. Meantime, I shall only say, that if these assertions were even but partially correct, they would make any defence on my part either an impertinence or an evidence of mental incapacity. But this defence of my writings on the Screw Propeller, when carefully read, will not, I believe, be accounted for by either of these alternatives. I undertake to show conclusively that Dr. Caird's statements are entirely contrary to fact.

The following facts pertaining to my papers and the discussions thereon, should of themselves go far to controvert these statements of Dr. Caird.

As a screw of any given size, shape, and pitch, and its movements in propelling, can by proper analysis be accurately ascertained and delineated geometrically in every part through each revolution and at all per centages of slip, the exact movement and velocity given to the water by the screw at every point can, therefore, be accurately ascertained and calculated.

All my former papers, four in number, demonstrating the true action of the screw propeller, from the first read in 1877 to the last in 1890, were based on this strict geometrical investigation of the action of the propeller under all conditions of dimensions, shape, pitch, slip and velocity, so that the propeller's action by such analysis was proved geometrically and quantitatively, as absolutely as any other geometrical problem, such as, "The sum of the angles of any triangle is equal to two right angles," etc.

Further, none of the professional experts or writers on the screw propeller known to me, including Rankine, W. Froude R. E. Froude, S. W. Barnaby, etc., have taken the precautio to found their theories and formulæ on this geometrical investiga tion, or on actual facts. Consequently, all their arguments an formulæ as applied to the screw propeller are, I am compelled t say, founded on erroneous assumptions, and have no scientific basi whatever. This is a strong statement, but there should be no diffi culty in proving its correctness to those who will fully study this o my former papers. This expectation is supported by the significan fact that though in the discussion of my paper of 1890 at th Institution of Naval Architects, mathematicians of the highes rank whose theories I had controverted took part, not one challenged my geometrical and other demonstrations, either o the true action of the screw or of the erroneousness of the theorie of Rankine, Froude, and others.

It will be conceded, by those competent to judge of such matters, that when a demonstration is submitted of the move ments, however complicated, of a material body of given dimensions, and supported by geometrical and quantitative proofs, it is exposed to instant detection, if incorrect, by all capable of investigating these proofs.

As I have submitted such proofs in every paper I have read, without in any one instance — *pace* Dr. Caird — having their correctness even challenged, I submit that this fact could only have occurred because they were correct, and this more especially as those most interested in confuting them were thoroughly competent to detect errors in the proofs submitted, if they had existed. These being the facts in the history of this controversy, I have every reason to hope that all who carefully follow the remainder of this paper will eventually agree that the above statement regarding the errors of the hitherto recognised professional experts is fully justified.

The Rankine theory of the propeller has been held as authoritative by professional experts since its publication in 1865, to the present day. This has doubtless been greatly owing to the deservedly high reputation of its author, and to the natural indolence which affects us all more or less, and hinders our engageing in any severe study. The further consideration of the subject at this time by this Institution should, therefore, be a matter of considerable scientific interest, and if fully carried out, should put an end to the numerous fallacies and the confused and contradictory ideas which continue to discredit screw propeller literature.

It is now over twenty-eight years since I read my first paper on this subject. A new generation of Members has grown up since then under advantages of scientific education not possessed by their predecessors, so that the subject matter of the paper should be more generally followed now than when it was first produced. As probably few of the present Members of the Institution have read these papers of mine, so summarily dealt with by Dr. Caird, it appears to me necessary, in order to give an opportunity to these Members and others, of judging for themselves whether Dr. Caird's statements regarding my papers are according to fact or otherwise, that I present the subject anew before the Institution.

I propose to deal with the subject by dividing it into sections in the following order:—

(1) To describe shortly how I was led at first to take up this subject of screw propellers, and to give a short account of the several papers and the circumstances which led them to being read.

(2) Demonstration of the true action of the propeller on the water by geometrical analysis, proving the actual movements imparted to the water by the blades in propelling.

(3) Examination of Prof. Rankine's theory of the reaction of the propeller and demonstration of its complete erroneousness.

(4) Description of the true basis of the reaction of screw propellers.

(5) Examination of the discussions referred to by Dr. Caird of the various papers read in Glasgow with comments thereon, also of the paper of 1890 specially noticing Mr R. E. Froude's remarks to which Dr. Caird called particular attention.

(6) Examination of Dr. Caird's criticism of my remarks on his paper on "Propeller Diagrams" of 1895-6, with concluding remarks on the controversy.

I feel fortunate in having an Institution so suitable as ours for the further consideration of this subject, as its forms give full opportunity to every one interested to leisurely study the matters at issue before the discussions are closed. It is therefore preferable in this respect, to such Institutions as that of the Naval Architects, where the discussions must close immediately after the reading of the papers. This Institution has also the advantage of having among its most active members the Professors of Engineering and Naval Architecture in our University, and also the Professors of Engineering and allied subjects in our Technical College, all of whom I trust will do me the honour of thoroughly investigating the demonstrations and arguments I have to submit.

Coming now to the several divisions of the subject, I believe that the first, which recalls the circumstances which led to my taking up this subject, will be of interest, and will tend to the better understanding of these papers as a whole.

First.—When the Institution of Naval Architects held its summer session in Glasgow in 1877 in conjunction with this Institution, I was asked, as a Member of the latter, to prepare a paper on some suitable subject, to be read at the joint meeting. At that time I was constructing propellers with portable blades of forged steel, machined all over, to make them true in pitch and thinner than any cast steel blades then used. These propellers were designed with the object of reducing the axial resistance, due to the greater displacement, and increased negative pressure behind thicker blades, when revolving at a high velocity. It had happened also that a few years before this period I had noticed a paper on "The Screw Propeller," by Mr Arthur Rigg, read before the Institution of Naval Architects, and other Institutions with much commendation. In this paper Mr Rigg illustrated by diagrams his views of the extent and direction of the motions imparted to the water by the blades of the screw in propelling.

As the motions of the water, represented by the diagrams, appeared to me to be clearly impossible, I therefore proposed to write a paper for this meeting on the screw propeller, with the twofold purpose of calling attention to some erroneous ideas regarding the action of the screw blades on the water by a demonstration of the motions actually generated, and of showing the form and purpose of the propellers I was then constructing. In preparing this paper, it appeared to me necessary, in order to give a true geometrical exhibition of the action of a blade on the water at various percentages of slip, to make complete drawings of the motions of a propeller blade of given size and pitch; I used one for this purpose, then working on an Anchor Line steamer, taking the normal revolutions at 60 per minute. The preparation and analysis of these drawings were to me of the greatest value, as many hitherto vague and indefinite ideas regarding the actual effect of the blades on the water became clear and self-evident, as every geometrical problem must become when correctly solved. This paper, which is recorded in the Transactions of the Institution of Naval Architects for 1877, sets forth the above objects as fully as I could do in an article which was required to be read in twenty minutes.

When so far advanced with this paper, I fell upon, for the first time, Prof. Rankine's famous paper "On the Mechanical Principles of the Action of Propellers." * I began to read this paper with much interest, the great scientific ability of its author leading me to anticipate much instruction from its perusal. At the first reading, I felt I had not been able to follow the argument appreciatively, though I tried hard, believing my failure to be

*Transactions, Institution of Naval Architects, 1865.

due to my own obtuseness. As a second reading yielded no better results, I laid aside Prof. Rankine's paper and completed my own on the lines on which I had already begun.

The fuller working out of my paper, and a further perusal of Prof. Rankine's, eventually absolutely convinced me that Prof. Rankine had entirely mistaken the nature and extent of the motions generated by the action of the screw blades, and that in consequence, the theory he had founded on this erroneous basis was radically wrong. I further became convinced that Prof. Rankine's mistake had arisen from his neglect to make a geometrical investigation of the movement of a screw blade making slip. I then brought a second paper before this Institution in the ensuing session of 1877-78, setting forth much more fully the principles embodied in my paper of 1877, demonstrating the true action of the propeller, and also calling attention to the erroneous basis of Prof. Rankine's theory. In the adjourned discussions which followed the reading of this paper, one Member called in question my objections to Prof. Rankine's theory, though no attempt whatever was made to prove my demonstrations incorrect. This led me to read a third paper in the session of 1878-79 "On the Reaction of the Screw Propeller, with a Review of the Theory of the late Prof. Rankine," in which, besides a demonstration of its irreconcilability with facts, I proved also its erroneous conception by diagrams and by the application of Prof. Rankine's own formula to actual cases.

In the discussions which followed the reading, and in that which took place fully six months after (for this discussion, like that of the previous paper, was adjourned to the opening of the following session), no attempt was made to call in question my arguments against Prof. Rankine's theory, though some depreciatory observations were made by the same member whose former remarks led to the writing of this paper, these remarks being evidently made to cover a retreat from an untenable position.

I then ceased writing further on this subject, until in 1889 Mr R. E. Froude read two papers before the Institution of Naval

Architects, "On the Part Played in Propulsion by Difference in Fluid Pressure," and "Remarks on Prof. Greenhill's Theory of the Screw Propeller." As I had heard Prof. Greenhill's paper read in the same Institution on the previous session, and as his theory was a variation of Prof. Rankine's, the reaction of the screw being calculated by his formula, I therefore brought my fourth paper before that Institution in 1890, "On Various Theories of the Screw Propeller," in which I called attention to the errors of Prof. Rankine's theory, and of various other writers on the screw propeller, all of them being more or less under his influence. In this paper, I again gave a demonstration of the true action of the propeller, as in my former papers, and likewise of the radical errors of Prof. Rankine's theory, showing also more or less fully the distinctive errors in the writings on this subject of Principal Cotterill, Prof. Greenhill, Dr. William Froude, Mr. R. E. Froude, and others.

As the discussions at the Institution of Naval Architects follow immediately after the reading of papers, and the practice is to hand printed copies of the papers to be read to the members just before the reading begins, I sent the MS. of my paper to the Secretary some weeks before the date of meeting, with the request to send printed copies of it, at least a week before the meetings began, to all the writers then living, whose views I had controverted. This request was carried out, so that all those writers had sufficient time to study my paper before it was read.

Notwithstanding this precaution to give time to those whose views I had controverted to prepare any proof they could find against my demonstrations of the true action of the propeller and the radical error of Prof. Rankine's theory, no attempt whatever was made to do this by any who took part in the discussion, though Dr. Caird has directed attention to Mr Froude's remarks on my paper in this discussion as having given a specially complete and conclusive refutation of my demonstrations.

As I shall later on quote these remarks of Mr R. E. Froude and others referred to by Dr. Caird, a convenient opportunity will be given to judge of the correctness or otherwise of Dr. Caird's statements.

Demonstration of the True Action of the Propeller.

Second.—I have already stated that a proper knowledge of the action of a screw propeller of any given dimensions, pitch, slip, and velocity on the water, can only be found by making an exact geometrical delineation of its movement at every part of the blades in a revolution. Such geometrical delineation, when properly analysed, will reveal exactly the only action possible by each and every part of the propeller, during each revolution under all conditions of working.

This investigation is made simpler by first examining the action of the propeller under the conditions of its being a screw of uniform pitch acting on water unaffected by the vessel's progress, the vessel also moving evenly. When the several relative motions of the propeller and water acted on are established under these primary conditions, it becomes comparatively easy to ascertain accurately the variations on these motions caused by currents set up by the motion of the vessel, when the extent and direction of these currents are determined, and likewise the effect of any current on the propeller or the propeller on the current, under any given direction and velocity. The effects of friction and of the displacement by the body of the propeller blades do not enter into this investigation.

The following propositions are established by the geometrical investigation of the propeller's movements:—

(1) A circumferential line across the face of a blade at any given diameter is in one plane.*

(2) When no slip occurs, these lines at all diameters within the propelling faces of the blades pass through the water without imparting to it any motion whatever.

* I am aware that a helical line across the face of a blade is not absolutely in one plane, though owing to its short length when tested with a flexible straight edge it appears so. The effect on the movement of the water of these circumferential lines is however *absolutely* the same as if made by a straight line, and that even if the blade be carried round a whole convolution.

(3) That, whether working with slip or without slip, the distance passed through per revolution by each point on a blade, at any diameter, is correctly represented by the hypotenuse of a right-angled triangle of which the base $=2\pi r$, and the perpendicular equals the ship's progress, or $\sqrt{(2\pi r^2 + (P-S)^2} = D$, D being the distance passed through per revolution; P, pitch; and S, slip.

(4) When slip occurs each point on the same circumferential line at any diameter moves through the same distance per revolution, but each succeeding point moves in a line somewhat abaft each preceding point and parallel to it, the distance between these parallel lines increasing as the slip increases.

(5) When slip occurs the water is moved normally to the face of the blade at any diameter at a uniform velocity, to the extent of the distance between the parallel lines described by the respective extreme points on the entering and following edges of the blade on the circumferential line of the given diameter.

(6) The distance between these two parallel lines, or the extent of motion given to the water by the propelling face of the blade at any given diameter, is found by dividing the slip of the water on the whole revolution, by the number of times the length of the arc of the circle across the blade at the given diameter divides the distance passed over in one revolution by a point in that arc; the quotient is the whole extent of the movement imparted to any particle of water by the propelling face of the blade, and the *time* in which this motion is made, is found by dividing the period of the revolution by the number of times the arc of the circle divides the distance passed over by a point in the arc in each revolution.

(7) Owing to the oblique action of the blade relatively to the line of progress, the slip of the water at any given

diameter is less than the slip of the screw, in the ratio of the base to the hypotenuse of a right-angled triangle in which the base = $2\pi r$, and the perpendicular = the pitch of the propeller.

Of these seven propositions, which cover the complete action of the propeller, the first and second are easily demonstrated. The first is a condition of the construction of a screw of uniform pitch. The second arises from the fact that all circumferential lines on the propelling face of a blade at any diameter, when no slip is made, coincide with the line of motion. The third is demonstrated

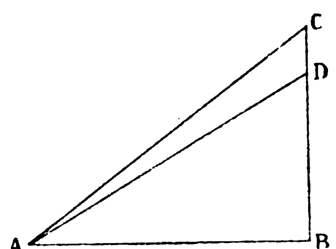

FIG. 1.

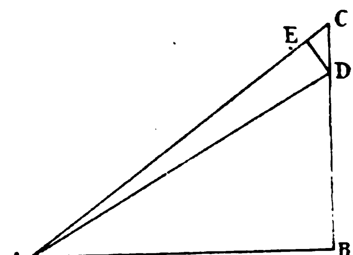

FIG 2.

as follows:—In Fig. 1, let A B, in the right-angled triangle A B C, = the circumference of the circle of a given diameter, and B C = the pitch of the screw which, when no slip is made, = also the progress of the ship per revolution of the screw; A C is then the distance passed through by each point of the blade at that diameter. When slip occurs = D C, then B D is the progress of the ship per revolution, and the line A D is the distance passed through by a point in the blade at the given diameter.

The fourth, fifth, and sixth propositions are more conveniently proved in conjunction with the seventh, which latter I now give. In the right-angled triangle, A B C, Fig. 2, let A B again = $2\pi r$, B C pitch of propeller, and B D progress of vessel per revolution of screw; A C is the distance passed through each revolution by a point in the blade at the given diameter when no slip occurs, A B being at right angles to the line B C of the vessel's motion; C A B is the angle of obliquity of the propelling face of the blade at the given diameter to a plane at right angles to the line of motion.

When a slip of the screw occurs = D C, A D is then the distance and direction passed over by a point in the blade at the given diameter per revolution, as already explained. If now D E be drawn at right angles to the face of the blade, that is, to A C, D E is the slip of the water per revolution at the given diameter, while D C is the slip of the screw at this and all other diameters; then, as A B C and D E C are similar triangles (their angles being equal), D E : D C :: A B : A C, thus proving proposition 7.

Having established the relative proportions of the slip of the water to that of the screw for one revolution, a most important point of the investigation is reached, that of proving the actual motion given to the water by a blade of any shape or form at any diameter or percentage of slip. The slip of the water relatively to the slip of the screw on the whole revolution being found by proposition 6, the factor which determines the actual movement of the water and the time in which it is made, is, as stated in proposition 6, the breadth of the blade. By "breadth," I mean the part of the circumferential line across the blade at the given diameter.

The line D E, divided by the number of times the breadth of the blade at the given diameter divides the line A D, gives the actual movement imparted to the water by the blade at that diameter; and the time in which that movement is made is found by dividing the period of the revolutions by the number of times the breadth of the blade divides the distance passed over by a point in the blade at that diameter in that period.

In order to illustrate and prove all these propositions, quantitatively as well as geometrically, and to show the difference between the actual motions made at different percentages of slip from those supposed by Prof. Rankine and his followers to be generated, I shall use the same propeller as I used in my first paper of 1877, and all subsequent papers, and thereby utilize the calculations and illustrations then made.

This propeller, with the blade on the flat, is shown in Fig. 3. It is 20 feet in diameter, 27·77 feet pitch, with a boss of 4 feet 11 inches in diameter. The breadths of the blades measured on the arc are:—At 5 feet diameter, or close to the boss, 43 inches; at 6 feet 8 inches diameter, 51 inches; at 12 feet 6 inches diameter, 52 inches; at 20 feet, or extreme diameter, 22 inches. This propeller is not given as one of superior design, but as one in actual work on a ship in 1877.

Fig. 4 shows the development of one revolution of this propeller at 12 feet 6 inches diameter and 10 per cent. slip, with the section of the blade at this diameter beginning and ending the revolution. The parallel lines on this diagram, between the beginning and ending of the revolution, show to scale the whole extent of the motion of the water, caused by a slip of 10 per cent. of this propeller at this diameter. In this Fig. the parallel lines equal to the movement imparted to the water when slip is made are shown as described in propositions 4, 5, and 6. The displacement of the water caused by the body of the blade is not shown on this Fig., only the slip motion.

Fig. 5 shows on a larger scale the movement of the water of the same diameter made by a movement of the blade equal to its own breadth. This diagram shows more distinctly the actual motion imparted to the water by the blade at this diameter, and how this motion is begun and ended in the passage of its own breadth. Figs. 6 and 7 show the continuous motion through the water of this section of the blade without slip, and with 10 per cent. slip; the displacement is of the blade only in the one, and in the other the displacement of the blade combined with that of the slip. In Fig. 7, and also in Figs. 9 and 10, the lines indicating the separate and combined movements of the water by slip and by the body of the blade, anticipate these respective movements when the blade moves in the direction of the arrows.

Taking the revolutions of this example propeller at 60 per minute, or one per second, with 10 per cent. slip, the following Table gives the movements made by the blade at the four given diameters, and the number of times the blade at these diameters passes over entirely new surfaces of water per second or per revolution:—

Diameters.		Length of arc in breadth of blade.	Motion imparted to water with 10 per cent. slip.	No. of times blades pass over new surfaces of water at this slip, per revolution.
Feet.	Inches.	Inches.	Inches.	
5	0	43	1·97	8·24
6	8	51	2·59	7·68
12	6	52	2·53	10·75
20	0	22	·82	36·93

These figures show the fact that with 10 per cent. slip (which is greater than a properly proportioned screw should make under ordinary conditions of working), the whole extent of motion imparted to any particle of water from its first coming into contact with the leading edge of a blade, until it receives its last touch from the following edge, is in this propeller only 1·97 inches at 5 feet diameter, 2·50 inches at 6 feet 8 inches diameter, 2·53 inches at 12 feet 6 inches diameter, and ·82 inches at 20 feet diameter, this latter being the most effective part of the blade. At 5 per cent. slip the motion imparted to the water would be slightly less than half the above, the distance AD, Fig. 2, passed through per revolution being greater at 5 per cent. than at 10 per cent., while the breadth of the blade, or divisor, remains the same. For the same reasons the slip motions given to the water increase in a greater than arithmetical ratio when the slip increases. Further, it should be noticed that the extent of the movements given to the water is directly proportional to the breadth of the blade; if the blade, in a given case, is made only one-half the breadth, the motion given to the water at the same percentage of slip would only be one-half in extent, but made in one-half the time. It should be noticed here also, that the motion imparted to the water by slip is, after it is begun, continued at a *uniform velocity*.

A further important fact is, that at any instant no motion is given to the water by the blade except across its own face or breadth, and there the particles acted on are not thrown off the blade, but remain in contact with it, and are merely pressed as it were into the contiguous mass—the small distance shown between the parallel lines in the diagrams. The observed motions and disturbances in the water at moderate slips are almost wholly made by the displacing action of the body of the blades (often increased by irregular pitches), which is quite a distinct action from the slip motion made by a true screw, though generally confounded with the latter. The movement of the water caused by a moderate slip, in a properly constructed screw, is scarcely noticeable, and is continuously undergoing a process of extinction by falling into the partly empty space left behind the body of the blade, somewhat as represented by Fig. 8. Figs. 9 and 10 show sections of a blade, the one making 5 per cent. and the other 30 per cent. slip. These figures were used in a previous paper to illustrate the mistake made by Dr. William Froude, in saying, "To assert that a screw works with unusually little slip is to give a proof that it is working with a large waste of power," and they show, *first*, the considerably greater displacement made by the blade when working at 30 per cent. than at 5 per cent. slip; *second*, the much greater movement of water in slip also made by the blade at 30 per cent. than at 5 per cent. slip. These greater displacements of water at 30 per cent. slip, besides reducing the speed of the vessel, waste a much larger proportion of the engine power than when 5 per cent. slip is made.

When the actual motions imparted by the blades to the water under any given dimensions, pitch, slip, and velocity are exactly determined in the manner explained, the effect of a following or other current can be comparatively easily investigated. For example, if the screw is working in a current following the vessel in a direct line at 5 feet per second, at the depth where the tips of the blades of the example propeller reach in passing their highest point, the blade will there arrest the motion of the current in passing to the extent of the velocity divided by the time of the passage of the blade. This time is $\frac{1}{36{\cdot}93}$ of a second, which, with the quotient subject to the reduction due to the oblique action of the blade, is found to be 1·48 inches of arrested motion. This added to the ·82 inches of slip movement imparted by the blade in still water gives 2·3 inches of slip, combined with the arrested current. The effect of the current can be found at any other diameter in a similar manner, but in a vessel with fine lines the following current does not extend to any considerable depth below the surface. Currents flowing in from the sides are similiarly calculable, and may be positive, negative, or neutral, according as the currents flow from aft, forward, or coincident with the angle of the face of the propeller.

Having now shown, geometrically and quantitatively, the actual extent of the motions imparted to the water by a screw of given dimensions, pitch, and slip per revolution, and how these motions can be ascertained under all other conditions of dimensions, pitch, slip, and velocity, my objections to Prof. Rankine's theory, and all others based upon it, will be more easily understood, and likewise the proof of the entire incorrectness of that theory. The incorrectness of the Rankine theory, and of all modifications of it, is necessarily completely proved negatively by simply stating that it is based on the supposition that the extent of the movement imparted to the water by, say, 10 per cent. slip, averages in the case of the propeller of this paper, from 18 to 14 times more than I have just proved it to be; further, it assumes that a cylindrical column of water in this case, 27·24 feet in length, can be generated by the revolution of a screw and forced astern by it, like a solid body, at an accelerated velocity, though the projected area of a blade may be less than one-twentieth of the area of the end of this column. Other impossibilities are also assumed. It will, however, be more satisfactory to prove the total incorrectness of this theory positively, as I have already undertaken to do.

Professor Rankine's Theory.

Third.—This theory, given in the author's I.N.A. paper of 1865, "On the Mechanical Principles of the Action of Propellers," though erroneous in its basis and defective in its treatment, is, owing to its definiteness, and being illustrated with practical examples, capable of being examined both geometrically and quantitatively. It deals with both paddle and screw propellers, but here we have to do with his treatment of the screw only.

In defining the principles on which his theory is based, Prof. Rankine says, in Section 8 of his paper, "The reaction of the stream of water, acted on by any propelling instrument, is the product of three factors: the mass of a cubic foot of water, the number of cubic feet acted on in a second, the velocity impressed on that water by the propellers." In Section 9: "The number of cubic feet acted on in a second is to be calculated by multiplying the sectional area of the stream by its velocity relatively to the ship. This sectional area is, for a screw, the area of the disc, less that of the boss, and the velocity of the stream relatively to the ship is the sum of two quantities—the velocity of the ship, and the velocity relatively to still water of the stream driven back by the propeller—or, in other words, the apparent slip of that stream." In Section 10: "For a screw, owing to the obliquity of its action, the slip of the stream driven back is less than the slip of the screw in the proportion of the square of the cosine of its obliquity to a thwartship plane." In Section 11: "The remaining factor of the reaction of the water—the velocity impressed by the propelling instrument when the propeller acts on water that was previously still—is simply the slip of stream already mentioned."

Prof. Rankine, in his algebraic investigation of the subject, works out the effect of the oblique action of the screw, referred to in Section 10, showing that the slip of the water is less than the slip of the screw. This effect I had discovered, and worked out geometrically, as shown in Fig. 2, before seeing it in Prof. Rankine's paper. He also gives a practical example of his theory by applying it to the case of H.M.S. "Warrior," which, with a screw 24 feet in diameter and 30 feet pitch, made on trial 12 per cent. slip at 54 revolutions per minute, and which with his formula gave an I.H.P. very nearly that obtained on trial. This result, however, is entirely owing to the abnormal size and pitch of the screw. Had he tested his formula on a screw more suitable for the limited engine power, one much less in diameter and pitch, the power by the formula with same speed of ship and I.H.P. of engines would not have been one-half, and this theory would never have been heard of.

I have to mention here that in working out the "Warrior's" results on the basis of his theory, as given above, Prof. Rankine assigns a quantitative value to the effect of friction on the blades and of the screw working in disturbed water. In testing Prof. Rankine's theory and formula, I shall include among the minor factors that of the effect of the oblique action of the screw only, and omit the effect of friction and working in disturbed water, as these latter are merely hypothetical, and do not affect the main issues of the investigation which are, I may remind you, the actual movements given to the water by the action of the screw under given conditions of dimensions, slip, and velocity, and the reaction obtained therefrom in propelling. Prof. Rankine's theory rests on the supposed existence of a cylindrical column of water generated by the screw, of definite length and area, and consequently of ascertainable weight, which the propeller throws astern a definite distance, necessarily intermittently, with a definite velocity dependent on the slip per revolution. The area and length of this column and its velocity being thus ascertainable according to this theory, under any given conditions of diameter, pitch, slip, and velocity, the thrust reaction is, therefore, made calculable by the formula $\frac{W v}{g}$.

The area of this reaction column, as defined by Prof. Rankine, is that of the circle described by the extremity of the propeller blades in their revolution, less the area of the boss; the length of the column = the progress of the ship per second, + the slip of the stream per second; and the velocity at which this column is driven back = the slip of the stream per second.

To give a practical example of this theory, treated geometrically and quantitatively, I again take the example propeller of this paper, which is 20 feet in diameter and 27·77 feet pitch, having a boss 4 feet 11 inches in diameter, and the velocity as before—one revolution per second. Fig. 11 shows the Rankine column of this propeller to scale, at 10 per cent. slip, with the spiral ends which it would necessarily have, but as it is more convenient for calculation to make the length and weight of the column as a plain cylinder of equal capacity, I have so represented it in Fig. 12. The length of this column is made up of the two parts G H, 25 feet in length, = ship's progress, and H I, 2·24 feet in length = slip of the water per revolution, which part is shown darker. The curved outline of the after end of the slip part of the column getting narrower, as it approaches the boss, shows the effect of the increasing obliquity of the blade as it approaches the centre in reducing the slip of the water. The extent and velocity of this slip, as calculated by Prof. Rankine's formula, varies from 2·52 feet at the extremity, to 1·35 feet at 5 feet diameter per revolution, and is sufficiently correct for calculation of cubical contents if taken at an average of 2·24 feet; consequently, the length of the column, from which the reaction is calculated by Prof. Rankine's theory, is 25 + 2·24 feet = 27·24 feet, and the velocity of the whole column per second in this case is 2·24 feet at 10 per cent. slip.

Fig. 12 shows the column made by the same formula at 30 per cent. slip, the ship's progress in this case being 19·44 feet per second, and the average slip 6·72 feet, making the total length 26·16 feet, and velocity per second 6·72 feet. The area of the column is in all cases 314 − 19, the area of the boss, = 295 square feet. I have shown in these figures a dark space behind each column equal to the slip per revolution. This represents a vacant space which, though non-existent, is absolutely necessary to permit the movement of the column required by the Rankine theory.

Before giving the quantitative results of Prof. Rankine's theory and formula, applied to the example propeller of this paper, at several percentages of slip, I would ask your attention for a moment to the supposed facts on which this theory is built. It is based on the supposition that a complete and detached cylindrical column of water can be formed by a screw behind itself each revolution, and thrown by it astern, in this case 2·24 feet with 10 per cent. slip, in a compact mass endwise, by one impulse.

Such effects presuppose several impossible things, for example, (*a*) the formation of a column of a definite length and area by a screw blade in continuous working; (*b*) that a column of water can be moved simultaneously like a solid body endwise by a blade or any instrument less than the area of the column itself; (*c*) that this slip movement of 2·24 feet per second can be made by one impulse, so as to make the $\frac{Wv}{g}$ formula used by Prof. Rankine for calculating the thrust force applicable—the slip movement being one of uniform velocity, as shown by my diagrams, and not accelerated; (*d*) that a detached column could be made by a screw under water of a definite length so that its weight could be calculable, and that a space could be formed behind this column by the screw into which it could be thrown, as Prof. Rankine's theory postulates.

There are other suppositions involved by this theory equally impossible, such as that propellers having two, three, or four blades, must generate two, three, and four equal columns, as each blade acts quite independently of the others. Other impossibilities may be mentioned, but enough have been given to show that such a reaction column could not exist. The following are examples showing the application of the formula to cases when 10, 20, and 30 per cent. slip is made by the example propeller :—

(1) The thrust H.P. obtained from the example propeller **at 60** revolutions per minute, with the screw making **10 per** cent. slip—

Let $V = 27{\cdot}77$ feet, or pitch of propeller.

$v = 2{\cdot}24$ feet, or mean slip of the stream per second.

$S = 25$ feet, or speed of ship per second.

$L = 27{\cdot}24$ feet $(S + v)$, length of column acted on by screw.

$A = 295$ square feet, or area of screw's disc — area of boss.

$W = A \times L \times 64$ weight of column in lbs.

$g = 32$ feet, accelerating effect of gravity per second.

$T = \frac{Wv}{g}$, or total thrust of the screw in lbs.

$P = \frac{T \times S}{550}$, or H.P. expended in thrust.

Here $W = (295 \times 27{\cdot}24 \times 64) = 514{,}291{\cdot}2$ lbs.

$\frac{Wv}{g} = \left\{\frac{514{,}291{\cdot}2 \times 2{\cdot}24}{32}\right\} = 36{,}000{\cdot}3$ or thrust in lbs.

and $\frac{T \times S}{550} = \left\{\frac{36{,}000{\cdot}3 \times 25}{550}\right\} =$ 1,636 I.H.P. expended in actual thrust at 14·8 knots.

(2) With the propeller making 20 per cent. slip—

$v = 4{\cdot}48$ feet, mean slip of stream per second.

$S = 22{\cdot}21$ feet, speed of ship per second.

$L = 26{\cdot}69$ feet, length of column acted on by screw.

The other definitions as in (1).

Here, $W = (295 \times 26{\cdot}69 \times 64) = 503{,}907{\cdot}2$ lbs.

$\frac{Wv}{g} = \frac{(503{,}907{\cdot}2 \times 4{\cdot}48)}{32} = 70{,}547$, or thrust in lbs.

$P = \frac{(70{,}547 \times 22{\cdot}21)}{550} = 2{,}849$ I.H.P.,

expended in thrust in propelling the ship 13·15 knots.

(3) With this propeller working at 30 per cent. slip—

$v =$ 6·72 feet, mean slip of stream per second.

S = 19·44 feet, speed of ship per second.

L = 26·16 feet, length of column acted on by screw.

Other definitions as before.

Here, W = (295 × 26·16 × 64) = 493,900·8 lbs.

$$\frac{Wv}{g} = \frac{(493,900 \cdot 8 \times 6 \cdot 72)}{32} = 103,719, \text{ or thrust in lbs.}$$

$$P = \frac{(103,719 \times 19 \cdot 44)}{550} = 3,666 \cdot 4 \text{ I.H.P.},$$

expended in thrust in propelling the vessel 11·51 knots.

These several amounts of H.P., which, according to Prof. Rankine's theory, would be obtained in thrust reaction from a propeller of the given dimensions and pitch at the three different percentages of slip, are not the gross I.H.P. of the engines, but merely the thrust H.P., and do not include what is used by the engines themselves, or by the friction of the propeller, or the resistance caused by negative pressure thereon. It is the H.P. used exclusively in overcoming what, according to Dr. W. Froude, is the ship's net resistance + the augmented resistance arising from the action of the screw. These are estimated by Dr. Froude, in his paper of 1876, "On the Ratio of Indicated to Effective Horse Power," to be respectively equal to about 40 and 18 per cent., or, together 58 per cent. of the gross I.H.P. of the engines. Taking this estimate here, the gross I.H.P. in these foregoing cases, worked out on Prof. Rankine's formula, are as follows:—

(1) 10 per cent. slip, and 14·8 knots speed of vessel, ...	:58:100::1636:2821 gross I.H.P.
(2) 20 per cent. slip, and 13·15 knots speed of vessel, ...	:58:100::2849:4912 ,, ,,
(3) 30 per cent. slip, and 11·51 knots speed of vessel, ...	:58:100::3666:6320 ,, ,,

There is the extraordinary result of 2821 I.H.P., giving a speed to the vessel of 14·8 knots at 10 per cent. slip, while no less than 6320 I.H.P. is consumed in giving the vessel 11·51 knots where 30 per cent. slip occurs.

These differences in slip would often be exceeded at sea under the variations in weather which constantly occur.

The fallacy of this theory is made doubly conspicuous when the formula is applied to this screw, making a slip of 5 per cent. The thrust I.H.P. is then only 871·6, and the gross I.H.P. 1502, the speed of the ship being 15·6 knots. In short, these practical applications of Prof. Rankine's theory to different percentages of slip in the same vessel, with the same screw working at 60 revolutions per minute, show that it breaks down as completely when tested quantitatively as when tested geometrically. It is indeed utterly inapplicable to any problems or calculations whatever connected with the screw propeller.

THE TRUE BASES OF THE REACTION OF SCREW PROPELLERS.

Fourth.—Having shown that Prof. Rankine's "Theory of the Reaction of the Screw Propeller" is erroneous in its conception, and does not remotely agree with the actual facts of the screw's action, it falls to me to show how the small compression of the water which I have demonstrated is all that is made by even considerable slip, can give a reaction from an element so unstable as water sufficient to propel the largest steamers at the highest speeds.

An experiment, illustrating the principles on which the reaction of a screw propeller is based, has probably been made by most here while standing in a rowing boat and moving the flat end of an oar edgeways while holding it nearly perpendicularly and immersed, say, 18 inches. If, while moving the oar so immersed at a velocity of 6 or 8 feet per second, a sudden lateral pull is given to the oar, the water will be found to offer for an instant almost as much resistance as a solid body. If, therefore, at this comparatively low velocity, a surface of about 18 inches by 4 inches offers so much resistance: How vastly increased will be the resistance to a surface 50 times greater moving at a vastly higher velocity?

As every circumferential line on the propelling face of a blade is in its action on the water exactly equal to that of a straight line in continuous motion, the whole surface of the blade, which is made up of these lines, acts like a flat blade pressing against the water while running over it at an exceedingly high velocity. The four blades of the example propeller of this paper have an aggregate surface of 112 square feet, and as the outer ends of the blades at 60 revolutions per minute with 10 per cent. slip move at the high velocity of 67·62 feet per second, it is evident that an enormous thrust reaction must be obtained with a very slight compression of water from the four large flat surfaces of these blades running over the inclined planes on which they press. The effect of a flat surface striking water at a high velocity is well known. Even a round body, like a cannon ball, striking on water at a great velocity, rebounds as if it had struck a solid body. The effect, therefore, of these four blades sweeping through the water at a velocity of nearly 70 feet per second at their outer ends, and over 37 new surfaces of water in that time, at their most effective surface, is about equal to the blades running over helically inclined planes of metal.

The water is the nut formed by the deep but short parts of the threads of the screw continually cutting their way into it, but without in the slightest degree impairing the effect on the working faces. The screw blades, thus running over the faces of the threads of the water nut, scarcely compress them owing to their great velocity and large surface. The water owing to its incompressibility and inertia, has not time to yield during the instant of pressure, as the blades glide over it. The yield of the water as I have shown, is, at 10 per cent. slip, only ·82 inches at the outer ends of these blades, but this is done in the 37th part of a second. The intensity of this action will be the more appreciated when I remind you that a heavy body falling freely in space at the earth's surface passes from a state of rest through only ·14 inches, or about one-sixth of this space in the same period. It would, therefore, require 36 times the energy of gravity to give an equal velocity to a body falling freely in space in the same time: How much more, then, would it require to give an equal lateral movement to a body of water surrounded and pressed upon by masses of the fluid under pressure?

With these facts before us, it is not difficult to understand how the reaction, or the law of equal and opposite forces, is fully satisfied, with only the slightest backward movement of the water being made by the blades. The formula $\frac{Wv}{g}$ is no more applicable for calculating the reaction of a screw propeller than it would be for finding the reaction of a screw working in a soft metal nut from the wear on the faces of the threads of the nut, caused by the friction and thrust of the threads of the screw passing over them.

Having thus shown geometrically and quantitatively the actual movements made by a screw propeller of given dimensions, pitch, and velocity, at different percentages of slip, and likewise having demonstrated both positively and negatively that the theory of Prof. Rankine is wholly erroneous, it follows that none of those writers who have adopted the Rankine theory, in whole or in part, are able to guide others, either scientifically or practically, in the construction or use of screw propellers.

The Discussions of my Various Papers Referred to by Dr. Caird.

Fifth.—At the reading of my first paper in Glasgow, at the summer meetings of the Institution of Naval Architects, on August, 1877, in which I gave the demonstration of the true action of the propeller, without reference to Prof. Rankine's theory, there was no actual discussion, the remarks made being purely of a complimentary character, the chief speaker being the late Mr John Scott Russell.

My next paper was read before this Institution on 23rd April, 1878. In this paper I called attention to the fact that the geometrical analyses of correct delineations of the motions given to the water by the screw in propelling, were essentially different from those which Prof. Rankine supposed to exist, and on which he had based his theory. This paper, as well as the previous one, I should mention, contained an investigation of the displacing action of the blades as well as of their propelling action, these actions being quite distinct from each other; and also showed, in connection with the former, the great practical advantages obtained from the use of thin blades of machine-forged steel, arising from their greatly reduced displacement and the reduction of negative pressure, when compared with thick cast iron blades, which were then in general use.

This paper was first discussed at a special meeting, held on 14th May of that year. Though a long discussion took place, none of my demonstrations of the true action of the propeller, or of the errors of Prof. Rankine's theory, were called in question. To give opportunity for a fuller discussion of the paper, the discussion was adjourned to the beginning of the 1878-79 session, and took place on November 26th, fully six months after the first discussion. At this latter discussion, a written criticism of considerable length was sent by Dr. John Inglis. The remarks of Dr. Inglis, at the previous discussion, were rather appreciative than otherwise, but further study during the long interval had evidently wrought a change, as the written criticism was distincly combative in its character. The much greater part of this criticism bore on that part of my paper which dealt with the displacing action of the propeller, and showed considerable misapprehension of the subject. As this displacing action is not here being dealt witb, I need not now further refer to it. What was remarkable in this deliberate criticism was, that no reference whatever was made to the chief purposes for which the paper was written. *Firstly*, The demonstrations given of the true action of the screw on the water in propelling, and *secondly*, The demonstrations of the entirely erroneous conceptions on which Prof. Rankine based his theory of the action of the screw propeller.

Dr. Inglis, however, in this criticism, did make an endeavour to show how a Rankine column could be produced, notwithstanding my demonstrations to the contrary. As this is the only, or at least the most definite, effort to uphold the reaction column of the Rankine theory in these earlier discussions, and is doubtless that which Dr. Caird referred to as having completely and conclusively refuted my "attack on Rankine," I shall quote it here in its entirety:—

"Mr Howden's objections to Prof. Rankine's statement, regarding the reaction of a propeller, contains some curious misconceptions. The action of a screw being on the end of a column (not of *unlimited*, but of *indefinite* length), the length of the column is added to as the propeller revolves, each part of the area of the end of the column being acted on in turn, the length of the piece added being equal to the advance of the propeller through the surrounding water. There does not, therefore, appear to be any difficulty in ascertaining the number of cubic feet acted on in a given time. Mr Howden speaks of the film of water as receiving the thrust: But what is at the back of that film? I suppose another film, and another, and so on until we get a column."

Prof. Rankine's idea of the generation of the reaction column of his theory, however erroneous and impossible, is, granting his hypothesis, coherent in itself and conceivable, but this column of Dr. Inglis, I must say, is altogether inconceivable. Dr. Inglis begins by correcting me for having stated that a Rankine column, if it existed at all, would be of unlimited length, or limited only by the extent of the ocean in which the ship was being propelled, by saying, "not of *unlimited*, but of *indefinite* length." The *italics* are Dr. Inglis'.

This correction for a supporter of the Rankine column is unfortunate, for the Rankine theory and formula are entirely based on the reaction column being of a *definite* length, in the case under discussion of 27·24 feet at 10 per cent. slip. Dr. Inglis then goes on to explain how the length of this indefinite column is added to as the propeller revolves, the addition in each revolution in this case being 25 feet. Then follows the remarkable statement, "There does not, therefore, appear to be any difficulty in ascertaining the number of cubic feet acted on in a given time." I would ask Dr. Inglis to give the cubic feet in such a column of indefinite length made by the example propeller of this paper at 10 per cent. slip, and also to explain how it could be pushed astern by the propeller, after being made up, at an accelerated velocity of 2·24 feet per revolution? Further, as this propeller has four blades acting separately and independently, I would also ask what becomes of the four columns which must, on the Rankine theory, be generated? It must be remembered that a propeller with four blades is a four-threaded screw, and that propellers with three and two blades are respectively three and two-threaded screws. It would be interesting if the supporters of the Rankine theory would explain, in ordinary language, the mysteries of the columns arising from the use of different numbers of blades in a screw.

Dr. Inglis, however, not content with his own column of indefinite length receiving an addition to its length of 25 feet per revolution, goes on to say, "Mr Howden speaks of a film of water as receiving the thrust: But what is at the back of that film? I suppose another film, and another, and so on until we get a column." If I had difficulty in following Dr. Inglis' previous description of his Rankine column I must confess to being still more puzzled by his second view of the generation of a column having quite the opposite character of the first. In the first the additions to the column were pieces 25 feet in length. In the second the additions are reduced to films. Before making further reference to this film column, let me say that I did not speak of "a film of water receiving the thrust" as Dr. Inglis puts it. I said that "in obtaining the thrust the propeller blades only slightly compress the surfaces of the water against which they bear in their passage over each succeeding field of water." In the case of the example propeller at 10 per cent. slip "the compression is only ·82 inches at the outer or most effective parts of the blades."

Dr. Inglis, in this new conception of generating a Rankine column by adding film to film, seems to have forgotten that when a screw blade has passed any point in a revolution it is never near the same point again and could not, therefore, continue to add film to film, unless, for successive periods in each revolution, the vessel only advanced a distance equal to the thickness of the film. If this thickness was equal to the compression of the water by the slip, this advance to give the thickness at the extremity of the blade would be, at 10 per cent. slip, as I have shown, only ·82 inches. Taking the average, however, over the blade, at 1·5 inches, this would require 200 revolutions of the screw to make up the addition of 25 feet on the column, and the progress of the ship would be reduced during these 200 revolutions to 25 feet. The maintenance of 14·8 knots under these conditions would require impulses, each 200 revolutions, advancing the ship about 5000 feet per second, which only catastrophal forces could accomplish. It is, therefore, clear that the formation of Dr. Inglis' reaction columns, by additions of films, is as impossible of accomplishment as is the ascertaining of the number of cubic feet in columns of indefinite length. I have to apologise for occupying time with these incongruities, but they are, I hold, the logical results of Dr. Inglis' descriptions of the Rankine column. If Dr. Inglis can give any less incongruous explanation of his descriptions of these columns I shall be pleased to hear it. But it is evident that any ttempt to explain the Rankine column or reconcile it with ctual facts must necessarily end in total failure.

Dr. Inglis continued his criticism of my objections to Rankine's theory thus: "The second objection is an extraordinary one," and then goes on with what may be called a dissertation on the movement of bodies. These remarks just mentioned refer to that point of my argument where I object to the weight of the column, and the formula $\frac{Wv}{g}$ being used for calculating the thrust force or reaction of the propeller, even if a column could be formed, on the ground that the screw could only give a uniform and not an accelerated motion to the column. As I have already given ample reasons for this objection in the previous part of this paper, and in all my other papers, I need not go over the same ground again. It is sufficient to say that Dr. Inglis' remarks altogether show that he has failed to understand the questions at issue.

In order to make my objections to the Rankine theory still more clear, I brought a third paper before this Institution in this same session of 1878-79, "On the Reaction of the Screw Propeller, with a Review of the Theory of the late Professor Rankine." This paper gave the full working out of Prof. Rankine's theory, with his own formula, on the cases of the example propeller working at 10, 20, and 30 per cent. slip as in the present paper, and the same arguments as given here were used, though on some points in a much fuller degree.

This third paper was read on 29th April, 1879, and discussed for the first time on 20th May. Dr. Inglis, who was present at the discussion, did not call in question one of my proofs of the untenability of the Rankine theory and reaction column, but instead of admitting the correctness of my proofs against this theory and consequent failure of his support of it, he, I regret to say, endeavoured to ride off the field as victor, by saying, "I had not the least intention of setting up as an apologist for Dr. Rankine, or of defending any particular theory of the screw propeller; I confess to be rather hopeless of any useful result from attempts to investigate theoretically that very complex subject; I simply desired to point out certain things in Mr Howden's paper which in my judgment were open to correction, independently altogether of any bearing they might have on the action of screw propellers, *and to show that if Dr. Rankine's theory failed, it did not fail for the reasons Mr Howden brought forward.*"

This concluding remark, which I have *italicised*, is a virtual denial of the correctness of my demonstrations, given in this special paper written to prove, in the fullest possible manner, the erroneousness of Prof. Rankine's theory, and is made, without one word of reference to these proofs, new or old, by one who had forcibly questioned the conclusions given in my previous paper, and attempted to defend Prof. Rankine. This mode of defence by evasion is, I submit, hardly a "correct" one. Dr. Inglis, under the circumstances mentioned, was, I consider, in honour bound either to prove I was wrong in my demonstrations, or to acknowledge his error. The discussion of this paper on the Review of the Rankine Theory, was also adjourned until the beginning of next session, when it took place on 25th November, 1879. Dr. Inglis did not appear on that occasion to reply to my criticism of his remarks made at the previous meeting.

As I have now given, in these quotations, those parts of the discussions of my papers of 1877-8-9, which most controverted my views on the propeller, and my proofs of the fallacy of the Rankine theory, it will be seen that they do not bear out in the slightest degree Dr. Caird's assertion that the most complete and conclusive refutation of my views was to be found in the discussions which followed my papers. It remains for Dr. Caird to show where this refutation is to be found in these or any other part of the discussions. Dr. Caird has, however, called special attention to my Institution of Naval Architects' paper of 1890, "On Various Theories of the Screw Propeller." This paper contains the same demonstrations of the real action of the propeller and the erroneousness of the Rankine theory, as given in this and my other papers, but it also includes criticisms of papers and articles on the screw propeller by Principal Cotterill, Dr. William Froude, Prof. Greenhill, Mr R. E. Froude, and others. As the several treatments of the propeller by these distinguished writers are based more or less on the Rankine theory, I do not require to notice them further here, as they necessarily fall with that theory.

Before this paper of 1890 was read at the Annual Meetings of the Institution of Naval Architects, I took the precaution, as already mentioned, of having advance copies of it printed, and sent by the Secretary eight days before it was read, to all those then living, whose views I had controverted, so that they might be prepared to meet my criticisms of their views in the discussion following the reading. In the discussion, however, not one of those to whom the advance copies were sent, or any other member, called in question my demonstrations of the true action of the propeller, or of the total incorrectness of the Rankine theory. These vital and principal points of my paper were left unchallenged, though they formed the bases of all my adverse criticisms of the writers whose views I controverted. It may, therefore, be reasonably claimed on this ground also that my demonstrations were unassailable.

Notwithstanding the fact I have stated, that not one of those I had specifically challenged, or any other member, made any attempt to controvert my demonstrations, Mr R. E. Froude, who took the leading part in the discussion, did raise a question on the dynamics of slip which was doubtless intended to defend the Rankine theory, so far, at least, as it makes the thrust of the propeller nearly directly proportional to the slip. I must mention here, as my belief, that Prof.

Rankine did not, and would not, have maintained that the thrust of a propeller was nearly proportional to its slip, though his theory works out so. Prof. Rankine, I believe, never tested his formula on various percentages of slip and therefore never discovered how it worked out.

As probably few now hearing me have read the arguments used by Mr Froude at this discussion, I give a verbatim quotation of the part bearing on the question now at issue, taken from the Transactions of the Institution of Naval Architects for 1890, page 257. "Mr R. E. Froude, my Lord, "in rising in response to the appeal or challenge addressed to "me by Mr Howden towards the conclusion of his paper, I wish "first to remark, in reference to the apologetic paragraph with "which the paper concludes, that for my part I shall esteem "myself very fortunate if my imperfect command of language "enables me to comment on Mr Howden's paper in terms as "courteous and well chosen as those which he has himself "employed. I turn first to the calculation on page 242, which "occupies a very prominent position in this paper, and which "Mr Howden regards as a *reductio ad absurdum* of Rankine's "theory. Let us see what the figures amount to. We have: "Given propeller. Given revolutions per minute. Slip per cent "10 to 30: Speed. Thrust in lbs., 36,000 to 104,000. I.H.P. "expended 2,800 to 6,300. So far from being self-condemnatory, "as Mr. Howden represents, these figures appear to me to be "the perfection of reason. With given revolutions per minute, "we find that a trebled slip produces (in round numbers) a "trebled thrust. This is surely a rational result. Secondly, "this trebled thrust maintained at a diminished speed requires "an expenditure of between two and three times the H.P. This "again is surely quite rational. Mr Howden makes it seem "paradoxical by assuming that the propeller is in both cases "propelling the same ship, but I must point out that the calcula- "tion says nothing about any ship. The calculation is solely "about a propeller. We choose our propeller, our revolutions "per minute, and our slip ratio and then determine the thrust "exerted; if we are to introduce a ship at all we must choose "one to fit the conditions in each case. If Mr Howden chooses "to introduce a ship possessing the remarkable characteristic of "requiring three times as much thrust to propel it at 11 knots "as it does at 15 knots, I must protest that the paradox is his "and not Prof. Rankine's."

It is difficult to reply to such a mode of argument as Mr Froude has here adopted. It reminds me of the art employed by a conjuror to baffle one's senses in order to make one believe that he, the conjuror, has actually done something which he has not done. Mr Froude here, by a juggle of phrases, tries to make it appear that I am responsible for the paradox or absurdity which the Rankine theory produces when applied to the variations of slip, which occur in every steamship under changes of weather, displacement, etc.

Taking Mr Froude's remarks so far as possible in their order, I have to say that I not only regard my calculations to which he refers as a *reductio ad absurdum* of the Rankine theory, but I claim that in conjunction with the demonstration of the actual motions given to the water by the propeller of this paper at 10 per cent. slip, I have absolutely proved it to be so, and also that the motion given to the water by slip is of uniform velocity and not accelerated as assumed by the Rankine theory.

Then the opinion of Mr Froude, "that a trebled slip produces (in round numbers) a trebled thrust" instead of being "the perfection of reason" as he considers it to be, can easily be shown to be contrary to both reason and experience, so that I must altogether deny what Mr Froude in the next sentence assumes he has proved by merely making a statement. He says:—"Secondly, this *trebled thrust* maintained at a diminished speed requires, etc., etc." This is merely begging the question at issue.

Mr Froude endeavours here to escape from the obvious dilemma which his argument creates by the following bit of sleight of hand: "Mr Howden makes it seem paradoxical by assuming that the propeller is in both cases propelling the same ship, but I must point out that the calculation says nothing about any ship. The calculation is solely about a propeller." Then follows a bit of distraction about choosing a propeller, etc., with this conclusion: "If Mr Howden chooses to introduce a ship possessing the remarkable characteristic of requiring three times as much *thrust* to propel it at 11 knots as it does at 15 knots, I must protest that the paradox is his and not Prof. Rankine's."

This mystifying style of argument can best be dealt with in detail. In the *first* place, I do not admit the trebled *thrust* which Mr Froude has here introduced as the equivalent of trebled *slip*. I am showing the absurdity of such a thing as this slip producing a trebled thrust. *Secondly*, I do not *assume* that the propeller in both cases is propelling the same ship. I merely state the fact. The Anchor Liner, to which the propeller of this paper was fitted, often made, on her ordinary voyages, greater differences in slip under different conditions of weather than from 10 to 30 per cent. and that without any apparent variation in thrust.*

Thirdly, I do not introduce a ship requiring three times as much *thrust* to propel it at 11 knots as it does at 15 knots. This paradox which Mr Froude thus endeavours to father on me is one entirely of his own creation, by his gratuitous introduction of the word *thrust* instead of slip. The paradox is a product of Prof. Rankine's

* A difference of only 20 per cent. slip in the same ship caused by good or bad weather is extremely moderate. The Atlantic passenger steamers of 25 to 30 years ago, when the ships were so much smaller and of much less power and speed than the enormous steamers of to-day, with speeds of from 18 to 23 knots and proportional I.H.P., often made extraordinary percentages of slip. There is an instance on record when the Cunard steamer "Russia," of note in her day, made a slip under stress of weather averaging over two days' steaming of no less than 70 per cent. I have not the particulars of the I.H.P. of this liner, but taking it at 3000 when making 10 per cent. slip, I may safely say that the I.H.P. under 70 per cent. slip did not on that occasion rise to 20,000, or that the engineers on board were conscious of any corresponding increase of thrust, as Prof. Rankine's theory postulates and Mr. Froude's asserts.

theory and of Mr Froude's argument. This operation on Mr Froude's part is very adroit, and would lead many astray, but it is not fair argument.*

Prof. Rankine's calculations in illustration of his theory were also of a propeller fitted to H.M.S. "Warrior." These calculations were, unfortunately, taken with one slip only, viz., that made on her short trial. If the calculation had been made with various slips, Prof. Rankine's theory would never have been formulated. Mr Froude's statement that the calculation he was criticising "says nothing about any ship," is, therefore, entirely incorrect, though it was convenient to ignore the ship and the various slips made by the screw when endeavouring to uphold the proposition that thrust is proportionate to slip.

I conclude my criticism of Mr Froude's remarks on my paper by calling attention to his notable description of the genesis of a screw—"We choose our propeller, our revolutions per minute, and our slip ratio, and then determine the thrust exerted; if we are to introduce a ship at all we must choose one to fit the conditions in each case."

*I have not time here to take up the question whether the thrust increases or decreases with increase of slip. It depends much on the form of the screw. With some forms it would be decreased, with others increased, as with proper forms a less proportion of the I.H.P. is spent uselessly. It may be sufficient in the meantime to show the utterly untenable position as regards the relation of slip to thrust, which Mr. Froude upholds, by an extreme case of slip experienced by every builder of marine engines on the Clyde, that of testing these engines with the ship tied hard up to the quay. As the ship in this case has no movement, the slip is then 100 per cent. With fine pitched screws of a certain form I have run engines faster when making this 100 per cent. slip than when on sea trial at full power, showing that no more power was required with the screw making 100 than when making 10 per cent. slip. Though no power whatever is used in driving the ship when this 100 per cent. is being made, all being used in driving the water astern, I have never found any appreciable indication of an increased thrust, though in most cases some increase must have occurred. The larger proportion of the power in such cases is wasted in churning the water.

From this description of designing a screw, it appears that the screw itself is the first and, it may be, the only consideration; the ship, if it is to be used at all, being quite a secondary, if not an unnecessary object, while the engines are not considered at all. After the propeller is "chosen"—I understand this expression to mean, *diameter* is chosen, as it is not likely that the Admiralty "stock" propellers of all sizes and pitches, though from the context, one would suppose that it stocked ships—after the diameter then is chosen, the revolutions are chosen, then the percentage of slip it is to work at, and from these factors the thrust exerted is determined. It appears unnecessary to have the slip and thrust of these self-sufficient propellers tested on a ship—but if such thing as a ship is introduced one must be chosen (from stock?) to fit the propeller, and allow it to fulfil the conditions of slip and thrust it was designed for. It follows, therefore, that if through some slight overlook on the part of the designer of the screw, or the provider of the ship, the calculated slip, and consequently thrust, are not produced, then the ship must be removed from the propeller and another ship fitted on in order that the propeller's designed results may be attained. It might be also that the revolutions decided on were short of requirements. This would, of course, be the fault of the engines and boilers supplied. These minor accessories would therefore require to be removed and another set fitted to allow the proper revolutions of the propeller to be attained.

The assumptions given above logically follow from Mr Froude's account of his autocratic screws, which must have ships and engines provided to give exactly the slip, thrust, and revolutions they are designed for, and must further require that the ships provided for them—unlike ships fitted with common screws—shall, with the same revolutions of engines, always maintain the same slip of screw and consequently the same speed at sea whatever the weather may be, favourable or unfavourable, otherwise the pre-determined thrust would not be obtained if the two chosen factors of revolutions and slip were altered. Mr Froude's experience, I believe, with screws and ships, has been exclusively with those of H.M.'s Navy. I have not had such special experience, but I shall go so far as to question the implied fact that the universal laws of nature which govern all other material things, are suspended in favour of H.M.'s ships fitted with these screws.

With ordinary engineers the designing of propellers proceeds in exactly the contrary way to that described by Mr Froude. The first consideration with them is the ship, its dimensions, speed, and displacement and carrying capacity on a given draught. Then the engines, to give the desired speed in the most economical and efficient manner to suit the character of the ship, would be designed, the propeller last of all to suit the ship and engines.

The size of the ship, with the stroke and power of the engines, would determine the diameter and revolutions of the propeller, also its pitch. As for the slip, the aim should be to make this as small as possible by having suitable blades, all slip being waste of power. To effect the highest efficiency of any propeller with the smallest possible slip, the surface of the blades used, and disposition of that surface in each case, is of vital importance.

Having now examined the discussions of my papers, in which discussions Dr. Caird asserted that my arguments were so completely and conclusively refuted as to make any further remarks by him a mere work of supererogation, I believe that it will be found that I have fulfilled what I undertook to do, viz.; to prove that Dr. Caird's statements were entirely contrary to fact, and that in no case were my demonstrations of the true action of the screw called in question, or my proofs of the errors of the Rankine and analogous theories challenged, or in any degree refuted. It remains now with Dr. Caird either to establish his assertions or to acknowledge his mistake.

Examination of Dr. Caird's Criticism of my Remarks on His Paper on "Propeller Diagrams" and Concluding Remarks.

Sixth.—I should have preferred to conclude this already very long paper here, but as Dr. Caird, in his criticism of my remarks on his 1895 paper (besides denouncing my papers on propellers, as a whole, in the words which have led me to bring this subject again before the Institution), further criticised my remarks on his paper and, doubtless in his estimation, conclusively refuted them, it is necessary that I should now defend these remarks, not having had a previous opportunity.

Dr. Caird, in the criticism to which I refer, said, "In Mr Howden's disproof of the 5th proposition, advanced by Mr Froude, there was very unexpectedly something to lay hold of. In the statement of that proposition which Mr Howden gave, within inverted commas as a quotation from his (Mr Caird's) paper, he quite gratuitously, and he need scarcely say erroneously, interpolated the word 'ships' in the definition of the symbol V_1, making it mean speed of ship's advance, instead of, as it was very clearly defined in the table of symbols on page 10, the actual speed of the screw through the wake current in which it worked. This had perhaps been done inadvertently, in which case it was to be regretted that carelessness should have led Mr Howden into so gross and palpable a blunder."

Dr. Caird has here kindly suggested a possible inadvertence or carelessness on my part as a palliation of what he calls a gratuitous and erroneous interpolation of "ship's" actual advance, instead of "screw's" actual advance through the wake current. While appreciating Dr. Caird's consideration in this instance, I fear I am unable to take full advantage of it. The remarks were made up very hurriedly just before the discussion took place, and as that is ten years ago I cannot recall all that occurred, but I have a strong impression that when I wrote "ship's" advance, I had Mr Froude's 5th proposition, as stated by Dr. Caird in the Transactions of the Institution, Vol. XXXIX., page 22, before me, where V_1 is stated to equal "Speed of advance," without reference to either ship or screw. I believe, however, that after my calculations were made, I noticed the fuller explanation of the symbols on page 10. The reason the word "screw" was not inserted was, doubtless, because I wished to deal with actual, and not hypothetical figures, as I knew that neither Mr Froude nor Dr. Caird could give the value of the wake. Another good reason was that whether the advance of the "screw" or the "ship" was used, it made no difference whatever on the two values of efficiencies given in my two equations. The advances of the screws and ship being equal in the two cases I gave, the comparative efficiencies of the screws were not in the slightest degree affected. The smaller screw, therefore, by Mr Froude's formula, gave 44 per cent. more efficiency, though it did only the same work as the larger screw on the same revolutions. The formula was, therefore, wrong. Had Dr. Caird examined Mr Froude's formula and my equations a little more closely, he would have discovered that whether ship's progress or screw's progress was used it did not affect the correctness of my illustration one straw, and this cry of "gratuitous and erroneous interpolation" and "gross and palpable blunder" would never have been raised.

Dr. Caird, after his discovery of this "mare's nest," goes on to show, as I understand, that if this 5th proposition had been applied to the cases of these 10 and 12 feet screws at other and different revolutions, it would have come all right, and shown equal efficiencies. This, he says, would be done by causing the 12 feet propeller to run at 94 revolutions per minute, and the 10 feet propeller at 124 revolutions. This, more than anything I could say, goes to show the entirely empirical and unscientific character of the formula, where to get from a screw a certain result not actually the best, but the best according to the formula, you require to change the engines. The engines in the ship I have given as an example ran probably from 65 to 70 revolutions per minute. To have put in a screw to run at 94 revolutions would have probably wrecked the engines, and to have used 124 revolutions with the 10 feet screw, would have been impossible. Ordinary shipowners could not afford to change engines to accommodate a formula which prescribes a certain number of revolutions for a given diameter of screw. What should be done in such cases is to change the screw and not the engines.

This formula was made up evidently to suit the results obtained from trials of screws of an empirical form used in fine ended vessels of H.M. Navy, where the necessity for reducing height and weight requires short stroked engines run at a high speed to obtain the necessary power. The propellers used in these ships have been altered in form from time to time until certain relations of diameter, revolutions, and shape of blade, become stereotyped as those producing the best results. Mr Froude's formula I doubt not would be useful in the hands of those using such ships and engines and form of screws in arriving at the diameter, revolutions, and pitch of screws which appeared to give the best results under the same conditions of working, but that this formula could guide one in discovering the actual principles which govern the real efficiency of screw propellers generally, and consequently lead one to obtain the highest efficiency, I must decidedly deny. On the contrary, this and other formulæ, based on mistaken ideas of the action of the propeller, have for the last 40 years prevented the most effective form of screws for steamers from being positively arrived at, and the true basis of the screw's reaction from being understood, causing the maze of confusion and contradiction which exists to this day regarding the action of the screw propeller in our technical literature.

This formula of Mr Froude's for "determining the most suitable dimensions of screw propellers" is of the same category as formulæ made up by Mr John Thom, which were brought before this Institution at the discussion of Dr. Caird's paper on "Propeller Diagrams," though published before that time. These formulæ were arrived at by taking the dimensions of a number of screws in steamers of various sizes and speeds then running, the dimensions, speeds, and power being obtained from the owners or builders of the ships, or otherwise. Two sets of constants are then obtained from the data in the following manner: For the first set, the disc area of the screw × speed^3 in knots ÷ the I.H.P. = constant. For the second set of constants, the projected area, looking fore and aft × speed of ship^3 ÷ I. H. P. = constant. Mr Thom gave the constants obtained by the application of the above formulæ to six steamers. In five steamers the first set of constants ranged from 171 to 225, and the second set from 58 to 69. These five steamers were the "City of Rome," "Furnessia," "Kowshing," etc."* Mr Thom, in explanation of his constants said, "By means of these formulæ it could be shown whether the proposed propeller would be efficient or not." He supported this claim by referring to the case of the "Iris," whose original screws, unfortunately, by reason of a mistaken theory on which they were proportioned, were made abnormally large. This is a rather easy way of proving the advantages of such formulæ, and it is a very large claim to make on such slender grounds.

These formulæ can only give a rough guidance to those who have no experience of their own of the ordinary proportions of screws for a given engine power on given revolutions as to diameter, pitch, and blade surface, and who are unable to obtain this information from any other source. What such persons would gain from the use of Mr Thom's formulæ would be that if the screws were made to give the constants of the formulæ (the required I.H.P. being always assured), then they might anticipate that they would obtain results, not of the highest efficiency, but probably not worse than those obtained from the screws of the "City of Rome," "Furnessia," etc. I have no knowledge of the actual efficiency of the screws in these and the other ships given as standards ten years ago, but

* See Transactions of the Institution, Vol. XXXIX., p. 40.

I am quite sure from analogous cases they could all be greatly improved. These formulæ, therefore, so far from leading to improvements in propellers or giving the slightest scientific information regarding their real action, have, as I have said of Mr Froude's formula, simply prevented improvement and left the science of the propeller in a greater state of confusion and mystery than before.

To effect the highest efficiency in a propeller from a given power, the smallest possible slip is to be aimed at, and the shape of the blades, as regards the disposition of surface, is of vital importance. In Mr Froude's formula the shape of the blades, number, and surface, or disposition of surface, have no place. In Mr. Thom's formulæ projected views of the blades are taken into account, but this, while a recognition of blades, is of minor importance. It even works the wrong way as an increase of pitch in a blade of the same shape and surface would give a reduced constant.

In Mr Froude's formula, though the blades have no place whatever, it is mentioned in some of his papers that they should be "pear" shaped, and Dr. Caird in his reply to my criticism in January, 1896, stated they should be "elliptical" in form. But in the name of science, what guidance can one receive from the mention of the words "pear shaped" or "elliptical in form," or by following certain formulæ, which will produce screws giving constants like those in the "Furnessia" or "Kowshing?" Pears have many shapes and ellipses can be almost infinitely varied; the "Furnessia" and "Kowshing," I venture to say, had imperfect screws, so that taking these formulæ as guides in order to obtain the most suitable "Dimensions for Screw Propellers" is something other than "beyond praise.".

Probably I may be told by Dr. Caird that I must use the proportion of pears or ellipses, as used by the Admiralty in their ships. If so, why, before giving such formulæ and curves to the world as guidance in screw making, did not the authors give the actual proportions of length to breadth of these pear or elliptical shaped blades? The actual reason is that all these professional screw formula makers, by refusing to receive the explanation of the true action of the screw propeller, given to them nearly 30 years ago, and by accepting instead, erroneous theories having no relation to facts, have, with their formulæ and so called curves of efficiency, not only deceived themselves, but created the unparalleled muddle which continues to this day in everything relating to the science of the screw propeller. This has prevented all practical improvements on a scientific basis. In the words of Tyndall, in a philosophical but somewhat analogous case, such theories and formulæ can as little give a man assistance in propeller making "as he can lift himself by his own waistband." They do not stand in the relation of cause and effect.

Speaking more positively, I say that instead of either the "pear" or elliptical" form of blades being necessary to obtain the "highest efficiency" with given diameter and revolutions, I am prepared to prove absolutely by actual trials that just because blades are pear or elliptical shaped they cannot yield the highest efficiency.

It is well known that, notwithstanding the hundreds of trials which have been made with propellers in the Navy during many years to obtain the highest efficiency under scientific direction, assisted by model trials in tanks and hundreds of real trials in ships, these screws have been found by recent trials to have been greatly lacking in efficiency. The alterations made by rule of thumb practice have resulted in obtaining an extra knot or so on highest speeds with the same power, than had been obtained from the formulæ screws. Most of the propellers which I see used in ordinary steamships are at this moment in somewhat the same condition of inefficiency. If there is an effective propeller in a ship, it is there more from accident than design, or at least, not from knowledge of the real cause of its superiority.

No better example of the bewildering confusion of views regarding the action of the screw propeller which exists among men, even of high scientific education and practical experience, is to be found than in the paper read before the Institution of Civil Engineers by Mr Sidney W. Barnaby, in the early part of 1890. This paper, as separately published, contains not only Mr Barnaby's own views of screw propellers, but those of almost every one in this and other maritime countries who were known to have written on propellers, or were conversant therewith; all such having been asked to assist at the discussion of this paper or to send contributions on the subject. The discussion was of the most varied and extensive character, occupying nearly four and a half times more space than the paper itself. What is most remarkable is, that of all the many distinguished and prominent men who took part in the discussion, hardly any two agreed on almost any important point, or could give any definite explanation of the points on which they differed.

Mr Barnaby himself began his paper thus:—

"The last paper read before this Institution upon the subject of the Screw Propeller, was written by Sir Francis Knowles in 1871. Sir Francis came to the conclusion that 'there must be some fixed form' of helix 'which is better than any other,' and he sought, by an elaborate mathematical analysis, to discover what that best form was.

"In striking contrast to this opinion as to the importance of form, was the statement made by Mr Robert Griffiths, at the close of almost a life's work upon the screw, that 'four strips of plate iron, set at an angle on the shaft, which would hold the engine to the speed you required, would give you within half a knot of the best screw ever made.

"There seems little doubt that the truth must be sought between these two extremes."

This remark of Mr Barnaby shows how after many years work in constructing and making experiments with propellers, also publishing treatises thereon, he was yet undecided as to the reasons why both of these statements should be rejected, and concluded "that the truth must be sought between these two extremes."

Sir Francis Knowles' quest after "some fixed form of helix better than any other" is a fruitless quest, even though one form and size of ship, one speed and one power of engine, were fixed for all time and for all purposes. There is much more than the helix concerned in finding the most suitable propeller. Such searches are of the same order as Dr. Caird's oracular dictum in his paper on "Propeller Diagrams." "There is one pitch, and one pitch only, which will satisfy the conditions of any case where I.H.P., revolutions, speed of advance, and diameter of screw are given." Such an assertion also shows how far short its author comes of comprehending the real factors involved in ascertaining the best propeller for any particular case. Mr Robert Griffiths' statement can be easily shown by the application of my geometrical analysis to be altogether wrong. Mr Barnaby, however, made expensive trials with flat and helical blades and then discovered how greatly the results differed. If Mr Barnaby had read the case of the two propellers in my paper of 1878 in the Transactions of the Institution for that year, Vol. XXII., pp. 46-48, where one of the propellers had much of the flat blade character, he would have found a geometrical analysis of this screw's action showing exactly the effect made on the water by such blades, and the manner and extent in which one part of the blade worked against the other part, correctly drawn and explained. By doing so, all the trouble and expense of making trials to discover what results would follow the use of flat blades would have been saved. Mr Barnaby in his paper finds great merit in Mr Thom's constants, and says that by their aid it is possible to determine approximately the best dimensions of screws to propel vessels of any given size and H.P.!

What I call special attention to is the tone of uncertainty which pervades the whole paper, and the absence of any defined principles of the screw's action as in all other treatises on this subject. This uncertainty and entire absence of scientific principle in regard to the screw propeller's action is, as I have already said, most impressively brought home to any open mind by the reading of the views of those who took part in the discussion of Mr Barnaby's paper. Every possible and impossible idea is introduced, each one claiming, apparently, equal right to a hearing, however contradictory these may be to each other; there is no common standpoint among them.

Mr Edward Reynolds (of Messrs. Vickers & Co.), one of the ablest of those who took part in the discussion, and who had probably made more large propellers than any other present, said, "he had been frequently urged by different Institutions to undertake such a paper himself, but he had been obliged to decline because from an academical point of view he knew nothing about the subject. He thought he knew all about propellers, but now, having made many hundreds for some of the most important ships in the world, he felt he knew nothing about the matter." Such is, and has been, the condition of the science of the screw propeller since it became almost the sole instrument for the propelling of steamships.

In concluding this paper, virtually one of defence, I am, as it were, forced to state my position in regard to the scientific treatment of the action of the screw propeller. I claim, after a long examination of other writings on the subject, that the demonstrations I have given in this and my four previous papers contain the only true and complete exhibition of the action of the propeller that exists in screw literature. These demonstrations, I submit, give the key to the solution of every problem connected with screw propellers and screw propulsion, which hitherto, owing to the world wide acceptance of erroneous theories of the screw's action, have appeared mysterious and insoluble.

I am conscious of having used much plainness of speech in my handling of the subject, and in referring to those who have been the chief advocates of erroneous theories—many of whom I hold in the highest respect. I believe, however, I am justified in this plain speaking, as all my previous endeavours, extending over these many years, to put the science of screw propelling on proper lines, have only obtained for me this recognition, voiced by an enthusiastic supporter of what I say are erroneous theories, that, all my published papers demonstrating the action of the propeller and the erroneousness of the views of the experts have been so completely and conclusively refuted in the discussions which followed their reading, as to make further notice of them a mere waste of time, while those other exhibitions of the screw's action which I had the temerity to question are beyond all praise.

Under these circumstances it appeared to me that my previous references to these expert views had not been sufficiently emphatic, and that a more direct style was absolutely necessary to gain a hearing. I apologise if I have erred now on the emphatic side. "The swing of the pendulum," about which so much is heard, in these exciting times, may probably have had its influence in this direction.

I trust I am not asking too much if I venture to request those who take part in this discussion to confine themselves in the first place to my demonstrations of the true action of the propeller and the erroneousness of Prof. Rankine's and similar theories, before taking up the secondary matters which have arisen from my review of the discussions of my previous papers. Hitherto these two principal points have been avoided.

Discussion.

Dr. ROBERT CAIRD (Member) said he presumed, considering the manner in which his name had been introduced into Mr Howden's paper and the prominence which had been given to it, that he might be permitted to open this discussion. He asked this solely for the purpose of making a personal explanation, and not in order to engage in a polemic which had already been before the engineering world for some twenty-eight years. He was very much surprised and equally vexed that any remarks of his made ten years ago

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should retain their power to rankle in Mr Howden's mind, and to provoke him to so tremendous a defence of his already well known position. He was glad of the opportunity of expressing to Mr Howden, before the Members of that Institution, his deep regret that any words of his should have appeared to savour of unfriendliness or to fall in any way short of the respect he felt for the attainments of so eminent a colleague. He confessed that, on re-reading his remarks in reply to Mr Howden, he could see how easy it would have been to avoid the personal note without invalidating the argument and so have saved Mr Howden the labour of preparing those famous papers of his for re-presentation to the Institution. It was a youthful indiscretion to allow himself to be drawn into the general discussion at all, even to the extent of signifying a preference for one line of argument over another, when there was nothing in the scheme of his paper calling for any examination of theories on the true action of a screw propeller. The position was shortly this. Mr Howden, in his 1890 paper, read before the Institution of Naval Architects, criticised adversely Rankine's method of investigation. Mr R. E. Froude replied, and in his (Dr. Caird's) remarks in the discussion on his paper, he referred students to that reply as a complete refutation of Mr Howden's arguments in his attack. If it were supererogatory for him to add anything to Froude's defence he might have denied himself the pleasure of saying so without in any way prejudicing the cause of truth. When the voluminous advance sheets of Mr Howden's paper reached him a week ago, his first impression was that the result appeared to be in bulk, not disproportionate to the period of incubation. But it seemed that by a series of accidents his obnoxious remarks were not brought under Mr Howden's notice until five years after publication, and another five years elapsed before he found health and leisure to issue his stupendous challenge. Now, he was aware that for him his criticism of Mr Howden's remarks in the discussion was "lengthy," but he was very much surprised that Mr Howden found it so, measured by the criterion of his own practice. He could not have spoken very long, as the report of what he said occupied only a trifle over two pages of the Transactions, and would not take longer in the delivery than the few minutes between eight o'clock and the time of Mr Howden's arrival at the meeting. To the best of his knowledge and belief, he added nothing to the report of his remarks in correcting the proofs for the press, and certainly never dreamed of his strictures escaping the keen eye of his censor. The paper which he had the honour of reading before the Institution, on "Propeller Diagrams," was merely a step in the evolution of the analysis of the action of screw propellers based upon certain clearly stated model experiments recorded by Mr R. E. Froude, and an attempt to show how the results of these experiments might be more easily and generally applied in current marine practice. The scope of these experiments was strictly limited, and he soon found the diagrams he recommended cumbersome; so much so, that he no longer used them, preferring an adaptation of Froude's 1892 method. And he was bound to say that during these momentous ten years, with the Damocles sword of Mr Howden's censure suspended over his devoted and all unconscious head, he had never once, in such practical work as had come his way, found Froude's curves fail him, either in analysis or design. It seemed to him that Mr Howden's procedure in that paper had been, by favour of the Committee on Papers, to reprint his Naval Architects' paper of 1890, with much matter, text and diagrams, that had already appeared in the Transactions of the Institution. To be fair, the complete discussion on all these papers should also be reprinted, and the whole considered together. But perhaps the Committee on Papers would pause before committing the Institution to so Herculean a task. He had never criticised Mr Howden's own method, for the simple reason that in his poor judgment there was no fault to be found with the geometry of his demonstration so far as it went. It was in his hydrodynamics that he found himself as another *Athanasius contra mundum*, alone and at issue with all the leading authorities on the subject, just as it was in that field that these authorities were found

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differing among themselves. It would not surprise him over much to find Mr Howden's geometrical method, if completely worked out according to the fundamental laws of hydrodynamics and tested experimentally, yielding results practically identical with those of Froude, based on Rankine's and his (Mr Froude's) father's theoretical work. He should like to say a word on the subject of the concrete example of two screws, one of 12 and the other of 10 feet diameter, exerting the same thrust and having the same speed of advance. Mr Howden, with an exasperatingly elusive dialectic, now objected to making revolutions a variable. If the nature of the case rendered a change of revolutions undesirable or impracticable, it was just as easy to make the pitch ratio of the 10 feet screw 1·6, that of the 12 feet screw being taken as before at 1·1, and the desired result was obtained. Indeed one might ring the changes upon revolutions, pitch, and surface, either separately or in conjunction. Subjoined was a little table showing the effect of making such changes, in revolutions and pitch, on the readings of Froude's curves, which would, he thought, make that matter clear.

Diameter	Pitch ratio	Revolutions	Slip ratio	Efficiency.
12′ 0″	1·1	94	20%	1·000
10′ 0″	1·1	124	26%	·975
10′ 0″	1·6	94	33%	·940

In conclusion, he had only to say that he still considered Mr Froude's remarks in the discussion of Mr Howden's 1890 paper, a conclusive refutation of the arguments advanced by Mr Howden in that paper against the validity of Rankine's method of investigation as developed in his 1865 paper to the Institution of Naval Architects, and to renew the expression of his regret that ten years ago he used terms, in stating that view, which Mr Howden had felt to be "depreciatory."

Mr W. J. Luke (Member) said that after Dr. Caird's remarks he thought that the ground was entirely cut from under his feet, because he so thoroughly concurred in the expressions regard-

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ing the substance of Mr Howden's paper; but in view of Dr. Inglis' remarks that a younger generation had grown up since 1878, and his invitation to them to take part in debating this matter, he did not think it would be out of place if he contributed to the discussion. Of course, he felt some diffidence in entering the arena and speaking on this subject owing to Mr Howden's seniority in Membership of the Institution. Those who were at the "James Watt" dinner would remember with what applause the President's remarks were hailed when he referred to Mr Howden's presence, and notified that Mr Howden was one of the two surviving original Members of the Institution. At the last meeting he came prepared to give Mr Howden's paper every sympathy, but, as the Secretary went on with the reading of it, he felt like that individual who was referred to by Bret Harte in the letter from "Truthful James" to "Bill Nye," when he said, "Is things what they seem, or is visions about." The Members were told that the paper was not very short, but, cut as it was, the Secretary took fifty minutes to read it, and he was very unfavourably impressed with what was read of the paper. Since then he had carefully gone through the paper, and he was bound to say that his unfavourable impressions were deepened, and that he remained unconvinced by Mr Howden's treatment of the problem of the screw propeller. He was not unacquainted with Mr Howden's views, because he had the satisfaction of hearing him read his paper at the meeting of the Institution of Naval Architects in 1890, and he had also heard the criticism of Mr R. E. Froude upon that paper. In his judgment, the answer that Mr Froude gave was complete, and left no more to be said. This paper was complete evidence that Mr Howden did not think so; and, as that gentleman, in his concluding remarks, appeared to think that the time for plain speaking to his opponents had come, he (Mr Luke) would endeavour to speak plainly on the subject of Mr Howden's paper. He hoped that everyone would acquit him of any want of personal respect, but he did not think that personal respect for the individual should stop one from plainly saying that

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he did not hold Mr Howden's opinions, especially when he thought that those opinions were fundamentally wrong. He felt bound to say that he thought Mr Howden's remarks upon page 176, and also the quotation that he made from Mr Froude's remarks on page 206, from the 1890 paper, could not be described as anything else than disingenuous. The paragraph he alluded to was as follows: "In the discussion of my paper in 1890 at the Institution of Naval Architects, mathematicians of the highest rank, whose theories I had controverted, took part, not one challenged my geometrical and other demonstrations, either of the true action of the screw or of the erroneousness of the theories of Rankine, Froude, and others." What were the facts? Three persons took part in the debate. Mr R. E. Froude completely controverted Mr Howden; Professor Greenhill made a few complimentary remarks as to his name being coupled with those of Rankine, Froude, and others; and Mr Macfarlane Gray was crowded out for want of time. He did not think that it was fair of Mr Howden to describe such a discussion by saying that mathematicians of the highest rank had taken part in the discussion, and that not one of them had challenged him. He hoped that the Members would refer to that discussion and see for themselves exactly what was said, and they would find that Mr Howden's remarks conveyed a false impression. He sincerely hoped that, as suggested by the previous speaker, when Mr Howden's paper was printed in the Transactions it would be accompanied by a reprint of all the papers in this connection, or at least by a complete reprint of Mr Froude's remarks on the 1890 paper. He could not bring himself to believe that, with all the scientific world on the one side and Mr Howden on the other, the matter was worthy of being dignified by the name of a controversy, though this was the heading of the paper. He had not come to the Institution to defend the memory of Professor Rankine or Mr William Froude, nor was he there to take up the cudgels on the part of any of the gentlemen who had been attacked; but Mr Howden's position seemed to be that he was fighting not only against the individuals whom he had written about in the paper, but he was fighting against Newton, and believed neither in the Laws of Motion nor the principle of the Conservation of Energy. Perhaps his modesty prevented him adding Newton to his list of antagonists. Mr Howden seemed to be incapable of understanding that the screw propeller was a reaction machine. It propelled the ship forward, and could only do so by the propeller exerting pressure against the water, and although Mr Howden saw that this pressure acted to push the ship forward, yet he asserted that it practically could have no effect in pushing a column of water astern. If the meeting chose to agree with Mr Howden, no more need be said, but it should be known that the whole body of scientific opinion on this matter was against Mr Howden, and he recognised it as being so, certainly as long ago as 1890. He (Mr Luke) was bound to say that in this particular case he must go with the majority. As to the geometrical delineation, nothing could be said against it, because it was only the delineation of the motion of a point on the surface of the propeller blade. Mr Howden took no account of the velocity of the following wake which was in many cases of considerable magnitude, and argued as if no such thing existed. This argument in effect denied the principle of the Conservation of Energy, because they could not have frictional resistance without its making itself manifest in the following wake. Mr Howden's argument and statements, therefore, that a small slip was necessary for good propulsion, were entirely erroneous, and they failed to show that he discriminated in any way between apparent and real slip. Then Mr Howden said that before there could be a Rankine column to be projected astern, there must be a space into which it could be projected. By exactly the same argument the ship could not be propelled forward unless there was a space into which it could be moved. How did Mr Howden explain that? The ship was pushed forward and the water gave way before it, and was it too much to believe that the water would give way and flow astern under the heavy pressure of the propeller? The third law of motion stated that action and reaction were equal and opposite. The propeller

Mr. W. J. Luke.
pushed the water with the result that, the water being mobile, stern momentum must be given to it. Mr Howden, in his references to the work of Mr R. E. Froude, seemed not sufficiently to bear in mind that Mr Froude's work upon the screw propeller was simply an endeavour to elucidate the results of experiments, and he put the experimental data forward in such a way as to make it suitable for analysis and the design of propellers. Recently there had been a very large mass of propeller experiments made in America, and if anyone felt disposed to take sufficient trouble to dive into the Transactions of the American Society of Naval Architects and Marine Engineers, which would be found in the library, he would see that this recent work went in the direction of supporting Mr R. E. Froude's experiments. The long and the short of it was that this paper was not wanted, even as a defence. The questions one most wanted to have answered about the propeller were: What was the influence of the thickness of the blades, and what was the influence of extension of the surface? Everyone was waiting the advent of some genius who would invent a good method of analysing trials so that each trial trip would be made a satisfactory basis of design for subsequent cases, but he was certain that no one could do that unless he had clear ideas of the action of the propeller and such as would fall in with Newton's dicta, which Mr Howden did not appear to have. The paper, even if it was looked upon as one of defence, was a mere mass of dogmatic assertions, based upon no proper conception of the fundamental laws of motion. That being his opinion, what he wanted to ask was: How came that paper to be accepted by the Institution? He hoped the Committee on Papers would not consider that he was unduly personal in his remarks, but he could not conceive how any scientific Institution could accept a paper like Mr Howden's, consisting as it did, only of ideas which were exploded fifteen or sixteen years ago, if not before. He could only say, in conclusion, that he thought the Committee on Papers had done the Institution harm in accepting Mr Howden's paper for publication in its Transactions.

Prof. A. Jamieson (Member) remarked that the previous speaker had shown how Mr Howden had neglected Newton's third law of motion, viz.:—"That to every action there was an equal and opposite reaction," and he was prepared to prove that Mr Howden had also run counter to Newton's first and second laws of motion. He argreed with Mr Howden's elementary geometry as far as Figs. 1 and 2 and propositions 1, 3, 4, and 7 were concerned, but he differed from his propositions 2, 5, and 6. In proposition 2, Mr Howden asserted that, "When no slip occurs, these lines at all diameters within the propelling faces of the blades pass through the water without imparting to it any motion whatever." Now, did Mr Howden here assert that no friction existed between any and all parts of the propelling faces and the water through which they passed and at the same time pressed severely upon? Did he further assert that the water which came directly into contact with the blades of the propeller, say near the boss, was not then set into motion by centrifugal force? Newton's first law stated that, "Every body continues in a state of rest, or of uniform motion in a straight line, except, in so far as it may be compelled to change that state by external force acting on it." Surely, friction between the screw blade faces and the water, together with centrifugal force due to the rotation of the screw, were both external forces and must act upon the said water which came into contact with the propelling faces of the revolving screw. In proposition 5, Mr Howden said, "When slip occurs the water is moved normally to the face of the blade at any diameter at a uniform velocity, etc." And when applying this proposition to test Rankine's theory, he said, "the thrust reaction is, therefore, made calculable by the formula $\frac{Wv}{g}$." Where W was given (on page 194) as the weight of column in lbs.; $v = 2{\cdot}24$ feet, or mean slip of the stream, per second; $g = 32$ feet per second; and $T = \frac{Wv}{g}$, or total thrust of screw in lbs. Here, there were no less than three distinct mistakes. *First*, $\frac{Wv}{g}$ was simply momentum, and could not be measured in lbs. *Second*, g was not a mere velocity = 32 feet per second, but the true acceleration due to gravity of 32 feet per second per second. *Third*, instead of v = 2·24 feet per second, he should have said: let $(v_2 - v_1)/t = a$ the acceleration; where, if t = one second, the time of each revolution in the case worked out; v_1 the velocity of the water at the commencement; and v_2 the velocity of the same water at the end of the same revolution; then,

$$T = \frac{W(v_2 - v_1)}{gt} = \frac{Wa}{g} \text{ in lbs.}$$

That was W/g, or the mass of water moved × the acceleration it received, due to the constant pressure or force from the face of the propeller acting upon it for one second, was equal to the thrust in lbs.; since, by "Newton's second law of motion"—"Rate of change of momentum is proportional to the force which causes it and takes place in the direction of the force." And *here*, the rate of change of momentum of the water was $W(v_2 - v_1)/gt$, or Wa/g. If Mr Howden had only made a series of careful experiments with differently shaped propeller blades under various conditions of pitch, speed, slip, form, area of blades, etc., and added the results of his observations to his plane geometry and theoretical reasonings, then the Members of the Institution would have felt truly grateful. Both he and the Members might then have learned something to their advantage. In fact, there was no reason why he should not now undertake or start such a set of experiments. For example, he could easily arrange to eject at will from the inside of the blades through small holes at the different radii, shown by Fig. 3, drops or tiny streams of coloured fluids having the same specific gravity as the water, but which would not readily spread or combine with it. He could then note or take instantaneous photographs of the different paths which these differently coloured fluids followed. It might, however, be conceded that Mr Howden's paper had made them all think and even wonder. Perhaps it would cause those who had the time and the inclination, to study and examine carefully the details of the many recen

American and other results referred to by Mr Luke. Who knew, that by so doing, someone might get one or two steps further towards the complete solution of this difficult and complicated problem in hydrodynamics.

Mr E. HALL-BROWN (Vice-President) said that, as Convener of the Papers Committee, he thought it was only right to say that he disagreed with Mr Luke to a certain extent. Mr Howden was one of their very oldest Members, and although he absolutely disagreed with his theories on Screw Propulsion, he did not think the Institution would suffer from the publication of his paper; and if it did nothing more, it would do the young men of the Institution good by sending them back to the literature on the subject to study the writings of Rankine, Froude, and Greenhill, for themselves. He thought the Council, in taking the matter entirely into its own hands, had done the Institution no harm, and had honoured one of its oldest Members by giving him full opportunity of stating his views, and he believed that the Members of the Institution would agree with the Council in its action.

Mr JAMES HAMILTON (Member) observed that he was not one of those who had the honour of being bracketed with the eminent authorities whom Mr Howden had referred to as professional screw formulæ makers, but although he had escaped attention up till now, he might confess that he produced a screw formula in the year 1903, and perhaps Mr Howden might happen upon it twenty years hence and criticise him with his accustomed vigour. He thought that the Members of the Institution were under an obligation to Mr Howden, as they were to others in other matters, for drawing attention to the fact that theories and methods were not in relation to present requirements, and that that side of the question should have some hearing—not that he could find a great deal to say in favour of the paper so far as he was concerned. The conclusions in Mr Howden's paper of 1877 did not seem to him to be a complete theory at all, but it showed clearly that he held two views, *first*, that on account of slip, a blade travelling obliquely at each part acted on ribbon-like spirals of water, the

Mr. James Hamilton.

width of which depended upon the breadth of the blade. These spirals were in the general direction down and forward on the one side of the shaft, and up and forward on the other side of the shaft. A *second* point was that the paths followed by the different blades were sufficiently clear of each other, as shown by the diagram in his 1877 paper, as to leave thick spirals of untouched water between the ribbon-like spirals acted on by the blades, and that therefore the whole mass of the water represented by the Rankine column was not given sternward motion, although the water was presumed to move aft at the same rate of slip as in the Rankine theory. So far as he could make out, the only difference between Mr Howden and Rankine was as to the quantity of water moved. The rate at which it was moved was the same in both cases. It came to the same thing whether one took the movement due to the breadth of the blade in a thirty-fourth part of a second, or the movement due to the complete revolution in one second when the circumference was thirty-four times the breadth of the blade. Mr Howden assumed spirals of water with untouched large or thick spirals between them as unmoved water, and therefore the whole column was not moved astern, although the rate was the same; but, unfortunately for Mr Howden, while that was the case when the Anchor liner that he referred to was in existence, if Mr Howden took the present Allan liners with turbine propellers, he would find that these spirals ran so closely together that there was no space of untouched water; and he would be forced to admit that the whole column of water was moved astern, the revolutions being so much faster than in the earlier case that, the blades simply cut up the whole column with no interval between. A great deal might be said upon this question, but he would content himself with what he had stated, and he thought that Mr Howden had stopped short of a complete theory. In another theory that he (Mr Hamilton) knew something about—which was more like Mr Howden's—Dr. Froude, a year after Mr Howden read his paper in 1877, practically covered the whole of Mr Howden's seven propositions. One could not see how resistance to the engines could be got by the propeller simply travelling downwards and moving circumferentially a small film of water. If they accepted Dr. Froude's version that the pressure on the blade was as the square of the velocity, it worked out very differently. It was a complete theory, but he might say all the same that anyone who suggested that the science and theory which all had been accustomed to, and which had served so well in the past, was not up to present requirements, deserved some credit, although they might not be in exact accordance with him.

Correspondence.

Prof. D. Robertson (Member) stated that the first idea which naturally struck a layman in connection with how the screw propeller worked, was, that it was a simple matter, and identical with the action of a screw in a nut, the water being the nut. But it was quite certain that that was not the case. The nut must not be allowed either to rotate or move lengthwise if the turning of the screw were to be effective, and there was nothing to prevent the water nut from going round with the screw, nor from moving away backwards from it. True, there was a common, but erroneous, notion that the mass of water behind it prevented the latter motion, but even that would not prevent the rotation. The next view which, judging from the simile of the cannon ball cited in the paper, seemed to be the one held by Mr Howden, was that the inertia of the water took the place of the fixing of the nut; that the blade suddenly struck the water, and that it in return struck back a blow on the blade. Something of that kind undoubtedly took place while the propeller was being started, but it was quite insufficient to account for the regular working of the screw, because inertia forces only occurred during acceleration. Of course, the advocates of that theory said that new water, which was not rotating, was continually being supplied to the blades by the motion of the ship. But let them test that theory. Suppose baffle plates to be placed fore and aft of the propeller so as to prevent longitudinal motion of the water until full speed was attained.

Then, with the ship at rest, let these plates be suddenly removed. As the water in which the blades worked would be rotating along with them, it was manifest that they could not act as a nut. But did anyone believe that the propeller would fail under those circumstances? A simpler, although perhaps less conclusive, test was open. Let the engines of a ship be started very gently, and run up to full speed very very slowly. The inertia forces referred to would then be extemely small, but if anyone thought the ship would not be propelled, let him try the experiment and see. Well, then: How did it work? The inexorable laws of mechanics required that, on the whole, there should be no change of momentum. The ship was continually giving out momentum to the water it dragged along with it or sent out as waves, and to the air which opposed its motion. If its speed was to be constant, it must take an equal amount from something else by giving that a motion backwards. Thus, one arrived at the stream of water projected backwards, whose rate of acquiring momentum must be equal to the force necessary to overcome resistances to the motion of the ship. It was, however, quite unnecessary to assume that that stream consisted of a column sticking out behind, or that it behaved like a solid, as Mr Howden seemed to think would be required on Rankine's theory. It would, in fact, spread out after leaving the propeller, and share its momentum with the surrounding water, and it really did not matter what became of it after it had got clear of the ship. But the same force would be exerted by a certain cylindrical column, and it was that hypothetical column that Rankine dealt with. If his results did not agree with the results of experiment, it was his rule for finding the section of this equivalent column that was at fault, and not the theoretical basis. It still remained to explain how the propeller projected the water backwards. The propeller was nothing but a specialised centrifugal pump, and should be designed as such. When it rotated, it carried the water round with it. Centrifugal force then caused the water to flow outwards from the centre, and, if the speed of rotation were high enough, the water would be driven out faster than it could enter from the side, and a cavity was formed, as was well known in connection with turbine propellers. The further out a particle of water got, the faster it had to go circumferentially to keep up with the blades. It thus got accelerated circumferentially as it went outwards, and the force producing that acceleration was nearly normal to the blade surface, and had thus a component parallel to the length of the ship, driving the ship forwards and the water backwards. Owing to this radial motion every particle of water would leave at a larger diameter than that at which it had entered. Consequently, more water must enter the central part of the propeller than left it there, and some that entered near the tips left by the periphery, unless the blades were curved over to prevent it. Mr Howden's method entirely failed to take any account of this radial motion, and consequently his diagrams did not show the actual movements of the water, and could not be said to prove anything at all. That the centrifugal theory was the correct one could be easily shown by experiment. Let a propeller, say of a small launch, be shrouded by thin metal cylinders concentric with the shaft, so as to prevent radial motion of the water, but to allow free axial flow. On the theory supported by Mr Howden, that would make no difference except what was due to the extra friction on the surfaces of these cylinders; whereas, according to the centrifugal theory, the screw would no longer act. To a mere outsider in shipbuilding matters, it seemed that the screw-in-nut analogy had obscured the real action of the propeller, and hindered advance in its design. The problem was in reality exactly the same as for the design of a centrifugal pump, without guide blades, taking in water at one side and giving it out at a larger diameter on the other. Looking at it in that way raised the question: Why not use guide blades fixed to the hull? All the rotational motion carried away by the water was sheer loss, and the conversion of some of that into motion backwards might possibly prove an economy. One might even go to the other extreme and put in guide blades to do all the work of deflecting the water backwards, the revolving blades being radial with curved edges to take the water smoothly. The thrust would then come directly on the hull and not on the shaft, and it would be possible to reverse the propelling force almost instantaneously by shifting these guides without stopping the engines at all. That would probably make a screw vessel as handy as a paddle steamer for manœuvring at piers, but might, however, be open to objection for sea-going traffic.

Mr R. E. Froude, F.R.S. (Hon. Member), considered that the constructive portions of Mr Howden's paper consisted of a series of geometrical propositions of an elementary character concerning the movements of points on a propeller blade, which, as such, were unexceptionable; they were, in fact, among those premised by the investigators whose work he denounced. Mr Howden observed that a cannon ball rebounded from water as from a solid; also that an oar, while moving edgeways through water experienced, to a lateral pull, "almost as much resistance as from a 'solid body,'" whence he surmised that the reaction of a propeller blade would be "vastly increased" compared to the latter. He also hinted, if a little vaguely, that this reaction had analogy to the inertia of a body falling under the influence of gravity; but here his science seemed to come to an end. Now all these reflections, unexceptionably true as they were, were but the A B C of the study of propulsion—rather, perhaps they were the A without the B C. What was wanted next was a study of how and why the mobile fluid came to offer that resistance to the cannon ball and the oar blade, and how at least some approach might be made to an orthodox quantitative expression of such resistance, in terms of those universal dynamical principles which governed the movement of the falling body. This study belonged to hydrodynamics, a branch of science in which (to judge from his paper) Mr Howden appeared to be lacking; and unless he showed some adequate understanding of it, it was a waste of time for those whom he criticised to concern themselves with his criticisms.

Dr. John Inglis (Member) was not aware that a screw propeller controversy existed until he received a note from

Mr Howden, intimating that he (Mr Howden) had written, inviting him to discuss a paper so entitled, which he now found occupying fifty pages of the Transactions. The advance copy, considerately furnished to him, arrived when his time was fully taken up with other matters demanding immediate attention, and even now he could not do more than glance at this lengthy production. Mr Howden did him too much honour. At Mr Howden's own request, he offered a few remarks on his paper in 1878; Mr Howden had the usual opportunity of replying, and availed himself of it to the fullest extent. What he (Dr. Inglis) had written, he had written, and, if there were any who took an interest in the views and opinions of Mr Howden and his critics of that date, let them read and judge for themselves. The "natural indolence" which Mr Howden alluded to would not allow him to be drawn into any revival of a discussion which had received decent burial twenty-eight years ago. The subject might have haunted Mr Howden all these years, but he (Dr. Inglis) was not going to have his repose disturbed by it now. Besides, did not Mr Howden emerge from the contest with the fruits of victory in the form of the gold medal of the Institution, and what more could the most exacting desire? As Mr Howden said, a new generation of better educated Members had grown up since 1878, and, so far as he was concerned, they might be left to discuss the rechauffé Mr Howden presented to them. He was content to be classed with Rankine, Froude, Barnaby, and others, who had not been shaken by Mr Howden's arguments.

Mr C. A. Matthey (Member) remarked it was curious to note that after all there was no difference between Mr Howden and Rankine as to the motion of the water in the immediate neighbourhood of the propeller blade; though they differed in the deductions they drew from that motion. Accepting Mr Howden's fifth proposition (also assumed by Rankine), that the motion of the water was normal to the surface of the blade, no one could question the accuracy of Mr Howden's geometrical construction. That gentleman seemed to think that, whereas he arrived at his result geo-

Mr C. A. Matthey.
metrically, Rankine had treated the matter by algebraical analysis; but there could be little doubt that the latter had used the very same geometrical construction. Thus, taking Mr Howden's Fig. 2, and drawing EF at right angles to CD, Fig. 14, the slip was

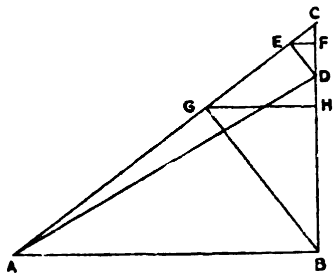

Fig. 14.

represented by CD, the actual motion of the water by DE, and the backward component of the motion of the water by DF. That was to say, the "slip of the water" was less than the real motion of the water in the ratio of DF to DE; and the real motion of the water was less than the slip of the screw in the ratio of DE to DC. Therefore, the slip of the water was less than the slip of the screw in the ratio $\frac{DF}{DE} \times \frac{DE}{DC}$; but, $\frac{DF}{DE} = \frac{DE}{DC} = \cos EDC =$ $\cos CAB$; that was, as Rankine put it, "the slip of the stream driven back" from the surface of the blade "was less than the slip of the screw in the proportion of the square of the cosine of its obliquity to an athwartship plane." If Mr Howden had kept to his geometry, instead of calculating by Rankine's formula, which he had misapplied in some way, he would have been spared some errors. On page 192 he said—"The extent and velocity of this slip" (that is, of the water) "as calculated by Professor Rankine's formula, varies from 2·52 feet at the extremity, to 1·35 feet at 5 feet diameter per revolution." Now, at the extremity, in the triangle CAB, Fig. 2, AB represented the circumference of a circle 20 feet in diameter, or 62·8 feet; CB the pitch of the screw, 27·77 feet; and C D the slip of the screw, 2·777 feet. The slip of the water was C D multiplied by the square of A B, and divided by the square of A C. A C was known, being the square root of the sum of the squares of A B and C B, or 68·7 feet. Working this out, the slip of the water at the extremity was found to be 2·32 feet. So at 5 feet diameter, in the corresponding triangle, the base A B was much shorter, being the circumference of 5 feet diameter, or 15·7 feet; C B was the same as before, namely, 27·77 feet; and the new hypotenuse A C was 31·9 feet. The slip of the water at this diameter then worked out at 0·67 of a foot. Again, on page 187, Mr Howden said—"The slip motions given to the water increase in a greater than arithmetical ratio when the slip increases." On reconsideration he would probably admit that this was not the case, seeing that in Fig. 2 and Fig. 14, the triangle C E D was always similar to itself, wherever the point D was taken; that was, whatever the slip C D, the real motion of the water D E, and its backward motion D F were strictly proportional. This suggested a graphic method of showing the distribution of speeds, and of estimating the reaction of the water driven astern and the energy impressed on it. In Fig. 14, if B G be drawn at right angles to A C, and G H at right angles to B C; then C B, to the proper scale, might be taken to represent the slip; and B G and B H would, to the same scale, be the real and sternward speeds of the water respectively. In Fig. 15, make B C the pitch and A B the circumference of the propeller to any scale. Choose any diameter, of which $A B^1$ is the circumference; draw $B^1 C^1$ at right angles to A B, $C C^1$ parallel to A B, and join $A C^1$; and draw $B^1 G^1$ at right angles to $A C^1$, and $G^1 H^1$ at right angles to $B^1 C^1$. Then, C B being the slip in feet per second, $B^1 G^1$ and $G^1 H^1$ can be rapidly found by means of a millimeter scale and a slide-rule, also in feet per second. The locus of H^1 was the curve shown, and its ordinates represented the varying sternward motion from the centre, supposing no boss, to the circumference. Fig. 16 showed the real speeds, all such lengths as $B^1 G^1$ being plotted as ordinates at their proper stations; while Fig. 17 showed

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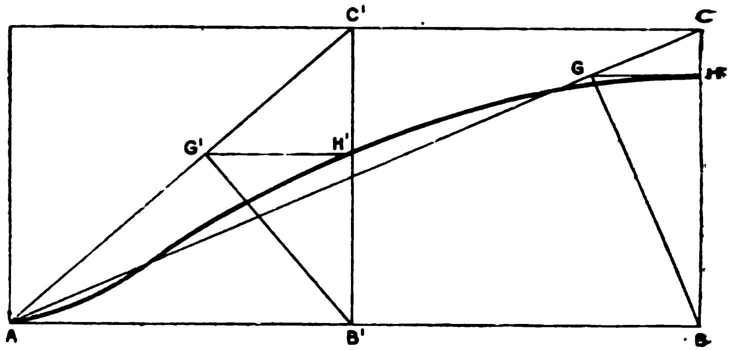

Fig. 15.

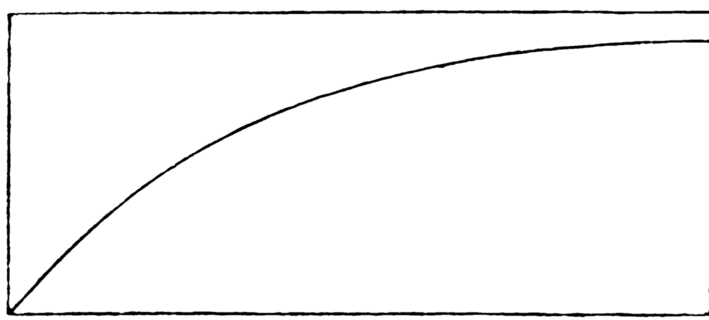
Fig. 16.

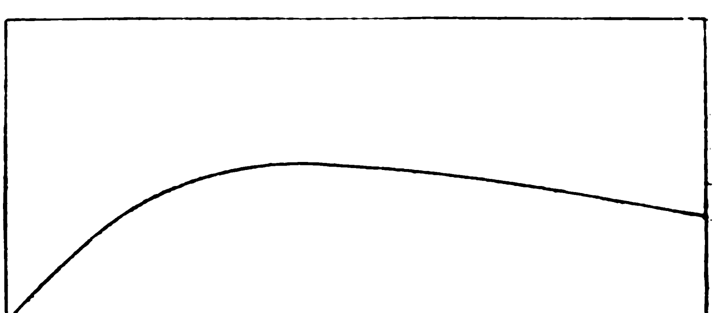
Fig. 17.

the tangential speeds, such as G^1H^1, in the same way. Now these motions occurred, both according to Rankine, and according to Mr Howden. They necessarily resulted from the hypothesis, assumed as an axiom by both investigators, that *the motion of the water was everywhere normal to the surface.* But while Rankine held that this motion took place all over the circle of the propeller, Mr Howden, it would appear, maintained that it only occurred at that part of the circle which was, for the moment, occupied by the blades. But, even on the latter supposition, there was surely a mean acceleration constantly being imparted to a column of water, although, *ceteris paribus,* that mean was less than it would be if the Rankine theory were correct. Mr Howden would not admit the formation of a column; he (Mr Matthey) would invite him to think, not of the *formation* of a column, but of something happening to a column which existed, whether the screw propeller were there or not. Suppose the ship to be towed with the propeller removed, and a mere ring of metal, the same diameter as the propeller, to occupy the place where the latter had been. Then there might be said to be a column of water passing through the ring. The column would not really move; it would stand still, and the ring would run over it; the speed with which the water approached the ring being the same as that with which it left it. Now, place the screw propeller inside the ring and rotate it, relieving the tow rope. As any cross-section of the column of water arrived at the front edge of the propeller, four patches of it, corresponding to the four blades, would, according to Mr Howden's own geometrical construction, immediately acquire a diagonal motion, partly sternward and partly tangential. It seemed indisputable that the tangential motion would be shared by the whole circle, because if two adjacent spokes of water, so to speak, went round, the intervening water would have to go with them. As to the sternward motion, however, it was fairly debatable whether it took place only over the four patches or over the whole circle. In either case, however, there was sternward motion of the column, though the average was more in one case than in the

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other. If one took the case of a propeller of which the whole circle was filled with blades, something like an American windmill, then, even on Mr Howden's theory, there was a sternward motion all over the circle, faster at the circumference than nearer the centre, but the same for the same diameter. The mean speed with which the column left the propeller was, therefore, greater than that with which it had approached it. Would not Mr Howden admit that this involved acceleration somewhere? He had appealed to Members to say whether or not he was right in saying that the sternward motion of the water in contact with the blade was one of uniform, and not of accelerated motion. Indisputably, the motion was uniform, on the hypothesis; but, equally indisputably, the motion had been accelerated. How were these facts to be reconciled? Clearly by supposing that the acceleration took place before the water got to the after surface of the blade, either suddenly or gradually. Rankine was credited with the theory that the acquisition of motion was instantaneous, so that the action might be represented by Fig. 18. Here L M was the diameter of the propeller, and L N its length; a column of water of diameter J K, greater than that of the propeller, approached it from forward. On arriving at the front edge of the propeller at $J^1 K^1$, it was suddenly accelerated, its diameter diminishing to that of the propeller. This diminution of cross-section resulted from the same volume passing at a greater speed; just as in a pipe of varying section, running full, the velocity was inversely as the area. There seemed every reason to believe that this sudden action could not take place. When a flat plate was moved either squarely or obliquely through water, the pressure in front of it was increased, while that behind it was diminished. The action was, therefore, something like that shown in Fig. 19. At J K then there was normal pressure, just in front of L M it was below the normal, from L M to N O it was above the normal, and at P Q it was again normal. Now it was a principle of hydrodynamics that when water moved from a place of greater to one of less pressure, acceleration took place. There

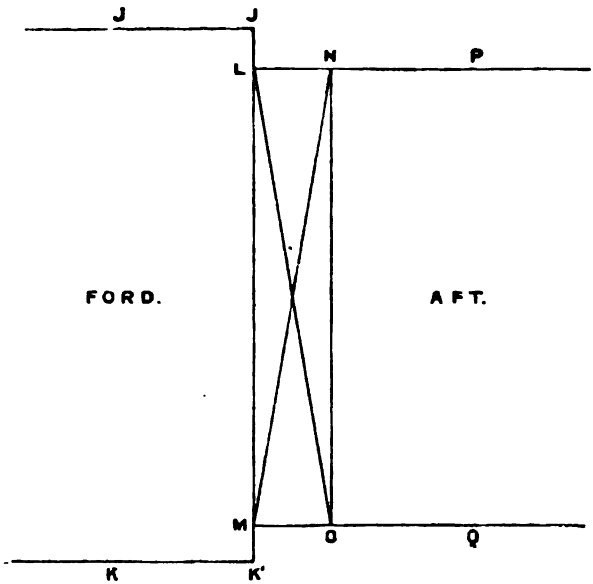

Fig. 18.

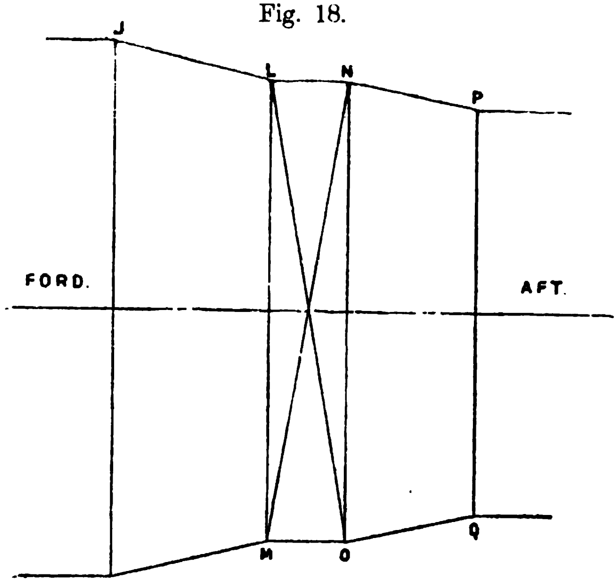

Fig. 19.

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was, therefore, acceleration from J K to L M; uniform motion at higher than normal pressure from L M to N O (satisfying Mr Howden), and again acceleration from N O to P Q, with further diminution of diameter. The Rankine theory said nothing about this second acceleration, the explanation of which was due to Mr R. E. Froude, and accepted by Mr S. W. Barnaby. But, neglecting this second acceleration, which might be questioned by some, the fact remained that both by the Rankine theory, and to a lesser extent by the Howden theory, the column of water running through the propeller's disc emerged at a greater speed than it approached. It might be compared to a round bar of iron going through a rolling mill, which went out behind quicker than it went in in front, and with a diminished section; only that in this case the increased speed was due to the diminution of section, and in the case of the propeller, the increase of speed caused the diminution of section. He (Mr Matthey) would ask Mr Howden a question which he hoped he would answer. Supposing, for the sake of argument, that there was something else than reaction, known to Mr Howden, which caused forward thrust, would he not admit that the sternward motion, shown to exist by his own geometry, did produce *some* recoil, and therefore, at least, contributed to the thrust? Another question was: Why should Mr Howden demand an empty space behind the column, for the latter to fall into? He did not require an empty space for the broadside motion of his blades, nor in front of the ship for the bows to fall into. The water was pushed away, and had to go somewhere else. It seemed a waste of words to discuss whether the column was "indefinite" or not. Its motion would soon be lost in the surrounding water; but even if it were not, its length would be definite, and would depend upon the length of time which had elapsed since the ship started. If she started at a point in mid ocean, and her speed were nine knots, while the real speed of the head of the column was one knot, at the end of one hour the head would be one sea mile distant from the starting point, and ten miles distant from the ship, and so for any time in proportion. In

Mr Howden's application of the Rankine theory of his propeller, he assumed a mean "slip of stream" of 2·24 feet per second. He did not say how he arrived at this figure; the resulting thrust horse power was 1,635. He was correct in taking $S + v$, and not S as the length of the column acted on; S was the length of the larger column J K, Fig. 19, before acceleration and contraction had taken place. He (Mr Matthey) arrived by graphic construction at a different result from Mr Howden. He drew Fig. 15 to a scale of one centimetre to the foot, and imagined the circle of the propeller, from the boss to the extremity, to be divided into fifteen annuli, each of six inches radial dimension; and measured the values of G^1B^1 and B^1H^1 for the mean diameter of each annulus. (See table, page 246). The thrust horse power was thus 1,360, while the horse power spent on the water was only 75. He had gone into these numerical matters because Mr Howden had appealed to Members to judge whether his demonstrations were right or wrong, and complained that hitherto they had been avoided. But a more important matter was the question raised by Mr Howden, as to whether the thrust increased when the slip increased, owing to the speed of the ship being reduced by a head wind, or, say, when towing another vessel. Here he (Mr Matthey) was in entire agreement with Mr Howden; he believed that the thrust did not increase, but remained nearly or quite constant. Mr Howden's argument, however, effectually demolished not only the Rankine method of calculating the thrust from the slip (but not the Rankine theory that thrust was due to the reaction of water with a sternward motion), but also his own geometrical construction, based on the theory of normal motion. There was in connection with the screw propeller a most wonderful and inexplicable, yet undeniable phenomenon, which upset all the theories he (Mr Matthey) had ever read. It was that, with given engine, steam pressure, ship, and propeller, the revolutions were nearly the same, whether the ship were allowed to go full speed or whether she were retarded or even stopped altogether by an external force. A tug's engine seemed to him to go at the same speed under all circumstances, even when trying

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The following table gave the result for 10 per cent. slip:—

Diameters of annulus feet.	Area of annulus. Square feet.	Length per second, feet.	Real velocity $B^1 G^1$, feet per second.	Sternward velocity $H^1 B^1$, feet per second.	Energy per second ft. lbs. $\frac{Wv^2}{2g}$	Forward reaction. lbs. $\frac{Wv}{g}$
5 & 6	8·64	25·77	1·47	·77	480	344
6 „ 7	10·21	25·97	1·64	·97	710	516
7 „ 8	11·78	26·16	1·79	1·16	980	715
8 „ 9	13·35	26·33	1·92	1·33	1290	935
9 „ 10	14·93	26·48	2·03	1·48	1620	1175
10 „ 11	16·49	26·62	2·12	1·62	1980	1420
11 „ 12	18·06	26·73	2·19	1·73	2300	1680
12 „ 13	19·64	26·84	2·26	1·84	2700	1940
13 „ 14	21·20	26·93	2·32	1·93	3050	2130
14 „ 15	22·78	27·01	2·37	2·01	3450	2470
15 „ 16	24·29	27·09	2·41	2·09	3810	2760
16 „ 17	25·98	27·15	2·44	2·15	4190	3050
17 „ 18	27·48	27·20	2·47	2·20	4350	3300
18 „ 19	29·06	27·25	2·49	2·25	4900	3560
19 „ 20	31·64	27·29	2·52	2·29	5450	3960
				Totals, -	41,260	29,955

unsuccessfully to haul off a ship which was aground, the slip being then 100 per cent. He would have liked to verify this before sending in this communication, but unfortunately the ice was only

Length per second.	Real velocity $G^1 B^1$	Sternward velocity $H^1 B^1$	Energy per second. ft. lbs	Forward reaction lbs.
7·7	14·7	7·7	14,400	1,030
9·7	16·4	9·7	26,800	1,920
11·6	17·9	11·6	43,500	3,160
13·3	19·2	13·3	55,500	4,700
14·8	20·3	14·8	91,000	6,505
16·2	21·2	16·2	120,000	8,650
17·3	21·9	17·3	150,000	10,800
18·4	22·6	18·4	189,000	13,400
19·3	23·2	19·3	219,000	15,700
20·1	23·7	20·1	256,000	18,400
20·9	24·1	20·9	294,000	21,100
21·5	24·4	21·5	330,000	24,000
22·0	24·7	22·0	366,000	26,400
22·5	24·9	22·5	400,000	29,100
22·9	25·2	22·9	455,000	33,100
		Totals, -	3,010,200	218,010

just breaking up on his river, and there was no craft under steam; but even if his memory were at fault, and the revolutions considerably less than when the tug was free, he was sure they were sufficiently fast to impress on the water, *on the theory of normal motion*, an energy greater than the indicated power of the engines. He

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would take Mr Howden's propeller and show that energy for 100 per cent. slip and full speed of engine. The speed of any annulus through the propeller was $H^1 B^1$, and its real speed $G^1 B^1$, to the very same scale as C B represented the pitch. Taking the same annuli as in the previous table, the table on page 247 was obtained. Here was a horse power of 5,470, and a thrust of 98 tons, which would make the thrust block seize and break the blades of the propeller. The theory of normal action clearly failed, whether the motion was supposed to take place uniformly over Rankine's column, or only over Mr Howden's four patches. How could, in Fig. 20, the same driving force take the blade from A to B in the same time that it took it from A to C? Common sense would indicate that the propeller would turn very much slower when the ship was held motionless than when she was free; but common-sense was wrong. The water was probably to a great extent carried round and round, so that there was not the quantity of fresh water indicated in the above table continually introduced and dismissed at the speeds shown. It was difficult to believe that the static balance of forces could be other than that shown in Fig 21, where EG was the fore and aft and DE and GF the thwartship direction; the thick line was the blade, and EF was at right angles to it. The tangential force at the crank-pin circle of the engine, "corrected to the driving point," might be supposed to act along DE; the triangle of forces showed GF this corrected force, EF the pressure on the blade, and EG the thrust. It mattered not what diameter was taken on the propeller; the correction of the driving force, and the variations of the angle of the blade were such that the same thrust was always obtained. While this seemed pretty clear, he (Mr Matthey) thought that this was such a difficult and obstruse subject that, he would like to see it verified whether the thrust of a screw tug was constant at all speeds, from full speed running free, then towing ships of various resistances, down to zero speed with her stem against the quay wall, full steam being turned on in every case. One almost regretted the disappearance of the geared screw engine, where

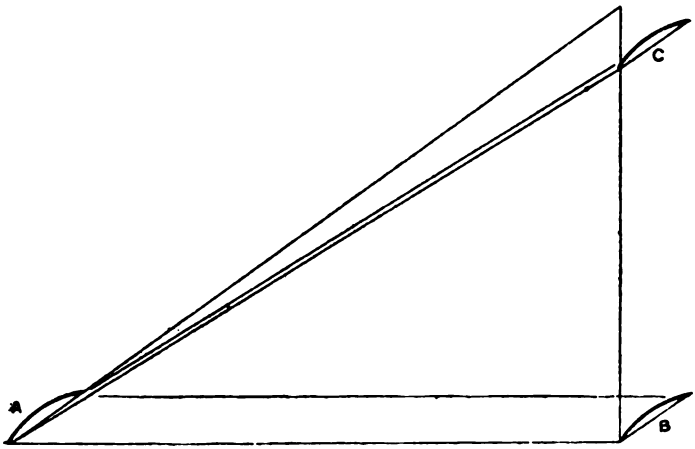

Fig. 20.

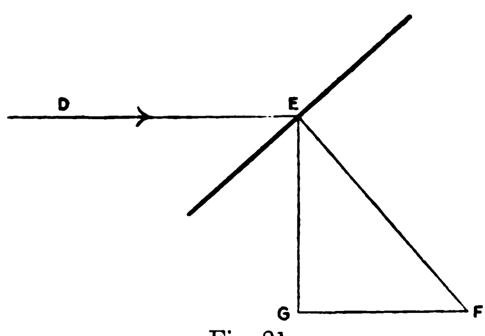

Fig. 21.

the fore end of the shaft was available for a thrust dynamometer; some useful trials might, however, be made in this direction with electric launches. He would bring these all too lengthy remarks to a close, by summing up as follows:—He agreed with Mr Howden that the Rankine theory failed to deduce the correct thrust from the dimensions and slip of the propeller. The correctness of Rankine's calculation of the "Warrior's" performance was a most egregious fluke. Both

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Rankine and Mr Howden were wrong in assuming that the motion of the water took place everywhere at right angles to the surface of the blade; the smallness of the variation in rotary speed of the propeller, with large variations of speed of ship owing to external resistance, disproved that assumption. Mr Howden was wrong in attributing the thrust to anything but inertia; that was, to the recoil of water driven astern. Rankine's expression $\frac{Wv}{g}$ was typically right; but his theory did not give the values of either W or v.

Mr HOWDEN in reply said that to those Members who had honoured his paper with their criticisms, he had to confess his regret that they had not followed his request to study first the vital parts of the paper, viz., the demonstrations (1) of the actual movements given to the water by the screw in propelling, and (2) of the erroneousness of Prof. Rankine's and all analogous theories. If this advice had been followed, he felt assured these criticisms would have been very different in character. A geometrical proof was absolute, it did not admit of being partly right or wrong. So were quantitative proofs based on actual measurements, quantities, weights, and velocities. If such proofs were submitted in support of any statement in geometry or mechanics, nothing was more easy than to show their incorrectness if such existed. He had submitted proofs fully worked out, both as to what was right and what was wrong, in this, as in his previous papers on the propeller's action, yet not one of those who had opposed his views had, during these twenty-eight years, ever proved against him a single error. After waiting in vain all these long years for any such proofs of error, he could not fairly be accused of undue haste in claiming his demonstrations to be unassailable. Notwithstanding these facts, at no former discussion of his papers on this subject had it been attempted, as in this discussion, to upset his demonstrations by narrations having no bearing whatever on the vital questions at issue; by assertions of errors made without the slightest supporting proof; and by the reiteration of the opinions and statements of writers on the subject which his demonstrations had proved, beyond cavil, to be entirely incorrect. It was certainly strange that all those mathematicians and experts who opposed his views on the propeller, should suddenly lose their knowledge of geometry and power of delineation and calculation when asked to put their objections to his geometrical proofs and calculations in similar form, and should begin to argue about assumed motions of water given by the propeller, motions they never attempted to prove, this being impossible as such motions did not exist. He would here ask his honourable opponents on this important subject, if it was fair, if it was even admissible in the discussion of an entirely mechanical subject like this—capable of being accurately delineated, geometrically analysed, and reduced to dimensions—to altogether ignore the demonstrations he had given of the real action of the propeller. These demonstrations, supported as they were by what purported to be absolute proofs, could only in fairness be denounced or rejected after they had been proved wrong, and that, not by unsupported assertions, however strong, but by definite geometrical and quantitative proofs, such as he had used in support of these demonstrations of the propeller's action. He submitted that no other method was in fairness admissible to any opponent. If any such could prove his statements wrong in this, the only legitimate way, he was prepared to make the fullest apology for what would then be his persistence in holding as right what had been proved to be wrong. But until such proof was forthcoming, he must necessarily hold that he had absolutely proved in these papers the real and only actions the propeller could make on the water under any given conditions. Before referring to the individual criticisms made in the discussion, it would, he believed, save some time and space if he first noticed some points which seemed to be held more or less in common by several Members who at the same time objected to his views. He would class these as follows:—

(*a*) That his geometrical demonstrations of the true action of the propeller might be correct so far as they went, but did not appear to go far enough, and stopped short of a complete theory.

(*b*) That his methods if carried further would probably yield results identical with Rankine and Froude, and that the only difference between Rankine and himself was the quantity of water moved, the rate of movement in both cases being the same.

(*c*) That he neglected the hydrodynamical effect of the propeller, which effect was said to be so important as to make all other demonstrations of no value.

(*d*) That he neglected the effect of the centrifugal action of the propeller.

(*e*) That he forgot that the views of Froude and Barnaby were founded on actual experiments.

(*f*) That he neglected or controverted Newton's three laws of motion.

Though the explanations given in this and in his previous papers should have rendered it unnecessary, he would, to prevent, if possible, further misunderstanding, take up, so far as his time would permit, each of these points again. *Firstly*, he would remind those who considered that his demonstrations did not go far enough and stopped short of a complete theory, that he claimed to have absolutely demonstrated geometrically and quantitatively, by means of the seven geometrical propositions and their application to an actual screw of given dimensions, how the exact extent of all its motions could be absolutely ascertained for any propeller under all the varying conditions of dimensions, shapes of blades, pitches, slips, and revolutions. His geometrical analysis proved the exact movement given to the water by every successive circumferential line on the blade under every possible variation of conditions. These demonstrations covered completely every movement of the screw in itself and its action on the water in propelling, and showed further how all these movements by any given screw could be graphically represented and absolutely calculated numerically. When all these movements were known, nothing remained unknown about the action of the screw propeller and no further theory was wanted. The word "theory" had here evidently been conceived as containing some intrinsic value in itself, over and above that due to demonstrations which gave complete knowledge of all the correlated facts, that was, all the phenomena connected with the screw's propelling action. The term "theory" was generally used or applied to phenomena, some parts of which, at least, did not admit of absolute proof, but were, for reasons given in the theory, most likely to be correct. Statements regarding the action of the screw propeller when fully demonstrated, as those in this paper, and understood, as all mechanical action should be, got beyond the region of theory into that of absolute knowledge of the important facts desiderated. It appeared to be necessary to mention here that this paper and those of 1879 and 1890 were limited to the consideration of the propelling movements of the screw. But his papers of 1877-78 also included the important consideration of the effect of the displacement of water by the body of the propeller. For the complete action of the screw the displacing movements as analyzed in these papers should also be studied, as these movements were quite distinct from the propelling movements. What he had not attempted in these papers was the formulation of rules to calculate thrust from compression of the water by slip, as he considered such as inapplicable for this purpose, as they would be for calculating the thrust from the wear on the shaft collars and thrust rings in the thrust block. Nor had he considered the effect of friction in these papers, not because it was unimportant, quite otherwise, but because it could not be ascertained without elaborate and expensive experiments. The only reliable way to find the thrust effects of different slips, under an equal power of engine, was by the use of a proper dynamometer, which could without great cost be easily applied to ships of 500 or 1,000 I.H.P. His

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analysis also provided for the exact calculation of the effect of the wake and of its varying effects at different depths whenever these different velocities were ascertained. He therefore held that his investigation of the propeller's action covered, with the above necessary limitations, all the movements any propeller could make. *Secondly*, those who thought that his methods if more fully worked out would probably be found to coincide with Rankine and Froude, showed what great confusion of mind existed as to the real action of the propeller and how little his demonstrations of this action had been comprehended even by those who wrote on the subject. Those who so spoke showed they had no proper conception of the rationale, either of his demonstrations or of the Rankine theory. Admitting as they did the correctness of his demonstrations "so far as they went," they gave their whole case away. If his demonstrations were correct then no other conclusions which differed from them could be correct. His conclusions rested entirely on geometrical proofs, the correctness of which could be examined. These showed that, the extent of the motions given to the water by the propelling face of the blade of his example propeller, at its extreme and most effective diameter, was ·82 inches when making 10 per cent. slip. By the Rankine theory the movement given to the water by this propeller at the same diameter with the same slip was 27 inches! No one who was convinced that the sum of the angles of any triangle was equal to two right angles could ever be led to believe by the strongest assertions that though in some cases this might be so, yet in some other triangles the sum of the angles might be equal to three or four right angles; nor was it possible that those who were convinced that two and two made four, would ever be persuaded by even the most plausible rhetorician that though these two sums together made four in ordinary calculations, yet in some calculations, such as those connected with the mysterious movements of the screw propeller, they might make five or even ten. Not one bit less absurd and incongruous were the ideas that, if he carried his demonstrations far enough they might be found to harmonise with the views of Rankine and Froude. The only point in common between the Rankine theory and the facts regarding the action of the propeller brought to light by his geometrical analysis, was that of the extent of the difference between the slip of the screw and the slip of the water *per revolution*. He called special attention to the agreement being limited entirely to the slip *on the whole revolution*, for what he proved to be actual slip made during the revolution as found by props. 6 and 7, Prof. Rankine assumed as being made from beginning to end of the revolution, which was a vital mistake. He had again to call attention to the crucial fact which distinguished and separated these demonstrations from all others on the motions imparted by the blades of a propeller, which was the division of the total slip of the water *per revolution* by the number of times the arc of the circle across the face of the blade at any given diameter divided the distance travelled by the blade in one revolution at that diameter. This gave the only true key to the solution of these propeller problems, and showed all other estimates of the movement of the water to be egregiously wrong. Even at 100 per cent. of slip, where the Rankine theory would at 20 feet diameter of this propeller give the movement of the water as 25·4 feet per revolution,—his analysis showed that the total movement imparted to the water by the blade at this diameter was only about 8¾ inches. This movement, of course, increased towards the root of the blade, on account of the increased breadth of the blade, its increased angle, and the reduction of its diameter. With the vessel remaining fixed in one position this movement would, of course, set up a continuous stream, but if the blade were reduced one-half in breadth the movement of the water per revolution at 100 per cent. slip would be reduced one-half also, and so on in proportion until, even with this slip, the movement of the water would scarcely be observed. These facts proved that the extent of the movement of the water was governed by the breadth of the blade, a fact entirely left out of account by all other writers on the screw propeller. The

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Rankine theory required for his example propeller at 10 per cent. slip a column of water 25 feet in length + 2·24 feet added thereto by slip, in all 27·24 feet in length, and detached in some unexplained manner from the surrounding water that it might be thrown in a mass each revolution 2·24 feet, in order to obtain the necessary thrust reaction as calculated by the $\frac{Wv}{g}$ formula. He had in all his papers already dwelt sufficiently on the impossibility of this motion that he need not go over the same ground again. It would suffice to repeat that whatever extent of motion was given to the water by the screw it was a *uniform motion*, and not given by one impulse, or accelerated, so that the formula $\frac{Wv}{g}$ would not apply even if the column existed, as only the friction of the moving column would then constitute the resistance. As a basis for calculating the reaction of the propeller, all columns, vortices, etc., were entirely inapplicable. As his demonstrations of the true action of the propeller proved that the phenomena they established were as far as the poles asunder from those on which Prof. Rankine's theory were based, it could no more be admitted that the latter were also correct, than it could be admitted that though two and two made four generally, in some cases they made five or ten. *Thirdly*, The hydrodynamics of the propeller. From the special references made by some Members to this branch of science, they seemed to consider it something mysterious and esoteric, known only to the initiated, and that his presumed lack of knowledge of this science rendered his demonstrations of no value whatever. As mysterious science was a contradiction in terms, he trusted he might, without irreverence, say, that after all what these critics referred to was merely the movements made on the water by the blades of the screw in propelling. The displacement of the water by the body of the blades and boss might also be taken into account, though it was the propelling movements which were really in the minds of these critics, the very actions about which all his latter papers had been written. He had flattered himself that he was the only writer on the science of the propeller who had shown its true hydrodynamical effect, though these critics doubted his having any knowledge of this science. They evidently had in their minds some grand movements of water; such as the Rankine column, rotating as some (though not Rankine) had it, or the grander conception of Mr Rigg, which they considered necessary to account for the reaction by which the ship was driven forward. As he had mentioned in his paper, it was the impossible hydrodynamics of Mr Arthur Rigg which first led him to consider the true action of the propeller. These, as conceived by Mr Rigg, were on a royal scale of magnificence. Mr Rigg's views were received with much acceptance at the Instituton of Naval Architects and other Institutions when read about the year 1868. In his (Mr Howden's) paper, read before the Institution of Naval Architects in 1890, he made some critical observations on this theory where they could be examined, page 252, Transactions of the Institution of Naval Architects, Vol. XXXI.* Suffice it to say here that, according to Mr Rigg's theory the blades of his (Mr Howden's) example propeller at 10 feet 3 inches diameter would, independently of slip (which he never mentioned) throw the particles of water with which they came into contact all round the revolution, a distance from the propelling faces of not less than 42 feet! Certainly

* "This theory (Mr Rigg's) has, however, evidently impressed many minds with some remarkable notions of the behaviour of the water within the 'sphere of influence' of a screw propeller, and along with some of the views of the late Mr. Robert Griffiths, appeared to have given rise to such ideas and expressions, now continually appearing in screw literature, as 'reverse currents,' 'screw race,' 'feeding the screw,' 'water passing into or through the screw,' 'screw spinning a rope of the wake,' 'rotation of the race,' etc. Some of these expressions seemed to rise not only from the idea of a great twisting and elongated motion being given to the water by the propeller, but also from the further idea of the propeller working without forward movement—in a partly inaccessible place, where the reluctant water was sucked and dragged into its embrace as into a turbine wheel, and after being whirled round for an indefinite period was thrown off sternward or angularly in a grand revolving current equal or nearly so to the area of the screw's disc." Mr. Froude used frequently such expres-

to such as considered such grand backward movements of the water as absolutely necessary to ensure a grand forward movement of the ship, his small retrogressive movement of one or two inches of water must appear ridiculous. It was true, nevertheless, and the opposite untrue. A large backward movement of water, that was, a large slip, meant a small forward movement of the ship. As this backward movement increased, though equal power was expended, the forward movement correspondingly decreased. This was, of course, all against the authorities, but all so much the worse for such authorities. Though it involved excessive repetition, he must reiterate that his analysis geometrically proved the real hydrodynamics of the propeller, and at the same time the impossibility of any such thing as a screw "race," "column"—rotating or otherwise—"vortices," "centrifugal action," etc. (which had hitherto occupied so uselessly, or rather disastrously, the minds of professional experts), being produced by the propeller's action and reaction under ordinary conditions of working. For still further illustration, take again the example propeller at its extreme diameter, where the propeller face of the blade, during a movement equal to its own breadth, only moved the water against which it pressed ·82 inches. It must also be noted that this ·82 inches was only completed at the end of the movement by the last point in the blade, the mean

sions as "water passing into or through the screw," "rotation of the race," etc. The water had no tendency whatever to pass "through the screw." It was the screw that passed through the water. If the ship was going against a strong current, the current would *assist* the turning of the screw. If on the other hand the current were running with the ship the effect of this following current was to *retard* the turning of the screw, the resistance to the turning of the propeller blades being increased thereby. He might add here that the almost universal idea of a body of water called a "race," being driven astern at some velocity by the action of the propeller was entirely illusory. What so appeared to those who spoke of a "screw race" arose doubtless from the forward movement of the vessel *leaving* astern the commotion caused by the rapid displacement of the water by the bodies of the screw blades. This apparent sternward movement or "race" as it was erroneously called, did not *recede* from the vessel. It actually followed it to some extent, under the influence of the wake.

movement of the water across the blade at this diameter, at any given instant, being one-half, or ·41 inches. Another notable fact was that the blade, at this diameter, at 10 per cent. slip, passed through a distance of 67·62 feet in one revolution, and at any given instant was *only acting on the water across its own face, and nowhere else.* As this face was only $\frac{1}{37}$th part of the distance passed over, the remaining 36 parts, *or fully 97 per cent. of the revolution remained unacted on.* Further, each particle of water touched by the blade had only been in contact with it $\frac{1}{37}$th part of a second, and had been moved ·82 inches at a *uniform velocity.* The flat propelling face of the blade only glided over the water face of the nut. The slip movement began as quietly as it ended, the movement of the water by the first *inch* of the blade being barely $\frac{1}{28}$th part of an inch, so that no impulse or blow was given to the water by the blade, and likewise no time, so to speak, for the water to yield to pressure. Then as the body of the blade left an empty space behind it, any sternward or angular movement given to the water against which the blade had pressed was extinguished by that water falling into this space. These important facts being fully understood, there was no difficulty in comprehending how the reaction of the propeller was obtained with the slightest sternward movement of the water. Before leaving the hydrodynamics of the propeller, it might be well, though it lengthened his reply, to examine Mr Froude's remarks on this point, as given in the discussion of his 1890 paper, which he had printed in full for distribution. It would be observed that Mr Froude unfortunately again confused the issue, and made it appear that he said exactly the opposite of what he did say by using AE in Fig. 2 for the breadth of the blade and DE for the movement of the water by the blade in moving its own breadth, and then went on to say "during a complete revolution of the propeller the water moved not only as Mr Howden says the distance ED (where AE is the blade width) but that distance multiplied by the number of times the blade width is contained in the distance of the spiral travel per revolu-

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tion." Mr Froude (besides being in error in taking A E of Fig. 2 as the width of the blade which gave a slip E D in moving its own with, for it was a width of blade equal to A C that gave E D) instead of using Fig. 3 of his (Mr Howden's) 1890 paper, or Fig. 4 of the present (where the 10 per cent. slip illustration was shown correctly to scale, and also the actual slip movement by the blade in the two close parallel lines) used Fig. 2, which in both papers showed the total slip *on the revolution*, to represent the slip on a movement of a blade width, a width which in this Fig. would be on the extreme diameter of the propeller equal to the whole convolution, or 68·62 feet. This was sufficiently confusing, but was much less than what followed, which was, as given above, "that he said the water moved not only the distance E D, but that distance *multiplied* by the number of times the blade width was contained in the distance of the spiral travel per revolution." How such a statement should be made after he had written all these papers to prove the exact contrary was difficult to comprehend. Any one reading and accepting this statement of Mr Froude must be impressed with the large volume of water dealt with by this propeller, not suspecting that this E D of Mr Froude was actually only ·82 inches at 10 per cent. slip, and that instead of this movement being multiplied 37 times in a revolution *remained at ·82 inches during the whole revolution*, though the screw dropped in the period 2·77 feet in slip. Mr Froude, notwithstanding all his (Mr Howden's) explanations, apparently did not understand what he was criticising, as his statement reversed his (Mr Howden's) geometrical proof. Mr Froude, after this statement, went on to refer to the case of the ricochetting shot given by him as illustrating the great resisting power of water when suddenly struck by even such a body as a round shot, and said:—"The reaction derived from this and all other cases arises alike from the circumstance that water is not only set in motion but that it is *dismissed* in motion; and in all cases by the quantity set in motion multiplied by the speed with which it is dismissed. To dispute this proposition is to dispute not only the received theories of the propulsion of vessels, but the first principles of hydrodynamics." If Mr Froude stated correctly here what were the *received* theories of the propulsion of vessels and the *received* first principles of hydrodynamics, he had no hesitation in saying that it was time that these received theories and first principles received further examination. The illustrations he had given afforded sufficient reasons for rejecting these theories and principles as stated by Mr Froude. A 100-lb. round shot of nine inches diameter, when it struck the water at a high velocity and moderate angle, did not appear to sink more than its own diameter, and rose again instantaneously. It scooped out a very inconsiderable quantity of water which it drove forward, upward, and around, when it struck the water, and rebounded therefrom at a somewhat reduced angle. The resultant or direction of the reaction of these forces would be nearly perpendicularly downwards so that the quantity and velocity of the water dismissed to give the required reaction, according to Mr Froude, must extend fathoms deep, the area struck being small and the forces great. Experience, however, showed that such reaction was obtained with extremely small motion of the water downwards. Should a small fish happen to be only a few inches right under the centre of the forces of reaction where this ball struck, it might receive a nervous shock, but no bodily harm from the "dismissed" water. Now this spherical shot, small but heavy, *striking* the water at such a tremendous velocity, say from 400 to 500 feet per second, must have a vastly greater effect in penetrating, moving, and dismissing water than that of a flat, broad surface, like a screw blade, which did not strike the water at all, but glided over it many feet under the surface at a high velocity, with a comparatively small pressure against the water per square inch of surface of blade. The water dismissed by the pressure of the blade face was a mere bagatelle, as his analysis showed. Multiplying its weight or quantity by the speed at which it was dismissed would not balance a hundredth part of the actual force of reaction given by the scarcely yielding water to the screw blades. There was in short

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practically no dismissal of water made by the screw blades at ordinary working slips, and therefore, according to Mr Froude, no reaction. The accumulated movement on a particle of water from the beginning to the ending of the line across the blade was exceedingly small and the velocity was uniform. The last touch given by the blade, as well as the first, was infinitely small. There could, therefore, be no dismissal. Mr Froude and his hydrodynamics had, in fact, here no material to work on. The particles moved did not rebound from the blade, but fell into the cavity left behind its body, which cavity, in proper screws, should always be greater than the quantity of water moved as slip by the face of the blade. These facts, brought to light by his analysis of the actual motions of the propeller, quite destroyed the hydrodynamical theory of its reaction in Mr Froude's sense. The reaction of the propeller rested more on hydrostatics than hydrodynamics. Its fallacy, like that of Prof. Rankine's theory, which Mr Froude defended, lay clear on the face of it. Take, for example, the case which he (Mr Howden) had tried again and again to bring home to the consciousness of his opponents on this question, where the slip was reduced one-half, say from 10 per cent. to 5 per cent., the engine power and revolutions remaining the same, the ship gained thereby an addition of 5 per cent. to her speed, the thrust and consequent reaction being necessarily increased to give the increased speed. This increased thrust was obtained by the power previously wasted in moving the double quantity of slip water being utilised for propulsion. Mr Froude's hydrodynamic theory applied here would give the 5 per cent. slip and increased speed, with only half the water dismissed at half the velocity. By this hydrodynamic theory the increased speed of 5 per cent. would thus be obtained by *one-fourth* the thrust power required for the lower speed. Prof. Rankine's theory, as he had all through shown in his various papers, was based on the same fallacy. It had always greatly astonished him how highly educated men should maintain such palpable fallacies when these had been pointed out, and a real solution of the questions at issue had been shown to them. He knew nothing in the history of science to equal the behaviour of those experts who had employed themselves in formulating theories regarding the action of the screw propeller. Though it was evident that this strange anomaly had arisen by their holding on to theories based on imaginary and impossible assumptions instead of ascertained facts, the difficulty remained, *why* this should specially happen amongst experts dealing with the action of the screw propeller? He had already given his opinion that very much of the existing extraordinary confusion of ideas regarding its action was owing to the high and merited reputation of Prof. Rankine, who so far back as 1865, when the screw propeller had but a short time before begun to displace the paddle wheel in propelling ships, formulated his theory, which to mathematicians in naval and engineering circles, who had not thought out the subject for themselves, appeared to be a complete and scientific exposition of the subject. When once such a theory regarding an apparently complicated subject took hold, and was taught in Universities and in Naval Colleges, it became doubtless difficult to convince those who had been so educated of its erroneousness. But it was still difficult to understand how such special prejudices should have arisen in reference to this one subject. Those who studied impartially the history of these theories of the screw propeller must, he thought, be convinced that nothing had done more to prevent the true action of the screw from being understood and accepted than the false conception of a great sternward movement of the water being necessary to obtain the required reaction such as that on which Prof. Rankine's theory rested. Examples of the maze of confusion and uncertainty existing in the minds of those who endeavoured to believe in these theories could nowhere be better shown than in three papers of Mr Froude, read before the Institution of Naval Architects, two in 1899, and one in 1892. In these papers the evidently sincere but vain attempts to grapple with the insuperable difficulties of the Rankine column were painfully manifest. This blind following of recognised authorities was not, however, confined to Mr Froude.

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It appeared to have affected all in the higher ranks of naval and engineering science. *Fourthly,* The long explanation of the action of the propeller blades given under the last head rendered it almost unnecessary to refer to this supposed centrifugal action of the propeller, though it was at one time very widely held, and as was evident from this discussion it still had a place in some minds. Centrifugal action could only be set up by an instrument revolving continuously among the same particles of water, which was exactly what was *not* done by propeller blades in screwing. It had been shown that the propeller blades were only in contact with the same particles of water for the merest fraction of a second, so that there was not the slightest tendency for the blades to set up any centrifugal action; on the contrary, the displacement of water, caused by the body of the propeller blades, was much greater towards the centre of the propeller where the large boss and the thick roots of the blades in their movements left large cavities to be filled up by the surrounding water, and necessarily caused a flow of the water from the outer parts towards the centre. This he had explained in his paper of 1878, where Fig. 6 illustrated the movement of the water towards the centre of the propeller. *Fifthly,* Mr Froude in his 1886 paper did not give sufficient information to enable one to understand how his experiments with model screws were carried out to provide matter for a definite criticism. It was only recently, by noticing some remarks by Mr Barnaby in reference to Mr Froude's trials with model screws, that he (Mr Howden) came to learn that Mr Froude's experiments were made in a similar manner to those recorded by Mr Barnaby in his paper of 1890, read at the Institution of Civil Engineers. Mr Barnaby's account of these trials was very interesting, and with the diagrams enabled one to understand the manner in which the slip and thrust were obtained, and the power as well as the curves of useful work and efficiency calculated. In these experiments by Mr Barnaby the model screw was placed at the end of a shaft projecting from the bow of a steam launch driven by an independent engine which was supposed to give a speed to the launch, during the experiments, of $4\frac{1}{2}$ knots. The model screw used, from which the diagrams were made, was 9 inches in diameter and 10·3 inches pitch. An independent engine turned the model screw which had necessarily to run up to 531 revolutions, or 456 feet per minute, to attain the same speed as the boat when driven by its own screw at $4\frac{1}{2}$ knots. Mr Barnaby's diagrams showed, however, a positive thrust at 500 revolutions on the model screw, so that either the actual average pitch must have been greater than 10·3 inches, or the speed of the launch at the moment these revolutions were taken must have been less than $4\frac{1}{2}$ knots; very probably the latter, as the trials were made in the River Thames where the speed could easily drop without being noticed. To create the various percentages of slip, the model screw necessarily required to run at a higher speed than the speed of the boat, and consequently the power required to be increased as the slip was increased. At 500 revolutions of the model screw the slip was 9·5 per cent., and the thrust was 1·75 lbs., as nearly as could be measured on the diagram, while the power expended was about 1,200 foot lbs. per minute. At 600 revolutions the slip was about 17·3 per cent. thrust, 6·6 lbs., and power expended 4,000 foot lbs. per minute. At 700 revolutions the slip was 29·3 per cent., the thrust 12 lbs., and the power expended 7,440 foot lbs. The speed of the boat at 500 revolutions appeared to have been 3·83 knots, at 600 revolutions 4·2 knots, and at 700 revolutions 4·1 knots. The thrust here rose in a much greater ratio than the slip, more especially as between that at 500 and 600 revolutions than between 600 and 700 revolutions, the power expended also rising in a much greater ratio between the 500 and 600 revolutions than between 600 and 700 revolutions. The curve of useful work in these diagrams was illegitimately made up by multiplying the speed of the launch by the thrust of the model screw, that was, the thrust of the model screw was credited with the speed given to the launch by the launch's independent engine. Further, the efficiency curve was obtained from the useful work divided by the power expended. Fig. 22 was a copy

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of Mr Barnaby's diagram showing the curves of thrust, useful work, power expended, and efficiency, with varying revolutions. He understood Mr Froude's slips and thrusts were obtained in the same manner as those of Mr Barnaby, but instead of using a launch to carry his model screws, these were carried on a truck running on rails over a tank, where the speed of the truck would be accurately calculated, and also the percentages of slip. The truck and model screws were also independently driven by separate engines, and the results calculated on the same lines as those employed by Mr Barnaby, including that of the curves of thrust, power expended, useful work, and efficiency. If he was correct in supposing that Mr Froude's data were obtained similarly to those of Mr Barnaby, he must say that the process was entirely different from that of a screw propelling a ship, and that any deductions from these experiments applied to the case of a propeller working with a slip in a steamship would be entirely misleading. In a steamship where large slip was being made, the engines were generally working at a less power than when small slip was made, and with fewer revolutions. In these model experiments even moderate slip could not be made at all without increasing both power and revolutions largely. In a steamship with engines at the same revolutions as when a small slip was being made, the slip might be trebled or more than trebled without any increase of power being used, or even with a less power. This depended very much on the form of the blades, but, at all events, more or less slip was not dependent, as in the model screw trials, on more or less power and revolutions of the engines. Mr Froude's model experiments were quite inapplicable to the case of ship propelling, as these artificial slips, as they might be called, of the model screws were entirely different from the natural slips occurring in propelling. In the latter no increase of power or revolutions was required to make slip, while in the former an appreciable slip could only be made by a large increase of power and revolutions. Mr Froude's endeavour in his criticism of his (Mr Howden's) 1890 paper to prove that a trebled slip produced a

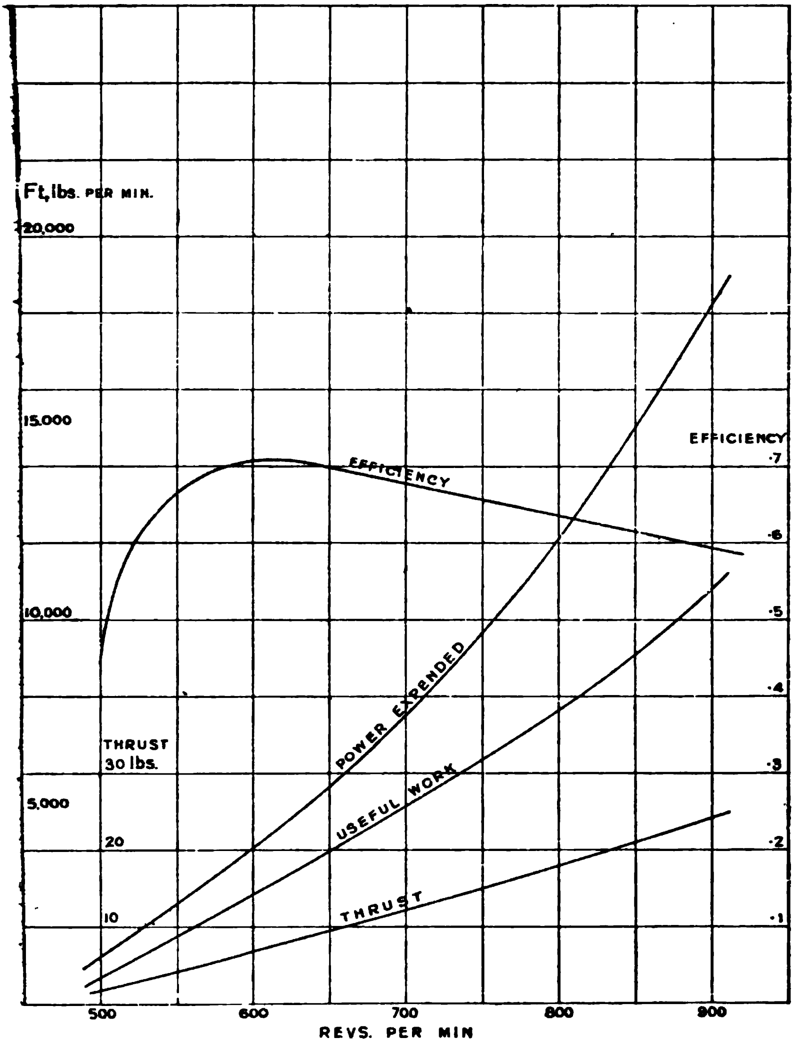
Ft, lbs. PER MIN.
20,000
15,000
10,000
5,000
THRUST
30 lbs.
20
10
EFFICIENCY
·7
·6
·5
·4
·3
·2
·1
EFFICIENCY
POWER EXPENDED
USEFUL WORK
THRUST
500
600
700
800
900
REVS. PER MIN

Fig. 22.

trebled thrust had evidently arisen from his being misled by taking the results of model experiments as being applicable to ordinary screw propelling in a ship. Arguments could be multiplied to show that there was no legitimate connection between these experiments and ship propelling, but he thought enough had already been said to prove this fact. It would be seen that he was correct in what he said, in criticising Dr. Caird's paper on "Propeller Diagrams," that the efficiency curves given in that paper, made up on Mr Froude's 5th proposition, were entirely misleading, being based on ideas having no foundation in fact. A screw of the highest efficiency was one that in any given case gave the highest speed to the vessel it propelled with the least expenditure of power. Mr Froude's highest efficiency was, he might say, obtained on almost the opposite conditions, the expenditure of power in obtaining the so-called efficiency having apparently been forgotten. *Sixthly*, That he neglected or controverted Newton's three laws of motion. This was rather an amusing charge. In his investigation of the propeller he did not trouble himself about these laws of motion. What he was concerned about was establishing the actual facts connected with the action of the screw propeller under any given conditions of working. This, he believed, he had accomplished. If so, then he was quite sure that Newton's laws would be satisfied. They always supported facts. Having now noticed the principal points of his paper criticised by those who had taken part in the discussion, he might now refer shortly to the individual character of their remarks. Beginning with his friend, Dr. Caird, he might confess that before hearing his remarks, he felt considerable curiosity as to the manner in which he would treat his demonstration of the real action of the propeller and the erroneousness of the Rankine and analogous theories, which demonstrations he so emphatically asserted had been absolutely refuted in all the discussions which followed the reading of his former papers. Of course he naturally hoped that Dr. Caird would do what was right by acknowledging his mistake and making an apology, both on his own account and in the interests of truth and justice. Remembering, however, the astonishingly uninformed condition of most audiences on this subject, he feared that Dr. Caird would, instead of doing what he ought to do, evade the issue, and back out of it by some stratagem. He knew if Dr. Caird attempted a straightforward frontal attack by counter geometrical and quantitative demonstrations, the result would be an open defeat, as his weapons would prove his own destruction. If again he attacked from behind his allies or champions, using them as a screen, those who, he had asserted, had in the discussions of his former papers utterly destroyed his (Mr Howden's) demonstrations, he knew he would also fail. These champions, as he had shown in this paper, instead of being victorious, merely showed their own misunderstanding of the subject and their failure to deal with his demonstrations. The tactics which he feared Dr. Caird would resort to had actually been followed. Dr. Caird had entirely refrained from approaching the questions at issue. His direct challenge Dr. Caird left wholly unanswered. The real matters under discussion were left unnoticed. Instead of occupying himself with arguments on vital points, Dr. Caird began a specious narrative, effusively candid in appearance, and went round the outskirts of these issues as if busy with them, but never approached them. After thus raising a veritable cloud of words he eventually rode off under cover of this cloud as if he had again "completely and conclusively refuted" all his (Mr Howden's) demonstrations by merely repeating his original statement to this effect. If such methods of conducting arguments on controverted points on mechanical subjects were believed to be fair or admissible by those who employed them, they must either hold the reasoning capacity of their readers or audience very cheaply, or have themselves a very inadequate idea of what was due to opponents in the conduct of such arguments. It might be of interest to notice some special features in the manner and matter of Dr. Caird's treatment of his (Mr Howden's) demonstrations *now*, compared with his tremendous attack of 1896. Dr. Caird was now extremely mild and apologetic,

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and, while endeavouring to maintain his original position, this was diplomatically kept in the background, and not openly asserted. Dr. Caird also spoke in a fine spirit of humility of his own 1895 paper on "Propeller Diagrams," as being a mere nothing to raise all this trouble about, "a mere step in the evolution of the analysis of the action of screw propellers," and ignored his own introduction to that paper as follows:—"Mr R. E. Froude's 1886 paper, read before the Institution of Naval Architects, marked an epoch in the investigation of the properties and behaviour of the screw propeller," after which he quoted the "fundamental propositions" laid down by Mr Froude in this paper, culminating in the famous 5th proposition which Dr. Caird found so effective as to be beyond praise, but which he (Mr Howden) unfortunately, after examination, could not find that it in any manner solved any material question regarding the propeller's action. It must also be remembered here that the title of this 1886 paper of Mr Froude's was "The Determination of the Most Suitable Dimensions of Screw Propellers," an object of the most important character connected with the propeller. It was remarkable that Dr. Caird's tactics should now lead him to so belittle his own, and his champion's paper. This was consistently carried out to the fullest extent, as Dr. Caird now meekly declined to defend those champions who, he formerly affirmed, had entirely demolished his (Mr Howden's) papers. Dr. Caird, for example, had not a word now to say in support of Dr. Inglis's wonderful column of *indefinite length* to which the screw added pieces of 25 feet each revolution, but which he held could be easily measured and weighed, or that other still more wonderful column of this same champion made up of films an inch or more thick each revolution, until a full column was made up; nor did he even defend Mr Froude's wonderful propellers which required a trebled power to force them to make a trebled slip. Even Dr. Caird's former accusations against him of "gross and palpable blunder," and other improprieties in his criticism of the "Propeller Diagrams" paper, which he had shown to be quite a mistaken charge,

were now conveniently forgotten. Dr. Caird continued his remarks in the same mild strain regarding the Author's geometry, which, though he still held it refuted by Mr Froude, yet considered it faultless so far as it went. The Author had already dealt with this point as well as the impossibility of his methods, if carried further, yielding, as Dr. Caird thought, results identical with Rankine and Froude. He had further also showed good reasons for standing alone against all the reputed leading authorities on the hydrodynamics of the propeller's action, and did not, therefore, require to say more on this subject. He only stopped one moment to notice Dr. Caird's figures given in illustration of the applicability of Mr Froude's curves to the case of the two screws in the same ship which he gave ten years ago, in disproof of Mr Froude's 5th proposition being a guide in determining the most suitable dimensions of propellers for steamships. Dr. Caird here showed how he would apply Mr Froude's curves to the case mentioned so as to produce screws on these diameters which would give the highest efficiency. The particulars were as follows:—

Diameter.	Pitch ratio.	Revolutions.	Slip ratio.	Efficiency.
12′ 0″	1·1	94	20%	1·000
10′ 0″	1·1	124	26%	·975
10′ 0″	1·6	94	33%	·940

It should be remembered that the two screws mentioned by the Author, which were applied to the same ship, gave equal speed with the same power and revolutions of engines, the pitches being alike and the surface of blades nearly alike, though differently disposed. The revolutions of the engines were under 70, and the slip from 5 to 10 per cent. according to weather, loading, etc. According to Dr. Caird, Mr Froude would have wanted a slip ratio of not less than 20 per cent. for the 12 feet screw, the pitch ratio being 1·1; highest efficiency being attained with 94 revolutions. For the 10 feet screw, with a slip ratio of 26 per cent., pitch ratio also 1·1, and 124 revolutions per minute, the efficiency was 2½ per

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cent. less than that of the 12 feet screw. An alternative was given for the 10 feet screw with a slip ratio of 33 per cent., the pitch ratio being 1·6 and the revolutions 94, the efficiency in this case being reduced by 9 per cent. from that of the 12 feet screw. A more complete condemnation of Mr Froude's formula could not have been given than was given by these figures of Dr. Caird. The revolutions, to begin with, would have been entirely unsuitable for the engines, if not impossible, while the power necessary to give the speed at these revolutions with such great percentages of slip would probably have been at least 20 per cent. more for the 12 feet screw, and 30 per cent. for either of the 10 feet screws. As he had said before, Mr Froude's efficiency was not concerned with the power expended, and the waste by slip was entirely ignored. In conclusion, he regretted to find that Dr. Caird, without bringing forward one proof, or one tangible argument, in support of his assertion that the Author's papers on the screw propeller were completely and conclusively refuted in the discussions which followed their reading, should consider it justifiable to reiterate that he still considered Mr Froude's remarks in the discussion of his 1890 paper "a conclusive refutation of the arguments advanced by Mr Howden in that paper." The remarks of Mr R. E. Froude were, he regretted to say, of a character which did not do justice either to his personal or inherited reputation. Mr Froude tried to belittle his work on the screw propeller as something of no moment whatever, and considered his propositions were merely of an elementary character, and already premised by those investigators whose work he denounced. Nor did he appear to Mr Froude to have got beyond the A B C of the subject, who questioned if he had ever attained the B C. He also appeared to Mr Froude to lack the knowledge of the science of hydrodynamics, and until he proved he possessed such knowledge Mr Froude would consider it a waste of time to concern himself with his criticisms. The character and spirit of such remarks placed them outside the pale of ordinary treatment. They had evidently been written under the influence of some feeling. It would give him all the more regret if his probably rough banter over Mr Froude's masterful screws had led to any irritation. He had no thought, and certainly no intention of giving offence, and regretted if he had unfortunately done so. His old friend and former antagonist on this subject, Dr. Inglis, had sent a characteristic communication, but not, he thought, in his happiest manner. Dr. Inglis had, he found, now retired from the contest, feeling doubtless in this case that "discretion is the better part of valour," and had taken shelter behind "Rankine, Froude, Barnaby, and others." Dr. Inglis' memory must have failed him in saying, regarding his paper of 1878, that he had offered a few remarks on it at his request, as, previous to his taking part in the discussion of that paper, he (Mr Howden) had had no communication whatever with him on the subject. He remembered, however, having sent him a corrected copy of that paper, which he got printed and sent to some of the Members of the Institution after the Transactions had been published, it having been, by mistake, printed there without some corrections he had previously made. The true theory of the screw propeller was not yet buried, as Dr. Inglis supposed, it was just beginning to come to fuller life. The remarks of Prof. Robertson were altogether so much out of line with all his views of the propeller's action that the time and space at his disposal did not permit of noticing them individually. He would only ask Prof. Robertson to do him the honour of reading his paper and studying his demonstrations and diagrams without bias, if possible, as he was sure this would correct most of his opinions. Prof. Robertson would find that the water, and nothing else, was the nut in which the screw worked, that the water did not rotate with the screw, that the blade did not suddenly strike the water, or that the water—like a pugilist—in return struck back a blow on the blade. The blade was immersed in the water, and if a proper screw were used the two worked in harmony and quietness. Prof. Robertson's proposal, to test the action of the propeller by placing circular discs fore and aft of it so as to prevent longitudinal motion of the water, and then to remove them suddenly when full speed was obtained,

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had this fatal objection, it could not be carried out because the vessel would never attain any speed under these conditions, as the screw would by them be prevented from screwing. On the other hand, the thin metal cylinder shrouding the periphery of the blades so as to prevent the radial action which Prof. Robertson supposed to be the principal action of the screw, would scarcely interfere with its efficiency instead of destroying it altogether, as Prof. Robertson thought it would. Prof. Robertson admitted he was but an outsider in shipbuilding matters, which indeed was evident. He hoped, however, a further study of his paper would lead him to change most of his present beliefs regarding the action of the screw propeller. Prof. Jamieson considered he ran counter to Newton's laws, but as this evidently arose from his neglecting to take the friction of the blades into account, he had no doubt that when he informed Prof. Jamieson that he had, as stated in this and all his other papers, purposely eliminated friction, Prof. Jamieson would exonerate him from any antagonism with Newton's laws of motion. He believed also Prof. Jamieson would, for the same reason, admit the correctness of his propositions 2, 5, and 6. Prof. Jamieson, in referring to the Rankine theory and the application of the formula $\frac{Wv}{g}$, undertook to show no less than "three distinct mistakes" in this application; but Prof. Jamieson, in so proposing, could not have read his paper very carefully, as he was not at all responsible for the application of this formula to the Rankine column. It was all the other way. He quite objected to the formula $\frac{Wv}{g}$ being used at all. It was Prof. Rankine's own formula, as applied by himself in illustrating his theory, and he merely showed how condemnatory it worked out for his theory when applied to different percentages of slip in the same steamship. Prof. Jamieson's attack on the formula of the Rankine theory was, therefore, all thrown away on him, as it was not his formula but Prof. Rankine's. He ventured to suggest, however, that Prof. Rankine was not so ignorant of Newton's laws as Prof. Jamieson's criticism of this formula seemed to imply. The remarks of Mr James Hamilton bore so much on matters concerning the action of the propeller, which he had already fully explained in reply to similar criticisms that he need not again refer to them. Mr Hamilton would find he had fully shown that the difference between Prof. Rankine's theory and his (Mr Howden's) was radical and complete instead of being very much alike. Mr Hamilton was necessarily quite wrong in supposing that the screw blades in the Allan Line turbine steamers cut up the whole water spaces between the blades "so that he would be forced to admit that the whole column was moved astern." He did not admit that any column of water whatever was moved astern, as there was no column to move. Nor did he admit that the water spaces between the blades were entirely cut up. Such ideas could only arise from entirely neglecting the geometry of the screw's action. If the water were entirely cut up by the screw blades working so closely to each other, the ship would necessarily have no speed. The water was only moved equal to the slip of the revolution divided by the breadth of the blade, as he had explained, and it would be found to be a comparatively small amount unless the screws were working with excessive slip, which he had no reason to suppose was the case. Mr Hamilton made a very extraordinary statement in saying that "Dr. Froude, a year after he (Mr Howden) read his paper in 1877, practically covered the whole of his seven propositions." It would have been flattering to him if Dr. Froude had done so, but nothing could be further from the actual facts than this statement. Dr. Froude's ideas on the subject were entirely opposed to his, as were shown by the conclusions arrived at. It was unnecessary to say more on this point, as anyone could ascertain its correctness by reading Dr. Froude's paper of 1878 and his (Mr Howden's) papers of 1877 and 1878. He had reserved Mr Luke's remarks for special notice, they being of a somewhat special character. Mr Luke began by telling how that Dr. Caird's remarks had cut the ground from under his feet, so thoroughly did he concur in Dr. Caird's views

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regarding his paper. Mr Luke then went on to explain why he, as a young man, took part in the discussion, and how at the previous meeting he was prepared to listen with sympathy to his paper, but unfortunately found it of a character that very unfavourably impressed him when hearing it read, an impression that was intensified on carefully reading it over afterwards. Mr Luke went on to explain that what had roused him so powerfully, were his (Mr Howden's) remarks on page 176, and also the quotation, "that, though at the discussion of my 1890 paper, mathematicians of the highest rank, whose theories I had controverted, took part, not one challenged my geometrical and other demonstrations, either of the true action of the screw or of the erroneousness of the theories of Rankine, Froude, and others," which remarks and quotation Mr Luke said, "could not be described as anything else than disingenuous." Further, Mr Luke continued, "he hoped that Members would refer to that discussion and see for themselves exactly what was said, and they would find Mr Howden's remarks conveyed a false impression." Mr Luke went on to tell that Mr Froude completely controverted him in that discussion, Mr McFarlane Gray was crowded out for want of time, Prof. Greenhill made a few complimentary remarks, etc. In reply to all this, he would merely repeat what he had said in his paper and call attention to the fact that, all those whose views he had controverted had advance copies of his paper sent them at least a week before it was read, so that they might be prepared to take part in the discussion. Mr Froude, Prof. Greenhill, and Mr McFarlane Gray, had full time at their disposal for making whatever remarks they had prepared. He was, in fact, the only one "crowded out." Mr McFarlane Gray said much more than was reported in the Transactions, but as much was of an irrelevant character he (Mr McFarlane Gray) evidently thought it better to leave it out. As he had taken the opportunity of printing, by permission of the Institution of Naval Architects, a full copy of the discussion of his 1890 paper, and had sent copies to the Secretary for distribution among the Members, it would be seen by all who read it how far Mr Luke was correct or otherwise in charging him with having given a false impression of that discussion. Mr Luke continued by asserting his (Mr Howden's) ignorance of the laws of motion, and of, in short, everything regarding the proper understanding of the screw, and that his paper was a mere mass of dogmatic assertions based on general ignorance. So much was Mr Luke impressed with the extreme worthlessness of his paper that, he could not conceive how any scientific institution could accept such a paper consisting only of ideas which were exploded some fifteen or sixteen years ago, if not before, a paper which would injure the Institution by being published in its Transactions. Possessing the common feelings of human nature, he confessed that such extraordinary personal denunciation in a meeting of this Institution was what he was quite unprepared for. In discussions at such meetings, more especially where scientific subjects were treated, even when much difference of opinion existed, one at least looked for courtesy not being entirely absent. When a striking departure from the usual amenities unexpectedly occurred, it was difficult for one to quickly adjust one's mind to the new and unpleasant situation. While Mr Luke was summing up the enormity of his offences, he (Mr Howden) seemed to lose his identity, and be no longer in the Institution in which in his youth he spent many a profitable and happy hour, but was now some other person in a Court of Justice under trial for some heinous offence, with a public prosecutor, zealous for the interests of the community, vehemently enumerating the crimes of the accused. The denunciation of the Committee on Papers must have partially recalled him to his senses, as he then felt that nothing less than expulsion from the Institution would expiate the enormity of his offences. It was difficult for him to understand why his paper had caused Mr Luke to make such condemnatory remarks; but, perhaps his early training had led him to consider that his (Mr Howden's) reference to the writings and formulæ of certain writers on the Screw Propeller (who were doubtless regarded by Mr Luke as the highest authorities on the subject) as

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being "founded on erroneous assumptions and without any scientific basis," was outrageous. If such were the case, it would not matter to Mr Luke whether he gave an unassailable geometrical proof of the correctness of his statements or not; no geometry or argument would convince him, or those equally prejudiced, that he could be anything else than wrong. He was, therefore, not long in regarding Mr Luke's criticism with absolute equanimity of mind. There was, he granted, a certain virtue attached to blind devotion to authority, but he ventured to submit that geometrical and mechanical questions could not be solved by simple denunciations. He hoped, however, that Mr Luke would yet apply his evident abilities to an unprejudiced study of his paper, which, if he did, he guaranteed he would come to conclusions regarding it quite the reverse of those he lately so forcibly expressed. The only other Member who took part in the discussion of February last, who remained to be noticed, was Mr E. Hall-Brown, who, after putting himself in line with the other speakers by stating that he absolutely disagreed with his theories (keeping like others the cause and nature of these disagreements carefully concealed), as Convener of the Committee on Papers, offered a somewhat faint protest against Mr Luke's censure of the Committee for allowing his paper to be read. He excused the forbearance of the Committee on the ground of his long connection with the Institution, and the fact that his paper would at least serve the purpose of sending the young men of the Institution back to the literature on the subject to study the writings of Rankine, Froude, and Greenhill, for themselves, and thereby eventually save the Institution from harm. This idea of saving the young men and the Institution from being damaged by his paper (the older Members, like himself, being damage-proof), struck him as so good that he, for one, felt ready to assist in this endeavour. He trusted the Council would approve and accept, even from so dangerous a Member of the Institution as himself, the offer he (Mr Howden) now made of £50 as a prize to any young Member who would, in the judgment of two competent neutral experts, one to be chosen by the

Institution and the other by himself, prove geometrically and quantitatively the erroneousness of his views on the action of the propeller, and at the same time the correctness of the theories of Rankine, Froude, Greenhill, or others who held views opposed to his. An interesting communication from a Member of the Institution, Mr Matthey, presently residing at Kiev, was sent to him by the Secretary while he was engaged with the replies to the Members who took part in the discussion on his paper in February. Frequent absences from town prevented him from reading Mr Matthey's communication until he had completed these replies. This communication was marked by much ability, and was written in a fair and scientific spirit; yet, somehow, Mr Matthey had from the outset missed his argument and mistaken his demonstrations, and thus having got upon the wrong track had continued to follow it throughout the whole of his argument. Mr Matthey began by stating "that there was no difference between Mr Howden and Rankine as to the motion of the water in the immediate neighbourhood of the propeller blade, though they differed in the deductions they drew from that motion." This remark gave the key to the whole of Mr Matthey's subsequent treatment of the subject and the mistaken conclusions at which he arrived. As he (Mr Howden) had already used a large part of his reply in controverting this mistaken idea that his view of the motion of the water by the blade was in any way like that arrived at by Prof. Rankine, he must refer Mr Matthey to what he had already written to show that he (Mr Matthey) was mistaken in the conclusions quoted. Mr Matthey had given himself much trouble in working out the motions imparted to the water over the whole surface of the blades on the view assumed by Prof. Rankine, as if such motions actually existed. If he had proved anything by his demonstrations, it had been that no such motions existed. It, therefore, became a mere waste of time to make up such diagrams and calculations as Mr Matthey had done in order to ascertain the thrust and I.H.P. of the propeller. He had already shown that the only agreement

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between Prof. Rankine and himself on this subject was that, the slip of the water at any given diameter was less than the slip of the screw per revolution in the proportion of DE to DC in Fig. 2 of his paper. Beyond this single point there was a complete difference. In the case of the example propeller at 10 per cent. slip, Prof. Rankine added the whole slip of the water per revolution to an imaginery cylindrical column 25 feet long by 20 feet diameter, in order to obtain a reaction or thrust from the movement of this mass in one second and by one impulse, a distance equal to the total slip of the water on the revolution. On the other hand, he proved that, instead of this 27 inches or so of slip movement of water being given to this imaginery column of about 27·24 feet in length, there was no such column in existence, and that the movement of water by slip, normal to the face of the blade was, at 20 feet diameter of this propeller, only ·82 inches, which was ascertained by dividing the length of the line DE of Fig. 2 by the number of times the breadth of the blade was contained in the line AD, which, at the extreme diameter, was a thirty-seventh part of DE. Fig. 4 of his paper showed to scale the actual movement of water at 10 per cent. slip with this screw at 12 feet 6 inches diameter, where the blade was much broader and the distance travelled per revolution much smaller than at 20 feet diameter. Mr Matthey, in his calculations, used the resultant of the components of the tangential and sternward movement of the slip in order to calculate the thrust and I.H.P. on Prof. Rankine's lines, and consequently reduced the extent of the movement from that used by him, which was simply the movement of the water by slip normal to the face of the blade. If the great movement of the water by slip, on which Prof. Rankine based his formula, actually existed, and if it were possible to make the formula $\frac{Wv}{g}$ applicable (both which suppositions, he said, were incorrect), then Mr Matthey's mode would give more exactly the thrust and power for any individual percentage of slip, but would not exhibit more exactly the error of the whole formula, as proved, when applied to different percentages of slip, which latter was the principal object he had in view in demonstrating the radical erroneousness of Prof. Rankine's theory. This would be more easily understood by pointing out that Mr Matthey made the *thrust* I.H.P. by his application of the Rankine formula at 10 per cent. slip as 1,360, while by his mode of applying the formula it was 1,635 I.H.P. If calculated in both modes, say for 5 per cent. slip., the I.H.P. would in each case be nearly one-half of these respective powers, and similarly, if applied to 20 per cent. slip, the I.H.P. would be nearly doubled in both cases. The point of his argument was to show the radical error of the formula in being based on erroneous assumptions, and in making the thrust nearly proportional to the slip, as he had before so fully explained. He had not further time at his disposal to take up every point Mr Matthey referred to, but most of his questions, he trusted, he (Mr Matthey) would find answered in his reply to similar points which emerged in the discussion. To these he added the following:—The acceleration of the water by the action of the propeller, referred to by Mr Matthey in connection with Figs. 18 and 19, was actually so infinitesimal (being thirty-seven times less in quantity and thirty-seven times less in velocity at the extemity of the blade to that assumed by Mr Matthey and Prof. Rankine), that it was unnoticeable, and was quite lost among the other movements. The displacement of the blades much more than neutralized this acceleration. It, therefore, did not and could not affect the water levels or currents before or abaft the screw. It was only when the slip was abnormally large, say 70 per cent. or upwards, that this acceleration could become a matter for consideration. In the case of 100 per cent. slip, with the ship's stem tied against a quay wall and the engines running at normal speed, the whole engine power would be employed in sending the water astern by the screw blades, and would induce a large current from forward towards the screw. This current assisted the engines in turning the screw. The expression, water passing "into and through the screw," used by Mr Froude and others erroneously when the screw

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was at work under ordinary percentages of slip, would then be permissible under these conditions, as the screw would have no forward movement in itself. It would, however, then be no longer acting as a screw but as an immersed wheel, with floats of varying obliquity, set angularly to its axis. Mr Matthey went so far as to calculate the thrust and I.H.P. of the propeller of his paper on this percentage of slip, using the Rankine formula. The result was that the formula gave a thrust and power that no ordinary proportions of thrust block or engines could bear. It would have been supposed that this conclusive proof of the erroneousness of the Rankine theory would have led Mr Matthey to discard it, but it did not, nor did he use proposition 6 of his paper to assist him in solving his difficulties, but used BG of Fig. 14 as the movement of the water given by the blade at 100 per cent. slip. Fig. 23 showed the actual slip given by the screw

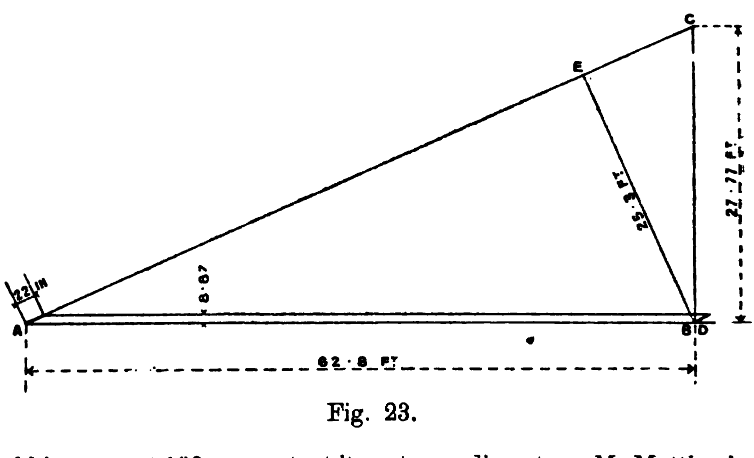

Fig. 23.

of his paper at 100 per cent. at its extreme diameter. Mr Matthey's BG and his DE at this diameter was 25·3 feet. The actual movement of the water, as shown by his analysis at this slip (100 per cent.), with twenty-two inches as breadth of blade, was barely nine inches. The AB, and also AD, of Fig. 23, was 62·8 feet, and the number of times the breadth of the blades was contained in A D was 34·2; and 25·3 feet, or D E divided by this number, was 8·87 inches. If Mr Matthey had studied his paper sufficiently he would no longer have felt it so mysterious that a screw might work at a slip of 100 per cent. on the same power and revolutions of engines as when working at 5 per cent. slip, the thrusts being equal. With some forms of blades and pitch ratios, the revolutions would be less at 100 per cent. slip with the same power than when at full speed at sea, and with other forms more. It was the same with paddle wheels, the revolutions might be more or less under these percentages of slip. This was dependent on the number, area, and immersion of the paddles. The other points about which Mr Matthey enquired were misunderstandings on his part, and were explained in the paper. He closed with a misapprehension. He (Mr Howden) *did* attribute the thrust to the inertia of the water, and to the fact that the reaction was obtained by the blade passing over new fields of water so quickly that no time was given to set up almost any motion by the face of the blade. As he had already expressed it, that owing to the velocity of the blade, it ran, as it were, over helically inclined planes of metal, so little did the water yield to the instantaneous pressure. He might be allowed to express, in closing this long argument, the conviction which he had always felt that if Prof. Rankine and Dr. William Froude had been spared in life until after he completed his paper on "The Review of Prof. Rankine's Theory," in 1879, they would have been the first to acknowledge the correctness of his demonstrations of the true action of the screw propeller. These were great men, as their works abundantly showed, men who had made those engaged in engineering and naval science and practice all over the world their debtors. They were men having the true scientific spirit which recognised truth from whatever quarter it came. He had not come much into personal contact with Prof. Rankine, but his grand manner, enhanced by his fine personal appearance, made him, as he regularly attended the meetings of the Institution, a never failing object of admiration to him (Mr Howden). The patient and courteous manner with which he

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gave explanations of questions, made by the most unenlightened of the Members, young or old, was so admirable to witness that he should never cease to remember it with pleasure. Prof. Rankine, besides being twice President, attended almost every meeting, and was constantly appealed to on all kinds of subjects, and never failed to respond. He was the Nestor of the Institution. Dr. Wm. Froude, he never met personally, though he had indirect communications with him. In 1878, after he had written his paper of that year, he was invited by Sir James Wright (then Chief of the Admiralty Engineering Staff) to see him on the matter of new screws for the "Iris." He called to see him on the subject when in London. Sir James was very desirous that he should go to Torquay and see Dr. Froude, with whom he had been in communication on the matter. He was very desirous to go, but some very pressing business prevented him from going at that time. The smaller screws with which the "Iris" made her successful trial were then far advanced, and were to be tried in a few weeks after his interview with Sir James Wright, so that the making of further screws was to be deferred until after this new trial. As was well known, the results were considered sufficiently good to obviate the necessity of making other screws. Some months after this trial, he received from Dr. Froude copies of his two last papers read before the Institution of Naval Architects bearing his own inscription, which were sent to him through the late Mr William Denny, who, in forwarding them, explained that he did so at Dr. Froude's request. Very shortly after this Dr. Froude sailed for South Africa, in December, 1878, and with universal regret died the following May near Capetown. He had never ceased to regret losing the opportunity of making Dr. Froude's personal acquaintance.

The President said he had at one time been vain enough to think that there was no man in the British Isles who knew more about screw propulsion than himself; but, after thirty years' experience, he had come to the conclusion that he knew nothing about screw propulsion, and he believed that the man had yet to be born who would be able to pose as an absolute authority on that subject. The Members should feel indebted to Mr Howden for the paper which he had given, and he asked them to give Mr Howden a hearty vote of thanks for the interesting manner in which the matter had been placed before them.

The vote of thanks was carried by acclamation.

NOTES ON SOME COMMON ERRORS IN THE USE OF ELECTRIC MOTORS FOR MACHINE DRIVING.

By Mr W. A. KERR (Member).

SEE PLATES XV. AND XVI.

Read 20th February, 1906.

THE Author has on so many occasions, in the course of business, met with specifications for continuous current electric motors for driving machinery, which, in his opinion, were by no means suitable for the purposes in question, that he thought a short paper on the subject at the present time, when motors are so generally used, might be of interest.

He considers that this is a peculiarly favourable time for such a paper, as, owing to the welcome boom in shipbuilding in this district, many of the Members of this Institution are doubtless considering the extension of their present equipment.

In all rotating engines the power in foot-pounds per minute is equal to the torque in pound-feet $\times$ 2π $\times$ R.P.M.

In most machines, for driving which electric motors are used, the power required varies directly as the speed, the torque being constant, though in some machines (as, for instance, centrifugal pumps) the power increases in a much greater proportion. The torque of a motor might therefore be considered its most important property, and the Author proposes to investigate this subject to a small extent for the ordinary forms of continuous current motors; and also to consider which of these forms should be adopted for driving certain common types of machines. The torque of a motor is proportional to the current in the armature, to the number of bars on the armature, and to the magnetic flux per pole. In any particular motor, which is wound for a given speed, voltage, and full load, whether it be series, shunt, or compound wound, there are two quantities which, at any other speed or load, may be variables. These are current in armature and flux per pole.

In what follows it is proposed to disregard the effect of armature reaction upon the total flux, as in modern motors this effect is extremely small. In a shunt wound motor the flux is a constant quantity, the torque, therefore, varying directly as the armature current.

Fig. 1 shows the variations of the torque with the current for a 60 B.H.P., 500-volt, shunt wound motor, recently installed in a Clyde shipbuilding yard, and running at 450 R.p.m. at full load. The dotted line in the same diagram shows the torque of the same motor, having the same armature and brush gear, but having series wound fields to give the same speed of 450 R.P.M. at the same full load.

At full speed with full load the torques of both the series and shunt wound motors are the same, and the currents are the same, as the efficiencies of both machines are practically identical. It is evident from inspection that the torque of the shunt motor, for small currents, is much larger than the torque of the series machine. With a current of 30 amperes, it is just double. This is opposed to the commonly held opinion that a series motor gives a much more powerful torque than a shunt motor, the usual argument being that, as in a series motor the torque varies as the square of the current, the torque must be larger. The users of this argument forget that one of the chief components of the torque is the magnetic flux, which is a constant quantity in a shunt motor, and a diminishing quantity with decreasing current in a series motor. Also, the statement that, in a series motor the torque varies as the square of the current, is only true for one particular point of the saturation curve, and is not even approximately true at other points. In fact the torque varies, as a rule, at much the same rate as the current itself for a considerable portion of the torque curve.

In speaking of the torque of a machine, the Author refers to the external torque available for performing work, not to the total torque, which has also to overcome the resistance of the armature to rotation, owing to friction of bearings, windage, eddy currents, etc., and with small armature currents, and the series wound motor therefore running at a high speed, these losses are large. In Fig. 1 the curves show the external torque.

Fig. 2 gives the saturation curve for the magnetic circuit of the motor in question, and the point at which the speed at full load is obtained is marked with a cross. This curve shows clearly that the magnetic flux falls very far short of increasing directly with the current in the upper portion of the curve. The origin of the wide-spread idea that a series wound machine has a torque varying with the square of the current is, of course, that in the early days designers, owing to lack of suitable materials and perhaps owing to lack of knowledge of the theory of the subject, worked at a very low point on the saturation curve, where an increase of current produces a large increase of flux. Fig. 3 shows the saturation curve of one of these machines, built some twenty years ago, and the point at which full speed full load was obtained is marked with a cross. It is obvious that a small increase of the current caused a practically corresponding increase in the flux, the torque increasing therefore approximately as the square of the current. This machine was, of course, worked with copper gauze brushes, which had to be moved as the load varied to prevent sparking, on account of the armature reaction causing distortion of the magnetic field. It is interesting to note that the reactance voltage of this machine at full load (calculated by Hobart's method) is as high as 14 volts, caused by the large number of armature turns per commutator section. The object of the designer in adopting a large number of armature turns was to economise copper on the field coils.

In modern machines, owing to the excellent magnetic properties of the cast steel obtainable for the magnets and yokes, and to the use of notched core armatures and small air gaps, it is possible to work with a much denser field, and therefore a much larger total flux; the number of armature turns pèr commutator section being reduced, and carbon brushes with fixed position at all loads employed.

Fig. 1 also shows the torque curve of the same 60 H.P. motor wound as a compound machine, having the series excitation at full load equal to about 20 per cent. of the total excitation, and the series coils assisting the shunt.

A true compound motor has the series coils opposing the shunt coils, so as to obtain a practically constant speed (neglecting any variation of speed due to the alteration of temperature of the machine) at any load; but the applications of this type of winding are comparatively few, and the Author does not propose to deal with them in this paper. An inspection of Fig. 1 shows that there is no valid reason for the adoption of a series wound motor, in order to obtain a large torque, at all events up to the full load of the motor; and a shunt motor is more suitable for that purpose, even the compound motor being inferior to the shunt motor. Above full load, however, the series and compound motors have the advantage, but not to a great extent, until a large overload is reached.

Fig. 4 shows the speeds of the motor with the three types of winding. It will be observed that the shunt motor runs at an approximately constant speed with any load up to nearly 50 per cent. overload, and that the compound motor varies to a moderate extent with the load. This effect can be greatly increased by increasing the proportion of series excitation to shunt excitation in the field winding, and it will be seen later the circumstances in which this should be done. The speed of the series motor varies greatly with different loads.

TYPE OF WINDING TO BE ADOPTED.

The conclusions to be drawn from Figs. 1 and 4 as to the type of winding to be adopted for any particular purpose, are as follows:—Motor for practically constant speed and constant torque, though not necessarily full load torque, shunt wound;

motor for practically constant speed and varying torque, shunt wound; motor for approximately constant speed, varying torque, and subject to sudden overloads, compound wound; motor for varying speed, and torque varying inversely as the speed, series wound. Motor for varying speed and constant torque should be shunt wound, with speed regulation effected by means of resistance switched, either automatically or by hand, into the shunt circuit. Motors of this type, having a speed variation of three to one, with practically no loss of efficiency, are commonly used; and the Author has had machines with a speed variation of nine to one, without a sign of sparking.

There are also several other methods of obtaining variable speed constant torque motors, by means of multi-voltage systems, or motor generators, patents for which have been taken out in many quarters; but it is doubtful if any of them are so low in first cost as simple motors with shunt regulation and constant voltage, and certainly in respect to cost of repairs and freedom from breakdown, this system has no rival.

The next point to be considered, is regarding motors which are required to give a large torque for an extremely short time at frequent intervals, and which are fitted with fly-wheels, or have fly-wheels fitted upon the machines which they drive. The function which the fly-wheel is intended to perform is, of course, to give up a portion of its stored-up energy at the moment of demand for power, and so to relieve the motor of abnormal demands and to equalise the drain upon the mains, in fact to reduce the peaks of the current curve. A fly-wheel stores up energy by virtue of its mass and velocity, and it is evident that it cannot part with any of that energy unless it is permitted by the motor to reduce its speed of rotation as the demand falls upon it.

A shunt wound motor, when a sudden demand comes upon it, runs at almost the same speed as before, the only reduction in speed being that due to the lost volts caused by the resistance of the armature and brushes to the passage of the increased current through them. In Fig. 4, the shunt motor, with an increase of load of 50 per cent., runs some 2 per cent. slower. This is a trifling reduction, and renders the fly-wheel of no practical effect, the motor having to supply nearly all the additional power suddenly called for. A shunt motor therefore is not suitable for this purpose.

The Author must plead guilty to having supplied many shunt motors fitted with fly-wheels, having found it easier to accept the customer's specification, and to supply fly-wheels, than to make the customer understand that he is throwing his money away.

Referring again to Fig. 4, it will be seen that the compound motor runs some 8 per cent. slower with an increase of load of 50 per cent. This is a sufficient reduction to permit the fly-wheel to do a reasonable amount of work, parting with over 15 per cent. of its kinetic energy. To determine the correct proportions of the fly-wheel, in any particular case, is a matter of some difficulty, and only an approximation can generally be made. It is necessary to know the permissible reduction of speed at the end of the demand for load, the amount and duration of that demand, the period available for recuperation, and the permissible increase of load on the motor. It is evident that the motor and fly-wheel which are suitable for a heavy load, applied for a very short time at very frequent intervals, are not suitable for the same intensity of load for a longer period, with longer intervals. For example, let it be assumed that the 60 H.P. compound motor is fitted with a fly-wheel, and is driving a machine which ordinarily takes 40 H.P. to drive it, the speed of the motor being 475 R.P.M. normally. Assume that the machine requires 147 H.P. for ten seconds, with one minute periods, that is with ten seconds excess demand and fifty seconds recuperation. The excess demand is, therefore, 107 H.P. for ten seconds = 588,500 foot-pounds of work, and this is to be done partly by the motor, but chiefly by the fly-wheel.

Assume also that the overload of the motor is not to exceed 50 per cent. of the normal full load of the motor, in this case equal to a current of 144 amperes. This is equivalent to a speed of motor of 420 R.P.M. at the end of the demand period. The reduction of speed of motor and fly-wheel is therefore from 475 to 420 R.P.M., or 11·6 per cent.

The horse-power of the motor at the end of the demand period is about 90, the excess therefore being 50 H.P. This excess varies from nothing to the maximum of 50 H.P., the average being 25 H.P. for ten seconds = 137,500 foot-pounds of work. The work to be done by the fly-wheel is therefore 588,500—137,500 = 451,000 foot-pounds.

To determine the proportions of the fly-wheel, first find the total energy it must store up. As its speed decreases by 11·6 per cent., it will part with 21·8 per cent. of its kinetic energy. Its *total* energy at 475 R.P.M. must therefore be $\frac{451{,}000 \times 100}{21 \cdot 8} = 2{,}068{,}800$ foot-pounds. A cast steel fly-wheel, 5 feet 6 inches in diameter, with a face 16 inches wide by 12 inches deep, would have this amount of energy, and as its peripheral speed is 137 feet per second, it would be quite safe. The work being done, the motor has to restore the 451,000 foot-pounds of energy to the fly-wheel in fifty seconds, this is an average of 16·4 H.P.

The cycle of the motor therefore varies from 40 H.P. at the commencement of the demand to 90 H.P. at the end, and then during the period of acceleration the power drops again until 40 H.P. is again reached at the moment of the next demand; the average power of the motor being 58 H.P.

Fig. 5 shows, by a full line, the current taken during two complete cycles; the dotted line showing the current that would be required if no fly-wheel were fitted. Though the total energy consumed is practically the same in both cases (the only difference being that due to the greater loss in the motor due to the larger current), a smaller motor can be used if a fly-wheel is fitted, than is possible in the other case. There are two reasons for this:—*Firstly*, the sparking difficulty; the limit of load in motors of this size is generally decided by the reactance voltage (especially in the case of high voltage machines, such as this one), and the large current required at the peak of the curve, equal to three times the full load current, would certainly cause the reactance voltage to reach an undesired figure. *Secondly*, the heating difficulty also would probably necessitate a larger machine; though the average current would be the same in each case, the heating effect is proportional to the mean square of the current (not to the square of the mean current), and would be much greater in the machine without a fly-wheel. Another advantage which Fig. 5 clearly indicates, is that a much smaller generating plant is required when a fly-wheel is fitted on the motor, the maximum current being about half that in the other case.

Another example of the effect of a fly-wheel may be of interest, and for this purpose a punching and shearing machine has been taken. This machine is capable of punching holes one and a half inches in diameter in plates one and a half inches thick, and of shearing the same plates. It is driven by means of a belt by a 22 H.P. motor, and has two heavy fly-wheels fitted upon the machine. Fig. 6 shows the horse-power time curves, the motor being compound wound with 20 per cent. compounding. It will be noted that one complete cycle when punching, and one complete cycle when shearing, are shown on the same diagram. The number of strokes per minute is 30, making a two-second cycle. It is difficult to tell the exact length of time taken in punching a hole, and as far as the Author is aware no experiments have been published. For the purpose of calculation, the time of punching the hole was taken at 25 per cent. of the time taken by the punch to pass through the thickness of the plate, and the pressure on the punch was assumed to be 195 tons. The pressure while shearing was assumed to be 165 tons, and the time taken to be three-quarters of the time taken by the blade to travel a distance equal to the thickness of the plate. These figures are affected by the angle of the blade, and the contour of the face of the punch; but they are believed to be fair average values.

It will be observed from Fig. 6 that the maximum power required while punching is much higher than the maximum power while shearing; but as the latter takes a longer time, the load on the motor is much more severe while shearing. In fact the motor is seriously overloaded. The fly-wheels are quite satisfactory while punching, but might, with advantage, be made heavier and larger in order to relieve the motor while shearing. This motor is of the variable speed type, and can be made to run 33 per cent. faster. If this were done the kinetic energy of the fly-wheels, assuming the motor at the end of the shear to reach the same terminal speed as at present, would be increased by 140 per cent.

Unfortunately the practice is to run the motor at its slow speed when dealing with heavy plates, for two reasons: *Firstly*, owing to the difficulty in handling heavy plates, and *secondly*, that, in shipyards at all events, the heavy plates are generally templet plates, and the holes must be accurately punched, a high speed not being desirable. When lighter plates are being handled the motor is speeded up and the kinetic energy of the fly-wheels increased, at the time when an increase is not necessary for power purposes. Fig. 6 shows clearly to what a large extent a correctly proportioned fly-wheel relieves the motor and generating plant.

The Author's intention in dealing at such length with the question of fly-wheels, is to emphasise the advantage they possess in many cases, and the uselessness of fitting them on shunt motors. Motor manufacturers will admit that they often receive enquiries somewhat of the following nature:—"One ten horse-power shunt wound motor, for 500 volts, 900 R.P.M., fitted with a two-feet fly-wheel, earliest possible delivery." The delightful vagueness of the specification of the fly-wheel (the diameter probably being fixed by the customer to give a safe peripheral speed for cast iron), and the absence of any information as to the work the motor is to perform, is somewhat distressing to the motor manufacturer; but he knows that if he delays quoting, in order to obtain the necessary information, the order will be placed elsewhere before his quotation arrives. He therefore quotes at once, adopting any fly-wheel pattern he has of the diameter specified, and if he obtains the order he trusts to fortune that the motor may prove equal to the work, and fortune is often very kind. If, however, the manufacturer were fully acquainted with the work to be performed, he could, in many cases, save his customer considerable sums in first cost and in running expenses.

Reversing Motors.

The next type of motor to be considered is the reversing motor. A reversing motor is seldom required to make lengthy runs in one direction, but is nearly always desired to run for a few seconds, or perhaps minutes, and then stop and reverse, and in this, rapid acceleration is a necessity. Acceleration is a function of the torque; therefore, in this case also the shunt motor has an advantage over the series motor. It also has a disadvantage, viz.: that owing to self-induction, the shunt coils take an appreciable time to build up the magnetic field, and the torque does not reach the amount shown in Fig. 1 until the field is fully excited. This is easily got over by keeping the shunt coils fully excited all the time the motor is required, and as the energy is only from one to (in small machines) five per cent. of the total current, the loss is trifling.

The constantly excited fields have the effect of bringing the armature to rest very quickly (when the armature current is switched off) owing to eddy currents in the core, and if a brake contact be fitted on the controller so that the armature can be short circuited through a resistance, the armature will act as a brake, and also assist in bringing itself to rest promptly. This is a very important property for a reversing motor to possess. It appears, therefore, that a shunt motor, with fields permanently excited, is the best type to use for frequent reversing and rapid acceleration. It is true, however, that some machines, having moving parts with but a small inertia, and requiring often to work with a small load, when an increased speed of running with a fair acceleration are desirable (such as the hoisting gear of jib cranes with an empty hook), may, with advantage, be fitted with series motors.

The following list gives a few common machines, and the types of motors which the author considers most suitable for them:—

Boring mills, ...	Shunt wound, variable speed.
Radial drills, ...	Shunt wound, variable speed.
Countersink drills, ...	Shunt.
Large lathes, ...	Shunt, variable speed; or where breaks occur in the work generally dealt with, heavy cuts being taken for a portion of the revolution of the face plate and the rest of the revolution being idle, such as truing the ends of bob weights on a crank shaft, compound with fly-wheel.
Small lathes, ...	Shunt variable speed.
Planing machines, ...	Compound with fly-wheel. A resistance may be automatically switched into the shunt circuit to increase the speed on return stroke with advantage.
Milling machines, ...	Shunt.
Shaping machines, ...	Shunt.
Slotting machines, ...	Compound with fly-wheel.
Cold saws, ...	Shunt.
Punching and shearing machines, ...	Compound with fly-wheel.
Plate bending rolls, ...	These are reversed frequently, and have great inertia and considerable friction, even if fitted with ball bearings. The driving motor should be compound, and may, with advantage, be fitted with a fly-wheel to add to the kinetic energy of the moving rolls, and relieve the motor by supplying the extra power required at the first nip of the plate, and it should be fitted with a magnetic or foot brake to stop the rolls quickly.

	The magnetic brake may be connected in series with the motor, as the initial current is large. The roll shifting motor should also be compound to get a large torque at starting. A series motor is not satisfactory, as the speed of the roll gets somewhat high, and it is difficult to stop it at the exact position required. A powerful magnetic brake should be fitted for this purpose.
Mortar mills, ...	Compound with fly-wheel.
Circular saw, ...	Compound, with small fly-wheel, to assis motor when the saw meets knots in the wood.
Band saw, ...	Shunt.
Frame saw, ...	Shunt.
Wood planer, ...	Shunt.
Mortising and tenoning machine, ...	Shunt.
Cargo winch, ...	Compound. These are often made series wound; but so much of the time of a hoist is occupied in easing the load out of the hold that the greater torque of the compound motor, with a small current, overbalances the quicker speed of the series motor with light loads.
Shipyard winch, ...	Compound. The distance at which the work is performed is often considerable, and great skill and care are required on the part of the winchman, if a series motor is used, especially with light loads.

Skull breaking winch,	This is usually fitted with a series motor, and as the load is constant, and the inertia of the tup, at starting to hoist, constitutes an overload, the series motor has the advantage.
Three-motor travelling crane, ...	In shops, where rough work is carried out and great nicety of handling is not required, a series motor is the best for hoisting, as with light loads the speed increases, and enables the work to be performed more quickly.

In iron foundries, especially where delicate ornamental work is done, delicacy of handling is the most important point, it often being necessary to raise or lower a box a quarter of an inch at a time. In this case, a compound motor has all the advantage. The small current required for a given small torque means that the craneman has to move his controller on to its first or second notch to move the load, in place of on to the fourth or fifth notch, as would be the case with a series wound motor, and he can therefore stop it more quickly. The motor should have its shunt coils permanently excited, and be fitted with a shunt brake, so that whatever the current in the armature, the brake may pull off quickly. A series brake does not pull off until a considerable current is passing through the armature, though once it is off, a small current suffices to hold it off.

In engine erecting shops a compound motor should be used for the same reasons. With a series motor a good deal of time is lost by the craneman raising or lowering the work too far. The travelling and cross-transverse motors may be series wound, as the inertia, even with an empty hook, is great, and the minimum load is considerable. A brake may be fitted with advantage. If, however, great delicacy of movement is required, these motors should also be compound wound, for the same reasons as have been advanced in the case of the hoisting motor.

Hoists.—Most electric hoists and lifts have balance weights fitted equal to the combined weight of the cage and half the ordinary load to be lifted. This enables a small motor to be used, and ensures economy in current consumed. It is evident that, with half load in the cage, the motor will have no work to do, save to overcome the friction, and if a series motor be used, it will run at a very high speed, and there will be considerable difficulty in stopping the cage at the right place. A compound motor is the most suitable, though shunt motors are often used. They should be fitted with shunt brakes, and the armature itself may be used as an additional brake with advantage.

Centrifugal Pumps.—The torque required at starting is very small. Until the critical speed is reached no water is delivered, and any small increase of speed above that point means a large increase in the water delivered, and therefore of the power absorbed. A shunt motor should be used, having a variable resistance in the shunt circuit, so that the exact speed to give the required delivery of water may be obtained.

Reciprocating Pumps.—Assuming the suction and delivery pipes to be charged, the torque of this type of pump is constant at any speed, with the exception that when running the friction of the water in the pipes comes into play, and the torque varies accordingly. A shunt wound motor is quite suitable, and may have speed regulation to vary the delivery. A series motor may also be used, having speed regulation, by shunting a portion of the current from the field coils to increase the speed, or by resistance in the armature circuit to reduce the speed. A series motor has one advantage for this purpose; but fortunately it does not often occur. If one of the suction valves gets hung up, preventing one of the pump barrels from working, the load on the motor is reduced, and it runs faster, the other two barrels (assuming it to be a three-throw pump) deliver more water, and the increased speed and noise draw the attention of the driver to the fault.

For pumps operated at a distance, a series motor is probably best. Only two cables are required, the starting switch being fixed in the engine room, and an ammeter in the circuit enables the driver to know, by any variation in the current, if attention is required at the pump. The Author was connected with the installation of a pump of this nature some ten years ago, which is still working successfully, the current being transmitted some two miles and the pump being visited about twice a week.

Roots' Blowers.—For cupola work these should be shunt motors with speed regulation by shunt resistance, so that the pressure and quantity of air delivered may be varied as the charge settles.

Smiths' Fires.—For such, shunt motors should be used.

It may be well to point out that the question of time of acceleration from rest, and energy expended, is a somewhat complex one, and that a great deal depends upon the method of controlling the current during the acceleration period. It is obvious that, if a motor is accelerating a machine which requires the full load of the motor to drive it at full speed, and if it be possible to so regulate the current by the starting switch that the current at once equals the full load current, and never exceeds it by more than a small fraction, it does not matter whether the motor be shunt, compound, or series wound, it will accelerate the machine in the same time with the same expenditure of energy. This, unfortunately, is an impossible condition, as supply companies do not allow the full load current to be drawn suddenly from the mains; but they insist upon gradual increases in steps of ten or twenty amperes, and in private installations, for the sake of generating plant and other motors and lights, it is not advisable to do so. It is, therefore, necessary to accelerate by gradual increments of current, and it is in the earlier stages that the shunt and compound motors have the advantage. If, however, the inertia be very great, and the operator impatient, he may move his switch so rapidly that a current much larger than the full load current is taken, and in this case the series motor gives the greatest torque and the most rapid acceleration; but the operator should be replaced by a more patient man.

In all the preceding, it has been assumed that the motor and the machine are direct connected, or, at all events, that there is no appreciable slip between the motor and the machine. There is one very interesting machine, however, which starts from rest, and, as made by one of the best known firms in this city, has purposely a very large slip. The reference is to centrifugal machines, either sugar centrifugals or hydro-extractors. In this particular type, the motor drives the basket through a centrifugal friction clutch. The motor, in machines of the latest type, is series wound, and is thrown on to the mains direct by a double pole switch, no starting resistance being employed.

The high self-induction of the series field coils prevents the sudden rush of current being excessive. In most cases which have come under the Author's notice, the initial current is not appreciably greater than that taken by the motor ten seconds later. The motor in a few seconds attains the speed corresponding to the current, the slippers of the friction-clutch fly out by centrifugal force, and the basket begins to revolve. The basket accelerates rapidly until it attains the same speed as the motor, when the motor and the basket accelerate together until full speed is obtained. The friction of the slippers represents a loss of energy of 50 per cent. of the motor output, until the motor and basket are running at the same speed, after which no such loss occurs. The average power taken during the acceleration period is often six or seven times the power taken when running at full speed, and the power at the start is often more than double the average power. A very specially designed motor is therefore necessary. The actual power depends upon the time of acceleration, and this varies with the class of sugar to be worked.

The interesting point in this machine is, that if a shunt or compound motor be used, there is a much greater loss of energy, as, owing to their much higher speed with a given current, the speed of the basket does not equal the speed of the motor until a much later period, and the energy lost, caused by the friction of the slippers, is much greater. There is also the disadvantage that some sort of starting resistance must be used with these motors.

On the other hand, the series motor has the disadvantage that, though the total energy required is less, the initial demand is greater; but, as usually, a number of these machines are used in one installation, and they do not all start at the same time, the generating plant may be practically the same as would be necessary with shunt or compound motors. Fig. 7 shows the current curve and speed curves for a basket and series motor of one of these machines. It will be noted that the basket speed never quite reaches that of the motor. This is probably due to vibration, causing a slip in the friction clutch, and there must be some slight loss in this; but it is also the case when shunt or compound motors are used.

It may be asked why the motor should not be direct coupled to the basket. The objection to this is, that the motor would have to contend with the inertia of the basket when starting, as well as its own inertia, and a very large starting current, necessitating a starting resistance, would be required. By introducing the friction slippers, the motor has only its own inertia and the friction of the slippers to overcome in starting.

One small error of erection, which often causes considerable trouble, may be pointed out. When motors are mounted on slide rails, belt stretching screws are provided, which bear against the motor frame, and take up the slack of the belt. These rails are generally placed so that the stretching screws are both in front of the motor. They should, to obtain security, be placed one at the front and the other at the back of the motor. By adopting this arrangement, the couple, which is caused by the pull of the belt, is resisted by the screws, and the stress is taken off the holding-down bolts.

The Author has known many cases, in which complaints have been made, that the motor speed fell off seriously upon increasing the load, and, upon investigating the matter, he found that both stretching screws were fixed at the front of the motor, and the holding-down bolts having worked loose, the pull of the belt had slewed the motor slightly out of place, allowing the belt to slip. Fig. 8 shows the two methods of fixing the rails.

The Author is aware that he has not advanced anything of much value in this paper, and he expects that many Members will not share some of his views; but he hopes, however, that the expression of these views may lead to a good discussion.

Discussion.

Mr JOHN KLINKENBERG (Member) observed that after careful perusal of the paper prepared by Mr W. A. Ker, he found that there were a number of statements put forward which called for a reply. On page 287, the Author stated that in his diagram, Fig. 1, the torque of the shunt wound motor at full load was equal to the torque of the series wound motor. The torque, of course, could not be different, as the output given by the motors at full speed was in both cases the same, but the question in adopting either a shunt or a series motor for power driving was not the torque at full load, but the starting torque. The Author stated, "It is evident from the diagram that with a current of 30 amperes, the torque of the shunt wound motor is just double the torque of the series motor." On the first page, Mr Kér himself stated that the torque of a motor was proportionate to the current in the armature and to the magnetic flux per pole, that was to say, with the same armature current, the torque varied with the strength of the magnetic field. Now, in the shunt motor, with a current of 30 amperes, the field was fully excited; while with the series motor, where 96 amperes required to pass through the series coils of the field to reach the maximum field strength, it was evident, in the case of the series motor, that the motor started on a very much weakened field, and with a field of only one-third the strength of the shunt wound motor, the series motor exerted half the torque of the shunt wound motor, actually proving that the torque of the series wound motor for the same condition was greater than the shunt wound motor. He failed to see that the Author had suceeded in proving that the series wound motor, as stated on page 288, running at a high speed, had considerably higher losses, owing to resistance of the armature, friction in

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bearings, windage, eddy currents etc., than the shunt wound motor. It would be interesting to have an explanation for what reasons a series motor was handicapped as compared with a shunt wound motor. The conclusion the Author drew from Figs. 1 and 4, that motors for varying speed and constant work should be shunt wound, that speed regulation effected by means of resistance switched into the shunt circuit should be used, "with a speed variation of 9 to 1," was surely an error. With pure shunt regulation of ratio, 9 to 1, the size of the motor adopted was altogether out of proportion to various other methods which could be adopted, and it was altogether doubtful whether satisfactory conditions for the field magnets could be arranged with such an enormous variation in speed. As a matter of fact, there were only one or two of the largest manufacturers who manufactured motors with a speed variation of 4 to 1, and some well known firms refused to go beyond 3 to 1, by means of pure shunt regulation. If variations of 5 to 1, 10 to 1, or 15 to 1, were required, the cheaper way, and certainly the more reliable way, was the multi-voltage system, which was universally adopted where large variations in speed were necessary, for instance, in paper works, and rotary printing machines. The *Glasgow Herald* newspaper had a machine of this description, which was recently installed, with a variation of 10 to 1 (if his memory were correct), which worked in every way satisfactorily, and was considerably cheaper than attempting to build a shunt wound motor with pure field regulation of 10 to 1. The Author, in the next paragraph, stated that it was of no practical effect to provide a shunt wound motor with a fly-wheel, as the reduction in speed was trifling. As a matter of fact, the minimum variation in speed between "no load" and "full load" was 5 per cent., but more generally 8 per cent. Further, the decrease in voltage, when a sudden load came on was, at the minimum, $2\frac{1}{2}$ per cent., but more likely from 3 to 4 per cent., giving, of course, a corresponding reduction in speed. Under the most favourable circumstances, therefore, the variation in speed in a shunt wound motor was $7\frac{1}{2}$ per cent., and the object of the fly-wheel was to assist the armature in overcoming the maximum load the motor was able to carry, and if there were no other advantage than preventing a drop of, say, 2½ per cent. in voltage, the purpose for which the fly-wheel was supplied was amply justified, especially in cases where power as well as lighting was taken from the same mains, as the drop of 2½ per cent. in voltage would cause fluctuation in the lighting. The advantages the Author claimed for the fly-wheel, in connection with a series machine or compound machine, held good in the same way with a shunt wound machine. He did not see that there was any disadvantage in running a motor slowly for shearing heavy plates, as the torque increased in inverse ratio with the speed. He must defend the users of electric motors who sent forward enquiries as quoted by the Author, namely, "supply one 10 H.P. shunt wound motor for 500 volts, at 900 revs. per minute, with a two-feet fly-wheel." This gave the manufacturer practically all the information he wanted—he knew that a 10 H.P. motor was required; the motor was to be shunt wound, that was to say, the manufacturer had to exert himself to build a shunt wound motor capable of exerting sufficient torque, fitted with a fly-wheel. No buyer would object to the manufacturer suggesting a different diameter of fly-wheel, and this, certainly, would prejudice him when the order was placed. In the case of reversing motors, on page 295, the Author adhered to his wrong statement that a shunt wound motor had the advantage over the series motor in case of acceleration, which was obviously a mistake. If his way of reasoning held good, the best thing that Tramway Companies could do, was to throw out all their series motors and substitute shunt wound ones. The suggestion made by the Author to keep the shunt coils in a reversible motor continuously excited was altogether objectionable from economical reasons. In a reversing motor, which only periodically did work and where the armature was stopped, the current consumed by the shunt was 5 per cent. on the minimum, but far oftener 8 per cent., and was not by any means trifling, as the Author stated. Take, as an

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example, any passenger lift running, say nine hours a day, the total expense for running the lift per annum, £35, and assume the circuit for the shunt every time the lift stopped was broken. If this shunt were to remain excited all the time, the cost per annum would be increased to £44, or an increase of 25 per cent. in the annual expenditure. He did not believe that the owner who had to disburse the additional 25 per cent. would take kindly to the explanation that it "was only a trifling increase." Besides, for electrical reasons, it was a constant source of danger keeping the shunt continuously excited. When breaking the shunt, finally, a separate shunt brake switch was required, and as often as not, when the works were finally shut down at night, the attendant of the machine omitted to open this switch, with the result that the switch-board attendant, when shutting off the supply at the switch-board, broke this shunt current, causing a very heavy induction on the motors; and only very recently an installation of four 100-H.P. motors broke down, and the armatures required to be completely rewound on account of this suggestion being adopted, of keeping the shunts continuously excited. The heavy induction caused an induction spark to destroy two coils of the armature, involving an expense of nearly £200. Another great disadvantage with motors, where a shunt was continuously excited, was that a motor built for intermittent work was dimensioned to carry no current for certain periods, but if the shunt was continuously excited, the temperature of the field would increase considerably beyond its normal, causing very soon deterioration of the motor. The claim the Auther put forward that only a constantly excited field brought the motor quickly to a standstill was erroneous, as it was quite easy to utilize the residual current in the field magnets, which was more than sufficient to bring the largest motor to an instantaneous stop if so desired. This property every motor had, whether reversible or not, and whether shunt, series, or compound wound. He failed to see why the Author recommended compound motors with fly-wheels for planing machines, and for wood planers, shunt wound motors. There was no more power required for planing cast-iron

or steel than there was for planing wood, and the same sudden loads came on which surely should require the same motor. For a shipyard winch, however, a compound motor was recommended, while for the skull breaking winch and three-motor travelling crane, a series motor was recommended. There was surely not more nicety of handling required in the shipyard winch than on the three-motor travelling crane, and all the advantages the series motor possessed, pointed to the adoption of this kind of motor. The Author altogether forgot the mechanical side of the question under discussion. In travelling cranes, the hoisting and lowering motor was invariably a series wound one, and the most accurate handlings required could be executed with this kind of motor. The motor, which was coupled to a self-locking worm, prevented the possibility of the motor running away, and the gradual starting torque of the series wound motor allowed a load to be lifted or lowered to 1-32nd part of an inch at a time. He knew cranes where a load of three tons was lowered between the pointers of a lathe by means of a 50-H.P. series wound motor, and there was no instance where more nicety and accuracy of handling was required than in a case like this. For the same reason, of course, iron founderies would exclusively use series wound motors. He had tested about 2,000 motors for crane purposes, and he was safe in saying that from 1 to 2½ per cent. only were anything else but series wound. Why a compound motor should be used for hoists he altogether failed to see. Somewhere the Author recommended the use of additional series windings to assist the shunt field in order to get a greater starting torque, but, by the Author's own showing on the first page, the torque was equal to the magnetic flux per pole; and on page 288 he stated that when a magnetic field was provided with a certain number of ampere-turns, the iron was practically saturated, which was, of course, a well-known fact. If it were possible to build a pair of shunt magnets, which saturated the iron in the field magnets, there was no use in providing additional series windings. These windings could not possibly increase the magnetic density of the iron, it being practically saturated, and it was mere waste of material and complication to provide an additional series winding, and perhaps arrange to cut it out after starting, requiring a more complicated motor, switch gear, and more wiring, an enormous disadvantage in cases where extreme simplicity was of the utmost importance. As it was possible to build a shunt wound motor with the field very near the saturation limit, the necessity of providing additional compound winding was obviated. On page 299, the Author recommended for centrifugal and reciprocating pumps a shunt wound motor, but in the same sentence stated that for pumps at a distance, series wound motors should be used. If for pumps, at a distance, series wound motors were an advantage: Why should it be a disadvantage to use them when the distance was small? The question of motor driving, as applied to steel rolling mills, mining, and other purposes had not been touched upon, and he specially regretted that no mention had been made in the paper of alternating current, as no doubt this mode of current was extensively used, and used under more trying conditions, and where continuous current would be absolutely hopeless.

Mr W. M'Whirter (Member) said there were some points in the paper on which he was not inclined to agree with Mr Ker, but the same might be said about what they had just heard from Mr Klinkenberg. When Mr Ker compared the series wound motor with the shunt wound motor, he did so in a general way. The Author would be willing to admit that there were conditions under which a series wound motor was more suitable than a shunt wound motor. To take the example of the tramway cars going up Renfield Street, their motors were very often much above full load. That meant, with these big loads a big drop in the voltage. Consequently, with a shunt wound motor the torque would fall quickly, while with the other the torque would be fairly well maintained. A series wound motor would take a cart up a hill, while with a shunt wound motor it might stop altogether. He thought, however, that Mr Ker did not anticipate a case of that kind, because the paper seemed to deal merely with the application of motors to machine tools and other machinery of various kinds where such a case would not exist. He quite agreed with the Author when he stated that a compound wound motor was the right thing to use for lifts. With lifts a compound wound motor had many advantages. To begin with, the series was thrown in just at the time one wanted to start, when the maximum torque was required. The series winding assisted very materially in reducing the rush of current which took place in motors just for the first second or two. Immediately on getting away, the series winding was cut out by a short-circuiting switch. And when the series was cut out acceleration obtained due to the fact that the magnetic field was reduced. Then if that were followed up, as was done in the best lifts, by introducing at the end of the controller movement resistances into the shunt circuit, greater acceleration was obtained, and when running thus a good speed was maintained. He had not read the paper in the way it should be read, and for that he was sorry, but it was a paper that all the young Members of the Institution ought to read through most carefully. He was sure there was matter in it that would well repay perusal. Mr Ker's remarks about fly-wheels were very much to the point. He did not think he was telling any tales when he said that in Glasgow, until very recently, they were hardly allowed to put down a motor without a fly-wheel. The Corporation made a distinct stipulation that fly-wheels must be fixed to motors wherever the work was at all of a fluctuating character. If the motor drove a circular saw there must be a fly-wheel, or if it was a guillotine there must be a fly-wheel, and so on. He did not think that that stipulation had as yet been altered, but he was afraid that now it was more honoured in the breach than in the observance. He believed a great many motors had fly-wheels, but these were stowed away.

Prof. A. Jamieson (Member) thought that Mr Ker had done well in bringing this paper before the Institution at the present time, since the reasoning and conclusions contained therein appealed directly to many Members who used, or expected to use, electric motors for driving shipbuilding and engineering tools.

As a rule, the owners and managers of engineering and shipbuilding works did not care to investigate very minutely the scientific principles and detailed proportions of the windings, etc., of the various kinds of electric motors; but they did wish to know their leading characteristics. Also, how each type of motor was best suited for driving a particular machine or a certain number of tools so as to turn out work most economically and expeditiously. Mr Ker had confined his remarks to continuous current motors of the series, shunt, and compound wound varieties, probably from the fact that he did not desire to overload his paper with too great a mass of details, and also from the fact that hitherto in most private self-contained local installations, these were already fitted upon the continuous current principle. By stating the available torque at the motor shaft or pulley Mr Ker had avoided all ambiguites in regard to the output capabilities of the motors referred to by him in his paper, and the clearly lithographed figures greatly helped to elucidate the Author's personal opinion. At the foot of page 286, it was stated that "the torque of a motor is proportional to the current in the armature, to the number of bars on the armature, and to the magnetic flux per pole." Now, the torque was not, strictly speaking, proportional to the magnetic flux per pole, but to the magnetic flux which entered the armature core, and which intersected or effectively cut the armature conductors; since one might have a greater or less percentage of magnetic leakage or short circuiting between the poles according to design or circumstances. On page 288 and elsewhere, the Author, when referring to Fig. 2, called the same a "saturation curve." It was not a saturation curve, but an ordinary magnetisation curve which ranged from 2000 to nearly 6000 kilo-lines per pole for that particular machine and material. The term saturation was one which had different significations under different conditions. For example, as generally applied by dynamo and motor designers, it meant that part of the magnetisation curve, beyond which it did not pay to evoke more lines of magnetic force per unit area of cross section in the iron or steel cores of, say, their field magnets. Ordinary good permeable motor iron or cast steel might be referred to as having reached saturation point when the intensity of magnetisation had 20,000 to 22,000 dynes per square centimetre. Whereas, Professor Ewing in certain well-known experiments, obtained double these densities of saturation, and yet he hoped to obtain still greater saturation of the same material! Attention might be drawn to other misapplications of terms and phrases in the paper, but it did not serve any good purpose in this case to be hypercritical. Mr Ker had explained very clearly the variations of torque in series, shunt, and compound wound motors, so that readers could form their own conclusions, or adopt those laid down by him as to which kind of winding was best suited for a particular class of work to be done. In actual practice, however, he (Prof. Jamieson) had seldom met with shunt wound motors which gave such a constant speed under such a wide range of load as that indicated by Fig. 4. And, even for that case he thought a fly-wheel attached to the motor spindle would prove beneficial in overcoming sudden variations under certain circumstances. Whilst inspecting, testing, and reporting upon electric motor installations as fitted into Clyde shipbuilding yards, where the motors were more or less exposed and the prevailing atmospheric conditions were damp, he had found it advisable to recommend that the field coils of shunt wound machines, which were frequently used, should be always in circuit and, therefore, constantly excited during working hours in order that the various parts might be kept dry by the mild heat derived from the comparatively smal $C^2 R$ losses, and the motors ready to start at a moment's notice without a hitch. Such instances were different from those of lift motors for dry buildings, and each case had to be considered upon its own merits, whilst every precaution should be taken to avoid a breakdown either by automatic devices or by strict rules and regulations such as that referred to by Mr Klinkenberg in the case of the four 100 H.P. motors. The applications of different kinds of alternate current motors would form a useful continuation or

Prof. A. Jamieson.
addition to the present paper, more especially to Members who contemplated taking advantage of the New Clyde Valley Power Company's high pressure alternate current turbo-generator supply.

Mr Wilfrid L. Spence (Member) thought that the Author was distinctly to be congratulated on having produced a paper which, to his mind, was at once sound and of a character to appeal to mechanical engineers, and it was to be hoped that some, at any rate, of the misconceptions in the application of motors would now disappear. He did not sympathise altogether with the hypercriticism of one of the speakers in finding fault with the Author for pointing out the torque characteristics of the different classes of motors, and for stating that the torque was the same at full load, because this was qualified by the further statement that the efficiency was also the same whether the motor was series, shunt, or compound wound. Broadly, he was completely in agreement with Mr Ker's paper, but more particularly so when he dealt with the subject of fly-wheels, which was a matter that electrical plant men had some difficulty over in endeavouring to make clear to clients and customers the true inwardness of fly-wheels in connection with electric motors. Coming to details, and referring to type of winding to be adopted, he would be inclined to add, in any complete schedule, motor for constant speed with constant *and predetermined* torque, series wound, but no series motor ever to be used with belt or single rope driving, and he would amplify the Author's version to read, motor for practically constant speed and varying torque *within the full load*, shunt wound. With regard to shunt regulation, the Author certainly did not advocate shunt motors for 9 to 1: But was that figure correctly given? Of course a 9 to 1 range shunt motor would be utterly uncommercial. A ratio of 3 to 1 was a good standard limit for mechanical reasons combined with commercial considerations; 5 to 1 was practicable, and 6 to 1 might be considered as the outside commercial limit. With regard to Mr Ker's remarks on the multiple voltage system, he could not say that here he agreed with him altogether, perhaps, because he had had great, while the Author had had but little, if any, experience with the system. For any considerable group of motors as in an engineering works requiring to run at speeds varying in the ratio of 5 to 1 up to 7 to 1 there was not any electrical system to approach it for cheapness and efficiency. It would never pay for a single motor, but it did handsomely pay for a lot. The multiple voltage system was in operation not only at the *Glasgow Herald* Office, but within the last few weeks at the *Evening Citizen* Office, on the system developed by him, and there would be before long four motors of 50 H.P. each running there on a single rotary converter smaller than any one of them. While championing the multiple voltage equipment in its own sphere against all other electrical systems, he did not wish to be understood as saying that, in his opinion, any method of electrical control was equal to a well arranged speed gear where three or four speeds in definite steps were satisfactory, as in the drive of a drilling machine for example. If six or eight steps were good enough the gear was still the best, and only in such operations as facing large surfaces in a lathe was the continuous variation of shunt control really greatly ahead of other methods. That brought him to ask where Mr Klinkenberg got his justification for saying that the multiple voltage system "was universally adopted?" Of course a a three wire system was not the multiple voltage system! He had already indicated concurrence with the Author on fly-wheels. The Author was unquestionably right, and his critic was unquestionably wrong. If not entirely futile it was certainly a sheer waste of good material to put fly-wheels on shunt motors. He had previously mentioned in that room the case of an 80 H.P. shunt motor driving a tube welding mill. The gearing was excellently arranged with a huge fly-wheel, but the motor took up to 130 H.P. at every weld because it would not let the fly-wheel get a chance. The shunt motor eventually broke down and was replaced with an over-compounded and compensated motor of the same nominal size, 80 H.P., but actually of slightly less physical dimensions. Doing the same work as before, the top load was only

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from 45 to 50 H.P.—all because the welding was now done by the fly-wheel, and the motor merely kept it spinning, the speed varying through some 15 per cent. or so in each cycle of operations. He was rather surprised that the Author had made no substantial reference to compensated machines which were *par excellence* the motors for speed variation on single voltage circuits, and for standing great overloads. In general, for speed variation, compensated motors should only be shunt wound; compound winding was out of place on compensated motors, unless great fluctuations of load were to be dealt with by means of a fly-wheel It would be agreed by all really conversant with the subject that such a schedule of applications was no mere empty form, each particular winding enabled certain corresponding features to be emphasised and taken advantage of, and if the full benefit derivable from motor driving was to be developed, the question of windings must be carefully gone into beforehand. This brought out a very interesting point. One speaker had asked why the Author confined himself to direct current machines only, and the answer was simply that there was substantially only one class of polyphase motor, the constant speed class, corresponding very closely indeed to the shunt wound direct-current motor. The essential difference between direct and three-phase motors was well seen here. With direct current one could get almost any desired characteristic without substantial loss of efficiency, while with polyphase current there was only the motor with constant speed—any variation of speed demanded was accompanied by a corresponding drop in efficiency—roughly cent. per cent.; hence the use of fly-wheels with three-phase motors was improper unless there was an elastic or slipping connection at some point in the drive. A corollary was that gear drives on fly-wheel machines, appropriate with over-compound direct-current motors, would be a failure associated with shunt-wound, direct-current or polyphase motors. He desired in conclusion to thank Mr. Ker for his paper.

The CHAIRMAN (Mr E. Hall-Brown, Vice-President) remarked that the question of motor winding was far more difficult than most people thought. He had been trying for some time to get a price for driving a hydraulic pump, and each electrician that had come into his place had told differently from the previous one. One wanted a compound machine and another wanted a simple shunt wound, and he was at a loss to find which was which.

Mr. SPENCE said that with a three-throw pump, taking into account the ordinary commercial length of connecting rod, the difference in delivery was of the order of 8 per cent. In a two-throw double-acting pump the variation in delivery was of the order of 28 per cent. These variations were worth taking into account in figuring out a motor.

Mr RICHARD A. McLAREN (Member) observed that his firm had some welding rolls driven by a motor, and he would like to point out that a slight difference in the heat of the tubes, as they came through the rolls, made a considerable difference in the power required. The power of the motor in question, with the same thickness of plate, but at a different temperature, might vary from 65 H.P. with one tube up to 120 H.P. with the next. That would account for a good deal of the difference referred to by Mr Spence, apart from any question of the design of the motor.

Mr SPENCE considered that would not account for it. The people who were running the 80-H.P. shunt motor were in misery—they knew the thing would break down, and just about the time the new motor was delivered it did give out. There could be no question about the correctness of the powers stated, because they were not based on single observations but on months of running in both cases.

Mr M'WHIRTER remarked that he knew the motor to which Mr Spence referred, and his explanation was the right one. He had seen it rolling a large number of tubes, and the difference of temperature did not account for the differences in power that he had witnessed. The variation in load was as Mr Spence had given it. It was not always the same, but there was no doubt

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whatever that the motor was very badly used owing to the type of winding.

Mr E. HALL-BROWN said the question came to be, where did the other 35-H.P. go? If the fly-wheel gave out work in the two seconds during which it was doing something, it must have taken up work in the fifty-eight seconds when it was doing nothing.

Correspondence.

Mr GEORGE STEVENSON (Associate Member) stated that a point which seemed to have led to a good deal of controversy in connection with the Author's paper was the question of fly-wheels on shunt wound motors. He thought this was one of those cases to which one might apply the platitude that "it was all right in theory but wrong in practice," at least that had been his experience in connection with polyphase motors, driving machines having a very variable load. A polyphase motor was, of course, much more rigid in respect to speed variation than the shunt wound D.C. motor, the speed being dependent only upon the periodicity, and the variation in speed with variation of torque being dependent on the slip. Naturally, therefore, one would expect that the Author's remarks regarding the application of fly-wheels to shunt wound D.C. motors would apply with greater force to the case of the polyphase machine. He found, however, that in practice that was not so. He had a case where a polyphase motor, of 11 B.H.P., was driving, through a coil friction-clutch, a mortar mill by means of a belt. The mill was fitted originally with the usual engine and fly-wheel, and when changed to electric driving, the crank disc was removed, a short length of countershaft was attached to the existing crank shaft, and the fly-wheel retained. Being desirous of finding out whether the fly-wheel was required, he had it removed, with the result that continual trouble was experienced with friction-clutch slipping, and the fly-wheel had to be replaced. He might say that the slip from no load to full load in this motor was 4 per cent. The motor, however, was at times overloaded to the extent of about 25 per cent., but he thought that the necessary reduction in speed required, in order that the fly-wheel might give up its energy, was due to slip of the belt. With regard to the question of keeping the shunts of D.C. motors permanently excited, this was a matter which depended altogether on the type of starting switch employed. When liquid starters were used, it was necessary always to keep the shunts on or else to provide some means of breaking the shunt with safety—a practice, however, which was not to be commended. Where liquid starters were used, he had been in the habit of coupling up a few incandescent lamps in series across the shunt coils, and found this quite satisfactory. He had had a great deal of trouble with liquid starting switches, and was not at all in favour of using them, more especially at pressures of 500 volts. Although he held no brief for A.C. motors, he could not help saying, in conclusion, that these machines were very much more satisfactory in every way than D.C. motors. They were simpler, more reliable, and more robust than the D.C. type. They cost less for repairs and maintenance, and were altogether more of an engineering job. He was quite sure that all engineers who had had any experience with both classes of plant would support his view.

Mr W. A. Ker, in reply, said that on hearing Mr Klinkenberg's remarks he had begun to think that he must have been very wrong in his statements, but Mr Spence's observations had restored his self-esteem to a certain extent. Mr Klinkenberg joined issue with him on fourteen different points. He stated that he (Mr Ker) said that from Fig. 1, with a current of 30 amperes, the torque of a shunt motor was double the torque of a series motor; but he stated that with a current of 30 amperes the shunt motor field was fully excited. Of course it was fully excited whatever the armature current might be. Then he went on to say that with the series motor where a current of 96 amperes was required to reach maximum field strength (he should say full load field strength) it was evident that the motor started with a very much weakened field, and with a field of

Mr W. A. Ker.

one-third of the strength of the shunt motor, the series motor exerted half the torque of the shunt motor, actually proving that the torque of the series motor with the same conditions was greater than the shunt motor. What did Mr Klinkenberg mean by "the same conditions?" He supposed he meant "with the same armature current?" If so then Mr Klinkenberg was quite wrong, and on a little reflection would probably admit that he was. With an exciting current of one-third the normal full load current the field of a series motor was about one-half the strength of the normal full load field—not one-third the strength as stated by Mr Klinkenberg; and as the torque of any motor was proportional to the armature current and the flux, the torque of the series motor was then one-half the torque of the shunt motor which had the full flux. If Mr Klinkenberg referred to Fig. 2 he would see that one-third of the ampere turns gave about one-half the flux. Mr Klinkenberg failed to see that the Author had succeeded in proving that a series motor had higher losses. He did not attempt to prove this; but merely stated the matter as a well-known fact. If Mr Klinkenberg doubted the accuracy of the fact, he would point out that at high speed the brush friction and bearing friction varied directly as the speed and that the work done by the motor did not affect these losses unless, of course, the film of oil in the bearings had got squeezed out, and the bearings seized, a condition which need not be considered. Also the windage varied somewhat as the square root of the cube of the speed, and therefore, of course, increased with the speed. The sum of the eddy current and hysteresis losses was much the same at any speed The total loss, however, of core friction and windage was higher at high speeds than at low speeds, but he did not think it necessary to trouble the meeting with curves plotted to actually show that. Mr Klinkenberg said: "The conclusion the Author drew from Figs. 1 and 4, that motors for varying speed and constant work should be shunt wound, that speed regulation effected by means of resistance switched into the shunt circuit should be used 'with a speed variation of 9 to 1,' was surely an error." Mr Klinkenberg had misconstrued his meaning. He did not recommend that variable speed motors having a range of 9 to 1 should be used, but only 3 to 1. He would not recommend 9 to 1 motors in every case, but where such a large range was required, and the voltage of supply was low, it could be easily obtained without sparking from well designed motors of standard make without commutating poles. The particular motors he referred to were for 110 volts, but when a voltage of from 250 to 500 was in question the problem was much more difficult. Mr Klinkenberg stated that, only one or two of the largest electrical manufacturers made motors with a speed variation of 4 to 1. He did not know if the largest manufacturers had the monopoly of brains in the electrical engineering world. He thought they were rather hampered by their patterns and designs, and that some of the best and most advanced work had been turned out by quite small shops. Mr Klinkenberg did not agree with him that a fly-wheel was of no practical effect on a shunt motor, and stated that as a matter of fact the minimum variation of speed between no load and full load was 5 per cent., and more generally 8 per cent. He did not know what motors Mr Klinkenberg was accustomed to, but they must be most inefficient. He had been privileged by a manufacturer of first-class motors to take particulars and tests from a number of standard machines in his works, and he had worked out the results. In order not to get results too favourable to his own view of the matter, he did not take any motor over 50 H.P., and he found the reduction of speed from no load to full load to be as follows:—

18 H.P. motor		3·9 per cent.	
20 ,,	,,	3·5	,,
24 ,,	,,	3·6	,,
38 ,,	,,	2·1	,,
40 ,,	,,	1·8	,,
50 ,,	,,	2·7	,,

These motors were wound for voltages varying from 250 to 500.

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That gave a maximum variation of speed in the worst case from no load to full load of 3·9 per cent instead of 8 per cent mentioned by Mr Klinkenberg. These figures were taken with a constant voltage at the terminals. Mr Klinkenberg suggested that with a sudden load there would be a decrease in voltage. That decrease should be very slight, and as it weakened the motor fields the decrease in flux tended to increase the speed of the motor, and to compensate for the small drop in voltage. Under the worst conditions then, from no load to full load, with a good shunt motor there was a drop in speed of 4 per cent.: the fly-wheel would, therefore, give out about 8 per cent. of its energy. These conditions never occurred in practice, as a motor never ran at no load, but always had some work to do even when the machine it drove ran idle, and the variation of speed of a shunt motor rarely exceeded 2 per cent., rendering a fly-wheel, in his opinion, useless. Mr Klinkenberg defended the inquiry quoted by him "supply one 10 H.P. shunt wound motor for 500 volts, at 900 revolutions per minute, with a two-feet fly-wheel." He said "that gave the manufacturer practically all the information he wanted—he knew that a 10 H.P. motor was required; the motor was to be shunt wound, that was to say, the manufacturer had to exert himself to build a shunt wound motor, capable of exerting sufficient torque, fitted with a fly-wheel." That appeared to him an odd way of looking at it. The motor was to do very variable work or the fly-wheel would not be required. The manufacturer was given the diameter of the fly-wheel which was to run at full load at 900 revolutions per minute, but the diameter of the fly-wheel and the speed did not give the value of the energy which was required to be stored in that fly-wheel. For that three dimensions and the velocity were required. Any fly-wheel fitted without careful calculation as to the work it had to do was not likely to do credit to the manufacturer. There were a good many manufacturers and contractors of Mr Klinkenberg's way of thinking, as he had found to the benefit of his pocket. Mr Klinkenberg confused the issue regarding the advantage of the shunt motor over the series motor for acceleration by referring to tramway cars, and suggested that all the series motors should be scrapped. He distinctly stated that it was only for currents less than the full load current that the shunt motor had the advantage. Car motors had starting currents much in excess of the full load current, and the series motor had a larger torque at starting. There were, of course, a considerable number of shunt car motors at work with great success, the economy in energy being considerable. These were on Rayworth's and Johnson-Lundell regenerative systems. Mr Klinkenberg did not agree with his suggestion to use the shunt coils in a reversible motor continuously excited owing to economical reasons, and he instanced the loss by doing so in a passenger lift. He did not recommend doing this in a passenger lift, as it was quite unnecessary, and it was only in machines where very small movements were required that he should advise it. Mr Klinkenberg suggested that the shunt current was from 5 per cent. to 8 per cent—he supposed he meant a percentage of the full load current. These figures confirmed his opinion that he was accustomed to very inefficient motors. The shunt coils of the six motors he tested, and of which he had just given the speed reduction, varied from 1·02 per cent. to 2·44 per cent. of the full load current—a very different thing from Mr Klinkenberg's 8 per cent. He also found that the shunt current of a 5 H.P. motor was under 6 per cent., and of a 2 H.P. motor under 8 per cent., so that even with these small sizes, as the current was so small, 8 per cent. of it was decidedly trifling. Mr Klinkenberg thought it a source of danger to keep the shunt continuously excited; the danger, however, was not in keeping it excited but in breaking the circuit, and it was surely less dangerous to break the circuit once a day than it was to break it 20 or 30 times an hour. Of course, in either case proper arrangements must be made to allow of the discharge of the current due to the induced voltage. He was glad to hear of Mr Klinkenberg's experience with an installation of four 100 H.P. motors which

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broke down, as he mentioned that the armature coils were destroyed by breaking the shunt circuit. There were some engineers who believed that the induced voltage from the shunt could not affect the armature even though one of the armature leads was connected to the shunt, and he knew of one case where a manufacturer had two armatures damaged in this way owing to faulty starting switches, which broke the shunt circuit without providing a path for the discharge. These switches and the wiring had been fitted by the owner, and the manufacturer of the motors disclaimed liability. The case went to arbitration, and was given against the manufacturer; the consulting engineer, who acted as arbiter, maintained that the field coil could not possibly affect the armature. In his own experience he had three times known the armature destroyed by field coil discharge, and he was glad to have his experience confirmed by Mr Klinkenberg. Mr Klinkenberg stated that his claim for a constantly excited field bringing the armature quickly to a standstill was erroneous and that the residual current in the field magnets was more than sufficient to bring the largest motor to an instantaneous stop. Apart from actual experiments and general practice which confirmed his statement: How could that possibly be? The residual current was dying down from a maximum to zero, whereas, with constantly excited fields the flux was constant at a maximum all the time. Of course, if Mr Klinkenberg meant by saying "It is quite easy to utilise the residual current" that he disconnected the armature from the line and put it in series with the fields so that the armature voltage excited the fields, that was simply the armature brake which he referred to on page 295, but not so effective as if the fields were permanently excited and the armature braked through a separate resistance. Mr Klinkenberg also stated that no more power was required for planing cast iron or steel than for planing wood, as the same sudden loads came on in each case. Probably those present knew from their own experience that that was not so. Wood planers seldom took more than 15 H.P., whereas iron planers

often took from 40 to 60 H.P. The load at reversal of the table of an iron planing machine was often from 50 to 100 per cent. over the load when cutting, whereas, with a wood planer the variation of load was comparatively small. Mr Klinkenberg stated that he (Mr Ker) recommended a compound motor for a shipyard winch, while for a skull breaking winch and a three-motor crane he recommended a series motor. If Mr Klinkenberg referred to page 298, he would see that for a three-motor travelling crane he (Mr Ker) recommended a series motor only in places where rough work was carried out, and no nicety of handling was required. Later on Mr Klinkenberg alluded to a motor on a travelling crane being coupled to a self-locking worm. That type of travelling crane was comparatively rare, owing to its inefficiency, and for which it did not matter what type of motor was employed, as the friction at starting was so great that a large current was required. For the travelling crane with spur gearing, however, the current at starting to lower was very small, and the large torque of the compound motor with small current enabled the load to be controlled much more easily. Mr Klinkenberg asserted that he had somewhere recommended the use of additional series windings to assist the shunt field. He had looked carefully through his paper, and he could not discover that he had said that or anything like it, and it was, of course, contrary to the recommendations which he had advanced. Mr Klinkenberg further observed that he had recommended for centrifugal and reciprocating pumps a shunt wound motor, but in the same sentence stated that for pumps at a distance series wound motors should be used. Again Mr Klinkenberg had failed to read his paper correctly. In one paragraph he (Mr Ker) recommended that centrifugal pumps should be fitted with shunt wound motors, and in another paragraph he recommended the same motor for reciprocating pumps, and said that for reciprocating pumps at a distance a series wound motor would be best, owing to two cables only being required. Surely two cables were better than three, as there was a lower first cost and less liability to derangement, and, if other things were equal, surely Mr Klinkenberg did not object to saving money. Mr Klinkenberg posed apparently as a champion of the series motor, yet when he (Mr Ker) recommended it he promptly fell foul of him. Mr Klinkenberg closed by expressing regret that he had not discussed the question of motors for steel rolling mills and mining and other apparatus. The subject of the paper was—Motors for driving machine tools, and although he had stretched it to include cranes, hoists, and pumps, he had not the conscience to include winding drums, coal cutters, etc., among machine tools, and it was perhaps as well that he had not done so, as Mr Klinkenberg had succeeded in finding fourteen points upon which he had joined issue with him in the paper, short as it was, and it was possible he might have found several times as many in a longer paper, Mr M'Whirter had made some kind remarks of commendation, and referred to Mr Klinkenberg's criticism regarding tramway cars, and answered him very effectively. He was pleased to hear that Mr M'Whirter agreed with him with regard to the use of compound motors for lifts. Professor Jamieson had treated him very gently in his lecture upon the improper use of terms, what he might, to use the political language of the moment, express as "terminological inexactitudes." He was afraid that if the Professor had known that some twenty years ago he was one of his students he would not have been so lenient with him. His excuse must be that he had the advantage of being under him one session only, and had not time to absorb his accuracy. The terms which he had used in this paper were those which he had been in the habit of using in the workshop and drawing office for over twenty years, and they were, he believed, in common use. Therefore he thought it better to retain the well-known terms and not introduce new ones. Professor Jamieson objected to his use of the phrase "magnetic flux per pole." He would be very glad if the Professor could give any term which could express this accurately, as the sentence he proposed was somewhat long for common use, and everybody knew that flux per pole was the flux radiating from the pole which entered the core and not flux per magnet. Professor Jamieson also objected to the use of the term "saturation curve" for the beta ampere-turn curves shown in Fig. 2, and suggested that it was an ordinary magnetisation curve. To his mind a magnetisation curve was one which had the ordinates representing beta, and the abscissae representing H; Fig. 2, had ampere turns instead of H, and this as great an authority as Professor Silvanus Thompson habitually called a saturation curve. Professor Jamieson mentioned Professor Ewing's experiments, and the high degree of intensity of magnetisation reached. He believed that there was no saturation point whatever of any magnetic material, that if sufficient magnetising force was applied the magnetic material behaved like a similar mass of air, and it was generally thought that there was no saturation point for air. He was glad that Professor Jamieson approved in certain cases of constantly exciting the field coils of shunt wound machines, especially for the purpose of keeping them dry. It was a precaution he had adopted on a good many occasions, and had never had any trouble from breaking the shunt circuit, as appropriate switches and resistance were provided. He quite agreed with Professor Jamieson, however, that each case must be considered on its own merits. Mr Spence referred to the speed range of simple variable speed motors with shunt control, and considered 5 to 1 the greatest variation that was practicable; but he (Mr Ker) thought that even 5 to 1 was sometimes difficult to obtain, as so much depended on the limits of speed. With low voltage machines it was much easier to obtain a large variation than with high voltage. From the cash point of view Mr Spence did not quite agree with his remarks regarding the multiple voltage system, which he had dismissed in a very short sentence along with other systems. He quite agreed with Mr Spence that, with a large number of motors, in which a considerable variation of speed was required, the multiple voltage system could be applied more cheaply and nearly as effectively as a number of variable speed motors with

Mr W. A. Ker.

shunt control. The increase or decrease of speed with that system was not so smooth as with shunt control, (with a large number of contacts on the control switch), and consisted of a number of steps. In his experience of that system he had found that though for one particular load the change of voltage was smooth, for any other load it caused jerks in the machine, to the detriment of the work. He had also found a difficulty in the automatic balancing, especially when overtime was being worked on one class of job only, the rest of the motors being idle. The shunt control motor was not subject to these drawbacks, and taking the cost of controllers, cables, etc., into account, it was only slightly higher in first cost even in a big installation. With regard to the remarks by Mr M'Laren, and the discussion upon them by Mr Spence, Mr M'Whirter, and Mr Hall-Brown, he was of opinion that the apparent discrepancy could be partly explained thus. The original shunt wound motor ran at almost constant speed even when welding, the overload being large. The over-compounded motor, on the contrary, ran 15 per cent. slower during the weld, the welding, therefore, took a longer time, and the motor put more work into the weld than appeared at first sight. Undoubtedly the motor would have to restore the energy given out by the fly-wheel, and must, therefore, take a larger current between welds than the original shunt motor. He had read Mr George Stevenson's contribution with interest; but he did not consider that the case cited was contrary to his contentions. He agreed that the polyphase motor was even more constant in speed than the shunt motor, and with the mortar mill in question a friction clutch and a belt had been adopted, presumably with a view to their slipping qualities, so that it was not surprising that they did slip. With the fly-wheel removed, the friction clutch slipped as soon as the resistance of the mill became excessive, relieving the motor of a heavy overload, and allowing the heavy runners of the mill to give up some of their energy (fly-wheel effect), owing to the reduced speed of the mill. With the fly-wheel replaced, its effect was added to that of the runners, so that a less reduction of speed of mill was able to overcome the resistance, and, consequently, less slipping of the clutch. He considered that this case, far from being "all right in theory; but all wrong in practice," formed an instructive object lesson confirming his statement. His contention was in effect that to use a fly-wheel effectively it was necessary to cause a reduction of speed of the "driver," when the load came on. In the mortar mill the "driver" was the driven part of the friction clutch, and it was allowed to slip by adjusting the pressure so that the friction was not sufficient to transmit more than a predetermined torque. If the friction clutch had been of ample design so that the wear was small, there would probably be no objection to it slipping, and it would fulfil the first object of its existence. With a compound wound motor the series winding caused automatically the reduction of speed of the "driver" without the loss represented by the friction of the clutch with the three phase motor in question.

On the motion of the Chairman, Mr Ker was awarded a vote of thanks for his paper.

REFUSE DESTRUCTORS.

By Mr H. Norman Leask (Manchester).

SEE PLATES XVII. AND XVIII.

Read 20th March, 1906.

Within the last five years a great deal has been written on the subject of the disposal of towns' refuse by fire and the utilisation of the resultant by-products. The more technical points have not, however, received the same attention, and it is in this direction the Author intends to confine his remarks.

To those more particularly interested, from an historical standpoint, the Author cannot do better than refer them to that excellent and instructive treatise, "Destructors and Disposal of Towns' Refuse," by Mr W. H. Maxwell, wherein the subject is dealt with at considerable length, also to various papers on the subject by Mr Charles Jones. As, however, the annals of this Institution do not record a paper on the subject, the Author feels that it would be out of place to enter into technical questions without making some reference to the history and the evolution of types of furnaces.

Ancient history records that the Jews, Romans, and Greeks, also the natives of India, employed fire for the purification of wastes.

Mr Maxwell draws attention to a rather peculiar find recorded in Lucian's "Ancient Rome in the Light of Recent Discoveries," viz., a pillar amongst the antiquities of ancient Rome bearing the inscription, "Take your refuse further on or you will be fined." It would appear, according to another author, that Christians gave up burning refuse about the fourth century.

It has come to the notice of the Author that the refuse of the city of Cairo has been employed for centuries to heat the Turkish baths in that city. This is probably the earliest known utilisation of the heat from the combustion of refuse.

About 1860 contractors for the collection and disposal of refuse in the metropolitan district found it difficult to secure land within a reasonable distance of the collecting area, and they, therefore, turned their attention to burning the same. To-day the same difficulty is no doubt the cause of many authorities erecting destructors.

The original furnaces were very crude, and failed to cope with the quantity of refuse to be burned. One of the main reasons, as pointed out by Mr Codrington, of the Local Government Board, was the deficiency of flue area, viz., about 3 square feet of flue to 110 square feet of grate. The first furnace which at all met the requirements, was invented by Mr Fryer, of the firm of Manlove & Alliott, of Nottingham, about 1876. Figs. 1 and 2 are views of published illustrations of this furnace. Reference to Figs. 4, 5, 6, 7, and 8, will testify to a family likeness existing between this furnace and certain furnaces before the public at the present time. The "Fryer" type of furnace seems to have held the field for more than ten years without any rival, and there is existing to-day many installations of this type. The first was erected in Manchester about 1876, and subsequently Birmingham, Leeds, and Bradford, imitated Manchester in rapid succession.

A furnace which created considerable attention about 1885 was known as the "Beehive," Fig. 3. This furnace was supposed to deal with thirty-six tons of refuse per day of twenty-four hours. To appearance it was constructionally weak, and could never satisfactorily deal with that quantity. It is of interest, however, to note that its cost was £443. Contrast this with a modern up-to-date furnace, capable of dealing with the same quantity, which would probably cost a sum of £4,000, complete with buildings.

Combustion in these early plants was slow and imperfect, and it was found necessary to introduce an independent coke fired furnace in the path of the flue gases in order to re-ignite the products of combustion from the furnaces; this device was known as "Jones' Fume Cremator," and was introduced about 1885. About this time Mr Young, of Glasgow, arranged a destructor with closed ashpit, and by a powerful fan facilitated combustion.

The first serious competitor to the "Fryer" type of furnace was the "Horsfall" destructor, first patented about 1887, Figs. 4 and 5, the latter being a more modern example. It would appear that Mr Horsfall supplied the air for the support of combustion in his furnaces by means of a steam jet apparatus—Warner's "Perfectus," Fig. No. 6 followed, patented in 1888. This furnace was an offshoot of the Fryer type as manufactured by the firm of Manlove, Alliot & Co., Nottingham.

In 1891 there were some 200 cells at work in the United Kingdom destroying about 500,000 tons of refuse annually.

About 1893 many forms of furnaces were patented, but do not seem to have been usefully employed. Those which survive are referred to below, and amongst them may be mentioned an arrangement which has been installed in a number of places, perhaps the most important example being the plant erected at Shoreditch, which consists of a water-tube boiler sandwiched between two cells (these latter resembling the Fryer type) in combination with a special storage and charging device (Bulnois & Brodie's), Figs. 7 and 8. In the same year the Beaman & Deas furnace was patented, Fig. 9. In 1894 Messrs Meldrum Bros. patented their well known "Simplex" type, Figs. 10 and 11.

The "Heenan" destructor, as now constructed, Fig. 13, was evolved from furnaces patented in 1893. Fig. 12 shows the "Heenan" twin-cell furnace as it was at first constructed, about 1898, the idea being to have two cells, each charged alternately, and to alternate the flow of the products of combustion so that the outlet was always over the incandescent fire. The idea of the maintainance of a damper in the hottest zone had to be abandoned, but it was found that, by introducing a deflecting arch and a single opening in the reverberatory arch the same effect could be obtained. Figs. 13 and 14 show the "Heenan" destructor as now constructed for back feeding.

About 1901, the "Sterling" destructor, Fig. 15, was put on the market, and has since met with some favour. These four latter furnaces may be said to have a family resemblance, and form a second group, whilst those mentioned previously belong to another distinct family or group. The prevailing feature of the first group may be said to be isolated cells, that is a number of grates each in a separate chamber, the latter communicating with a secondary combustion chamber by small passages or ports; whilst that of the second group is a primary combustion chamber common to a number of grates with a single outlet to a secondary combustion chamber, each grate having a separate closed ashpit.

The call for better sanitary measures on the Continent, and in fact all over the world, has given an impetus to the construction of furnaces by foreign makers, notably in Germany and Belgium. Lately a competition was held in Brussels, and no less than five new makers of destructors submitted schemes, four German and one Belgian. No doubt these furnaces are largely based on British practice, and it is also fairly certain that British engineers dealing with the question will have to regard German engineers as worthy rivals at no far distant date.

The larger proportion of early destructor plants in England was operated by natural draught, and the rate of burning does not appear to have exceeded six tons per day of twenty-four hours on a grate area of about thirty square feet. About the year 1894 forced draught was first applied systematically to refuse furnaces, and a much higher burning capacity with higher temperatures were obtained.

It is only fair to the memory of Mr Fryer to say that he foresaw the use of forced draught and heated air supply. Anyone doubting the advantage of the use of mechanical means for supplying the air for the support of combustion, cannot but be struck by the increase in the rate of burning and consequent higher temperatures obtained in the destructor field by this means. The rate of burning has now gone up, and 60 lbs. per square foot of grate area per hour is quite common, and has even passed 85 lbs.; temperatures also have risen from a mean of perhaps 800 degrees F. to a mean of nearly 2000 degrees F., in some cases rising higher than 3000 degrees F. Water evaporated per lb. of refuse has also risen from *nil* to over 2½ lbs. from and at 212 degrees F.

It is to be clearly understood that the aforementioned figures are merely diagrammatic, and that no attempt has been made to elaborate the details which are no doubt well worked out in all plants on the market at the present time, nor has the Author attempted to describe the furnaces in detail, as he feels that he could not do full justice to any type but the Heenan, for which he is largely responsible.

As might be expected, towns' refuse, that is trade and domestic refuse, varies according to the latitude and longitude and the habits and customs of the people in various countries, it also varies with the season of the year, and therefore it is not one of the easiest materials to deal with. In the South of England towns there is collected from 10 to 15 cwts. per 1000 inhabitants per day, in the Midlands it can be taken as 20 cwts., and in the north-east of England the quantity may rise as high as 40 cwts.

One very good indication of the nature of refuse in various parts of the world is the percentage of mineral matter it contains. In England the average percentage is somewhere about 27, on the Continent, it appears to rise to over 45, while at an installation lately erected in New York the percentage of clinker is only 3, after sorting, 60 per cent. of the refuse being removed and sold. In Australia it is about from 25 to 30 per cent. Another clear indication of how refuse varies in various places is the widths of the air spaces through the grates. In England the air spaces are commonly between one-eighth and three-eighths of an inch, in America, at the installation referred to above, the bars are spaced seven-eighths of an inch apart, while on the Continent, one of the best German destructors has no grate bars, but merely cast iron plates with small holes at intervals of about four inches. Again, in Britain, forced draught is resorted to, and the average pressure would be about two inches of water column in the ash-pit. In the New York installation natural draught is employed, whilst on the Continent a pressure equivalent to something like from twelve to fifteen inches has been used.

The destruction of refuse is nothing more or less than the combustion of poor fuel. The difficulties to be faced arises out of the abnormal quantity of mineral matter, the high percentage of moisture and the relatively small quantity of combustible matter contained in the fuel.

The manner in which the problem has been solved may be divided into two distinct groups, as already stated the distinctive feature of the earlier one being the division of the furnace into a number of isolated chambers, generally called cells, the other making provision for a furnace chamber common to a number of grates. The Author would submit as incontrovertible that the latter type has given the better results from the standpoint of high temperatures, more regular maintainance of the same, and more complete combustion with a consequent higher evaporative efficiency.

It is claimed for the isolated system that repairs can be carried out without affecting the operation of the adjacent furnaces; this, however, appears doubtful if the adjacent furnaces are in full work, as it is by no means uncommon to find the firebrick linings red hot at a depth of nine inches from the working furnace face, and almost impossible to bear one's hand on a wall eighteen inches thick. As the isolated system presents a larger perimeter of firebrick work exposed to the adherence of clinker, the repairs are also likely to be more frequent. In some makes this is obviated to some extent by fixing cast iron boxes through which the air for the support of combustion is passed on its way to the ashpit. The cubic contents of firebrick lining in a furnace of this type is no doubt somewhat greater than with the common combustion space type, and therefore more heat may be said to be stored, but this construction renders it more difficult to obtain a suitable outlet for the products of combustion, the passages being necessarily small, and if high temperatures obtained would rapidly become choked up and almost impossible to clean.

The common combustion space type of furnace has been unfairly termed a "Flue filled with fire bars." It has, however, many good points to recommend it, the most important being the maintainance of the temperature of combustion at a high level throughout the operation of charging and clinkering.

It is well known that CO and hdyrocarbons can exist in a furnace at the same time as an excess of oxygen, this is no doubt due to the high specific volume and lack of affinity between the elements when at a high temperature. If some means can be adopted for automatically mixing the products of combustion, CO and much of the hydrocarbon will disappear entirely. The Author claims that this is best carried out in the second group of furnaces, and that it is positively carried out when the reverberatory arch over the furnace is given an undulating form, which, as the "Heenan" type, Fig. 13, tends to produce eddies in the furnace chamber, thus mixing the gases thoroughly; so that when a furnace is being freshly charged, or being stirred prior to clinkering, or as is sometimes the case, an excess of air is passing through the material lying on one part of the furnace and an insufficiency in another, the final result in the secondary combustion or settling chamber immediately preceding the boiler is a gas high in CO_2, low in O, and without CO appearing. It is also to be noted that this undulating form increases materially the most effective radiating surface, and also the quantity of refractory materials for heat storage.

It is self evident that with a battery of grates, when one grate is being cleaned or charged, some proportion of the furnace is out of action, and unless some special means are taken the rate of combustion is temporarily suspended, and the quantity of heat evolved in the furnace is decreased. When dealing with a given quantity of refuse it is very advisable to split up the furnace into a number of small grates, in order that the cleaning and charging may be carried out with the minimum disturbance of temperature and quantity of heat evolved. It, therefore, becomes a question as to what is the commercial limit to which the furnace can be divided up and fitted with furnace doors, etc., the quantity of firebars would not be altered, but the number of doors, deadplates, and other accessories would be increased with each extra subdivision. Take a furnace of 100 square feet grate area, divided into six equal grates, and compare it with a furnace of 100 square feet grate area divided into three grates, it will be seen at a glance that the amount of furnace out of action in the latter case would be 33⅓ per cent., whereas, in the other case it would be about 17 per cent., and, therefore, when making the choice of a system it is well to compare the grate area with the number of separate grates, and give the preference to that system which has the largest number of separate grates and ashpits to a given grate area.

It is generally found that with plants which have large grates, that they also have a greater grate area to perform the same work. This means a lower rate of combustion, and to all who are conversant with furnace work, it will be apparent that it also means a reduction in the intensity of the temperature of combustion; now, whilst the total heat remains the same, the rate of transmission will vary as the difference in temperature between the medium to be heated and the heating medium, and, therefore, with well-proportioned boilers, better results can be obtained with the highest rates of burning.

Another distinctive feature of separating the first group of furnaces from the second group, is the almost entire omission in the second group of what is commonly termed a drying or dessicating hearth. For fuels containing a lot of liquid matter, some form of receptacle for catching this liquid within the furnace would no doubt be of advantage, but, to the Author, it appears an unscientific way of drying material to merely subject it to the action of radiant heat, and he thinks that a much more rapid and efficient means would be to place the material on a grating and pass a heated air supply through it, the advantage in heating the air supply being, of course, due to the increased absorbing power of heated air over that of air at ordinary atmospheric temperature. In practice it is found that material so treated is dried almost instantaneously, and when burnt in a common combustion chamber, the distilled gases momentarily disengaged from the material are immediately brought to a high temperature and burnt before they pass into the neighbourhood of the boiler. It is claimed, however, that with the former type, if an aperture is placed in front of the furnace over the grate itself, that the gases distilled from the material lying on the drying hearth pass over the hottest part of the fire before leaving the furnace, and are so completely burnt. This is probably the case when the cell is in full work, but it cannot very well be the case immediately after an isolated furnace has been cleaned out and recharged.

When a boiler is situated relatively to isolated cells, as in *Fig.* 8, the distilled gases from a freshly charged fire pass immediately into contact with the heating surfaces of the boiler, and the Author is of opinion that sufficient time has not elapsed to permit of complete combustion. Although this arrangement gives fair evaporative results, it is not due to completeness of combustion, but more probably to the direct action of flame on the heating surfaces of the boiler.

From personal experience the Author has found that the products of combustion leaving the chimney vary in colour and transparency according to the position of the boiler, that is to say, that when sufficient space is left between the boiler and the furnace for the flaming of the products of combustion to disappear, the gases leaving the top of the chimney are so clear and transparent that they can hardly be distinguished.

There are many ways of obtaining a high temperature in a furnace, and it may seem strange that the temperature can be too high in a furnace, but it is a fact. It may be so high that particles of dust carried into the settling chamber become molten, and on solidification require a great deal of labour and force to remove them. One of the simplest means of obtaining a high temperature is to work a furnace with a plenum above the grate bars, that is, combustion under pressure. It is well known that the effect of pressure is to reduce the specific heat of air, and, consequently, when a pressure above that of the atmosphere is created in the furnace, the temperature will rise; as the pressure above the grate seldom equals from half an inch to one inch of water, the calculated rise in temperature resulting from such a process would not be much above 50 degrees F. The actual observed increase in temperature, however, is very much greater than this, and is, no doubt, due to the fact that an air supply approximating more closely to the requirements of the fuel enters the furnace, also the entrance of cold air through the doors is absent, and, consequently, the calorific value of the fuel is dissipated over a smaller quantity of air. This method if adopted, however, has very serious inconveniences. *Firstly*, it is impossible to open any furnace door without allowing an outrush of the products of combustion, and, *secondly*, suitable doors for closing the furnace when in operation, would be difficult to manufacture and maintain. On the other hand, if there is a decided vacuum above the grate bars, on opening a furnace door large quantities of cold air will enter, with a consequent fall in temperature. It will, therefore, be seen that there is some mean point to arrive at which requires nice designing, in order that the best results can be obtained. Other means, however, can be adopted to obtain a higher temperature.

In the "Heenan" and "Meldrum" types of furnace, an air-heater or recuperator is placed in the path of the gases after they have passed through the boiler, and the air for the support of combustion is passed around the battery of tubes forming the recuperator, and is heated in its passage. In another type it is claimed that a heated blast is obtained by passing the air through cast iron boxes situated at the level of the grates in the side walls of the furnace, this latter device, however, is not a recuperator, and whatever heat may be given to the air does not result in a saving of the heat otherwise passing to waste in the products of combustion.

With the former type it may be taken that the air is raised in temperature about a quarter of a degree for every square foot of heating surface, and that the rate of transmission of heat from the gases to the air is about 1000 B.T.U. per square foot per hour. With the cast iron side boxes the Author has seen it stated that an ashpit temperature of from 400 degrees F. to 600 degrees F. can thus be obtained. Examine for a moment what this means. Taking the quantity of air required for 1 lb. of refuse at say 3½ lbs., and the heating surface exposed to this air at say 12 square feet per grate of 30 square feet in area, and that the rate of combustion on this grate is 30 lbs. per square foot of grate area per hour, it would appear that the rate of transmission is about 50,000 B.T.U. per square foot per hour, and the rise in the temperature of the air about 50 degrees F. per square foot of heating surface. Now, although the mean difference in temperature between the two sides of the plate is much greater in this case, such a rate of transmission would be abnormal, and is probably not surpassed in the firebox of a locomotive. It is evident that there must be some misapprehension possibly arising from taking the temperature of air in the ashpit, or some other position subjected to radiant heat.

It has been reported that Mr Bennis of Bolton once heated a 2-inch tube 50 feet long red hot, and maintained it at that temperature while air was forced through the pipe at the rate of 1000 feet per minute, the rise in temperature of the air was ¾ of a degree per square foot of surface in contact with the air. Under these extraordinary conditions it is seen that the rise in temperature of the air is only three times that obtained with the heaters employed with the "Heenan" type of furnace.

The value of heated air in refuse destructor furnaces is undoubtedly great. If the heat is taken from the waste gases this waste heat is utilised to absorb the moisture that may be in the fuel without drawing on the calorific value of the fuel to the same extent; further, the temperature in the furnace will be directly increased by an amount almost equal to the temperature of the entering air, and owing to the fact that an air supply approximating more closely to the theoretical requirements of the fuel can be used, the temperature is still further increased, and there appears to be little doubt that with a rise in temperature of the air for the support of combustion of 300 degrees F., there will be a corresponding rise in the furnace temperature of 600 degrees F.

The next point on which opinion seems to differ is whether the air for the support of combustion is better driven in by a fan or driven in and accompanied by steam. It is claimed for the latter that the steam keeps the firebars cool, and also becomes decomposed in the fire and forms a species of water gas; any cooling which may take place is, no doubt, due to the decomposition taking place in the bed of the fuel, and whilst it may be admitted that the heat absorbed by decomposition might be almost wholly regained in the furnace chamber if an additional air supply were admitted, it is more than probable that the heat absorbed in decomposition is not fully recovered. The users of such apparatus admit to 15 per cent. of the steam raised in the boilers being required to operate the steam jets, and on actual test it has been proved that equivalent to 1440 lbs. of steam per hour are required to supply air for the support of combustion at a pressure of say 1¾ inches of water in a four-grate plant, and taking the evaporation at 8000 lbs. per hour, it will be seen that 18 per cent. is required, and this with new apparatus and careful regulation.

The Author is of opinion that the claims made for the steam jets are not the real benefits which accrue, but are, in his opinion, the following:—*Firstly*, It enables clinker to be removed from the firebars with greater ease; and, *secondly*, the clinker is more open in character, a large percentage of steam, however, has the disadvantage of leaving the clinker very open and friable, and easily crushed, and therefore not suitable for many purposes.

With fan blast no trouble has been experienced with firebars when made of special simple section, and further, only some 3 to 5 per cent. of the steam evaporated in the boilers is required to operate the fan engine. To obtain the advantages of the steam jet with the fan, it is found useful to exhaust the fan engine into the air duct, as a small quantity of exhaust steam thus used performs all the functions of the larger quantity of live steam.

Actual tests taken by condensing the exhaust from the fan engine show, in the case of the King's Norton destructor, where some observations have been made which will be described, the quantity of steam required was only 4·17 per cent., and could be further reduced.

There are other advantages which can be claimed for the fan:—*Firstly*, That if one fan is coupled to a number of grates, and one of the group of grates is undergoing the operation of charging or clinkering, and, therefore, has the air supply totally or partially cut off, the pressure and quantity of air entering the other ashpits, forming the group or unit, rises, and consequently the rate of combustion on these grates is increased, so that in a group of four grates, with one undergoing cleaning or charging, the rate of combustion is not reduced by 25 per cent., but by something like 10 per cent. It is necessary, however, to construct the fan in a special manner to obviate the pressure rising two high. *Secondly*, The fan can be most usefully employed in ventilating the building in a positive manner, an arrangement for giving effect to this has been installed at King's Norton and works with remarkable success.

The most vexed question is that of the best means of feeding refuse fuel into a furnace. Now this fuel varies with the locality, with trades, and with seasons of the year, in fact it may be said to vary hourly, and will consist of such varied material as a load of vegetable matter or fruit, load of paper, straw, ashes, leather cuttings, oilcloth cuttings, rolls of oilcloth, mattresses, paper, tins, bottles, fish, slaughter-house offal, etc.

Five years ago it was common to see expressed in specifications a desire to receive schemes for charging furnaces mechanically, and much money, time, and trouble has been spent in endeavouring to arrive at this desideratum. Up to date it has not been achieved with any marked degree of success, and it may be said, with a great deal of truth, that plants giving the greatest satisfaction are those in which no such mechanical means exist. The material could, of course, be treated primarily, disentegrated and reduced to a uniform size, and then fed into the furnace in a simple manner, the cost of such machinery, and the maintenance and labour attending the same, however, exceed that of charging the furnace by hand. The Author has had the opportunity of inspecting such apparatus at work and of verifying these facts.

It is not a difficult matter to devise a furnace into which large quantities of refuse can be tipped, it is, however, a grave question as to whether it is advisable to proceed in this manner or not; if whole cart loads of refuse are tipped into a furnace no opportunity of selecting and varying the proportion of the material is permitted, nor can it be claimed that the charging of a furnace with a ton of refuse at a time is a scientific way of obtaining good combustion, it must necessarily mean great fluctuations in temperature, and it is questionable whether any saving of labour results. Picture a load of market refuse being discharged into a furnace, and subsequently a load of paper and straw, then a load of ashes, then large quantitives of shell fish and tins. Can anyone say that such a proceeding gives good results? For a very large plant connected to a common chamber, and where it is merely a question of getting rid of the refuse, there might be an excuse for such an arrangement, but under no other circumstances could such a proceeding be justified.

From personal experience on this point, the Author has found that in some districts, and at certain seasons of the year, such an arrangement could be worked with fair results, but it is certainly not applicable to all kinds of refuse, and from trials made with a view to ascertaining the effect on evaporation by charging at different intervals, he has found that by trebling the number of charges in a given time, the same quantity being burnt in that time, that the evaporative efficiency rose 20 per cent.

The other available means of feeding refuse into the furnace—all involving more or less labour with the shovel and non-automatic

—may be put under three heads, viz.:—Top feed, front feed, and back feed.

The top feed, *firstly*, requires an opening in the reverbatory arch overlying the grate, which weakens the arch. *Secondly*, it is also a source of danger to the men, and men have been known to fall through such an aperture, and to have been burnt alive. *Thirdly*, it involves greater capital outlay if the refuse is to be stored above the level of the grates in such a manner that it has to be got into the furnace with only one handling from the hopper. *Fourthly*, the aperture in the roof is liable to act as an outlet for the products of combustion, unless a high chimney is attached to the plant. *Fifthly*, feeding through an aperture in the roof involves two operations. The refuse must first be put into the furnace, and then spread in a suitable thickness over the grate. In order that this labour will be reduced to a minimum the aperture should be almost over the grate. This being so, any doors which close the aperture are subjected to the full radiant heat of the fire, and are very difficult to maintain.

Feeding from the front is the simplest form, and from this point of view has something to recommend it. To each grate there is only one opening into the furnace, and, therefore, the walls are weakened to a minimum. It is, however, at best, a compromise, because the height of the grate must be made suitable for the operation of clinkering, and also suitable for the operation of feeding. It is also trying to the men, as, owing to the opposite furnace wall being solid brickwork, and in an incandescent state, the workmen are subjected to the full force of the radiant heat. This effect also conveys to the lay mind a greater temperature, and, therefore, the prevailing idea is that this is the hottest type of furnace. This might be so, to the extent of 1 per cent., but when it is considered that this portion of the wall has a minimum effect of radiating heat on to the material lying on the grate, and that it only gives up its heat to the layer of gases immediately in contact with it, its work is not very important. The most serious objection to this arrangement is, however, that it is far from clean, and that the actual muscular effort required on the part of the men is very great.

With a back fed furnace, as in Fig. 14, most of these disadvantages are eliminated. The level of the floor on which the chargeman stands is arranged at a level most suitable for that particular operation, and the level of the clinkering floor is situated at its most suitable position. The feeding and clinkering are absolutely separated, and, therefore, it is impossible to mix green refuse with hot clinker withdrawn from the fire.

In these two latter arrangements the refuse is put on the grates in one operation, and put on as frequently as possible, and when and where required, thus greatly assisting in the maintenance of a regular rate of combustion and temperature. It is often stated that burning at a quick rate of combustion, and evaporating comparatively large quantities of water, must necessarily cost more in labour to operate. Judging from records of a number of months' working at several plants, which will be given hereafter, it will be seen that this is not the case, and that the labour costs are amongst, if not the lowest in the country.

The great desideratum is to avoid the handling of refuse altogether. Provided refuse has not entered into decomposition, and with the exception of certain portions of refuse which are offensive by their nature, and which by the way can be readily charged in an automatic manner, the handling of refuse is not an objectionable feature, especially if the storage space is cooled and ventilated.

The major portion of the refuse comes from private dwellings, and if it is collected and destroyed daily, it is almost entirely inoffensive, and it has to be handled several times by domestics, and also by the men performing the work of collection. One more handling, especially as the labour and capital outlay entailed is less, and the results better, need not be considered the *bête noir* as it appears to be.

Having described the most common form of furnace in use to-day and their accessories, the results which have been obtained with various furnaces in various parts of the world may be here considered, but before doing so the Author would express the opinion that the main points to be kept in view when designing or selecting a furnace are mainly the following:—

Combustion space should be sufficiently large to permit of complete combustion therein.

The boiler should be placed at such a distance from the source of heat that flames have ceased to exist.

The furnace chamber should be made common to a number of grates so that the temperature will be maintained and combustion will be complete.

There should not be an excess of wall surface exposed to the adherence of clinker, or otherwise repairs will be frequent.

The reverberatory arch should not be weakened in any way, either by forming apertures in the same, or allowing freedom for undue expansion.

The number of grates in proportion to the total grate surface should be large.

There should be no drying hearths.

A system of forced draught should be adopted which would assist in maintaining the rate of combustion as nearly uniform as possible.

The system of forced draught should not be wasteful in steam.

Recuperative means of heating the air supply are essential.

The Author has refrained from entering into the question of boilers as he fears the paper would become too lengthy. It may be said, however, that the water-tube boiler is that which enjoys the greatest popularity. It has the advantage of being more readily cleaned, and of giving a lower terminal temperature to the products of combustion, and it can be obtained in suitable sizes to suit almost any condition.

The Lancashire boiler has also its advantages, requiring less attention and having a larger storage capacity. It is, however, very difficult to clean, and cannot be obtained in such convenient sizes for working in conjunction with a group of grates.

When this paper was first under consideration, it was intended to discuss questions pertaining to the conjunction of refuse destructors with electrical stations, and the advisability of employing such means as thermal storage, electrical storage, and re-inforcing of the refuse; also the treating of mineral residuals. On attempting to deal with the subject, however, the Author was forced to come to the conclusion that the subject was in itself deserving of another paper. However, the re-inforcing of the refuse as it refers more particularly to the furnaces might be momentarily referred to. The value of a destructor when run in conjunction with an electrical generating station must depend on its reliability and regularity. One of the chief troubles which electrical engineers experience with the destructor is its irregularity of temperature and evaporative capacity, and the engineer will naturally set the destructor down at its minimum value, one which he can rely on, but one which is very far below the real capacity of the plant, if well designed and arranged. If some means could be adopted of levelling up so to speak the temperatures and quantity of heat generated at a very small cost, a great stride would be made. Experiments are now being made to ascertain what it would cost to level up the output of a destructor when working near its maximum capacity, but as they are not complete at the time of writing the paper the Author hopes to have an opportunity of communicating them to the Institution at some future date.

Table I. gives a lately published test of a plant erected by the Horsfall Company in Bradford. It will be noticed here that the engineer in testing the plant arrived at the consumption of the steam jets for forced draught by the method of deduction, and that the figure arrived at was very slightly over 10 per cent.

Table II. gives the result of a test on the "Sterling" type of destructor erected at Hackney.

Table I.

Test of Refuse Destructor at Bradford—No. 1.

Date of Test, ...	From noon March 15th to noon March 22nd, 1905, inclusive.
Duration, ...	168 hours.
Number and type of cells, ...	12 cells, single row, top fed
Total grate surface, ...	360 sq. ft.
System of forced draught, ...	Hot blast with steam jet blowers.
Average air pressure under grates, ...	1 inch of water.
Average steam pressure on blowers, ...	54 lbs. per sq. in.
Nature of refuse, ...	Ashpit, market, and paper.
Total quantity of refuse burned per cell per 24 hours, ...	9 tons 18 cwts. 1 qr.
Tons per man per shift, ...	6·6 tons.
Total clinker and ash* from refuse burned during test, ...	421 tons.
Number of fireman and chargers, ...	18.
Wages per day, ...	4s 10d.
Number of boilers and type, ...	Two marine type, Babcock & Wilcox, water-tube.
Size of boilers, ...	2,393 sq. ft. H.S. each.
Mean steam pressure on boilers, ...	146·5 lbs. per sq. in.
Total steam generated in boilers per hour, ...	13,042 lbs.
Total steam generated per lb. refuse from and at 212° F., ...	1·25 lbs.
Mean feed temperature, ...	195·6° F.
Mean main flue temperature,... ...	1880° F.
Mean temperature of flues leaving boilers, ...	496° F.
Economiser, ...	160 tubes.

Test at Bradford—No. 2.

Steam used by jets for forced draught (including feed-pump, economiser, engine, and leakage). The electric light engine was stopped and disconnected.

Date of Test, ...	March 22nd, 1905.
Duration of test, ...	6 hours.
Number of boilers in use†	One.
Water evaporated per hour, ...	2,283 lbs.

* Ashes were weighed wet as cooled.

† No. 2 Boiler was shut off completely.

TEST AT BRADFORD—No. 3.

Steam used for feed-pumps, economiser, and engine, and leakage. The steam jets and electric light engine shut off and disconnected.

Date of test, ...	March 22nd, 1905.
Duration of test, ...	$2\frac{1}{4}$ hours.
Water evaporated per hour, ...	1,003·6 lbs.

Note.—During test No. 2 the destructor cells were kept working at the same capacity as during No. 1 test, thereby deducting steam used per hour in test No. 3 when the steam jets were shut off from steam used per hour in test No. 2, the difference, namely, 1,280 lbs. of steam per hour is the amount approximately required to work the jets for forced draught when the cells are working at their guaranteed capacity.

TABLE II.

TEST OF REFUSE DESTRUCTOR AT HACKNEY ELECTRICITY AND REFUSE DESTRUCTOR STATION.

Date of Test, ...	4th & 5th Dec., 1902.
Atmospheric temperature, ...	29° to 36° F.
Character of fuel, ...	Unscreened ashbin refuse.
Number of cells used, ...	12.
Duration of test, ...	19 hours.
Cell hours worked, ...	215.
Average hours worked per cell, ...	17·9.
Total refuse burned, ...	299,649 lbs.
Refuse burned per cell per 24 hours, ...	14·9 tons.
Rate for entire plant per 24 hours,... ...	178·8 tons.
Feed water temperature—suction tank, ...	51·8°. F.
Total water evaporated—actual, ...	34,751 gals.
Do. do., ...	347,510 lbs.
Water evaporated per hour,...	18,290 lbs.
Average steam pressure above atmosphere (safety valve at 200 lbs.) per sq. in., ...	183·5 lbs.
Water evaporated per lb. of refuse—actual,	1·159 lbs.
Water evaporated per lb. of refuse from and at 212° F., ...	1·415 lbs.
Temperature of flue gases in main flue before economiser,...	537° F.
Temperature of flue gases in main flue after economiser, ...	335° F.
Average air pressure in ashpits, ...	2·40 ins.

Table III. gives particulars of a test carried out by Mr Stromeyer at Nelson. This test is remarkable for its completeness as a balance sheet was drawn out. It is, however, open to question whether a balance sheet can be accurately made up in dealing with refuse.

TABLE III.

TEST OF DESTRUCTOR AT NELSON.

Dates of trials, ...	13th Jan., 1903.	14th Jan., 1903.
Time of trial,...	10 a.m. to 5.45 p.m.	9-35 a.m. to 6.35 p.m.
Duration of trials, ...	7·75 hours	9·00 hours
Boiler pressure—mean, ...	135·1 lbs.	134·2 lbs.
Corresponding temperature,	358·2° F.	357·8° F.
Refuse burnt during trial, ...	45,416 lbs.	43,400 lbs.
Refuse burnt per hour, ...	5,837 ,,	4,822 ,,
Feed water supply during trial, ...	63,723 ,,	67,485 ,,
Feed water supply per hour,	8,191 ,,	7,498 ,,
Feed water supply per lb. of fuel, ...	1·419 ,,	1·555 ,,
Moisture in steam, ...	1·07%	1·034%
Temperature of feed, ...	37·3° F.	35·3° F.
Evaporation per lb. of fuel from and at 212° F., including steam jets, ...	1·698 lbs.	1·877 lbs.
Mean corrected gas analysis (volumetric):—		
Nitrogen N, ...	79·525	79·888
Oxygen O, ...	8·140	5·836
Carbonic acid CO_2, ...	12·205	14·233
Carbon monoxide, ...	·130	·043
Total, ...	100·000	100·000

Table IV. gives the result of some observations of a plant at Colonge which may be of passing interest. It is to be particularly noted that the percentage of clinker was extremely high, this being one of the prevailing features in all Continental refuse. At this plant the furnaces were clinkered in from a minute and a half to two minutes, which is a decided step in advance of British practice. The type was of the top feed description and great trouble was experienced with all the doors, in fact some of the doors could not be operated at all after working 12 hours.

TABLE IV.

TEST OF REFUSE DESTRUCTOR AT COLOGNE.

Duration of test, ...	30 hours.
Number of cells under test,...	3
Total refuse burnt, ...	26,880 kilos.
Rate of burning per hour, ...	896 ,,
Do. do. do. per sq. ft. grate area, ... about,	40 ,,
Percentage of clinker to total refuse, ...	46
Water evaporated per kilo of refuse—actual,	1·12 kilos.
Maximum temperature in combustion chamber, ...	1,070° C.
Average temperature of gases at chimney base, ...	300° to 410° C.
Average analysis of flue gases, ...	15% CO_2

Table V. gives the results obtained in New Zealand and South Africa, with a modified Beaman & Dea's type of furnace.

TABLE V.

TEST OF DESTRUCTORS AT JOHANNESBURG AND NEW ZEALAND.

	JOHANNESBURG.	NEW ZEALAND.
Rate of burning per hour per sq. ft. grate surface, ...	56 lbs.	64 lbs.
Rate of evaporation per lb. of refuse from and at 212° F.,	·73 lbs.	·75 to 1·25 lbs.
Temperature in combustion chamber, ...	2,000° F.	1,850 to 2200° F.
Percentage of clinker, ...	—	25 to 30

Table VI. gives the results obtained in a small destructor at Worthing, when dealing with refuse of low calorific value. This destructor plant provides the steam for two steam engines which have replaced four 24 H.P. gas engines, and the same has now been in operation for 12 months giving great satisfaction to the authorities. Table VI. also gives particulars of a test on a destructor at Levenshulme.

TABLE VI.—TEST OF "HEENAN" PATENT REFUSE DESTRUCTORS AT WORTHING AND LEVENSHULME.

	WORTHING.	LEVENSHULME.
Date of test,	Nov. 29th, 1905.	Dec. 2nd, 1904.
Duration of test,	6½ hours.	8 hours.
Number of cells,	2.	2.
Total grate area,	55 sq. feet.	50 sq. feet.
Type of boiler,	Water-tube.	Lancashire 2 flues, 28 ft. × 7 ft. 6 in. dia.
Heating surface of boiler,	1740 sq. ft.	
Class of refuse dealt with,	trade and domestic containing large percentage of vegetable matter.	
Total refuse burnt,	21,966 lbs.	32,648 lbs.
Average rate of burning per hour,	3,379 lbs.	4,084 lbs.
Average rate of burning per hour per square foot grate area,	61·44 lbs.	81·6 lbs.
Capacity of plant (2 cells) for 24 hours at above rate of burning,	36 tons 4 cwt.	43 tons 14 cwt. 2 qrs.
Total water evaporated (actual),	30,862 lbs.	50,625 lbs.
Equivalent water evaporated from and at 212° F.,	37,261 lbs.	
Evaporation per lb. of refuse (actual),	1·40 lbs.	1·55 lbs.
Equivalent per lb. of refuse from and at 212° F.,	1·69 lbs.	1·89 lbs.
Average rate of evaporation per hour (actual),	4,748 lbs.	6,325 lbs.
Equivalent rate of evaporation from and at 212° F.,	5,735 lbs.	
Average steam pressure maintained,	113 lbs. per sq. in.	147 lbs. per sq. in.
Average initial temperature of feed water,	52° F.	42·5° F.
Average temperature of combustion chamber,	2,106° F.	2,172° F.
Maximum temperature of combustion chamber,	2,552° F.	2,417° F.
Minimum, " " " "	1,850° F.	1,787° F.
Average temperature of chimney base,		700° F.
" " " air-blast after heater,		336° F.
Total weight of clinker obtained,	3,423 lbs.	7,280 lbs.
Percentage of clinker obtained (by weight),	15·55	22·00
Analyses of furnace gases,	CO_2 11·3, O 8·7, CO 0, N etc. by diff. 80·0	CO_2 15·6, O 4·8, CO 0, N etc. by diff. 79·6

Table VII. gives the results obtained with a plant of the "Heenan" type, and the results with a "Meldrum" destructor.

TABLE VII.

	HEENAN.	MELDRUM.
Date of test, ...	Nov. 14 '05	Feb. 15-16 '05
Type of plant, ...	Heenan's Patent (front feed)	Meldrum's Patent simplex regenerative furnace (front feed).
Number of cells, ...	3	3
Total grate area, ... sq. ft.	75	75
Type of boiler, ...	Water-tube H.S. 1966	Lancashire. 30′ × 8′ H.S. 1050 sq. ft.
Economiser, ...	None	Green's, 192 tubes, 1920 sq. ft. H.S.
Refuse destroyed per hour, lbs.,	3,665	4,200·9
" " " per sq. ft. grate area, ...	48·8	56
Percentage of clinker to refuse consumed, ...	26·5	27·9
Average temperature in combustion chamber, ... F.	*2,032°	2,500*
Average temperature after economiser and before chimney, F.	—	289·0°
Average steam pressure, per sq. in., ... lbs.	189·5	143·6
Temperature of feed entering tank (before softening), average, F.	45°	50·58°
Temperature of feed after softener, average, ... F.	112°	85·27°
Temperature of feed leaving economiser, highest 255°, lowest 193°, average, ... F.	(No Economiser)	216·5°
Total amount of water evaporated per hour, ... lbs.	6,882	9,592
Equivalent do. from and at 212° F., ... lbs.	7,942	—
Economiser duty, ...	—	11·5%

* Messrs Heenan and Froude aim to keep the average temperature in their combustion chamber at about 2,000° F. to avoid fusing of the dust in same.

	HEENAN.	MELDRUM.
Amount of water evaporated per lb. of refuse (including economiser), actual, ... lbs.	—	2·28
Amount of water evaporated per lb. of refuse from and at 212° F. ... ... lbs.	2·16	2·66
Temperature of air entering regenerator, ... F.	56·6°	59°
Temperature of air leaving regenerator, ... F.	273°	276°

Table VIII. gives results obtained at King's Norton.

TABLE VIII.

OFFICIAL TEST ON "HEENAN" PATENT REFUSE DESTRUCTOR AT KING'S NORTON.

Date of test, ...	Feb. 22nd, 1906.
Duration of test, ...	13·25 hours.
Number of cells under test, ...	3 (one unit).
Total refuse burnt, ...	56,280 lbs.
Equivalent rate of burning over 24 hours, ...	45·45 tons.
Rate of burning per hour, ...	4,247 lbs.
Do. do. per sq. ft. of grate area,	57 lbs.
Total clinker, ...	14,070 lbs.
Percentage of clinker to total refuse, ...	25
Total fine ash from under grate bars, ...	797 lbs.
Percentage of ash to total refuse, ...	1·4
Total water evaporated	120,900 lbs.
Average rate of evaporation per hour over whole test, ...	9,125 lbs.
Average temperature of feed water, ...	45° F.
Average steam pressure, ...	154 lbs.
Water evaporated per lb. of steam (actual), ...	2·15 lbs.
Equivalent evaporation per lb. of refuse from and at 212° F., ...	2·63 lbs.
Total steam used by fan engine per hour, 2 p.m. to 9-45 p.m., ...	436·7 lbs.
Percentage of steam used by fan engine over whole test in relation to total steam generated, ...	4·78%
Maximum temperature in combustion chamber,	2134° F.
Minimum do. do. do., ...	1518° F.
Average temperature of gases in combustion chamber, ...	1826° F.
Average temperature of gases before heater, ...	606° F.

Average temperature of gases at chimney base,	251° F.
Average temperature of air entering ashpit, ...	237° F.
Minimum temperature of steam, ...	516° F.

Average analysis—Seven samples taken over 75% of total time of test.

CO_2	O	CO	N
12·1	7·6	0	80·3

Labour cost, ... 6·45d per ton.
Two stokers at 4s 8d per shift (nine hours shift).

Remarks.

Plant under test consisted of:—

One unit of three cells, total grate area 75 sq. ft.
One water-tube boiler 1966 sq. ft. heating surface.
One superheater 345 sq. ft. heating surface.
One exhaust steam feed-water heater.
One fan direct coupled to engine (used to produce forced draught).

Temperatures at two points in combustion chamber were measured and automatically recorded by Callendar resistance recording pyrometer also by Féry radiation pyrometer. Observations of the latter were taken by a representative of the maker's every quarter of an hour, and compared with the resistance pyrometer, and were found to agree within 100 degrees F., the radiations giving the highest readings. Temperatures before heater were found by Le Chatelier thermopile pyrometer after heater by mercury pressure thermometer, and remainder by mercury expansion thermometer.

Air pressures and partial vacuums were taken by water gauges in places where small differences were expected by differential gauges reading to ·001 of an inch.

The products of combustion were analysed by an Orsat apparatus. Samples were collected by means of aspirator bottles over water previously saturated with CO_2.

There were seven samples taken over 75 per cent. of total period of test.

All instruments were calibrated before start of test.

The readings recorded on the Callendar pyrometer were corrected in accordance with formulæ supplied by Prof. Callendar.

Observations were taken every quarter of an hour, each observer starting to take readings simultaneously.

Steam generated was blown to atmosphere, after having been superheated, through an escape valve set to a lower pressure than the safety valves on the boiler.

The percentage of steam used on fan engine was obtained by condensing the exhaust over a period of 5·5 hours, the condensed steam being caught in vessels of known capacity.

The first steam raising plant operated in conjunction with an electrical generating station erected in America, has now been at work for some time, but full figures as to the working are not yet available, or published. The refuse, however, is of a very different character to that found in England, as the percentage of residual is only 3. Prior to the refuse being destroyed in the furnace, it is sorted, and marketable articles and materials are removed.

The heat given off in the furnaces is utilised in generating steam in Stirling boilers, and the steam operates electrical generators, the current being utilised in the lighting of the Williamsburg bridge. This plant enjoys the distinction of paying its way, without taking into consideration the energy generated. This is due to the sale of part of the refuse, 60 per cent. being sold for 1·50 dollars per ton.

The furnace belongs to the second group, or family, and is almost identical with the "Sterling" type of destructors. It is at present being operated by natural draught, which is rendered possible by the prior sorting of the refuse.

Some four years ago the engineer to the Urban District Council of King's Norton being desirous of obtaining the best possible results, sampled many loads of refuse collected in his district. These were handed over to an analyst, who duly reported and gave the calorific value of the refuse as 4300 B.T.U. The engineer put these figures before parties desirous of tendering, and asked for a guarantee on that basis. Messrs Heenan & Froude, Limited, guaranteed 1¾ lbs. of water per lb. of refuse from, and at 212 degrees F., and after exhaustive enquiries, the contract was ultimately let to them. The evaporative results will be noted as they appear to be the highest results that have been obtained in a modern refuse destructor without economisers, in any part of the world. The small percentage of steam required for operating the forced draught is also to be noted. The amount required for operating the pump was condensed on a previous occasion, and appears to be less than 2½ per cent.

The Heenan plant was erected at a cost £14,500, and consists of three furnaces, or units, each unit consisting of three grates, combustion chamber, water-tube boiler, superheater, recuperator, fan-engine, refuse-storage hoppers, etc.

The results obtained at this test have been equalled on many occasions during the past four months. The temperatures on the day of the test were lower than those recorded on former occasions, due to the flue dampers not being regulated.

Figs. 16 and 17 give respectively charts of the temperatures obtained in the case of the King's Norton destructor, Fig. 16 being by means of a Chatelier pyrometer, and Fig. 17 by means of a Féry radiation pyrometer.

It has been stated that temperatures cannot be ascertained with any degree of accuracy, but the Author is, however, of opinion that either of these instruments will give fairly accurate results with temperatures in the case of the Chatelier pyrometer below 1600 degrees C. This form of pyrometer is, however, costly to maintain, as during the course of the test temperatures often exceeded 3000 degrees F., the result being total destruction of the instrument. No such inconvenience or expense is attached to the Féry instrument. The results of working this plant for the past five months has been as follows:—

Labour, cost of charging the furnaces, burning the refuse, withdrawing the clinker, and depositing 18 yards from the furnaces, ...	7d per ton.
Cost of cleaning the plant, ...	½d ,,
Cost of skilled supervision, ...	1d ,,
Cost of cleaning buildings, machinery, including oil and waste, ...	¼d ,,

Rate of wages, 4s. 8d. per man per shift of 9 hours.

With the exception of supervision, these costs can be maintained on any plant consisting of three or six cells of equal capacity.

As the cost of labour during test was 6·45d per ton of refuse, it will be seen that the rate of working the test did not greatly exceed the ordinary rate of operating the plant, and the Author considers that he has by this example proved that, with an up-to-date modern destructor having a high efficiency both from an evaporative point of view and burning, is not more costly to operate than a destructor of the first group burning at a lower rate and giving lower evaporative efficiencies.

Discussion.

Mr John Wilkie, M.A. (Manchester), remarked that he had read Mr Leask's paper with considerable interest, and thought he deserved to be complimented for preparing and presenting to the Institution a paper which he considered, in many respects, an admirable one. As he had been responsible, in conjunction with the respective local engineers, for the most recent and the most successful destructor installations put down in this district, he felt a little inclined to protest against the manner in which Mr Leask had deemed it expedient to refer to the "Meldrum" furnace. Mr Leask appeared before them as a protagonist of the "Heenan" system. All engineers conversant with the subject were agreed that there was a remarkable similarity, indeed a practical identity, between the "Meldrum" and "Heenan" systems, so far as their essential features were concerned. At the outset, Mr Leask professed to deal with the history and evolution of types of furnaces, and on page 330 of the Transactions would be found the following statements:—"In 1894, Messrs Meldrum Bros. patented their well-known 'Simplex' type, Figs. 10 and 11. The 'Heenan' destructor, as now constructed, Fig. 13, was evolved from furnaces patented in 1893." Patented by whom? Not by Mr Heenan nor by Mr Leask, as neither of them had the slightest notion of taking up destructor work. The latter statement, following this reference to Meldrum's, was a remarkably loose one to come from an engineer, and was wholly misleading and unfair, the suggestion being that the "Heenan" destructor furnace, as now constructed, had a prior claim to the "Meldrum." What were the actual facts in the development of the "Heenan" and "Meldrum" furnaces? The most pertinent and the only admissible facts were those to be found in the records of the Patent Office. The "Meldrum" Simplex Furnace was patented in 1894, No. 17,869. In 1896, the "Meldrum" Simplex Regenerative Furnace was patented, No. 14,614, and the first plant was erected and put to work at Darwen in 1898. This was absolutely the first furnace in existence possessing the following distinctive features:—1st, A continuous furnace chamber; 2nd, a secondary combustion chamber; 3rd, steam generator; 4th, regenerator or air heater. The success of the Darwen plant was phenomenal, and might be truly said to mark an epoch in destructor practice. This furnace, Fig. 18, might be taken

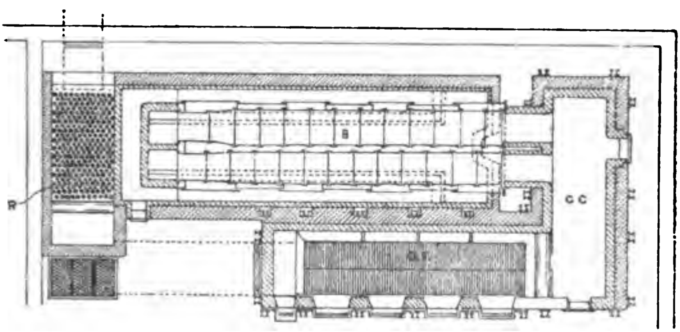

Fig. 18.

as representing the "Meldrum" furnace of to-day. The first furnace with which the name of Heenan could be at all identified was patented in 1897, and was known as the "Bennett-Phythian," No. 4323. It was put to work at Farnworth, near Bolton, but proved a complete failure, and was dismantled. That was followed by the "Heenan" twin-cell, which was a modification of the "Bennett-Phythian." It was patented in 1901, and was put to work originally at Rawtenstall. In the same year Messrs Howden & Co., of the City of Glasgow, patented a regenerator or air heater in conjunction with destructor furnaces, and this was embodied in the "Heenan" furnace, Patent No. 16,547. Subsequent patents for minor details, such as hollow front, corrugated arch, and mechanical charging, had been taken out by Messrs Leask and Heenan, but they had no reference to the general form and arrangement of the "Heenan" furnace so called. The

Mr John Wilkie, M.A.

really important and material point was that in 1902 the twin-cell system was abandoned, and the furnace illustrated

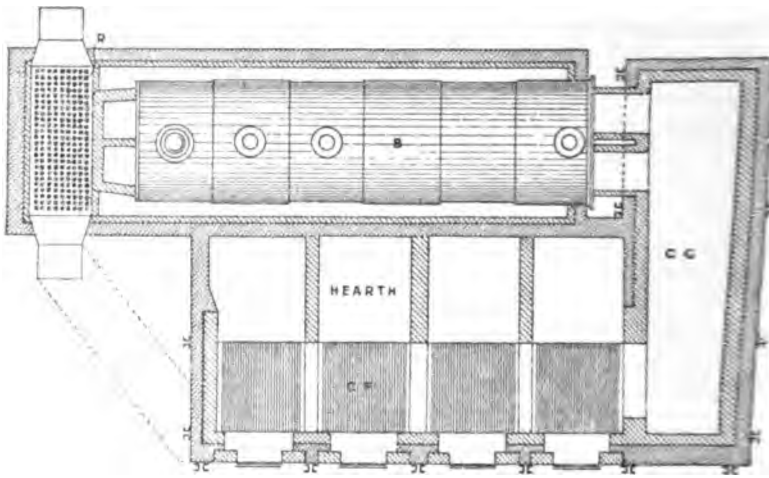

Fig. 19.

by Fig. 19 was boldly adopted as the "Heenan" standard furnace. In 1903 this plant was erected at Barrow. He asked anyone to examine the "Meldrum" furnace and the "Heenan" furnace as there represented. The former was reproduced from that excellent treatise of Mr Goodrich on "Refuse Disposal and Power Production," while the latter was reproduced from Mr Maxwell's work on the "Disposal of Towns' Refuse." It would be noted that the four essential and distinctive features of the "Meldrum" furnace were most faithfully copied. Mr Leask had since found it advantageous to omit the hearth, and he gave his reason for dispensing with it in his paper. As the system of air heating was Messrs Howden's, he left anyone to judge whether it was unfair, or not strictly true, to characterise this furnace as a "Meldrum" destructor Howdenised. He contended, and he ventured to think, that it would be agreed that some acknowledgement, however slight, was due from Mr Leask, as he well knew that any success which might be achieved on his plants was the product of brains and experience other than his own. It was only fair to state, however, that in Mr Leask's paper of March 4th, 1903, read before the Civil Engineers of Ireland, Dublin, the following remarks occurred:—"The 'Simplex' furnace, constructed by Messrs Meldrum Bros., brought out a type that embodied apparently new features. This type has been uniformly successful, which may be attributed to the makers attending to the scientific aspect of the laws of combustion and a rational form of furnace." One could understand him exercising a certain degree of diffidence and restraint in speaking of a competitor's claims, but the part played by Messrs Howden, in designing his air heater, really merited some recognition. Mr Leask truly said that "The destruction of refuse is nothing more or less than the combustion of poor fuel." Yes, and the combustion of poor fuel was obtained by the provision of a properly regulated air supply. When the air was heated, and the heater was placed in the path of the waste gases from the boiler, the problem became a more complicated one, as any mistake in the design of the heater, any restriction of areas, etc., might prove fatal to the success of the furnace. When Mr Leask decided that the Meldrum combination of air heater, steam generator, secondary combustion chamber, and continuous furnace, was the ideal one, and entrusted the design of the heater to Messrs Howden, he gave them the most crucial element in the combination to work out, on which success or failure entirely depended. The recent litigation between Messrs Howden and Messrs Heenan, in which the former were the plaintiffs, afforded no reason for ignoring their claims before a meeting of this Institution, and he trusted Mr Leask would avail himself of the first opportunity that offered itself to do them what any ordinary sense of justice dictated. On page 331, Mr Leask said "It is only fair to the memory of Mr Fryer to say that he foresaw the use of forced draught and

Mr John Wilkie, M.A.

heated air supply." Some people had foreseen the realisation of communication between the Earth and Mars, and Mr Leask would not have been unfair to Mr Fryer's memory if he had omitted this remark altogether. The extent of Mr Fryer's foresight and his appreciation of the scope of heated air supply and forced draught could be gauged by reference to his coadjutor's patent, Mr Alliott's No. 17630, 1887. To pass from what Mr Leask termed the historical to the technical portion of his paper, he had to say that he was generally in agreement with the remarks he made, and the arguments he adduced in favour of the continuous furnace chamber over the isolated cell system. He had, however, to dissociate himself entirely from the claims he made for his corrugated arch. Mr Leask claimed that the gases of combustion formed eddies, and were more thoroughly mixed, due to the undulations in the arch. He maintained that the particles projected from the furnace grate and the gases evolved in the process of combustion, followed the line of least resistance from the moment they were generated until emitted from the chimney shaft. Were Mr Leask's contention right, he would have had a higher CO_2 percentage than with the straight arch, but the figures given in the test selected by himself for comparison with his best were against him. He referred to Table III. The average of Mr Stromeyer's tests at Nelson was 13·2 CO_2. Mr Leask's *piece de resistance*, he supposed, was his King's Norton test, where the CO_2 average was 12·1. At Cambuslang, the latest straight arch furnace erected in Scotland, the average CO_2 was 16·3. Mr Leask's contention, therefore, fell to the ground, as the actual facts were against him. The corrugated arch, in his opinion, had nothing good to recommend it. Mr. Leask, however, was well advised in substituting it for the system of arch construction he advocated some years ago which was more efficient from the eddy standpoint, but so weak structurally that he was compelled to abandon it. The corrugated arch was a detail that differentiated the "Heenan" furnace from the "Meldrum," and this, no doubt, was Mr Leask's reason for retaining it. He was in entire accord with his remarks relative to the claims made for the "side box" system of air heating. The advocates of this system displayed an ignorance of the principles and facts long ago ascertained with reference to the transfer of heat through plates, that did no credit to their pretensions to that phase of engineering. Engineers in their specifications would do well to stipulate that no system of air heating would be considered that did not provide for the utilisation of the waste gases after leaving the boiler. On the question of fan *versus* steam jet, he did not agree with Mr Leask, nor did he admit the figures he ascribed to users of this apparatus. His authority was Mr Stromeyer, whose figures were 11 and 12 per cent., so that they did not reach the 15 per cent., still less the 18 per cent. he alleged. What he stated might be true of certain systems, but it did not apply to the "Meldrum," and in cases of that kind Mr Leask might be more specific. On that point it was vain to dogmatise, and gentlemen present could not do better than be guided by those who had used both. Mr Maxwell of Partick writing to the *Electrician*, December 5th, 1902, said—"The relative advantages of fan and steam blast is a point of great importance. I have made no tests, but from actual working we have found that with the latter a steadier steam pressure is maintained, and more steam per ton of refuse is available at the engines." As to the method of feed, that should in general be determined by the nature and quality of the refuse to be dealt with. He did not advocate any one type over any other. In some cases he would recommend a drying hearth, although this could generally be dispensed with. Meldrum's patent of 1896 showed a top feed, and in 1900 Messrs Meldrum erected the first back feed furnace. At the present moment they were erecting top, back, and front feed plants in several parts of the world. As to pyrometers,

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a Callendar's recording resistance pyrometer was first used in connection with destructors at Nelson, but he did not recommend that class of pyrometer for general use in a combustion chamber of destructor furnaces. They were very expensive and required frequent adjustment and correction. The Féry may be said to be an inferential instrument, and in his opinion was not so accurate as the Chatelier. It had this advantage, however, that it did not require to be inserted in the furnace chamber. For ordinary tests, heat recorders, such as Watkins', would give sufficiently accurate results, and had the further recommendation of small initial cost. As to tests, he had been carrying out destructor tests for nearly a dozen years, and long ago came to the conclusion that in these tests two factors had a determining influence on the results claimed. These were the bias of the contractor and the bias of the purchaser or their agents, and these factors could not be wholly eliminated. In general, their interests in securing the best results were identical, and tests, to be of value, should be carried out by absolutely independent and thoroughly qualified authorities. He did not, therefore, attach much importance to Mr Leask's figures for the King's Norton tests. Mr Leask must be perfectly well aware that an evaporation of 2½ lbs. of water per lb. of refuse was quite a phenomenal result, and was only possible with refuse far above the average in calorific value. Assuming that the refuse in that instance had a calorific value of 4,300 units, he would very much like to see Mr Leask's heat balance sheet for this test. He had always deprecated the undue emphasis that was put on figures obtained in tests other than independent. The real test of a plant was in regular every day work, and the cost of labour on tests was no criterion whatever. Do not, therefore, be misled by the 6.45d per ton quoted for this test. Mr Leask should have known that figures of this kind were misleading, and he thought Mr Leask would agree that no more telling, no more condemnatory evidence as to the futility and untrustworthiness of tests could be found than was contained in the current issue of the *Public Health Engineer*, 7th of April, 1906, page 253. That referred to the plant erected by him at Barrow about two-and-a-half years ago, and read as follows—"The Health Committee recommended a special expenditnre of £1300 on the refuse destructor, which had proved a failure. It cost originally between £8000 and £9000, but was defective and unsatisfactory, and the guarantee that it would burn up a certain amount of refuse and raise a certain amount of steam had only been accomplished by flogging the plant, which now requires improving agreed to." It was only fair to Messrs. Meldrum to state that that furnace was not quite so Meldrumised as the corrugated arch furnace. In conclusion, he would say that it was with feelings of regret that he took up this line of destructive criticism in regard to Mr Leask's paper, in many ways an excellent one. At the meetings of the Manchester Association of Engineers, he had had many friendly discussions with him, but there was a grave question of principle involved. The laxity of the patent system was well known, and it was only at the meetings of institutions such as this that the rights and claims of the inventors and manufacturers of patented specialties, as well as the justification of that moral rectitude—the proud boast of British engineering practice—could be vindicated.

Mr JAMES B. WYLLIE (Member) thought the paper under discussion was one of considerable interest, and he thanked Mr Leask for introducing this subject to the notice of the Institution. Mr Leask mentioned the fact that the refuse of Cairo had been employed for centuries to heat the Turkish baths in that city. Now the refuse of Cairo was burnt in a "Horsfall" destructor with satisfactory results. The furnace used was hand-fired, seven feet wide, and known as the "back-to-back" type. It was similar to the "Horsfall" destructor at Paisley, but with larger furnaces. Mr Leask, in

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referring to the different illustrations, said that a family likeness was to be found between the "Horsfall" destructor and those of the late Mr Fryer. This might be the truth, but improvements of great moment had been introduced. The refuse now could be burnt without nuisance, which was not the case with the "Fryer" type. The "back feed" type, which had now been copied both by Messrs Meldrum and by Messrs Heenan and Froude, was, he thought, admittedly the best type of furnace for hand-feeding yet evolved, and about ten times as many of this type had been supplied by the Horsfall Destructor Company as that furnished by any other firm, and it was only quite recently that other firms had given attention to this type. They used to say that "back feeding" was a mistake. Mr Leask drew attention to this family resemblance, and he thought anyone would recognise that in the so-called "Heenan" type there was very little difference from those he referred to. In regard to the question whether isolated cells or continuous grates—namely, a flue with grate bars in it—were the best, he might mention that repairs could be effected to one cell without stopping the others. This the Author questioned, and said that he did not think it would be possible. He (Mr Wyllie), however, could state with authority that repairs were carried out every day without interfering with the adjoining cells. Again, Mr Leask remarked that a furnace should not be provided with a drying hearth, but gave no convincing reason for this. The real reason, of course, was that, "a flue with grate bars in it" was a much less expensive form of furnace. A drying hearth, such as that provided, and shown in Figs. 4 and 5, was obviously a great advantage when dealing with wet stuff. Mr Leask considered that when the fire had been freshly drawn on, the cremating effect, when the hot gases were passed over the fire, did not exist. This was not so, because the furnace arch was heated up, and acted as a reservoir of heat, thus greatly assisting cremation. But

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beyond all that, there was the fact that the "Horsfall" main flue, or combustion chamber, mixed the gases from the whole block of cells as efficiently as they were mixed in the "Heenan" continuous grate, so that in the former there were two safeguards to the one in the latter, namely, (1) The cremation within the furnace, and (2) The mixing and cremation within the main flue itself. Further, Mr Leask observed that the repairs with separate cells were likely to be more frequent. From a recent report, issued by the St. Gilles Committee, special attention was drawn to the excessive repairs by its very shape and nature. Again, when referring to fans *versus* steam jets, Mr Leask said no trouble had been experienced with fire bars when made of special simple section. Perhaps, in his reply to the discussion, he would state how many spare sets of fire bars had been put in at Rathmines since the plant there had been set to work two years ago. He (Mr Wyllie) understood that a new set of bars had to be put in one or other of the cells every week. With regard to the method of heating the air by regenerators in the flues or side boxes, a regenerator in the flue reduced the temperature of the flue gases, and thereby either reduced the draught in the chimney or necessitated a larger and more expensive chimney. The gases ought to be brought down to about 500 degrees F. by fuel economisers, and any further reduction beyond that was a mistake. The "Horsfall" side boxes took the heat from the clinker where it was not required, and they actually did heat up the air in the ashpits to the temperatures claimed for them, namely, from 400 to 500 degrees F. Further, the percentage of steam used for the steam jets at Bradford, namely, ten per cent., had been improved upon in the "Horsfall" later designs, which combined the advantages of fans and steam jets by using a special method of moistening the air for combustion after it left the fan and before it passed through the grate bars. The tests mentioned by Mr Leask were of practically

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no value for the following reasons:—The duration of test was not always the same; the date when the destructor was built was not stated; the refuse was different; there were no average results during, say, a period of a year; and tests got up for the purpose of a paper (unless they had been obtained from reports of responsible officials) could be made to prove anything. He thought Mr Leask's main object had been to make Members of the Institution think that there was now only one perfect destructor in existence, namely, the "Heenan." Of course, he mentioned the "Meldrum" as a good second, and no wonder, after practically embodying the main features (not to speak of other destructors) in the so-called "Heenan" type.

Correspondence.

Mr H. B. Maxwell (Partick) considered that the Author had made two great mistakes in the paper. In the first place, he appeared to think that the chief mission of a destructor was to generate steam. Steam, however, was only a bye-product, the principal object being the cheap and efficient destruction of the refuse with the minimum of nuisance. In the second place, he quoted certain figures of evaporation without explaining that under ordinary working conditions the evaporation obtained was usually on an average only some 50 per cent. of what was obtained on tests, owing to the heat often being available at times when an electricity work had practically no load on. Thus in summer from 9 p.m. to 3 a.m. the load might be too big for the destructor alone, from 3 a.m. till the public works started at 6 a.m. the load would be practically *nil* as it would be also during the breakfast and dinner hours, and from 5-30 p.m. to 9 p.m. If then the destructor was to be worked under the best conditions as to economy in wages and maintenance by working at a steady temperature, a very large amount of heat would be wasted. Again, although refuse might be able to evaporate 2 lbs. of water from and at 212 degrees F. under test conditions with winter

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refuse, it was doubtful if it would evaporate half that amount with summer refuse, when, owing to no fires being used, the refuse had practically no ash in it. In most towns—very probably in those of which tests were given in the paper—it would be found that the average evaporative steam utilised by an electricity works for twelve months would be about ¾ lb. per lb. of refuse. In a paper of this description the whole facts should be stated so as not to leave a false impression on those who had not experience in the subject. It must also be remembered that a part of the steam generated would be needed for the fan engines. This he had found to vary from 5 to 15 per cent. of the total steam evaporated, according to the efficiency of the fan engine. It was impossible to obtain a single cylinder non-condensing fan engine which would use much less than 10 per cent. of the total steam. The most efficient method was by electric motor and moreover with this method of driving a constant check could be kept on the power used. He would like to add his entire disagreement with the following statement:—"The Author could submit as incontrovertible that the latter type has given the better results from the standpoint of . . . higher evaporative efficiency." He submitted that the exact opposite was incontrovertible, that it was evident that the higher evaporative efficiency must be maintained where the incandescent gases passed straight into the boiler instead of giving up a large amount of heat to an intervening combustion chamber. This was borne out in practice as there was hardly a single destructor of the single furnace type where a steady steam pressure could be maintained even with reducing valves, whereas at Partick at any rate a large percentage of the load was taken entirely by the destructor without any appreciable variation in steam pressure. Also with the separate cell type no difficulty had been experienced in repairing a cell with its neighbour at a temperature of 2500 degrees F. The front feed destructor had one advantage in very small installations, namely, low wages cost. It had, however, many disadvantages, the chief being that the firing of ordinary ashpit refuse with a shovel was

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a very lengthy and trying process so that the door was open practically the whole time. Shovelling ordinary ashpit refuse containing straw, vegetables, mattresses, tin cans, bits of rope and wire was not a pleasant occupation nor was it conducive to good language among the employees. It was generally recognised nowadays that the advantages obtained by heating the air supply were not nearly so great as by utilising the heat in economisers for heating the feed water. He might say in conclusion that he was not without hope that in the near future it might be possible to tip the refuse from the carts direct into large automatic moving grates, the clinker being automatically dumped and removed at the back. Such a method was exceptionally desirable in the interests of economy in wages and maintenance, and of public health.

Mr F. J. Rowan (Member) desired to congratulate Mr Leask on the excellence of his paper. There were several rival destructors on the market, but although he was identified with one particular form, Mr Leask had wisely refrained from discussing rival claims or viewing the subject from a personal standpoint, and degrading the paper to the level of a trade advertisement. He had treated the subject broadly, and reviewed several of the points of general scientific interest, which was in good taste and in keeping with the character of the Institution. There were, as he had indicated, further matters of general interest in connection with the use of destructors, and the Institution was to be congratulated on the prospect of another paper on these matters, which were alluded to on page 345, by a writer who could treat them in a scientific manner. Perhaps the paper might have been improved by treating the constructive features in greater detail, and it was to be hoped that Mr Leask would make this addition in the case, at any rate, of the "Heenan" destructor, in replying to the discussion. No doubt the advocates of rival forms would contribute such details regarding theirs. Mr Leask's modesty in that matter need not be allowed to wrong him by the exclusion of these details concerning the form of destructor with which he was most familiar. In his

(Mr Rowan's) opinion, altogether apart from any questions of variation in design, refuse destructors formed a very interesting class of furnaces, in which the unusual conditions of the use of a fuel of low calorific value and very varying composition, combined with the necessity for a thorough combustion at a high temperature, had to be met. The large bulk of the refuse treated in refuse destructors also necessitated special provision, and British engineers were to be congratulated upon having shown the way to the rest of the world regarding the working out of this problem to a successful issue. Turning to the paper, he (Mr Rowan) thought that the sentence on page 334, beginning "It is well known that CO, etc.," would be made a little clearer by the insertion of the words "of the gases," after "high specific volume." And similiarly, on pages 338 and 339, a few words seemed to be necessary to prevent misconception of the Author's meaning. The rise of the temperature of combustion, due to pre-heating the air supply, did not work out quite so favourably as Mr Leask's figures represented it. In an example quoted by him (Mr Rowan) in the "Practical Physics of the Modern Steam Boiler," where 1 lb. of carbon was taken, burning to CO_2, with air supply 20 per cent. in excess of the theoretical quantity, the *combustion* temperature, with air heated to 400 degrees F., was shown to be 375 degrees F. above that with air at atmospheric temperature. But it did not follow that the *furnace* temperature would be increased in the same ratio. However, Mr Leask rightly added that, with heated air, the quantity used in excess might be diminished, and this would react favourably on the furnace temperature. But he must not forget that a less quantity of heated air would convey a less number of heat units into the furnace, in which case the calculated combustion temperature would not be quite so high as, for instance, the 375 degrees F. quoted. So that when Mr Leask said, page 339, "with a rise in the temperature of the air for the support of combustion of 300 degrees F., there will be a corresponding rise in the furnace temperature of 600 degrees F.," he must mean that "a rise of 300 degrees F., Mr F. J. Rowan.

along with the added combustion temperature, due to dimunition of excess air supply," would cause a rise in furnace temperature of 600 degrees F. Even then, he (Mr Rowan) was not quite sure that such a good result would be realised except under certain conditions of utilization of the radiant heat produced in the furnace. Regarding the question of supplying the air by means of a steam-jet blower or by a fan, the only point that struck him (Mr Rowan) was that with this class of fuel, as there was no point to gasify it as in a gas producer, and the temperature of combustion should be maintained at a high point, only the minimum quantity of steam was wanted to preserve the grate bars and loosen the clinker. In a gas producer the steam was useful in lowering the temperature of combustion by the heat abstracted by its decomposition, but that heat was recoverable on burning the resulting gas which was enriched with hydrogen. Destructor furnaces did not, however, present these conditions; and he (Mr Rowan) should, therefore, imagine that the use of a fan blast, with a small quantity of exhaust steam, or some water, introduced into the ashpit, would best satisfy the conditions of working.

Mr T. C. Ormiston-Chant (Twickenham) considered that Mr Leask had ably dealt with the subject of Refuse Destructors, and thought it was a pity that the gentleman who opened the discussion had not dwelt at greater length on recent advances made in the types of destructors they upheld, rather than begin a controversy in patent rights. There were many questions he should like to ask Mr Leask, but he would confine himself to the following:— 1. Could he place before the Institution figures showing the difference in cost of disposal of refuse in various communities before and after destructors had been adopted? 2. Could he give instances where a destructor having been installed, the death-rate had decreased, and the number of cases of notifiable diseases diminished? An important point with destructors was that of nuisance due to dust and smell. Mr Leask had shown how, by means of a collecting ventilating duct, all dust and smell arising inside the building was drawn into the fan, and so projected into the furnaces. The high temperature of the combustion or settling chamber would destroy all objectionable odour: But what of the dust which, to some extent, must pass this point? In plants, where an air heater of the tube type was used, it was arrested in a very effectual manner, for, as the flue gases left the air heater, they flowed into a passage of about twice the area of the tubes, and therefore the velocity of flow was suddenly reduced. This change in velocity was very effective in separating the dust that remained suspended in the gases; moreover, its effect could easily be seen by noting the relative collections of dust at the chimney base of plants with and without a regenerator of this type. He noticed that the Author referred to German makes of destructors, and said that British engineers would have to take care of their laurels. He would, however, draw attention to the enormous expenditure of power entailed by any system of forced draught which required an air pressure of, say, twelve inches of water column in the ashpit. Compare the expenditure of power necessary to produce this pressure with that required in current English practice, where the pressure on the average was two inches of water. In the first case the fan brake horse power was

$$= \frac{V \times 2 \times 5{\cdot}2}{33{,}000 \times N},$$

and in the second case

$$= \frac{V_{\prime} \times 12 \times 5{\cdot}2}{33{,}000 \times N};$$

where V = vol. of air in cub. ft. per min.,
and N = the efficiency of the fan.

At a glance it could be seen that the power required was six times greater, and if the pressure were to rise to twenty-four inches in the ashpit the power would be twelve times greater than when the pressure by water gauge was two inches. So that if 10 H.P. were required with a plant of fifty tons per twenty-four hours burning

Mr T. C. Ormiston-Chant.

capacity, with an ashpit pressure of two inches, then 60 H.P. would be required in the case of an ashpit pressure of twelve inches, as the same quantity of air would be required to burn the refuse in each case. Such a consumption of power should surely be taken into consideration when comparing various types of plants. With regard to top feed plants: Was it not probable that they enjoyed a considerable patronage owing to the fact that, by reason of the arrangements of boiler and furnaces, and the type of furnace itself, no other method of feeding was possible, with the exception of front feed? He had tested plants of various kinds, fed in various manners, and there was no doubt in his mind as to the back feed type being by far the cleanest, and certainly the best and least tiring to the men working it. The Author's statement about the possibility of the temperature of the combustion chamber being too high, was borne out by his (Mr Ormiston-Chant's) experience. He had sometimes seen the dust fused into a mass so hard that a sledge hammer would not break a slab six inches thick. He might say that he had seen a plant with the method of ventilation described by the Author, and could speak for the entire efficiency of such an arrangement. In conclusion, he would say that, at all tests at which he had assisted, the utmost care had been taken by the testing staff to arrive at correct results, and no one could have taken more care or precaution to prevent incorrect or unreliable tests than the engineers of the various municipalities under whom he had the honour to work.

Mr J. H. THWAITES (London) agreed with the Author concerning the advantage of the common combustion space type of destructor, provided that the grates were kept separate as in the "Sterling" type, but where the grate was continuous without any bridge walls, the danger was too great that green unburnt refuse would be drawn out with the clinker from an adjacent fire in process of burning. It might be taken generally that the more cells or units there were discharging their gases into one common combustion chamber the better would be the combustion, and the more even would be the steaming results obtained Gas analysis, taken over a period of 24 hours, of which he had the diagrams, one taken in a cell and one in the combustion chamber common to four cells, strikingly proved the better results obtained in the latter. As to the area of the grate surface of any one cell of a battery, 25 square feet seemed to be the most generally accepted average, and he thought if the area was reduced very much below this, extra labour would be entailed in charging and clinkering, as well as extra capital cost in the erection of the plant. The Author mentioned that the "Meldrum" and "Heenan" types used heated air for forced draught; to these should be added the "Sterling" type, as in Denmark, with a 12-cell plant capable of burning at a maximum rate of something like 200 tons per day. Large regenerators were fixed with great success on the suction side of the fans, and there would be no doubt that, with refuse of poor calorific value a regenerator was an absolute necessity. The question of forced draught, as treated by the Author, did not give any very definite preference to either steam jet draught or fan draught, and he thought such losses might occur in condensing the steam from the fan engine at King's Norton, as would hardly justify taking the figure claimed of 4·17 per cent. as absolute. It seemed to him to be fairer to take a case where the fans were electrically driven from engines and dynamos, deriving their power from refuse destructor steam, and give the percentage as to the total electrical power raised during the test; this avoided any possibility of error, neglected waste through traps from condensation, steam used for feed pumps, and so forth. To give an example of such a case, he would quote a recent test carried out at Isleworth on a "Sterling" destructor. Total units of electricity generated, engines running partly non-condensing at 40 lbs. of steam per K.W. hour. Units used for forced draught, 74 B.T.U., percentage to total units raised, 4·6. If for condensing, the figure 32 lbs. per unit were taken, the percentage would be only 3·64, but an absolute figure was far preferable. He thought, also, that Mr Leask should, in giving the test figures at Hackney on the "Sterling" destructor, have given them as published, and not have left

Mr J. H. Thwaites.
out about half the figures, giving details of electricity generated, percentage of power raised used for forced draught, etc. The remarks condemning the top feed pipe of the destructor were only natural, coming from one whose particular furnace was usually front or back fed by shovel, sometimes called "putting it on by the spoonful." There was no need to make an opening in the reverberatory arch over the grate, and such a practice should be condemned altogether as faulty; as to capital outlay, the extra cost was fully justified by the better sanitary results, the better clinker, and easier and healthier conditions for the men working the destructor. It was hardly possible to shovel refuse which, as Mr Leask admitted, was composed of all sorts and sizes of material, without scattering it about the floor and raising a large amount of dust in which the men had to work, whereas, if the storage bin was well arranged for top feeding, the whole operation could be carried out without the men coming into contact with the refuse since long rakes were employed, and any amount, not necessarily a cart-load, could be put on the fire. It was quite unnecessary for smoke to come from the opening, and a chimney of 110 feet was quite sufficient in a properly constructed plant. The double handling of the refuse was rather a fallacy, since the labour cost for dealing with a ton of refuse in a "Sterling" plant of modern design, from the time it was tipped into the bin to the time it was removed into the clinker yard, about 25 or 30 yards from the furnaces, worked out at 6·1 pence per ton, this cost including the extra money given to a leading hand to attend to boilers, fans, and pumps. This figure showed even less labour cost than Mr Leask's mention of 6·45 pence per ton, with no extra supervision and with men at 4s. 8d. per shift, as against wages of 4s. 8d., 5s. 4d., and 5s., paid per 10-hour shift to men obtaining the result just given, with a top fed "Sterling" plant. Again, great loss occurred in shovel fed furnaces owing to the greater time that the charging doors were open, also the drying of the refuse upon the drying hearth in a top feed destructor, enabled a new fire to be got away and brought up to a great heat in far less time. In connection

with the list of main points to be considered when selecting a type of furnace, as given by Mr Leask, these were again directed against the top feed destructor, but he thought the specifications of many engineers in this country and abroad, asking for "top feed," indicated their preference after viewing the various types on the market. Finally, the figures given for evaporation per lb. of refuse were very misleading, since refuse in the North of England and the Midlands varied in calorific value very much when compared with London refuse, and was often superior to the extent of from 50 to 100 per cent. The best evaporation the "Sterling" destructor had obtained in London was 1·651 lbs. of water per lb. of refuse, from and at 212 degrees F., at the combined Electricity and Destructor Works at Bermondsey.

Mr D. M'Coll (Glasgow) stated that he had perused Mr Leask's paper very carefully, and it struck him as most interesting and instructive, his facts and deductions being well marshalled and lucidly stated. Passing over the historical portion, the first point on which he would remark was the type of furnace, and his preference was distinctly in favour of the continuous grate, it giving, in his opinion, the best combustion. In the case of cells, when one required repair those adjoining must also be thrown out of action as the heat would be so excessive that men could not work. Mr Leask's idea of constructing the reverberatory arch with undulations was certainly novel and ingenious, but he had not advanced proof of any decided advantage which would accrue from this, while on the other hand the arch would be difficult to build, and still more so to repair. Unless, therefore, very great improvement of conditions could be guaranteed by the adoption of this form, one would certainly abide by the plain arch. The question of forced blast and the best method of producing it was also discussed, and Mr Leask's preference was for a fan as against steam jets. Both of these methods were in operation in connection with the Glasgow Corporation Cleansing Department of which he had charge, and his experience was that the steam jet was the better, the results being more satisfactory. He

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admitted that the jet used most steam, but after all it was but a small proportion of the total generated, and there was this advantage, that the breakdown of a jet only affected the grate to which it was attached, whereas if the fan got out of order, the whole installation was affected. The deterioration in the quality of the clinker referred to had not come within his experience; in fact he considered the clinker produced in the steam jet furnace superior to that from the fan blast furnace, and he had never had the slightest difficulty in finding purchasers for it. The method of feeding the furnaces was a subject which had caused a considerable amount of discussion and of difference of opinion. In Glasgow the furnaces were constructed with a top feed, and the advantages referred to by Mr Leask had been experienced in their full force. Being just over the grate, the openings were exposed to the full radiated heat and required frequent renewal, which meant practically rebuilding the whole arch, and this ran the cost of upkeep to a very high figure. In a report which he had submitted recently he recommended the substitution of a front feed, having been satisfied that by this method the work could be done in a cleanly manner, the refuse by the one operation spread more evenly, and the cost of repairs materially reduced. There was no doubt that the dumping of large quantities of refuse into a furnace retarded combustion and lowered the temperature for the time being, and this was avoided by the front feeding process. He had only referred to one or two points which struck him, but, as he said, the whole paper was eminently instructive and suggestive, and well repaid perusal.

Mr David R. Todd (Member) stated that he had read Mr Leask's paper with that degree of interest and surprise that the statistics the Author gave were well calculated to excite, and since he had recently had an opportunity of testing their accuracy he ventured to hope that the following remarks, as a commentary on the figures might be of service to those who were interested in the question of refuse destructors. Generally speaking he submitted that the claims made by

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destructor makers were distinguished by other features than undue moderation, but when it was found that the average evaporative results of the four "Heenan" destructors, as given by Mr Leask, exceeded by 48 per cent. the average of all the others quoted in his paper, one was tempted to look closely into the matter. He thought that strict accuracy in his figures was more than usually incumbent on Mr Leask, since in developing his plant he had availed himself with conspicuous liberality (and that without acknowledgement) of the services and experience of other firms, and in this connection had, to some extent, imposed on them a responsibity they had no right to share. This was more worthy of remark in view of the fact that in recent practice the "Heenan" destructor embodied contradictory features in the same design, so that any benefit that might accrue by the adoption of one principle, or system, was more than neutralized by another. As Mr Leask disclaimed responsibility for particulars other than those connected with the "Heenan" destructor, his (Mr Todd's) remarks must necessarily be confined to this type, although he was very doubtful about the accuracy of the figures quoted in some other instances as well. The first thing that would be obvious to most people was the absence, in the Tables of tests, of information on the following points:—1. How the water alleged to be evaporated was measured? 2. The quality of the steam, whether it was wet, dry, saturated, or superheated, and if the latter the degree of superheat reached? 3. What precautions were taken (in cases where no superheater was used) to prevent priming, or if priming occurred how it was measured, and what deductions were made on that account in estimating the net evaporation? The doubtful character of refuse and fuel had been referred to. On page 354, Mr Leask credited King's Norton refuse, with a very substantial heat value, but it would not he thought convince many, especially when the size of average analytical samples were considered, that such tests, no matter how numerous, could be taken as a true measure of the average heat value of a mass so heterogenous in character as refuse, or that samples taken in 1903 would be true

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for 1905. As a rough approximation for practical purposes the calorific value of refuse had for a long time been reckoned at one-third to one-fourth the heat value of medium coal, and in fact, in a previous paper read before the Institution of Civil Engineers in Ireland, on 4th March, 1903, Mr Leask accepted this and assigned to refuse the average calorific value of 3,000 B.T.U. On his authority then in the following Table A, he had taken this figure as the basis of calculation for the heat value of refuse burned per hour. Table A showed in parallel columns the relative performances of the Babcock destructor fired boilers at Worthing and King's Norton, and that on page 351, compared with the corresponding duties of a similar boiler of nearly equal size, coal fired, with a mechanical stoker of Babcock & Wilcox's standard and most approved type. The figures of this test (with the circumstances of which he was fully conversant) were taken from that Company's published records. This trial was most carefully conducted, and a feature of special importance in the present comparison was, that to ensure absolutely dry steam being produced, the superheater was kept in action, and the steam leaving the boiler was moderately superheated about 89 degrees F. The fuel was elaborately tested, and found to have a calorific value of 10,992 B.T.U. The Lancashire boiler with which he had compared Mr Leask's Levenshulme test was of equal size to the latter, and was fired in a similar fashion to the Babcock boiler just mentioned, with coal of about equal value (10,846 B.T.U). The comparison would be readily understood; the respective heating surfaces, grate surfaces, etc., were tabulated, and the aggregate heat value in millions of British thermal units, available per hour in the case of the coal fired and destructor fired boiler (the latter at 3,000 B.T.U. per lb.) were given, and the measure of efficiencies of the latter compared with the former expressed in percentages, in terms of the water evaporated per square foot of boiler heating surface. It would be noticed that Worthing with fuel 2 per cent. less value in the aggregate, actually attained in efficiency only 8·7 per cent. below the coal fired boiler. Under the circumstances, this would

TABLE A.—Showing evaporative efficiency of boilers fired with waste gases from "Heenan" destructors compared with similar boilers "direct" fired with coal:—

PARTICULARS.	Babcock Boiler.		Lancashire Boiler.		Babcock Boiler.		Babcock Boiler.	
	Worthing Heenan Destructor.	Direct coal fired	Levenshulme Heenan Destructor.	Direct coal fired	King's Norton Heenan Destructor.	Direct coal fired	Heenan Destructor, page 351, Mr Leask's paper.	Direct coal fired
Total heating surface in square feet,... ...	1,740	1,827	845	970	1,966	1,827	1,966	1,827
Total grate surface in square feet, ...	55	35	50	29·15	75	35	75	35
Total weight of fuel burned per hour, lbs.	3,379	940	4,084	631	4,247	940	3,665	940
Rate of combustion per square foot per hour, lbs.	61·44	26·8	81·6	21·64	57	26·8	48·8	26·8
Percentage of ash and clinker, ...	15·55	10·19	22	19·04	25	10·19	26	10·19
Average calorific value of fuel per pound, ...	3,000	10,992	3,000	10,846	3,000	10,992	3,000	10,992
Total calorific value of fuel burned per hour in millions of B.T.U., ...	A. 10·13	B. 10·34	A. 12·25	B. 6·84	A. 12·73	B. 10·34	A. 11·0	B. 10·34
Percentage difference in total heat available from refuse compared with coal burned in same time = $\frac{A - B}{B}$, ...	% 2·03 less	...	% 79·1 more	...	% 23·1 more	...	% 6·37 more	...
Water evaporated per square foot of boiler heating surface per hour, ... lbs.	C. 2·722	D. 2·982	C. 7·5	D. 4·03	C. 4·64	D. 2·982	C. 3·5	D. 2·982
Percentage difference in evaporation per square foot of heating surface of destructor boilers, compared with direct coal fired boilers = $\frac{C - D}{D}$, ...	% 8·72 less	...	% 86·3 more	...	% 55·6 more	...	% 17·4 more	...

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excite considerable suspicion, "but it is only a little one" (Mr Leask said it was a small destructor, so he would let it pass), but coming to Levenshulme, King's Norton, and the unnamed plant on page 351, there was evidence that boilers, in combination with destructors, and fired with fuel, having potential values, 77, 23, and 6 per cent. in excess of a coal fired boiler, surpassed these latter in evaporative efficiencies by 86, 55, and 17½ per cent. respectively. The claim was absurd, and he asked Mr Leask if he seriously invited those among them, who could appreciate the difference between boilers, direct and separately fired (independent altogether of the special disabilities that attended destructors) to accept such figures. He could leave the matter here but it might be claimed, that he only argued the question by inference. This was true in any case as far as Worthing, King's Norton, and Levenshulme were considered. Fortunately or unfortunately, however, from whichever side it might be regarded, he had a good deal more in support of his assertion regarding the "Heenan" destructor mentioned on page 351. Mr Leask claimed for it an evaporative duty of 2·16 per lb. of refuse from and at 212 degrees F. The following Table B showed the actual results of nearly three months working. During one week only, that ending January 13th, was there any approach to the test results? but alas! this must be attributed not to the destructor but to a bad leak in the water pipe, which was only discovered when the weekly readings were being checked over. It might be urged with some appearance of reason that in consequence of varying demands for steam, the total heat available in the refuse was not properly utilized, but against this must be set these facts—1, that all the water registered by the meter was credited to the destructor, although a considerable proportion did not enter the refuse destructor boiler at all, and 2, the figures obtained at tests, referred to below, taken in conjunction with the average weight of refuse consumed per hour, proved an apparent evaporation considerably lower than shown in Table B. In this connection, he would suggest to Mr Leask that the apparent high

Table B.

Evaporative efficiency of "Heenan" destructor taken from electric power station records. Figures in colums 7, 8, and 9, were from meter readings, *not corrected*, for water not being used in boilers. For net quantitites entering boiler, see Table C:—

1906. Week ending.	Total weight of refuse destroyed.		Total grate surface in use.	Hours worked per week approximate.	Weight of refuse burned per hour, approximate.	Rate of combustion per sq. ft. of grate per hour.	Water evaporated as shown by meter readings.			Electrical units generated.	
							Total water evaporated.	Apparent rate of evaporation per sq. ft. heating surface.	Apparent evaporation per pound of refuse.	Total units.	Units per ton of refuse burned.
	Tons.	Cwts.	Sq. ft.		Lbs.	Lbs.	Gallons.	Lbs.	Lbs.		
January 6, ...	172	13	75	85·5	4550	59·8	35,000	2·08	·903	3827	22·17
,, 13, ...	174	8	75	85·5	4600	60·4	70,450*	4·19	1·8	3465	19·86
,, 20, ...	171	8½	75	85·5	4520	59·5	56,184*	3·34	1·46	3560	20·75
,, 27, ...	176	2½	75	85·5	4640	61·3	42,650	2·53	1·08	3486	19·8
February 3, ...	130	12¾	75	85·5	3430	45·3	32,210	1·91	1·10	3060	22·2
,, 10, ...	177	13½	75	85·5	4670	61·6	33,300	1·98	·839	4136	23·2
,, 17, ...	160	19½	75	85·5	4230	55·8	36,800	2·19	1·02	4263	26·5
,, 24, ...	159	1	75	85·5	4190	55·3	39,250	2·33	1·10	4005	25·18
March 3, ...	162	3½	75	85·5	4270	66·7	34,600	2·06	·953	4181	25·81
,, 10, ...	142	3	75	85·5	3750	49·4	32,820	1·95	1·031	4067	28·5
,, 17, ...	150	10¾	75	85·5	3965	52·2	43,200	2·56	1·28	3834	24·65
Average, ...	161	12¼	75	85·5	4256	56·7	41,488	2·46	1·143	3807	23·51

* Bad leakage discovered later.

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duty claimed by him, at least in the case of the destructor on page 351, was due to one or all of the following circumstances :—1. The water assumed to be evaporated was measured not by tank but by the station meter. 2. The water used for the general purposes of the station passed through this same meter, and a large proportion of the total quantity registered did not go near the boilers at all. 3. The steam generated by the boiler was very wet. It was in respect of this latter feature, of which there was no possible doubt, as a very few minutes stay in the engine room proved that he owed his knowledge of the circumstances and found the opportunity of testing the accuracy of Mr Leask's figures. When reading his paper, Mr Leask claimed that under certain conditions this refuse destructor boiler would be capable of supplying enough steam to generate 150 units per ton of refuse burned. Table B gave the station records in this respect, but the questions that caused most anxiety and demanded close investigation were :—1. The apparent abnormal consumption of water per unit of electrical energy generated; and 2. The determination of the quantity of water that was finding its way into the steam pipe, and how it could be prevented. It was agreed at the very outset, between the Borough engineer and himself, that any tests in which the station meter was used for measuring, could not be upheld as absolutely true in any strict or scientific sense, but as the arrangements of the station did not admit the possibility of employing tanks, and as the meter had been used in previous tests for the destructor and was in the last resort the arbiter of the station's liabilities for water consumed, it was decided to proceed on the following lines. The station was equipped with two Babcock & Wilcox boilers, one with 1,966 square feet of heating surface without superheater, and forming an integral part of the "Heenan" destructor plant. This boiler up to the present time, while the needs of the station were small, had supplied all the steam for the varying loads of the engine, up to 100 kilowatts. There was a second Babcock boiler of 2800 square feet heating surface, fitted with a superheater and coal fired, having no con-

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nection whatever with the refuse destructor. The water meter which was coupled to the town's mains discharged the water into an overhead storage tank, from which all the supply to feed the boilers and for the general purposes of the station was drawn. The intermittent demand for water apart from the boiler naturally introduced an element of great uncertainty, and special provision had to be made to deal with it. It was arranged to keep the water in the storage tank at a fixed level, registered by a pointer, and checked at each reading. The level was kept well below the overflow outlet to prevent any loss of water from this cause. In order to provide whatever water was wanted in the station, a hose and tap fed from the tank at constant head and running at uniform rate continually throughout the test was arranged for. The quantities discharged per hour by this pipe were ascertained by weight and corresponding deductions made from the amounts registered by meter at the conclusion of the test. The water gauge glasses were marked and the water in the boilers maintained as nearly as possible at a constant level, finishing at the mark at the close of the test. On the first day with the refuse destructor boiler only in use, the ordinary station load was carried, and a sufficient artificial load was arranged to maintain the output first at one-half, and then at full load. The electrical output registered by the recording watt-meter was checked continuously by independent volt- and am-meter readings. On the second day, the refuse destructor boiler was shut off entirely, all the steam for the engines being supplied by the coal fired boiler with superheated steam, the superheat varying from 70 to 100 degrees F. On this occasion a programme identically similar to that of the first day was carried out. The result of the first day's trial with the refuse destructor boiler showed an apparent average water consumption, taking the varying load throughout the day, of 43 lbs. per kilowatt. On the second day with superheated steam, this apparently stood at 25 lbs. per kilowatt. On the assumption that whatever percentage of error existed in one case, must also exist in the other, and making every allowance for the increased economy

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necessarily due to superheated steam, there still remained a large and significant difference in the weight of water consumed, which could only be accounted for by excessive "priming" or the discharge of water in gulps into the steam pipes. Now he did not propose to make any dogmatic assertions in consequence of these tests. The figures in spite of all the care that was taken to eliminate errors could in the nature of things only be approximately accurate. They were, however, relatively correct in respect to each other, or to any previous test where meter readings had been selected as the standard. The point of all this as far as Mr Leask's paper was concerned was:—If the refuse destructor boiler, supplying as it did, a mixture of steam and water, did so only to the extent indicated, how did this compare with the pounds of refuse consumed? He did not want to be unnecessarily exacting, and in view of percentage errors in the meter readings which probably existed, he would waive the question of priming, and would give Mr Leask the full benefit of the 43 lbs. per kilowatt generated. Accepting 43 lbs. per unit, at average loads, and taking the station figures for the last three months as shown in Table B, he had compiled Table C in which the destructor duty had been worked out on the basis of 43 lbs. per kilowatt. Instead of Mr Leask's figure of 1·877 lbs. per lb. of refuse, or the station figures, Table B, 1·143 per lb. in which all the water passing through the meter, whether going to the boiler or not was credited to the destructor, the figures corrected for boiler evaporation only at 43 lbs. per kilowatt, would average over the whole period less than one-half pound of water per lb. of refuse. He regretted that these notes had run in length beyond the limit he originally intended, but the challenge in Mr Leask's paper to his credulity, or the possibilities of the case, must serve as his excuse. In conclusion he would only add that he noticed Mr Leask had in his paper consistently raised, what most Members of the Institution would recognise as an old familiar friend, the air heater, to the five syllable rank of "recuperator." Perhaps the amplitude of his notions of figures, etc., justified the change. At any rate the name possessed what

Table C.

Evaporative efficiency of "Heenan" destructor, taken from electric power station records, with the necessary corrections made for water not passing through boilers. Total evaporation taken at test figures of 43 lbs. per kilowatt:—

1906. Week ending.	Total weight of refuse destroyed.		Total grate surface in use.	Hours worked per week, approximate.	Weight of refuse burned per hour, approximate.	Rate of combustion per sq. ft. of grate per hour.	Water evaporated on the basis of 43 lbs. per kilowatt.			Electrical units generated.	
							Total water evaporated.	Rate of evaporation per sq. ft. heating surface.	Evaporation per pound of refuse.	Total units.	Units per ton of refuse destroyed
	Tons.	Cwts.	Sq. ft.		Lbs.	Lbs.	Gallons.	Lbs.	Lbs.		
January 6, ...	172	13	75	85·5	4550	59·8	16,460	·98	·426	3827	22·17
,, 13, ...	174	8	75	85·5	4600	60·4	14,900	·887	·381	3465	19·86
,, 20, ...	171	8½	75	85·5	4520	59·5	15,300	·911	·399	3560	20·75
,, 27, ...	176	2½	75	85·5	4640	61·3	14,990	·910	·380	3486	19·8
February 3, ...	130	12¾	75	85·5	3430	45·3	13,350	·795	·456	3060	22·2
,, 10, ...	177	13½	75	85·5	4670	61·6	17,750	1·056	·446	4136	23·2
,, 17, ...	160	19½	75	85·5	4230	55·8	18,360	1·091	·495	4263	26·5
,, 24, ...	159	1	75	85·5	4190	55·3	17,230	1·026	·483	4005	25·18
March 3, ...	162	3½	75	85·5	4270	66·7	18,100	1·077	·498	4181	25·81
,, 10, ...	142	3	75	85·5	3750	49·4	17,498	1·040	·549	4067	28·5
,, 17, ...	150	10¾	75	85·5	3965	52·2	16,490	·982	·489	3834	24·65
Average, ...	161	12¼	75	85·5	4256	56·7	16,402	·977	·454	3807	23·51

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the "Heenan" destructor in most respects lacked, the merit of originality.

Mr William Warner (Nottingham) considered that the paper given by Mr Leask was primarily intended to boom the "Heenan and Froude" destructor, as it did not give much information, and none of the good qualities of other types, and it was also evident to him that the Author purposely withheld the improvements and details which had been invented by himself and others since destructors were introduced. In speaking of the "Warner" destructor he said "This furnace was an off-shoot of the 'Fryer' type." If any apprentice examined the details, he would at once see *that* it was no "off-shoot" at all, but a totally different constructed furnace, and it would not take a very experienced engineer *to see* that the points spoken so highly of in the "Heenan and Froude" destructor were precisely the same points as in all other well-known types, and the only difference to some furnaces was a kind of continuous grate, which was introduced many years ago, and tried by himself, when it was found troublesome with regard to feeding, clinkering, and the handling of the products of combustion. It seemed extraordinary that Mr Leask should make such grand points, when he must know that practically no destructor would do more than another when built upon modern lines, and as now constructed by four or five leading makers, and an engineer would guarantee to get equal results from the same kind of refuse with any one of these destructors.

Mr Leask, in reply, said that contrary to Mr Wilkie's statement that "he professed to deal with the history and evolution of types of furnaces," reference to his paper would prove that "some reference only would be made to the history," and that reference was made with a view to bring out the fact that there were two families of destructors; one distinguished by its grates being isolated and connected to a secondary combustion chamber, and the other wherein the primary combustion chamber was common to a number of grates. He had said that the "Heenan" destructor, as now constructed, was evolved from furnaces patented in 1893. This, perhaps, would have been better stated had he said that the "Heenan" destructor, as now constructed, was evolved from furnaces patented prior to 1894, not by Mr Heenan, nor by Mr Leask, nor by Messrs Meldrum. The statement was not so remarkably loose as Mr Wilkie would wish to imply, nor was it wholly misleading or unfair, the common combustion chamber type having in fact a prior claim to that made by Messrs Meldrum. When Mr Wilkie came to deal with actual facts, he went very seriously wrong. The most pertinent, but not necessarily the most admissible facts were those to be found in the records of the Patent Office, and he relied on those records for the statements he had made above. The name "Heenan" could not be identified in any way whatsoever with the "Bennett-Phythian" furnace. The "Heenan" twin-cell was not a modification of the "Bennett-Phythian." It was another way of carrying out a principle which had apparently been recognised by many engineers for at least half a century, and had been patented in many forms and on many occasions during that fifty years both at home and abroad. He did not deny the resemblance which existed between Messrs Meldrum's "Simplex" furnace and the "Heenan," but he claimed that Messrs Heenan and Froude had equal right to the features wherein the similarity existed. Mr Goodrich's work on "Refuse Disposal and Power Production," from which an illustration had been introduced by Mr Wilkie, and which was calculated to give an erroneous impression, was no doubt a very excellent treatise from Messrs Meldrum's point of view. Perhaps it was consistent with Mr Wilkie's idea of moral rectitude that Mr Goodrich, in publishing the compilation, did not disclose the fact that he was servant and representative of a particular maker. To those who knew, such a work was relegated to the category of a trade catalogue. The Author denied that any success that might be achieved on his plant was the product of brains and experience other than that of the destructor staff of his firm. In 1903 he had employed the words credited to him by Mr Wilkie, but he had used the word "apparently" advisedly. Mr Wilkie

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considered that he should have made some acknowledgement to Messrs James Howden & Co. for the use of an air heater in connection with his furnace. Although Messrs Howden might have perfected an air heater, it was questionable whether they were the originators of the idea. Reference to Bourne's work on the Steam Engine, published about 1859, showed that this was in the minds of all thinking engineers prior to that date. Mr Wilkie knew nothing of the relations between Messrs Howden and Messrs Heenan & Froude, suffice it to say that the relationship was one of buyer and seller, and called for no acknowledgement beyond payment of accounts. He could not follow Mr Wilkie's logical conclusion in his reference to Mr Fryer, but he thanked Mr Wilkie for having brought to his notice Mr Alliot's patent, No. 17,630, of the year 1887, which, on examination, disclosed a furnace wherein there was a common furnace chamber, a secondary combustion chamber and steam boiler, and a regenerator or air heater. This patent included or referred to the patent, No. 8690, 1885, of Mr Jones, for a fume cremator, which one could imagine probably inspired Messrs Meldrum in 1894. He did not think that the same course of reasoning or line of thought, as Messrs Meldrum had exhibited in their earlier patent, had finally evolved their 1894 patent. He thought that other engineers, on examining Patent 8690, would arrive at the same conclusion that he himself arrived at, and therefore that Mr Goodrich's reference to the fume cremator in his compilation entitled "Refuse Disposal and Power Production," was very near the truth when he (Mr Goodrich) said that "one should not make little of the bridge that carried one over." Mr Wilkie broke down his own contention with reference to the corrugated arch when he said that the particles were projected from the furnace. The gases flowing from the burning mass of fuel had some initial velocity on entering the furnace chamber, and, therefore, displaced and affected the stream lines which would be set up by the vacuum in the chamber. There was no necessity to dilate on Mr Wilkie's conclusion, but suffice it to say that the action described could be seen by the naked eye by any person inspecting the furnace. He could give a number of tests which showed CO_2 over 17 per cent., and that over long periods, but he maintained that it largely depended on the position at which the analysis was taken as to what the composition would be; the pull of the chimney having a material effect on leakages. Contrary to the impression which Mr Wilkie would like to convey, the system of arch construction which he stated had been advocated by Mr Leask some years ago, and still advocated by him for certain types of furnaces, the construction was not weak and had never caused the slighest anxiety nor called for repairs. The reason which Mr Wilkie gave for the arch of the furnaces being built in an undulating form was incorrect and the true and only reason was that stated in the paper. It was pleasing to note that Mr Wilkie was in accordance with him on at least one point, viz; that relative to air heating. With regard to the steam jet he gave Mr Stromeyer as his authority for the percentages of steam used. He thought he was right in stating that these were estimated percentages arrived at by a deductive method and that they were not diréctly measured, nor was he aware that Messrs Meldrum had ever dared to make public, figures in which the steam required for forced draught was measured by the evaporation in an independent boiler. They could not contend that this method was too expensive or too difficult to adopt, it would probably be too exact a method. Mr Goodrich had himself stated that it took 15 per cent. Unfortunately, Mr Maxwell's statement in the Electrical Engineer of 1892, could not be taken as a guide. Whereas Mr Maxwell himself said "I have made no tests" he (the Author) did not say that the evidence of Mr Maxwell was incorrect, but he maintained that the fault lay with the quantity of air supplied by the fan which was the crux of the whole question. The difficult part of the destructor to design was not the air heater, as alleged by Mr Wilkie, but rather the fan and distribution of the air supply, especially when dealing with fuel so irregular in quality and nature as refuse. Mr Wilkie had, for

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reasons best known to himself, been forced to cease to advocate one system of feeding over another, and the inclusion or omission of a drying hearth. Apparently he liked to run with the hare and hunt with the hounds. There were back-fired furnaces in vogue long before Messrs Meldrum built theirs in 1900. Mr Wilkie's judicial mind had now decided that all tests other than those carried out by entirely disinterested parties were not reliable. It was another example of the elasticity of the moral rectitude of which he had spoken that enabled him to still make use of those tests which he now claimed as worthless. He did not think it was possible to draw up a reliable balance sheet, no matter who tested the plant. He agreed with Mr Wilkie that the real test of a plant was its regular everyday work, and that the cost of labour on tests was no criterion except as to what could be done. Mr Wilkie had evidently been misled by the fact that in printing the paper the cost of burning the refuse had been accidently omitted, it was in the original manuscript that this cost was sevenpence per ton, and it continued at sevenpence per ton to this date, and it was with reference to the closeness of the cost of labour on the date of the test to the regular cost of labour that he had drawn attention. The condemnatory evidence quoted by Mr Wilkie from the *Public Health Engineer* was only condemnatory as regards the reliability of newspaper reports in matters of this kind, and he would quote from the *Public Health Engineer* the contradiction of the statement:—

Barrow.—"The notice which appeared in our issue of 7th April with regard to the destructor was written under a misapprehension of the facts. The surveyor and engineer (Mr J. Walker Smith), informs us that the electricity works and the destructor had been using one chimney, but owing to the extension of the electricity works this had now been found insufficient, hence it is proposed to build an independent chimney for the refuse destructor at a cost of £1000, which capital expenditure has till now been saved. The position of the new chimney being different from that of the old one, necessitates the removal of portions of the smaller plant

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and other modifications which will facilitate the working but will entail further expenditure of about £300. He also informs us that it is wrong to say that the refuse destructor is defective or unsatisfactory, what small difficulty has arisen has been caused absolutely by the back draught, fundamentally arising from the absence of chimney pull."

Readers could draw their own conclusion as to why this special notice was inserted by Mr Wilkie and to the moral rectitude displayed. It was unpardonable of Mr Wilkie because from his knowledge of other people's business he could not be wholly unaware of the true facts. He disagreed with Mr Wilkie that meetings of Institutions such as this was the place to discuss the rights and claims of inventors and manufacturers of patented specialities. The laxity in the patent system consisted in allowing individuals to patent the same thing without even being dished up in a different manner. He contended that in the twentieth century, in any industry which had existed for fifty years, it would be difficult for an engineer, however single minded and however inspired, to actually discover something which many other equally well furnished minds with equal opportunities had failed to recognise. Replying to Mr Wyllie's criticism, he believed that refuse could be burnt without nuisance in the "Fryer" type just as well as in some of the types at present on the market. The back feed type as constructed by Messrs Horsfall had never been copied by Messrs Meldrum or Messrs Heenan and Froude so far as he was aware. He would point out to Mr Wyllie that although the furnace arch was heated up and acted as a reservoir of heat, this heat hardly affected the gases generated in the furnace, and practically only those in contact with the arch. He thought that most engineers would give the preference to cremation and mixing within the furnaces, that was provided they wished to maintain the temperature therein. He would tell Mr Wyllie how many sets of firebars had been put in at Rathmines since the plant there had been set to work. Up to the date on which Mr Wyllie spoke twenty single firebars had been replaced in an instal-

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lation of six cells. He could not follow Mr Wyllie when he referred to the difference between reducing the temperature of the flue gases by means of an air heater or an economiser. If the water were returned from the economiser at say 250 degrees F., and in another case the air was supplied by an air heater at the same temperature, the gases leaving the economiser would be at a very much lower temperature than the gases leaving the air heater. In some cases it was advisable to employ both an air heater and an economiser, but this was seldom justified on the score of expense, and as the main object of the destructor was to destroy the refuse without nuisance, that system which had for its object the furthering of this purpose would be the only one to choose. Mr Wyllie could hardly have thought before he stated that the air in the ashpits was actually heated up to a temperature of from 400 to 500 degrees F., more especially when he said that the side boxes took the heat from the clinker where it was not required. He would maintain that if Mr Wyllie had thought for a moment before he had made this statement it would never have been made. It was a simple one to examine and he would proceed to do so, giving the benefit on every point to Mr Wyllie's contention. *Firstly*, assume that the refuse yielded one-third of its weight in clinker; *secondly*, that the whole of this clinker was in contact with the side boxes; *thirdly*, that the clinker was reduced in temperature from 1500 to 500 degrees F. before being withdrawn from the furnace; and *fourthly*, that the specific heat of clinker was say ·25. Basing the calculations on, say, 10 tons of refuse, it would be found that the heat available from the clinker would be about 2,000,000 heat units, whilst that required to heat the air to 500 degrees F. would be about 8,000,000 heat units, figures which he thought were sufficiently eloquent without further comment. He would submit, as he had already done in his paper, that it was impossible for Mr Wyllie to measure the true temperature of the air in the ashpit. Replying to Mr Maxwell, Mr Leask said he had never put forward the chief mission of the destructor as being to raise steam. All his efforts had been mainly directed to consume the refuse with a minimum of cost and without nuisance whatsoever. When this was done it followed as a corollary that the maximum steam would be generated. With regard to the second point raised by Mr Maxwell, he upheld the view that figures obtained in the tests quoted by him could be maintained under actual working conditions, and that in the destructors built by him where steam was fully employed, the average working conditions were a great deal higher than the 50 per cent. referred to. Mr Maxwell proceeded to point out that it was because the heat could not be utilised that the average evaporation was less than that obtained on tests. Readers would see that Mr Maxwell had evidently changed the opinion he expressed in the *Electrician* in 1902 as quoted by Mr Wilkie. He did not at all agree with Mr Maxwell on the point of higher evaporative efficiency. Whilst a larger amount of heat was given out by radiation in the intervening combustion chamber with the continuous type, a large amount of possible heat was never generated at all within the type of furnace from which Mr Maxwell was drawing his conclusions, and he would point out to Mr Maxwell that what he advocated on the one hand was negativing the desideratum of the destruction of refuse to a minimum of nuisance. He had pointed out in his paper that a boiler situated in the position indicated by Fig. 8 which, he believed, was similar to that existing at Partick, would give fair evaporative results, but that the gases would pass up the chimney in an unburnt condition. He would submit that the steady steam pressure said to exist at Partick was due not to this position of the boiler, as claimed by Mr Maxwell, but rather that the refuse was probably never allowed to burn out completely and be reduced to a hard clinker free from organic matter. As to the question of feeding the furnaces he maintained that, with top feed in the process of charging the furnaces the men were brought even more closely into contact with the refuse than with the shovel feed. Mr Maxwell was evidently arguing from a point of view of generating

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steam when he said that "it was generally recognised nowadays that the advantages obtained by heating the air supply were not nearly so great as by utilising the heat in economisers for heating the feed water." How would heating the feed water improve the combustion in the furnaces? He accepted Mr Rowan's correction and agreed with him that it would be very much better to insert the words "of the gases" after "high specific volume." He had examined the reference given by Mr Rowan in "Practical Physics of the Modern Steam Boiler," and he was forced to admit that the method adopted by Mr Rowan was probably a correct method of ascertaining the theoretical rise in temperature in the furnaces due to heating of the air. He was pleased that Mr Rowan had made his meaning more clear when he referred to the rise in temperature of the air for the support of combustion, as Mr Rowan had put the matter in exactly the way he had wished it to be construed. It was also pleasing to note that his feeling with regard to the steam jet *versus* fan produced draught was borne out by an engineer of such long and general experience as Mr Rowan. He agreed with Mr Chant when he (Mr Chant) said that it was a pity that the gentlemen who opened the discussion had not dealt at greater length with the types of destructors they upheld. With a view to promoting wider interest in the paper he had specially requested the Secretary of the Institution to send a copy of the paper to each of the makers of refuse destructors, and he thought in doing so he had fully fulfilled his obligations towards those makers, and that much interesting information would have been brought out thereby. He could not give any instances where the diminution of the death rate could be attributed directly to the destructor, but there were notable decreases in the death rate in towns since cleansing was actively carried out by the authorities. It was stated recently at Salford, that since the inauguration of the cleansing department, the death rate had diminished very considerably. It was to be noted that refuse destructors formed a very important adjunct to the cleansing departments of most cities. He was of opinion that the hydraulic mean depth of

the flues and all passages had more effect on the settlement of dust than almost anything else. No doubt the gases leaving the air heater acted in the manner described by Mr Chant, but the tubes themselves formed a very excellent dust catcher for the very finest particles. Mr Chant very properly pointed out that the types of destructors employing a very high water gauge in the ashpits would require a correspondingly high expenditure of power for the production of the draught. There were other drawbacks to the high pressure. Such a high pressure in the ashpits resulted in a considerable pressure in the furnace chamber itself, which, while it performed the good office of maintaining a high temperature and showing a high percentage of CO_2 rendered the maintenance of the furnace almost impossible from a cleansing department point of view. With regard to the top feed there was no doubt that this was chosen by many makers on account of the general arrangements of their furnaces, combustion chamber, and boilers. He was very interested to learn from Mr J. H. Thwaites that the "Sterling" destructor in Denmark used heated air for forced draught. He would point out, however, that the fans dealing with heated air would require a greater H.P. to operate them than when handling the same weight of air at atmospheric temperature, and would probably be less efficient and their upkeep more costly finally. He did not think he had unfairly dealt with the test figures at Hackney. He did not give such details when considering tests by other makers, or those in which he himself was interested, the reason being that so much depended on the type and size of engine and the load. The comparative measure of the value of the various destructors, from a producing point of view, was the evaporation of water. He had no interest whatsoever in condemning the top feed destructor; he had merely stated his experience, and he had, as a matter of fact, constructed more destructors of the top feed type than of any other, and therefore he thought that having knowledge of practically all the types it would give his experience some weight. He had not the slightest doubt that putting in the refuse by the spoonful, as Mr Thwaites had playfully called the

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shovel feed, was the best, and most makers of mechanical stokers had been endeavouring to do this for many years. No doubt the spoonfuls of refuse would require to be larger than the spoonfuls of coal. He could not see how the clinker was improved by the top feed as suggested by Mr Thwaites. His experience was to the contrary owing to the difficulty of getting with this arrangement of feeding a thick fire which was so necessary when dealing with material of so miscellaneous a character. He had proved to his own satisfaction at least, and the satisfaction of many engineers in addition, that the back feed was easier and more sanitary for the men working the destructor. He would like to know from Mr Thwaites the size of the plant, and for what period the cost of dealing with the refuse worked out at 6·1d per ton, and what was the cost of repairs? Mr Thwaites referred to many engineers in this country and abroad as asking for "top feed" as indicating their preference after viewing various types on the market. He (Mr Leask) could not accept that view. He admitted that most people, on first examining the question, as he himself had done, would imagine that the top feed was the most satisfactory, but he had found on enquiring from engineers, who had had 20 years experience of both top and back feed destructors, that they had come to the conclusion that back feed gave the most satisfactory results all round. He thought that if Mr M'Coll saw the undulating arch during construction he would observe that it was not more difficult to build than the straight arch, nor could the repairs be expensive. He would point out that with the removal of the apertures in the arch, the probability of having to repair the arch during the lifetime of the destructor was very small indeed. Mr M'Coll's experience of the steam jet and fans in connection with the Glasgow Corporation Cleansing Department was very interesting. He would like to know, however, what precautions Mr M'Coll had taken to ensure, even approximately, the same quantity of air being used when he compared the fans and the steam jets, as it appeared to him to hinge on this point. He had found that the kernal of the whole question of a refuse destructor,

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after a common-sense form of furnace, hinged on the air supply, and the fan had proved the most difficult part of the plant to design. From his experience he had found that to select a fan from a trade catalogue and instal it, and set it to work, was not likely to give good results. He had, after much difficulty, arrived at a type of fan that gave results which appeared impossible to beat. Such temperatures had been obtained as were inadvisable owing to the softening of the firebrick lining and the accumulations of liquid dust, and his endeavours were now turned in the direction of maintaining a fair temperature. He thought it a pity that Mr M'Coll had not stated from what point of view the results had been more satisfactory with steam jets. He felt that Mr Todd's desire had not been to enhance the value of the paper by adding further information, but rather to discredit an attempt to interest the Members of the Institution. With regard to the services and experience of other firms which Mr Todd alleged he had availed himself of with conspicuous liberality, he (the Author) was surprised at such a statement, as a cross-examination on certain correspondence must have left it fresh in Mr Todd's mind that such firms were without experience on the subject in question, and were desirous of obtaining the same. He was pleased to note that Mr Todd repudiated responsibility, and trusted that he would continue to do so. Had Mr Todd been desirous of imparting information to Members he would have stated what the contradictory features were, but such evidently was not his object. In reply to the questions raised he would say: *Firstly*, That sometimes the water delivered to the boilers was measured in tanks in the most approved manner, and sometimes by two meters specially calibrated for the test. *Secondly*, The steam was sometimes wet, dry, saturated, and even superheated, especially in the case of King's Norton where the minimum temperature of the steam was 516 degrees F. *Thirdly*, No extraordinary precautions were taken to prevent priming, and no deductions were made on that account in estimating the net evaporation. He was one of those engineers who did not think it possible to arrive at the calorific value of refuse with any degree

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of accuracy, but he might inform Mr Todd that a large number of samples were collected at the time of the test in 1906, in a similar manner to those that were collected in 1902, and that those samples were submitted to another analyst who reported that the refuse contained approximately 4500 B.T.U. Because he had stated in 1903 that in his opinion the average calorific value of refuse was about 3000 B.T.U. did not justify Mr Todd in using this arbitrary figure when constructing his Table A. On the face of it, it was absurd to employ this figure in conjunction with the elaborately tested and determined calorific values of another fuel. With the exception of Worthing the refuse burnt in the tests quoted by him was distinctly above the average. He would most certainly ask all engineers to accept the tests which he had published, and he did not object to Mr Todd parading these tests in conjunction with tests of various coal fired boilers in Table A, as the results in these Tables confirmed what would be expected by any intelligent engineer. He would point out that Mr Todd had employed the word "efficiency" in the text, whereas he ought to have employed the word "evaporation." Mr Todd had either not benefited by his experience, or he wished to convey an erroneous idea, and as the first premises were not admissible, one was forced to the second. If more than twice the quantity of heat were passed through the boiler one would expect the gases to have a higher terminal temperature and, therefore, a higher evaporation per square foot of heating surface, and that was exactly what had occurred. Again, referring to Table A instead of, in the case of Levenshulme, the quantity of heat passed through the boiler being 79 per cent. more than in the case of the boiler with which it was compared, the quantity of heat passed through was probably nearer 200 per cent. more. In the case of King's Norton the heat passed through the boiler instead of being only 23 per cent. more than the boiler with which it was compared was probably nearer 100 per cent. more, and in the last case mentioned the quantity of heat instead of being only 6 per cent. more was probably nearer 40 per cent. more.

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He therefore invited those who could appreciate the difference between boilers direct and separately fired, to accept those figures even if they admitted the special disabilities which attended destructors, and more especially if they took into consideration the actual condition existing in the combustion space of the boiler. To what lengths Mr Todd was prepared to go to discredit his figures became apparent when he constructed his Tables B and C, especially when the fact was taken into consideration that Mr Todd's firm had supplied the engines in connection with this station, and Mr Todd had availed himself of the opportunity to make himself familiar with the working of the destructor, and, therefore, was quite aware that during the three months' working referred to, a bye-pass, permitting unobstructed flow of the heat generated in the furnaces direct to the chimney, was kept open or closed in accordance with the demand for steam from the engine room. It was needless to say that he never had and did not make any claim for the figures of evaporation shown in Table B. Any further reference on his part after what he had said was unnecessary and he thought it was apparent to any engineer conversant with the working of electric lighting stations—in conjunction with destructors—that Tables B and C were grossly misleading. He still upheld that under certain conditions 150 units per ton of refuse could be obtained. He did not deny that 43 lbs. of steam and water were required per unit generated at average loads, but he would point out that he had strongly recommended the engineer at this station to adhere to the original scheme which he had submitted, which contained a superheater. In closing his remarks Mr Todd waxed facetious over the employment of the word recuperator. Had he read that portion of the paper commencing with the last paragraph on page 337, he would have seen that it was unnecessary for him to draw Members' attention to the terms of air heater or recuperator. He had employed the word to distinguish the air heater which he used from another device for heating the air which was not recuperative. It was a pity that Mr Warner had not availed himself of the

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opportunity afforded to bring out the special features and good qualities of his type and so prove his case. His remarks on the continuous grate were interesting when read in conjunction with Mr Wilkie's claims for the originality of Messrs Meldrum's patent. He regretted that the word "off-shoot" had given offence to Mr Warner, because such a proceeding was far from his intentions. He thanked the Members of the Institution for the manner in which his paper had been received, but he could not help expressing his regret that very little interesting information had been brought out in the discussion and correspondence.

On the motion of the Chairman, a vote of thanks was awarded to Mr Leask for his paper.

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ON EQUIMOMENTAL SYSTEMS AND THEIR USE IN APPLIED MECHANICS.

By Mr R. F. MUIRHEAD, B.A., D.Sc.

Read 1st May, 1906.

IN mechanics, the moment of inertia of a particle with respect to an axis, or about an axis, is the quantity mr^2, where m denotes the mass of the particle, and r its distance from the axis.

Any body, or set of bodies, in a given configuration, may be viewed as a collection of particles, m_1, m_2, m_3 . . . and its moment of inertia, with respect to an axis, is the sum of the moments of inertia of all the particles, viz.: $m_1r_1^2 + m_2r_2^2 + m_3r_3^2 + \ldots$, which, with the usual signification of the symbol Σ, may be denoted by Σmr^2.

This moment of inertia is of importance in the dynamics of rotating bodies.

But the term, "moment of inertia," is also applied, by analogy, to quantities derived from geometrical figures (which, of course, have no inertia). Thus, if the volume of a geometrical solid be supposed divided up into infinitesimal elementary volumes, v_1, v_2 . . . its moment of inertia, with reference to an axis, is the value of Σvr^2, and is the same as that of a mass of unit density occupying the same space as the solid in question. Similarly, the moment of inertia of a geometrical area, whose elements are $a_1, a_2, a_3, \ldots$, will be Σar^2, and that of a line consisting of elementary lengths l_1, l_2 . . . will be Σlr^2.

As such quantities have no real connection with inertia, it is perhaps better to use the term, "second moment with reference to an axis," instead of the term, "moment of inertia," and the former term may be used with reference to actual masses also.

Thus, the second moment with respect to an axis, of anything considered as made up of elements $e_1, e_2, e_3 \ldots$ of infinitesimal size, is the quantity denoted by Σer^2, where $e_1, e_2, e_3 \ldots$ may be elements of length, of area, of volume, of mass, or, in fact, of any definite quantities associated with points in space.

This is distinguished from the first moment with respect to the same axis, viz., Σer, by the fact that each distance is squared in the second moment, but not in the first moment.

Two things are said to be equimomental when, with respect to all possible axes, the first and second moments of the *one* are respectively equal to the first and second moments of the other. (It can easily be shown that if two bodies have the same mass, the same centre of inertia, and also the same second moments about the three principal axes at the centroid, then they are mutually equimomental; also that if two bodies have the same second moments about a certain number of axes, then they must have their centroids coincident, and be equimomental).

In the calculation of first and second moments, and of the position of centroids, it often simplifies matters considerably if one *can* replace a body (or area) by a simpler body (or area), which is equimomental with it.

It is the object of this paper to give some simple systems of points which are equimomental with the most commonly occurring types of bodies and areas; and to point out some advantages of their use in practical calculations. Proofs are omitted.

In applied mechanics, the moments of areas are more often required than those of bodies, but I will begin with the latter:—

I. Uniform solid cuboid (rectangular parallelpiped) of massM:-

The equimomental system consists of a particle of mass $\frac{2}{3}$ M at the mid point, and the rest of the mass equally distributed over the corners, as in Fig. 1.

II. Uniform solid cylinder (right circular):—

$\frac{M}{6}$ at either end of the axis of figure, and $\frac{M}{6}$ at its mid point, and the remaining half of the mass at the four extremities of two mutually perpendicular diameters of the mid circular section, as in Fig. 2.

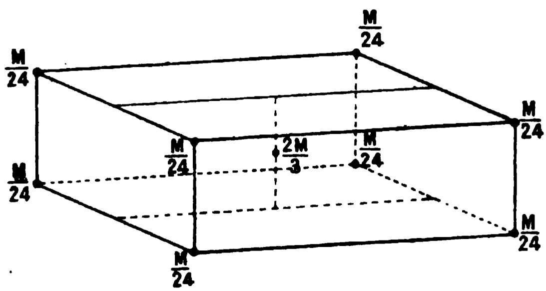

Fig. 1.

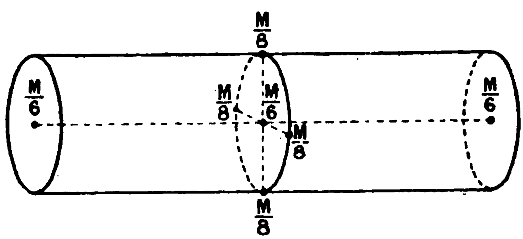

Fig. 2.

III. Uniform solid sphere:—

$\frac{M}{10}$ at each extremity of any three mutually perpendicular diameters, and the rest of the mass $\left(\frac{2M}{5}\right)$ at the centre.

IV. Uniform solid tetrahedron:—

(i.) $\frac{M}{20}$ at each corner, and the rest of the mass $\left(\frac{4M}{5}\right)$ at the centroid.

(ii.) $\frac{M}{10}$ at the mid point of each edge, and the rest $\left(\frac{2M}{5}\right)$ at the centroid.

V. Right cylindrical pipe:—

(i.) Three inner rings of mass $\frac{M}{6}$ each at the ends and middle of the bore, and one ring of mass $\frac{M}{2}$ round the middle of the outer cylindric surface as shown in Fig. 3. Here each ring can be conveniently replaced by four equal particles at the extremities of two mutually perpendicular diameters.

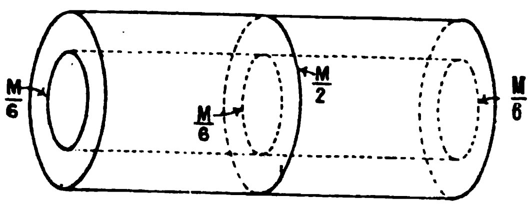

Fig. 3.

(ii.) Three particles of mass $\frac{M}{6}$ at the mid point and ends of the axis of figure, and a ring of mass $\frac{M}{2}$ and radius $\sqrt{a^2+b^2}$, concentric with the middle circular section, a and b being the inner and outer radii of the pipe.

VI. Right circular solid cone:—

(i.) $\frac{3M}{10}$ at the mid point of the axis, $\frac{2M}{5}$ at the centre of gravity of the solid, and $\frac{3M}{10}$ in a uniform ring round the circumference of the base. The ring may be replaced, as in V. (i.), by four equal particles.

(ii.) Six particles, five positive and one negative, as shown in Fig. 4.

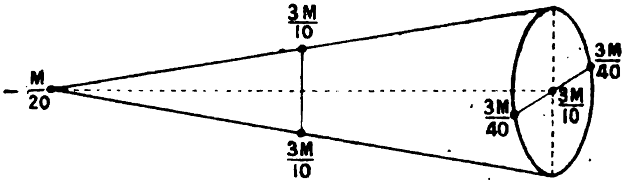

Fig. 4.

N.B.—It can easily be proved that if two systems be equimomental, they will remain so if they both undergo the same homogeneous strain. Hence the cases I., II., III., V., VI., can at once be generalized to include the oblique parallelepiped, the oblique elliptic cylinder, the ellipsoid, the oblique pipe, whose cross-section is bounded by two similar and similarly placed concentric ellipses, and the oblique elliptic cone; only "conjugate diameters" must be substituted for "mutually perpendicular diameters."

VII. Uniform triangular lamina or area:—

(i.) $\frac{M}{3}$ at the mid point of each side.

(ii.) $\frac{M}{12}$ at each corner, and $\frac{3M}{4}$ at the centroid.

VIII. Uniform quadrilateral lamina or area:—

$\frac{M}{12}$ at each corner, $-\frac{M}{12}$ at the intersection of diagonals, and $\frac{3M}{4}$ at the centroid.

IX. Uniform rectangular lamina or area:—

$\frac{M}{12}$ at each corner, and $\frac{2M}{3}$ at the centroid.

X. Uniform circular lamina or area:—

$\frac{M}{2}$ at the centre, and $\frac{M}{8}$ at each extremity of two mutually perpendicular diameters.

Note.—This can be extended to include the uniform elliptic lamina, if "conjugate" instead of "mutually perpendicular" diameters be taken.

XI. Uniform circular annulus of internal radius a and external radius b:—

$\frac{M}{8}$ at each of the points where the circular boundaries are cut by two mutually perpendicular diameters, as shown in Fig. 5. See note to X.

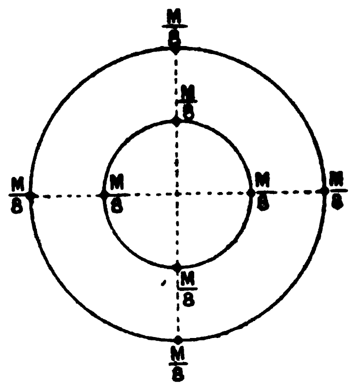

Fig. 5.

XII. Uniform straight rod or line:—

$\frac{2M}{3}$ at the centroid, and $\frac{M}{6}$ at each extremity as in Fig. 6.

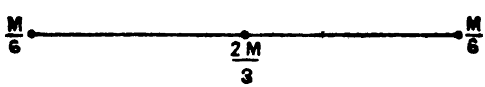

Fig. 6.

XIII. Uniform semi-circular lamina or area:—

(i.) $\frac{M}{8}$ at each of the two corners, with—

$$M\left(\frac{5}{4} - \frac{4}{\pi}\right),\ M\left(\frac{16}{3\pi} - 1\right),\ M\left(\frac{1}{2} - \frac{4}{3\pi}\right),$$

respectively at the central extremity, the middle point, and the circumferential extremity of the mid radius, as in Fig. 7.

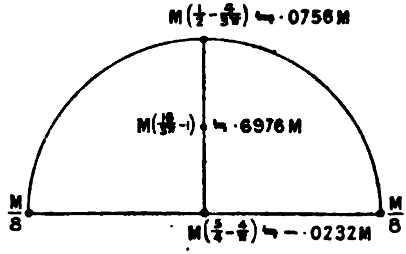

Fig. 7.

(ii.) (Approximately). Seven particles as shown in Fig. 8.

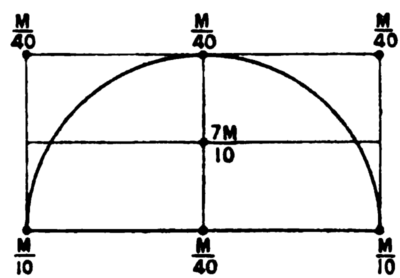

Fig. 8.

(iii.) (Closer approximation). Seven particles as shown in Fig. 9.

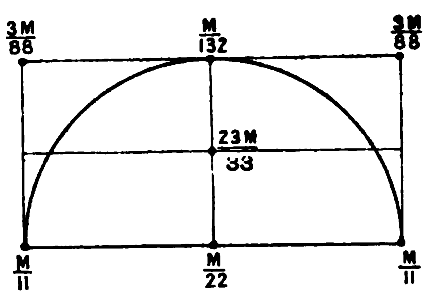

Fig. 9.

Note.—The system (ii.) gives the first and second moments exactly for all axes perpendicular to the straight boundary as well as for an axis coincident with that boundary, the maximum error (about 1 per cent.) being for an axis, parallel to this, passing through the middle point of the mid radius.

The system (iii.) has a much smaller maximum error, but the numbers are not so simple.

XIV. Parabolic segment:—

$\frac{M}{10}$ at each corner, $\frac{2M}{35}$ at the vertex, $\frac{2M}{35}$ at the middle of the chord, and $\frac{24M}{35}$ at the mid poin of the axis, as in Fig. 10.

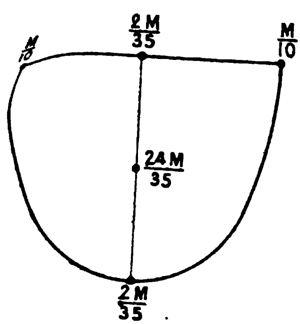

Fig. 10.

It is to be remarked, with reference to the above equimomental systems, that some may be looked on as particular, or extreme cases of others; for example, if the depth of the cuboid in I. diminishes indefinitely, it reduces to IX., while the diminution of the hole in the annulus of XI. to zero, reduces it to X.

It will be seen, in fact, that I. includes X. and XII.

V.	„	II., X., XI., and XII.
VIII.	„	IX. and XII.

This fact reduces considerably the effort of memory required to remember these equimomental systems.

But I do not, by any means, suggest that any one should burden his memory with the results here given. I think they would be useful in a calculator's pocket-book. On the other hand, if one were to memorize I., II., and III., this would give everything included in the well-known "Routh's Rule," and a great deal more as well, for "Routh's Rule" only applies to principal axes through the centroids, while the equimomental systems enable one easily to calculate the first and second moments about any axis.

It is interesting to remark in this connection that Dr. Routh himself seems to have been the first to consider the subject of equimomental systems of particles (see his "Dynamics of Rigid Bodies," Chapter I.), and a considerable proportion of the systems given above were discovered by him. I have tried to glean after his harvesting, and some of the systems given above are, I believe, new.* But my chief aim in this paper is not so much to give new results, as to call attention to the great practical value of these systems in facilitating numerical calculations of moments, etc. To attain this object, I add two or three examples of such applications to problems of common types:—

Example 1.—Find the depth of the centre of pressure on a trapezoidal area of dimensions given in Fig. 11, the upper edge being horizontal and three feet below the water level.

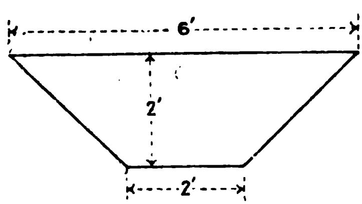

Fig. 11.

* Since the above paper was put in type, I have found that some of the systems given here had been previously published by Rehfeld in the *Archiv für Mathematik* for 1902, page 237.

As is known, the depth, D, of the centre of pressure is got by dividing the second moment of the area about a line in which its plane cuts the water surface, by the first moment about the same axis.

Now, dividing the area into two triangles of areas 6 and 2, as shown in Fig. 12, the equimomental point-system indicated in that figure is easily obtained.

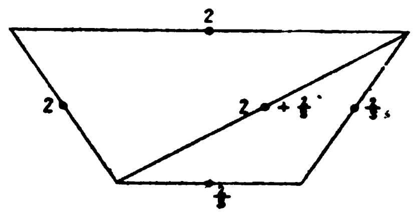

Fig. 12.

Noting that there are but three different depths for these points, then:

$$D = \frac{2 \times 3^2 + \frac{16}{3} \times 4^2 + \frac{2}{3} \times 5^2}{2 \times 3 + \frac{16}{3} \times 4 + \frac{2}{3} \times 5}$$

$$= \frac{6 \times 9 + 16 \times 16 + 2 \times 25}{6 \times 3 + 16 \times 4 + 2 \times 5} = \frac{360}{92} = \frac{90}{23} = 3\frac{21}{23}.$$

Or in tabular form:—

Area.	Depth.	First Moment.	Second Moment.
2	3	$6 = 6$	$18 = 18$
$5\frac{1}{3}$	4	$\frac{64}{3} = 21\frac{1}{3}$	$\frac{256}{3} = 85\frac{1}{3}$
$\frac{2}{3}$	5	$\frac{10}{3} = 3\frac{1}{3}$	$\frac{50}{3} = 16\frac{2}{3}$
Totals, - - - -		$30\frac{2}{3}$	- - 120
Multiplied by 3, -		92	- - 360

$$D = \frac{360}{92} = \frac{90}{23} \doteqdot 3{\cdot}92' \doteqdot 3'\ 11''.$$

Thus, the centre of pressure is $\frac{21}{23}$ feet below the upper edge.

Example 2.—A rectanglular sluice-gate, six feet wide and ten feet deep, is hinged at its lower edge, and the water stands to a height of eight feet on one side and four feet on the other. Find the horizontal force applied at the mid point of its upper edge, which will equilibrate the water pressure.

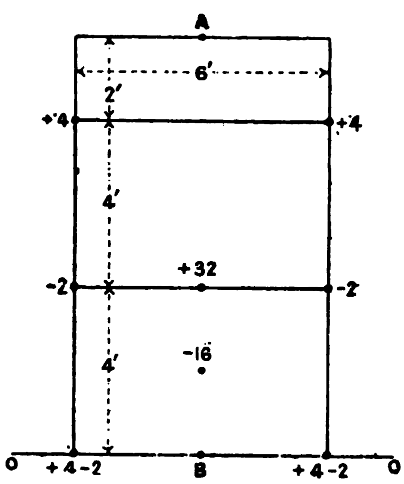

Fig. 13.

The equivalent point-areas are indicated in Fig. 13; those on one side being marked +, and on the other −, to indicate that the pressures on these are in opposite directions. Here, it is to be noted that the only point-areas that give any moment about the hinge O O are those at the mid points of the two areas. Hence, if F be the force acting at A, then, taking moments about O O :—

$$F \times 10 = (32 \times 4 \times 4 - 16 \times 2 \times 2) \times 62{\cdot}5 = 1000\,(32 - 4)$$
$$= 28{,}000.$$
$$\therefore\ F = 2800 \text{ lbs.}$$

If the hinge were at the *upper* edge and the force F′ acted at B, then, by moments about the upper edge:

$$10\,F' = (32 \times 4 \times 6 + 8 \times 8 \times 10 - 16 \times 2 \times 8 - 4 \times 4 \times 10) \times 62{\cdot}5$$
$$= 1000\,(48 \times 40 - 16 - 10) = 62{,}000.$$
$$\therefore\ F' = 6200 \text{ lbs.}$$

Example 3.—Find the neutral axis and the moment of inertia about that axis of the cross-section of a girder of dimensions shown in Fig. 14.

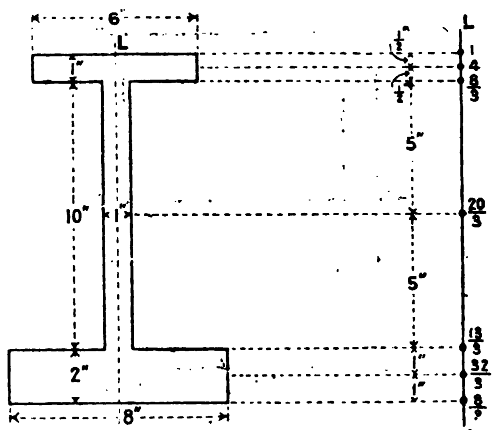

Fig. 14.

In this, as in many cases, a simplified point-system can be taken moving every particle into L L, the line of symmetry, as shown in Fig. 14, since one is only concerned with moments about axes perpendicular to the mid-line of the figure.

In the accompanying tabular calculation, the moments are taken with reference to the bottom line of the section as axis:—

Area.	Distance from Bottom Line.	First Moment.	Second Moment.
1	13	13 = 13	169
4	$\frac{25}{2}$	50 = 50	625
$\frac{8}{3}$	12	32 = 32	384
$\frac{20}{3}$	7	$\frac{140}{3} = 46\frac{2}{3}$	$326\frac{2}{3}$
$\frac{13}{3}$	2	$\frac{26}{3} = 8\frac{2}{3}$	$17\frac{1}{3}$
$\frac{32}{3}$	1	$\frac{32}{3} = 10\frac{2}{3}$	$10\frac{2}{3}$
$\frac{8}{3}$	0	0 = 0	0
32	—	161	$1532\frac{2}{3}$

Thus, if x be the distance from the lower boundary to the neutral axis, $x = \frac{161}{32} = 5\frac{1}{32}$.

Again, by a well known theorem as to parallel axes, the second moment about the neutral axis $= A_2 - Ax^2$

$$= 1532\tfrac{2}{3} - 32 \times (5\tfrac{1}{32})^2 = 722\tfrac{61}{96}$$
$$\doteq 722{\cdot}6 \text{ (inch)}^4 \text{ units.}$$

Example 4.—Find k, the radius of gyration of a uniform solid, consisting of two cylinders having their axis in line, as shown in Fig. 15, about a diameter of the smaller circular face.

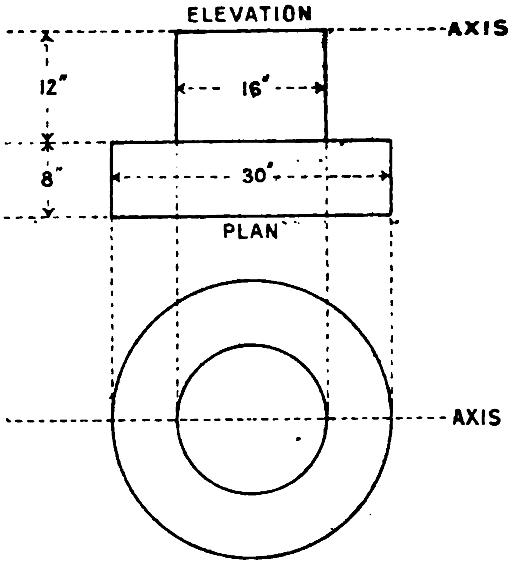

Fig. 15.

The two cylindrical volumes are in the ratio—

$$16^2 \times 12 : 8 \times 30^2$$
$$i.e.\ 32 : 75.$$

Hence, for our purpose, the equimomental system may be taken as in Fig. 15A, Thus, we have—

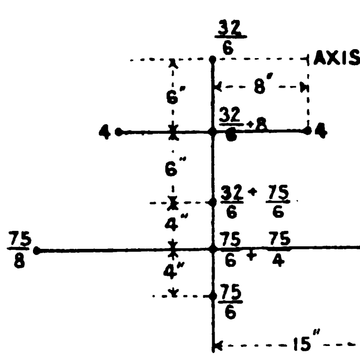

Fig. 15A.

$$(32 + 75)\,k^2 = 6^2\left(\frac{16}{3} + 8\right) + (6^2 + 8^2)\,8$$
$$+ 12^2\left(\frac{16}{3} + \frac{25}{2}\right) + 16^2\left(\frac{25}{2} + \frac{75}{4}\right)$$
$$+ (16^2 + 15^2)\frac{75}{4} + 20^2 \times \frac{75}{6}.$$

$\therefore\ 107\,k^2 = 25{,}866\tfrac{2}{3}$

$k^2 \doteqdot 241{\cdot}75$

$k \doteqdot 15{\cdot}55$ inches.

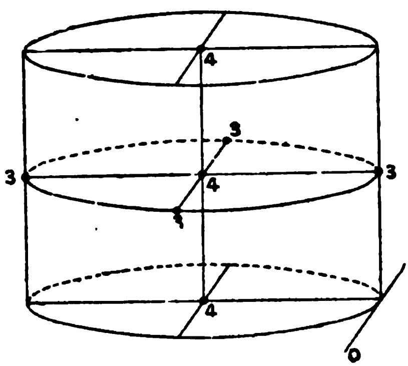

Fig. 16.

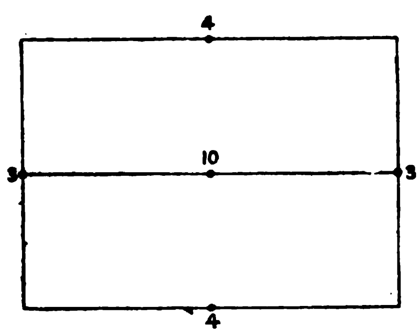

Fig. 16A.

Example 5.—Find k the radius of gyration of a uniform solid cylinder, of length twelve inches, and diameter sixteen inches, about an axis, which is a tangent to the circumference of one circular end. The required result here is independent of the mass, hence any convenient number, say twenty-four, may be chosen as its measure.

Again, the axis perpendicular to the plane of the diagram and passing through the point O, may be taken, and the simplified equimomental point-system indicated in Fig. 16A may be used.

Here,
$$24\,k^2 = (3 + 10 + 3) \times 6^2 + 4 \times 12^2 + (4 + 10 + 4) \times 8^2 + 3 \times 16^2$$
$$= 16 \times 36 + 4 \times 144 + 18 \times 64 + 3 \times 256$$
$$\therefore k^2 = 24 + 24 + 48 + 32$$
$$= 128$$
$$\therefore k = 8\sqrt{2} \doteq 11{\cdot}314 \text{ inches.}$$

These examples will perhaps suffice to indicate how calculations may be simplified by the use of suitably chosen equimomental systems.

If one had calculations to make of second moments, whether of masses or of areas, where moderate accuracy, say to within 1 per cent., would be sufficient, I have little doubt that with practice one could assign with certainty approximately equimomental point-sytems for complicated and irregular bodies and areas that would be sufficiently exact for the purpose. Moments of irregular areas can, of course, be got by the aid of integraphs and other mechanical integrators, but such aids are not always at hand when wanted.

If anything I have put before the Institution in this paper helps that humble but useful member of the engineering profession, the calculator, to economise his time and labour, my object will have been attained.

Discussion.

Mr H. BAMFORD, M.Sc. (Member), said that the principle of equimomental systems as enunciated by Dr. Routh had been known to him for many years past, and he had frequently made use of it in calculations. Hitherto, however, the value of the principle had generally been regarded by engineers as academical rather than

Mr H. Bamford, M.Sc.

practical, and had, consequently, received in the past but little attention from them. In developing the principle and reducing his results to a form eminently suitable for practical application in calculations, he considered the Author to have done a valuable piece of work and to be deserving of their special thanks. In the great majority of cases, however, with which engineers had to deal, he did not think the Author's methods were at all likely to supersede the methods already in use, but would be of value chiefly in dealing with those special cases of bodies having no perpendicular axes of symmetry, or where the axis of inertia was not parallel to an axis of symmetry. For bodies which were rectangular, elliptical or ellipsoidal in form, he was still of the opinion that Routh's rule was the best, viz:—

Moment of inertia about an axis of symmetry

$$= \left\{ \begin{matrix} \text{mass, volume,} \\ \text{or area,} \end{matrix} \right\} \times \frac{\text{(sum of squares of perpendicular semi-axes)}}{3, 4, \text{or } 5.}$$

the denominator being 3, 4, or 5, according as the body was rectangular, elliptical, or ellipsoidal. He would like now to draw attention to one or two points in the paper. In the first part the Author stated "It can be easily shown that if two bodies have the same centre of inertia, and also the same second moments about the three principal axes at the centroid, then they are mutually equimomental." That statement as it stood was not universally true; in order to be so it was also necessary for the bodies to be of the same mass. For a uniform triangular lamina or area—Case VII.—the Author gave two distinct equimomental point systems, viz: (i) and (ii); of these, the first, (i), was given by Routh and was simple in the extreme; but the other, (ii), while having no advantage whatever over (i) was more complicated, and therefore superfluous. Again, as any uniform quadrilateral figure A B C D might be regarded as consisting of two triangles, ABD and BCD, let M_1 be the mass, or area of A B D and M_2 that of B C D, and apply to each of these rule (i) of Case VII. An equimomental point-system was thus obtained for the quadrilateral consisting of a particle = $\frac{1}{3}$ M_1 at each of the mid points of AB and AD, a particle = $\frac{1}{3}$ M_2 at each of the mid points of B C and C D, and a particle = $\frac{1}{3}$ $(M_1 + M_2)$ at the mid point of the diagonal B D. If the quadrilateral were in the form of a square, a rectangle, or a parallelogram of mass or area M, the equimomental point-system would then reduce to a system of particles each equal to $\frac{1}{6}$ M at the mid points of the four sides and a particle = $\frac{1}{3}$ M at the centre. The above treatment of the general case of a quadrilateral figure, which could easily be extended to any rectilinear figure by dividing it up into triangles, appeared to him to have something to recommend it, as the resulting equimomental point-system did not involve the determination of either the centroid or the intersection of the diagonals, and was simpler than the one given by the Author—Case VII.

Mr W. J. Goudie, B.Sc. (Member), remarked that he had had an opportunity of reading an advance proof of Dr. Muirhead's paper, and he thought it was a most interesting and important contribution to this particular section of mechanics. Like Mr Bamford, however, he was somewhat doubtful as to whether this method of substitution would obtain any preference over the common methods usually employed for the ordinary run of engineering calculations. As a rule, momental calculations were associated with section-areas, and the necessary moment of inertia, or the radius of gyration, could be usually got from a table. He thought if Dr. Muirhead had given a few more examples, and worked these out by his method, and the most suitable alternative methods, that a clearer idea of the relative values of the equimomental system over other possible ones could have been obtained. He (Mr Goudie) found that three of the examples given, when contrasted with suitable alternative methods that would naturally be employed, did not reveal any particular advantage in favour of the method of substitution. He would prefer to solve Example 1 in the following manner:—

Dividing Fig. 11 into two triangles and a rectangle, then

1st moment of the two triangles about $WL = 2\ (2 \times 3{\cdot}66)$

1st „ „ rectangle „ „ $= 4 \times 4$

2nd „ „ two triangles „ „ $= \dfrac{2 \times 2 \times 2^3}{36} + 4 \times (3{\cdot}66)^2$

2nd „ „ rectangle „ „ $= \frac{1}{12} \times 2 \times 2^3 + 4 \times 4^2$

$$\therefore D = \frac{{\cdot}89 + 53{\cdot}58 + 1{\cdot}33 + 64}{30{\cdot}64} = \frac{119{\cdot}8}{30{\cdot}64} \doteqdot 3{\cdot}9 \text{ ft.}$$

Comparing this solution with the one given on page 410, there seemed to be nothing to choose between the two methods, as far as amount of calculation was concerned, but the method he (Mr Goudie) had employed possessed this advantage, that the preliminary disposition of area-elements was avoided. In Example 3, the substitution method applied was obviously not the most expeditious one that could be adopted. In addition to a preliminary distribution of six area-elements, there were six distinct tabulations and sets of calculations, as compared with three sets by the ordinary method, in which the moments of the upper flange, the web, and the lower flange were taken without any preliminary distribution at all. With regard to Example 4, it seemed to him that, by taking the known moment of inertia of each cylinder and applying the standard theorem already used in Example 3, the solution could be carried out in the time it would take to locate the twelve mass-elements on the skeleton diagram, Fig. 15A. The problem was rather an unlikely one from the mechanical engineer's point of view, but if he had to solve it he would do so as follows:—

Let M_1 = mass of the large cylinder.

M_2 = „ „ small „

l_1 = length „ large „

l_2 = „ „ small „

$$\text{Mass ratio} = \frac{M_1}{M_2} = \frac{30^2 \times 8}{16^2 \times 12} = \frac{2{\cdot}343}{1}. \quad \text{Then}$$

$$I_{(axis)} = M_1\frac{l_1^2}{12} + M_1\left(l_2 + \frac{l_1}{2}\right)^2 + M_2\frac{l_2^2}{3}, \text{ so that}$$

Mr W. J. Goudie, B.Sc.

$$k^2 = \frac{2{\cdot}343\ M_2 \left\{ \frac{l_1^2}{12} + \left(l_2 + \frac{l_1}{2} \right)^2 \right\} + M_2 \frac{l_2^2}{3}}{3{\cdot}343\ M_2}.$$

$$= \frac{2{\cdot}343 \left\{ \frac{64}{12} + 256 \right\} + \frac{144}{3}}{3{\cdot}343}$$

$$= 248{\cdot}7$$

$$\text{and } k = \sqrt{248{\cdot}7} = 15{\cdot}77 \text{ inches.}$$

He had given the preliminary algebraic expression, so that in the arithmetical portion the figures could be clearly followed; but in actual work this would be dispensed with, and the value of k^2 would be written down directly. Comparing the arithmetical portion with the solution given on page 415, it would be seen that his method entailed much less figuring and liability to error, since the numerator consisted of two terms as against six in the solution on that page. It was, perhaps, not quite correct to reason from the particular to the general, but from the standpoint of the practical calculator he thought that, if these three cases could be taken as indicative of the comparative merit of the equimomental and the common methods used in every day work, the former did not appear to offer much advantage as far as the saving of time and labour was concerned, and it would probably be reserved for special classes of problems where there was a difficulty in applying ordinary rules, as, for instance, where moments had to be taken about axes which were not principal axes of the figure or axes parallel to these. Apart from this aspect of the question, he thought Rules VII. to XII. would be handy as a check on the memory when the moment of inertia of the triangle, the rectangle, the circle, and the annulus, had to be applied in a calculation. For example, when dealing with shafts one was apt to confuse the moment of inertia about an axis in the plane of the section, with the polar moment of inertia or second moment about an axis perpendicular to the plane, and it was an easy matter to remember from Rule X. that the area-coefficient for the circular section was one-eighth, so that

$$I_{(polar)} = 4 \times \frac{A}{8}\left(\frac{D}{2}\right)^2$$

$$= \tfrac{1}{2}\frac{\pi}{4}\ D^2\ \frac{D^2}{4}$$

$$= \frac{\pi}{32}\ D^4,$$

which showed at once whether the value for the denominator was 32 or 64. Other applications would no doubt suggest themselves. He noticed that the mass and area-coefficients were given as vulgar fractions throughout. In Rule XIII., it would be better to simplify the bracketed quantities and give the area equivalents as $\frac{M}{8}$, $-$ ·023M, ·697M, ·075M. He thought that the value of the paper would be much enhanced if Dr. Muirhead would include Routh's rule, and indicate the general method of arriving at the results which he had embodied in these fourteen cases, showing its application, say, to the cylinder, Case II., and to the uniform semicircular lamina or area, Case XIII., for which three alternative results were given.

Professor Andrew Jamieson (Member), thought that if Dr. Muirhead gave the best mathematical proofs of how the masses were subdivided and allocated in Cases I., II., V., and a triangle. his excellent paper would form a still more valuable contribution to the Transactions.

Correspondence.

Prof. George A. Gibson stated that Dr. Muirhead had given one application to centres of pressure, and he ventured to give another. No doubt, so far as the daily needs of the engineer were concerned, the shapes of the areas for which the position of the centre of pressure was required were usually simple, but there was always a certain interest in extending a rule so as to include as many cases as possible in one statement. It might be noted that Case VIII., in the paper, included not only, as Dr. Muirhead stated, IX. and XII., but also VII. (ii.). The application he wished to make was to the problem of finding the depth of the centre of pressure of a quadrilateral ABCD, wholly immersed in a liquid. Let the depths of the vertices be a, b, c, d, respectively, the depth of the centroid g, and the depth of the point of intersection of the diagonals e; then by VIII., the depth of the centre of pressure was (putting M equal to 12 for convenience):—

$$\frac{a^2 + b^2 + c^2 + d^2 - e^2 + 9g^2}{a + b + c + d - e + 9g}.$$

$$\text{But } g = (a + b + c + d - e)/3 = (s - e)/3$$

where,

$$s = a + b + c + d.$$

When this value of g was substituted, the expression for the depth became

$$\frac{a^2 + b^2 + c^2 + d^2 + s^2 - 2es}{4\,(s - e)},$$

a result which was, of course, well known, but which could be readily obtained or recalled by following this method of demonstration. The familiar expressions for the depth of the centre of pressure, when the area was a triangle, a rectangle or a trapezium were easily obtained. Thus, if the quadrilateral were a trapezium, with the side AB in the surface of the liquid, one might put

$$a = o = b, \; c = d, \; s = 2c,$$

and if $AB = m$, $CD = n$, then

$$e = \frac{mc}{m + n}.$$

With these values, the expression for the depth became

$$\frac{m + 3n}{m + 2n} \cdot \frac{c}{2}.$$

If $m = n$, the trapezium became a parallelogram, and the depth was $\frac{2}{3}c$. For a triangle, with its base in the surface, one might put $n = o$; if the vertex was in the surface, and the base parallel to the surface, m might be put $= o$. The approximate formulæ XIII. (ii.) and (iii.) were of special interest, and the paper, as a whole, seemed to him to be of considerable value for the purposes the Author had in view.

Dr. MUIRHEAD, in reply, said, before referring to details, he wished to thank his hearers for the patience with which they had listened to his remarks on a somewhat dry topic, and to express pleasure at finding that he had several interested critics well acquainted with the subject. His sense of the value of these criticisms would be best attested by the fact that he had made some alterations in the paper as printed in the advanced proofs and as read at the meeting, to meet these criticisms. To Mr Bamford he owed the dectection of an oversight by which he had omitted equality of *mass* as one of the necessary conditions that two things should be equimomental. To Mr Goudie he was indebted for the suggestion that the numbers in XIII. (i.) should be given in decimals. This he thought was a decided improvement. In this connection he was glad to note that Mr Goudie did not insist upon ·125 being substituted for $\frac{1}{8}$, though he had known some practical calculators who insisted on putting every numeric into decimals, even when time and accuracy were both manifestly being sacrificed. As De Morgan pointed out at a time when decimal fractions were less in fashion than now, there were occasions when decimals were most appropriate, and others when vulgar fractions ought to be used; and the expert calculator would show his skill in choosing the best means to the end he had in view. The common-sense rule would seem to be that that kind of fraction should be used which would most expeditiously furnish the result of the required degree of accuracy. But this was by the way. If he had not availed himself of the criticisms, in altering the paper further, it was not that he ignored the value of the suggestions made, but that to give effect to them would carry him beyond his proper subject as indicated by the title. To avoid misconception he would say that he did not by any means consider that all, or even the majority of moment problems ought to be attacked by the method of equimomental point-systems. That was one of several methods that could be applied, and the calculator who had mastered it would have one more weapon at his command, and one which at times could be used with great effect, As for a comparison of methods, such as Mr Goudie aimed at drawing in one or more cases, he doubted if that could be fairly accomplished except by a calculator, expert in both methods, working out the same problem both ways, and timing himself. A comparison of the figures put down in an example for explanation was inconclusive, since they would be different from what a practical calculator would find expedient. It might be pointed out, however, that in cases when first as well as second moments were required, some economy was effected in using a Table as in Example 3, by the fact that each item of the *second moment* column was derived from the corresponding *first moment* item by simply multiplying it by the *distance*. Again checking was facilitated by comparing the total *area* and of *first moment* with the results of more direct methods for these. Some of his friendly critics again had suggested that proofs might be given. This, however, would be quite beyond the scope of the paper, and was unnecessary, as the methods for calculating moments, and many of the results, were given in the ordinary textbooks of applied mechanics. It was otherwise with regard to methods of discovering a simple, or the simplest possible equimomental point-system for a given body or figure; but here no general rule could be given, though certain transformations and points of view had repeated application to such problems. But the very absence of any rule made the problem an attractive one. It was true that theory showed that in all cases it was possible to assign a system of four* equal point-masses which should be equimomental to any given body,

* Or three in the case of a plane figure or lamina.

and that in an infiite number of ways; but in most cases these four points would not be simply related to the salient points or lines of the figure, so that a greater number of point-masses, and these not always equal, might form a better system for calculating purposes. To return once more to points of detail. Professor Gibson's remark that VII. (ii.) was included under VIII. as a special case, was interesting and, when pointed out, obvious, and very much to the point. The formula he gave for the depth of centre of pressure of the quadrilateral, with its special cases, was also very neat and interesting, though its neatness was more algebraic than geometrical. Of course to some minds a formula was preferable to a diagram; and both ought to be provided by mathematicians for the use of calculators.

On the motion of the President, Dr. Muirhead was awarded a vote of thanks for his paper.

SMOKING CONCERT.

The Members of the Institution and their friends met at a "smoker" in the Banqueting Hall of the Grosvenor Restaurant, Glasgow, on the evening of Friday, 13th October, 1905. Mr James Gilchrist, President, occupied the chair. Previous to the concert, a reception was held in an adjoining room set apart for the purpose. The toast of "The King" was followed by an excellent programme, well rendered by local artistes. The company numbered about 400.

CONVERSAZIONE AND EXHIBITION.

In connection with the Institution a conversazione was held in St. Andrew's Halls, Glasgow, on Friday evening, 10th November, 1905. About 1100, ladies and gentlemen, attended the function, many of the leading shipbuilders and engineers on the Clyde and elsewhere being present. Members and their friends were received by Mr James Gilchrist, President, Miss Gilchrist, and the Members of Council.

In the earlier part of the evening a promenade concert took place in the Grand Hall; while the latter part of the evening was devoted to dancing. A cinematograph display took place at intervals during the concert and between the dances.

Many interesting models and apparatus were exhibited in the Berkeley Hall, and evoked general admiration.

THE "JAMES WATT" ANNIVERSARY DINNER.

THE "JAMES WATT" ANNIVERSARY DINNER, under the auspices of the Institution, was held on Friday evening, 19th January, 1906, in the Grosvenor Restaurant, Gordon Street, Glasgow. There was a large and representative gathering, the company numbering upwards of 400 gentleman. Mr James Gilchrist, President of the Institution, was in the chair, and the croupiers were Messrs. E. Hall-Brown, Andrew Laing, and A. D. Wedgwood, Vice-Presidents of the Institution. At the Chairman's table were—The Hon. The Lord Provost, Mr William Bilsland; The Right Hon. Lord Inverclyde; Sir John Ure Primrose, Bart., LL.D.; Mr Nathaniel Dunlop; Dean of Guild Robert King; Bailie J. Bruce Murray; Mr James Weir; Deacon-Convener James Kirkwood; Admiral W. Wilson, R.N.; Mr A. Gracie; Mr J. M. Munro, President, Glasgow Section, Institution of Electrical Engineers; Mr James Howden; Rev. P. Macadam Muir; Capt. J. G. Heugh, D.S.O., R.N.; Mr L. MacBrayne; Prof. A. Barr, D.Sc.; Mr. R. T. Moore, D.Sc., President of the Mining Institute of Scotland; Mr John Ward; Mr David Colville; Mr A. Bilsland; Mr A. W. Sampson; Mr Thomas Russell, J.P., D.L.; Mr W. M. Alston; Mr T. R. MacKenzie; Mr Robert Caird, LL.D.; Mr J. Peacock; Mr John Keppie, President of the Glasgow Institute of Architects; Mr Anderson Rodger; Mr Henry Mechan; Mr William Brown; Mr Joseph Barrow; Colonel William Shanks, and Mr J. R. Richmond.

Letters of apology for absence were intimated from the Marquis of Ailsa, the Marquis of Linlithgow, the Marquis of Graham, the Earl of Glasgow, Lord Armstrong, Lord Overtoun, Sir John Stirling-Maxwell, Admiral Sir John Fisher, Sir Philip Watts, F.R.S., Sir Alexander Binnie, Mr John Sinclair, M.P., Mr C. Scott Dickson, K.C., and others.

Professor D. C. M'Vail.

The loyal toasts having been honoured,

Professor D. C. M'Vail proposed "The Imperial Forces." In doing so he drew attention to the fact that in the army and navy alone the staff were of two classes, that of the common soldier and common sailor who might become sergeants or petty officers but could not become commissioned officers, while in all other departments of life—engineering, shipbuilding, law, medical life—every lad who entered it had a marshal's baton in his knapsack. The army could never hope to obtain the services of the best classes of the community until the highest positions were open to every recruit. Recently there was talk of training soldiers for trades—joiners, shoemakers, etc. The true course was to train every soldier to be a soldier, every soldier that he might become an officer, and that every barrack should be a military college. Then the best of the younger men of the country would look on the army with the same favour with which they looked on engineering, commercial, or professional life.

Admiral Wilson, R.N., in replying, said that on the Clyde eight large warships, including two battleships, four first-class cruisers, and two scouts, had been completed during the year. He was glad to say that those eight ships had been immediately put into commission, and after leaving the Clyde they went straight to sea, instead of passing a period in one or other of the Royal Dockyards as had hitherto been the case. The engineers and shipbuilders on the Clyde should be congratulated on the results. What would happen in the future he could not tell, because it was all confidential. Everyone knew what was happening at present, but nobody could mention anything beyond the fact that there were four vessels building in four different yards on the river. He did not, however, suppose that they were likely again to finish eight ships in one year.

The toast of "James Watt" having been honoured in silence, the company standing, the Secretary stated that he had received the following message from the engineers assembled in Tokio the same day to honour the memory of Watt in a similar mannner:—

"From the Far East we greet you on the anniversary of the birthday of James Watt. As fellow-sharers in the benefits of his genius and activity we rejoice with you. May the bequests which we have together received from him continue to bind us closer in cordiality and urge us to mutual assistance."

To this message the following reply was cabled:—

> "We, the Engineers and Shipbuilders in Scotland, send hearty greetings to our confrères in Tokio on the anniversary of the birthday of James Watt, and congratulate our professional brethren in the Far East in sharing the fruits of Watt's discoveries and inventions. We also hope that succeeding generations of the peoples of the island homes of Japan and Britain may enjoy increasing comforts and privileges as the 'future miracles of mechanical power,' of which Watt laid the foundation, are harnessed for their behoof; and that they may be bound by ties of friendship and goodwill stronger even than exist between the two nations to-day."

Lord INVERCLYDE proposed "The City of Glasgow," remarking that they had with them for the first time the Lord Provost of the city and the chairman of the Clyde Trust as different officials. Referring to the speech of Admiral Wilson, Lord Inverclyde said he had come to the conclusion that the Admiral's place was in the House of Commons, for it was the first quality of a statesman to be able to make a speech and tell his audience nothing at all.

The Lord Provost briefly replied.

Mr NATHANIEL DUNLOP proposed "Engineering and Shipbuilding Industries." One engaged as he had been for more than half a century in the shipping of the Clyde, who had seen its rise and progress, should, he said, know something of what the country and the civilised world owed to James Watt, and to James Watt's successors. If the dwellers on Clydeside were still adherents of the cult of the ancients they would have built a temple to James Watt and worshipped him as a divinity. They did the next nearest to this when they, his kindred by profession, held anniversary festivals to his immortal memory. One often

Mr Nathaniel Dunlop.

wished it were permitted to the great men of the past to revisit the scenes of their early struggles and triumphs and to see to what they had led. If Livingstone could have but seen the Zambesi spanned at the Victoria Falls by a bridge forming part of a railway route from Cape to Cairo, its opening ceremony performed by the British Association, or if Watt could but got a glimpse of the engineering and shipbuilding industries upon the Clyde and the fleets that churned our river and traversed our ocean routes, with what amazement they would be filled, with what gratitude they would be stirred that they should have been instrumental in doing so much for mankind as had resulted from their labours and their genius. But these results could only have been achieved by the help of their successors, and he claimed for Clyde engineers and shipbuilders and their great industries the foremost place not in the nation only, but in the world. It might be that they had some qualms about the future—even the near future—fearing that their rivals on the Continent or across the seas might overtake, or even pass them in the race; but at present they held the lead, and with a fair field and no favour they need fear no rivals in the days to come. Would that they could count upon a fair field and no favour. One was almost tempted in the heated political atmosphere of the day to ask if it was certain that the men who were to be their legislators for a turn quite understood the needs of the situation, and were taking the proper line to preserve the position this country now held. In the earlier steamers of his firm, so little confidence was placed in steam propulsion that they made them full-rigged ships, and fitted them with lifting screws, so that when the engines broke down the propellers could be taken out of the water and sails resorted to. He wondered what modern engineers would think of such a suggestion to-day. Not only could they make reliable machinery, but they were ready to devise and provide new methods of propulsion to the enterprising shipowner. If he preferred turbines, they would make for him turbines. They would even, if he wished it, get rid of steam altogether and find him a new motive power. There was no limit to their ingenuity.

Dr Robert Caird replied, referring to the enterprise of the two companies represented there by Mr Dunlop and Lord Inverclyde, in applying the marine steam turbine to the prosulsion of Atlantic steamships.

Sir John Ure Primrose, Bart., in proposing "The Institution of Engineers and Shipbuilders in Scotland," said that, great and beautiful as the old days were, the present days were worth a thousand of them. He did not believe for a moment that Britons would be laggards in the race. It was born in their blood to be a countable factor in the destinies of the world.

The Chairman replied, referring specially to the history of the Institution and to the coming removal to more commodious premises. They had, he said, been fortunate in securing premises in the centre of the city, and they hoped to erect there a building which would be a credit to the Institution and an ornament to the city. The sum aimed at was £25,000, and as next year was the Jubilee of the Institution it would, he thought, be fitting if the celebration were held in the new premises, and particularly so if the premises were opened free of debt.

During the evening an interesting programme of vocal and instrumental music was submitted.

SMOKING CONCERT.

On Friday evening, 6th April, 1906, the second smoking concert of the session was held in the Banqueting Hall of the Grosvenor Restaurant, Glasgow. The programme was informal throughout, and Mr Mechan, who occupied the chair, called on the artistes at random.

The meeting was a great success and much enjoyed by all present. The company numbered 380.

MINUTES OF PROCEEDINGS.

FORTY-NINTH SESSION.

THE FIRST GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 24th October, 1905, at 8 p.m.

Mr JAMES GILCHRIST, President, was introduced to the Meeting by Mr JOHN WARD, Vice-President, and took the Chair.

The Minutes of the Extraordinary General Meeting, held on 23rd May, 1905, having been printed in the billet calling the Meeting, were held as read, and signed by the President.

ANNUAL REPORT OF THE COUNCIL.

The President said the Council had pleasure in submitting the Annual Report, and called upon Mr THOMAS KENNEDY to move its adoption.

Mr THOMAS KENNEDY, in moving the adoption of the Report, said he could add nothing by way of comment, but he was very glad to see such an improvement in the finances of the year, and he hoped it would continue.

Mr F. J. ROWAN seconded the motion for the adoption of the Report which, he thought, was an interesting record of the progress of the Institution.

Prof. ANDREW JAMIESON was exceedingly glad to see that during the past year the Institution had spent £50 on the best scientific books. As one of the most constant readers in the Library, he thought the Members might congratulate themselves upon the very good selection of books added to the Library during the past year. He trusted that the Library Committee would give every possible consideration to books proposed by Members of the Institution.

The President remarked that the Library Committee had been very zealous in the past in trying to further the objects to which Prof. JAMIESON had so kindly referred.

The motion for the adoption of the Report, on being put to the Meeting, was unanimously agreed to.

The new Members elected at the previous meeting were duly admitted.

PREMIUM OF BOOKS.

Mr J. G. JOHNSTONE, B.Sc., was presented with the books awarded for his paper on "The Uses of the Integraph in Ship Calculations," read during Session 1903-04.

Thereafter the President delivered his Inaugural Address. On the motion of Mr D. C. HAMILTON, the President was awarded a vote of thanks for his Address.

A paper was read by Mr E. M. SPEAKMAN on "The Determination of the Principal Dimensions of the Steam Turbine, with Special Reference to Marine Work."

The discussion on Mr SPEAKMAN'S paper was begun and adjourned.

The following candidates were duly elected:—

AS MEMBERS.

ALEXANDER, JOHN, Engineering Draughtsman, 31 Kelvingrove Street, Glasgow.

BELSEY, WALTER JAMES, Electrical Engineer, 91 Wellington Street, Glasgow.

BOAK, WILLIAM, Consulting Engineer, Messrs. Delmege, Forsyth & Co., Colombo, Ceylon.

EWING, GEORGE HAWKSBY, Engineer, Messrs. Ewing & Lawson, Ltd., Crownpoint Boiler Works, Glasgow.

FARNELL, ALFRED HENRY, Civil Engineer, Moorfield, Lenzie.

GRAY, Prof. ANDREW, LL.D., F.R.S., The University, Glasgow.

MORT, WILLIAM, Engineer, 41 Hamilton Terrace, W., Partick.

PARK, FRANKLIN ATWOOD, B.Sc., General Manager, The Singer Manufacturing Co., Kilbowie, Clydebank.

PARKER, GEORGE GLADSTONE, Naval Architect, Rossbank, Port-Glasgow.

SWANN, WILLIAM, Consulting Engineer, Messrs. Findlay & Co., Manilla, P.I.

From Students.

DICKIE, DAVID W., Naval Architect, 1 Alleyne Terrace, Quincy, Mass., U.S.A.

SIBBALD, THOMAS KNIGHT, Engineer, Messrs. Cook & Son, Ltd., Cairo, Egypt.

STEVEN, DAVID M., Marine Engineer, 9 Princes Terrace, Dowanhill, Glasgow.

AS ASSOCIATE MEMBERS.

BALLANTYNE, HUGH D., Engineering Draughtsman, Rose Cottage, Kilbirnie.

CALDWELL, JAMES, Electrical Engineer, 157 West George Street, Glasgow.

LANE, FRANK C., Inspector of Hulls, The Customs Service of the Philippine Islands, Iloilo.

LAIRD, ALEXANDER, Engineer Draughtsman, 172 Pitt Street, Glasgow.

LITTLE, JOHN PATERSON, Engineering Draughtsman, 100 Forth Street, Pollokshields, Glasgow.

MARTIN, GEORGE HOWE, Engineering Draughtsman, c/o Macfarlane, Strathend House, Strathleven Place, Dumbarton.

RANKEN, JOHN, Engineering Draughtsman, Fernlea, Wilson Street, Motherwell.

From Students.

HOLMES, JAMES, Engineer, c/o Robertson, 25 St. James Street, Paisley.

SHARPE, WILLIAM H., B.Sc., Engineer, Engineer's Office, Natal Government Railway, Pietermaritzburg, Natal.

WARD, GEORGE K., Shipbuilder, Garmoyle, Dumbarton.

WARD, JOHN Jun., Engineer, Garmoyle, Dumbarton.

AS STUDENTS.

AOYAGI, J., Apprentice Shipbuilder, c/o Minigle, 4 Bouverie Street, Yoker.

BERG, WILLEM E. G., Engineer Draughtsman, Avon Street, Motherwell.

DUFF, GORDON ALISON, B.Sc., Apprentice Engineer, c/o Donaldson, 99 Clarence Drive, Hyndland, Glasgow.

McLACHLAN, DAVID FARMER, Ship Draughtsman, 8 Highburgh Road, Hillhead, Glasgow.

MALCOLM, WILLIAM, Engineering Draughtsman, c/o Miller, 3 Hayburn Crescent, Partickhill, Glasgow.

MILLAR, DAVID C., Ship Draughtsman, 28 White Street, Partick.

ORMISTON, JAMES SIMON, Ship Draughtsman, 18 Percy Street, Paisley Road, W., Glasgow.

ROTHWELL, JAMES E. Student of Engineering, 2 Florentine Place, Hillhead, Glasgow.

WHADCOAT, HENRY CECIL, Engineer Apprentice, 130 Nithsdale Road, Pollokshields, Glasgow.

An Extraordinary General Meeting was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 21st November, 1905, at 7-45 p.m.

Mr James Gilchrist, President, occupied the Chair.

The Secretary read the circular which he had issued to the Honorary Members, Members, Associate Members, and Associates. Its terms were:—

"NOTICE IS HEREBY GIVEN that an Extraordinary General Meeting of the Institution of Engineers and Shipbuilders in Scotland will be held within the Hall at 207 Bath Street, Glasgow, on Tuesday, 21st November, 1905, at 7-45 o'clock p.m., for the following purposes, viz.:—

"(1) To consider and, if approved, to confirm a Minute of Agreement entered into on behalf of the Institution and the Royal Philosophical Society, dated 2nd and 4th October, 1905, whereby the Institution has agreed, *inter alia*, to sell its interest in the property at 207 Bath Street, Glasgow (excepting books, etc., as mentioned in the Agreement), at the price of £4000, with entry at Martinmas, 1905, and to take on Lease for two years from Martinmas, 1905, at a rent of £100 per annum and a payment of £120 per annum in respect of cleaning, heating, lighting, etc., the premises mentioned in the said Agreement. The said Agreement, and the relative letters between the Agents of parties of 12th and 24th October, 1905, will be submitted and read and explained at the meeting.

"(2) To consider the report of the Committee appointed by the Council to look for premises for the Institution; to consider the recommendation of the Council to acquire certain property for the Institution; and to confirm that recommendation and to authorise the Council accordingly.

"(3) To consider and dispose of any other competent business."

By order of the Council,

Edward H. Parker, *Secretary*.

The President made a statement as to the negotiations with the Philosophical Society, and thereafter the Secretary read the Agreement and letters mentioned in the circular calling this meeting. On the motion of Mr Ward, seconded by Mr Hogg, it was unanimously resolved that the Agreement and letters submitted be, and the same are hereby, adopted and confirmed; that the Council be, and they are hereby, authorised to sell the interest of the Institution in the property, 207 Bath Street, Glasgow, on the terms mentioned in the said Agreement and letters, and to take all necessary steps for completing the sale and obtaining the lease stipulated for in the said Agreement.

The President then explained the steps which had been taken by the Committee appointed by the Council to look out for premises for the Institution, and that after carefully considering the matter the Council recommended that the property, forming Nos. 33 and 35 Elmbank Street and 39, 40, and 41 Elmbank Crescent, be acquired for the Institution. A survey plan showing this property and the present premises of the Institution in red and blue respectively, was exhibited, and explanations were made. Thereafter, on the motion of Mr Alston, seconded by Mr Kennedy, it was unanimously resolved that the steps taken by the Committee appointed by the Council to look out for premises be approved, that the recommendation of the Council as to acquiring the subjects forming Nos. 33 and 35 Elmbank Street, and 39, 40, and 41 Elmbank Crescent, be adopted, and that the Council be, and they are hereby, authorised to purchase the said subjects, at a price not exceeding £5,300, upon such conditions as the Council may approve, and subject to there being no restrictions interfering with the purposes of the Institution, and to the title being approved by the Law Agents.

On the motion of Mr R. T. Napier, the meeting passed a vote of thanks to the President and Council for their labours on behalf of the Institution; and the President acknowledged the vote.

THE SECOND GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 21st November, 1905, at 8-15 p.m.

Mr. JAMES GILCHRIST, President, occupied the Chair.

The Minutes of the General Meeting, held on 24th October, 1905, having been printed in the billet calling the Meeting, were held as read, and signed by the President.

The new Members elected at the previous meeting were duly admitted.

The discussion on Mr. SPEAKMAN'S paper on "The Determination of the Principal Dimensions of the Steam Turbine, with Special Reference to Marine Work," was resumed and concluded.

On the motion of the President, Mr. SPEAKMAN was awarded a vote of thanks for his paper.

The following Candidates were duly elected:—

AS MEMBERS.

DUNDAS, DAVID, Engineer, Messrs. A. Watson & Co., 36 George Street, Glasgow.

FERGUSON, JOHN, Civil Engineer, 160 Hope Street, Glasgow.

MILLER, HUGH, Shipyard Manager, 67 Danes Drive, Scotstoun, Glasgow.

NAPIER, JOHN STEWART, Engineer, Herbertshire, Meiklebriggs, Paisley.

O'CONNOR, OWEN M'DONALD, Engineer, Curepipe, Mauritius.

STIRLING, JOHN, Engineer, Beechwood Villa, Drive Road, S. Govan.

WINNING, WILFRID LAWSON, Electrical Engineer, 99 Queensborough Gardens, Hyndland, Glasgow.

AS ASSOCIATE MEMBERS.

BAIRD, THOMAS H., Engineer Draughtsman, 12 Berkeley Terrace, Glasgow.

BROWNLIE, MATTHEW, Engineer Draughtsman, Meadowpark, Strathaven.

CAMERON, JOHN, Engineer Draughtsman, 29 White Street, Partickhill, Glasgow.

FOULIS, WILLIAM, Engineer, 2 Montgomerie Quadrant, Kelvinside, Glasgow.

GUTHRIE, WILLIAM ORROK, Engineer Draughtsman, 4 Crown Circus Road, Glasgow, W.

HERON, JOHN MURDOCH, Ship Draughtsman, 4 Merchiston Avenue, Edinburgh.

HOGARTH, ALEXANDER, Engineer Draughtsman, 1 Tantallon Terrace, Ibrox, Glasgow.

M'FARLANE, DUNCAN A., Engineer Draughtsman, 9 Dunolly Gardens, Ibrox, Glasgow.

MCHARDY, WALLACE BRUCE, Engineer Draughtsman, Flakedale, Hamilton.

PATERSON, GEORGE, Engineer Draughtsman, 27 White Street, Partick.

STEWART, ALEXANDER WALKER, Ship Draughtsman, 41 Comely Bank Avenue, Edinburgh.

STOTT, JOHN, Engineer Draughtsman, 103 Stevenson Drive, Shawlands, Glasgow.

THOMSON, JAMES, Jun., Engineer Draughtsman, 2 Glenavon Terrace, Partick.

TILLOTSON, FRANK, Engineer Draughtsman, 8 Woodlands, Albert Road, Langside, Glasgow.

YAMAKAWA, KIICHIRO, Ship Draughtsman, 8 Sutherland Drive, Hillhead, Glasgow.

AS STUDENTS.

BROWN, ANDREW, Apprentice Engineer, 7 Whittingehame Gardens, Glasgow.

HALKET, JAMES PITCAIRN, Jun., Apprentice Engineer, 7 Clydeview, Partick.

HENNINGSEN, SVEND, Student of Naval Architecture, c/o Ross, 136 Woodlands Road, Glasgow.

LINKLATER, VALDEMAR M'LELLAND, Ship Draughtsman, 20 Netherby Road, Trinity, Edinburgh.

TENNET, WILLIAM WHALEY, Apprentice Engineer, 155 Hyndland Road, Kelvinside, Glasgow.

WHITEHEAD, JOHN, B.Sc., Mechanical Engineer, Howford, Mânsewood, Pollokshaws, Glasgow.

THE THIRD GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 19th December, 1905, at 8 p.m.

Mr JAMES GILCHRIST, President, occupied the Chair.

The Minutes of the General Meeting, held on 21st November, 1905, having been printed in the billet calling the Meeting, were held as read, and signed by the President.

The new Members elected at the previous meeting were duly admitted.

A paper by Mr R. M. NEILSON on "The Evolution and Prospects of the Elastic Fluid Turbine" was read.

The discussion on Mr NEILSON'S paper was begun and adjourned.

A paper by Mr W. J. GOUDIE, B.Sc., on "The Application of Calculating Charts to Slide-Valve Design" was read.

Thereafter Mr W. C. MARTIN exhibited the Frahm Speed Indicator, and explained its action; and on the motion of the PRESIDENT, Mr Martin was awarded a vote of thanks for his exhibition of the instrument.

The following Candidates were duly elected:—

AS MEMBERS.

ANDREW, DAVID, Jun., Engineer, 116 Hope Street, Glasgow.

DOBBIE, JOHN GOURLAY, Superintendent Engineer, 203 West George Street, Glasgow.

MELLANBY, *Prof.* ALEXANDER LAWSON, D.Sc., Technical College, 204 George Street, Glasgow.

RANKIN, RICHARD LEES, Founder, Norwood, Balloch.

STOTHERT, JOHN KENDALL, Engineer, Messrs. Babcock & Wilcox, Ltd., St. Vincent Place, Glasgow.

TAINSH, JOHN A. G., B.Sc., Engineer, Messrs. Biles, Gray & Co., 175 West George Street, Glasgow.

WRAY, WILLIAM J. R., Electrical Engineer, 175 West George St., Glasgow.

AS ASSOCIATE MEMBERS.

BUCHANAN, GEORGE HAMILTON, Locomotive Draughtsman, 1 Wellfield Terrace, Springburn, Glasgow.

ELLIOTT SIMPSON, Engineer Draughtsman, 122 Darnley Street, Pollokshields, Glasgow.

M'MILLAN, THOMAS, Locomotive Draughtsman, 5 Balgray Hill, Springburn, Glasgow.

MARSHALL, JAMES EADIE, Marine Engineer, 18 Patrick Street, Greenock.

From Students.

SIMPSON, ADAM, Engineer, 12 Rupert Street, Glasgow.

AS AN ASSOCIATE.

M'LINTOCK, FINLAY, Director of Messrs. Sharp & Co., Iron Founders, Fisherwood, Balloch.

AS STUDENTS.

BRUCE, WILLIAM ROSS, Engineer, Oaklea, Hawkhead Road, Paisley.

CROMBIE, JOHN WALLACE, Apprentice Engineer, c/o Turnbull, 25 Iona Place, Mount Florida, Glasgow.

HILL, GERARD LEADER, Student of Naval Architecture, 4 Thornwood Terrace, Partick.

OLSEN, HAROLD M., Student of Naval Architecture, 37 Smith Street, Hillhead, Glasgow.

POLLARD HENRY, Engineer, Eaglehurst, Douglas, I.O.M.

RUSSELL, THOMAS, Engineering Draughtsman, Kilkerran, Greenock Road, Paisley.

WILLETT, EDWARD V. A., Student of Naval Architecture, 68 Lauderdale Gardens, Hyndland, Glasgow.

THE FOURTH GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 23rd January, 1906, at 8 p.m.

Mr JAMES GILCHRIST, President, occupied the Chair.

The Minutes of the General Meeting, held on 19th December, 1905, having been printed in the billet calling the Meeting, were held as read, and signed by the President.

The new Members elected at the previous meeting were duly admitted.

The President intimated that an invitation had been received from the American Philosophical Society, which read as follows:—

> "The American Philosophical Society has the honour to invite the Institution of Engineers and Shipbuilders in Scotland to be represented at the celebration of the Two Hundredth Anniversary of the birth of its founder, Benjamin Franklin, to be held in Philadelphia on April 17th, 18th, 19th, and 20th, 1906."

Thereafter, the Conveyance by the Institution in favour of the Royal Philosophical Society of Glasgow, which had been prepared in terms of the Agreement come to between the Institution and the Society, was submitted. The Conveyance was held as read, and it was resolved that the Agreement should be executed by the Institution, and the Meeting authorised, and hereby authorise, Mr JAMES GILCHRIST, President, Mr ARTHUR D. WEDGWOOD, Vice-President (two Members of the Council), and the Secretary, to sign the Conveyance, and to adhibit the Seal of the Institution to the Conveyance for, and in name, and on behalf of the Institution; which was accordingly done in presence of the meeting.

The discussion on Mr NEILSON's paper was resumed and concluded.

On the motion of the President, Mr NEILSON was awarded a vote of thanks for his paper.

The discussion on Mr W. J. GOUDIE's paper on "The Application of Calculating Charts to Slide-Valve Design," was postponed.

Thereafter, the Secretary read a paper by Mr JAMES HOWDEN on "The Screw Propeller Controversy."

The following candidates were duly elected:—

AS MEMBERS.

BELL, JOHN HART, Engineer, Messrs. Cochran & Co., Annan.

FLETCHER, ANDREW, Engineer, Hoboken, New Jersey, U.S.A.

GRIFFITH, EDWIN, Engineer, Manager, 36 Finnieston Street, Glasgow.

LONDON, WILLIAM J. A., Chief Engineer, British Westinghouse Works, Trafford Park, Manchester.

REID, ROBERT W., Marine Engineer, 958 Sauchiehall Street, Glasgow.

SCOTT, ALLAN, Engineer, Messrs. Chambers, Scott & Co., Engineers, Motherwell.

WARNOCK, THOMAS F., Consulting Engineer, 274 Bath Street, Glasgow.

WRIGHT, ROBERT, Superintendent Engineer, Sir John Rogerson's Quay, Dublin.

AS ASSOCIATE MEMBERS.

CUMMING, FINDLAY M., Marine Engineer, 4 Smithhills, Paisley.

GRIEVE, JOHN, Engineer Draughtsman, Burnbrae, Miller Street, Hamilton.

JANSON, JOSEPH W., Engineer Draughtsman, 83 Hyndland Street, Partick.
OLIVER, GORDON BERNARD, Naval Architect, St. Martins, Whittingehame Drive, Glasgow.
TODD, JOSEPH, Engineer, c/o Moffat, 104 Bothwell Street, Glasgow.

From Students.

BARNWELL, FRANK S., Elcho House, Balfron.
BARNWELL, RICHARD H., Elcho House, Balfron.

AS AN ASSOCIATE.

REID, WILLIAM, Machinery Merchant, 109 Hope Street, Glasgow.

AS STUDENTS.

KINLEY, WILLIAM L., Apprentice Engineer, c/o Heaton, 9 Alexandra Street, Partick.
MACGIBBON, JOHN, Engineer Draughtsman, Glenorchy, Scotstounhill, Glasgow.
MAKGILL, ARTHUR, Apprentice Engineer, 220 Langlands Road, South Govan.
MURRAY, ANGUS ROBERTSON, Apprentice Engineer, Strathroy, Dumbreck.

THE FIFTH GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 20th February, 1906, at 8 p.m.

Mr. JAMES GILCHRIST, President, occupied the Chair.

The Minutes of the General Meeting, held on 23rd January, 1906, having been printed in the billet calling the Meeting, were held as read, and signed by the President.

The new Members elected at the previous meeting were duly admitted.

The discussion on Mr. W. J. GOUDIE's paper on "The Application of Calculating Charts to Slide-Valve Design," was begun and adjourned.

The discussion on Mr. JAMES HOWDEN's paper on "The Screw Propeller Controversy," was begun and adjourned.

A paper by Mr. W. A. KER, on "Notes on Some Common Errors in the Use of Electric Motors for Machine Driving," was read.

The following candidates were duly elected:—

AS MEMBERS.

BAGSHAWE, BENJAMIN WYATT, Engineer, 50 Wellington Street, Glasgow.

ROGERSON, THOMAS BOND, Engineer Manager, East Thorne, Tollcross, Glasgow.

AS ASSOCIATE MEMBERS.

FERGUS, FRED. SMEATON, Marine Engineer, 494 Great Western Road, Hillhead, Glasgow.

ROBERTS, WILLIAM MIRRLEES, Engineer Draughtsman, 15 Ardgowan Street, Greenock.

AS STUDENTS.

GRANGE, GEORGE ROCHFORT, Apprentice Engineer, 3 Lennox Avenue, Scotstoun, Glasgow.

JONES, NOEL, Apprentice Engineer, 204 Langlands Road, Govan.

ROBERTSON, THOMAS ALSTON, Electrical Engineer, 46 Queen's Drive, Crosshill, Glasgow.

AN EXTRAORDINARY GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 20th March, 1906, at 7-45 p.m.

Mr JAMES GILCHRIST, President, in the Chair.

The Secretary read the notice calling the Meeting as follows:—

NOTICE IS HEREBY GIVEN, that an EXTRAORDINARY GENERAL MEETING of the Institution will be held within the large Hall at 207 Bath Street, Glasgow, on Tuesday, 20th March, 1906, at 7-45 o'clock p.m., to consider, and if approved, to pass the following Resolution, namely:—

That Articles 23, 25, and 27, of the Articles of Association of the Institution, be, and are hereby, cancelled, and that in lieu thereof the following Articles be, and are hereby, substituted, namely:—

23. The Office-Bearers in office at 30th April, 1902, shall continue in office till the First General Meeting of the Institution in October, 1902, when a new Council shall be elected in terms of these Articles. Such Office-Bearers shall be eligible for election for the new Council. Of the new Council, two Vice-Presidents shall retire in October of each of the years, 1903, 1904, and 1905, their places being filled by election, and the persons elected shall hold office until the expiry of the terms of office. Similarly of the new Council, six Councillors (being five Members and one Associate) shall retire in October, 1903, and a like number in October, 1904, and the remainder in October, 1905, their places being filled by election at these dates respectively, and their successors retiring at the expiry of the terms of office, and so on thereafter from year to year. The Vice-Presidents to retire in October, 1903 and 1904, shall be determined by lot among the six Vice-Presidents first elected, and the Members of Council to retire in October, 1903 and 1904, shall be determined by lot among the Members of the Council first elected. The Vice-Presidents and the Ordinary Members of Council who fall to retire at the dates mentioned, or who fall to retire at any time on the expiry of their term of office, shall not be eligible for re-election in the same capacity,* nor shall a retiring Vice-President be eligible for election as a Member of Council until one year has elapsed since the date of retiral.

25. In March of each year the Council shall meet and prepare a list of names for the election of Council for the ensuing year.* This list shall be submitted to the Members at the Monthly Meeting preceding the Annual Meeting, and the Members present may by motion, duly seconded, propose any additional names for any of the offices.

27. A vacancy occurring during any Session in consequence of the resignation or death of any Office-Bearer (except the President) shall be filled up by the Council, until the next Annual General Meeting for electing Office-Bearers. Any vacancy in the office of President shall be filled up at the

next General Meeting of the Institution. A person elected to fill a vacancy shall hold office for the period unexpired of the term of office of the Office-Bearer resigning or dying or being removed from office, and he shall * not be eligible for re-election.

The Resolution will be submitted as a Special Resolution, and passed by the required majority, will be submitted for confirmation as a Special Resolution at a Second Extraordinary Meeting, which will be subsequently convened.

By order of the Council,

EDWARD H. PARKER, *Secretary.*

Note.—The alterations and additions suggested by the Council consist of:—

(1.) The addition of the words "nor shall a Vice-President be eligible for election as a Member of Council" to Article 23, to be read after the word "capacity."*

(2.) The deletion of the words* "This list shall contain the name of the proposed President, and not less than two names of persons proposed by the Council for each vacancy in the class of Vice-Presidents, Ordinary Members, and Associate Members of Council" from Article 25.

(3.) The insertion of the word * "not" between the words "shall" and "be" in Article 27.

The President referred to the nature of the suggested alterations, and moved that the Resolution be passed. The motion was seconded by Mr MOLLISON, and carried unanimously.

THE SIXTH GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 20th March, 1906, at 8 p.m.

Mr. James Gilchrist, President, occupied the Chair.

The Minutes of the General Meeting, held on 20th February, 1906, having been printed in the billet calling the Meeting, were held as read and signed by the President.

The new Members elected at the previous meeting were duly admitted.

New Buildings—Competitive Plans.

The President intimated that after a great deal of time and labour the Council were in the position of being unanimous in the selection of the designs for the Institution's new buildings. The Council, he said, had invited competitive plans from architects practising in Glasgow, and not less than fifty-one firms had responded to the invitation. The plans were on exhibition at the Wellesley Buildings, 137 Sauchiehall Street, where the Members could see them. In making the selection, not a single Member of Council had the remotest idea who the authors of the various plans were. Each set of designs was numbered as received, while the same number was written on a sealed envelope, containing the name and address of the competitor. He had now pleasure in announcing that the winning number was 16; the others in order of merit being 48, 26, and 10 respectively. He then requested the Secretary to open the envelopes relative to these numbers and announce the name of the authors of the premiated designs.

The Secretary broke the seals of the envelopes, and declared the following as the winners in the competition:—First, No. 16, Mr John B. Wilson, 92 Bath Street; second, No. 48, Messrs. Mitchell & Whitelaw, 219 St. Vincent Street; third, No. 26, Mr H. E. Clifford, 225 St. Vincent Street; and fourth, No. 10, Mr W. F. M'Gibbon, 221 West George Street.

The President stated that according to the conditions of the competition these four sets of plans became the property of the Institution. The winning competitor would be the architect of the buildings; the second would receive a premium of £75; the third £50; and the fourth £25.

On the motion of Professor JAMIESON a vote of thanks was awarded the Convener and Members of the Committee on New Buildings for their careful examination and selection of plans.

The discussion on Mr. W. J. GOUDIE's paper on "The Application of Calculating Charts to Slide-Valve Design," was resumed and concluded.

On the motion of the President Mr. GOUDIE was awarded a vote of thanks for his paper.

The discussion on Mr. JAMES HOWDEN's paper on "The Screw Propeller Controversy," was postponed.

The discussion on Mr. W. A. KER's paper, on "Notes on Some Common Errors in the Use of Electric Motors for Machine Driving," was begun and adjourned.

A paper by Mr H. NORMAN LEASK, on "Refuse Destructors," was read.

The following Candidates were duly elected:—

AS MEMBERS.

BEALE, SAMUEL RICHARD, Engineer, Manager, The Crown Iron Works, North Woodside Road, Glasgow.

BURT, PETER, Engineer, Holly Bank, Bothwell.

DUNLOP, JOHN MITCHELL, Engineer, Messrs. Millar & Allan, Ltd., 93 Hope Street, Glasgow.

LAWSON, CHARLES BUCHANAN, Engineer and Boilermaker, Crown Point Boiler Works, St. Marnock Street, Glasgow.

LANG, JAMES, Engineer, Netherby, Johnstone.

LANG, WILLIAM B., Engineer, Springfield, Johnstone.

SUTHERLAND, JOHN, Engineer, Manager, The British Aluminium Co., Ltd., Greenock.

WASLEY, THOMAS J. J., Engineer, 21 Station Road, Coatham, Redcar, Yorks.

From Associate Members.

ATCHLEY, CHARLES ATHERTON, Electrical Engineer, 50 Wellington Street, Glasgow.

AS ASSOCIATE MEMBERS.

CALDWELL, JAMES, Engineer Draughtsman, 6 Clydeview, Partick.

CRAWFORD, JOHN DOUGLAS, Engineer, 64 Love Street, Paisley.

From Students.

SERVICE, WILLIAM, Marine Engineer, 173 West Graham Street, Glasgow.

AS AN ASSOCIATE.

SCOTT, HAROLD H. S., Shipowner, 94 Hope Street, Glasgow.

AS STUDENTS.

KIRKLAND, JAMES, Engineer Draughtsman, 23 Cross, Beith.

LOPEZ, JOAQUIN, Student of Engineering, 109 Sinclair Drive, Langside, Glasgow.

LINWOOD, CHARLES, Apprentice Engineer, 1 Clarence Drive, Hyndland, Glasgow.

M'CARTNEY, HUGH NEIL, Apprentice Engineer, 7 Granville Street, Glasgow, W.

MACLEAN, GAVIN THOMSON, Apprentice Engineer, 100 Springkell Avenue, Maxwell Park, Glasgow.

MANN, JOHN KENNEDY, Electrical Engineer, 37 Partickhill Road, Glasgow.

WARD, RICHARD J. L., Student of Naval Architecture, 67 Main Street, Glasgow.

AN EXTRAORDINARY GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 17th April, 1906, at 7-45 p.m., for the purpose of confirming the Resolution, passed at an Extraordinary Meeting of the Institution, held on 20th March, 1906, and which Resolution is embodied in the minutes of the Meeting of that date.

Mr E. HALL-BROWN, Vice-President, occupied the Chair.

The Secretary read the notice calling the Meeting and the Resolution. After some discussion, the motion that the Resolution be confirmed, was put to the Meeting by the Chairman and unanimously adopted.

THE SEVENTH GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 17th April, 1906, at 8 p.m.

Mr. E. HALL-BROWN, Vice-President, occupied the Chair.

The Minutes of the General Meeting, held on 20th March, 1906, having been printed in the billet calling the Meeting, were held as read and signed by the Chairman.

The new Members elected at the previous meeting were duly admitted.

The following nominations for Office-Bearers were then made:—*President*—Mr. JAMES GILCHRIST; *Vice-Presidents*—Messrs. ALEX. CLEGHORN and C. P. HOGG; *Ordinary Members of Council*—Messrs. WILLIAM BROWN, J. E. HARRISON, R. D. MUNRO, JAMES ROWAN, and PETER WALLACE; *Member of Council from Associate Class*—Mr. JAMES DONALD, J.P.

The discussion on Mr. JAMES HOWDEN'S paper on "The Screw Propeller Controversy," was again postponed.

The discussion on Mr. W. A. KER'S paper on "Notes on Some Common Errors in the Use of Electric Motors for Machine Driving," was resumed and concluded.

On the motion of the Chairman, Mr. KER was awarded a vote of thanks for his paper.

The discussion on Mr. H. NORMAN LEASK'S paper on "Refuse Destructors," was begun and concluded.

On the motion of the Chairman, Mr. LEASK was awarded a vote of thanks for his paper.

The following Candidates were duly elected:—

AS A MEMBER.

LEASK, HENRY NORMAN, Engineer, 4 Chapel Walks, Manchester.

AS AN ASSOCIATE MEMBER.

GRAY ROBERT, Marine Engineer Draughtsman, 88 Lennox Street, Possilpark, Glasgow.

THE ANNUAL GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 1st May, 1906, at 8 p.m.

Mr JAMES GILCHRIST, President, occupied the Chair.

The Minutes of the Seventh General Meeting, held on 17th April, 1906, having been printed in the billet calling the Meeting, were held as read, and signed by the President.

The new Members elected at the previous Meeting were duly admitted.

The following gentlemen were elected as Office-Bearers:—For Session 1906-07—*President*, Mr James Gilchrist. For Sessions 1906-09—*Vice-Presidents*, Mr Alexander Cleghorn and Mr C. P. Hogg; *Ordinary Members of Council*, Messrs William Brown, J. E. Harrison, R. D. Munro, James Rowan, and Peter Wallace; *Member of Council from Associate Class*, Mr James Donald, J.P.

A premium of books was awarded to Dr. J. Bruhn for his paper on "Methods for Estimating the Strength of Ships," and to Mr A. Melencovich for his paper on "Multiple Steam Turbines," read during Session, 1904-05.

The discussion on Mr James Howden's paper on the "Screw Propeller Controversy," was resumed and concluded.

On the motion of the President, Mr Howden was awarded a vote of thanks for his paper.

A paper by Dr. R. F. Muirhead, "On Equimomental Systems and Their Use in Applied Mechanics," was read and discussed.

On the motion of the President, Dr. Muirhead was awarded a vote of thanks for his paper.

The following Candidates were duly elected:—

AS MEMBERS.

Drummond, William, Engineer, 44 Polworth Gardens, Hyndland, Glasgow.

Sime, William, Engineer, Victoria Biscuit Works, Glasgow.

Voos, Armand, Superintendent Engineer, Chateau de Petaheid, Verviers, Belgium.

AS ASSOCIATE MEMBERS.

From Students.

Dobbie, Robert Brown, Engineer, 15 Leander Road, Brixton Hill, London, S.W.

Grant, William, Electrical Engineer, 40 Keppel Road, Chorlton-cum-Hardy, Manchester.

AS STUDENTS.

DENNISTOUN, ARCHIBALD B., Apprentice Engineer, Glenesk, Sherbrooke Avenue, Pollokshields, Glasgow.

DIXON, ERNEST M., Engineer Draughtsman, 1 Westbank Place, Smith Street, Hillhead, Glasgow.

ELLIOT, JAMES, Electrical Engineer, 89 North Street, Whiteinch, Glasgow.

REPORT OF THE COUNCIL.

Session 1904-1905.

On the occasion of the Opening Meeting of the Forty-ninth Session, the Council has pleasure in reporting that the affairs of the Institution are very satisfactory. Notwithstanding his illness, the President continued to take a deep interest in the work of the Institution; unfortunately he was unable to attend the Council meetings, but in his absence Mr. James Gilchrist ably presided. There has been a steady growth in the Membership of the Institution, resulting in a net increase of 49 for the year, compared with an increase of 17 for the previous session.

The Roll.

The changes which have taken place in the Roll during the year ending 30th September, 1905, are shown in the following statement:—

	Session 1903-1904.	Session 1904-1905.
Honorary Members,	8	8
Members,	1,013	1,023
Associate Members,	100	127
Associates,	88	91
Students,	193	202
	1,402	1,451

The elections were Members 39, Associate Members 17, Associates 9, and Students 43; while 1 Associate Member and 11 Students passed into the Members' Section, and 12 Students were transferred to the Class of Associate Members. In respect of deaths, resignations, and deletions the Membership was decreased by 59.

The Council regrets having to record the loss by death of the following:—Members—James Foster, Glasgow; James Gray, Old Cumnock; Edmund Hunt, Glasgow; David M'Call, Glasgow; John F. Miller, Glasgow; Edmund Mott, Cardiff; William Robertson, Glasgow; George Lennox Watson, Glasgow; John Wilson, Glasgow; John Young, Tighnabruaich. Associate—James Napier, Old Kilpatrick.

Meetings.

During the year the following interesting Papers were read, and these, together with the discussions thereon, are embodied in Volume XLVIII. of the Institution's Proceedings:—

"The Smoke Problem," by Mr. F. J. Rowan.

"The Breakage and Renewal of a Large Cylinder," by Mr. Hector MacColl.

"The Transmission of Power by Ropes," by Mr. Edwin Kenyon.

"Multiple Steam Turbines," by Mr. Alexander Melencovich.

"Methods of Estimating the Strength of Ships," by Mr. J. Bruhn, D.Sc.

"The Compounding of Locomotive Engines" by Mr. John Riekie.

"Some of the Effects likely to be Produced by the Gyroscopic Action of Steam Turbines on Board Vessels Pitching in a Sea," by Mr. J. Blacklock Henderson, D.Sc.

"Gyrostats and Gyrostatic Action," by Professor Andrew Gray, LL.D., F.R.S.

In addition to these papers the question of "The Board of Trade Regulations for Certificated Marine Engineers" was discussed at two meetings. The meetings held during the Session were nine in number.

The "James Watt" Anniversary Dinner took place on Thursday evening, 19th January, 1905, at the Grosvenor Restaurant, Glasgow, and was attended by a large number of Members and distinguished guests. A very enjoyable evening was spent, and the success of previous functions of a similar character was fully maintained.

A Smoking Concert was held in the banqueting hall of the Grosvenor Restaurant on the evening of Saturday, 3rd March 1905. The company present numbered about 300, and seemed to thoroughly enjoy the programme arranged by the Committee.

The Council desires to urge every Member to use his best efforts towards promoting the welfare of the Institution, by regularly attending the Meetings, by contributing papers or taking part in discussions, and by securing new Members.

STUDENTS' SECTION.

The Meetings held by the Students were seven in number. The Chairman of the Section, Mr. E. Hall-Brown, opened the Session with an address. At the subsequent meetings the under mentioned papers were read and discussed: —

"The Evolution of the Armoured Battleship," by Mr. A. J. Cameron.

"The Modern Equipment of Steam Boilers," by Mr. John Forrester.

"Experiments on Launching with Practical Conclusions," by Mr. D. W. Dickie.

"Some Points in Connection with Boilers," by Mr. F. J. Rowan.

Visits were paid to the following works during the Session:—

The North British Locomotive Works, Springburn.
Messrs. D. Rowan & Co.'s Engine Works, Glasgow.
Messrs. A. Rodger & Co.'s Engine Works, Govan.
Messrs. The Glasgow District Subway Co., Ltd., Glasgow.
The Glasgow Corporation Tramways Power Station.
The Fairfield Shipbuilding and Engineering Works, Govan.
Messrs. Penman & Co.'s Boiler Works, Glasgow.
Messrs. Stewart & Lloyd's Tube Works, Rutherglen.
The Glasgow Corporation Sewage Works, Dalmuir.

The Council takes this opportunity, while impressing upon the Students the great advantages which these visits to works offer, of thanking the Principals and Managers of the works visited during the Session, for the courtesies and kindnesses extended to the Students.

Improved Accommodation.

The Council has completed a provisional agreement with the Council of the Royal Philosophical Society for the sale to that Society of the Institution's half share in the buildings at 207 Bath Street, and this agreement will be submitted for approval of the Members at an early meeting. The Committee on Improved Accommodation has inspected several sites available for new buildings, and has had under consideration the extent of accommodation to be provided.

Board of Governors of the Glasgow and West of Scotland Technical College.

Mr. Andrew S. Biggart was appointed to represent the Institution on the Board of Governors of this College in succession to Mr. James Weir.

The College continues to maintain its high position both in regard to the standard of the work done and to the number of students. During the session just closed the day students numbered 530, and the evening students, 4,490; making a total of 5,020 individuals. The total number of class enrolments was 9,084, and the total number of "student-hours" was 406,221. All these figures show a substantial increase on the numbers of the previous session.

The energies of the Governors were successfully directed towards the completion of the first section of the new buildings in time for the opening of the Session 1905-1906. The work of the College is now carried on in the new buildings, but the ceremonial opening will not take place until a later period in the session.

Two important changes were made in the engineering staff.

Professor W. H. Watkinson was elected to the Harrison Chair of Engineering in the University of Liverpool, and on the unanimous recommendation of the Committee on Engineering, Dr. A. L. Mellanby, of the Manchester School of Technology, was appointed his successor. The development of the Department of Civil Engineering called for the strengthening of the staff in this section of the College work, and Mr. G. Moncur, B.Sc., of the Great North of Scotland Railway Company, was appointed lecturer in Civil Engineering.

BOARD OF GOVERNORS OF THE GLASGOW SCHOOL OF ART.

The Institution was represented on this Board by Mr James Mollison.

The Glasgow School of Art has made considerable progress during the past Session. Since the school came directly under the Scotch Education Department the Governors have re-organised certain sections of the work, two of which have been specially dealt with, viz., those of Architecture, and of Design and Decorative Art. In both of these sections professors have been appointed to take charge, and recently a conference between representatives from the Glasgow and West of Scotland Technical College and the Glasgow School of Art was held, when measures were adopted for co-ordinating the teaching of Architecture in the two Institutions. The establishment of such a course of study in Architecture meets a long-felt want, and will no doubt be taken advantage of.

During the Session 37 students received appointments as designers, teachers, &c.

By kind permission of the Principal of the Glasgow University, a course of lectures was given at the University by Professor John Cleland, M.D., F.R.S., to students of the School of Art, the subject being "Facial Expression." A lecture, delivered by Professor G. Baldwin Brown, M.A., Edinburgh, on "The Frescoes of the Sistine Chapel," was also much appreciated.

Considering the large number of students now receiving instruction, the necessity for increased accommodation is receiving consideration by the Governors; and as the school is now recognised as an essential part of the educational life of Glasgow and the West of Scotland, they have every confidence that their efforts will receive the assistance and support of the community generally.

Among the ordinary students attending the school are:—Teachers, designers, draughtsmen, architects, glass stainers, house painters, china painters, stone carvers, wood carvers, modellers, cabinetmakers, engravers, blacksmiths, engineers, accountants, and clerks.

Board of Trade Consultative Committee.

The Institution was represented on the Board of Trade Consultative Committee by Mr. John Duncan, Mr. E. Hall-Brown, Mr. James Hamilton, and Mr. George McFarlane.

During the year Mr. Hamilton resigned, and Mr. Fred. Lobnitz was appointed by the Council, to the Committee, in his stead.

Four meetings were held during the year, on 18th October, 1904, 7th February, 18th April, and 4th July, 1905, respectively.

The Engineering and Shipbuilding firms throughout the country submitted a number of matters to the Committee which were discussed and adjusted; and a number of important points are still under consideration.

Lloyd's Technical Committee.

The Institution was represented on the Technical Committee of Lloyd's Register of British and Foreign Shipping by Mr Sinclair Couper, Mr John Inglis, LL.D., Mr Richard Ramage, and Mr James Rowan.

The usual and statutory meetings of the Committee were held in London during the months of November and March, at which the following matters were dealt with:—

The height of tank side brackets.

The diameter of rivets for use in thin plating of yachts.

Bulkhead liners.

Deck stops for rudders.

Requirements for awning deck vessels, poops, bridges, forecastles, and deckhouses.

Amendments in the rules regarding refrigerating appliances on board ship and the electric lighting of vessels.

The proposed alterations in the rules on these subjects, as approved by the Technical Committee, were adopted by the General Committee.

FINANCE.

The surplus revenue for the session ending 30th September, 1905, as shown by the Treasurer's Statement, appended hereto, is £756 16s. 0d. The amount appearing at the credit of current account in the bank has since been transferred to deposit receipt.

TREASURER'S
INCOME AND EXPENDITURE ACCOUNT
GENERAL

ORDINARY INCOME.		1904-1905.	1903-1904.
I. *Annual Subscriptions received*—			
Members, ...	£1739 10 0		
Associate Members, ...	103 0 0		
Associates, ...	126 0 0		
Students, ...	88 0 0		
		£2056 10 0	£2035 10 0
II. *Arrears of Subscriptions recovered, less expenses*,		70 14 4	48 8 6
III. *Sales of Transactions*, ...		5 15 6	31 3 3
IV. *Interests and Rents*—			
Interest on ClydeTrust Mortgages, less tax, ...	£37 16 4		
Interest on Deposit Receipts, *less* Income Tax, ...	9 18 10		
Interest on Glasgow Corporation Loan, ...	3 12 7		
West of Scotland Iron and Steel Institute, for use of Library,	20 0 0		
Students, Institution C.E., for use of Library, ...	10 0 0		
		81 7 9	60 14 7
EXTRAORDINARY INCOME.			
Surplus on Smoking Concert, ...	£3 10 11		
Surplus on James Watt Dinner, ...	0 8 9		
		3 19 8	. . .
		£2218 7 3	£2176 1 4

STATEMENT.
FOR YEAR ENDING 30TH SEPTEMBER, 1905.
FUND.

ORDINARY EXPENDITURE.		1904-1905.	*1903-1904.*
I. *General Expenses—*			
Secretary's Salary, ...	...£400 0 0		
Clerk's Salary, ...	... 72 0 0		
Institution's proportion of net cost of maintenance of Buildings, etc.,	149 10 1		
Library Books, ...	.. 50 4 7		
Binding Periodicals and Papers,	12 8 1		
Stationery and Postages, etc.,	58 19 5		
Office Expenses, ...	.. 27 1 7		
Advertising, Insurance, etc., ...	5 6 0		
Travelling Expenses, ...	7 12 8		
Expenses of Students' Opening Meeting, ...	6 5 10	£789 7 10	*£734 11 9*
II. "*Transactions*" *Expenses—*			
Printing and Binding,	£419 4 1		
Lithography, ...	103 11 8		
Postages, ...	80 12 8		
Reporting, ...	18 6 0		
Delivery of Annual Volume, ...	23 5 0	644 19 5	*697 13 11*
EXTRAORDINARY EXPENDITURE.			
Fee for Valuation of Buildings, ...	£4 4 0		
Safe, Stand, Boxes, etc., ...	23 0 0	27 4 0	*18 2 0*
Surplus carried to Balance Sheet, ...		756 16 0	*725 13 8*
		£2218 7 3	*£2176 1 4*

BALANCE SHEET, AS AT

LIABILITIES.			As at 30th Sept., 1905.	*As at 30th Sept., 1904.*
I. *General Capital Account—*				
As at 1st Oct., 1904, ...		£5560 13 5		
Entry money, ...		56 0 0		
Surplus from Revenue, ...		756 16 0	£6373 9 5	*£5560 13 5*
II. *Life Members' Subscriptions,*			200 0 0	*160 0 0*
III. *Sundry Creditors,*			12 16 8	*6 10 0*
IV. *Subscriptions paid in advance,*			60 0 0	*65 5 0*
V. *Medal Funds—*				
Marine Engineering—				
Balance as at 1st Oct., 1904,	£582 9 6			
Interest received during year, £17 19s 2d, less Premium of Books, £5 0s 6d,	12 18 8	£595 8 2		
Railway Engineering—				
Balance as at 1st Oct., 1904,	£367 6 1			
Interest received during year,	11 4 6	378 10 7		
Students'—				
Balance as at 1st Oct., 1904,	£22 9 3			
Cost of medal and books, £4 1s 9d; *less* interest received during year, 13s 9d,	3 8 0	19 1 3	993 0 0	*972 4 10*
			£7639 6 1	*£6748 13 3*

30TH SEPTEMBER, 1905.

ASSETS.		As at 30th Sept., 1905.	*As at 30th Sept. 1904.*
I. *Heritable Property—* Total Cost,	£7094 16 2		
Of which one-half belongs to the Institution, ...		£3547 8 1	*£3547 8 1*
II. *Furniture and Fittings—* Valued at, say		65 10 0	*65 10 0*
III. *Books in Library—* Valued at, say		500 0 0	*500 0 0*
IV. *Investments—*			
Clyde Trust Mortgages, ...	£1200 0 0		
Glasgow Corporation Loan,	1000 0 0	2200 0 0	*1400 0 0*
V. *Medal Funds Investments—*			
Clyde Trust Mortgage,	£903 0 0		
On Deposit Receipt, ...	46 9 5	949 9 5	*949 5 2*
Note.—Balance of £43 10s 7d since lodged on Deposit Receipt.			
VI. *Arrears of Subscriptions—*			
Session 1904-1905—			
Members, ...	£154 0 0		
Associate Members, ...	11 0 0		
Associates, ...	4 10 0		
Students, ...	16 0 0		
	£185 10 0		
Previous sessions—			
Members, £105 10 0			
Associates, 2 0 0			
Students, 12 0 0	119 10 0		
Total,	£305 0 0		
Valued at, say		50 0 0	*50 0 0*
VII. *Sundry Debtors—*		1 19 0	*12 12 8*
VIII. *Cash—*			
In Bank, on Deposit Receipt	£162 16 1		
Do, on Current Account,	148 2 8		
In Secretary's hands, ...	14 0 10	324 19 7	*223 17 4*
		£7639 6 1	*£6748 13 3*

GLASGOW, *17th October, 1904.*—Audited and certified correct.

DAVID BLACK, C.A., *Auditor.*

ABSTRACT OF "HOUSE EXPENDITURE" ACCOUNT FOR SESSION 1904-1905.

Note.—The Account of the House Committee, of which the following is an abstract, is kept by Mr John Mann, C.A., Treasurer to the Committee, and is periodically audited by the Auditors appointed by the Institution and the Royal Philosophical Society.

EDWARD H. PARKER, *Secretary to the House Committee.*

INCOME.	12 months, to 30th Sep., 1905.	*12 months, to 30th Sep., 1904.*	EXPENDITURE.	12 months, to 30th Sep., 1905.	*12 months, to 30th Sep., 1904.*
Rents for Letting Rooms, ...	£67 14 6	*£110 16 0*	Salary to Curator, ...	£144 0 0	*£154 0 0*
Balance, being excess Expenditure, ...	299 0 3	*244 13 1*	Salary to Attendant at Library, Cleaning, etc., ...	80 0 0	*88 12 8*
Payable by Institution, ... £149 10 1			Feu-duty, Taxes, and Insurance,	50 15 1	*50 13 3*
Payable by Philosophical Society, 149 10 2			Alterations, Repairs & Renewals,	50 15 2	*19 19 8*
			Coal, Gas, and Electric Light,	38 3 2	*38 16 11*
			Stationery, Postages, and Incidental Expenses, ...	3 1 4	*3 6 7*
	£366 14 9	*£355 9 1*		£366 14 9	*£355 9 1*

GLASGOW, *17th October, 1905.*—Audited and certified correct.

DAVID BLACK, C.A., *Auditor.*

REPORT OF THE LIBRARY COMMITTEE.

During the session just closed the additions to the Library include 35 volumes, 6 pamphlets, and 56 Board of Trade Reports on boiler and steam-pipe explosions, by donation; 53 volumes by purchase; and 158 volumes received in exchange for the Proceedings of the Institution. Of the periodical publications received in exchange, and which lie on the tables in the reading-room, 25 were weekly and 22 monthly. One hundred and four volumes were bound.

The Institution possesses a complete set of the Abridgments of Specifications of Patents dating from 1617, which is available for reference purposes in the Library.

The Committee wishes to express thanks for the following donations to the Library:—

Donations to the Library.

Acworth, W. M., Elements of Railway Economics. 1904. From the Publisher.

Alexander, T., and Thomson, A. W. Twenty-six Graduated Exercises in Graphic Statics, with an Essay on Graphical Statics, 1905. From the Authors.

Bates, L. W. Project for the Panama Canal, with General Plans and Profiles, 1905. Pamphlet. From the Author.

Burns, David. Anthracitation of Coal. Pamphlet. 1904.

Engineering Standards Committee Publications—From the Committee.

Beams. Standard Sections of Beams.

Boilers. British Standard Specification for Structural Steel for Marine Boilers.

British Standard Tables for Copper Conductors and Thicknesses of Dielectric.

British Standard Screw Threads. 1905.

British Standard Pipe Threads for Iron or Steel Pipes and Tubes. 1905.

British Standard Specification and Sections of Flat-Bottomed Railway Rails. Folio. 1905, and

British Standard Specification for Tubular Tramway Poles.

British Standard Sections. Angle Bars, etc.

Cement. British Standard Specification for Portland Cement.

Electricity. British Standards for Electrical Machinery.

Forms of Standard Test Pieces.

Pipe Flanges. British Standard Tables of Pipe Flanges.

Properties of British Standard Sections.

Railway Rails. British Standard Specification and Sections of Bull Headed Railway Rails.

Report on the Influence of Gauge Length and Section of Test Bar on the Percentage of Elongation. By Professor W. C. Unwin.

Report on Temperature Experiments on Field Coils of Electrical Machines. Folio. 1905.

Shipbuilding. British Standard Specification for Structural Steel for Shipbuilding.

Tramways. British Standard Specification and Sections of Tramway Rails and Fish Plates.

Glasgow Herald. Shipbuilding and Engineering Annual for 1904. From the Proprietors.

Haldane, J. W. C. Life as an Engineer, its lights, shades, and prospects. 1905. From the Author.

Institution of Naval Architects. Vols. 27, 29-31, 38-45. 1886-1903. From Mr. E. M. Speakman.

Lindley, W. H., and Others. Gutachten über die Abnahme-Versuche vom Januar, 1900, an einer 1000 Kilowatt Dampfturbine und Alternator, von C. A. Parsons and Co. From Prof. A. Jamieson. Pamphlet.

Mann, John, Jr. Cost Records, or Factory Accounting, Pamphlet. 1903.

Mann, John, Jr. "Oncost," or Expenses. Pamphlet. 1904.

Neilson, R. M. Comparison of Different Types of Steam Turbine. Pamphlet. 1905. From the Author.

Society of Accountants' Year-Book, 1904-5.

BOOKS ADDED TO THE LIBRARY BY PURCHASE.

Attwood, Edward L. War Ships: a Text-Book on the Construction, Protection, Stability, Turning, &c., of War Vessels. 1904.

Barnett, S. J. Elements of Electromagnetic Theory. 1903.

Bauer, G. Marine Engineers and Boilers, their Design and Construction. Edited by L. S. Robertson. 2nd edition, 1905.

Bell, Louis. Art of Illumination. 1903.

Brassey's Naval Annual for 1905.

Camp, W. M, Notes on Track; Construction and Maintenance. 2nd edition; Chicago, 1904.

Carnegie, Andrew. James Watt. Edinburgh.

Hammer, W. J. Radium and Other Active Substances. 1903.

Hobart, Henry M. Electric Motors, Continuous-Current Motors, and Induction Motors: their Theory and Construction, 1904.

Horner, Joseph. Elementary Treatise on Hoisting Machinery, including the Elements of Crane Construction. 1903.

Hutton, Frederick. R. The Gas Engine: a Treatise on the Internal Combustion Engine Using Gas, &c. 1903.

Jamieson, Andrew. Text-Book on Steam and Steam Engines, including Turbines and Boilers. 14th edition. 1904.

Krause, Rudolf. Starters and Regulators for Electric Motors and Generators: Theory, Construction, and Connection. Translated by C. Kinzbrunner and N. West. 1904.

Leaning, J. Quantity Surveying, for Surveyors, Architects, Engineers, and Builders. 5th edition. 1904.

Lovett, W. J. A Complete Class Book of Naval Architecture. 1905.

Maclean, Magnus, Ed. Modern Electric Practice. 6 Vols.

Marsh, Charles F. Reinforced Concrete. 1904.

Official Year-Book of the Scientific and Learned Societies of Great Britain and Ireland, 1903-4.

Owen, H. Aids to Stability: a Practical Guide to the General Principles of Shipbuilding. New edition. 1904.

Parsons, H. de B. Steam Boilers: their Theory and Design. 1903.

Peabody, Cecil H. Naval Architecture. New York. 1904.

Poppleworth, W. C. Prevention of Smoke with the Economical Combustion of Fuel. 1901.

Pütsch, Albert. Gas and Coal Dust Firing. Translated by Charles Salter. 1901.

Ransome, Stafford. The Engineer in South Africa. 1903.

Robinson, Henry. Hydraulic Power and Hydraulic Machinery. 3rd edition. 1904.

Rowan, F. J. Practical Physics of the Modern Steam Boiler. 1903.

St. Louis International Engineering Congress, 1905, Transactions. 6 Vols.

Seaton, A. E. Manual of Marine Engineering. 15th edition. 1904.

Sewall, Charles Henry. Wireless Telegraphy; its Origins, Development, Inventions, and Apparatus. 1903.

Sexton, A. H. Producer Gas. Manchester.

Simpson, George. The Naval Constructor: a Vade Mecum of Ship Design for Students, &c. New York, 1904.

Soddy, Frederick. Radio-Activity: an Elementary Treatise from the Standpoint of the Disintegrating Theory. 1904.

Stodola, A. Steam Turbines, with an Appendix on Gas Turbines, and the Future of Heat Engines. 2nd edition. 1905. Two copies.

Stone, Herbert. Timbers of Commerce and their Identification, 1904.

Story, Alfred T. The Story of Wireless Telegraphy. 12mo.

Thomson, J. J. Conduction of Electricity through Gases. 1903.

Unwin, W. C. Testing of Materials of Construction. 2nd edition. 1899.

Webb, Walter L. Railroad Construction. 2nd edition. 1903.

Wellington, A. M. Economic Theory of the Location of Railways. 6th edition. 1903.

Wheeler, G. U. Friction and its Reduction. 1903.

Williamson, James. The Clyde Passenger Steamer: its Rise and Progress during the Nineteenth Century. 1904.

Woodworth, Joseph V. Hardening, Tempering, Annealing, and Forging of Steel. 1903.

THE INSTITUTION EXCHANGES TRANSACTIONS WITH THE FOLLOWING SOCIETIES, &c.:—

Aberdeen Association of Civil Engineers, Aberdeen.

American Institute of Electrical Engineers, New York.

American Institute of Mining Engineers, New York.

American Philosophical Society, Philadelphia.

American Society of Civil Engineers, New York.

American Society of Mechanical Engineers, New York.

Association des Ingénieurs sortis des Écoles Spèciales de Gand, Belgium.

Association Technique Maritime, Paris.

Bristol Naturalists' Society, Bristol.

British Association for the Advancement of Science, London.

Bureau of Steam Engineering, Navy Department, Washington.

Canadian Institute, Toronto.

Canadian Society of Civil Engineers, Montreal.

Collegio degli Ingegneri e Architetti in Palermo, Palermo.

École Polytechnic, Paris.

Edinburgh Architectural Association, Edinburgh.

Electric Club, Pittsburgh.

Engineering Association of New South Wales, Sydney.

Engineering Society of the School of Practical Science, Toronto.

Franklin Institute, Philadelphia.

Geological Survey of Canada, Ottowa.

Hull and District Institution of Engineers and Naval Architects, Hull.
Institute of Marine Engineers, London.
Institution of Civil Engineers, London.
Institution of Civil Engineers of Ireland, Dublin.
Institution of Electrical Engineers, London.
Institution of Junior Engineers, London.
Institution of Mechanical Engineers, London.
Institution of Naval Architects, Japan.
Institution of Naval Architects, London
Iron and Steel Institute, London.
Literary and Philosophical Society of Manchester, Manchester.
Liverpool Engineering Society, Liverpool.
Lloyd's Register of British and Foreign Shipping, London.
Magyar Mérnök es Épitesz-Egylet, Budapest.
Manchester Association of Engineers, Manchester.
Midland Institute of Mining, Civil, and Mechanical Engineers Barnsley.
Mining Institute of Scotland, Hamilton.
North-East Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne.
North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne.
Nova Scotian Institute of Science, Halifax, N.S.
Osterreichischen Ingenieur und Architekten-Verein, Wien.
Patent Office, London.
Royal Dublin Society, Dublin.
Royal Philosophical Society, Glasgow.
Royal Scottish Society of Arts, Edinburgh.
Sanitary Institute of Great Britain, London.
Schiffbautechnischen Gesellschaft, Berlin.
Scientific Library, U.S. Patent Office, Washington.
Shipmasters' Society, London.
Smithsonian Institution, Washington.
Société d'Encouragement pour l'Industrie Nationale, Paris.

Société des Ingénieurs Civils de France, Paris.
Société des Sciences Physiques et Naturelles de Bordeaux, Bordeaux.
Société Industrielle de Mulhouse, Mulhouse.
Society of Arts, London.
Society of Arts, Massachusetts Institute of Technology, Boston.
Society of Engineers, London.
Society of Naval Architects and Marine Engineers, New York.
South Wales Institute of Engineers, Cardiff.
Technical Society of the Pacific Coast, San Francisco.
University of Texas Mineral Survey, Austin.
West of Scotland Iron and Steel Institute, Glasgow.
Western Society of Engineers, Chicago.

PUBLICATIONS RECEIVED PERIODICALLY IN EXCHANGE FOR INSTITUTION TRANSACTIONS:—

Weekly.

American Machinist.
American Manufacturer and Iron World.
Automobile Club Journal.
Automotor Journal.
Colliery Guardian.
Contract Journal.
Electrical Review.
Engineer.
Engineering.
Engineering Record.
Engineering Times.
Indian Engineering.
Iron Age.
Iron and Coal Trades' Review.
Iron and Steel Trades' Journal.
Ironmonger.
L'Industria : Rivista Tecnica ed Economica.
Mechanical Engineer.
Mechanical World.

Nature.
Nautical Gazette.
Practical Engineer.
Revue Industrielle.
Railway Gazette.
Shipping World.
Stahl und Eisen.
Transport.

Monthly.

Cassier's Magazine.
Cold Storage and Ice Trades Review.
Electrical Magazine.
Engineering Magazine.
Engineering Press Monthly Index.
Engineering Review.
Light Railway and Tramway Journal.
Machinery.
Machinery Market.
Marine Engineer.
Marine Engineering.
Mariner.
Mines and Minerals.
Page's Magazine.
Petroleum World.
Portefeuille Économique des Machines
Science Abstracts.
Steamship.
Technics.
The Indian and Eastern Engineer.
Tramway and Railway World.

The Library closes for the Summer Holidays from the 11th July till 31st July inclusive.

Except during holidays and Saturdays, the Library is open each lawful day from 1st May till 30th September inclusive, from 9.30

A.M. till 5 P.M. On Saturdays the Library is open from 9.30 A.M. till 1 P.M.

On the 1st October and thereafter throughout the Winter Session, the Library is open each lawful day from 9.30 A.M. till 10 P.M., except on Saturdays, when it is open from 9.30 A.M. till 2 P.M.

Members have the privilege of consulting the Books in the Library of the Royal Philosophical Society.

The use of the Library and Reading Room is open to Members, Associate Members, Associates, and Students.

The Portrait Album lies in the Library for the reception of Members' Portraits. Members are requested when forwarding Portraits to attach their Signatures to the bottom of Carte.

The Library Committee is desirous of calling the attention of Readers to the "Recommendation Book," where entries can be made of titles of books suggested as suitable for addition to the Library.

A List of the Papers read and Authors' Names, from the First to the Thirty-Third Sessions, will be found in Vol. XXXIII. of the Transactions.

As arranged by the Council, a Register Book for Students lies in the Library for the inspection of Members, the object being to assist Students of the Institution in finding suitable appointments.

E. HALL-BROWN,
Hon. Librarian and Convener.

Annual Subscriptions are due at the commencement of each Session: viz.:—

MEMBERS, £2; ASSOCIATE MEMBERS, £1; ASSOCIATES, £1 10s; STUDENTS, 10s; LIFE MEMBERS, £25; LIFE ASSOCIATES, £20.
Membership Application Forms can be had from the Secretary or from the Sub-Librarian, at the Rooms, 207 Bath Street.

The Council, being desirons of rendering the transactions of the Institution as complete as possible, earnestly request the co-operation of Members in the preparing of Papers for reading and discussion at the General Meetings.

Early notice of such papers should be sent to the Secretary, so that the dates of reading may be arranged.

Copies of the reprint of Vol. 7 containing a paper on "The Loch Katrine Water Works," by Mr J. M. Gale, C.E., may be had from the Secretary; price to Members, 7/6.

Members of this Institution, who may be temporarily resident in Edinburgh, will, on application to the Secretary of the Royal Scottish Society of Arts, at his office, 117 George Street, be furnished with billets for attending the meetings of that Society.

The Meetings of the Royal Scottish Society of Arts are held on the 2nd and 4th Mondays of each month, from November till April, with the exception of the 4th Monday of December.

OBITUARY

Honorary Member.

Sir DIGBY MURRAY, Bart., was born on 31st October, 1829. He was the eldest son of the tenth Baronet of Blackbarony, Peeblesshire, and succeeded to the title on his father's death in 1881. Sir Digby was educated for the Royal Navy, and commanded numerous merchant ships, being the pioneer of the famous White Star Line of steamships, of the first six ships of which he was successively commander. From 1873 till 1896 he was a professional member of the Marine Department of the Board of Trade, and for twenty-two years was a Conservator of the Thames.

The family descends from John de Moravia, who possessed the lands of Blackbarony in the reign of Robert III., his representative at the beginning of the sixteenth century being slain at Flodden. The latter's grandson, John Murray of Blackbarony, was knighted at Stirling in 1593, and Sir John's own son was himself created a Baronet by Charles I., with remainder to his heirs male whatsoever.

Sir Digby Murray was the author of several scientific works, including "Ocean Currents and Atmospheric Currents," and the "A B C. of Sumner's Method." He died at Hothfield, Parkstone, Dorsetshire, on the 8th January, 1906.

Sir Digby was elected an Honorary Member of the Institution in 1891.

Members.

JAMES ANDERSON, who died on 25th September, 1905, was born at Bonhard, Scone, in the year 1845, and received his education in the boarding school conducted by Dr. Browning at Peebles. In 1863 he went to Glasgow, and served his apprenticeship as an engineer in the works of Messrs Randolph, Elder & Co. In 1869 he entered the service of Messrs G. & A. Harvey, Glasgow, and left that firm in 1870 to become manager to Messrs Wm. Robertson & Co., Clyde Street Engine Works, Glasgow. In 1871 he became a partner in the firm of Messrs Lees, Anderson & Muir, who had acquired the business of Messrs W. M. Robertson & Co. Three years later the firm became Messrs Lees, Anderson & Co., and after the demise of Mr Robert Lees, in 1884, Mr Anderson became sole partner of the firm.

Mr Anderson joined the Institution as a Graduate in 1874, and became a Member in 1880.

James MacLellan Blair was born at Glasgow in 1839, and received his education at the Glasgow High School. After serving an apprenticeship in his uncle's firm, Messrs P. & W. MacLellan, Clutha Iron Works, Glasgow, he supervised the carrying out of several important engineering contracts. In 1865 he established the firm of Messrs Blair & Gray, carrying on business at the Clydeside Iron Works, Glasgow, until 1872, when the partnership was dissolved. He then rejoined Messrs P. & W. MacLellan, and three years later became a partner in the firm. In 1890 the firm was formed into a limited liability company, when Mr Blair joined the board of directors, and he remained a director until his death, which occurred suddenly in London on the 19th April, 1906.

Mr Blair was elected a Member of the Institution in 1867.

Henry William Brock, who, died on 10th February, 1906, in his thirty-seventh year, was the elder son of Mr Walter Brock, chief of the firms of Messrs Wm. Denny & Brothers, shipbuilders, and Messrs Denny & Company, engineers, Dumbarton. He was born in Glasgow on 15th March, 1869, and removed with the family to Dumbarton when his father joined the late

Dr. Denny in business thirty-five years ago. He received his schooling at the Burgh Academy, Dumbarton, and Fettes College, Edinburgh, and early showed that he had inherited no mean talent for engineering, for which profession he was designed. In 1886, the subject of this memoir started his apprenticeship with Messrs Denny & Company in the ordinary way, going through the usual shop course. He then went to France to the works of the Forges et Chantiers, Havre, and added to his technical knowledge. From there he went to the east coast of England, where he served in the Central Marine Engineering works, gaining further practical experience. Thirteen years ago he returned to Dumbarton, and was assumed a partner in the firm of Messrs Denny & Company. Four years later he also became a partner in the shipyard firm of Messrs Denny & Brothers. Into the administration of the former concern he threw himself with enthusiasm and was charged with the oversight of the designing and technical sides of the business. A ruling principle guiding his professional career was a keen appreciation of the importance of small things. With infinite patience and protracted labour the late Mr Brock keenly investigated the minutiæ of his profession, and no habit of mind could be more valuable in the study of turbine propulsion, with which his name will be honourably associated.

When Mr Parsons began to demonstrate the possibilities of his steam turbine as a marine motor, Mr Brock was among the first attracted by the adaptability of the new engine—an engine fast revolutionising steamship propulsion. He was among the few on board H.M.S. "Viper," when with turbine engines she steamed at the great speed of 37 knots, and, several months thereafter, joined in the syndicate which commissioned Messrs Denny & Brothers to build, and Messrs Parsons & Company to engine, the Clyde passenger vessel "King Edward," the pioneer commercial turbine steamer. A couple of years later, Messrs Denny & Company secured turbine building rights from the Parsons Company, and under Mr Brock's direction built and fitted to a ship the first set of turbines constructed outside the inventor's own establishment. The ship in question was the "Lunka," belonging to the British India Steam Navigation Company, and now on service in the Persian Gulf. In the application of the turbine to marine propulsion, the deceased was specially honoured. He was selected as one of the experts on the Cunard Turbine Commission, which was appointed to consider the advisability of fitting turbine machinery into the two 25-knot Atlantic liners, which the Cunard Company agreed with the Government to build. In the deliberations and practical work of the Commission the late Mr Brock took a large share. He was responsible for the carrying out of exhaustive experiments on the "Arundel" and "Brighton," two Dumbarton-built sister ships engaged in the English Channel service, and fitted with reciprocating and turbine machinery respectively. The carefully-compiled results of this investigation had conclusive effect on the Commission's decision to recommend the adoption of turbines. But, unfortunately, while Mr Brock had the satisfaction of seeing the Cunard Company accept that recommendation, he was not spared to see the big liners accomplish their task.

Public work was a sphere of activity which did not appeal to the retiring disposition of the deceased. Yet he was ready to lend his aid, and associate his name, with all good objects. He joined the 1st Dumbarton Rifle Volunteers in the year 1887, enlisting as a private in C (Dumbarton) Company. He was promoted Lieutenant in 1892, and became Captain in 1894. This latter post he held for two and a half years, when he retired from the force.

Mr Brock joined the Institutiou as a Member in 1895, and for Sessions 1900-01 and 1901-02 acted as a Member of Council.

John B. Cameron was born at Glasgow in 1844. At an early age he entered the employ of Messrs Barclay, Curle & Co., Ltd., Glasgow, as an apprentice engineer. For many years he led a somewhat adventurous life in Buenos Ayres during the various revolutions there. The last twenty-one years of his life was spent in Glasgow as a consulting engineer. He died on 8th May, 1906.

Mr Cameron was elected a Member of the Institution in 1885.

WALTER DRUMMOND was born at Inverness on 24th May, 1869, and received his early education at the Albany Academy, Glasgow, after which he studied at the University of Glasgow. In 1884 he commenced an apprenticeship at the Caledonian Railway Works, St. Rollox, Glasgow; on the termination of which, in 1890, he was employed at the locomotive works of the Western Railway of France, Batignolles, Paris. Returning to Scotland he became manager of the Glasgow Railway Engineering Works at Govan, and since 1895 was managing director of the company. When on a visit to Wales he contracted influenza, and after-effects developed, necessitating an operation to which he succumbed on 8th July, 1905.

Mr Drummond became a Member of the Institution in 1895.

ROBERT MANSEL was born at Glasgow in 1828. Early in life he evinced a decided turn for mathematics and science which led him to attend the science classes at the Old Mechanics' Institution, and Anderson's College. In 1846 he proceeded to Glasgow University, where he was a distinguished student of Natural Philosophy under Professor William Thomson—now Lord Kelvin—in the first year of Professor Thomson's appointment to that Chair, and was chosen as his first experimental assistant. After completing his engineering studies under Professors Gordon and Macquorn Rankine, Mr Mansel entered the shipyard of Messrs Robert Napier & Sons, Govan, where he became a naval architect.

For more than a dozen years Mr Mansel was intimately connected with the design and construction of the various mercantile and war vessels built by Messrs Robert Napier & Sons, including the Atlantic passenger liners "Persia" and "Scotia," and the armoured frigate "Black Prince." In 1863 Mr Mansel joined Mr James Aitken in establishing at Whiteinch the well-known shipbuilding firm of Aitken & Mansel which for nearly thirty years built a series of up-to-date vessels, including blockade runners during the American Civil War, ocean, cargo, and passenger steamers, as well as cross-channel boats which worthily contributed to the reputation of the Clyde. Mr Mansel was a member of the Scottish Shipbuilders' Association at the time of its incorporation with The Institution of Engineers and Shipbuilders in Scotland in 1865, and he was elected to the presidential chair in 1878. As testified by the volumes of the proceedings, he contributed a number of papers to the Institution.

In 1881, during a strike in his shipbuilding yard, he took a special interest in the design and construction of the first electric drill and riveter invented by Mr Andrew Jamieson, for which he obtained data and made calculations of the work required to be done under different conditions.

Although Mr Mansel was naturally of a quiet and retiring disposition, he took a deep interest in educational questions; more especially those relating to scientific and technical education. He was a Member of Council of the College of Science and Arts from its commencement in 1880 until 1887, when it was amalgamated with Anderson's College. He voluntarily made, at his own expense and in his works, quite a number of substantial experimental models for Principal Jamieson's engineering classes, and annually gave prizes to stimulate the students in their studies of the subjects in which he was more especially interested.

During the later years of his life he maintained his interest in scientific questions, and contributed a series of articles to the *Engineer* on his pet subject, viz., "The Relations Between Speed and Power in Steamships."

Mr Mansel died on Sunday the 10th day of December, 1905, and was buried in the churchyard of Dunblane Cathedral.

JAMES M'EWAN, born at Crieff in June, 1830, served an apprenticeship with Messrs Campbell & Christie, iron founders, Glasgow. He subsequently became foreman of the works controlled by Messrs Alston & Gourlay, and left to take up an appointment with Messrs R. Laidlaw & Co., Alliance Foundry, Glasgow.

In 1871 he commenced business as a founder on his own account in London Road, and some ten years afterwards found it necessary to remove to larger premises at Whiteinch. He had the unusual honour of being twice elected deacon of the Incorporation of Hammermen, and demitted office for the second time only a month or two previous to his death, which took place at Glasgow on 11th January, 1906.

Mr M'Ewan became a Member of the Institution in 1884.

JOHN B. MCHOUL was born in Glasgow on the 22nd November, 1871, and received his education at the Abbotsford School, Glasgow. Leaving school, he joined the service of the Steel Company of Scotland as a clerk for a stipulated time, on the expiration of which he found similar employment in the office of the Palmer Shipbuilding and Iron Coy., Ltd., Jarrow. In 1892 he decided to become an engineer, and returning to Glasgow entered the works of Messrs Copland & Co., engineers, Dobbie's Loan, Glasgow, and served his apprenticeship. He gained further practical knowledge with Messrs A. & W. Smith, engineers, Cook Street, Glasgow, and then became a draughtsman with Messrs Babcock & Wilcox, Ltd., engineers, Renfrew, and three years ago he was appointed their assistant works manager.

He died suddenly on 26th July, 1906, at Scarborough, while on holiday.

Mr McHoul joined the Institution as a Graduate in 1899, and became a Member in 1903.

George Paton was born at his father's farm, Cloverhill, near Bearsden, Dumbartonshire, in 1856. He was educated at Maryhill Public School and at Glasgow University, where he laid the foundations of his extensive knowledge of engineering. After serving an apprenticeship with Messrs Martin & Dunlop, civil and mining engineers, Glasgow, he accepted a post in Japan in company with Prof. Alexander, where he remained five years. Returning to Scotland he joined the staff of the Clyde Navigation Trustees.

In May, 1887, he was appointed to the Chair of Land Surveying and Engineering at the Royal Agricultural College, Cirencester, which he held continuously till his death. In December, 1905, he went to St. Buryan, in Cornwall, intending to pass a portion of the College vacation, and on January 9th, 1906, while residing there, he was suddenly struck down by apoplexy and expired before medical aid could be obtained. His body was removed to the family burying place at Bearsden.

Professor Paton joined the Institution as a Member in 1887.

James Henry Rew died at his residence, Ardfern, Airdrie, on the 19th June, 1906, after a short illness. At his death he was manager of the Imperial Tube Works, Rochsolloch, belonging to Messrs Stewarts & Lloyds.

Mr Rew was born at Stanley, Perthshire, on 27th June, 1848, and received his early education at Whiteinch Public School, his father having left Stanley when the subject of this notice was five years old.

Having early evinced a mechanical turn of mind, Mr Rew was apprenticed to the late firm of Messrs Thomas Wingate & Co., and after serving his time was advanced rapidly to the positions of foreman and draughtsman, and shortly thereafter he occupied similar positions in the service of a firm of engineers in Maryhill. The late Mr John Wilson, at one time M.P. for Govan, appointed him, in 1876, principal foreman in his

Gorbals works, and then manager of his new tube works at Govan, which were designed and supervised during construction by Mr Rew, who was thus their original architect and engineer, the duties of which offices he continued to exercise and discharge in connection with all subsequent additions and reconstructions. These works, as originally designed, were completed in 1880, and Mr Rew conducted their management until 1898. In July of that year he was placed in charge of the large works then being projected by Messrs A. & J. Stewart & Menzies, Limited (now Messrs Stewarts & Llyods, Limited), and for which an extensive piece of ground had been acquired close to Airdrie. In the planning, laying-down, and equipment of these, the Imperial Tube Works, Mr Rew rendered able assistance to the present chairman of Messrs Stewarts & Lloyds, Limited, and his management of them was satisfactory and successful. Mr Rew was an engineer of great and varied attainments and extraordinary ability, who applied to the discharge of his duties well trained mental powers and resources, calm and mature judgment, and reliable experience. His employers respected him in a high degree for his ability, uprightness, and sterling character, and both employers and workmen, as also a large circle of friends, esteemed him as a man of honour, whom it was a delight and a privilege to know.

Mr Rew joined the Institution as a Member in 1896.

Daniel S. Sinclair was born in Glasgow on 8th March, 1859. He was educated at the Glasgow Academy, and thereafter served an apprenticeship with Messrs P. & W. McLellan, Ltd., Glasgow, and was later, for a short period, in the drawing office of Messrs Alley & McLellan, Ltd., Glasgow. During his apprenticeship, and afterwards, he attended classes in the Andersonian College, and in the College of Science and Arts, where he was a distinguished student, winning the Sir John Pender Gold Medal in Electrical Engineering, and taking the College Diploma in Electrical Engineering.

Subsequent to this he was, for one session, assistant to Professor Andrew Jamieson in the latter institution.

In 1884 he went to Cambridge as an assistant to Professor J. J. Thomson, in the Cavendish Laboratory. After being there two years he returned to Glasgow, and was two years in practice as a consulting engineer and electrician before accepting an appointment as general manager of an engineering works in Madras. He filled that position for some time, but finding the climate too trying he came home in 1894, and shortly afterwards entered the service of Messrs D. Stewart & Co., Ltd., London Road Iron Works, Glasgow, with which firm he remained till the time of his death, which occurred at Johannesburg on 5th September, 1905, where he had gone to represent his firm and superintend the installation of a large and important gas-driven electric lighting and power plant for the municipality of Johannesburg.

Mr Sinclair was an able business man and a capable engineer, and his sterling qualities were appreciated by all who knew him.

Mr Sinclair joined the Institution as a Member in 1901.

Thomas Muir Welsh was born at Greenock in 1835, and received his early training as an engineer with the firm of Messrs Scott & Sinclair, Greenock Foundry, now Scott's Engineering & Shipbuilding Co., Ltd.

In 1858 he left Greenock for West Hartlepool, having been appointed chief draughtsman with Messrs Thomas Richardson & Co., and he remained there till the summer of 1863, when he returned to the Clyde to fill the position of engineering manager with Messrs A. & J. Inglis, Glasgow. He became a partner of that firm in 1888, and on the conversion of the business into a limited liability company was appointed a director.

His experience as an engineer was large and varied, ranging from the simple low-pressure engines of his early days through practically every type of paddle and screw engine to the marine steam turbine, the construction of the latter having been commenced by his firm shortly before he was laid aside by his last illness.

He died at Kilmacolm on 27th September, 1905, aged 70.

Mr Welsh joined the Institution as a Member in 1889.

HENRY HARTLEY WEST was born at Salford on 17th September, 1837, and received his education at Kingswood. He was a son of the manse, his father, the Rev. F. A. West, once President of the Wesleyan Conference, was a most distinguished and influential minister of that connection, whose influence for good was far-reaching and lasting.

Mr West commenced his professional career as an apprentice to the late Mr John Jones, engineer, Liverpool, whose firm subsequently became known as John Jones & Son. In 1860 he was appointed resident engineer on the gunpowder works of Messrs John Hall & Son, of London and Faversham, and two years later he became manager to Messrs Pearson, Dannatt & Krüger, engineers and shipbuilders, Hull, and occupied that position until the closing of their works in 1863, which was brought about by the purchase of their premises for dock extension. In December, 1863, he received an appointment as a surveyor on the administrative and technical staff of the Underwriters' Registry for Iron Vessels, Liverpool, in which district he remained until 1867, when he was promoted to be chief surveyor in Scotland with his headquarters at Glasgow. He discharged the duties of that office zealously, successfully, and satisfactorily, and in March, 1875, he left Glasgow for Liverpool to assume the reins of office there as chief surveyor for the west and south of England, including London, being further promoted in the following year to be chief surveyor for the United Kingdom, an office especially created at that time. This post he filled with continued acceptance and credit until the amalgamation of the Underwriters' Registry for Iron Vessels with Lloyd's Register of British and Foreign Shipping in 1885.

When this event occurred, Mr West's long and well established reputation as a professional adviser and expert in engineering and shipbuilding questions, as well as his intimate acquaintance with shipowners all over the country, induced him to start business in Liverpool as a consulting engineer and naval architect, and in this connection he was eminently successful also. He was consulted upon, and was responsible for the distribution of material and the scantling arrangements to provide the requisite strength in some of the largest steamers afloat. His technical skill was frequently requisitioned in connection with important engineering matters, and as an arbiter his judgments were invariably accepted. In the question of mechanical road-traction he took a more than ordinary interest, and at the request of the Self-Propelled Traffic Association he consented to act as one of the judges of the road trials. He was also one of the delegates appointed to investigate and report upon the advancement made in the construction and development of motor traction in France.

For many years Mr West was a member of the principal technical institutions in Britain, and was a prominent figure at their meetings, as also a frequent contributor of important papers to their proceedings. He was also a Member of Council of the Institution of Naval Architects, and a Past President of the Liverpool Engineering Society.

He died at his residence, Hamilton Square, Birkenhead, on 13th August, 1906.

Mr West joined the Institution as a Member in 1868.

ALEXANDER WYLIE was born at Elderslie, near Johnstone, in the year 1847, and at an early age entered the employment of Messrs Brown, Malloch & Co., cotton spinners there. While still a young man he received an invitation to join the staff of the firm of Messrs J. & W. Weems, engineers, Johnstone, the senior partner of which firm, the late Mr John Weems, was a man of great inventive capacity; and Mr Wylie was largely associated with him in the development of his inventions, especially those connected with the manufacture of lead pipes and sheets. Mr Wylie's business tact and assiduity soon won for him a position in the firm, and he was assumed a partner in 1886.

After the dissolution of his firm some years later, he joined the late Mr John Wilson, ex-M.P. for Govan, and with him established the Vulcan Works, Johnstone, where he continued the manufacture of the specialties he had assisted developing in his former firm; and, further, as a result of the development of the electrical industries, he invented a machine for the covering of electrical conductors with lead in continuous lengths, and constructed several hydraulic machines for this purpose, giving a gross power of upwards of 10,000 tons. His invention was well received by the manufacturers of electric cables, and presses constructed by him are exclusively adopted in all the principal cable works in this country, as well as being extensively adopted by makers both in France and Germany.

Mr Wylie also invented machines for the manufacture of brass and yellow metal rods and sections by extrusion, which have also been largely adopted.

On all matters connected with the lead and cable trades, Mr Wylie was an acknowledged expert, and his advice was much sought after and greatly valued by all those interested in these manufactures.

He died, in his 59th year, on January 9th, 1906.

Mr Wylie joined the Institution as a Member in 1897.

Associates.

LORD INVERCLYDE was born on 17th September, 1861, and died at Castle Wemyss, on 8th October, 1905. His grandfather was one of the founders of the Cunard Company, and also the pioneer of the direct sea service between Scotland and Ireland, and of the first line of steamships between Glasgow and the Highlands and Islands of Scotland. To the unwearying energy and business ability of his father was largely due the success of the Cunard Company, with whose management he was from his early years associated.

George Arbuthnot Burns, second Baron Inverclyde, followed the traditions of his family. After receiving a liberal education, he made a lengthened tour abroad, visiting India, China, and Australia. On his return to this country he entered the office of the Cunard Company, where, passing through the principal departments, he acquired a thorough knowledge of the ramifications of the business. His father died in 1901, and was succeeded in the Chairmanship of the Cunard Line by Mr David Jardine, who retired less than a year afterwards. The subject of this memoir then became chairman, and remained in that capacity until his death, guiding the Company in many important negotiations. Throughout the Atlantic rate war, in which the Cunard Company fought the International Mercantile Marine Association, combined with the Hamburg - American Company and the Norddeutscher Lloyd, he acted for the Cunard Company and held out determinedly for the all-British character of that Line. Subsequently, in the negotiations with the British Government concerning the two subsidised express steamers, "Lusitania" and "Mauretania," for the Cunard service, he took the leading part and helped to organise the "Turbine Commission," a body of marine engineering experts, who investigated the question of applying turbines to the proposed vessels, and decided in favour of applying that type of machinery.

Lord Inverclyde was also a partner and director in the firm of Messrs G. & J. Burns, Ltd., and a director of the Glasgow & South Western Railway Company, and of the Clydesdale Bank. He took an active interest in many philanthropic and benevolent movements in the city of Glasgow, and for two years, from 1902, filled the office of Lord Dean of Guild of the city.

Lord Inverclyde joined the Institution as an Associate in 1904.

THOMAS MILLAR, general manager of the Gem Line of Steamers, owned by Mr William Robertson, was born on 16th August, 1855, at Hamilton, and received his early education there.

He died at his residence, Hazelwood, Langside, Glasgow, on 31st May, 1905.

Mr Millar joined the Institution as an Associate in 1898.

JAMES S. NAPIER, founder of the firm of Messrs Napier & McIntyre, iron merchants, Oswald Street, Glasgow, died at his home in West Kilbride on the 7th September, 1906, in his 77th year. Mr Napier was a son of Mr James Napier, brother of the famous Robert Napier, a pioneer of the Clyde shipbuilding industry, and was born at Glasgow on the 29th December, 1829. A shrewd, able, and upright man of business, Mr Napier was held in high esteem in commercial circles in Glasgow, but was more widely known for the great interest he took in religious and charitable work. With the poor of Glasgow especially, he had a deep sympathy, and readily supported every movement for the amelioration of their condition.

At various times he was connected with the management of different charitable institutions, of which he was a liberal supporter. Indeed, his generosity can hardly be overstated, for he spent a large income mainly in the interests of others.

Mr Napier was an Associate of the Scottish Shipbuilders' Association at the time of its incorporation with the Institution in 1865.

HENRY JAMES WATSON was born in Glasgow in 1833. On leaving school he entered the office of his father, who owned several wooden sailing ships trading between Glasgow and Quebec. On the death of his father the business was continued by Mr Watson and his brother under the name of

Watson Brothers, and they were among the first firms in Glasgow to own iron ships.

Mr Watson retired from business some years ago, and died at his residence Burnbrae, Bridge of Allan, on 9th June, 1906.

Mr Watson was an Associate of the Scottish Shipbuilders' Association at the time of its incorporation with the Institution in 1865.

LIST OF HONORARY MEMBERS, MEMBERS, ASSOCIATE MEMBERS, ASSOCIATES, AND STUDENTS

AT CLOSE OF SESSION 1905-1906.

HONORARY MEMBERS.

	DATE OF ELECTION.
KELVIN, Lord, G.C.V.O., O.M., P.C., LL.D., D.C.L., Netherhall, Largs,	1859
BRASSEY, Lord, K.C.B., D.C.L., 4 Great George street, Westminster, London, S.W.,	1891
BLYTHSWOOD, Lord, Blythswood, Renfrewshire,	1891
KENNEDY, Sir A. B. W., LL.D., F.R.S., 17 Victoria street, London, S.W.,	1891
WHITE, Sir WILLIAM HENRY, K C.B., F.R.S., LL.D., D.Sc., Cedar Croft, Putney Heath, London, S.W.,	1894
DURSTON, Sir A. J., K.C B., Westcomlea, Park Road, Blackheath, London, S.E.,	1896
FROUDE, R. E., LL.D., F.R.S., Admiralty Experiment works, Gosport,	

MEMBERS.

	DATE OF ELECTION.
AAMUNDSEN, JENS L., Amaliegade 6, Copenhagen, Denmark,	24 Jan., 1899
ABERCROMBIE, ROBERT GRAHAM, Broad Street Engine Works, Alloa,	21 Mar., 1899
ADAM, J. MILLEN, Ibrox Iron works, Glasgow,	G. 25 Mar., 1890 M. 22 Jan., 1895
ADAMSON, JAMES, St. Quivox, Stopford road, Upton Manor, Essex,	23 Apr., 1889
ADAMSON, PETER HOGG, 2 Thornwood terrace, Partick,	19 Mar., 1901
AILSA *(The most Honourable the Marquis of)*, Culzean castle, Maybole,	25 Jan., 1898

Names marked thus * were Members of Scottish Shipbuilders' Association at incorporation with Institution, 1865.

Names marked thus † are Life Members.

AITKEN, H. WALLACE, 147 Bath Street, Glasgow,	G. 24 Jan., 1888 M. 24 Jan., 1899
AITON, J. ARTHUR, Western Works, Hythe Road, Willesden Junction, London, N.W.,	24 Nov., 1896
ALEXANDER, JOHN, Engineer, Barrhead,	19 Mar., 1901
ALEXANDER, JOHN, 31 Kelvingrove street, Glasgow,	24 Oct., 1905
ALLAN, ROBERT, Demerara Foundry, Georgetown, Demerara,	30 Apr., 1895
ALLEY, STEPHEN E., 5 Huntly gardens, Kelvinside, Glasgow,	23 Nov., 1897
†ALLIOTT, JAMES B., The Park, Nottingham,	21 Dec., 1864
ALLO, OSCAR EDWARD, 100 Bothwell street, Glasgow,	22 Mar., 1904
ALSTON, WILLIAM M., 24 Sardinia terrace, Hillhead, Glasgow,	G. 15 Feb., 1865 M. 18 Dec., 1877
†AMOS, ALEXANDER, Glen Alpine, Werris Creek, New South Wales,	21 Dec., 1886
†AMOS, ALEXANDER, Jun., Braeside, 81 Victoria Street (North), Darlinghurst, Sydney, New South Wales,	21 Dec., 1886
ANDERSON, ALEXANDER, 176 Balgray hill, Springburn, Glasgow,	24 Nov., 1903
ANDERSON, ALFRED WALTER, Blackness Foundry, Dundee,	27 Oct., 1903
†ANDERSON, E. ANDREW, c/o Clinton, 13 Holmhead street, Glasgow,	21 Feb., 1899
ANDERSON, F. CARLTON, Messrs G. Harland, Bowden & Co., 196 Deansgate, Manchester,	23 Apr., 1901
ANDERSON, GEORGE C., 13 Balmoral drive, Cambuslang,	G. 24 Dec., 1895 M. 27 Oct., 1903
ANDERSON, J. GODFREY, B.Sc., c/o Messrs James Templeton & Co., Greenhead, Glasgow,	19 Mar., 1901
†ANDERSON, JAMES, Ravelston, Great Western Road, Glasgow,	26 Nov., 1901
ANDERSON, JAMES H., Caledonian Railway, Glasgow,	20 Dec., 1892
ANDERSON, JOHN, 40 West Nile street, Glasgow,	20 Dec., 1904
ANDERSON, ROBERT, Clyde Street, Renfrew,	26 Jan., 1897
ANDERSON, WILLIAM MARTIN, 102 Union street, Glasgow,	18 Dec., 1900
ANDERSON, WILLIAM SMITH, Alderwood East, Port-Glasgow,	21 Nov., 1899
ANDREW, DAVID, Jun., 116 Hope street, Glasgow,	19 Dec., 1905
ANDREWS, H. W., 128 Hope street, Glasgow,	A. 21 Dec., 1897 M. 24 Oct., 1899
ANDREWS, JAMES, Kelvin Engineering works, Kirkintilloch,	22 Nov., 1898
ANGUS, ROBERT, Lugar, Old Cumnock, Ayrshire,	28 Nov., 1860
ANIS, MOHAMED, Pasha, Chief of the Technical Department, P.W.D., Cairo,	24 Apr., 1894

APPLEBY, JOHN R., 133 Balshagray avenue, Partick,		21 Feb., 1905
ARCHER, W. DAVID, 47 Croham road, Croyden, Surrey,		20 Dec., 1887
ARNOT, WILLIAM, 91 Hyndland street, Partick,		26 Apr., 1904
ARNOTT, HUGH STEELE, 99 Clarence drive, Hyndland, Glasgow,	G. M.	26 Oct., 1897 22 Jan., 1901
ARROL, THOMAS, 32 Falkland mansions, Hyndland, Glasgow,		27 Oct., 1903
ARROL, THOMAS, Oswald gardens, Scotstounhill, Glasgow,		20 Nov., 1894
†ARROL, Sir WILLIAM, LL.D., Dalmarnock Iron works, Glasgow,		27 Jan., 1885
ARROL, WILLIAM, 47 Kelvinside gardens, Glasgow,		27 Oct., 1903
ATCHLEY, CHARLES ATHERTON, 50 Wellington street, Glasgow,	A.M. M.	24 Jan., 1905 20 Mar., 1906
AULD, JOHN, Whitevale foundry, Glasgow,		28 Apr., 1885
AULD, JOHN, Pollok buildings, Cockerhill, Glasgow,		21 Mar., 1905
AUSTIN, WILLIAM R., 61 Brisbane Street, Greenock,		23 Feb., 1897
BAGSHAWE, BENJAMIN WYATT, 50 Wellington street, Glasgow,		20 Feb., 1906
BAILLIE, ROBERT, c/o Stirling Boiler Company, Limited, Motherwell,		20 Nov., 1900
BAIN, WILLIAM N., 40 St. Enoch square, Glasgow,		24 Feb., 1880
BAIN, WILLIAM P. C., Lochrin Iron works, Coatbridge,		28 Apr., 1891
BAIRD, ALLAN W., Romiley, Erskine avenue, Dumbreck, Glasgow,		25 Oct., 1881
BALDERSTON, JAMES, Gateside, Paisley,		25 Jan., 1898
BALDERSTON, JOHN A., Vulcan Works, Paisley,		18 Dec., 1900
BALFOUR, GEORGE, Messrs J. G. White & Co., Ltd., 22a College hill, Cannon street, London, E.C.,		21 Mar., 1899
BALLANTINE, THOMAS, Messrs A. Stephen & Son, Linthouse, Glasgow,		24 Jan., 1905
BALLANTYNE, JOHN HUTCHISON, 116 Pollok street, Glasgow,		25 Oct., 1904
BALLINGALL, DAVID, c/o Messrs. Richard Hornsby & Son, Ltd., Spittlegate Iron Works, Grantham,		27 Oct., 1896
BAMFORD, HARRY, M.Sc., The University, Glasgow,		24 Nov., 1896
BARMAN, HARRY D. D., 21 University avenue, Glasgow,	G. M.	24 Apr., 1888 24 Oct., 1899
BARNETT, J. R., Westfield, Crookston,		22 Dec., 1896
BARNETT, MICHAEL R., 124 St. Vincent street, Glasgow,		22 Nov., 1887
BARR, Professor ARCHIBALD, D.Sc., Royston, Dowanhill, Glasgow,		21 Mar., 1882
BARR, JAMES, 67 Durward avenue, Shawlands, Glasgow,		20 Dec., 1904

BARR, JOHN, Glenfield Company, Kilmarnock,	A. 28 Oct., 1883 M. 25 Jan., 1898
BARROW, JOSEPH, Messrs Thomas Shanks & Co., Johnstone,	19 Feb., 1901
BAXTER, GEORGE H., Clyde Navigation works, Dalmuir,	22 Mar., 1881
BAXTER, P. M'L., Copland works, Govan,	G. 22 Dec., 1885 M. 15 June, 1898
BEALE, SAMUEL R., The Crown Iron works, North Woodside road, Glasgow,	20 Mar., 1906
BEARDMORE, JOSEPH GEORGE, Parkhead forge, Glasgow,	22 Nov., 1898
BEARDMORE, WILLIAM, Parkhead forge, Glasgow,	27 Oct., 1896
BEGBIE, WILLIAM, P.O. Box 3982, Johannesburg, South Africa,	15 June, 1898
*†BELL, DAVID, 19 Eton place, Hillhead, Glasgow,	
BELL, IMRIE, 49 Dingwall road, Croydon, Surrey,	23 Mar., 1880
BELL, JOHN HART, Messrs Cochran & Co., Annan,	23 Jan., 1906
BELL, STUART, 163 Hope street, Glasgow,	26 Feb., 1895
BELL, THOMAS, Messrs John Brown & Co., Ltd., Clydebank,	G. 26 Apr., 1887 M. 27 Apr., 1897
BELL, W. REID, Transvaal Department of Irrigation and Water Supply, Box 78, Potchefstroom, South Africa,	22 Jan., 1889
BELSEY, WALTER JAMES, 91 Wellington street, Glasgow,	24 Oct., 1905
BENNIE, H. OSBOURNE, Clyde Engine works, Cardonald, Glasgow,	25 Jan., 1898
BERGIUS, W. C., 8 Marlborough terrace, Glasgow, W.,	23 Jan., 1900
BEVERIDGE, RICHARD JAMES, 53 Waring street, Belfast,	22 Feb., 1898
BIGGART, ANDREW S., Inchgarvie, 39 Sherbrooke avenue, Pollokshields, Glasgow,	G. 20 Mar., 1883 M. 25 Nov., 1884
BILES, Professor JOHN HARVARD, LL.D., The University, Glasgow,	25 Mar., 1884
BINNIE, R. B. JARDINE, Carntyne Works, Parkhead,	24 Dec., 1901
BIRD, JOHN R., 10 Morrison street, Glasgow,	25 Mar., 1890
BISHOP, ALEXANDER, 3 Germiston street, Glasgow,	G. 24 Mar., 1885 M. 24 Jan., 1899
BLACK, JOHN W., 108a West Regent street, Glasgow,	G. 25 Oct., 1892 M. 27 Oct., 1903
BLAIR, ARCHIBALD, 21 Havelock street, Dowanhill, Glasgow,	G. 27 Oct., 1885 M. 27 Oct., 1903
BLAIR, DAVID A., Scotland street Copper works, Glasgow	23 Mar., 1897
BLAIR, FRANK R., Ashbank, Maryfield, Dundee,	G. 22 Mar., 1892 M. 21 Apr., 1903
BLAIR, GEORGE, Jun., 38 Queen street, Glasgow,	G. 22 Jan., 1884 M. 23 Feb., 1897
BOAK, WILLIAM, Messrs Delmege, Forsyth & Co., Colombo, Ceylon,	24 Oct., 1905

BONE, WILLIAM L., Ant and Bee works, West Gorton, Manchester,		23 Oct., 1883
BOOTH, ROBERT, Glengelder, Cowey road, Durban, Natal,		26 Jan., 1904
BORROWMAN, WILLIAM C., Strathmore, West Hartlepool,	G. M.	27 Oct., 1887 26 Oct., 1895
BOST, W. D. ASHTON, Adelphi house, Paisley,		25 Jan., 1898
BOW, WILLIAM, Thistle works, Paisley,		27 Jan., 1891
BOWMAN, WILLIAM DAVID, 21 Kersland terrace, Hillhead, Glasgow,	G. M.	22 Dec., 1891 24 Nov., 1903
BOWSER, CHARLES HOWARD, Charles street, St. Rollox, Glasgow,		21 Mar., 1899
BOYD, JOHN WHITE, 7 Royal Bank place, Glasgow,		24 Jan., 1905
BRACE, GEORGE R., 25 Water street, Liverpool,		25 Mar., 1890
BRAND, MARK, B.Sc., Barrhill cottage, Twechar, Kilsyth,	G. M.	24 Jan., 1888 21 Apr., 1903
BREINGAN, W. D., Barns place, Clydebank,		22 Jan., 1901
BREWER, J. ALFRED, 58 St Vincent street, Glasgow,		20 Nov., 1900
BRIER, HENRY, 1 Miskin road, Dartford, Kent,		22 Dec., 1891
BROADFOOT, JAMES, Lymehurst, Jordanhill, Glasgow,	G. M.	23 Dec., 1873 22 Jan., 1884
BROADFOOT, WILLIAM R., Inchholm works, Whiteinch, Glasgow,		25 Jan., 1898
*BROCK, WALTER, Engine works, Dumbarton,		26 Apr., 1865
BROCK, WALTER, Jun., Levenford, Dumbarton,		27 Oct., 1896
BROEKMAN, LOUIS, Standard Buildings, City square, Leeds,		22 Nov., 1904
BROOKFIELD, JOHN WAITES, Halifax Graving Dock Co., Halifax, Nova Scotia,	S. M.	18 Feb., 1902 20 Dec., 1904
BROOM, THOMAS M., 11 Union street, Greenock,		25 Apr., 1893
BROWN, ALEXANDER D., Dry Dock, St. John's, Newfoundland,		22 Dec., 1896
BROWN, ALEXANDER T., 18 Glencairn drive, Pollokshields, Glasgow,	G. M.	25 Feb., 1879 27 Oct., 1891
*†BROWN, ANDREW, London works, Renfrew,		16 Feb., 1859
BROWN, ANDREW M'N., Strathclyde, Dalkeith avenue, Dumbreck, Glasgow,	G. M.	25 Jan., 1876 24 Nov., 1885
†BROWN, DAVID A., 41 Rosslyn crescent, Edinburgh,	G. M.	23 Feb., 1897 27 Oct., 1903
BROWN, EBENEZER HALL-, Helen street Engine works, Govan,	G. M.	18 Dec., 1883 26 Feb., 1895
BROWN, GEORGE, Garvel Graving Dock, Greenock,		23 Mar., 1886
BROWN, JAMES, c/o Messrs. Scott & Co., Greenock,	G. M.	26 Oct., 1886 26 Jan., 1892
BROWN, JAMES M'N., 15 Falkland Mansions, Hyndland, Glasgow,		26 Jan., 1897

BROWN, J. POLLOCK, 1 Broomhill avenue, Partick, Glasgow, — G. 18 Dec., 1894; M. 22 Dec., 1903

BROWN, MATTHEW T., B.Sc., 21 Bisham gardens, Highgate, London, N., — G. 25 Jan., 1881; M. 18 Dec., 1894

BROWN, ROBERT, 7 Church road, Ibrox, Glasgow, — 18 Feb., 1902

BROWN, WALTER, Monkdyke, Renfrew, — 28 Apr., 1885

BROWN, WILLIAM, Kilrene, 7 Whittinghame gardens, Glasgow, W., — G. 27 Jan., 1874; M. 22 Jan., 1884

BROWN, WILLIAM, Albion works, Woodville street, Govan, — 21 Dec., 1880

BROWN, WILLIAM, Messrs Dübs & Co., Glasgow Locomotive works, Glasgow, — 17 Dec., 1889

BROWN, WILLIAM DEWAR, — 25 Mar., 1890

BRUCE, CHARLES ROSS, 37 Newton street, Greenock, — 20 Dec., 1904

BRUHN, JOHANNES, D.Sc., 23 Methuen park, Muswell hill, London, N., — G. 24 Oct., 1893; M. 22 Feb., 1898

BRYAN, MATTHEW REID, 1 Royal terrace, Springburn, Glasgow, — 24 Nov., 1903

BRYSON, WILLIAM ALEXANDER, 16 Charlotte street, Leith, — 27 Oct., 1896

BUCHANAN, JOHN H., 5 Oswald street, Glasgow, — 23 Jan., 1900

BUCKWELL, GEORGE W., Board of Trade Surveyors' Office, Barrow-in-Furness, — 27 Apr., 1897

BUDD, EDWARD R., Messrs G. & A. Harvey, Ltd., Albion works, Govan, — 20 Dec., 1904

BUDENBERG, CHRISTIAN FREDERICK, 31 Whitworth street, Manchester, — 20 Dec., 1898

BULLARD, E. P., Jun., Bridgeport, Conn., U.S.A., — 29 Oct., 1901

BURDEN, ALFRED GEORGE NEWKEY, Messrs J. W. Smyth & Co., Aegis buildings, Johannesburg, South Africa, — 20 Feb., 1900

BURNS, WILLIAM, J. L., Bankok Dock Co., Bankok, Siam, — A.M. 26 Jan. 1904; M. 25 Oct., 1904

BURNSIDE, WILLIAM, New Nile bridge, Rodo Island, Cairo, Egypt, — 27 Oct., 1903

BURT, PETER, Hollybank, Bothwell, — 20 Mar., 1906

BURT, THOMAS, 1 Royal terrace, Glasgow, — 22 Mar., 1881

BUTTERS, JAMES THOMAS, Percy Crane & Engine Works, Glasgow, — 19 Mar., 1901

BUTTERS, MICHAEL W., 20 Waterloo street, Glasgow, — 24 Oct., 1899

CAIRD, ARTHUR, Messrs Caird & Co., Ltd., Greenock, — 27 Oct., 1896

†CAIRD, EDWARD B., 777 Commercial road, Limehouse, London, — 29 Oct., 1878

†CAIRD, PATRICK T., Messrs Caird & Co., Ltd., Greenock, — 27 Oct., 1896

CAIRD, ROBERT, LL.D., Messrs Caird & Co., Ltd., Greenock, 20 Feb., 1894

CALDER, JOHN, 10 Prospect avenue, Ilion, New York, U.S.A., {G. 24 Feb., 1891 / M. 27 Oct., 1903}

CALDERWOOD, WILLIAM T., Stanley villa, Cathcart, Glasgow, 25 Jan., 1898

CALDWELL, JAMES, 130 Elliot street, Glasgow, 17 Dec., 1878

CAMERON, ANGUS, Union Steamship Co. of New Zealand, Dunedin, N Z., 18 Feb., 1902

CAMERON, DONALD, 7 Bedford circus, Exeter. 25 Feb., 1890

CAMERON, HUGH, 40 Camperdown road, Scotstoun, Glasgow, {G. 25 Oct., 1892 / M. 27 Oct., 1903}

CAMERON, WILLIAM, Arlington, Seedhill road, Paisley, 25 Mar., 1890

CAMPBELL, ANGUS, De La-Beche terrace, Sketty, Swansea, {G. 24 Jan., 1888 / M. 27 Oct., 1903}

CAMPBELL, DUNCAN, Carntyne foundry and engineering works, Parkhead, Glasgow, 23 Jan., 1900

CAMPBELL, HUGH, The Campbell Gas Engine Company, Halifax, Yorkshire, 18 Dec., 1900

CAMPBELL, JAMES, 104 Bath street, Glasgow, 18 Dec., 1900

†CAMPBELL, THOMAS, Maryhill Iron works, Glasgow, 20 Nov., 1900

CAREY, EVELYN G., 4 Sunnyside avenue, Uddingston, 22 Oct., 1889

CARLAW, ALEX. L., 11 Finnieston street, Glasgow, 24 Dec., 1895

CARLAW, DAVID, Jun., 11 Finnieston street, Glasgow, 24 Dec., 1895

CARLAW, JAMES W., 11 Finnieston street, Glasgow, 24 Dec., 1895

CARMICHAEL, ANGUS T., Medveid, Stuart avenue, Scotstoun, Glasgow, 19 Mar., 1901

CARRUTHERS, JOHN H., Ashton, Queen Mary avenue, Crosshill, Glasgow, 22 Nov., 1881

CARSLAW, WILLIAM H., Jun., Parkhead boiler works, Parkhead, Glasgow, {G. 23 Dec., 1890 / M. 27 Oct., 1903}

CARVER, THOMAS, A. B., D.Sc., 118 Napiershall street, Glasgow, 19 Feb., 1901

CHALMERS, WALTER, Ethel cottage, Bishopriggs, Glasgow, 23 Jan., 1900

CHAMEN, W. A., Royal chambers, Queen street, Cardiff, 22 Feb., 1898

CHISHOLM ROBERT, 1 Albany quadrant, Springboig, Shettleston, 29 Oct., 1901

CHRISTIE, JOHN, Corporation Electricity Works, Brighton, 22 Nov., 1898

CHRISTIE, R. BARCLAY, Messrs M'Lay & M'Intyre, 21 Bothwell street, Glasgow, 25 Apr., 1893

CHRISTISON, GEORGE, 13 Cambridge drive, Glasgow, 22 Feb., 1898

CLARK, JOHN, British India Steam Navigation Co., 9 Throgmorton avenue, London, E.C., 23 Jan., 1883

CLARK, WILLIAM, 208 St. Vincent street, Glasgow, 25 Apr., 1893

CLARK, WILLIAM, Companhia Carris de Ferro de Lisbon, Lisbon, Portugal,		22 Dec., 1896
CLARK, WILLIAM, 23 Royal Exchange square, Glasgow,		26 Jan., 1904
CLARK, WILLIAM GRAHAM, 29 Church road, Waterloo, Liverpool,		22 Feb., 1898
CLARKSON, CHARLES, Falkirk Iron works, Falkirk,		27 Oct., 1891
CLEGHORN, ALEXANDER, 14 Hatfield drive, Kelvinside, Glasgow,		22 Nov., 1892
CLELAND, W. A., Yloilo, Philippine Islands,	G. M.	25 Apr., 1893 25 Nov., 1902
CLYNE, JAMES, Messrs Clyne, Mitchell, & Co., Commercial road, Aberdeen,		18 Dec., 1900
COATS, ALLAN, Jun., B.Sc., Hayfield, Paisley,		23 Oct., 1900
†COBB, FRANCIS HILLS, Public Works Department, Berbera, British Somaliland,		24 Jan., 1905
COCHRAN, JAMES T., 52 Woodville gardens, Langside, Glasgow,		26 Feb., 1884
COCHRANE, JAMES, Resident Engineer's Office, Harbour works, Table Bay, Capetown,	G. M.	27 Oct., 1891 22 Dec., 1903
COCHRANE, JOHN, Grahamston foundry, Barrhead,		25 Mar., 1890
COCKBURN, GEORGE, Cardonald, near Glasgow,		25 Oct., 1881
COCKBURN, ROBERT, Cumbrae House, Dumbreck, Glasgow,		25 Jan., 1898
COLVILLE, ARCHIBALD, 51 Clifford street, Bellahouston, Govan,		23 Jan., 1900
COLVILLE, ARCHIBALD, Motherwell,		27 Oct., 1896
†COLVILLE, DAVID, Jerviston house, Motherwell,		27 Oct., 1896
CONNELL, CHARLES, Whiteinch, Glasgow,	G. M.	19 Dec., 1876 25 Mar., 1884
CONNER, ALEXANDER, 6 Grange Knowe, Irvine road, Kilmarnock,	G. M.	26 Feb., 1884 24 Jan., 1899
CONNER, BENJAMIN, 196 St. Vincent street, Glasgow,	G. M.	22 Dec., 1885 26 Oct., 1897
CONNER, JAMES, English Electric Manufacturing Co., Limited, Preston,		20 Nov., 1900
CONNER, JAMES,	G. M.	18 Dec., 1877 24 Nov., 1885
CONSTANTINE, EZEKIEL GRAYSON, The Stirling Boiler Co., Ltd., Motherwell,		26 Apr., 1904
COPELAND, JAMES,		17 Feb., 1864
COPESTAKE, S. G. G., 40 Queen Mary avenue, Glasgow, S.,		11 Mar., 1868
†COPLAND, Sir WILLIAM R., 146 W. Regent street, Glasgow,		20 Jan., 1864
CORMACK, Prof. JOHN DEWAR, B.Sc., University College, Gower street, London, W.C.,		24 Nov., 1896
COSTIGANE, A. PATON, Longcroft, Thorntonhall, Lanarkshire,		20 Jan., 1903

Coulson, W. Arthur, 47 King street, Mile-end, Glasgow, 15 June, 1898

Couper, Sinclair, Moore Park boiler works, Govan, {G. 21 Dec., 1880 / M. 27 Oct., 1891}

Cousins, John Booth, 75 Buchanan street, Glasgow, 22 Mar., 1904

Coutts, Francis, 280 Great Western road, Aberdeen, {G. 27 Oct., 1885 / M. 24 Jan., 1899}

Cowan, David, Coulport house, Loch Long, Dumbartonshire, 24 Apr., 1900

Cowan, John, 8 Wilton mansions, Kelvinside N., Glasgow, 27 Apr., 1897

Cowan, John, Clydebridge Steel Co., Ltd., Cambuslang, 16 Dec., 1902

+Cowie, William, 51 Endsleigh gardens, Ilford, Essex, 20 Feb., 1900

Craig, Alexander, 124 St. Vincent street, Glasgow, {G. 26 Nov., 1895 / M. 16 Dec., 1902}

Craig, Archibald Fulton, Belmont, Paisley, 25 Jan., 1898

Craig, James, Lloyd's Registry, 14 Cross-shore street, Greenock, {G. 20 Dec., 1892 / M. 21 Dec., 1897}

Craig, John, 32 Cartside quadrant, Langside, Glasgow, 22 Jan., 1900

Cran, John, Albert Engine works, Leith, 21 Jan., 1902

Crawford, James, 30 Ardgowan street, Greenock, 27 Oct., 1896

Crighton, James, Rotterdamsche Droogdok, Maatschapij, Rotterdam, Holland, {G. 23 Nov., 1897 / M. 20 Jan., 1903}

Crighton, John, 14 Cawley road, Hackney, London, N.E. {G. 26 Nov., 1901 / A.M. 20 Jan., 1903 / M. 22 Dec., 1903}

Crockatt, William, 179 Nithsdale road, Pollokshields, Glasgow, 22 Mar., 1881

Crosher, William, 74 York street, Glasgow, 24 Jan., 1899

Crow, John, Trynlaw, Merrylee road, Newlands, Glasgow, 25 Jan., 1898

Cunningham, Peter N., Easter Kennyhill House, Cumbernauld road, Glasgow, 23 Dec., 1884

Cunningham, P. Nisbet, Jun., Easter Kennyhill House, Cumbernauld road, Glasgow, {G. 22 Nov., 1898 / M. 3 May, 1904}

Cuthill, William, Beechwood, Uddingston, 24 Nov., 1896

Darroch, John, 93 Millbrae road, Langside, Glasgow, 24 Jan., 1899

Davidson, David, 17 Regent Park square, Strathbungo, Glasgow, {G. 22 Mar., 1881 / M. 18 Dec., 1888}

Davie, James, Johnstone Engine works, High street, Johnstone, 19 Dec., 1899

Davie, William, 50 Lennox avenue, Scotstoun, Glasgow, 22 Dec., 1903

Davis, Charles H., 25 Broad street, New York, U.S.A., 20 Nov., 1900

DAVIS, HARRY LLEWELYN, Messrs Cochran & Co., Ltd., Newbie, Annan,	G. 18 Dec., 1888 M. 23 April, 1901
DAWSON, CHARLES E., 571 Sauchiehall street, Glasgow,	21 Jan., 1902
DAY, CHARLES, Huntly lodge, Ibroxholm, Glasgow,	24 Nov., 1903
DELACOUR, FRANK PHILIP, Baku, Russia,	24 Apr., 1900
DELMAAR, FREDERICK ANTHONY, Sourabaya, Netherlands East Indies,	G. 24 Apr., 1883 M. 24 Oct., 1899
DEMPSTER, JAMES, 7 Knowe terrace, Pollokshields, Glasgow,	24 Jan., 1899
DENHOLM, JAMES, 3 Westminster crescent, Crow road, Partick,	21 Nov., 1883
DENHOLM, WILLIAM, Meadowside Shipbuilding yard, Partick, Glasgow,	G. 18 Dec., 1883 M. 21 Nov., 1893
DENNY, ARCHIBALD, Cardross park, Cardross,	21 Feb., 1888
DENNY, JAMES, Engine works, Dumbarton,	25 Oct., 1887
DENNY, Col. JOHN M., Helenslee, Dumbarton,	27 Oct., 1896
DENNY, LESLIE, Leven Shipyard, Dumbarton,	30 Apr., 1895
DENNY, PETER, Crosslet, Dumbarton,	21 Feb., 1888
†DEWRANCE, JOHN, 165 Great Dover street, London, S.E.,	19 Feb., 1901
DICK, FRANK W., c/o The Parkgate Steel & Iron Co., Ltd., Parkgate works, Rotherham.	19 Mar., 1878
DICK, JAMES, 12 Ronald street, Coatbridge,	18 Mar., 1902
DICKIE, DAVID W., 141 West 3rd street, Dayton, Ohio, U.S.A.,	S. 22 Mar., 1904 M. 24 Oct., 1905
DIMMOCK, JOHN WINGRAVE, Lloyd's Register of Shipping, 342 Argyle street, Glasgow,	22 Mar., 1898
DIXON, JAMES S., LL.D., 127 St. Vincent street, Glasgow,	G. 24 Dec., 1873 M. 22 Jan., 1878
DIXON, WALTER, Derwent, Kelvinside gardens, Glasgow,	26 Feb., 1895
DOBBIE, JOHN GOURLAY, 203 West George street, Glasgow,	19 Dec., 1905
DOBSON, JAMES, Messrs H. Pooley & Son, Albion Foundry, Kidsgrove, Staffordshire	G. 22 Dec., 1896 M. 25 Oct., 1904
DOBSON, WILLIAM, The Chesters, Jesmond, Newcastle-on-Tyne,	17 Jan., 1871
DODD, T. J., Lloyd's Register of Shipping, 342 Argyle street, Glasgow,	20 Nov., 1900
D'OLIVEIRA, RAPHAEL CHRYSOSTOME, Campos, Rio de Janeiro, Brazil,	20 Feb., 1900
DONALD, B. B., Low Balernock, Petershill, Glasgow,	G. 20 Mar., 1888 M. 24 Jan., 1899
DONALD, DAVID P., Johnstone,	21 Mar., 1899
DONALD, ROBERT HANNA, Abbey works, Paisley,	22 Nov., 1892
DONALDSON, A. FALCONER, Beechwood, Partick,	G. 27 Oct., 1896 M. 16 Dec., 1902

DONALDSON, JAMES, Almond villa, Renfrew,	25 Jan., 1876
†DOUGLAS, CHARLES STUART, B.Sc., St. Brides, 12 Dalziel drive, Pollokshields, Glasgow,	G. 24 Jan., 1899 M. 3 Mar., 1903
DOWNIE, A. MARSHALL, B.Sc., London road Iron works, Glasgow,	21 Nov., 1899
DOYLE, PATRICK, F.R.S.E., 7 Government place, Calcutta, India,	23 Nov., 1886
DREW, ALEXANDER, 154-6 Temple Chambers, Temple avenue, London, E.C.,	29 Apr., 1890
DRON, ALEXANDER, 59 Elliot street, Glasgow,	27 Oct., 1903
DRUMMOND, WILLIAM, 44 Polworth gardens, Hyndland, Glasgow,	1 May, 1906
DRYSDALE, JOHN W. W., 3 Whittingehame gardens, Kelvinside, Glasgow,	23 Dec., 1884
DUNCAN, GEORGE F., 12 Syriam terrace, Broomfield road, Springburn, Glasgow,	G. 23 Nov., 1886 M. 20 Mar., 1894
DUNCAN, GEORGE THOMAS, Cumledge, Uddingston,	15 Apr., 1902
DUNCAN, HUGH, 11 Hampden terrace, Mount Florida, Glasgow,	15 June, 1898
DUNCAN, JOHN, Ardenclutha, Port-Glasgow,	23 Nov., 1886
DUNCAN, ROBERT, M.P., Whitefield Engine works, Govan,	25 Jan., 1881
DUNCAN, W. LEES, Partick foundry, Partick,	18 Dec., 1900
DUNDAS, DAVID, Messrs A. Watson & Co., 36 George street, Glasgow,	21 Nov., 1905
DUNKERTON, ERNEST CHARLES, 97 Holly avenue, Newcastle-on-Tyne,	17 Feb., 1903
DUNLOP, DAVID JOHN, Inch works, Port-Glasgow,	23 Nov., 1869
DUNLOP, JOHN G., Clydebank, Dumbartonshire,	23 Jan., 1877
DUNLOP, JOHN MITCHELL, Messrs Miller & Allan, Ltd., 93 Hope street, Glasgow,	20 Mar., 1906
DUNLOP, THOMAS, 25 Wellington street, Glasgow,	19 Dec., 1899
DUNLOP, WILLIAM A., Harbour Office, Belfast,	23 April, 1901
DUNN, JAMES, Collalis, Scotstounhill, Glasgow,	23 April, 1901
DUNN, J. R., 42 Magdalen Yard road, Dundee,	16 Dec., 1902
†DUNN, PETER L., 815 Battery street, San Francisco, U.S.A.,	26 Oct., 1886
†DUNSMUIR, HUGH, Govan Engine works, Govan,	21 Apr., 1903
DYER, HENRY, M.A., D.Sc., 8 Highburgh terrace, Dowanhill, Glasgow,	23 Oct., 1883
EDWARDS, CHARLES, Greenock Foundry, Greenock,	26 Oct., 1897
ELGAR, FRANCIS, LL.D., F.R.SS., L.& E., 34 Leadenhall street, London, E.C.,	24 Feb., 1885

ELLIOTT, ROBERT, B.Sc., Lloyd's Surveyor, Greenock,	G. 24 Mar., 1885 M. 21 Feb., 1896
EWEN, PETER, The Barrowfield Ironworks, Ltd., Craigielea, Bothwell,	21 Mar., 1899
EWING, GEORGE HAWKSBY, Messrs Ewing&Lawson, Ltd., Crown Point Boiler works, Glasgow,	24 Oct., 1905

FAICKNEY, ROBERT, 3 Thornwood terrace, Partick,	20 Nov., 1900
FAIRWEATHER, WALLACE, 62 St. Vincent st., Glasgow,	24 Apr., 1894
FARNELL, ALFRED HENRY, Moorfield, Lenzie,	24 Oct., 1905
FERGUSON, DAVID, Glenholm, Port-Glasgow,	29 Oct., 1901
FERGUSON, JOHN, 160 Hope street, Glasgow,	21 Nov., 1905
FERGUSON, JOHN JAMES, Ard-Mhor, Kirn,	24 Jan., 1899
FERGUSON, LOUIS, Newark Works, Port-Glasgow,	G. 22 Jan., 1895 M. 26 Nov., 1901
FERGUSON, PETER, Rossbank, Port-Glasgow,	22 Oct., 1889
FERGUSON, PETER J., Carlogie, Greenock, W.,	G. 22 Jan., 1895 M. 26 Nov., 1901
FERGUSON, WILFRED H., 4 Thornwood terrace, Partick,	22 Nov., 1898
FERGUSON, WILLIAM D., 3 Mount Delphi, Antrim road, Belfast,	G. 27 Jan., 1885 M. 20 Mar., 1894
FERGUSON, WILLIAM R., Messrs Barclay, Curle & Co., Ltd., Whiteinch, Glasgow,	G. 22 Feb., 1881 M. 22 Jan., 1895
FERRIER, HUGH, Messrs Rankin & Blackmore, Greenock,	22 Dec., 1903
FIFE, WILLIAM, Messrs William Fife & Sons, Fairlie, Ayrshire,	28 Apr., 1903
FINDLAY, ALEXANDER, M.P., Parkneuk Iron works, Motherwell,	27 Jan., 1880
FINDLAY, LOUIS, 50 Wellington street, Glasgow,	G. 21 Feb., 1893 M. 27 Oct., 1903
FINLAYSON, FINLAY, Atlas works, Airdrie,	23 Dec., 1884
FINNIE, WILLIAM, Messrs Howarth Erskine, Limited, 3 Lloyd's avenue, London, E.C.,	20 Dec., 1904
FISHER, ANDREW, St. Mirren's Engine works, Paisley,	25 Jan., 1898
FLEMING, GEORGE E., Messrs Dewrance & Co., 79 West Regent street, Glasgow,	27 Oct., 1896
FLEMING, JOHN, Dellburn works, Motherwell,	24 Jan., 1899
FLETT, GEORGE L., 5 Walmer crescent, Ibrox, Glasgow,	22 Jan., 1895
†FLETCHER, ANDREW, Hoboken, New Jersey, U.S.A.,	23 Jan., 1906
FORSYTH, LAWSON, 97 St. James road, Glasgow,	18 Dec., 1883
FRAME, JAMES, 6 Kilmailing terrace, Cathcart, Glasgow,	23 Feb., 1897
FRASER, J. IMBRIE, Clifton, Row, Dumbartonshire,	G. 27 Apr., 1886 M. 27 Oct., 1903

Fujii, Terugoro, Eng.-Capt., Imperial Japanese Navy, Parliament Chambers, Great Smith street, Victoria street, Westminster, London, S.W., 21 Feb., 1899

Fullerton, Alexander, Vulcan Works, Paisley, 22 Dec., 1896

Fullerton, James, Abbotsburn, Paisley, 19 Mar., 1901

Fullerton, Robert A., 1 Strathmore gardens, Hillhead, Glasgow, 19 Mar., 1901

Fulton, Norman O., South Brae drive, Scotstounhill, Glasgow, G. 23 Feb., 1892; M. 19 Mar., 1901

Fyfe, Charles F. A., 2 Wellesley avenue, Belfast, G. 18 Dec., 1894; M. 28 Apr., 1903

Gale, William M., 18 Huntly gardens, Kelvinside, Glasgow, 24 Jan., 1893

Galletly, Archibald A., 10 Greenlaw avenue, Paisley, 22 Jan., 1901

Galloway, Andrew, South Mall, Westport, G. 24 Oct., 1893; M. 25 Oct., 1904

Galloway, Charles S., Greenwood City, Vancouver, B.C., 22 Jan., 1895

Gardner, Walter, 11 Kildonan terrace, Paisley road W., Glasgow, 20 Dec., 1898

Garnett, Sydney Harold, 144 St. Vincent street, Glasgow, 21 Feb., 1905

Gearing, Ernest, Rosehurst, Grosvenor road, Headingley, Leeds, 20 Mar., 1888

Gemmell, E. W., 73 Robertson street, Glasgow, 18 Dec., 1888

Gemmell, Thomas, Electric Lighting Department, St. Enoch Station, Glasgow, 24 Oct., 1899

Gibb, Andrew, Garthland, Westcombe Park road, Blackheath, London, S.E., G. 23 Dec., 1873; M. 21 Mar., 1882

Gifford, Paterson, c/o Messrs Bell, Brothers & M'Lelland, 135 Buchanan street, Glasgow, 23 Nov., 1886

Gilchrist, Archibald, 36 Finnieston street, Glasgow, 16 Dec., 1902

Gilchrist, James, 3 Kingsborough gardens, Kelvinside, Glasgow, G. 26 Dec., 1866; M. 29 Oct., 1878

Gill, William Nelson, 47 Kersland street, Hillhead, Glasgow, 23 Feb., 1904

Gillespie, Andrew, 65 Bath street, Glasgow, 20 Nov., 1894

Gillespie, James, 21 Minerva street, Glasgow, G. 24 Feb., 1874; M. 24 Mar., 1891

Gillespie, James, Jun., Margaretville, Orchard street, Motherwell, 18 Dec., 1900

Gillies, James, 14 Walmer terrace, Glasgow, 21 Mar., 1905

Gilmour, John H., River Bank, Irvine, 20 Feb., 1900

GLASGOW, JAMES, Soho Engine works, Paisley, 25 Jan., 1898

†GOODWIN, GILBERT S., Alexandra buildings, James street, Liverpool, 28 Mar., 1866

GORDON, A. G., c/o Messrs Shewan, Tomes, & Co., Hong kong, China, 23 April, 1901

GORDON, JOHN, 152 Craigpark street, Glasgow, 26 Mar., 1895

GORRIE, JAMES M., 1 Broomhill terrace, Partick, Glasgow, 22 Nov., 1898

GOUDIE, ROBERT, 37 West Campbell street, Glasgow, 27 Oct., 1903

GOUDIE, WILLIAM J., B.Sc., 6 Beaton road, Maxwell Park, Glasgow, G. 21 Dec., 1897; M. 29 Oct., 1901

GOURLAY, R. CLELAND, Glenfield, Paisley, G. 24 Dec., 1895; M. 27 Oct., 1903

GOVAN, ALEXANDER, Normanhurst, Helensburgh, 24 Oct., 1899

GOW, GEORGE, Aroha, Bellevue road, Mount Eden, Auckland, New Zealand, 20 Mar., 1900

GOWAN, A. B., Byram, Maxwell drive, Pollokshields, Glasgow, G. 24 Jan., 1882; M. 22 Jan., 1895

GRACIE, ALEXANDER, Fairfield Shipbuilding and Engineering Company, Govan, G. 26 Feb., 1884; M. 24 Nov., 1896

GRAHAM, JOHN, 25 Broomhill terrace, Partick, 23 Oct., 1900

GRAHAM, JOHN, 15 Armadale street, Dennistoun, Glasgow, G. 19 Mar., 1901; M. 21 Apr., 1903

GRAHAM, WALTER, Kilblain Engine works, Nicholson street, Greenock, G. 28 Jan., 1896; M. 15 June, 1898

GRANT, THOMAS M., 17 Clarence drive, Hyndland, Glasgow, 25 Jan., 1876

GRAY, Prof. ANDREW, LL.D., F.R.S., The University, Glasgow, 24 Oct., 1905

GRAY, DAVID, 77 West Nile street, Glasgow, 21 Nov., 1899

GRAY, WILLIAM, 6 Lloyd's avenue, London, E.C., 26 Jan., 1904

GRETCHIN, G. L., Works Manager, Chantiers Navals Ateliers and Founderies de Nicolaieff, Nicolaieff, Russia, 25 Jan., 1898

GRIFFITH, EDWIN, Engine works, Dumbarton, 23 Jan., 1906

GRIGG, JAMES, 135 Balshagray avenue, Partick, 20 Jan., 1903

GROUNDWATER, CHARLES LAMONT, c/o Messrs Mackay, Macarthur Ltd., Bankok, Siam, 21 Mar., 1905

GROVES, L. JOHN, Engineer, Crinan Canal house, Ardrishaig, 20 Dec., 1881

GUTHRIE, JOHN, The Crown Iron works, Glasgow, 27 Oct., 1896

HAIG, ROBERT, Dollarfield, Dollar, 22 Jan., 1901

HAIGH, WILLIAM R., 6 Elmwood gardens, Jordanhill, Glasgow, 22 Dec., 1896

HALKET, JAMES P., Glengall Iron works, Millwall, London, E., 26 Oct., 1897

HALL, WILLIAM, 8 Hope street, Edinburgh, 25 Jan., 1881

HAMILTON, ARCHIBALD, Clyde Navigation Chambers, Glasgow, {G. 24 Feb., 1874 / M. 24 Nov., 1885}

HAMILTON, CLAUD, 247 St. Vincent street, Glasgow, 15 June, 1898

HAMILTON, DAVID C., Clyde Shipping Company, 21 Carlton place, Glasgow, {G. 23 Dec., 1873 / M. 22 Nov., 1881}

HAMILTON, JAMES, Ardedynn, Kelvinside, Glasgow, {G. 26 Dec., 1863 / M. 18 Mar., 1876}

HAMILTON, JAMES, 6 Kyle park, Uddingston, 20 Nov., 1900

*†HAMILTON, JOHN, 22 Athole gardens, Glasgow,

HAMILTON, JOHN K., 230 Berkeley street, Glasgow, 15 May, 1900

HAMILTON, ROBERT SMITH, Flemington, Maxwell Park gardens, Pollokshields, Glasgow, 22 Mar., 1904

HARMAN, BRUCE, 35 Connaught road, Harlenden, London, N.W., {G. 2 Nov., 1880 / M. 22 Jan., 1884}

HARRIS, WILLIAM, 73 Robertson street, Glasgow, 22 Nov., 1904

HARRISON, J. E., 160 Hope street, Glasgow, {G. 26 Feb., 1889 / M. 22 Feb., 1898}

HART, P. CAMPBELL, 134 St., Vincent street, Glasgow, 24 Nov., 1896

HARVEY, JAMES, 224 West street, Glasgow, 24 Jan., 1899

HARVEY, JOHN H., Messrs Wm. Hamilton & Co., Port-Glasgow, 22 Feb., 1887

HARVEY, THOMAS, Grangemouth Dockyard Co., Grangemouth, 19 Dec., 1899

HAY, JOHN, Wansfell, The Grove, Finchley, London, N., 26 Nov., 1901

HAY, RANKIN, 44 Windsor terrace, St. George's road, Glasgow, 18 Dec., 1900

HAYWARD, THOMAS ANDREW, 18 Carrington street, Glasgow, 22 Mar., 1898

†HENDERSON, A. P., 30 Lancefield quay, Glasgow, 25 Nov., 1879

HENDERSON, CHARLES A., The Basin House, Exeter, {G. 24 Jan., 1899 / M. 27 Oct., 1903}

HENDERSON, FREDERICK N., Meadowside, Partick, Glasgow, 26 Mar., 1895

HENDERSON, H. E., 32 Curzon road, Waterloo, near Liverpool, {G. 22 Nov., 1898 / M. 3 May, 1904}

HENDERSON, Prof. JAMES BLACKLOCK, D.Sc., Royal Naval College, Greenwich, 20 Nov., 1900

HENDERSON, JOHN FRANCIS, B.Sc., Albion Motor Car Co., Ltd., South street, Scotstoun, Glasgow, 16 Dec., 1902

†HENDERSON, JOHN L., 25 Nov., 1879

HENDERSON, ROBERT, 777 London road, Glasgow, 19 Mar., 1901

HENDERSON, WILLIAM STEWART, Belwood, Coatbridge, 24 Nov., 1896

HENDIN, ALEXANDER JAMES, 14 Hamilton terrace, W., Partick, Glasgow, 22 Dec., 1903

HENDRY, JAMES C., Rosebank, Gartsherrie road, Coatbridge,	18 Dec., 1900
HENRY, ERENTZ, 13 Ann street, Hillhead, Glasgow,	20 Feb., 1900
HERRIOT, W. SCOTT, Ravenswood, Partick, W.,	28 Oct., 1890
HETHERINGTON, EDWARD P., Messrs John Hetherington & Co, Ltd., Pollard street, Manchester,	22 Nov., 1892
HIDE, WILLIAM SEYMOUR, Messrs Amos & Smith, Albert Dock works, Hull,	18 Dec., 1888
HILLHOUSE, PERCY ARCHIBALD, B.Sc., Whitworth, Busby,	3 May, 1904
HISLOP, GEORGE ROBERTSON, Jun., 13 St. James' place, Paisley,	18 Apr., 1905
HOGARTH, W. A., 293 Onslow drive, Glasgow,	20 Nov., 1900
HOGG, CHARLES P., 14 Blythswood square, Glasgow,	2 Nov., 1880
HOGG, JOHN, Victoria Engine works, Airdrie,	20 Mar., 1883
HÖK, W., 10 Karlaplan, Stockholm, Sweden,	29 Oct., 1901
HOLLIS, H. E., 40 Union street, Glasgow,	A. 20 Nov., 1897 M. 24 Oct., 1899
HOLMES, F. G., Town Hall, Govan,	23 Mar., 1880
HOMAN, WILLIAM M'L., P.O. Box 24, Bethlehem, Orange River Colony,	G. 26 Jan., 1892 M. 26 Oct., 1897
HORNE, GEORGE S., Corozal, Iverton road, Johnstone,	21 Feb., 1899
HORNE, JOHN, Dysart House, St. Alban's road, Carlisle,	23 Nov., 1897
†HOUSTON, COLIN, Harbour Engine works, 60 Portman street, Glasgow,	25 Mar., 1890
HOUSTON, PERCIVAL T., Coronation house, 4 Lloyd's avenue, London, E.C.,	G. 22 Nov., 1898 M. 2 May 1905
HOWARD, JOHN ROWLAND, 56 Osborne road, Levenshulme, Manchester,	18 Dec., 1900
HOWAT, WILLIAM, 58 Wilton street, Glasgow,	22 Feb., 1898
†HOWDEN, JAMES, 195 Scotland street, Glasgow,	Original
HUBBARD, ROBERT SOWTER, Townsend Downey Shipbuilding Co., Shooter Island, Richmond, New York,	19 Dec., 1899
HUME, JAMES HOWDEN, 195 Scotland street, Glasgow,	22 Dec., 1891
HUNT, WILFRED, 121 West George street, Glasgow,	24 Jan., 1905
HUNTER, GILBERT M., Newyards, Maybole,	G. 19 Oct., 1886 M. 26 Nov., 1889
HUNTER, JAMES, Aberdeen Iron works, Aberdeen,	25 Jan., 1881
HUNTER, JOHN, Bracklinn, Bearsden,	A. 22 Jan., 1895 M. 21 Mar., 1899
HUNTER, JOSEPH GILBERT, P.O. Box 671, Newport News, Va., U.S.A.,	24 Feb., 1891
HUNTER, MATTHEW, Burnbank, Whiteinch, Glasgow,	19 Mar., 1901
†HUTCHEON, JAMES, Craigholme, South Brae drive, Scotstounhill,	19 Mar., 1901

HUTCHESON, ARCHIBALD, 37 Mair street, Plantation, Glasgow,	22 Dec., 1896
HUTCHESON, JOHN, 37 Mair street, Plantation, Glasgow,	22 Mar., 1898
HUTCHISON, JAMES H., Shipbuilder, Port-Glasgow,	26 Mar., 1895
HUTCHISON, JOHN S., 107 Douglas street, Glasgow,	24 Apr., 1900
HUTCHISON, M., 50 Gibson street, Hillhead, Glasgow,	29 Oct., 1901
HUTSON, ALEXANDER, 17 James street, Liverpool,	19 Dec., 1899
HUTSON, GUYBON, Culdees, Minard road, Partickhill, Glasgow,	21 Mar., 1893
HUTSON, JAMES, 117 Balshagray avenue, Partick,	19 Dec., 1899
HYND, ALEXANDER, Federal Supply and Cold Storage Co., of South Africa, Ltd., Durban, South Africa,	27 Oct., 1903
†INGLIS, JOHN, LL.D., Point House shipyard, Glasgow,	1 May, 1861
INGLIS, JOHN FRANCIS, 46 Princes terrace, Dowanhill, Glasgow,	G. 26 Oct., 1897 M. 20 Jan., 1903
INNES, W., Metropolitan Electrical Station, Poplar, London,	G. 22 Feb., 1898 M. 27 Oct., 1903
IRELAND, WILLIAM, 7 Ardgowan terrace, Glasgow,	25 Feb., 1890
JACK, ALEXANDER, Cameron street, Motherwell,	21 Nov., 1893
JACK, JAMES R., Mavisbank, Dumbarton,	27 Apr., 1897
JACKSON, DANIEL, Rockville, Dumbarton,	24 Oct., 1899
JACKSON, HAROLD D., Caxton street, Anniesland, Glasgow,	G. 24 Mar., 1891 M. 20 Dec., 1898
JACKSON, WILLIAM, Govan Engine works, Govan,	21 Dec., 1875
JACKSON, WILLIAM STENHOUSE, 109 Hope street, Glasgow,	G. 29 Oct., 1901 M. 23 Feb., 1904
JAMIESON, Professor ANDREW, F.R.S.E., 16 Rosslyn terrace, Kelvinside, Glasgow,	26 Mar., 1889
JEFF, WILLIAM, Northfleet Engineering works, Northfleet, Kent,	18 Dec., 1900
JEFFERY, ARTHUR W., 71 Dixon avenue, Glasgow,	23 April, 1901
JOHNSTON, DAVID, 9 Osborne terrace, Copland road, Glasgow,	25 Feb., 1879
JOHNSTON, ROBERT, Eccleston, Wallace street, Kilmarnock,	22 Mar., 1898
JOHNSTONE, GEORGE, F.R.S.E., Marine Superintendent, British India Steam Navigation Co., Ltd., 16 Strand road, Calcutta, India,	21 Mar., 1899
JONES, ARTHUR J. E., 118 Napiershall street, Glasgow,	29 Oct., 1901
JONES, ARTHUR LLEWELLYN, Lloyd's Register, 342 Argyle street, Glasgow,	25 Oct., 1904

JONES, LLEWELLYN, The Stirling Boiler Co., Ltd., 25 Victoria street, Westminster, London,	25 Oct., 1892
JUDD, EDWIN H., Sentinal works, Glasgow,	G. 20 Dec., 1893 M. 26 Nov., 1901
KAY, ALEXANDER J., 21 Endsleigh gardens, Partickhill, Glasgow,	G. 24 Oct., 1893 M. 28 Apr., 1903
KEEGAN, THOMAS J. M., 18 Smal street, Johannesburg, South Africa,	22 Jan., 1901
KEELING, THOMAS, 42 Prospecthill road, Langside, Glasgow,	19 Feb., 1901
KELLY, ALEXANDER, 100 Hyde Park street, Glasgow,	23 Feb., 1897
KELSO, MATTHEW GLEN, 47 Oxford street, Glasgow,	27 Oct., 1903
KEMP, DANIEL, 62 Abbey drive, Jordanhill,	G. 23 Nov., 1886 M. 20 Dec., 1898
KEMP, EBENEZER, D., Messrs Cammell, Laird & Co., Ltd., Birkenhead,	G. 20 Feb., 1883 M. 25 Oct., 1892
KEMP, ROBERT G., 60 Abbey drive, Jordanhill, Glasgow,	G. 28 Oct., 1890 M. 2 May, 1905
KEMPT, IRVINE, Jun., 37 Falkland mansions, Hyndland, Glasgow,	G. 26 Feb., 1895 M. 27 Apr., 1897
KENNEDY, ALEXANDER M'A., Glenholm, Greenock,	30 Apr., 1895
KENNEDY, JOHN, Messrs R. M'Andrew & Co., Suffolk House, Laurence Pountney Hill, London, E.C.,	23 Jan., 1877
KENNEDY, RANKIN, Bute villa, Springboig, Shettleston,	3 May, 1904
KENNEDY, ROBERT, B.Sc., Messrs Glenfield & Kennedy, Kilmarnock,	23 Mar., 1897
KENNEDY, THOMAS, Messrs Glenfield & Kennedy, Kilmarnock,	22 Feb., 1876
KENNEDY, WILLIAM, 13 Victoria crescent, Dowanhill, Glasgow,	24 Apr., 1894
KER, WILLIAM ARTHUR, 124 St. Vincent street, Glasgow,	16 Dec., 1902
KERR, JAMES, Lloyd's Register of Shipping, Hull,	22 Feb., 1898
KERR, JOHN, 74 Dombey street, Toxteth park, Liverpool,	22 Mar., 1904
KEY, WILLIAM, 109 Hope street, Glasgow,	20 Feb., 1901
KINCAID, JOHN G., 30 Forsyth street, Greenock,	22 Feb., 1898
KING A. C., Motherwell Bridge works, Motherwell,	24 Jan., 1899
KING, J. FOSTER, The British Corporation, 121 St. Vincent street, Glasgow,	26 Mar., 1895
KINGHORN, A. J., 59 Robertson street, Glasgow,	24 Oct., 1899
KINGHORN, JOHN G., Colonial house, Water street, Liverpool,	23 Dec., 1879
KINLOCH, JAMES, 1320 Argyle street, Glasgow,	25 Oct., 1904
KINMONT, DAVID W., c/o A. H. Boyle, 102 Bath street, Glasgow,	G. 20 Feb., 1894 M. 19 Mar., 1901

†KIRBY, FRANK E., Detroit, U.S.A.,		24 Nov., 1885
KLINKENBERG, JOHN, 4 Derby street, Glasgow,		16 Dec., 1902
KNIGHT, CHARLES A., c/o Messrs Babcock & Wilcox, Ltd., Oriel House, Farringdon st., London, E.C.,		27 Jan., 1885
KNOX, ROBERT, 10 Clayton terrace, Dennistoun, Glasgow,		24 Nov., 1896
LACKIE, WILLIAM W., 75 Waterloo street, Glasgow,		22 Nov., 1898
†LAGE, RENAUD, Ilha do Vianna, Rio de Janeiro, P.O. Box 1032,		18 Apr., 1905
LAIDLAW, D., 147 East Milton street, Glasgow,		18 Mar., 1902
LAIDLAW, JOHN, 98 Dundas street, s.s., Glasgow,		25 Mar., 1884
LAIDLAW, ROBERT, 147 East Milton street, Glasgow,		26 Nov., 1862
LAIDLAW, THOMAS, 52 Norse road, Scotstoun, Glasgow,		26 Nov., 1901
LAIDLAW, T. K., 147 East Milton street, Glasgow,		18 Mar., 1902
LAING, ANDREW, The Wallsend Slipway Company, Newcastle-on-Tyne,		20 Mar., 1880
LAIRD, ANDREW, 95 Bath street, Glasgow,		22 Nov., 1898
LAMBERT, JOHN, Corporation Electricity Works, Perth,		18 Dec., 1900
LAMBERTON, ANDREW, Sunnyside Engine works, Coatbridge,		27 Apr., 1897
LAMBIE, ALEXANDER, Ravenshall, Port-Glasgow,		19 Mar., 1901
LANG, C. R., Holm Foundry, Cathcart, Glasgow,	G. M.	20 Nov., 1888 26 Nov., 1895
†LANG, JAMES, Netherby, Johnstone,		20 Mar., 1906
LANG, JAMES, Messrs George Smith & Sons, 75 Bothwell street, Glasgow,		24 Feb., 1880
†LANG, JOHN, Lynnhurst, Johnstone,		26 Feb., 1884
†LANG, ROBERT, Quarrypark, Johnstone,		25 Jan., 1898
†LANG, WILLIAM B., Springfield, Johnstone,		20 Mar., 1906
LAURENCE, GEORGE B., Clutha Iron works, Paisley road, Glasgow,		21 Feb., 1888
LAW, DAVID, 3 Westbourne drive, Ibrox, Glasgow,		20 Dec., 1904
LAWSON, CHARLES BUCHANAN, Crown Point Boiler works, St. Marnock street, Glasgow,		20 Mar., 1906
LEASK, HENRY NORMAN, 4 Chapel Walks, Manchester,		17 Apr., 1906
†LEE, ROBERT, 59 Brisbane street, Greenock,	G. M.	21 Dec., 1888 22 Mar., 1896
LEITCH, ARCHIBALD, 40 St. Enoch square, Glasgow,		22 Dec., 1896
LEMKES, C. R. L., 5 Wellington street, Glasgow,	A. M.	26 Feb., 1888 22 Mar., 1894
LENNOX, ALEXANDER, Messrs M'Kay & M'Arthur, Ltd., Oriental buildings, Bangkok, Siam,	G. M.	23 Jan., 1894 19 Mar., 1901
LESLIE, JAMES T. G., 148 Randolph terrace, Hill street, Garnethill, Glasgow,		25 Apr., 1893

LESLIE, WILLIAM, Viewmount, Emerald Hill terrace, Perth, West Australia,	24 Feb., 1891
LEWIN, HARRY W., 154 West Regent street, Glasgow,	20 Dec., 1898
†LINDSAY, CHARLES C., 180 Hope street, Glasgow,	G. 23 Dec., 1873 M. 24 Oct., 1876
LINDSAY, W. F., 203 Nithsdale road, Pollokshields, Glasgow,	19 Mar., 1901
LITHGOW, WILLIAM T., Port-Glasgow,	21 Feb., 1893
LIVESEY, ROBERT M., 24 Eleanor street, Cardiff,	26 Jan., 1897
†LOBNITZ, FRED., Auchinbothie, Kilmacolm,	G. 24 Mar., 1885 M. 20 Nov., 1896
LOCKIE, JOHN, Wh.Sc., 2 Custom House Chambers, Leith,	26 Jan., 1897
LONDON, WILLIAM J. A., British Westinghouse works, Trafford park, Manchester,	23 Jan., 1906
LONGBOTTOM, Professor JOHN GORDON, Technical College, George street, Glasgow,	22 Nov., 1898
LORIMER, ALEXANDER SMITH, Kirklinton, Langside, Glasgow,	G. 21 Nov., 1899 M. 27 Oct., 1903
LORIMER, HENRY DÜBS, Kirklinton, Langside, Glasgow,	G. 21 Nov., 1899 M. 3 May, 1904
†LORIMER, WILLIAM, Glasgow Locomotive works, Gushetfaulds, Glasgow,	27 Oct., 1896
†LOUDON, GEORGE FINDLAY, 10 Claremont Terrace, Glasgow,	25 Jan., 1896
LOWSON, JAMES, 10 West Campbell street, Glasgow,	27 Oct., 1903
LUKE, W. J., Messrs John Brown & Co., Ltd., Clydebank,	24 Jan., 1898
LUSK, HUGH D., c/o Mrs Nelson, Larch villa, Annan,	21 Feb., 1880
LYALL, JOHN, 33 Randolph gardens, Partick,	27 Oct., 1888

MACALPINE, JOHN H., 615 Walnut street, Philadelphia, U.S.A.,	20 Dec., 1898
M'ARTHUR, DUNCAN, The British Corporation Registry of Shipping, St. Thomas street, Sunderland,	20 Dec., 1904
M'ARTHUR, JAMES D., Oriental avenue, Bangkok, Siam,	26 Apr., 1898
MCAULAY, W.	22 Nov., 1898
MCCALLUM, DAVID BROADFOOT, 174 Cathedral road, Cardiff,	23 Feb., 1904
MCCALLUM, P. F., 93 Hope street, Glasgow,	G. 22 Nov., 1880 M. 27 Oct., 1903
†MACCOLL, HECTOR, Bloomfield, Belfast,	24 Mar., 1874
†MACCOLL, HUGO, Wreath Quay Engineering works, Sunderland,	G. 20 Dec., 1881 M. 22 Oct., 1889

M'COLL, PETER, 5 Thornwood gardens, Partick,	G. 18 Dec., 1883 M. 24 Jan., 1899
M'CREATH, JAMES, 208 St. Vincent street, Glasgow,	23 Oct., 1883
M'DONALD, ALEX., 9 Sutherland street, Hillhead, Glasgow,	24 Jan., 1905
MACDONALD, D. H., Brandon works, Motherwell,	24 Mar., 1896
MACDONALD, JOHN, Bridge Turbine Works, Pollokshaws, Glasgow,	G. 18 Dec. 1883 M. 21 Mar., 1899
MACDONALD, JOHN DRON, 3 Rosemount terrace, Ibrox, Glasgow,	19 Mar., 1901
MACDONALD, ROBERT COWAN, 47 Farnham terrace, Sunderland,	G. 21 Nov., 1899 M. 28 Apr., 1903
MACDONALD, THOMAS, 9 York street, Glasgow,	25 Jan., 1898
MACDONALD, WILLIAM, 4 Rosslyn terrace, Rutherglen,	22 Dec., 1903
MCDOUGALL, ROBERT MELVIN, 86 Dale street, Glasgow,	20 Nov., 1900
M'DOWALL, JOHN JAS., Vulcan Engine Works, Piraeus, Greece,	29 Oct., 1901
M'EWAN, JOSEPH, 35 Houldsworth street, Glasgow,	27 Jan., 1891
MACFARLANE, DUNCAN, 58 Hydepark street, Glasgow,	G. 26 Oct., 1897 M. 27 Oct., 1903
MACFARLANE, JAMES W., Cartbank, Cathcart, Glasgow,	2 Nov., 1880
MCFARLANE, GEORGE, 34 West George street, Glasgow,	G. 24 Feb., 1874 M. 24 Nov., 1885
+MACFARLANE, WALTER, 22 Park Circus, Glasgow,	26 Oct., 1886
MACFEE, JOHN, Castle Chambers, Renfield street, Glasgow,	22 Jan., 1901
M'GEE, DAVID, c/o Messrs John Brown & Co., Clydebank,	22 Dec., 1896
+M'GEE, WALTER, Stoney brae, Paisley,	25 Jan., 1898
M'GIBBON, W. C., 2 Carlton Court, Bridge street, Glasgow,	18 Dec., 1900
MCGREGOR, JOHN B., 6 Oxford terrace, Renfrew,	G. 18 Dec., 1883 M. 27 Apr., 1897
MCGREGOR, THOMAS, 10 Mosesfield terrace, Springburn, Glasgow,	26 Jan., 1886
M'ILVENNA, JOHN, 13 Caird drive, Partickhill, Glasgow,	19 Mar., 1901
MACILWAINE, GEORGE W., 7 Havelock street, Dowanhill, Glasgow,	18 Mar., 1902
M'INDOE, JOHN B., 15 Surrey street, Coatbridge,	21 Mar., 1899
M'INTOSH, DONALD, Dunglass, Bowling,	20 Feb., 1894
M'INTOSH, JOHN, 5 Douglas terrace, Paisley,	G. 22 Jan., 1895 M. 27 Oct., 1903
M'INTOSH, JOHN F., Caledonian Railway, St. Rollox, Glasgow,	28 Jan., 1896
MACKINTOSH, JOHN, 2 Buchanan terrace, Paisley,	G. 18 Dec., 1894 M. 28 Apr., 1903
MCINTOSH, THOS. WILLIAM, 58 Hydepark street, Glasgow	24 Nov., 1903

MACKAY, HENRY JAMES, 6 Sutherland terrace, Hillhead, Glasgow, 18 Feb., 1902

MACKAY, LEWIS CHAMBERS, 55 West Regent street, Glasgow, { G. 22 Dec., 1896 / M. 22 Nov., 1904 }

MACKAY, W. NORRIS, Messrs Arrol's Bridge & Roof Co., Ltd., Germiston works, Glasgow, { S. 22 Jan., 1901 / M. 25 Oct., 1904 }

M'KEAND, ALLAN, 3 St. James street, Hillhead, Glasgow, { G. 19 Dec., 1884 / M. 20 Mar., 1892 }

MCKECHNIE, JAMES, Messrs Vickers, Sons, & Maxim, Barrow-in-Furness, 24 Apr., 1888

MACKECHNIE, JOHN, 342 Argyle street, Glasgow, 20 Dec., 1898

MACKENZIE, JAMES, 8 St. Alban's road, Bootle, { G. 25 Oct., 1881 / M. 24 Jan., 1899 }

MACKENZIE, THOMAS B., Elenslee, Wilson street, Motherwell, { G. 23 Jan., 1885 / M. 26 Nov., 1893 }

MCKENZIE, JOHN, Messrs J. Gardiner & Co., 24 St. Vincent place, Glasgow, 25 Apr., 1893

MCKENZIE, JOHN, Speedwell Engineering works, Coatbridge, 25 Jan., 1898

MACKIE, WILLIAM, 8 Inverclyde gardens, Broomhill, Partick, { G. 21 Dec., 1897 / M. 24 Mar., 1903 }

MACKIE, WILLIAM A., Falkland bank, Partickhill, Glasgow, 22 Mar., 1881

MCKIE, J. A., Copland works, Govan, 25 Jan., 1896

†MACKINLAY, JAMES T. C., 110 Gt Wellington street, Kinning park, Glasgow, 27 Oct., 1896

M'KILLOP, PETER ALEXANDER, 45 Hope street, Glasgow, 21 Mar., 1905

M'KINNEL, WILLIAM, c/o Messrs S. Osborne & Co., Clyde Steel Works, Sheffield. { A. 21 Feb., 1893 / M. 22 Feb., 1898 }

M'LACHLAN, EWEN, 168 Kenmure street, Pollokshields, Glasgow, 21 Feb., 1899

MCLACHLAN, JOHN, Saucel Bank House, Paisley, 26 Oct., 1897

MACLAREN, JOHN F., B.Sc., Eglinton foundry, Canal street, Glasgow, 23 Feb., 1892

MACLAREN, ROBERT, Eglinton foundry, Canal street, Glasgow, { G. 2 Nov., 1880 / M. 22 Dec., 1885 }

MCLAREN, JOHN ALEXANDER, 22 Nov., 1898

MCLAREN, RICHARD ANDREW, South Gallowhill house, Paisley, 21 Apr., 1903

MCLAREN, WILLIAM, 9 Westbank quadrant, Hillhead, Glasgow, 26 Nov., 1901

MCLAURIN, DUNCAN, 217-219 Mercer street, New York, U.S.A. 23 Oct., 1900

MACLAY, DAVID M., Dunourne, Douglas street, Motherwell, 18 Dec., 1900

†MACLEAN, ANDREW, Messrs Barclay, Curle & Co., Whiteinch, 3 May, 1904

MACLEAN, Prof. MAGNUS, M.A., D.Sc., 51 Kersland street, Hillhead, Glasgow,	21 Nov., 1899
MACLEAN, WILLIAM DICK, Hilaturas de Fabra y Coats, Pasco de Gracia Barcelona, Spain,	25 Jan., 1898
McLEAN, JOHN, Messrs Weir & McLean, 45 Hope street, Glasgow,	16 Dec., 1902
McLEAN, JOHN, Lower Barraca, Valetta, Malta,	G. 21 Nov., 1899 M. 22 Dec., 1903
†MACLELLAN, WILLIAM T., Clutha Iron works, Glasgow,	21 Dec., 1886
McLELLAN, ALEX., Clyde Navigation Trust, 16 Robertson street, Glasgow,	G. 18 Dec., 1900 A.M. 18 Ap., 1903 M. 27 Oct., 1903
MACMILLAN, HUGH MILLAR, B.Sc., Messrs. Wigham, Richardson, & Co., Newcastle-on-Tyne,	18 Dec., 1900
*†MACMILLAN, WILLIAM, Holmwood, Whittingehame drive, Kelvinside, Glasgow,	Mar., 1863
McMILLAN, JOHN, Resident Electrical Engineer's Office, Falkirk,	G. 27 Jan., 1885 M. 24 Jan., 1899
McMILLAN, W. MACLEOD, Dockyard, Dumbarton,	22 Jan., 1901
MACMURRAY, WILLIAM, Taller Bisayas, Yloilo, Philippine Islands,	18 Mar., 1902
McMURRAY, THOMAS H., 22 Cliftonville avenue, Belfast,	22 Jan., 1901
M'NAIR, JAMES, Norwood, Prestwick road, Ayr,	26 Nov., 1895
MACNAMARA, JOSEPH, Chief Electrical Engineer, Egyptian State Railways, Cairo, Egypt,	20 Jan., 1903
M'NEIL, JOHN, Helen street, Govan,	23 Dec., 1884
MACNICOLL, NICOL, 6 Dixon street, Glasgow,	19 Mar., 1901
M'ONIE, PETER SMITH, 9 Grant street, Greenock,	20 Dec., 1904
MACOUAT, R. B., Victoria Bolt and Rivet works, Cranstonhill, Glasgow,	21 Mar., 1899
M'WHIRTER, WILLIAM, 214 Holm street, Glasgow,	24 Mar., 1891
MACK, JAMES, 22 Rutland street, Edinburgh,	G. 21 Dec., 1886 M. 20 Dec., 1898
MALCOLM, WILLIAM GEORGE, Boyack house, Pollokshields, Glasgow,	21 Feb., 1905
MANSON, JAMES, G. & S. W. Railway, Kilmarnock,	21 Feb., 1899
MARRIOTT, ALFRED, 44 Kelburne avenue, Dumbreck, Glasgow,	20 Dec., 1904
MARRIOTT, REUBEN, Plantation Boiler Works, Govan,	23 Feb., 1897
MARSHALL, ALEXANDER, Glenmavis, Melrose avenue, Rutherglen,	21 Mar., 1905
MARSHALL, DAVID, Glasgow Tube works, Glasgow,	22 Jan., 1895
MARSHALL, JOHN, Ashgrove, Kilwinning,	18 Dec., 1900
MARTIN, WILLIAM CRAMMOND, 10 West Campbell street, Glasgow,	27 Oct., 1903

MATHESON, DONALD A., Caledonian Railway Co., Buchanan street station, Glasgow, 26 Jan., 1897

MATHEWSON, GEORGE, Bothwell works, Dunfermline, 21 Dec., 1875

MATHIESON, JAMES H., Saracen Tool Works, Glasgow, 29 Oct., 1901

MATTHEY, C. A., c/o W. Hope Campbell, Esq., 42 Krestchatik, Kieff, S. Russia. 26 Oct., 1897

MAVOR, HENRY A., 47 King street, Bridgeton, Glasgow, 22 Apr., 1884

MAVOR, SAM, 37 Burnbank gardens, Glasgow, 20 Nov., 1894

MAXTON, JAMES, 4 Ulster street, Belfast, 22 Jan., 1901

MAY, WILLIAM W., Woodbourne, Minard avenue, Partickhill, Glasgow, 25 Jan., 1876

MAYER, WILLIAM, Morwell House, Dumbarton, 23 Feb., 1897

MECHAN, HENRY, Messrs Mechan & Sons, Scotstoun Iron works, Glasgow, 25 Jan., 1887

MECHAN, SAMUEL, 22 Kingsborough gardens, Kelvinside Glasgow, 27 Oct., 1891

MELLANBY, Professor ALEX. LAWSON, D.Sc., Technical College, 204 George street, Glasgow, 19 Dec., 1905

MELVILLE, WILLIAM, Glasgow and South Western Railway, St. Enoch station, Glasgow, 23 Jan., 1883

MIDDLETON, R. A., 20 The Grove, Benton, near Newcastle-on-Tyne, {G. 24 Jan., 1882 / M. 28 Oct., 1890}

MILLAR, SIDNEY, Harthill house, Cambuslang, {G. 26 Feb., 1889 / M. 21 Dec., 1897}

MILLAR, THOMAS, Messrs Gourlay Bros. & Co., Ltd, Camperdown Shipyard Dundee, {G. 25 Nov., 1884 / M. 27 Oct., 1903}

MILLAR, WILLIAM, Towersland, Octavia terrace, Greenock, 19 Dec., 1899

MILLER, ARTHUR C., 12 Caird drive, Partickhill, Glasgow, 19 Mar., 1901

MILLER, GEORGE M'EWAN, 3 Clydeview, Partick, 25 Oct., 1904

MILLER, HUGH, 67 Danes drive, Scotstoun, Glasgow, 21 Nov., 1905

MILLER, JAMES, Roebuck park, Carron, Stirlingshire, {G. 22 Nov., 1898 / M. 2 May, 1905}

MILLER, JOHN, Etruria villa, South Govan, {G. 23 Apr., 1889 / M. 2 May, 1905}

MILLER, ROBERT F., Messrs Wardlaw & Miller, 109 Bath street, Glasgow, {G. 25 Feb., 1890 / M. 27 Oct., 1903}

MILNE, CHARLES W., Fairmount, Scotstounhill, Glasgow, 26 Nov., 1901

MILNE, GEORGE, 10 Bothwell street, Glasgow, 22 Jan., 1901

MITCHELL, ALEXANDER, Hayfield house, Springburn, Glasgow, 26 Jan., 1886

MITCHELL, GEORGE A., F.R.S.E., 5 West Regent street, Glasgow, 25 Jan., 1898

MITCHELL, THOMAS, Gower street, Bellahouston, Glasgow, 20 Nov., 1888

MOIR, ERNEST W., c/o Messrs S. Pearson & Son, 10 Victoria street, Westminster, London, {G. 25 Jan., 1881 / M. 24 Jan., 1899}

MOIR, JAMES, 70 Wellington street, Glasgow,	16 Dec., 1902
MOIR, JOHN, Clyde Shipbuilding and Engineering Company, Port-Glasgow,	23 Feb., 1897
MOIR, THOMAS, 2 Heathfield terrace, Springburn, Glasgow,	23 Apr., 1901
MOLLISON, HECTOR A., B.Sc., 33 Fotheringay road, Maxwell Park, Glasgow,	G. 22 Nov., 1892 M. 20 Nov., 1900
MOLLISON, JAMES, 30 Balshagray avenue, Partick,	21 Mar., 1876
MONROE ROBERT, Eastbrook house, Dinas Powis, Glam.,	26 Jan., 1904
MOORE, RALPH D., B.Sc., Leabank, Bearsden,	27 Apr., 1897
MOORE, ROBERT H., Caledonian Steel Castings Co., Govan,	16 Dec., 1902
MOORE, ROBERT T., D.Sc., 13 Clairmont gardens, Glasgow,	27 Jan., 1891
MORGAN, ROBERT, Arnsbrae, Dumbreck, Glasgow,	24 Mar., 1903
MORISON, WILLIAM, 23 St. Andrew's drive, Pollokshields, Glasgow,	20 Mar., 1888
MORISON, WILLIAM B., 7 Rowallan gardens, Broomhill, Glasgow,	20 Nov., 1900
MORRICE, RICHARD WOOD, 117 Moss Side road, Shawlands, Glasgow,	23 Feb., 1897
MORRISON, ARTHUR MACKIE, Merchiston, Scotstounhill, Glasgow, W.,	G. 17 Dec., 1889 M. 3 Mar., 1903
MORRISON, WILLIAM, 11 Sherbrooke avenue, Pollokshields, Glasgow,	19 Feb., 1901
MORT, WILLIAM, 41 Hamilton terrace, Partick,	24 Oct., 1905
MORTON, DAVID HOME, 130 Bath street, Glasgow,	20 Nov., 1900
MORTON, ROBERT, 8 Prince's square, Buchanan street, Glasgow,	G. 17 Dec., 1878 M. 23 Jan., 1883
MORTON, ROBERT C., 16 Vinicombe street, Hillhead, Glasgow,	26 Nov., 1901
MORTON, THOMAS M. G., Errol works, Errol,	26 Jan., 1904
MOTION, ROBERT, Ancrum, Lenzie,	23 Feb., 1892
MOWAT, MAGNUS, Civil Engineer, Millwall Docks, London,	G. 26 Oct., 1897 M. 26 Nov., 1901
MOYES, JOHN YOUNG, 27 Moray avenue, Scotstoun, Glasgow,	27 Oct., 1903
†MUIR, HUGH, 7 Kelvingrove terrace, Glasgow,	17 Feb., 1864
MUIR, JAMES, Messrs John King & Co., Ltd., Engineers, Calcutta,	21 Feb., 1905
MUIR, JAMES E., 105 West George street, Glasgow,	22 Dec., 1896
†MUIR, JOHN G.,	24 Jan., 1882
MUIR, PETER GILLESPIE, 24 Laburnum avenue, Wallsend-on-Tyne,	18 Mar., 1902
MUIR, ROBERT WHITE, 97 St. James road, Glasgow,	21 Dec., 1897
MUMME, CARL, 30 Newark street, Greenock,	22 Oct., 1895

MUMME, ERNEST CHARLES, 30 Newark street, Greenock, { G. 22 Nov., 1892 / M. 20 Feb., 1900 }

MUNN, ROBERT A., Twynham, 5 Winn road Southampton, 22 Dec., 1896

MUNRO, JAMES, Torquil, Carmyle avenue, Carmyle, 16 Dec., 1902

MUNRO, JOHN, 51 Polwarth gardens, Hyndland, Glasgow, 23 Apr., 1901

MUNRO, ROBERT D., Scottish Boiler Insurance Company, 111 Union street, Glasgow, 19 Dec., 1882

MURDOCH, FREDERICK TEED, Nile House, Mansourah, Egypt, 25 Feb., 1896

MURDOCH, J. A., 23 Robertson street, Glasgow, { G. 25 Oct., 1892 / M. 20 Nov., 1900 }

MURRAY, ANGUS, Strathroy, Dumbreck, { G. 14 May, 1878 / M. 19 Nov., 1889 }

MURRAY, HENRY, Shipbuilder, Port-Glasgow, 22 Dec., 1896

MURRAY, JAMES, Rossbank, Port-Glasgow, 22 Dec., 1896

MURRAY, JAMES, Messrs Murray, MacVinnie & Co., Mavisbank quay, S.S., Glasgow, 26 Jan., 1886

MURRAY, RICHARD, 109 Hope street, Glasgow, 26 Oct., 1897

MURRAY, THOMAS BLACKWOOD, B.Sc., 92 Camperdown road, Scotstoun, Glasgow, 22 Dec., 1891

MURRAY, THOMAS R., Keverstone, Cleveland walk, Bath, 25 Feb., 1896

MYLES, DAVID, Northumberland Engine works, Wallsend-on-Tyne, { G. 20 Dec., 1887 / M. 19 Dec., 1899 }

MYLNE, ALFRED, 81 Hope street, Glasgow, { G. 26 Jan., 1897 / M. 24 Mar., 1903 }

NAGAO, HANPEI, c/o Taipeifu, Formosa, Japan, 24 Dec., 1901

NAPIER, JOHN STEWART, Herbertshire, Meikleriggs, Paisley, 21 Nov., 1905

NAPIER, HENRY M., Shipbuilder, Old Kilpatrick, 25 Jan., 1881

†NAPIER, ROBERT T., 75 Bothwell street, Glasgow, 20 Dec., 1881

NEEDHAM, JAMES H., Rossbank, Port-Glasgow, 18 Mar., 1902

NEILL, HUGH, Jun., 99 Clarence drive, Hyndland, Glasgow, { G. 21 Nov., 1899 / M. 3 May, 1904 }

NEILSON, JAMES, Alma boiler works, Glasgow, 24 Mar., 1903

NELSON, ANDREW S., Snowdon, Sherbrooke avenue, Pollokshields, Glasgow, 27 Oct., 1896

NIELSON, JOHN FREDERICK, Messrs John Brown & Co., Ltd., Clydebank, 24 Nov., 1903

NESS, GEORGE, 111 Union street, Glasgow, 23 Feb., 1897

NICOL, R. GORDON, 15 Regent Quay, Aberdeen, 20 Nov., 1900

†NORMAN, JOHN, 65 West Regent street, Glasgow, 11 Dec., 1861

NORRIS, CHARLES G., Messrs Mason's Gas Power Co., Ltd., Alma works, Levenshulme, Manchester, 29 Oct., 1901

O'CONNOR, OWEN M'DONALD, Curepipe, Mauritius,	21 Nov., 1905
O'NEILL, J. J., 19 Roxburgh street, Kelvinside, Glasgow,	24 Nov., 1896
OLIPHANT, WILLIAM, 207 Bath street, Glasgow,	23 Feb., 1897
ORR, ALEXANDER T., Marine Department, London and North-Western Railway, Holyhead,	24 Mar., 1883
ORR, JOHN R., Motherwell Bridge Co., Motherwell,	24 Jan., 1899
OSBORNE, HUGH, 108A West Regent street, Glasgow,	G. 22 Dec., 1891 M. 27 Oct., 1903
PARK, F. A., B.Sc., The Singer Manufacturing Company, Kilbowie, Clydebank,	24 Oct., 1905
PARKER, EDWARD HENRY, 11 Strathmore gardens, Hillhead, Glasgow,	16 Dec., 1902
PARKER, GEORGE GLADSTONE, Rossbank, Port Glasgow,	24 Oct., 1905
PARSONS, The Hon. CHARLES ALGERNON, M.A., C.B., Holeyn Hall, Wylam-on-Tyne,	28 Apr., 1903
PATERSON, JAMES V., The Moran Co., Seattle, State of Washington, U.S.A.	G. 24 Jan., 1888 M. 27 Oct., 1903
PATERSON, JOHN, Edradour, Dalmuir,	22 Jan., 1901
PATERSON, W. L. C., 5 Elmwood terrace, Jordanhill, Glasgow,	21 Nov., 1883
PATRICK, ANDREW CRAWFORD, Johnstone,	25 Jan., 1898
PATTERSON, JAMES, Maryhill Iron works, Glasgow,	22 Nov., 1898
PATTERSON, JAMES, 130 Elliot street, Glasgow,	18 Dec., 1900
PATTIE, ALEXANDER W., Hong Kong & Whampoa Dock Co., Hong Kong,	22 Jan., 1895
PAUL, H. S., Levenford works, Dumbarton,	24 Jan., 1899
PAUL, JAMES, Kirkton, Dumbarton,	24 Mar., 1903
PAUL, MATTHEW, Levenford works, Dumbarton,	G. 26 Feb., 1884 M. 21 Dec., 1886
PEACOCK, JAMES, Oriental Steam Navigation Co., 13 Fenchurch avenue, London, E.C.	G. 22 Nov., 1881 M. 21 Feb., 1899
PEARSON, THOMAS, c/o Mrs Tannahill, 26 Derby crescent, Glasgow,	2 May, 1905
PECK, EDWARD C., Messrs Yarrow & Company, Poplar, London,	G. 23 Dec., 1873 M. 23 Oct., 1888
PECK, JAMES J., 52 Randolph gardens, Broomhill, Glasgow,	22 Dec., 1896
PECK, NOEL E., 4 Ashgrove terrace, Partickhill road, Glasgow,	18 Dec., 1900
PENMAN, ROBERT REID, 36 Circus drive, Dennistoun, Glasgow,	25 Jan., 1898
PENMAN, WILLIAM, Springfield house, Dalmarnock, Glasgow,	25 Jan., 1898

PERITON, WILLIAM JOHN, 113[2] Drury buildings, 23 Water street, Liverpool,	25 Oct., 1904
PETROFF, ALEXANDER, 60 Thornton avenue, Streatham Hill, London, S.W.,	19 Mar., 1901
PHILIP, WILLIAM LITTLEJOHN, Sherbrooke, Box, Wilts,	24 Jan., 1899
PICKERING, JONATHAN, 50 Wellington street, Glasgow,	3 Mar., 1903
POCOCK, J. HERBERT, 39 Falkland mansions, Kelvinside, Glasgow,	29 Oct., 1901
POLLOCK, DAVID, 128 Hope street, Glasgow,	23 Feb., 1897
POLLOK, ROBERT, Messrs John Brown & Co., Clydebank,	22 Dec., 1896
POOLE, WILLIAM JOHN, 65 Renfield street, Glasgow,	20 Dec., 1898
POPE, ROBERT BAND, Engine works, Dumbarton,	25 Oct., 1887
PORTCH, ERNEST C., 37 Vicar's hill, Ladywell, London, S.E.,	G. 26 Oct., 1897 M. 25 Oct., 1904
PRINGLE, WILLIAM S., 15 Elm place, Aberdeen,	G. 24 Oct., 1893 M. 16 Dec., 1902
PURDON, ARCHIBALD, Craigie place, Port-Glasgow,	27 Apr., 1897
PURVES, J. A., D.Sc., F.R.S.E., 53 York place, Edinburgh,	25 Oct., 1898
PURVIS, Prof. F. P., College of Naval Architecture, Imperial University, Tokio, Japan,	20 Nov., 1877
PUTNAM, THOMAS, Darlington Forge Co., Darlington,	15 June, 1898
PYLE, JAMES H., 38 Elliot street, Glasgow,	23 Feb., 1897
RAEBURN, CHARLES E., 12 Vinicombe street, Hillhead, Glasgow,	24 Oct., 1899
RAIT, HENRY M., 155 Fenchurch street, London,	23 Dec., 1868
RAMAGE, RICHARD, Shipbuilder, Leith,	22 Apr., 1873
RANKIN, JOHN F., Eagle foundry, Greenock,	23 Mar., 1886
RANKIN, MATTHEW, c/o Messrs Rankin & Demas, Engineers, Smyrna,	G. 2 Nov., 1880 M. 20 Mar., 1894
RANKIN, RICHARD LEES, Norwood, Balloch,	19 Dec., 1905
RANKIN, ROBERT, Jun., 6 Brighton place, Govan,	22 Jan., 1901
RANKINE, DAVID, 238 West George street, Glasgow,	22 Oct., 1872
RAPHAEL, ROBERT A., 72 Minard road, Crossmyloof, Glasgow,	G. 24 Dec., 1895 M. 27 Oct., 1903
REED-COOPER, T. L., 70 West Cumberland street, Glasgow,	22 Dec., 1896
REID, ANDREW T., Hydepark Locomotive works, Glasgow,	G. 21 Dec., 1886 M. 18 Dec., 1894
REID, GEORGE W., Inchanga, Hillfoot, Bearsden,	21 Nov., 1883
REID, J. MILLER, 110 Lancefield street, Glasgow,	23 Mar., 1897
†REID, JAMES, Shipbuilder, Port-Glasgow,	17 Mar., 1869
REID, JAMES, 3 Cart street, Paisley,	25 Jan., 1898

†REID, JAMES B., Chapelhill, Paisley,	24 Nov., 1891
REID, JAMES G.,	G. 23 Dec., 1894 M. 21 Feb., 1899
†REID, JOHN, 7 Park terrace, Kelvinside, Glasgow,	G. 21 Dec., 1886 M. 18 Dec., 1894
REID, JOHN, Baltic Chambers, 50 Wellington street, Glasgow,	18 Dec., 1900
REID, JOHN WILSON, c/o Messrs Aspinwall & Co., Cochin, Malabar Coast,	21 Jan., 1902
REID, ROBERT, British India Steam Navigation Co , Ltd., Columbo, Ceylon,	2 May 1905
REID, ROBERT W., 958 Sauchiehall street, Glasgow,	23 Jan., 1906
REID, ROBERT SHAW, 45 Hope street, Glasgow,	21 Mar., 1899
REID, THOMAS, Jun., Potterhill, Paisley,	18 Dec., 1900
REID, W. J. H., Redlea, Linwood, Nr. Paisley,	16 Dec., 1902
REID, WILLIAM PATON, 35 Dunearn street, Glasgow, W.,	23 Feb., 1904
RENNIE, ARCHIBALD, 5 Bawhirley road, Greenock,	S. 31 Oct., 1902 M. 28 Apr., 1903
REYNOLDS, CHARLES H.,	G. 23 Dec., 1873 M. 22 Nov., 1881
RICHARDSON, ANDREW, Soho Engine works, Paisley,	26 Jan., 1904
RICHMOND, Sir DAVID, North British Tube works, Govan,	21 Dec., 1897
RICHMOND, JAMES, Roselyn, 95 Maxwell drive, Pollokshields, Glasgow,	G. 23 Jan., 1894 M. 23 Oct., 1900
RICHMOND, JOHN R., Holm foundry, Cathcart, Glasgow,	28 Jan., 1896
RIDDELL, W. G., c/o Messrs John Hastie & Co., Kilblain Engine Works, Greenock,	21 Feb., 1899
RIEKIE, JOHN, Argaith, Dumbreck, Glasgow,	29 Oct., 1901
RISK, ROBERT, Halidon Villa, Cambuslang,	23 Mar., 1897
RITCHIE, DUNCAN, 293 Onslow drive, Dennistoun, Glasgow,	16 Dec., 1902
RITCHIE, GEORGE, Parkhead Forge, Glasgow,	15 June, 1898
ROBERTS, W. G.	29 Oct., 1901
ROBERTSON, ALEXANDER, Jun., c/o Messrs Matthew Reid & Co., Kilmarnock,	22 Dec., 1896
ROBERTSON, ALEXANDER, 8 Darnley road, Pollokshields, Glasgow,	G. 26 Oct., 1886 M. 23 Feb., 1904
ROBERTSON, ANDREW R., 8 Park Circus place, Glasgow,	G. 12 Nov., 1892 M. 23 Feb., 1897
ROBERTSON, Prof. DAVID, B.Sc., 5 Elmgrove road, Cotham, Bristol,	G. 19 Dec., 1899 M. 28 Apr., 1903
ROBERTSON, DAVID W., Dalziel Bridge works, Motherwell,	26 Nov., 1901
ROBERTSON, DUNCAN, Baldroma, Ibrox, Glasgow,	24 Oct., 1876
ROBERTSON, ROBERT, B.Sc., 154 West George street, Glasgow,	20 Nov., 1900

ROBERTSON, ROBERT, Messrs Watson, Gow & Co., Ltd., Etna Foundry, Lilybank road, Glasgow,	18 Apr., 1905
ROBIN, MATTHEW, 58 Dumbreck road, Dumbreck, Glasgow,	G. 20 Dec., 1887 M. 25 Jan., 1898
ROBINSON, J. F., 17 Victoria street, Westminster, London,	24 Apr., 1888
ROBINSON, ROBERT, 54 Balshagray avenue, Partick,	3 Mar., 1903
*†ROBSON, HAZELTON R., 14 Royal crescent, Glasgow,	Original
RODGER, ANDERSON, Glenpark, Port-Glasgow,	21 Mar., 1893
RODGER, ANDERSON, Jun., Glenpark, Port-Glasgow,	G. 15 June, 1898 M. 3 May, 1904
ROGER, GEORGE WILLIAM, 4 Lloyd's avenue, Fenchurch street, London, E.C.,	G. 24 Nov., 1896 M. 18 Dec., 1900
ROGERSON, THOMAS BOND, East Thorne, Tollcross, Glasgow,	20 Feb., 1906
ROSE, JOSEPH, Westoe, Scotstounhill, Glasgow,	3 May, 1904
ROSENTHAL, JAMES H., Oriel House, 30 Farringdon street, London,	24 Nov., 1896
ROSS, J. MACEWAN, St. Helens, Troon,	G. 28 Nov., 1882 M. 27 Oct., 1891
ROSS, JAMES R., 7 Ashfield gardens, Jordanhill, Glasgow,	24 Nov., 1896
ROSS, RICHARD G., 21 Greenhead street, Glasgow,	11 Dec., 1861
ROSS, WILLIAM, 27 Thistle street, Glasgow, S.S.,	18 Dec., 1900
ROWAN, FREDERICK JOHN, 5 West Regent street, Glasgow,	26 Jan., 1892
ROWAN, JAMES, 231 Elliot street, Glasgow,	G. 21 Dec., 1875 M. 27 Jan., 1885
ROWLEY, THOMAS, Board of Trade Offices, Virginia street, Greenock,	18 Dec., 1888
ROY, WILLIAM, Bowden view, Melksham, Wilts,	G. 25 Jan., 1898 M. 21 Apr., 1903
ROYDS, ROBERT, B.Sc., c/o Mrs Dunbar, 12 Barrington drive, Glasgow,	20 Dec., 1904
RUDD, JOHN A., 177 West George street, Glasgow,	G. 24 Jan., 1888 M. 15 June, 1898
RUSSELL, ALEXANDER C., 3 Strathyre street, Shawlands, Glasgow,	G. 15 Apr., 1902 M. 22 Dec., 1903
RUSSELL, FREDERICK ALEXANDER, 20 Skirving street, Shawlands, Glasgow,	25 Jan., 1888
†RUSSELL, GEORGE, Belmont, Uddingston,	G. 22 Dec., 1858 M. 4 Mar., 1863
†RUSSELL, JAMES, Waverley, Uddingston,	G. 24 Nov., 1891 M. 25 Jan., 1898
RUSSELL, JAMES E., c/o Cluness, 25 Woodside quadrant, W., Glasgow,	G. 22 Dec., 1891 M. 27 Oct., 1903
RUSSELL, JOSEPH, Shipbuilder, Port-Glasgow,	22 Feb., 1881
RUSSELL, JOSEPH WILLIAM, 50 Charles street, St. Rollox, Glasgow,	G. 6 Apr., 1887 M. 25 Jan., 1898

SADLER, Prof. HERBERT C., D.Sc., University of Michigan, Ann Arbor, Michigan, U.S.A.	G. 19 Dec., 1893 M. 23 Oct., 1900
SALMOND, HENRY, 43 Oswald street, Glasgow,	18 Dec., 1900
SAMPSON, ALEXANDER W., Bonnington, 9 Beech avenue, Bellahouston, Glasgow,	22 Dec., 1896
SAMSON, PETER, Board of Trade Offices, 54 Victoria street, Westminster, London, S.W.,	24 Oct., 1876
SAMUEL, JAMES, Jun., 185 Kent road, Glasgow,	24 Feb., 1885
SANDERSON, JOHN, Lloyd's Register, Royal Exchange, Middlesbro'-on-Tees,	20 Feb., 1883
SAYERS, JAMES EDMUND, 157 West George street, Glasgow,	24 Dec., 1901
SAYERS, WILLIAM BROOKS, 189 St. Vincent street, Glasgow,	25 Oct., 1892
SCOBIE, ALEXANDER, 58 West Regent street, Glasgow,	G. 27 Oct., 1885 M. 23 Feb., 1904
†SCOBIE, JOHN, c/o Alfred Scobie, Esq., 58 West Regent street, Glasgow,	G. 25 Mar., 1878 M. 23 Oct., 1889
SCOTT, ALLAN, Messrs Chambers, Scott & Co., Engineers, Motherwell,	23 Jan., 1906
SCOTT, CHARLES CUNNINGHAM, Greenock Foundry, Greenock,	27 Oct., 1896
SCOTT, CHARLES WOOD, Dunarbuck, Bowling,	15 June, 1898
SCOTT, JAMES, Rock Knowe, Tayport, N.B.,	22 Dec., 1896
SCOTT, JAMES, Jun., Strathclyde, Bowling,	15 June, 1898
SCOTT, JAMES G.,	19 Mar., 1901
SEATH, WILLIAM Y., 121 St. Vincent street, Glasgow,	G. 23 Mar., 1886 M. 27 Oct., 1903
SELBY-BIGGE, D., 27 Mosley street, Newcastle-on-Tyne,	21 Feb., 1899
SHANKS, JAMES KIRKWOOD, Engineer, Beechfield, Denny,	23 Apr., 1901
SHANKS, WILLIAM, Tubal works, Barrhead,	15 June, 1898
SHARER, EDMUND, Scotstoun house, Scotstoun, Glasgow,	30 Apr., 1895
SHARP, JOHN, 28 Burnbank gardens, Glasgow,	G. 24 Oct., 1882 M. 22 Nov., 1898
SHARPE, ROBERT, Corporation Gas Works, Belfast,	22 Jan., 1901
SHEARER, Sir JOHN, 13 Crown terrace, Dowanhill, Glasgow,	23 Oct., 1900
SHEDDEN, WILLIAM, 3 Andrew's street, Paisley,	24 Oct., 1899
SHEPHERD, JOHN W., Carrickarden, Bearsden,	26 Mar., 1889
SHUTE, ARTHUR E., 12 Clydeview, Partick, Glasgow,	27 Oct., 1896
SHUTE, CHARLES W., 38 Rowallan gardens, Partick, Glasgow,	27 Oct., 1896
SHUTE, T. S., 8 Belvidere road, Sunderland,	G. 19 Dec., 1893 M. 22 Feb., 1898
SIBBALD, THOMAS KNIGHT, c/o Messrs Cook & Son, Ltd., Cairo, Egypt,	G. 26 Oct., 1897 M. 24 Oct., 1905

SIME, JOHN, 96 Buchanan street, Glasgow,	26 Jan., 1897
SIME, WILLIAM, Victoria Biscuit works, Glasgow,	1 May, 1906
†SIMPSON, ALEXANDER, 175 Hope street, Glasgow,	22 Jan., 1862
SIMPSON, ROBERT, B.Sc., 175 Hope street, Glasgow,	25 Jan., 1887
SIMPSON, WILLIAM, 15 Regent Quay, Aberdeen,	20 Nov., 1900
SINCLAIR, NISBET, 2 Gardenside avenue, Carmyle,	G. 20 Mar., 1877 M. 20 Dec., 1887
SLIGHT, GEORGE H., Jun., c/o James Slight, Esq., 131 West Regent street, Glasgow,	G. 28 Nov., 1882 M. 22 Oct., 1889
SMAIL, DAVID, c/o Messrs George Webster & Son, 19 Waterloo street, Glasgow,	22 Jan., 1901
SMALL, WILLIAM O., Douglas avenue, Carmyle,	23 Feb., 1897
SMART, LEWIS A., Birkbeck Bank Chambers, Holborn, London,	22 Mar., 1898
SMILLIE, SAMUEL, 71 Lancefield street, Glasgow,	A. 24 Jan., 1888 M. 22 Feb., 1898
SMITH, ALEXANDER, 653 Shields road, Glasgow,	G. 24 Nov., 1891 M. 29 Oct., 1901
SMITH, HERBERT GARDNER, Hartfield, Helensburgh,	26 Nov., 1901
SMITH, HUGH WILSON, Netherby, N. Albert road, Pollokshields, Glasgow,	25 Jan., 1898
SMITH, JAMES, Tinley Manor, Chakas Kraal, Durban, South Africa,	23 Oct., 1888
SMITH, JAMES A., Union Bank house, Virginia place, Glasgow,	G. 18 Dec., 1894 A.M. 28 Apr., 1903 M. 27 Oct., 1903
SMITH, OSBOURNE, Possil Engine works, Glasgow,	24 Dec., 1895
SMITH, ROBERT, c/o Mrs Chisholm, 229 North street, Glasgow,	20 Mar., 1900
SMITH, ROBERT, Burnlea place, Milton of Campsie,	21 Feb., 1905
SMITH, ROBERT BRUCE,	20 Jan., 1903
SMITH, WILLIAM J., 207 Nithsdale road, Pollokshields, Glasgow,	24 Jan., 1899
SNEDDON, RICHARD M., 45c Whifflet street, Coatbridge,	G. 21 Nov., 1899 M. 18 Mar., 1902
SNEDDON, W. R., Shipyard, Irvine,	22 Jan., 1901
SNOWBALL, EDWARD, 10 Broomfield terrace, Springburn, Glasgow,	22 Feb., 1870
SOMERVAIL, PETER A., Dalmuir Ironworks, Dalmuir,	25 Jan., 1887
SOMERVILLE, THOMAS A., P.O Box 271, Dundas, Ontario, Canada,	22 Feb., 1898
SOTHERN, JOHN W., 59 Bridge street, Glasgow,	29 Oct., 1901
SPALDING, WILLIAM, Inspector General de Maquinas, Armada de Chili, Valparaiso,	G. 25 Oct., 1892 M. 16 Dec., 1902
SPENCE, WILFRID L., 31 St. Vincent place, Glasgow,	28 Apr., 1903

SPROUL, A., 13 Greenlaw avenue, Paisley,	19 Mar., 1901
STARK, JAMES, 13 Princes gardens, Dowanhill, Glasgow,	27 Oct., 1896
STARK, JAMES, Penang, Straits Settlement,	G. 22 Dec., 1891 M. 26 Jan., 1904
†STEPHEN, ALEXANDER E., 8 Princes terrace, Dowanhill, Glasgow,	18 Dec., 1883
†STEPHEN, FREDERICK J., Linthouse, Govan,	30 Apr., 1895
STEPHEN, J. M., 12 Campania place, Govan,	19 Mar., 1901
*†STEPHEN, JOHN, Linthouse, Govan,	
STEVEN, DAVID M., 9 Princes terrace, Dowanhill, Glasgow,	G. 15 June, 1898 M. 24 Oct., 1905
STEVEN, JAMES, Eastvale place, Kelvinhaugh, Glasgow,	23 Oct., 1900
STEVEN, JOHN, Eastvale place, Kelvinhaugh, Glasgow,	26 Oct., 1897
STEVEN, JOHN A., 12 Royal crescent, Glasgow,	G. 22 Nov., 1881 M. 3 May, 1904
STEVEN, JOHN WILSON, 8 Clarence Drive, Hyndland, Glasgow,	20 Dec., 1898
STEVEN, WILLIAM, 37 Cranworth street, Hillhead, Glasgow,	23 Jan., 1894
STEVENS, JOHN, Marsden, Renfrew,	23 Mar., 1897
STEVENSON, WILLIAM F., 49 Park drive, South, Whiteinch, Glasgow,	18 Dec., 1900
STEWART, ALEXANDER W., 55 West Regent street, Glasgow,	23 Jan., 1894
†STEWART, JAMES, Harbour Engine works, 60 Portman street, Glasgow,	25 Mar., 1890
STEWART, JAMES, Messrs L. Sterne & Co., 155 North Woodside road, Glasgow,	25 Oct., 1898
STEWART, JAMES, 3 Keir street, Pollokshields, Glasgow,	23 Feb., 1904
STEWART, JAMES C., 54 George square, Glasgow,	24 Dec., 1901
STEWART, JOHN GRAHAM, B.Sc., Ault Wharrie, Dunblane,	22 Mar., 1892
STEWART, W. MAXWELL, 55 W. Regent street, Glasgow,	21 Nov., 1899
STIRLING, JOHN, Beechwood villa, Drive road, S. Govan,	21 Nov., 1905
STOTHERT, JOHN KENDALL, Messrs Babcock & Wilcox, Ltd., St. Vincent place, Glasgow,	19 Dec., 1905
STRACHAN, ROBERT, 55 Clifford street, Ibrox, Govan,	22 Nov., 1898
STRATHERN, ALEXANDER G., 41 Blairhill street, Coatbridge,	25 Apr., 1899
STUART, JAMES, 94 Hope street, Glasgow,	22 Oct., 1889
STUART, JAMES TAIT, 2 Bowmont terrace, Kelvinside, Glasgow,	18 Dec., 1900
SURTEES, FRANCIS VERE, Messrs Lobnitz & Co., Ltd., Renfrew,	19 Feb., 1901

SUTHERLAND, JOHN, The British Aluminum Coy., Ltd., Greenock,	20 Mar., 1906
SUTHERLAND, SINCLAIR, North British Tube works, Govan,	21 Dec., 1897
SWANN, WILLIAM, Messrs Finlay & Co., Manila, Philippine Islands,	24 Oct., 1905
SYME, JAMES, 8 Glenavon terrace, Partick,	23 Jan., 1877
TAINSH, JOHN, A. G., B.Sc., Messrs Biles, Gray & Co., 175 West George street, Glasgow,	19 Dec., 1905
TANNETT, JOHN CROYSDALE, Vulcan works, Paisley,	25 Jan., 1898
TATHAM, STANLEY, Montana, Burton road, Branksome park, Bournemouth, W.,	G. 21 Dec., 1880 M. 15 June, 1898
TAVERNER, H. LACY, 3 Owen mansions, Queen's Club gardens, West Kensington, London, W.,	22 Dec., 1896
TAYLOR, BENSON, 21 Thornwood avenue, Partick,	20 Nov., 1900
TAYLOR, JAMES, 3 Westminster terrace, Ibrox, Glasgow,	16 Dec., 1902
TAYLOR, PETER,	28 Apr., 1885
TAYLOR, ROBERT, 28 Ardgowan street, Greenock,	27 Oct., 1896
TAYLOR, STAVELEY, Messrs Russell & Company, Port-Glasgow,	25 Mar., 1879
TAYLOR, THOMAS, 73 Margues de Camillas, Manila, Phillipine Islands,	29 Oct., 1901
TERANO, Prof. SEIICHI, College of Engineering, Imperial University, Tōkyō, Japan,	21 Feb., 1899
THISTLETHWAITE, JOHN DICKINSON, Mechanical Engineer, Harbours and Rivers Department, Brisbane, Queensland,	28 Apr., 1903
THODE, GEORGE W., Brandes Strasse, 9, Rostock, I.M., Germany,	27 Jan., 1885
THOM, JOHN, 5 Hillington Park crescent, Glasgow,	26 Feb., 1889
THOMPSON, W. B., Ellengowan, Dundee,	14 May, 1878
THOMSON, Prof. ARTHUR W., D.Sc., College of Science, Poona, India,	26 Apr., 1887
THOMSON, G. CALDWELL, c/o Messrs Thomas Firth & Sons, Lalamander Steel Works, Riga, Russia,	24 Oct., 1893
THOMSON, GEORGE, 14 Caird drive, Partickhill, Glasgow,	18 Dec., 1883
THOMSON, GEORGE, C., 53 Bedford road, Rockferry, nr. Birkenhead,	G. 24 Feb., 1874 M. 22 Oct., 1889
THOMSON, JOHN, 3 Crown terrace, Dowanhill, Glasgow,	20 May, 1868
THOMSON, R. H. B., Govan Shipbuilding yard, Govan,	26 Feb., 1895
THOMSON, ROBERT, Messrs Barr, Thomson & Co, Ltd., Kilmarnock,	25 Jan., 1898
THOMSON, WILLIAM, 20 Huntly gardens, Kelvinside, Glasgow,	G. 23 Dec., 1884 M. 27 Oct., 1896

Thomson, William, Royal Institution Laboratory, Manchester,	17 Feb., 1903
Tidd, E. George, 68 Gordon street, Glasgow,	22 Oct., 1895
Tod, Peter, c/o Messrs E. H. Williamson & Co., Engineers, Lightbody street, Liverpool,	G. 27 Oct., 1885 M. 27 Oct., 1903
Todd, David R., 39-40 Arcade Chambers, St. Mary's Gate and Dean's Gate, Manchester,	G. 25 Jan., 1887 M. 25 Oct., 1892
Torrie, James,	18 Mar., 1902
Tullis, David K., Kilbowie Iron works, Kilbowie,	23 Nov., 1897
Tullis, James, Kilbowie Iron works, Kilbowie,	23 Nov., 1897
Turnbull, Alexander, St. Mungo's works, Bishopbriggs, Glasgow,	21 Nov., 1876
Turnbull, Alexander Pott, 65 West Regent street, Glasgow,	25 Jan., 1898
Turnbull Campbell, 190 West George street, Glasgow,	G. 27 Oct., 1891 M. 27 Oct., 1903
Turnbull, James, 7 Carlton avenue, Seymour grove, Manchester,	G. 22 Mar., 1892 M. 27 Oct., 1903
Turnbull, W. L., 190 West George street, Glasgow,	G. 27 Oct., 1891 M. 27 Oct., 1903
Turner, Thomas, Caledonia works, Kilmarnock,	22 Jan., 1901

Voos, Armand, Superintendent Engineer, Chateau de Petaheid, Verviers, Belgium,	1 May, 1906

Waddell, James, 15 Moray place, Glasgow,	23 Mar., 1897
Walker Archibald, Netherby, Walm Lane, Cricklewood, London, N.W.,	26 Nov., 1901
Walker, John, Hillside, Newlands road, Newlands,	G. 20 Nov., 1894 M. 19 Dec., 1899
Wallace, Duncan M., 65 Union street, Greenock,	27 Oct., 1896
Wallace, James Loch, 15 Clifford street, Glasgow, S.S.,	18 Feb., 1902
Wallace, John, Jun., 1 Compton road, Winchmore Hill, London, N.	G. 26 Jan., 1892 M. 22 Jan., 1901
Wallace, Peter, Ailsa Shipbuilding Co., Troon,	23 Jan., 1883
Wannop, Charles H., Messrs A. Stephen & Son, Linthouse, Glasgow,	G. 24 Feb., 1885 M. 22 Mar., 1904
Ward, J. C. A., 121 North Side, Clapham Common, London, S.W.,	22 Nov., 1898
Ward, John, Leven Shipyard, Dumbarton,	26 Jan., 1886
Warde, Henry W., 69a Waterloo street, Glasgow,	15 June, 1898
Warden, Willoughby C., 68 Gordon street, Glasgow,	24 Mar., 1896
Warnock, Thomas F., 274 Bath street, Glasgow,	23 Jan., 1906

WARNOCK, WILLIAM, FINDLAY, 274 Bath street, Glasgow, 21 Jan., 1902

WASLEY, THOMAS J. J., 21 Station road, Coatham, Redcar, Yorks, 20 Mar., 1906

WATKINSON, Prof. W. H., 15 Croxteth road, Liverpool, 19 Dec., 1893

WATSON, JAMES W., 6 Kirklee road, Kelvinside, Glasgow, 17 Feb., 1903

WATSON, JOHN, 9 Woodside crescent, Glasgow, W., { G. 22 Nov., 1898 / M. 25 Oct., 1904 }

WATSON, ROBERT, 10 East Nelson street, Glasgow, { G. 22 Mar., 1881 / M. 29 Oct., 1901 }

WATSON, WILLIAM, Clyde Shipping Company, Greenock, 24 Nov., 1896

WATT, ALEXANDER, Inchcape, Paisley, 25 Jan., 1898

WATT, ROBERT D., 106 Hamilton place, Aberdeen, { G. 27 Apr., 1880 / M. 27 Oct., 1903 }

WEBB, R. G., Messrs Richardson & Cruddas, Byculla, Bombay, { G. 21 Dec., 1875 / M. 26 Oct., 1886 }

WEBSTER, JAMES, North British Locomotive Co., Ltd., Atlas works, Springburn, Glasgow, 21 Mar., 1899

WEDDELL, ALEXANDER H., B.Sc., Park villa, Uddingston, { G. 22 Dec., 1896 / M. 16 Dec., 1902 }

WEDDELL, JAMES, Park villa, Uddingston, 22 Dec., 1896

WEDGWOOD, A., Dennystown Forge, Dumbarton, 18 Dec., 1900

WEDGWOOD, ARTHUR D., Forgemaster, Dumbarton, 26 Jan., 1897

WEIGHTON, Prof. R. L., M.A., 2 Park villas, Gosforth, Newcastle-on-Tyne, { G. 17 Dec., 1878 / M. 22 Nov., 1887 }

†WEIR, GEORGE, Yass, near Sydney, New South Wales, 22 Dec., 1874

†WEIR, JAMES, Holmwood, 72 St. Andrew's drive, Pollokshields, Glasgow, 22 Dec., 1874

WEIR, JOHN, 46 Lawrence street, Partick, { G. 22 Apr., 1884 / M. 26 Nov., 1895 }

†WEIR, THOMAS, China Merchants' Steam Navigation Co., Marine Superintendent's Office, Shanghai, China, 23 Apr., 1889

WEIR, THOMAS D., Messrs Brown, Mair, Gemmill & Hyslop, 162 St. Vincent street, Glasgow, { G. 19 Dec., 1876 / M. 26 Feb., 1884 }

WEIR, WILLIAM, Holm foundry, Cathcart, Glasgow, { G. 28 Jan., 1896 / M. 22 Nov., 1898 }

WEIR, WILLIAM, 231 Elliot street, Glasgow, 22 Jan., 1901

WELCH, ARCHIBALD, Clune bank, Port-Glasgow, 21 Feb., 1905

WELSH, JAMES, 3 Princes gardens, Dowanhill, Glasgow, { G. 24 Nov., 1885 / M. 26 Oct., 1897 }

WEMYSS, GEORGE B., 57 Elliot street, Hillhead, Glasgow, { G. 28 Nov., 1882 / M. 22 Jan., 1901 }

WHITE, RICHARD S., Shirley, Jesmond, Newcastle-on-Tyne, 20 Feb., 1883

WHITEHEAD, ALEXANDER CULLEN, c/o Messrs Whitehead Bros., Engineers, P.O., Box 2786, Johannesburg, S.A., 27 Oct., 1903

WHITEHEAD, JAMES, Howford, Mansewood, Pollokshaws, Glasgow,	6 Apr., 1887
WILLCOX, REGINALD, J. N., Messrs Fleming & Ferguson, Ltd., Paisley,	28 Apr., 1903
WILLIAMS, LLEWELLYN WYNN, B.Sc., Cathcart, Glasgow,	22 Feb., 1898
WILLIAMS, OWEN R., B.Sc., Railway Appliance works, Cathcart, Glasgow,	20 Nov., 1900
WILLIAMS, WILLIAM,	23 Jan., 1900
WILLIAMSON, ALEXANDER, 67 Esplanade, Greenock,	21 Mar., 1899
WILLIAMSON, Sir JAMES, C.B., 27 Cedar road, Clapham Common, London, S.W.,	23 Dec., 1884
WILLIAMSON, JAMES, Marine Superintendent, Gourock,	24 Mar., 1896
WILLIAMSON, ROBERT, Ormidale, Malpas, near Newport, Mon.,	20 Feb., 1883
WILSON, ALEXANDER, City Chambers, Glasgow,	28 Jan., 1896
WILSON, ALEXANDER, Hyde Park Foundry, Finnieston street, Glasgow,	23 Feb., 1897
WILSON, ALEXANDER HALL, B.Sc., Messrs Hall, Russell, & Co., Aberdeen,	23 Oct., 1900
WILSON, DAVID, Arecibo, Porto Rico, West Indies,	25 Oct., 1887
WILSON, GAVIN, Clyde Navigation Chambers, 16 Robertson street, Glasgow,	22 Oct., 1889
WILSON, JOHN, 101 Leadenhall street, London, E.C.,	24 Dec., 1895
WILSON, JOHN, 256 Scotland street, Glasgow,	22 Dec., 1903
WILSON, SAMUEL, 39 Camphill avenue, Langside, Glasgow,	3 Mar., 1903
WILSON, W. H., 261 Albert road, Pollokshields, Glasgow,	22 Feb., 1898
WILSON, WILLIAM CHEETHAM, 122 Balgray hill, Springburn, Glasgow,	24 Nov., 1903
WILSON, WILLIAM J., Lilybank Boiler works, Glasgow,	30 Apr., 1895
WINNING, WILFRED LAWSON, 99 Queensborough gardens,	21 Nov., 1905
WOOD, ROBERT C., c/o Messrs A. Rodger & Co., Shipbuilders, Port Glasgow,	23 Mar., 1897
WRAY, WILLIAM J. R., 175 West George street, Glasgow,	19 Dec., 1905
WRENCH, WILLIAM G., 27 Oswald street, Glasgow,	25 Mar., 1890
WRIGHT, ROBERT, Lloyd's Register of Shipping, 342 Argyle street, Glasgow,	22 Dec., 1896
WRIGHT, ROBERT, 3 Sir John Rogerson's quay, Dublin,	23 Jan., 1906
WYLLIE, JAMES BROWN, Messrs Wyllie & Blake, 219 St. Vincent street, Glasgow,	G. 25 Oct., 1887 M. 26 Jan., 1897
YARDLEY, ROBERT WILLIAM, Heysham Tower, Heysham, near Morecombe,	22 Mar., 1904

YOUNG, DAVID HILL, 30 Melville street, Pollokshields, Glasgow,	G. / M.	20 Nov., 1900 / 15 Apr., 1902
YOUNG, THOMAS, Rowington, Whittingehame drive, Kelvinside, Glasgow,		20 Mar., 1894
YOUNG, WILLIAM ANDREW, Millburn House, Renfrew,		26 Mar., 1895
YOUNGER, A. SCOTT, B.Sc, 141 Fenchurch street, London, E.C.		24 Nov., 1896

ASSOCIATE MEMBERS.

Adam, John William, Ferguslie villa, Paisley,		28 Apr., 1903
Agnew, William H., Messrs Cammell, Laird & Co., Birkenhead,	G. A.M.	28 Nov., 1882 27 Oct., 1903
Ainslie, James William, 28 Ancaster drive, Anniesland, Glasgow,	G. A.M.	26 Nov., 1901 28 Apr., 1903
Allan, James, 326 West Princes street, Glasgow,	G. A.M.	24 Jan., 1888 2 May, 1905
Anderson, David, B.Sc., 21 Portland road, Holland Park avenue, London, W.,		20 Dec., 1904
Anderson, James, 77 Billiter buildings, Billiter street, London, E.C.,	A. A.M.	24 Apr., 1900 17 Feb., 1903
Anderson, Thomas, c/o M'Queen, 7 Grantly street, Shawlands, Glasgow,	G. A.M.	29 Oct., 1901 28 Apr., 1903
Arbuthnott, Donald S., c/o Messrs Charles Brand & Son, 65 Renfield street, Glasgow,	G. A.M.	23 Oct., 1888 27 Oct., 1903
Ardill, William, 17 Chatham grove, Withington, Manchester,		17 Feb., 1903
Arundel, Arthur S. D., Penn street works, Hoxton, London, N.,	G. A.M.	23 Dec., 1890 27 Oct., 1903
Baird, Thomas H., 12 Berkeley terrace, Glasgow,		21 Nov., 1905
Ballantyne, Hugh D., Rose cottage, Kilbirnie,		24 Oct., 1905
Barbour, James Clinkskill, 4 St. Thomas square, Newcastle-on-Tyne,		24 Jan., 1905
Barnwell, Frank S., Elcho house, Balfron,	S. A.M.	18 Feb., 1902 23 Jan., 1906
Barnwell, Richard H., Elcho house, Balfron,	S. A.M.	18 Feb., 1902 23 Jan., 1906
Bennett, Duncan, 9 Leslie street, Pollokshields, Glasgow,	G. A.M.	26 Oct., 1897 27 Oct., 1903
Berry, Davidson, 4 Newlands park, Newlands, Glasgow,	G. A.M.	19 Mar., 1901 27 Oct., 1903
Blair, Archibald, 25 Peel street, Partick,	G. A.M.	27 Oct., 1891 3 May, 1904
Boyd, James, c/o The Borneo Coy., Ltd., Ban Sarawak, Dutch Borneo,		22 Mar., 1904
Brown, William, 22 Leven street, Pollokshields, Glasgow,	G. A.M.	26 Nov., 1901 21 Apr., 1903
Brownlie, Matthew, 4 Edmiston drive, Ibrox, Glasgow,		21 Nov., 1905

BUCHANAN, GEORGE HAMILTON, 1 Wellfield terrace, Springburn, Glasgow,		19 Dec., 1905
BUCHANAN, WALTER G., 17 Sandyford place, Glasgow,	G. A.M.	27 Jan., 1891 28 Apr., 1900
BUCKLE, JOSEPH, 30 Dumbarton road, Ferry road head, Yoker, Glasgow,	S. A.M.	31 Oct., 1902 28 Apr., 1903
BUTLER, JAMES S., 21 Hamilton terrace, W., Partick,	G. A.M.	22 June, 1901 3 May, 1904
CALDWELL, JAMES, 157 West George street, Glasgow,		24 Oct., 1905
CALDWELL, JAMES, 6 Clydeview, Partick,		20 Mar., 1906
CAMERON, ANGUS J., 43 Union road, Exeter,	G. A.M.	20 Nov., 1900 2 May, 1905
CAMERON, JOHN, 29 White street, Partickhill, Glasgow,		21 Nov., 1905
CLEGHORN, GEORGE, 2 Clelland place, Ibrox, Govan,		27 Oct., 1903
COCHRAN, ALEXANDER, Messrs Burns & Co., Ltd., Howrah, Calcutta,		3 Mar., 1903
COLEMAN, HENRY CHARLES, Isaac Peral 25, Cadiz, Spain,		3 May, 1904
COOK, ROBERT TEMPLETON, 2 Wyndham park, Ardbeg, Rothesay, N.B.,		25 Oct., 1904
CRAIG, JAMES, B.Sc., Netherlea, Partick,	G. A.M.	22 Feb., 1899 28 Apr., 1903
CRAWFORD, JOHN DOUGLAS, 64 Love street, Paisley,		20 Mar., 1906
CUMMING, FINDLAY M., 4 Smithhills Paisley,		23 Jan., 1906
DEKKE, K. S., Bergen, Norway,	G. A.M.	22 Dec., 1891 27 Oct., 1903
DIACK, JAMES A., 4 Rosemount terrace, Ibrox, Glasgow,	G. A.M.	22 Jan., 1895 27 Oct., 1903
DICKIE, JAMES BLACK, B.Sc., Sorrento, Terregles avenue, Pollokshields, Glasgow,		20 Dec., 1904
DOBBIE, ROBERT BROWN, 15 Leander road, Brixton Hill, London, S.W.,	S. A.M.	24 Oct., 1899 17 Apr., 1906
DRYSDALE, HUGH R. S., 24 Kilmailing terrace, Cathcart, Glasgow,		17 Feb., 1903
DUNLOP, ALEXANDER, 14 Derby terrace, Sandyford, Glasgow,	G. A.M.	21 Dec., 1897 28 Apr., 1903
EDMISTON, ALEXANDER A., Ibrox house, Govan,	G. A.M.	22 Feb., 1898 27 Oct., 1903
ELLIOTT, SIMPSON, 122 Darnley street, Pollokshields, Glasgow,		19 Dec., 1905
FALLON, ALFRED H., c/o Mrs A. Dowie, 59 Gardner street, Partick,		17 Feb., 1903

Faut, Alexander, 3 Holland place, Glasgow,	G. A.M.	19 Dec., 1899 21 Apr., 1903
Fergus, Alexander, 7 Ibrox place, Ibrox, Glasgow,	G. A.M.	22 Dec., 1891 3 May, 1904
Fergus, Fred. Smeaton, 52 Lawrence street, Partick,		20 Feb., 1906
Ferguson, Daniel, 27 Oswald street, Glasgow,		27 Oct., 1903
Fernie, John, 33 Partickhill road, Partick, Glasgow,	S. A.M.	31 Oct., 1902 28 Apr., 1903
Findlater, James, 124 Pollok street, Glasgow, S.S.,	G. A.M.	19 Dec., 1899 23 Feb., 1904
Findlay, Edwyn Alfred, 5 Cranworth street, Hillhead, Glasgow,		25 Oct., 1904
Fletcher, William Dawson, 11-15 East Vermont street, Kinning Park, Glasgow,		23 May, 1905
Foulis, William, 2 Montgomerie quadrant, Kelvinside, Glasgow,		21 Nov., 1905
France, James, 8 Hanover terrace, Kelvinside, Glasgow,	G. A.M.	26 Oct., 1897 27 Oct., 1903
Frost, Evelyn F. M., 21 Burnbank gardens, Glasgow,	S. A.M.	31 Oct., 1902 28 Apr., 1903
Gallacher, Patrick, 72 Fulbar street, Renfrew,		21 Apr., 1903
Gilchrist, James, B.Sc., Caledonian Railway Company, Buchanan street, Glasgow,		26 Apr., 1904
Gilmour, Andrew, 34 Hamilton terrace, Hamilton, West,	G. A.M.	20 Dec., 1898 2 May, 1905
Grant, William, 40 Keppel road, Chorlton-cum-Hardy, Manchester,	S. A.M.	24 Oct., 1899 1 May, 1906
Gray, Robert, 88 Lennox street, Possilpark, Glasgow,		17 Apr., 1906
Grieve, John, Kinclaven, Miller street, Hamilton,		23 Jan., 1906
Guthrie, William Orrok, 4 Crown Circus road, Glasgow, W.,		21 Nov., 1905
Hay, James, Devon bank, High Crosshill, Rutherglen,		20 Dec., 1904
Heron, John Murdoch, 4 Merchiston avenue, Edinburgh,		21 Nov., 1905
Hogarth, Alexander, 1 Tantallon terrace, Ibrox, Glasgow,		21 Nov., 1905
Holmes, James, c/o Robertson, 25 St. James street, Paisley,	S. A.M.	17 Feb., 1903 24 Oct., 1905
Horn, Peter Allan, 29 Regent Moray street, Glasgow	G. A.M.	26 Oct., 1897 27 Oct., 1903
Howie, William, c/o Messrs David Rollo & Son, 9 Blackstone street, Liverpool,	G. A.M.	23 Apr., 1901 28 Apr., 1903

HUTCHEON, ALEXANDER, 5 Belmont street, Hillhead, Glasgow, 20 Dec., 1904

HUTCHISON, ROBERT, c/o Messrs Burns & Co., Engineers, Howrah, Calcutta, G. 24 Oct., 1899; A.M. 27 Oct., 1903

I'ANSON, JOSEPH, 83 Hyndland street, Partick, 23 Jan., 1906

IRVINE, ARCHIBALD B., 5 Strathallan terrace. Dowanhill, Glasgow, G. 20 Nov., 1894; A.M. 27 Oct., 1903

JOHNSON, HERBERT AUGUST, 41 James street, Holderness road, Hull, 22 Mar., 1904

JOHNSTONE, ALEXANDER C., 307 Ruchill street, Ruchill, Glasgow, G. 25 Jan., 1898; A.M. 27 Oct., 1903

JOHNSTONE, JOHN GAVIN, B.Sc., 11 Maxwell terrace, Pollokshields, Glasgow, 22 Dec., 1903

JOHNSTONE, ROBERT, Sala de Desenho, Arsenal da Mavinha, Lisbon, G. 26 Apr., 1895; A.M. 27 Oct., 1903

JONES, T. C., 17 Kent Avenue, Jordanhill, Glasgow, G. 23 Nov., 1897; A.M. 27 Oct., 1903

KIRK, JOHN, Killearn Lodge, Helensburgh, G. 20 Nov., 1894; A.M. 28 Apr., 1903

KNOX, ALEXANDER, 10 Westbank terrace, Hillhead, Glasgow, G. 23 Nov., 1897; A.M. 22 Dec., 1903

LAIRD, ALEXANDER, 172 Pitt street, Glasgow, 24 Oct., 1905

LAMB, STUART D. R., Contractor's Office, Camden house, Southwick, Sunderland, G. 23 Jan., 1900; A.M. 23 Feb., 1904

LANE, FRANK C., The Customs Service of the Philippine Islands, Iloilo, 24 Oct., 1905

LEARMONTH, ROBERT, Electricity Offices, Whitaker buildings, Victoria square, Bradford, G. 26 Nov., 1901; A.M. 21 Apr., 1903

LE CLAIR, LOUIS J., Societe, Anonyme Westinghouse, Sevran (Seine & Oise), France, G. 24 Nov., 1896; A.M. 21 Apr., 1903

LEE, JOHN, Dunton house, Thorpe road, Peterborough, G. 26 Jan., 1886; A.M. 21 Apr., 1903

LITTLE, JOHN PATERSON, Annandale, Riverside road, Newlands, Glasgow, 24 Oct., 1905

LITTLE, SIMON MURE, 32 Sutherland ter., Glasgow, W., 24 Jan., 1905

LOUDON, JAMES MAY, 22 Clarendon street, Glasgow, A. 21 Jan., 1902; A.M. 2 May 1905

LOWE, JAMES, c/o Wilson, 92 Langside avenue, Langside, Glasgow, G. 24 Oct., 1899; A.M. 23 Feb., 1904

LYNN, ROBERT R., 7 Highburgh terrace, Dowanhill, Glasgow, 20 Jan., 1903

LYONS, LEWIS JAMES, 119, 33rd street, Newport-News, Virginia, U.S.A.		23 Feb., 1904
McCULLOCH, JOHN, 49 Arlington street, Glasgow,	G. A.M.	23 Oct., 1900 3 May, 1904
McEWAN, JOHN, 3 Norse road, Scotstoun, Glasgow,	G. A.M.	26 Oct., 1887 28 Apr., 1903
McFARLANE, DUNCAN A., 9 Dunolly gardens, Ibrox, Glasgow,		21 Nov., 1905
McGILVRAY, JOHN A., 555 Govan road, Govan,	G. A.M.	26 Oct., 1897 27 Oct., 1903
McHARDY, WALLACE BRUCE, Flakedale, Hamilton,		21 Nov., 1905
McINTYRE, JAMES N., 33 Hayburn crescent, Partick,	G. A.M.	20 Nov., 1900 27 Oct., 1903
McIVOR, JOHN, Moss cottage, Nitshill, Glasgow,		3 Mar., 1903
McKENZIE, WILLIAM JOHN, 5 Westbourne drive. Ibrox, Glasgow,		21 Feb., 1905
McMILLAN, THOMAS, 5 Balgray Hill, Springburn, Glasgow,		19 Dec., 1905
MACKIE, JAMES, 371 Bath street, Glasgow,	G. A.M.	23 Mar., 1897 28 Apr., 1903
MACKINTOSH, R. D., P.O. Box 6075, Johannesburg, South Africa,	G. A.M.	20 Nov., 1893 27 Oct., 1904
MANNERS, EDWIN, 21 Leslie street, Pollokshields, Glasgow,		17 Feb., 1903
MARSHALL, JAMES EADIE, 18 Partick street, Greenock,		19 Dec., 1905
MARTIN, GEORGE HOWE. c/o Macfarlane, Strathend house, Strathleven place, Dumbarton,		24 Oct., 1905
MARTIN, JAMES, 7 Woodend drive, Jordanhill, Glasgow,		20 Dec., 1905
MEEK, WILLIAM M'CARTER, 21 Thornwood avenue, Partick,		25 Oct., 1904
MELENCOVICH, ALEXANDRE, 21 Peel street, Partick,	S. A.M.	31 Oct., 1902 22 Nov., 1904
MENZIES, GEORGE, 20 St. Vincent crescent, Glasgow,	G. A.M.	22 Jan., 1889 24 Nov., 1903
MILLAR, JOHN SIMPSON, 55 Gardner street, Partick,	G. A.M.	20 Nov., 1894 22 Dec., 1903
MILLAR, WILLIAM PETTIGREW, Elmbank, Easterhill street, Tollcross, Glasgow,	G. A.M.	18 Dec., 1900 17 Feb. 1903
MILLER, JAMES W., 84 Portland place, London, W.,	G. A.M.	20 Dec., 1898 2 May, 1905
MITCHELL, ALEXANDER ROBERTSON, 375 Glasgow road, Clydebank,		24 Nov., 1903
MITCHELL, R. M., 24 Howard street, Bridgeton, Glasgow,	G. A.M.	23 Nov., 1897 22 Dec., 1903
MORGAN, ANDREW, 67 Devonshire street, Higher Broughton, Manchester,	G. A.M.	18 Dec., 1900 22 Dec., 1903

MORRISON, A., Alt-na-craig, Greenock,	G. A.M.	23 Nov., 1897 3 May, 1904
MUIR, ANDREW A., 189 Renfrew street, Glasgow,	G. A.M.	22 Nov., 1898 23 Feb., 1904
NORMAN, MYLES GARNET, Karonga, Bracken Brae road, Bishopriggs,		18 Apr., 1905
NOWERY, W. F., c/o Jack, 71 Grant street, Glasgow,	G. A.M.	21 Dec., 1897 28 Apr., 1903
OLIVER, GORDON BERNARD, St. Martin's, Whittinghame drive, Glasgow,		23 Jan., 1906
PATERSON, GEORGE, 27 White street Partick,		21 Nov., 1905
POLLOCK, GILBERT F.,	G. A.M.	27 Jan., 1895 2 May, 1901
RALSTON, SHIRLEY BROOKS, 39 Bentinck street, Glasgow, W.,	G. A.M.	23 Feb., 1897 23 Feb., 1904
RANKEN, JOHN, Fernlea, Wilson street, Motherwell,		24 Oct., 1905
RIDDLESWORTH, W. HENRY, M.Sc., 63 Polworth gardens, Partickhill, Glasgow,	G. A.M.	24 Oct., 1899 28 Apr., 1903
ROBERTS, WILLIAM MIRRLEES, 15 Ardgowan street, Greenock,		20 Feb., 1906
ROBERTSON, ALFRED, J. C., 591 St. Catherine street, West, Montreal, Canada,		16 Dec., 1902
ROBERTSON, JOHN, Jun., 7 Maxwell terrace, Shields road, Pollokshields, Glasgow,		20 Jan., 1903
ROSS, JOHN RICHMOND, Messrs Balfour, Lyon & Co., Valparaiso,	G. A.M.	25 Oct., 1898 26 Jan., 1904
ROSS, THOMAS C., 13 Hampden terrace, Mount Florida, Glasgow,	S. A.M.	21 Apr., 1903 2 May, 1905
RUSSELL, JOHN, Orchard street, Motherwell,		21 Feb., 1905
SANGUINETTI, W. ROGER, Public Works Department, Selangor, Malay States,	G. A.M.	20 Feb., 1900 2 May, 1905
SAUL, GEORGE, Yloilo Engineering works, Yloilo, Phillipine Islands,		21 Apr., 1903
SERVICE, WILLIAM, 173 West Graham street, Glasgow,	S. A.M.	26 Nov., 1901 20 Mar., 1906
SHARPE, WILLIAM H., B.Sc., Engineer's Office, Natal Government Railway, Pietermaritzburg, Natal,	G. A.M.	24 Dec., 1895 24 Oct., 1905
SHEARER, JAMES, 30 McCulloch street, Pollokshields, Glasgow,		3 Mar., 1903

Sloan, John Alexander, 37 Annette street, Crosshill, Glasgow,	G. A.M.	25 Jan., 1898 25 Oct., 1904
Smith, James, 4 Clydeview, Partick, Glasgow,	G. A.M.	18 Dec., 1900 28 Apr., 1903
Smith, James, 23 Barrington drive, Glasgow,	G. A.M.	20 Dec., 1892 27 Oct., 1903
Simpson, Adam, 12 Rupert street, Glasgow,	S. A.M.	3 May, 1904 19 Dec., 1905
Speakman, Edward M., The Parsons' Foreign Patents Co., Ltd., 9 Throgmorton avenue, London,		16 Dec., 1902
Sperry, Austin, 2100 Pacific avenue, San Francisco, Cal., U.S.A.,	G. A.M.	23 Mar., 1897 22 Mar., 1904
Steele, David J., Davaar, 41 Albert drive, Pollokshields, Glasgow,	G. A.M.	20 Dec., 1898 27 Oct., 1903
Stephen, David Belford, 19 Aitken street, Alexandra Park, Glasgow,		24 Nov., 1903
Stevens, Thomas, 55 Ferry road, Renfrew,		21 Apr., 1903
Stevenson, George, Hawkhead, Paisley,	G. A.M.	22 Nov., 1898 24 Mar., 1903
Stevenson, George, Carron Company, Wellpark, Larbert,	G. A.M.	24 Apr., 1900 25 Oct., 1904
Stewart, Alex. Walker, 41 Comelybank avenue, Edinburgh,		21 Nov., 1905
Stirling, Andrew, 3 Greenvale terrace, Dumbarton,	G. A.M.	21 Dec., 1875 22 Dec., 1903
Stirling, William, c/o Allan, 1159 Argyle street, Glasgow,		25 Oct., 1904
Stobie, Peter, 33 Kelvinhaugh street, Glasgow,	S. A.M.	31 Oct., 1902 28 Apr., 1903
Stott, John, 103 Stevenson drive, Shawlands, Glasgow,		21 Nov., 1905
Symington, James R., Broomieknowe, Kilmacolm,	G. A.M.	21 Dec., 1886 26 Jan., 1904

Taylor, J. F., 23 Roslea drive, Dennistoun, Glasgow,	G. A.M.	23 Nov., 1897 27 Oct., 1903
Thomson, James, Jun., 2 Glenavon terrace, Partick,		21 Nov., 1905
Tillotson, Frank, 8 Woodlands, Albert road, Langside, Glasgow,		21 Nov., 1905
Todd, Joseph, 47 Camperdown road, Scotstoun, Glasgow,		23 Jan., 1906
Tostee, Evenor, (Fils) Forges et Fonderie de Providence, Flacq, Mauritius,		26 Jan., 1904

Ure, Sebastian, G. M., 514 St. Vincent street, Glasgow,	22 Dec., 1903
Utting, Samuel, 65 Warwick road, London, S.W.	22 Dec., 1903

WARD, GEORGE K., Garmoyle, Dumbarton,	G. A.M.	23 Apr., 1901 24 Oct., 1905
WARD, JOHN, Jun., Garmoyle, Dumbarton,	G. A.M.	23 Apr., 1901 24 Oct., 1905
WELSH, GEORGE MUIR, 3 Princes gardens, Dowanhill, Glasgow,	G. A.M.	21 Dec., 1897 28 Apr., 1903
WHITELAW, ANDREW H., B.Sc., 74 Dundonald road, Kilmarnock,	G. A.M.	20 Nov., 1900 27 Oct., 1903
WILLIAMSON, ALEX., B.Sc., Craigbarnet, Greenock,	G. A.M.	20 Nov., 1900 20 Dec., 1904
WOODS, JOSEPH, 87 Grosvenor Road, Ilford, Essex,	G. A.M.	25 Feb., 1896 27 Oct., 1903
WOODSIDE, HUGH R., Artnox, Dalry, Ayrshire,		16 Dec., 1902
YAMUKAWA, KUCHIRO, 8 Sutherland drive, Hillhead, Glasgow,		21 Nov., 1905
YOUNG, JOHN, Jun., c/o Messrs Wallsend Slipway and Engineering Co., Ltd., Wallsend-on-Tyne,	G. A.M.	23 Nov., 1897 2 May, 1905

ASSOCIATES.

ADDIE, FRANK R., 8 Westbourne gardens, Kelvinside, Glasgow,	18 Dec., 1900
*AITKEN, THOMAS, 8 Commercial street, Leith,	
ALLAN, HENRY, 25 Bothwell street, Glasgow,	23 Jan., 1900
†ALLAN, JAMES A., 25 Bothwell street, Glasgow,	29 Oct., 1901
ARMOUR, WILLIAM NICOL, 40 West Nile street, Glasgow,	24 Nov., 1896
BARCLAY, THOMAS KINLOCH, 41 Ann street, Glasgow,	20 Mar., 1900
BEGG, WILLIAM, 34 Belmont gardens, Glasgow,	19 Dec., 1886
BLAIR, HERBERT J., 30 Gordon street, Glasgow.	23 Feb., 1897
BOWLES, GEOFFREY TATTON, Lieutenant, R.N., 25 Lowndes square, London, S.W.,	25 Oct., 1904
BOWMAN, FREDERICK GEORGE, 21 Kersland terrace, Hillhead, Glasgow,	22 Mar., 1904
BRECKNELL, GEORGE W., 79 West Regent street, Glasgow,	21 Feb., 1905
BROWN, Capt. A. R., 34 West George street, Glasgow,	21 Dec., 1897
BROWN, THOMAS J., 233 St. Vincent street, Glasgow,	29 Oct., 1901
BUCHANAN, JAMES, Dalziel Bridge works, Motherwell,	26 Nov., 1901
CAYZER, Sir CHARLES W., Bart., M.P., Gartmore, Perthshire,	27 Oct., 1903
CHRISTIE, WILLIAM, 4 Westminster gardens, Hillhead, Glasgow,	18 Apr., 1905
CLARK, ROBERT, 21 Bothwell street, Glasgow,	23 Feb., 1904
CLAUSSEN, A. L., 118 Broomielaw. Glasgow,	22 Jan., 1892
CLYDE, WALTER P., Messrs Dobbie, M'Innes, Ltd., 45 Bothwell street, Glasgow,	24 Oct., 1899
CRAIGIE, JOHN, 113 South Cromwell road, Queen's park, Glasgow,	25 Oct., 1904

Names marked thus * were Associates of Scottish Shipbuilders' Association at incorporation with Institution, 1865.

Names marked thus † are Life Associates.

DAWSON, DAVID C., 12 York street, Glasgow,	27 Oct., 1903
DEWAR, JAMES, 11 Regent Moray street, Glasgow,	22 Dec., 1897
DODDRELL, EDWARD E., 11 Bothwell street, Glasgow,	26 Oct., 1897
DONALD, JAMES, J.P., 123 Hope street, Glasgow,	19 Dec., 1899
FARNELL, JOHN A., 11 Charing Cross mansions, Glasgow,	21 Feb., 1905
FERGUSON, PETER, 19 Exchange square, Glasgow,	27 Apr., 1897
FORREST, WILLIAM, 60 Dalziel drive, Pollokshields, Glasgow,	19 Feb., 1901
GARDINER, FREDERICK CROMBIE, 24 St. Vincent place, Glasgow,	20 Feb., 1900
GARDINER, WILLIAM GUTHRIE, 24 St. Vincent place, Glasgow,	20 Feb., 1900
GOVAN, WILLIAM, Belhaven, Milngavie,	21 Feb., 1905
GRAHAM, The Most Honourable The Marquis of, Buchanan Castle, Glasgow,	22 Mar., 1904
HAMILTON, DAVID JOHN, 9 Princes gardens, Glasgow, W.,	2 May, 1905
HENDERSON, JOHN B., Messrs John Brown & Co., Ltd., Clydebank,	22 Mar., 1904
HOLLIS, JOHN, c/o Messrs John Brown & Co., Ltd., 144 St. Vincent street, Glasgow,	23 Nov., 1897
HOPE, ANDREW, 50 Wellington street, Glasgow,	27 Oct., 1903
INVERCLYDE, The Right Honourable Lord, 30 Jamaica street, Glasgow,	23 Oct., 1900
KINGHORN, WILLIAM A., 81 St. Vincent street, Glasgow,	24 Oct., 1882
KIRSOP, JAMES NIXON, 79 St. George's place, Glasgow,	29 Oct., 1901
KYLE, JOHN, Cathay, Forres, N.B.,	23 Feb., 1897
M'ARA, ALEXANDER, 65 Morrison street, Glasgow,	22 Nov., 1892
MACBETH, GEORGE ALEXANDER, 65 Great Clyde street, Glasgow,	24 Jan., 1899
MACBRAYNE, DAVID HOPE, 119 Hope street, Glasgow,	22 Mar., 1904
MACBRAYNE, LAURENCE, 11 Park Circus place, Glasgow,	26 Mar., 1895
MACDOUGALL, DUGALD, 1 Cross-shore street, Greenock,	26 Jan., 1897

M'INTYRE, T. W., Kirkmichael house, Maybole, Ayrshire,	24 Jan., 1893
MACLAY, JOSEPH P., 21 Bothwell street, Glasgow,	18 Dec., 1900
M'LINTOCK, FINLAY, Fisherwood, Balloch,	19 Dec., 1905
M'PHERSON, Captain DUNCAN, Mavisbank, Gourock,	26 Jan., 1886
MERCER, JAMES B., Broughton Copper works, Manchester,	24 Mar., 1874
MOWBRAY, ARCHIBALD H., Sutherland house, Stirling,	22 Feb., 1898
OVERTOUN, The Right Hon. Lord, Overtoun, Dumbartonshire,	27 Oct., 1903
PAUL, ROBERT, 82 Gordon street, Glasgow,	18 Apr., 1905
PAIRMAN, THOMAS, Auld manse, Busby,	23 Jan., 1900
PRENTICE, THOMAS, 175 West George street, Glasgow,	24 Nov., 1896
RAEBURN, WILLIAM HANNAY, 81 St. Vincent street, Glasgow,	20 Feb., 1900
REID, JOHN, 30 Gordon street, Glasgow,	22 Dec., 1896
REID, WILLIAM, 109 Hope street, Glasgow.	23 Jan., 1906
RIDDLE, JOHN C., c/o Messrs Walker & Hall, 8 Gordon street, Glasgow,	15 June, 1898
ROBERTSON, WILLIAM,	27 Apr., 1897
ROBINSON, DAVID, Hilbre, Balshagray avenue, Partick,	16 Dec., 1902
ROXBURGH, JOHN ARCHIBALD, 3 Royal Exchange square, Glasgow,	20 Feb., 1900
SERVICE, GEORGE WILLIAM, 175 West George street, Glasgow,	24 Nov., 1896
SCOTT, HAROLD H. S., 94 Hope street, Glasgow,	20 Mar., 1906
SERVICE, WILLIAM, 54 Gordon street, Glasgow,	23 Jan., 1900
SLOAN, WILLIAM, 53 Bothwell street, Glasgow,	20 Feb., 1900
†SMITH, GEORGE, c/o Messrs George Smith & Sons, 75 Bothwell street, Glasgow,	22 Jan., 1901
SMITH, JOHN, 41 Kelvinside gardens, Kelvinside, N., Glasgow,	22 Feb., 1898
SOTHERN, ROBERT M., 59 Bridge street, Glasgow,	18 Feb., 1902
STEWART, CHARLES R., Messrs J. Stone & Co., 46 Gordon street, Glasgow,	29 Oct., 1901

STEWART JOHN G., 65 Great Clyde street, Glasgow,	18 Dec., 1890
STRACHAN, G., Fairfield works, Govan,	26 Oct., 1891
TAYLOR, FRANK, 70 Hatfield road, Bedford Park, London, W.,	24 Dec., 1901
TAYLOR, WILLIAM GILCHRIST, 123 Hope street, Glasgow,	23 Jan., 1900
THOMSON, WILLIAM H., 32 Albert Road East, Crosshill, Glasgow,	19 Feb., 1901
WARREN, ROBERT G., 116 Hope street, Glasgow,	28 Jan., 1896
WEIR, ANDREW, 102 Hope street, Glasgow,	25 Jan., 1898
WHIMSTER, THOMAS, 67 West Nile street, Glasgow,	24 Oct., 1899
WILD, CHARLES WILLIAM, Broughton Copper Company, Limited, 49-51 Oswald street, Glasgow,	24 Mar., 1896
WILLIAMSON, JOHN, 99 Great Clyde street, Glasgow,	28 Apr., 1903
WILLOCK, FREDERICK GEORGE, 109 Hope street, Glasgow,	21 Mar., 1905
WREDE, FREDERICK LEAR, 25 Bentinck street, Greenock.	25 Jan., 1898
YOUNG, JOHN D., Scottish Boiler Insurance Company, 111 Union street, Glasgow,	19 Dec., 1882
YOUNG, ROBERT, Baltic Chambers, 50 Wellington street, Glasgow,	16 Dec., 1902

STUDENTS.

AITKEN, JOHN, Beech cottage, Balshagray avenue, Partick,	28 Apr., 1903
ALEXANDER, ROBERT, 33 Melville street, Portobello,	23 Oct., 1900
ALEXANDER, WILLIAM, The Wellington Technical School, Wellington, N.Z.,	19 Mar., 1901
ALEXANDER, WILLIAM, 13 Lawrence street, Partick,	25 Oct., 1904
ALISON, ALEXANDER E., Devonport, Auckland, New Zealand,	22 Nov., 1898
ANDERSON, ADAM R.,	23 Mar., 1897
ANDERSON, JOHN, Jun., 3 Crow road, Partick,	2 May, 1905
ANDREW, ARCHIBALD, 4 Thornwood terrace, Partick,	23 May, 1905
AOYAGI, J., c/o Mrs Sutherland, 1 West End Park street, Glasgow,	24 Oct., 1905
Ap.-GRIFFITH, YWAIN GORONWY, c/o Logan, 128 Byres road, Glasgow,	3 Mar., 1903
APPLEBY, JOHN HERBERT, 133 Balshagray avenue, Partick,	27 Oct., 1903
APPLETON, EVELYN, Rosevale, Windsor road, Renfrew,	20 Dec., 1904
BAIRD, JAMES, Romiley, Erskine avenue, Dumbreck,	26 Jan., 1904
BARTY, THOMAS PATRICK WILLIAM, c/o Messrs. Formans & M'Coll, 160 Hope street, Glasgow,	18 Dec., 1900
BELL, H. L. RONALD, Redargan, Drumoyne drive, Govan,	22 Mar., 1904
BERG, WILLIAM E. G., 290 Duke street, Glasgow,	24 Oct., 1905
BERTRAM, R. M., 9 Walmer road, Toronto, Canada,	24 Jan., 1899
BINLEY, WILLIAM, Jun., 504, 73rd street, Brooklyn, New York, U.S.A.,	21 Mar., 1899
BISSET, JOHN, 35 Harriet street, Pollokshaws, Glasgow,	18 Dec., 1900
BLACK, JAMES, 3 Clarence street, Paisley,	18 Dec., 1900
BONE, QUINTIN GEORGE, c/o Shearer, 23 Belmont street, Hillhead, Glasgow,	19 Dec., 1899
BROOM, WILLIAM A., M.A., Rothmar, Campbeltown,	20 Dec., 1904
BROWN, ALEXANDER TAYLOR, 1 Broomhill avenue, Partick, Glasgow,	26 Oct., 1897
BROWN, ANDREW, 7 Whittinghame gardens, Glasgow,	21 Nov., 1905
BROWN WALTER GEORGE, 35 Burnbank gardens, Glasgow,	2 May, 1905
BRUCE, WILLIAM ROSS, Oaklea, Hawkhead road, Paisley,	19 Dec., 1905

Buchanan, Joshua Miller, 25 Hickman road, Penarth, Cardiff,	21 Nov., 1899
Bunten, James C., Anderston Foundry, Glasgow,	20 Nov., 1900
Callander, William, 10 Ashburnham Road, Bedford,	24 Dec., 1901
Cameron, Charles, 126 Paisley road, west, Glasgow,	25 Oct., 1904
Cameron, Ivan Johnstone, P.O. Box 365, Nelson, British Columbia,	24 Jan., 1905
Clark, William W., 32 Grafton square, Glasgow,	20 Dec., 1904
Clover, Mat., Jun., Roselea, Willaston, near Chester,	22 Dec., 1903
Cochrane, John, 15 Ure place, Montrose street, Glasgow,	24 Dec., 1901
Cormack, James Alexander, 101 Clarence drive, Partickhill, Glasgow,	24 Nov., 1903
Cran. J. Duncan, 11 Brunswick street, Edinburgh,	21 Jan., 1902
Crawford, Archibald, P.O. Box 558, Pretoria, S.A.,	18 Dec, 1900
Crichton, James, B.Sc., c/o Hunter, 308 Byres road, Glasgow,	22 Mar., 1904
Crighton, Arthur Edward,	21 Mar., 1905
Crombie, John Wallace, c/o Turnbull, 25 Iona place, Mount Florida, Glasgow,	19 Dec., 1905
Cubie, Alexander, Jun., 2 Newhall terrace, Glasgow,	23 Jan., 1900
Cuthbert, James G., Suir Bridge Railway works, Waterford,	21 Nov., 1899
Dennistoun, A. B., Glenesk, Sherbrooke avenue, Pollokshields, Glasgow,	1 May, 1906
De Sola, Juan Garcia, Sacramento, 57, Cadiz, Spain,	20 Mar., 1900
Dewar, Robert D., 4 Battlefield avenue, Langside, Glasgow,	21 Mar., 1905
Dias, Christopher, 132 Mains street, off Sauchiehall street, Glasgow,	16 Dec., 1902
Dickie, James S., San Mateo, California,	19 Dec., 1899
Dixon, Ernest M., 1 Westbank place, Smith street, Hillhead, Glasgow,	1 May, 1905
Dobbie, Robert B., 15 Leander Road, Brixton Hill, London, S.W.,	24 Oct., 1899
Dornan, James, 21 Minerva street, Glasgow,	20 Jan., 1903
Dornan, John D., 21 Minerva street, Glasgow,	22 Mar., 1904
Drysdale, William, 3 Whittingehame gardens, Kelvinside, Glasgow,	16 Dec., 1902
Duff, Gordon Alison, B.Sc., 20 Park road, West Kirby, Cheshire,	24 Oct., 1905

DUNCAN, ALEXANDER, c/o E. G. Fraser Luckie, Esq., Hacienda, Andalusia, Huacho, Sayou, Peru, 23 Apr., 1901
DUNLOP, JOHN, 9 Oakfield terrace, Hillhead, Glasgow, 21 Mar., 1905
DUNSMUIR, GEORGE, Matheran, 27 Sherbrooke avenue, Pollokshields, Glasgow, 21 Apr., 1903

ELLIOTT, JAMES, 89 North street, Whiteinch, 1 May, 1906

FAIRLEY, JOHN, 124 Pitt street, Glasgow, 21 Nov., 1899
FAIRWEATHER, GEORGE A. E., 26 Nov., 1901
FERGUSON, JOHN, Bellevue, Clydesdale street, Hamilton, 20 Dec., 1904
FERGUSSON, W. L., 48 Connaught road, Roath, Cardiff, 22 Dec., 1891
FISH, N., 69 Mayfair avenue, Ilford, Essex, 18 Feb., 1902
FLEMING, ARCHIBALD L, c/o Rankin, 280 Bath street, Glasgow, 20 Dec., 1904
FRASER, JOHN ALEXANDER, 969 Govan road, Govan, 26 Jan., 1904
FREER, ROBERT M'DONALD, 10 Nithsdale drive, Strathbungo, Glasgow, 27 Oct., 1903

GALBRAITH, HUGH, 2 Hillside villa, Kentish road, Belvidere, Kent, 20 Dec., 1898
GARDNER, HAROLD THORNBY, Thorncliffe, Skermorlie, 26 Apr., 1904
GIBB, JOHN, 17 Thornwood drive, Partick, 24 Jan., 1899
GRAHAM, JOHN, 16 Summerfield cottages, Whiteinch, Glasgow, 26 Apr., 1904
GRANGE, GEORGE ROCHFORT, 3 Lennox avenue, Scotstoun, Glasgow, 20 Feb., 1906
GRENIER, JOSEPH R., c/o Mrs M'Master, 307 St. Vincent street, Glasgow, 3 Mar., 1903

HALLEY, MATTHEW WHITE, 43 Lawrence street, Partick, 22 Mar., 1904
HALKET, JAMES PITCAIRN, Jun., 7 Clydeview, Partick, 21 Nov., 1905
HANNAH, JOHN A., 112 Govanhill street, Glasgow, 26 Nov., 1901
HARVEY, WILLIAM BARNETT, B.Sc., 7 Marchmont ter., Kelvinside, Glasgow, 22 Nov., 1904
HENDERSON, JOHN A., 22 Mar., 1904
HENNINGSEN, SVEND, Charlotsenborz, Copenhagen, Denmark, 21 Nov., 1905

Henricson, John A., c/o A. B. Sandoikens, Skeppsdocka, och Mek, Varkstad, Helsingfors, Finland,	19 Dec., 1899
Herschel, A. E. H., Mayfield, Bearsden,	19 Dec., 1899
Hill, Gerard Leader, 4 Thornwood terrace, Partick,	19 Dec., 1905
Hodgart, Matthew, Linnsburn, Paisley,	22 Dec., 1903
Holland, Henry Norman, South Wales Electric Power Co., Treforest, Pontypridd,	22 Nov., 1898
Holland, John C., 50 Gibson street, Hillhead, Glasgow,	20 Dec., 1904
Hotchkis, Montgomery H., Crookston house, near Paisley,	24 Dec., 1901
Houston, David S., 83 Kilmarnock road, Shawlands, Glasgow,	27 Oct., 1903
Howie, John, 110 Camperdown road, Scotstoun, Glasgow,	25 Oct., 1904
Hoyt, Charles S., B.A.,	22 Mar., 1904
Hutton, W. R., 97 Queensborough gardens, Hyndland, Glasgow,	23 Apr., 1901
Irons, James Hay, 66 Norham street, Crossmyloof, Glasgow,	19 Feb., 1901
Jankins, Garnet E.,	3 May, 1904
Johnston, Hector, c/o Campbell, 4 Roxburgh street, Hillhead, Glasgow,	22 Dec., 1903
Jones, Noel, 204 Langslands road, Govan,	20 Feb., 1906
Kimura, N., Marine Inspector's Office, H.I.J.M.'s Consulate-General, Shanghai,	23 Apr., 1901
King, Charles A., 86 Lexham gardens, Kensington, London, S.W.,	25 Apr., 1898
Kinghorn, David Richard, Ardoch, Prenton, Cheshire,	23 Oct., 1900
Kinley, William, L., c/o Heaton, 11 Alexandra street, Partick,	23 Jan., 1906
Kinross, Cecil Gibson, 25 Katherine drive, Govan,	22 Dec., 1903
Kirby, William Hubert Tate, c/o Mrs Barrie, 21 Endsleigh gardens, Partickhill road, Glasgow,	26 Apr., 1904
Kirkland, James, 23 Cross, Beith,	20 Mar., 1905
Lemon, Ernest J. H., c/o Rutherford, 49 Barcaple street, Springburn, Glasgow,	20 Dec., 1904
Liepke-Röed, Carl, 9 Grosvenor terrace, Glasgow,	20 Dec., 1904
Linklater, Valdemar M'Lelland, 20 Netherby road, Trinity, Edinburgh,	21 Nov., 1905

LINWOOD, CHARLES, 1 Clarence drive, Hyndland, Glasgow, 20 Mar., 1906
LLOYD, HERBERT J., Brecon road, Builth, Wells, 21 Dec., 1897
LOCHHEAD, JAMES M'CULLOCH, Brenfield, Scotstounhill, Glasgow, 25 Oct., 1904
LOPEZ, J., 109 Sinclair drive, Langside, Glasgow, 20 Mar., 1906
LOW, ARCHIBALD N., Dunlea, Partickhill, Glasgow, 20 Dec., 1904

M'AULAY, ALEX., 1 Leven Grove terrace, Dumbarton, 20 Dec., 1904
M'CARTNEY, HUGH NEIL, 7 Granville street, Glasgow, W., 20 Mar., 1906
M'CLELLAND, HAROLD R., Redargan, Drumoyne drive, Govan, 22 Mar., 1904
M'CLURE, WILLIAM, 48 Claremont street, Glasgow, 20 Dec., 1904
M'CRACKEN, WILLIAM, York street, Parnell, Auckland, New Zealand, 27 Oct., 1903
M'DONALD, CLAUDE KNOX, Lennoxvale, Maryland drive, Craigton, Glasgow, 22 Mar., 1904
M'FARLANE, JOHN K., 20 Kelvinside gardens, N., Glasgow, 20 Dec., 1904
M'GENN, HENRY HAMILTON, 46 Claremont street, Glasgow, W. 21 Mar., 1905
M'GREGOR, ROBERT, 22 Westminster terrace, Sauchiehall street, Glasgow, 25 Oct., 1904
MACGREGOR, J. GRAHAM, 4 West George street, Glasgow, 18 Feb., 1902
MACGIBBON, JOHN, Glenorchy, Scotstounhill, Glasgow, 23 Jan., 1906
M'HARG, W. S., The Grove, Ibrox, Glasgow, 19 Mar., 1901
M'INTOSH, GEORGE, Dunglass, Bowling, 22 Jan., 1895
MACKAY, HARRY, J. S., 53 Deansgate Arcade, Manchester, 22 Feb., 1898
M'KEAN, JAMES, 3 Buchanan terrace, Paisley, 22 Dec., 1903
M'KEAN, JOHN G., c/o Miss Hair, 17 Ocean view, Whitley Bay, Northumberland, 23 Oct., 1900
M'LACHLAN, CHARLES ALEX., Kia-Ora, Bogston avenue, Cathcart, Glasgow, 21 Apr., 1903
M'LACHLAN, DAVID FARMER, 8 Highburgh road, Hillhead, Glasgow, 24 Oct., 1905
MACLAREN, JAMES ERNEST, 3 Porter street, Ibrox, Glasgow, 23 Oct., 1900
M'LAURIN, JAMES H., 34 Park circus, Ayr, 18 Dec., 1900
M'LAY, J. A., 577 Stretford road, Old Trafford, Manchester, 17 Feb., 1903
MACLEAN, GAVIN THOMSON, 100 Springkell avenue, Maxwell park, Glasgow, 20 Mar., 1906
M'MILLAN, DUNCAN, 186 Paisley road west, Glasgow, 27 Oct., 1903
M'MILLAN, DUNCAN MURRAY, Millbrae, Milngavie, 2 May, 1905

MACNICOLL, DONALD, 25 Katherine drive, Govan,	23 Apr., 1901
M'WHIRTER, ANTHONY C., 214 Holm street, Glasgow,	21 Dec., 1897
MAKGILL, ARTHUR, 220 Langlands road, S. Govan,	23 Jan., 1906
MALCOLM, WILLIAM, c/o Davie, 34 Thornwood avenue, Partick, W.,	24 Oct., 1905
MARSHALL, ALEXANDER, Brightons, Polmont station,	18 Mar., 1902
MAITLAND, JOHN M., 13 Rosslyn terrace, Glasgow,	22 Jan., 1901
MANN, JOHN KENNEDY, 37 Partickhill road, Glasgow,	20 Mar., 1906
MAY, ANDREW, Woodbourne, Minard avenue, Partickhill, Glasgow,	20 Dec., 1904
MELVILLE, ALEXANDER, c/o Messrs J. A. Millen & Somerville, King street, Tradeston, Glasgow,	20 Feb., 1900
MERCER, JOHN, c/o Matheson, 7 Fairlie park drive, Partick,	22 Oct., 1895
MILLAR, ALEX. SPENCE, Towerlands, Octavia terrace, Greenock,	16 Dec., 1902
MILLER, DAVID C., 28 White street, Partick,	24 Oct., 1905
MILLIKEN, GEORGE, Milton house, Callander,	18 Feb., 1902
MITCHELL, JOHN MACFARLAN, 2 Wilton mansions, Glasgow,	25 Oct., 1904
MORE, THOMAS, 595 Cathcart road, Glasgow,	24 Jan., 1905
MORISON, THOMAS, 23 St. Andrew's drive, Pollokshields, Glasgow,	21 Nov., 1899
MORLEY, JAMES STEEL, 4 Gloag place, West Calder,	20 Feb., 1900
MORLEY, THOMAS B., B.Sc., 5 Walmer terrace, Ibrox, Glasgow,	27 Oct., 1903
MORTON, W., REID, 2 Fountainville avenue, Belfast,	26 Oct., 1897
MUIR, JAMES H., Prospecthill, Gourock,	26 Jan., 1892
MUNDY, H. L., Ormsby Hall, Alford, Lancs.,	24 Oct., 1899
MUNRO, GEORGE W., 12 Rothesay gardens, Partick,	24 Jan., 1905
MURRAY, ANGUS ROBERTSON, Strathroy, Dumbreck,	23 Jan., 1906

NEIL, ROBERT, 89 Carmichael place, Langside, Glasgow,	20 Mar., 1900
NIVEN, JOHN, c/o Messrs Lynch, Basreh, Persian Gulf,	22 Nov., 1898

OLSEN, HAROLD M., 1 Union street, Greenock,	19 Dec., 1903
ORMISTON, JAMES SIMON, 18 Percy street, Paisley road, Glasgow,	24 Oct., 1905
ORR, Prof. JOHN, B.Sc., Technical College, Johannesburg,	26 Mar., 1895
O'SULLIVAN, ANTHONY, 54 Daisy street, Govanhill, Glasgow,	23 May, 1905

PARR, FREDRIK, 16 Eton place, Hillhead, Glasgow, 22 Mar., 1904
PATERSON, A. STANLEY, Maryville, Bearsden, 24 Jan., 1905
PATERSON, JOSEPH BARR, c/o Henry, 38 White street, Partick, 22 Mar., 1898
PATON, THOMAS, 5 Tor terrace, Gourock, 20 Dec., 1892
POLLARD HENRY, The Orchard, Greenlaw drive, Paisley, 19 Dec., 1905
PRENTICE, HUGH, Box No. 105, Postal Station B., Cleveland, Ohio, U.S.A., 26 Apr., 1898
PRESTON, JOHN C., 343-5 Sussex street, Sydney, New South Wales, 6 Apr., 1887

RAMSAY, JOHN C., 72 Norse road, Scotstoun, Glasgow, 19 Feb., 1901
REID, HENRY P., 103 Queensborough gardens, Glasgow, 20 Dec., 1898
RICHMOND, TOM, 71 Kintore road, Newlands, Glasgow, 20 Feb., 1900
ROBERTSON, ROBERT M., 26 M'Lelland drive, Kilmarnock, 15 Apr., 1902
ROBERTSON, THOMAS ALSTON, 46 Queen's drive, Crosshill, Glasgow, 20 Feb., 1906
ROSS, FRANCIS CECIL, Beech Lawn, Hessle, R.S.O., Yorks., 20 Dec., 1904
ROTHWELL, JAMES E., 2 Florentine Place, Hillhead, Glasgow, 24 Oct., 1905
RUSSELL, THOMAS, Kilkerran, Greenock road, Paisley, 19 Dec., 1905

SADLER, JOHN, Collindale works, Hendon, London, N.W., 23 Oct., 1900
SAYERS, W. H., 19 Mar., 1901
SCOTT, G. N., 7 Corunna street, Glasgow, 17 Feb., 1903
SELLERS, FREDERICK W. B., 26 Apr., 1904
SEMPLE, JOHN SCOTT, 44 Brayburne avenue, Clapham, London, S.W., 26 Apr., 1904
SEMPLE, WILLIAM, Coral Bank, Bertrohill road, Shettleston, 21 Jan., 1902
SEXTON, GEORGE A., c/o Prof. Sexton, G. & W. of S. Technical College, Glasgow, 24 Nov., 1896
SHARP, JAMES R., 24 Oct., 1899
SHEARDOWN, HAROLD E., c/o Mrs Cowrie, 4 Highburgh road, Dowanhill, Glasgow, 20 Dec., 1904
SMITH, ALEXANDER, 77 High street, Kinghorn, 24 Dec., 1901
SMITH, CHARLES, 3 Rosemount terrace, Ibrox, Glasgow, 24 Apr., 1894
SMITH, JAMES, 44 Cleveland street, Glasgow, 31 Oct., 1902
SMITH, JAMES, Jun., 118 Ladybarn road, Fallowfield, Manchester, 27 Oct., 1903
SMITH, WILLIAM, British Post Office, Shanghai, 28 Apr., 1903
SPENCE, JAMES, Jun., Rubislaw terrace, Aberdeen, 20 Dec., 1904

SPIERS, ERNEST J., 76 Stepney green, London, E.,	20 Dec., 1904
SPROUL, JOHN, 13 Greenlaw avenue, Paisley,	3 Mar., 1903
STEVENS, CLEMENT H., c/o Messrs Blandy Bros. & Co., Las Palmas, Grand Canary,	22 Dec., 1891
STEVENSON, ALLAN, 165 Kenmure street, Pollokshields, Glasgow,	26 Nov., 1901
STEVENSON, WILLIAM, 1 Mosley street, Newcastle-on-Tyne,	25 Jan., 1881
SUTHERLAND, ALEX., 12 Regent park terrace, Strathbungo, Glasgow,	24 Jan., 1905
TAYLOR, ANDREW P., 47 St. Vincent crescent, Glasgow,	19 Dec., 1899
TAYLOR, JOHN DOUGLAS, Jeanieslea, Oxhill road, Dumbarton,	26 Apr., 1904
TENNENT, WILLIAM WHALEY, 155 Hyndland road, Kelvinside, Glasgow,	21 Nov., 1905
THOMAS, NEVILL SENIOR, c/o Messrs Topham, Jones & Railton, H.M. Dockyard, Gibraltar,	24 Mar., 1903
THOMSON, GRAHAME H., Jun., 2 Marlborough terrace, Glasgow,	22 Feb., 1898
THOMSON, JOHN A., British Linen Bank house, Langholm,	20 Dec., 1904
TOD, WILLIAM, 948 Sauchiehall street, Glasgow,	22 Feb., 1898
VICK, HENRY HAMPTON, 23 Broomhill terrace, Partick,	25 Oct., 1904
WADDELL, ROBERT, 19 Kelvinside terrace, S., Glasgow,	20 Dec., 1904
WALLACE, HUGH,	24 Oct., 1899
WARD, RICHARD J. L., Grafton terrace, Bentinck street, Greenock,	20 Mar., 1906
WATSON, JAMES, 35 Regent Moray street, Glasgow,	24 Dec., 1901
WHADCOAT, HENRY CECIL, 481 Victoria road, Glasgow,	24 Oct., 1905
WHITEHEAD, JOHN, B.Sc., Howford, Mansewood, Pollokshaws, Glasgow,	21 Nov., 1905
WILLETT, EDWARD, V. A., 68 Lauderdale gardens, Hyndland, Glasgow,	19 Dec., 1905 19 Dec., 1905
WILLIAMSON, GEORGE TAYLOR, Craigbarnet, Greenock,	22 Mar., 1904
WILLIAMSON, EDWARD H., 214 Langlands road, South Govan,	27 Oct., 1903
WILSON, THOMAS, 12 Barrington drive, Glasgow,	20 Feb., 1900
WILSON, ROWAND, 3 Cecil street, Ibrox, Glasgow,	25 Oct., 1904
WITHY, VIVIAN, Kenmore, Bowling Green terrace, Whiteinch, Glasgow,	31 Oct., 1902

Wood-Smith, George F., Union Switch & Signal Co., Swissvale, Pennsylvania, U.S.A., 26 Oct., 1897

Work, John C., 22 Mar., 1904

Young, George M., B.Sc., 268 Kenmure street, Pollokshields, Glasgow, 24 Dec., 1901

Young, James M., Auldfield place, Pollokshaws, Glasgow, 22 Jan., 1901

Young, J. M., Ravenscraig, Ardrossan, 17 Feb., 1903

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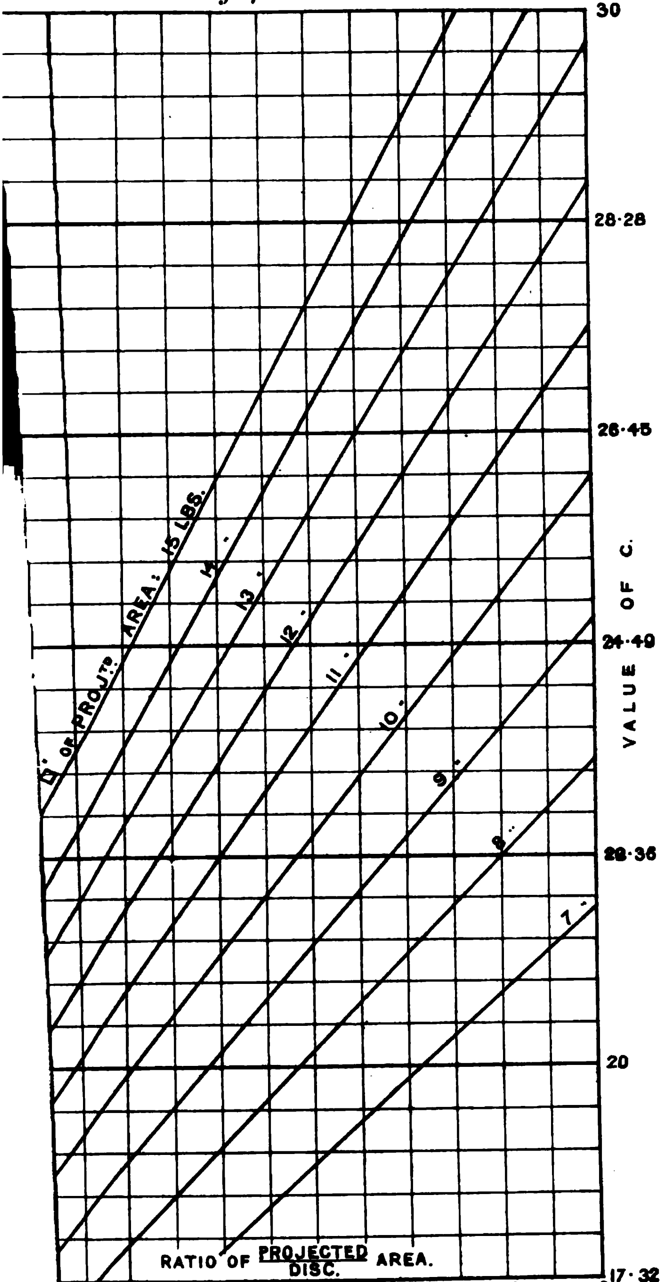
Fig. 4.



O-EFFICIENTS FOR TURBINE PROPELLERS.

$$\text{N FEET} = \sqrt{\frac{\text{ACTUAL THRUST OF SCREW IN LBS.}}{\text{CO-EFFICIENT CORRESPONDING TO DESIRED PRESSURE AND AREA RATIO.}}} = \sqrt{\frac{T}{C}}$$