CHAPTER IV

The Problems of Radical Innovations

Very rarely in the history of any type of engineering product a complete innovation in design occurs. While it would be extremely difficult to give a general definition drawing a clear-cut line between an innovation in the sense in which the word is used here and an important change in design which is not an innovation, the distinction is clear enough in the case of aircraft engines since the end of the First World War.

All the development of all types of reciprocating engines done after 1918 consisted essentially of progressive refinement of well-known basic designs. Numerous attempts were made during this period to develop engines of types not hitherto successfully used in aircraft, but almost all these engines were of types which had long been used in other applications. Aircraft Diesel engines are an example: Diesel engines had been used for a wide variety of purposes before there were any genuine aircraft engines of any sort, and the development of aircraft Diesels was merely an attempt to refine this well-known type sufficiently to compete with the standard spark-ignition or Otto engine in terms of weight. These attempts at refinement of the Diesel type were very largely based, furthermore, on the use of knowledge which had been acquired in the development of conventional aircraft engines: there was no need to create a whole engineering technique *de novo*.

There has been, however, one really radical innovation in aircraft power plants since the end of the First World War, involving a complete departure from all established methods of design and construction. This, of course, was the gas turbine, especially the turbojet form of gas turbine, which displaced the propeller as well as the reciprocating engine which drove it. The important difference between an innovation of this sort and the development, say, of an aircraft Diesel, is that whereas a very large part of the background required for development

of the Diesel could be drawn from experience with standard aircraft engines, only a very small part of the background needed for turbine development could be obtained from this source, and the rest had to be newly created.

Many of the problems involved in promoting the development of this radical innovation were the same as those involved in the development of any nonstandard type of engine such as the Diesel or even air-cooled engines in the 1920's, or, in the United States, liquid-cooled engines in the 1930's. A radical innovation like the turbojet involves some special problems in addition, however, and these deserve separate discussion.

The Sources of Innovations

Undoubtedly the most striking single fact in the early history of turbojets is that nowhere in the world was the first development of this new type of engine due to an established producer of conventional aircraft engines. The early history of turbojet engines is recounted in detail in Chapters XII through XVI of Part II. Very briefly, the turbojet was "invented" at least as early as 1921 (p. 324), and the basic principle was generally known to aeronautical engineers long before any actual development was done.

The first actual development capable of reducing this well-known principle to practice was begun independently and almost simultaneously in Germany and in Britain early in 1936. In Britain the first project was conceived by an officer of the Royal Air Force who had begun as an RAF mechanical apprentice, and was carried out by a new company, Power Jets, formed for that purpose with capital obtained from investment bankers unconnected with the aircraft industry (cf. pp. 336-339). In Germany, the first project was conceived by a university student and was carried out and financed by the Heinkel Airplane Company (cf. pp. 377-379). A second project was begun in Germany about a year later as an offshoot of a turboprop development which had been conceived by the head of development in the Junkers Airplane Company and was being carried out at the expense of that company without the knowledge of the Junkers Engine Company (cf. pp. 379-381).

It was only after the work being done by the Heinkel and Junkers airplane companies became known to the German Air Ministry that the Ministry decided, in 1938, to support development of turbojets. It was the government which first suggested to the established engine builders that development of the new type of engine should be begun, and it was only with some difficulty that they were persuaded in 1938-1939 to undertake the job, even though the government bore all the expense (cf. pp. 386-388). In Britain, a second turbojet development was not begun until late 1939, and then it was by a government research institution rather than a private firm (cf. p. 356). British engine builders did not become seriously interested in turbojets until a Power Jets engine actually flew in 1941 (cf. pp. 355-356).

The United States was far behind both Germany and Britain in beginning the development of turbojets, but even there the first project for such an engine, drawn up in 1940, was made by an airframe builder, Lockheed (cf. pp. 448-450), and the first actual development resulted from the work of a committee set up at the initiative of the Army (pp. 458-461).

The history of the turbojet makes it very clear that the engine industry can by no means be counted on to propose development of a radical innovation as soon as it is technically practicable to do so. This is as it should be, since to a large extent the efficiency and effectiveness of the engine industry come from its specialization in the task of improving existing types of engines by continual refinement. If the engine builders were to divert a large part of their efforts to studying and experimenting with every new type of engine to be suggested, they would be unable to carry out their essential task.

The fact that innovations are more likely than not to come from outside the established industry means, however, that the government must not look with prejudice upon schemes for the new engines which come from sources with no experience in engine development. Such prejudice would be more than natural, since the services have been continually harassed by proposals for new types of engines (and for new types of aeronautical materiel of all sorts) from sources obviously incompetent to produce a sound proposal, let alone to develop it. The

services have in the past maintained a very open mind concerning such proposals and have probably erred in the direction of supporting too many "cats and dogs" rather than in giving support only to the established companies. The important thing is to recognize that despite the high ratio of failures to successes, this open-minded policy must be continued.

The Need of Government Support in the Early Stages of an Innovation

All three of the earliest turbojet developments, Power Jets' in Britain and Heinkel's and Junkers' in Germany, were completely or almost completely financed from private funds from 1936 (1937 in the case of Junkers) until 1939. This might seem to justify a general policy of relying on private capital to carry a radical innovation to the point where its promise can be evaluated on the basis of concrete evidence rather than paper calculations. But before reaching such a conclusion, it will be well to examine this early history of turbojets a little more closely.

Backing for the early development of the first British engine was secured only by a series of fortunate but unlikely accidents (pp. 336-339). After completely failing to obtain support for development of his turbojet in 1930, Whittle himself had completely given up hope and had even allowed his patent to lapse. It was a result of pure chance that the project was revived through the interest of two ex-officers of the RAF, and even these two men had almost given up hope of financing the project before they finally came, through a chain of personal acquaintanceships, to the firm of investment bankers which put up the original capital. The fact that this firm could be interested in the project was largely due to the thorough scientific training of one of the members, certainly not the sort of background commonly found in investment banking concerns. Finally the subsequent history indicates that even this firm might have refused to back the project if it had foreseen either the true magnitude of the expenses which would be incurred before a flyable engine could be built or the difficulty of obtaining assistance from the government.

The fact that the Heinkel Airplane Company undertook its turbojet development in 1936 was entirely due to the personal acquaintance between Ernst Heinkel and the university professor who taught the young student who had conceived the engine. Virtually all the engineers on Heinkel's staff were initially skeptical of the project, and it would seem highly improbable that it could have been sold to Heinkel without this direct personal connection (cf. pp. 377-378). The engineer who was responsible for beginning the turboprop and turbojet work of the Junkers Airplane Company was himself in a position of some authority as the head of airframe development in that concern, but even so it is not at all certain that he could have persuaded the management to undertake a project so far outside of its regular work and in direct competition with the Junkers Engine Company had it not been that the chairman of the firm believed, on the whole without any justification, that the engineer in charge of development in the engine company was overconservative in his policies and that progress ought to have been made much more rapidly and more easily than it could in fact be made (cf. p. 379). In the spring of 1939, furthermore, the Junkers airframe division refused to continue financing development of these engines before any one of them had been brought to a point where it could run under its own power. It may be remarked that the German pulsejet and rocket developments were entirely dependent on government financing almost from the beginning (cf. p. 381 f).

In the United States neither Lockheed, where the first American designs of a turbojet were made, nor the Northrop airplane company, which proposed in 1940 to develop a turboprop, was willing to do any actual development at its own expense, only the preliminary studies being financed in this way (cf. pp. 447, 450). A year or two before this, some engineers in the turbosupercharger group of the General Electric Company had proposed the development of a turbojet to the management of the company, but the proposal had been rejected (cf. p. 445).

Unwillingness to risk more than a very limited amount of money on an aircraft engine is in fact only natural on the part of a company whose ordinary business is not the making of aircraft engines. Such a development requires facilities which the

company does not already have, the risk is greatly increased by the fact that the company has little or no background in the field, and even if the project is successful the return is far away in an uncertain future. The research and development funds available to airframe companies, for example, had to be used for work on airframes if the companies were not to lose out to competition. A large company such as General Electric undoubtedly could have found the funds, but aviation in general was remote from any of its major activities and virtually unknown to the management.[1] Its management could scarcely be expected to foresee a market sure enough and large enough to justify the development of a new type of aircraft engine in which the aircraft-engine specialists were not even interested.

Thus while it is not possible to point to an important innovation which failed because of lack of government support in its very early stages, the history of turbojets is enough to prove that a policy of refusing support in those stages would be extremely hazardous. Owing to the increasing cost of aeronautical development and to the probably increasing distinction between military and civilian products, it is not at all certain that it will be possible in the future to rely even as much as in the past on the financing of engine development by private funds. It would seem that only by a most happy accident could another radical innovation in the field of engines be financed in this way. The military services must therefore be prepared to finance such innovations without waiting for a demonstration of their practicality from an already partially developed product.

The most obvious objection to this conclusion, that radical innovations should be supported with public funds before they have given any real demonstration of their practicality, is that the money spent in this way will detract seriously from the in-

[1] General Electric did have a connection with the aircraft-engine industry through the supercharger business, on which it had almost a monopoly, but it must be remembered that this supercharger business was an insignificant part of General Electric's total business, and that the entire development costs of even this small-scale activity had always been directly paid for by the engine builders or the government. GE had been willing as early as 1903 to risk its own money to develop an industrial gas turbine (cf. p. 325), and by 1940 the Schenectady Steam Turbine Division was doing a good deal of work on industrial gas turbines at the company's expense (cf. p. 459), but these were machines for the sort of uses with which the company was familiar.

tensive development of conventional engines which is absolutely essential for security. A host of unorthodox engines were proposed to the services in the period between the two wars: barrel engines, cam engines, Diesel engines, sleeve-valve engines, steam engines, and others, in addition to gas turbines, which were the only ones of any real value in the end. It is certainly true that the services could not possibly have afforded to support the intensive development of all these engines and of conventional engines as well, and it is equally true that there would be no use in having a number of very promising weapons partially developed if this could be done only at the cost of neglecting the full development of proven weapons.

In fact, however, adequate government support for all really promising innovations even in their very early stages does not imply a financial burden which would seriously reduce the regular development of established types of engines. First, although the complete development of any engine, whether of a completely new or of a well-known type, is necessarily an extremely expensive process, only a relatively small amount of preliminary development, or better, experimentation, is needed to show whether an innovation like the turbojet has promise or not. The total cost of Power Jets' work from its beginning in 1936 to the middle of 1939, when it had definitely shown that the turbojet was not a dream but a practical new type of propulsive system, was only some $100,000. The total cost of Heinkel's development over the same period of time was little if any greater than this, and it led not merely to a promising bench engine but to an engine which actually demonstrated its value in flight. It was only at this point that it became necessary to decide whether to invest really large sums of money, and by this time it was clear that the results to be gained from turbojet development were more than worth the cost, even though it should prove very great.

Second, while it is true that even $100,000 put into each of all the various unorthodox engines proposed between the wars would have been a serious drain on the total funds available for all development, the number of innovations which could show real promise even on paper was not so great. There was, in fact, a great difference between the turbojet and all the other

unorthodox engines proposed between the wars, and this difference could have been seen even at the time. The turbojet promised enormous improvement in airplane performance on the basis of assumptions which were reasonable, even if they were not certain. All the other engines mentioned above, on the contrary, promised at the most very limited gains, and in most cases experience had already shown that the practical obstacles to the attainment of these limited gains were very great.

The real trouble with the various unorthodox engines on which public funds were spent with no result in the United States between the wars was that even granting that they were perfectly practical technically, they did not promise enough superiority over existing engines to make it worth while to spend enough money to make them work. As a result only small amounts were spent, and these amounts were a total loss. A good example is the development of sleeve-valve engines sponsored by the Navy in the 1930's. Research already done in England had shown that the single sleeve was basically a workable form of valve. The chief advantage claimed for it was that by its use more power could be obtained from a highly supercharged, high-power engine than could be obtained with conventional poppet valves. Therefore, if a sleeve-valve engine was to be developed at all, it should have been a high-power engine, in direct competition with the engines built by Wright and by Pratt & Whitney, and money should have been spent not merely at the same rate at which those two companies were spending money on the improvement of their poppet-valve engines, but enough faster to make up for lack of previous experience with the sleeve valve. The development of small sleeve-valve engines at small annual expense which was actually sponsored by the Navy at this stage could not possibly accomplish anything at all. If there was to be no full-scale development of a high-power engine, there should have been nothing more than single-cylinder research, which would not have been a noticeable financial burden even in that period of limited funds.

Certainly no one would recommend that *all* radical proposals be supported without discrimination; and the decision to award support should be based not only on the possibility of overcoming the difficulties, which is necessarily uncertain, but on the gains to be made if the difficulties are eventually overcome. Even with very small total appropriations, preliminary tests of the practicality of all proposed innovations having real promise on paper could almost certainly be financed without detracting noticeably from the development of conventional engines.

The results to be obtained from further development of established types of engines are relatively certain and relatively near in time; practical results are far away in an indefinite future when it is a question of either true basic research or the first experimentation with a radically new device — such experimentation is in fact applied research rather than true development. Thus there is naturally a strong temptation for any agency administering both research and development to divert money and men from research to development. For this reason both the Congressional Aviation Policy Board[2] and the President's Air Policy Commission[3] have recommended explicitly or by implication that funds for research be segregated in military appropriations from funds for development.

As far as the sort of applied research involved in experimentation with innovations is concerned, the quality of the man with the authority to decide which innovation shall be tried and which shall not is certainly the most important requirement for sound policy. It has been argued above that the services can probably afford to give a full and fair trial to all really promising innovations, but only if money is not wasted on the cats and dogs which absorbed so much in the United States before 1939. Once more it is apparent that the men who administer engineering for the services must be selected solely on the basis of their capacity and training and must be allowed to gain and use the widest possible experience by long tenure of office.

Who Should Develop an Innovation?

Study of the problems encountered when a new firm tries to compete in the development of a conventional aircraft engine

[2] *National Aviation Policy*, p. 45.
[3] *Survival in the Air Age*, p. 89.

led in Chapter III to the conclusion that whenever possible such a development should be placed in the hands of an established engine builder. It may seem, however, that this conclusion is no longer valid when the engine to be developed is a radical innovation, since at least a large part of the established firm's experience will no longer be applicable to the problems to be encountered. The policies on turbojet development originally adopted by the German and the British Air Ministries were diametrically opposed on this point.

Although the British government had always followed a policy of strongly discouraging the entry of new firms into the reciprocating engine business, as we have already seen, it originally followed the opposite policy on turbojet development. The evolution of this policy is told in Chapter XIII (pp. 352-358). Briefly, from 1939, when extensive financial assistance was first given to the new type of engine, until late in 1941, the British policy was to leave the development of the Whittle engine entirely in the hands of Whittle's company, Power Jets. No aircraft-engine firm was to be involved at all, and the automobile company which was to do the quantity production of the engine was to do that only, its authority over the design being limited to the making of minor mechanical changes which would facilitate production. In Germany, on the contrary, when the Air Ministry decided in 1938 to support the development of turbojets, it immediately set out, as is told in Chapter XIV (pp. 386, 393 f), to persuade the established engine builders to develop the new type of engine, and by 1939 had succeeded in getting all the major firms to begin a project of that sort. Even the two projects already being carried out by manufacturers of airframes were to be transferred to engine companies, and in order to bring this about the Ministry at first refused to give the airframe firms any financial support in their engine work; but this part of the original policy could not be completely carried out. Heinkel refused to give up its project, and although turbojet development was stopped by the Junkers airframe division, its projects were taken over by Heinkel rather than an engine builder.

The history of turbojet development under these opposed policies seems to lead inescapably to the conclusion that although a radically new type of engine is more likely to be proposed by an outsider than by an established producer of aircraft engines, the development of the new engine can be carried out expeditiously only by a firm with experience in the development and production either of aircraft engines or — in rare cases — of some product even more closely related to the new type of engine.

The strongest evidence for this conclusion is found in the history of the Heinkel turbojets, told in Chapter XIV (pp. 405-411). The Heinkel Airplane Company had built the first turbojet to fly anywhere in the world and had flown it in August 1939, when the Junkers Engine Company was just beginning the design of its turbojet, but the Junkers engine was in service by 1944, and some 5,000 were built before the end of the war, while Heinkel failed to have an engine in production or even ready for production at the end of the war. Heinkel's failure was largely due to two serious errors in general development policy. First, this firm failed to realize the extent of the development that would have to be done on any aircraft-engine design before it could be got ready for production. This failure led the firm to divide its resources among a number of projects from 1939 to 1942 instead of concentrating on a single one and making it work. Second, although by 1942 the Heinkel 006 turbojet, despite inadequate development, was showing better performance than any other German engine, the firm in that year followed the advice of the new head of turbojet development in the Ministry, a young engineer with little practical experience in development, and dropped all its existing projects to start out on a new engine with a compressor of a completely new and undeveloped type.[4] In addition to these two major errors of policy, experienced German powerplant engineers who visited the Heinkel engine establishment have stated in interviews that it was in general run more like a research laboratory than a true development organization, and that no design could have been brought by such methods to readiness for production and service.

[4]It is true that the 006 was too small for the applications foreseen in 1942, but at that late date it would certainly have been wiser to design a larger but very similar engine, which could have made maximum use not only of the experience gained on the 006 but also of the work being done by Brown-Boveri, Brueckner and Canis, and others on compressors of the axial type used in the 006.

The same mistake that was made by Heinkel in 1939 was made by the Junkers Airplane Company at the very beginning: instead of selecting a single design and concentrating on making it work by intensive development, a great number of different unorthodox engines were undertaken, with the result that no one would possibly be got ready in reasonable time even if the basic design was sound (cf. pp. 380-381). Besides this, the basic design of the turbojet, on which the major emphasis eventually came to be placed, was certainly too complex for a first engine of a new type. The combined result of the dispersion of effort, the lack of facilities, and the complexity of the design was that this turbojet was not able to run under its own power until 1942 (after it had been taken over by Heinkel), about five years after the design was laid down (p. 407). During this entire five-year period it was therefore virtually impossible to do any work whatever on the mechanical development of the engine. As an example of the opposite practice followed by an experienced engine builder, the Junkers Engine Company's 004 was run little over a year after designing was begun.

The tendency of inexperienced firms to start with too complex a design is also illustrated by the turbojet design laid down by Lockheed in the United States. This engine was even more complex than the Junkers Airplane Company's, and almost certainly could never have seen service in the war even if development had been begun as soon as the designs were ready, in 1941. When development actually was begun, in 1943, other engines were already available to take care of short-term needs, and a long-range project like this one was fully justified; but if it had been the first turbojet to be developed in the United States, as it was the first to be proposed, the difficulties encountered in the development would very probably have led to its abandonment before it had had a chance to demonstrate the basic soundness of the turbojet principle.

Unlike Heinkel and the Junkers Airplane Company, Power Jets followed development policies which were generally sound. Whittle's original design was made as simple as possible,[5] and

[5]It was not until 1938, however, that Whittle changed from a single combustion chamber to ten cans, and thus for the first time made possible independent testing of the combustion system on the compressed-air supply available to him. The Junkers Engine Company saw the need of this from the first.

he consistently refused to undertake any basic changes that were not absolutely necessary. Thus although he considered the possibility of a straight-through combustion system in 1940, he refused to divert any of his limited resources from the development of the reverse-flow type on which all previous work had been done (cf. p. 367, n. 36). But despite the fact that its general development policy was sound, Power Jets' progress was seriously delayed by lack of technical experience and by lack of the resources available to any first-rate engine builder. Thus at the same time that Whittle was making remarkable advances in some aspects of compressor design on the basis of theoretical reasoning, in other aspects he made mistakes which would almost certainly have been either avoided or quickly corrected by a firm like Rolls Royce, which had had extensive experience in supercharger development and which could quickly produce apparatus to make possible the independent testing of the compressor. The most serious of all Power Jets' handicaps was the lack of an adequate experimental shop. The original construction and all the modifications and reconstructions of the Power Jets engine were carried out by a builder of industrial turbines, a firm of a sort which was simply not set up to turn out experimental engines as rapidly as the experimental shop of a first-rate aircraft engine-builder.

As soon as arrangements had to be made for the quantity production of the Whittle engine, difficulties appeared which were even more serious than those which had been encountered theretofore. Since Power Jets had neither the staff nor the facilities to produce in quantity, the Air Ministry arranged for production by an automobile manufacturer. This firm was authorized to make minor, purely mechanical changes in Power Jets' design when it would facilitate production, and this arrangement worked poorly from the very first, with the producer believing that more extensive changes were needed while Power Jets believed that no changes were called for whatever (cf. p. 359).

The upshot of all these difficulties was that late in 1941 Power Jets was deprived of control over the development of the production version of the Whittle engine, and the process was begun of converting Power Jets into an organization whose

sole function was basic research. Another year's experience convinced the automobile manufacturer originally responsible for production of the engine that it lacked the technical skill required to complete its development, and both development and production were transferred to an established builder of aircraft engines, Rolls Royce.

The only outside firm which showed itself able to compete in development of turbojets with the experienced builders of aircraft engines was the General Electric Company. This firm was brought into the turbojet field very late, when the Army arranged in 1941 for the manufacture of the Whittle engine in the United States. General Electric's development of the I-16 starting from Whittle's designs and then of the independent I-40, recounted in Chapter XVI (pp. 462-466 and 473-475), progressed about as rapidly as any turbojet development. But General Electric had quite unusual advantages, particularly in its great experience with turbosuperchargers, which was far more extensive than that of any other firm in the world. And equally important, General Electric's turbojet development organization suffered from no lack of facilities or staff: the company was given every opportunity to set itself up as a fully equipped manufacturer of this new type of aircraft engine.

It would seem clear that experience in the development of conventional aircraft engines gives a very great advantage in the development of even a completely novel type of aircraft engine, although it is possible in special cases that experience in development of some other type of machine may be of equal value. Brilliant theoretical engineering will not replace either experience or adequate experimental facilities. Even if an inexperienced firm succeeds despite its handicaps in developing an innovation well and rapidly, there will be extremely difficult problems to solve in arranging for quantity production of the developed article. If production is done by the firm which has developed the engine but which has no experience in production, the creation of an efficient production organization is slow and expensive. In addition, this cost will ordinarily be an economic waste, since the government can support only a limited number of engine firms and the creation of a new firm will presumably make necessary the destruction of an old one which has already created a development and production organization. If, on the contrary, production is entrusted to some firm which has had experience in production but which has not been responsible for the design of the engine, conflicts over producibility of the design are very likely to arise.

The obvious conclusion is that wherever innovations originate the government should make every effort to have them developed either by an established engine builder or by a firm which, while lacking experience with aircraft engines, has had other development and production experience peculiarly appropriate to the project in hand. If no experienced firm can be interested in an innovation in its very early stages, the initial, small-scale experimentation will have to be done by an inexperienced firm, but the government should strive to arrange for the transfer of the development to an experienced firm as soon as the results of this preliminary work have shown a real probability that the development will be practical and profitable. If all appropriately qualified firms fail to recognize the promise of the new type of engine even after the government has decided that its practicality has been demonstrated and that it is time for full-scale development to begin, then probably the only sound course is to give the original developer all the assistance necessary to set himself as a fully equipped developer *and manufacturer* of engines: half-way measures are too likely to amount simply to a waste of more money than would have been wasted if nothing at all had been done. If, on the other hand, it is the originator of the innovation who refuses to accept any arrangement with an established producer, then the only possible course for the government to follow is that followed by the Germans: to give all necessary support to established manufacturers in developing competing engines of the same sort. This need not prevent the giving of a fair reward to the originator of the innovation, but the need to give such a reward must not be allowed to prevent the government from following a sound policy in respect to the industry as a whole.

Conclusions

(1) Although progressive refinement of proved types of aircraft engines usually comes from the established producers,

radical innovations in design are extremely unlikely to come from that source. The government should give a fair hearing to proposals for innovations regardless of their source.

(2) The government should be prepared to finance applied research on an innovation even before its practicality has been demonstrated if theoretical study indicates that it may be of really great value.

(3) A limited amount of applied research should suffice to show whether an unorthodox engine should be dropped or developed intensively. Small-scale development after this point can accomplish nothing and is a waste of funds.

(4) Despite the fact that a large part of its experience and facilities may not be directly applicable, an established builder of conventional aircraft engines can develop a radically new type of engine much more rapidly than any other sort of firm, with the rare exception of a firm experienced in the development of some machine peculiarly related to the new engine.

(5) If no experienced firm can be interested in an unorthodox engine while it exists only in theory, the initial applied research can be done quite effectively by an inexperienced firm, but once the point is reached where genuine development of a service engine should begin, then either the project should be transferred to an experienced firm or a competitive project set up in one.

(6) If for some reason no experienced firm will undertake to develop the innovation, then the firm doing the work should be set up as a full-scale producer of engines.