CHAPTER VII

The Origins of the Air-Cooled Engine in the United States

AT the outbreak of the Second World War in 1939 the air-cooled engines manufactured in the United States by the Wright Aeronautical Corporation and the Pratt & Whitney Aircraft Company were generally recognized to be the best American engines of any type, and at least the equal of any air-cooled engines in the world in general excellence; and they had been so recognized for most of a decade. These engines powered all the Navy's airplanes of all types and all the Army's airplanes other than fighters; by the end of the war they powered one of the Army's two best fighters. All American transports, both civilian and military, had been equipped exclusively with air-cooled engines for almost a decade, and almost all the latest postwar American transports, flying on both American and foreign airlines, are still so equipped. This chapter recounts how the manufacture of so successful a type of engine came to be established.

THE SITUATION AT THE END OF THE FIRST WORLD WAR

The State of the Air-Cooled Engine Abroad

The earliest intensive development of aircraft engines had taken place in France, and the best of the early engines had been air-cooled. The French had developed air-cooled engines of all three types, rotary, radial, and in-line, years before the First World War, and during the war air-cooled engines of sizes up to about 850 cu in. displacement and about 150 hp, mostly of the rotary type, had been used with great success. The early builders found it very difficult, however, to make air-cooled engines much larger than this, and thus they turned

to the development of the water-cooled type. Between 1912 and 1914 the Daimler Motor Company in Germany had developed for aircraft use the Mercedes type of water-cooled engine with welded steel cylinders, and this type of cylinder construction was the basis not only of the standardized American war-time engine, the Liberty, but also of the British Rolls Royce aircraft engines and a number of other water-cooled engines with welded steel cylinders. By the end of the war the water-cooled engine with cylinders cast en bloc had also been well developed abroad, where its outstanding representative was the French Hispano-Suiza. At the end of the war the outstanding Allied service engines were the 360-hp Rolls Royce Eagle VIII and the 220-hp Hispano-Suiza.

Very little effort was made during the war in France and Germany to develop air-cooled engines of much over 150 hp, but as has been told in the previous chapter the British government had begun in 1917 to give very strong support to a number of projects of this nature. In 1922 Armstrong Siddeley put in production the two-row 14-cylinder 1,512-cu in. Jaguar with a rating of over 300 hp, and in the same year Bristol had put in production the single-row nine-cylinder 1,753-cu in. Jupiter with a rating of about 400 hp. During the first half of the 1920's these two engines gradually became adopted for a wider and wider variety of uses, and after about 1927 they were by far the most widely used engines in Britain for every use from fighters to reconnaissance flying boats and commercial transports.

The State of the Aircraft-Engine Industry in the United States

In the United States, after the automobile manufacturers had ceased the building of Liberty engines with the Armistice and returned to their ordinary pursuits, only three firms were left with adequate facilities to carry on peacetime production of aircraft engines. These were the Curtiss Aeroplane and Motor Corporation, the Wright Aeronautical Corporation, and the Packard Motor Car Company. Of the three, only Curtiss had been engaged in the building of aircraft engines before the war. Except for a few very early experiments, Curtiss had built only water-cooled engines, and even these had been built in purely experimental quantities until 1914, when the British ordered several hundred of the 90-hp OX. This and the very similar but slightly larger OXX (100 hp) were the only Curtiss engines produced on a large scale during the war; they were never powerful enough for anything but trainers, and by the end of the war they were obsolete even for that purpose. In 1916 Curtiss had brought out the experimental 12-cylinder 1,145-cu in. water-cooled K-12, designed by C. B. Kirkham, which developed about 400 hp. The development of this engine was delayed by the government's decision to have only one, standardized 400-hp engine, the Liberty, produced during the war, but immediately after the Armistice Curtiss concentrated nearly all its efforts on the development of the K-12.[1]

The second established aircraft-engine manufacturer was the Wright Aeronautical Corporation. The Wright-Martin Aircraft Corporation had been founded in 1916 to produce the French water-cooled Hispano-Suiza engine on license and had done so with considerable success and profit, selling large quantities to the French and later to the American government also. In 1919 most of the assets of the company were disposed of to the manufacturer of Mack trucks, but a certain portion[2] was used to form the Wright Aeronautical Corporation, which continued with the eight-cylinder water-cooled Hispano-Suiza engines as its only developed products. Of the various French models of this engine, only the 718-cu in. 180-hp model known in the United States as the E was actually in production at the time of the foundation of the new company; the 1,127-cu in. 300-hp H, however, was ready to go into production.

The third company, Packard, had had its first real experience with aircraft engines in helping to design and then producing the Liberty engine. After manufacture of the Liberty was

[1]Kirkham had also designed and built a six-cylinder, 200-hp K-6 which was really just half of a K-12. Development of this engine was also resumed after the war, but it was always treated as a by-product of the K-12.

[2]The total value of the assets transferred to Wright Aero was about $5.5 million, but $3.0 million of this was a reserve for contingent liabilities of the Wright-Martin Corporation, and another $0.5 million represented undistributed net assets of Wright-Martin, so that the usable net assets of Wright Aero at its foundation were about $2 million.

dropped at the end of the war, Packard had no engine in production. Various experimental water-cooled engines were built for the Army and Navy in the next years, but it was not until 1924 that Packard again had an aircraft engine in quantity production.

In addition to these three companies, there were several small firms building experimental engines and occasionally producing a small "quantity" order for one or the other of the military services. Chief among these was the Aeromarine Plane and Motor Company. Even these small and largely experimental concerns, however, were working with water-cooled engines almost exclusively. Air-cooled engines were being built only by the tiny Lawrance Aero-Engine Corporation, in a plant consisting of a three-story loft building in Manhattan. In 1919 this company had just begun its first production of a few three-cylinder 60-hp air-cooled radials which it had itself designed and developed. No American builder at this time produced an air-cooled engine even in the 150-hp class, which had been well established abroad for years, let alone an engine comparable to the 300- and 400-hp engines soon to go into production in England.

The fact was that after the first beginnings of heavier-than-air flight had been made in the United States, the major development of all aeronautical materiel had been carried out in Europe, while only a few inadequately financed experimenters carried it on in the United States. When the United States entered the war and suddenly realized the need of aviation, there was nothing to do but get into production as quickly as possible. For engines in the low-power training class the existing Curtiss OX and OXX models were ordered and French rotaries were built on license; in medium power an existing American source for the French Hispano-Suiza was used; and for high power the automotive-engine industry pooled its talents to design the Liberty along lines established in the main in Europe. It was only after the Armistice that development of aircraft engines began to be carried out in the United States on a scale comparable with that which had long existed abroad.

The Financing of Aircraft-Engine Development in the First Half of the 1920's

The outstanding feature of the market for aircraft engines of all sizes in the United States after the Armistice was the existence of huge quantities of war-surplus engines of all sizes and types, many of them completely unused, which were offered for sale at prices only a small fraction of cost. The extremely low price of the surplus engines meant that it was impossible to sell even a much superior new engine for civilian use until after the middle of the decade. During the first half of the decade there was no real national policy on aviation, and this meant that even for military use there was no hope of displacing the surplus engines simply by putting a superior new engine on the market. By far the largest part of all military flying was done with surplus engines for years after 1919, and large numbers of new airplanes were designed to use old engines until after the middle of the 1920's. It was not until 1934 that the use of the Liberty by the Army was finally stopped.[3]

Consequently there was no reason whatever for private capital to risk any appreciable funds in the development of new aircraft engines. The only possible financing for new development was direct payment by the government from special funds allocated to research and development. Virtually every cent going into the development of engines came from this source until the events which close this chapter occurred in 1925 and 1926.

If the government was to pay directly for the development of engines, proposals were sure to be made that the government do the development in its own laboratories in order to prevent private firms from making what some people considered unearned profits. Precedents for such a system were numerous in the arsenals and shipyards in which all sorts of military and naval equipment had long been developed. Much military

[3]See *Disposal of Surplus Aircraft and Major Components Thereof*, Report of the War Contracts Subcommittee to the Committee on Military Affairs...June 26, 1944 (78 Congress, 2d Session, "Senate Subcommittee Print" No. 6) (Washington: Government Printing Office, 1944), pp. 74, 80-91.

equipment was not only developed but produced by the services themselves, and proposals to produce aircraft and aircraft engines in the same way were by no means lacking.

Within the services themselves there was a good deal of discussion immediately after the war concerning the parts to be played by industry and government in the development of new equipment. The Navy had the stronger tradition of designing and building its own materiel. This tradition had been extended to airframes before the end of the war, and continued in this field after the war was over; although some airplanes were bought from private firms, many were designed and built by the Navy itself. In the field of engines, however, the people successively put in charge after the war were all line officers, not members of the Bureau of Construction, and they all relied completely on industry for both development and production. The Navy's technical intervention in details was limited to the making of suggestions, although of course the Navy was ultimately completely responsible for the choice of which engines and which firms were to be supported and which were to be dropped. As we shall see, the Navy felt free not only to spend its experimental funds where it thought best but also to make quantity purchases of engines which it considered promising even when they were not the best available for immediate use.

The Army followed a very different policy. After a brief period immediately after the Armistice in which competitions were held to select the best designs produced by private firms, a policy was adopted whereby all major design decisions concerning engines to be developed under Army contract were made directly or at least formally approved by the Army's technical establishment at McCook Field. Some of these decisions were embodied in complete designs at McCook Field and were developed there, although the actual making of the components was usually done by private firms on a job-shop basis. Other engines were only laid out at McCook Field, the detailed designing and the entire construction being left to a private firm, but even in these cases the actual testing was almost all done by the Army, and it was the Army which interpreted the results of the tests and decided what changes should be made in the design. This policy, of course, was the only one really in accord with the existing laws which called for strict price competition in all government procurement, since price competition would not work without detailed specifications on which to base the bids.

The history of the early development of air-cooled engines in the United States thus affords an excellent opportunity to compare the effectiveness of two diametrically opposed policies of technical control by the government when both were maintained under identical economic and technological conditions.

The Development of a Medium-Power Air-Cooled Engine: the 200-hp Whirlwind

The Early Lawrance Engines

Before the First World War Charles L. Lawrance had designed engines for racing cars, and then after studying some of the problems of airplane design in Paris had begun development there of a water-cooled aircraft engine with aluminum cylinders. On his return to the United States after the outbreak of war he had continued to work on this engine, financed by the New London Ship and Engine Company, but the appearance of the much lighter Hispano-Suiza engine soon led to its abandonment.

In 1915 Lawrance and four associates formed the Shinnecock Airplane Company with about $15,000 capital to develop a light private airplane. It soon became clear that there was no suitable engine for such a plane, and the company undertook the development of a two-cylinder air-cooled engine designed for this purpose by Lawrance. In 1917 it was decided to separate the two activities; the S. S. Pierce Airplane Company was formed as successor to the Shinnecock company to continue work on the airplane, while a separate Lawrance Aero-Engine Corporation was formed to take over the engine.

The Lawrance Aero-Engine Corporation was capitalized at $50,000, but only $30,000 of this represented cash, and of this amount $9,000 was used to repurchase stock originally issued to the S. S. Pierce company as successor of the Shinnecock

company for the value of work done on the engine at the latter company's expense. The Lawrance corporation consisted of a staff of about five engineers. Its "plant" was simply a drafting room on Broadway in New York City; all the parts for tests and for experimental engines were purchased from outside shops. The two-cylinder model A engine as finally built developed about 30 hp and weighed nearly 200 lb. In 1917 a nonexclusive license for its manufacture was sold to the Army for about $2,000, and 450 of these engines were built during 1918 by the Excelsior Motor and Manufacturing Company for use in non-flying Penguin trainers. The Lawrance corporation was paid about $18,000 for engineering advice to Excelsior in addition to the $2,000 paid for the license.

Not long after rights to the two-cylinder engine had been sold to the Army, Lawrance learned that Grover Loening was developing for the Navy a very small seaplane called the Kitten, and the two men decided that if Lawrance's two-cylinder engine could be redesigned with increased power and greatly decreased weight, it would be a suitable power plant for the new airplane. This idea was presented to the Navy a few months after the sale of the model A to the Army. Responsibility for aircraft engines in the Navy lay at this time in the Bureau of Engineering, where Commander A. K. Atkins was in charge of the Division of Aviation, with Lt. Commander S. M. Kraus directly in charge of aircraft-engine design. Atkins and Kraus were much impressed by Lawrance's enthusiastic conviction that he could do the job and agreed to finance it completely, the Navy taking the entire risk. Lawrance was given a cost-plus contract for the development of a two-cylinder model N engine, of 121 cu in. displacement and about 30 hp, to weigh only 80 lb. The model N engine was built and delivered about 40 hp on test, but it ultimately appeared impractical to obtain the desired airplane performance from a two-cylinder engine, and at Lawrance's request the Navy altered the contract to provide for development of a somewhat more powerful three-cylinder engine, the design for which Lawrance had laid down already in 1916.

Various difficulties were experienced with the experimental prototype of the three-cylinder engine, known as the model B, but these were gradually overcome by the joint efforts of Lawrance and of the Navy's engineers. This work resulted by the end of 1918 in the model L, of 223 cu in. displacement, developing 65 hp maximum for a weight of 147 lb, and a thoroughly satisfactory power plant for the times. Although the Navy itself in the end found very little use for the Loening Kitten and hence for the L, and bought only about half a dozen of the engines, the Army after testing an initial order of three bought a "quantity" order of about a dozen L-2's in 1921 for use in the Sperry Messenger liaison airplane.[4] Seven or eight engines were even sold commercially for use on private planes. For a company of the size of Lawrance's, these sales of 20 or 30 engines were a real commercial success.

The Navy contracts for the N and L engines provided the Lawrance corporation with enough business to move from its design office to a loft building in 1918 or early 1919. Here a relatively well-equipped shop was set up, with facilities which sufficed for Lawrance's future experimental work and also for the production of the small lots of model L's sold during the next three years.

The Creation of the 200-hp Lawrance J-1

In 1919 discussions were begun between Lawrance and both the Army and the Navy which ultimately led to the production of the nine-cylinder model J-1 engine. This became the first really popular American air-cooled engine, and its success was the first decisive step in the establishment of the air-cooled type in the United States.

The Army at this time desired a light engine of about 150 hp for trainers. While the Wright model-E Hispano offered a well-proved engine of the desired size, the Army was impressed by the excellent record made abroad by air-cooled engines and wanted to have the type developed in America. Lawrance's three-cylinder model L was showing considerable promise on test, and Lawrance was the only manufacturer with any experience at all with air-cooled engines. In 1919 the Army gave him a contract for a nine-cylinder engine

[4] The exact number of engines is uncertain, but six airplanes were bought in 1921 and there were probably some spare engines.

known as the model R. This engine was to use cylinders virtually identical to those of the L, giving a displacement of 670 cu in., was to have three carburetors each supplying only three cylinders as in the L, and in general was to have as few changes as possible from the designs already being tried in the smaller engine. The contract was very liberal in its terms, specifying a minimum power (140 hp) and maximum weight, but requiring no endurance test. Since it was standard Army policy at this time to assume that the Army by signing a contract for an experimental engine assumed responsibility for the design, an acceptance test was little more than a test of reasonable skill and honest workmanship on the part of the contractor.[5] After the first engine had been extensively tested and modified according to ideas contributed by both Lawrance and the engineers at McCook Field, the Army on March 25, 1920, gave Lawrance a contract for three more R engines, which were delivered in 1921. One of them passed a 50-hour endurance test in that same year, developing 147 hp at 1,600 rpm for a weight of 410 lb.

During this same period Lawrance had been engaged under Navy contract in the development of a similar but larger engine, the J. Since the development of this model and its subsequent purchase in quantity by the Navy were the first decisive steps in the establishment of the air-cooled type in the United States, we must digress briefly to examine the state of naval aviation just after the First World War. During the war American naval aviation had consisted exclusively of flying boats used for anti-submarine patrol, but the British had developed ship-based aviation quite extensively, flying airplanes both from special aircraft carriers and later from ordinary warships, especially battleships and battle cruisers.[6] The American Navy decided after the war to investigate systematically the ways in which aviation might be of use to the fleet, and the operation of airplanes from battleships was tried in the Caribbean maneuvers which began in January 1919. The launching facilities,

[5] See Captain George E. A. Hallett, "A Method of Developing Aircraft Engines," *SAE Journal* 10, 1922, pp. 457-473.

[6] On the history of ship-based aviation, see Commander Peter Bethell, R.N., "Ship Flying and Aircraft Carriers," *Engineering* (London) 156, 1943, pp. 1-4, 41-44, 61-63, 101-105, 141-144, 161-163.

following the British practice, consisted simply of a platform mounted on top of the forward gun turrets, affording about 60 feet of run. If the ship was headed into the wind, a very small, light plane with the greatest power then available could just gain flying speed by running to the end of the platform, diving clear of the ship, and climbing just before it hit the water.

All the airplanes which the Americans used for ship-based flying in 1919 were British; the best were the Sopwith Camel pursuit with a 130-hp Clergêt air-cooled rotary and the SE-5 with a water-cooled 180-hp Hispano-Suiza. The air-cooled type of engine seemed naturally the best suited for this use, since it was appreciably lighter for given power and thus permitted a shorter take-off, but the rotary engine was incapable of development to much higher power than it was already delivering; need of greater power was the reason for the use of the Hispano-Suiza in the SE-5. Even before the first nine-cylinder 140-hp model R had been completed for the Army, Lawrance proposed a slightly larger nine-cylinder model J to the Navy. This seemed to be exactly the engine which the Navy needed, and since the Navy had been favorably impressed by the performance of Lawrance's 60-hp three-cylinder model L, even though little use for it had been found, a contract was awarded to Lawrance for development of the J. This contract, dated February 28, 1920, called for five engines, to produce 200 hp at 2,000 rpm; the bore and stroke were each ¼ in. greater than in the three-cylinder L and the Army nine-cylinder R, so that the displacement was 787 cu in. instead of the 670 cu in. of the model R, but otherwise the engine was very similar to the R.

The Navy contract for the J was not on a cost-plus basis like the earlier contract for the two- and three-cylinder engines, and it called for an endurance test in addition to specifying power and weight like the Army contract for the R, but even so, Lawrance's risk in accepting it was small. Like most Navy contracts for experimental engines throughout the 1920's, it provided separate payment at fixed prices for each of the various stages in the whole process of design and development. A payment was to be made on delivery of preliminary information, another for preliminary designs, others for the completed

engine, for the running of final tests, and for final information and final drawings. The prices set for the early stages were purposely made generous to provide a cushion for unforeseen difficulties in the actual construction of the engine and for alterations which testing might show to be necessary in order to meet contract specifications. Even if the engine as built failed to meet the agreed performance so that payment for the complete engine was refused, a large part of the contractor's expenses up to that point would have been covered by the payments for the earlier stages. While the prices were based on the assumption that the contractor had reasonable skill and experience, so that a complete newcomer might lose a good deal, Lawrance's success with the model L was a reasonably good assurance against loss on the J.

The First Quantity Order for the J

Before the first experimental model J engines were delivered, naval aviation had been put on a considerably sounder footing by the creation in mid-1921 of the Bureau of Aeronautics, with Rear Admiral W. A. Moffett as Chief, Lt.-Commander S. M. Kraus in charge of procurement, and Commander J. C. Hunsaker in charge of design. Lieutenant B. G. Leighton, who earlier in 1921 had been put in charge of aeronautical engines in the Bureau of Engineering, was now put at the head of the engine section of the new Bureau of Aeronautics. Even before the creation of the new Bureau the importance of naval aviation had been greatly increased by the decision made in 1920 to develop aircraft carriers, following the example of the British, who had used carriers extensively in the war.[7] The first American carrier was the old collier Jupiter, renamed the Langley, conversion of which was begun in 1920 and completed in 1921.

One of the first tasks of the new Bureau was the design of a modern fighter airplane for use on the new carrier, and Hunsaker was busy with this design early in 1921. The size of the projected airplane was fixed by the size of the elevators and the deck on the Langley, and an airplane of the size thus fixed required an engine of about 200 hp. Hunsaker's first designs

[7]Cf. Bethel, loc. cit. supra, p. 15, no. 1.

were based on the 200-hp water-cooled Hispano (Wright E-2), the most reliable engine of this power in existence, an improved version of the 180-hp Hispano used on the SE-5. While these design studies were being made, the Navy obtained and tested one of the Army's nine-cylinder Lawrance model R engines. Its performance was promising enough to persuade Hunsaker to design an airplane around the larger model J, which had not yet been tested. According to calculations, the airplane with the R not only would be smaller and more convenient than the Hispano-powered version but would outperform it as well.

When the first model J engine was delivered to the Navy, in May 1921, it produced the promised power but broke down after a few hours of running on the test stand; the 50-hour endurance test established by the Navy in 1917 was not passed until eight months later. The Navy had been convinced by its experience with aviation in the war, confirmed by the maneuvers of 1918-1919 and subsequent fleet operations, that existing engines were so unreliable, especially at full throttle, that aircraft were of virtually no real use to the fleet; their frequent forced landings in overwater service made them more trouble than they were worth. Once the pressure of war production was ended, Atkins, and after him Leighton, strove continually to persuade the engine manufacturers to devote their principal efforts to improving the reliability of their engines by prolonged running at full throttle until some part failed, redesigning the part, running until something failed again, and repeat. The running, redesign, and rebuilding were all paid for by the Navy.

Thus when the Navy was apparently faced with a choice between the superior performance of the Lawrance J and the much greater reliability of the Hispano, the Navy's general policy seemed to indicate clearly that the latter should be chosen. Leighton believed, however, that the cooling of the Lawrance J was perfectly adequate; its breakdowns were due to mechanical defects of the same sort as those which were gradually being corrected in liquid-cooled engines, and many of the most serious troubles were actually in the accessories rather than in the engine proper. Consequently it was reasonable to expect that the same process of running until failure and redesigning would produce the same reliability in this engine

that it was gradually producing in liquid-cooled engines. What was more, statistics collected by the Navy on engine failures in service showed that a fifth of all failures were due to the radiators, water-pumps, and plumbing,[8] and from these an air-cooled engine was sure to be free. Funds were available which would revert to the Treasury if not spent before the end of the fiscal year 1921, and a quick decision was necessary. Thus although the Navy would have preferred to wait until an experimental engine had passed its 50-hour bench test and had been tested in flight, it was decided to order 50 of the engines immediately and to go ahead with the construction at the Naval Aircraft Factory of 50 planes for them. Lawrance's contract was signed on June 30, 1921; a verbal agreement was made that production would not begin until one of the experimental engines had passed the 50-hour type test.

Lawrance's own facilities were completely inadequate for filling an order of this size. Lawrance therefore contracted with the De La Vergne Machine Company of New York, a manufacturer of Diesel engines and other machines, to manufacture the heavier and larger parts of the engine, while the smaller parts were made and the engines assembled by the Lawrance corporation itself. The price asked by Lawrance was high, partly because of the high price required by De La Vergne for manufacturing articles with which that company had no experience, but it was accepted by the Navy without quibbling, and progress payments were agreed on. The contract involved considerable risk for the Lawrance corporation, however, even though its terms were generous. Tooling for production required advances from the Lawrance corporation to De La Vergne of some $400,000, and the tooling was nearly completed by De La Vergne and most of the money was paid over before the first of the engines had passed the 50-hour Navy endurance test mentioned above. The entire $400,000 had to be borrowed, and since the capital of the Lawrance corporation was not a tenth of this amount, the loan could not have been secured and the contract could not have been carried out

[8] According to E. E. Wilson, *SAE Journal* 19, 1926, p. 622, 60% of all Navy engine failures were due to plumbing, and of this 60% about one-third were due to each of the fuel, oil, and coolant systems.

without the personal guarantee of four wealthy stockholders in the Lawrance corporation.

The Success of the Lawrance J and the Wright-Lawrance Merger

No time was lost after the delivery of the first experimental J-1's before beginning an intensive program of improvement of the model, with active collaboration between Lawrance and the Navy. The Navy paid the entire expenses of running and redesigning, while the actual rebuilding was done by Lawrance and the ideas tried out in the rebuilt engines came from both Lawrance and the Navy's engineers. After a good deal of work had been done a J-1 was finally got through its 50-hour type test in January 1922, when it developed a maximum of 233 hp at 1,800 rpm and received a normal rating of 200 hp at 1,800 rpm. It weighed 476 lb. Actual manufacture of the first 50 production J-1's now began at once, since the company had been confident enough of success to go ahead with tooling in its own plant and at De La Vergne.

As far as performance was concerned, the J-1 quickly justified the faith the Navy had placed in it. In 1922 all the versions of the new Navy fighter were tested in competition: the TS-1 and TR-1 with air-cooled Lawrance J-1's, the TS-2 with a water-cooled Aeromarine U-8D, and the TR-3 with a water-cooled Wright E-2 (Hispano). The performance of the two planes with air-cooled engines was repeatedly shown to be clearly superior.[9]

This superior airplane performance was essentially due to the lightness of the air-cooled engine. The water-cooled E-2 Hispano, which was rated at exactly the same 200 hp as the J-1, weighed 470 lb without its radiator and coolant, or almost exactly as much as the J-1, which required no radiator or coolant. These added about three-quarters of a pound per horsepower to the installed weight of the E-2, which was thus about 30% greater than the installed weight of the J-1. In the opinion of the Navy engineers the Navy's Vought UO observation seaplane, which by 1923 was equipped with a 200-hp air-cooled J instead of the previous 250-hp water-cooled U-873, carried as much payload and had as good performance as the Army's DH airplane with a 400-hp water-cooled Liberty, and yet was only half as large.

[9]On October 7, 1922, a TR-1 with the Lawrance engine won the Curtiss Marine Trophy race in Detroit, but this race alone proves little, since the TR-3 with an E Hispano was forced out with a broken propeller. The TS-2 with a U-8D was forced out by loss of cooling water.

The one respect in which even the advocates of the air-cooled engine often admitted at this time that it might prove inferior was the drag of the exposed cylinders, which made it probable that airplanes with such engines would have a lower top speed than similar planes with liquid-cooled engines of equal power. The Navy's engineers, however, were confident that the difference in speed, if any, would not be great, while in any case extreme speed in level flight was of secondary importance in airplanes for naval service. For the Navy's uses any possible loss in top speed was more than outweighed by the better rate of climb, greater cruising range, smaller dimensions, and shorter take-off, all due to the lower weight for given power.

Another reason for the Navy's support of air-cooled engines was its belief that this type of engine would ultimately be much easier to maintain. Although as of 1921 or 1922 there was certainly more work to be done on the J-1 than on a highly-developed engine like the Wright E-2, any given maintenance operation was easier on the individual exposed cylinders of the radial than on the monobloc in-line engines like the E-2 or Curtiss D-12 (the successor of the K-12), where a whole bank had to be disassembled to get at a single cylinder; and the Navy believed, as has been said, that after the air-cooled type had received equal development the elimination of water pumps and plumbing would markedly decrease the total amount of maintenance. Since maintenance crews and maintenance space were severely limited on board ship, this advantage was particularly attractive to the Navy.

Even the greatest superiority in performance and ease of maintenance, or any other advantage, was of little value to the Navy, however, unless satisfactory reliability could be attained; and the passing of the 50-hour type test in January 1922 was only a first step in this direction. Continued testing and improvement of the production J-1's during 1922 showed that the Lawrance corporation's facilities were too small and its staff too little experienced to be satisfactory as the sole source for all further development of 200-hp air-cooled engines. In addition, the production of the first 50 engines showed that the arrangement by which the job was split between two different firms, one of which had no experience in aircraft engines and no real interest in the product, was far from satisfactory.

For these reasons the Navy began before the middle of 1922 to try to promote more rapid development and more satisfactory manufacture by creating competition in this field, and invited both the established aircraft-engine companies, Wright and Curtiss, to undertake the development and production of engines of the same size and type as the Lawrance J. Curtiss, however, was completely uninterested at this time in air-cooled engines in general, and in addition had very little interest in developing any engine in the 200-hp class. In 1919 Curtiss had modified its 400-hp K-12 into the C-12, and when the reduction gears continued to give serious trouble had built and tested the direct-drive CD-12 in 1920 under Navy contract. Modifications of the design had been made in accordance with the results of the tests of the CD-12, and in 1921 the D-12 had been brought out. This engine had met immediately with great success, taking the world speed record in 1922, and continuing for some time to be one of the best high-power engines in the world. Far greater profits were to be made at this time (and at most later times) with high-power engines than with medium-power engines. With limited funds for the purchase of new engines the Army would make do with war surplus for its trainers and other light airplanes, and would use the funds for the purchase of new engines for first-line combat planes where the use of the best available engine would have the greatest value; engines of at least 400 hp were already demanded in 1922 for both bombers and fighters. As we have seen, there was no civilian market for new engines of any size at this time, so that the only important application for new medium-size engines was in carrier-based Navy airplanes. The Navy's total aviation appropriations, however, were roughly only half those of the Army, and a good part of them was used for the development of large seaplanes which needed high-power engines. Thus the total value of the medium-

power engines which would be bought for ship-based airplanes was much smaller than the value of the high-power engines which could be sold for Army airplanes and large Navy seaplanes. Consequently, Curtiss wished to devote virtually all its efforts to the development of the D-12, and refused to divert them in an attempt to develop a 200-hp air-cooled engine. The company had not even made a strong attempt to develop its six-cylinder water-cooled 200-hp engine as a serious competitor to the Wright Hispano, even though this engine was simply half of the twelve-cylinder D-12, so that its development would have posed very few new problems.[10]

Wright seemed to be a much more likely competitor for Lawrance, since its principal product at this time was in the 200-hp class, and it had been actively interested ever since 1919 in the development of air-cooled engines. Even Wright, however, was not interested in air-cooled engines in the 200-hp class. In 1921-1922 Wright was developing two new engines: the water-cooled type T of 1,947 cu in. displacement, undertaken in 1921 for the Navy as a replacement for the Liberty in the Navy's largest seaplanes,[11] and the air-cooled R-1,[12] nearly twice as large as the Lawrance J and intended to produce 350 hp, which had been undertaken in 1920 for the Army.[13] These two engines, it was hoped, would eventually secure for Wright a share of the really profitable large-engine field, where Curtiss was virtually alone at the time. While these engines were being developed, however, sales of the already developed 200-hp model E and the 300-hp model H Hispanos would have to constitute almost the entire substance of Wright's business, so that their continuance for some time was necessary if the company was to continue as a profitable concern.

After Lawrance received his first production contract in 1921 there had been some negotiations for the manufacturing to be done by Wright, and Richard F. Hoyt, the chairman of Wright, had actually advocated the purchase of the Lawrance corporation. F. B. Rentschler, the president of Wright, was convinced,

[10]The 200-hp engine never progressed beyond the C-6 model brought out in 1919.
[11]See below, p. 182.
[12]Not to be confused with the Lawrance R.
[13]See below, pp. 177-179.

however, that Lawrance could not by himself produce an engine successful enough to take the market from the model E Hispano, while all Wright's available engineering talent and facilities not occupied with the new T and R-1 engines were required to deal with the day-to-day problems arising in the production of the Hispano and in the continual improvement which was increasing its output to some extent and its reliability enormously. On the other hand, he believed that once Wright's large air-cooled engine was in production it would be an easy matter, if the Navy's demand for 200-hp engines continued, to produce a 200-hp air-cooled engine which would put Lawrance out of business. For these reasons Wright had finally decided in 1921 not to manufacture the 50 J-1's, and in 1922 refused the Navy's request to develop a competing engine.

The Navy, nevertheless, convinced that it had immediate need for a 200-hp air-cooled engine and determined not to await the pleasure of the large companies for the development of a better one, gave Lawrance contracts in May 1922 and February 1923 for a total of 60 additional engines. In part this action was due to the superior performance of the airplanes powered by the J-1 over those powered by the Hispano, but to at least an equal degree it was due to the Navy's firm belief that, because of the absence of a water-cooling system, the J-1 would ultimately be even more reliable than the Hispano, despite the fact that at this time the reliability of the J-1 was barely passable whereas the Hispano was making endurance runs both on the bench and in flight which were extraordinary for the time.

At the same time that the Navy was giving additional orders to Lawrance, however, it put more pressure on Wright, which did not have a product like the D-12 that permitted virtual independence of Navy wishes. The Navy informed Wright that it would buy no more 200-hp Hispanos and would cannibalize its existing engines of that model rather than buy spare parts. When the usual time for awarding most contracts arrived in the middle of 1922, at the end of the fiscal year, this policy was literally carried out. Since the Army had never been much interested in the 200-hp engine, this meant virtually

the end of sales of that model. Three hundred of the larger Hispanos, the 300-hp model H, had been ordered by the Army in 1921 for use in fighters, and this order filled the Wright shops during most of 1922, but in that year it became clear that future Army fighters would be powered by the Curtiss D-12, and that consequently the H Hispano was as dead as the E.

Under this pressure Rentschler finally yielded and, with the Navy's approval, took the shortest road to production of a 200-hp air-cooled engine by purchasing the Lawrance corporation. Lawrance was persuaded by his stockholders that even though the Lawrance corporation was now making excellent profits it would be advantageous to sell out to Wright and thus put the further development as well as the production of the J-1 in the hands of a company with much greater resources. The negotiations were accomplished late in 1922 and the sale was formally made on May 15, 1923. Wright paid $500,000, half in stock and half in cash, for assets which were written down at once to $403,000. C. L. Lawrance became vice president of Wright. The production of a part of the engines for which Lawrance already had Navy contracts was carried out in the Wright plant.

As soon as Wright took over the production of the Lawrance engine in 1923, it brought out a new model of the same basic type known as the J-3.[14] This new model made no changes in basic design, but the most critical parts were considerably strengthened, and there was some simplification of the accessories. A year later the model J-4 was brought out with cylinders of fundamentally better mechanical construction, based on the Hispano engine.[15] At this time Wright introduced the name by which the engine has been popularly known ever since: the Whirlwind. The further history of the Whirlwind was influenced by new lines of development and is set forth below in connection with the story of these new developments.

[14]An experimental J-2 built by Lawrance was never put in production.

[15]Lawrance's cylinder had been of cast aluminum with a steel liner; the aluminum cylinder was fastened to the crankcase by means of a flange, which broke continually. In the J-4, as in the Hispano, the flange was on the steel liner, while the aluminum cylinder became a muff screwed and shrunk on to the liner.

The Development of Large Air-Cooled Engines (400-500 hp)

The history of American air-cooled engines under 1,000 cu in. displacement is remarkably simple and self-contained up to 1925, as has been shown in the previous section. From 1915 to 1923 there was a single technical line of development, carried out by the Lawrance Aero-Engine Corporation. This firm, with a certain amount of aid from Army and Navy engineers, created the American tradition in this type and size of engine, and after the purchase of the Lawrance corporation by Wright the latter continued for two years to develop the 200-hp engine almost entirely uninfluenced by other developments of air-cooled engines being conducted at the same time.

The early technical history of "large" American air-cooled engines — over 1,000 cu in. displacement — is only very slightly related to the history of the smaller size, and is very much more complex. Whereas a single firm and its successor developed small engines almost singlehanded, and the very first engines produced were useful even if far from perfected, industry and the Engineering Division of the Army Air Service spent six years before the combined results of their efforts brought forth a usable large engine.

The Army Competition of 1919 and the Wright R-1

The history of high-power air-cooled engines in the United States begins with a design competition announced by the Army in 1919. The Army knew of the progress being made in Britain with the development of high-power air-cooled engines; either at this time or shortly thereafter examples were bought of the Armstrong Siddeley Jaguar, the Cosmos Mercury, and the ABC Dragonfly,[16] all of which developed between 300 and 400 hp. The Army wanted an American engine developed of the same general size and type, and issued a specification calling for an air-cooled engine to develop 350 hp, or only 50 hp less than the Liberty, which was the largest American engine of any type then available.

[16]On the history of all these engines, see the preceding chapter.

The Lawrance Aero-Engine Corporation was unable to enter this contest because its capital was insufficient to permit it to take an Army contract under the rules announced, although Lawrance did design an engine of the power requested and submit it informally to the Army. The contest was won by a design submitted by Fred Weinberg for a nine-cylinder radial of 1,465-cu in. displacement, and second place was taken by the Wright Aeronautical Corporation with a design for a 1,454-cu in. nine-cylinder radial known as the R-1. Both engines were built at the Army's cost under contracts signed in 1920 and were tested in the latter half of 1921. The Weinberg engine was a virtually complete failure and was immediately abandoned. The Wright R-1 did develop the promised 350 hp but had many faults, the worst of which were with the cylinder.

McCook Field Cylinder Development and the Curtiss R-1454

When the R-1 was tested in the latter half of 1921, there was a British civilian engineer employed at McCook Field, S. D. Heron, who, as has been told, had worked with A. H. Gibson in his fundamental study of air-cooled cylinders conducted at the Royal Aircraft Factory in 1915-1916.[17] It was his opinion, based on the results of the Factory's research, that the poultice type of cylinder used on the R-1 would never be really satisfactory, and that the basic knowledge required for the design of a better one already existed in the results of this research.[18] As a result both of this opinion and of comparative tests of the Cosmos Mercury, which had poultice cylinders, and the Armstrong Siddeley Jaguar, which had cylinders of the type recommended by Heron, the Army decided to develop a basically sound cylinder rather than try to make the R-1 work by improvement of details.

[17]See above, pp. 124-125.

[18]The general lines of the R-1 cylinder were modeled on the poultice cylinder of the British Cosmos Jupiter engine, the designs of which had been shown in 1918 to engineers from the Wright-Martin corporation; for the meaning of "poultice" construction, see above p. 135, n. 21. It is true that the Jupiter eventually became a successful engine with this cylinder, and in part the difficulties with the Wright cylinder were due to the use of different methods of construction from those of the Jupiter, especially the use of a shrunk-on head and shrunk-in valve seats. Even as constructed on the Jupiter, however, the poultice cylinder was ultimately made to work only by extremely ingenious, energetic, and costly development, and was given up in 1929 in favor of a cylinder with an all-aluminum head.

Design and development of air-cooled cylinders were accordingly begun at McCook Field at once, under Heron's direction. The aim was to produce a cylinder which would not only be almost twice as large as the cylinder on the Lawrance J-1 but would have a considerably higher "brake mean effective pressure" (bmep), i.e., would tolerate a higher pressure due to compression and burning of the fuel-air mixture, so that each power stroke of the piston would deliver more energy per cubic inch of cylinder capacity. It was hoped, in fact, that the bmep could be made as high as that of contemporary water-cooled engines. This development led to various improvements in detail over the cylinders already developed at the Royal Aircraft Factory, but its most important result was simply the establishment for the first time in the United States of the general principles which had already been demonstrated (although they were not universally accepted) in Britain.[19]

The first successful cylinder produced by Heron incorporating these principles was known as the type J.[20] After this cylinder had been thoroughly tested, probably well into 1922, the Army asked Wright to rebuild the R-1's with cylinders of this design. Wright objected very strongly, alleging that the Army design was unsound, but eventually accepted a contract to do the construction.

One other important change was made about this time either in one of the original R-1's or in one of the rebuilt engines with type J cylinders. The Armstrong Siddeley Jaguar had shown that a more even distribution of fuel and air to the cylinders of a radial engine could be secured by passing the mixture of fuel and air through a centrifugal blower running at crankshaft

[19]These were: (1) that adequate valve cooling could be obtained only if the valves were inclined to each other at a broad angle so that sufficient cooling air could flow between them; (2) that contrary to almost universal belief two valves were superior to a greater number in air-cooled cylinders, at least up to the size and power contemplated at that time; (3) that the steel cylinder barrel should be open at the end, the entire head being of aluminum; (4) that the barrel was better cooled by integral fins than by having the aluminum head cover it like a muff; and (5) that the best method of attaching the aluminum head to the steel barrel was by screwing and shrinking it on. The first three of these conclusions had been established by Gibson; Armstrong Siddeley had been the first to use the last two. Every one of these conclusions except the fourth was contrary to the design of the Wright R-1; every one but the first was contrary to the Lawrance J, which was too small to use four valves anyway.

[20]This has no connection, of course, with the Lawrance type J-1 engine.

speed, from the rim of which the mixture was led by a separate pipe to the intake port of each cylinder. The arrangement was known as a "rotary induction system". Under a contract awarded by the Army, which as has been said had bought and tested a Jaguar, a rotary induction system was designed for the R-1 by the Lawrance Aero-Engine Corporation and built into an R-1 engine by Wright very shortly after the merger of the two companies in March 1923.

The remodeled R-1's with type J cylinders were delivered late in 1922 or early in 1923 and were tested for several months; bench tests were followed by flight in a DH-4 (where the R-1 replaced the Liberty) and in a specially built Loening PA-1 fighter. Another experiment was made when one of the engines was rebuilt by the Allison Engineering Company according to an Army design with extremely short connecting rods in order to reduce the over-all diameter of the engine. This proved a failure because of the excessive angularity of the rods which resulted from their excessively short length. The type J cylinders on the other R-1's proved generally successful, but the engine had various mechanical weaknesses, particularly in the two-piece crankshaft.

On the basis of all these tests the Army drew up a detailed specification for a complete redesign of the engine, while at the same time it had Heron begin the design and development of a still better cylinder, to have enclosed valve gear "automatically" lubricated by oil from the pressure system of the engine, the first such cylinder designed anywhere for a radial engine. The Army specification for the R-1454, as the remodeled engine was to be known,[21] was issued on August 15, 1923; the making of the detailed design and the construction were opened to pure price competition. Curtiss' bid, submitted on November 13, 1923, was lower than the others, including Wright's, and on January 16, 1924, Curtiss received a fixed-price contract for the construction of three engines with an option for three more. The delay of five months between the issuance of the specification and the signing of the contract is typical of the delays inherent in this method of developing an engine.

[21]The engine was known as the R-2 until 1924, when the name was changed to accord with a new standard system of nomenclature.

The Army specification called for a first engine to be built with type J cylinders but with provision for later modification to use the cylinder with automatically lubricated valve gear currently being designed by Heron. The engine was to deliver at least 390 hp at 1,700 rpm. The split crankshaft of the Wright R-1 was to be replaced by a solid shaft with split master rod. One very important step forward was taken by changing the "rotary induction system" to a genuine built-in supercharger geared to the crankshaft, such as had been included in the original experimental model of the Armstrong Siddeley Jaguar, but which had been turned into a mere rotary induction blower running at crankshaft speed before that engine was put in production.[22]

The first R-1454 engine was delivered by Curtiss to the Army about September 1924, some nine months after the contract was signed. When put on test by the Army, it delivered up to 405 hp at 1,650 rpm. Before the end of 1924, however, Heron had built the new cylinder for the R-1454 known as the type M, and it was put on test in January 1925. On February 9, 1925, Curtiss was instructed to proceed to rebuild the engine with the new cylinder, but it was not until late in the year that the rebuilt R-1454 was in the Army's hands. The period of nine months required for the original designing and building of the first R-1454 seems not unreasonable, but the fact that nearly as long was taken to rebuild this engine with new cylinders would seem to indicate that the priority given to the project by Curtiss was not very high. It is very difficult, moreover, to understand why the Army had the first R-1454 rebuilt instead of having Curtiss build a completely new engine with the new cylinders. This meant that although there was no delay in cylinder development, since the Army could and did do extensive testing of the M cylinder on single-cylinder engines while the R-1454 was being rebuilt, all testing and development of the rest of the engine were completely suspended during most of the year 1925.

The initial tests of this first R-1454 with type-M cylinders, conducted in the latter part of 1925, revealed a number of

[22]The drive for the R-1454 supercharger was to be based on that designed by Heron and F. M. Green for Armstrong Siddeley in 1917, before the geared-up drive was eliminated from the Jaguar; cf. above, p. 132.

difficulties of the sort normally encountered with the first experimental engine of a new model, both in the new cylinders and in the rest of the engine. Among other things the automatic lubrication of the valve gear gave trouble because owing to the lack of a proper sump the engine failed to scavenge properly. All the troubles, however, were the sort of thing which was to be expected with a new engine, and gave no reason to think that there would be unusual difficulties encountered in their solution. Despite the troubles, furthermore, before the end of 1925 the engine had passed a 50-hour type test, consisting of 45 hours at 90% of its rated 390 hp and five hours at full rated power, for a weight of 830 lb.

On February 9, 1926, the Army instructed Curtiss to proceed with the building of the second and third engines called for in the contract, incorporating certain changes shown to be advisable by the results of the tests of the first. Meanwhile the first engine was sent to the Douglas Aircraft Company to be installed in place of a Liberty in an O-2 observation plane. There is no record that this airplane was ever flown, but when the second and third engines were delivered in June 1926, one of them was immediately flown in place of a Curtiss D-12 in a Curtiss P-1 fighter, designated XP-3 with the new engine.

Just about the time these flights were made, however, a much better engine appeared, the Pratt & Whitney Wasp, which not only delivered slightly more power than the R-1454 but weighed only 650 instead of 830 lb and was a good deal cleaner and more reliable. It was flight-tested about the same time as the R-1454 in an F6C-4, the Navy equivalent of the XP-3, and gave very much better performance. Since the Wasp incorporated most of the best features of the R-1454, and had many additional advantages of its own, both Curtiss and the Army were ready by September to abandon the R-1454. Curtiss began at once to lay out a 12-cylinder two-row engine, the H-1640, which it hoped would greatly surpass the Wasp in power while having a considerably smaller frontal area. The last of the three R-1454's already built was put in the McCook Field museum, and a contract made in 1925 for the three additional engines for which the Army had an option was cancelled by the agreement of both parties.

The Wright P and Simoon Engines

The appearance of the Wasp was the end result of a long process begun when the Navy became interested in the development of a large air-cooled engine. Until 1923 the Navy had been uninterested in air-cooled engines larger than Lawrance's model J. We have seen that its interest in 200-hp air-cooled engines was due first of all to their especial suitability to ship-based airplanes. In the only other type of naval aircraft existing at this time, large flying boats for patrol, the need for short take-off, rapid climb, and small size was not so pressing as in ship-based aircraft, and since their purpose was the making of over-water flights of several hours' duration, reliability was the all-important consideration. In addition, the early air-cooled engines had such high fuel consumption that for long flights the total weight of an air-cooled engine plus its fuel was greater than that of a water-cooled engine plus its cooling system and its fuel. In Britain also, the last field to be conquered by the air-cooled engine was that of long-range aircraft, where the water-cooled Napier Lion was supreme until 1926.

Thus in the earliest days the Navy concentrated all its efforts on improving the reliability of the Liberty engine, which powered all these boats. When a replacement for the Liberty was considered, the natural course was to choose the type which could deliver the great power needed with the least uncertainty due to novelty of design, and with good fuel economy. The first engine thus undertaken was the 1,948-cu in. water-cooled Wright type T, designed initially to produce 500 hp which it was hoped ultimately to increase to 700. The contract for this engine was given in 1921, and the 50-hour type test was passed by the T-2 early in 1922, the same year in which the 400-hp Curtiss D-12 passed its type test. During 1922 and 1923 Wright tried very hard to make the water-cooled T into a successful competitor to the Curtiss D-12 as a power plant for racing airplanes. The rated power was increased to 575 hp in the T-3, brought out in 1923, and for two or three years this engine was standard for long-range Navy boats and seaplanes.

By 1923, however, experience with the Lawrance J and improvements made in its fuel consumption, the progress made

at McCook Field in the design of large air-cooled cylinders, and reports of the success of large British air-cooled engines had given the Navy more faith in the feasibility of air cooling for large engines. The various defects which had made the first J-1's extremely unreliable had been corrected at least well enough to permit the Navy to announce officially in 1923 that for outputs up to 300 hp it would in the future use only air-cooled engines, and the lower weight of the air-cooled type and the eventually superior reliability hoped for from the elimination of the radiator system were strong inducements to support the development of an air-cooled engine large enough for the long-range patrol boats.

About the middle of 1923, before the Army had called for bids on its redesigned R-1454 version of the R-1, a contract was signed between the Navy and Wright for three large air-cooled engines to be built successively. The first was to be a 400-hp 1,652-cu in. engine known as the P-1. C. L. Lawrance had just become vice president of Wright,[23] and the design of the P-1 was based on the one informally submitted by Lawrance to the Army at the time of the 1919 competition. It is highly probable that the entrance of Lawrance into the management of Wright was an important factor in the Navy's decision to award Wright the contract for the P engines, since the Navy officers in charge of engine development had an extremely high opinion of Lawrance's talents as a designer.

Because of the general fear of the head resistance of radial engines, the design of the P-1 attempted to limit an engine with twice the displacement of the J to a frontal area no greater than that of the J. The cylinder was based on the general principles demonstrated by Heron at McCook Field, in that it had an aluminum head screwed and shrunk on a steel cylinder with integral machined fins, and had only two valves whose stems were inclined to each other at a wide angle; but chiefly because of the limitation on the diameter of the engine the valves were arranged fore and aft instead of side by side. Just as the Army did at that same time in the R-1454, Wright in the P-1 gave up the split crankshaft of the R-1 and substituted a split master rod.

[23] Cf. above, p. 175.

The P-1 was tested in 1924, and extensive flight tests were made in a Douglas DT-2 airplane. The performance of the engine was not satisfactory, however; it was very rough, the peculiar arrangement of the valves gave rise to trouble, and the excessively small diameter caused excessive side pressure on the pistons and other troubles just as in the Army's small-diameter R-1 tested about this same time.[24]

In March of this same year, 1924, Lt.-Commander E. E. Wilson succeeded Leighton as head of the engine section in the Bureau of Aeronautics, and a month or two later the two men made a tour of the country to observe the state of engine development. At the Curtiss plant Wilson became convinced that the company was far from anxious to hasten the development of the R-1454, since all the rights to that engine belonged to the Army and it was in exactly the same power class as Curtiss' own engine, the water-cooled D-12. Even at Wright Aeronautical, Leighton and Wilson found far less enthusiasm for the air-cooled P than for the water-cooled T, although the former was as much Wright's own engine as the latter.

It is natural to ask why, in the face of the great enthusiasm of the Navy for air-cooled engines and the great, immediate, and profitable success of the medium-power Whirlwind, Wright should still have been so cautious in the development of a high-power air-cooled engine. It is true that there were still some very serious technical obstacles to be overcome before a successful large air-cooled engine could be built; Heron's work at McCook Field had by this time shown the way to adequate cooling, but very serious mechanical problems remained. The trouble was not, however, that these technical problems involved a risk of direct loss of money spent in development, since although the Navy permitted the design of the P to remain the company's own, it paid the full cost of development and Wright assumed no risk. The real reason why the technical problems in the large air-cooled engine were an obstacle was that the primary function of the engineering department of a manufacturing company is to give the company a salable product; if engineering talent and facilities are too exclusively devoted to a long-term project, the company may find itself

[24]Cf. above, p. 179.

in the meanwhile with nothing to manufacture. The first call on Wright's engineering department was now the improvement of the Whirlwind, which accounted for almost all the company's production. Of its two large engines, the water-cooled T was both further developed, having been begun two years before the air-cooled P, and contained less unknowns, so that Wright naturally tried to make the T a salable product before devoting its full energies to the development of the P.

Wright, however, was quite ready to go ahead with the large air-cooled engine on a scale which fitted in with the other activities of the company, and in 1924 work was begun on the second engine called for in the 1923 contract with the Navy. This engine, called the P-2, had the same bore and stroke as the P-1, but the excessive limitation of the frontal area was removed. At Wilson's suggestion the P-2 incorporated several good features which he had observed on the Curtiss R-1454, especially the built-in supercharger. The construction of the P-2 cylinder and the arrangement of the valves were derived from Heron's type J cylinder of 1922; the valve gear was enclosed as it was on Heron's type M cylinder, designed in this same year, 1924, although Wright did not attempt automatic lubrication as the type M did.[25]

At about the same time that the P-2 development was begun, F. B. Rentschler resigned as president of Wright, effective September 1, 1924. He had found himself in increasing disagreement with his directors, and had decided that it was impossible to manage a concern of this sort when none of the directors had either an appreciable stock interest or, in his opinion, a real understanding of the nature of the business and particularly of the highly technical engineering problems on the proper solution of which the business depended for its existence. His earlier disagreement with the chairman, Hoyt, over the proposed acquisition of the Lawrance Corporation[26] is perhaps typical, although this had been only one of a large number of matters in dispute.

[25]It is probable but not certain that Wright decided to use enclosed gear after Wilson and G. J. Mead, Chief Engineer of Wright, had inspected Heron's drawings of the type M cylinder.

[26]Cf. above, pp. 173-174.

Late in 1924, or several months after work was begun on the P-2, Wright accepted a new Navy contract, to develop an engine intermediate in size between the Whirlwind and the P-2. This new engine was known as the Simoon. The Navy's Whirlwind-powered Vought UO, an observation plane carried on ships other than carriers, was now too small, and Vought was working on the design of a replacement, the O2U. The design was restricted to use of existing catapults, and Vought concluded that the engine must not weigh over 650 lb and must develop at least 350 hp. The Navy believed that such an engine might also make a good replacement for the water-cooled Packard 1500 and Curtiss D-12 in fighters for use on the new carriers, Lexington and Saratoga then being built.[27] Wright decided, in agreement with the Navy, that the quickest way of obtaining the desired engine would be simply to scale down the larger P-2 from a displacement of 1,652 to 1,176 cu in., which would give the desired weight of 650 lb. Development of the Simoon was begun at once.

The Formation of Pratt & Whitney: The Wasp

By 1925 both the technical and the economic circumstances surrounding the development of a 400-hp air-cooled engine were very different from what they had been a few years before. Technically, air-cooled engines of this size were now being used in large quantities in Britain and also in Europe; in the United States two engines had now been flown (the R-1 in 1923 and the P-1 in 1924), and promising bench tests were being obtained from the Curtiss R-1454 and the Wright P-2; the latter passed a type test later in 1925. The difference in the economic situation was even more important. The Navy was almost sure to buy an engine of 350 hp (or more) in quantity for the Vought O2U; provided that the engine was good enough the Navy was almost sure to buy still larger quantities for the fighters which would very soon have to be procured to equip the two large new carriers, the Lexington and Saratoga, carrying nearly a hundred airplanes each, which were launched in the first part of 1925. Until recently the

[27] These ships had been laid down as battle cruisers and were converted to aircraft carriers as a result of the Washington treaty of 1922.

profits to be made from the development of an engine of this size and type were so uncertain and so remote that manufacturers scarcely considered them in planning their engineering programs; the work done had to be paid for in full by the government, and it had to take second place after projects which seemed likely to yield a salable product in the near future. By the beginning of 1925, however, the profits to be made in this field seemed as real, and as soon attainable, as those to be made on water-cooled engines.

In 1925 F. B. Rentschler, the former president of Wright Aeronautical, formed a new company whose only product, at least at first, would be high-power air-cooled engines. At the time of his resignation from Wright some of the key personnel, including the Chief Engineer, George J. Mead, and the Assistant Engineer in Charge of Design, A. V. D. Willgoos, had assured him that if he ever returned to aviation they would like to join with him again. Rentschler was confident that given a free hand these men could in a reasonably short time develop an engine superior to the Simoon, which was handicapped by being merely a scaled-down version of the larger P-2.

For backing, Rentschler turned to Niles-Bement-Pond, whose president, James K. Cullen, was an old family friend. Niles-Bement-Pond had emerged from the war with both plants and cash for which it was unable to find profitable employment, and Cullen sent Rentschler to inspect the unused facilities of its subsidiary, the Pratt & Whitney Company, in Hartford. One of the buildings there was adequate for the purpose, and Cullen agreed that if the Navy was sufficiently interested in Rentschler's proposals, Niles-Bement-Pond would provide sufficient capital to set up a new company on these premises.

Rentschler now secured the collaboration of his old friends in Wright, and preliminary sketches and performance estimates of a new engine were roughed out. With these he went to the Navy to learn its attitude toward his project and, if possible, to obtain a contract covering the costs of the development, such as the Navy had given for all new engines developed for it up till then. The Navy was glad of an opportunity to create competition for Wright in the manufacture of air-cooled engines, both because it believed that competition would hasten development and lower prices, and because Admiral Moffett, the head of the Bureau of Aeronautics, feared charges that the Navy was supporting and protecting a monopoly. Thus although the Navy felt that the time was past when a development contract could be given to an untried company, and told Rentschler that he would have to develop the engine on his own resources, it informed him that experimental funds were being set aside for the purchase of six experimental engines if Rentschler could demonstrate a promising prototype, and that if the six experimental engines were satisfactory a production contract would be awarded at a price high enough to amortize the entire cost of development, provided that this did not make the price of the engine higher than that of the Curtiss D-12.[28]

With this assurance Rentschler succeeded in financing his undertaking completely with private capital. An arrangement was concluded with the Pratt & Whitney Company by which the latter was to invest an initial sum of $250,000, estimated to be the amount needed to carry the work up to the point of testing a first engine, and, if this engine proved promising, to invest at least $1 million more for further development and production tooling. The new firm, Pratt & Whitney Aircraft Company, was incorporated on July 23, 1925. Half its common stock was given to its management and half to the old Pratt & Whitney Company, which also received $2 million of preferred stock, or somewhat more than the actual amount of its cash investment. The principal personnel of the new company all came from Wright Aeronautical; among the most important in addition to Rentschler, who became President of Pratt & Whitney Aircraft, were George J. Mead, who became Vice President, and A. V. D. Willgoos, who became Chief Engineer.

The new Pratt & Whitney Aircraft Company began designing in August 1925, and the work progressed with unusual speed. It was necessary to beat the Simoon before the Navy could standardize on that engine. The engineering team was

[28]The price of the D-12 at this time was about $9,100. The price ultimately set for the first production Wasps was about $8,750, $750 of which was for amortization of development.

small, compact, and used to working together, and they were free from all the day-to-day distractions of production and service engineering which are inevitable in an established company with engines actually in production. Finally, they were starting with a clean slate and were not limited by concern for any existing designs or fixtures. It was this freedom to do as they thought best which made possible the ambitious goal they had set themselves, at the Navy's request, of obtaining 400 hp instead of the 325 at which the Simoon was now rated with no increase in weight.

The essential differences from the Simoon which were responsible for the superior performance of the Wasp were two. First, instead of a cast crankcase as used on all previous American radials, the Wasp had a very cleverly designed forged crankcase which was so much lighter than the cast crankcase of the Simoon that the Wasp could have a displacement of 1,344 cu in. instead of the 1,176 of the Simoon for the same total weight.[29] Second, instead of the split master rod used in the Curtiss R-1454 and the Wright P and Simoon engines, the Wasp followed the original R-1 in using a two-piece crankshaft so that a solid master rod could be used.[30] This arrangement made possible a speed of 1,900 rpm instead of about 1,650, with a proportional increase in power, and in addition eliminated what was at that time a serious cause of short life and poor reliability in large radials even at low speed and power.[31]

The cylinder design of the Wasp was also a definite improvement over anything that had been done before, although in

[29]The first radial engine with a forged crankcase was a British engine, the Bristol Jupiter; cf. above, p. 142. The Wasp's forged crankcase saved even more weight proportionally than the Jupiter's, since the design was better suited for forging to minimum weight without excessive scrap. Although the original designs of the Wasp called for a forged crankcase, one could not be obtained immediately, and the first few experimental Wasps were run with cast crankcases; the first engines with forged crankcases were run in the first half of 1926.

[30]The first experimental Wasps were run with split master rods while the two-piece crankshaft was being developed.

[31]Split rods were later made to work with excellent success, e.g., on the R-1830 and the R-4360, but it seems clear that in 1925 the more rapid route to higher rpm was the use of a solid rod. Bristol in England had type-tested the Jupiter V with a two-piece crankshaft and solid master rod in October 1924, obtaining a maximum rating of 480 hp at 1,900 rpm instead of the 436 hp at 1,750 rpm of the otherwise identical Jupiter IV, and this development was known to the engineers who designed the Wasp, but whether it was an important cause of their decision to use this construction cannot be determined.

this case the advantage was not one leading to higher power. The arrangement of the valves and the finning and the use of enclosed valve gear descended from Heron's work via the Wright P-2, but the enclosed valve gear was improved by making the rocker-box an integral part of the cylinder casting.

The Wasp was tested on the block early in 1926 and flown on May 5 in the Wright Apache. It was soon type-tested and given a normal rating of 400 hp at 1,900 rpm at sea level. It was astonishingly successful for a new engine; despite the fact that the Simoon had passed its type test in 1925 and was ready for production, the Wasp was so much more powerful (400 against 325 hp) for the same weight that the Simoon was never put into production. As we have already seen, the first tests of the Wasp in the Curtiss fighter also led to the immediate abandonment of the R-1454 by Curtiss and the Army. Immediately after testing the six experimental engines, the Navy gave an order for 200, and commercial sales of 28 engines for use on the Boeing 40 mailplane followed even before the first Navy quantity order had been filled. These engines were delivered before the end of 1927; the receipts completely amortized the cost of development and left enough over for a satisfactory profit.

The Pratt & Whitney Hornet and the Wright R-1750 Cyclone

Although the Wasp attained the goal of 400 hp originally set by the Navy for the larger Wright P engines, the Navy was now anxious for still more powerful air-cooled engines to replace the water-cooled Packard 2500 engine which had succeeded the Wright T. These large engines were wanted particularly for use in the torpedo-bombers planned for the new carriers, which were to go into service in 1927, and the Navy was pressing for the completion of the large engines even before it had tested the first Wasp.

Almost as soon as the first experimental Wasp had been built, therefore, early in 1926, Pratt & Whitney proceeded to lay down the design of the Hornet along very similar lines, but with a displacement of 1,690 instead of 1,344 cu in., and with a 2:1 reduction gear to drive the propeller. This engine was first run in June 1926, and about a year later, in 1927, it passed

its Navy type test at 525 hp at 1,900 rpm for a weight of 840 lb. Despite the fact that the British at this same time were conclusively demonstrating the very considerable gains to be made from the use of geared propellers,[32] and were stopping almost all production of direct-drive high-power engines, there was no demand for geared engines in this country. It was a direct-drive version of the Hornet, weighing 775 lb, which Pratt & Whitney succeeded later in 1927 in selling in quantity to the Navy for use in the Martin T4M airplane. As far as the Navy was concerned, all existing water-cooled engines were now obsolete.

Wright Aeronautical's 1,652-cu in. P-2 Cyclone had passed the Navy type test at 435 hp and had been flight-tested already in 1925, but development was virtually at a stop during the entire latter half of that year. The engineering department of the company was seriously handicapped by the loss of its Chief Engineer and Chief Designer to Pratt & Whitney in July 1925, and the acting Chief Engineer, C. F. Taylor, was fully occupied with bringing out a new model of the Whirlwind, the J-4B. Cooling was greatly improved in this new model, which made use of the McCook Field advances in cylinder design and marked the first important departure of the Whirlwind cylinder from Lawrance's original design as far as cooling was concerned.

At the beginning of 1926 E. T. Jones, until then head of the power-plant section at McCook Field, was made Chief Engineer of Wright, and S. D. Heron came to Wright at the same time. These two men also gave their first attention to Wright's only important production article, the Whirlwind. The changes made in the J-4B had been strictly limited to those which could be made in the cylinder without involving changes elsewhere in the engine, even in the valve gear. Jones and Heron proceeded to redesign the cylinder completely, making such changes in the rest of the engine as this required. The cylinders, with enclosed valve gear, were based on the type K developed by Heron at McCook Field in 1922, and exhaust-valve cooling was further improved by the use of valves internally cooled by a mixture of sodium and potassium nitrates, which

[32]Cf. above, p. 146, and below, p. 202.

had been developed by Heron for the Army about 1922.[33] This was the first model of the Whirlwind to have a fuel consumption approximately as low as contemporary water-cooled engines.

Meanwhile the P-2 Cyclone with its output of 435 hp from 1,652 cu in. was at once rendered completely obsolete by the appearance of the Wasp with an output of 400 hp from only 1,340 cu in. Consequently early in 1926, while work on the redesign of the Whirlwind was still in progress, Jones, Heron, and Lawrance began the design of a completely new Cyclone, known from its displacement as the R-1750. This engine, like the contemporary Pratt & Whitney and Bristol engines, had a solid master rod with a split crankshaft. The cylinder design was based on Heron's type M, with some modification along the lines of the Wasp although the rocker boxes were still bolted on instead of being cast integral with the cylinder.[34] The internally cooled valves proved on the J-5 Whirlwind were incorporated. In 1927 the R-1750 passed a type test at 500 hp, and the Navy adopted it at once for use in its two-engine flying boats. About a hundred engines were sold in the next year.

The Establishment of the Air-Cooled Engine in the United States

The Pratt & Whitney Wasp was very probably the best unsupercharged direct-drive air-cooled engine in production anywhere in 1927. The latest unsupercharged direct-drive Bristol Jupiter in production in 1927 was the VI, which with a compression ratio of 5.3:1 (the Wasp's ratio was 5.25:1) had a normal rating of 440 hp at 1,700 rpm at sea level for a weight of 720 lb. The specific weight of the Jupiter was thus 1.64 lb/hp, or virtually the same as that of the original Wasp A, rated 400 hp at 1,900 rpm for 650 lb, or 1.63 lb/hp. The cylinder design of the Jupiter was distinctly inferior, however. The

[33]See Appendix to this Chapter.

[34]Willgoos's integral rocker boxes were patented, but the validity of the patent was later considered to be questionable because of prior use on a European motorcycle. In any case the real reason they were not used on the R-1750 was not the existence of the patent but the fact that Wright was not yet convinced of their superiority; such delays in the acceptance by one firm of a new feature developed by another, even when the advantages of the new feature are demonstrable, are unfortunately not infrequent.

poultice head[35] had to be rebedded at intervals of 300 hours at the most; the valve gear was open and allowed water and dirt to enter it and allowed oil to be scattered by the gear over the engine, and the inadequate cooling of this cylinder meant that its 1927 output was its extreme limit, whereas the output of the Wasp was rapidly increased. In March 1928 Pratt & Whitney began deliveries of the improved Wasp B. This model, with more fins on the cylinder and various components strengthened, was rated 450 hp at 2,100 rpm normal for a weight of 670 lb, or 1.49 lb/hp. It was not until Bristol put a Jupiter with a forged, all-aluminum cylinder head in production in 1929 that the basic Jupiter engine was again on an equal footing with the Wasp.

It was still some time, however, before an American engine equaled either of the two British air-cooled engines, the Bristol Jupiter and the Armstrong Siddeley Jaguar, in two respects: supercharging and the availability of a geared drive. The lack of a geared propeller drive in the first two or three years of the Wasp was due rather to lack of demand than to the unwillingness or inability of the company to provide it; as we have seen, the Hornet was originally built in 1926 and type-tested in 1927 with a geared drive, but was first put in production with direct drive because that was what the Navy demanded. In 1929 the Wasp C was put in production with a 2:1 reduction gear.

The original Wasp had an integral gear-driven blower, but the tip speed of 285 fps (5:1 gear) was too low to provide any supercharging, and the blower served solely to provide more even distribution of fuel and air among the cylinders. In the B Wasp put in production in September 1927 the standard supercharger tip speed was increased, but only to 441 fps (7:1 gear), still insufficient to provide real supercharging. Even the 10:1 gear incorporated in one version of the Wasp C, brought out in 1929, gave a tip speed of only 630 fps and maintained the rated 450 hp at 2,100 rpm to only 6,000 feet. In Britain Armstrong Siddeley had a supercharged Jaguar, rated 410 hp maximum at 9,000 feet, in squadron service on the Siskin fighter in 1926. The supercharged Bristol Jupiter VII was type-tested in May 1928 at a rating of 420 hp normal or

[35]Cf. above, p. 134, n. 21.

460 hp maximum at 12,000 feet, and was in service late in 1928 or early in 1929.

No American liquid-cooled engine, however, had better supercharging than the American air-cooled engines and the years 1927 and 1928 mark the final and complete establishment of the air-cooled engine in the United States. The exciting long-distance and endurance flights of these years, led by Lindbergh's in 1927, were almost all powered by Whirlwinds. Far more important ultimately were the successes of the larger engines. After testing the Wasp in the O2U and in the F6C-4 and F2B fighters, and the Hornet in the T4M torpedo plane, the Navy officially announced in 1927 that it would use no more liquid-cooled engines in any one- or two-place airplanes. Commercial aviation advanced much more rapidly in the United States after July 1927 when Wasp-powered Boeing 40's showed that airmail could be carried profitably for half what it cost in DH's with Liberty engines and began a long series of genuine commercial planes designed around air-cooled engines.

The Army remained unconvinced of the suitability of air-cooled engines for pursuit planes for some time after the Navy accepted them, but even this remaining hesitation ended in 1928. In the national air races held at Los Angeles in that year the Navy entered the first fighter really designed around an air-cooled engine, the Wasp-powered Boeing XF4B. While there was no direct competition between this airplane and the Army's most advanced liquid-cooled pursuits, the XF4B made a high speed of 172.3 mph against 147.7 mph of the Army's standard P-1B with a D-12 engine developing the same power as the Wasp. Even more important was a race from the ground to 10,000 feet altitude and return; the XF4B accomplished this in 5.92 minutes while the P-1B which came in second took 7.08 minutes. General Fechet, the Chief of the Air Corps, was so impressed by this performance that he placed a verbal order on the spot, with the result that the Army received production fighters of this model, which it designated P-12, even before the Navy got its first production F4B's.[36]

[36]In January 1929 maneuvers were held in which the Navy simulated an air attack from its carriers on the Panama Canal, which was defended by the Army. The superior performance at altitude of the Navy fighters with slightly supercharged Wasp engines over the Army Curtiss fighters with heavier, unsupercharged D-12's was the primary reason for the success of the Navy's attack.

From 1927 on it was no longer necessary for the military services to support the development of air-cooled engines by contracts which directly paid all or even a large part of the costs incurred. Development of the higher-powered engines was still due primarily to military support, but this support could now be much more efficiently extended through the profit motive. After the passage of the Vinson-Trammell Act and the Air Corps Act of 1926, the services had procurement programs which definitely called for the regular purchase each year of reasonably large quantities of new engines, and this market was appreciably extended by the rapid growth of commercial aviation. With the appearance of both the Pratt & Whitney Hornet and the Wright R-1750 Cyclone in 1927 there was direct competition between two manufacturers of a single class of air-cooled engine, and this competition was in the class where it could do the most good, that of the highest power. Wright could depend on a certain backlog of almost noncompetitive business in the Whirlwind size, and Pratt & Whitney could do the same in the size of the Wasp, but the two companies had to contend energetically for the real profits, which were to be made from high-power engines, and there was no hesitation on the part of either one to risk a good share of its gross revenue in development in order to secure profits in the future.

Development contracts continued to be given by the services, but in the case of air-cooled engines their nature was completely different from what it had been earlier. Instead of paying the entire costs of a development, they usually amounted only to the cost of building the handmade engines which were delivered to the services for test; the much greater costs of the actual design and development were charged off by the companies as a current cost of operation. Thus the pattern was formed which to a large extent accounts for the rapid improvement of American air-cooled engines in the 1930's.

Summary

Because the profits to be made on production of a 200-hp air-cooled engine seemed too small, the established American engine builders refused to develop one for the Navy despite the fact that the Navy was willing to pay in full for the work. A very small firm, the Lawrance Aero-Engine Corporation, finally produced a tolerably successful engine of this sort, and by purchasing this engine in quantity and refusing to buy the generally superior water-cooled Wright-Hispano, the Navy forced Wright to take over the development of the Lawrance engine in 1923. The use of Wright's superior facilities and experience quickly produced the first really successful air-cooled engine in the United States, the Whirlwind.

High-power (400-hp) air-cooled engines owed their American origin entirely to the initiative of the armed services. The attempt of the Army to have an Army-designed engine developed by a private firm was a failure, but research done by the Army itself did solve certain of the most serious technical problems of this type of engine, and these results were taken up by engineers of Wright Aero working under Navy contract. By 1925 the Navy was sure enough of the future of large air-cooled engines to guarantee a market for an engine of this type meeting certain specifications, and acting on this assurance former engineers and executives of Wright Aero formed Pratt & Whitney Aircraft and brought out the highly successful Wasp entirely at private expense.

APPENDIX TO CHAPTER VII

The Origin of Internally Cooled Valves

One of the chief problems encountered in valves is that of conducting heat away from the head rapidly enough to keep it from overheating and warping. Heat escapes from the head in two ways: through the valve seat during the time the valve is closed, and at all times by passing down the stem and out through the valve guides. If the rate at which heat passes from the head to the portion of the stem in contact with the guides can be increased, the latter method can be made more effective. An internally cooled valve is one with a closed, hollow stem containing a certain amount of some substance which is liquid at the operating temperature of the valve. This liquid moves back and forth with the motion of the valve, absorbing heat when it is at the head end and transferring this heat to the stem when it is at the other end.

The British had tried valves internally cooled by mercury in 1913-1914, but without much success. During his research on air-cooled

cylinders conducted at the Royal Aircraft Factory in 1915-1916, A. H. Gibson had used water as the coolant in a valve with a radiator on the end of the stem, pointing out that the reason the earlier, mercury-cooled valves had failed to cool was that the mercury did not wet the interior of the valve. The water-cooled valve, however, proved liable to burst as a result of the exceedingly high pressures which developed in operation. The water-cooled valve could not be used in modern engines in any case, owing to the radiator, but Gibson's work demonstrated in principle the value of internally cooled valves in large two-valve air-cooled cylinders.

A little later C. F. Kettering and Thomas Midgley of the Dayton Electric Company (Delco) also experimented with mercury-cooled valves. They had learned before 1921 that the coolant should wet the valve, and tried tin-plating the surface of the steel to accomplish this. This method was licensed by Delco to the Fansteel Products Company for development and commercialization but never amounted to much, although it was used in the Lawrance L-2 and J-1 engines, partly because this valve was a very minor project for Fansteel, partly because it was developed primarily for cheap air-cooled stationary engines so that the company officials were too conscious of the cost of the product, and partly because this method of wetting was inherently a poor one.

Heron became interested in internally cooled valves because ordinary valves would not stand up in the new air-cooled cylinders which he was developing for the Army since 1921 (cf. above, p. 178). His difficulties were actually due to defects in the valves he received, but at the time he did not know this. His first coolant was the eutectic mixture of sodium and potassium nitrates, which he thought of when he saw that the bath of this mixture used in heat-treating processes wetted the pot so well that it crept out over the sides. Shortly after trying this method he thought of using metallic sodium or potassium or a mixture of the two when he read that such a mixture was used in high-temperature thermometers. Although only the salt coolant had then been tested, patents on both salt and metallic coolants had been applied for before the end of 1922; the patents were granted in 1928.

The development of the sodium cooled valve was considerably accelerated by information supplied by Graham Edgar of General Motors Chemical Company (the forerunner of the Ethyl Gasoline Corporation) in 1925. The part of the original patent application referring to metallic coolants (sodium or potassium or an alloy of the two) called for the addition of a salt such as caustic soda which would make the metal wet the interior of the valve. Edgar pointed out that sodium or a sodium alloy was likely to wet without the use of a salt, and that a very small quantity of sodium added to mercury made the mercury wet glass in the manufacture of mirrors. Edgar's information in regard to the manufacture of mirrors immediately gave Heron the idea that the mercury-cooled valve could be improved by the use of a small amount of sodium in the mercury, instead of tin-plating the interior of the valve as Midgley and Kettering had done. Heron, however, did not pursue the improvement of the mercury-cooled valve but preferred to keep on with his own idea, as engineers very often do, without fully investigating the alternative possibility. In this case, however, the decision was fortunate, since it resulted in the development of internally-cooled valves by the Rich Tool Company (now a part of the Eaton Manufacturing Company), one of the two major valve manufacturers in the United States, rather than leaving it entirely in the hands of Fansteel, to whom the mercury-cooled valve was an unprofitable nuisance. Rich approached the problem from the aircraft point of view: first make it work, then worry about the cost.