CHAPTER X

The Development of Liquid-Cooled Engines in the United States in the 1930's

From 1932 to 1939

By 1932 the Army had become convinced that Curtiss-Wright, whose Conqueror was the only American liquid-cooled engine still in production, could no longer be looked to as a source for a really modern engine of that type. By this time the Conqueror-powered P-6 fighter was generally inferior to the contemporary Wasp-powered P-12 and P-26 at a time when (as has been said) a British fighter, the Hawker Fury, with a Rolls Royce liquid-cooled engine had performance at altitudes of 15,000 to 20,000 feet which the Wasp-powered American fighters could not equal. Technically, the Army considered the basic design of the Conqueror ill-suited to high-temperature cooling, and experiments conducted at Wright Field about 1931 had convinced the Army that far higher outputs per pound of weight were possible in a liquid-cooled engine than could ever be achieved by further development of the basic design of the Conqueror. The Army was convinced, furthermore, and probably rightly, that Wright Aeronautical would never again enter whole-heartedly into the development of a new liquid-cooled engine.

The Army concluded that it was not worth while to continue using its experimental funds to support development of liquid-cooled engines by Wright and stopped doing so in 1932. This meant the end, at least for a time, of all hope that liquid-cooled development could be financed in the same way as air-cooled development, with the larger part of the costs being paid out of profits from production. The Army accepted this as a necessity, however, and during the rest of the decade what funds it had available for liquid-cooled development were spent elsewhere.

Navy Support of Wright Aeronautical: 1930-1936

The Navy did support the development by Wright of two new liquid-cooled engines in the first half of the 1930's. This was part of a special "high-speed development program" which was undertaken by the Navy in 1930 as a result of concern over the growing superiority of foreign airplanes to American in top speed, especially as demonstrated in the 1929 Schneider Trophy contest and again in 1931. The share of the cost of these two developments borne by the Navy was large, owing to the very limited market which the company foresaw for such special-purpose engines; and since the Navy's funds for this purpose were very small the developments were on a comparatively small scale.

The first of the two engines was a completely unhappy design. In 1926 Curtiss had designed a two-row, 12-cylinder, air-cooled radial, the H-1640, which was very small in diameter. Although this engine had been generally unsuccessful, Wright and the Navy decided in 1930 that because of its very small diameter (the importance of which in reducing drag was generally much exaggerated at that time) this basic design, converted to liquid-cooling and with the cylinders somewhat enlarged, would make a good racing engine. The new engine was ultimately to have four rows of six cylinders each, a displacement of 4,240 cu in., and an output of about 2,000 hp; development was to begin with a two-row portion, which was known as the H-2120. The extremely small diameter entailed excessive angularity of the connecting rods as well as a peculiar motion of all but the master rod, and general development was much delayed by an attempt to develop a "true-motion" rod which was ultimately abandoned. Testing and development continued from about 1933 to 1936, when a 100-hour development test was run at 1,000 hp. The Navy, however, then withdrew support from the project, apparently not so much because of the faults of this particular engine as because it had decided to revert to its old policy of using and developing air-cooled engines exclusively. The company, convinced by then that the design was mechanically very poor, made little effort to persuade the Navy to change its decision and dropped the project.

About 1932 the Navy had also undertaken to support development by Wright of another liquid-cooled engine, a 12-cylinder vee known as the V-1800. This engine, which was intended to replace the Conqueror, had individual cylinders specifically designed for high-temperature cooling and was to be supercharged to about 12,000 feet. The V-1800 was first run late in 1932 or early in 1933, and in June 1934 underwent a 50-hour development test, all of which was run at 800 hp. Shortly after this test was completed, however, the Navy was forced by lack of funds[1] to abandon most of its high-speed program and to cease support of the V-1800. The Army refused any appreciable support, and the company did not wish to do further development at its own expense.[2]

The Army's Resources

The resources with which the Army in 1932 undertook to create a new source for liquid-cooled engines were absurdly small in comparison with the magnitude of the task. It is true that in the years 1930-1936 the Air Corps appropriations averaged about $30 million, and that in the years 1937-1939 they increased from $50 to $75 million, but only a tiny part of this was available for research and development, and about half of this part was required for the salaries of the Wright Field establishment. Thus, even if service-test procurement is included with research and development expenditures, there was available for payment to manufacturers for development of all aeronautical materiel only some $1.5 million per year from 1930 to 1935 and perhaps $3 to $4 million from 1936 to 1939. Of this, only between a quarter and a third could be used for power plants of all types, and of course a certain part of this share had to be used for special military development of air-cooled engines and for the purchase of samples of new engines developed at private expense. For supporting the development of liquid-cooled engines, the Army had available about

[1]The Navy received $220,000 for its high-speed program in the appropriation for fiscal 1932 and the same amount in fiscal 1933. A private contribution of £100,000 ($500,000) paid only a part of the cost to the British of participation in the Schneider Trophy contest in 1931.

[2]The design was sold to the Russians and at their expense enough work was done to raise the rating of the engine to about 900 hp.

$150,000 a year in the first half of the 1930's and about three times as much in the latter half.

The inadequacy of these amounts can best be appreciated by comparing them with the annual engineering budgets of either Wright Aeronautical or Pratt & Whitney: out of its revenue from concurrent quantity production each of these two principal makers of air-cooled engines alone annually spent on development an amount from five to ten times as great as the Army could afford to pay for development and service test to all manufacturers of liquid-cooled engines together. Out of these limited resources the Army gave aid to two companies, Continental and Allison, continuously from 1932 to the end of the decade, and, although in smaller extent, to two others, Lycoming and Pratt & Whitney, in its second half.

Continental

About 1930 experiments were begun at Wright Field at the instigation and under the direction of S. D. Heron to determine whether it was true, as had been asserted by the English engineer H. R. Ricardo, that the poppet valve had already reached its limit in specific output (power per cubic inch of cylinder capacity) and should be replaced by sleeve valves. These experiments were made on a single-cylinder engine using the air-cooled cylinder developed by Heron in 1923-1924 for the converted Liberty engine; to secure adequate cooling at very high outputs a water jacket was constructed around the barrel of the cylinder and a spray of water was directed on its head. Specific outputs far higher than the limit stated by Ricardo[3] were obtained at once, and with this encouragement further experiments were made with the air-cooled cylinder converted to genuine water cooling by the construction of a complete water jacket. The specific outputs obtained from this cylinder (cf. below, p. 670) were so far superior to those of any current engine, air- or liquid-cooled, that the Army at once became enthusiastic over the idea of developing a "Hyper"

[3]One of the most important reasons why this engine (and all later poppet-valve engines) could so far exceed the limit set by Ricardo was the use of internally cooled valves, which had been developed by Heron for the Army in the 1920's (cf. Chapter VII, Appendix, p. 197), but which were not adopted in Britain until 1931.

cylinder along these lines and of using it as the basis of a new liquid-cooled engine, which was to have a normal rating of 1,000 hp with 1,200 hp for take-off.

The Hyper cylinder was to have the same 4⅝-in. bore as the air-cooled Liberty which had been used in the experiments, but to permit higher speeds of rotation the stroke was to be shortened from 7 in. to 5 in., giving a displacement of 84.0 cu in., or a total of 1,008 in the 1,000-hp 12-cylinder vee-type engine which was to be built around it. The Army also decided that in order to operate satisfactorily with ethylene glycol at 300° F, which was considered desirable in order to minimize the weight and drag of the radiator,[4] the cylinders would have to be constructed individually, not en bloc, despite the contribution of rigid block construction to the reliability of an in-line engine with its long, flexible crankshaft, and despite the greater length of an engine with individual cylinders.[5]

In 1932 an agreement for the engineering and development of this cylinder and of the engine employing it was reached between the Army and the Continental Motor Company. Continental had been in the 1920's the most successful manufacturer of engines for automobiles and trucks built by other makers. It had entered the aviation field in 1928 with a medium-power air-cooled radial, and in October 1931 had received a Navy contract for a radial air-cooled engine with single-sleeve valves.[6] The company had earlier had an unimportant contract with the Army for a single-sleeve-valve liquid-cooled engine, which was dropped because of poor performance at the time the Hyper project was undertaken.

Continental's role in the Hyper project was essentially to be nothing but routine engineering and testing. The Army not only had decided upon the basic principles and the size of the Hyper cylinder but also had laid down the main lines of the

[4]It was only at the end of the 1930's that the Army requirement was lowered to 250° F after experience with the Allison had shown that an engine operated with a coolant temperature of 300° transferred so much heat to the oil that the total size of combined oil and coolant radiators was just as great as when the coolant was kept at 250°.

[5]It was and still is argued by many, however, that individual cylinders would be preferable in any case because of greater ease of production and freedom from head and block cracks.

[6]This was the valve advocated by Ricardo (cf. above, p. 268).

complete engine in which it was to be used, and the first two years of work were actually done in a special office set up by the company in Dayton to be near Wright Field.

The original cylinder, Hyper No. 1, was tested in 1933. Its intended power, 1.00 hp/cu in., was extremely high for the time — the Rolls Royce Merlin was designed in this same year for an initial rating of 750 hp or 0.46 hp/cu in.[7] — and for the fuel of Performance Number[8] 75 on which the Army intended to obtain this rating. Wright Field soon began to worry also about the possibility of obtaining a supercharger adequate to give this very high specific output. Finally, it became known that foreign liquid-cooled engines were being based on considerably lower specific power. In 1934 the Army instructed Continental to proceed with a cylinder of somewhat larger size (118.8 cu in. instead of 84.0) and reduced performance, Hyper No. 2.[9] The output aimed at from what was then a 1,425-cu in. engine was still 1,000 hp, amounting to 0.70 hp/cu in. This goal seems to have been reasonable enough: the Rolls Royce Merlin was type-tested in 1936 at 0.62 hp/cu in. on 68-PN (87-octane) fuel, and as far as detonation was concerned this rating could have been raised to about 0.70 hp/cu in. by the use of the 75-PN fuel the Army planned to use in the Hyper engine.

At this time the first design studies were made of a complete engine in which the new type of cylinder was to be tried out. The Army's original intention had been a 12-cylinder vee, and both the power-plant branch at Wright Field and the company would have preferred for mechanical reasons to adhere to this plan. The airplane branch at Wright Field, however, was then absolutely convinced that the engines of virtually all future airplanes, including even fighters, would be buried in

[7]By the end of the war the Merlin had reached an emergency rating of 1.20 hp/cu in. (1,980 hp), and with water injection the Packard-built Merlin obtained a rating of 1.33 hp/cu in. (2,200 hp), but these ratings were a result both of long and intensive development and of much better fuels than were available in 1932.

[8]See below, p. 603, n. 4.

[9]Even this larger cylinder with a displacement of 118.8 cu in. was only 10% larger than the 108 of the Rolls Royce Kestrel, which the British now thought too small, and was 14% smaller than the 137.4 of the Merlin, development of which had been begun by Rolls Royce in the same year as Hyper No. 1 (1932).

the wings for the sake of higher speed, and at their insistence the Army specified that the new cylinder be the basis of a "flat" or opposed engine. This was the origin of the Continental O-1430.

It was not until 1938 that the first complete O-1430 was actually built; it passed its 50-hour development test at 1,000 hp in 1939, two years after the Allison had passed a full 150-hour type test at this same power and three years after the Rolls Royce Merlin had been type-tested at 1,030 hp. In the first six years of the project, from 1932 to 1938, Continental had done virtually nothing but single-cylinder development. This sort of work normally accompanies development of any engine, and a certain amount had to precede building of a complete engine when the basic cylinder was so radically different from what was known and tried, but work should have begun on a complete engine long before six years had passed.

The slowness of this development is largely explained by the fact that the total investment in the engine by 1939 was less than a half million dollars, virtually all supplied by the Army; the development expenses in these first seven years had been about a fourth of those of Allison in the seven years from 1930 to 1937. Wright Field had believed in 1932 that the 1,000-hp engine could be quickly produced and sold in quantity to the Army for use in fighters and perhaps for other applications also, and it was hoped that the company would then use a part of the profits on these sales to help finance the development of larger liquid-cooled engines in the same way that the development of new air-cooled engines was being financed. As technical difficulties appeared to delay the attainment of this goal, it might have been expected that the company would push the project with every possible effort, since the market for its chief product was rapidly disappearing as almost all automobile manufacturers began to make their own engines. The company's other products were unimportant; its other aviation project, sleeve-valve air-cooled radials, was far from complete, and even if successful would directly face the competition of Wright and Pratt & Whitney instead of having the relatively clear field open to a modern liquid-cooled engine. Despite this fact, however, the company was unable or unwilling to put any appreciable amount of its own funds into the project.[10]

As far as ability was concerned, it is true that since 1930 the company had been losing money at a rate of $2,000,000 or more per year, and that between 1929 and 1934 its working capital had shrunk from nearly $10,000,000 to $300,000, but it had nevertheless continued during this period to invest in a single-sleeve-valve automobile engine, $753,000 being written off as a loss in 1935. The real difficulty was simply the company's lack of faith, not in the technical soundness of the project, but in the prospect of sales of even a successful product. Even though some engineers at Wright Field believed that engines based on the Hyper cylinder might prove best for all types of combat planes, no one at all foresaw any commercial use, and the company thought of it as purely a fighter engine and did not believe that the probable market for fighter engines was large enough or sure enough to warrant the risk of any company money. It was the huge prospective market which encouraged heavy investment in an automotive engine despite all financial difficulties.

Thus the entire burden of financing the development was left to the Army's experimental funds. All Continental's contracts with the Army were of the fixed-price type, each individual contract specifying in detail the work to be done in the "phase", i.e., the portion of the whole job, which it covered, and management insisted on a signed contract for every expense, however small. The formalities made necessary by the laws governing Army procurement meant that there was considerable delay in negotiating a new contract as each new phase was begun, and work virtually stopped during these intervals. Since the Army's experimental funds were so slight that it could not afford to give a contract unless a need were conclusively demonstrated, even such obvious precautions as the provision of spare parts to provide for breakage in test were not made by either side. Test facilities were at least an equally serious problem, since the company would not buy special ones and the Army's procurement rules prevented Army payment

[10]Until 1940 all construction and testing were paid for by the Army; the company contributed various design studies of multicylinder engines.

for them as a cost of development; on occasion they were lent by the Army.

By the time the O-1430 had got through its development test in 1939, if not still earlier, the Army had decided that 1,000-hp engines were obsolete for all purposes. As will be explained directly, they had also concluded that the power needed for large airplanes could not possibly be obtained from an engine of the displacement of the Continental even if its power was pushed to the limit of development. Wright Field hoped, however, that the output of this engine could be increased enough over the original aim to suffice for a fighter. Fighter wings were then much too thin to make a submerged installation, and since the opposed engine was an inconvenient type to install in the nose of a single-engine fighter it was decided to develop the engine as a vee. The company would have much preferred a vee of the standard upright type, but the tactical officers of the Air Corps had become convinced that they wanted an inverted vee for improved visibility,[11] and early in 1939 instructions were given to Continental to drop work on the O-1430 and begin work on an inverted IV-1430.

Allison[12]

The Continental O-1430, which was almost entirely designed by Wright Field, represented Wright Field's own ideas of the proper basic principles for a modern liquid-cooled engine. The next engine to be considered, the Allison V-1710, was a design of completely private origin. There is a second, equally important difference between the two developments: the Continental development was begun at Army initiative and every step was fully paid for with Army funds; the Allison was begun at private initiative and more than half supported out of private funds.

[11]The decision to use inverted rather than upright vees was largely if not entirely due to Colonel Charles A. Lindbergh, who held no active position in the Army. Lindbergh had recently inspected the new German airplanes and had been much impressed especially by flying the Messerschmitt Me 109, which had an inverted-vee Daimler-Benz 601 engine. Continental would have preferred an upright vee both because it believed it easier to install and because it would have been easily interchangeable with the Allison in airframes designed for that engine, but the top authorities of the Air Corps insisted absolutely on an inverted engine.

[12]R. M. Hazen, "The Allison Aircraft Engine Development," *SAE Journal* (*Transactions*) 49, 1941, pp. 488-500.

The Allison Engineering Company had been until 1930 little more than a large and well-equipped precision job shop. It had been founded to build and repair racing cars competing on the Indianapolis speedway, and its only regular production was of steel-backed lead-bronze bearings, mostly used in aircraft engines, although it built to order a large variety of gears and of extension and angle drives for all kinds of high-power engines. The company had built a number of experimental marine engines, and had had a good deal of experience in the conversion of Liberty engines to improved designs provided by the Army and Navy. Allison's first independently designed aircraft engine had been a six-cylinder 765-hp two-stroke Diesel for airships, built under a Navy contract of 1927. This engine had passed its preliminary tests successfully but was dropped by the Navy because of the difficulty of recovering sufficient water for ballast from the exhaust of a two-stroke, Diesel engine.

In the latter half of the 1920's, as has been told, the Army was becoming enthusiastic over the possibilities of reduced weight and drag indicated by the results of its experiments on high-temperature cooling, but believed that the cylinder design of the standard water-cooled engine of that time, the Curtiss Conqueror, was basically unsuited to it (cf. above, p. 261, n. 11). Knowledge of these facts led Allison's manager, N. H. Gilman, to make preliminary designs in 1928 of a cylinder better suited to high-temperature cooling. Gilman tried to get a development contract from the Army, but the Army preferred to rely on Curtiss as being an established and experienced engine builder. In 1929, after the death of James Allison, the company was bought by the Fisher Brothers Investment Corporation, and at the instructions of Lawrence P. Fisher, Gilman designed and built a small six-cylinder liquid-cooled engine for a "family plane", using a cylinder construction much like that sketched out the year before. This project was continued when Allison was sold by Fisher Brothers to General Motors later in 1929, and tests of the cylinders during 1930-1931 indicated that they were very well suited to high-temperature cooling. The project was dropped, in 1931, as part of a general retrenchment program due to the depression.

Early in 1930 Gilman had also sketched out a larger 12-cylinder engine, aimed at an output of about 750 hp, which was specifically designed for glycol cooling and for the use of a turbosupercharger; the possibility of using the turbosupercharger was, of course, one of the Army's chief reasons for supporting the development of liquid-cooled engines. General Motors, which wanted a product which would lead to regular production, had already begun to be very dubious of the advisability of continuing with liquid-cooled aircraft engines, since by far the largest share of the market seemed to be going to air-cooled engines. Gilman nevertheless persuaded the corporation to let him make a general layout of his liquid-cooled engine at the company's expense, and this was the origin of the V-1710.

The Army still refused support when the layout was presented at Wright Field, since it still hoped in 1930 that Curtiss's successor, Wright, would continue development of the Curtiss liquid-cooled engines and would come through with an improved design, and at the same time doubted very much whether Allison had the necessary background for independent development of a high-power engine. In any case, the Army already believed that even though the Allison block might be superior to the Conqueror block for 300° glycol, what was really needed was individual cylinders; it was this belief which ultimately led in 1932 to the beginning of the development of the Continental engine. Wright Field suggested, however, that Allison try to sell its engine to the Navy, for which the Hall Aluminum Aircraft Company was designing a new four-engine flying boat, the XP2H-1, too large for the power then developed by an air-cooled engine.[13] Allison accordingly approached the Navy, and the Navy did become interested in the engine, although primarily for another reason. The Navy at this time was using German Maybach engines in its airships, and was anxious to have a suitable American engine developed for this purpose. Air-cooled engines were not considered suitable for airship use, both because of difficulties with cooling at low air speed and because it was believed possible to obtain much better fuel economy with a specially designed liquid-cooled engine.

[13] The Cyclone and Hornet were both rated 575 hp in 1930.

On June 28, 1930, the Navy gave Allison a contract for one engine to develop 650 hp at sea level. This engine, known as the V-1710-A, was to make possible a thorough test of Allison's basic design before going on to develop a specialized model for airship use. It was first run in August 1931; after various changes had been made and the blower ratio had been raised from 7:3 to 8:1,[14] the engine in 1932 passed a 50-hour development test, running with a club propeller on a rigid stand, at 750 hp at 2,400 rpm. On January 24, 1933, a contract was given for three reversible model B engines with no blower at all, for airship use; the Navy planned to buy 20 more engines as soon as these experimental engines were proved, and it was only because Allison was informed of these plans that the company was willing to accept the contract for the three experimental engines. The first B engine was built in 1933, but development proved a long task, and it was not until September 1934 that the necessary tests were passed by the first engine and construction of the other two was begun. On the day these two engines were ready to ship, February 12, 1935, the Macon was lost, and with it the Navy's airship program ended. The planned production order for 20 engines never materialized.

Meanwhile the Army had become interested in the engine. While the Army believed that the Continental engine, whose development was just beginning, would ultimately be superior to the Allison, it was becoming probable that the Continental development would take a number of years, and since hope in Wright had been given up, the Allison seemed to be the only possible way of arriving at a 1,000-hp, turbosupercharged, liquid-cooled fighter engine before the Continental was ready. In December 1932 the Army ordered a slightly modified version of the original Navy engine, with a larger impeller and other changes aimed at ultimately making the Allison into a 1,000-hp rather than a 750-hp engine. The new engine, the V-1710-C1, was delivered in June 1933, and in the next year it passed a 50-hour development test on the dynamometer at a rating of 800 hp at 2,400 rpm. In March 1934 the Army ordered one more V-1710 for type test, and in June 1934 ordered ten addi-

[14]The integral supercharger or blower in these engines supplied no more manifold pressure than could be used even at sea level.

tional engines, two with carburetors as before and eight with Marvel fuel injectors, which the company disliked but in which the Army had great hopes at this time. These orders convinced General Motors that the development should be backed with additional funds.

In the spring of 1935 the Army with some difficulty persuaded Allison to put an improved C1 engine through a 50-hour development test on the dynamometer at 1,000 hp, and the successful running of this test greatly encouraged the Army in its support of the engine. An attempt was then made at a 1,000-hp type test, but the engine got through only a very short period of the test before it broke down owing to the different conditions imposed by running on a rigid stand with a full flight propeller instead of on a dynamometer as in the 50-hour development tests. The rest of 1935 was lost in futile attempts to get the engine through the type test by modification of details of the design before it was finally decided that major design changes were required. The worst troubles were with breakage of the crankshaft and the reduction gear (which used an overhung pinion) and with cylinder block cracks. These parts were completely redesigned in a few months early in 1936, but although the engine could then be run for periods of 20 or 25 hours before breakdown, these runs showed that a number of other changes had to be made.

At this point a new engineer, R. M. Hazen, was put in charge of the work. The engine was then almost completely redesigned, the most important changes being the design of a completely new manifold system, the alteration of the coolant passages to be more effective with a viscous coolant like glycol, redesign of the combustion chamber, and new pistons. After these changes had been made, the V-1710-C6 in the latter half of 1936 got through 141 hours of a type test at 1,000 hp. In December 1936 the Army began extensive flight-testing of the earlier C4 model, in a Consolidated XA-11A[15] two-seat fighter.

Detailed development of the C6 produced the V-1710-C8, which passed its type test in March 1937. The normal rating on 87-octane fuel was 1,000 hp at 2,600 rpm at sea level; the

[15]The PB-2A without a turbosupercharger.

engine weighed 1,230 lb. This was only a few months after the Merlin passed a type test on the same fuel at the corresponding "international" rating of 990 hp at 2,600 rpm for a weight of 1,335 lb (cf. above, p. 219 and p. 220, n. 24).

At the same time that these urgent changes were being made in 1936 in the basic engine (C model), Allison at the Army's request developed another model, the D1, with an extension propeller shaft for the Bell four-place fighter or "destroyer" known as the XFM-1 Airacuda, which the Army had ordered in 1936. Since the company's engineering staff assigned to the V-1710 at this time consisted of less than 25 engineers, with an experimental shop of a little over 100, it was fortunate that the development of this special drive proved to be a fairly short job.

The first impressive demonstration of the merits of the Allison engine was made early in 1937, when Don R. Berlin, Chief Engineer of the Curtiss Aeroplane Division of Curtiss-Wright, persuaded the Army to test the C8 with a turbo in the Curtiss P-36 Hawk fighter, normally equipped with the air-cooled R-1830-13. The XP-37, as this experimental airplane was known, made a top speed of 340 mph at 20,000 feet, compared with 300 mph at 10,000 feet for the P-36.[16]

The success of the XP-37 had a very great influence on the Army's plans for future fighters. In addition to ordering 13 service-test YP-37's and the same number of YFM-1's, the Army during 1937 gave contracts for experimental prototypes of two new fighter airplanes based on the turbosupercharged Allison: in June 1937 the two-engine Lockheed XP-38 Lightning was ordered, and in October the single-engine Bell XP-39 Airacobra. This meant, however, that Allison then had to develop two more special engine models: a C9 with left-hand rotation for the XP-38, and an E2 with a new extension drive eight feet long and a remote reduction gear for the XP-39. A little later Allison began work on the F model with a com-

[16]The best of the contemporary American fighters was the Curtiss P-36. Exact figures for the performance of the original P-36 of 1936 and 1937 are difficult to obtain. After some changes had been made in the engine installation, it was officially rated 300 mph maximum at 900 hp at 10,000 feet, but its R-1830-13 engine was rated 900 hp at 10,000 feet, and the effect of ram should have brought the maximum speed at a somewhat higher altitude.

pletely different reduction gear, which located the propeller shaft 10 in. higher and eliminated the difficulties with the overhung pinion. In addition to backing these plans for liquid-cooled fighter engines, moreover, high officials in the Army now believed that liquid-cooled engines would soon displace air-cooled in weight-carrying airplanes as well, and development of a double engine, the V-3420, was accordingly begun by Allison in 1937.[17] At the same time Allison had to continue improvement of the engine which had had the original success in the XP-37; this improvement resulted in the C10 engine, still rated 1,000 hp normal on 87-octane fuel, but with 1,150 hp at 2,950 rpm instead of 1,000 hp at 2,600 rpm for take-off; this engine was used in the service-test YP-37's received in 1938-1939.

During the development of these engines in 1937 and 1938 Allison was very much worried by the fact that all the Army's plans for the use of its engine depended on the turbosupercharger. There was still a great deal of development to be done before the turbosupercharger and its controls could reach the degree of reliability necessary for general service use, and in addition there were still unsolved problems with propellers and ignition at the 20,000 foot altitude reached with the turbo.[18] During 1938, about a year before the delivery of the turbo-supercharged XP-38, XP-39, and YP-37's, the Army became convinced, largely by the arguments of Allison, Curtiss, and Bell, that it was unwise to risk everything on the turbosupercharger, and that a medium-altitude fighter should be developed. As a result of this decision one of the production P-36A's was converted in 1938 into the XP-40 by using the C13 Allison, for which a single-stage blower of higher pressure ratio had been developed; this model had a military rating of 1,090 hp at 2,950 rpm at 10,000 feet. The XP-40 was first flown in October 1938, and after some improvements had been made it

[17]Some of the engineers at Wright Field would have preferred a still larger engine, and wanted a design with a single crankshaft. Allison very wisely refused to undertake anything more novel than the V-3420, which was simply two V-1710's geared together on a common crankcase, and the head of the engine laboratory at Wright Field, Colonel E. R. Page, liked very much the ease of production which resulted from interchangeability of most of the parts with the V-1710.

[18]There was still a great deal of trouble with the controls of the turbo as late as 1942 in the P-38.

won the Army fighter competition held in the spring of 1939.

The success of the XP-40 in 1939 brought orders for the V-1710 which at last put an end to nine years of continual losses suffered by Allison in its development. From 1930, when active development of the V-1710 began, through 1937, when the type test was passed, the Navy and Army had spent over $1 million on the Allison development, including what was paid to Allison for installing and flight-testing it in various airplanes. This was about twice the total cost of the first seven years of the Continental development, and yet for Allison the project had never paid its way, and in every year but one had failed to cover even the direct costs without any allotment of overhead or general administrative expense. The company's own investment was $900,000, or more than the total received from the government for direct engine development. The yearly investment of the company in capitalized engineering had in fact usually been greater than the income from the company's other business, so that the project could not have been completed had Allison been unable to draw on the resources of General Motors. Even so, the funds available had been so limited in proportion to the size of the undertaking that development was seriously retarded; it has already been mentioned that until about this date the total engineering staff working on the engine was some 25 people. The total cost of some $1.5 million by the time the type test was passed in 1937 is not to be considered large in proportion to the accomplishment: it is only slightly over one half what was spent on the R-2800 before that engine was put in production by Pratt & Whitney, a company with incomparably more background knowledge and experience. Even the passing of the type test and the successful flight tests early in 1937 in the XP-37 and in September in the XFM-1 by no means sufficed to put the engine in the class of a profitable product. The only orders which resulted were from the Army: one for 40 of the D model engines for the YFM-1, and one shortly thereafter for 20 of the C for the YP-37, both received late in 1937. These orders accounted for all Allison's production until well into 1939; 11 of the engines were delivered in 1938, the remainder in 1939.

After the winning of the fighter competition by the XP-40 in the spring of 1939, the Army in April 1939 placed an order for 393 engines; this was increased in June to 969 engines for $15 million, the largest engine order yet placed by the American government. The demonstration of the XP-40 to the French mission shortly after the competition led quickly to a French order for 815 engines of the C model. In the spring of 1940 the British ordered 3,500 engines of the C, D, E, and F models. By the end of 1941 it had been possible to amortize almost all the capitalized development costs of the engine over the more than 6,000 engines delivered by then, but it should be remarked that this number of engines represented the total military requirements for high-power engines of all types for ten normal prewar years.

Lycoming

A liquid-cooled cylinder and 12-cylinder flat engine of extremely high specific power, very much like the Continental Hyper engine, were developed by the Lycoming Manufacturing Company[19] along technical lines almost identical to those of the Continental, and the two developments were approximately concurrent in time. The chief differences between the developments were, first, a much smaller degree of direct Army participation in the design of the Lycoming engine, and second, a considerably greater willingness of Lycoming to proceed on its own initiative and to a certain extent with its own funds.

In the fall of 1932, only a few months after Continental had undertaken its Hyper project, Lycoming on its own initiative undertook a similar project. No invitation had been given by the Army and no proposal was made by Lycoming at this time, but it was, of course, general knowledge that the Army was intensely interested in an extremely small 1,000-hp liquid-cooled engine. The cylinder designed by Lycoming to meet this general specification turned out to be intermediate in size between the Army's Hyper No. 1 and Hyper No. 2; its displacement was 102.8 cu in., giving a total displacement of 1,234 cu in. in a 12-cylinder engine. Like the Hyper engine,

[19]After October 1939 the Lycoming Division of the Aviation Corp.

the Lycoming engine was to be built with individual cylinders rather than a block.

The single cylinder was built and tested after a year and a half, in the spring of 1934, and the results were sufficiently promising for the Army to give a first development contract to Lycoming about a year later, in 1935. The single-cylinder development test was passed in 1936, and the company proceeded to design the 12-cylinder O-1230 engine around it. To comply with the Army's wishes for an engine which could be installed in a wing, the same opposed cylinder arrangement was used which the Army had specified for the Continental engine.

The O-1230 was ready for test late in 1937, only two years after the first Army contract was signed, whereas it was not until the next year that Continental, which had already had a contract in 1932, even began construction of its O-1430. The greater rapidity of Lycoming's development cannot be attributed either to superior company resources or to more generous treatment by the Army. Lycoming's engineering staff was of about the same size as Continental's, and Lycoming's test facilities were neither more nor less adequate on the whole than Continental's. Lycoming received no Army money at all until 1935, and after that no more on the average than Continental. The Army contracts with Lycoming were of the same fixed-price type as those with Continental, so that neither firm had any assurance that the Army would pay for extra work which should unexpectedly seem desirable. Thus the only important reason for Lycoming's more rapid progress seems to have been simply that the company believed in its engine and the market for it enough to risk some of its own money rather than tolerate excessive delays.[20] This attitude was shown at the very beginning, when the company invested over $50,000 in the project before any contract was at hand, and throughout the course of the work, as the company's investment rose to about $500,000.

[20]In the early stages of the work Lycoming probably profited by access to Continental's previous results through hiring a certain number of engineers away from Continental. This help cannot have been of great importance, however, since Lycoming was very soon more advanced than Continental.

The first bench tests of the O-1230 were made in 1937. It was flown in 1938 installed in the nose of the XA-19A Vultee attack bomber, which had been designed for the R-1830. The performance of the airplane, which was of course not designed for a modern low-drag installation, was about the same with either engine. The Army was by then interested, however, in the immediate development of much more powerful liquid-cooled engines, and already in 1937 Lycoming had discussed with the engineers at Wright Field sketches of a double O-1230, or H-2470, intended to satisfy the tentative specifications for long-range engines issued in 1936. Since a type-tested 1,000-hp liquid-cooled engine was already available in the Allison, Lycoming in 1938 decided definitely to give up the 12-cylinder engine. The Army, which really wanted a much larger engine, did not fully approve of the H-2470, but Lycoming decided to proceed with it. The O-1230 was, however, put through its 50-hour development test in March of the next year, 1939, at the original goal of 1,000 hp.

Pratt & Whitney

By this time a fourth company, Pratt & Whitney, was working on high-power liquid-cooled engines. The company's first attempt at a liquid-cooled engine had been a five-bank or four-row radial 20-cylinder engine undertaken for the Army in 1931 but dropped in the next year after the first tests had shown it to have very little promise. For the next two years the company had done nothing with liquid-cooled engines. In 1935 it had resumed development of liquid-cooled cylinders at the Army's request and continued this work in the next two years.

Early in 1936 the company began to consider the construction of an engine with greater power output than it was thought possible to obtain from a two-row radial. At this time even the two-row radial was far from being fully developed to its maximum output,[21] and the company apparently did not

[21]The largest radial under development by Pratt & Whitney early in 1936 was the 14-cylinder R-2180, which was developing 1,400 hp and was virtually ready for production. Wright at this time was just beginning development of the 14-cylinder R-2600, aimed at an initial rating of about 1,500 hp, and the 18-cylinder R-3350, aimed at about 2,000 hp. In August 1936, Pratt & Whitney began planning for an 18-cylinder 2,600-cu in. engine in addition to the R-2180. Later in

(Footnote continued on next page)

even consider attempting a radial of more than two rows. Instead, preliminary plans were laid for developing a multi-bank in-line engine, and a program of tests was begun to determine whether air or liquid cooling was preferable for such an engine.

Late in 1936 or very early in 1937, before these three-cylinder tests were completed, the Navy issued a request for an air-cooled engine rated 2,300 hp for take-off. While Pratt & Whitney believed that this rating could ultimately be reached with a two-row radial, it was expected that, as always in the case of a new engine, the requirements would gradually be raised above the original goal set by the services, and in response to the request Pratt & Whitney in February 1937 submitted preliminary estimates of an air-cooled 24-cylinder X of 3,130-cu in. displacement. The Navy informed the company that it was prepared to award a contract for its development. Very shortly thereafter, however, before the engine was laid out in detail and before the Navy contract was signed, Pratt & Whitney decided on the basis of its three-cylinder tests that it was dubious whether this engine could be air-cooled without excessive drag, especially as its power was increased beyond the original 2,300 hp. In April 1937 the company accordingly proposed that liquid cooling be substituted in the X-3130, with no other substantial changes in design. The Navy, while still believing in principle that air cooling would probably be superior in the long run even in the largest engines,[22] was persuaded that liquid cooling was the only solution at the time, and in June 1937 gave Pratt & Whitney a contract for a six-cylinder portion of an XL-3130. The contract served rather to show the Navy's approval of the project than to pay any appreciable share of the costs, since the Navy obligated only about $100,000 for the six-cylinder test engine, and allocated only $300,000 to the entire project, which was certain to cost several millions before the engine was in production.

1936 the firm learned that Wright's 2,600-cu in. engine was already well advanced. As a result, the R-2180 was never put in full production, and the displacement of the planned 18-cylinder engine was increased from 2,600 cu in. to 2,800 cu in. Even this engine, however, was initially aimed at only about 2,000 hp.

[22]Just about a year earlier the Navy had rejected the Wright H-2120 because it was liquid-cooled; cf. above, p. 266.

In the latter half of 1937 Army officials in Washington, their faith in liquid-cooled engines increased by the type-testing of the Allison and especially by its performance in the XP-37 early in 1937 (see above, p. 278), asked Pratt & Whitney to develop another liquid-cooled engine. Pratt & Whitney, however, had in 1936 begun planning for a large 18-cylinder two-row radial, the size of which had finally been set in March 1937 at 2,800 cu in., and which was running that summer.[23] With the XL-3130 it had undertaken for the Navy, this made two completely new engines, and the company was not at all eager to undertake still a third. The Army, however, exerted very great pressure, and the company agreed. The engineers at Wright Field were unaware of the existence of this project for about a year. The reason for this peculiar state of affairs is not known, but it is known that the top officers of the Air Corps were often unable to understand why Wright Field did not obtain results more quickly, and it may be conjectured that these officers decided that they could get the results more quickly by going to a major company than Wright Field could through its dealings with Allison, Continental, and Lycoming.

Some time before this, in April 1937, George Mead, Vice President for Engineering of the United Aircraft Corporation, of which Pratt & Whitney Aircraft had become a unit, had made a visit to England from which he returned with considerable enthusiasm for H-type sleeve-valve liquid-cooled engines. There had been for years a large school of engineers, particularly in England, who believed that any further increase in the specific output (power per cu in. of displacement) of individual cylinders would require the use of sleeve instead of poppet valves,[24] and Pratt & Whitney had been investigating this type of valve in 1935-1936. In 1937 the British were enthusiastic over the prospects of the Napier Sabre, a 24-cylinder H-type engine with sleeve valves, intended to develop unusually high power for its 2,240-cu in. displacement by running at extremely high

[23]Cf. above, n. 21.

[24]It will be recalled that it was Ricardo's statements to this effect which had prompted the Army's research in 1930-1931 that led to the "Hyper" poppet-valve cylinder and the Continental O-1430. By the middle of the 1930's Bristol was on the verge of going in for sleeve valves exclusively on its new air-cooled radials.

rpm. Mead seems to have become convinced about this time that sleeve-valves and an H arrangement were preferable to poppet valves and an X for a 24-cylinder in-line engine.

Although the exact chronology of Pratt & Whitney's liquid-cooled projects in 1937-1938 is not completely certain, the first result of Mead's new ideas seems to have been in the design of the new engine undertaken for the Army. In 1937 Douglas had submitted to the Army designs for a new medium bomber based on radial air-cooled engines. Mead decided to build a liquid-cooled engine specifically for submergence in the wings of this airplane, and Pratt & Whitney laid down the design of a 24-cylinder, H-type, sleeve-valve engine known as the X-1800, with a total displacement of 2,240 cu in., aimed at an initial output of 1,800 hp. Work began in 1938. The contract with the Army, which was not actually signed until May 1939, was like the Navy contract for the XL-3130 in providing more moral than financial support for the project. It called for payment of $402,500 for four X-1800 engines, a sum which would just about cover building the engines by hand and flight testing them, with nothing left over to apply toward actual development costs.

In November 1938, the 1937 Navy contract for the XL-3130 was amended at Pratt & Whitney's request to substitute sleeve valves and H arrangement[25] as in the Army's X-1800 for the poppet valves and X arrangement of the original Navy engine. The six-cylinder portion of an H-3130 called for by the amended contract was delivered in 1939.

The New Wright Projects

The original Curtiss line of engines had come to an end in 1935, when a last sale of 100 Conquerors was made to the Army for use in the Consolidated PB-2A; development of the Conqueror had virtually stopped some two years before (see above, pp. 261-262). At about the same time the company abandoned

[25]Mead may have intended to make the engine suitable for submerged installation like the Army engine, but if this is true the notion was soon given up, since by 1940, when the XL-3130 had finally evolved into a complete engine known as the H-3730, no effort was made to minimize its thickness. The change may have been due simply to layout difficulties with a poppet valve X: cf. above, p. 244.

the two new liquid-cooled engines which it had begun for the Navy about 1930-1931, the H-2120 and the V-1800 (pp. 266-267), and for two years after 1936 Wright did nothing at all with liquid-cooled engines. This, however, was the period when the Army was most anxious to obtain a liquid-cooled engine suitable for submergence within airplane wings, and about 1938 Wright was given an Army contract for the development of a 24-cylinder 1,800-hp engine to be designed for this purpose.[26] This, of course, would put Wright in direct competition with the Pratt & Whitney X-1800. The original intention was to install the engine in the wings of a fighter; then it was decided that a fighter's wings would be too thin, but that the engine could be used in the wings of an attack plane.

Further studies showed, however, that a submerged installation would create impossible problems with the structure and in addition would leave no space for fuel and landing gear. At the same time progress with the design was making it apparent that when all the accessories were in place a specially designed "flat" engine was no longer flat anyway. Although the Army continued to be interested in this type of engine, their intended use now being in bombers, the company was becoming convinced that it was hopeless. Early in 1939 Wright proposed to the Army that very small frontal area could be obtained with a six-row, 42-cylinder liquid-cooled radial with cylinders of extremely short stroke: their displacement was only 51 cu in., compared with 137 in the Merlin or 84 even in the Hyper No. 1. The company believed that the small size of the cylinder could be fully made up for by higher speed of rotation, and that the 2,160-cu in. engine could produce 2,500 hp. This project was accepted by the Army, and a contract for an experimental two-row section of the R-2160 was given in June 1939, the project of a "flat" engine being definitely abandoned a few months later.

[26]This engine was related to the H type in that it consisted of two 12-cylinder two-bank engines with their crankshafts, geared together, but it differed from most of the H engines in that the 12-cylinder components were not of the cpposed arrangement but were vees. This arrangement of two vees joined together was also used by Allison in the V-3420, and Allison like Wright believed that the resulting engine was just as "thin" and well-suited to submerged installation as a true H.

Liquid-Cooled Engines After 1939

The Situation in 1939

By the middle of 1939 the Air Corps Research Board had decided that the 1,000-hp engine was obsolete and that the primary needs in the liquid-cooled field were for: (1) flat engines of 1,800 to 2,000 hp for submerged installation in bomber wings, (2) multibank engines of 1,800 to 2,400 hp for nacelle installation in bombers,[27] and (3) inverted vee engines of 1,500 to 1,800 hp for pursuit planes. The situation was then evaluated by a design competition held in September or October and appeared somewhat as follows:

(1) The new power requirements for flat engines could only be attained by an H type,[28] not by a 12-cylinder opposed engine. Pratt & Whitney's X-1800 was nearly ready for test. Wright's flat engine had never got beyond the design stage and was on the point of being abandoned. Continental had made preliminary studies of an H-2860, i.e., a double O-1430. The Lycoming H-2470 and the larger Pratt & Whitney H-type engine were not entered in the competition. The Pratt & Whitney engine was a Navy project, and apparently Lycoming also had by this time entered into the negotiations with the Navy which led to a contract a little later (cf. below).

(2) In the nonflat multibank category, Allison had already tested its double-vee 3420,[29] development of which had been begun in 1937. The only other contender was the 42-cylinder Wright R-2160, which was still in the design stage.

(3) In the inverted vee category, the Continental IV-1430 was the only entry, and it failed to meet the required power rating.

This "competition" and its results are an interesting illustration of what competitive procurement under the experimental-procurement regulations of section 10k of the Air Corps Act

[27]The Board (which was not composed primarily of Wright Field engineers, and which consistently failed to realize the length of time required to develop a new engine) was talking at this time of the need for bomber engines producing 4,000 to 5,000 hp, and complained that the manufacturers could not be interested.

[28]Or the modified H proposed by Allison and Wright; cf. above, p. 287, n. 26.

[29]The Board did not classify this as a flat engine, although it did so classify the Wright twin vee, and although Allison claimed that the 3420 with the accessories installed was "flatter" than the true H engines.

actually meant at this time. The designs sent in were rated formally as follows:

Pratt & Whitney	X-1800	730.5 points
Wright	R-2160	715.5 points
Continental	H-2860	658.0 points
Allison	V-3420	610.0 points
Continental	IV-1430	disqualified

Despite the fact that their engines led the field, it was debated whether contracts should be given to Wright and Pratt & Whitney, since they had declared that they would continue their work in any case. Contracts were finally given them, but according to the Army the reason was at least in part the desire to follow a new pay-as-you-go policy[30] on development, by which the Chief of the Air Corps hoped to save money when the developed products were ultimately procured in quantity. The only tested engine meeting the requirements of the competition was the Allison V-3420, but development of this engine was given a low priority because of the pressing need for improving the V-1710, which was the only liquid-cooled engine actually in production. Although the Continental IV-1430 had been disqualified as not meeting the minimum power requirement set by the Army, and although the Allison V-1710 was already in quantity production, the Continental H-2860, which met the requirement, was dropped, and the most important contract given was for the Continental IV-1430. It was decided that the Continental should devote all its efforts to making the IV-1430 a successful competitor to the Allison, rather than build an H-2860 to compete with the Pratt & Whitney H-type X-1800. Continental agreed that it could not develop more than one engine at a time, and it much preferred not to have to compete with Pratt & Whitney in the field of very high power.

H-Type Engines: Pratt & Whitney and Lycoming

In the category of high-power H-type engines, the Army after 1939 at first relied completely on the Pratt & Whitney

[30]This was the Army's name for the policy, but it is scarcely exact. Cf. above, p. 286, on the terms of the May 1939 contract for the Pratt & Whitney X-1800.

X-1800, by now intended to produce 2,000 instead of 1,800 hp, and with its displacement increased from 2,240 to 2,600 cu in. The Navy, in June 1939, had also given a new contract to Pratt & Whitney, for development of a single cylinder of an H-3730; this was the original 3130 enlarged by increasing the bore without fundamental redesign.

In the middle of 1939, however, George Mead, who had been the chief sponsor of liquid-cooled development within Pratt & Whitney, resigned as Vice-President of United Aircraft and was replaced by L. S. Hobbs. The top management of Pratt & Whitney, both the Chairman of United Aircraft, F. B. Rentschler, and the President of Pratt & Whitney, E. E. Wilson, were already very dubious of the advisability of trying to develop an engine of a type with which the company was unfamiliar, at the cost of less rapid development of its air-cooled engines. By this time the air-cooled R-2800 was nearly ready for production with an initial rating of 1,850 hp and a certainty that this could soon be increased to at least 2,000 hp. The X-1800, on the other hand, was still an undeveloped engine, which even when developed promised no more power than the R-2800, while the one feature which had at first seemed most attractive, its supposed suitability for submerged installation within a wing, was by then believed by the company to be impracticable. Finally, Hobbs was convinced that the air-cooled radial was inherently lighter than the liquid-cooled in-line, and Hobbs seems to have attached more importance to weight and less to drag than Mead had done. Accordingly Pratt & Whitney early in 1940 sought and obtained permission from the Army to cancel the contract for the X-1800 development; the company had to forfeit the payment due for work already done, but this in any case would have amounted to only a small fraction of the total cost of the development to this date.

The case of the larger Pratt & Whitney liquid-cooled engine, the H-3730 being developed for the Navy, was not the same, since this engine was intended for an output definitely higher than could possibly be obtained from a two-row radial, and its development was accordingly continued. In fact, at about the same time that the X-1800 was being dropped, early in 1940, the company on its own initiative began construction

of the first complete H-3730; a Navy contract for this phase was not signed until June. Hobbs believed, however, that although no one had yet proved that a radial of more than two rows could be cooled without excessive drag, no one had yet made a real attempt to find out. Inspired in part by the recent reductions made in the drag of radiators for liquid-cooled engines as a result of thorough and fundamental aerodynamic studies, Hobbs started a program of similar research on the cooling of air-cooled engines, including for the first time a detailed study of air flow over every part of the engine. After this research had led to the conclusion that by proper design the cooling drag of air-cooled engines could be made so low that any remaining disadvantage compared with liquid-cooled engines would be more than compensated for by the other advantages of air cooling and of radial form, a systematic investigation was made of various layouts for an air-cooled engine of more than 18 cylinders. The best arrangement was found to be a four-row radial with the rows staggered. Wind-tunnel tests of a mockup of a 3,000-hp engine with 28 cylinders very similar to those of the R-2800 showed that the cooling drag would be surprisingly low.

While this research was being carried out, the question of production facilities as well as that of development facilities and manpower began to influence the company. Production had already begun to expand greatly in 1940, and management was becoming convinced that it was very probable that the United States would soon be in the war and that still greater production of service engines would be necessary. The liquid-cooled H-3730 had virtually nothing in common with the company's air-cooled engines, and its production would have required a completely separate set of machine tools in a separate factory. Since even aside from the problem of production, management was opposed in principle to the development of a liquid-cooled engine unless it was indisputably necessary, the H-3730 was dropped with the permission of the Navy as soon as the results of the research program were known, toward the end of 1940, and development of the R-4360 was begun. The company again assumed the loss of the relatively small portion of the costs of the development done to date which were to have been paid by the government as well as the much larger share which would have been paid by the company in any case. This was the end of Pratt & Whitney's development of liquid-cooled engines, which since 1937 had cost over $2 million of the company's funds.

The only remaining high-power flat engine was the Lycoming H-2470. As we have seen, Lycoming had begun preliminary studies of this 24-cylinder engine in 1938, when it became clear that the o-1230 developed for the Army was too small for the times. The Army refused to support the H-2470 on the grounds that even this engine was now too small, but in the summer of 1939 support was obtained from the Navy,[31] which then believed that although the R-2800 promised to offer one successful engine of about 2,000 hp very soon, the only other air-cooled prospect in this power class, the R-3350, might not be ready for a long time, while the existence of at least two sources for 2,000-hp engines was desirable both to secure competition in development and to make sure of adequate resources for production. After Pratt & Whitney abandoned its X-1800 early in 1940, the Army became interested in the Lycoming engine and in October arranged to buy two engines under the Navy contract with Lycoming.

The first H-2470 was run in July 1940 and seems to have passed a development test in January 1942. Its performance seemed so promising that without waiting for a plane to be built and flight tests to be made the Navy in May 1942 sent a letter of intent ordering 100 engines, 50 of which were for the Army, delivery to begin in 1943. The principal use for which the Navy intended the engine was the new Curtiss F14C fighter, the first carrier fighter designed with a liquid-cooled engine since 1925. On the basis of this order a new Lycoming factory was set up in Toledo exclusively for the production of the H-2470.

Before this factory went into production, however, the Navy decided that although the engine was technically very promising, and might have had great value if it had been ready sooner, it would be available in quantity too late to be of use in the war, and accordingly cancelled its contract. The Army continued

[31] The contract was signed in December 1939.

to give limited support to the H-2470 and flight-tested it extensively in 1943 in the Vultee XP-54, which had been designed primarily for the Pratt & Whitney X-1800. By the time these tests had been made, however, it was clear that the H-2470 could not possibly be ready in time to be of use in the war, and the Army dropped the project before the end of 1943.

In addition to the payments received from the services, well over $1 million of Lycoming money had been spent on the H-2470, besides the half million spent on its predecessor, the O-1230. These losses could be ultimately recovered only because the great expansion of wartime production made it possible to charge them off against Lycoming's successful products.

Multibank Engines for Nacelle Installation: the Allison V-3420 and the Wright R-2160

In the multibank field, the only contenders were the Allison V-3420 and the Wright R-2160. Development of the former was not pressed until late in the war because of the desperate need for continuing improvement of the V-1710. Late in the war plans were made for producing the V-3420 in very large quantity for use in a high-speed low-altitude fighter, the P-75, but only about 100 engines were produced before the project was dropped.

In June 1939, as we have seen, a contract had been given for tests on a 14-cylinder unit of the 42-cylinder Wright R-2160. These tests, carried out from July to September of the next year, 1940, indicated that all the novel features, such as the divided crankshaft geared to high-speed shafts driving the propeller reduction gear, were sound, and that the difficulties were in the conventional elements, such as the intake manifold and the valves. It was believed that a complete engine could be ready for flight test by the end of 1941, and two experimental pursuit planes, the XP-58 and XP-69, were designed around the R-2160. When Wright complained in November 1940 that the Army had shown "so little interest in the form of contracts", the Army almost immediately gave an order for five more engines. When these engines were built and tested, however, it gradually appeared that the basic principle of the engine was at fault: this engine represented the all-time extreme in smallness and multiplicity of cylinders, as well as an unusually high ratio of bore to stroke, and it proved extremely difficult to make the engine light enough in proportion to the power developed.[32] The desperate need for the R-3350 engine to power the B-29 coupled with the great difficulties encountered in the development of that engine forced Wright early in the war to reduce the amount of effort being put on the R-2160, and to abandon it completely in 1943. No complete engine was ever delivered.

V-Type Engines: the Continental IV-1430

In the pursuit category, there was great hope for several years after 1939 in the Continental IV-1430. It was believed by the Army at this time that the engine could be brought in a reasonable time to readiness for service at a military rating of 1,600 hp at 3,000 rpm at 25,000 feet with a turbo,[33] and that although its life would be very short at this power the engine would nevertheless be highly attractive for use in an interceptor. A reviewing committee set up in December 1939 did question the company's ability to fulfill its promises, in view of its past performance, but in the latter half of 1939 Continental had raised a considerable amount of new capital and reorganized its management, and in 1940 an understanding was reached between the Army and the company that the latter would put at least $250,000 of its own money into the work and would accept verbal assurances from the Army without waiting for written contracts. In 1940 the Army's belief in the Continental engine was so great that it persuaded several manufacturers to design new pursuit planes around it, and in 1941-1942 the Army financed the building of a new Continental factory in Muskegon, nominally for the production

[32]The most serious difficulties at first were with the valve gear and were principally due to the unusually great ratio of bore to stroke. After the valve gear had been successfully redesigned, the engine was brought to a rating of 2,350 hp, but the volumetric efficiency was poor owing to the cramping of the intake manifold required by the extremely small diameter of the engine. Redesign of the manifold was in progress when the engine was abandoned.

[33]This meant a bmep of 296 psi. Actually the Army in 1939 planned to use the engine at a bmep of 325 psi on fuel of 150 PN, but had to revise this figure when it gave up hope that 150-PN fuel would be available for service.

of small trainer engines, but actually tooled with equipment adequate for the production of the IV-1430.

Nevertheless progress failed to be made as rapidly as had been hoped. A year was spent before the first experimental engine was even ready to be put on test, in January 1941. Over a year more was spent before a preliminary test was successfully completed at 1,600 hp in May 1942. A production contract for 100 engines was signed in November 1942, but this contract was subject to the passing of a type test before delivery, and as this test failed to be passed the contract was reduced, first to 50 and then to 25 engines. The IV-1430 was extensively flown during 1943 in the Lockheed XP-49, a modified Lightning ordered in 1940, and in the McDonnell XP-67, another twin-engine fighter ordered as late as fiscal 1942. Before the end of 1943, however, the Army had at last decided that the engine could not possibly be used in the war, and the production contract was finally cut to eight engines for experimental use.

In March 1944 a type test was partially completed, and the eight engines were released; the military rating was 1,600 hp at 3,200 rpm at 70.0 in. manifold pressure, for a weight of 1,655 lb. In July a war emergency rating of 2,100 hp at 3,400 rpm at 87.8 in. was established, but a type test seems never to have been fully completed.

The Chrysler IV-2220 constituted still another attempt at an 1,800-hp vee-type pursuit engine sponsored by the Army. This engine does not properly form part of our story, since its development was not begun until after 1939, the first contract being given in 1941, but it is worth pointing out that the first engine was not tested until the end of 1942, and the project was finally dropped in 1944 before a type test had been passed.

Thus the one liquid-cooled engine in this or any category which was actually used in production quantities — or even passed a type test — at any time during the war was the Allison V-1710, which had already gone into production in 1939.