TRANSACTIONS

of the

ROYAL SCOTTISH SOCIETY OF ARTS

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VOL. XIX—1914-1925

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CONTENTS OF VOLUME XIX

NOTE

During part of the period of the Great War and following years (1916-1921) the ordinary activities of the Society were entirely suspended.

Shortly after the resumption of the ordinary meetings in 1921, it was felt that, as the publication of Transactions *constituted an essential feature of the work of the Society, an effort should be made to issue a small volume dealing, as far as possible, with the period from 1914 up to the date of bringing out the first part of the Edinburgh Journal of Science, Technology, and Photographie Art in October 1926.*

The object in view was, primarily, that of maintaining continuity of publication in order that the Society might continue in the position of being able to reciprocate, as in the past, with other Societies and Institutions. The happy result of these long standing interchanges has been to provide the Royal Scotttsh Society of Arts with a valuable Library of Proceedings and Transactions which, through the recent munificance of the Carnegie United Kingdom Trust, is now so housed, bound, and catalogued as to be readily available not only for consultation by the Fellows, but also by serious Students in any part of Scotland who may be desirous of availing themselves of the facilities provided.

The volume in question will perform the important function of further informing the Fellows and Associates elected since 1921 regarding the foundation and original aims of the Society and as to the steps recently taken towards securing its post-war reorganisation and adaptation to present day requirements.

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Vol. XIX. 1914-1925

ROYAL SCOTTISH SOCIETY OF ARTS.

The first volume of the *Transactions* of the Royal Scottish Society of Arts was issued in the year 1841, and the publication of *Transactions* was continued without interruption until 1914.

The Preface to the first volume above referred to summarises so completely the objects of the Society as to be worthy of reproduction in full :—

> "THE SOCIETY FOR PROMOTING THE USEFUL ARTS IN SCOTLAND was instituted at Edinburgh in the year 1821. The principal objects of its founders were, to stimulate and reward genius and mechanical industry, and to afford a ready and useful medium of intercourse among men of all ranks, who were engaged either in the pursuits of Science or in the various practical departments of the Arts and Manufactures. By means of such an institution, it was conceived that publicity could be given to discoveries and inventions with the least possible delay—that while, by public discussion, error and empiricism would be exposed, correct principles and talent would, on the other hand, be evolved, and duly appreciated—and that, Science and Art being thus united, results would be produced of the utmost importance both to individual enterprise and public utility.
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> "These views having met with general approbation, arrangements were made for extending the Society's influence over an ample field, and for rendering its meetings easily accessible, as well as generally interesting, to all ranks of the community.
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> "The Members were divided into three classes—Honorary, Ordinary, and Associate—and their number is now 440.
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> "The Revenue consists of an Annual Contribution of £1, 1s. from each of the Ordinary Members, or of a composition in lieu thereof ; and of Donations or Legacies. The Funds are at present in a prosperous state, and have been considerably assisted by a handsome donation of £400 from the trustees of the late Alexander Keith of Ravelston and Dunottar, Esquire ; being a portion of the sum of £1000 bequeathed by him for the promotion of Science and the Arts ; the interest arising from which, by the terms of the gift, is applied by the Society in awarding Prizes or Medals for 'inventions, improvements, or discoveries in the Useful Arts, which shall be primarily submitted to the Society.' A Medal has accordingly been struck, bearing the arms of the founder, and called the KEITH MEDAL.

"The Ordinary Meetings are held once a fortnight from November to May, on the Monday evenings, at 8 o'clock, in the Royal Institution Buildings, Princes Street. At these meetings new Inventions, Models and Drawings are exhibited, which are freely examined and commented on by the Members and others present, and then remitted to properly qualified Committees for their more minute examination and subsequent report. Written communications and essays are also read and fully discussed; and such of them as are considered generally interesting, or of sufficiently practical utility, are first published quarterly, in the *Edinburgh New Philosophical Journal*, and afterwards annually by the Society, in Parts or Fasciculi, containing not only the 'Select Papers,' but also an abridgment of the whole transactions of the previous year. The present volume comprises four of these Fasciculi, all of which have been distributed gratis to the Members. The publishing arrangements were of but comparatively recent date, and hence the reason why only one volume of the *Transactions* has as yet appeared.

"The Society likewise publishes annually a List of Premiums for New Inventions and Discoveries, and for Essays on scientific and practical subjects—and the Prizes are publicly delivered to the successful competitors, either in Money or Honorary Medals, at the first ordinary meeting in November of each year, being the Annual General Meeting.

"Some years subsequent to the institution of the Society, a Museum was also formed. This Museum contains a collection of Inventions, Models and other works illustrative of the progress of Science and Art in Scotland.

"Lastly, a Royal Charter has recently been obtained, conferring on the Society, under the name of 'The Royal Scottish Society of Arts,' all the usual privileges of a corporate body, and thereby placing it, in many important respects, on an equal footing with the highest class of Institutions in the country. A copy of the Charter of Incorporation will be found in the Appendix.

"THE ROYAL SCOTTISH SOCIETY OF ARTS, therefore, is eminently calculated to improve the numerous processes and the machinery employed in the Arts and Manufactures of the country. It is proper to keep in view, however, that while every encouragement is given to scientific inquiry, inventive genius, and practical skill, and the greatest care is taken that nothing shall appear to receive the approbation of the Society without at least due deliberation—still, it must occasionally happen that, in the investigation of first principles, in the application of these to Designs, Models, or Experiments on a small scale only, and in ultimately reducing them to practice, fundamental errors and practical obstacles will be overlooked, which may render discoveries and processes, apparently highly valuable in themselves, ultimately inapplicable to any useful purpose. Hence the Society does not hold itself in any degree responsible for the opinions which may be formed at its Meetings or by its Committees, nor for the views promulgated in the Essays or other communications which may appear in its published *Transactions*. The value of these opinions must be held to rest entirely on the authority of their respective authors, and on the obvious utility of the improvements or discoveries themselves—the Society's principal aim and only duty being to stimulate and reward, according to the best of its abilities, innate genius, persevering industry and practical talent, whether they appear in the productions of the man of learning and science, the master tradesman, or the journeyman artizan."

No fundamental change occurred in succeeding volumes until 1906, when for a single year the *Transactions* were issued monthly as the *Journal of the Royal Scottish Society of Arts*. This departure from the previous style and the reasons therefor, may best be summarised by giving in full a note to the Members from the President of that date, Professor T. HUDSON BEARE :—

"TO THE MEMBERS OF THE ROYAL SCOTTISH SOCIETY OF ARTS.

"With a view of publishing the Papers read before the Society at a much earlier date than has hitherto been the custom, it has been decided to issue the proceedings of the Society in the form of a Monthly Journal, and the first issue of this Journal now makes its appearance.

"In adopting this course the Society is only doing what is done by other Scientific Societies. The Society of Arts, London, publishes all its papers in the form of a Weekly Journal ; the two great Geographical Societies, and several other Scientific Societies, publish their Papers and Transactions in the form of Monthly Journals.

"The *Journal*, which will appear on the first of each month, will contain the following matter :—

1. Notices of Meetings of the Society to be held during the current month.
2. Proceedings of the Society during the preceding month, including reprints of the Papers read, and reports of discussions.
3. Notes on new Technical Books, and additions to the Library.
4. General notes on manufacturing and industrial matters.
5. A list of Meetings to be held during the current month by Edinburgh Scientific Societies.

"During the current Session two very important departures in the work of the Society have taken place :—(1) the institution of the Keith lectures, and (2) the change from the annual volume of *Transactions* to a monthly *Journal*.

"May I, as President of the Society, express the hope that these changes, both of which are intended to make the Society more valuable, will stimulate Members to take a greater interest in the proceedings and work of the Society. The Society badly wants new members, and must have new members, if it is to continue to carry on its work. I appeal, therefore, most earnestly to Members to mark their appreciation of these changes by making strenuous efforts to secure an increase in our membership. Many of our Members are Life Members, and, as the Society's working expenses are encroaching seriously upon its available resources, the only remedy is to secure an increase in the annual revenue by increasing considerably the number of members. If every Member of the Society would endeavour to secure at least one additional member, the whole difficulty would disappear.

"*(Signed)* T. HUDSON BEARE, *President.*"

The twelve parts of the *Journal* in question constituted Volume 17, but the previous form was resumed in the succeeding and final volume, which was completed in 1914.

Following on extended deliberations by the Council, it was unanimously resolved at the Annual Meeting of the Society, held on 8th November 1915, to suspend the ordinary Meetings "having in view the difficulty of satisfactorily carrying on the business of the Society on account of the existing disturbed state of affairs in the Country owing to the War."

Meetings of Council were held from time to time, but it was not until 1921 that it was felt to be practicable to resume the ordinary activities of the Society.

A Special Meeting of the Society was convened by the Secretary, Professor R. Stanfield, for 27th June of that year, and the Fellows were earnestly requested to attend with a view to considering the whole position of the Society and offering suggestions for its future. In advance of this Meeting a further circular letter was issued to all the Members by the late Councillor D. W. Kemp, as follows:—

> "You will have received a circular from the Secretary of the Royal Scottish Society of Arts convening a Special Meeting of the Society for Monday evening, 27th inst., at 8 p.m. in the Hall, 117 George Street.
>
> "As an old Fellow of the R.S.S.A., and having for half a century taken a warm interest in its affairs, I take the liberty of addressing you at this crisis in the history of the Society, hoping that you will make a very special effort to be present.
>
> "Owing to the suspension of the activities of the Society during, and since, the War, you may not realise that this year is the centenary of its foundation, and coinciding as it does with one of the infrequent visits of the British Association to Edinburgh, it surely behoves us to show some signs of vitality, and to prove that the present Fellows are worthy trustees of the traditions and splendid work of the past of which our printed *Transactions* are not the only evidence.
>
> "The Society is still, in my opinion, able to fulfil a highly useful purpose in the City, but to do so two things at least are necessary: adaptation to the needs of the present day, and a largely increased membership.
>
> "With a view to having these and any other relevant matters thoroughly discussed, it is very desirable that you should attend.
>
> "*(Signed)* D. W. Kemp."

The following are two of the letters received in answer to this circular:—

Copy Letter from Wm. Allan Carter,* Stamford Hall, Gullane, to D. W. Kemp, Ivy Lodge, Trinity, dated 26th June 1921:—

> "I duly received your letter of 24th inst. with reference to the meeting to be held in George Street on the evening of 27th inst., but regret that as I am confined to bed it will not be possible for me to attend. I always think that there is a large field open for the energies of the Society, but the position will want some beating up. The lines of action will have to be materially altered, and I think the first thing to do is to appoint a strong Committee

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* Secretary 1889 to 1906; President 1908 to 1911.

to take the whole matter in hand to secure a large influx of new members and to appeal for papers of a high scientific order, taking care, of course, not to conflict with the Royal Society of Edinburgh. Fewer meetings, higher class papers, and perhaps an alteration in the hour of meeting might all tend to bring back the popularity of this fine old Society.

"*(Signed)* WM. ALLAN CARTER."

Copy Letter from T. HUDSON BEARE,* B.Sc., Edinburgh University, to D. W. KEMP, Ivy Lodge, Trinity, dated 25th June 1921 :—

"I am very sorry I cannot be at the meeting of the Society of Arts on Monday night. I am leaving for Liverpool at 10.10 that morning, and shall be away until Wednesday.

"I am of opinion that it would be most disastrous to wind up the Society. The Society is capable, as you say, of doing really good useful work for the City, but we must bring it up to present day requirements, and we must get a very much larger membership.

"Would you kindly read this expression of my views to the meeting, and express my great regret that I cannot be present.

"*(Signed)* T. HUDSON BEARE."

At this Special Meeting the President, Lt.-Col. ALEX. OGILVIE, O.B.E., submitted a most exhaustive statement of the whole position, under the following main headings :—

(1) The financial aspect of the Society.
(2) The Council's deliberations.
(3) Suggestions for the future.

It was eventually decided that :—

(1) Every effort should be made to recommence the Meetings of the Society in November 1921, utilisation being made of that being the Centenary of the Society to stimulate enthusiasm in its post-war reformation.

(2) A dinner should be held early in October, to be followed by an informal discussion on the programme for the opening Session.

The general feeling of the Meeting was in agreement with the views expressed by the President that a strenuous effort should be made to obtain a large increase in the Membership, and towards that end it would be advisable to reduce the annual subscription to 10/6.

The necessary alteration in the Laws was accordingly effected by means of two Extraordinary Meetings of the Society held on 13th and 18th July 1921, respectively.

It was also decided that the existing Laws covered the election of ladies as Fellows or Associates of the Society.

CENTENARY DINNER—28TH OCTOBER 1921.

"The dinner to celebrate the centenary of the Royal Scottish Society of Arts was held in Ferguson & Forrester's Rooms, Edinburgh, last night. The Society was instituted in 1821 with the title 'Society for

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* President 1905 to 1908.

the Encouragement of the Useful Arts in Scotland,' and when incorporated by Royal Charter in 1841 it received the present name. The original title indicates generally the objects still sought to be promoted by the Society. Lt.-Col. Alexander Ogilvie, O.B.E., B.Sc., M.I.E.E., the President, occupied the chair, and there was a large attendance of ladies and gentlemen, including Sir Joseph Dobbie, Dr. W. B. Blaikie, Councillors D. W. Kemp and F. J. Robertson, Major Peebles, Dr. T. W. Drinkwater, Principal Laurie, and Professors Baily and Stanfield.

OVERHEAD WIRES IN EDINBURGH.

"Professor Baily, Heriot-Watt College, in proposing 'The City of Edinburgh,' alluded to the tramway question and traction generally. They were told, he said, that the overhead system was already a back number. He had been associated with traction for about thirty years, and he had seen system after system come up against the overhead wire. He did not admire the overhead wire in every respect, but it had one pre-eminent advantage—that it was a long way cheaper than anything else. During those thirty years he did not know how many systems had been proposed, and one after another had gone, and there was absolutely nothing that could come up against the electric tramway. If they wanted to have cheap fares in Edinburgh the Tramway Committee would have to go in for the overhead system. The tramway manager was a very sound man, and he thought they could trust his judgment and knowledge.

"Councillor F. J. Robertson, who replied, said that as a Town Council they were agreed that they must have overhead electric traction in Edinburgh, but they had reserved, in deference to certain extremely important Societies in Edinburgh, the question of Princes Street. The more one travelled abroad the more one was impressed with the possibility of a dual system. In Brussels, where they had an overhead electric system, a conduit system was in operation in the principal boulevards. He stood a short distance from one of those main streets for the purpose of testing the amount of time which was necessary in order to transfer from the overhead to the underground system, and found it could be done in ten seconds. If it was possible to prevent wires in Princes Street by a dual system which would work satisfactorily and which would not be too expensive, then he thought there was a good deal to be said for it. It was to some extent a technical question, but they must have a thorough-going, reliable system.

THE OBJECTS OF THE SOCIETY.

"The Chairman, in proposing the toast of 'The Royal Scottish Society of Arts,' referred to the conditions prevailing in 1821, and reviewed the original aims of the Society. The printed prospectus of the Society, dated June 1821, affixed to the front (inside) cover of the first minute-book, contained a list of the office-bearers, including David Brewster, LL.D., F.R.S., as director, and the Lord Justice-Clerk, the Lord High Commissioner, the Lord Advocate, and Sir Walter Scott as Councillors. The prospectus also contained an opening paragraph pointing out that the advanced state of education among the working classes, which elevates them above those of other nations, has called forth powers of invention which have hitherto been allowed to languish in obscurity and neglect. 'With the restoration of peace, the vigour with which the rival arts and industry of foreign States have been revived, make it all too obvious that the superiority of our own can only be sustained by the most liberal and efficacious excitement of mechanical talent.' Then followed the statement of the fact that a Society of Arts had been for some years projected in this metropolis, and was first announced to the public in December 1819 under the name of 'Society for Promotion of the Mechanical and Useful Arts in Scotland—for rewarding Inventions of Public Utility, and disseminating Useful Knowledge among the industrious classes of Society.'

"The objects of the Institution were to encourage the mechanical and chemical arts by :—(1) Awarding prizes—either in the form of money or honorary medals—to the authors of useful inventions or valuable processes ; (2) assisting inventors in securing the just advantages of their labours ; (3) performing useful experiments or making trials of machinery when the inventors themselves have not the means of carrying their ideas into effect ; (4) depositing models of new inventions and interesting machines in a hall erected for that purpose ; and (5) disseminating useful knowledge among the industrious classes of Society. The first recorded meeting in this minute-book was the general meeting of the Society held in Edinburgh on 9th July 1822, when the Rt. Hon. Sir Samuel Shepherd, Lord Chief Baron, Vice-President, was in the chair. The list of members present contained eminent citizens of the time, and was headed by the Rt. Hon. the Lord Provost of Edinburgh, who at that time was, along with the Principal of the University and the President of the Royal Society, appointed member of the Council, *ex officio*. Thus the Society was established, and so it had been carried on by citizens in Edinburgh prominent in the world of science, industries, and arts.

R. L. STEVENSON A CONTRIBUTOR.

"The first volume of the *Transactions* was published in 1841, when the membership was 440. Reference was made in the preface to the museum which had been formed, and which contained a collection of inventions, models, and other works illustrative of the progress of science and art in Scotland. This volume covered a period of about 10 years (1830-1840), and contained 62 contributions, all most interesting and many of a high order and value on a great variety of subjects, founded mainly on scientific knowledge applied to industries, arts, and crafts, for improvement on their known devices. Thirteen similar volumes recorded the proceedings and contributions up to the close of last century. In short, they provided a most valuable record of investigations, inventions, and improvements by all industrious classes in their city for the last 100 years—from eminent Professors, engineers, lawyers, down to the humblest citizen interested in the general advancement of his craft. It might be interesting to observe that they included a contribution by Robert Louis Stevenson, read before the Society on 27th March 1871, on 'A new form of intermittent light for lighthouses.' For the first fifty years they had the great industrial advance which was more or less concerned with mechanical progress, and for the second fifty years they had electrical science coming in with the invention of the first dynamos. These two features were reflected in the contributions to those fourteen volumes. At the same time the civil, mathematical, chemical, and physical sciences were in constant evidence in the papers submitted.

A CENTRE OF SCIENTIFIC LIGHT AND LEADING.

"By 1829 the prize fund was in active operation—assisted largely by the donation to the Society of £400 from the late Mr Keith of Ravelston—still existing as their Keith Fund. In that year ten prizes, amounting to £48, 6s. were awarded. So, right onwards, an average of ten prizes and medals was awarded annually, of values ranging from £40 to £60. Now their prize fund amounted to over £4000, the interest (annual) from which was available for awarding prizes as approved by the Prize Committee and the Society year by year. A most complete library existed containing a valuable collection of general scientific works and transactions of all other leading scientific societies. It had only to be more widely known to be taken fuller advantage of. The Society possessed most excellent accommodation in their own property at 117 George Street, comprising hall, library, and reading room, so that altogether it was fully equipped for most useful continued activity as a centre of scientific light and leading in the applied arts and crafts. The difficulties that presented themselves to the Council were twofold. The first was common to all activities, and that was the general apathy which one ascribed to the result of the war. They could not stir up enthusiasm, but they hoped the apathy would disappear. The second difficulty was rather greater. They suffered from the age of specialism, but they felt that there was still a field for their Society in encouraging young men in the arts and crafts to obtain a higher knowledge and to increase their form and type of production. (Applause.)

NAVIGATION OF THE AIR.

"Councillor D. W. Kemp, who is the senior member of the Society, having been a Fellow for over fifty years, replied. He was an optimist. He believed the Society had a great future. They could do a great deal, not only for Scotland, but for their own city. He thought they might be helpful to the Corporation, for example, in discussing at some of their meetings electrical questions, such as lighting and traction. He thought it was in 1827, in Sir David Brewster's time, that a model was submitted on the navigation of the air. It was interesting to think of the enormous progress made in aerial navigation since 1827.

"Dr. T. W. Drinkwater proposed the toast of "Allied Societies," and Mr B. A. Pilkington, F.R.S.E., acknowledged. The toast of "Arts and Crafts" was given by Mr C. Norman Kemp, B.Sc., and Mr Alexander Mackenzie replied.

"Dr. W. B. Blaikie, who said he had been a member for over forty years, proposed the toast of "The Chairman." He observed that the Society was for many years the happy home of the amateur inventor. The amateur inventor was pretty well a back number. If they could only get specialists to lecture to them, he thought Mr Ogilvie would find that the ranks would fill up again. If they looked over the proceedings they would see that many of the most important inventions were first shown at that Society."

The Scotsman, October 29, 1921.

ROYAL SCOTTISH SOCIETY OF ARTS
KEITH LECTURES, 1925

FOUR LECTURES ON THE "FABRIC OF THE UNIVERSE"

I.

THE MATERIALS FOR EVOLUTION

THE first of the Keith Lectures of the Royal Scottish Society of Arts was delivered by Professor WILLIAM PEDDIE, D.Sc., F.R.S.E., in the Society's Hall, 117 George Street, Edinburgh, on 9th February 1925. The subject of the course is "The Fabric of the Universe," and the lecture dealt with "The Materials for Evolution." Principal Sir J. ALFRED EWING, K.C.B., Hon. President, occupied the chair.

Professor Peddie said that speculation regarding the nature of matter, that is, the material of which our universe is composed, is at least as old as the time of the Greek philosophers. Speculation of that early type is not necessarily unscientific, although, in virtue of deficiency of data, it could scarcely lead to results of value. In the hands of Lucretius sound reasoning was introduced and led to a correct result although it was based upon false data. The scientific age proper with regard to atomic and molecular theory was ushered in when chemical philosophy became founded upon quantitative results, which established the law of definite-combining proportions, and these in whole-number values at least approximately. So the idea of a fixed minimum of each simple substance and a fixed minimum of each compound substance, that is, of an atom or a molecule, became established. If matter is atomic and molecular in its structure there must be in any substance an average distance apart at which the centres of two neighbouring molecules are situated. Otherwise stated, there must be on the average a definite number of molecules included within a definite linear range, such as one inch or one centimetre, or a definite number included within a definite volume such as a cubic inch or a cubic centimetre.

A Remarkable Estimate

An early and ingenious attempt to determine the latter number was made in Edinburgh by Sir John Leslie, who stated that a single grain of musk could scent for twenty years the often-renewed air of a large room. He concluded that the grain must contain 320 quadrillions of particles at least. If, as Tait pointed out, a quadrillion has its usual British meaning of a billion millions, the estimate was remarkable. Two of Kelvin's four famous and epoch-marking estimates were discussed in detail, one depending on electrical properties of solids, the other on a property of liquids. From his four estimates Kelvin laid down limits between which, he said, actual values must in all probability lie. Dozens of methods, some of which were described, all independent, based upon different phenomena, electrical, magnetic, optical, thermal, etc., of solids, liquids, and gases are now available. All agree very closely in the magnitude deduced, and the mean of all lies almost exactly midway between Kelvin's two limits. About 500,000,000 molecules placed in a straight line at their average distance apart in liquids or solids would only extend to a length of one inch. Otherwise stated, there are about 100 millions of millions of millions of millions of molecules in a cubic inch of the materials.

Overwhelming Evidence.

It is not true that such numbers are inconceivable. By means of lantern slides modes of making mental representation of them were illustrated. No microscope can ever make a molecule, or even the average distance between two neighbour molecules in a solid, visible to the eye. Yet the evidence for the accuracy of the result is quite overwhelming. The probability that so many utterly distinct methods of estimation, based on many entirely different phenomena and lines of reasoning, could agree so closely and yet give a false result, is almost zero. In the last lecture of the series it will appear that the distance can now be actually measured, and the values which are observed agree with the estimates. Small particles of solid matter suspended in fluid act like molecules and verify the molecular laws.

II.

THE second of the Keith Lectures of the Royal Scottish Society of Arts was delivered on 23rd February 1925 in the Society's Hall, Edinburgh, by Professor WILLIAM PEDDIE, D.Sc., F.R.S.E. The subject of the course is "The Fabric of the Universe."

Professor Peddie said that in the previous lecture the evidence for the view that matter consists of molecules or atoms had been considered, along with the wonderfully concordant estimates of their size made by various independent physical methods. In the present lecture it was first pointed out that electrical phenomena show that, if matter is atomic, electricity must also be so. Electrical investigations had therefore to be resorted to in order to settle the question whether or not the chemical atom is really the smallest portion of matter.

An electrical discharge was passed through a vacuum tube containing a residuum of gas. The path of negatively charged particles was made evident by a fluorescent screen inside the tube which glowed when struck by the rays. The electric charge, the speed of motion, and the mass of these particles (called cathode rays or negative rays) can be measured. The mass is found to be about a two-thousandth part of the mass of a hydrogen atom ; thus the atom has been subdivided, and the charge, absolutely constant in amount, is the atom of electricity previously alluded to. It is called the electron.

Rontgen, or X, rays were also shown, and their evidence regarding the number of electrons contained in an atom was discussed. These considerations led to a short treatment of the modern quantum theory according to which energy can only be emitted in quantities which are multiples of definite units. Its application in connection with the phenomena under discussion was pointed out, and other corresponding phenomena were referred to.

The natural radio-active occurrence of the emission of electrons was then dealt with and shown to correspond to the vacuum tube emission of cathode rays ; while the emission of positive particles, the so-called X-rays, corresponds to the vacuum-tube emission of positive rays, the mass in both cases being of atomic magnitude. In fact, the X-ray is the positively charged nucleus of a helium atom from which an electron has been expelled. The amounts of energy involved in the two cases, however, are vastly different, showing that in the radio-active process the expelled electron comes from the very core of the atom. If an X-particle is expelled the atom steps back two places in the list of atoms arranged according to chemical and physical properties. If an electron is expelled the atom steps forward one place, so increasing the atomic number by unity. Thus the whole genealogy of radio-active atoms can be determined.

Observations on the deflection of X-particles by collision with atoms or molecules show that the atomic number is equal to the number of positive charges in the nucleus, and that the nucleus is excessively small—about one ten-thousandth part of the atomic size or even smaller. These and other considerations exhibit the atom as having a small positive core round which electrons circulate in relatively wide orbits like planets round the sun. But the quantum conditions allow only some definite orbits to be described, and no way of accounting for this fact, and for the fact that the electrons do not radiate while describing these orbits, has been found as yet.

The lecture was illustrated by lantern slides and experiments.

III.

THE PHENOMENA OF STARS

The third of the Keith Lectures of the Royal Scottish Society of Arts was delivered on 9th March 1925 in the Society's Hall, Edinburgh, by Professor **William Peddie**, D.Sc., F.R.S.E. The subject of the course is "The Fabric of the Universe."

In the first lecture the evidence for the existence of atoms and molecules was considered along with the question of their size; and, in the second, the disintegration and formation of atoms, evident in radioactive processes, was described along with their artificial disintegration through bombardment by the positively charged helium nuclei (*a* particles) ejected from radioactive atoms in their own process of disintegration. In the present lecture the actual life history of the atoms in so far as it is evidenced by the phenomena of stars was detailed.

Wonders of the Spectroscope.

The spectroscope, Professor Peddie stated, does not merely inform us regarding the particular kinds of atoms which are sending light to us from the most distant star. It can also tell us the period of revolution of the components of a double star, their speeds of motion, their masses, and their distance apart, even though the star is so far off that no telescope can show it to be double. In this way it enables us to step out into space and lay down, at the star itself, a measured baseline which enables us, in cases in which telescopic resolution is possible, to find the distance of the star from the earth. Also, with the aid of theoretical investigations regarding the proportion of atoms which have lost one or more of their electrons, together with experimental determinations of the energy needed for the ejection of the electrons, it enables us to tell the temperature of the outer layers of a star; and theory can then indicate the immensely higher interior temperatures. Other methods of determining the temperatures were also alluded to. The stars are divided into classes in accordance with the nature of the light which they emit. The temperature varies greatly amongst the different classes, but not greatly amongst the stars of any one class.

TWO GROUPS OF STARS.

From the apparent brightness of a star whose distance is known, the absolute brightness which it would have if it were at a given fixed distance can easily be calculated. Amongst stars of any one class a large difference of absolute brightness can only be due to a difference of absolute size. And a relation has been found between absolute brightness and the ratio of the intensities of two absorption lines in the spectrum, quite independently of knowledge of the distance of the star. Thus the spectroscope by itself enables us to find the size of a star. It appears that stars occur in two groups, giants and dwarfs, the size of the giants not varying much from the hottest to the coldest visible stars. This exhibits the development of a single star from the stage of a cold, greatly expanded, but gravitationally contracting, gas, growing hotter as it contracts until it becomes luminous and of greater and greater brightness. This goes on until the cooling by radiation overbalances the heating by contraction, and the temperature slowly falls till the star becomes a non-luminous and therefore invisible dwarf.

All the above considerations were illustrated by lantern slides, and then additional slides were shown which exhibited the evolution of a whole universe of stars from a single immense gaseous nebula. The tidal effect of another passing nebula causes it to emit, from opposite ends of a diameter, two streams of matter which form spiral arms and ultimately break up and condense into separate stars. Our system of stars, including the Milky Way stars as the remains of the arms, has been so formed. Illustrative slides were shown, and the development of planets from a condensing star by tidal action due to the rare near passage of another star was discussed also.

IV.

ARRANGEMENT OF ATOMS IN SUBSTANCES

THE last of the Keith Lectures of the Royal Scottish Society of Arts was delivered on 23rd March 1925, in the Society's Hall, Edinburgh, by Professor WILLIAM PEDDIE, D.Sc., F.R.S.E. The subject of the course is "The Fabric of the Universe."

The special part of the subject dealt with last night was the arrangement of the atoms in solid substances. This practically meant, said Professor Peddie, their arrangement in crystalline substances, that is, those in which geometrical disposition is evident. Here we were not concerned with the nature and structure of an atom itself, but only with the relative positions of the atoms in the solid edifice. The frequently made statement that the atom consists of a positively electrified core around which the negative electrons circulate in wide circuits like miniature planets around a miniature sun might only very remotely, possibly even not at all, correspond to actuality. Yet certainly some of their laws of action were similar to those of such a system, and, when presumed, led to marvellously accurate prediction of certain phenomena which originate in the atom.

MEASURING MOLECULAR DISTANCES.

A sheet of white paper scatters light in all directions. It would still send light in all directions if it were discontinuous and made up of little patches arranged in rows and columns at regular intervals. An eye viewing it from a sufficient distance would not perceive that it was discontinuous. But if white light were falling upon it, and if the distance between neighbouring patches were of the magnitude of visible waves of light, the eye would perceive coloured light of a wave-length which would depend only upon the angle at which it was viewed and the distance of the patches from each other. Thus, if the angle is measured along with the wave-length, the distance between neighbouring patches can easily be calculated. Now the distance between adjacent molecules is so small that visible light cannot suit, but, fortunately, the wave-length of X-rays or of the "gamma" rays emitted by radioactive bodies is comparable with molecular and atomic distances; and, further, their wave-lengths are known. Thus the distance between successive layers of molecules in a crystal can be calculated whenever the angle at which the rays are scattered is measured. This is done by electrical means since these rays produce electrical effects. In this way molecular distance is actually measured and so is now no longer speculative. The measurements found are in entire agreement with the calculations made by the various indirect methods which were described in the course of the first lecture.

A New Method.

The X-ray method described is that devised by Sir W. Bragg in modification of Laue's original method by transmission through a crystal, which the lecturer also described; both methods being fully illustrated by lantern slides. A new method, applicable to magnetic crystals, was then illustrated in detail. This method gives independent verification of results obtained by Bragg, and indicates the solution of various problems of crystalline structure, such as questions of stability of molecular arrangement, twinning and counter twinning, and the peculiar optical characteristics of crystals of chlorate of potash. In concluding the course, the lecturer remarked that the whole subject might equally be regarded as the most recent version of the first chapter of Genesis or of the last chapter of Revelation.

ROYAL SCOTTISH SOCIETY OF ARTS

A Special Meeting to consider the position of the Society and suggestions as to future policy was held on June 27th, 1921.

A Dinner to celebrate the Centenary of the Society was held on October 28th, 1921—Lt.-Col. Alexander Ogilvie, O.B.E., B.Sc., M.I.E.E., President of the Society, occupied the Chair.

SESSION 1921-22.

The following Communications were received :—

Opening Address on "Searchlights in War Service,"—by ALEXANDER OGILVIE, O.B.E., B.Sc., M.I.E.E., President, 14th November 1921.

On "Fuel Oil,"—by A. F. BAILLIE, London,—read 28th November 1921.

On "The Modern Motor Cycle: Its Design and Construction,"—by R. W. STANFIELD,—read 12th December 1921.

On "Electric Traction as applied to the Edinburgh Tramways" (No. 4983),—by R. STUART PILCHER,—read 16th January 1922.

On "Modern Methods of Brick Manufacture" (No. 4984),—by Principal A. P. LAURIE, M.A., D.Sc., F.R.S.E.,—read 30th January 1922.

On "The Universal Bosshead-clamp" (No. 4985), and "The Reflex Lantern" (No. 4986), — by ANDREW H. BAIRD, F.R.P.S., — read 13th February 1922.

On "Some Improvements in X-Ray Apparatus during quarter of a century" (No. 4987),—by C. NORMAN KEMP, B.Sc., A.I.C.,—read 13th February 1922.

On "X-Rays in a Military Hospital, and their applications in modern scientific research" (No. 4988), — by Mrs BERTHA KEMP, M.A., D.Sc.,—read 13th February 1922.

On "A Modern X-Ray Equipment by the Cox-Cavendish Electrical Co. Ltd." (No. 4989),—by EDGAR W. HOLNESS,—read 13th February 1922.

"An Investigation of the Ionised Atmosphere around Flames by means of an Electrified Pith Ball" (No. 4990),—by Dr. DAWSON TURNER, F.R.S.E., and D. M. R. CROMBIE,—read 27th February 1922.

"A New Mine Rescue Apparatus" (No. 4991),—by Professor HENRY BRIGGS, Ph.D., D.Sc., A.R.S.M., M.I.M.E.,—read 27th February 1922.

"Aviation" (Keith Lectures),—by Lieut.-Col. W. O. RAIKES,—delivered 6th, 13th, 20th and 27th March 1922.

"A readily-destructible Material suitable for the conveyance of Confidential Communications" (No. 4992), and

"Some experiments on Sound Detection with special reference to Ball Microphones" (No. 4993),—by BASIL A. PILKINGTON, F.R.S.E.,—read 17th April 1922.

REPORT OF THE COMMITTEE APPOINTED TO AWARD PRIZES FOR COMMUNICATIONS READ OR REPORTED ON DURING THE SESSION 1921-1922.

Your COMMITTEE having met and carefully considered the Communications laid before and definitely disposed of by the Society during the Session 1921-1922, begs to report that it has awarded the following Prizes :—

To Principal A. P. LAURIE, M.A., D.Sc., F.R.S.E.,—for his paper on "The 'Pier Method' of Building Brick Walls" (No. 4984).
A Keith Prize, value Seven Sovereigns.

To Andrew H. Baird, F.R.P.S.,—for his paper on "The Universal Bosshead-clamp" (No. 4985).

A Makdougall-Brisbane Medal.

To Dr. Dawson Turner, F.R.S.E., and D. M. R. Crombie for their paper on "An Investigation of the Ionised Atmosphere around Flames by means of an Electrified Pith Ball" (No. 4990).

Each a Makdougall-Brisbane Medal.

To Henry Briggs, Ph.D., D.Sc., A.R.S.M., M.I.M.E.,—for his paper on "A New Mine Rescue Apparatus" (No. 4991).

A Keith Prize, value Seven Sovereigns.

To Basil A. Pilkington, F.R.S.E.,—for his paper on "A readily-destructible Material suitable for the conveyance of Confidential Communications" (No. 4993).

A Hepburn Medal.

The hearty thanks of the Society are due to Alexander Ogilvie, O.B.E., B.Sc., M.I.E.E., for his Opening Address, delivered on the 14th of November 1921, and to Messrs A. F. Baillie, R. W. Stanfield, R. Stuart Pilcher, Dr. Bertha Kemp, and Edgar W. Holness for their Communications.

All of which is reported in name and by order of the Prize Committee by

C. NORMAN KEMP, *Secretary*,
Convener ex-officio.

KEITH BEQUEST.

Applications having been received for Grants for Research

From Bertha Kemp, M.A., D.Sc., for "Investigations in the Applications of X-rays to the examination of Materials, with special reference to the radiographic appearances of abnormal conditions in Timber," and

From the Research Committee of the Edinburgh Radio Society, per Mr William Winkler, Secretary, for "Investigations connected with the Armstrong Super-regenerative Wireless Receiving Circuit,"

the Council have recommended, and the Society approved, the following awards :—

To Mrs Bertha Kemp, *Sixty Pounds.*

To The Edinburgh Radio Society, *Twenty Pounds.*

Society's Hall, 117 George Street,
Edinburgh, 10*th November* 1922.

SESSION 1922-23.

The following communications were received :—

Opening Address on "Some Notes on the Development of the Internal Combustion Engine,"—by Professor R. STANFIELD, M.Inst.C.E., F.R.S.E., President, 13th November 1922.

Inspection of Mechanical and Electrical Engineering Laboratories of Heriot-Watt College (No. 4995),—27th November 1922.

"Modern Theories of the Structure of the Atom" (No. 4996),—by Professor H. S. ALLEN, M.A., D.Sc.,—read 11th December 1922.

"Perpetual Motion and the Radium Clock" (No. 4997), — by J. H. ALEXANDER, M.B., C.M., — communicated by Secretary, 15th January 1923.

"A Linkage for describing Equal Areas" (No. 4998), and "A Radial Integrator" (No. 4999), — by E. M. HORSBURGH, M.A., D.Sc., F.R.S.E.,—read 15th January 1923.

"A Special Two-way and Sampling Stop-cock" (No. 5000),—by C. NORMAN KEMP, B.Sc., A.I.C., and GEORGE ROMANES, B.Sc.,—read 15th January 1923.

"Stone Preservatives" (No. 5001),—by Principal A. P. LAURIE, M.A., D.Sc., F.R.S.E.,—read 29th January 1923.

"An Improvement on the Briggs Equalising Apparatus" (No. 5002),—by WILLIAM FULDE,—read 12th February 1923.

"Radio Telephony from the Amateur Standpoint" (No. 5003),—by WILLIAM WINKLER,—read 12th February 1923.

"X-Rays" (Keith Lectures),—by W. HOPE FOWLER, M.B., Ch.B., F.R.C.S.E., — delivered on 26th February, 12th and 26th March, and 9th April 1923.

REPORT OF THE COMMITTEE APPOINTED TO AWARD PRIZES FOR COMMUNICATIONS READ OR REPORTED ON DURING THE SESSION 1922-1923.

Your COUNCIL having met and carefully considered the Communications laid before and definitely disposed of by the Society during tbe Session 1922-1923, begs to report that it has awarded the following Prizes :—

To E. M. HORSBURGH, M.A., D.Sc., F.R.S.E.,—for his papers on "A Linkage for describing Equal Areas" (No. 4998), and on "A Radial Integrator" (No. 4999).

A Makdougall-Brisbane Prize, value Seven Sovereigns.

To C. NORMAN KEMP, B.Sc., and GEORGE ROMANES, B.Sc.,—for their paper on "A Special Two-way and Sampling Stop-cock" (No. 5000).

A Keith Prize, value Seven Sovereigns.

To Principal A. P. LAURIE, M.A., D.Sc., F.R.S.E.,—for his paper on "Stone Preservatives" (No. 5001).

A Hepburn Prize, value Seven Sovereigns.

To WILLIAM FULDE,—for his paper on "An Improvement on the Briggs Equalising Apparatus" (No. 5002).

A Keith Prize, value Seven Sovereigns.

The hearty thanks of the Society are due to Professor R. Stanfield, M.Inst.C.E., F.R.S.E., for his Opening Address, delivered on 12th November 1922, and to Professor H. S. Allen, M.A., D.Sc., J. H. Alexander, M.B., C.M., and William Winkler, for their Communications.

All of which is reported in name and by order of the Council by

C. NORMAN KEMP, *Secretary*,
Convener ex-officio.

KEITH BEQUEST.

Grants for Research.

During the Session 1921-1922 Research Grants were awarded

To Bertha Kemp, M.A., D.Sc.,—for "Investigations in the Applications of X-Rays to the examination of Materials, with special reference to the radiographic appearances of abnormal conditions in Timber," and

To the Research Committee of the Edinburgh Radio Society, per William Winkler, Secretary,—for "Investigations connected with the Armstrong Super-regenerative Wireless Receiving Circuit."

Preliminary Reports have been received as follows :—

From Dr. Kemp.—A careful search through the literature indicated that practically no work had been done on the lines proposed, excepting the examination of aeroplane timber, etc., by Knox and Kaye during the War, and various radiographic studies of timber, plants, etc., published by the American General Electric Company and others to illustrate the performance of certain types of X-Ray tubes. The experimental work was then commenced and is still being continued, but was interrupted for some time by the transference of attention to the X-Ray examination of coal in consequence of an enquiry received. This field of investigation also was found to have been almost entirely neglected, and was soon seen to have important and far-reaching possibilities, the preliminary results having formed the subject of a Communication submitted by Mr C. Norman Kemp on 16th February 1924 to the North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne, and now published in the *Transactions of the Institution of Mining Engineers* (Vol. LXVII., Part 1, pages 59-83). In this work Mr Kemp was fortunate in having the collaboration of two other Fellows of the Society, Mr William M'Laren, M.A., B.Sc., and Mr J. Leslie Thomson, B.Sc.

I hope to submit to the Society a Communication on the original subject—the X-Ray examination of Timber—during the course of next Session, and Mr Kemp is giving a preliminary note on "The X-Ray Analysis of Coal" at the last Meeting of the present Session.

From Mr Winkler.—It was proposed to investigate the possibility of Armstrong's Super-regenerative Radio Receiver. The necessary material was procured and the apparatus assembled by our Members. After prolonged investigation and experimentation it was considered that this type of receiver was not suitable without several modifications for receiving telephony, but was capable of an incredible factor of amplification, and well suited to the reception of continuous wave Morse signals. We shall be glad to give a full and detailed Report some time during next Session.

SESSION 1923-24.

Conversazione held in Heriot-Watt College, 3rd November 1923.

The following Communications were received :—

"Hydro-Electric Developments with special reference to Railway Electrification" (No. 5004), — by Professor STANLEY PARKER SMITH, D.Sc.,—read 12th November 1923.

"The Development of the Supply of Electricity in Edinburgh, and a description of the New Generating Station" (No. 5005),—by FRANK A. NEWINGTON, M.Inst.C.E., M.I.E.E., — read 26th November 1923.

"The Carbonisation of Coal for Smokeless Fuel and Industrial Gas" (No. 5006),—by ROBERT MACLAURIN,—read 10th December 1923.

"The Thermionic Valve and its Application to Broadcasting" (Keith Lectures),—delivered by Captain P. P. ECKERSLEY,—on 14th and 28th January, 11th and 18th February 1924.

"The Evolution and Physics of the Golf Ball" (No. 5007),—by CHARLES L. ABERNETHY, M.A., B.Sc., F.R.S.E.,—read 25th February 1924.

"A New Type of Aircraft as a Proposed Solution of the Problem of Aerial Transport" (No. 5008),—by W. SHOLTO SHEPPARD,—read 17th March 1924.

"The Rubber Industry in Edinburgh"—A Review—(No. 5009),—by W. A. WILLIAMS, F.I.C., F.R.S.E.,—read 14th April 1924.

"The X-Ray Analysis of Coal"—A Preliminary Note—(No. 5010),—by C. NORMAN KEMP, B.Sc., A.I.C.,—read 5th May 1924.

REPORT OF THE COMMITTEE APPOINTED TO AWARD PRIZES FOR COMMUNICATIONS READ OR REPORTED ON DURING THE SESSION, 1923-1924.

Your COMMITTEE having met and carefully considered the Communications laid before and definitely disposed of by the Society during the Session 1923-1924, begs to report that it has awarded the following Prize :—

To ROBERT MACLAURIN,—for his paper on "The Carbonisation of Coal for Smokeless Fuel and Industrial Gas" (No. 5006).

A Keith Prize, value Twenty Sovereigns.

The hearty thanks of the Society are due to Professor S. PARKER SMITH, Messrs FRANK A. NEWINGTON, CHARLES L. ABERNETHY, W. SHOLTO SHEPPARD, and W. A. WILLIAMS, for their Communications.

All of which is reported in name and by order of the Council by

C. NORMAN KEMP, *Secretary,*
Convener ex-officio.

KEITH BEQUEST.

Grants for Research.

Your Council have considered an application from Mr C. Norman Kemp on behalf of himself and his colleagues, Messrs William M'Laren, and J. Leslie Thomson, and also Messrs G. Victor Thom and J. G. Ogilvie who are collaborating with them, for a Grant towards the cost of additional apparatus required for the continuance of their technical X-Ray research on Fuels.

The Council recommend the award of £85.

A Communication on the work already carried out will be presented to the Society during the current Session.

SESSION 1924-25.

The following communications were received:—

"Wireless Control of Air Traffic" (No. 5011),—by Lieutenant Duncan Sinclair, R.A.F.,—read 13th October 1924.

"Testing the Human Machine" (No. 5012),—by James Drever, M.A., B.Sc., D.Phil.,—read 1st December 1924.

"Stone Decay and Preservation of Buildings" (No. 5013),—by Principal A. P. Laurie, M.A., D.Sc., F.R.S.E.,—read 8th December 1924.

"A Clockwork Control for the Carrel-Dakin treatment of Septic Wounds by Intermittent Douching" (No. 5014),—by Charles W. Cathcart, C.B.E., F.R.C.S.,—read 12th January 1925.

"The Carbogen Reviving Apparatus" (No. 5015),—by Henry Briggs, D.Sc., A.R.S.M., F.R.S.E.,—read 12th January 1925.

"An Improved Knife-Clamping Apparatus for the large flat-cutting Cambridge Microtome" (No. 5016),—by Thomas D. Hamilton, F.R.M.S., by kind permission of J. W. Dawson, M.D., D.Sc., F.R.C.P.E.,—read 12th January 1925.

"The Industrial Applications of the Hele-Shaw Variable Stroke Pump" (No. 5017),—by John T. Wight, M.I.Mech.E., F.R.S.E.,—read 26th January 1925.

"The Fabric of the Universe" (Keith Lectures),—by Professor William Peddie, D.Sc., F.R.S.E.,—delivered 9th and 23rd February and 9th and 23rd March 1925.

"Mussels as a Pest and a New Method for their Control; with special reference to Experiments in connection with Portobello Electric Station" (No. 5018),—by James Ritchie, M.A., D.Sc., F.R.S.E., Royal Scottish Museum.

"The Examination of Materials by means of X-Rays, with special reference to Applications in the Technology of Coal" (No. 5019), —by C. Norman Kemp. B.Sc., F.R.S.E., Wm. McLaren, M.A., B.Sc., and J. Leslie Thomson, B.Sc.

REPORT OF THE COMMITTEE APPOINTED TO AWARD PRIZES FOR COMMUNICATIONS READ OR REPORTED ON DURING THE SESSION 1924-1925.

Your COMMITTEE having met and carefully considered the Communications laid before and definitely disposed of by the Society during the Session 1924-1925, begs to report that it has awarded the following Prizes :—

To THOMAS D. HAMILTON, F.R.M.S.,—for his Paper on "An Improved Knife-Clamping Apparatus for the Large Flat-cutting Cambridge Microtome" (No. 5016).

A Makdougall-Brisbane Medal.

To JAMES RITCHIE, M.A., D.Sc., F.R.S.E.,—for his paper on "Mussels as a Pest and a New Method for their control" (No. 5018).

A Hepburn Prize, value Five Sovereigns.

To C. NORMAN KEMP, B.Sc., F.R.S.E., WM. McLAREN, M.A., B.Sc., and J. LESLIE THOMSON, B.Sc.,—for their Paper on "The Examination of Materials by means of X-Rays" (No. 5019).

A Keith Research Grant, value Ten Sovereigns.

The hearty thanks of the Society are due to Lieutenant SINCLAIR, JAMES DREVER, M.A., B.Sc., D.Phil., Principal A. P. LAURIE, CHARLES W. CATHCART, C B.E., F.R.C.S., Professor HENRY BRIGGS, and JOHN T. WIGHT for their Communications.

All of which is reported in name and by order of the Council by

C. NORMAN KEMP, *Secretary,*
Convener ex-officio.

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A barrow-load of small mussels, of which thirty-two barrow-loads developed in 300 yards of 42-inch pipe in twelve months.

Heap representing thirty-two barrow-loads of small mussels removed, dead, from condensing plant after a short length of piping had been treated with heated water.

REPORTS

on

I.—THE PREVENTION OF THE GROWTH OF MUSSELS IN SUBMARINE SHAFTS AND TUNNELS AT WESTBANK ELECTRICITY STATION, PORTOBELLO.

and

II.—THE POSSIBLE BLOCKING OF THE PORTOBELLO TUNNELS BY SEAWEED.

By
JAMES RITCHIE
M.A., D.Sc., F.R.S.E.
Royal Scottish Museum, Edinburgh.

EDINBURGH
PRINTED BY M'LAGAN & CUMMING
1927

CONTENTS

(1.) MUSSEL REPORT.

Danger of Mussel Infection in Westbank Tunnels.

The Combating of the Mussel Danger.

(2.) SEAWEED REPORT.

INTRODUCTORY.

Early in 1919, when the erection of the new Electricity Generating Station at Portobello was about to commence, the Electricity Committee of Edinburgh Town Council and their consulting engineers, Messrs Kennedy & Donkin, foresaw that difficulties might arise from the accumulation of mussels in the large tunnels through which water for condensing purposes was to be conducted from the sea. After a preliminary discussion with the Committee and with Sir Alexander Kennedy and Mr S. B. Donkin, I was invited to plan and carry out a series of experiments with the object of discovering whether a means could be devised to prevent such interference as had already been encountered at many places where sea-water was used for similar purposes. The experiments were carried on over a period of two years, but the foresight of the Committee was rewarded in that, when the Station was opened in the summer of 1923, a method of dealing with the mussel growth had been devised and had already proved to be effective.

The following Reports are printed in the form in which they were submitted to the Electricity Committee of Edinburgh Town Council on 29th December 1921, but I have added a short Appendix indicating the mussel prevention that has been carried out at the Station, and giving some observations made after the Station was in full running order. To the Electricity Committee and their technical officers (especially Mr Frank A. Newington, Mr E. Seddon and Mr Lingard) and advisers I am indebted for many facilities, and to the Committee for permission to reproduce the Reports submitted to them.

I.—REPORT ON THE PREVENTION OF THE GROWTH OF MUSSELS IN SUBMARINE SHAFTS AND TUNNELS AT WESTBANK ELECTRICITY STATION, PORTOBELLO.

1. *The Problem.*—The experience of many stations on various parts of the coast of Britain where sea-water has been conducted through intake pipes, led the Committee to believe that growths of mussels and other marine creatures and plants would tend to accumulate within the intake tunnels at Portobello, ultimately reducing seriously both the volume and the speed of the current.

The problems to be decided were: first, whether this danger of internal growths actually existed in the case of the tunnels at Westbank, since it is not universally present on all parts of the coast; and, secondly, if the danger occurred, to discover by what means it could best be combated, and the growth of the marine organisms prevented or destroyed.

2. *The General Plan of Observations and Experiments.*—To solve these problems I planned a series of observations and experiments to be carried on at least throughout a complete year in order to determine the likelihood and rate of mussel growth, to discover the periodic mussel seasons, which had not been determined in the Forth, and to settle the best means of dealing with the mussels. These plans involved the anchoring of an experimental buoy in the vicinity of the sea-ends of the tunnels, and the erection of a series of tanks in which mussels for experiment could be kept alive. The scheme necessitated regular observation and tow-netting of the Forth at short intervals in the neighbourhood of the tunnels, and regular examination of the buoy itself, as well as a long series of laboratory experiments.

The results of these observations and experiments, and the conclusions to which they have led me are summarised in the following paragraphs.

3. *The Nature of the Growths within Intake Shafts.*—While the main obstruction in the blocking of intake shafts and tunnels has been set down solely to mussels, these form only one of a set of marine organisms which are liable to settle on and grow within pipes. Probably the earliest of the organisms to gain a footing are various species of the smaller seaweeds, and these form a shelter and foothold for

creatures such as mussels, which in turn form a bed which collects mud and other debris, wherein live such as tube-building worms (Polychaets), ribbon-worms (Nemertines), and several forms of sea-lice (Amphipods) and sea-spiders (Pycnogons). But owing to their rate of growth and rate of multiplication, mussels soon assume dominance in this asssortment of creatures and become the outstanding factor in the effective interference with water supplies. For this reason our endeavours were concentrated upon the mussel growths.

4. *The Invasion of Intake Shafts by Mussels.* — Adult mussels are fixed to rocks, stones, seaweeds, or almost any submerged object by a series of fine threads of horny (chitinous) material, known as the "beard" or byssus. So fixed, they are incapable of movement, and only in unsatisfactory conditions of the surrounding water do they drop the anchoring byssus, and move slowly along by extending, fixing and pulling themselves after a thin but muscular "foot." This, their only power of movement, is very limited ; in the experimental tanks they occasionally moved only a few inches in the course of a night ; and there is therefore little likelihood that shafts, rising some distance above the sea-bottom, as do those at Westbank, would be invaded by adult mussels from neighbouring beds.

But the young stages of mussels, just after they have developed from the egg, and until, as my observations have shown, they are about 0.25 mm. (one-hundredth of an inch) long, are free-swimming, and are borne to and fro by the tide and currents. It is during this period of the mussel's life that the invasion of intake-tunnels takes place, for in the neighbourhood of mussel-beds the larvæ are sprinkled in quantity throughout the sea, and the constant current of inflowing water carries them into and throughout the length of the tunnel. It is obvious also that the numbers which pass along with a constant current of some velocity are much greater than the numbers at any given point in the open and relatively stationary sea, and the chances of infection of the tunnel, provided the current is not too swift to prevent settling, is by so much increased.

The free-swimming larvæ in themselves would be of no account in the tunnels owing to their minute size, but when they are about a month old and about one-hundredth of an inch long, they develop a byssus-gland and byssus and settle on almost any object with which they may come in contact.

It is at this stage, the duration of which was the object of many observations, that the effective invasion of a tunnel takes place, for once the young mussels have attached themselves firmly, they gather their food from the surrounding water and their growth is moderately rapid (as a subsequent section shows). Moreover, it is clear that the increased volume of sea-water with its contained micro-organisms, due to the constant flow within the tunnel, affords a more abundant food supply than would be available in the open sea, so that the growth of the mussels fixed within the tunnel is certain to be more rapid than of those in the open sea.

Danger of Mussel Infection in Westbank Tunnel.

5. *Position of Shafts in Relation to Mussel Beds in the Firth of Forth.*—The shafts leading to the tunnels open to the sea in the Firth of Forth opposite King's Road, a distance of 1575 feet seawards of Westbank Place, and about 600 feet beyond low-water mark of spring tides. The most extensive bed of mussels in the near neighbourhood is that west of Leith Pier, which has an estimated area of 550 acres. But, while the sandy or muddy bottom through which the shafts rise affords no foothold for the development of mussel beds, there are in close proximity on the south, about a mile away, dense patches of mussels, some of which are uncovered at low tide, at the rocks west of Joppa, and on the north about the Black Rocks. Still nearer are to be found abundance of well-grown mussels clustering on the wooden supports and pipes of the various sewage outfalls, both north and south of the shafts.

It must be remembered, however, that close proximity of a mussel-bed is not essential for the infection of a tunnel, for the free mussel larvæ or spat are carried by tides and currents very considerable distances from the places of their origin.

It is clear, therefore, that the Westbank tunnels are very suitably situated for receiving a heavy infection of spat from the surrounding sea.

6. *Observations as to the Settling of Mussel Spat in the Neighbourhood of the Tunnels.*—The supposition that mussel spat was likely to infect the tunnels was checked and confirmed in various ways. At various times, many townettings were made, with a silk-gauze net of bolting cloth having about 190 meshes to the square inch, in the sea close to the position of the shafts; and during the spatting season, the material caught in the tow-net revealed the presence in varying abundance of larval mussels.

Still more telling was the evidence afforded by the experimental buoy, anchored some 100 yards seaward of the sea-ends of the shafts, for within a few weeks of its being placed in position, young mussels had settled on parts offering suitable foothold, and in the course of the summer a thick layer of mussels developed on every suitable surface.

Excellent confirmatory evidence was given by the wooden piles sunk at different times in connection with the boring of the upright shafts. These invariably became coated with young mussels at levels below high water-mark, the numbers of mussels being greater towards the permanently submerged portions of the piles. Another interesting fragment of evidence was gained from the piles, owing to their being stationary ; the mussels were not dispersed with equal density on each surface of a pile, the tendency being for the western and northern faces to be less thickly coated than the eastern and southern. The buoy also was most thickly coated on the shoreward side. The indication, therefore, is that the majority of the mussels settling in the neighbourhood of the shafts are carried thither from a southerly and easterly direction, that is, they are brought there by the flood tide.

These evidences, then, show quite clearly that the Westbank tunnels cannot, under ordinary circumstances, hope to escape from a heavy infection of mussel spat every season.

7. *Rapidity of Mussel Growth in the Neighbourhood of the Shafts.*—The interference of a water supply by mussels depends upon their growth as well as upon a copious infection, for the increase of mass is much more due to growth than to the settling of new individuals. Constant observations were therefore made to determine the rate of growth in the neighbourhood of the shafts (since growth varies greatly in different localities), so that a rough estimate might be made of the rapidity with which appreciable interference with the inflow might take place. The Portobello area is, unfortunately from our present point of view, most suitably placed for the rapid growth of mussels, owing to the amount of organic matter discharged from many sewers in the neighbourhood, and the consequent abundance of micro-organisms which subsist upon it and on which the mussels in turn feed.

The following is a much condensed summary of the observations on growth.

On May 11th, 1920, an experimental buoy to which apparatus was attached was anchored 100 yards north of the sea ends of the tunnels, the particular position being chosen so that the buoy might be free from abnormal influences, such as muddy water due to the actual workings at the shafts. Samples of mussels were periodically obtained from the buoy and examined at the buoy and in the laboratory. The results as regards growth were :—

Date.	Approximate Average Size.	Greatest Size.
1920. July 18.	About 0.3 mm. ($\frac{1}{75}$-in.)	1 mm. ($\frac{1}{25}$-in.)
Aug. 10.	About 2 mm. ($\frac{1}{12}$-in.)	6 mm. ($\frac{1}{4}$-in.)
Aug. 25.	,, 10 mm. ($\frac{2}{5}$-in.)	12.5 mm. (say $\frac{1}{2}$-in.)
Oct. 23.	,, 24 mm. (say 1 in.)	28 mm. ($1\frac{1}{10}$ in.)
1921. Apl. 20.	,, 32 mm. ($1\frac{1}{4}$ in.)	36 mm. ($1\frac{1}{2}$ in.)
Aug. 25.	,, 40 mm. ($1\frac{11}{20}$ in.)	54 mm. ($2\frac{1}{10}$ in.)

Growth appears to be particularly rapid during the height of summer, so that in five months mussels of the year reach a length of roughly about one inch. But even during the winter, a considerable increase of size takes place, for mussels collected at the buoy on April 20, 1921, almost a year after the mooring of the buoy, gave an average of about 32 mm. or say $1\frac{1}{4}$ inches, and a maximum of 38 mm. or $1\frac{1}{2}$ inches. Four months later (August 25th) many mussels on the buoy exceeded 2 inches in length.

The increase in growth is greater than that assigned to the generality of mussels in Scottish waters, for Mr W. L. Calderwood states that in favourable estuarine localities a size of 2 inches is attained only in about *three years*, and that in unfavourable localities the same size is reached only in four to eight years.* The more rapid growth at Portobello, where 2 inches is attained in fifteen months, is to be attributed, as I have indicated, to favourable feeding conditions due to the presence of abundant sewage.

But from the point of view of interference with water supplies, MASS GROWTH is of more significance than individual growth, and in this connection the following observation is of considerable interest. After five months in the open sea the layer of mussels clustered underneath the wooden fender of the buoy measured in depth at places taken at random, 2 inches, 3 inches, and $3\frac{1}{2}$ inches.

The speculation is a hazardous one, owing to the different conditions due to a moderately rapid current with the tunnels; but were a similar growth of mussels to take place along the tunnels, the sectional area of the tunnels, 4 ft. 9 in. in diameter, would be reduced in five months by about $3\frac{3}{4}$ square feet. It is clear that such a reduction, increasing with the development and fresh settling of mussels, would in the course of a few years become a serious hindrance to the inflow of water, for not only would the actual size of the tunnel be appreciably decreased, but the roughness of the mussel coating would retard the velocity of the current along the sides of the tunnel.

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* "Mussel Culture and Bait Supply," London, 1895, p. 56.

One of the Sea-Water Tunnels under construction. The difficulties in the way of treatment for marine growths are indicated by the great size of the tunnels, $4\frac{1}{2}$ feet in diameter, capable of passing $2\frac{1}{2}$ million gallons of water per hour.

8. *Will the Settling of Mussels be Affected by the Currents in the Tunnels?*—I regret that I have not had an opportunity of carrying out any direct experiments to discover the exact speed of current which would prevent the settling of the floating spat, but observations have been made in other places which indicate the possibilities within the range of the currents in the Westbank tunnels. For the first few years the possible discharge in the tunnels will be 21,666 gallons per minute, giving an approximate velocity of 180 feet per minute, though when the Station is increased in the future the velocity may rise to 480 feet per minute. But Dr. Dodgson, who has been investigating shell-fish questions for the English Board of Agriculture and Fisheries, has stated that mussels have been known to settle in a current of a velocity of 7 knots an hour, or 710 feet a minute. It is clear, therefore, that the Westbank currents, which are of moderate speed compared with this, will form no obstacle to the settling of mussel spat.

It is to be remembered also that the settling of a young mussel is a comparatively rapid process, consisting of the secretion of slimy threads which attach and harden on contact with the water, so that the period of slack water in the tunnels, between the suction and discharge flows in the alternating current, will always afford opportunity for settling.

Further, it must be remembered that the outer surface of the shafts, where they project above the sand, are certain to become coated with growths of mussels, and it is possible that from this source there may be a fairly constant migration of adult mussels over the top of the pipe and through the grid into the interior of the shaft. But this possible migration, so far as numbers go, may, I think, be reckoned as of little significance.

9. *Influence of Depth of Tunnels on Mussel Growth.*—I refer to this point because I understand that there was some idea that the sinking of the tunnels to a depth of some 35 feet below low tide-level of spring tides would place them beyond the range of mussel growth. Such an idea is erroneous, however, for the largest and most vigorous mussels are those in beds situated at some depth below low-water mark. In natural conditions mussels are known to live at least down to a depth of 10 fathoms, or 60 feet, close on twice the depth of the tunnels; but even were spat in natural conditions unable to settle at such a depth, the current in the tunnels insures that spat shall have access to every part of the inside surface, and, since micro-

organisms which form the food of the mussel also are conveyed by the current, overcomes any difficulty that nature might have as regards depth distribution.

The Combating of the Mussel Danger.

10. *Methods in Use Against Mussel Growth.*— Since it became evident early in the course of the observations that the Westbank works would be liable to exceptionally heavy infection and to exceptionally rapid growth of mussels within the tunnels, attention was soon directed towards methods which might diminish infection, or destroy the mussels after they had settled.

Various methods have been employed at different stations where trouble has arisen owing to the blocking of inflow pipes by mussels, and a survey of these methods was made in order to discover whether they offered a satisfactory basis for procedure in the case of the Westbank tunnels.

One private firm at Leith Docks flushed a pipe in which mussels grew with Sulphuric Acid of considerable strength, once a year. There are many objections to this method. In tunnels of the enormous capacity of those at Westbank, it would be impracticable on the score of expense; the action of the acid would in course of time seriously corrode the iron of the tunnels; the dead mussel shells would accumulate in the tunnels or would be washed up by the current till they blocked the base of the landward shaft; and lastly on the ground of my experiments, I am doubtful of the efficacy of the method to destroy completely the whole of the mussels.

Various mechanical methods have been adopted. I understand that in a pipe at Dundee a solid iron ball, closely fitting the circular pipe, is driven seawards by a reversed current, crushing the mussels as it goes. As it stands, this method is impracticable in a tunnel 4 ft. 9 in. in diameter, and even on a small scale it must induce serious strain on the jointings of the sections of the pipe. But I considered a modification of the mechanical method to which reference shall be made later.

In the pipes at Portobello Baths a somewhat similar mechanical method has been employed, a cleaning apparatus having been dragged forcibly along the length of the pipe by an attached rope or light chain.

A very interesting experiment on original lines was made at Portsmouth, where by arrangement of suitable anode and cathode an electrical discharge of some intensity was allowed to flow on the mussel-coated surface of the pipe. The results were satisfactory, but the difficulty of insulation rendered the method so troublesome that it was abandoned.

Lastly, there has been used the primitive method of emptying the pipes and of sending an army of men to chip off the accumulations of marine growths when they threatened to cause serious interference. In the Westbank tunnels, nearly a third of a mile long, the expense of such a method puts it out of count, if simpler means are available.

11. *Prevention of Entry of Mussels.*—The suggestion has been made that a grid at the sea-end of the tunnel might be arranged so as to prevent the entry of mussels. But I have shown that the danger of infection arises not from the adult but from larval mussels, and that the majority of mussels in the neighbourhood of the tunnels settle when they are only $\frac{1}{75}$ of an inch long. The mesh of a grid which would prevent the ingress of such invaders, would require to be about 80 to the inch ; and such a mesh would obviously prevent the entry of any water current worth considering.

12. *Prevention of Settling of Mussels within the Tunnels.*—A series of experiments was devised to discover whether any surface would be found that would hinder the settling of mussels. Blocks of a standard size, 10 cm. cubes, were coated with different materials and were attached to eyes specially placed below sea-level under the fender of the experimental buoy. The materials chosen for the testing were iron, copper, zinc, lead, galvanised iron, glass, pitch, creosote, green anti-fouling preparation, white lead paint, and as a control, a plain pitch pine block. The blocks were placed in position on 15th May 1920. After the care given to the preparation of this experiment, I regret to say that interference with the blocks by trippers boating in the neighbourhood, to whom the experimental buoy became a goal to be reached, almost completely destroyed its value. On 11th July only four blocks remained of twelve placed in position, the remainder having been broken from or otherwise removed from their attachment. The four blocks remaining showed that while on zinc, galvanised iron and white-lead paint considerable growths of seaweed and young mussels had taken place, the copper-covered block was entirely free from growth of any kind whatsoever.

I am inclined to think, however, that no solution of the problem lies in specially coating the inside of the tunnels ; for any anti-fouling preparation requires periodic renewal, and a metallic coating of, say, copper suggests the possibility of setting up an electrical interplay between the metal of the tunnel and the surface coating, which would cause rapid deterioration of the tunnel surface.

13. *The Mechanical Method.*—In the case of circular pipes I am convinced that an apparatus could be devised which, driven by the current reversed, would effectively clean the pipes of adherent growths without damage to the tunnels. Such an apparatus was planned, but, on learning that several of the tunnels were not circular in section, I had to abandon the idea.

14. *Experiments with Chemical Solutions.*—The earlier experiments were aimed at discovering a chemical solution which in a limited time might destroy mussels attached to the tunnels. The size and capacity of the tunnels imposed serious restrictions on the chemicals which could be regarded as suitable in the present case ; for it was necessary that the chemical should be obtainable in highly concentrated and, if possible, liquid form, to allow of ready dilution in an enormous volume of water, and it was also necessary, since the total capacity of a tunnel was about 174,000 gallons, that the chemical should be a cheap one, if the method was not to be ruled out on the score of expense.

In this connection several enquiries were made to discover whether a waste product of manufacture, of no commercial value, might be available for use. In particular the waste products of paper-mills, which have a reputation for proving fatal to fish life in rivers to which they are admitted, were investigated. It was found, however, that in this case the waste products were associated with the elements of calcium carbonate in some form, and that the risk of bringing about a deposition of lime on the inner surfaces of the tunnels and perhaps even on the turbines themselves, was too great to be incurred.

It will be unnecessary to describe in detail the many experiments carried out with chemical solutions. The shortest summary of results will serve the immediate purpose, especially as, it may be admitted at once, the results offered no solution of practical value.

Mussels were immersed in acid solutions of varying strengths, and while these were found to kill the mussels eventually, the period required to cause death was too prolonged to be of service in the case of the Portobello tunnels. Thus, even in solutions of sulphuric acid strong enough to damage the surface of the shell, the mussels survived for several days, and on being replaced in normal sea water, opened and functioned normally. In view of the fact that the Board of Agriculture and Fisheries had found that weak solutions of mineral acids were effective in killing mussels, the following experiments were tried. In sea water containing sulphuric acid in the proportion of 10,000 parts of the former to 1 of the latter, mussels were kept for varying periods up to 240 hours. On transference to normal sea water all proved to be alive and healthy. The failure of such experiments is partly due to the action of a mussel on finding itself in contact with any harmful substance, when it immediately closes the valves of its shell so tightly that no fluid can enter. Attempts were therefore made to find a fluid which would overcome this difficulty by penetrating the closed shell and so reaching the animal within. It was found that the shell was permeable to fresh water, and that this had, as well, a deleterious effect on the mussels. But the actual effect depended greatly upon the size of the mussel, the smaller individuals being most quickly influenced. Thus, while mussels of 29 mm. length were alive and healthy after 120 hours' immersion in fresh water, others, varying from 5 mm. to 10 mm. long, were dead after 49 hours. It was hoped, therefore, that sulphuric acid in fresh water in the proportion of 1 to 10,000, would prove more effective than the similar strength in sea water, and while this was so, the results offered no practical solution, for a 30 mm. mussel was dead only after 192 hours. The experiments were "controlled" by mussels of similar size to those experimented upon, placed in normal sea water of similar volume.

It was obvious that death after eight full day's immersion was of no value from the present point of view, where any diversion of a tunnel from its proper purpose was to be avoided as far as possible. The chemical experiments were therefore abandoned, and investigation was concentrated upon another line of attack, the possible value of which was suggested by observations made during some of the chemical experiments.

15. *Heat Experiments.*—Some of the chemical experiments were conducted in an outside shed at the temperature of the outer air, and during a hot period in the summer of 1920, it was observed that the survival period of mussels in experimental solutions was reduced. The indication was that heat had a deleterious effect upon the existence of the mussels, and this observation, with the knowledge that heat would be available at the Electric Station, led to the series of experiments summarised below. In these experiments the mussels were placed in a glass vessel containing normal sea water, along with a thermometer. This again was placed on a tripod within a larger glass vessel containing fresh water which surrounded the smaller vessel to the level of the sea water within. The whole simple apparatus, which

ensured as far as possible a uniform rise in temperature throughout the sea water, was placed on an asbestos plate over a gas flame of variable size, regulated according to the period of time over which it was determined to conduct any particular experiment.

(*a*) A first experiment was devised simply to test the effect of heated water. Mussels of various sizes were placed in a vessel of sea water at 60° F., and the temperature was raised gradually so that in 22 minutes it reached 106° F. The mussels, which at this stage showed abnormal behaviour, such as wide gaping of the shells, were then transferred to normal sea water at air temperature. All were found to be dead.

(*b*) Several experiments were then made to test the exact range of temperature which proved fatal. Throughout these experiments close observation was kept on the behaviour of the mussels, and at various stages in the rising scale of temperature individuals of different sizes were transferred to normal sea water, their subsequent behaviour there being noted. The results of those may be given in the shortest possible summary.

In every case the experiments began at air temperature (ranging from 43° to 58° F.), the temperature was raised gradually till the completion of the experiment.

Mussels of various sizes were tested, and it was found that after being in sea water raised up to 100° F., the first test being made at 69° F., all the mussels, large and small, survived and functioned normally when replaced in sea water at air temperature. When the 100° F. temperature was reached, the mussels had been immersed in gradually heating water for periods ranging from twenty-five to fifty minutes. At 104° F. the first mussels were found to be dead on transference to normal sea water, but the action of heat was clearly selective to some extent, for while the smallest mussels, about 11 mm. long, were killed, larger mussels of from 39 to 41 mm. in length were found to survive. At 106° F. (times of immersion varying from twenty-two to sixty-three minutes) all mussels failed to revive in normal sea water, and beyond this temperature up to 120° F., no mussels were found to survive.

It is clear, therefore, that the raising of the sea water outflow throughout the length of the tunnels to a minimum temperature of 106° F., or, to allow a margin for safety, to 110° F., will kill all mussels within the tunnels.

(*c*) Since the degree to which the outflow must be heated is a matter involving increased cost with increased temperature, experiments were devised to test whether a prolonged immersion at a lower temperature would be as effective as a short immersion at 106°-110° F.

Mussels kept for rather over twenty-four hours in a temperature of 60° F. were found, on transference to normal sea water, all to be alive and healthy.

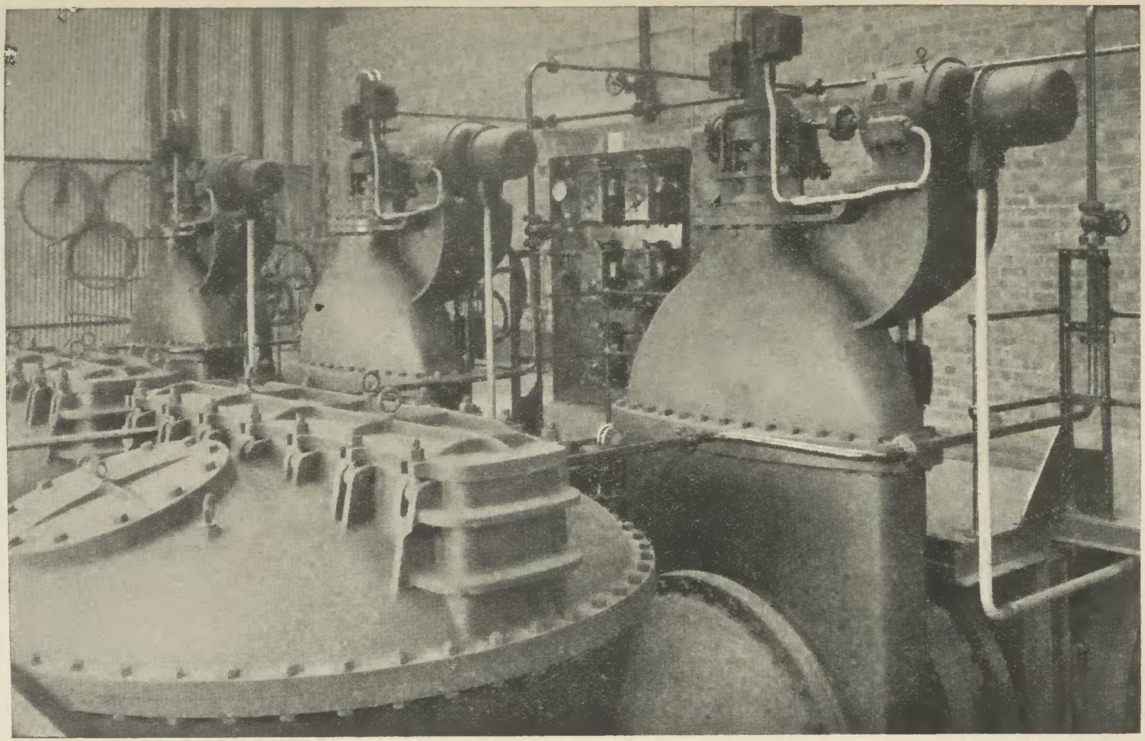
Mussels kept for four hours in a temperature the maximum of which rose to 84° F. were found to be alive and normal; but when kept for fourteen hours or longer at this temperature they were found not to revive in normal sea water.

Prolonged immersion at a temperature reaching 84° F., or as a safe margin 90° F., appears to be as effective in destroying mussels as a short immersion at a temperature 20° F. higher.

(*d*) A simple test was made to determine the time required to kill mussels at a highly lethal temperature. Mussels of various sizes, ranging from 6 mm. to 36 mm. in length, were taken fresh from normal sea water in the experimental tanks and were plunged in sea water at 111° F. After two and a half minutes the six individuals were transferred to normal sea water and all were found to be dead.

16. *Problem of Dead Mussels in Tunnels.*—A method having been discovered whereby the mussels might be killed, there remained a problem due to the fact that the shells and bodies of the destroyed mussels would still remain in the tunnels, where the former might accumulate in the course of years, or might be carried by the current to the grids at the turbine end of the tunnel.

It is known that under certain conditions, mussels may cast themselves free from the byssus, or mass of silky threads which anchors them; and it was hoped that under the influence of heated sea water this reaction might take place, and that the mussels, released from their anchorage, might be carried with the outflow current to the base of the seaward shaft, whence they could be removed. To test the point, mussels in normal sea water were allowed to attach themselves overnight to the sides of a glass jar by freshly spun byssus or "beard." The temperature of the water was then raised to a lethal point. At about 102° F. some of the mussels were seen to tighten themselves against the glass of the jar by contracting the muscles to which the byssus was attached, so that the byssus became wholly included within the shells. But although all the mussels were found to be dead, all remained firmly attached to the byssus, which also retained its hold. The mussels dropped from their attach-



Head of shaft at shore end of tunnel, indicating the size of the plant the interior of which was likely to be overgrown by mussels.

ment only after several days, when decay had destroyed the tissue in which the byssus was imbedded.

Since, therefore, there was no simple method of getting rid of the shells of large or moderately large mussels within the tunnels, another way had to be discovered of avoiding the inconvenience to which these shells might give rise. The desired method clearly is to kill the mussels soon after their settling on the sides of the tunnels, while the shells are still so small that they may be transported by the current in the tunnels and so delicate that they can do no possible damage to the turbines or other apparatus. The following paragraph deals with the determination of a suitable period at which mussel destruction must take place.

17. *Determination of Maximum Periods for Destruction.*—The determination of a suitable period for destruction is a matter of some economic importance: for the super-heating of an outflow not only increases the coal consumption, but reduces the power efficiency of the station for the time being. The less often that super-heating is found to be necessary, therefore, the greater the saving that will be effected. Because of the importance of this matter careful observations were made over the whole period of the experiments to determine the rate of growth of mussel spat after fixation. Although I have not had an opportunity of making a complete and detailed summary of all the collections gathered, the following are preliminary results.

Measurement of a group of 465 very young fixed mussels showed that while a few individuals settle when the shell is only 0.25 mm. ($\frac{1}{100}$-inch long), the majority at the time of settling are 0.3 mm. ($\frac{1}{75}$-inch). A clean rope end was attached to the experimental buoy on May 15, 1920. This rope end, with the cluster of mussels which had grown upon it, was removed on August 10, 1920, and the individual mussels in the collection were measured. The highest point in the graph depicting the results fell at about a length of 1 mm., but the largest mussel in the series was 6 mm. long. Since, in order to ensure a safe margin, it is wiser in the problem before us to reckon with maximum growth, we must assume that on a clean but favourable surface, young mussels attach themselves and reach a length of 6 mm. in eleven weeks. Collections made later in the season seem to indicate somewhat more rapid growth. Allowing for this, I reckon that a mussel may attain a length of 6 mm. or $\frac{1}{4}$-inch in from seven to eight weeks.

In order again that I may err on the safe side, I assume that the shells of a young mussel, of 3 mm. or $\frac{1}{8}$-inch in length, at which stage the shells are extremely delicate and transparent, would, if carried in an inflow current, cause no possible damage to the structures of the turbines or other apparatus through which the inflow passes before it is discharged again into the sea.

Judging from my observations on growth, the 3 mm. stage is attained some four weeks after a clean but suitable surface is exposed to the floating mussel spat.

My opinion, therefore, is that the tunnels will be kept clear of mussel growth, and that no harm can arise from the presence of the shells of destroyed mussels, if an outflow heated throughout a tunnel to 110° F. is passed through a tunnel once every four weeks, during the spatting season in the area concerned.

18. *Duration of Spatting Season in Tunnel Region.*—It is a difficult matter to define within limits the duration of the spatting season, for the ripening of eggs and sperms ("male seed") seems to depend to a great extent upon the temperature of the surrounding water during the spring months, and this is subject to great variation, particularly in shallow-water areas, such as those in which lie the mussel beds from which the spat found in the neighbourhood of the Portobello tunnels is derived. As a rule, in this area, the season of heaviest spat extends from the latter part of April throughout June and July till August, but in favourable conditions spat may be set free even in February and in unfavourable conditions may continue to be shed into the autumn months. Indeed it is possible that at no period of the year is it safe to say that isolated mussels may not be setting free their reproductive elements.

On consideration of all the facts, I am of opinion that a reasonable margin of safety would be observed were the douching of the tunnels with heated water to be continued at the intervals stated from the beginning of March till the end of October, and that douching might be discontinued during November, December, January, and February.

19. *Control Observations.*—The presence of an iron grid at the mouth of each sea-shaft at Portobello offers a ready method of checking the efficiency of the methods here recommended whenever they come to be applied on the large scale. In the first place, the grid will form an excellent foothold for mussels, and it is likely that they will settle and grow upon it. In the second place, the temperature of the heated outflow current will be at its minimum on reaching the grid, which will lie in the sea beyond the end of the shaft. Examination of the grid immediately after a heated outflow

has been passed, should therefore give a good indication of the condition of the mussels within the tunnel ; for if the mussels on the grid are found to have been destroyed by the current at its minimum temperature, it will be certain that all the mussels within the tunnel will also have been killed. Should many mussels be found alive on the grid, a very improbable discovery, the indication would be that a minimum temperature of 110° F. has not been reached at the sea end of the tunnel. If such a temperature, after trial, is regarded as unattainable, the heated outflow will have to be continued for a longer period, and until the control observations at the grid prove that it has been effective.

RECOMMENDATIONS.

Basing a solution of the problem of the prevention of mussel growth in the Portobello shafts and tunnels on the observations and experiments here described, I recommend the following procedure, which I believe would be thoroughly effective :—

1. That a reversed current or outflow of heated sea water be passed down each tunnel, and that it be passed until all the water in tunnel and shafts has attained a minimum temperature of 110°F., by which time all the mussels will have been killed.

2. That it is unnecessary to pass such heated water daily or even weekly, but that to prevent undue development of the mussels in the tunnels the heated current be passed once every four weeks during the spatting season.

3. That, for all practical purposes, the spatting season and the season during which douching must be continued, may be reckoned from the beginning of March till the end of October.

4. That immediately after the first application of the above recommendations control observations be made at the grid on the end of the sea-shaft to test the efficacy of the heated overflow.

(Signed) JAMES RITCHIE,
29*th December* 1921.

APPENDIX TO MUSSEL REPORT.

Since the opening of the Electric Station at Portobello the method described above has been in force, and except on one occasion, to be mentioned later, no trouble has been caused by mussel or other growths within the tunnels, though there is abundant evidence that, in the absence of preventative methods, serious disturbance is certain to ensue.

In practice it has been found that, in reducing the vacuum so that the outflow water after passing over the condensers should be raised to a temperature of 106° F., the coal consumpt has been so increased as to render the method exceedingly costly. Recourse has therefore been taken to the alternative method of running an outflow at a temperature nearing 90° F. for a longer period, the period being approximately twelve hours. In the normal course of the working of the Station the sea-water which passes over the condensers is raised 18° to 20° F., so that the additional temperature required is not so difficult to attain.

On 26th June 1923, in the company of Mr Powell and Mr Lingard, I made a test to discover the degree of loss of heat between the Station and the sea-shafts in the course of the routine of mussel destruction. In the Station the temperature of the outflow, after passing over the condensers, was 89° F. at 10.30 a.m., at 11 a.m. 87° F., and at 11.30 a.m. 89° F. We then visited the sea-shaft of the out-current and there, at 12.30 p.m., the temperature at a depth of 18 ft. in the shaft was 83° F. The distance between the Station shaft and the sea-shaft is 1570 feet, so that the loss of temperature in so great a distance is not serious, especially as the minimum temperature is practically that which, according to my laboratory experiments, is fatal to mussel survival when prolonged for fourteen hours.

An examination of the interior of the tunnels which I carried out at a later stage showed that, while here and there in angles of the shafts a few mussels were found adhering, all were dead. An accidental occurrence which led to this examination is worth recounting because it shows (1) the risks which the tunnels run of being clogged with mussels in uncontrolled conditions, and (2) the efficiency of the heated water method of destruction.

In the afternoon of Saturday, 27th October 1923, it was reported to me that large quantities of mussels had entered the condensers, so effectively interfering with the apparatus that the Station had to be put out of gear and the city's tramways had to be run on current from the old Power Station in Dewar Place. I visited the Station after midnight, by which time the sea ends of the tunnels had been sealed and the tunnels emptied of water. The number of mussels which had entered the condensers was almost beyond belief, as many as thirty-two barrow loads having been removed and dumped outside the building. The empty tunnels were examined without revealing a source from which the mussels had come. But it turned out that, in the routine flushing of the tunnels for mussel destruction, two sections of piping between the turbine house and the pumping house, each some 150 yards long, had been neglected. The desirability of treating this pipe also became evident, and a current, heated to about 90° F., was passed through it. The chocking of the condensers was the result. The thirty-two barrow loads of mussels represented the mussel growth in 300 yards of 42-inch pipe from 5th November 1922, when sea-water was first run in the pipes, to 27th October 1923, a period of less than eleven months—a sufficient indication of the trouble which might arise from accumulations of mussels throughout a protracted period. All the mussels were dead. The accident gave an excellent demonstration of the efficacy of moderately heated water as an agent of destruction.

II.—REPORT ON THE POSSIBLE BLOCKING OF THE PORTOBELLO TUNNELS BY SEAWEED.

In response to an enquiry by Messrs Kennedy & Donkin, dated 9th September 1920, concerning the possible blocking of the Portobello tunnels by seaweed and the measures which might be taken to prevent such blocking, the following observations were made.

The dangers to be anticipated from seaweed are

(1) The entry of seaweed into a tunnel and consequent interference with the grid, or apparatus at the station end of the tunnel.

(2) The blocking of the grids on the sea ends of the tunnels, so that the intake current is impeded and reduced.

Entry of Seaweed into Tunnels.—The danger of the entrance of seaweed into a tunnel protected by a grid, depends upon the size of mesh of the grid and upon the kind of seaweed likely to find its way to the tunnel entrance. Observation of the weed-covered rocks in the neighbourhood of the tunnel suggests that only two groups of seaweeds are of practical importance in this connection. Of these the Bladder-wrack and its allies (*Fucus*) occurs on rocks between tide-marks, and although the fronds are slender enough to enter a comparatively small mesh (say 1 inch square), the length of the plant is sufficient guarantee that it will generally drift broadside against the grid, where it will be caught. The second seaweed, the oar-weed (*Laminaria*) grows upon rock or stones beyond low-water mark, but the great length and breadth of the fronds (which may be six inches across) ensure that it will be effectively caught at the grid.

Blocking of Grid by Seaweed.—If the grid is efficient in checking the entry of seaweed into the shafts, the second danger has to be faced, namely, that the grids may become so encumbered with weed that the inflow is impeded. The essence of this danger lies in the quantity of seaweed likely to find its way to a grid ; and to determine this, many observations were made.

(*a*) Many tow nettings of the content of the sea in the neighbourhood of the sea shafts have been taken with a finemeshed silk net. These have revealed the presence of many small organisms in the neighbourhood, as well as the presence of microscopic algæ in such quantity as to give, in the mass, a brown tint to the sea; yet such organisms or algæ could have no ill effect on the flow or on the condensing apparatus. But the tow nettings, although they have been taken in fairly rough as well as in calm weather, have not revealed the presence of any floating weed of the larger species.

(*b*) Examination of the rocks in the neighbourhood of the tunnels has shown that Bladder-wrack, although present, occurs in much less quantity than on most coastal areas; and although the amount of oar-weed growing in the neighbourhood could not be determined without a considerable amount of dredging to a depth of several fathoms, I believe, from observations made at low spring tides, that this weed also is not abundant in the near locality.

(*c*) It has been found that, as a matter of fact, seaweed is seldom cast ashore in quantity in the neighbourhood of the tunnels in normal weather.

These observations indicate that under normal conditions the grids at the sea shafts will be unlikely to be encumbered by weed.

Danger of Seaweed in Storms.—Bladder-wrack and oar-weed, when alive, are firmly attached to rocks, stones, or some substantial substratum. Therefore, in ordinary weather conditions, little danger is to be feared from floating weed. But in storms or during a heavy sea-swell masses of weed are torn from their foothold, and this weed, set adrift, may possibly cause a blocking of the grids. The danger may arise during the storm from fresh, floating weed, or after the storm from the re-entry to the sea of masses of weed cast ashore during the storm.

Observations have been made to determine when this danger is likely to be greatest at the Portobello tunnels.

(*a*) It has been found that an off-shore wind causes little seaweed to be cast up on the Portobello shore.

(*b*) On-shore winds are, therefore, most to be feared; but it has been found that even with a considerable north-westerly wind, the amount of seaweed cast ashore at Portobello is as a rule of small amount. A striking difference in this respect has been noticed between the shore east of Granton breakwater and the shore at Portobello; for when a north-westerly gale has piled up masses of seaweed at the former place to a depth of some $1\frac{1}{2}$ to 2 feet, the quantity on Portobello beach has been negligible. Indeed the only winds which have been found to strand troublesome quantities of seaweed in the neighbourhood of the tunnels are northerly and, more especially, north-easterly and easterly gales.

Floating Booms at the Grids.—A suggestion has been made that floating booms might be constructed and placed to catch seaweed before it came into contact with the grids. As, however, fresh seaweed is heavier than sea water and sinks in still seawater, and as the only floating seaweed is likely to be dried wrack which has re-entered the sea after having been stranded, the erection of floating booms seems to be unnecessary.

Other Floating Debris.—Apart from the organisms and plants naturally present in sea water, a vast amount of other debris is often in evidence in the sea about the opening of the tunnels. A small and unimportant amount of this consists of straw, leaves, fragments of branches and such like, carried down by the Figgate Burn which enters the sea near the west end of Portobello Promenade; but the vastly greater amount consists of pieces of paper and filth voided by the many large sewers near the tunnels. As these sewers lie to the east as well as to the west of the tunnels both ebb and flow tide will tend to carry the filth towards the intakes, except when an off-shore wind sets the general drift seawards. Undoubtedly there are occasions when the sewer debris will enter the tunnels in quantity, for it has often been noticed by me during tow-netting in the proximity of the intakes; but in view of its nature and of the necessity of retaining a reasonably large mesh on the grid, I do not see how its entry can be avoided.

Conclusions and Recommendations.—(1) I think that with a suitable mesh on the protecting grid and with the employment of ordinary precautions there is little fear of seaweed entering the shafts or blocking the grids.

(2) An ordinary precaution, I would suggest, would be that after a storm, particularly from east or north east, when the sea runs most heavily upon the Portobello shore, the grids should be cleared of weed by manual labour from a boat, the weed being taken ashore and destroyed and not left floating in the neighbourhood; or, alternatively, that

(3) An experiment should be tried after the first storm to test whether a reversed current of some velocity sent down

a tunnel would dislodge the weed and set it adrift before it had become entangled on the grid. The most favourable time for trying the experiment would be at full ebb or full flood tide, when the natural motion of the sea is at its minimum. Should this experiment prove successful, this mechanical method of clearance might be permanently substituted for the manual method indicated in paragraph (2).

(4) Consideration should be given to the designing of a grid of such a shape that in spite of partial blocking by seaweed during a prevalent run of the sea, a sufficient free surface would remain to allow an unimpaired current of inflow water to reach the condensers.

(Signed) JAMES RITCHIE,
6th January 1922.

NOTE.—The substance of this Report, excepting the observations since made on the occurrence of drift weed at Portobello, was communicated in a letter to Messrs Kennedy & Donkin, in response to their queries, on 13th September 1920.

FUEL OIL

(Illustrated by Lantern Slides).

READ MONDAY, 28th NOVEMBER, 1921,

BY

A. F. BAILLIE,

LONDON.

The subject of fuel oil is of great and growing importance, and I much appreciate the honour that your Society has conferred upon me by asking me to read a paper on this subject.

Fuel oil is frequently spoken of as "crude oil," but this is not correct, because the crude petroleum oil as it issues from the well contains certain light fractions of the gasoline and kerosene series, which it is not only desirable to extract from the crude by distillation on account of their higher values, but which, if left in the crude oil and used as fuel, would be a wasteful procedure, and, further, would lower the flash-point. This flash-point has been very properly fixed for fuel oil by British authorities, viz.: Lloyd's Register of Shipping, 150° F.; London County Council, 150° F.; and British Admiralty, 175° F.

Slide No. 1.—Los Narranjos Well.
Slide No. 2.— Ditto ditto.
Slide No. 3.— Ditto ditto.
Slide No. 4.— Ditto ditto.

The crude is, therefore, subjected to what is known as a "topping process," which is a distillation that cuts out those lighter fractions, leaving a product having a calorific value of approximately 19,000 B.T.U.'s per lb., that product being called "fuel oil."

Fuel oil is used firstly at the wells for raising steam in connection with the drilling of these wells. It is also used at the refineries as a heating agent under the stills, and also as a fuel for steam raising in various types of boilers. Fuel oil is further used in steamships, for generating steam in their boilers for supplying the main engines. Again, fuel oil is used for steam raising in numerous types of land boilers, also on locomotives and heating furnaces for metallurgical work.

In the consumption of fuel oil as a heating agent, it is first necessary to divide finely or atomize the fluid, so that it can be mixed with the necessary quantity of air, to make the resultant a combustible mixture. This process is called "atomization," and is effected by means of apparatus called "oil-fuel burners." These burners are manufactured by various engineering firms and come under three systems :—

(1). Air-Jet System.
(2). Steam-Jet System.
(3). Pressure-Jet System.

The first system uses air under pressure as an atomizing agent. Low-pressure air is blown from a motor-driven fan, although for special classes of work, such as the manufacture of electrical bulbs and other white glass ware, high-pressure air has in the past been used, and is supplied by blowers or compressors. For some particular classes of work it has been found to be an advantage to take all the air for atomizing and combustion through the burner, and in this case, the air is intermingled with the oil in the burner, the proportion being 207 cubic feet of air per lb. of oil. Thus, due to all the air being under control, an oxidizing or reducing flame can be obtained at will. For other classes of work, the usual procedure is to take approximately 60% of air through the burners and induce the necessary extra quantity of air from the atmosphere to complete combustion.

The second system, viz., the steam-jet system, uses steam under pressure as an atomizing agent. It is usual to take this steam from an auxiliary stop valve on the boiler or from a tee on the auxiliary steam line, and reduce the pressure of this steam from boiler pressure to 15 to 25 lbs. per square inch. The proportion of steam required for atomizing, say Mexican Fuel Oil, is approximately .3 lb. of steam per lb. of oil, or, on the other hand, say $1\frac{1}{2}$ to 2% of the total steam evaporated. Again, with the steam-jet type of burner, the requisite amount of air to complete combustion is induced from the atmosphere.

The third system, viz., the pressure-jet system, sprays the oil under pressure by means of a steam-driven pump, and also uses steam temperature to thin or reduce the viscosity of the oil. This latter system has been developed during the last 10 years to such an extent that it is recognized as the most economical system for burning oil under land and marine boilers. In this system oil is drawn from the storage tanks by means of a steam-driven pump through suction strainers and pumped through fuel-oil heaters and discharge strainers to the fuel-oil burners. The object of the suction strainers is to collect any foreign matter in the oil so as to protect the suction and discharge valves of the pump. The object of the heaters is to raise the temperature of the oil to such a degree that oil, when intermingled with sufficient quantities of air, is suitable for combustion. The object of the discharge strainers is that, after the oil is passed through the heaters, a certain amount of foreign matter is released and is then trapped by these strainers so as not to choke the nozzle of the burners, as these nozzles are very fine, ranging from 1 to 2.5 mm. The hot oil under pressure issues from the burner in the form of a fine whirling mist, the process of which is termed "atomization." The necessary air for combustion is introduced through special furnace fronts, which slightly pre-heat the air and impart to it a rotary motion in the opposite direction to the burner spray, in order thoroughly to intermingle and mix the oil spray and air supply, and so give complete combustion in the furnace. The quantity of air for combustion is under absolute control by means of dampers or air controls, fitted to the furnace front. These air controls can be fitted when using either natural or forced draught.

These three types of burners have their various uses; the steam jet being used generally for small land boiler plants, the pressure-jet system for large boiler plant and marine purposes, and the air-jet system for furnace heating and metallurgical work.

For comparative purposes, and assuming each of these systems tested under a steam boiler, we would obtain a thermal efficiency of approximately 78% for the steam-jet system, 80% for the air-jet system, and 85% for the pressure-jet system.

As before mentioned, fuel oil is used as a heating agent under the boilers at the wells for producing steam for drilling purposes. The burners used in these cases are always the steam-jet type of burner, as steam is always available from the boiler line, and, again, as the last degree of economy has not to be studied at an oil well, it is a simple and useful tool, the working of which can be easily handed over to native labour. The burners used at the wells are usually those manufactured by Best, of New York, Mammel, Von Boden Ingles and Urquhart.

The next step in the use of fuel oil is at the refineries, as applied to the stills and steam boilers. In refineries, where they have a heavy end to deal with, i.e., a product approaching a liquid asphalt at high temperatures, it is usually the practice to burn a portion of this heavy end under the stills and boilers. This heavy end at a temperature of about 600° F. is run from the stills into storage tanks, which are lagged so as to eliminate a drop in the temperature of the fluid. From the outlet of the storage tank this heavy fuel is discharged by means of a steam-driven pump to an oil line in the front of the boilers or stills. If the fluid is stored for any length of time the temperature drops to, say, 350° F. It is therefore necessary to by-pass the fluid through another line, in which is installed an oil-fired heater much on the lines of a Dutch oven, so as to raise the temperature again to about 600° F. before the fluid reaches the supply line to boilers. This oil line is continued and discharged back to the main tank. It will, therefore, be noted that when using very heavy oils in the refineries it is necessary to keep this oil continually circulated, otherwise, due to cooling of heavy oil in the pipeline, great difficulty would be experienced. It may be interesting to note that with this heavy oil, in some cases where the stills and boilers are some distance from the storage, it is necessary, apart from running a steam line under the oil line and lagging them together, to instal boosting pumps, passing the heavy oil through various sections until it reaches the fuel-oil burners on the stills or boilers. With this very heavy fuel oil it is necessary to spray it into the still furnaces or boiler furnaces at a pressure of 200 lbs. per sq. in. and at a temperature of 550° F.

It has been found that when using very heavy fuel oils, as described above, it is essential, in case of any shutting down of the plant, to have fitted a compressed-air system to these oil lines, so that the line can be completely emptied of fuel, for, if not, the fuel would congeal and solidify in the pipes.

It will, perhaps, be questioned as to why this very heavy fuel oil should be utilized with all these difficulties attendant on its use. The reason for using this very heavy fuel oil is that at the present moment there is not a large enough world's market for its use, so that the percentage of this heavy fuel that cannot be marketed must be used in the refineries, otherwise the heavy fuel would become a drug on the refineries.

Slide No. 5.—Tampico Refinery—General View—Refining.

Slide No. 6.—Tampico Refinery — General View—Receiving Tanks.

Slide No. 7.—Tampico Refinery — Crude Stills, Economizers and Condensers.

Slide No. 8.—Tampico Refinery—Oil-fired stills.

Slide No. 9.—Tampico Refinery—Interior of Pump House.

Fuel oil is used in steamships as a heating agent in the ship's boilers for generating steam to drive the main and the auxiliary engines, and it is the general practice to adopt the pressure-jet system of oil burning. The fuel oil used must have a flash-point of over 150° F. closed to conform with Lloyd's and Board of Trade regulations. In most cases the pumping and heating equipment is placed in the boiler room so as to be adjacent to the attendant, whose duties are in the stokeholds. In some cases, however, fuel oil having a flash-point as low as 79° F. has been used. In this case, to conform with Lloyd's and Board of Trade regulations, it was necessary to instal an isolated pump room extending from the upper deck to the ship's bottom. In this isolated pump room were placed the oil ends of the transfer pump and the fuel-oil boiler supply pumps, also the fuel-oil heaters. On the stokehold side of the isolated pump room were placed the steam ends of the transfer pump and the fuel-oil boiler supply pumps. The reason for fitting this isolated pump room was that any vapours that might be evolved from the fuel-oil heaters and boiler supply pumps would be contained in the isolated pump room and could not escape to the stokeholds, thereby eliminating danger of fires. To ensure further safety a steam-driven suction fan was placed inside the isolated pump room and controlled by an extension spindle from the stokehold. This fan was run periodically to clear any gases that might have collected in the isolated pump room. A lift was also fitted for convenience of engineers and against any possible cause of gassing of men.

Slide No. 10.—'Tween decks of "San Fraterno," showing oil-tight hatches.

Slide No. 11.—Pumps on "San Fraterno."

Slide No. 12.—"San Fraterno" discharging at Thames Haven.

Fuel oil when used on board ship is usually stored either in double-bottom tanks, cross-bunker tanks, deep tanks or side pockets.

In the early days of oil burning, fuel oil was pumped from any of these compartments into a gravity supply tank placed on the main deck. From this supply tank the fuel oil gravitated to steam-jet burners placed on the furnace fronts of the boilers. In those days the steam used for atomizing ranged from anywhere between 5 and 10% of the total steam evaporated, usually nearer 10%. It then dawned on the Superintendent Engineers that they were losing a large quantity of steam when using this class of burner, and it meant either carrying a large extra reserve of feed water or installing additional evaporators to cope with this loss of water. Steam-jet burners for use on board ship were finally discarded, on account of the aforementioned difficulties.

The next step taken was to introduce compressed-air-jet burners for use on board vessel. As the horse-power of the steamers increased it was found that to supply sufficient air atomizing by means of air-jet burners the auxiliary machinery necessary was very large and cumbersome and took up a lot of valuable space in the engine room, and, furthermore, the maintenance charges were extremely heavy. For these reasons, the air-jet system was discarded.

The system used to-day generally is the pressure-jet system of oil burning, as already described.

Slide No. 13.—Oil-fired boilers of "San Fraterno."

The modern method of using fuel oil on board ship is as follows :—

Fuel oil is sucked from double-bottom or other tanks by means of an oil-fuel transfer pump discharging into two settling tanks placed on the main deck, each of these settling tanks having a capacity of 24 hours' supply. The tanks are fitted with heating coils, giving at least one square foot of heating surface per ton of oil carried. The object of these heating coils is to reduce the viscosity of the oil in the settling tanks over a period, say 20 hours, so that if inadvertently any water has contaminated the fuel oil it will settle out much more easily by aid of heat. It will be seen, therefore, that to obtain 20 hours' heating in each of these 24 hours' supply settling tanks, the fuel-oil transfer pumps should be of such a size as easily to handle the day's supply in about four hours.

From the settling tanks the oil is sucked by means of boiler fuel-oil supply pumps and thence discharged through heaters and filters to the burners on the boiler front as described before. At the bottom of the settling tanks drain cocks are fitted and connections led from these to a special pocket in the bilge in the boiler room. A connection can also be taken from the suction side of the fuel-oil transfer pump and another from the discharge side with a connection overboard, so that the drainage water from the settling tanks can be discharged overboard by means of this pump.

When using Mex fuel oil, .950 specific gravity, it has been found that, with the exception of double-bottom tanks, it is not necessary to heat the oil to transfer it to the settling tanks. If double-bottom tanks are used, however, it is always advisable to have steam heating coils in the vicinity of the suction pipes, so as to reduce the viscosity of the oil, as in this case the oil has to be lifted, whereas, in the case of cross bunkers, deep tanks and side pockets, the oil will flow to the pump. In the settling tanks, with the same class of oil, it should be heated up to at least 100° F., as by this preliminary heating it takes a certain load off the fuel-oil heaters, as the oil has not to be heated up, say, from 40 to 260° F. Therefore, one operation is split up into two operations, viz., preliminary heating in the settling tank and a final heating in the fuel-oil heaters.

It is sometimes necessary for oil companies to use a fuel heavier than that supplied to the ship owners, so as to ease accumulation of stocks at the refineries. This heavy oil is carried in the cross bunker adjacent to the boiler room, and is handled through settling tanks, etc., to the burners. In this case the oil is usually heated up to about 135° F. in the cross bunker, and in the settling or measuring tanks to about 180° F., and finally in the fuel-oil heaters to a temperature of 270° F., at which most efficient burning results are obtained.

To obtain actual running results on a very heavy Mexican fuel oil the writer had a trip across the Western Ocean some time ago. The following is a result of one of the series of tests carried out on one of the E. O. T. Co.'s vessels :—

Details of Boilers.

Type of Boiler	Single-Ended Scotch Marine.
Number of Boilers	4.
Length of Boiler	12′ 0″ mean.
Diameter of Boiler	16′ 3″.
No. of Furnaces per Boiler	4.
Diameter of Furnace (inside)	$40\frac{7}{16}''$.
Type of Furnace	Deighton Corrugated.
Total Heating Surface, all Boilers	10,088 sq. ft.
Combustion Space per Boiler	598 cu. ft.
System of Draught	Howden Forced.
System of Fuel Oil Burning	Wallsend - Howden Pressure Jet.

Details of Main Engines.

Type of Engines	Quadruple Expansion Tweedy Balance.
Diameter of Cylinders	28½″ × 41″ × 58″ × 84″
Length of Stroke	54″.
Steam Pressure per Square Inch	220 lbs.

Details of Test.

Duration of Test—Time occupied	120 hours.

Weather Conditions—

State of Atmosphere (Barometer)	29.67″.
Temperature of Atmosphere	67° F.
Smoke at Funnel Top	Slight.

Fuel Oil—

Specific Gravity at 100° F.	·982.
Calorific Value in B.T.U.'s per lb.	18,500.
Tons of Oil consumed on Test	195.
Tons of Oil consumed per Day	39.
Tons of Oil consumed per Hour	1.625.
Lbs. of Oil consumed per Hour	3,640.
Lbs. of Oil consumed per cu. ft. of Combustion Space	6.09.
Lbs. of Oil consumed per I.H.P.	·976.
Lbs. of Oil consumed per Knot	324.
Temperature of Oil in Cross Bunker	135° F.
Temperature of Oil in Measuring Tanks	170/190° F.
Temperature of Oil at Burners	260/270° F.
Temperature of Air at Fan	105° F.
Temperature of Air at Burners (top)	265° F.
Temperature of Air at Burners (bottom)	225° F.
Temperature of Stokehold	110/118° F.
Temperature of Smoke-boxes	655° F.
Temperature of Uptakes	520° F.
Temperature of Base of Funnel	475° F.
Pressure of Oil at Burners	100/120 lbs.
Pressure of Air at Fan	$1\frac{5}{8}''$ to $1\frac{3}{4}''$.
Pressure of Air at Burners (top)	$\frac{5}{16}''$ to $\frac{1}{2}''$.
Pressure of Air at Burners (bottom)	$\frac{11}{16}''$ to $\frac{15}{16}''$.
Pressure of Air at Base of Funnel	$\frac{7}{16}''$ to $\frac{1}{2}''$.
Number of Burners in use	16.
Size of Burners in use	No. 18.
Number of Heaters in use	3.
Double Strokes of Fuel-Oil Pump per min.	8/9.

Water—

Temperature of Sea	80° F.
Temperature of Feed Water	235° F.
Tons of Water evap. on Test (actual)	3,096.6.
Tons of Water evap. on Test (from and @ 212° F.)	3,201.7.
Tons of Water evap. per Day (actual)	619.32.
Tons of Water evap. per Day (from and @ 212° F.)	640.34.

Tons of Water evap. per Hour (actual)	25.8.
Tons of Water evap. per Hour (from and @ 212° F.)	26.68.
Lbs. of Water evap. per Hour (actual) ..	57.803
Lbs. of Water evap. per Hour (from and @ 212° F.)	59.765.
Lbs. of Water evap. per sq. ft. of H.S. (actual)	5.73.
Lbs. of Water evap. per sq. ft. of H.S. (from and @ 212° F.)	5.924.
Lbs. of Water evap. per lb. of Fuel (actual)	15.88.
Lbs. of Water evap. per lb. of Fuel (from and @ 212° F.)	16.419.
Factor of Evaporation	1.034.
Thermal Efficiency	85.73%.
Power Developed, etc.—	
Total	3,729 I.H.P.
Revolutions per Minute	66.
Speed in Knots per Hour	11.23.

An interesting comparison was made by the American-Hawaiian Steamship Company some years ago when they carried out actual tests on one of their vessels, the s.s. "Arizonan," burning coal and fuel oil respectively.

The results obtained are given below :—

COMPARATIVE DATA : COAL *v.* OIL FUEL—S.S. "ARIZONAN" ON TWO VOYAGES.

American-Hawaiian Steamship Company.

Covering passages from New York, Pacific Coast Ports, Hawaiian Island Ports, and return to Philadelphia, via Straits of Magellan out and home. Gross Tonnage 8,672, Twin Screw, Three Boilers, Howden Forced Draught, 215 lbs. pressure, Quadruple Expansion Engines.

	Mean Displacement out, in Tons.	Mean Displacement home, in Tons.	Steaming Time. Days.	Round Voyage. Days.	Average Speed. Knots.
Voyage No. 3— Using coal	16,882	16,660	143.33	186	9.01
Voyage No. 4— Using oil	15,930	17,280	125.25	161	9.95

The actual cost of fuel consumed on those voyages was practically the same.

It will be noted that when using fuel oil against coal the average speed of this vessel was increased almost by one knot per hour, and that 25 days were saved on the round voyage, 18 days were saved owing to the increased speed, and 7 days were saved owing to reduction in time of fuelling oil against coal. The boilers and engines on both of these tests were operated at their maximum capacities. The saving in victualling, manning, and also the increased freight earnings, etc., together with the days saved per round voyage, amounted to approximately £4,000 per trip.

Slide No. 14.—" Arizonan."

Fuel oil is largely used as a heating agent in land boilers in the various countries where oil is directly competitive with coal, and is used principally in electric power stations and mills. These plants are invariably fitted with the pressure-jet system of oil-burning, due to its acknowledged economy over other systems.

Slide No. 15.—Central Argentine Power Station, No. 1.
Slide No. 16.— Ditto ditto No. 2.
Slide No. 17.—Lensbury Oil-fired Boilers.

In this country we have a few cases where manufacturers have converted their boilers solely from coal-burning to oil-burning. Again, in these cases they have been always carrying a heating load and manufacturing products which require essentially a given volume of heat at a given temperature over a specific time.

When coal-firing, owing to the fact that the fires have to be periodically sliced and cleaned, the steam fluctuates so much that the products the manufacturers were aiming at were not as perfect as they desired. It was therefore suggested that fuel oil be adopted, not so much a question of price, but because by turning out a better quality product they could afford to pay a higher annual fuel bill. These suggestions were in some cases adopted and the desired results obtained.

It may be interesting to consider the figures obtained at a large London factory, where their Lancashire boilers were converted from coal-firing to oil-firing, as follows:—

	Coal.	Oil.
Duration of Test	24 hours	12 hours
Calorific Value of Fuel	11,451 B.T.U.	18,750 B.T.U.
Quantity of Fuel consumed per Hour	889 lbs.	955.6 lbs.
System of Firing	Hand firing	“White” pressure system
Pressure of Oil at Burners	—	80 lbs.
Temperature of Oil at Burners . .	—	230° F.
Average Steam Pressure	56 lbs.	68 lbs.
Average Feed Water Temperature . .	126° F.	130° F.
Quantity of Water evaporated per Hour from and at 212° F. . .	6,419.6 lbs.	13,809 lbs.
Water evaporated per lb. of Fuel from and at 212° F.	7.221 lbs.	14.44 lbs.
Quantity of Water evaporated per Hour per sq. ft. of Heating Surface from and at 212° F.	3.675 lbs.	7.945 lbs.
Temperature of Gases at Base of Stack	615° F.	485° F.
Temperature of Boilerhouse . .	100° F.	75/85° F.
Thermal Efficiency	60.91%	75%
Percentage of Rated Evaporation . .	100.0	215

It will be noted in the comparative tests that when using fuel oil the evaporation per lb. of fuel was doubled and, again, the boiler rating was increased over 100%.

The temperature of the boiler-house was also much lower.

Again, in these manufacturing factories a great point made was the cleanliness, freedom from dust and ashes, etc., and also, in the crowded parts of London, the fact of the cartage being considerably reduced, probably by 70%.

Slide No. 18.—Oil-fired Boilers.

Locomotives in South America, the United States and Eastern Europe have for many years been running on fuel oil in place of coal.

As far back as 1890 Mr. Urquhart converted a large number of locomotives from coal to oil firing on the Russian railroads, using mazout as fuel.

Of recent years the principal change over has taken place on the Mexican railroads, where practically all the railroads have been converted. In December, 1910, Mexican railroads were running on coal only; in June, 1911, 20% had converted; in December, 1911, 80% had converted; in June, 1912, 90% had converted, and by December, 1912, the whole of the railroads were converted from coal to oil firing.

Slide No. 19.—Chart showing reduced consumption of fuel as Mexican Railway was gradually converted from coal to oil.

In locomotive practice the steam-jet system of atomizing is favoured, probably owing to its simplicity and to the fact that it only required a tee connection off the steam lines for jetting purposes, and again, steam is always available in the round house for lighting up.

I understand the pressure-jet system of oil-burning was tried on some of the Indian railroads some five or six years ago. The system was found to be economical, but, on the other hand, the heating and pumping unit was too cumbersome to be comfortably fitted into the cab of the existing locomotive. The objection on this score was so strong that the pressure-jet system was discarded in favour of the steam jet. It may be interesting to view the following figures, which is a statement showing comparative tests with coal and oil on the Inter-oceanic Railway of Mexico. This railway connects Vera Cruz on the Gulf of Mexico with the Port of Acapulco on the Pacific, and has a total mileage of 1,035.

COMPARATIVE TESTS WITH COAL AND OIL—INTER-OCEANIC RAILWAY OF MEXICO.

COAL.

Test No.	Time Running.		Miles Run.	Speed.	Lbs. Water evap.	Lbs. Fuel used.	Water evap. per lb.	Gross Weight of Train in tons of 2,000 lbs.
	h.	m.						
1	3	18	35.4	10.73	43,277	8,580	5.04	173.52
2	3	28	35.4	10.20	41,575	8,140	5.11	173.50
3	3	29	35.4	10.17	42,985	8,580	5.00	172.37
4	3	34	35.4	9.92	46,106	10,340	4.46	173.64
5	3	38	35.4	9.75	43,586	11,220	3.88	184.83

Oil.

1	3 40	35.4	11.53	50,612	4,397	11.51	173.77
2	3 16	35.4	10.81	46,699	4,390	10.64	176.11
3	2 53	35.4	12.28	39,046	4,073	9.59	175.62
4	2 33	35.4	13.88	41,591	3,833	10.85	163.74
5	2 47	35.4	12.73	45,305	4,157	10.90	174.85

Summary.

Time getting up 180 lbs. steam from cold	Coal—98 minutes
Ditto do. do.	Oil— 70 minutes
Improved Speed with Oil over Coal (average)	20.2%
Improved Evaporation per lb. Oil	6.05 lbs. or 130%
Lbs. of Coal per 100 ton miles	15.07 lbs.
Lbs. of Oil per 100 ton miles	6.85 lbs.

One valuable feature of the use of fuel oil on foreign railways is the immunity it affords from the number of compensation claims arising out of fires taking place, due to the sparks from wood or coal engines setting fire to crops and forests. Some years ago the State Forester to the Public Service Commission of the United States strongly recommended a prominent American railroad to convert from coal to fuel-oil firing in view of the frequent devastation of the adjoining country caused in this way.

In locomotive practice the cost of handling is also reduced.

We learn that in the States some few years ago oil could be handled from tank cars to storage tanks and thence to locomotives for about .03 cents per ton, while the average for handling coal ran about 5 cents per ton.

Again, from experience, it is stated that the usual wastage of coal in handling between shipment and consumption is from 8 to 10%, whereas, when handling fuel oil this loss is entirely eliminated.

There are no men required to load up the engine or clean out ashpans. There are no ashpits to empty, or ash to be loaded up and hauled away to be unloaded on to waste ground. Fuel oil practically handles itself, and the man attending to the water pumps can also supervise the supplies of fuel to the locomotives.

Slide No. 20.—Oil-burning locomotive on Southern Pacific Railway. Total weight of engine and tender, 277 tons.

In this country tests have recently been carried out on oil-firing the Watt-type locomotive of the London and North-Western Railway, this locomotive being in daily service between London and Birmingham. It may interest you to know that 450 gallons of oil were consumed between London and Birmingham to pull a train having a total weight of approximately 400 tons. The mileage from London to Birmingham is 115, so that the consumption runs out at less than one gallon of oil per 100 ton mile.

Slide No. 21.—L. & N.-W. Railway locomotive on Scarab system of oil-burning.

In this locomotive the burner was placed at the tube plate end of a special extension below the foundation ring of the firebox, taking the place of the ordinary ashpan. The flame is projected towards the rear end of the firebox, and thence deflected towards the tube plate. The ashpan has a false bottom formed of brickwork slabs curved towards the back end in order to deflect the products of combustion upwards. The sides of the ashpan are lined with firebrick to a point just above the foundation ring, otherwise the whole of the heating surface of the firebox is available for steam generations.

Three burners are installed. The one in the centre, the main burner, is used when the locomotive is working at full load ; the two wing burners are controlled by one valve and are of a much smaller capacity, only being used when standing with steam up.

The arrangement of these burners gives the best path to the flame and the products of combustion round the firebox to the tube plate, so that in actual practice the whole of the firebox is filled with flame.

A low arch is provided immediately over the burners in order that the heat of the first ignition of the oil spray may be concentrated and complete combustion effected as soon as possible. A small arch below the coal-firing door deflects the rush of flame from this door, and another arch across the centre of the firebox deflects the flame all over the firebox surfaces and distributes evenly over the tube plate.

A certain quantity of air is admitted through the burner casings. This air is not under control, and only provides the oxygen necessary for the initial combustion of the spray. A further portion of air enters the furnace from a number of small holes in the firebrick false bottom of the ashpan a few feet in front of the burner nozzle. Additional air enters through a damper placed in front of the firebox and is heated by its contact with the hot surfaces of the ashpan exposed to the flame. This air is then passed into the furnace, close to the back plate of the firebox, and being highly heated in its passage is admitted to the furnace so as to provide the necessary oxygen to complete the combustion in the already ignited oil spray.

The steam for atomizing is taken from the boiler line through a reducing valve, into a receiver, at a pressure of 15 lbs. per square inch. This receiver acts as a water collector, and is blown out periodically, so as to ensure dry steam reaching the burner. In the Scarab application of oil-burning, before this steam reaches the burner it is passed through a calorized steel pipe, placed in the bottom of the firebox, in order to superheat the steam. It is stated that this calorized pipe is non-oxidizable at high temperatures, and has a very much longer life than an ordinary untreated steel pipe. A tee-piece and control valve are fitted in the steam line, so that the engine can be started up from cold, either by taking steam from another locomotive or by means of compressed air in the round house. Steam is also led to a heater on the outboard side of the tank on the tender, so that oil may be heated up to reduce its viscosity between the oil tank on the tender and the burner on the locomotive. On the pipeline between the heater and the burner a steam connection is fitted, so that at the end of the day the line can be cleared of oil, otherwise difficulties might be found the next day when attempting to start up, due to the oil becoming much more viscous at the low temperature throughout the night.

The main oil tank is placed on the tender, and is fitted with a steam-heating coil close to the outlet, so as to provide sufficient heat to enable viscous oil to flow freely from the tank to the heater.

A thermometer is placed in the oil pipeline so as to register the temperature of the oil, which acts as a guide to the fireman.

It is also advisable in cold countries, apart from the heating of the oil in the storage tank, and in a special heater on its way from the storage tank to the burner, to have these oil-pipes steam jacketed between the control on the cab and the burners themselves, so that the oil reaches the burners at a temperature of at least 100° F.

In the early years of this century a French engineer introduced the subject of oil as an auxiliary, to which in the past little attention had been paid. The main advantages of auxiliary firing, he remarked, lay in being able to obtain at will a large increase in the power of boilers. The combustion of the petroleum does not in any way prejudicially affect that of coal; in fact, by the introduction of jets of petroleum, the condition and efficiency of combustion are improved by more completely mixing the gases. It is, therefore, not correct to consider the evaporative power of coal as identical, when passing from ordinary to auxiliary firing, as the coal end efficiency should be largely increased.

Admitting this as a principle, and supposing the quantity of water evaporated by the coal to be constant, the extra evaporation, due to the better mixing of gases, is credited to the petroleum.

Several evaporative trials were made with coal only and coal and oil firing on the same boiler of a French Navy ship. When burning coal alone at the rate of 18.8 lbs. of coal per square foot of grate area per hour, and when burning coal and oil in different proportions of oil at the rate of 21.3 and 21.7 lbs. of mixed fuel per square foot, the results were as follows :—

Test No.	Fuel used.		Lbs. of Fuel per sq. ft. of grate area.	Water Evaporated per lb. of Fuel used.	Remarks.
	Coal.	Oil.			
1	100%	—	18.8	9.05	—
2	55%	45%	21.3	11.34	25% evaporative increase over No. 1.
3	36%	64%	21.7	14.12	56% evaporative increase over No. 1.

These tests are encouraging and serve as a basis for further experiment, but the question was not developed until about six years ago, when power-station engineers started taking a keen interest in the subject.

The theory was that a poorer class of coal could be used in conjunction with oil fuel than could be burned satisfactorily under the boilers, due to the fact that the poor classes of coal tended to cake on the links of the chain grate stokers, thereby retarding the necessary quantity of air from being drawn through the bars to complete combustion.

The result was that the poor classes of coal were merely covered with a smouldering mass, which travelled slowly along the bars and was dumped into the ashpit as a partly consumed coal. This ash, on analysis, would probably have contained a very high percentage of combustible matter, thereby causing a very much higher quantity of coal to be burned per hour to maintain, say, rated evaporation.

When fuel oil is applied, the theory is that owing to the almost perfect combustion obtained thereby, the combustible gases rising from the coal-fuel beds were quickly ignited, causing the top of this mass to become much more incandescent, thereby tending to airify the bottom mass, which would then allow sufficient air to be drawn through to complete the combustion of the rest of the poor-class coal.

Sufficient interest was taken in this theory for a large London power station to give their sanction for tests to be carried out under one of their coal-fired Stirling water tube boilers. One burner was introduced into each side of the boiler, approximately 25% from the back of the grate, the burners being opposite one another. The fuel oil was stored in an overhead tank, capable of holding three or four days' supply. The oil then gravitated to the burners which were of the Kermode steam-jet type, operating with steam as an atomizing agent, at a pressure of about 25 lbs. per square inch.

The coal test was carried out on a nutty slack, having a calorific value of 10,400 B.Th.U., and a boiler efficiency of 69.25% was obtained. The temperature of the combustion chamber was 2,648° F., and uptake 660° F.

The final of a series of experimental mixed-burning tests was carried out on a nutty slack, having a calorific value of 10,300 B.Th.U'.s, and Mexican fuel oil having a calorific value of 18,750 B.Th.U.'s. A boiler efficiency of 74% was obtained, and the temperature of the combustion chamber was 2,850° F., and uptake 628° F. The proportion of oil to coal on a B.Th.U. basis was 8% and on a weight basis 4·96%.

It will be noted, therefore, that in addition to the previous claim of the pioneers of this system, a large increase in the boiler rating can be quickly attained, and also that rated evaporation was much more mobile with mixed firing than with coal firing.

In a Yorkshire factory in the wool-combing industry the Lancashire boilers were fitted with auxiliary oil-burning apparatus. The steam generated was used partly for driving the factory and partly for supplying boiling water for the wool-combing process.

Slide No. 22.—Auxiliary firing—hand-fired.

Slide No. 23.—Auxiliary firing—mechanical stokers.

When using coal only there was a period of 1½ hours in the morning and again in the afternoon, when the demand for steam for heating water was so great that the driving engine was starved of steam, and its output was reduced accordingly.

To overcome this difficulty, auxiliary oil burners were fitted, and when the extra load came on the burners were put in operation. A steady head of steam resulted, thus ensuring output to the full capacity of the plant.

Another method of using oil as an auxiliary is in ironworks, where metal is melted in a blast furnace and manufactured into pig-iron.

The rough ore is placed in the blast furnace. During the process of melting, certain gases are given off; these are collected, piped to the boiler house, and used as a heating agent. The boiler generates steam, the steam is piped to the blowing engine, the blowing engine generates air, which is passed through a heating chamber. This air finally reaches the blast furnace, and is intermingled with the gases of the coke to form a combustible product.

In some qualities of ore the calorific value of the gases given off is poor. Now when this happens, the steam pressure from the boiler will drop, owing to sufficient heat not being applied. In former days coal was then thrown on to the grate to assist in maintaining steam pressure. The furnace in a cold state, due to low calorific value of the gases, was not incandescent enough to produce gases from the coal to form combustion. Therefore, the steam pressure dropped, and the air pressure to the blast furnace dropped, consequently the output of the blast furnace dropped.

To fire the coal and raise up the steam pressure to the requisite amount would take 1 to 1½ hours, and due to this lost time it would take 7 to 9 hours at full steam pressure to bring back the blast furnace to its proper working condition.

Now, by the modern application of oil fuel in place of coal, if a bad batch of gas comes through, instantaneous combustion will take place as soon as the oil burners are turned on, and the steam will be maintained at one uniform pressure, the air pressure to the furnace being maintained and an output of so many tons per hour guaranteed.

Some few years ago this method of auxiliary oil firing was fitted to a blast furnace plant and results noted over a period of a month. The cost of oil as against coal was slightly less, and when using oil an increase of 8 to 9% of finished pig-iron resulted.

When fuel oil is delivered to customers' works by either barge or rail tank car, it is handled in various manners :—

Slide No. 24.—Tank barge for inland water transport.

Slide No. 25.—Rail tank cars.

Slide No. 26.—Motor wagon.

Firstly, fuel oil is pumped from barge or rail tank car to overhead storage tanks, usually of 30 tons capacity each, and preferably steam heated, to keep the viscosity of the oil as low as possible during the winter months. From these storage tanks oil gravitates through 2½ to 3-in. piping towards the burners attached to furnaces.

This system is called the "gravity system."

Secondly, fuel oil is gravitated from barge or rail tank car to underground storage tanks, of the dimensions aforementioned, i.e., much larger capacity than rail tank car. These tanks should again be steam heated. From this storage the oil is circulated around the works by means of a steam or electrically-driven pump, the terminal end of the pipeline returning to the storage tank, so that any oil not consumed by the furnaces is returned to the storage tank.

This system is called the "circulating system," and is preferable to the afore-mentioned "gravity system," as, due to the high viscosity of oil fuel in the winter months, it is preferable to have a pump pressure behind the oil instead of depending on the gravity pressure, i.e., with the pump you can obtain pressure of about 50 lbs. per square inch, whereas when depending on gravity the maximum will be about 8 lbs. per square inch.

Fuel oil is largely used as a heating agent for billet heating or drop stampings.

The furnace is usually of a rectangular shape, fitted with an air-jet type of burner at one end, and a counterblast at the other end, the handling doors being in the sides.

The air pressure is usually obtained from a fan giving a pressure up to 28" W.G.

Both the air and oil supply should be preheated by the exhaust gases on their way to the burner.

The oil consumption per 100 lbs. of metal heated for drop stamping is approximately 9 lbs.

Again, the nut-bolt makers are large users of fuel oil.

Slide No. 27.—Nut and bolt furnace.

The construction of the furnace is on similar lines to that of a billet-heating furnace, except that it is usual on a bolt-making furnace to work two sides, and in some cases four sides are worked. The rough bars for the bolts are cut to length cold, then the pins, as they are termed, are put each separately into a hole in a special brick let into the side of the furnace. Thus only the end to form the bolt-head is heated. The nuts are made from flat-bar material heated the full length that it will go into the furnace. The nuts are then stamped off hot.

The consumption on a nut-making furnace gives approximately 4 lbs. oil per 100 lbs. metal heated, and a bolt-making furnace 4·5 lbs. oil per 100 lbs. metal produced.

A test on a bolt-making furnace 9 in. by 12 in. by 20 in. in the Midlands gave 400 to 500 gross of $\frac{3}{4}$ in. to 1 in. diameter bolts per week, on a consumption of 300 gallons of oil.

The rivet-heating furnace is another type of furnace to which oil has been applied successfully. A large Clyde firm, on a three weeks' test, turned out 4 tons 8 cwt. of heated rivets on a 118-gallon consumption of oil, which gives 10·3 lbs. oil per 100 lbs. rivets heated.

The outstanding features in using oil on the above types of furnaces are the increased production, which is 100 % to 400 %, depending on class of work and conditions, also the great saving in floor space.

The metal-melting industry offers great scope for the use of fuel oil, and it is used extensively on brass, aluminium and cast-iron melting furnaces.

Slide No. 28.—Buess Metal Furnace.

Slide No. 29.—Monometer Metal Furnaces.

The brass and aluminium are usually melted in lift-out type of furnaces. These consist of a plumbago crucible set in a cylindrical furnace, in the case of a single furnace, and an air-jet burner is applied tangentially at the bottom so that the flame rises in a spiral round the pot. In the case of a battery of pots, the burners are placed at both ends of the battery.

For larger type brass-casting work a tilting furnace is employed. This consists of a pot holding 600 lbs. in a furnace, the whole mounted on trunnions, so that the pot can be tilted for pouring.

For still larger melts an open-hearth type of furnace is employed, holding about three tons of metal. The burner in this case plays across the top of the metal and the molten metal is removed by means of ladles.

Slide No. 30.—Tin ore smelting furnace.

The following results have been obtained on the above type of gun-metal melting :—

Tilting furnace : 10 lbs. oil per 100 lbs. metal (finished).

Open-hearth furnace : 10 lbs. oil per 100 lbs. metal (finished).

Lift-out furnace : 12·5 lbs. oil per 100 lbs. metal (finished).

The chief advantages in using oil are increased output, increased life of pots and decreased metal losses.

Cast-iron melting and steel making is usually carried out on a "Stock" convertor furnace. This consists of a large egg-shaped wrought-steel receptacle, brick-lined, and balanced horizontally on trunnions. The charge is half-ton to three tons of pig-iron. The oil is forced into the burner hot at a pressure of about 40 lbs. The air for atomization is pre-heated, and blown in at a pressure of $1\frac{1}{2}$ to 2 lbs. After the pig-iron has reached the necessary state of fluidity the oil is shut off and air alone at a pressure of 3 to 4 lbs. is blown through, which converts the pig-iron to steel.

On this class of furnace the oil consumption is 15 lbs. per 100 lbs. for melting only, and 40 lbs. per 100 lbs. for total fuel consumption, including lighting and heating up.

A large number of glass works use fuel oil for melting purposes. It is applied both to pots and tanks. The pot furnace from which white or flint glass is produced, consists of an earthenware pot in which the sand is placed to form glass. The heat is applied in a similar manner to that of a metal-melting furnace.

The tank type of furnace consists of a large open tank with an arched roof, of a capacity ranging from 2 to 200 tons. The mixture of sand and cullet, i.e., scrap broken bottles, is fed in through a charging door in the end or side of the tank, and the burner flames play across the top of the charge until it fuses. The molten glass is then drawn off from the tank at the opposite end to the burners, and is blown into bottles. Tanks are used for the manufacture of blue, black, amber and pale green glass.

The temperatures in the pot furnaces and tanks are approximately 2,750° F. and 2,400° F. respectively.

The consumption on tank furnace is 37 lbs. oil per 100 lbs. finished glass produced.

Another field in which fuel oil is used is steel melting. The following results were obtained by an Italian firm using fuel oil for heating open-hearth Siemens-Martin steel furnaces :—

The furnaces are basic of 65 tons capacity, four in all, 11 metres long by 5 metres broad by 3·4 metres high, at the centre of the arch. There are five charging doors, and each section is built on the separate arch principle. The furnaces are charged with molten pig-iron from a large mixer.

The temperature obtained is 1,650° C., and an output of 150 tons of steel for 24 hours per furnace on an oil consumption of 16·5 to 18·75 tons, which gives 11 to 12·5% fuel consumption. The air for atomization in this case was 4 kilos per square cm.

The above furnaces are some of the types of furnaces to which fuel oil is being applied. There are also many more classes of heat treatment of materials to which fuel oil is, and can be, applied at the present time.

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Royal Scottish Society of Arts

KEITH LECTURES, 1922

AVIATION

A COURSE OF FOUR LECTURES

DELIVERED BY

LIEUTENANT-COLONEL W. O. RAIKES
OF THE AIR MINISTRY

WITH A FOREWORD BY
MAJOR-GENERAL SIR F. H. SYKES,
G.B.E., K.C.B., C.M.G., M.P.

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FOREWORD

THE number of true believers in aviation, though growing steadily, is as yet small. Of these the vast majority are those who know its history—knowledge having proved a sure foundation for faith.

The spread of such knowledge brings nearer the world peace which is the most valuable incentive in pressing forward this war-developed art. From personal sympathies and mutual understanding throughout the world, made possible by the increased rapidity of intercommunication which aviation offers, will come peace between nations and the welding together of the British Empire as a unit in the maintenance of civilisation.

And, when air transport reaches this stage of development, these lectures will furnish a simple text-book from which rising generations will learn the conditions under which man first "flew wooden kites over oil engines!"

F. H. SYKES.

CONTENTS

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

The
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LIST OF ILLUSTRATIONS.

FIRST LECTURE.

SECOND LECTURE.

THIRD LECTURE.

FOURTH LECTURE.

ROYAL SCOTTISH SOCIETY OF ARTS
KEITH LECTURES, 1922

FOUR LECTURES ON
AVIATION

I.

LAMPADA TRADUNT

When first I realised that I was to have the honour of addressing the Royal Scottish Society of Arts upon the subject of Aviation on the notable occasion of the Centenary of its formation, I gave no little thought to the lines upon which I should draw up these papers.

You had already reached a mellow old age long before aviation had assumed any practical form, and I think—if I may say so with all reverence—we took it as a compliment that you, when celebrating the 100th Anniversary of your foundation, should have wished to hear something of this, one of the youngest of the sciences. I as one of the humblest of its apostles would ask you to bear with me while I endeavour to tell of some first attempts in aviation; the devotion of the early pioneers and the very considerable success which had been hardly won by 1914. Then came ordeal by battle. Progress in the forcing-house of war was almost uncannily rapid and was entirely concentrated on one object—the destruction of fellow-men. Then peace, and I shall try to show how, by making use of the lessons of war, we are gradually building up this new method of transport for peaceful ends. Finally, the future, when you and I will travel normally by air, as we do now by ship and rail, and if we can peer a short distance into the future without treading too closely on the skirts of imagination, perhaps we may see how much the air is going to mean to the Empire, to human intercourse, and thereby to the betterment of mankind, thus forging a link which may ultimately even prohibit war.

I have only scratched the surface of the subject and have tried to treat of it in the light of a new faith. I understand that the majority of my listeners are technical and they may therefore resent the historical method in which these pellets of information are presented. Of them I would crave indulgence. If there are some, however, who, like Oliver Twist, would ask for more, these papers will not have been entirely useless if they induce such to inquire where a further brew may be obtained.

Unlike the moon and Yum-yum, I am very shy, but before proceeding to read my paper there is one small protest I should like to make on your behalf. When considering these papers—and in true dilettante style I wrote the headlines first and built the papers round them—mainly because I was coming to an ancient seat of learning, but partly I confess to cover a multitude of shortcomings, I evolved Latin headlines; one even came from the Vulgate. Imagine my chagrin on hearing from your honoured Secretary that as your members are not on the whole classical scholars, he trusted that he might be pardoned if he circulated the English headlines only. Has Edinburgh then, in the whirl of modern progress, forgotten the Humanities?

It is but fitting that this series of lectures should begin with some account of the early struggles of those who, when the torch of flight was first kindled, passed it with undying faith from hand to hand, to whom also we owe the seeds of our present knowledge of those new regions which the science of aeronautics has thrown open to man.

In legend and chronicle accounts have been handed down of those who, in past centuries, in spite of failure and reverse, preserved their faith in the possibility of flight. Yet little is commonly known of the early struggles of British pioneers, and it is to them therefore that the majority of my words this evening will be devoted.

From earliest time and down through the ages man has envied, prayed and striven to emulate the effortless flight of the bird; the Psalmist sighed for wings, and tales of miraculous flight exist in the folk-lore of many races. The first account of a flight achieved by man has come down to us from mythical times. Therein we learn how Icarus, the son of Daedalus, smug with the knowledge that stone walls and even a labyrinth do not a prison make and intoxicated with the first rapture of flying, soared high above his anxious father, until the rays of the insulted sun melting the binding of his wings, plummet-wise he fell into the sea beneath.

In these latter days flight is too common for such first elation to endure, but those who, in the opening of the present epoch of mechanical flight, experienced for the first time that rush at dawn from the still-shadowed earth into the pure and sunlit air above, could dimly realise the feelings of Icarus, and desire, like him, to climb still farther into the blue.

Much later in the world's history we find the facile brain of Leonardo da Vinci tackling the problems of flight and pointing straight towards results that centuries later were achieved. More than 400 years ago John Damian, a royal physician in Scotland, endeavoured to fly from the castle walls of Stirling. He escaped indeed the fate of Icarus, but was locally considered to have justly deserved, for his impiety, the broken leg he sustained.

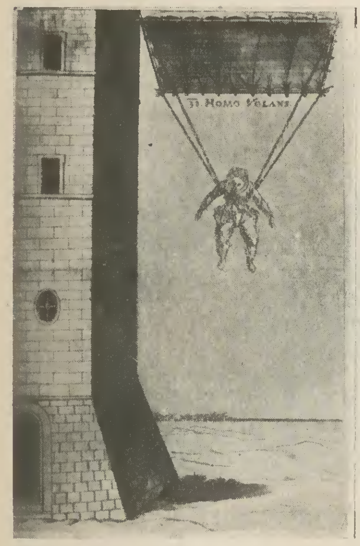
THE DAWN OF FLIGHT.

In 1767 Dr Black of Edinburgh University first suggested the use of a hydrogen balloon, and in 1783, the French leading the way with the brothers Montgolfier as constructors and Pilâtre de Rogier as pilot, the real start of ballooning may be said to have begun. Edinburgh again came to the fore with one of the earliest attempts at a human journey by balloon in these islands when, in 1784, James Tytler ascended in a fire balloon and travelled half a mile. The next year the Channel was crossed from Dover by M. Blanchard and Dr Jefferies, and ballooning had taken its place among our private sports and pastimes.

It was not till early last century, however, that the idea of the modern aeroplane took shape, when Sir George Cayley published a treatise forecasting much of what a hundred years later was found to be fact. Towards the end of the century Lilienthal, Langley, Pilcher, Hargraves and Ader were taking the first steps along the path leading to modern aeronautics, and the rapid development of motoring was bringing a practical aero-engine within sight. Hardly had the present century opened and the dream of flying become a reality, when the brothers Wright made the first flights in a controlled power-driven machine at Kitty Hawk, U.S.A., on 17th December 1903.

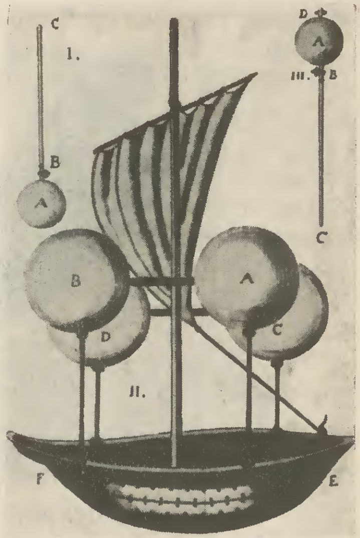
Meanwhile in Europe those who were tackling the same problem, spurred on by the news of the Wright successes and inspired as by a wind " that sets in with the autumn that blows from the region of stories," were making steady progress. But that the large majority had as yet no belief in the possibilities of flight is well illustrated by the extract quoted below from the Engineering Supplement of *The Times*, dated 24th January 1906. It is headed " New Attempts in Aviation."

> " Mr A. V. Roe sends us the following :
>
> " ' It may be news to some of your readers that flying with the heavier-than-air type of machine is now an accomplished fact—I allude to the Wright Brothers' $24\frac{3}{4}$ miles motor-driven aeroplane flight. Although great publicity does not seem to have been given to the fact, it is nevertheless one of the greatest achievements of the time. . . . The method of flying may be divided into two classes: namely, the lighter-than-air type and the heavier-than-air type. In the former we have the balloon, and some very



The earliest representation of the Parachute, designed by Verantio, an Italian, after a small drawing by Leonardo da Vinci (1595).

(*By courtesy of Mr J. E. Hodgson.*)

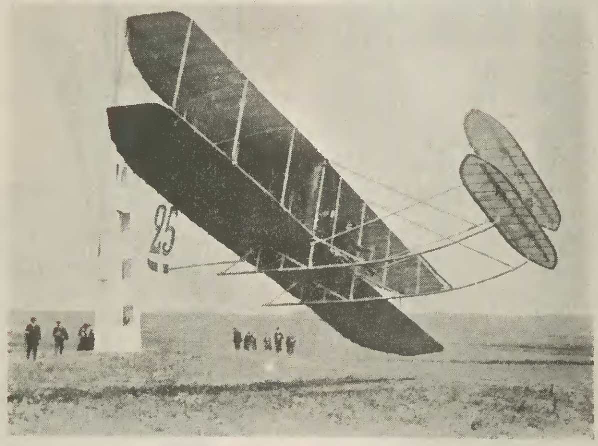


Lana's Flying Boat, 1670. The earliest "lighter-than-air" project.

(*By courtesy of Mr J. E. Hodgson.*)

First ascent of a Hydrogen Balloon—piloted by Charles and Robert. Descended at Nesle after a flight from Paris of about 25 miles (1/12/1783).

(*By courtesy of Mr J. E. Hodgson.*)



WRIGHT MACHINE IN FLIGHT.

AIRSHIP "ASTRA TORRES" LANDING AT FARNBOROUGH, 1913.

Owing to a mishap, the back of the airship was broken, but she was repaired and able to give important assistance during the early days of the Great War.

excellent results have been obtained with motor-driven cigar-shaped balloons, but those can never be really practical, as they offer such a large resistance to the wind. The future of the latter type when worked on the aeroplane system is enormous. . . .

" 'I now propose . . . to construct on the Wright system. If immediate steps are taken, I see no reason why a motor-driven aeroplane built in this country should not be gliding over England by the middle of the summer. I would be pleased to meet someone who will join me in the effort.' "

From the above it would appear that even Mr Roe's vision was limited as to airships, but on the whole question of mechanical flight the editorial comment of *The Times* is withering. Thus :

" Whilst giving that encouragement to new enterprise denoted by the admission of what is patently a free advertisement to our literary columns, it is not to be supposed that we in any way adopt the writer's estimate of his undertaking, being of the opinion, indeed, that all attempts at artificial aviation on the basis he describes are not only dangerous to human life, but foredoomed to failure from an engineering standpoint."

But mark " how the avenging power of fact wipes out the self-created delusions " of journalistic experts. Let us take *The Times* of 20th December 1921, fifteen years on. Here we find not just an editorial comment but a full-fledged leader headed " British Civil Aviation," wherein is deplored the lack of public support in this country for such a national necessity as aviation.

" The contrast," it states, referring to British and American efforts, " is the latest and one of the most striking examples of the alarming way in which we are being left behind in the international air race. . . . It is the public itself which is most to blame in the matter. Until the people of this country realise for themselves the vital truth that 'the strength of the British Empire depends upon good communications'—and by good communications is meant the development of air—and insist on their being established, there is no prospect of any real improvement."

Although the majority of the enthusiasts were at this period to be found in France, Ellehammer, a Danish engineer, was actually the first in Europe to make a free flight—in September 1906. By the time Wilbur Wright arrived in France in 1908 Farman and others were closely treading in his footsteps, and had learned enough to be able to profit, and advance more rapidly, by the experience of the original pioneers.

Bleriot, Delagrange, Santos-Dumont and many another name leapt into fame, as first one and then another made successful flights. From now on, aviation was no longer regarded as the dream of a lunatic, but as a new science which must eventually affect the whole of mankind.

In Britain the nation as a whole was not seized with enthusiasm for this new art. Yet an ever-growing band of pioneers was fighting the same battles as those in America and on the Continent, sometimes on lines of their own, sometimes by strictly following where others had led. Cody, Roe, Moore-Brabazon and Cockburn were amongst the foremost.

To Mr A. V. Roe, however, must be attributed the first flight in a machine of all-British construction, though this did not take place until three years later than the time he optimistically anticipated in his letter already quoted. Fitted with a 9 h.p. Jap engine, this paper-covered triplane was the progenitor of the large majority of war-type machines. Difficulties these pioneers experienced, not merely mechanical. The local authorities at Lea Marshes threatened to summons Mr Roe if he dared commit such a crime as to try to fly within their authority. However, the local policeman was a sportsman, and with his aid the first flight was successfully performed in the early hours of a summer morn. The precious machine was, however, a delicate and capricious subject, and generally after each "hop," as we should call the flights, some part caught fire and a hasty scurry to the River Lea ensued for the wherewithal to extinguish the flames.

A Band of Enthusiasts.

As it became clearer how much had yet to be learnt, early endeavour to secure secrecy disappeared. The necessity for large open spaces as aerodromes, and the natural gregariousness of man soon brought about the concentration of kindred spirits at two or three flying grounds.

Brooklands, Hendon, Eastchurch, Salisbury Plain were the places where the early history of British aviation was written. Enthusiasts of all types and kinds were here grouped into friendly bands with one sole object to which all their energies were directed. Friendly rivalry there was of the keenest over detail, but the advancement of flying was that for which they lived, and every step forward was acclaimed as heartily by rival as by assistant. Every hop, every flight, every failure was watched and studied in minutest detail by those who, struggling to enter this new domain, knew that only too often one mistake meant death, and who therefore spent all their waking moments studying the effects of their own and others' actions, and endeavouring to discover why such actions produced such results. In those days no one really knew how to fly and faults of material were inextricably intermingled with personal errors.

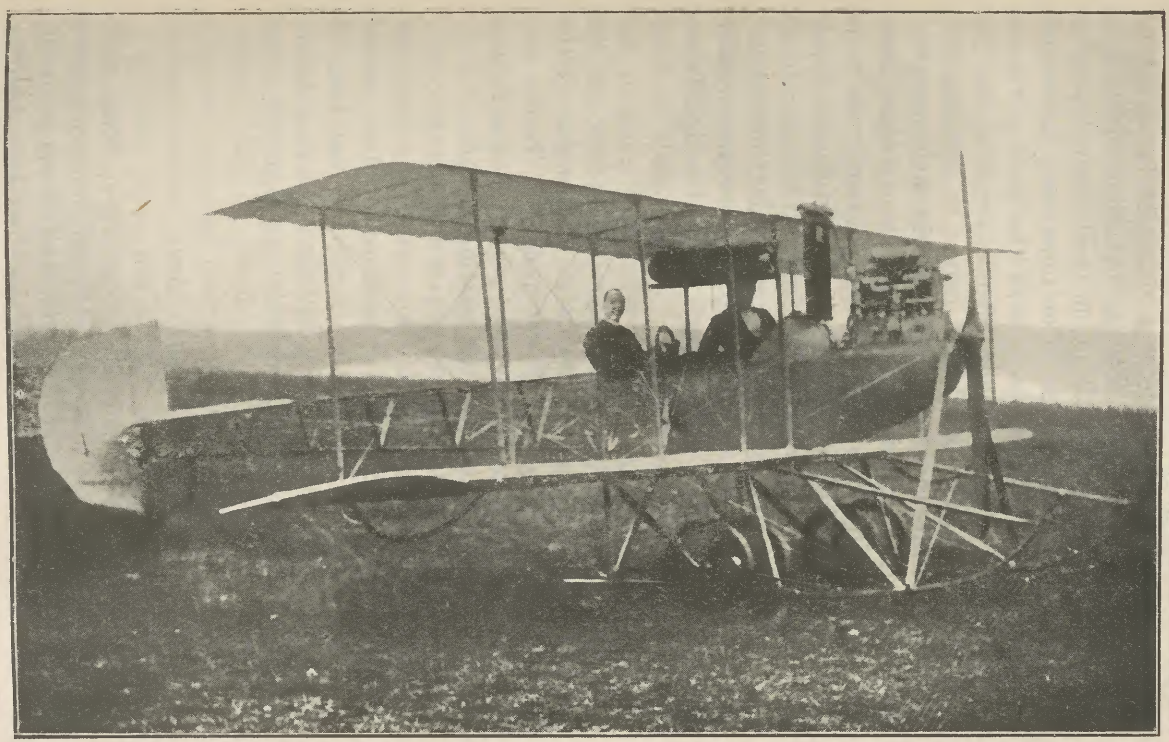
Theories how flying should be done naturally existed, and many of them were to show themselves correct, but how to apply the theory in practice, and how to ascertain whether failure was due to faulty theory or incorrect practice—those were the problems that these pioneers had to face. The necessities of life were cut to a minimum, comforts ignored—flying and flying only was the aim of their existence.

Up before dawn to seize the hours of calm—remember they had yet to master their machine before they conquered the wind—or possibly not to fly but to make an early start at building or repairing the machine on which their hopes were set. On they worked till dark put an end to their day. Hasty meals eaten off petrol tins—meals flavoured with lubricating oil, filings and shavings. No time to waste on washing; besides water was precious. For couch, a shakedown in the dusty shed, the village was too far off.

Day after day such was the programme, varied only by assistance lent to, or given by, friendly rivals in other sheds, and long arguments over guttering candles as the evenings grew darker. Perhaps its first time out some accident wrecked the machine and the whole work was to be begun over again; perhaps success was attained and after a few hops the glory of having flown a complete circuit provided just excuse for a celebration in the nearest town; perhaps some error added one more to the list of casualties, and the little coterie was broken up.

But the torch was handed on, though the last holder was no longer there to see its light.

The majority of the public, in England at least, in these early days, if they realised the fact of human flight at all, looked upon aeroplanes as sporting but dangerous toys. It was therefore with a sensible shock that the civilised world suddenly realised that the age of mechanical flight was not a figment of fanatical imagination, but was in fact arriving in their own lifetime. The cause of this shock was the crossing of the Channel by M. Bleriot on 25th July 1909. The previous gallant failure of M. Latham had merely confirmed the man-in-the-street in his opinion that aviation had no practical value. But this was a different matter, and its importance was evidenced by the world-wide publicity given to the feat. Leaving Les Baraques near Calais very early in the morning he landed at Northfall Meadows near Dover forty minutes later, having crossed the Channel at a



ORIGINAL AVRO BIPLANE WITH 35 H.P. GREEN ENGINE, 1911.

height of from 150-300 feet, and at an approximate speed of 45 m.p.h.

August of that year saw an Aviation Meeting at Rheims, when the general public had their first view of flying as it then was. The most notable feature of this meeting was the success of the 50 h.p. Gnome rotary engine. A really light engine, about $2\frac{1}{4}$ lbs. per horse-power, capable in skilled hands of running with regularity, it provided a firm basis on which the aeroplane designer could erect his plans. Its advent began a new chapter in flying history, enabling rapid progress to be made, first in piloting and then in experimental design, comparatively unhampered by engine failure. I say comparatively, for it still only meant that three or four hours total running could be obtained without taking the engine down for overhaul, but this was a big advance over the few minutes flights, or at most half an hour, hitherto the limit.

Cockburn, the only British representative at this meeting, was the first to fly with this engine. Other pilots to whom it was offered preferred, before they endangered their own, to see whether the Englishman would break his neck with this rotating monster.

The sensational feature of the last day was the contest for the altitude prize. Latham made the most impressive flight, and when he returned to *terra firma* it was found that his barograph registered 504 feet, the next best being Farman, with 358 feet. During the war 20,000 feet was a normal height for photographic reconnaissance.

Lighter than Air.

During this period progress was also being made on the side of lighter than air. The balloon as mentioned above came into existence in 1783, and efforts at making it both self-propelled and steerable had been made at spasmodic intervals. One of the most notable balloon ascents in England was that carried out by Messrs Glaisher and Coxwell from Wolverhampton on 5th September 1862. An estimated height of 7 miles was attained. At this height the barometer pressure was 7 inches and the temperature minus 11·9° F. Mr Glaisher became insensible before reaching this altitude—there was no oxygen on board—and Mr Coxwell's hands were frozen, so that he was only able to open the valve by tugging at the cord with his teeth.

Santos-Dumont in 1898 produced the first airship fitted with a petrol engine, and continued to experiment on these lines until 1907. The first Zeppelin was produced in 1900—a monster for those days of 11,300 cubic metres (approximately 400,000 cubic feet).

Zeppelin III made a flight from Lake Constance to Berlin in August 1909 and returned to her shed at Lake Constance after those in charge had experienced many difficulties and anxieties from engine troubles and propeller breakage. The troubles of the airship pioneers were similar to those met with in aeroplanes, but aggravated by the size of the ship and its far greater cost. The difficulties of handling these large but fragile vessels were very great and many of the earliest were wrecked through misadventure on the ground.

An awakening of public and official interest took place in Great Britain in 1909, at which time serious research work was begun under assistance from the Government.

Rolls, Grace, M'Clean and Ogilvie began to come to the fore as pilots, followed closely by such as Robert Loraine, Dickson, Radley, Sopwith and others. Indeed proof was afforded that even pigs can fly, when Moore-Brabazon carried a porker on a flight at Eastchurch.

In 1910 came the London-Manchester flight, which particularly caught the public fancy, as it provided a sporting contest between Paulhan and Graham White. Rolls was the first British aviator to cross the Channel, performing an out-and-home flight to Sangatte without landing on French soil. One of the best of British pilots at this time, he was killed later in the year through the breakage of part of his machine when competing at the Bournemouth meeting.

Cecil Grace, another of the best of our pilots, who had done much for the advancement of flying, was missing later in the year, having apparently become lost in the fog when returning to England from Calais.

Nature never fails to exact her toll from those ambitious humans who pry into her closely guarded secrets and endeavour to evade her restrictions. But it must be remembered that though individually that toll was heavy, the cause—nothing less than the conquest of the air—was worthy a great sacrifice. And always those left behind, nothing daunted by the fate of those who had gone before, kept on pressing up the steep incline and ever strove to draw a lesson from disaster.

Thus in the manner of his going Rolls warned us that unexpected stresses were encountered by a machine under certain conditions and that repairs must be executed with the greatest care. Grace pointed out that navigation was as essential in the air as on the sea.

Many another, whose name would now convey nothing, helped by his death to make it safe for us to learn to fly. An instance—a fine summer morning at Brooklands, calm and sunny, several pupils in various stages are hard at work. One is coming in towards the aerodrome on a monoplane at a good height. He switches off as he approaches. "Fool," says a watching instructor, "put your nose down, or put your engine on." But no, the pilot keeps the machine level fore and aft and losing speed suddenly side-slips almost vertically and nose-dives. His height is enough to allow him to recover control, and he does so, but he is now flustered, or has not learned by experience what is his error. He repeats it, this time much lower, and though he nearly regains control he crashes in a field.

Two lessons were rubbed into the pupils that day: the first, "Keep your head when you get into difficulties;" the second, "Use a suitable belt," for it was clear that with proper support to keep him to his seat no fatal results need have resulted from this accident.

There is, or used to be, at Brooklands a certain sewage farm, the bugbear of the pilot in embryo and possessing an unholy attraction for machines when in difficulties.

A pupil, feeling his wings strongly sprouting, invites a friend to accompany him as passenger. He starts off with his engine running badly, and should have landed at once, but with hopeful carelessness carries on. With insufficient power he tries to turn and slowly falling on the turn the engine splutters and dies and a muddy fountain rises from where the machine has settled—the wettest part of the sewage farm!

A few of the onlookers run towards the scene but stop on the edge and jeer as two muddy and odoriferous figures squelch their way out. "Serve you right for trying to carry on with a dud engine" is all the sympathy they get and being already dirty they are sent back to begin dismantling the wreck.

1910 saw the first London-Paris flight, by Moisant, and about the same time the first collision in the air took place at Milan, when Captain Dickson was seriously injured, an Antoinette monoplane, flying above him, coming down on top of his Farman machine.

In April 1911 the first non-stop flight from London to Paris was carried out, and during the year long-distance races took place—Paris-Madrid, Circuit of Europe and Circuit of Britain.

In the latter event two Frenchmen, "Beaumont" and Vedrines, had a close race for first place, and the only other two competitors to finish were two Englishmen, Valentine and Cody.

Careful experiments were meanwhile being carried on by Germany with airships of the Zeppelin type, but untoward accidents in England and France had somewhat discredited the dirigible in those countries where the attention of enthusiasts was being directed more and more towards the aeroplane. Two French airships had, however, crossed the Channel in 1910 and Willows in the tiny airship of his own construction had carried out some fine flights in England.

The real advance during this period in heavier-than-air craft was that made in actual piloting. With increased knowledge more skilled instructors produced better results. Graham White, Valentine, Hamel, Graham Gilmour, Morison, Pizey, Pixton and many others came to the fore. That unimpaired sight was desirable was amusingly demonstrated by one pilot who imagined his machine was just on the ground when it was still 25 feet up. In full view of the onlookers he proceeded to undo his belt and prepare to get out. His machine disapproved and after performing various, to him unexpected evolutions, disintegrated itself on the ground close to a group of his friends, and from the wreckage he emerged smiling, still with a monocle in the eye that had deceived him.

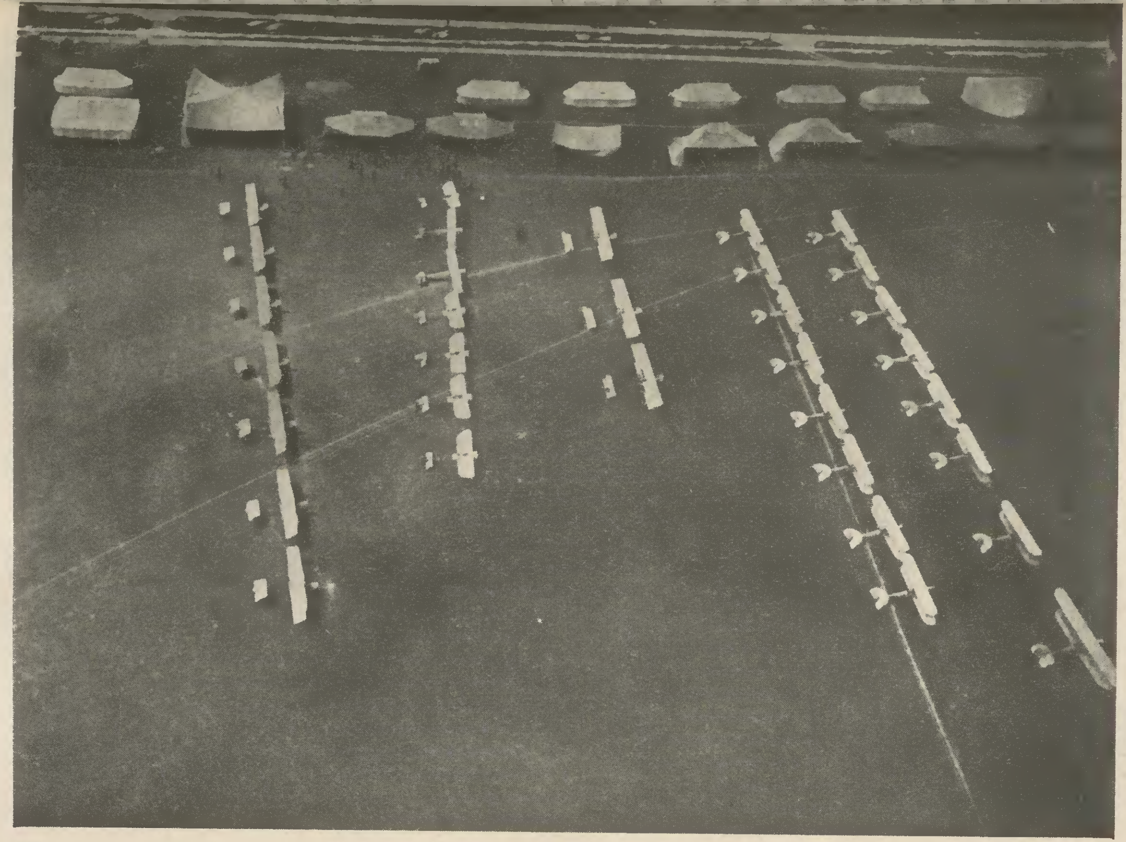
The first Avro biplane, of which the well-known present-day Avro is a direct descendant, after various vicissitudes was sold to Commander Swann, who fitted it with floats. It then became the first all-British twin float machine to leave the water.

First International Certificates.

In many countries the introduction of ballooning as a sport had led to the formation of Aero Clubs, and these clubs were associated internationally in the Federation Aeronautique Internationale.

When flying came into being these bodies naturally took a keen interest in the matter and the F.A.I. became the authority which laid down international rules for the sporting side of aviation. One of its earliest actions was to determine the proficiency to be attained by a pupil before he could be considered a fully fledged aviator and carry passengers or take part in flying contests.

The first rules of this nature came into force in England on 1st March 1910 under the ægis of the Royal Aero Club of the United Kingdom.



MILITARY WING, ROYAL FLYING CORPS, ON SALISBURY PLAIN, MAY 1914.

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The modern pupil would hardly consider these tests difficult, consisting as they did of three circular flights of 5 km. each, terminating in each case with a landing not more than 150 metres from a suitably selected point on the aerodrome. The first two certificates were issued to Moore-Brabazon and Rolls and by the end of the year forty-five had been issued by the Royal Aero Club.

These certificates contained, *inter alia*, a sentence in various languages, asking all public authorities to give assistance to the bearer, and that even now they are sometimes useful is shown by the experience of two British pilots who recently delivered machines to Morocco. Fully viséd passports were of no avail in obtaining permission to leave that country, but the little sentence in Spanish on their Aero Club certificates opened the official doors for them.

The French Aero Club started issuing similar certificates in 1909, and by the end of 1910 had issued 345, of which 19 were to British subjects.

As knowledge of flying increased it became desirable to make the test somewhat more severe, and that which came into force in England on 15th February 1911 included two flights of 5 km. each, performed in figures-of-eight round points not more than 160 metres apart and an altitude flight of at least 50 metres. Landings had to be effected within 50 metres of a selected point.

By this time the 50 h.p. Gnome engine was widely used, and in particular in those machines on which the majority of the tuition was carried out. The rotating mass of this engine made a certain difference in the manner of controlling the machine when turning, according as to whether the turn was to the right or to the left. Ingeniously misapplied imaginations had exaggerated this into a serious gyroscopic effect, and as the normal turns round an aerodrome were to the left, there was quite a belief in some quarters that the chance of still being alive after a turn to the right was small.

At one school this entirely erroneous idea was successfully eradicated when Graham Gilmour, visiting the aerodrome, heard pupils debating the point with bated breath and immediately went up and carried out sharp steeply banked turns in either direction over the sheds. From then on that fable became a joke.

STICK AND STRING.

What of aeronautics as a branch of engineering at this period of stick and string? Frankly, engines excepted, the engineering side did not really exist. Valuable laboratory research had been and was being carried out, more particularly by Eiffel in Paris, while Lanchester, Bryan and Bairstow were leading the advance in England. But real knowledge of the conditions and stresses to be met by an aircraft in flight were almost wholly lacking, and it was only ignorance of the possibility of manœuvres, that are now normally performed, that prevented pilots in those days stressing their weak machines far beyond their capacity.

The nature of the structure that they utilised is perhaps best shown by this extract from *The Engineer* of 21st February 1913.

> " In the air the easy, graceful motion of an aeroplane and its apparent superiority to the action of natural forces are our only impressions. But a leisurely examination of the machine at rest destroys the illusion. To the engineer, at any rate, the shoddiness of its structural parts is disquieting, to say the least of it. . . .
>
> " At present the aeroplane, engine excepted, is in general a thing of rubber, wood, piano-wire, glue and fabric. These are the materials, not of the engineer, but of the German toymaker."

Machines were built of parts which looked as if they might be right, rather than for some more solid reason. For instance: a pupil was once inspecting a machine which he was shortly to fly when the designer came in, and after a minute or two said: "I think there are too many wires in this machine; let us take out this and this and this." And it was so!

While there was also the celebrated thrush test, alleged to have been employed by a certain firm. I should explain that this test consisted in liberating a captured thrush from the pilot's seat of a new aeroplane. If the thrush could fly clear without touching a bracing wire the machine was deemed too weak!

MILITARY INTEREST.

Progress had now reached a point when the military authorities began to realise that a fourth arm was in the making. Something which might enable commanders to see the other side of the hill; which might ultimately replace cavalry; which in the first manœuvres on which it was employed effectively showed that methods of concealment hitherto in use were out of date and useless. As a result of this interest the Royal Flying Corps, consisting of a naval and a military wing, was formed in 1912. A young officer of cavalry, Captain (temporary Major) F. H. Sykes, was placed in command of the Military Wing.

Samson, Gerard, Longmore and Gregory were the earliest members of the Naval Wing, having been privately taught by M'Lean and Cockburn, while Burke, Brooke-Popham, Patrick Hamilton, Barrington-Kennett, Reynolds, Becke, Longcroft and others were early in evidence in the Military Wing.

Reynolds it was who, in 1911, succeeded in reaching the ground in safety, though upside down, having lost control in a thunder squall.

A competition for aircraft to comply with a military specification was held in 1912. A summary of the specification to be filled was as follows:—

Machines were to be two-seaters, capable of carrying a live load of 350 lbs., in addition to fuel, for 4½ hours.

Top speed was to be not less than 55 miles per hour, and climb to 1000 feet was to take not more than 5 minutes. The angle of glide was not to be steeper than 1 in 6.

Certain minor points were also included, and in addition some "desirable attributes" were outlined. Of these latter the most important were "efficient silencer" and "self-starter." The qualities asked for were in fact the attributes of a successful aeroplane, and only in a secondary sense "military requirements." While the main conditions quoted would be child's play to a designer nowadays, these two "desirable attributes" are still conspicuous by their absence, though at last a beginning has been made on their development (Table I.).

It was during the military competitions that what became widely known as "Parke's dive" occurred and gave rise to much discussion at every aerodrome and in the technical press. In the light of our present knowledge it is clear that when returning from a three hours' test flight the pilot stalled the machine—a totally enclosed Avro—and got into a spin.

Little Parke, however, was not one of those who lose their heads in a crisis and finding that the machine did not respond to what he assumed were the correct movements of the controls, he tried those he imagined to be incorrect and recovered control in time to avoid what the onlookers assumed to be a certain crash. On landing, he at once wrote out an account of what had occurred, thus providing the first full story of a non-fatal spin. But it was not only in regard to controls that knowledge was lacking in regard to strength required. Of four machines bought as a result of the trials—Cody and M. Farman biplanes, and Deperdussin and Bristol monoplanes—all except the Farman broke in the air shortly afterwards, and much investigation had to be carried out and many lives were lost as the price of the high degree of security from such failures now attained.

As the knowledge of piloting progressed, new manœuvres were tried, and by 1914 looping, side-slipping

TABLE I.

SUCCESSFUL MACHINES AT THE MILITARY COMPETITIONS, 1912.

Order of Merit.	Type.	Engine.	Speed at Ground Level. (m.h.p.).		Climb to 1000 ft. (mins.).	Weight (lbs.).		Weight (lbs.) per	
			High.	Low.		Gross.	Load.*	Sq. Ft.	H.P.
...	Specification . .	...	55 (min.)	...	5 (max.)				
1	Cody . . .	120 h.p. Austro-Daimler	72·4	48·5	3·5	2658	710	5·55	23·8
2	Deperdussin . .	100 h.p. Gnome	69·1	59·0	3·0	1854	670	6·1	23·4
3	Hanriot . .	100 h.p. Gnome	75·2	59·9	2·7	1866	701	6·4	24·0
	M. Farman . .	70 h.p. Renault	55·2	37·4	4·0	1919	601	2·9	26·8
...	B.E. 2 . . .	70 h.p. Renault	70·0	40·0	2·76	1700	620	4·55	23·5

* Load, as here given, includes fuel, crew and military load.

and so on were included in the necessary accomplishments of an exhibition pilot.

In May 1914 the whole military wing of the R.F.C. was concentrated on Salisbury Plain, and a parade of all the useful machines of that force was thus inspected by the foreign military attachés so shortly before the outbreak of the war.

FIRST STEPS IN ENGINEERING.

Development of aeronautics was meanwhile making rapid progress; but the aeronautical world was composed of a medley of inventors, amateurs and enthusiasts, with rarely, if ever, any real engineering training Design was a matter of first importance, but there were no professional designers. However, under the pressure of military requirements engineering principles began to be applied, theories were tried out in practice, and rule of thumb was reduced to formula.

For these first steps in aeronautical engineering credit is largely due to the Royal Aircraft Factory at Farnborough, through which aeronautical supplies for military purposes were obtained. Working in close conjunction with the Advisory Committee for Aeronautics established by the Government in 1909, and with the National Physical Laboratory, where a new department had been organised for the investigation of aeronautical problems, many full-scale tests were carried out.

A staff of competent engineers was gradually collected and the factory attacked the details of the problem. Private makers of aircraft, fearing the paralysing effect of official control and dreading a Government monopoly, were not too ready to co-operate, but the education they obtained in their dealings with the officials of the factory really laid the foundations upon which they later erected those designing establishments which produced such excellent work during the war.

So many unknowns existed that obviously ample opportunities for differences of opinion were provided. The design of undercarriages, for instance, even now in its infancy, was then almost entirely guesswork, and the factory method of test of a new design was the eminently practical one of taxi-ing the machine at a good speed over a selected bit of rough ground. In those days criticised as a cruel and unnecessary test, no modern machine would suffer ill effects on the ground selected. It cost one designer, however, four new undercarriages, which all failed at the same point, before he would be convinced that the official critics were right in their opinion that a certain fitting incorporated in his design was too weak.

A standard of strength, based upon the then knowledge of conditions in the air, was set up for military machines.

Strength to withstand six times the load in normal flight was the factor aimed at, and somewhat inaccurately this was termed a " factor of safety." As it was realised that it was quite possible to stress a machine in the air, so that these limits were exceeded, the term "load factor" would have been more appropriate.

Early in 1914 a B.E.2 machine which had been in use by the R.F.C. for some eight months was flown back to Farnborough from Montrose and tested to destruction under a sand load to determine whether the structure had suffered depreciation during use.

The breakage actually occurred with considerable suddenness when a load of about 8·4 times normal load had been applied. It was not possible for the witnesses to determine exactly which part first broke, but it appeared that the breakage of a wire threw an impulsive load on the wing structure and so made everything collapse together.

The " factor of safety " of the main spars, though not exactly determined, was shown to exceed 5·8 and 5·7 on the back and front spars respectively.

The official report of this test makes the following deduction as to the strength of the spars, expressed as aeroplane performance: "Instantaneous flattening out after a dive at 91 m.p.h. would not cause breakage, though no machine should be dived at such a speed."

That is rather a striking example of how, even in circles intimately associated with aircraft, eyes were blind to forthcoming developments in their use—more especially when it is considered that, within a few months, dives at much higher speeds were ordinary incidents of the war in the air.

The period of "stick and string" was, however, rapidly coming to its close, and by August 1914 the advance made towards the use of engineering practice in aeronautics was such that machines of factory design supplied to the R.F.C. were built by outside firms to definite drawings with specified limits and to detailed specifications for each part.

Thus on the outbreak of the war the ground had already been prepared upon which to erect that huge edifice of aircraft design and construction which was so soon to be in urgent demand.

Not unworthy are these pioneers of flight to rank high among the heroes of history. Many of their names are already forgotten, and it is difficult for us to picture the courage possessed and sometimes the agony of mind in strange conditions undergone by those first airmen.

Therefore:

"Let us now praise famous men,
Men of little showing
For their work continueth.
. . . . .
Broad and Deep continueth
Great beyond their knowing."

II.

BELLONA.

THE first of this series of lectures on aviation dealt mainly, you will remember, with the doings of enthusiastic pioneers, and showed how before the war the hobby of an enterprising few was, by the pressure of military requirements, being converted into one of the newest branches of engineering. This evening we shall see how a vast increase in practical use under war conditions, combined with well-directed research work, bred from the "stick and string" vehicle of the pioneers the well-fitted and elaborate aircraft which was in use when the armistice came.

A FRESH SERIES OF PROBLEMS.

On the date of the declaration of war between Great Britain and Germany, the British Air Service consisted of a Naval Wing, known as the Royal Naval Air Service; a Military Wing, known as the Royal Flying Corps; and a Central Flying School. The Naval Wing, which was controlled by the Admiralty, comprised an airship squadron, recently taken over from the Military Wing, and three aeroplane and seaplane squadrons with a total of 93 machines. The Military Wing, which was controlled by the War Office, comprised four aeroplane squadrons with a total of 179 machines. The two wings had a total combined personnel of 197 officers and 1647 other ranks.

In the same way as the "contemptible little army" grew into that mighty instrument which on every front and throughout the world showed that *Nemo me impune lacessit* still held true, so the flying services waxed in power exceedingly and at the time of the armistice comprised close on 200 service and 200 training squadrons, with a combined personnel of close on 300,000.

For the first two and a half years of the war this organisation remained constant, that is to say, the R.N.A.S. units worked in the main with the Navy and the R.F.C. units with the Army. But as the war reached more and more the "grip" period and every screw and split pin became of value, the authorities paid more earnest attention to mass production, and found that this division of effort was uneconomic and in many cases an actual hindrance. In February 1917 an attempt was made to remedy the defects by the formation of an Air Board, on which both Admiralty and War Office were represented, while aircraft supply was placed under, and what is more, tackled and successfully solved by the Aircraft Production Department of the Ministry of Munitions, under Sir William, now Lord Weir. The actual administration of the two services, however, still remained separate. Although improvement was attained under these new arrangements, there was still considerable duplication of effort, and it was finally decided to amalgamate the two services and place them under one central control. Accordingly, in January 1918, a Secretary of State for Air was appointed (Lord Rothermere). The Air Board was reconstituted as the Air Ministry and took over the administration of both the Naval and Military Air Services, which were amalgamated to form the Royal Air Force in April 1918.

These administrative details are somewhat dry, but it is well to get our forest laid out properly and its shape firmly fixed in our minds before we examine more closely into the trees.

Aircraft, as you already know, may be divided into two main classes: heavier and lighter than air. The specialised duties of heavier-than-air craft, whether over land or sea, may be subdivided into:—

(1) Fighting.
(2) Artillery co-operation.
(3) Reconnaissance, photographic work, etc.
(4) Bombing.

The one real duty of lighter-than-air craft, with the exception of kite balloons, which are fixed and used for artillery work, is reconnaissance. I am aware that this statement may be disputed by you who are wont to associate the Zeppelins with much broken glass, often an ugly death, and a terror that used to stalk by night. But the fact remains that the original task for which the airship was designed was long-distance reconnaissance. The side-line of frightfulness, into which the airship was pushed, against the advice of those who knew best her capacity, was incidental, and when properly countered broke down.

These specialised duties, both of heavier and lighter-than-air craft, were the logical outcome of war. In the early days, however, all the duties which ultimately called for the specialised machines were heaped upon the shoulders of one devoted pilot. He was reconnaissance, fighter and artillery spotter all in one.

When on 13th August 1914, four squadrons of the Military Wing, Royal Flying Corps—56 machines in all—flew across the Channel from Dover, there were none who knew, there were only a few who guessed, what enormous developments would take place in the air before the end of the war, and how very soon no big gun would be fired without registration by air and no commander would move unless aerial eyes were up in front of him.

Immediately on arrival in France the R.F.C. were in the thick of it. For a short time they were based on Maubeuge, and it was largely due to the report brought in by one of the British machines, showing that Von Kluck was moving diagonally across the British front, that enabled the allied advance to the Aisne to be successfully undertaken.

FIRST FIGHTS.

Very early in the war fighting in the air began and it was soon found that the pilot could obtain the most accurate shooting by the use of a fixed gun laid by manœuvring his machine. Soon the less efficient pusher type of fighting aircraft disappeared and all machines were fitted with machine-guns firing through the propeller arc. To attain this result with safety, some form of synchronising mechanism was necessary, otherwise the propeller would rapidly be shot away. Such things did happen when the gear supplied was not properly adjusted as, for instance, in the case of a B.E.12 near Dover.

The pilot in question had not seen his gear properly adjusted on the ground and took the machine out over the sea to test his gun. Very shortly after pressing the trigger one blade of the propeller departed, cut off by the stream of bullets. The unbalanced fly-wheel effect of the remaining three blades ripped the engine clean out of the machine which, with its centre of gravity shifted far aft, fluttered down tail first to the sea, from which the bewildered pilot was rescued by a launch.

In its earliest design the necessary gear took the form of a wedge-shaped piece of steel attached to the propeller blades, thereby deflecting bullets off the blade.

Difficult and expensive to make, this device was not satisfactory, as the deflected bullets took at times unwonted paths dangerous to the pilot. The next step was the design of a system of cams and interconnecting links operated, either off the engine, or off an attachment to the propeller, which prevented the gun from firing when the shot would strike the propeller. Complete re-designing was necessary for any new type of machine or combination of machine and engine, while frequent adjustment was necessary, and wear at joints rendered stray shots in the propeller by no means unknown. These difficulties were eventually overcome on British aircraft by utilising one of the most interesting recent developments—the Constantinesco wave-transmission gear.

A cam, on the back of the propeller, operated a generator which transmitted a high frequency wave in oil along a length of copper pipe—led in whatever was the most convenient way — to a trigger motor on the gun. This actually fired the gun instead of preventing it from firing. Further development of this device, with slight alteration to the gun, permitted the rate of fire to be increased from the normal maximum of 600 rounds per minute to 1000 per minute, and thus increased the pilot's chances of getting in a hit during the very brief instant that his opponent was in a favourable position for a shot. With a few standard fittings this gear could readily be adapted to any machine, and once its little peculiarities were known in the squadrons, it proved entirely successful.

Among the earliest combats in the air was one at Dunkirk, when Captain Holt, in a single seater machine, armed only with a rifle tied to a strut, and this firing at 45° to the line of flight, attacked, bald-headed, a group of ten enemy bombing machines.

So disconcerted was the enemy by this bold single-handed attack, that the sight of further English machines approaching caused them to drop their bombs in the fields instead of on the town, and to return hurriedly to their own lines. At Boesinghe, too, a few days before the first gas attack was launched by the Germans over this area in April 1915, the pilot of an enemy machine was shot, with a rifle, by the observer in an Avro. The enemy machine crashed just in front of the French lines at this point, its observer being taken prisoner uninjured.

The first machines to reach the front fitted for fighting, though not originally designed for this purpose, were four M. Farman, carrying stripped Lewis guns. Lack of speed made these machines of little use in chasing the enemy, and on one occasion, at least, one of these devoted arm-chairs returned to its aerodrome held together more by faith than works, having been practically stationary over a hostile battery against a head-wind while trying to shoot down a hurriedly-retreating and faster foe.

One of the earliest machines designed specifically for fighting, was the F.E.2., a two-seater machine with the propeller behind. Normally it was fitted with a 120 h.p. or 160 h.p. Beardmore engine, and its chief defect was its large "blind spot" to the rear. The enemy soon discovered this defect and took full advantage of it. But one squadron of this type—the machines of which had a better performance, having 250 h.p. Rolls Royce engines —successfully utilised the enemy's knowledge of this weakness to inflict upon him many severe blows.

Over the lines the patrol would go, while the enemy scouts gathered joyfully above as vultures scenting a kill. In numbers sufficient to instil themselves with confidence, down swooped the enemy, but by the time they were within range, the patrolling machines were formed in a circle, each closely following the one in front —there were no "blind spots," and no matter from which direction they attacked, the enemy were met by a hail of bullets. Beaten off with heavy loss the enemy retired in discomfiture and the patrol returned cheerfully to breakfast. Remember, however, that in nearly every case a westerly wind was blowing the circling patrol still further into the enemy's territory, and you will realise what careful judgment was required on the part of the leader of the patrol to induce the enemy to attack in good time, so that when the fight was over sufficient fuel would still be in hand to enable his machines to get home.

Although fighting in the air began thus early, it did not reach serious proportions until the middle of 1915, and from then on until the end of the war it steadily increased in intensity. Records of results achieved are not available before July 1916, but Table II. shows you, in tabloid form, a summary of the work done after that date. Perhaps the two most striking figures are enemy aircraft accounted for, **7908**, and bombs dropped, **7945** tons, while incidentally to attain these objects over 1,000,000 hours—or over 100 years—were flown.

SIGHTS.

Both the bringing down of machines and the accurate dropping of bombs entailed the use of sights and proved two of the most difficult problems with which the flying services were faced. Obviously if one machine was approaching an enemy, both moving at high speed—towards the end of the war, pilots used to dive at something like 200 miles per hour—there was not much time to draw a bead on the opponent. Rocketing pheasants or woodcock side-slipping between trees are, in comparison, easy targets.

All kinds of ingenious suggestions were made and experiments tried to give the necessary allowance, and at the same time to provide something not too complicated for the use of the ordinary pilot. There was not much time, as a rule, you see, for him to make calculations. In the end the simplest form of sight was found to be the best. The two forms in use at the end of the war were the Ring sight and the Aldis sight.

The Ring sight is so designed that if fixed at the correct distance from the gunner's eye and aimed at an enemy aeroplane crossing at right angles—whether on the same plane or climbing or diving—and if the trigger is pressed as the target cuts the ring, a hit should result.

The Aldis sight is a telescopic sight with an arrangement of lenses which neither magnifies nor diminishes and includes a similar arrangement of rings. In effect it is the same as the Ring sight, with the added advantage that distance from the gunner's eye is immaterial.

For instruction in gunnery the Hythe camera gun was developed by which the pupil photographs his target in the actual position it occupies when he presses the trigger.

In bombing it was still more difficult to aim accurately, the speed of the machine, its height above the ground, and the strength and direction of the wind all affecting the aim. Many forms of elaborate bomb sights were designed, but eventually their use was confined to night work, when a trained observer could usefully employ them comparatively unhampered by enemy action. In day bombing much good work was accomplished by the individual judgment of pilots flying very low, but the normal raids

TABLE II.

RESULTS OF OPERATIONS IN THE AIR.

	July 1916 to 11th November 1918.	1st January 1918 to 11th November 1918.									
	Western Front.	Independent Force.	Home Forces.	5th Group and Naval Units.	Italy.	Egypt.	Mesopotamia.	Salonika.	Palestine.	30th Nov. India (Aden).	Total.
Enemy aircraft accounted for, *i.e.* brought down or driven down	6,904	150	8	470	405	25	6	59	81	...	7,908
Our machines missing.	2,484	111	...	114	44	9	13	8	24	...	2,810
Bombs dropped (tons).	6,402	540	...	662	59	43	25	130	74	30	7,945
Hours flown. . .	889,526	11,784	...	39,102	25,206	7,022	7,862	13,417	21,848	579	1,016,346
Rounds fired at ground targets . . .	10,238,182	353,257	...	...	222,704	50,937	107,563	193,354	735,550	7,527	11,858,137
Photographs taken .	401,375	3,682	...	3,440	14,596	8,135	66,720	15,587	27,039	542	501,116
Enemy balloons brought down . .	258	...	...	...	...	...	...	...	...	...	258

NOTE.—Records are not available of results obtained by Expeditionary Force, Western Front, prior to July 1916, or by 5th Group and Naval Units, or in Eastern Theatres prior to January 1918. The absence of these records, however, will not materially affect the totals shown as regards enemy aircraft accounted for, our machines missing, or the weight of bombs dropped, owing to the comparatively recent growth in intensity of aerial fighting and the smaller number of aircraft engaged.

were carried out on the artillery principle of "plastering" the target.

The whole formation of machines dropped the bombs simultaneously on a signal from their leader. The leader had a very simple form of sight to assist him in flying directly towards the target and gave the signal at an instant selected on his own judgment. A camera carried on the leader's machine and another on the rear machine showed by their photographs the actual positions of the bursts, and enabled the leader to allow for any error and improve his results in future raids.

THE FORCING HOUSE OF WAR.

What of the machines to carry these guns and bombs and sights? Demand always outstripped supply, and always the cry from the front was for better performance —*i.e.* climb and speed and weight-carrying capacity—better field of view, better offensive armament, better manœuvrability. Design and construction were continuously speeded up and research into aeronautical problems was pushed on as rapidly as possible. Demands from the front, however, could seldom await the slowly learned facts of the patient workers in laboratories, but had frequently to be met by forcibly overcoming difficulties in an empirical manner.

Thus when the Martinsyde "Elephant," a single seater bombing machine, first came into use, a series of accidents took place, in which the fuselage broke just in front of the tail plane.

Investigation showed that there was no real knowledge as to the forces that might be applied to the tail plane in flight. The difficulty was satisfactorily though crudely overcome in this instance by taking a new machine of the same type and loading its tail plane till the fuselage broke. Other similar machines were then strengthened, so that the fuselage would stand a 50 per cent. greater load on the tail, and no further accidents occurred.

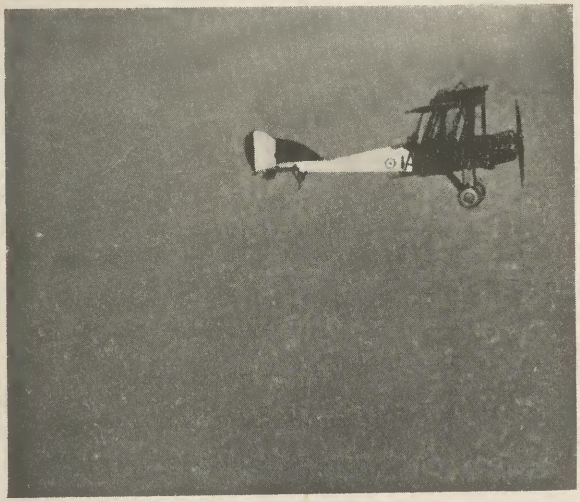
Even in the use of materials heart-breaking problems were continually encountered.

Two or three squadrons of one type—the F.E.8—were in the field fighting hard and the task of keeping them up to strength was sufficiently arduous, when suddenly one evening a telephone message was received from France to the effect that immediate replacement was required of all the rudders of the effective machines. The cause, entirely unexpected, was this. The rudders of these machines were made of a duralumin framework covered with fabric. One rudder was found to be broken and on inspection it was discovered that for some reason which even now is, I believe, obscure, but may possibly have been due to some error in manufacture of the material, the copper and aluminium, of which duralumin is an alloy, had set up an internecine strife between their particles. Under influence of the infinite number of electric cells thus set in operation, the material itself was rapidly disappearing.

Inquiries showed that similar machines at home were similarly affected, though the first and oldest of the type showed least symptoms of the trouble. You can well imagine for yourselves the day and night rush to re-design the parts for different materials, and to hasten the supply of rudders of wood, and later of steel, to the units at the front.

Errors in workmanship, too, provided their unanticipated problems.

Several squadrons of that well-known fighting machine, the Bristol Fighter, had been in successful operation for many months, when suddenly a series of accidents took place, in which it was clear that the planes had collapsed in the air. Action was immediately taken to strengthen the compression members in similar planes, but the trouble only disappeared when it was traced down to overtightening of the tension members. In one shop the initial tension in these tie rods had gradually been increased so that the compression ribs before flight were actually in



B.E.2c IN FLIGHT.

AN "INVERTED" CAMEL AT TURNHOUSE.

a few cases under more than their normal calculated load in flight. With a spell of cold weather still further increasing the tension in the steel tie rods, there was every chance that the overtaxed plane would fail, and so it happened, until the root of the trouble had been discovered.

The Royal Aircraft Factory at Farnborough was now no longer relied upon as the main source of design. Specifications were issued for single seater and two-seater fighters, artillery reconnaissance machines and day-bombers or long-distance photographic machines, and these requirements were met by various designers.

As the use of aircraft in the war expanded and as the wastage from fighting in the air grew heavier, the demands on the factories at home increased far beyond the capabilities of the constructors. Ever more firms were pressed into the business until even those who could only be termed engineering firms by a distinct stretching of that term were hard worked. It was, I believe, Sir Percy Girouard who in a moment of post-prandial hilarity termed such firms our "greengrocers." Where a regular aircraft constructor was set to work on a machine not of his own design he always endeavoured to get alterations adopted, possibly mere alternative methods of attaining the same result, possibly an improvement or frequently the reverse. In any case such were anathema from the military point of view, where standardisation was of the utmost importance, if squadrons equipped with one type of machine, made by various firms, were to be efficient. The "greengrocers," however, had no such notions; their sole idea was to turn out their work to the letter of the drawings and specifications, and the results they achieved bore comparison with those of the best engineering shops (Table III.).

THE PRICE OF KNOWLEDGE.

Continued increase of knowledge as to the stresses met with by aircraft in flight, enabled the individual parts to be designed of a reasonable strength. Failures, however,

Table III.

OUTPUT OF MACHINES AND ENGINES.

	August 1914 to May 1915 (10 months).		June 1915 to February 1917 (21 months.)		March 1917 to December 1917 (10 months).		January 1918 to October 1918 (10 months).	
	Machines.	Engines.	Machines.	Engines.	Machines.	Engines.	Machines.	Engines.
R.F.C. . . .	530	141	7137	8917	12,275	...	...	...
R.N.A.S. . .	No record	No record	No record	No record	1,246	...	...	...
R.A.F. . . .	...	...	...	...	...	...	26,685	29,561
Total . .	530	141	7137	8917	13,521	13,979	26,685	29,561

did occur where desire rather than knowledge had fathered the design or where faulty parts had escaped the eye of the inspection staff.

A D.H.4 flying above the clouds at Hounslow came down in bits scattered over the surrounding fields. A machine returning in formation from a bomb raid suddenly broke up when well over our side of the lines. It was not until the first D.H.9A was under test at Martlesham that the probable cause of such accidents was discovered.

Similar in most details to the D.H.4, this machine carried a heavier load, and when being watched by skilled observers suddenly broke up as the pilot was about to land.

There could be no doubt in this case that the accident was due to the breakage of the tail plane under down load.

Research on tail planes had by this time made considerable advance and a further short investigation on models in the wind channel proved that some of the assumptions hitherto made in tail design were erroneous.

Different stresses from those previously anticipated were to be expected and the margin of safety on the D.H.4 tail was very small, while that on the D.H.9A tail only existed at all if the material and workmanship were well above the average. Strengthening of the existing tails and re-design of those for new machines was carried out with the utmost rapidity and the accidents ceased.

Much of our progress was bought with valuable lives, and the price of knowledge was heavy. One of those whose loss was a serious blow was E. T. Busk. Graduating at Cambridge under Professor Bertram Hopkinson, who also was killed during the war while piloting himself, he was one of the band of hard-working engineers collected at the factory. He devoted himself mainly to testing out in practical flight the theories of stability enunciated by others, and to him we owe much of our present knowledge of the subject. On one such flight his machine from some unascertainable cause took fire, and crashed to the earth.

In this respect, however, British aircraft were far superior to those in use by our foes. Whether their theory was at fault, or whether they deliberately went much further in the direction of sacrificing safety to performance, I cannot say, but from the time that our pilots were first required to send in reports on their fighting, the same remarks continually recur: "The enemy machine broke in the air," or "Its wings came away," while similar failures of our machines under the stress of fighting were very rare.

. The war had forced on the development of aeronautics both in theory and practice, though from the very nature of the urgent demand for concrete results, theory tended to lag behind performance and hit-and-miss experiments to forge ahead of solid research. The state of our knowledge at the end of 1918 can perhaps best be realised, by those technically interested, from a study of Bairstow's *Applied Aero-Dynamics*; Pippard's *Aeroplane Structure*; and Watt's *Design of Screw Propellers.*

The problem of lateral stability had hardly been tackled though little remained to be learned in regard to the more urgent question of longitudinal stability, while the performance of a machine, the design of which had been worked out on paper, could be predicted with considerable accuracy.

ADVANCE IN ENGINEERING.

Early in the war the urgent demand for increased performance and therefore for reduction in structure weight had caused the load factor of 6, previously adopted, to be reduced to 4. This factor may seem low, but in actual practice it was found to be adequate where the best materials and workmanship were employed.

Improvement in engines, however, permitted the load factor to be raised gradually without unduly impairing performance, and in 1918 the factors employed for new types were as much as 8 on the front and 6 on the back spar for fighting machines, though the highest factor on machines actually in use at the front was in no case more than 6 (Table IV.).

The engine development that had taken place in this period is of considerable interest. All of our machines which went to France at the beginning of the war were fitted with French engines. At the end of the war the majority of our machines had engines of British design and construction, though a certain number of French-built engines were in use and a number of British-built engines of French design, while one American engine was also employed (Table V.).

Such use of foreign engines was, however, due to the output of engines in Great Britain being insufficient to meet the demand and not because suitable engines of British design and construction did not exist.

Indeed progress in this respect had been so marked that France has now returned the compliment and is endeavouring to arrange for the construction in that country of one of the latest engines of British design—the Napier "Lion."

The great attention given to detail in the construction of aero-engines and the continually increasing knowledge on the part of mechanics looking after them in service had also improved reliability.

In the aircraft themselves also the most careful attention to detail was necessary if structure weight was to be reduced to a minimum for the strength laid down, and the maximum performance obtained with a given engine.

The cutting down of weight both in aircraft and engines implied highly stressed parts and left little margin for variations in material. It was in this way that aeronautics was forced by the pressure of its needs to stir the quiet waters of the older branches of engineering and eventually to leave its mark in the form of a great expansion of knowledge of the materials employed.

There was nothing actually new about the materials employed in aircraft construction, but the outstanding

TABLE IV.

DEVELOPMENT OF SPECIALISED MILITARY AIRCRAFT IN SIX YEARS—FROM 1912.

Type.	Engine.	Speed m.p.h. at		Climb (mins.)		Height.*		Loading.	
		10,000	15,000	10,000	15,000	Gross.	Load.	Sq. Ft.	H.P.
Military Competitions, 1912.	Specification.	55 at ground level.		1000 in 5 mins.		Say 1800.	Say 650.	Say 6·0.	Say 24·0.
Training.									
Avro 504 K	110 Le Rhone	80	...	23·6	...	1853	558	5·65	14·5
Fighters.									
Martinsyde F. 4	300 H.S.	142·5	136·5	6·7	11·8	2,289	579	6·95	7·5
S.E. 5	200 Viper H.S.	...	120·0	10·8	20·8	1,988	520	8·00	9·8
Sopwith Snipe	200 B.R. 2	118·0	112·5	8·8	17·8	1,950	710	7·2	8·55
Bristol Fighter	275 Rolls	113·0	105·0	11·8	23·8	2,848	845	7·00	10·4
Reconnaissance and Day Bombing.									
D.H. 4	360 Rolls	130·0	124·0	11·3	20·9	3,576	1067	8·2	9·9
D.H. 9	240 Siddeley Puma	110·0	101·0	18·9	38·8	3,316	1115	7·6	13·8
D.H. 9A	400 Liberty	120·0	114·0	11·8	22·8	4,220	1450	8·55	10·65

Reconnaissance and Day Bombing.									
D.H. 4	360 Rolls	130·0	124·0	11·3	20·9	3,576	1067	8·2	9·9
D.H. 9	240 Siddeley Puma	110·0	101·0	18·9	38·8	3,316	1115	7·6	13·8
Ship Aeroplanes.									
Sopwith Camel	150 B.R. 1	119·0	113·0	11·5	25·0	1,530	494	6·7	10·2
Parnall Panther	230 B.R. 2	103·0	...	17·1	...	2,595	1267	8·0	11·4
Night Bombing.		M.p.h. at 6500		Climb (mins.) 6500					
H.P.O./400	2/360 Rolls	84·5		27·2		13,360	4858	8·1	18·6
Vickers Vimy	2/ do.	95·0		33·0		12,500	5399	9·4	17·4
H.P.V./1500	4/ do.	95·(8750)		18·5		24,700	8490	8·55	17·2
Torpedo Aeroplanes.		Knots at 6500							
Sopwith Torpedo	200 Arab	89·		15·7		3,883	1684	6·85	18·75
Blackburn Blackbird	360 Rolls	78·5		16·2		5,700	2472	8·35	16·5
Seaplanes.									
Hamble Baby	110 Clerget	78·0		25·0		1,946	560	7·6	17·1
Short 184	260 Sunbeam	73·0		33·8		5,363	1660	7·9	20·8
Fairey 3 C	360 Rolls	96·0 (2000)		9·5		4,800	1408	10·08	13·5
Flying Boats.									
F 2 A	2/360 Rolls	80		16·5		11,084	3362	9·75	16·1
F 5		86		16·1		12,268	4245	8·7	17·8

* Load, as here given, includes fuel, crew and military load.

TABLE V.

DEVELOPMENT OF BRITISH AERO-ENGINES, 1914-1918.

	1914. Test Figures, War Office Trials, 1914. Engines used during the War, British Construction, but Foreign Design.			**1918.** Examples of Results obtained in Production Engines. All of British Design and Construction.					
Name	**Anzani.**	**Beardmore Austro-Daimler.**	**Gnome Mono-Soupape.**	**Siddeley Puma.**	**Rolls Royce Eagle.**	**Napier Lion.**	**R. A. F. 4D.**	**B.R. 2.**	**Cosmos Jupiter.**
Type	Radial	Vertical	Rotary	Vertical	Vee	Arrow	Vee	Rotary	Radial
Cooling System	Air	Water	Air	Water	Water	Water	Air	Air	Air
Number of Cylinders	10	6	9	6	12	12	12	9	9
B H.P	100·2	129	104·2	240	350	450	196	238	400
M.E.P. (lbs. sq. in.)	72·5	94·3	96·0	118·1	124	122	107	95·3	109·5
R.P.M.	1100	1275	1200	1400	1800	2000	1800	1300	1650
Weight per B.H.P. (lbs.)*	4·64	4·52	2·64	3·25	3.3	2·52	3·42	2·1	1·75

* Inclusive of cooling system.

fact in the earlier days of the war was the lack of any certainty that two batches of the same material from the same manufacturers would be really similar, while if the unfortunate designer was correctly to anticipate the finished part, he must know that his specification would be properly filled.

Thus in regard to timber, new specifications and new tests were evolved and methods of building up laminated members, of splicing, jointing and machining were devised, all on lines that may with advantage be applied to any commercial practice where strength without excessive weight is required.

The manufacture of glue, previously based largely on tradition, was developed upon a scientific and reliable basis.

In metals the whole process of production was affected, both as regards steel and the light alloys.

I do not wish to imply that new practices were forced upon the unwilling manufacturer. True, in some cases faulty tradition and old-established prejudice were hard to break down, but each industry as a whole welcomed the fresh air of the new demands, co-operated to the utmost in studying the new facts brought out and endeavoured to raise their products to the highest standard. But for the demands of aeronautics, and the large scale of these demands due to the war, these new steps on the path of knowledge would hardly have been gained.

Thus alloy steels were very fully developed and that of 60/70 tons ultimate stress, giving 40/50 ft. lbs. on impact, became the backbone of engine construction. High chromium and tungsten steels were necessary for the exhaust valves of engines working at the high pressures and temperatures of aero-engines, and these materials were eventually established in commercial production. Special plant for heat treatment, and knowledge on the part of the operators, were both extensively developed. A new light was thrown upon the art of forging, special steels and special shapes, hitherto regarded as impossible to forge, were tackled and produced on a commercial basis.

LIGHT ALLOYS.*

Previous to the war aluminium alloys were in use for engine crank cases and other castings which were lightly stressed, but the main feature that characterised the alloys of that date was unreliability, due to ignorance of the numerous factors which affected the qualities of the finished product. Aluminium pistons, highly desirable for internal-combustion engines, owing to their greater heat-conducting power as compared with cast-iron, had been tried experimentally and rejected as hopelessly unsatisfactory. A considerable range of investigations into this subject had been begun by the Alloys Research Committee, but the results were not yet available.

War conditions gave a great expansion of the resources available for research, and production was on such a scale as to repay the time and trouble necessary for the elimination of the difficulties met with in dealing with these materials in the workshops.

As a result we have :—

(1) A standard 3 per cent. copper, 14 per cent. zinc alloy, suitable for general use in castings. Known as L5 during the war, the latest B.E.S.A. specification of this material is 2L5 of November 1921.

(2) A 12 per cent. copper alloy for use in pistons and parts subject to high temperatures. The latest specification here is B.E.S.A. 2L8 of November 1921.

The next important step was the experimental production of a 14 per cent. copper, 1 per cent. manganese alloy. The effect of the inclusion of manganese upon the tensile strength was so marked that further research was prosecuted; ultimately, however, this alloy was superseded by what is known as the Y alloy, containing 4 per cent. copper, 2 per cent. nickel, and 1½ per cent. magnesium.

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* Originally an addendum to the fourth lecture, this section is now more suitably inserted here.

This alloy, which has been forged and rolled with very successful results, can now be obtained commercially to B.E.S.A. specification L24 of November 1921. The Royal Airship Works at Cardington found that they could work this alloy to a one-ton range in tensile strength, which is a distinctly closer margin than that of four tons necessary for the normal mild steel used in ship construction. It also possesses considerable powers of resisting corrosion even when exposed to sea-water.

As illustrations of some of the difficulties met with and overcome during the investigations into these alloys I may mention that the method of adding other metals to the aluminium has considerable effect upon the material produced.

Nickel, for instance, when added by itself produced capricious results, and satisfaction was not obtained from the nickel-aluminium alloys till the method of adding the nickel in the form of a "hardener," containing 20 per cent. nickel and 80 per cent. aluminium, was discovered and adopted. On the other hand, the use of this method in adding magnesium was found to lead to difficulties in forging, which were overcome by adding the metal in the pure state just before casting.

All of these cast alloys are considerably improved by suitable heat-treatment, in so far as their mechanical properties are concerned, the tensile strength in some cases showing a remarkable increase, and the correct temperature for annealing, in connection with cold working of aluminium alloys, whether for rolling, drawing to section or wire-drawing, is of great importance.

All these alloys "age" or "age-harden" usually during the first few days after casting. The amount of such ageing varies somewhat with the different alloys, but the general result is an increase in the tensile strength of the casting concerned. This increase may amount to as much as 30 per cent., though possibly that maximum may not be attained for some months.

These materials are really solutions of various metals in aluminium and the ageing is due to the precipitation from the solid solution of particles of such compounds as $CuAl_2$ which are not readily soluble in aluminium except at a high temperature.

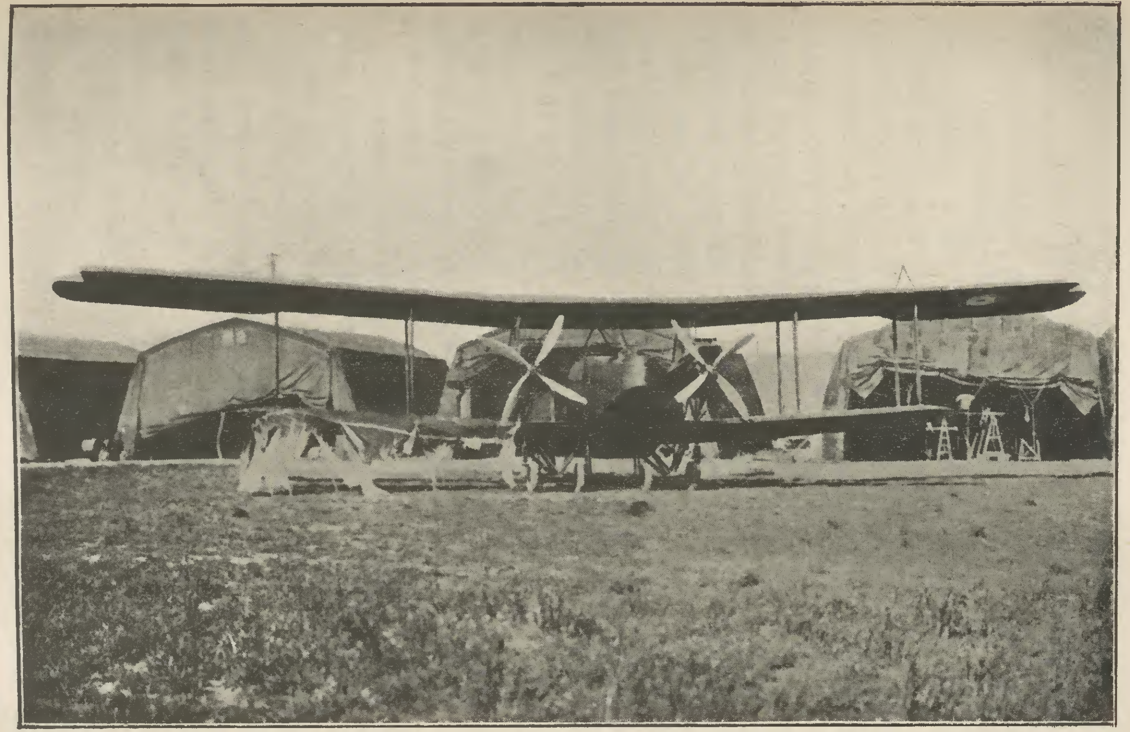
Such appreciable changes in the properties of these materials, while they do not point towards deterioration, indicate internal changes continuing over a period of years. Investigations into the matter have not yet extended over a sufficient period to say more than that after the first five years the further changes are of little importance and that for the first ten years the changes are all in the same direction, and appear to be so slow that for all normal purposes the alloys may be regarded as stable.

In general, while very careful attention to detail is necessary during the whole course of manufacture of these alloys, no difficulties are met with which are not readily overcome by intelligent workmen adhering strictly to instructions. Those more particularly interested in this subject are recommended to study the Eleventh Report of the Alloys Research Committee, which can be obtained from the Institution of Mechanical Engineers or through any bookseller.

The light alloys were known in an uncertain fashion in pre-war days, but, through the demand for them in aircraft, reliable methods of reproduction were developed, so that the engineer of to-day may be sure of obtaining the material he needs.

It was to motoring that aviation owed the development of engines of sufficiently low weight/horse-power ratio to render flying practicable; that debt is now being paid back in the form of a wide new range of high-grade materials hitherto beyond the reach of the automobile engineer.

But possibly the best view of the advances so made in our knowledge of materials can be obtained by a comparison of the specifications issued by the British Engineering Standards Association in 1914 with those of the present day. The increased knowledge of materials



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there displayed is very largely due to the war demands of aviation.

The Human Factor.

All this output of machines and equipment, however, would have been useless without the men to fly them ; and the question of the supply of specialised personnel was another problem which had to be faced. Table VI. shows the development. You will note that as compared with 197 officers in August 1914, there were in October 1918, 27,906. At the beginning of the war the main source of supply was the Central Flying School at Upavon. On the conclusion of the armistice there was a total of 199 training squadrons, including those established in Canada and Egypt, and the pupils under instruction, inclusive of cadets, numbered 30,000. Up to the armistice 21,957 pilots had been trained and graduated as efficient for active service. The training of pilot and observer personnel was one of the heaviest responsibilities of the Air Ministry and it is believed that the British system of training finally evolved is the best in existence, a belief confirmed by the eagerness with which foreign countries have adopted British methods and engaged British instructors.

Throughout the birth and growth of aviation, and even more throughout the war, the human, the psychological element played an important part. Swiftness of brain and the almost instantaneous inter-communication between brain and action are perhaps the first essentials of a successful pilot. Such essentials often resulted in high-strung temperament, and queer beliefs and legends were accepted almost as gospel. To slower minds, many such theories and beliefs would have been laughed out of court.

At the outset, apart from the tragic tale of the Montrose ghost, one of the most striking instances of this form of belief was that of the R.E.8. One of the easiest machines to fly—one actually brought back in safety to well within our lines the bodies of its pilot and observer killed in action over the German lines—it was welcomed with acclamation

TABLE VI.

PERSONNEL.

	August 1914.			December 1916.			December 1917.			October 1918.		
	Officers.	Other Ranks.	Total.	Officers.	Other Ranks.	Total.	Officers.	Other Ranks.	Total.	Officers.	Other Ranks.	Total.
R.F.C. . . .	147	1097	1244	5982	51,915	57,897	15,522	98,738	114,260			
R.N.A.S. . .	50	550	600	2764	26,129	28,893	4,765	43,050	47,815			
Royal Air Force .	...	...	...	...	...	...	...	...	...	27,906	263,842	291,748
Total . .	...	...	1844	...	...	86,790	...	...	162,075	...	...	291,748

by artillery squadrons in France when it replaced the then obsolete B.E.2c.

At home in its early days it acquired the reputation of a man-killer and accident after accident occurred. True, inadequate tuition of the pilots who were being turned out at that time and the additional chances of errors in piloting rendered possible by the adjustable tail plane, then a recent improvement, were both important factors in this distressing problem. But the main root of the trouble was undoubtedly psychological. Distrust of the machine had originated who knows where, but the actual effect was that pilot after pilot climbed into one of these machines under the firm impression that he was going to his death. Climbing steeply and possibly starting its first turn the machine stalled, nose-dived, crashed, the burst petrol tank distributed its contents over the still running engine and a day or two later a few charred bones were interred.

Matters were so serious at Coventry, at which depot the majority of these machines were collected, that the authorities at an explosive factory close by were seriously concerned, lest a machine might crash into one of their stores with catastrophic results.

One after another, pilots serving at head-quarters at home went down to test these death-dealing monsters and endeavour to discover for themselves the cause of the trouble. But under their piloting there was no difficulty and they could only report that the machine would fly itself if let alone. Eventually a few pilots were sent back from overseas and formed a nucleus of sceptics at the depot. They jeered at the "horrible reputation" and by their example cleared away the dread which had clouded the minds of the less experienced pilots at home. Then only did the trouble pass.

WIRELESS AND PHOTOGRAPHY.

It is not possible within the brevity of one paper to deal adequately with the various war activities of the R.A.F., and you must forgive if I do no more than mention two of its most important functions—co-operation with artillery and photographic work.

It was realised from the first that one of the most important duties of the aeroplane would be co-operation with the artillery, and various methods of communication between machines and batteries or ships were devised. By the end of the war wireless telegraphy was in general use for this purpose, and its sister, wireless telephony, was rapidly coming into use for communication between machines.

The original and at first the only duty of the aeroplane in war was reconnaissance; but with the development of trench warfare it became necessary to supplement reconnaissance reports with detailed and accurate information as to the position of enemy trenches, location of batteries, etc. Aerial photography, experimented with before the war, was rapidly developed for this purpose, and successful photographic reconnaissances were carried out at heights up to 22,000 feet.

During the first month that a photographic section operated in France only 40 negatives were taken. During October 1918, 23,247 negatives were exposed, and approximately 650,000 prints issued.

ARCHIE AND ONIONS.

But the aircraft did not have it all their own way. By no means. Quite apart from the attention of their own kind in the air they had anti-aircraft guns of every kind and description, and of increasing accuracy, to contend with on the ground. Kite balloons, clumsy monsters at the best of times, were a particularly attractive prey. An enemy balloon in flames was a pleasing sight—but not so pleasant for the occupant who frequently had to make his escape by parachute. A balloon-strafing expedition was a regular preliminary to any offensive movement, and on one occasion an individual pilot brought down three Hun balloons before breakfast one morning.

Then there was "Archie." In the earlier days however little was seen by our pilots of the enemy in the air, the coughing crash of anti-aircraft shell soon made itself heard and sometimes felt. In those days though our machines flew low—as a rule not above 6000 feet, and sometimes as low as 3000 feet—shooting was poor and the guns were few in number and readily identified by their different types of shell. These explosions were looked upon rather in the light of an amusing daily greeting whose absence would almost be regretted, and each gun was soon presented with an individual nickname by those at whom it was aimed. That of Archie, given to one particular gun, spread with unreasoning rapidity throughout the army, and very soon became the generic term for all anti-aircraft artillery. Various developments took place in the attack from the ground upon aircraft, and of these the "flaming onion" was not the least known.

PARACHUTE DESCENT.
Observer leaving machine travelling at 120 m.p.h.

I am personally ignorant of the exact nature of this projectile which was entirely different from the ordinary Archie shell, but the first pilot that encountered it in the air reported with annoyance that he had been attacked by a "flaming onion," that he strongly objected and that he hoped the enemy would reconsider the matter and discontinue this revolting practice.

The following instances of the effect of Archie upon our machines may be of interest.

An R.E.8 had its controls on both its starboard planes damaged by A.A. fire. The observer, leaning over the side of the fuselage with his Lewis gun in his hands, somewhat as the crew of a racing yacht beating to windward, helped the pilot to keep the machine sufficiently level to enable him to land it safely, though the elevator controls were the only ones left in usable condition.

One of our Bristol Scouts, returning to its aerodrome found our own A.A. shells bursting some hundreds of feet above it. Thinking a hostile machine must be close by, the pilot climbed to the level of the bursts. The firing continued, but there was no enemy to be seen, so, gathering that our guns were firing at himself, he returned home. Shortly after landing, some gunners dashed up in a car to seize souvenirs of the German machine they claimed to have brought down.

A D.H.2 received a direct hit from an enemy A.A. gun, the shell passing through both sides of the nacelle in front of the pilot's legs without touching him or otherwise damaging the machine.

Lighter than Air.

Hitherto I have dealt mainly with heavier than air, but so far as those are concerned who did not have the good fortune to take part in the fighting overseas, acquaintance with hostile aircraft was mainly confined to the night-prowling, ghostly and wholly unpleasant Zepp. Very vulnerable when once we had found out how to fight them with fast-flying scouts and searchlights, they did a lot of damage, and might have done a great deal more if they had not had a habit of losing their way and being rather anxious to get rid of their bombs and hurry home. I believe that you in Edinburgh experienced a very unpleasant raid. Literally miles of broken glass and many deaths. These monsters used to carry something like 2 to 2½ tons of bombs, some very large ones, and it really was extraordinary how little damage, comparatively speaking, they contrived to do. Altogether there were 55 airship raids on Great Britain. One of the largest took place on the night of 19th-20th October 1917, and had as its objective the industrial centres of England. Although the wind on the ground was light, at 16,000 to 20,000 feet—the height to which the airships climbed on approaching their objectives—a northerly gale was blowing. This entirely upset calculations, and the raid ended in disaster for the enemy, four of the eleven airships which took part

CHART OF ZEPPELIN RAID ON EDINBURGH
1st-2nd April 1916.

being driven southwards and wrecked. This was partly due to British weather, as in Armada days still a firm ally, but it was also due to trouble with the engines which, from some defect or negligence, had stopped, and then owing to the great height at which the ships were travelling, froze up and could not be restarted.

BOMBING.

In the early days, pilots carried a few small bombs to be dropped by hand as opportunity offered, but bombing rapidly increased on all fronts, and the weights of individual bombs rose from 20 lbs. in 1914 to 3000 lbs. at the armistice. Unfortunately we never reached Berlin. The armistice came just too soon, but in October 1917, a brigade was organised to work from the Nancy area against the German iron and chemical industries in the Rhineland. This Independent Air Force gradually increased to 10 squadrons and, had the war gone on, would have been increased to 48 squadrons by May 1919. Although actual results may not have been very great, the moral effect of the systematic bombing of such centres as Mainz, Ludwigshafen, Mannheim and Cologne was considerable, and the German High Command was forced to withdraw at least 20 fighting squadrons from the western front in an attempt to deal with this menace.

FIGHTS IN THE AIR.

I have left till the last some few details, culled at random from dry official dispatches, of those fights in the air of which we may all well be proud.

Five of our machines commenced a general engagement with from twenty-five to thirty enemy machines. One of our machines had to glide down with its engine stopped and was only saved by another of ours driving off the two enemy machines attacking it from behind until the engine got going again. All our machines returned safely, while five of the enemy were definitely destroyed and four driven down out of control.

An S.E.5 attacking an enemy formation brought one machine down and when attacking another, collided with it. The top plane of the German machine was carried away by the under-carriage of the S.E.5 which was turned upside down but recovered control.

Four of our machines attacked four of the enemy. The enemy leader was first shot down, then two other German machines went down in flames, the pilot in one escaping on a parachute, while, when the fourth machine was attacked, its interplane struts fell out, the planes folded up and the hostile patrol was thus wiped out.

Of individual fights, this is perhaps one of the best examples. Major Barker, who was on a refresher course from England with No. 201 Squadron, while on patrol on a Sopwith Snipe, attacked an enemy two-seater at 2000 feet over the Forêt de Mormal, and the German machine broke up in the air. He was then fired at from below and wounded by a Fokker biplane, and fell into a spin, from which he pulled out in the middle of a formation of 15 Fokkers, two of which he attacked indecisively. He then got on the tail of a third, which he shot down in flames from a range of 10 yards. He was again wounded and fainted; on recovering, he regained control of his machine and was attacked by a large formation of the enemy, one of which he shot down in flames from close range. He was then hit in the left elbow, which was shattered, and he again fainted, his machine falling to 12,000 feet before he recovered. Another large formation of German aircraft then attacked him and, noticing heavy smoke coming from his machine, he believed it to be on fire, so tried to ram a Fokker. He opened fire on it from close range and the hostile machine burst into flames. Major Barker then dived to within a few thousand feet of the ground, but found his retreat cut off by eight of the enemy, at which he fired a few bursts and succeeded in shaking them off, returning to our lines at a few feet from the ground, where he finally crashed near our balloons. During the latter part of this combat Major Barker was without the use of both his legs and one arm, and brought his machine back by controlling his engine by the switch alone.

CONCLUSION.

Such in very brief and inadequate outline was the growth of British aviation during the war. The subject is too big to cover in one brief hour and I am aware of many omissions and shortcomings, but you have heard something, both from the technical and also the human side of this great power, which in the next war will be the deciding factor. In this, the first in which aircraft were employed, a glamour inevitably attaches to those who fought and died thousands of feet above their fellows' heads in France and Italy, in Palestine and the Dardanelles, in Thrace and Russia. Perhaps among the poppies where so many brave men lie, there's a special little whisper reserved for airmen of a—

"... far bell ringing
At the setting of the sun,
And a phantom voice is singing
Of the great days done.
There's a far bell ringing,
And a phantom voice is singing
Of renown for ever clinging
To the great days done."

III.

BALBUS MURUM ÆDIFICAT.

THE first of this present series of papers on aviation dealt with the pioneer period. In the second we saw how this pioneer effort was fused in the crucible of war into one of the most terrible weapons of destruction to which man has yet laid his hand. In this, the third, we may see how the lessons learned in war are being applied in peace, and that even in the air swords may be turned into ploughshares.

Peace hath its triumphs no less than war, and there were not wanting men in England who, noting the great development of air during the fighting, were far-sighted enough to look ahead, and to apply beforehand the hard lessons of war to the requirements of peace. That is the only advantage conquerors have. We are told that the victor in war is in reality the vanquished—from the financial point of view at any rate. But he can after all have the satisfaction of applying, at least on paper, the experience gained in battle. So it was in this case, and in 1917 an influential Committee, known as the Civil Aerial Transport Committee, was set up under the Chairmanship of Lord Northcliffe to report how best aviation, admittedly a war product, could be utilised under peace conditions. The report was a weighty and well-considered document, deserving of more attention than it has perhaps received. There is one objection to it, and that is the term "civil." It smacks too much of something directly opposed to military, and yet still under Government control. As an amendment "commercial" is suggested.

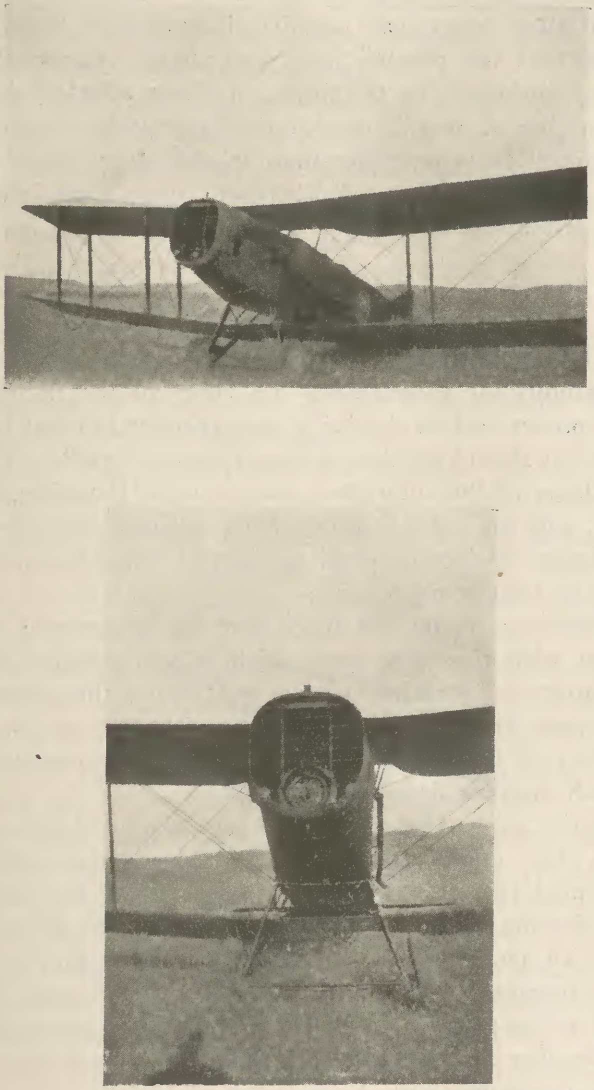
The strength of the air power of the British Empire must lie in its commercial development, and commercial air development is not in the least the same thing as civil air development. But in the heat of the moment I stray from my subject, which is based on the old, old text, "Balbus is building a wall." We believe as the corner-stones of our creed—

(1) That aviation is destined ultimately to play a most important part in the development and closer linking up of the collection of States known as the British Empire;
(2) that only by the proper development of commercial aviation, thereby providing a reserve from which to draw in case of need, can present unproductive outlay on armaments be reduced;
(3) that in aviation we have something which, by promoting personal contact and thus eliminating misunderstandings, may ultimately prohibit war.

All three of these articles of faith are more properly reserved for the final paper of this series, but in this I propose to attempt to show you how we are working towards those ends.

Back to School.

When the war came to an end even those who knew most about the uses of aircraft in battle were babes in knowledge as to how best it could be used in peace. What types were required, what safety conditions were necessary? What risks could be taken and what could not? What was the cost of travelling by air; what traffic could be tapped so that air-transport might establish itself commercially? Such were some of the questions that had to be and must be answered before faithful believers in the future of the air can convince the British public, ever sceptical of innovation, that this new form of transport has come to stay.



TWO VIEWS OF A "BRISTOL FIGHTER" WHICH SHED ITS PROPELLER DURING A FLIGHT TO ROME, SEPTEMBER 1919.

Before, however, the "progressives" could be allowed to put their ideas into practice, it was clear from war's lessons that the possible uses and abuses of aircraft had to be considered in the light of their effect upon the normal life of mankind, and that safeguards had to be introduced to protect the man in the street from those who desired to live and move and have their being in the world above him.

THE CODE OF THE AIR.

The discussion of the terms of peace offered an unique opportunity for ascertaining the views of the nations on these points, and for obtaining an agreement in regard to the code that should regulate international air traffic. Representatives of the interested nations were, therefore, set to work, and on 13th October 1919 a Convention for the regulation of international air navigation was signed in Paris by twenty-six States.

Declaring in the first place that the sovereignty of the air lay with the state over which it was situated, that is affirming the doctrine *Usque ad Cœlum*, this document laid down the conditions under which the air over the territory of the signatories might be freely navigated by aircraft of other signatory states.

Rules as to the nationality and airworthiness of aircraft, the qualifications required from the operating personnel, the documents to be carried, and the necessity for obeying the Customs laws of the state flown over, were all included, while detailed rules of the air were fully specified on lines very similar to the rules of the road at sea; and in addition international arrangements for weather reporting and standardising maps were carefully drawn up.

The rules in regard to airworthiness—in other words the standard of safety that was to be laid down—was the problem which gave the compilers of the Convention most difficulty. No civil standard existed as yet anywhere, and how could international agreement be obtained on a point on which there was no agreement between the various technicians in any country?

Eventually the broadest rules only were specified, and the standard minimum requirements were left to the judgment of individual states until the whole question could be investigated by the International Commission, the setting up of which to control air matters was one of the important objects of the Convention.

Although the majority of the signatory states are now working to this Convention, it is not yet actually in force internationally, the various negotiations necessary before the deposit of ratifications by the various states having occupied a long and wearisome time.

What it is hoped may prove the final touches to the various arrangements are now, however, being given, and it is anticipated that a sufficient number of ratifications will be deposited in the very near future to enable the I.C.A.N.—the International Commission for Air Navigation—to be set up.*

The British Delegation were largely responsible for the form of the various rules included in the Convention, and based as they were on our Air Navigation Regulations for 1919, little change will be necessary in our domestic laws to bring the Convention into force in this country.

In Great Britain civil flying, prohibited during the war, was made legally permissible again on 1st May 1919. The short distances and highly-developed existing communications in these islands offered little prospect of sufficient paying traffic being available for this new and, as yet, commercially untried form of conveyance. Pleasure flying, however, offered attractive possibilities, and in the first five months over 58,000 passengers were carried for short flights. The profit-earning capacity of the undertakings which carried out this work was largely independent of the type of machine employed, the organising ability and

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* The I.C.A.N. was formally inaugurated in Paris by M. Poincaré on 11th July 1922.

attention to detail on the part of the promoters being by far the more important factors.

It was, however, to the Cross-Channel routes that those desirous of establishing regular air services turned their attention. A large existing traffic by rail and sea suffering the inconvenience and discomfort due to the changes from rail to boat, and boat to rail, and the sea crossing offered a reasonable prospect that adequate paying loads might be obtained. When, therefore, in August 1919, international air traffic was first allowed, it was between London and Paris that the first route was opened, and from then until the end of 1921, over 11,000 passengers have been carried across the Channel.

Pioneers, however, seldom reap a large reward for their efforts, and here was no exception. But at least before the task of establishing a commercial air line proved too great for the resources of the first companies to undertake the task, they had stabilised many of the difficulties to be overcome, thereby providing for those that followed a clearer view of the problems to be surmounted.

APPLICATION OF KNOWLEDGE.

We saw at our last meeting how knowledge of aeronautics had greatly increased during the years of war, and how its ramifications had affected many branches of engineering. But all this knowledge had been obtained and studied from a purely military point of view, and commercial purposes required its consideration from an entirely different standpoint. From this new aspect it was clear that many gaps existed which it was essential to fill. Aerodynamic requirements are indeed similar in aircraft for either war or peace, but there are other characteristics which diverge widely as they are viewed from the angle of peace or war.

A machine may be designed to carry a ton load for military uses, but its load is highly condensed in the form of bombs and ammunition. While then such a design may be most excellent for its appointed duty, it is clearly most improbable that it will equally well carry a ton of passengers under comfortable conditions.

The comfort of the pilot, too, though given some attention during the war, becomes a far more important detail if he is to carry passengers day in and day out without impairing their safety through fatigue due to avoidable discomfort.

The commercial value of improvements in the design of details is also of importance. Under war conditions little emphasis was laid upon the saving of labour, while the fact that a part wore out rapidly was a reason, but not a strong reason, for its re-design.

Very different are the requirements of peace when improvements in detail design may make all the difference in the balance sheet of an air transport firm.

Control cables must be so arranged that the possibilities of fraying are eliminated, cowling that takes two men an hour to remove is hopelessly wasteful, and rapidly perishing rubber joints fitted in the petrol system to take up vibration become an ineffective and expensive luxury.

During the war also while knowledge was gradually collected on the subject of silencing aero-engines it was never fully applied; the great importance of increased performance eliminating the possibility of introducing such an improvement which implied additional weight and possible loss of power.

Silence, however, or at least reduction of noise, is of very great importance to the air transport firm which desires to attract paying passenger traffic, and much attention is therefore being devoted to the study of this question at the present time.

In this connection there is the pleasant tale of two distinguished foreign engineers who were bringing their wares, the very latest thing in engine silencers, to lay at the feet of the British Air Ministry. Customs officials at the port of entry scenting Bolshevism and some preternaturally overgrown bomb, were suspicious of the "baby" shaped something like an overgrown torpedo, and refused it right of entry. "Tell us more," they said. But the engineers being strategists, misdoubting their ability in halting English to explain the properties of their invention, and fearing consequent delay, hit upon the following brilliant solution. They were, they said, "artistes" who had been engaged at a London theatre, and this, pointing to the presumed engine of destruction, was their turn. Officialdom could raise no objection to this ingenuous statement, and the inventors passed on their way rejoicing.

Another engineering problem is that affected by the question of passenger accommodation. Consider the passenger cabin, still very limited in its cubic capacity per head, passing rapidly through the cold air, and you will realise that interesting and difficult problems of ventilation and heating arise. So far, this question has not been tackled properly by aircraft designers, and it has now become an urgent matter, if the passengers so much desired by the air transport firms are to be encouraged to come forward in sufficient numbers.

Jonah's whale may have been, and probably was, capable of carrying twenty people quicker than an express train, but can you imagine any useful traffic being attracted to such an ill-ventilated and malodorous conveyance?

The normal standard of ventilation, 3000 cubic feet of air per hour per person, is not attainable in an aircraft cabin at present. Such a rate of change of air in a present-day cabin, comprising in all some 300 cubic feet, seating ten passengers, would result in unbearable draughty conditions.

Professor Leonard Hill has, however, pointed out that if the cooling, drying and radiant energy conditions are satisfactory, the supply of fresh air necessary may be much below the standard. To afford a means of determining these conditions he invented the Kata Thermometer.

The actual method of use of this instrument is as follows: Dipped into hot water until the liquid overflows into the bulb at the top of the instrument it is then taken out and held in the space, the ventilation of which it is desired to measure. With a stop-watch the time taken by the thermometer to cool, from 100° to 95°, is measured in seconds. The figure so obtained is divided by the factor marked on the thermometer.

Let us take as examples an instrument with a factor of 40, which takes 3, 4, 5 and 6 minutes to cool down the necessary 5° in different spaces. Dividing the number of seconds in each case by 40, we get as results 4·5, 6, 7·5 and 9. Experiments have shown that the information given by this instrument is an accurate guide to the adequacy of the ventilation so tested, and that if the results be between 6 and 8, the conditions may be considered satisfactory.

In the first of our four cases, then, we find the space too cold and draughty; the second and third are satisfactory; while in the fourth the ventilation is inadequate.

It appears probable that with satisfactory heating arrangements twenty or less changes of air per hour will prove satisfactory in aircraft cabins, but as yet this has not been proved in practice.

Although in the early days Cody, in cold weather, provided himself with foot-warmers heated by the water circulating from his engine, no real attempts have since been made to provide suitable heating arrangements for passenger aircraft. Much, therefore, has yet to be done before a satisfactory solution is obtained of this problem which is intimately bound up with that of ventilation.

As regards the main features of commercial aircraft to-day, the most important requirement is to increase the useful load while maintaining the same cruising speed and avoiding increased running cost or higher landing speed. In other words we have to increase the efficiency of the machine and obtain a higher ratio of lift to drag. Various designers are working at this aerodynamic problem, and such improvements as the Fairey flap, which practically gives a wing of variable camber, the Handley-Page slotted wing or similar developments, are expected, when tried out, to give a real step in advance. In no case, however, have these as yet been tried on a commercial machine.

You will remember that in the first lecture reference was made to the test to destruction of a B.E.2 at Farnborough in the spring of 1914. The technique of such tests has been brought to a highly-developed state by the Royal Aircraft Establishment—as the factory was entitled when the Royal Air Force came into existence in order to avoid confusion due to identical initials.

In no branch of engineering is it so true as in aeronautics that fatal results may follow simple errors, and certain forms of weakness may escape detection by the most careful checking of calculations or the most efficient inspection during construction.

The calculation of the stresses due to the offset mounting of a member may be highly complex or distortion under load may bring about unexpected failure.

Loading tests in which the actual conditions in flight are simulated as accurately as possible are of great value in showing the designer what is likely to occur in such a way and what he should avoid. Unless suitable precautions are taken to prevent complete collapse of the structure under test—such as occurred in the case of the B.E.2 to which I have previously referred—it may, however, be difficult or impossible to determine with accuracy the location of the primary failure.

The success of such tests depends largely upon the employment of simple and methodical arrangements, and very considerable attention has been given to this point at the R.A.E. where, as far as possible, they are reduced to a simple routine.

SALUT TO ADVENTURERS.

We have touched on some of the problems which require solution before this new form of transport can come into its own or successful—and by this word is implied economic—routes can be established. The first Knights of the Air were not worried in the same way with economic finalities. They were only there to show that quite apart from fighting nothing had yet been contrived by man which could touch air transport as a means of reaching the ends of the earth and for linking up the Empire. Almost immediately after the armistice there was an epidemic of big flights. And although an attempt will shortly be made to encircle the earth, certain venturesome spirits are already sighing that there are no new worlds, at least on this planet, to conquer.

During the war a Handley-Page had already flown from England to India, and as soon as possible after the armistice the Air Ministry undertook the survey of the India-Australia route, and in the case of the Cairo-to-Cape route, not only the survey, but also the preparation of aerodromes. More recently a route has been surveyed by the R.A.F., across the Syrian desert from Palestine to Bagdad, and this route is now regularly used both for the conveyance of His Majesty's mails to Iraq and the passage of aircraft reinforcements to that country. Normally, as you are aware, the way to Bagdad from Egypt is *via* the Red Sea, Bombay, thence back to Basra and so by rail or steamer to Bagdad. The journey from Egypt takes as a minimum sixteen and often twenty-three days. By air you can breakfast in Cairo and dine in Bagdad. It has been done. And the normal time for the carriage of mails by this route is two flying days.

For various reasons, mainly finance, it has not yet been found possible to develop the Cairo-Karachi route, and since survey, beyond the construction of one or two isolated aerodromes, the India-Australia section has remained on paper only.

No regular flying has yet been done along the Cairo-Cape route and it would appear regrettably probable that those aerodromes to the south of the Sudan, as far as Bulawayo, will fall into desuetude. Few people have any idea of the stupendous work involved in plotting and constructing this air route through Africa. Three survey parties set out and between them at a cost as nothing compared with a railway survey, quite apart from the laying of the tracks, selected sites, constructed aerodromes and laid down supplies at an average of 280 miles throughout the length of Africa. And all this in a little over twelve months. There were in all forty-three aerodromes of which twenty were oil and petrol stations. At N'dola alone, a typical instance of aerodrome construction in bush country, 90,000 trees were logged and removed and 107 ant-hills, comprising something like 25,000 tons of earth, were levelled.

In February 1920, various competitors started to fly from England to the Cape, but only two, Van Ryneveld and Brand were destined, after many and varied excursions and alarums to reach their destination. Meanwhile Ross Smith and his brother had made an extraordinarily successful flight in twenty-eight days from England to Port Darwin, Australia, and perhaps most wonderful of all, Alcock and Brown had in June 1919 crossed the 3000 miles between Newfoundland and Ireland in sixteen hours.

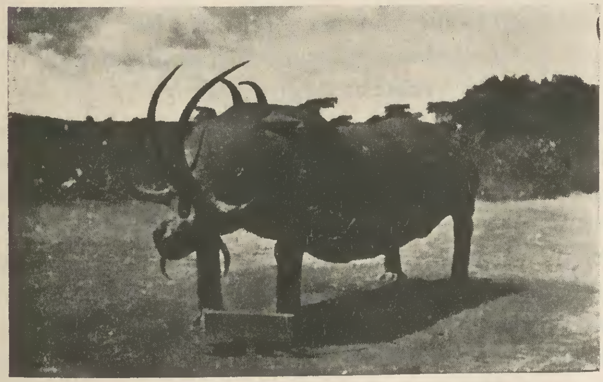
Organisation.

But no more than does one swallow make a summer does one flight make a route; and we should be the first to point out the fallacy of the argument that because the Empire routes have at various times been flown, regular communication by air could to-morrow be established throughout the Empire. Development will be sectional. Here a little and there a little. Sometimes linking up with existing means of transport, sometimes, as in the case of Cairo-Bagdad, constituting the only direct means of transport. Gradually the various sections will converge and coalesce and our long-distance air routes will become an accomplished fact.

As in most other activities the spade-work, the ground

CAIRO-CAPE TOWN AERIAL ROUTE.

A clearance on the aerodrome at N'Dola.



"BRONTOSAURUS" AT N'DOLA.

What Dr Chalmers Mitchell missed.

Dr P. Chalmers Mitchell, F.R.S., Secretary, Zoological Society, was passenger on a machine which failed to reach N'Dola during a gallant attempt to fly from Cairo to the Cape.

organisation in the case of the air, is all-important. And ground organisation is not summed up in the useful portmanteau word aerodromes. There are other things to be considered, chief among which may be mentioned

(*a*) Supplies and communications.

Of the construction of aerodromes I have already told you something. In the little matter of supplies I am not sure how many times the engine is changed on the short railway journey of 400 miles from London to Edinburgh, but it seems to me to be at least three. It is futile therefore, until the secret of perpetual motion has been solved, to expect air transport to carry on over thousands of miles and hour after hour at speeds vastly exceeding the modern express train without either relays or adequate facilities of spare engines and a thousand and one other desiderata. Frequent and large supplies at suitable points along the route of petrol and oil are self-evident necessaries.

But it is on good communications that the efficiency of a route, when the other details have been supplied, most chiefly depends. Communications are required for

(1) Terminal control of traffic.
(2) Messages to and from aircraft.
(3) Weather reporting.

Normally the modern aircraft outstrips the telegraph. Besides, apart from a long line of poles and wire strung out across the desert, the terrestrial clerk at some halting-place along a route is unable to communicate by line telegraphy with an aircraft which is almost certainly out of sight, and ten to one not even in his vicinity. It is moreover, absolutely essential for the pilot to know as accurately as possible the state of the weather along the routes over which he is flying. And so wireless telegraphy and wireless telephony have been pressed into use.

The strides made during recent years in this science have been little short of marvellous, while by general adoption of the valve system much of the early difficulty in obtaining clear reception has been eliminated. It verges on the uncanny, a few miles out of Le Bourget—the Paris aerodrome—to have a pilot literally ring up Croydon over 200 miles away and give the position of his machine, the type of weather through which he is passing or any other information that may be required or sought. To the uninitiated, replies may at first seem a little faint and blurred, but this soon clears as the ear becomes attuned and something like the following conversation passes between the pilot in the machine and the far-away aerodrome or another pilot within range:—

"Hullo, Croydon! Hullo, Croydon! GEAUK" (registration number of the machine) "calling, GEAUK calling, am passing over Beauvais, weather clear, weather clear, ten passengers on board, over." Possibly in fog—the worst enemy of aircraft — a pilot may be uncertain of his position. It may be gloriously clear where he is flying above the clouds, but below except at rare intervals landmarks are indistinguishable and since leaving the aerodrome he has flown by compass. Perhaps, too, there is a wind on the beam which has the effect of drifting him off his true course. A call goes out asking to be given his position. In this case his request is dealt with by two wireless stations, the London aerodrome at Croydon and Pulham in Norfolk. By combining the two readings Croydon is able accurately to determine the exact position of the lost sheep, and by degrees to shepherd him exactly over the fold where he would be.

Weather reports are similarly transmitted at request to the pilot in the air, and traffic often deflected from an aerodrome enveloped in fog to one which is clear. In so far at least as European air traffic is concerned, the geographical position of Great Britain renders that country of very great importance both for hourly weather messages between termini and the broadcasting of synoptic weather telegrams for making weather maps and forecasts. As an instance of the importance of this work, it may be mentioned that something like 190 weather reports from all over Europe are received in the Air Ministry every day.

With the present instruments available for aircraft, wireless telephony is effective up to about 250 miles. Wireless telegraphy is only limited by the power of the transmitter, but in view of the weight involved, the range of the instruments with which present-day machines are equipped may be said to be about 400 miles.

NIGHT FLYING.

Night flying which became such an important feature in the later phases of the war has not yet really been tackled commercially. Until the various problems therein concerned have been successfully solved commercial flying cannot hope adequately to compete with existing means of communication except over extended distances. Here the great speed of the vehicle during the hours of daylight makes up for its inactivity during the hours of darkness. For instance, a man who knows that by posting his letter at 6 o'clock in the evening it will be delivered in Paris first thing next morning is unlikely to make use of the air post which does not start till next morning. On the other hand, if the destination is at such a distance that a machine starting at dawn, say 6 A.M., arrives at its destination before the train which left at 9 P.M. the previous evening, it is obvious that even without night flying aircraft could contend with normal means of transport. But taking the average speed of express routes at 40 miles per hour—a somewhat generous allowance—it will be seen that the distance between the two points must be in the neighbourhood of 800 miles before, other things being equal, aircraft can come into the picture as mail carriers.

We have not wished to try to run before we had learned how to walk, but it is possible from the various plans now being discussed that night flying—or at least flying that starts in the darkness to arrive in daylight or *vice* *versa*—will begin this summer. And that brings us to the vexed question of lighting. You would be astonished if you flew with me from London to Paris by night to find how invisible certain well-illuminated areas appear from the air and how useless some beacons are to the aerial traveller. With a view to development extensive experiments have been and are being carried out. The French are erecting a powerful aerial light, and the route from Croydon to the coast will, by this autumn, be well equipped with guiding lights. The lighthouses employed by us are most ingenious arrangements. By means of a sun valve sensitive to light, mechanical apparatus is set in motion according as it is dark or light, and the beacon becomes automatic, requiring attention only once every six months or so. We had a particularly conscientious little fellow at Croydon. During the last eclipse and after a hard night's work he suddenly realised that all was not well with the world. A gloom almost Cimmerian surrounded him, and determined to offer his quota in the struggle between the powers of light and darkness, he came to life again with a rattle as all his machinery got to work. The eclipse passed and still puzzled, rather like the hen who under the influence of electric light is said to lay a second inadvertent egg, the lighthouse sank back with a sigh and a conviction of "something accomplished, something done" to resume his disturbed slumber.

DIVERGENCIES BETWEEN WAR AND COMMERCIAL TYPES.

Our main subject last week, you will remember, was the impulse given to aviation by the war. Naturally types peculiarly suited for certain specific war purposes resulted. But the same attributes are not necessarily required, at least in such a high degree, by the machine to be devoted to peaceful purposes, while others out of place in the war vehicle are essential. Reliability, both of engine and general construction, are essential in either case. In fact almost more so in the commercial as against the war vehicle. In the one risks are inadmissible and limits must be extended rather than cut down; in the other risks must be faced if certain results have to be attained. Again the "ceiling" of the commercial machine is comparatively secondary. It is unlikely at present at any rate, that air travellers from London to Paris will wish to go photographing cloud panoramas, or even the earth from which they have come, at a height of 20,000 feet. To begin with, at that height the cold is intense. Then, too, the ability of modern war machines to climb almost vertically is unnecessary in the commercial counterpart. A modern scout—or perhaps a modern bomber is a more exact analogy—can reach 15,000 feet with full load in from twelve minutes to twenty-five minutes. Provided that a commercial machine can get off the ground with a moderate run and climb say 2000 feet in five minutes it fulfils all immediate requirements. The Channel nowadays is crossed more often at 2000 feet than at 5000 and I should doubt whether during the whole of last summer machines on the London-Paris route ever went above 7000 feet.

Divergencies between war and commercial types must therefore become more and more marked and it is in this respect we hold that commercial aviation can repay some of its debt to its militant stepmother. Just because some new type or new invention happens along the nation cannot afford to re-equip the Royal Air Force. Programmes are laid down years ahead. The idea can, however, be tried out on commercial machines and having been shown of proven worth may afterwards be adopted by the fighting arm.

It was such an innovation as this which was encouraged by the Civil Aviation Department of the Air Ministry in the competition held at Martlesham in the autumn of 1920. One of the prizes was given for an amphibian—a machine which would combine the qualities of aeroplane and flying boat and be equally at home on land or sea. When the

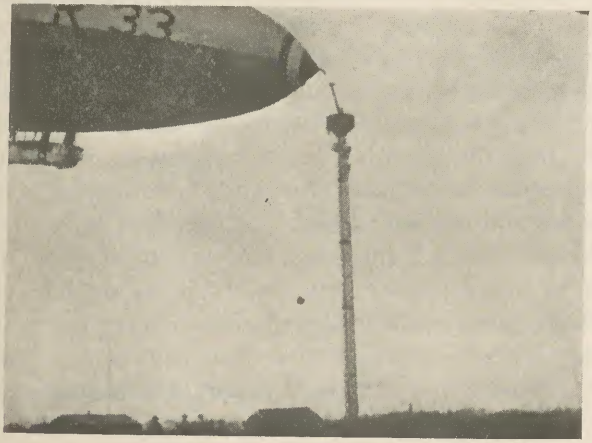
THE D.H.34—A MODERN COMMERCIAL MACHINE.

conditions were first published I remember how certain designers used to come and see us and tell us with tears in their voices that we were asking for the moon. But in the result when the tests came on several efficient amphibians were produced, and when the Royal Air Force saw one of these remarkable machines alight on the water, cautiously let down its—gender obviously neuter—wheels, waddle like some vast saurian of olden time up on to the shore, describe a stately minuet round the pier at Felixstowe, then back into the water, tuck up its wheels—I had almost said feet—and fly away, they at once set to work to develop the ideas for their own purposes.

Lighter than Air.

I am aware that airships at the moment are under something of a cloud. There have been several hideous accidents of late and mainly from reasons of finance the Government has decided to close down the airship stations and sell the stock. Whether the powers are right or wrong time alone can show, and it is not the part of this paper to plead the merits or demerits of the case. That other countries do not agree with us we shall see in the concluding paper. But here, too, great progress has been made since the termination of the war, not so much from the point of view of construction as from that of handling. Hitherto the difficulty of getting these monsters safely to earth and in and out of their sheds was an ever-present worry to their commanders.

The latest ships are nearly 700 feet long—they could just moor between the Scott Memorial and the North British Hotel. They required 300 men at a modest computation to handle them and even in the lightest of breezes were "kittle cattle." Thanks, however, to the mooring mast, with which most successful experiments were carried out last summer, many of these disabilities have been eliminated. The number of men required has been cut down from 300 to 8; the average time to moor a ship has also been much reduced, and at Pulham ships used to arrive at and leave the mast in winds up to 45 miles per hour. Indeed, like a good ship she even prefers a stiffish breeze as the head resistance offered facilitates both approach and departure. The idea of the mooring mast originated as far back as 1912, but was only recently perfected. It consists of: (*a*) a mast equipped with a cup-shaped attachment mounted on gymbals; (*b*) a complementary fitting on the bow of the airship; (*c*) two side guys for steadying the ship; (*d*) a cable led some distance to windward and passing through the cup-shaped attachment on the mast to a winch and drum. At Pulham we had to use a traction-engine—the only makeshift available. The airship approaches the mast and drops a rope. This is shackled on to the cable by a nimble attendant and after various rites have been performed, in particular trimming the ship so that she is slightly down by the stern, the traction-engine begins to clank her in.



R.33 MAKING FAST AT THE MOORING MAST.

It only requires comparatively few extensions of the present arrangements to envisage lifts and other etceteras which might have come direct from Kipling's *With the Night Mail.*

PROGRESS ABROAD.

Abroad, progress has been diverse but not, except in one or two notable instances, as marked as might have been expected. Neutral countries have not experienced the impulse of the war to teach them the advantages of aviation; Germany has been debarred under the terms of the Peace Treaty from developing as she would otherwise most certainly have done. The United States have been hampered from lack of unity of control, but important work is going on in connection with the carriage of mails. Holland, making use of British engines, ran during last summer most efficient services to London and Paris and will reopen these routes and probably extensions in the coming season. But so far as Europe is concerned it is in France that the most important progress has been made. Whatever may be her difficulties and shortcomings in regard to finance and material France realises that in commercial aviation she has a complement to her military air power which in time of need may prove of incalculable value. No effort, therefore, is being spared to push out tentacles in every direction. A daily service is run from Paris to Prague, thence tri-weekly to Warsaw, with ultimate regular extensions to Bukarest and Constantinople. While apart from a number of internal services and the important Paris-London service, a service is being run five days a week from Toulouse to Casa Blanca in Morocco and an extension to Agadir will shortly be in operation. This route is now carrying as many as 80,000 letters a month. Airship sheds are also being erected at Marseilles, at Orly near Paris and at various points on the northern African coast.

Taking therefore a sober view of aviation as a whole we may, I think, justly assert that important progress has been made and that very large development will gradually take place. Regularity is essential if the merchant is to be induced to send his goods by this new method, or the traveller to adopt it as a matter of course and not merely for the sake of the experience. That this efficiency is gradually being attained may be seen by studying the statistics of the flights by British machines on the London-Paris route.

In 1920 the percentage of flights completed in less than four hours was 80 per cent., while only in four months of that year was the figure for the month above that average. In 1921 the percentage had risen to 89 per cent. and only in four months was the figure for the month below 90 per cent.

Safety again is an important consideration, and while the increased efficiency shown by the figures I have just given implies fewer forced landings and therefore increased safety, it were well to study also the accident statistics. The number of passengers killed and injured of all those carried in British machines was as follows:—

Year.	No. carried (round Nos.).	No. killed.	No. injured.
1920	42,300	10	6
1921	42,700	1	2

The total number of accidents involving any injury to the occupants of the machines was:—

1920.	1921.
14	6

These numbers include accidents in which only pilots were injured.

These figures show how our British firms are progressing in the direction of the safe operation of aircraft, and meanwhile they are learning under the pressure of their annual balance sheet how, while securing safety, to reduce running costs. While insurance rates stand at their present high figure — due partly to the small total amount of premium income—a decrease in safety increases costs more than any corresponding saving can counterbalance, so that there is no tendency to secure economy by taking risks. Careful study of detail and success in obtaining sufficient traffic to keep machines hard at work, instead of uselessly depreciating in idleness, is bringing costs down step by step to a reasonable figure.

Time, too, is bringing that experience in organisation necessary for the success of any business, and it will, we believe, be but a short while longer before British air transport firms will be standing solid on their own feet, unsupported and untrammelled by State aid or State control.

It is to the building of these foundations that our efforts are directed, and those eyes which are guided by knowledge of the spade-work of the past, can now see where the first bricks will soon, we hope, be well and firmly laid, of the edifice of Imperial Air Communication.

One would hesitate to say that the air is to be the last great sensation offered to man, but it is the latest; the possibilities are immense and the prospect fascinating. At least, if it does not open the way to a new heaven and a new earth, it brings the one nearer to the other. Were it wrong, therefore, to suggest that by neglecting the opportunity which now lies ready to her grasp, England may run the grave risk of forfeiting for ever the mastery of the air?

As Adam lay a-dreaming beneath the Apple Tree,
The Angel of the Air he offered all the Air in fee.
    But Adam did not crave it,
    Nor the voyage he wouldn't brave it,
Singing: "Air and Water, Earth and Fire,
        What more can mortal man desire?"
            (The Apple Tree's in bloom.)

As Adam was a-working outside of Eden-Wall,
He used the Earth, he used the Seas, he used the Air and all;
    And out of black disaster
    He arose to be the master
        Of Earth and Water, Air and Fire,
        But never reached his heart's desire:
            (The Apple Tree's cut down!)

IV.

VIDEMUS PER SPECULUM.

WE have already dealt, however inadequately, with three phases of aviation; first, the "stick and string" period and the early pioneers; second, the application and extension of that early knowledge to the requirements of war; third, the application and again extension of those self-same lessons to the requirements of peace. Remains the future, a dangerous and withal attractive proposition with which I for one, having neither the imagination of an H. G. Wells nor the pen of a Kipling, hardly dare treat. At least, however, we have one sure foundation on which to base our premises. The future is inevitably founded on the past, and demand creates supply. In early days, if I remember aright, because the King's edicts demanded speed, "the posts rode upon mules and camels." In the days when Sappho loved and sang, news of a victory or demand for reinforcements was passed from hand to hand by relays of men running. And as most parts of the world are sundered the one from the other by the "unplumb'd salt estranging sea," communications over these wastes also became necessary. From the early junks which still ply in the Eastern mains we pass to the "grave Tyrian trader" and the triremes, quinqueremes and argosies of later times. Thence, always lusting after more speed, to the clippers which immediately preceded the era of steam. Famous ships, such as the *Taiping*, *Cutty Sark* and *Flying Cloud*, which performed a remarkable run of 512 miles in 24 hours when on a passage from New York to San Francisco; and the *Thermopylæ*, which averaged 300 miles a day for 17 days when on a voyage from the Cape to Melbourne. On the trade of these ships much of your wealth in Edinburgh is based. In the west, as roads improved, the single-pack animal tended to give way to the coach, and if you really wanted to go very fast, say to Gretna Green, you went post with a chaise of two, four or even more horses. Such was the limit of progression, dependent on the fickle breath of the wind or on animal fibre and muscle, until the advent of steam and the internal-combustion engine. The first steamship, the *Royal William*, crossed the Atlantic in 1833. The first train ran from Stockton to Darlington on 27th September 1825. Incidentally, on that occasion a disbeliever in innovations interposed his body in a belief that he could stop or at least delay progress and suffered the extreme penalty for his pains. In 1895 the first motor car in England took the road; and the first organised reliability trial from London to Edinburgh and back took place in 1900.

EARLY MOTOR CAR.

(*By courtesy of Illustrated London News.*)

Steam, then, began to be used just 100 years ago. Progress since then has been almost vertiginous. Indeed, Dr Butler says somewhere that progress in communications would seem to advance in a geometrical progression. He concludes that the present era is the only one worth living in. The early days would have been too slow, the future too swift. Express trains average, we may say, something under 50 miles an hour; a great liner which maintains much over 25 knots is looked upon as a greyhound. There are many who positively state that the economic limit of present-day sea and land transport is already passed. Save to view the scenery, he would be laughed at who now drove always in a coach to London, thereby taking a minimum of four days in the effort.

The future lies in the air: but what are its possibilities, in what sphere is it likely to be most useful, and how, if at all, will it affect the march of civilisation?

In all these questions, however apparently simple it may be to frame an answer, we are as those seeing through a glass darkly and the answer must inevitably to some extent be speculation. And yet we know enough not to let imagination run riot. No need to stake our reputation on voyages to the moon or Mars, putting a girdle round the earth as Puck in some unheard-of space of time, or to insist that the air is immediately going to revolutionise our world. Man, at least in these northern climes, is by nature conservative. There are those who not so long ago looked with disfavour and distrust upon the introduction of steam and machinery into our factories.

So will it be with the air. I chanced the other day when looking out my train to come to Edinburgh, to turn up Paris—you will forgive me if I confounded the two beautiful towns—and noticed that the air route is already given as an alternative method of travelling to the French capital. Most satisfactory, thought I, but though there must be many who see it, few there be that take advantage and fewer still who realise its significance. But we who have watched over the acorn of aviation since first it was planted hold it as a tenet of our creed that sooner or later the air must predominate and that it is one of those essentials, like reading and knowledge, which a nation, if it is to remain " first class," cannot afford to be without.

PROSPECTS.

There are two sides of this development—military and civil. With the first it is not so much my province to deal. It is not difficult for anyone endowed with ordinary imagination to picture the havoc of the next war, with the results of this—mere samples, mind you—still fresh in the mind. Hordes of bombing aeroplanes concentrating daily and nightly on the nerve centres of the country. Huge machines, disgorging their human freight with machine guns at some vantage-point behind the lines to cut communications, hold important points and generally make life impossible for the enemy. All staff work and particularly telephones—the nervous system of the staff—underground, almost in a coal mine, for the penetration and explosive power of even the present bomb is colossal. Fleets useless unless they can submerge and even then watched as the mouse by the hawk; whole districts burned by incendiary bombs; populous centres stinking with ugly corpses and fetid gas.

It is more difficult to picture the peaceful development of the air unattired in that pomp and circumstance in which war is decked merely to hide the resultant heartache. We believe, however, that in the development of commercial aviation we have a weapon of peace which will do more to cause that wars shall cease, and to remove misunderstandings, than any international instruments hitherto forged for that purpose.

All wars are in a great measure traceable to inability to understand the other person's point of view. Remove that lack of understanding and you remove at the same time one, if not the chief cause of war. Is it for a moment conceivable that Washington would have achieved anything if negotiations had been carried on by means of dispatches, even if those dispatches had been the most brilliant ever written and continued over a generation. But a few weeks personal contact accomplished more than tons of paper and gallons of ink could ever have achieved. So is it with the Empire; so is it with the world at large. A danger spot appears somewhere. It takes days or weeks by the present methods to reach the place. Recourse is had to the frigid unsympathy of the telegraph instead of two men on either side of a table having it out. And it is here that the air can help.

But, someone will ask, if then the air is such a potent cause for goodwill and potential use, why has not development been swifter? There are three reasons:—

(1) But for the war, development would not have reached anything like the stage it has. War, prodigal of treasure, mistress of invention, forced on air development to an unnatural degree and one which the world is not yet sufficiently educated to adopt as its present standard.

(2) The aeroplane is not, as yet, a scientific masterpiece, nor has a really commercial vehicle been designed. It can fly at high speeds, but for limited periods only; its useful load is limited as compared with other public means of transport, and even now the engine is sometimes known to stop.

(3) A commercial implement cannot and never will develop if its existence is held to be justified only by its potential use in war, and never allowed to take its own path. To give two instances only—war demands great speed and what we call a high ceiling. We do not wish in commerce, as a rule, to go much over 5000 feet, and the speed of the fighting scout is not at present required. What we must have is an engine which will never let you down.

Divergencies between the war and commercial types of machine are already appearing and will tend to become more marked. But the real cleavage and therefore the real development will not come until those who control our research realise that the requirements of war and peace are as distinct as the battleship from the ocean liner.

THE ATOMIC THEORY.

While, however, I have deprecated too visionary ideas of the future in so far as aviation is concerned, I feel I must refer to one development which may seem to be in the regions of romance. Those of you who are, or have been, readers of Jules Verne will know how many of his imaginings are now commonplaces of our existence. Why, then, should not the same come true in the case of H. G. Wells, who, first in story, put before his readers as a new source of power the forces stored in the atom. Already, among others working in the same field of research, Professor Rutherford at Cambridge has succeeded in his laboratory in breaking up atoms of nitrogen and aluminium and liberating their pent-up energy by a bombardment with alpha particles from Radium C. Previous endeavours to the same end by using the beta particles had failed. But the alpha, 8000 times the weight of the beta, brought up as the heavy artillery, succeeded when the lighter field guns had made no impression on the atomic defence. Here then is the beginning. Just as the violin's note rightly attuned will shatter the crystal bowl, just as the middle C of the piano, rightly struck, will cause the note, an octave higher, to resound, so, though yet to be discovered, the right synchronous vibration, utilising the factor of resonance, will, with a minimum expenditure of energy, cause the selected atom to crumble and free its contained power.

The first arduous part of the ascent may well be conquered in the next twenty years, and another twenty may see the desired result attained—an engine drawing unlimited power from the atmosphere in which it works, carrying as fuel solely an insignificant mass to provide the source of bombardment of the atoms of the air. This is no dream but the goal at which to-day a small band of scientists is aiming. With such a source of power the fullest advantage could be taken of speeds not now economically practicable, and where can such speeds safely be developed if not in the air?

True, with high speeds new difficulties will be encountered. Even now, when the maximum air speed so far attained is 200 m.p.h., it is known that difficulties arise when the speed of sound is approached. The air flow round the plane then breaks down and the lift falls off so that the machine will not fly.

But this problem—something analogous to cavitation in the case of a water propeller — has only just been encountered, and suggestions as to how it may be overcome, or its ill results diminished, are already under investigation. Before it arises in practice we have far to go, as it does not become a danger till we are travelling at some 10 miles a minute.

Careful as Kipling was to avoid that accurate technical description of his engine and machine which might—I say "might" advisedly —have enabled the enterprising constructors of our time to carry out his design in actual fact the machine described in *With the Night Mail* may be nearer realisation than we think.

Ricardo's experiments, in which by utilisation of hydrogen the amount of petrol required can be reduced by one-third, is also a step, if not an atomic step, along the right road.

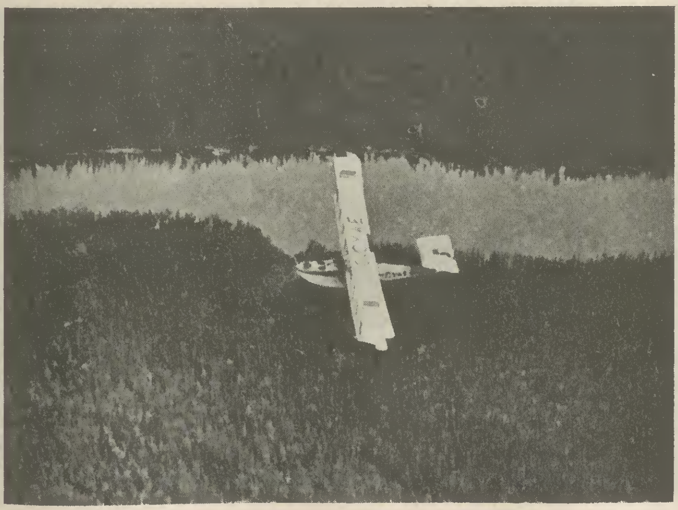
The immediate future—say the next five to ten years —is not, however, likely to give us such a tremendous forward step as would be implied by the development of atomic power. Improvement in detail only is to be anticipated in that period as regards engines. In aircraft—heavier than air—the main improvements will probably aim at an increase in the percentage of the total weight which is available for load. At the present

Distant view of Forest and Lake area. Altitude 3000 feet.
Note Point of Land (X).

Nearer view of Point of Land shown at X in Photo No. 1.
Altitude 1000 feet.

(*By courtesy of Canadian Air Board.*)

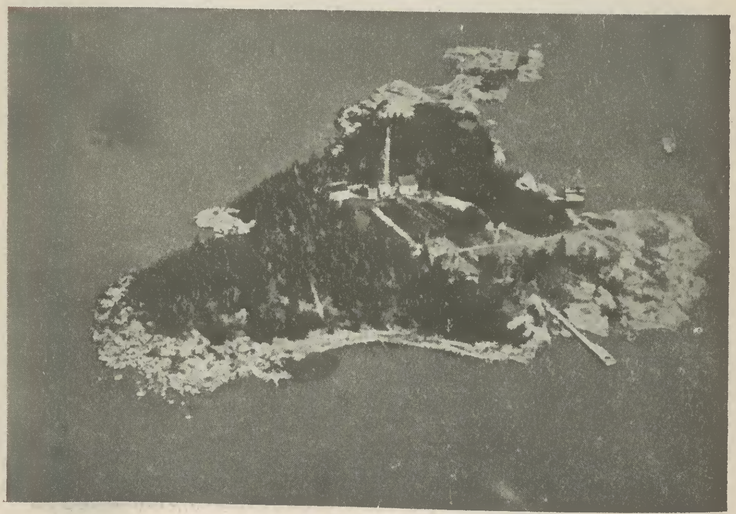
"Close-up" view of same area showing actual timber types. Altitude 200 feet.



A Flying Boat on patrol as seen from another machine above it.

(By courtesy of Canadian Air Board.)

Landing supplies for fire fighters on lake near scene of fire.



Comparison of the old and the new way. Look-out tower at Norway House, Lake Winnipeg.

(*By courtesy of Canadian Air Board.*)

time the crew, fuel and useful load together amount, roughly, to some 35 per cent. of the total weight fully loaded. If this can be increased to 45 per cent. a considerable advance will have been made, and to this end tend the present endeavours to increase the ratio of lift to drag.

A decrease in resistance of the body obtained by careful design and a reduction in that due to interference between the body and the airscrew are steps on the road, for the latter of which considerable research is essential. Variable pitch airscrews and landing gear that can be drawn up into the body are also probable developments of the near future while, if only for reliability, the elimination of rubber in the shock absorbing gear is urgently necessary.

A fruitful source of trouble, the rubber tyre, is still in use, as, weight for weight, it is still the best form of shock absorber for withstanding the stress of landing.

HELICOPTERS.

On this much discussed subject I may inform you that important developments may shortly be expected. We really have got a helicopter which has actually flown and on the design of which steady progress is being made. This machine has already attained considerable heights, is under complete vertical control and can hover. It can also move in a horizontal direction at an approximate speed of 10 miles per hour, though this has not yet been proved.

Although experiments are going on abroad, it is not known whether they have reached such an advanced stage.

So far as can be seen, the principle of the helicopter, as at present designed, cannot be applied to the normal aircraft. It is an entity in itself and may be looked upon rather as an improvement of the kite balloon in that it can ascend and descend and move horizontally under its own power, rather than an arrangement which can be fitted to an aeroplane to enable it to ascend or descend vertically or remain stationary over any given object.

AIRSHIPS.

You may have noted that in my foregoing remarks I have said nothing about the airship. This is not because of lack of faith in craft lighter than air. We have tried to regard the air as a whole, and in our web of the future the airship takes its place as pre-eminently the long-distance vehicle. Unhampered by frontiers, careless of whether the route lie over sea or land, unmindful of fog or darkness, a cruising speed of sixty knots already in sight, the airship has advantages over the aeroplane for long-distance work which must sooner or later be recognised and lead to important developments.

The trade-winds which blew the clippers back to port can, too, be utilised by airships, so that the longest way round is sometimes the shortest way home.

At the present stage the airship, too, has her troubles, which must be got over, before she can take her place as a common carrier. These may be summarised as frailty of design; perishable nature of gas-bags and difficulty of handling.

This last may be said to be in a fair way of solution by the general adoption of the mooring mast, so successful last year at Pulham, to which I referred last week. German ingenuity has already perfected a method whereby the life of the gold-beaters' skin used in making the gas-bags is much increased, while various substitutes for this expensive tissue are under examination. To turn out the necessary amount of gold-beaters' skin for the gas-bags of one modern airship, say of 3,000,000 cubic feet capacity, requires 500,000 cattle, so that until some substitute is found, airships have an initial overhead charge to bear which is difficult to maintain. In regard to construction, canvas and an intricate system of girder bracing will gradually give way, as lift increases, to an inner shell of firmer construction which will effectively prevent the careless or inquisitive passenger from making a hole, as at present seems the desire of some, and the fear of others.

That the airship will come into its own there can be no doubt. If for reasons of finance and lack of imagination, leading to a policy of "ca' canny," our authorities are at the moment indisposed to take further steps in this direction, the United States and Germany are not going to let the matter rest. Under the terms of the Peace Treaty, Germany is forbidden to possess an airship of over 30,000 cubic metres (approximately 1,000,000 cubic feet), too small to be of much avail in international traffic. But she is constructing a ship of close on 3,000,000 cubic feet for the United States, and under her auspices negotiations are far advanced for the inauguration of an airship route between Spain and South America—a little matter of seventy-two hours' flight as compared with the present fortnight.

LINKS OF EMPIRE.

The power of Imperial Rome was based upon the Roman roads. When these began to decay the Empire began to decay with them. All history shows that only by the improvement of communications can progress and unity be ensured. It is open to doubt whether, if communications between this country and America had been as swift as they are now, there would have been a "tea-party" in Boston Harbour and the subsequent loss to Great Britain of the United States. So with the British Empire, and if present methods of communications have reached their economic limit there remains only the air in which to develop higher speeds.

In the following table the time of transit by steamer and rail between London and the various capitals of the Empire is compared with that by air, the figures for air transit being based on the assumption that the routes are properly organised, with relay and other stations, and a continuous speed of 60 miles an hour for day and night flying is maintained :—

	Miles (By Air).	By Steamer and Rail. Days.	By Air. Days.	By Air. Hours.
Ottawa . . .	3,480	10	2	10
Delhi . . .	5,810	18	4	1
Melbourne . .	12,930	34	8	23
Wellington . .	13,870	44	9	15
Cape Town . .	7,740	17	5	9

In spite, however, of the almost endless possibilities of the future it were unwise at the moment to jump to the conclusion that we can forthwith, as by the touch of a wand, create routes within the Empire. Such great events can only be achieved by the slow processes of trial and error, and we must still be some years from the inception of regular lines between London, Cairo, Cape Town, Karachi, Singapore and Melbourne.

And here we have an interesting political study of the position of Great Britain in the new era. Hitherto the seas have ensured her splendid isolation. Her position guarding the Western gateway of Europe has enabled her to take toll and ensured to her a predominant position. All that is now changed. She may still lie on the Western fringe of Europe, but she is no longer the hub. She has been relegated to the circumference of the flying circle and her very isolation may prove her undoing. She can reach no Dominion with the exception of Canada and no Dominion reach her without crossing the territory of a potential foe and in plotting the future it were well not to forget that air stations throughout the Empire within reasonable distance the one from the other are likely to be as important to this realm as ever were coaling stations.

The Reservoir of Air Power.

Mahan writes that the foundation of sea power is based upon a flourishing industry. He further shows how the great French Minister, Colbert, under Louis XIV, faced with the necessity of providing a fleet, succeeded in doing so by the cultivation of the purely military effort. This system, however, not being based on a flourishing industry, withered away like Jonah's gourd when Government favour was withdrawn. Again, in 1778 on the outbreak of hostilities with Great Britain, France, through her maritime conscription, was able to man at once fifty ships of the line, while England by reason of the dispersal over the globe of that very shipping on which her naval strength so securely rested had much trouble in manning forty at home. During the whole of the succeeding period, France was never able to place more than seventy-one in commission, while Great Britain by calling up her resources and making free use of her mercantile marine was by 1782 able to place 120 ships in commission.

Substitute air for sea and the analogy is the same. Ships of war date as such from Armada days. Before then, and afterwards, too, to a great extent merchantmen when necessary left their peaceful pursuits and became converted men o' war. Such a conversion is not unknown even in our own days. In the sonorous words of the Articles of War: "It is the Navy whereon, under the good providence of God, the wealth, safety and strength of the kingdom chiefly depend." Does it? I suggest, heretical though it may appear, that it is not on the Navy that the safety of this realm will in the processes of evolution depend, but on the air. France, with the instinct of the Latin race, has realised this. I wonder whether you have been reading the recent Articles in *The Times* on this subject? Listen to this extract from a statement by Marshal Foch:

> "The military mind imagines that the next war will be on the same lines as the last. That has never been the case and never will be. One of the great factors in the next war will obviously be aircraft. The potentialities of aircraft attack on a large scale are almost incalculable, but it is clear that such attack, owing to its crushing moral effect on a nation, may impress public opinion to the point of disarming the Government and thus becoming decisive."

How can this threat be adequately met? It cannot be done by increasing the standing Air Force to what would be equivalent to a permanent war footing. In the first place, the strain upon the financial resources of the country would be unbearable; in the second, it would entail conscription which this country will not have in time of peace. How does the Navy expand in time of need? By embodying the flourishing Mercantile Marine. Similarly the Air Force can only adequately expand when the moment of trial comes, if behind it is a large and flourishing commercial aviation.

I have endeavoured to tell you something, a very little something, of the wonders and possibilities of the air,—past, present and future. Perhaps in a few years' time a lecturer in this same hall on "Modern Transport" may jeer at our present crude ideas of aviation. It would be pleasant to know, even if we are ourselves then fitted with wings—white or black—that some of us here in Edinburgh to-night can turn on our fellow shades and breathe a discreet "Told you so."

In the opening paper of this series we saw the torch of flight being passed from hand to hand. In the closing pages we still but see as in a glass darkly. Let us therefore go forward without wavering and without hesitation, knowing that in the end *perseveranti dabitur.*

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The
Rubber Industry in Edinburgh
A REVIEW

Lecture Delivered before the Royal Scottish
Society of Arts, Edinburgh
14th April 1924

BY

W. A. WILLIAMS, F.I.C., F.R.S.E.

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The Rubber Industry in Edinburgh

A Review

By W. A. Williams, F.I.C., F.R.S.E.

Ladies and Gentlemen,

I think my thanks are due to your Council for their invitation to speak to you on the Rubber Industry in Edinburgh, for it has been the means of bringing into reality an intention often thought idly about but never achieved till now; and it would still no doubt have been one of those undertakings awaiting an appropriate opportunity for execution had it not been impressed upon me that this was a very fitting occasion to make the effort.

I refer to the piecing together of what data is available to make some coherent story to account for the existence of an old-established industry like the manufacture of rubber in Edinburgh, and I intend to give a short, if somewhat sketchy, account of its progress and development, and the position it occupies to-day as a centre of that industry in Great Britain, if not the Empire.

When one looks around at other manufacturing industries and their conception and growth in certain localities, it is not so difficult to account for the occurrence—the alkali trade in proximity to the salt deposits in England, the iron and steel works adjacent to the mines, and nearer home, the oil refineries shadowing the shale beds. But no such ready answer is available to our question as to why seventy years ago should have seen the birth in Edinburgh of an industry which has grown into large undertakings. Edinburgh, a city of historical associations, the seat of learning, the haunt of tourists, and the home of advocates and the medical profession, with little or no manufacturing associations, surely offered little inducement or attraction for such an enterprise, especially so as its raw material had to be brought long distances for fabrication; the principal ingredient, rubber, from abroad, cotton goods from Lancashire, and the necessary chemicals from whatever source they could be obtained. It is interesting to note in connection with this matter that at least one of the drugs that was required in fairly large quantities was imported from America.

We must now leave Edinburgh for a little and trace the experiments that were being conducted and efforts that were being made elsewhere to bring articles made of rubber into a condition of commercial success. In the earliest stages rubber was used as a solution spread on articles, principally for the purpose of waterproofing, and the name of Macintosh is associated with these goods to this day. As will be readily understood, the application in this form had its limitations, and with this early history we are not interested this evening, it having practically no connection with Edinburgh.

In the efforts being made in America to utilise rubber for wearing apparel, it is on record that overshoes made by the natives of Brazil from raw rubber moulded on clay moulds were imported in large quantities into America. Returns show that round about 1825 these imports reached a figure of 500,000 pairs per annum. Attempts were made to manufacture imitations of the native article from crude rubber imported from Brazil, which were more or less satisfactory. Then followed a period of manufacture utilising the knowledge of dissolving rubber in a solvent, probably turpentine, but with disastrous results, owing to the overshoe sooner or later becoming soft and tacky. At this stage an epoch-making discovery was made by an American, Charles Goodyear, which was undoubtedly the foundation stone on which the industry has been built up, namely, the discovery of vulcanisation by heating with sulphur, which changed completely both the chemical and physical nature of the rubber, so that after treatment it was no longer affected by solvents, resisted changes of temperature, both heat and cold, remained soft and pliable under these changes of climate, and did not become hard in winter or soft and tacky in summer.

We very fortunately have on record a complete account of Goodyear's work, written by himself and published in book form at New Haven, Connecticut, in 1855 under the title of "Gum Elastic." There are very few copies in existence, but one is fortunately preserved in the library of the North British Rubber Company here in Edinburgh and is a valuable reference in these historical matters. In itself this book is a model of how experimental work should be recorded, and it is a great pity that experimenters of these earlier days were not of the same painstaking order, and so left on record an account of their work.

It appears that Charles Goodyear, who had no manufacturing experience in the rubber trade, first took up his experiments somewhere about 1830, probably being attracted by the unsatisfactory behaviour of the articles being offered for sale, as I have just previously mentioned. His earliest

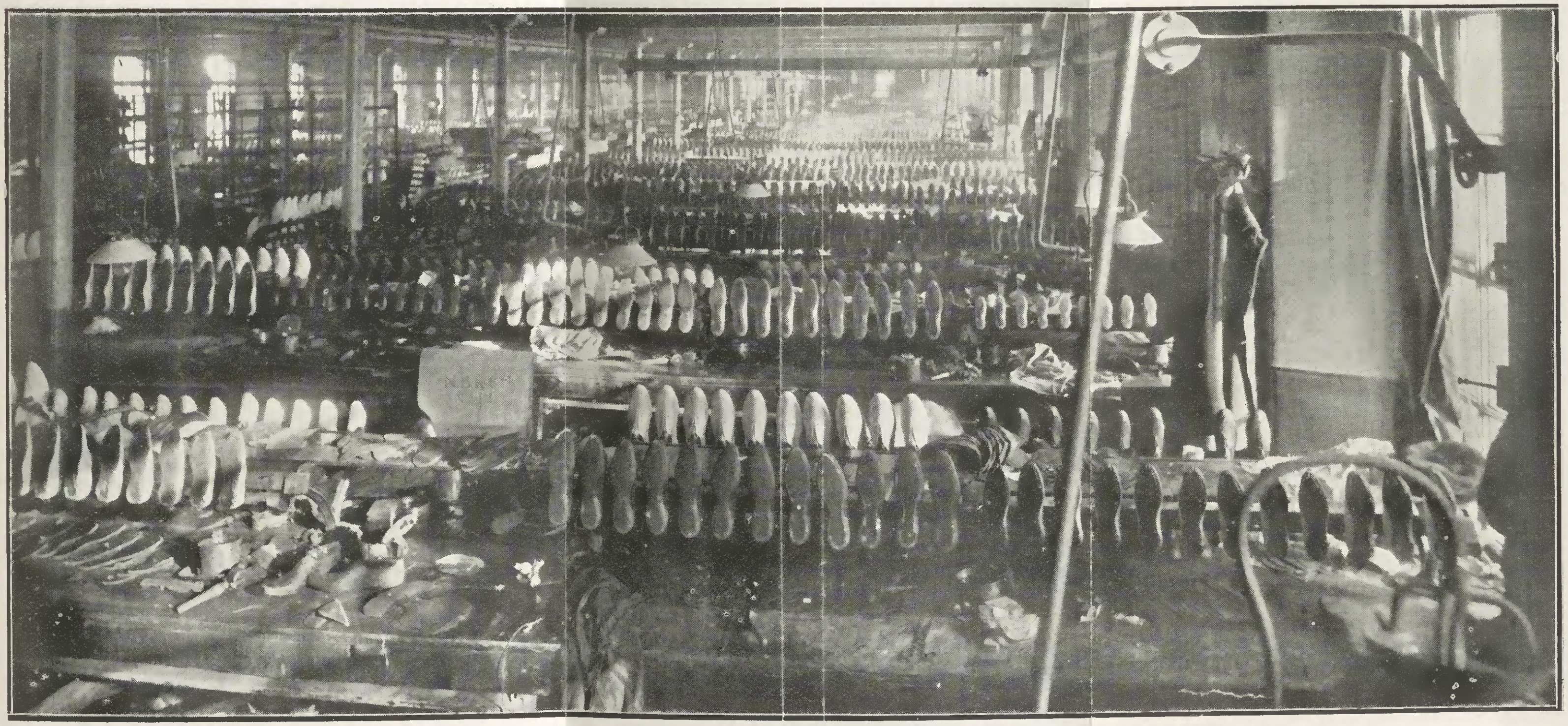

FIG. 1.—RUBBER SHOE MAKING

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trials were on the lines of mixing or compounding the rubber with magnesia and later with lime; subsequently treating with lime water, which gave a drier article. They, however, showed little improvement in resisting in wear the development of stickiness. The next step forward was what he termed the acid gas process, which consisted of dipping the made-up goods in a solution of nitric acid followed by a dip in a bath of bleaching powder, the method being derived from attempts to remove bronze powder by nitric acid from rubber articles. He considered this process of such value that a patent was taken out in America in 1837. He licensed several companies to carry on the manufacture on these lines and invested his own capital in a similar undertaking. As we know to-day, rubber so treated would very quickly suffer from decomposition, with the consequence that Goodyear had to meet many claims for loss and compensation from his customers for his goods having proved unsatisfactory. As a result his factory was wound up and Goodyear left at this stage a poor man. However, his spirit was undaunted and he still apparently had faith that by further experimenting, a method would be evolved which would produce the rubber in such a form that these subsequent disabilities in the manufactured article would be eradicated. He has on record that he acquired from Nathaniel Haywood a patent which Haywood had taken out at his suggestion in 1839 for the employment of sulphur as a compounding ingredient. It is to be noted here that Haywood's patent was not for vulcanisation, but only in the nature of a compounding material that sulphur was employed, but Goodyear had noticed that on exposure to sunlight some effect was produced and the article became more resistant. Probably Goodyear appreciated in some way that this was the effect he was striving for, and now turned his attention to an investigation of this matter.

With his previous bitter experience of failure and heavy financial losses through marketing articles that had not been subjected to a period of observation to ascertain if they were stable and free from decomposition in time, and on the other hand pressed for some method of arriving at a conclusion without the tedious process of waiting months, Goodyear cast around for some experimental method of testing his products after manufacture. He initiated a method which is fundamentally what we still employ to-day, namely, subjecting the rubber to heat treatment, which he no doubt considered analogous to the summer season, during which time of the year his troubles had manifested themselves. To carry this out he subjected the sample to the crude method of heating before a stove. At the same time he had formed the opinion that his earlier failure with the acid gas process was in some way attributable to the presence of white lead which he had used as a compounding material, and consequently, to satisfy himself that his new sun-cure process was of value or not, he made up his samples with sulphur and white lead to see if the latter would have the same decomposing effect.

We can imagine his surprise, and to a man of his acute observation his realisation of what the change meant when, instead of the rubber softening and melting, it changed its character completely and became tough and resistant, and found he had obtained the result he had been striving after. He had discovered the vulcanisation of rubber ! During the early part of 1840 he followed this up, using both steam and hot air as a heating medium, until he had perfected his process to his own satisfaction.

He now found that owing to the previous failures and serious financial losses that he could not obtain any assistance to carry out his new process on a manufacturing scale, nor sufficient even to patent his process, he himself being unable to supply the necessary funds owing to his previous failures, and it might be said he was existing almost in a state of poverty. Consequently it was not until early in 1844 that he obtained the patent for his invention, which he took out in America, England and France, the application being made in 1843.

In passing, it is of interest to note that during the period between the discovery and the patenting of the process by Goodyear, he had carried out certain negotiations with Macintosh without disclosing the nature of the process. Through this medium certain samples came into the possession of Thomas Hancock, from which he in turn evolved his patent process, also employing sulphur as the vulcanising medium; but, what was to be subsequently an important point in the manufacture of certain goods, such as boots and shoes, omitted the presence of lead compounds which was essential for what is known as the dry heat process of vulcanisation. I mention this circumstance as it is sometimes claimed that Hancock was the discoverer of vulcanisation, but in my opinion there is no doubt the honour belongs to Goodyear. Proof of this is obtained by his depositing in the Patent Office, United States of America, a claim for record dated the 6th December 1841. In his own words an application for a patent was not made owing to his pecuniary embarrassments. Hancock's patent was taken out on the 30th May 1844.

It was now realised in America that Goodyear's process was a sound one, and the manufacture of overshoes, so essential for the American climate, progressed steadily. In 1847 overshoes so manufactured were exported to England, with the result that an action was lodged by Hancock for infringement of his patent. This claim was upheld in the English Courts, resulting in the American company making an arrangement with Hancock for exclusive rights for export of their products into England. This brought about a remarkable situation, for although the Hancock patent had been sustained in law, it was not technically possible to manufacture overshoes by his patent, owing to the fact that it did not claim lead compounds as a necessary ingredient, which was one of the claims of the Goodyear patent granted in England. Consequently the English manufacturers such as Hancock were unable, even though they were so inclined, to carry on the manufacture of overshoes without coming to some arrangement with Goodyear. This they did not do and the American factory was left for some considerable time with a clear field for their operations.

Under the old Patent Laws operating at the time of which I am speaking, separate registration was necessary in England and Scotland, and Hancock had only covered his invention in England. This little omission on the part of Hancock was undoubtedly the reason of the inception in Edinburgh of the first rubber factory. You have probably been thinking I have been a long time away from the subject of my lecture—"The Rubber Industry in Edinburgh"—but I was anxious to trace why it should have seen the light of day in the capital of Scotland, and to make it clear it has been necessary to wander through rather a maze of historical data. With that explanation for leaving our own city, now that it has brought us to Scotland it is not so difficult to explain why Edinburgh was selected.

Now that the manufacture of rubber overshoes and boots had shown itself a remunerative undertaking in the United States, an American syndicate had concluded that it held out attractive prospects in Europe. I have no record of their deliberations or the source of their advice, but they were shrewd enough to realise that the flaw in Hancock's registration in not covering his patent in Scotland opened to them the opportunity for which they were seeking. Accordingly in the autumn of 1855 Mr Henry Lee Norris and Mr Spencer T. Parmelee crossed from New York and landed in Glasgow, with the object of making such necessary arrangements for the starting up of a factory for the manufacture of rubber boots and overshoes under the Goodyear patent. They did not find premises suitable for their requirements in the west, but during their enquiries obtained information in respect to factory premises standing vacant in Edinburgh, known as Castle Mills.

On inspection this building proved to be exceptionally well suited to their purpose, being one of the finest models of manufacturing premises to be found at that time. Formerly a silk factory that had proved unsuccessful, it only required the installation of the necessary machinery to equip it, and offered the prospect of being on a productive basis at an early date without any delays such as would have been necessitated by building operations.

Mr William Judson, an advocate of New York, had made such arrangements with Charles Goodyear that he had acquired a licence to manufacture in England and Wales, subject to certain conditions; also an assignment of the Goodyear patent in respect to Scotland under the separate regulations then existing, the material wording of the latter being "the sole privilege of making, using, exercising and vending an invention of Improvements in the preparation of caoutchouc or india-rubber and in manufacturing various fabrics of which caoutchouc forms a component part within Scotland." This latter assignment of the Goodyear patent is the only one that is of interest to us, and Mr Judson now entered into an agreement with the American syndicate already referred to whereby he assigned his rights in the invention to The North British Rubber Company, trading under the name of Norris & Company, this agreement being dated 9th August 1856. Although the agreement was only signed in August 1856, the work of installing the factory had been pushed forward and by this time they were actually turning out overshoes. Mr Norris was the General Manager and Mr Parmelee the Works Superintendent.

There is in the issue of *Chambers' Journal* of the 12th September 1857 an article on Vulcanised Rubber Shoes, the introduction of which I should like to quote, reading as follows:—

"The manufacturing spirit of the present age seems to have formed an extraordinary alliance with chemistry. A plain man who tries to keep abreast of this branch of the national progress must find amazing difficuly with the mere technology of the subject. For example, our genuine old Windsor Soap is now changed into a substance called glycerine; wax candles are utterly extinguished in the market by another substance called paraffin; and soda is fast being superseded by the crystals of hydrochlorate of lime. In fact, there is no limit to the singular catalogue of compounds which the manufacturer and the chemist between them have contrived to form out of the constituents of this unhappy world.

"These references have arisen from a visit we paid the other day to a new manufactory in the neighbourhood of

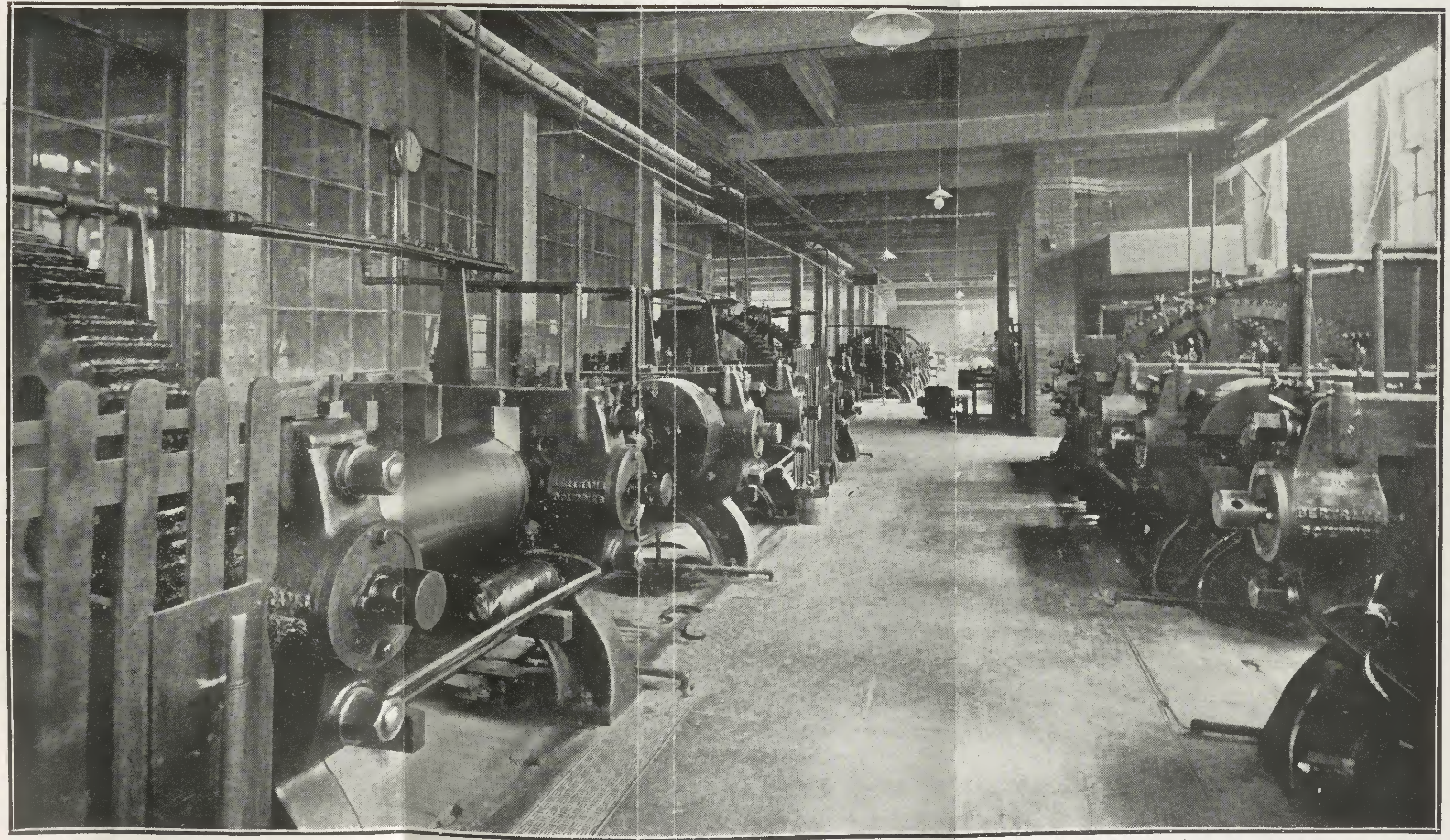

FIG. 2.—MILL ROOM—NORTH BRITISH RUBBER CO., LTD.

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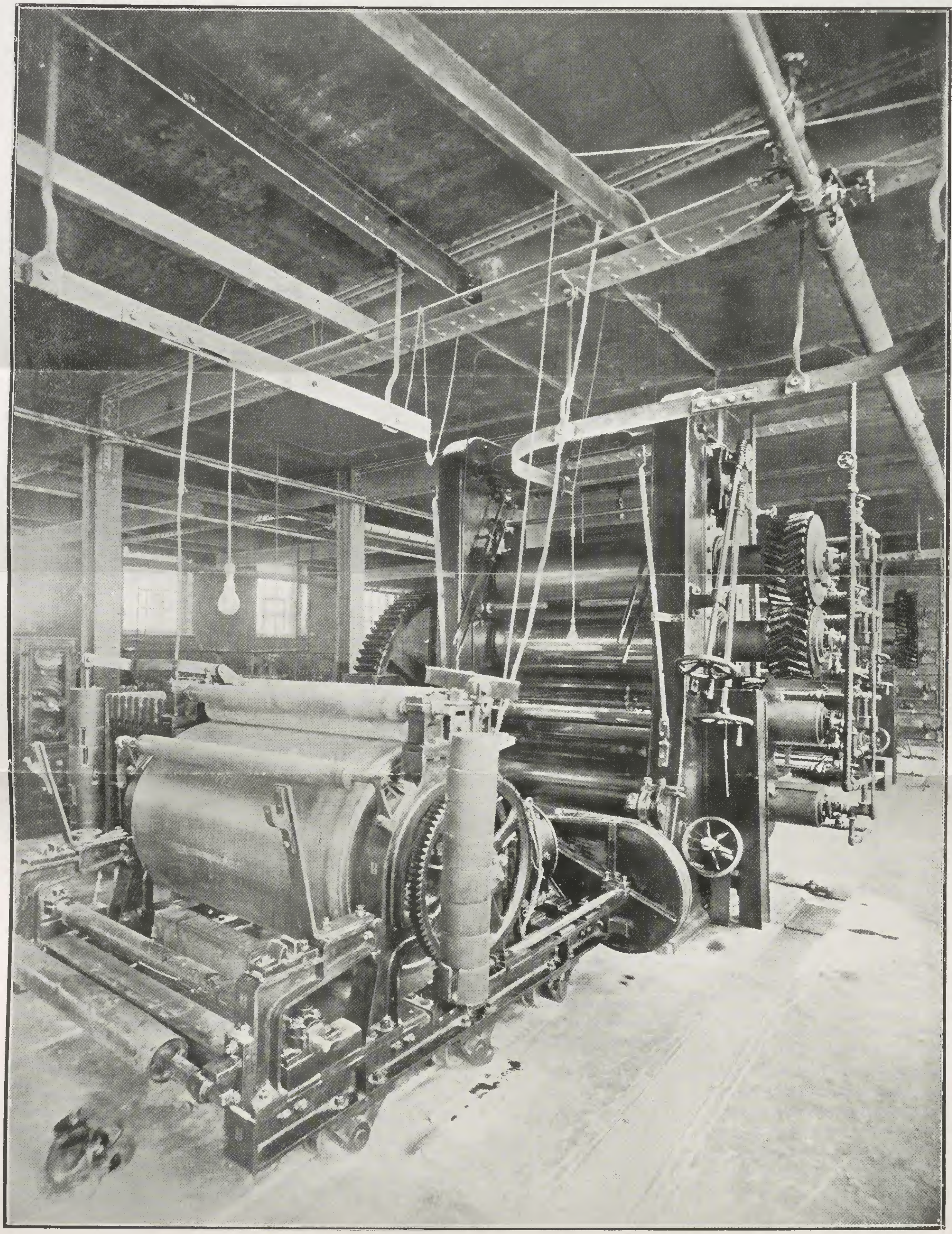


FIG. 3.—CALENDER.

To face page 9

Edinburgh, the staple article of which is vulcanised india-rubber. A company of American capitalists from the regions of New York have actually invaded the classical metropolis of the north, and in less than a year have raised up a concern of great magnitude. The thing strikes us as so curious and so important from a social point of view, that we have taken some trouble in enquiring into the whole subject." Following this there is given a description of the factory process as then in operation.

In 1857 the Limited Liability Companies Act came into force, and for the purpose of registration under this Act the formal dissolution of the firm of Norris & Company was effected and The North British Rubber Co., Ltd., came into existence, the first factory of its kind in Scotland, and an opportunity was taken with the introduction of further working capital to initiate the manufacture of belting, hose and mechanical goods, some of these under the patents taken out in the name of Mr Parmelee.

With these articles the practice adopted with success in America was closely followed in their manufacture, and reference was made in the advertisements and catalogues to the Goodyear patents and attention specially drawn to the fact that solvents were not employed, the object apparently being to draw a distinction between these products and those offered by Macintosh and Hancock, who had developed along the line of dissolving their rubber in coal-tar naphtha or turpentine. Time has proved that the statements in these advertisements were correct, as the manufacturing processes, as far as this country is concerned, first adopted in Edinburgh are now carried on in all factories and are fundamentally identical with the method of fabrication to-day, nearly seventy years afterwards. In passing, it may interest you to see photographs of a price list of 1859, drawing attention to these points I have mentioned, and a sight of a testimonial from Mr James Bertram, whose firm is well known in Edinburgh, written in 1858.

At this date was also first introduced the rubber-soled canvas shoe, which has now grown into such a popular line of footwear, especially at the seaside resorts in the summer season.

With the development of The North British Rubber Co., Ltd., it lost its purely American character, as capital was subscribed by residents in Edinburgh and Leith; and the next important development was by a number of those same shareholders in 1861, when the Scottish Vulcanite Company was formed. Adjacent ground to The North British Rubber Company was acquired, and factory premises were erected for the manufacture of hard rubber articles, principally combs.

This concern had a long period of great prosperity and continued as a separate company till 1910, when it was acquired by The North British Rubber Company, afterwards being run as one undertaking. This branch still continues to manufacture hard rubber combs as the major portion of their production, and it is the only factory of its kind in Great Britain. Of recent years the demand for other articles in hard rubber or vulcanite has been catered for, especially telephone parts, and, of more recent date, parts and material for wireless apparatus.

A year or so following the formation of the Scottish Vulcanite Company, a firm styled Thornton, Currie & Co. started business in Gilmore Park, but in 1866 they removed to Dalry Road, carrying on the manufacture of water-proofing and making up of articles from proofed cloth, under the name of William Currie & Co., its present name; Mr Wm. Currie, the senoir partner, who is still actively engaged in the business, being the patentee of the Eclipse golf ball in 1877.

In this same year the Victoria India Rubber Mills, situated in Leith Walk, were opened as a proofing factory. In 1894 this concern, which had been carried on as a private company, was converted into a limited liability company under the title of the Victoria Rubber Co., Ltd. Extensions were immediately thereafter made by the addition of a rubber boot and shoe factory, which with the proofing work, still continues as the main business of the company.

The growth of an important industry in the city, employing a large percentage of the industrial population represented by these firms is, strange to say, to be attributed to the persistent experimenting and undertaking, under very adverse circumstances, of an American, Charles Goodyear, together with the Patent Law regulations which made it possible to inaugurate this manufacture in Scotland; and with the establishment and success of the first firm these others, from that encouragement and example, embarked on similar undertakings. While it is within the realms of possibility that Edinburgh, under different conditions, may have had its rubber industry, we have to take facts as we find them, and the circumstances in this case are unusual and not without interest.

A matter of some interest at about the period of our history we have now reached was the experimental work in connection with the adaptability of rubber to road transport, carried out in the Edinburgh district between 1868 and 1875 by Mr R. W. Thomson. In the issue of the *Scotsman* of the 24th October 1868 they state, "Frequent mention has recently been made to the road steamer invented by Mr R. W. Thomson, of Edinburgh, and the new application of india-rubber embodied therein. The peculiarity of Mr Thomson's carriage is that the

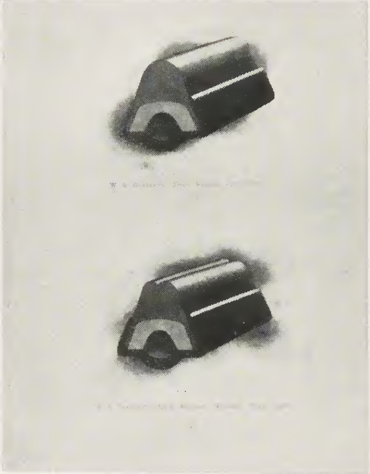
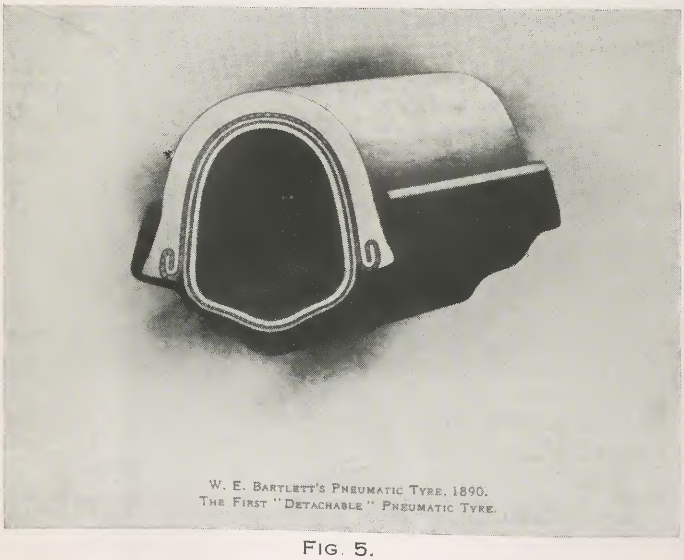


FIG. 4.—ORIGINAL BARTLETT "CLINCHER" TYRE.
PATENTED 1889.



W. E. BARTLETT'S PNEUMATIC TYRE. 1890.
THE FIRST "DETACHABLE" PNEUMATIC TYRE.

FIG. 5.

To face page 11

tyres of the wheels are composed of huge rings of vulcanised rubber. These tyres were made by The North British Rubber Company and are the largest pieces of material ever manufactured, each tyre weighing 750 lbs."

Whilst to-day the manufacture of tyres of this size presents no difficulties, at the date of these experiments it was no mean achievement.

The tests of the engine were carried out, I believe, between Edinburgh and Balerno, and were so satisfactory that several were built, some of which were shipped abroad. These engines were made with four wheels, but at later dates the three-wheel tractor was adopted and is to-day still being used, the tyres made the same, in every respect to the early experiment.

From this date to the late eighties there is nothing much of note, no outstanding feature connected with the industry other than the normal development which naturally took place with the application of rubber manufacture to an increasing demand from other industries for supplies that suited their purpose and the satisfying of the individual wants for wearing apparel and comfort, and while the factories in Edinburgh took their share in this development there is nothing that calls for special comment; but now with the desire for an easier and less fatiguing means of locomotion, attention was directed to improvements in cycle tyres as a means to that end.

There was nothing remarkable in the placing around the wheel a solid band of rubber as a cushioning device, it being stuck or sprung into position on a grooved rim, but the evolution from this I would like to follow for a little with you, as this was really the pioneer work from which was evolved the motor tyre that made the motor car of to-day possible, the essential principle of which we can claim the credit of being achieved in Edinburgh.

It can be safely said that at this time the tyre question was in a generally unsatisfactory condition, and the first patent for the beaded-edge tyre (which contained the germ of the idea on which all subsequent patents were based) was taken out by Mr W. E. Bartlett on July 24th, 1889. (Fig. 4.) This patent was for a rubber tyre and rim, for the success of the invention was dependent on the form of rim as much as the construction of the rubber tyre itself. The cushion tyre as well as the solid were already on the market, but both these tyres were either held in position by cementing to the rim or by a coil of wire embedded in the tyre, both of which methods were insecure fixtures. In the words of Mr Bartlett's specification it was claimed, "To form a rubber tyre with about three-fourths of its cross section circular or thereby, and the remaining part, or part in combination with the metal tyre, is expanded into a dovetail shape which is pressed into a dovetail groove in the metal tyre (or in non-technical language, rim) and so held to the wheel ; " a semi-circular groove was formed at the base of the dovetail portion of the tyre and immediately next to the rim for the purpose of an air cushion or chamber. The metal rim was of special design, the sides of which inclined towards the centre, forming recesses into which the dovetailed part of the tyre was held. The circumferential measurement of the rubber tyre was identical with that of the rim, so that the rubber was not in tension, neither was it held by cement of any kind, and by its peculiar construction was inseparable from the rim, and yet could be removed by a simple hand tool. This was the introduction of the first Clincher Tyre, easy of application, secure in position, and which, by its air chamber made cycling more comfortable than with other types in vogue.

The original Dunlop patent of 1888 suffered from the same drawbacks as the solid tyre in its method of attachment, as the canvas flaps by which the tyre was attached to the wheel were held by means of india-rubber solution, these flaps being carried over the metal rim and fastened on the inside between the spokes. I mention this so that you may more readily appreciate the difference in the method of attachment between the Dunlop and Bartlett patents, as the next step was the application of the 1889 Bartlett principle to the purely pneumatic tyre, the patent for which was taken out on 21st October 1890. (Fig. 5.) There had been many inventions for pneumatic tyres, all having for their object the prevention of puncture, which with the introduction of the pneumatic tyre was considered its great drawback, and this, together with the difficulties of detachment for repair, stood in the way of its popularity. Bartlett appreciated that what was wanted was an easily detachable tyre as a means of access for repairing the air tube to which damage was often unavoidable, and produced with this object the first detachable pneumatic tyre under the protected name of the "Clincher," which it will be seen from the photographs was a development of the solid tyre patent of 1889.

The virtue of this pneumatic tyre in comparison with others that were before the public was its extreme simplicity, as all that was necessary was a release of the internal air pressure for the removal of the outer band or cover to give accessibility for repair, and extremely simple in its form of attachment. The success of the tyre was practically immediate, and as a consequence during the succeeding year or so, many patents were applied for and granted to other inventors. Most of these, however, got no further, as they were of no practical utility or had already been anticipated. The only one of any merit which should be mentioned is that of Welch's patent introduced by the Dunlop Company, it being of the detachable tyre type accomplished by inextensible wire edges as distinct from the Clincher bead. At the same time the Clincher was being modified and improved. The outer arch of rubber which I have shown you in the illustration was originally made on the flat. This was now moulded and so more easily retained its shape, and it was also made lighter and with ribs moulded on the surface to give better road grip. The inner tube was made of pure rubber instead of with a fabric insertion as previously, and the rim was lightened in weight. It ultimately arrived in the form which has been the standard tyre construction for many years past and as you know it to-day, and which is so familiar that I need not describe it further; but pass on to more interesting facts, not, however, without paying tribute to the production of Mr Bartlett, which made road transport possible and comfortable.

Many infringements of the Bartlett patent were now being offered to the public, and it became necessary for The North British Rubber Company, who held the patent, to take legal steps to protect their rights, as otherwise it was becoming obvious that any advantages from the invention would be lost to them. The cases in the Courts are interesting from their novelty and the eminent personalities that appeared both as counsel and expert witnesses. The first case was against an English company, and amongst the counsel were Mr Fletcher Moulton, Q.C., afterwards Lord Moulton, and Sir Richard Webster, and as witnesses Sir Frederick Bramwell and Mr Dugald Clerk. The case came before the Court on the 26th February 1894, and judgment in favour of the plaintiffs was made on the 12th June, much delay being occasioned by the Judge calling for an independent expert report, as he had found the expert evidence most confusing.

The second case was against an American company, who, in spite of the decision given in the case just mentioned, continued to manufacture and place on the market, tyres which infringed the Bartlett patent. This case came before the Chancery Division of the Royal Courts of Justice, London, on the 12th November 1895. Six counsel were briefed, those appearing for The North British Rubber Company being the same as in the previous successful case. The array of experts was also swelled, those in the previous case also appearing, and Lord Kelvin, in addition, as a witness for the defendants. The trial lasted ten days, with judgment for the plaintiffs. The judgment was appealed against, and in due course came before that Court with three judges sitting. The hearing of counsel occupied five days, and judgment was given on the

18th February 1897 upholding the finding of the Lower Court. Intimation was given by defendants' counsel that the case would be carried to the House of Lords, and the final hearing came before them on the 6th December 1897, before five judges, including the Lord Chancellor. Counsel again occupied five days in their addresses, and the House of Lords confirmed the judgment of the two Courts below. This protracted lawsuit had lasted from the 12th November 1895 till the 1st April 1898, a period of two years and five months, and in giving judgment the Lord Chancellor strongly commented on the length of time the case had been before the Courts and the number of days it had occupied; the book of evidence he had before him contained 500 printed quarto pages. This protracted lawsuit was an endeavour to try to break down what was admitted to be, by persons who had a knowledge of the matter, a master tyre patent, and it was the first patent case brought before the House of Lords in which the invention of a pneumatic tyre was in question.

Although the patentees had been successful in the litigation, it was realised that with the popularity of this type of tyre further infringements were almost certain to arise, and when the opportunity presented itself to sell the patent to the Dunlop Company, advantage was taken of the substantial offer made, with the purchaser taking the responsibility of defending the patent and the original patentees making conditions with the sale which enabled them to continue manufacturing and selling to the public.

This, then, was the foundation originating in Edinburgh on which was built up that further development of the pneumatic tyre which made the motor car a possibility. Most of you are possibly well acquainted with the aspect of road transport, and time will not permit of going more closely into its development, so that I will pass on. Before finally leaving this part of the subject, however, it is worth mentioning those tests of endurance, not only of the tyre but of the riders, which were performed during the cycling boom period. Many of you will remember those record-breaking rides of twenty-four hours and the Land's End to John o' Groats journeys. I would like to draw attention to two exceptional feats as they will probably never be repeated, and are, I think, remarkable both for human endurance and for the materials with which they were performed. In October 1893 Charles Terront performed his famous ride of 2,000 miles from Petrograd to Paris, part of the journey over awful roads, finishing at the Velodrome Buffalo in Paris, where an enthusiastic crowd was awaiting him; his time being 14 days, 7 hours, 31 minutes. The other remarkable journey was that of R. L. Jefferson in 1898, who rode from

England to Khiva in Chinese Turkestan, right across Europe and Western Asia, a distance of 5,482 miles, and when one considers this journey across indifferent roads and districts where roads were non-existent, fording streams and crossing deserts, it was a marvellous feat of endurance accomplished in four and a half months. Both of these performances were successfully accomplished on ordinary push bicycles shod with pneumatic tyres, the product of an Edinburgh factory.

The development of the industry, not only in Edinburgh but in other parts, had up to this time been successfully accomplished by those responsible for the manufacture without technical assistance or any fundamental knowledge of the materials they were handling as far as their chemical or physical reactions were concerned, and great credit is due to their power of observation and application in building up an industry with so little material for their assistance. The visualising of its potentialities and the grasp of the subject is evidenced in the published book of Charles Goodyear which I have previously mentioned, as there is practically no application of rubber as employed to-day that is not mentioned in that publication. The research instinct and its application to practice was strongly in evidence, and it was fortunate that men of this calibre were attached to the industry in these early days.

At about the time we have reached in our narrative the chemist and the physicist began to take a hand in the industry, and from small beginnings the manufacture is now one of technical control, without which it is doubtful if the rapid advancement of the last twenty-five years would have been achieved. I can remember the first laboratory in an Edinburgh factory. It was really something of a makeshift arrangement, a corner of the works having been found to accommodate the chemist, who was looked upon as something of an experiment, and with expectations in some quarters no doubt far beyond his powers of attainment. As time went on, however, it was realised that whilst the laboratory was not the means of immediately solving all the factory troubles and difficulties, it was at least of some assistance in these difficulties, and a good friend in helping to negotiate the pitfalls of manufacture, with the result that to-day, it is the nerve centre through which the factory operates. Such matters as the testing of materials chemical and physical, and the checking of processes, are the ordinary evolution of laboratory control which call for no comment, but the application of specialised branches of science are of interest in their service to modern rubber manufacture as applied here in our own city, and I might briefly mention them.

The advancement in electrical engineering and the employment of higher voltages brought with them a more exacting demand upon the manufacture of insulating articles for which a rigid guarantee had to be given. In hard rubber this has to be manufactured in some instances to withstand a test of 125,000 volts per one millimetre of thickness, and for such articles as linesmen's gloves and shoes, these have to be tested to withstand up to 10,000 volts. As these goods are all delivered certified, the necessary test plant to subject them to these voltages was installed in the laboratory where all the goods are tested before delivery.

For many, if not most purposes, pure rubber is unsuitable, and it is necessary to mix or compound the rubber with other ingredients to obtain the desired result. Where mechanical factors enter into consideration, research has indicated that not only does the chemical reaction enter into the question, but physical conditions are materially responsible for the ultimate characteristics, influenced by particle size of the ingredients used. It must be realised that we are dealing with powders and materials in a fine state of division, so that the microscope has been pressed into service and microphotography now plays its part in deciding as to whether certain compounding ingredients are suitable or not when specific results are to be obtained. At first, observations were made simply by examination under a microscope, but whilst this gave some indication as to specific surface, the examination was not sufficient to give any recording data for future consideration, nor sufficiently accurate to throw any light as to the difference of behaviour of materials that were, as far as chemical examination was concerned, identical. Considerable advance was made and the camera was also pressed into service and microphotographs obtained from which some indication of particle size could be obtained by measurement. Magnifications from 600 to 1,600 were used, and whilst with the coarser materials the lower magnification gave good results, with the higher power which was necessary for the examination of very fine powders, the difficulty at once presented itself of obtaining sufficient definition, and as a result any measurements, owing to the lack of definite hard outlines, were unreliable. (Fig. 6.) To overcome this a method that was accompanied with a fair degree of success was adopted. The microphotograph was taken with a magnification of 700, at which degree good and sharp definition could be obtained with reasonable care with the finest pigments. From this a lantern slide was made, and this projected on a screen, and so further magnified ten times. There was then available a large scale picture of our pigment with a magnification of 7,000, from which reasonably accurate measurements could be made. By this

FIG. 6.—MICRO-PHOTOGRAPH—ZINC OXIDE

To face page 16.

Fig. 7.—Micro-Photograph of Stretched Section of Rubber containing Whiting.

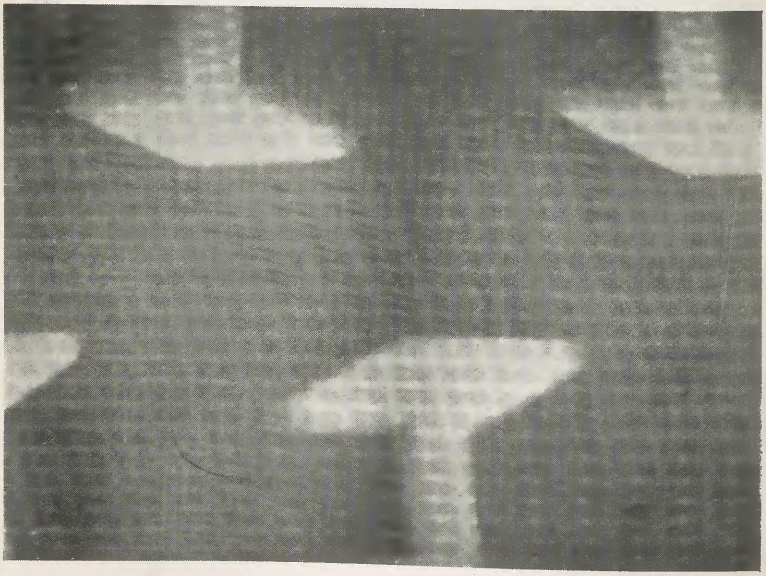


Fig. 8.—X-Ray Photograph Through Tyre Tread

To face page 17

method, measurements of particle size have been made as low as 0·3 of a micron, and in the hands of the works chemist has been a valuable adjunct to the purely chemical examination of compounding ingredients, throwing light upon the toughening power of certain ingredients that could not possibly be explained from the chemical laboratory.

These examinations have been taken one step further in investigating the functioning of a compounding ingredient, when the manufactured article is subjected to stress strain conditions with which a large percentage of the factory products have to comply. It was conceivable that the coarser the particle the greater its disintegrating action on the vulcanised rubber compound mix when subjected to repeated deformation, and some insight was desirable into the particle size that could be allowed for certain purposes. This line of investigation furnished reliable evidence which the laboratory could utilise in writing their formulæ for specific purposes. (Fig. 7.)

This branch of the technical side of the industry is of growing importance, and I have given no more than an outline of present application to manufacturing control, but those who are interested can obtain more detail from publications that have already appeared in several journals.

You will appreciate that physical conditions and factors as much as chemical reactions are responsible for the characteristics of our manufactures and the unseen to the naked eye must be taken into our calculations when working for some definite property in the final product. In order, therefore, that we may still further control our operations another field of examination and research has been utilised and X-ray examination and photography applied; on the one hand in checking continuous manufacture and on the other investigating problems which otherwise would have been impossible of elucidation. In the latter case it is possible by X-ray photographs to determine the exact position of different rubber mixings in a composite article, where from visual examination no such differentiation could have been obtained. As an example of this field of research a motor tyre may be built up with several grades of mixings in its composition, and it is extremely difficult to detect where these different qualities are placed by visual examination. Consequently for chemical analysis it is impossible to know where to separate the sample, but with an X-ray photograph in the hands of the chemical laboratory this is simplified, as you will readily see from the picture. Further, in manufacture, it is possible to detect the flow in moulding of the different rubber mixings, which after hydraulic pressure during vulcanisation often take up a different form from that in which they were built in their raw state, and thus corrections can be made in the building to obviate flow in the wrong direction or in excess. (Fig. 8.)

For the routine control of manufacture X-rays have been applied in the making of golf balls. This has been possible owing to the fact that balls are composed of a higher specific gravity core to the windings of rubber threads and cover, and with this construction it is of a necessity essential that the heavy core should be placed centrally. The process of winding and covering may, and does in some cases displace the heavy core, with the result that such a ball will not behave rationally. Consequently, it has now become the practice to examine all the balls at this stage of manufacture by an X-ray cabinet, rejecting those that show central core displacement.

The disastrous effects of balls with displaced centres, such as I have shown, on the play of the best of golfers can be imagined. If the displacement is in a vertical plane with the ball's flight, the effect will be similar to that of a wheel with one side heavier than the other, and consequently it will revolve in a jerky fashion, or if rolling along the ground go forward with a series of impulses, quickly when the centre of gravity is falling and slower in the reverse direction. Generally, however, the centre of gravity will be revolving in an orbit around the true centre of the ball, giving the effect of bias. One can easily conceive the exasperation in putting, for instance, with a ball that prefers travelling in curves to that of straight lines. The Gilbertian punishment of elliptical billiard balls is small fry to such a golfer's dilemma.

My narrative would not be complete without some reference to the Great War period when the rubber trade, as with all other industries, was called upon for super effort in the production of war material. Most, if not all of us think of that period as one of harrowed and anxious times, which we trust will never recur, but blended with a pride in the achievement of tasks undertaken, many of which have been lost or dimly remembered in our anxiety to let these years record their work in our ultimate victory.

We here in Edinburgh took our full share of those responsibilities, and whilst I am not going to detain you with particulars of what may be termed the commonplace requirements that were demanded of the rubber factories—interesting enough as records of enormous output for those intimately concerned in the industry—to this audience I might mention one or two particular undertakings which at this date, do not, I think, mean the divulging of any official secrets.

The fighting of the submarine menace was perhaps, one

FIG. 9.—PHYSICAL LABORATORY—NORTH BRITISH RUBBER CO., LTD.

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of the most difficult problems of the war, and whilst it was not so difficult a matter to deal with the " U " boat when he had made his presence known in characteristic fashion, attention was directed to some method of forestalling his intentions before there was any opportunity of putting them into operation. With perseverance this became fairly successful. As far as the Navy and our harbours were concerned entirely so, and in the case of merchant shipping equally reliable when instructions were strictly obeyed. The method was one of listening-in. In the case of shipping, a microphone was attached to the ship exactly in the same manner as a ship's log. The microphone itself was enclosed in a rubber container which was generally referred to as a fish (one of which I have here), made with fins to ensure an even keel when being towed. At the other end of the line at some convenient place on board, instead of the familiar dial of the log this was replaced by a headphone, and by this means it was possible to detect the presence of any under-water craft for a considerable radius. For harbour work the microphone container was of a different form, generally a ball, as it was sunk in a fixed position, there being no necessity for towing. These were placed at known positions, connected up to a central listening station with a switchboard, so that any part of the harbour could be plugged in. To give you some idea of the delicacy of this method of detection, on one occasion when I was at the Forth Control Station, which was situated on the north shore not far from Aberdour, it was possible to hear quite distinctly the rattle of boiler chipping operations of some of the fleet five miles away. The men on duty at the Control were able to notify the approach of any ship into the Forth before even being sighted, and what was of extreme value, with their experience they could generally identify the ship. At night this method of detection was absolute, it being known just what ships were on patrol, and consequently a stranger had no chance of slipping through. The most interesting part of this application of rubber covered microphones was perhaps, their fitment to our own submarines in the shell of the ship, and I believe we had this advantage over the Germans that whilst they had some such form of detection, they were at the disadvantage that with their instruments they had to stop their engines to listen, whilst we could carry on and still get perfect reception. This was all an application of the rubber fitting which the enemy was sadly deficient in. I had the opportunity of listening to the German equipment on a captured submarine, and unless they later made improvement it was of little value as reception was so blurred that except to a very trained ear the internal noises of the "U" boat itself were sufficient to obliterate every other sound.

You will perhaps be wondering how our men were to know the sound of a German submarine unless they had been unpleasantly near one. Here again, rubber came to the rescue! You of course are aware that gramophone records are made of hard rubber. I was not let into the secret of how the records were obtained, but at the Anti-Submarine Training School all those who had the authority, or in my case the privilege, had the spectacle of a class intently listening to a gramophone playing, not the latest craze in dance music, but a grimmer tune, that of the "U" boat.

In the countering of another form of German culture, the Edinburgh factories were heavily called upon, and under conditions when speed of production and reliability were essential to meet the call of the unexpected. We were totally unprepared and with no appliances or equipment, as has been recorded elsewhere, to meet the German gas attacks, and the demand was made for immediate supplies of anti-gas equipment in the form of respirator tubes, breathing valves and anti-gas mask fabrics. These were all forthcoming, and with the latter the Victoria Rubber Company were actively engaged. I am informed by them that they produced for the fighting services just on half a million square yards of this special fabric for the manufacture of gas masks as a protection to our men against this hideous form of warfare.

From these references to our participation in the special forms of warfare in the sea and on land, let me pass to the air where the technical knowledge available here was of such material assistance in both the offensive and defensive aspects of the campaign, and was on more than one occasion able to assist in difficulties, where apparently help from other quarters was unavailable. Such a statement sounds incredible, but history has shown that as a nation we were unprepared in many ways, and as far as our lighter-than-air craft equipment went, the question of supplies to the services was certainly in a dangerous position. For some years prior to the war we had made repeated efforts to obtain orders for gas-bag material for the construction of airships and balloons, and although we were actually supplying material to the French Government from the Edinburgh factory for airship construction, we could not get our people to encourage us with a single order. As affairs turned out, it was fortunate that we had continued our efforts in spite of these rebuffs, which were most discouraging, as the only source of supply our own people would use was German, the bulk of their requirements being obtained from the Continental Company of Hanover.

With the outbreak of war in August 1914, supplies naturally ceased, and the Navy, who at this period were solely responsible for lighter-than-air craft, were left without the means of continuing their construction. At this stage someone remembered that in the north possibly lay the solution of the difficulty, and the speaker spent the best part of a night in the constructional sheds at Walney Island, getting the particulars of the gas-bag material that was needed to complete two ships of the Parseval type, numbers 6 L and 7 L, which were urgently required for service. The requisite fabric was supplied within a few weeks, as, fortunately, from our experience of the French ships, we had the technical knowledge to enable us to proceed at once with the work. Although I have no actual knowledge of their performance, both these ships went into commission and, no doubt, rendered a good account of themselves, being used for coast patrol work on the East Coast and carrying out a great number of night cruises. As far as our participation in their completion was concerned, I am afraid we received little recognition. It was all in the day's work, so to speak, and the only acknowledgment of the situation I should like to quote appeared in a book, "The British Aircraft Industry," published immediately after the war. Speaking of these early days it states, "the first obstacle was the supply of a suitable fabric. The only British firm with a knowledge of balloon fabrics at that time was The North British Rubber Company of Edinburgh." You may be interested in the general particulars of design of these Parseval ships. Their length was 312 feet, width 57 feet, height 70 feet, gross capacity 36,000 cubic feet, 360 h.p., maximum speed 40 miles per hour, with an endurance of 1,000 miles at full power.

The necessity in the land campaign of close observation of troop movements, and particularly the spotting and controlling of artillery fire, produced an ever-increasing demand for captive or kite balloons. The demand was first made in 1915, and, again quoting the publication just referred to, it is stated that the first British kite balloon manufactured was from cloth supplied by the Victoria Rubber Company, Edinburgh. The advantages of this method of observation were quickly realised, and brought a heavy demand upon the Edinburgh factories. Up to this period, spotting had been done entirely by aeroplane, and many a good aeroplane pilot had wasted hours in flying slowly round in a circle watching a certain spot, waiting for the German guns to disclose their positions. Occasionally, I am told, our battery with which they were working became bored and moved their position whilst the observer was still in the air, and when he did signal it was to a friend who was not there. It was found better policy to send up kite balloons and so free an aeroplane pilot for work more suitable. An artillery officer, more experienced in fire control, did much better in the balloon, being in direct telephone communication with his battery and not fluttering round sending signals to a deserted hole in the ground.

With the increasing size of our Army the call for balloon material became greater than the factory capacity at Castle Mills, and was incidentally the cause of much indignation from residents in Edinburgh as to why, when such stringent regulations were imposed as to the showing of lights at night, the North British Rubber Company were allowed to have a glare at Fountainbridge that could be seen for many miles around. The explanation is a simple one and was a case of necessity. It was decided that a new block of buildings had to be erected and time was an important factor. A four-storey building, 190 feet by 55 feet, built of reinforced concrete and brick, as steel was unavailable, was erected. The instructions were received in September 1916, and the building and machinery had to be ready by the following Spring; that was the order! Building had to be proceeded with, therefore, during the winter months and with reinforced concrete was no easy undertaking. Night and day work was resorted to, and you will realise brick laying cannot be successfully done in the dark. The whole operation was accordingly illuminated at night by large electric lamps out in the open, and, in addition, fires were kept going around the concrete work to keep off the frost, which we were unfortunately troubled with. Hence the complaints and letters in the papers, &c., suggesting pro-German tendencies, illustrated by the beacon to attract the enemy air raiders. But fears were groundless. The lights were controlled by one service switch which could plunge the place into darkness instantly and the fires doused in a few minutes. The speaker was in telephone communication with the Scottish Defence, who used to ring up at all odd hours, sometimes, I thought, for their amusement. The call was "Field Marshal's call only"; that meant "all right, do nothing," and to be pulled out of your bed at any uncomfortable hour to receive this call produced anything but a good opinion of the Field Marshal, whoever he may have been. I did omit to answer the call on one or two occasions, but then my front door bell was furiously rung shortly afterwards by a policeman who came to enquire what I was doing. Apparently the explanation sufficed, and I suppose they realised I was human and must sleep sometimes, as no dire penalties befell me.

For a period, practically the whole of the requirements of the kite balloon service were supplied by the Edinburgh factories, but as the importance of this arm of the fighting services increased, and also the demand, it was necessary for security of supplies not to be dependent on one factory from which the bulk of the material was obtained, with the danger of this manufacture being cut off by fire or air raid. Consequently, when these further additions were completed, the ever-increasing demand over this output was spread to other works around the country.

One interesting matter I might mention in connection with unexpected and sudden demands was that occasioned by the entry of America into the war. We were informed they were not in a position to equip themselves with balloons and we should need to help out the United States Army. No doubt some of this was done, but we in Edinburgh were able to give such assistance that, whilst not manufacturing the balloon fabric, we could give America just that information to enable them to manufacture quickly for their own requirements. We took into The North British Rubber Company representatives of the American Air Force, who were also technical rubber men, and showed and told them all we knew. Further, when their instruction, which was of the intensive kind, was complete, we sent back with them to America a practical man to see their plant operating properly. It was fortunate also that we had supplied to America, from our works here in 1911, machinery of the type suitable for this class of work, so that no delay was met with in the shipping or building of machinery. By this means we did our bit in giving the United States Army their eyes to see with.

One other achievement in this sphere was the manufacture of a special type of fabric which successfully withstood the severe climatic conditions of the Palestine and Mesopotamian campaigns. The balloons that were used in the European fields of operation were found to be quite unsuitable for the East, and gave a very limited service. This difficulty was overcome by a special protective manufacturing process, a product of the factory research staff.

The facts of a little game of bluff we practised on the Germans by means of decoy or miniature balloons may be of interest. The real kite balloon had a capacity of 37,000 cubic feet, and was flown at a height of something like 4,000 feet and upwards well behind the trenches, generally several miles. To make the enemy think he was under observation, and to induce him to fire his batteries and disclose gun positions, exact miniatures of these full sized balloons were flown. They were of a capacity of 600 cubic feet and reached an altitude of 1,000 feet, a doll being put in the basket to represent the observer. To make the illusion perfect they were let up from the forward trenches in the half light of early morning. The stunt was, I believe, quite effective for a time, until the enemy got wise and shy of early morning K.B. efforts.

Altogether during the war the Edinburgh factories manufactured over $2\frac{1}{4}$ million yards of balloon cloth, and at the time of the Armistice were turning out something like 50,000 yards per week, part of which was being converted into the finished balloon, and the balance being sent elsewhere to balloon constructors. The control work in the hands of the aeronautical laboratory, which was installed at Castle Mills to supervise and test the manufacture, was no mean achievement. Time is not available to refer to this in any detail, except to say that at the height of productive capacity eighty diffusion tests for checking hydrogen leakage and some hundreds of tensile tests were carried out every twenty-four hours. The rapid development of kite balloon manufacture was one of the marvels of the war, only possible through the research work of a private enterprise which also promptly responded to the requirements of airship construction and made possible the wishes of the Air Department under conditions of emergency and great difficulty.

With that, ladies and gentlemen, I must bring my discourse to a close. Time has not been available to give you many details which have been necessarily omitted, and with others touched on my remarks have been simply in outline and can convey to you nothing but a sketchy description of the subject. I trust, however, it has been sufficient to give you an intelligent history of the growth of the rubber industry in our city, and to indicate that our efforts have not been without their effect for the good of the industry as a whole. In times of emergency we were able to take our full share in the Empire's call for assistance, and in the help we gave to America we were able to repay any debt of sentiment to that country, occasioned by the enterprise of a few of their citizens establishing the rubber industry in Edinburgh.

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ROYAL SCOTTISH SOCIETY OF ARTS

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Gray, on True Measure of Probabilities of Survivorship between Two Lives.
Grisdale, on Agriculture and Forestry.
Grove, on Correlation of Physical Forces.
Grove, on Progress of Physical Science.
Guthrie, on Graphic Tabulation.
Guthrie, on Thermo-Dynamic Analysis of Gas Engine.
Guthrie, on Thermo-Dynamic Analysis of Steam Engine.

Hardy, on Methods of Approximation.
Harper, on Automatic Expansion Gear for Steam Engines.
Hartley, on Indicator Diagrams.
Hayter, on The Amsterdam Ship Canal.
Hedges, on Principal Systems of Electric Light in England and United States.
Henriksen, on The Iron Ore Deposits in Sydvaranger.
Henriksen, on Sundry Geological Problems.
Higham, on Policy Holder against The Company.
Holley, on Chemical and Physical Analyses of Phosphoric Steel.
Holt, on Progress of Steam Shipping.
Horsley, on Pipes for the Thirlmere and Bombay Water Works.

Ingleby, on Knop's Turbine.
Ireland, on Motor Cultivator (see " Horseless Age ").

Jellicoe, on Surrender of Policies of Assurance.
Jenkin, on Braced Arches and Suspension Bridges.

Kendall, on Inventor of Morse Telegraphy.
Kenney, on Isthmus of Suez Canal.
Kenyon, on Dock Construction.
Kiernan, on Continuous Brakes.
Kiernan, on New Methods of Signalling, &c.
Kirkaldy, on Tensile Strength of Wrought-Iron and Steel.

Lachlan, on Uniform System of Meteorological Observations.
Lane, on Cleft Palate and Hair Lip.
Laws, on Railway Bridge over River Tyne at Wylam, Northumberland.
Leslie, on Flow of Water through Pipes, Conduits and Orifices.
Leslie, on Hooghly Floating Bridge.
Lesseps, on Isthmus of Suez Question.
Levi, on Prof. Leoni and the Proposed Chair of Commercial and Political Economy at Edinburgh University.
Longridge, on Construction of Heavy Ordnance.
Longridge, on Evaporation of Lancashire Boilers.
Longridge, on Evaporative Power of Locomotive Boilers.
Longridge, on Flow of Water through Level Canals.

Mackenzie, on Risk of Fire from Steam and Hot-Water Pipes.
Mackenzie, Salmon and Williams, on Harbour and Dock Works.
Mackay, on Use of German Yeast in this Country.
Maclagan, on Composition of Bread.
Macoun, on Agriculture and Forestry.
Maiden, on Collection and Preservation of Raw Products.
Mallet, Lambert and Avern, on Bridges on the Punjab Northern State Railway.
Mallet, on the Coefficients of Elasticity and Rupture in Massive Forgings.
Mallet, on Deflection of Girders by Rapidly Passing Loads.
Mallet, on Observation of Earthquake Phenomena.
Marten, on Explosion of Boilers and other Vessels.
Mather, on Technical Instruction.
Millar, on Strain and Fracture in Bars of Various Materials.
Millar, on Transmission of Vocal and other Sounds by Wire.
Morsaut, on Coal-Washing Apparatus at Bessèges, France.
Mortimer, on The Chalk Water Supply of Yorkshire.
Morton, on Maximum Elasticity and Density of Vapours.
Mountmorres, on Commercial Possibilities of West Africa.
Muir, on Construction of Track of Railways.
Muir, on Light Railways.

Napier, on Most Profitable Speed for a Fully-Laden Cargo Steamer.
Napier, on Pressure Logs for Measuring Speed of Ships.
Napier, on Soft-Water Springs of Surrey Lands.

Napier and Hope, on Utilisation of Sewage.
Nasmith, on Automatic Sprinklers.
Nasmith, on Growth of Industries at Home and Abroad.
Nasmith, on Modern Cotton Carding Machine.
Nasmith, on Recovery of Bye-Products of Coke Manufacture.
Nasmith, on Ring Spinning Machinery.
Newall, on Law of Patents for Inventions.
Newman, on A New Snow Plough.
Nichols, on The Roman Forum.
Nicol, on Inventor of Screw Propeller.

O'Connor, on Marine Crank-Shafts.
Ordnance Survey (Scotland) Committee's Report.
Owen, on Raw Materials.

Parkes, on Immigration.
Parr and Kressmann, on Spontaneous Combustion of Coal.
Paterson, on Testing of Pipes and Pipe-joints in the Open Trenches.
Peat Charcoal for Sanitary and Agricultural Purposes—Irish Amelioration Society.
Perry, on Mechanical Engineering in Electrical Industries.
Phipson, on Heating and Ventilating Apparatus of Glasgow University.
Pickwell, on Encroachments of the Sea from Spurn Point to Flamboro' Head.
Pinckard, on Clerical, Medical and General Life Assurance Society.
Playfair, on Chemical Principles involved in the Manufactures of the Exhibition.
Pole, on Ventilation of Mount Cenis Tunnel.
Potter, on Railway Work in Japan.
Prestwich, on Construction of Tunnel between England and France.

Rankine, on Effect of Storms on Sea Walls and Bulwarks near Edinburgh.
Renold, on System in Engineering Works.
Renton, on Part 1—Economy of Fuel on Board Steam Vessels.
Part 2—Earl of Dundonald's Patent Tubular Marine Boiler.
Ritchie, on Architect of Heriot's Hospital.
Robertson, on Large Blasts at Holyhead.
Robertson, on Mud Banks of Narrakal and Allippey.
Robertson, on Science Education Movement.
Robertson, on Utilisation of Sewage.
Robinson, on Ether.
Robinson, on Highgate Hill Cable Tramway.
Royal Society of Canada, on Unification of Time at Sea.
Russell, on Operations of Improvement Trust (Glasgow).
Rymer-Jones, on The Temnograph.

Sandeman, on Portland Cement Concrete.
Sang, on Theory of Linear Vibration.
Schroller, on Ammonia Still, &c.
Scott and Redgrave, Bernays and Grant, on Portland Cement.
Sergêevsky, on Finland.
Shaw, on Small Motive Power.
Smith, on Direct Reading Micrometer Wire Gauge.
Somerville, on Patent Safety Gun.
Squire, Whitley and Copperthwaite, on Earthwork Slips.
Stevens, on Wood Paving in London.
Stevenson, on Earthquake in Scotland and Ireland.
Stevenson, on Floating and Fixed Lighthouses.
Stevenson, on Improvements to River Lune Navigation.
Stevenson, D. and T., on Sir David Brewster's Memorial on Dioptric Lights: also reply to Sir David Brewster's Reply to former.
St Hilaire, on Isthmus of Suez Canal.
Stooke, on Rural Water Supply.
Stuyvaert, on Statique Dynamique.
Suez Ship Canal, Report and Plan.
Sugden, on The Four Large Steam Engines.
Swan, on Capillary Attraction exhibited by Chloroform, &c.
Swan, on Total Eclipse of Sun, 1851.

Target, on The Main Drainage of Paris.
Thermal Efficiency of Steam Engines, Committee's Report.
Thompson, on Electro-Magnetic Mechanisms.
Thompson, on Light Draught Steel P.S. "Terranora" for Ocean and River Navigation.
Thomson, on Sanitary Engineering.
Twelvetrees, on Calculating Reinforced Concrete Beams.

Unwin, on The Centrifugal Pump.

Ventilation and Lighting of the House, Committee's Report.
Vernon-Harcourt, on Engineering Progress in Foreign Countries.
Viceajee, on Hand Minting of Coins of India.
Vladmirov, on Revolution in Finland.

Wallace, on Adulteration of Dairy Produce.
Waring, on Drainage, Irrigation and Cultivation of the Albufera of Alcudia Majorca.
Washington, on Mapping of a District with Reference to a Central Meridian.
Wells, on The Anderton Hydraulic Lift.
West, on Manufacture and Distribution of Gas, &c.

Westland, on The Calder Viaduct.
Williams, on Combustion du Charbon.
Williamson, on Electric Lighting.
Willotte, on The Removal of Sunken Rocks in Brest Harbour.
Wilson, on Drainage and Improving 1,500,000 Acres of Desert Land.
Wilson, on Lubrication.
Winslow, on Protection of River and Harbour Waters from Municipal Wastes.
Wise, on Patent Agents.

ABRIDGMENTS OF SPECIFICATIONS RELATING TO PATENTS FOR INVENTIONS

Acids, Alkalies, Oxides and Salts, 1622-1883.
Aeronautics, 1815-1866.
Agriculture, 1618-1876.
Air, Gas, and other Motive Power Engines, 1635-1876.
Anchors, 1796-1866.
Artists' Instruments and Materials, 1618-1866.

Books, Portfolios, Card-cases, &c., 1768-1866.
Brewing, Wine-Making and Distilling Alcoholic Liquors, 1877-1883.
Bricks and Tiles, 1861-1866.
Bridges, Viaducts and Aqueducts, 1750-1866.
Brushing and Sweeping, 1699-1866.

Calico and other Fabrics: Bleaching, Dyeing and Printing, 1617-1883.
Carriages and other Vehicles for Common Roads, 1625-1866.
Carriages and other Vehicles for Railways, 1807-1866.
Casks and Barrels, 1797-1866.
Chains, Chain Cables, &c., 1634-1876.
Cooking, Bread-making and Preparation of Confectionery, 1634-1866.
Cork, Preparing and Cutting, Bottling Liquids, &c., 1777-1866.

Drain Tiles and Pipes, 1619-1855.
Drains and Sewers, 1619-1866.

Electricity and Magnetism, 1839-1883.

Fabrics, Dressing and Finishing, &c., 1620-1876.
Farriery, 1719-1866.
Fire-arms and other Weapons, Ammunition and Accoutrements, 1588-1866.
Fire Engines, Extinguishers, Escapes, Alarms, &c., 1625-1866.
Food, Preservation of, 1856-1866.
Fuel, Preparation and Combustion of, 1620-1865.
Furniture and Upholstery, 1620-1866.

Gas, Production and Applications of, 1681-1866.
Grain-Grinding, and Dressing Flour and Meal, 1623-1866.

Harbours, Docks and Canals, 1617-1866.
Hinges, Hinge-joints and Door Springs, 1775-1866.
Hydraulics, 1617-1866.

Ice-making Machines, Ice Safes, Ice Houses, 1819-1866.
India Rubber and Gutta Percha, including Air, Fire and Water-proofing, 1859.
India Rubber and Gutta Percha, Preparation of, 1791-1866.
Iron and Steel, Manufacture of, 1857-1883.

Lace and other Looped and Netted Fabrics, 1675-1864.
Lace-making, Knitting, Netting, &c., 1675-1866.
Lamps, Candlesticks, Chandeliers, &c., 1637-1866.
Letterpress and Similar Printing, 1858-1876.
Locks, Latches, Bolts, and Similar Fastenings, 1774-1866.
Locomotion, Aids to, 1858.

Manure, 1856-1866.
Marine Propulsion, 1618-1866.
Masts, Sails, Rigging, &c., 1625-1866.
Medicine, Surgery and Dentistry, 1620-1866.
Metallic Pipes and Tubes, 1741-1876.
Metals and Alloys, 1861-1883.
Metals, Plating or Coating with Metals, 1637-1865.
Milking, Churning, and Cheese-making, 1777-1866.
Mining, Quarrying, Tunnelling and Well-sinking, 1618-1866.
Music and Musical Instruments, 1694-1866.

Nails, Rivets, Bolts, Screws, Nuts and Washers, 1618-1866.
Needles and Pins, 1755-1866.

Oils, Animal, Vegetable and Mineral, 1617-1863.
Oils, Fats, Lubricants, Candles and Soap, 1617-1866.
Optical, Mathematical and other Philosophical Instruments, 1636-1866.

Paints, Colours and Varnishes, 1618-1866.
Paper, Cutting, Folding and Ornamenting, 1636-1876.
Paper, Pasteboard and Papier Mâché, 1858-1866.
Photography, 1839-1876.
Pottery, 1626-1866.
Printing, 1851-1861.

Railways, 1770-1866.
Railway Signals and Communicating Apparatus, 1840-1866.
Raising, Lowering and Weighing, 1617-1866.
Roads and Ways, 1619-1866.

Saddlery, Harness, Stable Fittings, &c., 1625-1866.
Safes, Strong Rooms, Tills and similar Depositories, 1801-1866.
Sewing and Embroidering, 1756-1883.
Ship Building, Repairing, Sheathing and Launching, &c., 1618-1860.
Skins, Hides and Leather, 1627-1866.
Spinning, 1624-1866.
Steam Culture, 1618-1856.
Steam Engine, 1618-1866.
Steering and Manœuvring Vessels, 1763-1866.
Sugar, 1663-1866.

Tea, Coffee, Chicory, Chocolate and Cocoa, 1704-1866.
Toys, Games and Exercises, 1672-1866.
Trunks, Portmanteaus, Boxes and Bags, 1635-1866.

Umbrellas, Parasols and Walking Sticks, 1780-1876.
Unfermented Beverages, Aerated Liquids, &c., 1774-1866.

Ventilation, 1632-1866.

Washing and Wringing Machines, 1691-1876.
Watches, Clocks and other Time-keepers, 1661-1866.
Water, Purifying and Filtering, 1675-1876.
Waterclosets, Earth Closets, &c., 1775-1866.
Wearing Apparel, 1631-1883.
Weaving, 1820-1866.
Writing Instruments and Materials, 1635-1866.

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