CHAPTER II

Development at Private Risk: American and British Policy Compared

American and British Policy on Financing Engine Development

Virtually all development of aircraft engines in the United States during the first few years after the Armistice of 1918 was financed directly by the government, the entire cost being paid under development contracts awarded for each project undertaken. The circumstances which made this policy the only one possible at the time are set forth in detail in Chapter VII (see p. 160).

About 1926, however, a radical change took place in American policy, as is explained in Chapter VII (p. 195). From this time on, by far the larger part of the cost of development of air-cooled radial engines, which became the standard American type by 1930 and remained so throughout the ensuing decade, was paid by private firms out of revenue from quantity production and sales. During this period the firms still usually tried to obtain a government development contract very early in the course of a new development, if not actually before work was begun, but in the majority of cases they were satisfied with — if they did not prefer — a contract which barely covered the cost of the handmade engines delivered to the government for test, leaving the much larger cost of the actual development to be paid by the firm itself. Such a contract was sought, not primarily for the payment involved, but as evidence that the government was seriously interested in the project and hence likely to buy the resulting engine in quantity if the development succeeded.

Direct payment by the Army or the Navy of all or a large part of the costs of development continued to be necessary after 1926 only for projects where the major manufacturers did not believe that quantity sales would follow with sufficient certainty in sufficient number and without too long a wait. Some projects of this sort were undertaken by the major manufacturers themselves, but most of the development done wholly or largely at the direct cost of the government was carried out by firms which were not regular producers of aircraft engines.

Throughout the period between the First and Second World Wars, British development of aircraft engines was carried out by private industry, and the technical control over design was entirely in the hands of the firm doing the development.[1] Thus once the British industry had recovered from its postwar difficulties, which were much the same as those faced by the American industry, one might have expected the evolution in Britain of the same system of financing the larger part of development by the firms themselves which was evolved in the United States after the middle of the 1920's.

In fact, however, the British government has always paid directly and in full for the entire cost of all development of military engines.[2] In Britain, as in the United States, a certain amount of development was done by companies which had no production, or not enough to finance development of new high-power engines, and this work obviously had to be financed by

[1]From about 1913 to 1916 by far the larger part of British development of both aircraft and engines had been done by a government agency, the Royal Aircraft Factory; but as is told in Chapter VI (p. 126), a definite change in policy made in 1916 stripped the Factory of the right to design or develop complete aircraft or engines, and it became an institution for research like the NACA. Its name was changed in 1918 to the Royal Aircraft Establishment. After 1918 it was occasionally proposed that the government make its own engine designs, to be developed by private firms, but these suggestions never received serious consideration.

[2]The only possible exception of any importance at all was the early work of the Bristol Aeroplane Company's new engine division, created in 1920: cf. below, p. 153. By about 1926 at the latest, however, the government had begun to pay the development costs of all Bristol's military engines in full. During the 1920's there was so little development of engines for commercial use that the government made no attempt to distinguish between such development and development of military engines. Even in the 1930's virtually all new basic types were developed originally and primarily as military engines and as such fully paid for by the government, although Bristol, the only firm with an appreciable commercial business, did pay from private funds for the development of special commercial models of basic military types, e.g., the development of the Jupiter X FBM for Imperial Airways from the X F. The small 16-cylinder octagon Bristol Hydra of 1933 seems to have been the only case of a new type developed strictly or primarily for the civil market. This engine was developed completely at private cost after the design had been submitted to the government and the government had refused support because it deemed the design unsound.

direct government contract. But the British government paid directly and in full even for development done by the established companies with considerable production, Rolls Royce and Bristol.

There were, it is true, a few cases in the history of both Bristol and Rolls Royce where a military engine was a "private venture." The actual private risk involved in these private ventures was, however, always very small: the work was never carried at private expense for more than a relatively short time, and often even the expenses incurred during this short period were far from being a genuine risk. Private ventures occurred in two sorts of situations. In one, there was a genuine risk: when a firm went ahead and began development of a new engine even though the government did not believe that the design proposed by the firm would be of value and refused to support it.[3] Often, however, the government approved of the work from the first, but was temporarily short of funds.[4] In neither case, so far as could be learned, was a private venture ever carried at private expense beyond the building of a prototype and the running of the initial tests.

In all these cases an established producer of engines risked a relatively small amount of his resources in a new engine. This study has uncovered only one case where a British firm actually tried to break into the aircraft engine field at private expense. That firm was the Fairey Aviation Company. In 1924 Fairey obtained a license to produce the American Curtiss D-12 in Britain and gave up his plans only after very strong dissuasion by the government (cf. pp. 204-205). About 1930 Fairey again tried to enter the field, bringing an engine known as the Prince to the flight test stage entirely at private risk and expense. Again the Ministry refused even to consider a newcomer to the field (p. 205, n. 4). This policy was just the contrary of the

[3]In the case of the Bristol Pegasus, for example, the government did not at first see the utility of developing a new type of exactly the same size as the existing Jupiter, but full support was given after the company had carried the work at private expense up to the running of the first engine.

[4]For this reason, both the Kestrel and the Merlin were begun as private ventures of Rolls Royce, as is told in Chapter VIII. The government had approved each project before the company began work — had actually persuaded the company to undertake the Kestrel — and had definitely promised support as soon as a new appropriation was received.

United States Navy's policy which led to the formation of Pratt & Whitney by agreeing in advance that if the firm could produce an engine meeting certain specifications, the Navy would buy it in quantity. It is interesting to speculate whether the British government would not also have profited by allowing Fairey to establish himself as an engine builder if he could, even if this meant dropping support of one of the two relatively unsuccessful firms, Napier and Armstrong Siddeley, whose development of high-power engines depended entirely on government subsidy.

Historical Causes of the Difference in Policy

A number of factors contributed to this striking difference between the policy of the major American firms, which were willing to do most of their development at their own expense, and that of the major British firms, which spent little if any money not covered by a direct government contract. The most obvious reason for the difference was simply that the American military services had very much less money than the British for expenditure under development contracts. Even in the early 1920's the British Air Ministry had over $500,000 a year for development of engines alone. In 1928 the appropriation was $1.1 million; by the middle of the 1930's, before the rearmament program of 1936, it had risen to about $4 million; in 1938 it was about $5 million. All these sums, furthermore, were regularly overspent by about a fourth.[5] These resources are to be contrasted with roughly $500,000 available annually to the United States Army for experimental engine procurement in the first half of the 1930's, rising to perhaps $1.5 million by 1939. The funds of the United States Navy for experimental engine procurement were even smaller than the Army's, so that the total of the two together was appreciably lower than the British funds, while the cost of development was very much greater in the United States than in Britain.[6]

[5]The deficits were covered in part by transfers from airframe development funds and in part by deficit appropriations.

[6]Engineers familiar with conditions in both countries report that labor costs in the United States were about double those in Britain, although the cost of materials was roughly the same in the two countries.

Even if the American services had had more money to spend in direct support of development, however, the successful part of the American industry would probably have refused to depend on development contracts as the British did. When an American service gave even a fixed-price development contract covering any large part of the total cost of a project, all the technical details of the work had to be agreed on in advance, and every minor change from the written document required a bothersome negotiation with officials at Wright Field or in Washington before it could be authorized. Cost-plus-fixed-fee contracts were still more bothersome, with elaborate and unrealistic legal rules governing the determination of allowable costs.[7] In Britain, on the contrary, the firms, and particularly the strong and successful firms, Bristol and Rolls Royce, were able to get government support for the projects which they themselves deemed the best; and very extensive changes in the contract, both in its technical provisions (which in any case were not detailed) and in its financial terms, could be quickly made by a summary procedure, in small matters through the agency of the Ministry's representative on the spot without even referring to the main offices. Rather than accept the interference and the delays involved in an American contract which paid anything like the full cost of the development, the American firms preferred, when they could, to employ their engineers on those projects which in their own judgment were most likely to lead to quantity sales and thus to profits, and to run the corresponding risk of not having a product to sell in sufficient quantity to support future developments.

Risk and Profits Under the Two Systems

The distinctive characteristic of the American system was, in fact, not so much the source of the funds used to pay the costs of development as the private firm's responsibility for the soundness of the projects undertaken. The American services did not force the companies to capitalize development cost and

[7]Cf. U. S. Congress, Aviation Policy Board, *National Aviation Policy* (Washington, Government Printing Office, 1948) (80th Congress, 2nd Session, 1948, Senate Report 949) p. 37.

then charge it against the engine model for which it had been incurred, but allowed them to consider it as overhead and include it in setting the price for engines currently in production. Because the larger part of sales was made to the government, most of the money used for development under the American system was actually supplied by the government more or less as the work proceeded, just as it was under the British system. Under the British system, however, the government backed the fundamental soundness of the project in advance, and if it failed because of lack of utility or any reason at all other than incompetence on the part of the firm in its execution, the government had no reason to diminish the share of that firm in awarding development contracts in the future. Thus although Napier had not a single really valuable engine on the market from the eclipse of the Lion in the late 1920's (cf. p. 215) to the appearance of the Sabre during the Second World War, the government paid Napier for the development of a whole series of in-line air-cooled engines during the 1930's. Under the American system, a firm which committed a large part of its resources to a project for which no use was found, however brilliantly the project was executed in itself, would soon have found itself without sales to which it could charge the cost of engineering and thus without any means of supporting further developments.

The British companies were allowed a 10% profit on their production until the great expansion of 1936, which was largely financed or insured by the government. Since this was as large a profit margin as was permitted to the American firms, while government support was given in Britain for exactly those projects which the British firms believed to have the best possibilities of success, they really enjoyed the best of both worlds: maximum likelihood of profits (in their own judgment) at absolutely no risk to themselves. British development contracts were in fact liberal enough for the companies to make a small but genuine profit on development itself, even if no production followed.

The Cost of Engines to the Government Under the Two Systems

Probably the most common argument in favor of direct payment by the government for development is that it simplifies the setting of a fair price for subsequent quantity procurement. About 1939 the United States Army was talking of establishing a pay-as-you-go policy on development largely for this reason (cf. p. 289).

It seems to be assumed in this argument that there is some percentage of straight manufacturing costs which is a "fair" profit and which will lead to a "fair" price. Such an assumption may have a good deal of validity when the product developed for and bought by the government is only a small part of the company's total output, especially when the company only occasionally develops a new product for government use and then continues to sell the product to the government over a period of time and in quantities which cannot be foreseen in advance.

This simple approach is, however, scarcely applicable to companies like those which manufactured large aircraft engines in the United States between the wars: the continual development of new models was a large part of the reason for their existence, and the larger part of their sales was to the government. In such firms there is no independently existing engineering staff which can be temporarily assigned to a particular project desired by the government and upon its completion be returned to work on other projects in which the government has no interest. The development staff, which is the heart of the aircraft-engine company, must be given continuous work on aircraft engines if it is to remain in existence; it cannot be dissolved when one project is completed and then recreated at a moment's notice when the government wants another project begun.

Engineering costs are thus very genuinely overhead expenses rather than expenses incurred only because certain specific projects are undertaken. It follows that, unless the government has decided that a particular firm should go out of business within a few years at the most, it is simply meaningless to talk about a fair profit on quantity production alone without at the same time providing for payment of the overhead costs incurred in the development of new models. Whether payment for development is in form separate or combined with payments for quantity production, the total revenue must be sufficient to induce the firm to maintain, not only production facilities of the size the government believes necessary for military security, but also a development staff and facilities which enable the firm to hold its own in the face of competition. Only an adequate profit on the firm's over-all operations will accomplish these two objectives. The British saw to it that the firms had such a profit by continuously awarding development contracts to the firm's full capacity and pricing them with a liberal allowance of costs plus a genuine profit, in addition to the fixed 10% on quantity production; the Americans achieved the same result by counting engineering as a cost of production and basing the profit on quantity production on this over-all basis. In the case of firms of the class now under discussion (those with important quantity production), the end financial result of the two systems was thus approximately the same, from the point of view of both the firms and the government.

Thus as far as development done entirely for military use is concerned, the two systems were economically equivalent. When, however, the engine companies had a fair amount of export business, as the British had ever since the early 1920's, and the Americans since the beginning of the 1930's, or commercial business, as the Americans had since the late 1920's, the American system was probably the fairer to the government. Almost all export engines were straight military models, and civilian engines have always and in all countries been mere modifications of engines originally developed for military use. Under the British system the companies were obliged to pay out of their own pockets only the relatively small cost of making these minor modifications on civilian engines, and were allowed to make whatever profit they could from both export and civilian sales[8] in addition to the legal 10% on sales to the government. Under the American system, receipts from civilian sales could be made to carry their fair share of the total engineering overhead if the government negotiators took the company's nongovernment business into account when settling the price of military engines.

[8]The government occasionally collected nominal royalties on patented features developed under government contract and used in export or commercial engines.

Finally, the principle of pay-as-you-go on development costs added to the principle of standardized "fair profit" margin on quantity production tends to remove a good deal of the incentive for doing development as economically as possible. In the United States this incentive has been maintained because prices for sales to the government as well as to other customers have been set at least as much by comparison with a competitor's price for a similar article as by investigating the manufacturer's cost of production. According to a general impression among American engineers which it is impossible to test objectively and which is reported here without any guarantee of correctness, the British tended during the 1930's actually to build and test a whole variety of designs in cases where American firms would have selected the one or two which seemed most promising.

In conclusion, there seems to be no financial advantage for the government in a pay-as-you-go policy on development, and it involves at least a risk that the total cost to the government will be greater than when development is financed at private risk.

British and American Engines at the Outbreak of the War

Desirable as it is to have a system of financing development which obtains the most work for the least cost to the government, it is vastly more important to have one which results in fully adequate engines. It would seem *a priori* likely that by paying separately for development in time of peace, when quantity production for military use is necessarily small, the government could secure (1) development of a greater variety of specialized types and sizes of engines, instead of selection by the firms of a few all-purpose models; and (2) development of each type in the way best suited to military use, rather than with compromises made in order to suit airline use as well. These two hypotheses must be tested by a detailed comparison of the results of British and American peacetime development. After such a comparison has been made here, the reasons for the differences discovered will be discussed in the following section.

Variety of Engine Types and Sizes

In one respect the British clearly had a wider variety of engines than the Americans when war came in 1939. The British had fully developed engines of both the air-cooled and the liquid-cooled types, whereas the United States had only air-cooled engines actually in production and service in 1939, while the liquid-cooled Allison, production of which began in 1940, suffered from serious difficulties during that year and part of the next. There is, furthermore, no doubt that the availability of liquid-cooled engines was of great military advantage to the British in the first several years of the war. It is shown in Chapter XI (pp. 303-306) that even the Allison engine was definitely superior as a fighter power plant[9] to any American air-cooled engine to be used in an Army fighter before 1943, and the British Merlin was a better engine than the Allison during most if not all of this period.

The United States, on the other hand, had more powerful engines fully ready for service in the early years of the Second World War than the British did. The most powerful engine in production by Rolls Royce in 1939 was the Merlin, then rated about 1,000 hp. Bristol had four engines in production, the poppet-valve Mercury and Pegasus and the sleeve-valve Taurus and Hercules. The first three of these Bristol engines, however, all had about the same rating of 1,000 hp, only the Hercules being in a really different category, near 1,500 hp; and both of the sleeve-valve Bristol engines got into extremely serious difficulties as soon as true quantity production began, so that the Hercules saw virtually no service at all until 1941-1942.[10] In the United States, Wright Aero and Pratt & Whitney each had a well tried 1,000-hp engine (the R-1820 and the R-1830 re-

[9]Except for climb at high altitude, but this was a question of supercharger development and not of engines as such.

[10]Very little use was made of the sleeve-valve Taurus, which was dropped from production before the end of the war.

spectively) in service in 1939, and Wright in addition had the 1,500-hp R-2600, which had been in production since 1937. Pratt & Whitney also had put a larger engine, the 1,400-hp R-2180, in production in 1937, and the only reason that this engine had been dropped was that it was being replaced by a still more powerful engine, the 1,850-hp R-2800, which was in production by 1940 (cf. p. 290). It was not until 1942 that the British had in production a fully successful engine, the Rolls Royce Griffon, which could compete in power with the R-2800;[11] almost the entire development of the Griffon had remained to be done after the beginning of the war.

The Heaviness of American Engines

It has often been asserted that whereas British engines were designed and developed with military service exclusively in mind, the military utility of the engines built by the major American firms was diminished because their design and development were largely directed at use on civilian airlines, where the superiority of American engines in 1939 is virtually uncontested.

British engines are said first of all to have been developed to have the highest possible maximum or combat power for the lowest possible weight, whereas American engines were made heavy in order to secure reliability in commercial operation. A comparison on the basis of weight between British engines and engines developed at private risk in the United States and aimed at commercial as well as military applications unfortunately cannot be complete. The Allison liquid-cooled engine, although it was about half financed at private risk, was completely directed at the military market, so that the only American engines which can show the effects, if any, of development for both a civilian and a military market are the products of Wright Aero and of Pratt & Whitney. These firms, however, built only air-cooled engines. Since there can be no real doubt that although the air-cooled engine has a definite inherent advantage in lower weight for given power, the liquid-

[11]In 1940, when the R-2800 was rated 1,850 hp, Rolls Royce had begun production of the 1,800-hp Vulture, but that engine was never really successful and was dropped in 1941. Cf. Chapter VIII, pp. 243-244.

cooled engine has a definite advantage in lower drag,[12] it would be misleading to compare American air-cooled engines with the liquid-cooled engines produced by Rolls Royce on the basis of weight alone, while it would be overly complex to try to compare them on the basis of weight and drag simultaneously. Thus a comparison of "specific weights" or ratios of weight to power will be made here only between the products of Wright and of Pratt & Whitney in the United States and the air-cooled radials built by Bristol in England.

At the beginning of the war the specific weight or ratio of weight to power was just about the same for Bristol engines as it was for American air-cooled radials, although the American engines were rated on better fuel. Using emergency or combat power rating as the basis of the comparison, and taking engine models all of which had a critical altitude of about 15,000 feet, we find that the Bristol Pegasus and Mercury on fuel of Performance Number[13] 68 (87-octane) and the Wright G-200 Cyclone on roughly equivalent, 74-PN (90-octane) fuel all weighed about 1.3 lb/hp; the Pratt & Whitney R-1830 was a little heavier, weighing about 1.4 lb/hp, although it was rated on very much better, 100-PN (100-octane) fuel.[14] By late summer 1940, moreover, Bristol had improved the Pegasus to a specific weight of 1.2 lb/hp at about 13,000 feet and the Mercury, using 100-PN fuel, to 1.0 lb/hp at 10,000 feet, while the latest models of the Cyclone and R-1830 still remained at about 1.3 and 1.4 lb/hp respectively at similar altitudes.[15]

[12]See Chapter IX, pp. 253-254, and Technical Appendix A, pp. 678-684.

[13]On Performance Numbers, see Heron below, p. 603, n. 4.

[14]Data supplied by Bristol: Pegasus 18 (used in Wellington) type-tested February 1939 at 885 hp at 15,500 feet for combat, weight 1,140 lb; Mercury 8 (used in Blenheim) type-tested October 1939 at 840 hp at 14,000 feet for combat, weight 1,035 lb. Wright list of engines available December 1939: Cyclone G205A rated 1,000 hp at 13,500 feet for five-minute military use, weight 1,302 lb. Pratt & Whitney list of engines available September 1939: R-1830 single-stage specification 5095: 1,050 hp at 13,100 feet for five-minute use, weight 1,460 lb. It should be pointed out that altitude ratings of British engines are somewhat unreliable since the British had neither test stands which could simulate altitude conditions nor torquemeters which could measure true power in flight.

[15]Sources as above. Pegasus 18 given MAP rating July 1940 of 965 combat hp at 13,000 feet on 68-PN fuel. Mercury 15 (improved model for Blenheim) given Air Ministry rating August 1940 of 995 combat hp at 9,250 feet on 100-PN fuel. Cyclone G205A rating virtually unchanged in December 1940 Wright list; still rated on 74-PN fuel. Pratt & Whitney list of September 1939 lists R-1830 single-stage specification 5101 to be in production in 1940 (already type-tested by September 1939): 1,050 military hp at 14,000 feet, weight 1,490 lb.

Thus in the early part of the war American air-cooled radials did in fact have appreciably greater specific weight than Bristol engines. The true inferiority of American engines in this respect was probably not quite so great as the ratings seem to show, since American ratings were guaranteed by the manufacturer whereas British ratings were not. This fact frequently made American manufacturers hesitate to submit their engines for type test at a higher rating, whereas the British firms were always striving for a type test at the highest rating possible. In addition, American regulations considered an attempt at a type test as not having succeeded when subsequent inspection of the engine showed certain types of incipient failure which in Britain did not disqualify an engine that had not actually failed during the test. During the war military necessity led the American military authorities on various occasions to issue technical orders permitting operation of engines at outputs greater than those guaranteed by the maker. But despite the tendency to rate American engines lower than British engines of equal inherent capacity, it was not until after combat experience had shown the necessity of more power that American engines were developed to be capable of a ratio of power to weight fully equal to that of Bristol engines.

Specific Features of Primarily Military Utility

In addition to being heavier than British engines of the same power output, it has often been said that American engines showed their semicivilian character in various specific features of their design. Probably the leading example is the absence of a device present on all British engines in 1939, the variable-datum automatic boost control. This was an automatic regulating mechanism which enabled the pilot to use the maximum power which could safely be taken from the engine under any conditions by simply opening his throttle as far as it would go; he had no need to pay attention to the various factors such as altitude which set the limit to safe power and then be careful not to exceed this limit. An automatic power control is unnecessary in airline service, where flying is done in a careful routine by experienced pilots, but its absence led to the ruining of many American engines by inexperienced military pilots.

That this lack of automatic boost control was a very serious military weakness of American engines is scarcely open to question,[16] but in certain other features of primarily if not exclusively military utility American engines were ahead of British engines. The most striking example is probably two-stage supercharging, which was put in production on the Pratt & Whitney R-1830 in October 1939,[17] two years before the first British two-stage engine, the Merlin 60, was put in production (November 1941).[18] Another example is the floatless carburetor which enabled the Thunderbolt with its R-2800 engine to follow the Fw 190 through an abrupt pushover which the Merlin-powered Spitfire could not follow because of its float-type carburetor.

The Effects of the Two Systems of Financing on Technical Development

The comparison made in the preceding section between British and American engines wholly or largely developed in time of peace and actually used in quantity for military purposes in the early years of the Second World War led to the following conclusions:

(1) The British had a distinct advantage in the possession of a fully reliable liquid-cooled engine in 1939, but the United States had an equally important advantage in the possession of a reliable 1,500-hp engine at the outbreak of the war and of a very good 1,850-hp engine in 1940.

(2) American engines were heavier than British engines in proportion to their power, a characteristic which combat soon showed the need of correcting.

(3) So far as specific features of primarily military utility are concerned, the engines of one country were superior in some respects while those of the other country were superior in others, and the net balance seems to be roughly equal. It would seem

[16] Whether there should be provision for *deliberate* override of such a control is a different question.

[17] It was used on all the Grumman F4F-3 Wildcat carrier fighters produced in quantity for use by the United States Navy; the first production F4F-3 was accepted in July 1940. An outline of the history of the two-stage R-1830 will be found below, p. 305 n. 7.

[18] On the two-stage Merlin, see Chapter XIV, pp. 229-231.

quite certain that the presence of such features in British but not American engines or vice versa is to be attributed, not to any difference in national policies on engine development, but to the presence or absence of foresight and capacity on the part of particular engineers in government and industry in their treatment of the particular problems in question.

To a certain extent the lack of very large engines in Britain in 1939-1941 is due to deliberate choices made in the 1930's, but in the case of Bristol the British system of financing development seems to have been at least partly responsible. Pratt & Whitney and Wright Aero minimized the cost and risk of developing multirow engines by making maximum use of components and design features tried and proved in their single-row engines. Bristol, on the contrary, could afford to make a complete change to sleeve valves before attempting any multirow engine because the risk was entirely borne by the government and because there was no need to justify the investment quickly by production of a salable product. The troubles encountered with sleeve valves when they were first put in production and service seriously weakened the contribution of Bristol in the early part of the war.

It remains to consider whether it was in fact the influence of the civilian transport market, operating through the system of development at private risk and expense, which led to the failure of the major American engine builders to produce a liquid-cooled engine like Rolls Royce and to the heaviness of their air-cooled engines compared with those of Bristol.

Lack of resources was certainly not the reason why neither Wright Aero nor Pratt & Whitney developed a liquid-cooled engine in the 1930's. Either of those firms could have afforded to develop an engine like the Allison or the Merlin entirely at its own cost. Since American (like British) commercial operators were fully committed to air-cooled engines (cf. pp. 194, 256), it does seem plausible at first glance that the two major American firms had decided to develop only air-cooled engines because only that type could be sold for civilian as well as military use.

This argument overlooks, however, the very considerable difference between the military markets themselves in the two countries. Whereas the British Air Ministry paid very little attention to development of naval aircraft, the Navy had an important share of total aircraft appropriations in the United States, and the Navy from 1927 until late in the 1930's had an announced policy of using only air-cooled engines for ship-based aircraft (cf. Chapter VII, p. 194 and Chapter IX, p. 257). For heavy military aircraft, it was quite generally believed throughout the 1930's, in Britain as well as in the United States, that the air-cooled engine would be superior (cf. pp. 210-211, 258), and although the Merlin ultimately powered the best of the British heavy bombers (the Lancaster), such an application was not even planned before the Merlin had been actually in production for years. The Merlin was developed almost entirely as an engine for land-based fighters (cf. pp. 215-216, 244). The Royal Air Force always emphasized strongly the importance of this type of aircraft, but in the United States it was never so important in relation to other types of Army aircraft as it was in Britain, and for a number of years in the middle of the 1930's the Army was seriously considering the complete abolition of single-seat fighters.

Thus the concentration of the two major American firms on air-cooled engines should not be attributed to the influence of the commercial market: the characteristics of the American military market itself give a more than adequate explanation.

The second important question is whether the heaviness of American engines in the early part of the war was actually due, as is often asserted, to the desire of the American manufacturers for great durability in commercial service rather than maximum performance in military service. What evidence there is on the actual motives of the engineers who designed these engines would all seem to show, on the contrary, that their intention was exactly the same as that of British engineers, viz., to produce the best military engine they could, modifications necessary for commercial service being made subsequently.

A more likely explanation of the greater weight of American engines is simply that the engineers of Wright Aero and Pratt & Whitney were — rightly or wrongly — more conservative than those of Bristol, believing that it was better to go to a larger engine than to try to push a smaller one too far. In this

respect German engineers followed a technical policy very much like the American policy, although they were thinking in terms of military use exclusively. Justification for this technical decision to develop very large rather than very highly rated engines is to be found in the actual performance of wartime fighters, a class of aircraft where the case for a small, highly rated engine is stronger than it is in any other. The P-47 Thunderbolt and F4U Corsair with the Pratt & Whitney R-2800 gave very useful service during the Second World War, whereas no first-line fighter powered by a Bristol engine was in service until after the end of the war.

It must also be remarked that development for commercial purposes has on occasion brought results which ultimately proved of great military value but which would not have been attained if development had been restricted to clearly foreseen military objectives. The most striking example is the controllable-pitch propeller. Work was done in Britain on such propellers very early: one was built in 1924 by Armstrong Siddeley, and later a fair amount of work was done on the Hele-Shaw propeller. This work came to nothing, however, because there was no immediate military need for the device — or rather, because no one realized the need. In the United States also, the controllable-pitch propeller would have been dropped if it had depended entirely on military support. There, however, it was found that only with the controllable-pitch propeller could the Boeing 247 transports take off with a reasonable pay load from airfields at high altitudes in the Rockies, and the resulting orders resulted in the first economic manufacture and further development of the device.[19]

The Essential Role of Profits Under the British System

Finally, whatever effects the requirements of the commercial market may have had on American design and development, it is more than doubtful that such effects could have been eliminated or greatly altered by the application of the British system of direct payment for military development. This would have

[19]The two-position manually controlled propeller was in service on 247's in 1933. Late in 1934 these began to be replaced by constant-speed propellers with automatically controlled pitch.

been true even if the American services had been willing and able, like the British government, to give genuinely profitable contracts paying the entire cost of all needed development. The real reason why the American companies paid more attention than the British to the commercial field was not the relatively smaller United States government contracts but the relatively greater profits to be made on commercial sales. Commercial sales, which were far larger in volume in the United States than in Britain,[20] were notably more profitable per unit than sales to the government,[21] while any sort of quantity production was, of course, far more profitable than the most generous development contracts.[22]

Proof of the ineffectiveness of development contracts as an incentive when some other line seemed more likely to lead to quantity production can be found in the British record itself. Chapter VI (pp. 135-137) relates how the British firm of Cosmos dropped development of the government-supported Mercury in 1918 in order to concentrate on development of the initially unsupported Jupiter because the firm believed that the Jupiter was more likely to be used in quantity. When the British government concluded after tests of the American Curtiss D-12 engine that a similar engine of monobloc construction should be developed in Britain, it first requested Napier to undertake the job, offering as usual to pay the entire cost. Napier, however, disagreed with the government concerning the desirability of monobloc construction and insisted on going ahead with an engine of another type, which ultimately proved a failure (cf. Chapter VIII, pp. 206-207). Although the British government was quite willing to support the development of the Merlin as an inverted engine, and even though Rolls Royce

[20]Cf. Sir A. H. Roy Fedden, "The Future of Civil Aviation," *Journal of the Royal Society of Arts* 92, 1944, p. 425.

[21]Engines used by the military services were bought by them directly from the engine manufacturer and supplied as government furnished equipment ("GFE") to the airplane builder. The bargaining power of the services was naturally greater than that of an individual airplane builder or airline.

[22]It is true that commercial air transportation existed in the United States only because of government subsidy, so that in effect the development of commercial engines was as much a result of government policy as the development of military engines. A comparison between the effectiveness of sponsoring development indirectly through subsidizing commercial aviation and the effectiveness of direct military support of development would be, however, a subject for a separate study.

itself preferred this form, it was dropped as is told in Chapter VIII (p. 216) as soon as the airframe builders showed dislike.

Despite its willingness to give generous development contracts, the British government was unable to keep Rolls Royce in the aviation field at all during the period 1919 to 1921, simply because, as is explained in Chapter VIII (pp. 200-201), there seemed to be greater opportunities for profit in automobile manufacture. In the latter half of the 1920's, as Chapter VI (pp. 150-151) shows, and similarly during most of the 1930's, the British government was unable to get Armstrong Siddeley to put a really serious effort into development of high-power engines. This was largely because the firm's trainer-engine business filled the factory with production and thus eliminated the one really powerful incentive to development; under the British system the firm's manufacturing profits were limited to 10% of manufacturing costs, and a change to an improved or a larger engine could not in itself increase profits.

All large-scale development done by all British firms was, in fact, on projects chosen by the firms, so that as has already been emphasized the really important incentive for British development was the prospect of profits, just as in the United States. What the British system of financing really accomplished was simply to reduce private risk if not to eliminate it entirely from the pursuit of profits.

Conclusions

(1) The essence of the system by which development of high-power air-cooled engines was financed in the United States from 1926 to 1939 was not so much the source of the funds used as complete responsibility of the private firm for the utility of its development engineering as well as for competence in its execution.

(2) There is no reason to believe that the British government obtained either engine development or production engines at a lower cost by having all development done under contract and in return for direct payment by the government. There is some reason to believe the contrary.

(3) The two systems led to the existence in the two countries at the outbreak of the Second World War of series of engines of

about equal over-all technical merit and military utility. Specific points of superiority or inferiority do not seem to be a result of the difference between the systems of financing development.

(4) Development for commercial use has occasionally produced results later found to be of great military value.

(5) In any case, the willingness and ability of a government to give profitable development contracts has apparently never sufficed to persuade a first-rate firm to make an intensive effort on one project when the firm has believed that some other project was more likely to lead to quantity production and profits.