THE ART OF THE AVIATION ENGINE

This article is an account of the first Louis Blériot Lecture given by Air Commodore F. R. Banks, C.B., O.B.E., before the Association Française des Ingénieurs et Techniciens de l'Aéronautique in Paris and is reproduced from "Flight" of May 13th, 1948, with permission of the Author and Editor.

That an Englishman has been accorded the distinction of presenting the first Louis Blériot lecture must be regarded as a graceful gesture and a further pointer to the *entente cordiale aéronautique* which has, for so long, spanned the Channel separating France and England.

Air Commodore F. R. Banks, C.B., O.B.E., F.R.Ae.S., M.I.A.E., M.S.A.E., who served as Director-General of Engine Production and, later, as Director of Aero Engine Research and Development in the Ministry of Aircraft Production during the recent war, said in the introduction to his lecture that he was deeply appreciative of the honour done him, and expressed the hope that his will initiate a long list of lectures honouring that great man of French aviation whose name has been given to the series. This was the second occasion upon which the author had been invited to deliver an address to the Association Française des Ingénieurs et Techniciens de l'Aéronautique and it was with great pleasure that he was able again to meet his French friends.

Previous papers by the author and others have dealt with the working principles and specialist problems of the aviation engine, but no one had as yet described how this type of engine is conceived and developed to the state of series production, nor has it been understood why some manufacturers are more successful than others in this respect. When, however, he was asked by the Association to present another paper, the lecturer decided that, in view of the importance of the occasion, the time had arrived to describe the evolution of the aviation engine.

Power, Volume and Weight

A particular feature which distinguishes the aviation engine from all other forms of prime mover is that it must meet a stringent weight limitation and, at the same time, produce high power from small volume. Another important difference is the relative lack of finality in aviation : the demands made upon the aero engine have always been exacting and are not likely to be any easier in the future. This is particularly true at the present time of the aviation gas turbine—an entirely new form of prime mover now in its infancy which must be subjected to the same intensive development as the piston engine before it can be considered to have attained the equivalent state of refinement.

The term "life" is difficult to define because at each period of overhaul or revision, the engine will be brought to its original standard of quality by any replacements which are necessary. The operating life of an individual air line engine is likely to vary from 3,000 to 12,000 hours before the engine is discarded. Some of the more moderate duty types of American engine of about 30 litres capacity, which have been in air line service for over ten years, have achieved a total working life per engine as high as 20,000 hours. The utilization factor, which represents the useful running time per year for an engine or an aircraft, including overhauls or revisions, will average about 3,000 hours.

The lecturer then went on to give some comparisons between the lives of aero

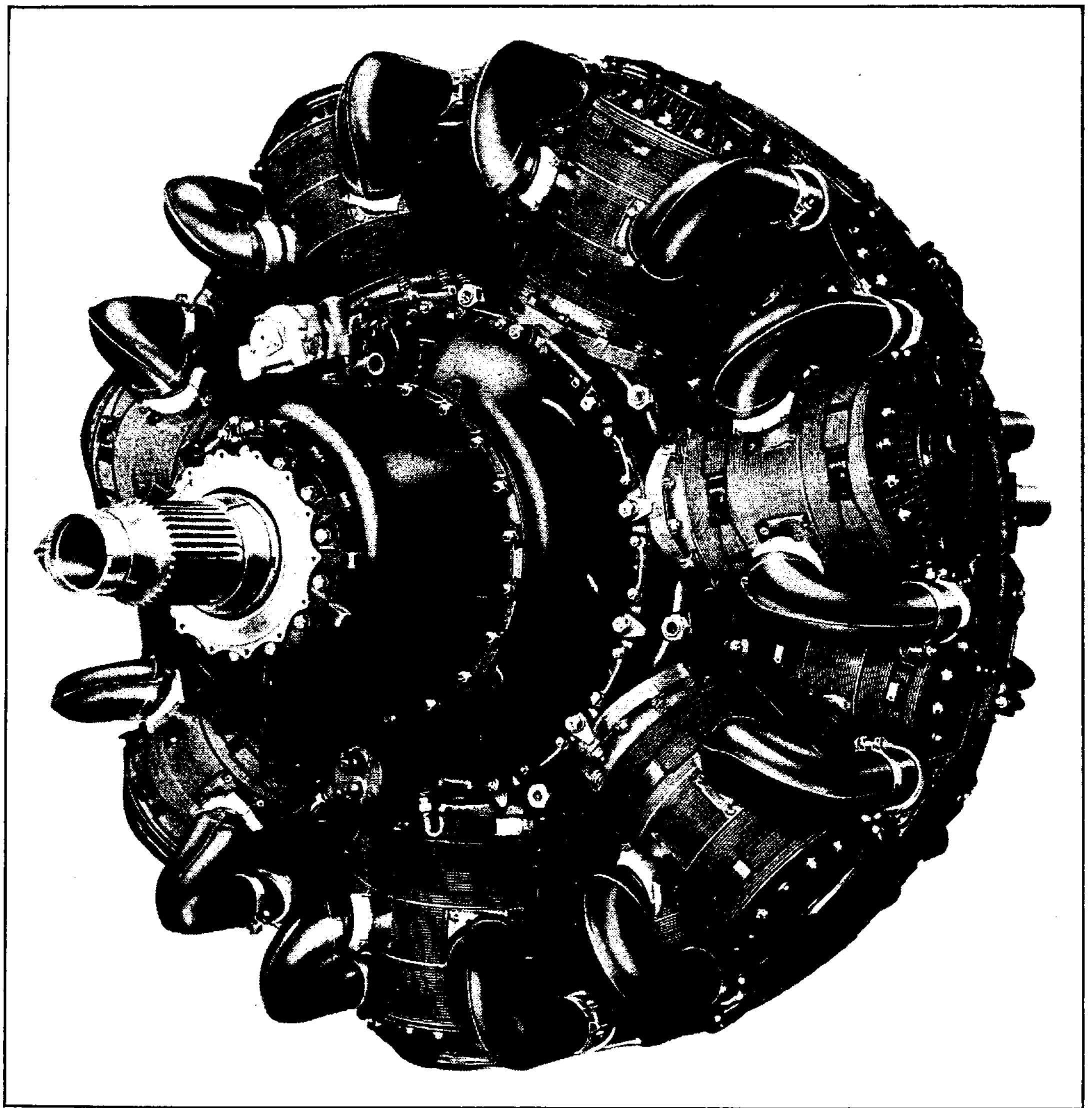

FIG. 1.—BRISTOL AEROPLANE COMPANY'S "HERCULES 630" ENGINE

engines and steam and diesel railway locomotives and demonstrated that there was surprising parity in many respects.

After reviewing the birth and development of the aviation engine, Air Commodore Banks observed that, in a period of more than forty years of aviation, the power of the individual engine has increased from 35 h.p. to more than 3,500 h.p. And the altitude at which sea level power can now be maintained has risen from sea level to greater than 10,000 metres.

The aviation engine industry, which was born in the first world war, is unique as an industry because it flourishes mainly as the result of national support. This is distinct from nationalization, with which it should not be confused. Unlike the traditional armament business, the aviation engine industry has useful application in peace, but it enjoys government support because of the military potentialities of the aircraft.

It is not usually appreciated how few active aviation engine companies there are in the world to-day. The total number of firms manufacturing high-duty engines barely exceeds fifteen, excluding Russia, Germany and Japan, and the number of really active firms who are building successful engines to-day can almost be counted on the fingers of one hand.

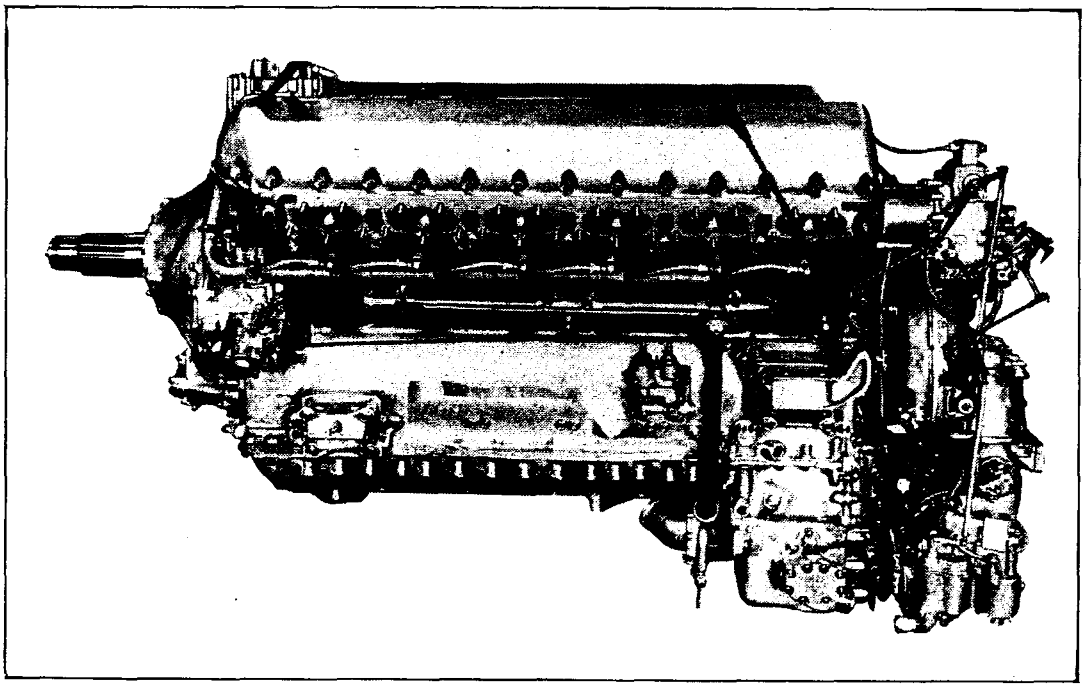

FIG. 2.—SINGLE-STAGE, 2-SPEED, SUPERCHARGED ROLLS-ROYCE " GRIFFON " ENGINE

Specific Problems

Turning then to a review of some of the specific problems encountered in the creation of a successful aero engine, the lecturer pointed out that, important as was liaison between the technical (design and experimental) sections and the production department, it is essential that the technical people must have the final decision in the case of any argument between them and the production department as to the suitability for production of the design of the engine or its components.

Experience has shown that the time taken to design, develop and get the first or " Mark I " version of a prototype piston engine into production is between four and five years. In the present state of knowledge this also holds true for the airscrew turbine, and even the turbo-jet with an axial compressor will take little less time to develop.

Air Commodore Banks devoted some time to a survey of the system of contracts and official ordering of engines in this country, and then went on to consider the organization and working capacity of a typical aircraft engine firm. On the subject of design and development, he observed that, in the case of the piston engine in the recent war, the most economical British engine built, in terms of manufacturing or man-hours, was the 12-cylinder, 60 deg V, liquid-cooled, poppet valve type. The next in order of merit was the sleeve-valve radial engine of about the same maximum power, whilst the engine requiring the greatest number of man-hours in its manufacture was the 24-cylinder, opposed type, liquid-cooled, sleeve-valve engine with two crankshafts. The actual manufacturing times for each of these three types was of the order of 3,000, 3,300 and 6,500 man-hours respectively, at a production rate per factory of 400 to 500 engines per month.

There is one very important factor which is not often appreciated. This concerns the ability and capacity of a firm to develop engines intensively. In other words, when buying an engine, it is power and performance which are actually being purchased ; and the firm most active in the technique of development will produce better performance from an engine of given size and weight

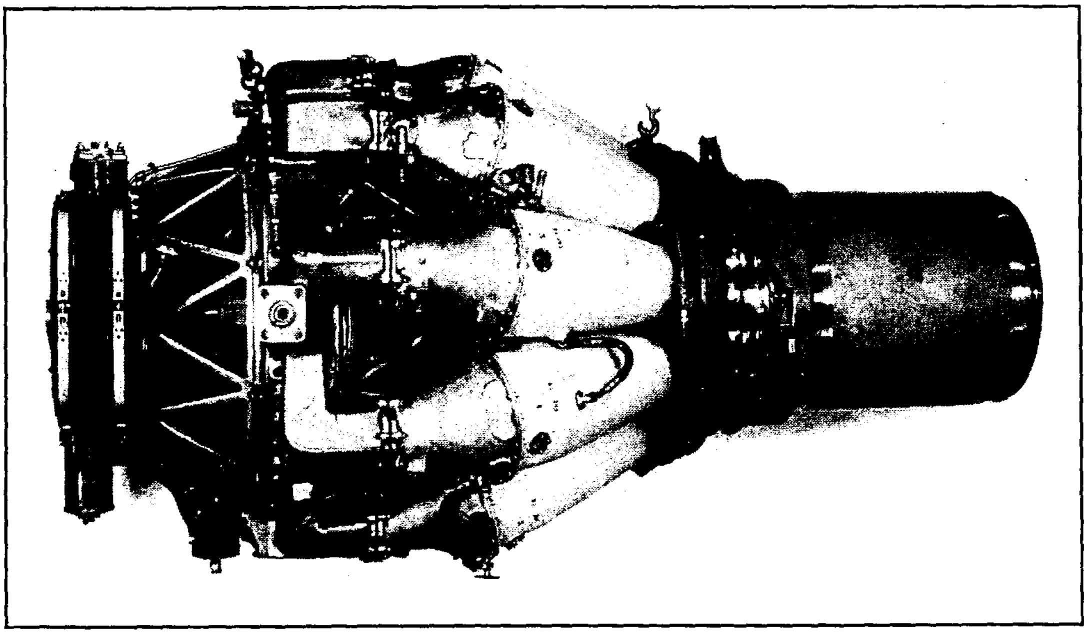

FIG. 3.—THE ROLLS-ROYCE " DERWENT V " AS FITTED IN THE GLOSTER METEOR WHICH GAINED THE WORLD SPEED RECORD IN 1946

than another firm which may offer only the same performance from an engine of, say, 25 per cent. larger capacity. Intensive development, however, always pays and finally leads to the production of engines of lower cost.

The Whittle-type jet turbine, with a double-sided single-stage compressor and a single-stage turbine giving a static sea-level thrust of 5,000 lb, requires somewhat less manufacturing or man-hours than a 60 deg V-type, 12-cylinder, liquid-cooled engine of about 2,500 h.p. take-off rating. But the jet turbine costs considerably more per pound of structure weight than the piston engine.

Man-hours involved in the design and manufacture of a prototype airscrew turbine with an axial compressor are from 10 to 15 per cent. greater than those needed for a large 24-cylinder, twin-crankshaft, liquid-cooled, sleeve-valve piston-engine, assuming the same maximum power for both engines to be of the 3,500 h.p. order.

Cost of a prototype engine varies somewhat with its size or maximum power, and complexity, but is between £10 and £20 per pound of structure weight. As an example, a large liquid-cooled engine of 3,500 h.p. which weighs 3,700 lb will cost about £15 a pound, or £55,000. An airscrew turbine of about the same maximum power will weigh much less but will absorb more design hours and cost more per pound to manufacture in prototype form. Therefore, the total cost will be of the same order as that of the equivalent piston engine, assuming a weight of 2,900 lb at £20 per pound, or £58,000.

The lecturer said that he had frequently been asked what he considered should be the average number of engine hours run per year in developing a prototype engine and, in this connection, stated that the total running time on the test bed and in flight before the first " Mark " of a prototype engine is ready for type test will be 5,000 or 6,000 engine-hours in a period of three to three and a half years, involving about ten engines.

Equipment required for calibrating and testing the components of a gas turbine is far more elaborate and expensive than any used for piston engines. In the past three or four years, equipment has been installed at some of the British and American firms which runs into hundreds of thousands of pounds

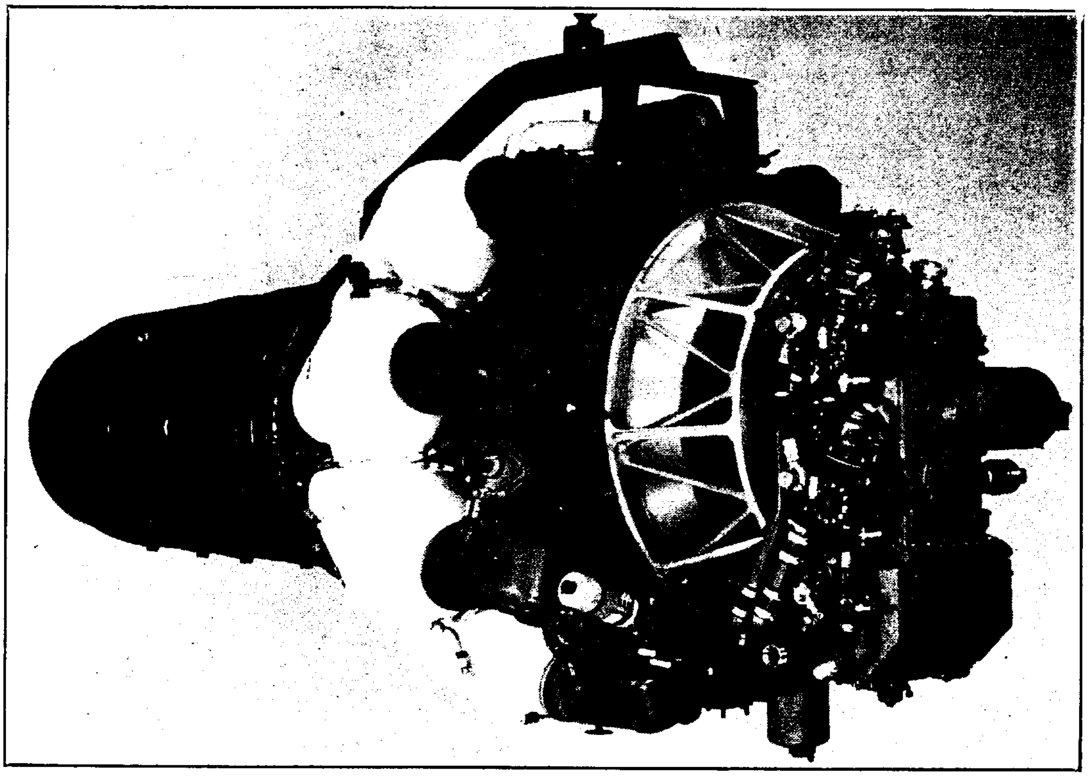

FIG. 4.—ROLLS-ROYCE " NENE " ENGINE

sterling and tens of millions of dollars. In some cases, the equipment was supplied at government expense, but one or two firms provided comprehensive equipment at their own cost. Air Commodore Banks then made the trenchant observation that air, in the quantity and condition required for testing gas turbines, is a very expensive commodity.

He then went on to say that, in order to test complete and full-scale jet engines at conditions of altitude and temperature simulating 11,000 metres (tropopause) and minus 60 deg C., the cost of the test plant is equivalent to £20,000 for every pound of air per second capacity provided for the engine. For instance, if an engine can consume, say, fifteen pounds of air per second at 11,000 metres, the total cost of the plant will be in the order of £300,000.

Subsidized Research

The lecturer gave it as his opinion that the best and only practical way to help the aviation engine industry is for a government to provide its research establishment with the more expensive and elaborate facilities, such as the high-altitude test tunnel and compressor and turbine test houses with an available power of, say, 40,000 h.p. Aerodynamic test equipment for investigating blade forms, etc., must be provided and, also, comprehensive facilities for combustion research. Some of this equipment already exists in the research establishments and in the firms, both in Great Britain and America. But America has the most complete research and testing facilities for gas turbines in the world.

Chief among the points made by the lecturer in his summing-up were that :

(*a*) If successful aviation engines are to be built, the industry must have properly controlled government support in the form of sound technical requirements, followed by orders. The industry should not be nationalized because of its highly competitive nature and the fact that, in times of peace, manufacturing licences and engines are sold to other countries who may prefer to deal direct with the firm, or firms. These countries may also have a government-supported aviation engine industry which would resent competition with one that was government controlled, or nationalized.

(*b*) Engines should always be built to meet specific aircraft requirements and, therefore, very good liaison with the aircraft manufacturer and his designer is essential. There must be mutual trust and confidence in each other's products. But it is more important that the engine manufacturer enjoys the full confidence of the aircraft builder.

(*c*) Very heavy expenditure is involved when providing complete development and testing facilities for gas turbine components ; much heavier than that required for the equivalent facilities for a piston engine. Between £2,000,000 and £3,000,000 would be necessary to manufacture and install the equipment. Some firms prefer to be independent of the government in regard to capital expenditure and provide their own, less elaborate, equipment. Others pay for the buildings (test houses) and also own the land upon which these stand, but ask the government to provide the experimental equipment installed, on the basis that this equipment may be rendered quickly obsolete.

(*d*) More time is at present required (between 10 and 20 per cent.) to design and manufacture a prototype airscrew turbine of the axial compressor type, ready for test, than that required for a piston engine of equivalent power. Even a small airscrew turbine with a two-stage centrifugal compressor exceeds in total design hours, the time taken to design the more conventional piston engine of somewhat greater power. The most economical engine in terms of design and manufacturing hours, is the classic Whittle-type jet turbine, which absorbs about one-quarter of the design hours of a large airscrew turbine.

(*e*) The life of a piston engine, as a type, has been about ten years, sometimes more, before becoming obsolete. During this time, its performance will have been much improved by continuous development. This is important, since it takes five years to create an engine and it would not be very economical to design and develop an entirely new engine whenever an increase in performance was required. This also applies to the gas turbine but it is unlikely that there will be the same large percentage increases in power which have been characteristic of the piston engine in the last twenty years. The gas turbine is virtually a "full throttle" engine and, therefore, the more that is learned on compressor, combustion and turbine behaviour, the greater is the possibility of the prototype engine quickly giving its designed power in development and the less likelihood of much increase during the life of the engine.

(*f*) There is no substitute for operating an engine in actual flight conditions and until the gas turbine, particularly the air-screw turbine, has had many thousands of engine-hours in the air, little will be known of its practical possibilities and running economy.

The gas turbine has suffered more than any other engine from irresponsible publicity and changing requirements, largely because of the mistaken idea that it can be designed and developed quickly. The result is that gas turbines have been created on the drawing board and, as quickly, discarded for other creations on paper. There has already been a recession and some aircraft which were to have airscrew turbines are threatened with extinction or, at least, a reduction to the basis of one or two prototypes only.