CHAPTER III

Development Directly Supported by the Government

ALTHOUGH the United States after 1926 differed markedly from Britain in relying principally on profits and private risk to finance the larger part of the development done by the established producers of high-power aircraft engines, it was necessary in the United States as in Britain to provide direct government support of engine developments which the military services believed essential but which the established producers did not care to undertake. It has been mentioned in the preceding chapter, for example, that although private risk had provided the United States with the most adequate range of air-cooled engines in the world, it had not produced a fully developed liquid-cooled engine by the outbreak of the Second World War. There would, in fact, have been no American liquid-cooled engine in 1939 at all if the development of this type had been left entirely to private risk. The seriousness of the lack is shown beyond question by the fact that British fighters were consistently superior at altitude to United States Army production fighters from the early 1930's until 1943 (cf. p. 252). Even in the case of the very successful air-cooled engines, certain extremely important military features had been paid for to a very large extent by direct government contract: the outstanding example is two-stage supercharging, which has been mentioned above (p. 54).[1]

THE INSUFFICIENCY OF DEVELOPMENT CONTRACTS AS INCENTIVES

At the conclusion of Chapter II it was pointed out that even under the British system, where the firms expected all military development to be paid directly and in full by the government, the firms had never devoted any great portion of their efforts to projects which they themselves did not believe to be the most

[1]Accomplishments of direct government support such as turbosupercharging are reserved for discussion in Chapter V as being almost independent accessories rather than integral features of the engine. Cf. pp. 249, n. 4, 305, n. 7.

likely to lead to production and to profits. The United States services have on occasion tried to obtain development in return for direct payment alone, and it is important to compare the results of such procedure with the results obtained when both profits and direct payment were offered as incentives. The history of the early development of air-cooled engines in the United States, recounted in detail in Chapter VII, itself offers an opportunity to compare the effectiveness of development contracts with and without a prospect of profits as an additional incentive.

Immediately after the end of the First World War both the Army and Navy independently set about obtaining an air-cooled engine of about 200 hp. There was no experience whatever in the United States with air-cooled engines of more than about 100 hp, although the British had done a good deal by the end of the war toward development of air-cooled engines of over 300 hp. Contracts were first given to the Lawrance Aero Engine Corporation, which had previously developed a successful 60-hp air-cooled engine with the aid of Army and Navy contracts, but it soon appeared that this company was too small to develop a fully reliable 200-hp engine in reasonably short time, and other difficulties arose because Lawrance did not have adequate facilities for production.

By 1922 the Army had lost interest in 200-hp air-cooled engines, but the Navy was still intensely interested in them as replacements for the 200-hp Hispanos which powered most of its ship-based aircraft, and set out to try to persuade one of the established manufacturers, Wright or Curtiss, to compete with Lawrance in the development of this type of engine. But although the Navy was not only willing but eager to pay either of these companies for the work, neither was willing to undertake it. Curtiss's 400-hp D-12 dominated the American market for large engines at this time, and profits on large engines were so much greater than on medium, 200-hp engines that Curtiss was unwilling to divert engineers from improvement of the D-12 to the development of a 200-hp engine of any sort. Wright's principal business was in the medium-power field, its only important product being the 200-hp Hispano-Suiza, but the management felt that the company's current position in this

market was safe with this water-cooled engine because the Lawrance company could never build a 200-hp engine as reliable as the Hispano; Wright preferred to use its engineering resources for the development of high-power engines which could challenge Curtiss in the more profitable 400-hp market. The Navy finally secured its objective, but only by forcing the Wright company to do what it wanted by flatly refusing to buy any more Hispanos, or even any spares for existing engines, despite the fact that they were very superior to the Lawrance engine as it was at that time.

In the case of the Curtiss R-1454 high-power air-cooled engine, the Army's policy actually removed any possibility of real profits from a successful development. The history of this engine has already been discussed in Chapter I, where it was shown that the development was sure to be extremely slow because of the technical inefficiency of the process by which it was carried out. The development would very probably have failed for lack of incentive, however, even if Curtiss had had full technical responsibility. Early in 1924, only a few months after the contract was signed, a representative of the Navy Bureau of Aeronautics became convinced during a visit to the Curtiss plant that while the basic design of the R-1454 was in general superior to that of its only competitor, the Wright P-1, Curtiss was putting very little enthusiasm into its development. This impression is borne out by the actual history of the engine. Nothing else can very well explain the fact that Curtiss took over nine months to detail and build the first R-1454 and nearly the same amount of time merely to rebuild it with new cylinders designed by the Army; at this same time Wright could completely design and build engines of the same size and type as the R-1454 in about six months, and Pratt & Whitney designed and built the first Wasp in less than five.

The most probable inference would seem to be that Curtiss put very little enthusiasm into the R-1454. Such a lack of enthusiasm would have been only natural, since successful development of the R-1454 was very likely to result in actual financial loss to Curtiss. Until the passage of the Air Corps Act of 1926, the only unquestionably legal method by which the Army could purchase engines was by issuing a detailed specification, asking for bids, and awarding the production contract to the low bidder. This was the method which the Army applied to the R-1454. The contract for detailing and construction of the experimental engines was awarded after a first round of bidding on the Army's original design specification, and Curtiss had won this contract by submitting the low bid. The rights to the design of the R-1454 remained the property of the Army, and as soon as the experimental engines were satisfactory the Army intended to issue the detailed designs in a new specification and invite new bids for quantity production. Thus even if Curtiss got the quantity award, its profits would be nothing like those it could make on its own directly competing engine, the D-12. It seems very probable that Curtiss's low bid on the Army specification was due, not to a real desire to make the R-1454 into a usable engine as rapidly as possible, but to a desire to keep in touch with the general progress of air-cooled engines in case the type should become important at some time in the future.

Quite clearly a development contract, however liberal in its terms and its administration, is by itself no incentive to an established company: the real profits are made on quantity sales of a successful product, and the company will be really enthusiastic in its work only if it believes (1) that the project is technically sound, (2) that an adequate market will be found for the product, (3) that development of the new product will not lead to loss of greater profits on existing products. Without these beliefs a development project is at best nothing but a nuisance in a first-rate firm, and in many cases is still worse because it diverts engineering facilities and manpower from other projects which the company does believe will lead to production and profits.[2]

[2]There are only two real exceptions to the rule that a company will be hostile to developments in the ultimate marketability of which it has no real belief. The first occurs when the project is very small compared with the total engineering capacity of the firm. During the 1930's both Wright and Pratt & Whitney undertook various projects of this nature at the request of the government: the compound Wright Cyclone (below, p. 441 f) is one example. In these cases the amount of development capacity diverted is small enough for the company to be willing to please its main customers even if it is reasonably sure the project will find no market. The second occurs when the other work of the firm is small compared with the project covered by contract. In this case the firm may feel that it profits by acquiring experience which it could never acquire in its regular business.

This means, of course, that a development contract which denies the right of a company to make any profit from quantity production of the developed article, or makes the profits unduly small or uncertain, is almost certain to be ineffective. As is shown specifically by the history of the Curtiss R-1454, it is absolutely necessary to leave "design rights" to a product in the hands of the concern developing it. The possession of design rights to the complete engine is far more important to the company than any number of patents on particular features when the product is of an old and well-known type, as reciprocating internal-combustion engines were in the 1920's.[3] Design rights, moreover, are not so likely as patent rights to expose the government to being held up by absurdly high claims for very small contributions, a thing which has occasionally happened when patent rights were left in the hands of companies most of whose business was not with the government.

Desirability of an Assured Market

Since profits on quantity production are the only real incentive for private industry, and development payments are at best only a form of assistance, not a genuine incentive, it is even more important for government to hold out the most vivid possible prospects of profits than it is to make its development contracts attractive as such. On occasion the government has done this by virtually guaranteeing a market for the product to be developed.

The best example of a guaranteed market is the case of the Pratt & Whitney Wasp, the first successful American high-power air-cooled engine. A detailed story of the numerous projects which ultimately led to this engine is told in Chapter VII (pp. 176-190). Very briefly, the immediate antecedents of

[3]Patents are, in fact, of little if any positive value to the manufacturers of reciprocating engines, who usually take them out simply to protect themselves against the trouble of litigating claims under patents which might be filed by outsiders. Alternative constructions are virtually always possible, and would be used if patent holders demanded more than very modest royalties for a license. The value of the patented design as a part of a complete engine is so much greater than any possible royalties that the engine builder would do the work of design and development even if no patent protection were possible. The situation is quite different when the product is completely novel, as in the case of the early turbojet engines: cf. Chapter XIII, pp. 336-337.

the Wasp were the two engines, the P-1 and P-2, built by the Wright company at the Navy's expense in 1923-1925, the same period during which Curtiss was working on the R-1454. Wright was quite willing to accept the Navy contract for this work, since it believed in the possibility and utility of a large air-cooled radial. Even so, the company was definitely unwilling to hasten work on these air-cooled engines to the point where it would detract from the development of a new large water-cooled engine, the T, which it was developing at the same time. There was an immediate market for the T in large Navy patrol planes and boats, and Wright hoped that it might also compete with the Curtiss D-12 in high-speed aircraft, whereas there were no definite plans for applications of the large air-cooled engine.

About 1924, however, the Navy began to work on a new observation plane. It was decided that to power it an air-cooled engine was needed of a size larger than the Whirlwind, which Wright had in production, but smaller than the experimental P engines, and late in 1924 the Navy gave Wright a contract to develop an engine of the proper size. Early in 1925 a former president of Wright, who had resigned in the middle of 1924 and was considering the foundation of a competing company, asked the Navy whether it would give a development contract for a second engine of this same size. The Navy refused to give such a contract to a company with no record of performance, but did give a definite assurance that if a new company could demonstrate a successful engine of this size ahead of Wright, the Navy would buy it in quantity for the new observation plane. At the same time the new carriers Lexington and Saratoga were within two years of completion, and the Navy had made it known that if a good air-cooled engine of the proper power should be available the Navy would prefer it to water-cooled engines for the new aircraft to be based on these carriers.

On the basis of this information Pratt & Whitney Aircraft was formed and the Wasp was developed entirely at private risk and expense. The organizer and president of the new company was the same man who only a year before, as president of Wright, had strongly resisted the Navy's request to hasten the development of air-cooled engines at the Navy's expense.

Of course circumstances only rarely permit as definite a guarantee as the one which led to the development of the Wasp. This guarantee could be given only because the work previously done by Wright on large air-cooled engines both gave a clear indication of the results that could be achieved and made it seem likely that they could be achieved within a very short space of time. No military service could foresee its needs with equal certainty in a case where several years had to pass before the product could possibly be ready. Nevertheless the services, and particularly the Army, could have added a great deal to the effectiveness of their development contracts in the 1930's if they had given even such limited assurances concerning their procurement plans as were technically perfectly possible.

The most striking example of the harmful effects of a failure to make clear that a quantity market really existed is to be found in the history of the development of liquid-cooled engines in the United States in the 1930's. The development of a surprisingly large number of liquid-cooled engines was paid for entirely or to a large extent by both the Army and the Navy during this decade, but the record of this work as told in Chapters IX to XI makes it perfectly clear that the attainment of usable results was very much delayed because the manufacturers were not at all sure that even a successful engine could be sold in profitable quantities. The Navy could scarcely have done anything to change this state of mind, since it always really hoped that the air-cooled engine could be made to do all its work, but the Army did believe in the need of a liquid-cooled engine and yet failed to make any manufacturer believe that worth-while profits could be made by the sale of such an engine.

It is true that until nearly the end of the 1930's no engine was close enough to what the Army wanted for a guarantee of sales of a specific engine to be given to its maker, but so specific a guarantee was probably unnecessary. The principal reason for pushing the development of liquid-cooled engines at this time was, as is explained in Chapter IX (pp. 251-252), that they seemed very likely to give the best fighter performance at altitudes above 10,000 or 15,000 feet. Various private firms were convinced of this, so that the first essential of a successful development was present: belief of the manufacturer in the technical soundness of the project. The liquid-cooled engine was also generally believed, however, to have definite inherent disadvantages which would very probably outweigh its advantages for all applications other than fighters, and which might well give inferior performance even in fighters in certain respects, especially climb at low altitudes. If the Army really wanted high-altitude fighters, then without committing itself to any particular standards of performance, and still less to any particular engine, it could have declared that high-altitude performance would be very heavily weighted in future quantity purchases of fighters, and that if a fighter was produced within a reasonable time showing a real superiority in this respect over existing models, at least a certain guaranteed quantity would be bought.

As it was, no manufacturer could be at all sure of worthwhile sales even if he succeeded in a very short time in producing the best engine in the world for high-altitude fighters. This was not primarily because of the danger that the Army might have insufficient appropriations when the new engine was ready for production, although the services have always complained very strongly of the system of year-to-year appropriations. Except for a very short time in the depression of the early 1930's, military appropriations were in fact quite tolerably regular in amount from year to year, so that the services could have gone very much further than they did in laying down long-range programs. Although the word "guarantee" has been used above for the assurance of a market which the services did offer to the industry on occasion and might well have offered on others, a formal, written guarantee would usually have been completely impossible for technical reasons even if long-term appropriations had been possible. All that was needed was an informal assurance concerning the service's plans so far as the service itself could foresee them, and a great deal of the uncertainty concerning future plans was due to the service's own policy of making frequent changes in the personnel responsible for general procurement plans. This policy was as harmful in its results as the practice already discussed of making frequent changes in the personnel responsible for engineering as such.

This is not to say that a guaranteed market should or could be offered as a part of the incentive for every development, or even perhaps for the majority. But what can be said with confidence is that the services should do everything in their power to foster continuity in their procurement planning and should have the continuity in personnel which would make possible the giving of assurances in such cases and to such extent as they are permitted by the state of technology at the time.

The Administration of Development Contracts

In an art advancing as rapidly as that of aircraft engines, where a good engine obtained too late is of little more value than no engine at all, it is obviously essential that the services should see to it not only that the firm's desire to succeed be aroused by the prospect of profits but also that the contracts themselves and the procedures by which they are negotiated and administered should involve as little delay as possible. That development can in fact proceed fully as rapidly and effectively under development contracts as it can when it is financed by private firms themselves is proved beyond question by the British record. The detailed story of the Merlin told in Chapter VIII shows that Rolls Royce took no more time to design and develop this engine than any American firm took to carry out any project of comparable magnitude.

In the United States, however, development paid for by the government under contract has apparently without exception proceeded far more slowly than development financed by the manufacturer himself. In some cases this has been largely due to a factor already discussed, the specification by the government of unsound features of design. In addition to such technical problems, however, the way in which the contracts were awarded and administered itself led to serious delays.

The services have always complained that their worst troubles in sponsoring development programs lasting more than a single year, i.e., virtually all programs of real importance, have been due to the fact that their experimental funds are appropriated for only a year in advance, and that they cannot even carry money already appropriated over to another year because of the rule that money unexpended at the end of the year reverts to the Treasury. This last mentioned rule is of no apparent value and very probably of real harm, and the Congressional Aviation Policy Board has recommended that it be abolished.[4] But the system of appropriating funds for only a single year was by no means the sufficient or even the most important reason for the slowness of development in the United States under government contract, as is shown by the fact that development could proceed in Britain just as rapidly under government financing as it could in the United States under private financing even though appropriations were made in Britain exactly as in the United States, for only a single year. The really important weaknesses in the American system of administering development contracts can best be discovered by comparing that system with the eminently successful one used in Britain.

As in the United States, the top British official in charge of aeronautical research and development was always a military man, an officer of the Royal Air Force, who represented research and development in the Air Council, an executive board composed of the Secretary and the Undersecretary of State for Air and the heads of the various divisions of the Air Ministry.[5] This military officer, however, was directly concerned only with very broad over-all policy, and decisions concerning particular research and development projects, even the most important, were usually made by subordinates who were in general permanent civil servants.

Basic research and also all long-range development, such as single-cylinder work in the case of reciprocating engines or the early work on gas turbines, were controlled in Britain by a Director of Scientific Research, who was always a civilian. Development of complete airframes or engines along generally

[4]Aviation Policy Board, *National Aviation Policy*, p. 35.

[5]Control of production and supply was sometimes combined with control of research and development and sometimes separate; according to these changes the title of the officer in charge of development varied: Director-General of Supply and Research from 1919 to 1922, Air Member for Supply and Research from 1922 to 1934, Air Member for Research and Development from 1934 to 1938, and Air Member for Development and Production from 1938 to the war.

proved lines was under a Director of Technical Development,[6] who until 1940 was always an RAF officer; but at least in the case of engines he exercised little if any direct control, and virtually all major decisions were made by the Assistant Director of Technical Development for Engines, who was always a civilian. The subordinate staffs were entirely civilian. This organization is in striking contrast with that used in the United States, where both the Army and the Navy have almost always had a military officer at the head of each branch of development, including specifically the development of engines.

There was great stability in Britain both in the post of Director of Scientific Research and in that of Assistant Director of Technical Development for Engines. The former was held by only two men between 1925 and the Second World War,[7] and the second of the two had been Deputy Director during the entire tenure of the Directorate by the first. The Assistant Directorate of Technical Development for Engines was held by only two men during the entire period between the wars.[8] This stability is again in striking contrast to the American practice, where the officer at the head of each section at Wright Field or in the Bureau of Aeronautics has usually held his post for a tour of duty of only a few years at the most. Stability of personnel was of the greatest importance, since it accomplished the larger part of all that could have been gained from authority to make legal contracts running several years in advance. If a British official promised that a project would be supported until completion, the firm could rely on that promise; the corresponding American official could not even be sure that he would be in charge of the project a single year later. Lack of stability in direction in the United States meant, for example, that the amount of money allotted to the development of the turbosupercharger, a program which went on from 1918 to the Second World War, fluctuated year by year from a few hundred dollars to over $50,000. Stability of personnel was, in fact,

[6]Until 1924 there was a single Director of Research who combined the two functions.

[7]H. E. Wimperis from 1925 to 1937, then D. R. Pye.

[8]Lieutenant Colonel L. F. R. Fell from 1919 to 1927, and Major G. P. Bulman, from 1928 to 1943. Both men were civilians, their military titles coming from service in the First World War.

probably more valuable than the authority to issue long-term contracts would have been: American firms have complained that disputes have frequently arisen over meanings when a new officer has been assigned to administer an existing contract.

In the United States the same organizations within the Army and Navy which controlled the awarding of development contracts to private industry also ran tests of engines and of components and accessories and reached their own conclusions concerning the merits of various features of the design and concerning ways of improving them. The technical staff of the British Air Ministry, on the contrary, did not even carry out the type-testing of service engines, which was done at the plant of the manufacturer under the supervision of a representative of the Director of Aeronautical Inspection, an official completely independent of the Directors of Research and Development. The Directors of Research and Development did control the work of the Royal Aircraft Establishment, but the work of that organization, like that of its counterpart, the NACA, was usually long-range research and not concerned with the design and development of specific engines or components thereof. Partly as a result of this separation of functions, British engine-development contracts never contained detailed design specifications as American contracts usually did. If the government believed that a certain design feature or a whole engine of a particular size or type was desirable, it would suggest this to one or more firms, as the basic idea of the Kestrel was proposed to Napier and Rolls Royce (Chapter VIII, pp. 205-207), but formal design or performance specifications were never set up.[9] Although the British government on occasion accepted designs from private industry containing the same errors of technical judgment which the American Army put in

[9]In the case of airplanes there was a more formal procedure, normally starting with a government specification stating the performance characteristics, etc., of the desired airplane, followed by the submission of designs and bids by the industry, with prototype contracts being awarded usually to the two best paper designs, and then a production contract being awarded for the prototype which proved better in test. The essential reason for this difference between engines and airframes was the fact that airplanes were usually designed to suit Air Staff requirements, whereas the Air Staff set no requirements for engines as such. Even in the case of airframes, however, a number of the most successful designs were "private ventures": the Hawker Hurricane and the deHavilland Mosquito are two of the best known later examples, while the Fairey Fox was an extremely important one of the mid-1920's.

its specifications, as has already been pointed out, the British system did have the unquestionable merit of wasting very little time in arguing over technical matters before a contract was awarded.

A British engine development contract was ordinarily given for the construction of a certain number of experimental engines; in addition, there was usually provision in the same or in supplementary contracts for payment at a specified rate per hour for a certain number of hours of experimental running. The price per engine and per hour was fixed by negotiation based upon the cost to the company, but although the statements of the company concerning its costs were formally checked there seems to have been almost no controversy between the government and the firms over what costs were allowable and what were not, and the government permitted very wide differences in the amounts allowed to different companies per hour of experimental running. The contracts were always for a fixed price, but when the work proved to cost more than the estimate and the Ministry agreed that the excess was "fair and reasonable," additional payment to cover the excess was always allowed in an amendment to the contract. The price was intended to allow a genuine and attractive profit to the firm, and the firms agree that they did in fact profit directly from their experimental work. The contracts awarded by the Directorate of Scientific Research, which covered single-cylinder development, development of components, etc., as well as true basic research, were even less specific in their terms than the contracts given by the Directorate of Technical Development. They ordinarily provided simply that the sum of money involved should be spent in work on a certain problem; no definite results were required to fulfill the contract.

In the United States, the price of a development contract was always kept down by the services to the absolute minimum needed to cover the foreseeable costs with a very small profit at best, allowable costs were very strictly defined,[10] and a fixed-price contract was literally what its name stated. When a

[10]The President's Air Policy Commission recommended that manufacturers be encouraged to take research and development contracts by liberalizing policies regarding cost allowances: *Survival in the Air Age*, pp. 90-91. Cf. also the report of the Congressional Aviation Policy Board, p. 37.

project proved, as it often did, to cost much more than had been anticipated, it was extremely difficult if not impossible for the firm to do anything but absorb the difference as a loss.

Amendments to increase the amount of a contract to cover additional work whose desirability became apparent during the execution of the contract were quite common in British engine development and were quite willingly accepted by the Assistant Director[11] in charge as long as he continued to believe in the desirability of the project. With the posts of authority held by permanent officials, it was not even serious if the Ministry was temporarily out of funds: a promise could be given that funds would be assigned from the next appropriation and the firm could go ahead in full confidence that the promise would be honored.

In the United States no such informal commitments could be made, or carried little weight if they were made, since no officer could be sure he would still be in charge when the time came to honor it. Thus a firm which wished to be sure of reimbursement was obliged to wait until funds were actually available. Even with funds actually available, an American firm which wished to avoid all risk could not rely on an informal agreement with a government official as a British firm could do, because of the marked difference between the legal restrictions on procurement in the two countries. In the United States the Treasury would pay only those bills whose validity could be demonstrated beyond legal question;[12] in Britain, government

[11]During the course of the work additional expenses which might seem desirable could, up to a certain rather liberal limit, be approved by the resident representative of the Ministry without reference to the Assistant Director.

[12]The famous Douglas case of 1935-1937 is the outstanding example of the American practice and is worth citing even though it is an airframe rather than an engine which is involved. In 1935 the Douglas Aircraft Company had won an Army design competition for a transport plane and was given a contract for a quantity. The Fairchild Aircraft Corporation protested to the Comptroller General on the grounds that its design would have won over the Douglas plane if proper consideration had been given to price. The Comptroller General examined the terms of the competition and in an opinion of February 19, 1936, announced that the award was illegal because no price competition had existed and the kind of competition which had been held was not in accordance with the Air Corps Act of 1926. Payment to Douglas was accordingly held up, while the Secretary of War and the Comptroller General argued over the proper interpretation of the Act. It was not until April 7, 1937, that the Attorney General finally put an end to the dispute, declaring that Douglas's contract was legal in all but two immaterial details, and that payment should be made. This delay for more than a year of a payment of over a million dollars caused great embarrassment to Douglas, whose working capital had been seriously depleted by its fulfillment of the contract.

officials in general had the power of making commitments within their own sphere binding on the government, and in the absence of actual fraud the Treasury would honor a commitment even if it was considered that the official who had made it had acted unwisely. The official might be discharged, but the payment would not be held up if the firm had entered into the agreement in good faith.

The only way in which the serious delays involved in waiting for a formal contract before beginning each new step in a project could be avoided in the United States was by the investing of private funds in sufficient extent to bridge the gaps between government contracts. During the 1930's two American firms, Continental and Lycoming, both attempted, as is told in Chapter X, to develop a liquid-cooled engine along identical technical lines, laid down by the Army. Continental was the Army's original choice to carry out the project, and received Army development funds three years before Lycoming did. Lycoming, however, was willing to invest a small amount of private funds in its engine, whereas Continental would spend nothing without a formal contract to cover it. The result was that the Lycoming engine made appreciably more rapid progress than the Continental. The total amount spent by Lycoming was no greater than the total spent by Continental, since the private funds spent by Lycoming no more than made up for the greater amount of Army funds received by Continental, but Lycoming's willingness to go ahead on its own prevented the delays which were inevitable when each step to be taken had to be negotiated between the contractor and the Army and then formalized by a contract. One of the most important recommendations of the Congressional Aviation Policy Board is that calling for a more flexible procedure for awarding government contracts.[13]

To conclude, the fact that development wholly paid for under development contracts could be done with great rapidity in Britain, although it was extremely slow in the United States,

[13]U.S. Congress, Aviation Policy Board, *National Aviation Policy*, p. 36. Cf. also Tom Lilley *et al.*, *Problems of Accelerating Aircraft Production during World War II* (Boston, Harvard University, Graduate School of Business Administration, Division of Research, 1947), p. 66.

was due to four main features of the British system of awarding and administering such contracts:

(1) The government official in charge of engine development did not try to control the details of engine design.

(2) He held office for a long term, so that if he agreed with a company on a long-range project, the company could count on government support as long as the project showed any promise.

(3) He could informally commit the government, so that the company could act on his word without waiting for a formal contract.

(4) Minor matters could be quickly and definitely decided by subordinate officials. The lack of such an administrative system appears to have been responsible for the slowness of development under government contract in the United States to a far greater degree than the fact that appropriations were made for only a year at a time, a fact which was equally true in Britain.

Development by New Companies — the Need for Adequate Resources

The fact that rapidity of development is as essential to the success of an aircraft engine as technical soundness of development means that in general it is necessarily extremely difficult for a newcomer to the field to compete with the established producers. The British Air Ministry believed this so strongly that during the entire period between the wars it not only discouraged but in effect prevented the entry of new firms into the field, even when one of these firms actually brought an engine to the stage of flight-testing entirely at private expense (see p. 205, n. 4). F. R. Banks, the Director of Engine Research and Development in the latter part of the Second World War, recommends specifically that "new firms should not be encouraged if there is already a sufficient number of engine manufacturers to meet the . . . demands."[14]

Both the American military services followed the contrary policy, giving encouragement and if possible a certain amount

[14]F. R. Banks, "The Art of the Aviation Engine," *Journal of the Royal Aeronautical Society* 52, 1948, p. 547.

of financial aid to any serious firm which appeared with a reasonably promising design. In one case, that of Pratt & Whitney, this led almost immediately to the creation of a new major producer, but Pratt & Whitney had unique advantages, as is shown in Chapter VII: its president, vice president for engineering, chief engineer, and other key personnel were men with long experience, not only in the general field of aircraft engines, but in working together as a team at Wright; and the design of the Wasp was directly based on all the development of similar engines done by Wright during the six years before the foundation of Pratt & Whitney. Aside from this unique case, to which generalizations about new companies obviously cannot apply, the scores of developments undertaken by numerous outsiders after 1918 produced not a single high-power engine ready for service in 1939, and only one engine which gave service during the war, the Allison.

The reasons why there have been so many failures for only one success in these attempts to establish a new producer of high-powered aircraft engines can best be seen by examination of the history of the developments of liquid-cooled engines carried out in the 1930's by Allison, Continental, and Lycoming which is told in detail in Chapter X. The extreme slowness of all these developments can be seen at a glance: whereas the development of the liquid-cooled Rolls Royce Merlin took just four years from the beginning of the design to the first use in service (1933-1937), it required ten years (1930-1940) to put the Allison V-1710 in service, and development of the Continental and Lycoming engines was dropped after 11 years of work (1932-1943) had failed to produce a useful product.

The Continental and Lycoming engines were both very radical designs technically, and it will be best to postpone the problem of distributing the responsibility for their failures between technical and other causes until the history of the Allison V-1710 has been examined. This engine was of very nearly the same displacement as the Merlin, was designed along the same basic lines, and was aimed at the same power, so that there was certainly no technical reason inherent in the engine itself why the development of the Allison should have been so much slower than that of the Merlin. It is true that this was

Allison's first venture in the development of a high-power engine, while the Merlin was only an enlarged and modified version of the Rolls Royce Kestrel, which had been in service since 1927, and that Allison made engineering blunders which a more experienced firm might not have made. None of these blunders, however, was more serious than the Merlin's ramp-type cylinder head, which had to be replaced in great haste in 1936 after being used throughout almost all the previous development of the engine.

The story of the ramp-type head is, in fact, a good indication of the real underlying cause of the more rapid progress of the Merlin; it was used on five successive experimental models before it was finally discarded, but all these five models were designed, built, and tested within less than two years. From the very first, work and money were expended on the Merlin at a far more rapid rate than they were expended on the Allison. This was in part due to the Air Ministry's ability to spend more money on such a project than could be raised by the American services and Allison combined, but in part it was due also to the ability of Rolls Royce to make use of money at greater rate, i.e., to its command of greater facilities and manpower.

The availability of more money meant that Rolls Royce could build at least two engines of each of its earliest experimental models and half a dozen of its later ones, whereas for the first four years Allison built only one example of each successive model. Thus Rolls Royce's development could proceed far more rapidly, since testing did not have to stop completely every time an engine broke down or was taken apart to change even a minor feature of the design.

The availability of greater facilities and manpower enabled Rolls Royce to design and build the original model of the Merlin in a space of eight or nine months (early 1933 to October) and to design and build subsequent models in even less time than this, whereas it was 14 months after Allison received its first Navy contract before the first V-1710 could be designed and built. Even when it was not a question of a completely new model, the development of the V-1710 was frequently delayed by the need of waiting on a too small experimental shop for replacement parts after a failure occurred.

Greater rapidity in designing and constructing and more continuous testing meant that Rolls Royce could try out an incomparably greater variety of designs than Allison in a given space of time. Within two years Rolls Royce had built and tested both its original model and a new model with a completely new cylinder head, whereas Allison in the same space of time tested only its original design. Within the third year of the Merlin development Rolls Royce designed, built, and tested four successive new models, whereas the third and fourth years together of the Allison development produced one very slight modification of the original engine and one really new model, a reversible engine for use in airships. The pace of the Allison development was slightly increased at the beginning of the fifth year of the project, when Army orders were received for 11 engines, but this order did not mean that Allison could proceed immediately to build and be paid for these engines: acceptance was subject to adequate performance, and the result was that only one engine was actually accepted and paid for in 1935 and two in 1936.

The Merlin passed a type test at 1,000 hp after somewhat less than four years of work, while the Allison did not pass a type test at this rating until nearly seven years had been spent. But Allison had built and tested only about eight engines, excluding reversible unsupercharged airship models, from the beginning of the development to the passing of the type test, whereas Rolls Royce had built about two dozen engines between the same two points in the history of the Merlin.

In terms of man-hours rather than of calendar years, Allison thus appears not to have done too badly, and it would seem at least quite possible that if resources had been available on the scale on which they were available to Rolls Royce, Allison might have accomplished the initial stage of development, culminating in the first type test, as rapidly as Rolls Royce. A similar conclusion can be drawn from comparison of the Allison with the Pratt & Whitney R-2800. The R-2800 went from design to production in less than four years, but in these four years Pratt & Whitney spent on its development nearly twice what Allison had spent to get the V-1710 through its type test.

The type test is only the initial step on the way to a successful service engine, and after it was passed the development of the Allison continued to be slow compared with that of the Merlin. The Merlin I had serious defects, but the Merlin II, which was in production in August 1937, less than a year after the first 1,000-hp type test was passed, was a fully reliable engine. In contrast it was not until late 1940, or over three years after the passing of the first 1,000-hp type test, that a reliable Allison was in production. Allison's lack of service experience was a very important cause of the slow improvement of the V-1710 at this stage. Production Merlins (Merlin I's) were in service in squadrons less than a year after the type test was passed, whereas only about a dozen service-test Allisons were built and flown in the two years after the type test, and it was only after another year that the engine began to enter large-scale service. In part this was because the British government had ordered the Merlin into production several months before it passed its type test, whereas the United States Army waited several months after the Allison passed its type test before placing orders for a relatively small number of service-test engines. An even more important cause, however, was Allison's lack of adequate production facilities.

If the fact that the Allison took 11 years to reach the stage reached by the Merlin in less than six is only too understandable after comparison of the resources available to the two firms, it becomes clear that the Continental and Lycoming engines did not have the slightest chance of success. The total cost of the first seven years of the Continental development was only a fourth of Allison's during the seven years which brought the V-1710 through its type test, and Lycoming spent money at about the same rate as Continental. The first complete Lycoming engine was not built until 1938 and the first complete Continental not until 1939. It is true that both the Continental and the original 12-cylinder Lycoming engines were too small to have been of use throughout the war, but it is shown in Part II (pp. 298-300) that there seems to have been no inherent reason why these engines could not have been brought to their design rating of 1,000 hp well before that power began to be obsolescent in 1940. Lycoming actually dropped the 12-cylin-

der O-1230 in 1938 to develop a double, H-type engine of 2,470-cu in. displacement; this was larger than any liquid-cooled engine to see service in the war, and again there seems to have been no inherent technical reason why it could not have been ready for service early in the war. It is in any case simply impossible to base any judgment of the potentialities of these designs on the record of actual accomplishment when the developments were carried out with such insignificant resources.

The principal lesson to be learned from the history of the development of these liquid-cooled engines in the 1930's is that, as Banks emphasizes repeatedly,[15] any attempt to develop a high-power aircraft engine will almost certainly fail unless resources are available in fully adequate quantity. The Continental and Lycoming engines were doomed to failure from the start, and unless adequate funds could be found no funds at all should have been wasted. If the Army was convinced that a new source of engines had to be created, the only sound course was to set out with the definite intention of creating a new engine manufacturer with manpower and facilities comparable with those of the established manufacturers, and to let this manufacturer gain experience in development, production, and service engineering as rapidly as possible. This would have meant making the original assignment the development of an engine which could be put in production within a very short period, and the subsequent purchasing and use of this engine at least in limited quantities whatever its merits as compared with other available engines. This was essentially what the British government had done in the early 1920's in order to establish Bristol as a second source for air-cooled engines: considerable numbers of the Bristol Jupiter were bought and put in service even though it was generally inferior to the Armstrong-Siddeley Jaguar until 1926 (cf. p. 142). The United States Army did ultimately obtain a very useful liquid-cooled engine in the Allison V-1710 despite the unsoundness of the policy it followed, but it obtained it very late, and it obtained it at all only because in the period from 1930 to 1937 Allison invested out of its own pocket a sum greater than all it received from the Army.

[15]Ibid., pp. 533, 535, 540.

The Army seems not to have been unaware of the validity of this general point of view even in 1932, since it was Wright Field's definite plan to have the Continental engine in production very quickly, and to let the company use the profits from quantity sales to build up its development resources and to finance further development. But the Army did apparently make a hopelessly low estimate of the cost of arriving at this stage. In addition, the Army certainly made a most serious mistake in spreading out its very limited funds between two companies (Continental and Allison) from the very beginning in 1932, and among three from 1935 (when Lycoming was given a contract) rather than concentrating them in a single company. The motive for this was most understandable: the Continental engine was technically radical, and the Army did not feel that it ought to risk everything on this project when the Allison offered a fairly promising engine of a more conservative type; and in 1935, when the Continental seemed to be making very slow progress, it was only natural to give a contract for a similar engine to Lycoming, which was willing to risk a certain amount of its own funds in the project. But again it would seem to be perfectly certain in hindsight that this was an incorrect approach to the problem. The first requirement was to have in existence a manufacturer with adequate resources for development, and if funds were not available to maintain more than one such manufacturer (if indeed they were sufficient for one), then it was completely useless to give support to additional engines however promising they might appear or whatever other reasons there might be for desiring their development.

To conclude, the record of a great number of projects shows that it is almost impossible for the development of a high-power engine to be carried out rapidly enough for the result to be of use unless the firm carrying it out has resources comparable with those of the established producers of such engines. The Allison could never have competed with the Merlin had it not had nearly three years' head start. The enormous difficulty of creating these resources for a new firm implies that the government should make every effort to persuade some established firm to carry out any major project the government believes

necessary. If no established firm can or will undertake the project, then it should be dropped unless the government is able to provide a new firm with all the resources required.

Conclusions

(1) Private enterprise cannot be counted on to undertake certain militarily essential developments at its own risk, and these must therefore be paid for directly by the government under development contracts.

(2) A development contract alone, even if it pays all the costs of a project, will usually not be a sufficient incentive for industry. The only fully adequate incentive is the manufacturer's conviction that profits can be made on future quantity production. Development contracts must therefore avoid any terms which unduly restrict the possibility of profits on production, and the government should do everything possible to convince the manufacturer that a potential market exists.

(3) The government should make every effort to sell any major project to an established builder of aircraft engines. Only when no such firm can be interested should an untried firm be considered, and then only if the government is both able and determined to provide this firm with fully adequate resources.

(4) Since all major development programs run over a number of years, it is most desirable that the government officials administering them have long tenure of office.

(5) Development under government contract has been very seriously slowed down in the United States by excessively restrictive legal requirements. These should be relaxed so that government officials will have more of the liberty enjoyed by their British counterparts.