# CHAPTER I

## *Government Conduct and Technical Control of Research and Development*

THE problems in relations between government and industry encountered in the development of aircraft engines fall into two principal categories, technical and financial. The technical problems, which are to be discussed in the present chapter, center on two leading issues: shall government agencies (specifically the armed services) attempt to develop engines themselves, and if not, to what extent shall they exercise technical control over developments carried out by private industry. Policies varying widely in respect to these two questions were actually followed by the United States Army and Navy at various times during the period between the First and Second World Wars, and a study of the results obtained under these various policies should be a valuable guide for the formation of a correct policy for the future.

### DEVELOPMENT BY GOVERNMENT ITSELF

After the end of the First World War the United States Army adopted a definite policy of assuming complete technical responsibility for the design of all aircraft engines whose development the Army financed,[1] and in many cases went even further, actually carrying out the development of new engines itself. Engineers at McCook Field made detailed designs of new engines, assembled them (perhaps buying some or all of the parts from outside job shops), tested them, modified the design, procured new parts, and in general directly carried out the entire development process.

The 750-hp liquid-cooled 18-cylinder W-1 engine designed in 1919 and first tested in 1920 is the leading example of direct

[1]Captain George E. A. Hallett, "A Method of Developing Aircraft Engines," *SAE Journal* 10, 1922, pp. 457-462.

government development. After tests of the first model had been carried out, the improved W-1A was designed and six engines were built. When these engines had been tested, a contract for production of ten W-1B's was awarded to Packard Motor Car Company. Shortly thereafter, however, the engine was dropped, and a projected larger engine of the same type, the W-2, was never developed. The W-1B was generally unsatisfactory in its original form, and development proceeded so slowly that before it was in a satisfactory state the monobloc Curtiss D-12 had rendered obsolete the welded steel cylinders and W-type arrangement of the Army's design. Later in the 1920's other projects were handled by the Army in the same way, notable among them being a 24-cylinder air-cooled X-type engine, but each of these projects was eventually abandoned when it became clear that it could not compete with contemporary engines developed by private industry. After the 1920's the Army made no more attempts to carry out a development completely on its own.

During the 1920's the Navy relied entirely on private industry for design as well as development of all its aircraft engines. In the 1930's the Naval Aircraft Factory in Philadelphia did make one attempt, on orders from the Bureau of Aeronautics, to carry out in the field of engines its intended function of a "yardstick manufacturer." It undertook the development of an in-line air-cooled trainer engine, and a tolerably successful product emerged, but better engines were available from private industry and the Navy engine was abandoned. The fact that even the Army made no attempts after the 1920's actually to carry out its own developments is adequate proof that the services themselves had become convinced that it was virtually impossible to achieve success by this method.

Even if government development of engines had led to a product suitable to be put in production and service, a most serious difficulty would have been encountered in the next phase. No aircraft engine has ever remained in production for much more than a few months before the need or at least the desirability of extensive modifications has become apparent, and often if not usually plans for such modifications are already well in hand even before the first model starts coming off the





lines. The manufacturer of the engine is, of course, very considerably aided in making these modifications by intimate knowledge of the development history of the engine, by the easy availability of parts from the production line, and by direct knowledge of the service experience of the production model. If a government-developed engine had been put in production, its further improvement would have been subject to a great deal of delay owing to the separation of development from manufacture and service.[2]

Finally, competition between private firms makes two vital contributions to development by private industry: the urge to achieve success as rapidly as possible, and the means for judging a given design not by theoretical arguments but by actual comparative test. These have been largely if not entirely absent in work done by government itself. Whether a given project takes one year or two, and even whether it succeeds or fails, the military organizations have continued on a virtually unaltered footing. The amount of funds they have received has depended not on objectively measured success but on arguments before laymen on a Congressional committee. And even the fact of success or failure has been difficult to determine objectively when the same men have been charged with comparing an outside product with one in the design of which they themselves had had a part: the most honest engineer, placed in such a position, will tend to compare the demonstrated, present performance of the outside product with what he hopes and believes will be ultimately achieved by his own.

## Government Control of the Details of Development Done by Private Firms

Even when the Army did not try to carry out the complete process of development itself, it took the position, as we have seen, that it alone was responsible for all major design decisions in all cases where it was directly financing the development of a new engine. In some cases, such as that of the Lawrance air-cooled engines at the beginning of the 1920's (see pp. 162-163), this meant only that the Army approved the design pro-

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

posed by the firm; in others the Army accepted most of a private design but ordered certain features changed, such as the use of fuel injection on the Allison in 1934 (see pp. 276-277); but in other cases the Army itself laid down all the major features of the design and left only the detailed engineering to the private firm.

The stories of two engines developed nominally by private industry but with complete Army dictation of all the basic principles of the design are recounted in Part II. The first was the Army's first high-power air-cooled radial, the Curtiss R-1454, a detailed account of which will be found in Chapter VII. Briefly, after testing the privately designed R-1 built by Wright on an Army contract in 1920, the Army first had Wright rebuild it with completely new cylinders developed at McCook Field by an Army engineer, and then in 1923 issued a specification for a new engine, the R-1454, incorporating a number of fundamentally changed design features. The entire industry was invited to submit bids for detailing and constructing an experimental lot of engines according to the specification; the award was made purely on a price basis, the low bidder being Curtiss. One R-1454 was built and delivered within about a year, but after a short period of testing the Army instructed Curtiss to rebuild it with a new cylinder developed at McCook Field. The rebuilt engine was delivered by Curtiss to the Army late in 1925.

Meanwhile the Navy had given Wright a contract in 1923 for development of an air-cooled engine of about this same size. Wright had designed, built, and tested its first design, the P-1, within one year (1923-1924), and then had designed, built, and tested a considerably revised engine, the P-2, again within a single year, 1924-1925. The P-2 profited considerably by incorporating several features of the Army's R-1454, including the general principles of cylinder design which had been developed at McCook Field. In 1925, after the P-2 had been tested, a number of Wright's key personnel broke away to found the new Pratt & Whitney Aircraft Company, where they produced a still further improved air-cooled radial, the Wasp. This engine was ready for test by the services in the first half of 1926, only a short time after the Army had begun its first tests of the second version of the R-1454.





The Wasp demonstrated such decisive superiority over the R-1454 in comparative flight tests that all further development of the latter engine was dropped at once. The original design of the R-1454, however, had been definitely superior to that of the P-1, the direct ancestor of the Wasp, which had been designed at the same time that the Army issued the design specification for the R-1454, in 1923. Thus the fact that the R-1454 was decisively outperformed by the Wasp in 1926 is of very considerable interest.

The real trouble with the R-1454 was that two years passed between the fixing of most of the features of the design in 1923 and the first extensive bench testing late in 1925 and almost three years before the first flight tests were made in 1926. During all this time the only real development leading to improvement on the 1923 design was that done on the cylinder. But however excellent the original design features of a new aircraft engine may be, it can only be perfected by a long process of testing, modifying, and testing again; and if this process is carried out too slowly, the engine will be obsolete before it is usable. During this same period, 1923-1925, Wright had designed and built the P-1 engine, discovered its worst faults by extensive bench and flight testing, used this knowledge to design the much improved P-2, and had built and tested both that engine and a scaled-down version, the Simoon. It was the experience thus gained which guided the important mechanical improvements made in 1925 by former Wright engineers in the design of the Pratt & Whitney Wasp, and it was these improvements which in 1926 made that engine so superior to the R-1454.[3]

The excessive slowness of the development of the R-1454 was no accident. In part it was due to Curtiss's peculiar business position, as will be pointed out elsewhere (pp. 63-64), but slowness was inherent in the technical process by which the engine was developed. Construction was in the hands of one organiza-

[3]This does not mean, of course, that the experience gained from the Wright engines automatically created the improvements made in the Pratt & Whitney Wasp; these improvements were due to the excellent engineering of that engine. But the number of departures from the current practice which could be made at one time was strictly limited, and experience with the earlier engines showed which features of the design were in most pressing need of improvement.

tion while design and testing were in the hands of another, and the McCook Field engineers who were responsible for the design and testing were necessarily involved in a number of other activities at the same time. The separation of design from manufacture, together with the restrictive rules governing Army procurement, meant that five months had to be lost (from August 1923 to January 1924) between the fixing of the general specifications for the R-1454 and the beginning of detailed designing; the Wright P-1 was designed, built, and put on test within approximately this same period. It meant also that an improved engine could be obtained only after a complete engine had been built and shipped by Curtiss to the Army, after the Army had then fitted this job into its over-all testing program, run tests on the whole engine, and at last returned it to Curtiss with instructions for rebuilding, and after Curtiss had fitted the rebuilding into its engineering and manufacturing program.

A private firm developing its own engine has a tremendous advantage in the fact that it can make continuous improvements by modifying the design of each inadequate part as soon as tests show its inadequacy, whereas the Army's facilities and personnel sufficed for only a very limited amount of this sort of work, and this work was considerably delayed by the civil service regulations applied to the Army's drafting offices and shops. When a modified component was desired, the usual method was to have the new component manufactured by an outside supplier, a necessarily slow process which was much further delayed by the legal requirements calling for competitive bids. This difficulty of obtaining experimental components is probably one of the chief reasons why most modifications were left to be tested until the entire engine was redesigned and rebuilt.

Another very serious difficulty with the detailed direction of the development of the R-1454 by the Army arose from the fact that the Army was necessarily interested in far more engines at one time than any one manufacturer. In general, successful manufacturers have refused to try to develop more than two new engines at one time, even when governments have been willing to pay all the costs and thus make possible the acquisition of all the personnel and facilities required. When even





first-class firms have been willing originally to undertake a larger number of projects, they have often been obliged to drop some in order to hasten the success of the others. In order to concentrate on the Merlin and Griffon, Rolls Royce dropped the 24-cylinder Vulture in 1941 after four years of work had already brought the engine to the state of limited production (see p. 244).

It is true that Rolls Royce's dropping of the Vulture was attributed to "pressure of war." Nevertheless strong emphasis must be placed on the fact that in time of peace as well as in time of war, unless a development is carried out within a short enough time, it might as well not be carried out at all, because the result will arrive too late to be of use. The only real difference in this respect between wartime and peacetime development is that it is only in time of war that this truth is fully realized. In the latter half of the 1930's the British firm of Bristol, which had previously concentrated almost exclusively on the development of two sizes of poppet-valve radials, decided to undertake the development of a whole new line of four sleeve-valve radials at one time. This undertaking seemed possible because there was no immediate pressure for engines for combat; but the result was that when war came none of the engines was within less than two years of readiness for full quantity production and satisfactory service.[4]

The second example of an engine development by a private firm under the detailed control of the government is the Continental vee-type liquid-cooled IV-1430, a full account of which will be found in Chapters X and XI. Research which was begun at Wright Field about 1930 showed that the power which could be got from a single liquid-cooled cylinder was very much greater than that which was being obtained from any engine then in service or on any builder's drawing boards. The Army decided to have a complete engine built based on a small liquid-cooled cylinder of extremely high output per cubic inch. Other research being done at Wright Field at this time led the Army to decide that the coolant should operate at the very high temperature of 300°F in order to minimize the weight

[4]On Bristol's position at the outbreak of the Second World War, cf. Chapter II, p. 50, n. 55.

and drag of the radiator, and Wright Field engineers decided that in order to make this possible the engine would have to be built with individual cylinders instead of the monobloc construction then standard for liquid-cooled engines.

In 1932 the Army contracted with the Continental Motor Company to develop an engine along these lines, expecting that it could be got into production and service within a very few years. Difficulties quickly appeared, however, and six entire years, from 1932 to 1938, were spent in trying to obtain a single cylinder which would meet the Army's specifications. Meanwhile, at the urging of the Airplane Branch at Wright Field, the Chief Engineer of Wright Field had ordered the use of the flat or opposed cylinder arrangement so that the engine could be installed entirely within the wing of an airplane, but by the time the first complete engine was ready for test, in 1939, this type of installation had been given up as impractical. The engine was then redesigned as a vee, but at the insistence of the Army's tactical officers it was made an inverted rather than an upright vee. By this time the engine was so far behind the competition that it should have been dropped, but it was actually not until 1943 that plans for its production were given up.

To a very large extent the reason for the complete failure of the Continental IV-1430 to produce usable results was simply lack of money, and we shall discuss elsewhere (below, pp. 77-83) the uselessness of even attempting development unless sufficient resources are available. Lack of money was not, however, the only reason for failure. The Army's insistence on maintaining its original specifications for coolant temperature, however much this delayed the building of a multicylinder engine, would alone have sufficed to put the entire development behind its competitors. As is told in Chapter VIII, Rolls Royce designed and developed the Merlin and put it in full quantity production in a year less than the Army spent on single-cylinder development alone. Then after six years had been spent in merely getting a satisfactory cylinder, another year was lost because the first complete engine was made in the flat arrangement in order to suit one particular type of installation. The inverted arrangement next specified was another serious handicap, since it meant that it was necessary, at this late date and





with no previous experience, to face all the problems of developing an installation for an inverted engine.[5]

The dominant impression gained from a survey of the history of the Continental engine is that either the Army lacked the sort of executives in charge of engineering decisions whose presence is absolutely essential for the control of a successful engine development, or that having them the Army system prevented them from properly carrying out their most important function. Any aircraft engine contains a host of compromises, since a gain in one direction may very well be outweighed by a loss in another, and a high order of both intelligence and experience is required if the whole development is to be coordinated and made to yield a useful product before the basic conception is obsolete. Rolls Royce, like all successful aircraft-engine builders, was controlled by such men, and although Rolls Royce's chief engineer had himself designed a new type of cylinder which it was hoped could be used in the Merlin (cf. p. 217), the development of the engine as a whole was not made to wait upon the perfecting of this cylinder. The result was that although the new cylinder had to be given up after over two years of work, in 1936, the rest of the engine was then in good shape, and a very rapid change to an older, proved cylinder design immediately produced a power plant ready for service (cf. pp. 218-219).

The same failure of Army-directed development to sacrifice individual features of merit in order to hasten the success of the engine as a whole is also seen in the history of the R-1454. The second cylinder developed for this engine at McCook Field had automatic lubrication of the valve gear. This later became standard on American air-cooled radial engines, beginning with the Wasp in 1934, and it proved to be a feature of very great utility. Furthermore, the basic design of these later gears was very similar to that of the Army cylinder; and although the latter was unsuccessful when first tested on the R-1454, it could have been made to work successfully by a very

[5]That such an installation was perfectly possible is shown, of course, by the Germans' exclusive use of it, but that the problems were difficult is shown by the strong objections which were raised by the British airplane builders in 1932 when Rolls Royce originally proposed to build the Merlin as an inverted vee, and which led Rolls Royce to build the Merlin in the conventional upright form (cf. p. 216).

small amount of further development. Yet the engineer who designed this Army cylinder himself later testified that Pratt & Whitney had been wise in waiting a number of years before putting automatically lubricated valve gear on its engines, since more immediately important work would have been delayed thereby.

Lack of judgment similar to that shown by the United States Army in connection with the development of the R-1454 and IV-1430 was shown by the official in charge of turbojet development in the German Air Ministry from 1939 to the end of the war. As is told in Chapter XIV, Junkers, whose 004 engine was produced in large quantity before the end of the war, and the BMW Engine Company, production of whose 003 was well begun, both largely disregarded the Ministry's ideas and designed their engines as they saw fit. Heinkel, however, which had built the first turbojet actually to fly anywhere in the world, followed the Ministry's request in 1942 and dropped its 006 engine, which was beginning to show excellent performance, and undertook to develop the 011, with a compressor of a new and completely undeveloped type preferred by the Ministry (p. 408). The 011 was still far from ready for production at the end of the war. It is quite possible that simply because of insufficient manpower and experience Heinkel could not in any case have had an engine ready for service before the end of the war, but all possibility of success was lost when the firm dropped the partly developed 006 for the completely new 011. Had not Junkers and BMW continually and successfully resisted the urging of the Ministry to design for higher performance than they believed desirable, it is highly probable that these firms too would have failed to have engines ready for service before the end of the war.

A private firm must maintain a proper balance in directing the general program of development or the firm fails; a government establishment tends to become a collection of specialists, each promoting his specialty whatever the effect on more necessary objectives. This is seen also in cases where the basic design of an engine was taken from a private source, and the government's intervention was limited to the specification of certain features. Two examples are found in the history of the liquid-





cooled Allison V-1710. This engine first showed real promise in 1934, and the Army placed orders for 11 engines. But although the very limited resources of the company should certainly have been concentrated on development of the basic engine, which was far from ready for service at this time, the Army ordered Allison to begin at once to develop a model with fuel injection as well as the original model with carburetion, and further complicated the task by specifying the same 300°F coolant temperature which was causing so much trouble with the Continental.

The evidence would seem to show that a government service lacks three of the most essential requirements for success in managing the technical details of development:

(1) An organization capable of carrying on all the needed separate but related activities simultaneously and rapidly.

(2) Engineer executives with both the authority and the judgment to coordinate all these activities and make the choices and compromises necessary for achieving success before the basic design is obsolete. (Whether the lack of judgment shown in the past has been due to lack of capable men or to a system which prevents such men from showing their capacity is a question of such importance that it will be discussed in a separate section below (pp. 35-39).

(3) Unification of continuing development with manufacture and service of the already developed models of the same basic type.

It is hopeless for an organization working under such handicaps to try to carry out or even to control the technical details of development. All the evidence collected in this study would seem to show that detailed design and development of an engine should be the responsibility of a private firm.

## Responsibility of Government for General Course of Development

The discouraging results of attempts at development carried out or controlled in its details by the military services has apparently resulted in the acceptance by the services of the doctrine that they should have no voice at all in the design of new aeronautical material. According to the "National Aeronautical Research Policy" of 1946,[6] which has been expressly approved by the Congressional Aviation Policy Board,[7] "application of research results in the design and development of improved aircraft and equipment... is the function of the industry," while only "evaluation" of this equipment and "the exploration of possible military applications of research results are considered to be the function of the Army and Navy."

The military establishments can by no means, however, discharge their full responsibilities by the negative policy of letting industry follow its own judgment, desirable as this may be within its proper sphere. While industry can and should be given the greatest liberty in deciding the details of development, there is no way for the services to escape responsibility for positive control of the general course of development, even if they desire to do so. The services could, of course, cease to formulate their own specifications for the major design features of any new engine, but even if only proposals submitted by private industry are considered, the services could not afford to finance more than a fraction of the engines proposed; and the fact that a proposal comes from industry is naturally no guarantee that it is sounder than when it comes from government. The failure of the Continental Hyper engine, for instance, was in some part due to the fundamental aim laid down by the Army, an extremely high ratio of power to size; but although the British government had a definite policy of never intervening to set up technical specifications of this sort, its acceptance of a proposal from

[6] *To Establish a National Air Policy Board*, Hearings on S.1639, Committee Print, 79th Congress, 2d Session, Senate Committee on Interstate Commerce (Washington: Government Printing Office, 1946), pp. 242-244.

[7] U. S. Congress. Aviation Policy Board, *National Aviation Policy* (Washington: Government Printing Office, 1948) (80th Congress, 2nd Session, 1948, Senate Report 949), p. 43.





private industry led to the expenditure of tremendous sums of government money on the Napier Sabre, which had exactly the same basic aim of high power from extremely small displacement. Although the Continental engine was ultimately dropped whereas the Sabre was finally put in service in small quantities in the last two years of the war, it is at least not unlikely that the Continental — in a 24-cylinder H-type version — could have been pushed through to the same sort of qualified success as the Sabre if the American government had supported it to the extent to which the British government did the Sabre. In general, the United States Army has probably erred more than the Navy in interfering in the design of particular engines, but the Navy has probably spent more money than the Army in supporting the development of "cats and dogs" proposed by private firms. These have usually been small firms, not the established builders, but even the latter have contributed a few.

In theory the government could exclude all projects except those from established manufacturers willing to finance their own development, and thus avoid responsibility for choosing which projects should be supported and which should not, but the government still could not avoid controlling the general policy of those manufacturers by the opinion it gave as to the probable future military utility of the engines proposed. One of the clearest examples of this is the first two-row radial to be put on the market in the United States, the Pratt & Whitney R-1535. After beginning experiments with two-row engines in 1929, Pratt & Whitney had decided early in 1931 to develop an engine of 1,830-cu in. displacement as its first of this type, believing that for any smaller displacement single-row engines were preferable because they were lighter and simpler. The Navy insisted, however, that an engine of extremely small frontal area was needed for its fighters and dive bombers, and Pratt & Whitney, despite its conviction that the idea was unsound, responded later in 1931 by undertaking to develop a 1,535-cu in. engine almost entirely at private expense.

It is in any case not only inevitable but desirable that the government should guide the general course of development, since the record shows that private industry cannot be relied upon even to advocate, let alone finance, the development of every type of needed materiel. Even after the American D-12 engine had demonstrated the superiority of the monobloc vee-type 12-cylinder water-cooled engine for high-speed aircraft in the first half of the 1920's, neither of the two British producers of liquid-cooled engines proposed of its own accord to develop such an engine. As is told in Chapter VIII (pp. 205-207), the British government, after testing some engines bought in the United States, first tried to persuade Napier (which was at that time the most successful and best established of all the British builders of aircraft engines) to develop a similar engine, but Napier refused though the government was ready to pay the entire cost. The government then persuaded Rolls Royce to do the job; it was only after this development had been begun as a result of the government's urging that the company finally became convinced of the superiority of the vee-type engine over its own X-type engine of the same power. Rolls Royce then dropped the X-type engine to develop the vee into the Kestrel, which was the direct ancestor of the Merlin of the Second World War. Napier, following its own technical judgment, rapidly sank into a long period of obscurity.

The earliest establishment of the air-cooled engine in the United States was due in exactly the same way to direct intervention of the government to control the general course of development. The Lawrance Aero Engine Corporation, which was the one private firm willing to develop 200-hp air-cooled engines at the beginning of the 1920's, had insufficient resources to carry this development to a fully successful conclusion, while none of the larger firms with adequate staff and facilities was willing to enter this field. Chapter VII relates (pp. 172-175) how the Navy decided, before having actual proof, that 200-hp air-cooled engines would be superior to liquid-cooled engines for its ship-based aircraft, and adopted a policy toward the industry which forced the Wright Aeronautical Corporation to enter the field. Had the Navy not intervened in this way, it would never have received the excellent engines which powered many of its best ship-based airplanes from about 1923 to about 1926, and which were also a great stimulus to the development of larger air-cooled engines.





In the case of the earliest development of high-power (400-hp) air-cooled engines, one of the two major engine builders, Wright, believed that the type was worth developing, but the other major firm, Curtiss, was absolutely convinced that air cooling was impractical for an engine of so high an output. Again the services were obliged to decide before obtaining concrete proof whether it was worth risking the cost of an attempted development. After Wright Aero's first large air-cooled engine, built at the Army's expense, had had trouble with cooling, the Army had to decide whether to try to eliminate the trouble by refinement of Wright Aero's cylinder design or to try to develop a fundamentally better design. The Army took the latter course over Wright Aero's very strong objections, and the new cylinder developed for the engine by the Army itself became the ancestor of all modern American air-cooled cylinders.

Again, as Heron shows in his history of aviation fuel (below, pp. 556, 599), the decision to develop the use of leaded fuel was reached by the Army as a result of its own investigations, and the development of engines to use this fuel had almost to be forced by the Army on a part of the engine industry, which feared the difficulties that lead would create.

The most striking proof of the need for government intervention to control the general course of development is to be found, of course, in the history of aircraft gas turbines. The special problems of such radical innovations are reserved for a separate chapter, but in the present connection it must be pointed out that nowhere in the world did a single established engine builder undertake the development of turbojets until either persuaded to do so by government, as in Germany, or confronted with a demonstrably successful turbojet developed with extensive government aid as in England and in the United States.

Even in matters of detail the government often cannot avoid responsibility even if it wants to. For example, the Army had to choose whether the Allison should be developed with a gear-driven supercharger capable of altitude supercharging or should rely on the turbosupercharger for altitude performance. Such a decision, depending as much on plans for applications of the engine as on engine performance by itself, simply could not be made by any private firm. For a long time the Army banked on the turbo alone; it was not until 1938 that the first Allison with integral altitude supercharging was built for use in the XP-40 (cf. p. 279). This C13 model of the V-1710 had to be brought out as a rush job, and there was no time for any systematic development of the supercharger. Between 1938 and 1941 Allison made certain minor improvements in the supercharger, but there had been insufficient time, resources, and trained personnel to do a thorough program of development. The result was that from 1940 through 1942 the Army had no engine suitable for a medium-altitude fighter. The results of this mistake were really much more serious than, for example, the results of the Army's technical intervention in the matter of fuel injection on the Allison. Once more the fault was lack of over-all balance in the Army program: the turbo was one of the really brilliant successes of the Army-directed and sponsored development, but the Army should certainly not have concentrated on it to the exclusion of intensive development of gear-driven superchargers.

Again, when Allison did produce a two-stage supercharger for the V-1710, in 1942, it proved to be of such a form that it could not be installed in the best available airframe, the Mustang, which as a result was converted to use the Merlin instead of the Allison, around which it had been designed. Responsibility for this error is probably to be shared between Allison and the Army, since the development began after it was already perfectly clear that airframe production would scarcely be able to meet the demand, but it was certainly the Army which was primarily responsible for coordination of engine design with general procurement plans.[8]

## Government Research

In addition to their essential and unavoidable role of controlling the general course of development, the military services of the United States have on occasion made extremely valuable direct contributions by their own research, if not by their at-

[8]It is uncertain how far the Army's policy was caused by its early dislike of the Mustang. The P-63 Kingcobra was ready for production with the two-stage Allison about as soon as the engine itself was ready for production.





tempts at development. The research done by McCook Field in the early 1920's on the design of air-cooled cylinders, which set the general pattern for all American air-cooled cylinder design, and Wright Field's research in the 1930's on the value of leaded fuel, which was directly responsible for the development of high-octane fuels and suitable engines, have already been mentioned. Many other examples could be named; several are mentioned in Part II of this study. For example, McCook Field was responsible for the early development of the technique of casting air-cooled cylinders. This work started on the basis of British foundry practice as of 1919, but building on what McCook Field had accomplished by 1923 American industry was able by 1926 to produce incomparably better castings than the British, and to cast forms which the British could not cast successfully at all (cf. below, p. 148, n. 39). Again, it was work done by the Army between 1923 and 1930 which demonstrated the value of high-temperature liquid cooling and which developed the coolant used by Rolls Royce on the original Merlin from 1935 to 1939, as well as by Allison on the V-1710.

All these examples are illustrations of the fact that certain types of research have been better done by the military services than by industry, if indeed the work could economically have been done by private industry at all. The refusal of the engine firms in the early 1920's to devote more than a limited amount of time to the development even of complete air-cooled engines (see pp. 172-175, 184-185) is certainly proof that no qualified engine builder would have been willing to carry out a program of cylinder development on the scale on which it was done by the Army even if the Army had been willing to pay all the costs. During the whole of the 1920's no private firm even attempted to carry out such a systematic investigation of a large variety of basic designs for a single component of an aircraft engine of any type. Research on the performance of leaded fuel was the sort of thing which no private firm could do on a large scale at its own expense, since the results could scarcely be used to create a competitive advantage for the firm, while it was scarcely logical for the government to give one competitive engine builder a contract for research the results of which were equally and directly applicable to all engines. Since, on the other hand, no other private agency had the facilities for full-scale fuel testing, the only logical place to carry out the tests was in a government laboratory. The cooling system of liquid-cooled engines is an example of an orphan accessory, in which neither the engine nor the airframe builder had a direct interest; problems of this sort of accessory are discussed in more detail on pages 119-121.

It is certainly true that the opportunities for doing valuable research within the military establishments were already far less extensive in the 1930's than they had been in the 1920's. First of all, the industry was far richer and far better equipped by then than it had been in the 1920's. The amount of research done by industry in the 1930's on cylinder design, for example, was probably greater than that done by the services in the whole period between the two wars, and included fundamental studies of problems like heat flow as such in addition to straight development of cylinders for specific engines. Second, conditions of work at Wright Field in the 1930's were no longer nearly so favorable to research as they had been in the 1920's. As the military establishments grew in size, more and more paper work and reports came to be required of their engineers, and civil service regulations on work in the shops and drafting offices came to be more and more rigidly observed, while the formalities of competitive procurement were enforced, largely as a result of various Congressional investigations, to the point where all work was seriously delayed whenever it was necessary to purchase parts or material.

It would seem, however, that it is still possible for the military establishments to do useful research in certain cases. The most obvious case is where the services have available facilities which are not available elsewhere. Some facilities required for research, such as wind tunnels and altitude chambers, are so expensive that the country can afford only one or a very few. The services must have them for testing of material submitted to them by industry, and if after this function is fulfilled there is time available for research, it would be absurd not to use them.

An even more important justification for research by a military establishment arises simply when no one else does a piece of research for which the military establishment sees the necessity. That such cases will continue to arise is not at all unlikely, despite the fact that private firms have become obliged to do more and more basic research at their own expense. The basic economics of private industry demand that a firm bring out a salable product as rapidly as possible, even if government is willing to pay the whole cost of development. A company cannot in general afford to devote more than a very small fraction of its engineering resources to systematic basic research on a given problem if it believes that there is a shorter way to the production of an engine which can be used and sold.[9] Almost all the true research done by industry has been undertaken only when and because no more direct approach seemed capable of reaching a usable solution. Thus after the research by McCook Field and Allison which led to the substitution of the copper-lead bearing as a much superior replacement for babbitt early in the 1920's, no really systematic research was done by industry (or anyone else) on bearing materials until the very end of the 1930's. Then, after finding itself completely unable to stop failures on one of its engines when it was used in high-speed dives, Pratt & Whitney began the research which led to the production of silver-lead bearings.

The most logical government agency for carrying out basic research is, of course, the National Advisory Committee for Aeronautics, whose specific function this is. Little has been said here about the work of the NACA because until the very end of the 1930's, i.e., throughout the entire interwar period which is the primary subject of this study, by far the largest part of that agency's work was in the field of airframes rather than engines.[10] Undoubtedly the NACA will play a much greater role in engines in the future, with the large and excellent facilities and staff of the new laboratory for engine research built at Cleveland during the Second World War.





[9]It is usually only in the largest companies that genuine long-term research (as distinguished from direct product development) is done on a significant scale.

[10]The NACA itself has never emphasized any piece of research in the general field of engines among its important accomplishments before the Second World War. See, for example, the list of achievements based on testimony of the NACA in *Aircraft* (*Production, Development, and Research*), Additional Report of the Special Committee Investigating the National Defense Program, 79th Congress, 2nd Session, Senate Report 110, part 6 (Washington: Government Printing Office, 1946), p. 140.

It would be, however, not only unnecessary but undesirable to adopt a policy under which the NACA would be the only government agency allowed to do basic research on aircraft engines. The National Aeronautical Research Policy of 1946,[11] although seeming to assume that in principle all research should be done by the NACA, provides that "for important problems whose practical solution appears to be especially difficult, the NACA, the aircraft industry, Army, Navy, [and others] may work on various aspects of the same basic problem." Even this is too restrictive: if a piece of research needs to be done, and if someone outside the NACA has men and facilities available while the NACA has not, it would be unwise to wait until the NACA had men and facilities available. Of even greater importance is the possibility that one of the services may see that a certain piece of research is necessary but be unable to convince the other members of the NACA that it is.

The only really necessary prerequisites for the successful conduct of research by any agency, public or private, are first and foremost the presence of a man capable of carrying it out, and secondly the existence of conditions which permit him to work efficiently. The real reason for the existence of a central research agency like the NACA is to facilitate research by having a valuable collection of men and apparatus in one place, but this is by no means a reason for giving such an agency exclusive authority to do work which could be done elsewhere.

The reason why government agencies have on occasion been successful in research whereas they have uniformly failed in their attempts to develop finished products is that there is a very great difference between the general method of procedure which leads to success in research and that which is successful in the development of complete engines. Research consists essentially in the consideration of all the possible solutions to a given problem and the systematic investigation of all which seem to have any real possibility of success. If the final results of the research are to be valid, the work cannot be hurried by the omission of any steps which are essential to a complete understanding of the problem. The assertion that the object of research is knowledge rather than a product is only another

[11] *To Establish a National Air Policy Board*, Hearings, p. 244.





way of stating these facts. Genuine research, furthermore, at least usually does not call for a highly coordinated attack on several different problems, of which all the results must be incorporated in a single result if they are to have any real value.

Thus the great weaknesses of the government establishment—lack of coordination and of executives with the ability and authority to stop all activity except that most likely to lead quickly to a usable result, and slowness of action due to civil service and other regulations — are not nearly so harmful in their effect on basic research as they are on development, which must produce a serviceable product within a certain time or be worthless.

## Personnel in Military Engineering Establishments

If ever favorable conditions were present for the undertaking of technical development by a government establishment, these conditions were present at McCook Field in the early part of the 1920's. The American aircraft-engine industry was small, poor, and inexperienced, and McCook Field became in a sense a school for aspiring engineers, many of whom later became prominent in private industry. Very few really first-rate engineers remained with the Army very long, however, and in the 1930's the average caliber of the staff was by no means what it had been before, although there have always been a few exceptionally able individuals.

First and perhaps most important of the reasons for the inability of the government to obtain really first-rate engineers, or to hold them once it has obtained them, is the well-known inadequacy of government salaries compared with those offered by industry. This inadequacy obtains, however, only at the higher levels; at lower levels government salaries are actually somewhat higher than those offered in industry.[12] The system is thus both wasteful of public money, by paying more than is necessary to employees of the categories which receive by far the largest share of total wages, and completely unsuited to

[12] The following distribution is taken from data on a large sample of "scientists" in government and industry published in U. S. President's Scientific Research Board, *Science and Public Policy, A Report to the President by John R. Steelman* (Washington: Government Printing Office, 1947), Vol. 3, "Administration for Research." p. 245: *(Footnote continued on next page)*

retaining those junior engineers who demonstrate real ability. The few really outstanding engineers whom the government has been able to hire and retain in the field of aeronautical development have usually been of certain special types. Most of them have been distinguished for research rather than for their ability to direct and coordinate a complex program of engineering. A man who enjoys genuine research often has a better opportunity in government than in industry simply because there is not the single-minded concentration on getting out a salable product in minimum time.

Not only are the best salaries to be obtained in government service relatively low, but the regulations imposed by the civil service system make even this inadequate reward work very inefficiently as an incentive to effort and initiative. The civil service system makes promotion depend to a very large extent on seniority, and really rapid advancement of an unusually capable engineer is virtually impossible.[13] The other side of the picture is the fact that the job of the civil service engineer is secure so long as he respects the regulations and is not grossly inefficient.[14] There is virtually no penalty for being a mediocre engineer, and it is extremely difficult to get rid of a mediocre engineer to make a place for a better one.

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SCIENTISTS IN GOVERNMENT AND INDUSTRY, CLASSIFIED BY SALARY AND AGE

| | *21-30 yrs.* | | *31-40 yrs.* | | *41-54 yrs.* | | *55 yrs. and over* | | *All Ages* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Govt.* | *Ind.* | *Govt.* | *Ind.* | *Govt.* | *Ind.* | *Govt.* | *Ind.* | *Govt.* | *Ind.* |
| *Salary range* | | | | | | | | | | |
| Under $3,000 | 24% | 36% | 4% | 6% | 2% | 7% | 0% | 0% | 8% | 16% |
| $3,000-$5,000 | 74 | 54 | 61 | 45 | 50 | 26 | 12 | 18 | 57 | 42 |
| $5,000-$8,000 | 2 | 10 | 31 | 43 | 43 | 41 | 75 | 45 | 31 | 31 |
| Over $8,000 | 0 | 0 | 4 | 6 | 5 | 26 | 13 | 37 | 4 | 11 |
| | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Median Salary | $3,700 | $3,520 | $4,500 | $4,940 | $4,900 | $6,260 | $6,500 | $7,100 | $4,480 | $4,600 |

Two striking facts emerge from this table: (1) Median salaries are not very much lower in government than in industry for any age group (being actually higher in the youngest group), and the over-all government median is less than 3% lower than the corresponding figure for industry. Although there would be a somewhat greater difference between averages than between medians, the net cost to the government of creating the same salary distribution as obtains in industry would be very small. (2) Within every age group, industry has a higher percentage than government in both the lowest and the highest salary brackets; the government system makes inadequate provision for the recognition of merit.

[13] Ibid., pp. 152 ff.
[14] Ibid., pp. 157 ff.





The practice in the American military establishments of filling executive posts with military officers on short tours of duty even in engineering organizations such as Wright Field or the Naval Aircraft Factory is in itself virtually enough to insure that these organizations will have ineffective administration, whatever the native capacity of the officers may be. It is continually necessary to fit both the detailed projects being carried out by the government itself and the much more extensive work being done by industry into the general picture, and only a man with both great natural engineering and executive ability and also a maximum of both general experience and intimate acquaintance with all the work in hand can choose correctly which of these projects shall be dropped, which modified, and which used. Such experience and such knowledge simply cannot be possessed by an officer who fills an executive engineering post during a tour of duty of a few years at most.

It is to be observed, however, that the typical mistake of officers without experience in engineering is not that with which they are popularly charged, excessive conservatism, but rather the exact opposite. They have in general underestimated the practical difficulties involved in a development they desire, and tried to go too far all at once, thinking it a waste of time and money to proceed in smaller steps. Examples of this are numerous. The W-1 engine which McCook Field attempted unsuccessfully to develop in the very early 1920's was more powerful than any engine in service anywhere in the world for years thereafter; the Continental engine, of which the basic design was laid down by Wright Field in 1932, aimed at more power per cubic inch than was achieved by any engine in service before about 1943; the air-cooled R-1454 designed in 1923 was to have more supercharging than any engine in service before the 1930's. The Chief of the Air Corps was to a very large extent personally responsible both for importing the Whittle turbojet from England in 1941 and for stimulating independent American development of gas turbines through the special Durand Committee of the NACA (Chapter XVI). Tactical officers of the Air Corps, dissatisfied with existing carburetors and with the unwillingness of the one established manufacturer to develop something better, forced Wright Field to purchase and test the SPE floatless carburetor despite the opinion of the Wright Field engineers that it could not possibly succeed (cf. pp. 516-517). Toward the end of the 1930's a high official of the Air Corps, convinced by British arguments that the sleeve valve was superior to the poppet valve, did all that he could to persuade one of the two major American engine builders to switch all its development to sleeve-valve engines; fortunately the engine builder refused to do so. Tactical officers at the end of the 1930's were continually urging Wright Field to begin development of liquid-cooled engines far more powerful than the Allison V-1710 and Continental IV-1430, although development of those engines was far from complete.

The counterpart of this overenthusiasm and underestimation of the difficulties involved in realizing a paper project is a tendency to become discouraged and discard an actual development when the inevitable difficulties appear. The British military authorities were ready early in the 1920's to abandon the development of the Bristol Jupiter, which ultimately became the best British air-cooled engine. Tactical officers of the United States Army were ready at the end of the 1930's to discard the turbosupercharger, and did eliminate it from both of their single-engine fighters, the P-40 and P-39; it was saved on the B-17 only by the persistence of its sponsors at Wright Field, who finally succeeded in making an overwhelmingly convincing flight test in 1939.

Occasionally during the period between the two World Wars the services assigned officers to positions of engineering responsibility for considerable periods of time, but even so the positions have never carried sufficient rank and distinction. In the period before the Second World War the position of Chief Engineer of Wright Field was of very great importance: its holder reported directly to the Chief of the Air Corps, and was almost absolute in his authority over all the Air Corps' research and development. Such a position, one would think, would carry a rank and distinction equal to few and second only to the Chief of the Air Corps; one would expect it to be sought out as the culmination of a successful career for an officer interested in engineering. Yet the most forceful and one of the most able men to hold that post during the time it existed, a trained





engineer with a doctorate from the Massachusetts Institute of Technology, held only the rank of major while he filled it from 1928 to 1934, and subsequently was "advanced" by becoming the executive officer of the Chief of the Air Corps, then being assigned to the Industrial College and the War College, and finally becoming Chief of Staff of the GHQ Air Force. In the Navy the situation was somewhat better, since there was a definite career open to specialists in engineering, but even in the Navy the possibility of advancement open to these Engineering Duty Only (EDO) officers was severely limited in comparison with that open to officers of the line.

Unless the entire military system of rewards and promotions can be changed to recognize that engineering is as important as any tactical function and to reward it accordingly, the American services would very probably profit by following the British example of having military officers participate only in the setting of objectives, leaving the highest strictly engineering posts in the hands of civilians.

### Conclusions

(1) The military services are in general incapable of developing a complex finished product such as an aircraft engine, although they are capable of doing highly valuable research on problems which are neglected by private firms or for which private firms have not the facilities. While the share of the NACA in the research done by government in the field of engines will undoubtedly be larger in the future than it was before 1939, the services should not be prevented from doing research for which they have men and facilities available.

(2) Whenever possible, all technical decisions involved in the development of an aircraft engine should be made by a single authority, that of the firm carrying out the development. Intervention by the government in specific details will very likely result in harm to the over-all development, although there have been occasional cases where government insistence on certain features of design against the company's opinion has been justified.

(3) The government has no way of escaping the sort of technical intervention in the general course of development which is

inherent in the use of experimental funds to support some developments and not others, or in the opinions which it expresses concerning the military utility of a proposed engine or a certain feature of the design of a proposed engine.

(4) If the government had originated no developments, but had limited itself to choosing between projects recommended by established engine builders, some of the most important forward steps in the history of aircraft engines would have been most seriously delayed.

(5) Because of this very serious responsibility which cannot be passed on to private industry, everything possible should be done to make the service engineering organizations as capable as possible. The top posts should certainly be filled by the ablest specialists who can be found rather than by officers assigned for brief tours of duty. The record as shown in this study would certainly seem to bear out the soundness of the recommendation of the President's Air Policy Commission[15] that in so far as responsible technical posts are filled by officers of the armed services, the capabilities of first-class scientists should not be wasted by transferring them to purely military duties, and that scientific work should not be a hindrance to their rapid advancement. In so far as civilians are concerned, the record again bears out the recommendation of the same commission, that all legal limitations be removed from the salaries which can be paid to the ablest men.[16]

(6) Ideally, responsible engineers in government service should be given the same freedom of action enjoyed by their counterparts in private industry; in return they should be held responsible, not merely for compliance with regulations, but for the success or failure of their over-all program. Whether such steps are practical under the American political system, is, of course, highly dubious, but this is a problem for students of public administration and cannot even be discussed on the basis of the evidence collected in this study.

[15]U.S. President's Air Policy Commission, *Survival in the Air Age* (Washington: Government Printing Office, 1948), p. 96.
[16]Ibid., p. 95.