# CHAPTER V

## *The Development of Accessories*

Many parts of an aircraft engine are often bought from outside specialists rather than being made by the engine manufacturer himself. Some of these "specialties," such as valves and bearings, are ordinarily considered integral parts of the engine. Others are commonly known as "accessories," but many of these so-called accessories are absolutely essential for the functioning of the engine and are just as much a part of it as valves and bearings. Examples are superchargers, magnetos, and carburetors. The performance of the engine as actually installed in the airplane is vitally affected by still other accessories which are not even classified as engine accessories, and in the design and selection of which the engine builder, at least in the United States, usually plays no part at all. Examples are oil coolers and the radiator of a liquid-cooled engine.

The fact that essential parts of the whole engine or power plant are often developed by other firms than those developing the engine itself means that the financing and the technical direction of their development involve certain peculiar and important problems.

### The Need for Competition

Although it has often been more difficult to maintain competition in the development of accessories than in the development of complete engines, owing to the smaller gross value of the business, there can be no question that competition is the most effective single stimulus for development of improved accessories as it is for engines as a whole. A classic demonstration of this is afforded by the history of the origin of floatless, nonicing carburetors in the United States.

At the end of the First World War most if not all carburetors used on aircraft engines employed a float as an essential part of the control system. The proper operation of this float was pre-





vented by many of the maneuvers through which the airplane was put, and in addition the design of these float-type carburetors made them inherently subject to throttle icing. As is told in Chapter XVIII, Stromberg entered the aircraft field about the time of the Armistice with a carburetor of this description, and by early in the 1920's had secured a complete monopoly of aircraft carburetors simply by default of all competitors, who were uninterested in the very small production which was involved. During the entire decade of the 1920's and until 1935 Stromberg continued to adhere to its original basic design in spite of its inherent faults. It is true that great improvement was made in the float-type aircraft carburetor during this period, but throttle icing was prevented only by the use of heat, which resulted under some circumstances in a serious loss of power, and many of the modifications introduced to cure the troubles directly due to the float were palliatives rather than cures.

There was, on the other hand, no real technical obstacle at all to the development of a carburetor which would completely eliminate the float and would also prevent most throttle icing. A floatless carburetor for automobiles was developed before the end of the 1920's, although the float was scarcely objectionable in automobiles. The basic patent on the control used in the floatless, nonicing carburetor put in production by Stromberg in 1938 actually existed in the 1920's, and was simply purchased by Stromberg after it had been used in this new carburetor.

During the entire period of its monopoly, however, Stromberg made no attempt to develop a carburetor inherently suitable for aircraft. It may be that until fairly late in the 1920's there was no market which could have paid for the development and the higher manufacturing cost of a floatless carburetor, but by 1930 at the latest the introduction of dive bombing and growing concern over icing had created such a market. Still Stromberg apparently made no attempt to develop a new and better type of carburetor until 1935, when the first competition was created in aircraft carburetors by the appearance of the Chandler-Groves floatless carburetor on the market. Almost immediately after this, Stromberg's engineering staff and facilities were more than doubled at the firm's own expense, and work was begun which soon led to the development of a floatless carburetor.

Thus one of the valuable results of competition is financial: it forces the manufacturer to invest a substantial part of his receipts in development. This is by no means the only value of competition, however. An at least equally important effect is the stimulation it gives to the purely technical thinking of engineers, who are very likely to become set in the belief that a given end should be accomplished by given means, and to be willing to admit that other means are superior only after someone else has shown them to be. Although he had been considering the problem of a floatless carburetor for several years, and had even had a Navy contract to develop one about 1930, the man put in charge of Stromberg development in 1935 first tried to meet the competition of Chandler-Groves by further refinement of the old float-type carburetor. It was only after very strenuous attempts to equal the performance of the Chandler-Groves in this way had failed that he at last set out to develop the floatless, nonicing Stromberg pressure carburetor, the only carburetor used on new American high-power aircraft engines after 1945.

The effect of absence of competition in accessory development can be seen equally well in the history of American superchargers, told in the Appendix to Chapter XVII (pp.501-507). Very slow progress was made in the aerodynamic design of American centrifugal superchargers during the period that General Electric was the sole source for the entire industry. From their first appearance on production engines, in 1927, American superchargers were seriously inferior to contemporary superchargers in Britain, where superchargers were developed by the engine companies themselves and were thus involved in the general competition between engines. More rapid progress was made in the United States as soon as Wright Aeronautical undertook to design its own superchargers in 1937; this progress was not to any significant extent a result of any recent advance in basic aerodynamic knowledge, and it could just as well have begun years before. It is highly probable, moreover, that both the services and the engine builders would have been glad to pay the cost of an improved supercharger if one had been





offered to them. The reason they did not actively seek out such improvement seems to have been that the whole subject was left so completely in the hands of General Electric that neither the services nor the engine companies knew how inefficient existing superchargers were or what this was costing in terms of engine performance. Competition, if it had existed, could not have failed at least to make the users conscious of the actual performance of superchargers and of the magnitude of its effect on over-all engine performance.

Competition can accomplish little, of course, unless each competing specialist has sufficient resources for development. To a certain extent competition will tend to bring forth the necessary resources. This happened in the case of carburetors after 1935, as has been said; and if it is correct to assume that competition would in itself have made users conscious of the weaknesses of existing superchargers, then the necessary funds for supercharger development would surely have been made available. The history of the development of fuel injection systems told in Chapter XVIII (pp. 533-542) shows, however, that competition between Eclipse and Bosch in the latter half of the 1930's simply divided the Army's and Navy's experimental funds between two sources and left neither with enough. But the value of competition in the design and development of accessories and other specialties appears to be so great that whenever it can possibly be done the government should maintain at least two sources of supply with adequate resources for development, even though this may mean not only the award of experimental contracts to two firms instead of one but also the purchase of articles for service at appreciably higher prices than could be got if they were bought from a single source.

The need and utility of patent protection have been asserted much more vigorously in the United States by specialist accessory manufacturers than by engine builders, who in general regard patents as of little if any positive value (cf. above, p. 65), and believe that the real defense of their competitive position is continual progress and the resulting inability of any copier to be better than several years behind. It is argued that the case of accessories is quite different, because it is relatively easy to go directly into production on the basis of a copied accessory design, whereas an engine cannot be produced even from detailed designs without either extensive assistance from the original developer or else very considerable new development. Consequently, so the argument runs, unless the firm which develops a new type of accessory or even an improvement on an old one can patent its contribution, an outsider can easily come in and manufacture it, thereby preventing its originator from recovering the cost of development.

Certainly this much is true: the government should be willing to pay a price for any article high enough not only to cover the cost of efficient manufacture but to amortize the cost of development at a rapid rate. But the services themselves have always been fully committed to this principle, and actions in violation of it have been rare and unimportant if there have been any at all. The savings which could have been made by refusing to repay the costs of development of airframes are incomparably greater than those which could be made on accessories, and airframe designs are in general unpatentable; yet the services have insisted on purchasing airplanes from the original designer whenever it was possible to do so and on paying a price which fully covered the cost of development.

The objection to leaving complete patent rights in the hands of industry is not so much that the owners can extort exorbitant prices from the government; the government's bargaining power is usually great enough to prevent this. The real danger arises from the fact that a firm well protected by patents is not under the same pressure to improve its product as one whose only possible defense is in keeping ahead of its competitors by continual improvement of its product. If the services continue to realize as they have in the past the importance of maintaining a few strong companies in each field of supply, there would appear to be no reason to change their policy of demanding a free license under any patents developed with their assistance. Normally the price paid by the government for the physical product would be the same as if it included a specific charge for the use of the patent. If, however, a competitor developed a generally superior article, lacking only one or two patented features, the patents on these features could not be used to prevent competition.





### The Specialized Accessory Manufacturer and the Engine Builder

There is almost no integral part of an engine or accessory really vital to the functioning of an engine which has not at some time been developed and produced in his own plant by at least one major manufacturer. The existence and the utility of the independent specialty supplier cannot therefore be taken for granted. There are, in fact, a number of very strong reasons for ceasing to purchase most if not all accessories from specialists, and for having them developed by each engine company for itself.

Components or accessories which are a really vital part of the engine can be fully developed only as a part of the development of the engine as a whole, or at the very least by means of prolonged testing on the engines on which they are to be used. The initial development of a carburetor can be done by the use of an air box which simulates the flow of air to an engine, but the final development requires a great deal of running on the engine on which the carburetor is to be used. Speed-density fuel-metering systems, which have been adopted in place of carburetors on postwar Rolls Royce engines, are still more dependent on development on the engine itself. As is told in Chapter XVIII (pp. 527-528), the system used on the Griffon was developed by Rolls Royce itself; and although the system used on the Merlin was developed by a specialist, the work was entirely done at the Rolls Royce plant and in the closest collaboration with Rolls Royce engineers. It would seem not unlikely that one of the reasons why no attempt was made to develop a speed-density metering system in the United States was that on the one hand such a system could scarcely be developed by an independent supplier for technical reasons, while on the other hand none of the American engine companies, with two or three brief exceptions, either attempted to design fuel-metering systems of any type or was intimately associated in the design (as opposed to subsequent development) of these systems by the specialists.

In the case of fuel injection, development is even more intimately connected with the actual engine on which the injector is to be used. Bosch attempted from 1935 to about 1940 to develop such a system with very little work on actual engines, as is told in Chapter XVIII (pp. 533f, 540f), and it was thought by the Army that the Bosch injector was making very good progress, but when adaptation to specific engines was begun in 1940 it was quickly found that it was not simply adaptation which was lacking: the development was really just beginning. Furthermore, two accessories supplied by different specialists may be interdependent; the carburetor affects the performance of the supercharger critically in some cases, and the injection of the fuel metered by the Stromberg pressure carburetor into the impeller of a General Electric supercharger could be developed only by an engine builder, in that case Pratt & Whitney (cf. p. 523).

Theoretically the independent specialist could equip himself with test engines of the models on which his product is to be used and with the necessary test stands and equipment, but economically this has been insufficient if not completely impossible. For a long time the manufacturers of fuel-metering systems (carburetors and injectors) had no facilities at all for testing their product on actual engines. Until 1936 Stromberg could run its carburetors only in air boxes; the Chandler-Groves carburetor was put in production in 1937 before that company had even an air box adequate to test it, and neither Chandler-Groves nor the Chandler-Evans Corporation, which manufactured two carburetors widely used in the Second World War, ever had an engine test stand. Virtually all the development running of Chandler-Groves and Chandler-Evans carburetors on engines was done by the engine companies at their own expense; the air-box testing was done by the services. Even in the case of the Stromberg floatless carburetor, the engine companies did incomparably more running than Stromberg could afford to do. Compared with the single engine stand which Stromberg had for all the engine models on which the carburetor was to be used, Wright in 1937 had one and sometimes two engines running 24 hours a day on this carburetor in addition to one or two on the Chandler-Groves; later on, when the engine business had expanded because of the war, Pratt & Whitney at one time had three engines of a single





model running 24 hours a day on the development of the Stromberg carburetor alone. Finally, in the case of most accessories, testing in actual flight is an absolutely essential part of development, and for this the specialist has always been completely dependent on the engine builder except to the small extent to which the services have done flight testing as a part of the development rather than of the evaluation of accessories.

The engine companies were willing to give assistance in accessory development and usually even to pay the specialist a part or all of the cost of his own work (usually in the form of very high prices for the first few experimental articles) because of the great effect an improvement in the specialty would have on the over-all performance of the engine. The specialist could not even theoretically have afforded to do the work at his own expense, since a price for the accessory high enough to amortize the cost could never have been maintained by an outside supplier, even though the cost of the work could be fairly easily charged off by the engine builder.

The necessity of extensive collaboration in the development of accessories obliged the engine builders to form continually growing staffs of engineers specifically assigned to development of each accessory, and it was proposed from time to time to use these staffs to do the original design and basic development of improved accessories, rather than restrict them to collaboration with an outsider. Despite the fact that the outside specialists have usually been given direct access to all the engine company's test facilities and test results, development by the engine company itself would probably help in obtaining a quicker and more reasonable settlement of the sort of controversy which has occasionally arisen from divided responsibility. In one case, for example, a carburetor specialist blamed the induction system of the engine for difficulties which the engine builder blamed on the carburetor; in another the specialist supplying the supercharger blamed poor performance on the inlet and collector designed by the engine company while the engine company blamed it on the supercharger. In the latter case the controversy mentioned was in fact the immediate cause of the engine company's decision to undertake its own supercharger development.

Development of accessories by the engine builder himself is almost the only possible way of developing types of accessories too closely associated with the engine to be sold as "packages" at all: an example is a fuel-injection system developed by Pratt & Whitney in the early 1930's, which consisted of a large number of separate elements each separately built into the engine. Finally, the design and development of accessories within the engine companies might help to promote the making of more careful studies of engine requirements to use as the basis of the design of the accessory; the lack of such studies was particularly harmful to the development of fuel injection systems.

Reasons like these have in fact led in a few cases to the elimination of the independent specialist, examples being Wright's decision in 1937 to design its own superchargers and Rolls Royce's production of its own fuel-metering system for the Griffon; on numerous occasions they have led engine builders to the verge of such action. There are, however, a number of very strong reasons for the maintenance of the independent specialist, both from the ultimate customer's point of view and from that of the engine company itself.

Accessories bought from specialists have probably cost less in most cases than if the engine companies had developed and produced them. Usually each basic model of an accessory has been used with only minor modifications on the engines of two or more manufacturers, who have thus shared both development and tooling costs which each would have had to assume in full if he had produced his own accessories. Even when a particular model of an accessory has been used by only a single engine manufacturer, the specialist's production know-how has often produced worth-while savings. For this reason even the superchargers designed by Wright's own engineers were produced by the General Electric Company.

In the very early days of their history the engine builders probably could not have afforded to develop and produce their own accessories, if they had wanted to. Even after they had acquired greater resources, the economy effected by buying from a specialist was still of interest. Although the engine builders have had to build up groups of specialists to aid in the development of each accessory, these staffs are of neither the





size nor the quality which would be necessary if they were to be solely responsible for the design and development of the accessory in question. The staff of the specialist serves as a sort of task force on which the engine builder can call when a problem arises without being obliged to keep this staff permanently on his payroll. In most cases it has not been so much the number of engineers on the staff of the specialist which has been important as the quality of the engineer at the head of that staff. The specialists' chief engineers have usually been men of very broad experience outside as well as within the field of aircraft applications of their specialty, and probably no aircraft-engine company could have hired or retained such men in the necessarily very subordinate position of directing the development of a single one of the many parts and accessories of the engine.

Even assuming that the engine builder could hire engineers as capable as the specialist of taking full charge of accessory development, American firms have always preferred to rely on outsiders wherever they could. They have felt in general that the larger their organizations became, the more complex they were to administer, and the more time was used in administration. They have been influenced to an even greater degree by the belief that purchase of an accessory from an outsider lessened the burden on their top engineering personnel. However good their subordinate engineering staffs may have been, the top personnel have always been directly involved in the final decision of all questions concerning the design and development of everything designed by the engine company itself, and there have always been more problems of this sort than the top personnel could study fully.

From the customer's point of view, there are several serious objections (in addition to cost, which is less important than results) to the development of accessories by the engine builder himself. The fact that independent specialists produce for more than one engine firm has probably had a beneficial effect because the independent could serve as a clearing house where the experience (and to a considerable extent the ideas and suggestions) of several engine builders could be compared and combined.

Slow as the specialists have often been in introducing innovations such as floatless carburetors, as contrasted with progressive improvement of existing basic designs, they have been under a stronger compulsion, provided that competition was present, to consider the desirability of innovations in their specialty than the engine builder would have been. The engine builder's primary task has always been to improve one or two particular engines as rapidly as possible, and to improve them as whole engines. For this reason the engine builder would always be tempted if not forced to divert his specialists from the development of a radically new accessory in order to get the existing model to function properly on some particular engine. The engine builder has not ordinarily suffered severely because he fell behind his competitors in the design of any one accessory, as is illustrated by the success of Pratt & Whitney engines in the late 1930's and early 1940's despite their continued use of superchargers much inferior to those on Wright engines (cf. pp. 504-506). The independent, on the contrary, although he has certainly been obliged to pay attention to his customer's immediate needs, has also been obliged — if competition existed — to undertake long-range fundamental improvements or lose his customers in the end. Wright's adoption of the Chandler-Groves carburetor apparently had little effect on Pratt & Whitney, but it forced Stromberg immediately to devote greatly expanded engineering facilities and staff to the development of a still better carburetor (cf. p. 522).

It seems almost certain that the development of his own accessories by each engine builder would tend to delay not only the making of improvements in design but also the general introduction of such improvements after they had been introduced on one particular make of engine. This is not primarily because the use by competitors of a specific design would be prevented by patents: the engine companies have not in general tried to maintain their positions by exclusive use of patented features of design, and the government in any case has sufficient control over the situation to force the granting of licenses if this should become necessary. But progress made in the design of an accessory by one engine builder might very possibly remain unknown to other engine builders for a considerable period of time. Thus it was several years at the end of the 1930's before Pratt & Whitney was even aware that the superchargers it was using were very considerably inferior to those which Wright was designing for itself. When one engine builder did try to adopt an improved accessory developed by another, serious difficulty would arise because he would lack the background of development needed as a guide in the modification of the accessory to suit his particular engines, and under normal circumstances assistance would scarcely be furnished by a competitor.





Perhaps most serious of all, an engine builder actively engaged in developing an accessory himself would be very unlikely to give full consideration to an alternative construction proposed by anyone else, even if it was made fully available. A striking example is Wright's delay in making use of the silver-lead bearing developed by Pratt & Whitney and offered free to Wright during the Second World War, although this bearing was quite clearly superior to anything else in existence. The reason is that any group of engineers tends, as has already been mentioned, to become convinced that a design which it has brought forth is basically the soundest design possible, and to concentrate on its development without giving really impartial consideration to the merits of a design produced elsewhere. It is obvious that the best of several competing designs or devices is far more likely to be chosen if the judge is not himself a competitor, as he must be when an engine builder develops his own accessories.

Finally, besides running the risk of harming the development of the accessories themselves for the reasons just given, absorption of accessory development by the engine industry would hinder if it did not prevent the appearance of new competition in the engine industry itself. The creation of Pratt & Whitney in 1925 and its effect on the development of air-cooled engines in the United States, or the creation of Power Jets in 1936 and its effect on the development of turbines in England, is more than enough proof of the necessity of making the entrance of new companies into the engine industry as easy as possible. Chapter III has already pointed out that the creation of a new source of aircraft engines is necessarily extremely difficult, and if a new firm had to design and develop all its own accessories this would be far more difficult still.

On balance, the existence of independent specialists has in general been of great value, at least when there has been competition among the specialists. The existence of such specialists should be maintained in the future unless there are imperative reasons for the contrary course in an individual case. But their work must always be critically judged by the engine manufacturer, who must have a staff adequate to perform this function, and who must avoid the unquestioning acceptance which he has sometimes accorded to the work of the specialist in the past.

### The Armed Services and the Development of Accessories

Broadly speaking, there are two possible policies which the services might follow in regard to the design and development of those accessories which are essential parts of the engine. The one which has almost always been followed in the past is to intervene in the process, setting up specifications for the performance and on occasion for design of the accessory itself, running tests, approving or disapproving the use of a given accessory by the engine manufacturer, and paying the specialist supplier directly for development of a new type or model of his accessory. The other possible policy would be to leave the choice of accessories and responsibility for securing the needed development to the engine builder, whether he procures the accessory from a specialist or develops it himself.

In many cases the government's direct intervention in the development of an accessory has been financial only. Very frequently trouble has been experienced with an accessory in service, the engine manufacturer and the accessory specialist have been consulted, and there has been general agreement either on the specific remedy to be tried or on the proposition that the solution should be left to the specialist. When the difficulty has been of the nature of a defect from which the engine was guaranteed to be free, it has been up to the engine manufacturer to see to it that a remedy was found, and to pay the specialist for his work if necessary. If on the contrary the





difficulty was one which was to be expected, arising for example from the use of an existing model of carburetor on a new type of engine, or from putting the engine to a new use, or simply from a desire to raise existing standards of performance, then it was often the government which contracted with the specialist for the necessary development.

Direct dealing between the military services and specialists has also arisen because the services have had the only facilities available for carrying out certain tests, the cost of the facilities being too great for either the specialist or the engine builder. A classic case of the 1930's was the refrigerated air box, which is the only means except actual flight for testing the altitude performance of carburetors, and which permits the making of certain sorts of observations which it is impractical to make in flight. As is told in Chapter XVIII (p. 521), tests of the Chandler-Groves carburetor in the Army's refrigerated air box led to the discovery that fuel boiled in the carburetor owing to lack of venting, and it was only logical that the Army proceeded to contract directly with the specialist to eliminate this difficulty in an improved model.

In most if not all such cases the award of a government contract directly to the specialist met with approval all around. The engine builder was glad to have the government assume the burden of paying the specialist for his part of the work, and went ahead to make his own, usually much more costly, contribution by testing the improved device on his engines and supplying the specialist with the resulting data. In many such cases direct dealing between the government and the specialist was definitely preferable to working entirely through an engine company: since the results of the work were equally applicable to a number of engines, it would have been undesirable to favor one engine builder by having the work done through him rather than through another, and wasteful to pay all the engine builders for getting the same job done.

The difficulties which have arisen because of direct dealing between the services and the specialists have almost always been due to technical rather than financial disagreement. The most common occasion of technical disagreement has been the development of an entirely new device, rather than of the modification of one already in use by one or more engine manufacturers. When no device of the type desired has yet been brought to the point where it is ready to be installed on an engine even experimentally, or when only paper schemes exist and there is no physical article in existence at all, then unless some engine builder voluntarily takes responsibility for the development, it is virtually inevitable that the services will have not only to support the initial development financially but also to take responsibility for important technical decisions. Chapter XVIII (pp. 530-533) relates, for example, how the development of the Marvel fuel injector was taken up by the Army in 1927, when there was no multicylinder injector in existence which an engine builder could even be asked to test; the Army had to decide on its own whether the project was technically worth while or not. The same thing was true of the new design for a fuel injector proposed by Eclipse to the Navy in 1930 and of that which the Army gave to Bosch to develop in 1935 (cf. pp. 533-535).

There has been much criticism of the Army's direct intervention in the design of new accessories, and there can be no question that the Army has on occasion obliged a specialist to use a design feature which has subsequently been shown to be unsound: a good example is the electric control for fuel injection which the Army instructed Bosch to develop in 1935 and which, after six years of development, had to be abandoned in favor of a hydraulic control proposed by Bosch (cf. p. 540 f). The alternative usually proposed for the setting of design specifications by the government is that the government should set a specification that deals with performance alone, allowing complete freedom in design to its contractors. In the case of a completely new device, however, it is usually impossible to set reasonable performance specifications before the device has been built, tested, and at least partially developed. In any case, the award of government funds to all contractors willing to attempt to meet a performance specification is impossible unless government funds are limitless.

It has been said that the Navy intervened less than the Army in development generally and in the design of fuel injectors in particular, but the Navy's decision to support the development





of an injector with a speed-density control as proposed by Eclipse (cf. p. 535), and not to support any other fuel injector, was in effect as much an intervention in design as the Army's decision to have an injector with electric mass-flow control developed by Bosch (pp. 533-534). While Army or Navy engineers may be well advised in a particular case to yield to a more experienced engineer in industry, still it is the Army or Navy engineers who are ultimately responsible for the results obtained, and it would be as easy and as unjustified to criticize their record for the waste of funds on impractical schemes proposed by outsiders as for insufficient support of sound schemes so proposed. The S.P.E. carburetor (cf. pp. 516-517) is a case of complete failure of a private design; and although the Chandler-Groves carburetor, the design of which was disapproved by the Army, gave useful service, still the design was soon agreed to be basically unsound and the carburetor ultimately went out of use (cf. pp. 517-521, 524-525). If it is argued that the S.P.E. carburetor proves nothing because contracts should not be given to firms with inadequate background and experience, it can be answered, first, that there was no choice, since the only experienced source was unwilling to undertake the job at that time, and second, that although the Chandler-Groves carburetor, which was designed by a very experienced engineer, was not simply foolish like S.P.E., still it was basically unsound and inferior in several respects to the old standard float-type carburetor.

Certainly, however, no government specialist who had himself designed any device should have been given the nearly impossible task of judging fairly between it and a competing device from another source. The electric control for fuel injection which Bosch developed for the Army from 1935 to 1941 had been originally devised by the engineer in charge of fuel injection at Wright Field. It was this same man who refused to support the Eclipse injector because it had a speed-density control, despite the fact that the electric control was completely unproved whereas extensive flight testing of the Eclipse injector was convincing an airline that it should be put in production (cf. p. 537).

Perhaps the greatest benefits which the existence of a separate Army and Navy conferred on technical development arose from the fact that if one service became absolutely committed to a certain line of development, the other service almost always chose to support another. The Navy's support of Eclipse prevented the complete failure of the fuel-injection program which would have resulted from the Army's exclusive support of Bosch; the Army's insistence that the design of the Holley carburetor was unsatisfactory was an important factor in producing the much superior Chandler-Evans (cf. p. 524 f), in which the Navy showed little interest. Unfortunately the advantages thus gained from separate services were frequently diminished by the unwillingness of one service to accept results obtained by the other even after there had been ample time for the facts to be demonstrated. There is probably no cause for criticism in the fact that in 1942 the Navy concluded that further development of fuel injection was not worth while at the same time that the Army was putting all its resources behind it, but it seems extraordinary that in 1949, after five years of production and extensive service experience with fuel injection, the Navy still refuses to use it for any engine or any type of service while the Army is anxious to have it on every engine in every type of service. This unfortunate unwillingness of one engineer or group of engineers to accept a design or device proposed or developed by another, or to give up a design or device proved unsound by another, is, of course, found probably fully as often in the rivalry between private firms as in that between the services (cf. p. 111).

Even when they avoid intervention in the design of an accessory the services will necessarily control its development to a very considerable extent by the performance specifications which they set. Few if any objections seem to have been raised in principle to the setting of such specifications by the services, although it might be argued that the decision whether an accessory was adequate could be left to the engine manufacturer in the same way that the decision whether a valve is adequate is left to him. Particular specifications have been frequently criticized, however, on the grounds that they have been excessively demanding. There seems to be general agreement, for example, that the specifications for fuel-injector performance set by the Army in the latter half of the 1930's were so difficult





to meet at that time that they seriously discouraged development, whereas there can be no question that the primary object of any specification should be to obtain the best article obtainable rather than to define an ideal. The Army's carburetor specifications of this same period are said to have been written around the old Stromberg float-type carburetor in such a way as to exclude new designs with points of superiority which ought to have outweighed the points of inferiority which in fact have made them unable to meet the specification. On the whole, competition was more effective than any specification in securing the best possible performance, and the Navy's acceptance of the Chandler-Groves carburetor, which the Army refused to use, was more than justified because it introduced competition into carburetor development, even if the first Chandler-Groves carburetor was as unsatisfactory as the Army claimed.

The extreme slowness of the development of fuel injection in the United States was probably due, however, not so much to the technical intervention of the Army in questions of design or to unduly high performance specifications as to the fact that almost the entire development had to be done by specialists alone, controlled only by the Army's and the Navy's own tests and evaluations. The Army failed in its attempts in the first half of the 1930's to persuade the engine manufacturers of the advantages of fuel injection, and although the Army and the Navy bought a fair number of injector-equipped engines in the 1930's, the engine manufacturers usually did nothing more than equip their engines with the injection systems as they then were. As soon as the two major engine companies really set to work on fuel injection in 1940-1941, progress became much more rapid (cf. pp. 539 ff). Whether these firms were right or wrong in believing as they did in the latter half of the 1930's that fuel injection was on the whole inferior to carburetion, the same conclusion emerges: the active collaboration of the engine builders is essential to the development of accessories.

A problem arises, therefore, when the services feel that there is a real need for a certain accessory or type of accessory while the engine builders are convinced that it is unnecessary or even harmful, as was the case with fuel injection during the period

1935-1940. But despite the temptation in such a case for the service to try to carry out the development by working with the specialist alone, the chances of success are probably too poor to be worth the effort: if the development of an accessory cannot be carried out with the cooperation of the builders of the engines on which it is to be used, it is very unlikely that it can be carried out in spite of them. Fortunately this problem is not likely to be serious under most circumstances. Although they have naturally been unwilling to risk much of their own money on projects in which they did not believe, the engine companies have on the whole been willing to make a sincere effort to assist in any accessory development strongly desired by the services, when the latter have been willing to pay the cost. Although Pratt & Whitney continued to believe that fuel injection was inferior to carburetion, it accepted an Army contract to work on injection when one was offered in 1941, and the one American fuel injector eventually put in production and service had a control system first suggested and tried out by Pratt & Whitney (cf. p. 542).

The fact that accessory development can scarcely be carried out successfully without the whole-hearted participation of the engine builder has led to proposals that the whole responsibility, financial as well as technical, be placed upon the engine builder. The services would cease to contract directly with specialists; the engine builder would employ specialists at his own discretion and simply as a part of the process of developing his engines. On the other side it is argued that if the services cease to give direct contracts to specialists for the development of new types of accessories, and leave the responsibility for accessory development entirely in the hands of the engine builders, the latter may undertake to develop their own accessories where they do not do so already, and that once the engine builders have developed an accessory of their own they will not give fair consideration to a competing device offered by a specialist. As has been shown, however, the engine builders have by no means been anxious to assume the burden of developing their own accessories when they could buy satisfactory ones outside, and the danger in question is not one which seems likely to arise frequently if at all.





Transfer of complete responsibility for accessory development to the engine manufacturer would, on the other hand, result in very great simplification of procedure and the elimination of the possibility of technical disputes such as those dwelt on immediately above. These advantages seem very probably to outweigh the slight danger that the engine builders will try to concentrate all accessory development in their own hands.

### Power-Plant Accessories Which Are Not a Part of the Engine

Certain accessories which are not a part of the engine itself have nevertheless a vital effect on its performance and utility as installed and used in the airplane. Examples of such independent accessories are turbosuperchargers, starters, and the cooling system of a liquid-cooled engine. It has already been shown that the largest part of the financial burden of the development of engine accessories fell on the engine builders, only a relatively small part being borne by the specialist supplier himself or by direct government support of the specialist, and that successful technical conduct of the development was also essentially dependent on the contributions of the engine builder. Since American engine builders have rarely if ever played any significant part, either financially or technically, in the development of the independent power-plant accessories, that development has presented problems even more difficult to solve than those encountered in the development of engine accessories proper.

The airplane manufacturer, of course, would seem to have a still larger stake in the performance of the airplane as a whole than the engine manufacturer, and hence it would seem that he might make himself responsible for the development of those accessories for which the engine builder has no responsibility. In fact, however, he has not done so: the airplane manufacturer has almost always simply bought accessories such as radiators as they were offered to him or specified by the government. No investigation has been made during this study into the reasons why the airplane firms have behaved in this way; it is worth pointing out, however, that this behavior has been the same in Britain as in the United States.

Since neither the engine nor the airframe manufacturer has taken responsibility for development of independent power-plant accessories, the natural result has been that their development has always been directly controlled and financed by the government. The turbosupercharger is an extremely valuable contribution which is due financially to the Army's experimental funds alone, and technically to close collaboration between the Army and General Electric. No engine builder showed any enthusiasm for the turbo until the 1940's, let alone assisting financially in its development, and no other example shows so clearly that the military services have on occasion been fully justified in insisting on a particular technical line although the engine builders were uninterested if not hostile.

Electric starters were used on aircraft for a long time before they were accepted by the Navy, the reason being that the Navy did not feel that their utility justified their weight. There was ample reason *a priori* to believe that this weight was greater than necessary, since no one had ever determined exactly what power was needed for starting any particular engine, and as a result the starter had a large although unknown margin of power available; this margin not only added weight to the starter, but required an unnecessarily large and heavy battery. The only prewar supplier of electric starters, Eclipse, had no facilities for making the necessary tests on engines, and nothing was done until the Navy's Aircraft Engine Laboratory itself took the problem in hand about 1943. Tests of engines in the Navy's refrigerated test room resulted in a set of requirements which enabled the manufacturers to design a starter which was both much lighter and much better suited to the characteristics of the battery.

British engine manufacturers, unlike their American counterparts, have often taken a hand in the development of power-plant accessories even though they were not strictly parts of the engine itself. The most striking example is Rolls Royce's development of the cooling system, which is described in Chapter VIII (pp. 231-242).[1] Although the entire decade of the

[1]British engine builders began to develop their own turbos in the mid 1920's, but the work was dropped before the effectiveness of this approach could be determined.





1920's had produced very little improvement in cooling systems for liquid-cooled engines, progress in such respects as the elimination of loss of coolant due to local boiling was made rapidly once Rolls Royce set to work in 1929. In the middle 1930's development by Rolls Royce, partly based on research by the Royal Aircraft Establishment (the British NACA), led to a genuine revolution in the science of minimizing radiator drag by use of proper dimensions and proper cowling and ducting. In the United States very similar work with similar results was done at the same time, but it was done by Army engineers at Wright Field. At the end of the 1930's the intervention of Rolls Royce in the mechanical design of the radiator itself led to marked reductions in its weight; similar reductions were not made at that time in the United States, where the mechanical design of the radiator was left in the hands of the specialists.

Study of the development of engine accessories proper showed that the services have not been able in general to direct the development of an accessory as efficiently as an engine builder, and the conclusion was reached that responsibility for such development might well be transferred to the engine builders. There remains, however, the class of independent power-plant accessories for the development of which the American services must remain responsible unless the American procurement system is changed in such a way as to oblige the engine builders to assume responsibility.

### Conclusions

(1) Engine accessories can scarcely be successfully developed without the active participation of the engine builders.

(2) Nevertheless, the system of purchasing accessories from independent specialists rather than having them developed by the engine builder himself is to the government's advantage in general.

(3) Development is likely to lag, however, unless there is competition between at least two suppliers of any particular accessory.

(4) In any case, but especially in the absence of competition, the engine builders and the government should examine the

work of the specialist more closely than they have sometimes done in the past to make sure that progress is being made as rapidly as possible, and the engine builder should be less hesitant than he has sometimes been to take over the development of an accessory when this becomes necessary.

(5) Direct intervention by the services in the development of accessories has had harmful effects which can probably be eliminated in many cases by making the engine builder responsible for his accessories in the same way that he is responsible for the integral components of his engine, although the services would still have on occasion to stimulate the development of particular accessories by special contracts with the engine builder for that purpose.

(6) The services will have to remain directly responsible both financially and technically for the development of power-plant accessories which are not actually parts of the engine, although a revised procurement system which would cause the engine builder to take a greater interest in such accessories would be desirable.