The Whittle Jet Propulsion Gas Turbine*

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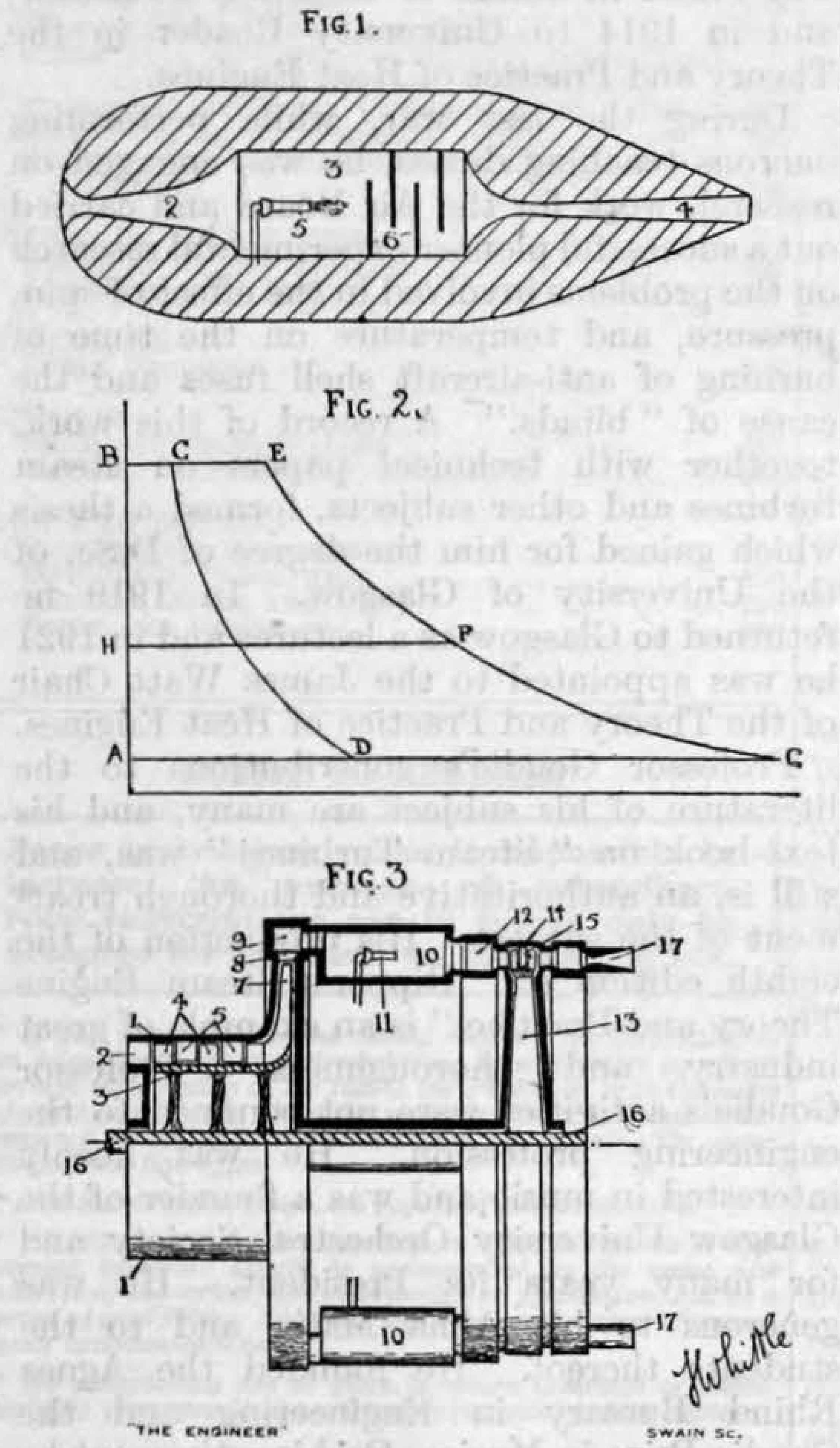
No. I

Introduction and General Outline

THE main argument against the gas turbine was that the maximum temperatures permissible with materials available, or likely to be available, was such that the ratio of positive to negative work in the constant-pressure cycle could not be great enough to allow of a reasonable margin of useful work to be obtained, after allowing for the losses in the turbine and compressor. There seemed to be a curious tendency to take it for granted that the low efficiencies of turbines and compressors commonly cited were inevitable. I did not share the prevalent pessimism because I was convinced that big improvements in these efficiencies were possible,



The upper drawing—the thermo-propulsive duct—had to be deleted from the specification

Fig. 1—*Reproduction of Drawings Illustrating British Patent No. 347,206, filed* January 16th, 1930

and, in the application of jet propulsion to aircraft, I realised that there were certain favourable factors not present in other applications, namely :—

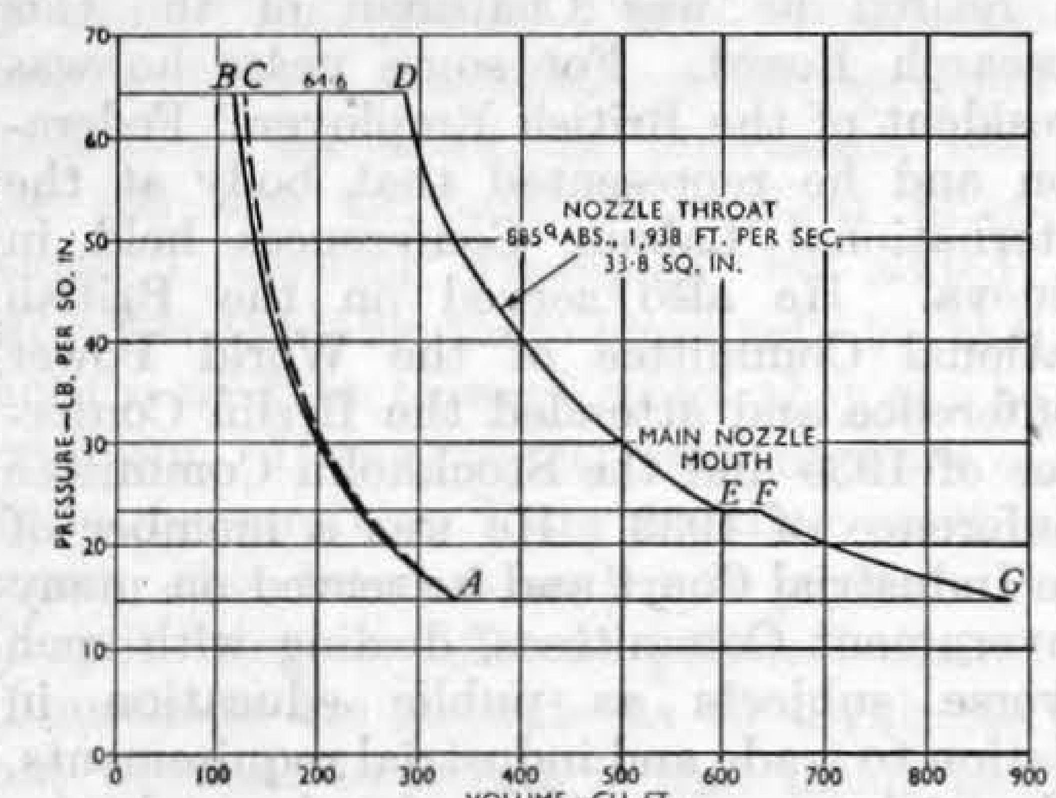
(1) The fact that the low temperatures at high altitudes made possible a greater ratio of positive to negative work for a given maximum cycle temperature.

(2) A certain proportion of the compression could be obtained at high efficiency by the ram effect of forward speed, thereby raising the average efficiency of the whole compression process.

(3) The expansion taking place in the turbine element of such an engine was only that which was necessary to drive the compressor ; and therefore only part of the expansion process was subject to turbine losses.

Outline.—I first started thinking about this general subject in 1928, in my fourth term as a Flight Cadet at the R.A.F. College, Cranwell. Each term we had to write a science thesis, and in my fourth term I chose for my subject the future development of aircraft. Amongst other things, I discussed the possibilities of jet propulsion and of gas turbines ; but it was not until eighteen months later, when on an instructors' course at the Central Flying School, Wittering, that I conceived the idea of using a gas turbine for jet propulsion. I applied for my first patent in January, 1930. The principal drawing of the patent specification as filed is reproduced in Fig. 1. It may be seen that I tried to include the propulsive duct, or "athodyd," as it has since been called, but this had been anticipated at least twice, so the upper drawing and relevant descriptive matter had to be deleted from the specification.

The idea was submitted to the Air Ministry, but was turned down on the ground that as it



Sea level cycle.

Assumptions :—Compressor efficiency, 70 per cent.
Turbine efficiency, 70 per cent.
Axial velocity at turbine exhaust, 1020ft. per second.
Efficiency of final expansion, 90 per cent.
Weight of air, 26 lb. per second.
Weight of fuel, 0·3635 lb. per second.
$\gamma = 1 \cdot 4$ for compression $= 1 \cdot 379$ for expansion.
$K_p = 0 \cdot 24$ for compression $= 0 \cdot 25$ for combustion and expansion.
Static thrust, 1240 lb.

Fig. 2—*The Pressure-Volume Diagram, Design Assumptions, &c., on which the Initial Design of the Experimental Engine was Based*

was a gas turbine the practical difficulties in the way of the development were too great.

During 1930 I tried to interest various firms in the scheme, but met with no success ; for the most part they thought the same way as the Air Ministry. It is probably also true that in their view the prevalent industrial depression made it anything but a favourable moment for expensive ideas of this sort.

Nothing very much happened for a few years. I gave up hope of ever getting the idea to the practical stage, but continued to do paper work at intervals, until, in May, 1935, when I was at Cambridge as an engineer officer taking the Tripos Course, I was approached by two ex-R.A.F. officers (Mr. R. D. Williams and Mr. J. C. B. Tinling), who suggested that they should try to get something started. Though I had allowed the original patent to lapse through failure to pay the renewal fee, and though I regarded them as extremely optimistic, I agreed to co-operate. I thought that there was just a bare chance that something might come of it.

We eventually succeeded in coming to an arrangement with a firm of investment bankers (Messrs. O. T. Falk and Partners), which led to the formation of Power Jets. Ltd., in March, 1936. Before Power Jets was formed, O. T. Falk and Partners obtained the opinion of a consulting engineer (Mr. M. L. Bramson), who gave a wholly favourable report. The initial sum subscribed was £2000, and with this we cheerfully went ahead.

The President of the Air Council was a party to the agreement which resulted in the formation of Power Jets, and the Air Ministry was a shareholder from the start in that a proportion of the shares alloted to me was held in trust for the Department.

During the negotiations leading to the formation of Power Jets, I was working on the designs of an experimental engine. Messrs. O. T. Falk and Partners placed an order with the British Thomson-Houston Company, Ltd., for engineering and design work in accordance with my requirements in advance of the formation of the new company. Power Jets placed the order for the manufacture of the engine (except the combustion chamber, instruments, and some accessories), with the British Thomson-Houston Company in June, 1936.

The engine was to be a simple jet propulsion gas turbine having a single-stage centrifugal compressor with bilateral intakes, driven by a single-stage turbine directly coupled. Combustion was to take place in a single combustion chamber through which the working fluid passed from the compressor to the turbine.

We were going beyond all previous engineering experience in each of the major organs. We were aiming at a pressure ratio of about 4/1 in a single-stage centrifugal blower when at the time, so far as we knew, a ratio of $2\frac{1}{2}$/1 had not been exceeded. We were aiming at a breathing capacity in proportion to size substantially

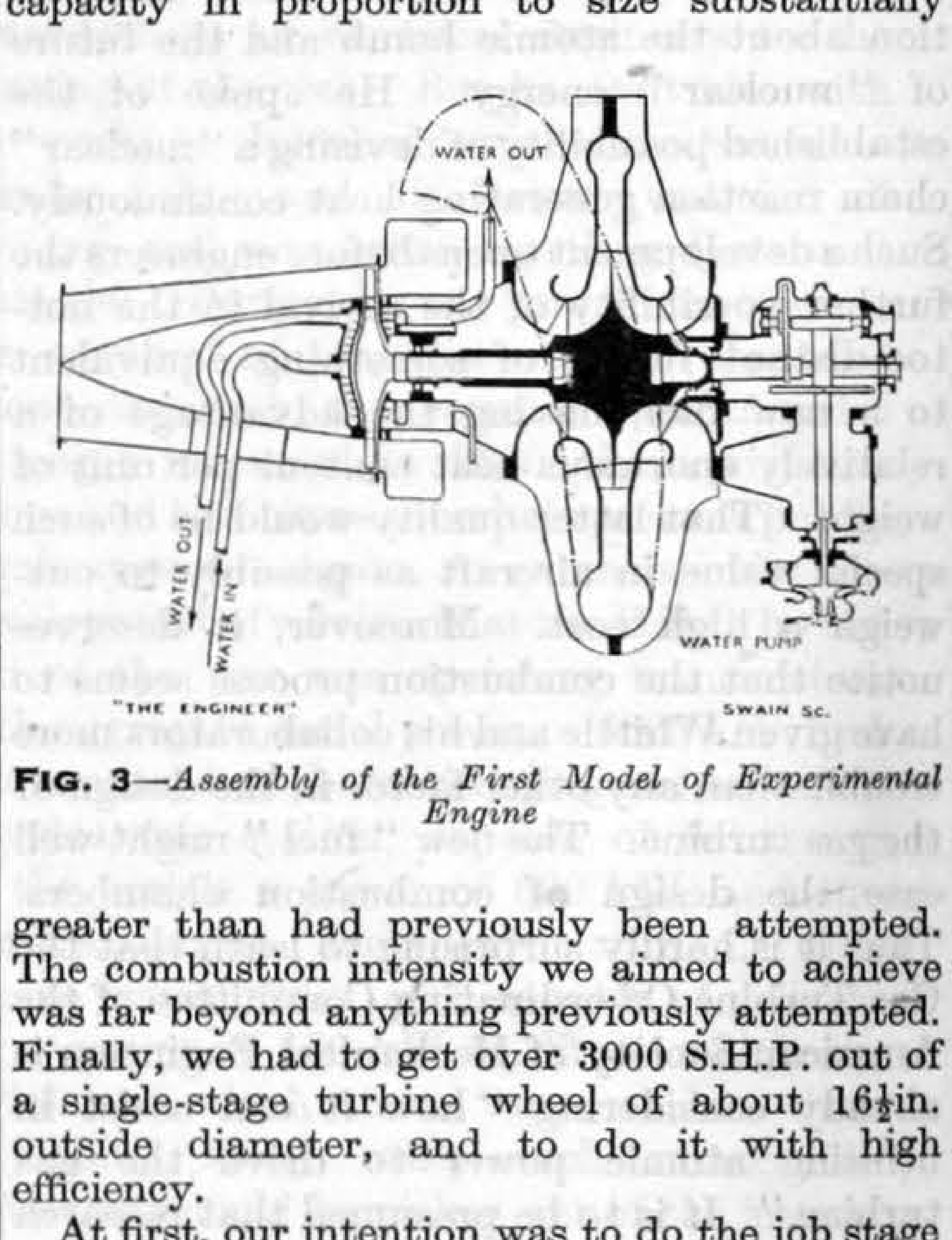


Fig. 3—*Assembly of the First Model of Experimental Engine*

greater than had previously been attempted. The combustion intensity we aimed to achieve was far beyond anything previously attempted. Finally, we had to get over 3000 S.H.P. out of a single-stage turbine wheel of about $16\frac{1}{2}$in. outside diameter, and to do it with high efficiency.

At first, our intention was to do the job stage by stage—that is, to make a compressor and test it ; then to add a combustion chamber to the compressor ; then to test a turbine alone ; and finally to build an engine—but we very soon realised that this was likely to be a long and costly pro ess and we decided to go for a complete engine right away.

This first engine was based on a design for flight, but was not intended for flight ; and though it was designed to b e very light by normal engineering standards, we did not put forth special efforts to make it as light as possible.

I was fairly confident in the compressor and turbine elements, but felt rather out of my depth with the combustion problem, and so (in 1936) I visited the British Industries Fair with a view to enlisting the aid of one of the oil burner firms, but the requirements I specified were considered to be far too stringent by most of them until I met Mr. Laidlaw, of Laidlaw, Drew and Co. Though he recognised that we were aiming at something far in advance of previous experience in this field he considered the target possible of attainment, and so it was with his help that we attacked the combustion problem.

While the engine was in course of design and manufacture, we carried out a number of combustion experiments on the premises of the British Thomson-Houston Company, with apparatus supplied by Laidlaw, Drew and Co., until we considered that we had enough information to design a combustion chamber. Power Jets therefore placed the contract for the design and manufacture of the combustion chamber with Laidlaw, Drew and Co.

* First James Clayton Lecture. Institution of Mechanical Engineers, October 5th. Abstract.

† Special Duty List, R.A.F., attached to Power Jets (Research and Development), Ltd., Whetstone, Leicester. The statements and opinions expressed herein are the personal views of the lecturer, and are not to be taken as in any way representing the opinions of the Air Ministry or the Ministry of Aircraft Production.

By this time the Tripos Examinations at Cambridge were over, and the Air Ministry had agreed that I should stay for a post-graduate year. This was really a device to enable me to continue work on the engine, and so a considerable proportion of my time was spent at the British Thomson-Houston Company's works in Rugby.

Testing of the engine commenced on April 12th, 1937, and continued intermittently until August 23rd. These early tests made it clear that the combustion problem was by no means solved, and that the compressor performance was far below expectations. Nevertheless, they were sufficiently encouraging to show that we were on the right track.

THE DESIGN AND TESTING OF THE EXPERIMENTAL ENGINE

The Design and Testing of the First Model: Design.—The first engine was designed with a specific target in mind. It was a very optimistic one, but, nevertheless, it formed the starting point and is worth recording. The aim was to propel a very "clean" little aeroplane of about 2000 lb. "all up" weight at a speed of 500

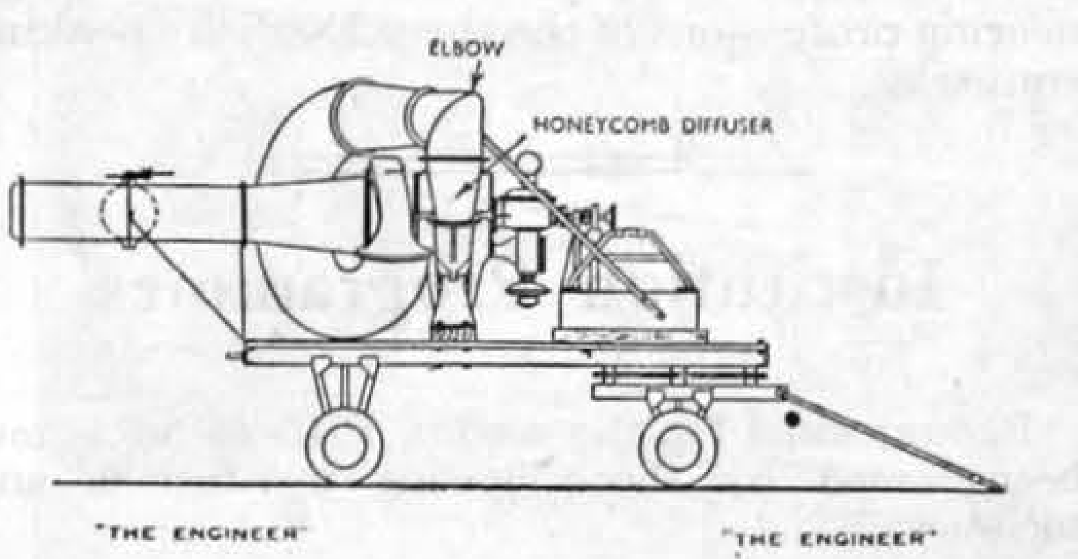


FIG. 4—*Test Assembly of First Model of Experimental Engine*

m.p.h., at a height of the order of 70,000ft. This speed was estimated to correspond to that of minimum drag at that height, *i.e.*, this high speed was also the most economical speed for the height. It was estimated that a net thrust at this height of 111 lb. would be required.

The size of engine corresponding to the data was considered to be the smallest in which the necessary accuracy of machining could be obtained without excessive manufacturing costs.

The design assumptions and leading particulars are given in Table I, and the pressure-volume cycle shown in Fig. 2.

TABLE I.—*Leading Particulars of First Edition of Experimental Engine*

Dimensions are in inches.

Compressor impeller—	
Tip diameter	19
Tip width	2
Outer diameter of eye ...	10·75
Inner diameter of eye ...	5·5
Number of blades	30
Material	Hiduminium RR 56
Compressor casing—	
Inner diameter of scroll ...	31
Material	Hiduminium RR 55, DTD. 133 B
Turbine—	
Mean diameter of blades...	14
Blade length	2·4
Material of blades	Firth-Vickers Stayblade
Material of disc...	Firth-Vickers Stayblade
Blade chord	0·8
Number of blades	66
Maximum speed—	
Revolutions per minute ...	17,750

Figs. 3, 4, and 5 illustrate various features of the design, which are further amplified in Figs. 6, 7, 8, and 9.

The assumption of 80 per cent. adiabatic efficiency for a centrifugal compressor running at a tip speed of 1470ft. per second was very optimistic indeed, and received a good deal of criticism, but I felt confident that we could design to avoid many of the losses which were occurring in all centrifugal compressors of which I had knowledge at the time. The general view was that we should be fortunate if we got 65 per cent. adiabatic efficiency.

We went for the double-sided compressor because we wanted to get the greatest possible breathing capacity in proportion to size. I also counted on this feature to give a reduced proportion of skin friction losses.

We aimed at having as many blades on the impeller as manufacturing limitations would permit, in order to keep the blade loading as low as possible. In particular, it was hoped that by keeping the pitch-chord ratio of the rotating guide vanes small we should avoid stalling at the intake, as I believed then—and still believe—that this is one of the main sources of loss in centrifugal compressors.

No diffuser blades were fitted to the blower casing at first. Two stages of diffusion were aimed at. The intention was to obtain partial diffusion in the bladeless vortex space between the impeller tips and the scroll, and to convert

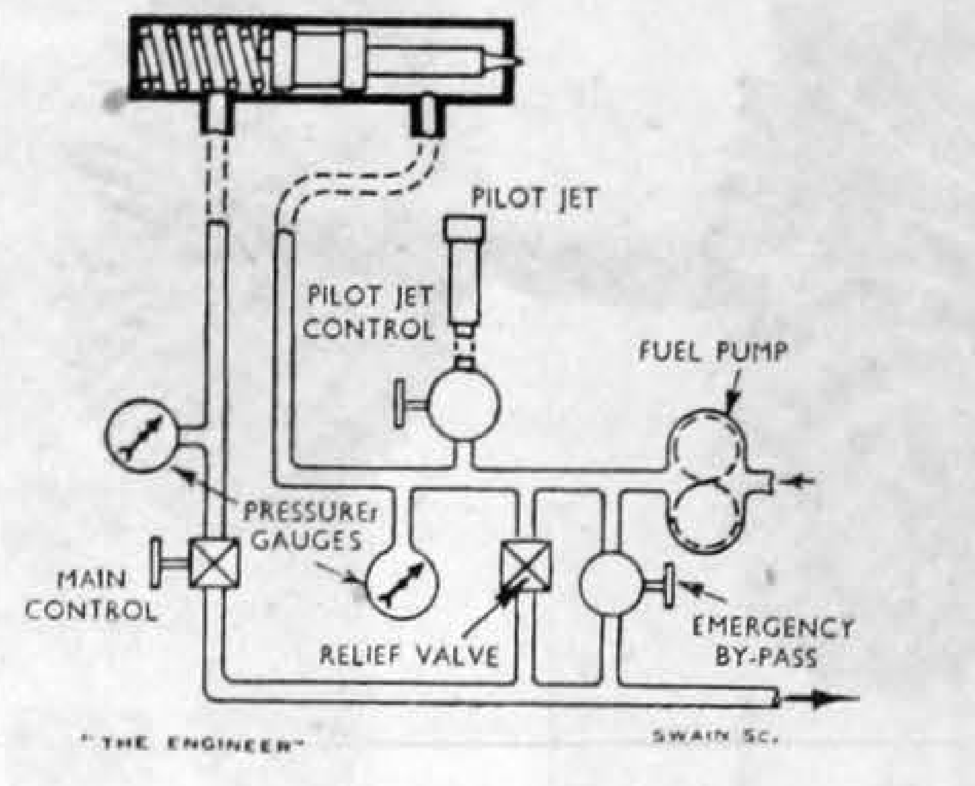


FIG. 5—*The Fuel System Used in the Early Tests of the First Model of the Experimental Engine*

most of the remaining kinetic energy into pressure in the "honeycomb" diffuser through which the air passed from the compressor scroll to the combustion chamber.

The turbine nozzle arrangement was very unorthodox, as no nozzle blades were used. The idea was that most of the expansion took place in the convergent-divergent entry to the nozzle scroll which was shaped to cause the discharge of the gases through its annular mouth with constant axial velocity, the whirl velocity corresponding to that of a free vortex, *i.e.*, constant angular momentum. This nozzle design was the source of considerable controversy, and though I am not very proud of it now, I thought it a good idea at the time. It is of considerable interest in retrospect, because it became evident later than I had not succeeded in conveying to others what I had in mind.

Air tests were made on a half-scale model of this nozzle, and though very rough they seemed to show that it would behave approximately as expected.

The design of the rotor assembly needed much careful thought. It was considered necessary to use unbored forgings for both the turbine wheel and compressor impeller, also to use an overhung turbine rotor, as it was thought that the provision of a satisfactory bearing support on the exhaust side of the turbine would be very difficult. The bearing housing assembly which contained one of the two water jackets for the turbine cooling could not be split in the diametral plane. These considerations governed the rotor design.

Testing.—As already mentioned, the testing of the engine under its own power began on April 12th, 1937. The very first attempt to start was successful, in that the engine ran under its own power, but it accelerated out of control up to about half its designed full speed. This happened several times, and altogether it was a very alarming business, so much so that in the early days the individuals in the vicinity did more running than the engine.

The starting procedure was as follows:—The engine was motored at about 1000 r.p.m. and the pilot jet (which injected an atomised spray) was switched on and ignited by means of a sparking plug and hand magneto. The motoring speed was then raised to about 3000 r.p.m., and the main control opened slowly. The engine would then accelerate under its own power; but, as I say, not always under control. The explanation of the first few uncontrolled accelerations was simple when we found it, and may be understood by reference to the diagram of the early fuel system, shown in Fig. 5. If the spill line from the burner was not full of fuel the needle valve of the burner would be forced into the fully open position when the fuel pump ran. We were frequently breaking the fuel line and doing various motoring tests, so that often, unknown to us, there was a "lake" of fuel in the combustion chamber. Other uncontrolled accelerations were caused by the sudden opening of the burner needle valve after initial sticking; by loss of temper in the burner spring through overheating, &c. Fortunately, none of these uncontrolled accelerations took the engine beyond about 9000 r.p.m.

No trouble was ever experienced in starting except when the ignition failed through cracked electrodes, or when mistakes were made in the assembly of the fuel lines.

The overheating of the burner already referred to was a serious problem, and as a result of it a fairly drastic change in the combustion system was made. We changed over to downstream injection. Five runs were then made with this

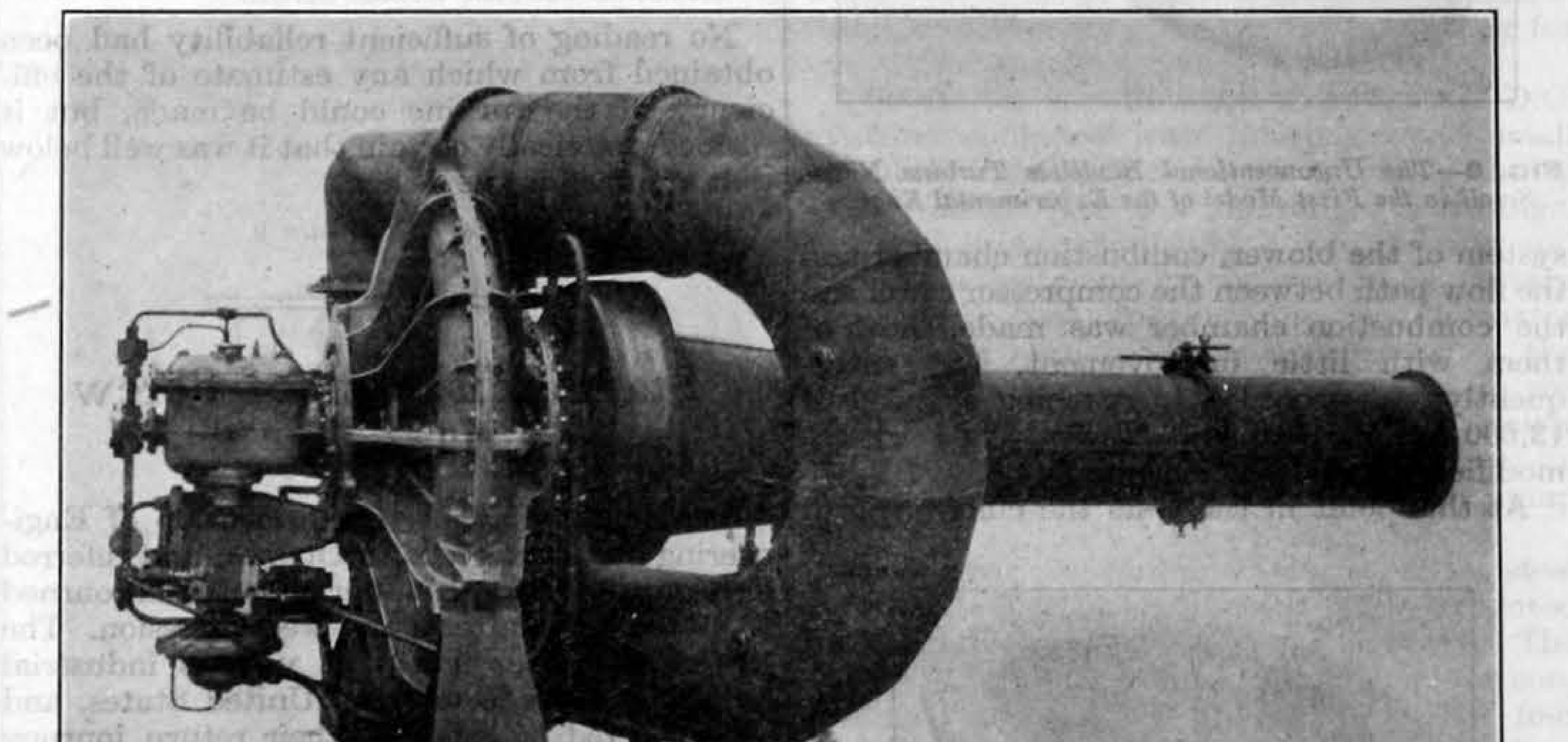


FIG. 6—*First Model of the First Experimental Engine*

system up to maximum speeds of about 8500 r.p.m., but the combustion was so bad that this speed could not be exceeded. Any further opening of the control seemed to result only in the burning of more fuel aft of the turbine.

Many attempts to improve the combustion were made by a series of modifications to the combustion chamber, and some improvement was achieved—we managed to get up to a speed of 11,000 r.p.m. for 10 min. This series of runs ended when the compressor impeller fouled the casing after running for 4 min. at 12,000 r.p.m.

The damage to the compressor and impeller casing was only slight, but as it had now become clear that the delivery pressure from the compressor was much below expectations, we decided to fit diffuser blades in an effort to improve the blower performance before further testing. We th n managed to attain a speed of 13,000 r.p.m., but the compressor performance still left much to be desired. Moreover, the combustion had deteriorated, and as this was believed to be due to the nature of the flow from the compressor scroll to the combustion chamber, many modifications to improve this

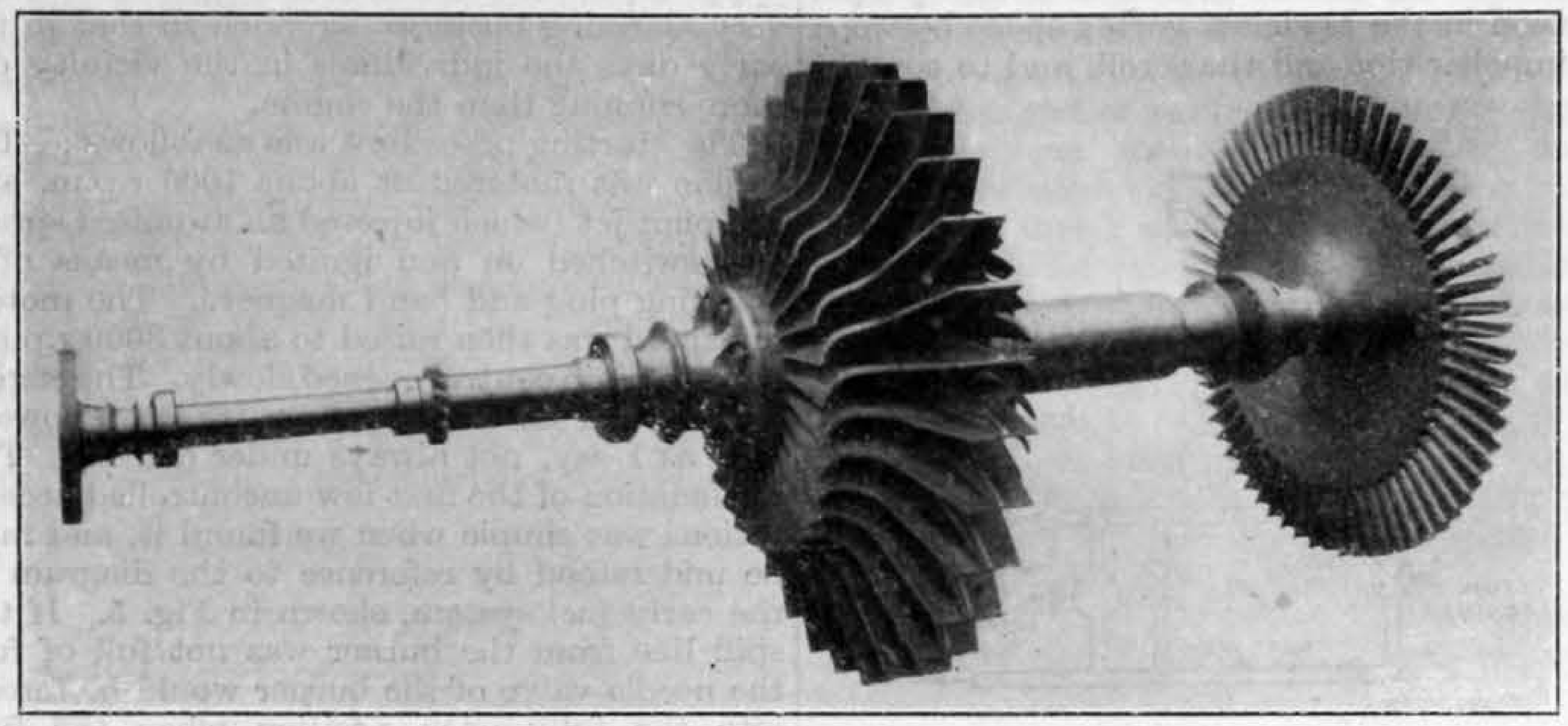


FIG. 7—*Rotor Assembly of First Experimental Engine*

flow were made, but without noticeable improvement. There was evidence of a flow reversal in the elbow, but we did not realise how severe this was until (in one test late in the series) flames were seen through a small hole which had been drilled in the neck of the blower casing scroll.

A series of rapid modifications to the diffuser

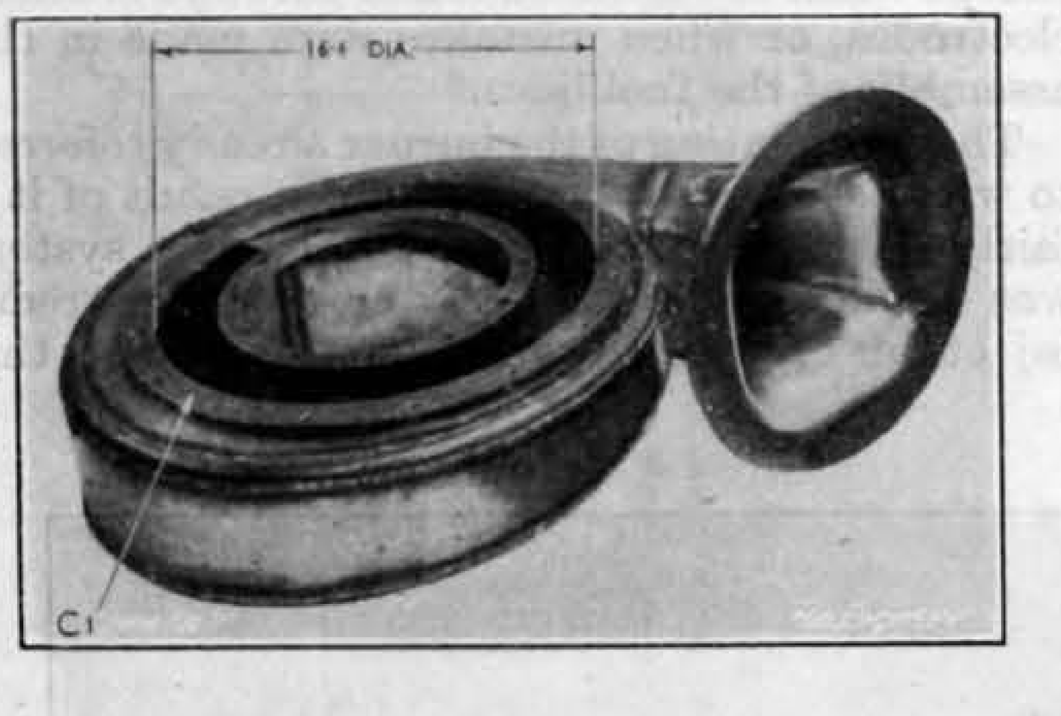


FIG. 8—*The Unconventional Bladeless Turbine Nozzle Scroll in the First Model of the Experimental Engine*

system of the blower, combustion chamber and the flow path between the compressor scroll and the combustion chamber was made, most of them with little improvement, but subsequently we succeeded in reaching a speed of 13,600 r.p.m. with the blower fitted with a modified set of diffuser blades.

At this point in the tests the chief engineer

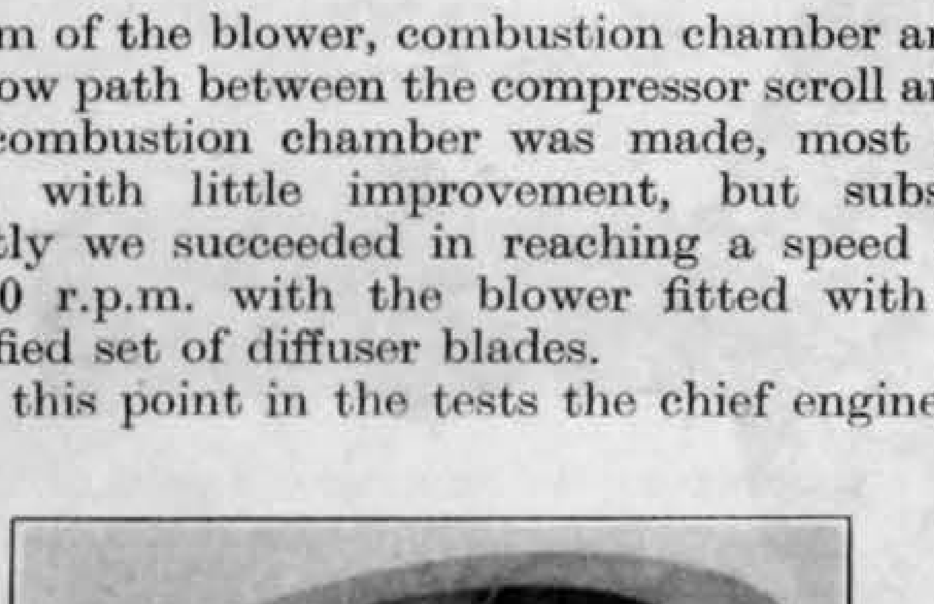


FIG. 9—*The "Honeycomb" Diffuser used in the First Model of the Experimental Engine*

of the British Thomson-Houston Company considered it unwise to run at speeds higher than 12,000 r.p.m. in the open factory, and this was the speed limit for the remaining tests of the first model.

A return to upstream injection was made, the burner now being insulated against overheating by using a fuel-cooling arrangement. Combustion appeared to be improved, and for the first time no part of the casings reached glow heat at speeds of up to 12,000 r.p.m.

Testing was now suspended for the following reasons :—First, because the speed restriction of 12,000 r.p.m. made it necessary to find a new site for running at higher speeds, and, secondly, because it was decided to make major modifications to the general arrangement.

The tests so far had been very disappointing, but there were many encouraging features. We had demonstrated that there was no particular difficulty in starting or in control. There was also plenty of evidence which suggested that the whole scheme was well worth developing, though it had become obvious that much hard work lay ahead.

The principal defects of that particular arrangement were shown to be :—

(1) Poor compressor efficiency.

(2) Excessive preheating of the air to the rear intake, owing to the disposition and temperature of the combustion chamber.

(3) Very unsatisfactory combustion.

(4) Excessive frictional loss in the unorthodox turbine nozzle scroll.

No reading of sufficient reliability had been obtained from which any estimate of the efficiency of the turbine could be made, but it eemed practically certain that it was well below that assumed in the design.

(To be continued)

Standardisation of Screw Threads

THE Conference on the Unification of Engineering Standards held in Ottawa, and referred to in one of last week's Journal notes, adjourned on October 7th after a two weeks' session. The British delegates will visit various industrial centres in Canada and the United States, and are expected to leave on their return journey later this month. It can be stated that the fundamental differences between British and American screw thread forms, which caused tremendous production and supply difficulties during the war period, were resolved to the point at which the delegates were prepared to return to their respective countries with a specification of a basic thread form that will provide a unified standard for all countries employing the inch system. The basic form, it is stated, retains the best features of the present forms and, at the same time, a series of associated diameters and pitches have been worked out which, it is believed, will simplify existing practice and yet provide an adequate range of choice for all requirements. It is also felt that the proposed change would involve the minimum amount of departure from existing practice consistent with the obtaining of a common standard for general-purpose threads to the inch system of measurement. Agreement was also reached on Acme and sub-Acme threads, and the agreed specification will be submitted to the national standards bodies in Britain, America, and Canada, so that what is termed an "A.B.C." standard will be speedily approved. Mutual understanding was reached on specifications for small screws and various screws and threads used in the optical and scientific instrument trades, and on buttress thread forms. Considerable progress was made in gathering data on high-duty studs in light alloys, but a great deal more exploratory work is, it is felt, required. Drawing practice and its unification were discussed, and it was agreed that this subject be actively pursued. Pipe threads were dealt with and an invitation to the British and Canadian representatives to continue discussions of this subject at the November meetings of the American Petroleum Institute were given. On the question of limits and fits, a further meeting with the British delegates will be held in New York before the return of the delegates. Suggestions were forthcoming on precision and gauging methods, with a view to the co-ordination of future practice. Proposed specifications for screw threads and connections for gas cylinders were presented. On the whole, this third Conference exemplified the spirit of collaboration which prevails among the engineering professions of the three English-speaking countries.

Institution Programmes

PROGRAMMES for the session 1945–46 have now been issued by the following institutions and societies :—

INSTITUTE OF MARINE ENGINEERS

November 13th, 1945 : "Development in Turbine Blading," by J. G. Monypenny.

December 11th : "Deck Machinery, with Particular Reference to Latest Developments," by T. Brown.

January 8th, 1946 : "Elements of Propulsive Efficiency," by F. H. Todd, B.Sc., Ph.D., M.I.N.A.

February 12th : "The Development of the Opposed-Piston Marine Oil Engine, with Special Reference to Engine Dynamics," by W. Ker Wilson, D.Sc., Ph.D., Wh. Ex.

March 12th : "Strain Gauges," by Dr. F. Aughtie.

April 9th : "Engine-Room Lay-Out, with Special Reference to Pipe Work," by Lieut.-Colonel G. Rochfort, M.C., D.S.O.

April 30th : "Lubricating Oils and their Characteristics," by C. Lawrie and Colonel S. J. M. Auld.

May 14th : "Air Preheater Design, Construction, and Maintenance," by W. Crawford Hume.

September 10th : The President's Address.

October 8th : "Vacuum Refrigeration," by W. Sampson.

November 12th : "Resistance Welding in Engineering Construction," by S. Hunter Gordon.

ROYAL AERONAUTICAL SOCIETY

October 18th, 1945 : "Aircraft Engine Oil Cooling," by F. Nixon, B.Sc., M.I.A.E., F.R.Ae.S.

November 1st : "A Critical Review of German Long-Range Rocket Development," by W. G. A. Perring, F.R.Ae.S.

November 15th : First British Empire Lecture, "Australian and Empire Air Transport," by W. Hudson Fysh, D.F.C.

November 29th : "Aspects of German Aeronautical Development," by W. J. Stern.

December 11th : "Meteorology and High-Altitude Aviation," by Professor Dobson, F.R.S.

December 19th : "Atomic Disintegration," by Professor N. Feather, Ph.D., F.R.S.

OVERSEAS TRADE STATISTICS.—Publication of the Board of Trade's monthly trade accounts will be resumed in the normal form beginning with January, 1946. They will give particulars of all our principal imports, exports, and re-exports, with a considerable amount of information on trade with individual countries. Accounts relating to Great Britain's overseas trade in the first half of 1945 have already been published, and the Board of Trade will publish detailed trade accounts for the first nine months of 1945 and further accounts for the whole year. In addition, a monthly summary (on the lines of those issued during 1940) will be published showing the July and August figures for each group distinguished in the overseas trade statistics ; further summaries will be published for October and for November. The July and August summary will be published during this month.