CHAPTER IX

The Special Economic Status of Liquid-Cooled Engines in the United States in the 1930's

THE economics of the development of liquid-cooled engines differ radically from those of the development of air-cooled engines in the United States in the 1930's. The characteristic pattern of air-cooled development in this decade was one of largely private initiative supported mainly by private funds earned by the sale of a successful product. The characteristic pattern of liquid-cooled development, on the contrary, is one of almost complete support by government development contract, and the total private risk on liquid-cooled engines during the decade was of the order of a tenth of the amount invested in air-cooled engines. The development of liquid-cooled engines in the 1930's is thus in a certain sense a counterpart of the development of high-power air-cooled engines in the first half of the 1920's, when virtually nothing was done without government payment in full for every step. The results of this government-sponsored development of liquid-cooled engines, however, were far less satisfactory than the results of the earlier government-sponsored development of air-cooled engines in the United States, or than the contemporary government-sponsored development of liquid-cooled engines in Great Britain.

In reality, there was a world of difference between the problems involved in stimulating the development of high-power air-cooled engines in the early 1920's and those involved in stimulating development of liquid-cooled engines in the 1930's. As has already been shown in Chapter VII, the industry in 1919 was without a single high-power engine of American design which could stand comparison with any of a number of engines in production or under development abroad, while economically the period from 1919 to 1926 was marked by the absence of a market for newly developed engines which

was either large enough on the average or regular enough from one year to another to create a sound and prosperous industry. By 1926 the industry was incomparably better established, both technically and economically.

Technically, by 1927 American engines of both the water-cooled and air-cooled types had been evolved which were fully competitive with the best that Europe could offer. Success had been achieved first with the water-cooled type, as was to be expected. A first-rate engine, the 1,150-cu in., 400-hp D-12, had appeared already in 1922, and was a highly developed engine by 1927;[1] a larger and more powerful engine, but very similar in general principles of design, the 1,550-cu. in., 575-hp Conqueror, had just been put in production in 1926. Both these engines were made by the Curtiss Aeroplane and Motor Company. Besides the two Curtiss engines there were the 1,500- and 2,500-cu in. 12-cylinder engines designed and built by the Packard Motor Car Co. Although they were by no means the equal of the Curtiss engines in general excellence, and showed some very serious faults in operation, still these two engines were very light for their power, and both the Army and Navy had had great hopes in their ultimate success. The years 1926-1927 also marked the appearance of the first successful American high-power engines of the newer, air-cooled type, the story of which has been told in detail in Chapter VII. The 400-hp Wasp was put in production by Pratt & Whitney in 1926, and the 525-hp Hornet and Cyclone were put in production by Pratt & Whitney and by Wright in 1927; all three of these engines had met with immediate sales in profitable quantities.

Economically, the situation from 1926 on was as different from what it had been only a few years before as it was technically. First of all, there was a very rapid expansion in the actual and anticipated market for new high-power aircraft

[1]This engine took the world's speed record in 1922 at 224 mph and raised it in 1923 to 267 mph. As late as 1927 the world's record had been raised to only 278 mph. The 1923 Schneider Trophy race was won by a D-12, and the 1925 race was won by a somewhat enlarged version of the same engine, the V-1400. As has been told in Chapter VIII, some D-12's bought by the British airplane builder, C. R. Fairey, and installed in his Fox two-seat bomber (1925), showed such excellent performance that the British Air Ministry awarded a contract to Rolls Royce for development of an engine designed along the same general lines.

engines which can almost be dated exactly to the year 1926-1927. The first factor in this expansion was a considerable growth in the actual use of high-power engines. In 1926, after seven years of poverty and uncertainty in government procurement of aircraft, legislation was at last passed which created for both military services a definite and greatly enlarged program of quantity procurement of new aircraft. Army and Navy aircraft appropriations in fiscal 1929 were double what they had been in fiscal 1925. In civilian transport operations a limited expansion had taken place with Ford and Fokker tri-motor airplanes in 1925-1926; in 1927 Boeing began extremely profitable airmail operations which were widely interpreted as an indication of a great expansion of civilian transport activities in the near future. By the end of the decade a great many (though by no means all) responsible persons in the aircraft industry were convinced that the day was at hand when transport activities would create a market actually exceeding that of the military services.[2]

Second, it was at about this time that it at last became clearly more economical to use modern high-power engines than to use the much cheaper war-surplus Liberties.[3] For commercial use the first successful high-power air-cooled engines showed an even more important economic advantage: their lower weight for equal power permitted an increase in payload which was very largely responsible for the fact that now the cost of carrying airmail was cut in half when the Wasp-powered Boeing 40 appeared in 1927.

Finally, Lindbergh's flight in 1927 undoubtedly was a great stimulus to the industry generally by making it much easier to obtain capital from ordinary investors.

In 1925-1926 a high-power engine, the Wasp, had for the first time been developed and put on the market at private

[2]Many responsible people even believed at the end of the 1920's that private flying would soon create a market comparable in importance with military and transport, but this does not concern us here, since the engines sold in the private market were not of the high-power class with which we are solely concerned.

[3]Even before 1926 one of the chief arguments used by the Navy in requesting money from Congress for new aircraft engines had been that it was actually cheaper to buy a modern engine with a life of 300 hours before overhaul than to recondition a Liberty and then give it a major overhaul at the end of each of three 75-hour periods in order to obtain the same total service.

risk. The cost of the development had been completely amortized and a profit made out of sales within about a year after the engine was put on the market, and from this time on the profit motive definitely replaced direct government payments as the primary incentive for the development of new high-power engines. The development expenses of the major engine manufacturers increased more than fivefold in the next ten years, while only a very small part of these expenses had to be paid directly by the services. The services did, to be sure, continue to enter into development contracts with manufacturers of engines, but in the case of the two large and successful builders of high-power engines of the 1930's, Wright (which merged with Curtiss in 1929) and Pratt & Whitney, these contracts ordinarily paid very little of the costs of the actual development, amounting in most cases to roughly no more than the direct cost of the handmade engines delivered to the services for test. The contracts served, not to pay the costs of development, but to provide an incentive for it by giving a token of the real interest of the services in the new engines, and hence of the probability of quantity sales of such engines in the future.[4]

This decline in the importance of government subsidy in the financing of engine development was, of course, only relative. There was no absolute decline—rather an increase, except for two or three years in the worst of the depression — in the amounts paid out under development contracts, but in the case of most air-cooled engines these sums soon became only a small fraction of the total amounts being expended on engine development. Virtually all the new private financing of engine development, however, was devoted to the air-cooled engine, whereas liquid-cooled development continued throughout most of the 1930's, just as in the 1920's, to be done only in return for direct payment by the government.

[4]This was usually true of development aimed at general improvement of an engine, production of a more powerful engine type, and similar projects of general utility. Projects of less general interest, such as production of a special high-speed version of an engine or development of a type of supercharging desired by only one service, were sometimes paid for to a very large extent by the service desiring the development. Each case depended on the belief of the manufacturer in the marketability of the product and on the state of the development funds of the service.

The Technical Merits of the Two Types of Engine Compared

The industry's concentration on air-cooled engines rested, of course, on a generally accepted conviction that sales of air-cooled engines would far exceed those of the liquid-cooled type, and this conviction rested in turn on an engineering evaluation of the actual and probable merits of the two types of engines in each of the various uses to which they might be put, together with an estimate of the probable sales of engines for each of those uses. Thus in order to understand the background of liquid-cooled development in the 1930's, it is necessary to follow this evaluation of the merits and marketability of the two types of engine in some detail.

It is unfortunately impossible to resolve the first or technical part of the problem simply by pointing to the comparative performance of airplanes equipped with the two types of engine. If a given airplane is equipped alternately with the two types, it can usually be argued that its inferior performance with one or the other is due to the fact that the given airplane design is less well suited to that type of engine. If two different airplanes are compared, it can be argued that the inferior performance is due simply to inferior airplane design. In any case, it is only very rarely if at all that there are available for comparison engines of both types, of comparable output, which can fairly be said to represent equally well the best that could be expected of their respective types. This was especially true in the United States after about 1932, when everyone was agreed that the liquid-cooled type was by no means so highly developed as the air-cooled. Finally, even if agreement could have been reached that one type or the other was definitely superior in existing power categories and installations, it was always necessarily a matter for theoretical argument which type would be superior for much greater outputs and entirely different installations.

Thus the policies both of the companies and of the armed services had necessarily to be based largely on purely technical arguments concerning what might be rather than what had been achieved. These arguments are set forth in some detail

in Technical Appendix A (pp. 665-692); here we shall simply summarize those conclusions which would probably have been accepted, although with more or less qualification, by a reasonable majority of those competent to judge, and try to indicate the extent of the differences of opinion on questions where there was no agreement.

Of all the figures measuring the performance of an aircraft engine, one of the most important is its "specific weight," or the ratio of its weight to its power output. With the weight of the engine must of course be included the radiator, piping, and coolant if the engine requires them. From the first appearance of a successful American high-power air-cooled engine in 1926, the chief advantage of this type over its liquid-cooled competitor was a decisively lower specific weight. In 1930 this advantage was so great as to be all-decisive so far as a comparison between American engines actually in production was concerned.

As for what might be achieved by further development, however, the situation was far less clear. The first complicating factor was that of the altitude at which the power was measured. Probably the greatest weakness of the air-cooled engine at this time was its inability to use a high degree of supercharging. Although American air-cooled engines actually had more "built-in" supercharging by a gear-driven supercharger than the production version of the one first-line American liquid-cooled engine, the Conqueror, still there was more than enough evidence to prove that at this time the liquid-cooled engine could handle more supercharging as soon as superchargers were available to deliver it. This was partly because the air-cooled engines were deficient in cooling at altitude — in the first half of the 1930's they barely got by near sea level — and partly because the mixture of fuel and air could be compressed to a much higher temperature and pressure without causing detonation in a liquid-cooled engine than in an air-cooled engine.

This meant that although the ratio of weight to power at low altitude was far lower for air-cooled engines in the first half of the 1930's, the difference became very much smaller above 11,000 or 12,000 feet. In the United States the comparison was at this time more potential than actual, since the only superchargers capable of maintaining full engine power to these altitudes were turbosuperchargers, which were only experimental and had so many difficulties of their own that they were far from ready for general service. The validity of the argument, however, was fully demonstrated by the known performance of a British fighter, the Hawker Fury, with the liquid-cooled Rolls Royce Kestrel engine. Above 10,000 feet, this airplane outclimbed the lighter American P-12 and P-26 fighters powered by the Wasp by a very considerable margin.[5] It was not until about 1935 that even the American makers of air-cooled engines claimed to be able to equal the performance of liquid-cooled engines at high altitude.

The demonstrated merits of the liquid-cooled engine at high altitude were outweighed in the United States about 1930 by its much greater specific weight at sea level, but about this time there began to be evidence indicating that the specific weight of the liquid-cooled engine at low altitude might be very much reduced, at least enough so that its inferiority in this respect would no longer outweigh all other possible advantages. The first piece of evidence was the demonstrated performance of the 1931 Rolls Royce R engine. This engine, weighing only 1,630 lb, had won the Schneider Trophy at an output of 2,300 hp, had set the world's speed record at an output of 2,530 hp, and had run for one hour on the bench at an output of 2,783 hp. The second was the development of high-temperature cooling with ethylene glycol instead of water as the coolant, which

[5]At the beginning of the 1930's the production Fury I with the Kestrel I S engine was capable of 214 mph at 13,000 feet and 207 mph at 20,000 feet, and could climb to 20,000 feet in 9.67 min. The contemporary P-12B with the Wasp C had a maximum speed of 171 mph at about 7,000 or 8,000 feet, and took 10 min. to climb to 16,500 feet. The production Fury II of 1933 with the Kestrel VI had a top speed of 220 mph maintained to 19,500 feet, and could climb to 20,000 feet in 8.64 min. The contemporary P-26A with the Wasp H was slightly faster, with a maximum speed of 235 mph, but required 11½ or 12 min. to climb to 20,000 feet, despite the fact that the all-up weight of the P-26A was only 3,039 lb while that of the Fury II was 3,609. Only about half of this 570-lb difference in weight was due to the cooling system of the Kestrel. (Publications give 4.6 min. for the climb to 10,000 feet and 29,200 feet for the absolute ceiling of the P-26A. The time to 20,000 feet has been computed from these data and the 7,500-foot rated altitude of the engine.)

The Wasp C (production in 1929) had a normal rating of 450 hp at 6,000 feet, which would mean 370 hp at 11,500 feet, where the Kestrel I S (production in 1930) had a normal rating of 480 hp. The Wasp H (production in 1932) had a normal rating of 570 hp. at 7,500 feet, which would mean 500 hp at 11,000 feet, where the Kestrel VI (production in 1933) had a normal rating of 600 hp.

made possible a very considerable reduction in the weight of the radiator and coolant required for a liquid-cooled engine of given power. The last was a series of experiments conducted at Wright Field by S. D. Heron about 1931, which were believed by the Army to indicate that the power of a liquid-cooled engine of given dimensions could be very greatly increased — perhaps doubled — by more modern design.

Ultimately both the weight saving anticipated from the high-temperature cooling and the high power output of 1 hp/cu in. aimed at by the Army as a result of Heron's experiments were fully realized in British production engines. The realization, however, took far longer than enthusiasts had anticipated in 1931, and in the meantime air-cooled engines also had made great advances. Probably the most reasonable view in the early 1930's was that the air-cooled engine would continue to have the advantage at low altitude. On the other hand, it was only late in the 1930's, after much improved fuels had become available and methods had been developed of producing air-cooled cylinders with much closer finning, that air-cooled engines could equal the liquid-cooled engine at altitude.

The question of second importance in choosing between air and liquid cooling was probably that of drag. During the early 1920's, the argument urged most strongly in the United States against the development of air-cooled engines, especially of the radial type, had been that they would create excessive drag. Most of the force of this argument disappeared immediately after the first flight tests of the first successful American high-power air-cooled engine in 1926, when the Curtiss Hawk showed about the same top speed with the air-cooled Wasp as it did with the equally powerful water-cooled D-12. By 1930, however, the question was again in doubt, as high-temperature cooling began to reduce the drag of liquid-cooled engines very considerably while improved cowling and baffling began to do the same for the air-cooled type. On the whole it was probably agreed by a majority that the liquid-cooled in-line engine had and would continue to have the lower drag in single-engine airplanes. The drag of the best American fighter in production in 1939, the Curtiss Hawk, was reduced by over 20% when the liquid-cooled Allison was substituted for the air-cooled R-1830. In multiengine airplanes, on the other hand, the advantage was certainly small if it existed at all when the engine and radiator were installed in the usual fashion in a nacelle. For a time in the middle 1930's there was much interest in proposals to submerge liquid-cooled engines and their radiators in the wings of multiengine airplanes, but before suitable engines had been developed increasing speeds had increased engine size and decreased wing thickness so much that this was no longer feasible. It was still possible to secure a certain reduction of drag by submerging the radiator if not the engine, but even this was attended by such an increase in difficulty of maintenance that it was ultimately done in only one important multiengine airplane, the British Mosquito light bomber.

In addition to lower drag in single-engine aircraft, the liquid-cooled in-line engine was alleged to have two other advantages in the most important type of military single-engine airplanes, viz., fighters. The first was capacity for longer periods of use of the maximum power which the engine was mechanically able to withstand, since the reservoir of coolant delayed destructive overheating. This advantage was undoubtedly a real one early in the 1930's, but it was much reduced later on both because the new high-temperature cooling systems had less reserve capacity and because the cooling of air-cooled engines became less marginal.

The second advantage claimed for liquid-cooled engines in fighters particularly was superior visibility. Early in the 1930's Army pilots were violently opposed to the use of the NACA cowl on air-cooled engines because they believed it restricted visibility in the air excessively; without the cowl, however, the air-cooled engine would have been unable to compete with the liquid-cooled. By the second half of the 1930's pilots had become used to the cowl, and few if any complaints were heard on the score of visibility in the air.[6]

The air-cooled radial, on the other hand, had very important and undeniable advantages in ease of maintenance and in lesser vulnerability in military service. The greater ease of maintenance was due both to the absence of a liquid cooling

[6]But see below, p. 273, n. 11.

system and to the greater accessibility of individual, radially arranged cylinders. Lesser vulnerability was due to both the absence of a radiator forming an additional target and to the fact that whereas a single puncture in a liquid-cooling system meant the almost certain breakdown of the engine in a very short time, the air-cooled engine could continue to function even after sustaining numerous hits on its cooling fins and sometimes even after the actual disablement of a cylinder.

The arguments summarized above are the principal ones advanced during the 1930's in support of one type of cooling or the other as applied to engines of approximately equal power. There was another quite different problem involved in the cooling controversy which became of primary importance about the middle of the decade. This was the problem of obtaining the greatest possible power from a single engine.

Arguments concerning the best type of cooling for an engine far larger than any actually existing were of course even less possible to support with direct evidence or to resolve with conclusive demonstrations than those already discussed. It would seem, however, that until 1940 or later it was more probable that a very large engine could be produced in a reasonably short time if it was of the liquid-cooled in-line type. This belief rested on the very sound basis that there were less unknowns involved. A 24-cylinder liquid-cooled engine can be fairly easily produced by simply joining together two 12-cylinder in-line engines, each with its own crankshaft, thus reducing the whole problem essentially to one of gear design alone. This simple procedure, moreover, gives what is the most compact, although not the lightest, form of 24-cylinder engine. The in-line form, however, was usually considered unsuitable for air cooling, both because an air-cooled in-line was more difficult to cool than a radial and because it was very likely to weigh nearly as much as a liquid-cooled in-line of the same displacement and more than a liquid-cooled in-line of the same power. In the radial form, the one best suited to air cooling, more than 18 cylinders were virtually out of the question in a two-row engine, and the use of more than two rows presented complex new problems not only in mechanical design but in cooling as well. As we shall see, the most powerful engine under development in the United States from 1937 until 1940 was in fact a 24-cylinder H-type liquid-cooled engine. Its developer, Pratt & Whitney, had persuaded the Navy to back this development (less financially than morally) despite the fact that until 1937 the Navy had been completely committed to air-cooled engines and the company not only had never produced a liquid-cooled engine but had previously done very little experimenting with the type. It was only when Pratt & Whitney undertook the four-row 28-cylinder R-4360 in 1940 that an air-cooled engine existed even on paper which might equal the power of liquid-cooled engines under development both in the United States and abroad.

The Marketability of Air-Cooled and Liquid-Cooled Engines

As soon as the first successful air-cooled high-power engine appeared in the United States, in 1926, its very much lower weight for given power led to its rapid adoption for all sorts of applications. It was primarily the lower weight of their air-cooled engines and the resulting gain in payload which made the Ford, Fokker, and Boeing transports so much more economical as commercial aircraft than their predecessors with water-cooled engines. At this same time British air-cooled engines were driving water-cooled engines from the British commercial market. The same low weight of the air-cooled engine which made it immediately dominate the civilian transport market led quickly to its general acceptance for such military weight-carrying aircraft as bombers and patrol planes. The last great step in the establishment of the air-cooled engine as a successful type in this country, the Army's 1928 order for the Boeing P-12 fighter with the Wasp engine (cf. above, p. 194), was based on superior performance rather than on greater payload, but this superior performance was also entirely due to lower specific weight. Air-cooled engines had become standard for British fighters about five years before (cf. above, p. 140).

Although it was possible throughout the 1930's to build up a theoretical case for the proposition that liquid-cooled engines could be made as light as air-cooled for the same power, it was

nearly certain, so far as concerned the altitudes at which most flying was actually done in the United States during this decade, that any such reduction in the weight of the liquid-cooled engine could be achieved only at a considerable sacrifice of reliability and durability if at all. Thus the possibility and profitability of marketing a new liquid-cooled engine in this country in this period depended on its showing some very marked superiority in other respects to the air-cooled engine.

One of the potential superiorities claimed with considerable plausibility for the liquid-cooled engine throughout the 1930's was that its performance at altitudes of 15,000 or 20,000 feet would be better than that of air-cooled engines. At no time in the 1930's, however, did this possibility offer much assurance of a market for engines in the calculable future. For weight-carrying airplanes the liquid-cooled engine remained unattractive, even granting that it would perform better at altitude; one of the most critical problems with this type of aircraft has always been that of take-off, and since the liquid-cooled engine was likely to develop less power for given weight at take-off, its possibly superior performance at altitude was of little use. This same inferiority at take-off and in low-altitude climb meant that it would be virtually impossible to interest the Navy in the liquid-cooled engine even for fighters. For civilian passenger transport there was another reason why high-altitude performance had little attraction in the 1930's. This was the fact that flight at high altitude was highly uncomfortable without pressurized cabins, which were not developed until late in the decade. It was not until about 1937 that a major airline showed any real interest in high-altitude flying.

Thus the one field where the possible superiority of the liquid-cooled engine at altitude promised to be of much use was in Army fighters, and it was in fact only in this type of airplane that the Army made experimental or quantity installations of turbosupercharged liquid-cooled engines during the 1930's. Even here the probability of finding a profitable market was exceedingly uncertain, since the turbosupercharger was not developed to adequate reliability for general service until the very end of the decade. As late as 1938, in fact, Allison, Curtiss, and Bell actually persuaded the Army to remove the turbo from the Hawk and Airacobra fighters, both of which had it in their original form.

Another advantage consistently claimed for the liquid-cooled engine throughout the 1930's was lower drag, but as has been shown, the justification for this claim as regards multiengine airplanes, whether military or civilian, was highly dubious, and its importance even if true was slight. Even if the air-cooled engine did have slightly higher drag, the extra fuel consumption which this would have caused could be fully compensated for by a still slighter reduction in speed,[7] leaving the entire weight advantage of the air-cooled engine for extra payload. Even for military uses where high speed was essential, the air-cooled engine was so much lighter that except at extreme long range it could have the extra power and carry the extra fuel required for equal speed and still carry an appreciable extra payload.

Again the one field where the advantage claimed for the liquid-cooled engine seemed likely to be both real and useful was that of single-engine airplanes, i.e., fighters, and again the peculiarities of the Navy's known needs and announced policy meant that a market was likely to exist in Army fighters only. Most of the minor advantages claimed for the liquid-cooled engine, such as superior visibility and greater capacity for overload in combat, applied primarily to this same field.

It was only reasonable to conclude that so long as the required power could be obtained from either type of engine, the air-cooled engine would almost certainly hold the entire Navy and civilian markets and all the Army market except for fighters, and this conclusion was in fact drawn by a great majority of persons qualified to judge. A market depending entirely on the purchases of a single class of airplane by a single service in peacetime was, however, bound to be both small in total quantity and highly irregular from year to year. It is scarcely a wonder, then, that the idea of producing for such a market exclusively seemed quite unattractive, while to regain even this unattractive market with a new liquid-cooled engine meant very large expenses on development.

[7]Total fuel consumption over a given distance varies directly with the drag coefficient but with the square of the speed.

The nature of the economic problem would be changed considerably if the liquid-cooled engine was capable of significantly greater power than the air-cooled engine. This seemed quite possible at two times during the decade of the 1930's: at the very beginning, when air-cooled engines were still far from reaching 1,000 hp, and between 1937 and 1940, when powers well in excess of 2,000 hp were being sought. It is most significant to observe that in both of these periods even the Navy was willing to use experimental funds to foster the development of liquid-cooled engines, and that likewise in both these periods both the two major manufacturers of air-cooled engines were willing to spend some of their own money on development of liquid-cooled engines, ceasing to do so only when they were convinced that the desired powers could be attained by air-cooled engines.

The Decline of the Liquid-Cooled Engine: 1928-1932

In 1927 there were four manufacturers of high-power aircraft engines which were able to spend appreciable sums of their own money on development: Pratt & Whitney, Wright, Curtiss, and Packard. Of these, while the first two were then exclusively producers of air-cooled engines, Curtiss and Packard had so far been successful only as producers of liquid-cooled engines. Belief in the superiority of the air-cooled engine for most uses and in the growing importance of the commercial market was so strong, however, that Packard quit the liquid-cooled field almost immediately, while within four years almost all development of the Curtiss Conqueror had come to a stop.

In the case of Packard this reaction was precipitated by a disagreement with the Army over design and manufacturing standards and policies, as a result of which the Army about 1928 completely withdrew all development assistance from the company. As soon as subsidies ceased Packard dropped all further work on its liquid-cooled engines.[8] This was not,

[8]The last new Packard liquid-cooled aircraft engine was the 24-cylinder X-2775, which developed over 1,250 hp. This engine was essentially two 1500's with a common crankshaft and slightly shortened stroke. Two such engines were built under Navy contract in 1926-1927; the first was intended for the 1927 Schneider Trophy race, but was not flown in the race because of difficulties with the floats.

however, because the company thought that aircraft-engine development could not be worth while if it had to be carried out at the company's own expense. On the contrary: although Packard believed it too difficult to compete directly with the established air-cooled gasoline engines of Wright and Pratt & Whitney, the company undertook development of an air-cooled Diesel entirely at its own expense. This engine was ready for flight test in September 1928, and the company spent a very considerable sum of its own money on the project before it was finally abandoned about two years later.

It is tempting at first glance to explain Packard's policy after 1927 simply by the particular situation of its liquid-cooled engines in the existing market. The company's last important quantity sales had been to the Navy for use in the FB-5 fighter, and the Navy in 1927 had officially announced that in the future it would use nothing but air-cooled engines in one- and two-place airplanes. The Army, on the other hand, which was the only remaining customer for liquid-cooled engines, was buying only Curtiss engines in quantity at this time, and the dispute with Packard over design and manufacturing policy meant that Packard would have had to risk a great deal on development before it could hope for any sales at all. But however persuasive this explanation may seem, the size and type of the Diesel which Packard developed on its own resources show clearly that the company had in fact abandoned the military for the commercial market. The engine was of just about the same size and output as the Whirlwind, which was by far the most popular engine for civilian transports (chiefly Ford and Fokker trimotors) until it was replaced by the Wasp in 1927-1928, but which already in 1926 was too small for any military use except in trainers.

Curtiss's situation was quite different so far as the existing market for its liquid-cooled engines was concerned. Whereas the H-1640 which it brought out in 1928 to compete with Wright and Pratt & Whitney in the air-cooled field had met with very little success, sales of the liquid-cooled Conqueror continued in very substantial and profitable volume. In fiscal 1929, 1930, and 1931 the Army bought as many dollars' worth

of Conquerors as it did of all air-cooled engines of equal size;[9] in 1932 Conquerors actually accounted for nearly two-thirds of Army expenditures on engines of this size.

In view of these sales it would almost seem as if the further development of the Conqueror could not have failed to be pushed by Curtiss and by its successor, Wright Aeronautical.[10] Curtiss did continue to spend a good deal of both its own money and the Army's on the development of the Conqueror, but despite this spending its progress was very slow. In 1928 the original 575 hp of 1927 was raised to 600 hp, but this increase was the last for four years. In 1932, a year after Wright had taken over, the output of the engine was finally raised once more, but to only 650 hp direct drive or 625 hp geared.[11] The only real accomplishment during these four years was the production of an experimental supercharged model known as the Superconqueror, and even this engine had only about half the supercharging of the contemporary Rolls Royce Kestrel.

In 1932 Wright brought out its first really successful air-cooled high-power engine, the F model of the Cyclone, which marked not only an increase from 575 to 700 hp but a great increase in reliability.[12] This engine was chosen by Douglas

[9]Over 1,500-cu in. displacement: Pratt & Whitney Hornets, Wright Cyclones, and a few Curtiss H-1640's.

[10]The Wright Aeronautical Corporation was merged with Curtiss in 1929 to form the Curtiss-Wright Corporation. Both Wright and Curtiss continued to exist as operating companies, however, and for two years the engine-development staffs and shops remained separate. In 1931 the two staffs were united, the Curtiss men moving to the Wright plant. The former head of Curtiss engine development, Arthur Nutt, became vice president of engineering of Wright Aeronautical, while Wright's chief engineer, P. B. Taylor, remained in that post.

[11]To a certain extent, this lack of progress was due to a technical controversy between the company and the Army. High-temperature cooling, one form of which had been developed by Wright Field between 1923 and 1930, and which was absolutely essential if the weight of liquid-cooled engines was to be reduced to a figure at all competitive with that of air-cooled engines, was introduced to production Conquerors in 1930, but serious difficulties were experienced in service, and these were blamed by the Army on the company's design while the company blamed the Army's requirements. The Conqueror cylinder consisted of a steel barrel with an integral closed head screwed into contact with an aluminum head block. At the cylinder temperatures obtaining with water cooling the steel remained in good contact with the aluminum, but when ethylene glycol, the coolant developed by the Army, was used at 300° F, as the Army required, the difference between the thermal expansions of the two metals produced leaks from the cooling jacket into the cylinder. The company maintained that the Army's temperature requirement was unduly high, while the Army maintained that the Curtiss cylinder design was obsolete.

[12]This was the first Cyclone with a forged crankcase.

for use in its new Airliner which became the DC-2. As has already been shown, there was every reason to believe at this time that by far the larger part of the total market for large engines would go to the air-cooled type. Wright was additionally convinced of this by recent experience. In 1929 Transcontinental Air Transport had tried some Curtiss Condor transports with Conqueror engines, but had soon switched to Fords with air-cooled engines. In 1931 Eastern Air Transport had also tried Condors powered by Conquerors, and these too had been abandoned after only about a year of trial. Now that Wright had secured a real entry into the commercial market with the F Cyclone it was only natural that it should try to secure and extend its hold in competition with Pratt & Whitney by giving first priority on all its development resources to the Cyclone rather than to a new liquid-cooled engine which, even if it satisfied the Army, could have very limited sales at best. If Curtiss had continued as a separate company, the development of liquid-cooled engines might well have been pressed even if the only market was in Army fighters, since it was the only field in which Curtiss had enjoyed success, but once liquid-cooled engines were only another product of a company which also produced a successful air-cooled engine, and which believed (correctly) that by far the greatest share of the total engine market would go to the latter type, it was inevitable that the resources assigned to the development of the Conqueror would be reduced in favor of engines in the company's line which promised greater ultimate profits.

The Military Need for Continuing Development of Liquid-Cooled Engines

It was clear by 1932 that if the development of liquid-cooled engines was left to the same financing and the same incentives as the development of air-cooled engines, the liquid-cooled engine would soon be hopelessly obsolete. Already by 1932 American liquid-cooled engines, which had been as good as any in 1925, were inferior to the Rolls Royce Kestrel. But although it was highly probable that the air-cooled engine would continue supreme in most applications, it was by no

means possible at any time in the 1930's to demonstrate conclusively that this would always be true of all applications. In so far as aircraft engines were put to civilian uses, all these possibilities could be rightly neglected; the "expectation" of profits from liquid-cooled development was far too small to justify the large sums which it would have to cost if success was to be even possible, and in a rational economy an unprofitable undertaking is a wasteful one. For military use, however, the stakes were higher. If the liquid-cooled engine proved ultimately to give superior performance, even if it should be only in a single important use of a single type of aircraft, an air force without a good liquid-cooled engine would be at a most serious disadvantage in case of war. And if such a superiority should be demonstrated by foreign liquid-cooled engines after development of the type had been neglected for a number of years in this country, it would require a long and perhaps fatal period to overcome the disadvantage.

Thus there can be no question that the services were fully justified in doing all they could to foster the development of liquid-cooled engines. Every major foreign country consistently promoted the development of both air-cooled and liquid-cooled engines, no matter which type seemed the better at a given moment. The two most successful countries, Britain and Germany, not only supported development of both types, but maintained competition in each field by having two major firms working continually on each type. The abandonment by the United States of either type would have been a completely indefensible gamble.

It was pointed out at the beginning of this chapter that there is a superficial resemblance between the economic status in the United States of liquid-cooled engines in the 1930's and that of large air-cooled engines in the early 1920's. If we wish to understand the differences between the two courses of development, it is of prime importance to remember that in reality the motivation and objective of the two developments were completely different. The large air-cooled engine was thought of in the early 1920's as having great theoretical advantages for all sorts of applications but as presenting certain unsolved and formidable technical obstacles. Government support of the manufacturers and the Army's research on air-cooled cylinder design were necessary to overcome these obstacles. The liquid-cooled engine in the 1930's, on the contrary, was a known and proved type but was thought of as having far less promising applications in the over-all market. Government support of the manufacturers was to a large extent a substitute for the incentive of profits from prospective quantity production.