PART II

CHAPTER VI

The Origins of High-Power Air-Cooled Engines in Britain

By the middle of the First World War the most powerful aircraft engines in use in every country were water cooled. Experiments begun even before the end of the war soon led, however, to the development of air-cooled engines which could compete with the most powerful water-cooled engines. The story of the development of these air-cooled engines and of the way in which they became established as standard service types gives an excellent opportunity to study not only the respective contributions of government and industry to purely technical progress but also the problems involved in creating a source of supply for a technically new product.

Background: Developments up to the Middle of 1917

At the outbreak of the First World War there was no real aircraft-engine industry in Britain. A few firms had engaged in the experimental production of aircraft engines, but all of them together had produced a total of only perhaps a hundred engines up to the outbreak of the war, and none of the engines so produced was put in quantity production during the war. The British air force at the beginning of the war used almost nothing but foreign engines, most of them French, built either in France or in Britain on license. Chief of the French engines were the 80-hp Gnome rotary and the 70-hp Renault V-8 at the outbreak of the war, and a little later the Clergêt and Le Rhône rotaries, all of them air-cooled. The only important non-French design in production in Britain early in the war was the six-cylinder 120-hp water-cooled Beardmore, a slightly modified copy of the six-cylinder Austro-Daimler, which arrived on the front a few months after September 1914.

The only British design to be put in production at the beginning of the war, arriving at the front a few months later, was the product of a government organization, the Royal Aircraft Factory.[1] This institution had been created in 1909 — the new name was given in 1912 — by reorganizing the Royal Engineers Balloon School with civilian personnel. The activities were still supposed to be restricted to balloons, but the new head, Mervyn O'Gorman, an enthusiast who combined great energy with great ability, had almost immediately branched out into the field of heavier-than-air machines, and had undertaken the development of both airplanes and engines. Under him Mr. (eventually Major) F. M. Green was Chief Engineer, with a very able staff which continued during the war to be enriched by new additions. Some of these men, such as G. S. Wilkinson, J. E. Ellor, and S. D. Heron, later became very well known in the aircraft-engine industry, while still others who did not ultimately enter the industry, such as Professor A. H. Gibson, made equally important contributions to engine development during their stay in the Factory.

Already by 1913 the Factory had built an engine which was superior to anything else in Britain. This was the 90-hp Raf 1, an eight-cylinder air-cooled vee derived very largely from the French Renault. At the outbreak of the war this engine was put in production by a number of automobile manufacturers. In September 1914 the Factory designed a water-cooled engine, the 200-hp Raf 3, which was produced in small quantities although it was not very successful, and the Factory continued during the war to design other water-cooled engines. The main emphasis, however, was on the air-cooled type, largely because Green believed that it was simpler, less vulnerable, and lighter. In December 1914 a larger, 12-cylinder air-cooled vee known as the Raf 4, producing about 140 hp, was designed; in 1916 the improved version known as the Raf 4A was put in production in large quantity by the automobile industry.[2] In 1915-1916 the Factory carried out the first

[1]On the general history of this institution, see S. Child and C. F. Caunter, *A Historical Summary of the Royal Aircraft Factory and its Antecedents: 1878-1918* (Report No. Aero. 2150) (Farnborough: Royal Aircraft Establishment, 1947).

[2]About 7,000 engines of Factory design were produced during the war, mostly 1B's (designed in 1916) and 4A's.

really systematic research on the fundamental principles of the design of air-cooled cylinders to be conducted anywhere in the world. By the end of 1916 this program, which was directed by Professor Gibson and in which S. D. Heron played a very important role as designer, had already gone a long way toward establishing what ultimately became universally accepted as the correct basic principles of this art.[3]

In September 1916 the Factory produced the design of a new and still larger air-cooled engine, this time of a completely different type: the new Raf 8 was a 14-cylinder, two-row, 1,374-cu in. fixed radial. The radial form was chosen in preference to the in-line vee because for a given number of cylinders of given size it had far less crankcase and crankshaft and thus was much lighter. A static or fixed radial was chosen in preference to the hitherto popular rotary type primarily because it was believed that much more power could be got from a fixed radial than from a rotary of the same size, even before deducting from the gross power of the rotary the 25% or so which was lost in the windage of the rotating cylinders. A two-row engine was designed rather than a single-row simply because more power (about 300 hp) was wanted than it was believed possible to get from the nine cylinders which were the practical maximum with a single row.[4] The use of two rows was not a radical innovation even this early, since an Anzani 10-cylinder two-row radial had been run successfully at the Factory itself already in 1914,[5] and six-cylinder two-row Anzani radials had been actually in production as early as 1910.[6]

[3]These were: (1) the cylinder head should be of aluminum, since less weight of this metal is required to conduct away heat at a given rate than of any other material; (2) the head should be all one piece, since metal-to-metal joints are difficult to maintain in good thermal contact; and (3) the head should be designed to offer the shortest possible escape along a path with the largest possible cross section for the heat generated at the hottest points of the head.

[4]The Factory had designed a nine-cylinder single-row radial, the Raf 2, in October 1913 and had tested it a few months later. This engine developed about 120 hp.

[5]This engine had cylinders 4.5 in. x 6.1 in. for a displacement of 982 cu in. It weighed 493 lb and on its 1914 trials at the Factory developed 125 hp at 1,200 rpm. These data are from an Anzani publication. — The Factory was doubtless familiar also with the Smith Static, on which see text below, p. 128 and n. 11.

[6]That the Anzani engines never got anywhere themselves seems to have been due principally to the fact that the company experimented with too many different models and did not put enough development into any one.

By 1916 a private aircraft-engine industry capable of doing its own designing had begun to exist in Britain, largely because although the Army had relied almost entirely on the Royal Aircraft Factory for its airframe and engine designs, the Admiralty had from the first encouraged private firms to design their own. The best of the engines brought out with Navy support were the V-12 water-cooled Eagle and the similar but smaller Falcon, which Rolls Royce, Limited, had designed on the basis of a Mercedes racing-car engine supplied to it in 1914 by the Admiralty, and the Bentley Rotary, which was an improved Clergêt air-cooled rotary.[7]

The private British airframe industry had made even more progress by 1916 than the engine industry, and a number of people believed that as a result the Navy was getting better airplanes than the Army. In 1916 the matter came to a crisis over the BE-2C airplane, a modification made in 1914 of a 1911 design, which the Army had adopted as its standard production airplane in the early part of the war. The BE-2C in its time had been an excellent machine, but when the German Fokker, the first true fighter in the war, appeared in 1915, it was hopelessly outclassed, chiefly because it lacked the synchronized gun of the Fokker. Because a large number of pilots were killed, a press campaign, fostered particularly by the private airframe industry, was launched in favor of leaving all design to industry and making the Royal Aircraft Factory into a merely consultative research establishment. The accusation was made in Parliament that the Factory was being misrun, and in May 1916 a committee was set up to investigate. Before the end of the year this committee recommended that the Factory should be strictly limited to research, and should not build even experimental prototypes. The War Office promptly sent corresponding instructions to the Factory.[8] With its functions thus drastically reduced, the Factory of course no longer had need of most of its staff, and many of its members were drained off

[7]The Navy had also supported the large variety of engines developed by the Sunbeam Motor Car Company, but despite the fact that Sunbeam engines were the principal reliance of the Navy in the early part of the war, none of the series was very successful.

[8]This investigation was also at least partly responsible for the reorganization of the Air Board by the new Lloyd George government in February 1917, on which see below, p. 130, n. 16.

at once into private industry. At the suggestion of Lt.-General Sir David Henderson, the Director General of Military Aeronautics, the Chief Engineer, at that time Capt. F. M. Green, left in January 1917 to become Chief Aeronautical Engineer of the Siddeley Deasy Motor Car Company, Ltd, with the primary task of developing the new BHP water-cooled engine into a serviceable state. At his own request Green was given authority to develop the Raf 8 air-cooled radial as well, but with priority definitely second to that of the BHP. Green took S. D. Heron with him to Siddeley Deasy and put him in charge of the design of the radial engine.

The first service support for the development of fixed radial engines came from the Admiralty. On April 5, 1917, the Air Board, acting on the desires of the Admiralty, issued a specification known as Scheme A for a new fighter engine, calling specifically for a radial air-cooled engine to develop not less than 300 hp and to be not over 42 in. in diameter. The Navy's reasons for specifying an air-cooled engine were probably the usual difficulties of those times with water-cooled engines. The plumbing and radiator leaks from which all water-cooled engines suffered were additionally serious in the Navy because a successful emergency landing was virtually out of the question for an airplane flying over water. In addition to leaks, furthermore, water-cooled engines in those days were very slow and troublesome to put in operation, particularly in winter. They required as much as 15 minutes of warming up before they could be flown; and in winter, since there were no satisfactory antifreezes in use, they had to be drained as soon as they were stopped and then refilled with hot water when it was desired to put them back in operation.[9] It is also likely that the Navy believed that the air-cooled engine would be lighter than the water-cooled, and in order to take off from carriers at this time it was necessary to have the lightest possible engine.[10]

The Admiralty had, furthermore, already had occasion to be

[9]There was a period of several weeks during the war when because of frost no British aircraft with water-cooled engines could fly at all.

[10]Although it had sponsored and used the Rolls Royce water-cooled engines for its bombers and heavy seaplanes, the Navy was also sponsoring the development of the Bentley air-cooled rotary for all uses where its power was sufficient. This engine, however, was at this time aimed at only 150 hp or so.

encouraged about the prospects of the air-cooled static two-row radial. In January 1915 the American John W. Smith had come to England to sell the design of an air-cooled radial which he had designed and built. This was an 875-cu in. engine with 10 cylinders in a single row but with the connecting rods offset and bearing alternately on either crank of a two-throw crankshaft.[11] The Admiralty had become interested in this engine almost at once and had conducted tests on it which seemed to indicate that it had the possibility of being developed into a successful model.[12]

The Air Board specification of April 1917 was answered with designs and bids from Brazil-Straker and Company, Ltd, Siddeley Deasy, and Vickers, Ltd, for 14-cylinder two-row engines, and from ABC Motors, Ltd, for a single-row engine. The winning design was the Brazil-Straker Mercury, and the firm received an order for 200 engines.[13] Brazil-Straker and Company, Ltd, was an important prewar automobile manufacturer which had become involved in the building of aircraft engines under license during the war. The Chief Engineer and technical director of the company, A. H. Roy Fedden, had persuaded the company at the outbreak of the war to enter this field, and after going to France to look at the engines being produced there had obtained an option on the Clergêt rotary. At the government's request, however, the company had instead rebuilt a large number of Curtiss trainer engines (OX and later OXX), then had built Rolls Royce Hawks and Falcons, and in 1917 was building eight-cylinder Renaults for training use. At Fedden's suggestion the company had entered the competition for the design of an air-cooled engine, since under the terms of its previous agreement with Rolls Royce the company was disbarred from producing a water-cooled engine of its own. In addition, Fedden had very carefully inspected and had been much impressed by the Smith air-cooled static radial; even though he did not believe that it was a practical engine as then designed, its performance was a factor in convincing him that a static air-cooled radial was possible.

[11]The Smith Static was an unorthodox design in many other respects as well; see the description in *Aerosphere 1939* (New York: Aircraft Publications, 1940), pp. 719-720.

[12]The engine was both bench and flight tested by the Admiralty. According to *Aerosphere 1939*, p. 719, the engine was flown for 2,000 [*sic*] hours, and tests were made by the British Army which showed an output of 150 hp. The engine convinced the men in charge of Admiralty aircraft engines that a static radial could be developed with as good mep and as good specific weight as the very successful rotaries, and a contract was given to Heenan and Froude for its production. Only a few had been produced when the contract was cancelled after the Armistice.

[13]The existence of this government specification and competition has been denied by a number of people active in the government at the time. According to *Jane's All the World's Aircraft, 1919* (London: Sampson Low, Marston & Co., Ltd., 1919), p. 63, however, "The Mercury...was introduced to satisfy Air Board Scheme A issued in April 1917"; and according to *Jane's* 1923, p. 6c, the "original design" of the Armstrong Siddeley Jaguar, the story of which is told below, "was the result of an ideal specification issued by the engine section of the Air Board in ... 1917." Although this latter statement is incorrect, as will be shown, it confirms the existence of the specification. It is interesting that the original diameter of the Jaguar was 42 in. and the design power 300 hp, exactly the figures said to have been specified by the Air Board. Was the Raf 8 design the *origin* of the Air Board specification? Vickers designed and partially developed a 14-cylinder two-row air-cooled radial with 5 in. x 5 in. cylinders giving a displacement of 1,374 cu in. This engine was destroyed in testing before the Armistice, and after the Armistice Vickers decided that in view of the enormous surpluses of war engines and the very reduced scale of peacetime aviation it would be profitless to continue in the engine business.

The Dragonfly Episode: 1917-1919

The normal course of air-cooled engine development in Britain was seriously disturbed from the fall of 1917 until the middle of 1919 by a most curious episode, that of the ABC Dragonfly. About October 1917 ABC Motors, Ltd,[14] submitted to the government an experimental model of a single-row, seven-cylinder, 657-cu in. air-cooled radial called the Wasp, designed by the company's chief designer, Granville Bradshaw. This engine performed quite well on its initial tests, developing 170 hp for 290 lb weight. Almost as soon as these initial tests of the Wasp had been run, Bradshaw submitted the designs of a larger, nine-cylinder engine, the 1,389-cu in. Dragonfly. He claimed that this engine would deliver 340 hp for little over 600 lb weight, and urged the government to go ahead with this engine (of which not even an experimental model had been built) rather than the smaller Wasp. The Dragonfly, like the Wasp, was very ingeniously designed for ease of production, and Bradshaw was very adroit in his sales technique, alleging as advantages both this ease of production

[14]The predecessor company, All British Engine Co., Ltd, had been founded and had started building aircraft engines in 1912. Neither All British nor ABC, however, had yet had any model in quantity production.

and the great advantages which it was claimed would be derived from its cylinders with copper plated steel fins, despite the fact that the work of Gibson at the Royal Aircraft Factory had shown that such cylinders were by no means the best for air-cooled engines.

On the basis of these claims and the very good bench and flight performance of the Wasp, both the government and the airplane industry quickly became convinced that the Dragonfly was the most promising new engine design. Throughout the war engine production had lagged behind airframes, and the situation was particularly critical in 1917 — in October the British were forced to accept defective French engines because nothing better was available. As a result, despite the fact that the crisis was to a large extent due to the fact that an untried design (the Sunbeam Arab) had been put into production early in 1917 without sufficient preliminary testing and had proved utterly useless when it appeared in May,[15] Sir William Weir, the Director of Aeronautical Supplies in the Ministry of Munitions[16] decided against the advice of his technical experts to standardize on this completely unproved engine. The manufacture of virtually all other engines except the Rolls Royce Eagle and Falcon and the Siddeley Deasy Puma (the former BHP) was to cease before 1919 in order to have the Dragonfly produced by manufacturers all over the country.[17]

In 1918, after the Dragonfly was already in full production — 1,147 were produced before the contract was cancelled — it was discovered that it was far from being a usable engine. The weight was 656 lb, considerably more than Bradshaw's estimate, and the power developed was found in bench tests to be at the most 315 hp at 1,800 rpm, while at the rated speed of 1,650 rpm only 295 hp or less was developed instead of the promised 340. What was much worse, the engine vibrated terribly in flight tests and virtually disintegrated after only a few hours in the air. In an attempt to remedy the cooling deficiencies which limited the power, new pistons were installed, and in the latter half of 1918 the valve-cooling deficiency was remedied by the installation of cylinder heads of the type developed by Gibson and Heron; this work was done by the Royal Aircraft Establishment (hereafter RAE), as the Royal Aircraft Factory had been renamed in June 1918.

Even after the cooling of the Dragonfly was partially remedied, however, the vibration difficulties remained. By the latter part of 1918 the extreme gravity of these difficulties was realized, but fortunately the Armistice prevented the crisis which would have occurred in 1919 because of the country's complete commitment to this engine. Some attempts were made to salvage it in 1919, but it was finally realized that in order to cure the vibration a completely new crankcase, crankshaft and connecting-rod design, i.e., a basic redesign of the entire engine, would be required.[18] Since, as we shall see, there were by then other air-cooled radials which were showing real promise, the obvious conclusion was drawn and the Dragonfly was abandoned without further ado.

The Initial Establishment of the Jaguar: 1917-1921

The engine ultimately sold as the Jaguar by the firm of Armstrong Siddeley Motors, Ltd, of Coventry was the developed version of the Royal Aircraft Factory's 1916 design known as the Raf 8, the origin of which has been set forth above. The company which sold it was the Siddeley Deasy company under a new name but still under the ownership and management of J. D. Siddeley.

[15] Hilary Aidan St. George Saunders, *Per Ardua; the Rise of British Air Power 1911-1939* (London: Oxford University Press, 1944), pp. 214-215.

[16] There had been a general reorganization of aeronautical procurement in February 1917, and responsibility for design and supply had been transferred from the Admiralty and the War Office to the hands of Sir William Weir, who was a member of the Air Board as well as of the Ministry of Munitions. (In January 1918 he became Director-General of Aircraft Production in the newly created Air Ministry.)

[17] At the same time that the Air Board had issued its specification for radial engines in April 1917, it had issued a specification for a new fighter airplane. About the end of 1917 it decided that the only one of all the designs submitted which should be put in production was the Nieuport Nighthawk, to be powered by the ABC Dragonfly.

[18] The engine suffered from both actual dynamic imbalance, the counterweights providing static balance only, and an extreme case of synchronous torsional vibration, although the nature of this latter phenomenon was not understood at the time. Bradshaw had accidentally designed his engine to run exactly on its major critical vibration frequency; the other builders of radial engines at this time had escaped this difficulty sheerly by good luck.

The original design of the Raf 8, as has been said, was brought to Coventry at the beginning of 1917 by Capt. F. M. Green, the former Chief Engineer of the Royal Aircraft Factory, when he became Chief Aeronautical Engineer of Siddeley Deasy. Green's primary assignment had been to develop the BHP engine, which now became known as the Siddeley Puma, but he was anxious to develop the air-cooled radial and obtained permission to work on it from the start, although at lower priority. Siddeley knew of the tests of the Smith Static and of the Admiralty's favorable impression of it (above, p. 128), and this was very probably a factor in his decision to develop the Raf 8. In April 1917 the Air Board issued its Scheme A, calling for a 300-hp radial air-cooled engine not over 42 in. in diameter. This specification fitted the Raf 8 exactly (cf. ibid., n. 13), and Siddeley submitted the design of the engine to the Air Board, but it seems to have been beaten by the Cosmos Mercury;[19] Siddeley nevertheless continued with its development.

The cylinder design of the Jaguar, by S. D. Heron, was derived from the systematic study of air-cooled cylinders carried out at the Factory in 1915-1916 by Gibson and Heron. This engine was thus the first to have, at least in principle, a cylinder head of the modern type, constructed entirely of aluminum, and with two valves inclined at a rather large angle to each other. The original design called for an integral aluminum head and finned muff shrunk over a steel liner, but at Siddeley's instructions this was altered to an aluminum head screwed to a steel barrel by a short thread; this type of construction, which became universally used within a decade, had been first tried by Siddeley in his water-cooled Puma.[20] The Factory design also included an integral gear-driven supercharger, the first on any radial, designed by J. E. Ellor; after experiencing repeated breakage of the gears in Coventry, Green and Heron added a system of centrifugal clutches to protect the gearing.

[19]According to one source there were two winners in this competition, one of whom was Siddeley. Sources close to Siddeley Deasy at this time, however, know of no government contract for the Jaguar such as was given for the Cosmos Mercury; if one was given, it was certainly canceled before the middle of 1919.

[20]The original BHP, from which the Puma was derived, used the Hispano construction, where a closed liner was threaded over its whole length and screwed into an aluminum muff. The change to an open liner and short thread was due to Siddeley himself.

In the middle of 1917 Siddeley instructed Heron, who was in charge of the Jaguar, to substitute for the two-valve head a head with three horizontal valves, and Heron left the company rather than make this change. Siddeley eventually gave up the idea, but for two years the company was without any designer with real experience in aircraft engines. A year and a half later, almost immediately after the Armistice, Green quit his position as Chief Aeronautical Engineer. His position in the airframe work of the company varied from time to time thereafter, but in the engine activities he was never again more than a consultant without any authority. The Chief Engineer of Armstrong Siddeley throughout the period of this chapter was F. R. Smith, a man of considerable practical good sense, but overly cautious and without any training in scientific engineering, and unable to exert any great influence over Siddeley. His functions were rather those of a head of the drafting room than those of a chief engineer. In the middle of 1919 Siddeley hired S. M. Viale, a man with very considerable experience in this field, as chief designer for aircraft engines, and Viale held this position for the rest of the period covered by this chapter. Viale, however, was interested much more in new design than in development, and in any case had little or no influence on policy.

Development of the Jaguar seems to have lagged after the summer or fall of 1917, in part because of the pressure of Puma development and production, but undoubtedly chiefly because of the government's commitment to the Dragonfly. Siddeley seems to have decided to resume serious development of the engine about June 1919; the Dragonfly had then been proved a failure, and Siddeley received a government contract, probably the first one, for the Jaguar.

The engine at this time could not run over about 1,100 rpm, principally because as the cylinder heads heated up they became loose owing to differential expansion. Viale redesigned the engine in many respects. The cylinder heads were attached by a lock nut tapered in such a way that as the cylinder heated up the joint became tighter rather than looser, the valve gear was changed to eliminate the very long rocker arms of the original design, and the timing gear was altered. In addition, Siddeley decided that the supercharger should be eliminated for the time being, since the drive was not entirely satisfactory in its present state, and he believed that it was better to develop the basic engine without this added complication.

By about the middle of 1920 the redesigned engine was running fairly well, and a few experimental engines were bought by the government; these engines developed about 300 hp. Siddeley then suggested that rather than going on to develop the gear-driven supercharger, which promised to give a certain amount of trouble, and the cost of which would be hard to recover in the existing generally depressed state of aviation, an impeller should be mounted directly on the crankshaft without gears as in the Smith Static. Such a fan would scarcely increase the pressure of the air, but it would serve to improve the mixing of the fuel with the air and thus to secure more equal distribution of both to the cylinders. This was done, and at about this same time the stroke of the engine was increased from 5 in. to 5½ in., bringing the displacement up to 1,512 cu in. In June 1922 this enlarged and improved version of the Jaguar passed the official type test of the Air Ministry and was put in production.

The Initial Establishment of the Bristol Jupiter: 1917-1921

The Ministry of Munitions had in 1917 given to the Brazil-Straker company a production order for 200 Mercury engines, as has been told. The design of this 14-cylinder, two-row, 1,223-cu in. engine, made by Brazil-Straker's Chief Designer, L. F. G. Butler, under the direction of the Chief Engineer, A. H. R. Fedden, was completely independent of the work done up to this time by the Royal Aircraft Factory. It used a three-valve cylinder head of the poultice type,[21] and instead

[21]The poultice cylinder consists of a steel barrel with the upper or head end closed; the valve seats are contained in this integral head. Since more heat has to be dissipated from the head than from any other part of the cylinder, while steel is a poor conductor of heat, it was not possible to cool the head as the barrel was cooled, by fins machined directly in the steel. Consequently a finned aluminum cap or poultice containing the valve guides and ports was placed on top of the steel head. This meant, however, that the path from the source of heat inside the cylinder to the radiating fins was long and indirect, whereas Gibson's research at the Factory (cf. above, p. 124 f) had shown that the use of large masses of aluminum to conduct heat over long distances was unsatisfactory. In addition, the thermal contact between the steel head and the aluminum cap was bound to become poor because of the different rate of thermal expansion of the two materials.

of a master rod with articulated link rods had side-by-side rods of the type usual in rotary engines. The design was completed in July 1917. Very early in 1918 the Mercury was run on the bench, and in April it was flown for the first time, in a Bristol Scout F-1. Here it gave very good performance, much better than the water-cooled Sunbeam Arab which was the original power plant of this airplane. The Mercury was rated at a normal output of 315 hp and a maximum of 347 hp.

Early in 1918, the Brazil-Straker company was bought by new owners and renamed the Cosmos Engineering Company. This change in ownership made no difference in the organization or personnel of the company, and almost immediately the new company undertook the development of a second air-cooled radial. This was a nine-cylinder single-row engine named the Jupiter, with a displacement of 1,753 cu in. Fedden presented a sketch of the Jupiter to the government early in 1918, and in July received informal assurance of government support.

The company's principal reason for undertaking the new engine was simply the complete acceptance which the government had given to the single-row Dragonfly. As we have seen, one of the chief reasons why the government had decided to have the Dragonfly produced to the exclusion of almost all others was its ease of production, and although this was in part due to the fact that it had been ingeniously designed with this specific end in view, it was also inherently true that for the same output a single-row engine could be built with considerably less labor than a two-row.[22] Since by this time Fedden believed that a nine-cylinder single-row engine could be developed to about 500 hp, and since 500 hp was all that anyone was thinking of as even a remote objective for air-cooled engines at that time, there was no hope of beating out the Dragonfly with a two-row engine on the grounds of output. In fact, the 14-cylinder Mercury had a displacement of only 1,223 cu in. whereas the Dragonfly had 1,389 cu in. and the Jupiter actually had 1,753 cu in. At the low speeds of the aircraft of those days, the increase in drag due to the 52½-in. diameter of the Jupiter

[22]Modern experience has shown that a single-row can be built with about 20% to 25% less labor than a two-row of the same displacement, although of course equal displacement will normally give somewhat more power in the two-row engine.

compared with the 41⅝-in. of the Mercury was felt to be a negligible drawback. By the fall of 1918 Cosmos had decided to concentrate on the Jupiter rather than the Mercury and was putting a good deal of its own money into the development.

The Jupiter, like the Mercury, utilized a poultice-type cylinder head, although because of the larger size of the cylinder there were four valves instead of three. Fedden used this construction despite his knowledge that the research of the Royal Aircraft Factory had led to the conclusion that the best type of head was of solid aluminum. Fedden was afraid of the problems involved in attaching the all-aluminum head to the barrel, and serious difficulties were in fact experienced with the attachment of the all-aluminum head of the Jaguar for a number of years after 1918. Furthermore, Fedden was not convinced that the cooling of the all-aluminum head was actually superior, while he believed that the problem of securing contact between the steel and aluminum of the poultice head could be solved, despite the difference in the rate of thermal expansion, by sufficient ingenuity in bolting the two parts together and by the use of Invar packing pieces. Four valves were used instead of two as recommended by the Factory because Fedden anticipated higher engine speeds than those currently in use and thought that two valves would not give sufficient breathing capacity. Two versions of the Jupiter were designed: one with direct drive and one with a planetary reduction gear.

Almost immediately after the Armistice the government cancelled its production contract for 200 Mercuries, but very shortly thereafter gave Cosmos an experimental contract for about six Jupiters, and probably Cosmos could also have got a development contract for the Mercury. Since, however, the company believed that the only hope of going into production was with the nine-cylinder Jupiter, further development of the Mercury was almost completely dropped;[23] a type test was never attempted.[24] The settlement reached with the government covered Cosmos's expenses on this development approximately in full.

[23]A certain amount of testing continued in 1919, and in April a Mercury in a Bristol Scout set a new climbing record of 5.4 minutes to 10,000 feet and 16.25 to 20,000.

[24]The engine could deliver its rated 315 hp only for a short time, not enough to pass the type test.

Beginning about the end of 1918 the company concentrated almost entirely on the development of the nine-cylinder Jupiter. The first direct-drive engine had been completed in October 1918 and was first run a few days before the Armistice. Before the end of 1919, a year later, it had undergone several long runs on the bench and had been flown, although only for brief periods, in a Bristol Badger, one of the planes which had been designed for the ABC Dragonfly. In 1919 the Sopwith Aviation Company, Ltd, used the Cosmos Jupiter in a racing seaplane which seems to have been by a considerable margin the fastest entry in the Schneider Trophy contest of that year.[25]

The cost of the Jupiter development proved far higher, however, than had been anticipated when the experimental contract was accepted, and in February 1920 the Cosmos company failed and all work stopped. Probably only two engines had been delivered to the government and paid for by this time, and since the price even for all six would not have covered the cost of the development to date, there was a very large deficit in the Jupiter development account.

The government was very anxious to have the development of the Jupiter continued. While Cosmos's affairs were in liquidation, the government had Fedden put the engine through the newly established official 50-hour type test, which it was the first engine to pass. After Fedden had discussed with various companies the possibilities of taking over the Jupiter engine and the Cosmos staff, the government assisted him with very strong pressure on the directors of the Bristol Aeroplane Company[26] to reach an agreement in August 1920. By this agreement Bristol took over for £15,000 assets of the Cosmos company having a book value of £60,000, including all patents and all material parts of the Jupiter engine. Bristol received a government order for 10 experimental engines for a

[25]The race was a fiasco owing to fog and poor organization, but at least the British observers were unanimous about the speed of the Sopwith. See, e.g., *Flight* 11, 1919, pp. 1225 and 1247. The plane is described, ibid., pp. 1154 and 1183-1185.

[26]The government said that if Bristol did not take over the Cosmos engine, the government would take it over itself.

sum of £25,000, and the Bristol directors accepted Fedden's estimate that he could within two years produce a 500-hp engine weighing not more than 650 lb for a total expenditure, including the setting up of the new plant, of not over £200,000. Fedden became Chief Engineer of the newly created Bristol Aero-Engine Department, and Butler remained as Chief Designer. The new department began work in September 1920 with a total staff, both engineering and mechanical, of about 35 men, of whom about a dozen were former employees of the Cosmos company. There were seven people in the drawing office.

By the end of a year, in the fall of 1921, the new engine department of Bristol had spent over £197,000 out of the estimate of £200,000 (most of it, of course, on equipment rather than direct development), and the directors were seriously considering closing down the department. In September, however, the Jupiter II[27] became the first engine to pass the Air Ministry's 100-hour type test, which had just replaced the 50-hour test set up in 1919. The normal rating given was 385 hp at 1,575 rpm, and the maximum 400 hp at 1,625 rpm. In October the engine was shown in the Paris Salon Aéronautique, and there it scored a decisive success, the purchase of a license by the Société des Moteurs Gnome et Rhône. Although this company was really no longer sound technically, its reputation gained before and during the First World War was still very great, and its purchase of a license from a new and unknown organization was an enormous moral success.[28] In December 1921 came a second great success: the British government gave Bristol its first production order, apparently for 42 engines with 100% spares.

[27]The II seems to have differed from the I principally in the use of a patented valve gear which compensated for thermal expansion.

[28]During the next decade virtually all of Gnome-Rhône's engineering was in the hands of two Englishmen sent over by Bristol: Norman Rowbotham, who came in 1922 to organize the production of the Jupiter and who became Chief Engineer and general manager, and Roger N. Ninnes, who came about a year later and who became Chief Designer. Until late in the 1920's Gnome-Rhône did little but manufacture according to the latest Bristol designs, although it did, in 1925-1926, introduce one very important innovation of its own, the Farman reduction gear, which was licensed to Bristol in 1926.

The Period of Intense Competition: 1922-1926

In June 1922 the Armstrong Siddeley Jaguar passed its first type test, under the old 50-hour schedule, at a normal output of a little over 290 hp and a maximum of over 330 hp. In 1923 the rating was raised to 320 hp at 1,500 rpm normal and 360 hp at 1,650 rpm maximum. In August 1924 the Jaguar passed the new 100-hour test at a still higher rating, 385 hp at 1,700 rpm normal and 425 hp at 1,900 rpm maximum. This rating seems to have remained unchanged for the next two years.

In addition to the increase in power of about one-third obtained during this period, one very important new feature was added to the engine. Not long after the 1922 model with the mixing fan had gone into production, Siddeley undertook the development of a geared-up supercharger, involving both the improvement of the drive and the use of a larger and better impeller. The drive was of course developed by the Armstrong Siddeley staff, but a number of sources were tried for the design of the impeller and diffuser. After an Armstrong Siddeley design was found aerodynamically deficient, an RAE design was tried but found to fail because of vibration. A design was then bought from the British Thomson-Houston Company; this design, which involved a large, vaneless diffuser, gave fairly good results at first and was put in limited production, but soon had to be abandoned since as the power of the engine was increased it was impossible to increase the diameter of the diffuser proportionally. The design finally adopted was developed by the Armstrong Siddeley staff; an engine so equipped was finally put in production about 1925 and entered military service in the Siskin IIIA fighter in 1926.

At the same time that these improvements were being made in the Jaguar, Armstrong Siddeley had produced various other engines. In 1919 or 1920 the government had bought about 60 of the 40-hp two-cylinder air-cooled Ounce, an engine which had originally been built in 1919 simply as a test rig, but had performed so well that the government had ordered it produced for a light airplane. The really important success, however, was the single-row, seven-cylinder, 150-hp Lynx, which was simply one half of the Jaguar. The company had apparently decided very early to bring out such an engine, but it would appear that the early development was concentrated on the Jaguar and that although a prototype was built about 1920 the Lynx was not in production until 1922, shortly after the Jaguar, and was produced directly from drawings based on the current model of the Jaguar. Virtually no development was required to make it a great success; it profited from the best features of the Jaguar's design while being completely free from the worst fault of that engine, to be discussed later, the weakness of the two-throw crankshaft. The Lynx was sold in quantity almost at once to the government for use in the Avro 504 N trainer,[29] and continued to be produced in large quantities for this purpose until the 1930's; it accounted for a good share of the prosperity of the Armstrong Siddeley company over the whole decade of the 1920's.

Armstrong Siddeley was beyond question the dominant British manufacturer of air-cooled engines throughout the period from 1922 to 1926. In 1923 the British government adopted as its first completely postwar standard fighters the Gloster Grebe and the ship-based Fairey Flycatcher; both were powered by the Jaguar.[30] By 1926 there were five squadrons of Grebes in service, and when this fighter began to be replaced beginning about 1925, its successor was the Armstrong Whitworth Siskin, also powered by the Jaguar. During this same period, 1923 to 1926, Jaguars were sold abroad (mostly on exported fighters, such as the very successful Hawker Danecock) in larger quantities than any other British engine.[31]

Siddeley's position was inherently strong because he also owned an airframe company, Armstrong Whitworth Aircraft, Ltd, so that he was sure of having airframes designed around his engine. The Siskin fighter was built by Armstrong Whit-

[29]Photographs and a description of the Lynx are given in *Jane's* beginning with the 1920 issue. Informed sources stated, however, that it was put in production from drawings after the Jaguar was in production and that its first use was in the Avro 504N. The Avro 504N appears in *Jane's* first in the 1924 issue, and no airplane is listed with the Lynx in any earlier issue.

[30]Experimental versions of both airplanes were tried with the Bristol Jupiter, but only the Jaguar-powered versions were produced and used in quantity.

[31]In part, however, the greater number of sales made abroad of the Jaguar than of the Jupiter was due to the fact that Bristol sold a license for the Jupiter to Gnome-Rhône in 1921 and to manufacturers in other countries later on.

worth, and in 1926 Armstrong Whitworth brought out the Argosy, a 20-passenger transport powered by three Jaguars, which was put in service by Imperial Airways on the London-Paris route.[32] This was the first British transport with air-cooled engines to go into regular service, and was the first British transport to make commercial aviation a paying proposition. Once it was tried, no more transports were built around the water-cooled Rolls Royce Eagle and Napier Lion which had been the standard engines for this purpose since 1920.

Although its output was greater, the Jupiter II type-tested in September 1921 was far from being the equal of the contemporary Jaguar. Fedden continued, however, to push the development of his engine with remarkable drive and energy; he persuaded the Bristol directors to plow back most of their profits into development facilities, and the government continued to pay most if not all of the direct costs of the work. In March 1923 the Jupiter IV, development of which had been largely financed by a government order for 10 experimental engines at about £2,000 apiece, was type-tested with a rating of 390 hp at 1,575 rpm normal or 436 hp at 1,750 rpm maximum, and besides having a maximum rating 36 hp higher than the Jupiter II its reliability was considerably better.

The first really large production order for a Bristol engine was a government order for the Jupiter IV, of which 88 were delivered in 1924 and 76 in 1925, enough to keep Bristol's production department fully occupied during these two years. Some of these engines were used in 1924 and 1925 to equip two squadrons of Hawker Woodcock fighters, the first service squadrons to be equipped with Bristol engines; others were used to equip two other production airplanes, the Parnall Plover ship-based fighter and the Bolton-Paul Bugle twin-engine day bomber.

Development of the engine continued at a rapid pace, and in the two or three years after the introduction of the Jupiter IV two very important improvements were made. The chief obstacle to an increase in power through an increase in rpm

[32]On the history of British transport aircraft from 1919, see the chapter by John Stroud, "British Air Transport," in C. Harvard Gibbs-Smith, *The New Book of Flight* (London: Oxford University Press, 1948), pp. 131-154.

had soon been realized to be the weakness of the split master rod, and as early as November 1922 drawings had been begun of a two-piece crankshaft, which permitted the use of a master rod with a solid big end. The drawings were completed in June 1923; an experimental Jupiter V was built by November 1923 and passed the government type test in October 1924 at 480 hp at 1,900 rpm maximum, to be compared with the 436 hp at 1,750 rpm maximum of the Jupiter IV, which had been type-tested in the previous year and was currently in production. The Jupiter V was not put in production, however, since a second important improvement was on the point of being adopted.

This second improvement was the replacement of the cast aluminum crankcase by a forged one of the same material. The design of the forged case had been begun in July 1923 and completed in December 1923, although the first parts were not produced until May 1925 and an engine with the new case was not run until June 1925. This engine passed the government type test in July 1925; there was no noticeable increase in output, but the weight of the engine was appreciably reduced, from 780 lb in the IV and V to 720 lb.

The Jupiter VI with the forged crankcase as well as the two-piece crankshaft and solid master rod was put in production early in 1926, and became the first completely successful Bristol engine. In 1926 the government placed a quantity order for the first really successful Jupiter-powered fighter, the Gloster Gamecock, exactly like the Jaguar-powered Grebe except for the engine. In 1926 or 1927 the Westland Wapiti general-purpose two-seater with a Jupiter VI was adopted as standard and used in very large numbers by both the British and Australian Air Forces. Besides being used in these and other production military aircraft, the Jupiter VI was the first Bristol engine to make a success in commercial transport, and virtually inaugurated British long-range transport. It was used on the new deHavilland three-engine Hercules, brought out in 1926, with which Imperial Airways inaugurated its England-to-India service, later extended to Australia.[33] Commercial uses seem to have accounted for about 30 of the approximately 160 Jupiter VI's produced in 1927, while export accounted for 30 more.

[33]The Jupiter VI produced in France by Gnome-Rhône was adopted as standard by KLM on its Fokkers.

The Jaguar Outclassed by the Jupiter: 1926-1929

In the year 1926 the Jaguar and the Jupiter were probably on about an equal footing competitively, everything considered. There were two features of the Jaguar's design which were superior to the Jupiter: supercharging and an all-aluminum cylinder head.[34] The one great advantage of the Jupiter in 1926 was its greater output: 450 hp normal or 485 hp maximum, against 385 hp normal or 425 hp maximum for the Jaguar. For high-speed airplanes, however, this was partly or wholly counterbalanced by its 60% greater frontal area.[35] Reliability seems to have been about equal. The Jaguar had a longer period between overhauls in commercial service (owing probably to the need of rebedding the Jupiter cylinder head), but the general standard of workmanship was definitely better in the Jupiter.

During the years 1926-1929 Bristol succeeded in equaling or surpassing Armstrong Siddeley's achievements in both the features which had constituted the chief advantages of the Jaguar in 1926. It is interesting to observe that in both cases Bristol got its first valuable experience from a special racing engine.

Toward the end of 1925 Bristol proposed to the government the development of a special engine to compete in the 1927 Schneider Trophy race, and received a contract in the sum of £13,000 for three experimental engines. This seems to have been the first occasion on which an attempt was made to enter an air-cooled engine in this race since the Sopwith with a Cosmos Jupiter of 1919 (cf. above, p. 137). The special engine designed for the purpose, called the Mercury, retained the 5¾-in. bore of the Jupiter, but the stroke was shortened to 6½ in. instead of 7½ in., reducing the displacement from

[34]But on the cylinder head see below, p. 147, and above p. 136.
[35]Cf. the performance of the Flycatcher with the two engines given by *Jane's* 1927, p. 37.

1,753 to 1,520 cu in. The change was made primarily to reduce frontal area,[36] but also to permit higher speeds of rotation which gave better propeller efficiency in a high-speed airplane. In order to obtain the desired output from the engine it was intended to use a good deal of supercharging even at sea level, and in order to support this "ground boosting" it was necessary to develop cylinder heads and pistons capable of dissipating heat at a much greater rate than the contemporary Jupiter was capable of doing.

The aerodynamic design of the supercharger was supplied by the RAE, which was at this time the only British organization carrying out systematic research on superchargers. The geared drive with its protective clutch system was derived from that designed by Green and Heron for the Jaguar in 1917, but it was very greatly improved by the addition of a spring element in the drive. It was only several years later that this valuable feature was adopted for Armstrong Siddeley engines.

Since the poultice cylinder head was incapable of cooling at the output contemplated for this engine, a new cylinder head was designed. Based on experimental single-cylinder work which had been begun as early as 1922, the new head, with a penthouse roof, was constructed entirely of aluminum and screwed to an open-ended barrel. Great difficulties were experienced in obtaining sound castings, but the RAE finally succeeded in producing them. The pistons of the Mercury were forged, this being the first use of forged pistons on any Bristol engine; Armstrong Siddeley had adopted forged pistons a year or two before this, but it was characteristic that the Bristol design now made detailed improvements which were not made in the Siddeley design, particularly the adoption of the short wrist pin which ultimately became almost universally accepted.

The Mercury also marked an important step in Bristol's work on the problems of torsional vibration, being the first engine which that firm ran at a speed higher than its major critical, and the first engine which anyone had so run intentionally.

[36]The diameter was reduced from 53 in. to 47.6 in., giving a 19% reduction in area. One of the major factors in Bristol's decision to develop an engine of reduced frontal area was the outstanding performance of the American water-cooled D-12 in various races in the period 1922-1925.

The Mercury was built by August 1926 and was delivered to the government in January 1927, at which time it developed 808 hp at 41.6 in. manifold pressure for 684 lb weight; outputs of up to 960 hp at 46.2 in. had been obtained for short periods on the test bench. The racer in which it was installed, the Short Crusader, was wrecked before the race owing to crossed control wires, but it had shown before this accident that its speed was remarkable for an airplane with an air-cooled engine. Although it overheated badly and was 30 to 35 mph slower than the best contestants powered by water-cooled engines, so that no further attempts were made to build a Schneider Trophy contestant with an air-cooled engine, the success of the supercharger and of the new cylinder heads and pistons had an important influence on the future development of Bristol engines.

The first element to be taken from the Mercury for use in the Jupiter was the supercharger. After a preliminary attempt at obtaining an altitude engine in 1923-1924 by the use of the turbosupercharger then being developed by the RAE, an attempt which failed of complete success for various reasons,[37] Bristol had tried to obtain altitude performance without a supercharger by means of high compression ratios. A high-compression version of the Jupiter VI was actually put in production.[38] This simple solution, however, had the disadvantage of reducing the power available for take-off, and after the success of the gear-driven supercharger on the Mercury

[37]The Jupiter III had been first tested with a turbo of RAE manufacture in December 1923, and during 1924-1925 various Jupiter IV's were flown with RAE turbos with some success. The engine cooled poorly at altitude, however, and in addition there was trouble with the turbine bearings. Despite this difficulty Fedden was for some years the most enthusiastic person in the British engine industry for supercharging, and in 1925-1926 had proceeded to build four engines equipped with turbosuperchargers of Bristol design and manufacture; these were basically Jupiters, but with the supercharger they were known as Orions. The first of these engines seems to have been flown in a Gloster Goring in 1926. The Orion was unable to climb above about 6,000 feet, and the RAE was unable at the time to discover the reason; later it was recognized to be bad matching of the compressor to the engine. Whether this was the principal reason for the abandonment of Bristol's experiments with the turbo, or whether it was because of the metallurgical and mechanical difficulties experienced, or because of poor cooling, is not clear. The last two Orions were delivered to the RAE in 1930, and the turbo was abandoned by Bristol.

[38]The standard military Jupiter VI, with a compression ratio of 5.3:1, was rated 480 hp maximum at sea level; the altitude engine, with 6.3:1 compression, was rated 460 hp maximum at 5,000 feet.

racer in 1926-1927, and after the appearance in service of the supercharged Jaguar in 1926, Bristol set about producing a genuine altitude version of the Jupiter. The supercharged Jupiter VII was first run in April 1927 and was type-tested in May 1928 at a rating of 460 hp maximum at 12,000 feet. The supercharger of the Jupiter was soon recognized as distinctly superior to that of the Jaguar.

The second major improvement in the Jupiter after 1926 was the development of a geared version of the engine. The original geared version of the Cosmos Jupiter had been run a little when the work was taken over by Bristol in 1920, but had soon been dropped in favor of more pressing problems. In 1926 flight trials were made in England of a French Jupiter with the Farman bevel epicyclic reduction gear, which Gnome-Rhône on its own initiative had just introduced to the Jupiter engines it built on Bristol license. The performance of the airplane with the geared engine was much better than with the standard Jupiter VI, whereas when the power of the ungeared engine was increased by increasing the rpm the performance of the airplane was actually worse, owing to reduced propeller efficiency. Bristol bought the rights to this reduction gear from Gnome-Rhône in February 1927 and began testing in April. It was then discovered that the Farman gear was not only a reliable device for reducing propeller rpm but also a very great help in solving the vibration problems involved in running the engine at higher speeds, since it damped the second-order vibrations and reduced the main period from about 2,000 to about 1,100 rpm. After Bristol had refined the design of the gear, the geared Jupiter VIII and IX were type-tested and put in production in 1928. Both were rated at 2,200 rpm maximum. In order to dissipate the greater amount of heat generated at the higher rpm their fin area was increased over that of the Jupiter VI, but otherwise the VIII and IX were virtually the same as the VI except for the gearing. The increase in rpm gave an increase in maximum output from 485 hp for the VI to 525 for the IX, with the same 5.3:1 compression ratio. The supercharged geared X was rated 530 hp maximum at 16,000 feet against 460 hp at 12,000 feet for the supercharged direct-drive VII.

The Armstrong Siddeley Jaguar was produced in a geared version at about the same time as the Jupiter. After a simple spur gear of the firm's own design was tried and found unsatisfactory, rights to a simple epicyclic gear were bought from the French firm of Lorraine-Dietrich. The Farman bevel epicyclic gear used by Bristol was considered by Armstrong Siddeley but was rejected as being both more difficult to produce and much more subject to errors of assembly. As far as can be learned, the simple gear was perfectly satisfactory on the Jaguar.

Throughout the history of the Jupiter up to 1928, one of its greatest fundamental weaknesses was its poultice cylinder head. In the early 1920's Fedden had believed that the problems of manufacturing an aluminum head and of securing it to a steel cylinder were at least as serious as those of maintaining contact between an aluminum poultice and a steel cylinder. Careful development of the poultice cylinder had succeeded in giving it a life of about 200 hours in the Jupiter IV and 300 in the Jupiter VI, and the rebedding necessary after this limit had been reduced to a fairly simple routine operation. Even after it had become clear that the poultice head was a real limit to output, Fedden hesitated to change. One reason was that a change would have meant scrapping the old production tooling, which the directors of the company would have regarded with suspicion, especially since they were rather dubious about the engine department in general until about 1926. Another, probably more important, reason was that there were other problems, particularly vibration, which were in even more pressing need of the resources available for development.

About 1926-1927, however, two new factors entered the picture. First, the output of the Jupiter was obviously pushing the cooling capacity of the poultice head to its extreme limit — as we have seen, it had already been necessary to use a different head in the Mercury racing engine designed in 1925 and built in 1926. Second, American air-cooled radials appeared on the market in 1926 with cylinders having all-aluminum heads which, although they were descended from the old work of the RAE, had been so much improved that they were very much superior to the current cylinders of either the Jaguar or the

Jupiter. By 1929 Bristol's most important licensee, Gnome-Rhône, was well under way with the development of a new engine of its own, retaining the mechanism of the Jupiter but using cylinders derived from American engines; in 1930-1931 Gnome-Rhône gave up its Bristol license and put these engines in production.

The first step taken by Bristol was to adapt to the Jupiter the head used on the racing Mercury. Such a cast all-aluminum head was put in limited production early in 1927 and used on a small number of Jupiter VI's. It was successful in operation, as it had been on the Mercury, but production was excessively costly owing to a very high rate of scrap.[39] As a result it was decided to go to a forged aluminum head with machined fins. After single-cylinder tests of such heads screwed and shrunk on steel barrels had been made in 1927, a complete Jupiter engine with such cylinders was put on test in March 1929. In June Bristol began production of a whole new series of Jupiters with forged heads, corresponding otherwise to the basic Jupiter VI and its supercharged and geared variations numbered from VII to XI; these new engines were designated by the old model number with the letter F added. The series VI to XI forged-head engines were the last models of the Jupiter; they were in production from 1929 to 1933.

Once the improved Jupiters were in production, the market for the Jaguar shrank very rapidly. In 1927-1928 the last large order of Jaguar-powered Siskins was delivered — enough to equip five squadrons; by 1931 this airplane was no longer produced. It was replaced by the Bristol Bulldog, powered by a supercharged Jupiter VII. This fighter, brought out about 1927, was in limited production for the RAF in 1928, and by 1930 was in full production and was being sold to foreign

[39]The very successful American heads were cast, but British foundry technique was not the equal of American at this time. American technique had come from Britain, but methods of casting air-cooled cylinders had been greatly improved by E. H. Dix, Jr., at McCook Field (see "Foundry Production of Air-Cooled Cylinders," *SAE Journal* 12, 1923, pp. 53-56) and then by the Wright Aeronautical Corporation in its own foundry and by Alcoa for Pratt & Whitney Aircraft Company. The RAE had developed a casting technique and produced the all-aluminum heads for the Mercury, but the RAE was naturally unwilling to undertake systematic quantity production, and Bristol itself was obliged to cast the new Jupiter heads.

countries also. The Gloster Gamecock II with an unsupercharged Jupiter VI remained in service until about 1930, while the identical Grebe II with a Jaguar was converted to a trainer about 1928. Forged-head Jupiters were used on a very large number of military aircraft of other than fighter types, types which previously had usually been powered by water-cooled engines. Examples are the Boulton Paul Sidestrand III twin-engine day bomber, the Handley Page Hinaidi twin-engine night bomber, the Westland Wapiti single-engine general-purpose airplane, and the Supermarine Southampton X and Short Rangoon three-engine flying boats. In the commercial field the new Handley Page 42 Hannibal, ordered about 1928 by Imperial for its India route, was originally designed for either the Jupiter or the Jaguar, but soon standardized with the Jupiter. Eight of these airplanes went into service in 1931, replacing the deHavilland Hercules.

The basic reason for the eclipse of the Jaguar was simply its lower power, and the basic reason for the lower power was insufficient development.[40] The same explanation holds for the inferiority of its supercharging. There was, it is true, one feature of the basic design which made it inherently difficult to increase the output very much. This was the fact that the two-throw crank-shaft was not supported by a center bearing. So little intensive effort was made to increase the output, however, that it was not until well after the end of the 1920's that the Armstrong Siddeley staff was finally convinced that the basic design would have to be changed in this respect.[41] Furthermore, the problems of torsional vibration, which were perhaps the most serious single obstacle to the development of radial engines in 1920, were gradually being solved for single-row engines during the 1920's by the joint efforts of Bristol and the RAE, but were not really solved for two-row engines until the 1930's. Again a large part of the reason was lack of adequate development by Armstrong Siddeley.

[40]While it is true that the Jupiter had 16% larger displacement (1,753 instead of 1,512 cu in.), the smaller cylinders of the Jaguar should have been capable of somewhat more power per cubic inch.

[41]An enlarged Jaguar known as the Panther was brought out in 1929 with a crankshaft exactly like that of the Jaguar, and the same design was used on the still larger Tiger announced in 1932.

The principal reason for the lack of adequate development by Armstrong Siddeley was the character of J. D. Siddeley. Although his only engineering training was his practical experience in building automobiles, Siddeley did not hesitate to direct the engineering policy of his company in detail even against the advice of his trained engineers. In the early trial-and-error days of engine development this had been less serious, and Siddeley's errors were at least in part compensated by his good hunches, such as the short-thread attachment of the cylinder head of both the Puma and the Jaguar. As the state of the art progressed, however, this became a more and more serious handicap, since although Siddeley was always very receptive to suggestions for new basic designs, or for the addition to existing designs of a new feature such as a supercharger or reduction gearing, he simply did not understand the necessity of genuine development, i.e., of perfecting a design by large amounts of running till failure, followed by small but vital improvements in the parts which failed. Furthermore, not only were Siddeley's own engineering decisions based on sheer intuition, but he was completely unable to appreciate the need for any sort of scientific calculation or research by members of his staff. It was not until 1932-1933 that the company had three single-cylinder test rigs at once. Again, although the Jaguar was the first British engine with a supercharger, it was not until many years after the supercharger was in production that Siddeley bought a supercharger test rig.

This lack of equipment, which was accompanied by a lack of qualified engineering personnel, was not due to any lack of funds; the company was very prosperous throughout the 1920's, with large sales of both the Jaguar and the Lynx; and in any case the government was actually anxious to give contracts paying the full costs of new developments which Siddeley refused to accept. In fact, the very prosperity of the company may have been in part responsible for the lack of progress. Siddeley's position was that since the Jaguar was selling very well, there was no reason to improve it; and even after Jaguar sales had declined the continuing sales of the Lynx trainer engine meant that the company never lacked for production

orders virtually up to its full capacity.[42] Bristol, on the contrary, although it had made several attempts to develop smaller engines than the Jupiter, never had any commercial success in this line, so that its only hope of keeping its production department occupied was to have the best high-power engine available at all times.[43]

There can be no question, however, that the one most important factor in Bristol's success was the immense personal drive of its Chief Engineer, Fedden, which stimulated the engineers of the company to give their best efforts, persuaded the management of the company to approve courses of action he believed technically advisable, and obtained from the government the funds needed to support the work. Members of Bristol top management were probably little different from Siddeley in their natural attitude toward development, but Fedden succeeded in persuading them to do energetic development while no one in Siddeley's organization did the same.

Rather than try to develop the Jaguar to compete with the Jupiter as that engine was developed after 1926, Armstrong Siddeley in 1929 announced a new engine, the Panther,[44] of basic design almost identical to that of the Jaguar but with the bore enlarged to give a displacement of 1,667 cu in., only 5% less than the Jupiter's 1,753 cu in. This engine, however, never was able to give an output in proper proportion to its size, largely because of the weakness of the crankshaft design, which would have been shown up before this time if the proper amount of work had been done on the Jaguar. About 1932 Armstrong Siddeley announced the Tiger, a further enlarged

[42] About 1930 the Lynx was replaced as a trainer engine by the somewhat larger but very similar Cheetah, which enjoyed an even greater success and was still in production in 1949. There seems to be no doubt that the success of the Cheetah discouraged development of high-power engines by Armstrong Siddeley in the 1930's.

[43] The three-cylinder 100-hp Lucifer which Bristol took over from Cosmos was offered for sale until 1930, but total production over this period was under 100 engines. The two-cylinder 18-hp Cherub, which won a government competition in 1923, and the slightly larger Cherub III brought out in 1925 had had still smaller total sales when they were driven off the market by the deHavilland Gipsy when it appeared in 1927. The Titan, a 200-hp engine with five Mercury cylinders announced about 1928, was never put in production at all, while the Neptune, a 290-hp seven-cylinder engine, was produced in very small quantity for only a year or two (1929-1930).

[44] First called the Jaguar Major.

Panther which was no more successful than that engine. Thus by the early 1930's Armstrong Siddeley was through as a producer of high-power engines. The company continued to prosper with the production of the Lynx and then of the Cheetah trainer engines, but throughout the decade before the war Britain had only one producer of high-power air-cooled engines, Bristol.

SUMMARY

Research done by a government agency, the Royal Aircraft Factory, established most of the basic principles of design ultimately adopted in all modern air-cooled aircraft engines; later chapters will show that this is only one of many cases in which research by government agencies has made important contributions to the development of aircraft engines.

Development of service engines, on the other hand, was entirely carried out by private firms. On the basis of a design produced by the Factory, the private firm of Armstrong Siddeley developed the first modern air-cooled engine, the Jaguar, which was put in extensive service beginning in 1923. To maintain competition in this field the British government supported the efforts of Bristol to develop a second air-cooled high-power engine.

The great value of competition is shown by the fact that by 1926 Bristol by energetic development had made its Jupiter at least the equal of the Jaguar despite the fact that several features of the Jupiter design were inherently inferior. After 1926 Armstrong Siddeley rapidly fell behind because it refused to do sufficient development even though the government was always willing to pay for it. One of the principal reasons for the firm's attitude was that its large trainer-engine business gave it all the production it could handle: this is only one of many illustrations of the fact that the only really effective incentive for development is the hope of profits, and that government development contracts are usually only an aid, not a genuine incentive.

APPENDIX TO CHAPTER VI

MAGNITUDE OF BRISTOL ENGINE-DEPARTMENT ACTIVITIES

Statistics have been obtained giving the yearly value from 1920 through 1930 of all British government contracts with Bristol for poppet-valve engines. Since on the average probably nine-tenths or more of Bristol development was paid by the government, and at least two-thirds (usually more) of all sales were to the government, these figures are a very good indication of the total activity of the Bristol engine department up to about 1930. They exclude the single-cylinder work on sleeve valves which began in 1926, but the first multicylinder sleeve-valve engine was not built until 1932, so that the value of the work excluded is small.

YEARLY AMOUNT OF BRITISH AIR MINISTRY ORDERS FROM AERO-ENGINE DEPARTMENT OF BRISTOL AEROPLANE COMPANY: 1920-1930
(In thousands of pounds sterling)

Year	*Research and Development, including Experimental Engines*	*Production Engines*	*Overhauls Production Spares*	*Total*
1920	25	0	0	25
1921	30	0	0	30
1922	9	18	3	30
1923	29	105	37	171
1924	2	142	11	155
1925	18	141	4	163
1926	46	78	22	146
1927	97	205	34	336
1928	123	326	47	496
1929	37	477	158	672
1930	77	357	184	618

The total government payments to Bristol for the development of the entire Jupiter series, over the period 1920 through 1931, were £195,000 for 97 experimental engines, plus £153,000 of research contracts.[45] In 1931 Bristol alleged that it was £120,000 out of pocket on development costs to date, and to amortize this deficit the government authorized the addition of a sum of £50 to the selling price of future production engines.

The first "quantity" production of Jupiter engines was of 18 Jupiter II's and 24 Jupiter III's during 1922 and 1923.[46] In 1923

[45]This does not include any allotment to the Jupiter for its share of the general research contracts not connected with any specific engine. This allocation, however, would not increase the above figure significantly.

[46]But see above, p. 138.

a much larger government order was received for the Jupiter IV, and this and supplementary orders kept the production department fully occupied for the next two years: 88 were delivered in 1924 and 76 in 1925. The first great success of the company was with the Jupiter VI, of which 142 were delivered in 1926. Deliveries of that engine and of its geared and/or supercharged variants numbered VII to XI amounted to 176 in 1927, 175 in 1928, 297 in 1929, and 470 in 1930.

After 1925 a certain part of this production — perhaps a quarter or a third on the average — was for customers other than the British government. Of a total production of about 175 engines in 1927, about 65 were for non-British-government use, and about 55 of these were Jupiters (the other 10 being Lucifers). In 1928, 50 out of 180 were nongovernment and over 40 of these were Jupiters. In 1929, 135 out of 300, and in 1930, 130 out of 460 Jupiters were for other customers than the British government.[47] A certain part of these non-British-government sales were for civilian transport, where Bristol had a fair amount of business beginning with the choice of the Jupiter VI in 1926 by Imperial Airways for use on the deHavilland Hercules. According to Fedden ("The Future of Civil Aviation," *Journal of the Royal Society of Arts* 92, 1944, p. 425), however, total sales for commercial transport of all British engines averaged only 30 per year in this period. Thus the larger part of these non-British-government sales of Bristol engines must have been for foreign military uses. These were fairly small because by this time Jupiters were manufactured under license in every important country in Europe and also in Japan. The foreign production under license was, in fact, greater than Bristol's own production, at least up to 1928. It is said that in the years from 1920 to 1928 about eight times as many engines of Bristol design were produced in Europe, including England, as of any other one design.

The entire force of the Aero-Engine Department of the Bristol Aeroplane Company at its foundation in August 1920 was about 35 men, including engineers, designers, help, and workmen; of these about seven were engineers and designers. Growth through the 1920's was at a fairly constant rate up to a plateau reached about 1928, at which time there were about 90 engineers and designers

[47]These figures on the uses of Bristol engines come from a list of annual production which naturally does not correspond year by year with the figures given previously on deliveries, but does not check exactly either with a second list of total production.

and about 200 in the experimental shop.[48] Total employment in the Bristol Aero-Engine Department was approximately as follows:

Year	*Total*	*Year*	*Total*
1920	50	1926	700
1921	100	1927	850
1922	150	1928	1,050
1923	250	1929	1,750
1924	350	1930	1,900
1925	550		

[48]These figures have no documentary support; records give the total size of the Bristol engine department year by year but do not divide this into experimental and production.