CHAPTER XI

The Results of American Liquid-Cooled Engine Development

The Abandoned Projects

Five manufacturers, four of them without previous experience with high-power liquid-cooled engines, undertook the development of such engines in the United States between 1930 and 1939. In some cases these engines were begun at company initiative, in others at the Army's request, but in most cases they received extensive financial support from either the Army or Navy or both. In 1930 Allison began development of the V-1710 at its own initiative, receiving a limited amount of financial support from the Navy from 1930 to 1935 and continuous payment of about half the total costs from the Army after 1932. In 1932 Continental undertook the O-1430 (later IV-1430) at the Army's request, and the Army paid its expenses continuously and in full. In 1932 Lycoming began the O-1230, most of the expenses being paid by the Army from 1935; in 1938 this engine was used as the basis of the H-2470, which the Navy supported beginning late in 1939. In 1931 the Army persuaded Pratt & Whitney to produce an R-2060 at the latter's own cost; this engine was soon dropped. In 1937 Pratt & Whitney sold what became the H-3730 to the Navy, and the Army persuaded Pratt & Whitney to undertake the X-1800; in these two cases the government promised only token support, and even this was only paid in part owing to later cancellation of the project. In 1939 Wright reentered the field with the R-2160, designed with little reference to its earlier experience with liquid-cooled engines, and received an Army contract covering a part of the costs. Still other engines were undertaken by other firms after 1939.

Only one of all these engines, the Allison, was developed in time to be of use in the war. The R-2060 was an abortive attempt on which little effort was spent and which probably should not be counted, but all the other engines which have been listed, and some others which were begun after 1939 and have not been described, were serious efforts on which a good deal of money and effort were spent. The later Pratt & Whitney projects, the H-3730 and X-1800, were abandoned because the company felt that it could do better by devoting its men and facilities to the development of air-cooled engines, but no such substitution was made in the case of any of the others. The engines begun very late in the 1930's or in the 1940's probably had no chance of succeeding in time even if their basic design was excellent. The engine of latest design to see service in the war was the Rolls Royce Griffon, which was not extensively used until 1944 although the design had been begun in January 1939, and which had the great advantage of being very similar to and only a little larger than the Merlin, which was well developed by 1939.

The designs of two of the abandoned engines, however, the Continental and the Lycoming, were begun in 1932, a year before that of the Rolls Royce Merlin, but even these engines had to be abandoned because they were not ready soon enough. The reasons for the failure of these engines to see service deserve examination in detail.

There is no doubt that the basic reason for the abandonment of the Lycoming O-1230 in 1938 and of the Continental IV-1430 in 1943 was that the power which they delivered was too small. Other engines producing as much or more power were fully developed and in service at these dates, and there was no sense in proceeding with the O-1230 or the IV-1430. The power at which the Army aimed in 1932 was not at fault, however. This goal was 1,200 hp for take-off and 1,000 hp normal. The Rolls Royce Merlin was designed a year later, in 1933, for 750 hp, and even though it was always anticipated that this would eventually be increased, it is certain that Rolls Royce did not then plan on even a combat (five-minute) rating of over 1,000 hp for a long time to come if ever. It must not be forgotten either that from 1934 on, the Army was planning on powering its fighters by not one but two of these 1,000-hp engines, submerged in the wings. Even when the war broke out in 1939 no country had in service a fighter powered by an engine which exceeded the rating which the Army took as its goal in 1932.

It is quite a different question to ask whether an engine as small as the Continental, let alone the Lycoming, could have continued to be useful throughout the war. The answer to this question is almost certainly that it could not. The smallest successful combat engine in the war was the Merlin, which had a displacement 64% larger than the 1932 Continental design, 34% larger than the 1932 Lycoming, and 16% larger than the final Continental engine of 1934. Even the Merlin could not have competed with the larger liquid-cooled engines used by the Germans had not German supercharger development fallen far behind Rolls Royce's. The Army did not intend, however, that the Hyper engine which it designed in 1932 should be used in combat ten years later; it intended it for use in the near future, and planned from the beginning on the development of larger and more powerful engines based on experience gathered with the original engine. The real cause of the failure of the Continental and Lycoming engines to see service was that they came through only after their original aim of 1,000 hp had been outmoded by other, larger engines. Since their original goal was high for the date at which it was set, the real problem is why these engines took so long to reach that goal that they were thus overtaken.

A number of technical reasons have been alleged for this slowness of the Continental and Lycoming developments. First of all, it is commonly argued that the Army made a fatal mistake in trying to get this power from too small a displacement, i.e., in aiming at too high a specific power. The piston speeds aimed at in these engines were not exceptionally high, however, and it is mainly fuel and not the engine itself which sets the other limit on specific power, namely the mean effective pressure. It has been shown above (p. 270) that although the Hyper No. 1 was probably doomed to failure, the Hyper No. 2 should have had no trouble at all as far as detonation was concerned on the 75-PN fuel the Army planned to use in it; and

even the Lycoming O-1230 should have had no trouble with detonation at a 1,000-hp rating as soon as fuel of 87-PN or better was available. Wright Field might be more legitimately criticized for having based its plans in 1932 on the use of a fuel which might not have been available in sufficient quantity for service use in time of war; but on the other hand, as Heron has shown (see below, p. 605), it was to a very large extent the Army's work in demonstrating the additional performance made possible by better fuel which led to the availability when the war did come of the fuels of 100 PN and higher which were one of the most important factors in Allied superiority in the air.

Whether mechanical reliability and durability would have been exceptionally difficult to obtain at the design power of the O-1230 or O-1430, no one can really say, since a complete O-1230 was not built until 1937, and a complete O-1430 not until 1938, and by then the power requirements had increased so much that although these engines were put through their development tests at the original ratings in 1939 no attempts were made to type-test them at these ratings. The O-1230 was replaced by the H-2470, while the goal of the Continental was raised to 1,600 hp military, and it was at this rating that the mechanical difficulties occurred which prevented it from ever completing a type test.

The use of individual cylinders instead of block construction, specified by the Army, undoubtedly made it somewhat more difficult to eliminate cracking of the crankcase and trouble with the bearings, and it is argued that this fact alone necessarily delayed development seriously if indeed it did not guarantee the failure of the Continental and Lycoming engines. But the R-4360 is a very successful engine with seven individual cylinders on each throw of a four-throw shaft; two much smaller cylinders on each throw of a six-throw shaft was probably no more of a problem.[1] Individual cylinders, on the other hand,

[1]A much stronger objection to individual cylinders is that a monobloc engine is more compact and therefore lighter. The single-speed single-stage Continental ultimately weighed 1,655 lb, or 18% more than the 1,400 lb of the corresponding Merlin 47 and various other single-speed single-stage models although it had 14% less displacement. This would have been a probably fatal competitive disadvantage, since it meant that the Continental would have had to produce 37% more power per cu in. to equal the Merlin in terms of power per lb., but it is not the reason why the Continental engine failed to come through at all.

were indisputably much easier to produce, and this greater ease of production not only would have been of value if the engine had been built in quantity, but should have actually facilitated development by making it easier to build experimental engines and to alter cylinder design in accordance with experimental results. Some of Rolls Royce's most serious difficulties in development came from the great difficulty of making changes in the design of the cylinder block.

The simplest way of all of considering the technical side of the problem is this: the fact that the Continental ultimately got through most of a type test at a military rating of 1,600 hp, achieved a war-emergency rating of 2,100 hp, and was extensively flown using 1,600 or 1,700 hp for take-off, shows conclusively that there was no purely technical reason why, given adequate resources and adequate skill in the development, and assuming the availability of adequate fuel, the engine might not have been brought to its 1934 design rating in about the same time that the Merlin was brought to its 1,030-hp rating, i.e., in a period of a little over three years from the time the design was begun.[2] If work on the Continental had proceeded at the rate at which it was done on the Merlin, it would certainly have taken not more than one year instead of two to decide that the original 1932 cylinder size was too small, and if work on the larger O-1430 had been begun in 1933 and carried out with Rolls Royce's speed, the O-1430 would have been in production in 1936. The Army was already anxious by that time for engines of much higher output than 1,000 hp, and the experience gained with this small engine could have been profitably put to use, as the Army had always planned to do, in the development of a larger engine, whether it was a 12-cylinder engine with larger cylinders or a 24-cylinder H like the Lycoming H-2470, which was in fact begun in the middle of 1939.

The real trouble was not that the development of a complete Continental O-1430 was so difficult, but that it was begun so late. Whereas the first complete O-1430 was not built until

[2]While this was a lower specific power than that aimed at in the Continental, it must be remembered that almost no additional development was required to bring the Merlin up to that specific power once the proper fuel was made available in September 1939.

1938, six years after the project was begun, Rolls Royce built about two dozen complete Merlins between early 1933, when design was begun, and October 1936, when the Merlin II was type-tested at a combat rating of 1,030 hp.

Only one technical factor seems to have been involved in this long delay before the first complete O-1430 was built. This was the Army's insistence on the use of coolant at a temperature of 300°F, which made the development of a satisfactory cylinder far more difficult than it would have been at 250°, and led the Army to postpone the building of a complete Hyper engine while waiting for a completely satisfactory single cylinder. By the end of the 1930's experience had shown that the 300°F coolant temperature, which had been specified by the Army in order to reduce the size of the radiator, actually made necessary such an increase in the size of the oil cooler that the radiator and the oil cooler together were as large as when the coolant was used at 250°F. It can scarcely be doubted, furthermore, that the whole fundamental philosophy of this approach was in error; the history of all successful engines seems to show that the only sound course of engine development is to build a complete engine at a very early stage, even if it has to be at very modest performance specifications, and to develop the whole engine subsequently to higher performance.

The chief causes of the slowness of the Continental and Lycoming developments were, however, not technical but administrative and economic. One of the worst was the series of delays involved in negotiating a new contract as one phase of the work was completed and another was to be begun. Such delays were completely avoided by Rolls Royce and by all British manufacturers, since they could reach an understanding on informal terms with the government and then proceed with absolute assurance that they would be paid in full for their work. This could never be done in the United States, and the only way in which these delays could be avoided was by the investing of private funds in the work in at least sufficient extent to bridge the gaps between government contracts. This was what was done in fact by Lycoming, and it is the principal reason why the Lycoming engine made somewhat more rapid progress than the Continental. It is important to observe, however, that the reason that this attitude caused more rapid progress was not so much the fact that the total amount spent was greater — it probably was not, since the private funds no more than made up for the lesser amount of Army funds — as the fact that genuine eagerness on the part of the company prevented those delays which were inevitable if each step to be taken had to be negotiated between the contractor and the Army and then formalized by a contract.

Far more important was the simple lack of adequate resources for use in the two developments. We have already seen that the total amount spent in the first seven years of the Continental development was about a quarter of what was spent in the same period of the Allison development. When a comparison is made with a major company the difference is still more striking. The combined total of the funds available to the Army and those which the two companies could have raised at best would not have permitted anything like Rolls Royce's construction of about two dozen experimental Merlins between 1933 and 1936. And since the two American companies were undertaking completely new engines, for which they had virtually no background experience, they would have had to have even greater resources than Rolls Royce to make progress at the same rate of speed as that company, whose Merlin was not greatly different from the Kestrel, which had accumulated a wealth of service experience.

The Allison

The one American liquid-cooled engine to see service in the war was the Allison V-1710, which was put in production in 1939. It was of the same basic type and very nearly the same size as the Rolls Royce Merlin, and from 1937 to 1939 it looked as if the Allison might well be a good competitor of the Merlin. The top speed of 340 mph attained by the turbo-supercharged XP-37 in 1937 was the same as that attained by the prototype of the Merlin-powered Spitfire in 1936, and the 20,000-foot altitude at which the XP-37 reached its maximum speed was 4,000 feet higher than the best altitude of the Spitfire.

A still more impressive performance was given by the turbo-supercharged Allison in the two completely new fighter prototypes which the Army ordered in 1937, and which were the first American airplanes to take full advantage of the liquid-cooled in-line engine by using radiator installations of really modern design (cf. above, pp. 235-238). In April 1939 the single-engine Bell P-39 Airacobra did 400 mph at 20,000 feet, and in the latter half of 1939 the twin-engine Lockheed XP-38 Lightning registered a top speed of 413 mph at 20,000 feet.

Uncertainty about the possibility of developing a fully satisfactory turbosupercharger led the Army, however, to drop the turbo from the Hawk and the Airacobra in 1939. The Airacobra proved unsatisfactory in various respects[3] and was little used in combat except by the Russians, and the turbosupercharged Lightning was not in full production until the end of 1941, so that it was in the P-40 without a turbo that the bulk of the Allison's early war service was performed.

The prototype XP-40 was a P-36A rapidly converted to use the C13 Allison, which had a normal rating of 1,000 hp at 10,000 feet and a military rating of 1,090 hp at slightly higher altitude. In the spring of 1939 the Army held a design competition for fighters in which speed was evaluated at 15,000 feet. In winning this competition the XP-40 defeated not only the Y1P-37 with the turbo Allison but also four entries with various recent models of the air-cooled R-1830, all of which had outputs about equal to that of the Allison.[4] It demonstrated a top speed of 342 mph at 12,200 feet, which was decisively superior

[3]The production P-39 was a little faster than the P-40 and climbed a little better, but its advantage in these respects was small and was offset by the fact that it was not so maneuverable. Its armament was very poor for aerial combat, since it carried three types of guns, each with a different muzzle velocity, and in shooting at a moving target a lead which was correct for any one of the types would be wrong for the other two. The range of the P-39 was very short, and the airplane was so compact that it could not be fitted with additional tanks. In addition, it was a difficult airplane to control, and for some time had very serious trouble with vibration. Thus the P-39 was never successful as a fighter. In the early part of the war its cannon and its visibility made it a good ground-support airplane, and it was used in this way by the Russians and to a limited extent by the United States in the Pacific; but at this time, when the United States was on the defensive, it had little need of ground support, and by the time the United States was on the offensive in Europe the far better P-47 was available for this duty.

[4]These entries with R-1830 engines were an improved Seversky P-35 known as the XP-41 with the turbosupercharged R-1830-19 rated 1,050 hp normal at 11,000

(*Footnote continued on next page*)

to the 315 mph at 15,000 feet of a P-36A converted for this competition to use the latest available single-stage model of the R-1830 (the -31). The 342 mph were attained, moreover, with what were known to be incompletely developed radiator and installation designs. By the fall of 1939 development had brought the XP-40 to the point where it could do 366 mph at 15,000 feet.

The French had ordered large numbers of the R-1830-powered Hawk 75 and 75A (the export versions of the P-36 and P-36A) in 1938, but when their purchasing mission inspected the airplanes entered in the 1939 fighter competition they concluded, like the Army, that the Allison-powered P-40 was definitely the best, and placed orders for a considerable number. A little later they ordered P-38's and P-39's as well. In the first months of 1940 the new British mission under Sir Henry Self surveyed the available American fighters, and like the French chose the P-40 as the best.[5] Owing to the time required for Allison to get into production, none of the P-40's ordered by the French was delivered in time to go into combat before the fall of France. The first deliveries were made to the British late in 1940, and "there seemed to be little to choose between a P-40 and a Hurricane in the course of a mock dogfight."[6]

It seems clear that from 1938 to 1940 pursuits with the single-stage Allison were definitely superior in speed and about equal in climb to any fighters which were or could be designed around the single-stage model of its only important competitor for

or 17,500 feet, and three variants of the P-36 with airframes virtually identical to that of the XP-40; one with the R-1830-25, rated 950 hp at 14,300 feet normal, one (the XP-42) with the -31, rated 1,000 hp at 14,500 feet normal, and one with the two-stage R-1830B2, rated 1,050 hp normal at 17,500 feet. On this two-stage engine, see below, n. 7. The only other entry was a very small airplane powered by the R-1535.

[5]The British also ordered a large number of an improved model of the P-40, known as the P-46, which existed only on paper. The P-36 and the improved XP-42 were not even seriously considered. After the French and British programs were combined, later in 1940, the airplanes on order were: 500 P-40's, 1,000 P-46's, 200 P-39's, and 800 P-38's.

[6]*Aircraft of the Fighting Powers* Vol. 2 (Leicester, England: The Harborough Publishing Company Limited, 1941), p. 32. According to General Chennault, the P-40 in 1941-1942 was agreed by both British and Americans to be actually superior to the Hurricane then in the Far East. C. L. Chennault, *Way of a Fighter* (New York: G. P. Putnam's Sons, 1949), p. 56.

fighter service, the air-cooled R-1830. It is true that it became possible in 1939 to build a fighter around the new two-stage R-1830 with much better climb at altitudes above 15,000 feet than could be obtained from the single-stage Allison or any other single-stage engine, but the fighter with the 1938 model of this two-stage R-1830 which was actually entered in the 1939 fighter competition was a failure, owing to faults in both the engine and the installation, and Curtiss made no attempt in 1939 and 1940 to sell it to the British or French. Later in 1939 Grumman succeeded in making a satisfactory installation of an improved model of the engine in its XF4F-3 Wildcat Navy fighter,[7] but even this airplane, although it outclimbed

[7]The earliest development of two-stage supercharging in the United States was begun by Pratt & Whitney in 1934. For several years a very large part of the cost of the work was paid by the Navy; the company could anticipate neither a civilian market, since airline operators were not much interested as yet in high-altitude flying, nor an Army market, since the Army was basing its plans on the turbosupercharger exclusively, but the Navy had little confidence in the turbo and hence was ready to back the two-stage development. The first work was done on an R-1535, the engine chosen by the Navy, and the first such engine was flown in the fall of 1935 on an XF3U-1. In September 1935 work was also begun on a two-stage R-1830B; the first experimental engine was shipped to the Navy in February 1936 and was flown on an XTBD-1. Both these engines had the two impellers mounted on a common shaft driven through a fixed gear ratio and accordingly gave very poor performance at low and medium altitude. Pratt & Whitney then concentrated on development of intercooling and on the development of a two-speed independent drive for the first stage; this took some time, and the first R-1830SB2 so equipped was not ready for flight until 1938. This was the engine which was used in the fighter competition held in the spring of 1939; its normal rating was 1,050 hp at 17,500 feet. The installation in the P-36 entered in this competition, the first to be made in any fighter, was very poor, and great advances were made in the next two years through work done by Pratt & Whitney itself. The basic engine itself was greatly improved in the next version, the R-1830SC2-G, which was first flown in the XF4F-3, in February 1939. Even this engine, which had a normal rating of 1,050 hp at 22,500 feet on 100-octane fuel, suffered from trouble with surging at altitude, and the trouble was not remedied until Pratt & Whitney gave up complete reliance on an outside supplier for the design of its superchargers and itself undertook to develop this component. The first work done by Pratt & Whitney on the supercharger resulted in a modified diffuser and inlet which produced the R-1830SC5-G used in the production F4F-3 and rated 1,000 hp at 19,000 feet normal. Deliveries of this production engine began in October 1939; the first production F4F-3 was accepted by the Navy in July 1940, and was the first airplane anywhere in service with two-stage supercharging. In 1942 Pratt & Whitney itself installed in a P-40 airframe the two-stage R-1830-SSC7-G. This was a much improved version of the two-stage engine, and was incomparably better installed as a result of all that had been learned from experience since 1938 on the installation of two-stage engines. When this airplane was flown in September 1942 it showed a top speed of 389 mph at 22,700 feet and climbed to 15,000 feet in 5.5 min. and to 20,000 feet in 7.7 min. by using military power for the entire climb.

the XP-40 by a very large margin above 15,000 feet,[8] was very much slower than the XP-40 at all altitudes. The maximum speed of the XF4F-3 was 330 mph at 19,500 feet, where the XP-40 could still do about 360 mph, while at 15,000 feet, where the XP-40 made 366 mph, the XF4F-3 could do only about 300 mph.

What has been said above throws some light on the question of whether the Allison development led to an engine which gave better airplane performance than other American engines available at the time the Allison was put in production, in the middle of 1939. It is even more important to inquire whether the Allison was as good an engine of its type as was possible in the state of the art at this time, whether or not the type was useful, for the primary purpose of this chapter is not so much to inquire whether the engine should have been developed as to determine whether the development was well carried out. Since there is no question that the outstanding liquid-cooled engine of the war was the Rolls Royce Merlin, an engine of the same type and within 3% of the same displacement as the Allison, this question can best be investigated by comparing the Allison with the Merlin.

A meaningful comparison between the Merlin and the Allison cannot be made as of the middle of 1939 because the two engines were rated on different fuels at that date, the Allison on 100-PN and the Merlin on 68-PN (87-octane). The first British ratings based on 100-PN fuel were established about the end of 1939 (cf. above, p. 222) and at this time the production Merlin II and III used as the power plant of the Hurricane I and Spitfire I were given a combat rating of 1,160 hp at about 13,500 feet. The C15 Allison in production at this time for use in the P-40 had a military rating of 1,040 hp at 14,300 feet. The single-stage superchargers of the two engines were roughly equal in pressure ratio and efficiency, and the reason for the

[8]The XF4F-3 also outclimbed the XP-40 below 15,000 feet, but by a much smaller margin, and this superiority was almost if not quite entirely due to the fact that the XP-40 airframe weighed about 1,000 lb or 20% more than the XF4F-3, rather than to any differences in the engines. The weights of both airplanes were considerably increased before they went into service, but the early production P-40's were still a good 1,000 lb heavier than the F4F-3's, and the later ones were 2,000 lb heavier.

lower maximum power of the Allison was simply its lower mechanical strength.[9]

After this time the comparison between the Merlin and the Allison becomes more complex. In the middle of 1940 Rolls Royce put into production a new and much more efficient single-stage supercharger, so that differences between subsequent ratings of the engines are partly due to differences in the basic engines and partly due to the differences in the superchargers. A rough comparison of the basic engines can be made, however, by considering simply the military or combat power of fully supercharged engines without regard to the altitude at which it was obtained; the effect on maximum engine power of the better efficiency of the Merlin supercharger was just about offset by its higher pressure ratio.[10]

Even the rating of 1,040 hp given to the C15 Allison could not be maintained at first, and about the middle of 1940 the engine had to be derated for a time to 900 hp, principally because of trouble with the reduction gear. The 1,040-hp rating was restored toward the end of 1940, and the engine was fully reliable at this rating,[11] but it was not until the middle of 1941 that the military rating of fully supercharged production Allisons was brought to equality with that of the corresponding American-built Merlins.[12] In that year the Allison F3R had a military rating of 1,150 hp; the Merlin XX, which had been in production by Rolls Royce since 1940, received an American military rating of 1,120 hp when it was put in production by Packard in the United States. From this time on the maximum power of the Allison, disregarding the altitude at which this power was obtained, remained quite competitive with that of

[9]The earlier C13 Allison of the end of 1938, used in the XP-40, had had a rating of 1,090 hp; the reduction made in the C15 was due to mechanical troubles at the higher rating.

[10]The Merlin III with the old supercharger had a British combat rating of 1,160 hp at about 13,500 feet at the same manifold pressure at which the Merlin XX with the new supercharger was rated 1,175 hp at 20,500 feet.

[11]See C. L. Chennault, *Way of a Fighter*, p. 136, on the performance of the C15 engines of the P-40Bi n China.

[12]In September 1940 arrangements were concluded for Packard to build the Merlin under license. After an extraordinarily rapid and excellent job of redrawing the engine to conform to American production standards and practices, the first two V-1650-1's (Merlin XX) were run in August 1941, and the engine was in full production in 1942.

the Packard-built Merlin, and the fact that it was slightly inferior at times is probably fully explained by the fact that in order to secure better fuel economy the compression ratio of the Allison had been raised in 1937 to 6.65:1 whereas that of the Merlin was only 6:1.[13]

Before the end of 1941 the really serious trouble with the Allison-powered P-40 in combat was not due to insufficient power but to the altitude at which the power was obtained.[14] Until 1938 Allison had done very little with the development of the geared supercharger on the V-1710, since the Army relied entirely on the turbosupercharger for altitude performance, and this meant that the pressure ratio desired in the integral blower was low and no real development was necessary to obtain this low ratio at a quite tolerable efficiency. When Allison and Curtiss persuaded the Army in 1938 to try a V-1710 without a turbo in the XP-40, the C13 engine with a built-in blower providing sufficient supercharging for altitude had to be brought out as a rush job, and little or no improvement was made in this single-stage supercharger between 1938 and 1941. Rolls Royce, on the contrary, in 1940 put in production on the Merlin XX and all later models a new supercharger with very remarkable gains in both pressure ratio and efficiency. The result was that whereas the 1,150-hp military rating of the Allison F3R of 1941 could be maintained to only 11,800 feet, or the 1,125 hp of the F20R and E19 of 1942 to only 14,600 feet, the 1,120-hp military rating of the Packard-built Merlin XX called the V-1650-1 could be maintained to 18,500 feet.

[13]This difference in compression ratio was irrelevant so long as the power of the Allison was limited by mechanical strength, but once the strength was brought to the point where the power limit was set by detonation, the 10% higher compression ratio tended to limit the power to 10% less, and only a third of this difference would have been offset by the larger displacement of the Allison.

[14]It is perhaps worth pointing out, however, that the inferiority at altitude of the P-40 to the Me 109 in Africa in 1942-1943 was not due to any German superiority in supercharger design; the DB-601 engine neither had more power than the Allison at this time nor maintained it to higher altitude. The superiority of the Me 109 was due entirely to the fact that it weighed only 5,520 lb gross while the P-40 weighed between 7,000 and 8,000 lb. The first-line German fighter over Europe from 1942 on was the Focke-Wulf 190, powered by the 2,560-cu in. BMW 801 air-cooled radial. Like the DB-601, this engine had only a single-stage supercharger, but its displacement was so much larger than the 1,710 cu in. of the Allison or the 1,649 of the Merlin that it was hopeless for either of these engines to compete at altitude unless they had two-stage or turbosuperchargers.

By 1942 both Rolls Royce and Allison were ready to go into production with two-stage superchargers for their engines.[15] The Rolls Royce supercharger was built in compactly as a part of the engine, largely if not entirely in order to permit substitution of the two-stage for the single-stage engine with a minimum of alteration in existing airframes. Allison, on the contrary, had made the auxiliary stage a separate unit, largely in order to simplify production by building all its basic power sections on a single line and then adding a single-stage, two-stage, or turbosupercharger as might be needed. This meant that installation of the two-stage engine would have required extensive modifications in any airframe designed for the single-stage engine. Rolls Royce, furthermore, had put an aftercooler between the supercharger and the engine, thus making possible the use of higher pressure ratios than could be used with the Allison, which had neither an after nor an intercooler. The Allison E11 of 1942 had a military rating of 1,150 hp at 22,400 feet; the Packard-built Merlin 61 of the same year, known as the V-1650-3, was rated 1,210 hp at 25,800 feet. Above its critical altitude the superior efficiency of the Merlin supercharger gave the Merlin an increasing advantage over the Allison.

Allison, on the other hand, had a hydraulic drive for the auxiliary stage with continuously variable speed, such as was used on the single-stage supercharger of the Daimler-Benz 601 engine used in the Me 109, while Rolls Royce had merely a two-speed drive. This meant that while the Merlin had a clear superiority at and near the two altitudes at which it was designed to give peak performance, the Allison was about its equal between these two altitudes and below the lower of them. In 1944 Allison itself installed a late model of its two-stage engine, the V-1710-119, in an experimental light-weight version of the Mustang. The top speed of this airplane, the P-51J, was 491 mph at 27,400 feet. The light-weight XP-51F with the Packard Merlin is not comparable, since the engine model was the V-1650-3, which was three years older than the V-1710-119.

[15]The two-stage Allison was first run in the spring of 1941, but this was only the beginning of the development of the drive. Rolls Royce had a two-stage bomber engine (Merlin 60) in production in November 1941, but production of the two-stage 61 for fighters did not begin until March 1942; see above pp. 229-230.

The heavier P-51H with the V-1650-9, a model contemporary with the V-1710-119, did 487 mph at 25,000 feet.

By the time the Allison and Merlin two-stage engines were available, in the latter half of 1942, the American Army had finally recognized that the best available fighter airframe was the P-51 Mustang, which had been designed in 1940 around the single-stage Allison and had used that engine up to that time. Since conversion to take the two-stage Merlin was a relatively simple job, whereas conversion to take the two-stage Allison would require extensive modifications and consequent serious delays in production, the Merlin was chosen. The two-stage Allison was used in the new Bell Kingcobra (P-63), but this airplane, like the Airacobra from which it was derived, had a number of weaknesses unconnected with the engine and was never used as a fighter on the Western front (cf. above, p. 303, n. 3). The one first-line airplane in which the Allison continued to be used after 1942 was the Lightning, the only one of the prewar designs to retain the turbosupercharger. This airplane continued to play an important part as a fighter during most of 1943, and was finally displaced from that role only when the Mustang, a much later design, appeared at the front.[16]

To sum up: the Allison V-1710 was a better medium-altitude fighter than was or could have been available in production with any air-cooled engine from 1940 until the R-2800 was put in fighter service in 1943, but it was deficient throughout this period in performance at altitude, compared with either the Rolls Royce Merlin or the Pratt & Whitney R-1830, and for the first part of the period was seriously below the Merlin in power output.

The deficiency in performance at altitude up to 1942 is to be very largely attributed to the fact that until 1938 the Army had based its plans entirely on the turbosupercharger. Because of this fact Allison had had little incentive to develop gear-driven superchargers with higher pressure ratios or better efficiency;[17]

[16]The inferiority of the Lightning to the more modern Mustang was not due to the engine; the turbosupercharged Allison was as powerful as the two-stage Merlin at about 25,000 feet and more powerful at higher altitude.

[17]Or to develop a two-speed drive for its single-stage supercharger.

even Pratt & Whitney, a company with far greater resources and whose plans had not been largely based on the turbo, had done nothing with the aerodynamic development of superchargers until the end of 1938, when the company was driven to it by trouble with its two-stage supercharger. Then in 1938-1939 the turbo was eliminated from the two pure fighters using the Allison (P-39 and P-40), leaving them with inadequately developed single-stage superchargers. It was simply impossible for Allison to produce a single-stage supercharger as good as that of the Merlin XX as rapidly as Rolls Royce; the supercharger of the Merlin XX was based on intensive development by an experienced staff since 1938, and this program rested in turn on Rolls Royce's continuous development of its own superchargers since 1927 (cf. above, pp. 225-229).

By 1942 Allison had developed a two-stage supercharger, only a year after Rolls Royce, but had made it of such a form that it could not be conveniently installed in the best available airframe, the Mustang, and the Packard-built two-stage Merlin was substituted for the Allison in this airplane. Responsibility for this error is probably to be shared between the company, which chose this design for its supercharger, and the Army, which permitted its development. The development began after it was already perfectly clear that airframe production would scarcely be able to meet the demand, and both should have considered the problem of modification of existing airframes without causing serious delays in production.[18]

The reasons why it was not until 1941 that Allison was in production with an engine which equaled the reliability of the Merlin at approximately equal power are more complex. The fact is the more surprising because the development of the Allison was begun nearly three years before that of the Merlin: the Allison was laid out and a Navy contract had been signed by June 1930, whereas the design of the Merlin did not begin until early in 1933. Since the two engines were of the same displacement and the same general construction, there was no

[18]It is uncertain how far the Army's policy was caused by early dislike of the Mustang. The P-63 Kingcobra was ready for production with the two-stage Allison not long after the engine itself was ready for production.

obvious technical reason why the development of the Allison should have been so much slower.

In comparing the histories of the two engines it must be remembered from the first, however, that whereas this was Allison's first venture in the development of a high-power engine of any type, the Merlin was nothing but a slightly enlarged version of the Kestrel, which had been in full production and service since 1927. Outside of the larger size, the only important difference between the production Kestrel and the original Merlin was the use in the latter of an integral block and crankcase, which was given up very early in the development; and the only important difference introduced during the original development was the ramp head, which proved a failure and had to be given up in favor of a head of exactly the original Kestrel type before the engine could be got through a satisfactory type test. All the other differences between the two engines introduced during the original development of the Merlin were matters of detail.

From the very first, work and money were expended on the Merlin at a far more rapid rate than they were expended on the Allison, and this remained true at least until 1939. This action was in part due to the availability of larger funds for development of a liquid-cooled engine in the hands of the Air Ministry than in those of the American Army and Allison combined, but in part also to the ability of Rolls Royce to make use of money at greater rate, i.e., to its command of greater facilities and manpower. The availability of more money made it possible for Rolls Royce to build at least two engines of each of its earliest experimental models and half a dozen or a dozen of its later ones, whereas for the first four years Allison was able to build only one example of each successive model. This meant that Rolls Royce's development did not have to stop completely every time an engine broke down or was taken apart to change even a minor feature of the design. The availability of greater facilities and manpower meant that Rolls Royce could design the original engine and build two examples in a space of eight or nine months (early 1933 to October 1933), whereas it was 14 months after the Navy contract was signed, or probably about 16 months after verbal assurance was given, before the

first Allison could be designed and built. Inadequate shop facilities meant that Allison's development was considerably delayed by the need of waiting for replacement parts to be manufactured after a failure occurred.

The difference in rapidity of work was great even at the beginning of the two developments. Within two years Rolls Royce had built and tested the original A model, and then designed, built, and put on test two engines of the B model with a completely new cylinder head (February 1935). In the same space of time (to mid-1932) Allison had built and tested only the original engine with two different blower ratios and was building a very slightly altered B model. After the end of the first two years the difference in favor of Rolls Royce became enormous: within the third year of the Merlin development (March 1935 to May 1936) the C model with separate block and crankcase and the D, E, and F models with other changes were all built and tested. Allison spent half of its third year (to the end of 1932) getting its second model through development tests, and in the second half (to mid-1933) built one engine (C model) for the Army and one reversible airship engine for the Navy; the fourth year of the development (up to mid-1934) was entirely passed in getting these two engines through their development tests.

The pace of the Allison development was slightly increased at the beginning of the fifth year of the project (mid-1934), when Army orders were received for eleven engines, but this order did not mean that Allison could proceed immediately to build and be paid for eleven experimental engines; acceptance was subject to adequate performance, and the result was that only one engine was actually paid for in 1935[19] and two in 1936. The Army payments were so far from covering development costs (as distinct from the building of experimental engines) that the engineering staff of the company was scarcely increased and virtually all of the not inconsiderable private capital being put in the development was used on running expenses rather than on new facilities. Altogether Allison had built only about a dozen engines, three of which were reversible

[19]Allison also sold two reversible engines to the Navy in that year.

airship models, from the beginning of the development in 1930 to the time the 1,000-hp type test was passed early in 1937. Rolls Royce built nearly two dozen experimental engines between the beginning of the Merlin development early in 1933 and the passing of the 1,000-hp type test late in 1936, and in the middle of 1936 had begun production on an order for 180 service engines, even though the experimental engines had not yet passed a satisfactory type test.

Lack of money, manpower, and facilities was, however, by no means the only cause of the slow pace of the Allison development. One of the most surprising facts in the history of the engine is the very late date at which it was first put up for a type test. No type test seems to have been attempted until 1935, five years after the development had been begun,[20] and the result of the test was the discovery that although it had been thought that the development was nearly complete it was really almost at its very beginning. It seems almost incredible that either the company or the military services should have allowed more than a year or so to have passed before beginning this sort of testing; the Merlin was type tested less than 18 months after the designing of the engine was begun, and it was one of the first two engines built which passed the first test, in July 1934. This test, to be sure, was not at the full output ultimately obtained from the Merlin, but it was a valuable step in the development of the engine. Less than a year later, in May 1935, the Merlin was put up for type test at a rating of slightly over 1,000 hp, and it was the difficulties revealed in repeated unsuccessful attempts at this test which to a large extent guided the subsequent development of the engine.

Another similar factor delaying the development of the Allison was the lateness at which systematic flight testing was begun. Very extensive flight testing of the Merlin was started in April 1935, little more than two years after the design of the engine was started, and it was one of the two engines of the first model built which was the first to be flown. In the case of the Allison, on the contrary, the first flight tests were not made until late in 1936, over six years after the development was

[20]The unsupercharged reversible airship model had never passed a full type test, although it had passed a 150-hour dynamometer test at 650 hp in September 1934.

begun, and actually a year after the Merlin was flown. This meant first of all that a great number of future difficulties with the engine were not revealed until very late in the development. It also meant in particular that it was not until late in the 1930's that it was finally discovered that there was no advantage to be gained by enforcing the Army's requirement of 300° F coolant (cf. above, p. 269, n. 4.); the course of development might have been appreciably simplified if the requirement had been reduced to 250° earlier in the process.

There can be little question that the Army made a serious error when in the middle of 1934 it compelled Allison to undertake the development of a new model of the engine equipped with fuel injection as well as the original engine with a carburetor. It is not that there were not good reasons for this requirement: fuel injection was thought at the time to have certain very great advantages over a carburetor, especially the float type of carburetor which was the only one then in existence; and since the Marvel injector, the only one then available, could be built for a 12-cylinder engine but not for a 14-cylinder engine, it was thought that one of the advantages of the in-line engine would be its ability to use injection (cf. p. 532). Despite these reasons, however, to impose this requirement at this stage in the development of the Allison engine was certainly a mistake; especially in view of the limited resources available, nothing should have been allowed to interfere before a sound and proved basic engine had been developed. The Army's action was additionally open to criticism because the Marvel injector was itself far from being completely developed.

Despite all these outside factors which delayed and complicated the development, it is difficult to understand why certain weaknesses of the Allison design were so slow in being corrected. The most striking of these by far is the reduction gear, which was of a type that had been tried before the Allison was designed, and which — as Wright Field engineers pointed out to the company from the beginning — had never been known to succeed. It was this gear which was the first part to fail in the attempted type test of 1935, but the next year was largely wasted in trying to remedy the trouble with minor changes before it was finally decided that the gear and crankshaft had to be redesigned, and even then the basic type of gear with an overhung pinion was left unchanged. It was not until 1938 or 1939 that development was begun of the F model in which a new type of gear was used. As late as 1936 it was found that the coolant passages in the block were not properly designed to provide adequate cooling with glycol. Very little was known in 1930 about the proper design of a block for glycol cooling, and it is not at all surprising that the first design was inadequate; but even granting the lack of resources which made the development proceed slowly this should have been discovered and remedied long before six years had passed. In 1936 a basic redesign of the manifold system was also found to be necessary, and while it is true that this discovery may have been somewhat delayed by the Army's insistence on development of an injection engine, still the original engine and all the work done until mid-1934 had been based on the use of a carburetor exclusively. This constitutes evidence of poor judgment, not in the making of the original mistakes, but in the company's undue slowness to recognize its mistakes as such and correct them.

Such were the most important reasons why it took Allison almost twice as long as Rolls Royce, seven years instead of three and a half, to pass a type test at almost exactly the same rating. The passing of a type test does not mean, of course, that an engine is sure to be adequately reliable in service, and in fact neither the first production model of the Allison nor the first production model of the Merlin was at all satisfactory as a service engine. But whereas the Merlin was fully ready for service by the middle of 1939 at the latest, and probably by the middle of 1938,[21] the Allison was completely unsatisfactory in 1940, and could not equal the Merlin's power in service until 1941, despite the fact that it was type-tested only a few months after the Merlin at an equal rating.

The factors which delayed the progress of the Allison from type test to full service reliability at fully competitive power are not greatly different from those which delayed it before, except that one new factor now entered: lack of sufficient service

[21]There is no information available on service difficulties with the Merlin II, which was put in production in August 1937, nor is it known whether minor changes were made in it between August 1937 and its first use in the war.

experience. Deliveries of production Merlin I engines began in July 1936, despite the fact that that model did not pass a type test until November of that year, and then could not have passed it unless the regulations had been especially relaxed. Even a service-test order for the Allison was not given, on the contrary, until November 1937 and deliveries on this order did not begin until late in 1938.[22] It is at least equally important that Rolls Royce already had production facilities which enabled that company to turn out the production Merlin I's fairly rapidly — 180 were produced within about a year — whereas Allison had no production facilities at all and had to acquire them before production could begin. While the Army was certainly at fault in waiting most of a year after the passing of the type test before it gave an order for service-test engines late in 1937, it was Allison's lack of facilities which was responsible for the fact that of these 60 engines only 11 had been delivered by the end of the next year, 1938. Even if the Army had given a production order immediately after the passing of the type test, it would certainly have taken at least until 1939 before genuine quantity production could begin. This, of course, is just one of the inevitable difficulties involved in creating a new source of supply for so complex a product as a high-power aircraft engine.

The lack of airplanes in which to fly the Allison was a serious handicap to making full use of what little service-test production there was in 1938 and 1939. Even if Allison had been able to deliver more than 11 of the 60 service-test engines before the end of 1938, very few of the additional engines could have been flown before the end of 1939. Thirteen engines of this order were for 13 YP-37's, which were ready as soon as the engines, but 26 were for 13 YFM-1 Airacudas, only one of which had been delivered by the end of 1939, and the rest were spares. The Merlin I, on the contrary, was already being used by a full

[22]This difference, however, is not entirely due to a wiser policy on the part of the British Air Ministry than on the part of the American Army as regards engine development *per se*. The British were literally forced into their action by the fact that the whole planning of the RAF was based very largely on the Merlin, and that airplanes were already in production for which no alternative engine was available. In the United States it was not until after the type test was passed that a prototype airplane was designed for the Allison.

squadron of Fairey Battles in May 1937, and additional squadrons were rapidly being formed, so that a good deal of information was gathered which could be used to modify the Merlin II before that engine was put in production in August 1937. The first squadron of Hurricanes, powered by Merlin II's, was formed in December 1937, only four months after production of the engine began.

Allison's task was complicated after the passing of the type test by the Army's desire to have three special models developed for installation in three unorthodox airplanes. If we leave out one new model (C9) whose only difference from the standard engine consisted in opposite direction of rotation, there were still two with really distinctive features. Allison already in 1936 had begun development of the D model with an extension propeller shaft for the Airacuda; this work continued during 1937. In 1938 the E model was begun, with a longer, high-speed extension shaft and a remote reduction gear for the P-39. In addition, Allison began work in 1937 on the development of a twin V-1710 known as the V-3420 in accordance with the Army's desire for a 2,000-hp bomber engine; fortunately the firm refused the Army's request to develop a completely new and still larger engine, and chose the design which involved the least additional problems beyond those already encountered with the V-1710.

The Army's reasons for desiring all these engines to be developed were perfectly good in themselves. The Airacuda was a type of airplane which the tactical thinkers of the day believed would be extremely valuable, while the Airacobra seemed to offer a number of advantages over the more conventional type of single-seat fighter, and neither airframe could be developed and tested unless the Allison was made available with the proper drive. The fact that the Airacuda ultimately proved to be a useless type of aircraft had nothing at all to do with the engineering as such of either the airframe or the engine, while the weaknesses of the Airacobra had nothing to do with the special drive. As for the V-3420, an engine of this power was badly needed for the type of bomber which current thought demanded, and it was far from certain in 1937 that another 2,000-hp engine would be soon available: development

of the R-2800 and the R-3350 was just beginning. Nevertheless, although these projects might have been justified if Allison had had the resources and experience of Rolls Royce,[23] it would seem to be clear that nothing should have been allowed to detract from the primary job of getting a usable basic engine when the company doing the job had such limited experience and resources.

The one new model whose development after 1937 was certainly justified was the F, intended as a replacement for the C in the same installations but with a number of changes the need for which was indicated by experience and in particular with a completely new reduction gear of orthodox and sound design. It is difficult to understand why this model could not be brought through a first type test until June 1940, so that it could not be put in production until 1941. Some of the reason for the latter part of the delay may have lain in the fact that the tooling which had been set up for the production of the Allison had been designed along the lines used in the automobile industry, with very specialized machines which made for a minimum of labor used but for a maximum of difficulty in introducing a change of models.

Summary

The apparent lack of an adequate market for liquid-cooled engines was the major factor in the abandonment of this type by the major American manufacturers early in the 1930's. The apparent advantages of the type for certain specialized military applications led the services, on the other hand, to support its continued development throughout the 1930's. Because the major manufacturers were disinterested, most of

[23] During the period from 1933 to 1939 Rolls Royce, in addition to developing the Merlin, worked on the development of a two-stroke engine and a large air-cooled X, continued the development of the Kestrel until 1935 and in 1939 brought out a completely new engine of the same size (the Peregrine), and in 1937 began development of the 24-cylinder Vulture, which was type-tested in August 1939. Even after the resources assigned to all these projects had been deducted, however, Rolls Royce still had more available for the Merlin than Allison had for all its projects; and, even more important, it did not hesitate to draw from the resources assigned to the other projects when a crisis was encountered in the development of the Merlin.

this work had to be done by small firms with inadequate experience, facilities, and manpower; and the funds at the services' disposition were far too small for the purpose. Primarily as a result of these factors, two of the three projects begun early in the 1930's came through too late to see any service whatsoever.

Only the Allison V-1710 was ready in time to be used in the war: it had been begun somewhat before the other two, and Allison had invested nearly $1 million in it before quantity sales began. Even so, the V-1710 was far behind the Rolls Royce Merlin until about 1941, and in some respects (especially supercharging) was never the equal of the Merlin. Despite these weaknesses, however, the Army's sponsorship of liquid-cooled engines in face of the coolness of the major engine builders was more than justified by the results: Allison-powered fighters were on the whole superior to fighters powered by any other American engine until 1943 or 1944.