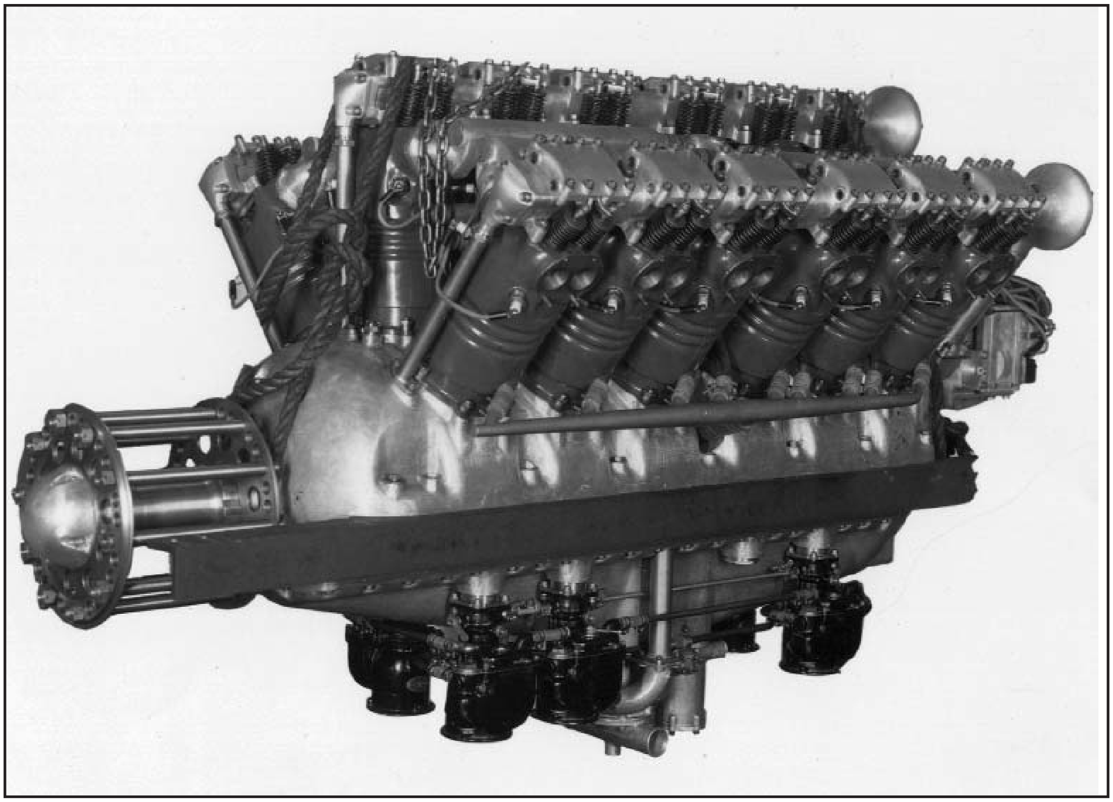
The Engineering Division W-1

A Tale of Great Expectations

by Robert J. Neal



The U.S. Army Air Service Engineering Division W-1

Background

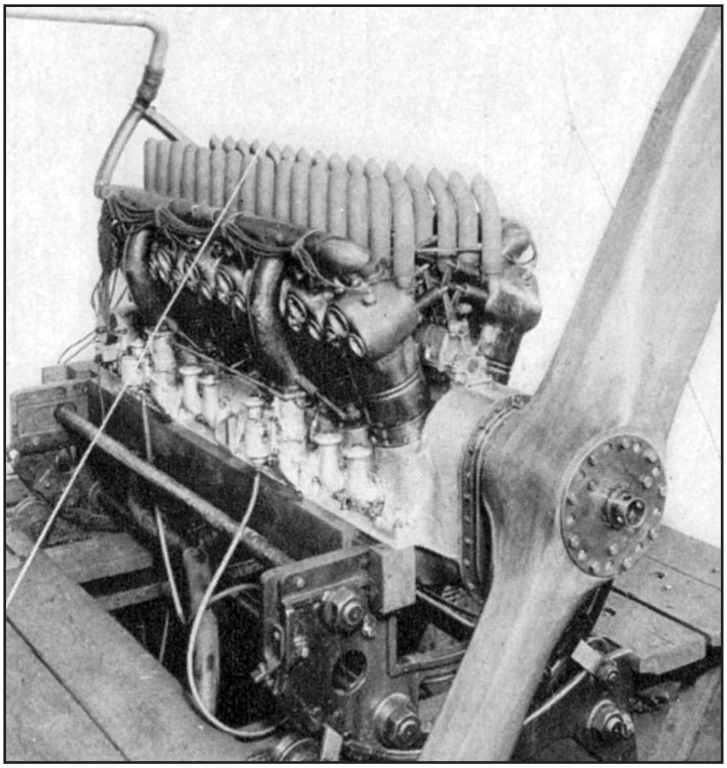
At the time the United States entered World War I there were no aircraft engines in series production either here or abroad of 400 HP. The Liberty was designed to fill that need. By the end of the war the Liberty was considered a reliable engine with a rating of 400 HP @ 1,700 RPM. Its actual output was 425 HP @ 1,700 RPM and 450 HP @ 1,940 RPM. All the major powers were showing considerable interest in designing larger and larger aircraft engines to power larger bombers, an aircraft type they felt were going to be of great importance in warfare.

Glenn D. Angle, engineer in charge of airplane engine design for the Engineering Division from late in the war until 1924, wrote two articles for *Aviation* magazine in which he discussed in depth the division's efforts along that line—as it concerned the W-1 engine. The first article was about the problems of "Water Leaks in Welded Steel Cylinder Water Jackets" and was published in the August 6, 1923 issue. In it he discussed various engines world-wide which used different types of thin metal external attached water jackets. He noted that the Liberty and all other current engines which used welded steel water jackets suffered to some degree from the problem of water leaks. He then went into considerable detail in discussing the water leak problems from which the W-1 engine suffered and the various methods they were using to try to cure them. As we shall see, the W-1 had been in development for some three years by this time and the problem was far from cured.

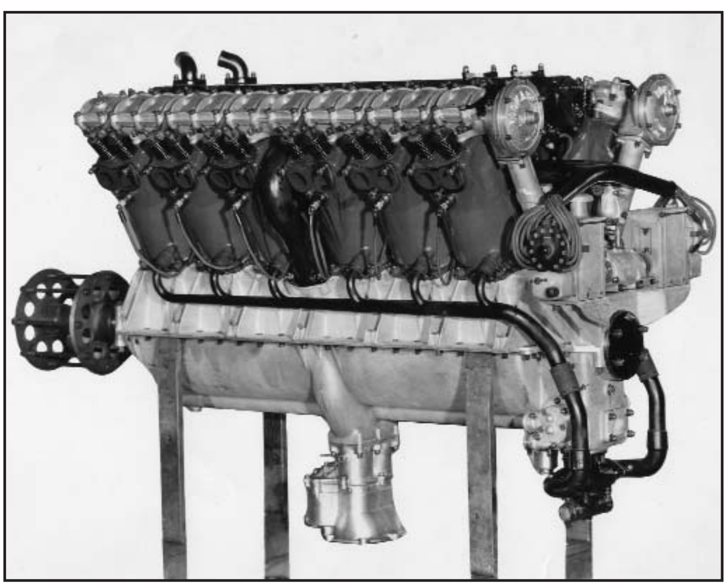
The second article, "Progress Toward 1000 HP Aircraft Engines", appeared in the February 25, 1924 issue. This article was actually written some time earlier as a McCook Field document and then modified somewhat and submitted to *Aviation* for publication, a practice that was fairly common during this period. The delay is apparent in the fact that in the January - February - March 1924 issue of *Air Service Technical Bulletin No. 38* the Engineering Division officially noted that they had abandoned all further development of the W-1 series of engines. In the *Aviation* article he went to some length into the world-wide history of the development of this class of aircraft engine. It gives us a good thumbnail glance at the development of this size engine up to late 1923 but, interestingly, does a better job with overseas engines than American ones.

Although it contended to cover all those engines in the 600 HP and above class, the only US engines mentioned were the W-1 and the ill-fated Duesenberg Model H built during the war. Actually there were at least five other engines in this class which had been built in this country. By 1924 eleven Packard 1A-2025 engines had been built for the Army, the first of which had been contracted for on November 4, 1919 after a series of correspondence in which Col. Vincent of Packard proposed the engine beginning on February 10, 1919. These engines were rated at 550 HP @ 1,800 RPM and capable of 600 HP @ 2,000 RPM. In 1923 the Army contracted Packard to design and build an experimental 1A-2200 engine. This engine was built and passed its 50-hour test by October of 1923 with a rating of

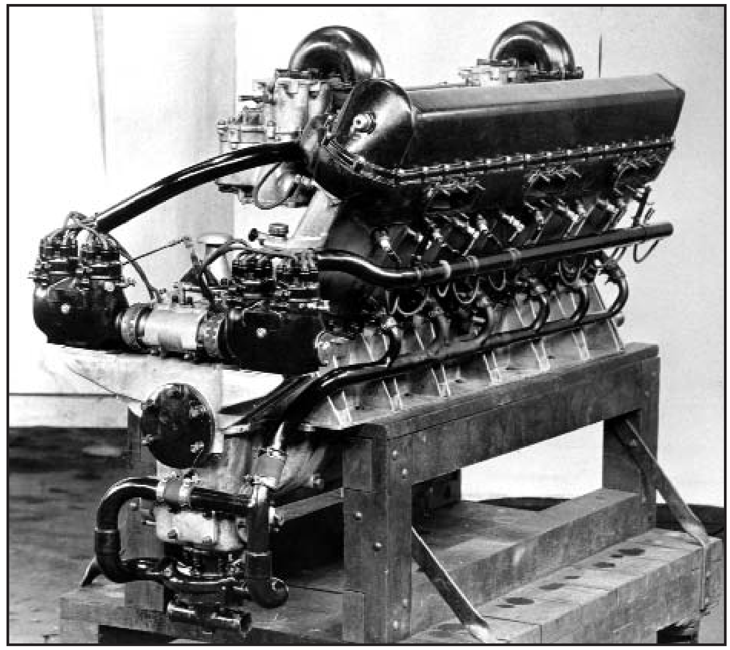
680 HP @ 2,000 RPM. A larger version 1A-2500 engine rated at 800 HP @ 2,000 RPM was then contracted for and had been completed and put on tests by the time this article was published. The Navy had contracted the development of the Wright "T" series of engines beginning in early 1922. By 1923 it had evolved into the T-3 with a rating of 650 HP @ 2,000 RPM. In addition to these, for which either the Army or Navy had actually contracted, in June of 1921 the



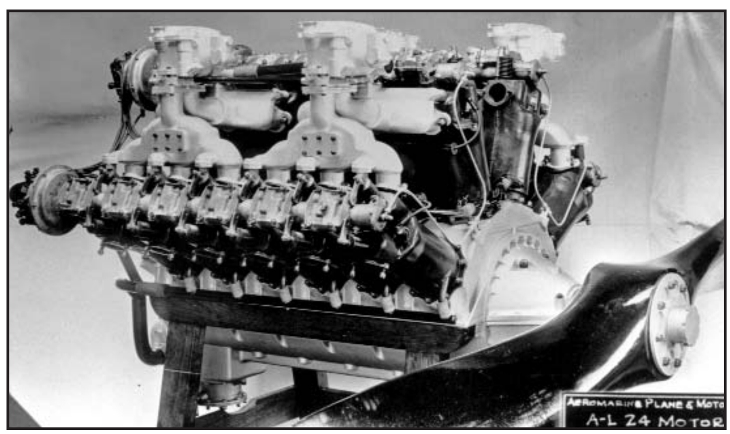
The Spur-Geared Version of the Duesenberg Model H on a Test Stand During WWI. Weighing 1,575 lb, it was rated at 800 hp @ 1,800 RPM. A 45° V-16 with an overall length of 88.75" as compared to 69.75" for the Liberty, the engine never successfully passed full power tests without failures and the design was abandoned after the Armistice.



The Packard 1A-2025 was designed just after WWI and was contracted by the Army from 1919 to 1921 with a total of 11 being built. Rated at 550 hp @ 1,800 RPM they were capable of 600 hp @ 2,000 RPM.



The Packard 1A-2200 was rated at 680 hp @ 2,000 RPM and instigated the design of the 1A-2500 model. Only one example was built but the 2500 series was built in modest numbers. The 1A-2200 was meant to test the design of a new cylinder and valve system. The purpose was served by mounting only one bank of the twelve cylinders on a 1A-2025 crankcase and testing. The cylinders carried four plugs, a feature of the W-1 and Navy 1A-1551 but not of any other Packard-built engines. The valve and head was of Packard design, but the four plugs per cylinder were no doubt Engineering Division instigated.



The Aeromarine AL 24 engine submitted to the Engineering Division in 1921 for consideration for use in large bombing airplanes, the purpose of the design of the W-1 series of engines. The design was turned down without even submitting it to tests. It incorporated as many Liberty components as possible, using 75% standard Liberty items. It was obvious that the Army was committed to continued development and use of the Liberty for some years to come. Aeromarine felt this would be a logical solution to building an 800 hp class engine using available and proven designs destined to see continued use and development for some time to come. The Army did indeed continue to develop the Liberty into the late 1920s and kept it in active service until 1935. The division appears to have been committed to developing their own design and, at this point, nothing was going to interfere with its completion. The W-1 used only two design features that might be considered basic improvements on those of the Aeromarine proposal- magneto ignition and four spark plugs per cylinder, both of which ultimately proved to be poor choices.

Aeromarine Plane and Motor Co. had built and submitted to the Army an 850 HP @ 1,650 RPM engine called the AL-24. This was an individual-cylinder double V 24 engine built around four banks of Liberty cylinders and valve train. Carburetors were Stromberg NA-L5 used by the Air Service on supercharged Liberty engines.

As a matter of interest, the Glenn Angle article stated that "only thirteen airplane engines, rated not less than 600 HP, have been designed and built. Seven are of French design, three are British, two are American, and one is Italian. As far as can be determined from the information available, only six of these engines have received any degree of development. Three engines are of British design, and the other three were produced in France, Italy and the U.S.A."

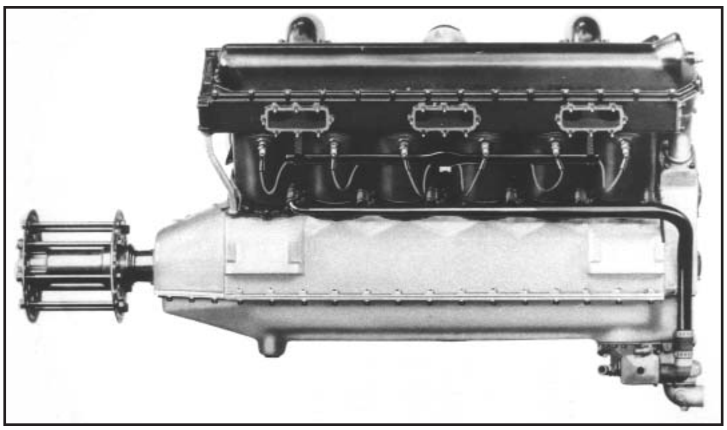
The U.S.A. engine referred to was, of course, the W-1 designed by the Engineering Division. The European engine designs which had received development were noted. The British engines were the Rolls-Royce Condor, Napier Cub and Sunbeam "Sikh"; the French was the Farman 600 HP and the Italian the Fiat A 14.

Before we go on to document the design and testing history of the W-1 engine series it might be interesting to study, in chart form, the basic features of the noted European and American comparable designs of this period. This, of course, only shows the technical features of the engines. It does not necessarily prove they would become reliable performers in service operation, although most did.

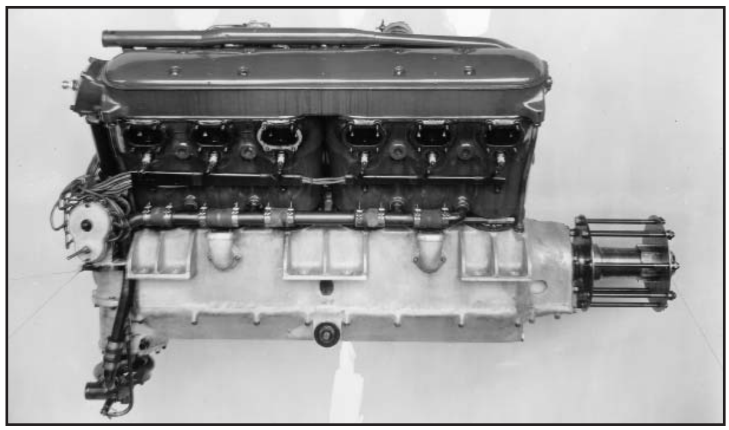
Initiation of the W-1 Project

I have thus far found no specific reference indicating the exact date on which the Engineering Division made the decision to design and develop a 700 HP class engine. I do have their weekly progress reports from June 1918 to January 4, 1919 and the project is not mentioned. Since they would invariably mention such projects in these reports, it is safe to say it was not initiated until after the latter date. The first mention I have found was in the Engineering Division Technical Orders (TO) No. 10 dated November 1919 in which they report "The development of an 18-cylinder water-cooled engine, built up with three sets of six cylinders in a row is progressing rapidly. Sufficient drawings are expected to be completed in January, 1920, to submit to contractors for bids. This engine is a direct drive to the propeller and should develop from 750 to 800 H.P. at 1800 R.P.M." I also have copies of all the TOs from No. 1 through No. 7 of April. 1919 and it is not mentioned in any issue. One would therefore date the decision between April and November of 1919. An educated guess would be September or early October of 1919.

Also of interest was the listing in TO No. 10 of the newly set up airplane type designations (Type I through Type XV) accompanied by notes regarding activities on plane designs within each type. Under some types was the note "no further action since last report" so they must have been listed also in TO 8 or 9 as they were not yet listed in TO 7 or prior. W-1 type engines would eventually be proposed for airplanes in three of the new types:



The Packard 1A-2500, follow-on to the 1A-2220. Produced in a series ending in the supercharged 4A-2500, the Army used it to power LB-1 and HB-1 bombers; the Navy used it in more than 100 torpedo bombers.



Wright T-3, the last of the Wright "T" series. The T-2 and T-3 engines were used primarily by the Navy for Martin torpedo bombers, powering a total of about 65 of these types.

600 HP Class Aero Engines of 1917-1924

Designer	Model	Bore x Stroke (inches)	Configuration	Disp (in^3)	Rated Power (HP @ RPM)	Weight (lb)	Pwr/Wt (lb/HP)
Engineering Division	W-1A	5.50 x 6.50	W 18	2,779	700 @ 1,700	1,814	2.59
Aeromarine	AL-24	5.00 x 7.00	Dbl V 24	3,387	850 @ 1,650	1,492	1.76
Packard	1A-2025	5.75 x 6.50	V 12	2,025	550 @ 1,800	1,142	2.08
Packard	1A-2200	6.00 x 6.50	V 12	2,205	680 @ 2,000	N/A	N/A
Packard	1A-2500	6.38 x 6.50	V 12	2,540	800 @ 2,000	1,120	1.40
Wright	T-3	5.75 x 6.25	V 12	1,947	650 @ 2,000	1,150	1.77
Rolls-Royce	Condor III	5.50 x 7.50	V 12	2,138	650 @ 1,900	1,310	2.02
Napier	Cub	6.25 x 7.50	X 16	3,682	1,000 @ 1,800	2,450	2.45
Sunbeam	Sikh	7.00 x 8.27	V 12	4,033	850 @ 1,400	1,952	2.29
Farman	600	5.12 x 7.09	W 18	2,626	600 @ 1,860	1,848	3.08
Fiat	A 14	6.69 x 8.27	V 12	3,488	650 @ 1,550	1,740	2.67

Note: The Sunbeam Sihk was also known as the Coatalen.

Type VI: three seat Ground Attack - Armored (GA)
Type XI: Day Bombardment (DB)
Type XIII: Night Bombardment Long Distance (NBL).

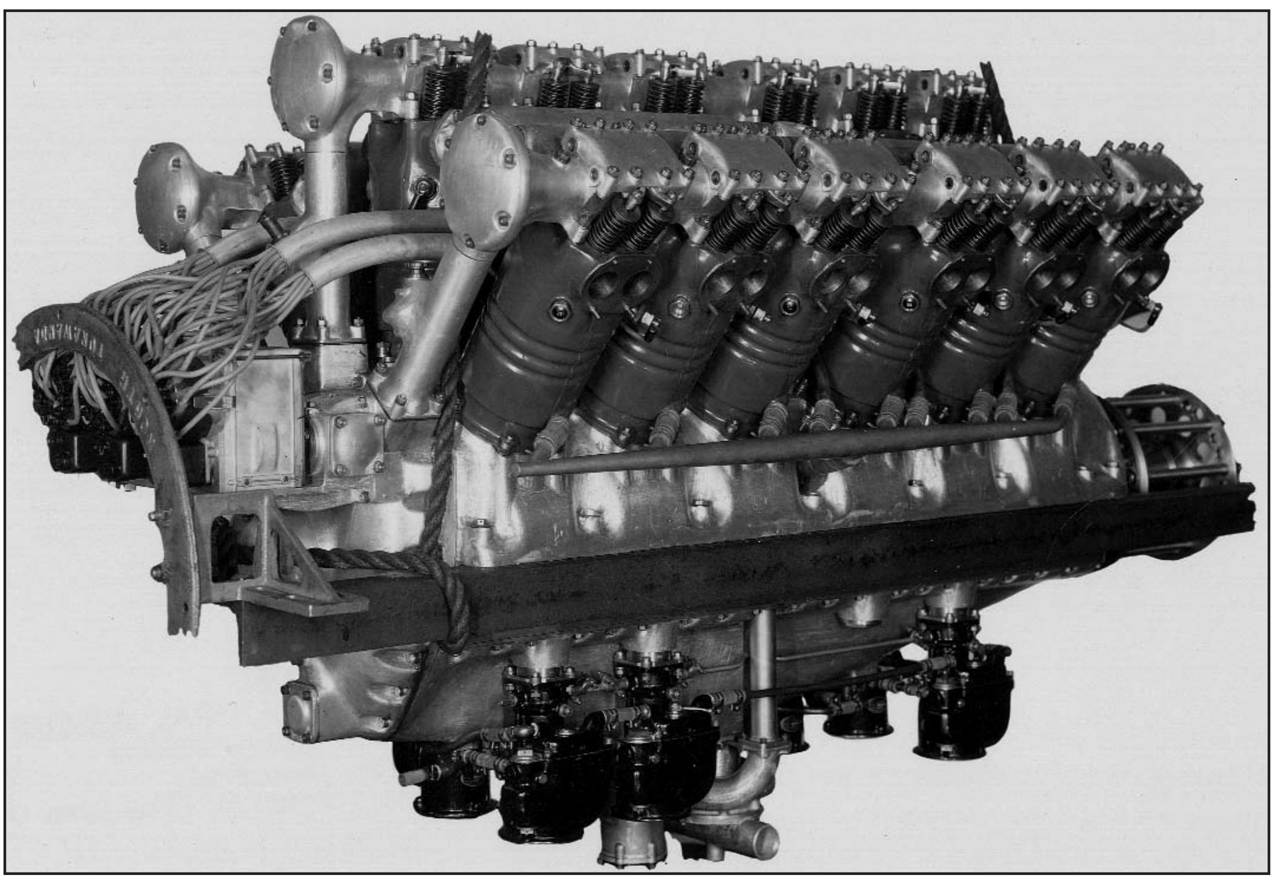
Enough parts had been received from vendors to begin the first single-cylinder test on the universal test engine in January of 1920. (E.O. 508-4) (E. O. stood for Expenditure Order) It was a dynamometer only test and immediately revealed failures. Most could be said to be of a type that was to be expected in a new design. They had several spark plug failures, four valve spring failures that were charged to improper heat treatment, and two valve guide failures by breakage at the shoulder. All would result in attempted corrections. However, the handwriting appeared to be on the wall, as the saying goes. Valve guide failures continued to plague the project almost until it was eventually abandoned in early 1924, and spring failures were never cured. To them were soon added cylinder water jacket leaks which exceeded considerably those for which the Liberty was known.

Other single-cylinder testing continued and in September of 1920 an output of 43.91 HP and BMEP of 132.3 PSI was achieved. By December of 1920 they were ready for the first single cylinder endurance test. Unfortunately that test was aborted after the test engine failed at the cylinder adapter flange. (E. O. 508-16)

By this time the first engine was well into assembly and first testing was expected to begin in January of 1921. It was the first (AS 94626) of four built by the Packard Motor Car Co. on contact to be assembled by the Engineering Division at McCook Field. The remaining three were assembled later. The fourth engine was numbered AS 95012 but so far we have found no direct references giving the AS numbers assigned to the second and third.

Basic W-1 Engine Specifications

At this point we need to present a description of the basic engine design. The W-1 aviation engine was an 18 cylinder "W" type engine consisting of three banks of six cylinders each, with an included angle of 40^{o} between each bank. It was designed by the Engineering Division. The bore was 5.500" and the stroke 6.500". The cylinders were steel forgings with a welded water jacket of sheet-steel stampings. There were four valves per cylinder. The valves were operated by overhead camshafts through rocker arms. The cylinders were mounted separately on the crankcase and were held down by means of six studs and nuts for each cylinder, one of the studs being common to two cylinders. Ignition was furnished by three magnetos mounted on the rear of the engine. An interesting note regarding the ignition is that each cylinder had four spark plugs but in the first engine only three were used as there were only three magnetos. The Dixie 1800 magneto for use on 18-cylinder engines was a new design produced specifically for this engine. Glenn Angle, who was chief of the design section at the time, said in his coverage of the engine in *Aerosphere 1939* that only three 18-cylinder magnetos were available at the time and that is why. Late engines utilized four magnetos and, of course, all four plugs. It is interesting that the engineering drawings of the original engine show it equipped with three magnetos. The carburetion was furnished by six single Stromberg NA-S6 carburetors mounted below the engine, three on a side. Rated horsepower was 700 @ 1,700 RPM. Compression ratio was 5.41:1 and displacement was 2,778.6 in^3. Dry weight was about 1,725 lb. Power to weight ratio was thus 2.46 lb/HP. Cylinders were numbered from aft end to propeller end with left, center and right banks. Firing order: 1L, 6C, 1R, 5L, 2C, 5R, 3L, 4C, 3R, 6L, 1C, 6R, 2L, 5C, 2R, 4L, 3C, 4R.



AS 94626, the first W-1 engine assembled and tested. Note the rear spark plug holes on the right bank of cylinders have filler plugs rather than spark plugs. The engine had only three 18-cylinder magnetos.

Reader Advice

From this point I will attempt to cover the history of the W-1 (and W-2 and W-3) engine testing and production as well as that of the airplanes that were designed to use it. In addition, I will try to come to a proper conclusion as to why the project ultimately failed. The events which controlled the outcome overlapped and interleaved throughout the more than four and one half years the project was active. The reader is strongly advised to refer to the chronology charts often while reading the text. Otherwise, it is difficult to keep the events and their effects straight in ones's mind.

Assembly was completed in early January of 1921 and the engine was put on dynamometer tests. It suffered numerous failures during the first 10 hours of running, most apparently caused by lack of lubrication because of too small oil passages to various parts. Testing from January to March was done with stops to enlarge oil lines or passages after failures, replace worn or broken parts etc. The test was discontinued at that point because of excessive crankcase cracks.

The engine was assembled with a new crankcase and various other parts and given a dynamometer calibration test on March 28, 1921. After a few test runs the first period of its standard 50-hour endurance test was begun on April 11. The first serious problem occurred at the 16.75 hour point at which time the spring retaining collar for the front intake valve of cylinder 6 Right failed allowing the valve to drop into the cylinder. The resulting damage required replacement of the piston and cylinder. Inspection of the crankcase through the cylinder hole revealed cracks in the crankcase in the No. 6 bearing supports. It was felt that no damage would result by continuing the test and thus it was continued.

Over the remainder of the test several forced stops were made and a number of worn or failed parts were replaced either then or between five-hour runs. The test continued until the engine began to weave badly at the 45.75 hour point and was stopped. It was found that the crankcase was so badly cracked that the test was terminated.

After teardown inspection all defects, prior failures and replacements were documented. A list follows:

Total Replacements During 50-hour Test

Cylinders:		2		
Valve springs:	intake	31	exhaust	25
Valve guides:	intake	7	exhaust	7
Valves (replaced):	intake	3	exhaust	6
Valves (ground):	intake	20	exhaust	20
Spark plugs:	cracked porcelains	16	fouled	16
Valve spring retaining collar:		2		
Venturi tube bracket (carburetor):		2		
Main discharge nozzle (carburetor):		1		
Magneto:		1		
Magneto breaker:		1		
Valve tappets (inlet):		13		
Pistons:		1		
Tachometer adapter drive shaft:		2		
Cylinder water leaks:		5		

All valve guides in the left and right bank were badly worn.

Even with the above noted problems, the engineers considered the engine ran remarkably well compared with other first experimental engines.

As a result of the noted problems the crankcase was redesigned for greater strength and a number of other failed or excessively worn parts were redesigned or otherwise changed.

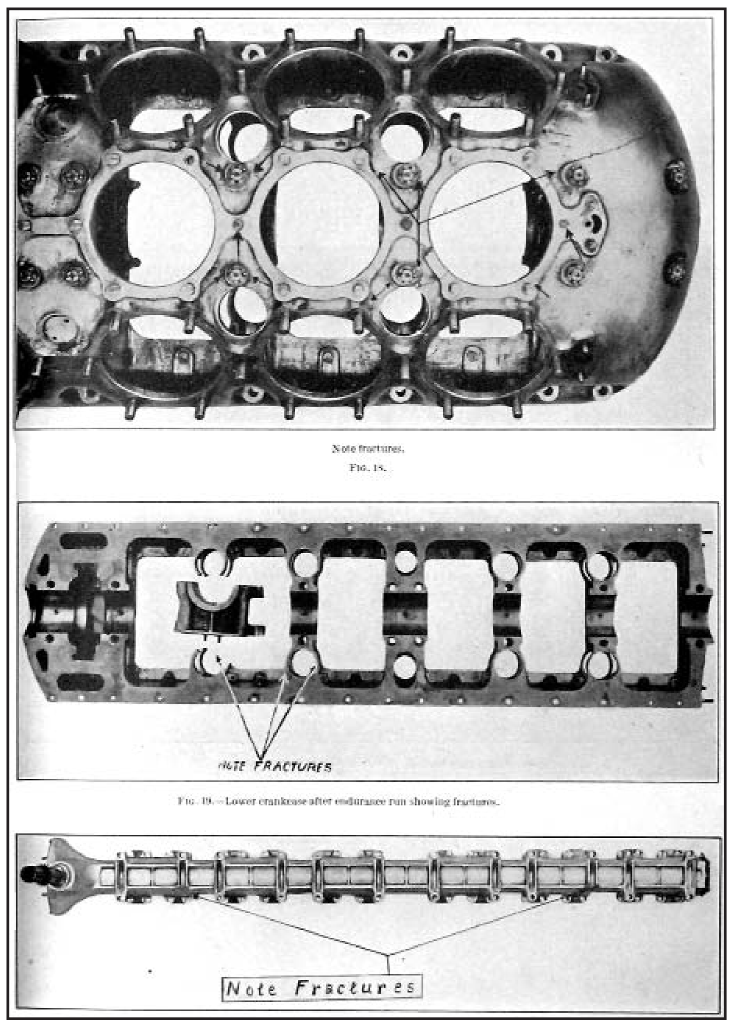
Meanwhile, on the strength of the initial single cylinder tests and confidence in the design of the engine, the Engineering Division had requested bids for the design and construction of W-1 powered planes in the Day Bomber (DB) class in September of 1920 and for W-1 powered ground attack (GA) class as well.

Of historical interest at this point is the fact that the Air Service had contracted for the construction of two NBL-1 (Night Bomber Long Distance - type XIII) aircraft with the Witteman-Lewis on June 23, 1920. This plane was designed for the Engineering Division by Walter H. Baring at the instigation of General Mitchell as an American answer to the giant six-engine bombers of Germany. It was to be powered by six Liberty engines and its wing span of 120′ and gross weight of 32,203 lb make it the largest airplane so far constructed in America.

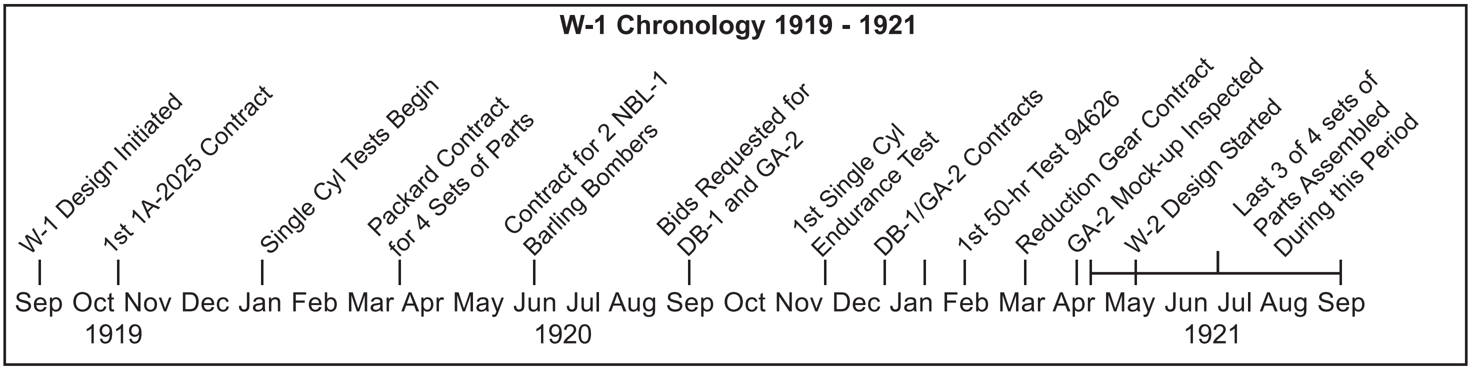
Because of general historical interest and the fact that the W-1 engine is eventually proposed for this class of airplane, I will follow the history of the NBL type to its end as this article progresses.

W-1 Stand-Alone Reduction Gear

The first 50-hour test of the W-1 was barely completed when the Engineering Division contracted Allison Engineering of Indianapolis to design and build a stand-alone reduction gear for the engine. This decision was no doubt influenced by a very recent contract by the division for a similar gear for the Liberty. (See page 298 of *A Technical & Operational History of the Liberty Engine* by the author.) Originally described as a spur-type with herringbone



Crankcase and Cam Housing Cracks from 50-hr Test No. 1



gears on 10″ centers with 1,700 RPM input giving 950 RPM output (the Liberty type did have herringbone gears), it was ultimately built with straight-cut gears.

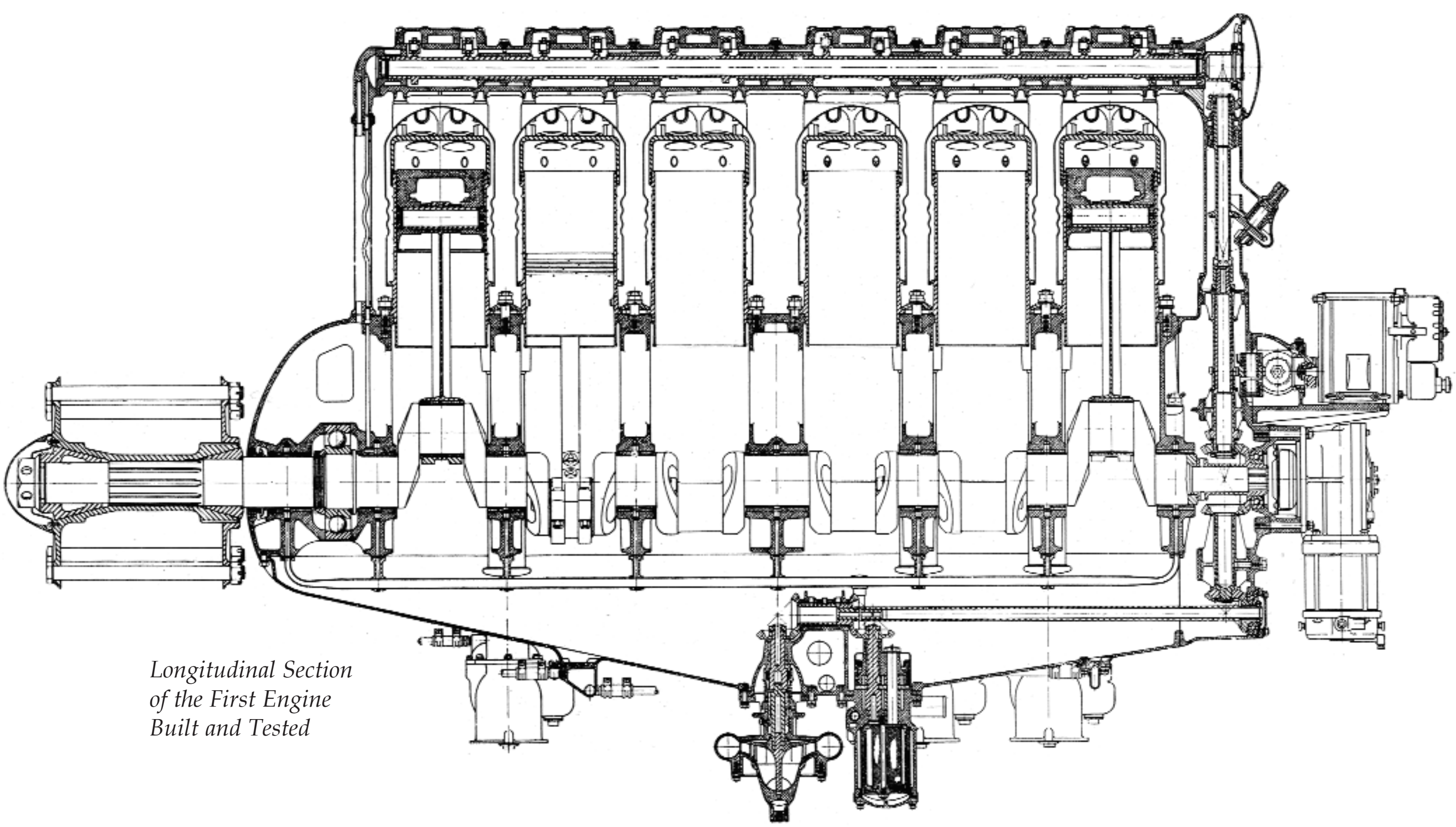
Although the proposal and contract were initiated in early 1921, the finished product was not given its acceptance test until May of 1923 (mounted on the first W-1A of the Packard contract for 10 production engines).

Four-Plug Ignition Notes

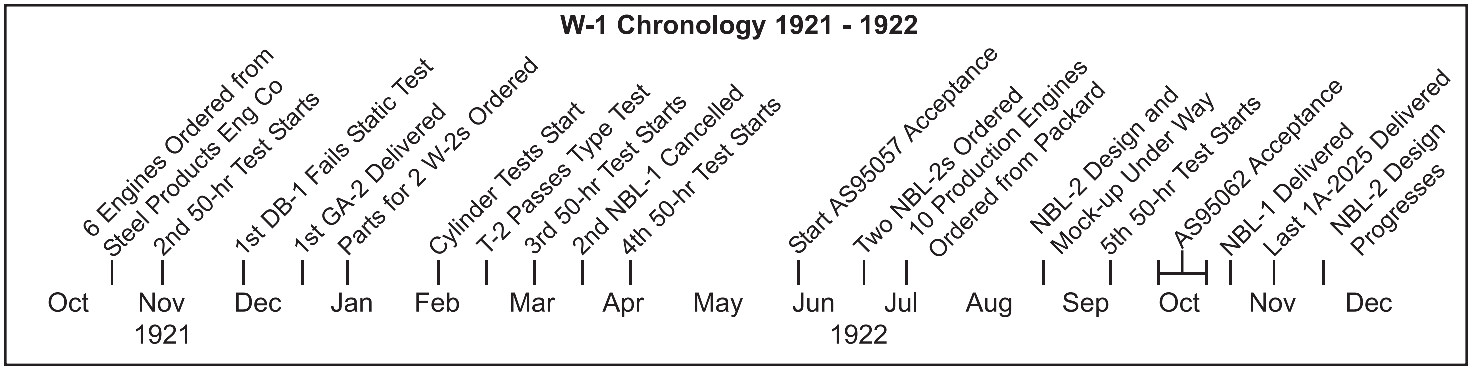
Not long after this first 50-hour test was completed the Engineering Division conducted a very comprehensive test to determine the power output obtained by uses of various combinations of plugs in both W-1 and W-2 cylinders. This was accomplished by control testing of these two cylinder types on the single-cylinder Universal Test Engine. The results were documented on September 1, 1922 in Air Service Information Circular No 401.

Tests on the 5.500″ x 6.500″ W-1 cylinder were done on a 5.5:1 compression ratio cylinder using both blended and unblended fuel. Tests on the 6.500″ x 7.500″ W-2 cylinder were run on a 4.5:1 compression ratio cylinder using unblended fuel. The general result found was that as long as detonation is controlled by either use of blended fuel or control of spark advance, or both, “there is no definite drop in power with reduction in the number of plugs until ignition is restricted to one side of the combustion chamber.” In other words, the use of two, three or four plugs per cylinder results in the same power output so long as a two plug combination was on opposite sides of the combustion chamber. Thus, early in the testing process they found that the normal two-plug layout produced as good a result as did a four-plug layout.

Interestingly, in spite of these findings they moved to a four-plug configuration after the first 50-hour test and continued with it until the end even though a two-plug configuration would have reduced costs and complexity and, perhaps more significantly, reduced total engine weight by as much as 60 pounds. I do not have specific weights of the total ignition system of a W-1 engine but I do have them for a 12-cylinder Dixie magneto ignition system for the Packard 1A-2025, which is 53.1 pounds. A single Dixie 18 magneto weighed 18 pounds and, in addition, it fed 18 cylinders with 18 plugs and 18 sets of high tension wires instead of 12. Changing the W-1 to dual instead of quad ignition would remove two magnetos and 36 plugs and their associated ignition wires.



Longitudinal Section of the First Engine Built and Tested



The designers' original weight estimate, before the engine had been constructed and assembled, was 1,503 pounds. Actual weight as first tested was 1,725 pounds. By the time development was discontinued in 1924 the engine weighed 1,851 pounds with starter, generator, magneto ignition and propeller hub.

The September 1920 type XI bid request resulted in the signing of contract 348 with Gallaudet on December 24, 1920 for the construction of three DB-1 airplanes. By February 26, 1921 the mock up of the airplane had been inspected. At this time the first W-1 was still in its first performance test.

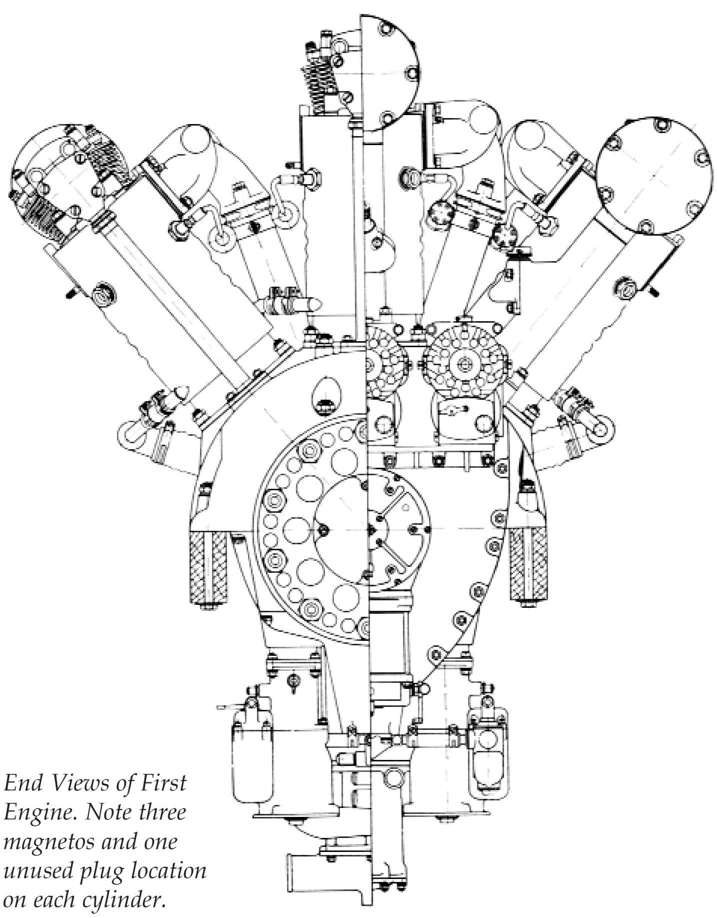
By the time that first 50-hour test run had been completed the Engineering Division had already started the design an even larger version of the 40º W engine. This one was to be the W-2 with a rating of 1,000 HP @ 1,400 RPM and a bore and stroke of 6.500" x 7.500" for a displacement of 4,479.66 in^3. Total weight was to be about 2,400 pounds. By May of 1921 the design was far enough along that they anticipated contracting a set of parts shortly. It appears they were ordered late in 1921.

Also by this date (December 20 of 1920.) they had let contract 346 to Boeing for three GA-2 type VI airplanes to be W-1 powered and the first mock up had been inspected.

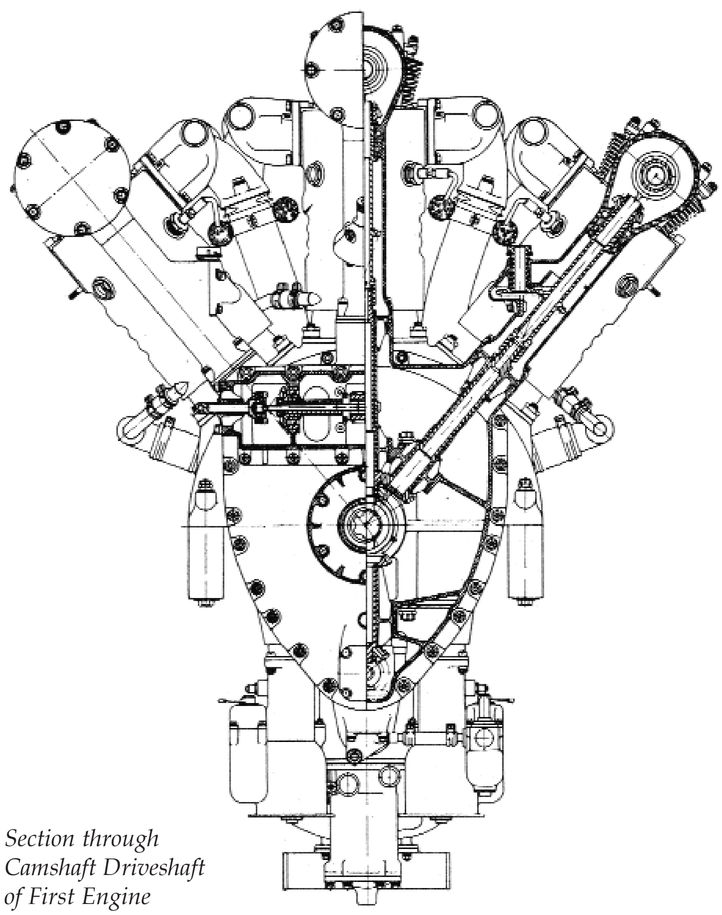
The engine was rebuilt with a heavier design crankcase, redesigned water pump, ball bearings replacing plain type for gear bearings, redesigned oil passages, new types of valves and springs, four rather than three magnetos and various other small changes. The engine now became known as the W-1 modified type.

In November of 1921 this engine began another 50-hour test. At this point they began to list the 50-hour tests by name. This was known as the second 50-hour test of the W-1 and the first 50-hour test of the W-1 modified type.

This same engine (AS 94626 and the first engine assembled) continued to be the principal test engine throughout the life of the project and was eventually subjected to a total of five 50-hour tests.



End Views of First Engine. Note three magnetos and one unused plug location on each cylinder.



Section through Camshaft Driveshaft of First Engine

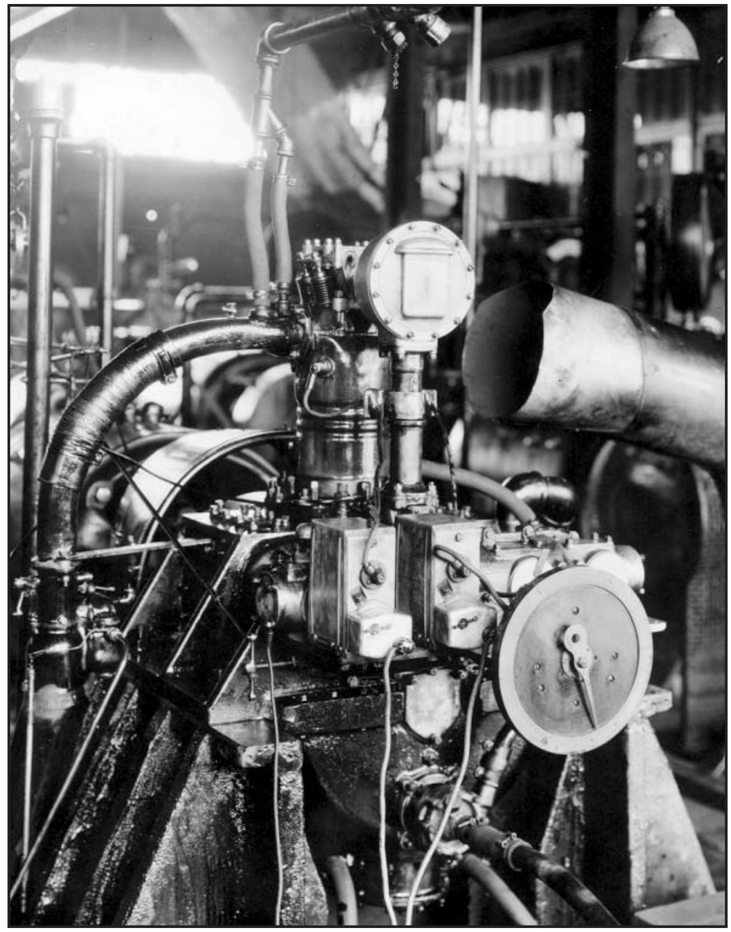
This second 50-hour test was completed in early January of 1922. As a result, a number of relatively minor changes were initiated to correct assembly and maintenance difficulties but the primary problems were continual water leaks in cylinders, worn valve guides, burned exhaust valves and broken valve springs.

Even though early testing was beginning to show the engine was going to need refinement and had some problems, expectations were still high and plans went forward rapidly. Expectations were that problems would be resolved in a timely fashion, after all, the primary difficulties seemed to lie within areas, water jacket leaks and valves and their springs, which had never been insurmountable problems in the past.

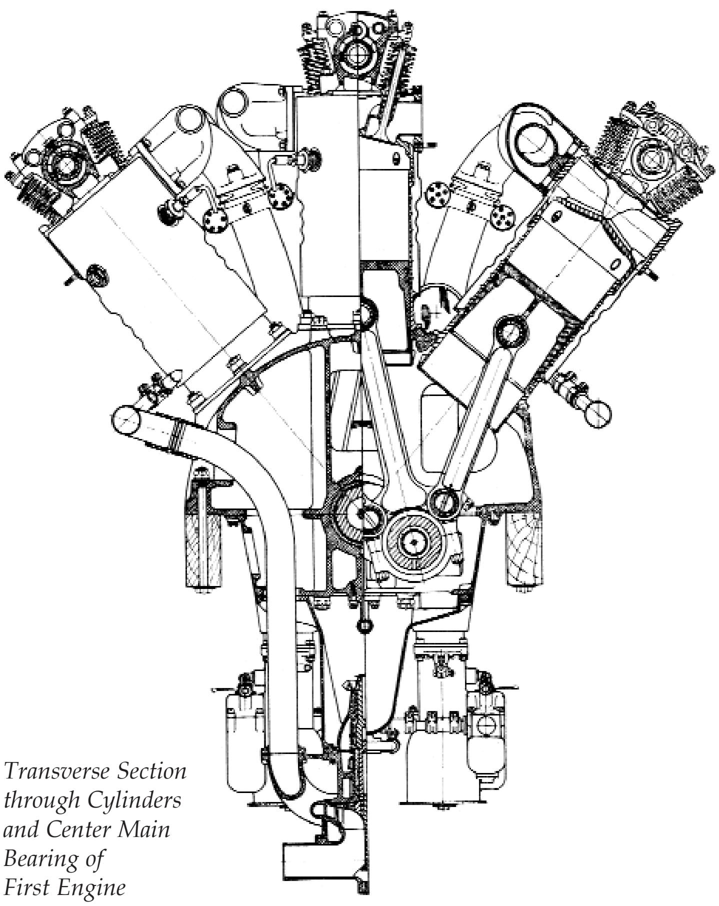
An Additional Six Engines Ordered

Thus in October or November of 1921 parts for an additional six engines had been ordered on a lowest bidder basis. Steel Products Engineering Co. of Springfield, Ohio built most (but not all) of the parts. This order included advance delivery of a variety of cylinder designs which were to be tested with a view of determining the cause of and a cure of the water leaks, valve guide ware and spring breakage.

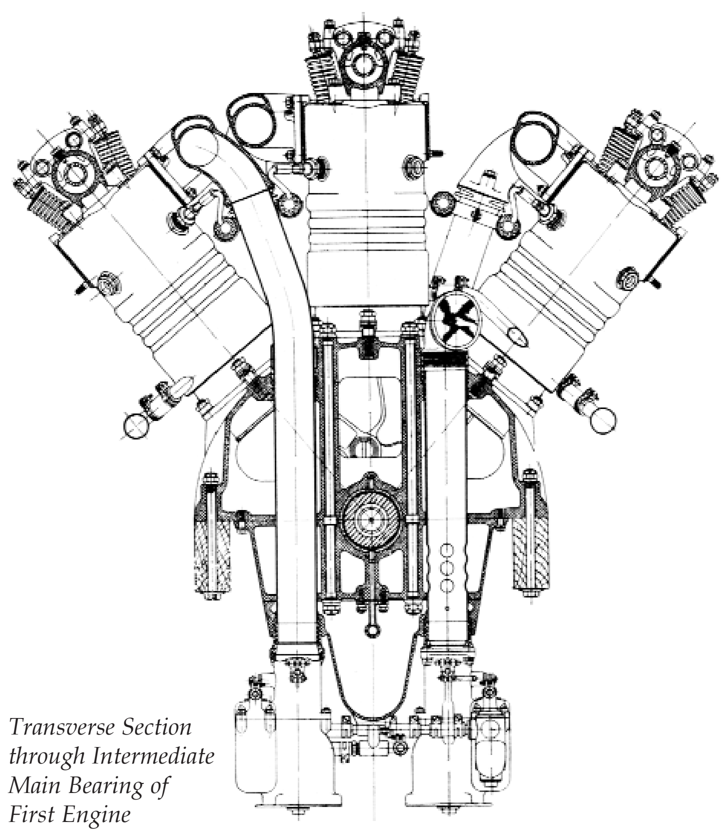
Tests of the first cylinder began in February of 1922. (All prior cylinders used on W-1 engines had been built by Packard.) Results were not good and water leaks were worse than before. By March 5 an additional eighteen cylinders had been delivered. All eighteen failed acceptance inspection because of water jacket leaks under pressure tests and dimensional discrepancies. They picked the best of the lot for further tests. These initial cylinders were of a design called XW-1A and testing continued until June 22, 1922. Results were not particularly good.



Testing of Steel Products Engineering Cylinder on the Universal Test Engine in early 1922



Transverse Section through Cylinders and Center Main Bearing of First Engine



Transverse Section through Intermediate Main Bearing of First Engine

Ten Production Engines Ordered from Packard

Testing was then switched to a second batch of cylinders referred to as the W-1A design, considered as the design intended for use on a batch of ten "production" engines that had been ordered from Packard in early July of 1922. These underwent tests during July and August of 1922 and fared much better and were determined to be "much more satisfactory" as production cylinders.

Meanwhile, backing up in time a bit, the last three engines of the original four, for which Packard built the parts, were assembled and tested between about April and October of 1921. The last of these, AS 95012, was sent to Boeing and installed in the first GA-2 airplane delivered. Static testing began in January of 1922, taxi testing in February and flight tests in March. The first engine was, of course, AS 94626. I do not currently know what AS numbers were assigned to the middle two engines.

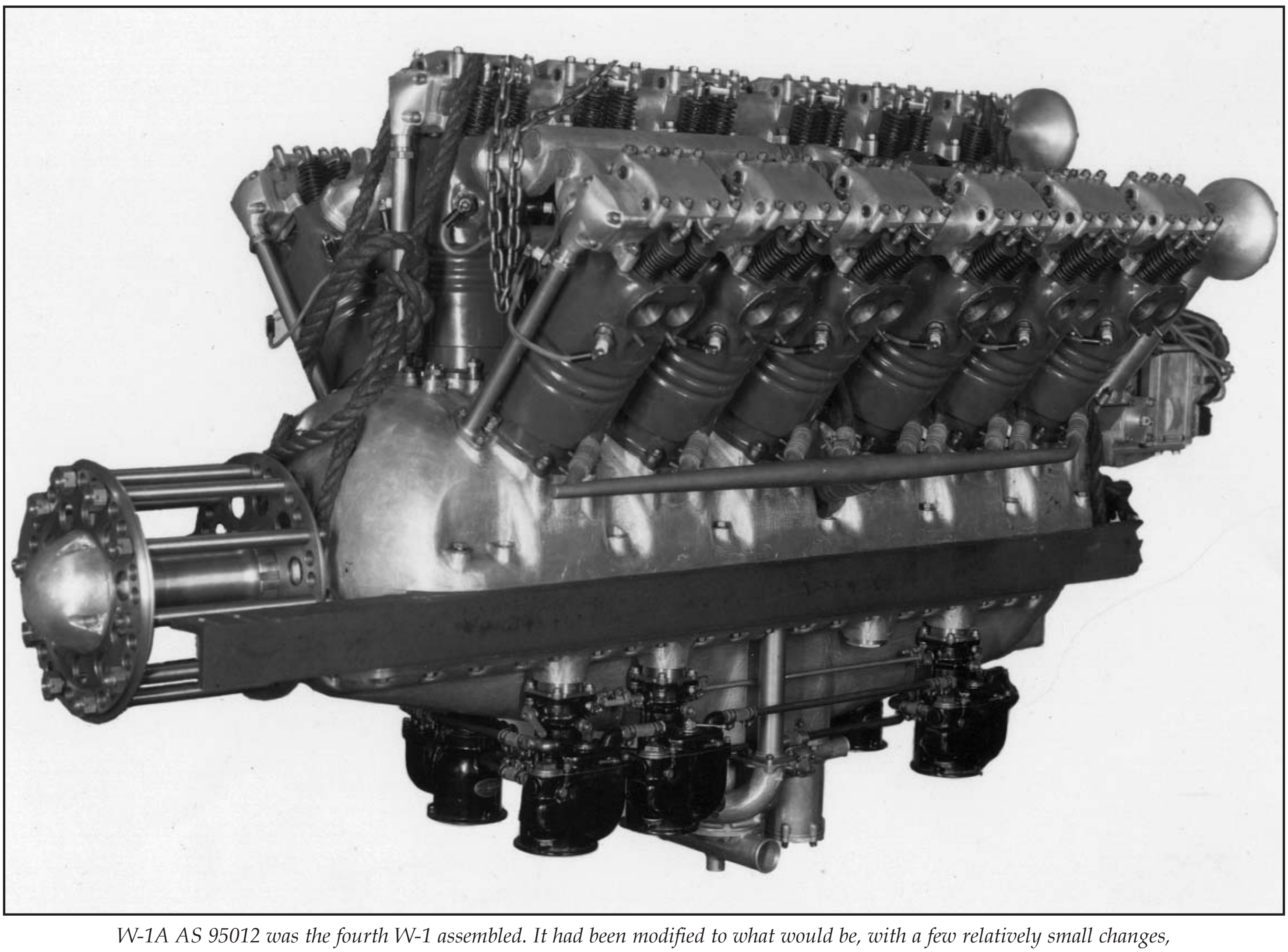
After testing results were obtained from the first GA-2 (AS 64235), some changes were ordered in the second article and the contracted third GA-2 was canceled.

The first Gallaudet DB-1 had been delivered for static test on December 5, 1921. It failed those tests and was also seriously (more than 2,000 pounds) overweight. A drastic redesign was required for the second plane and the third was canceled. The first DB-1 (AS 64238) never had an engine installed.

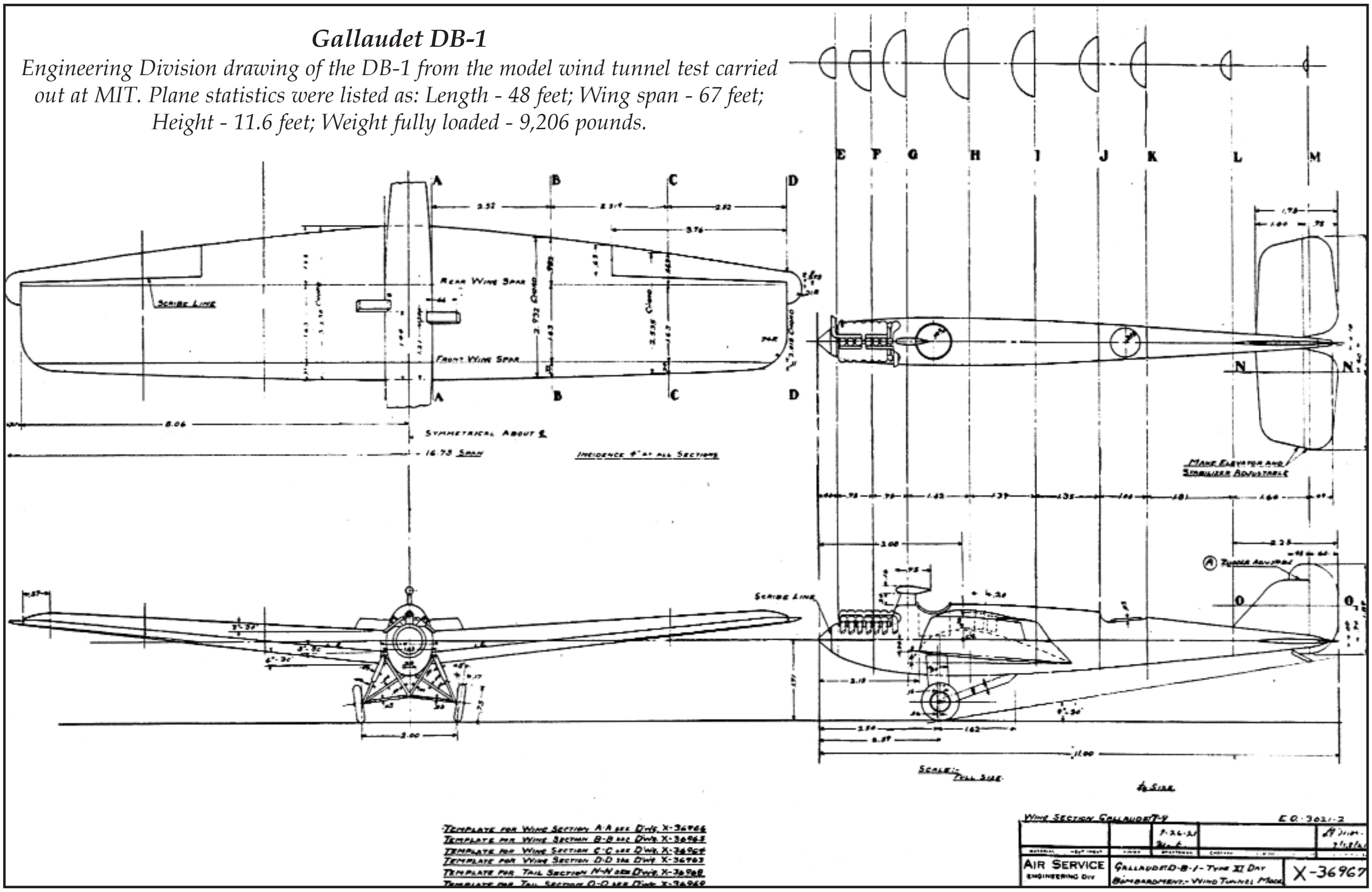
Parts for the six engines from Steel Products Engineering arrived and assembly began in late 1921. As was the case with the test cylinders from the same venders, there were many rejected parts needing rework or replacement. As a result acceptance tests did not begin until June of 1922. The first engine was AS 95057. It was intended to ship this engine to Boeing for installation in the second GA-2 airplane. Initial tests showed the upper crankcase had numerous sand holes allowing oil leaks. Testing continued and at about ten hours No. 3 master rod failed and threw the rod cap through the crankcase. The crankshaft and all No. 3 pistons and cylinders were damaged. The failure was caused by the breaking of the cap bolts.

It was decided to use any remaining good parts from the disassembled AS 95057 and build up a second engine as AS 95058 to replace AS 95057 as the engine to be shipped to Boeing. Tests had determined that improperly heat treated rods had caused the bolt failures so all rods were replaced. The assembly of AS 95058 was completed on August 26 and tests started on the 28th. Acceptance tests were completed on August 31, 1922.

The third engine, AS 95059, was assembled and run on the dynamometer for preliminary tests. During that run the spool gear shaft driving the oil and water pump seized. During disassembly a broken rod bolt was found. This caused the removal of all rod bolts for testing. It was found that all were defective.

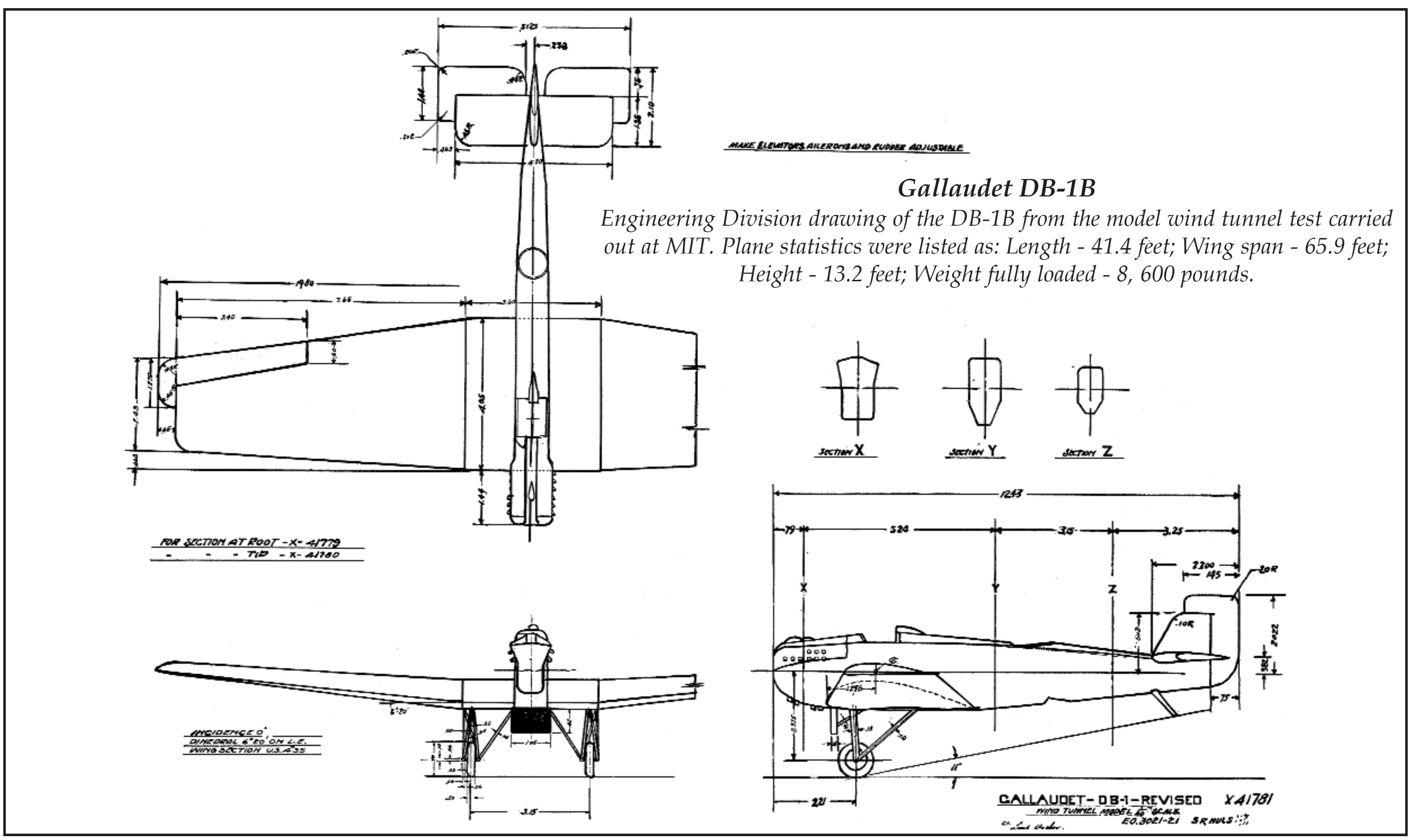


W-1A AS 95012 was the fourth W-1 assembled. It had been modified to what would be, with a few relatively small changes, the W-1A production engine. This engine was installed in the first Boeing GA-2 (AS 64235) built.



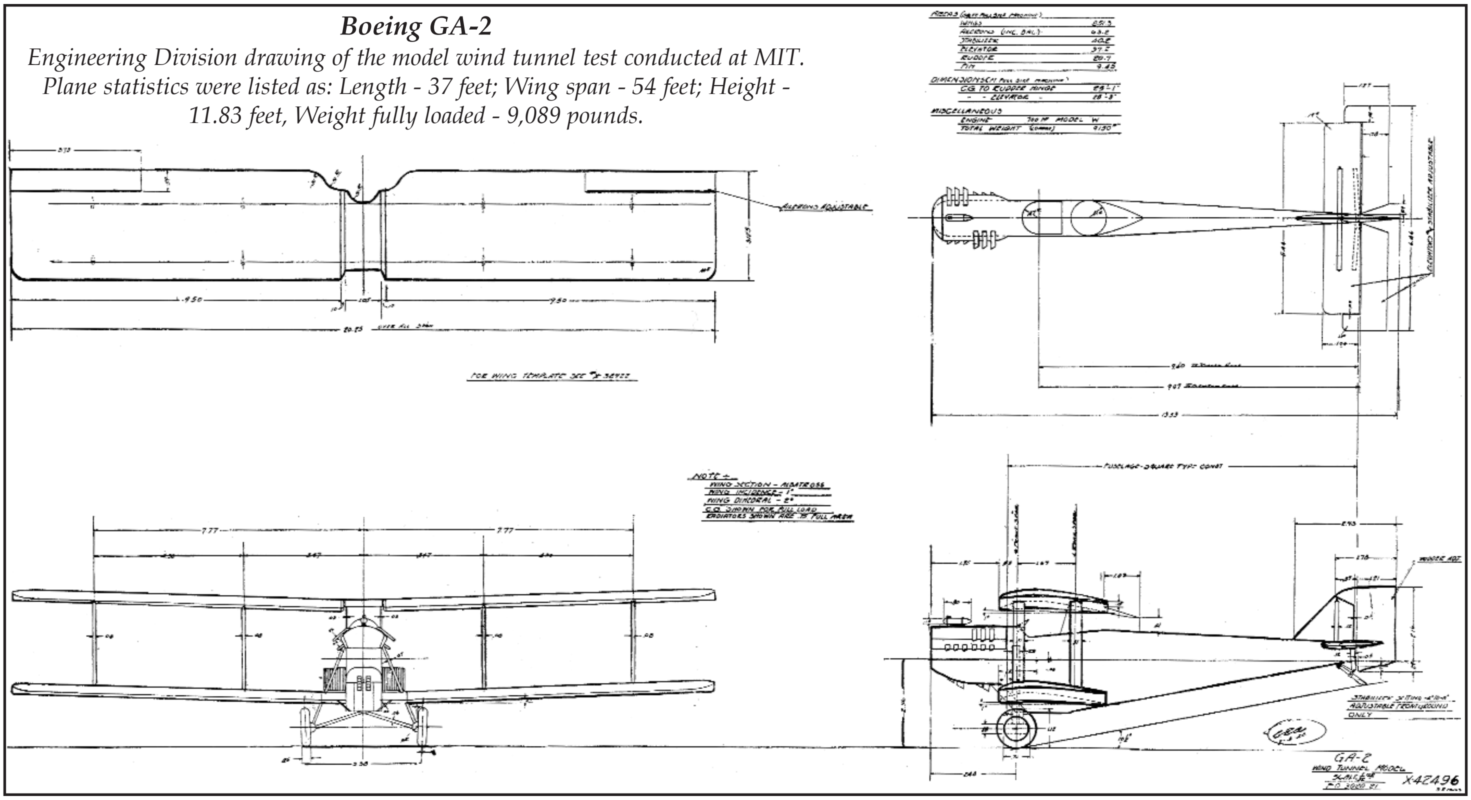
Gallaudet DB-1

Engineering Division drawing of the DB-1 from the model wind tunnel test carried out at MIT. Plane statistics were listed as: Length - 48 feet; Wing span - 67 feet; Height - 11.6 feet; Weight fully loaded - 9,206 pounds.

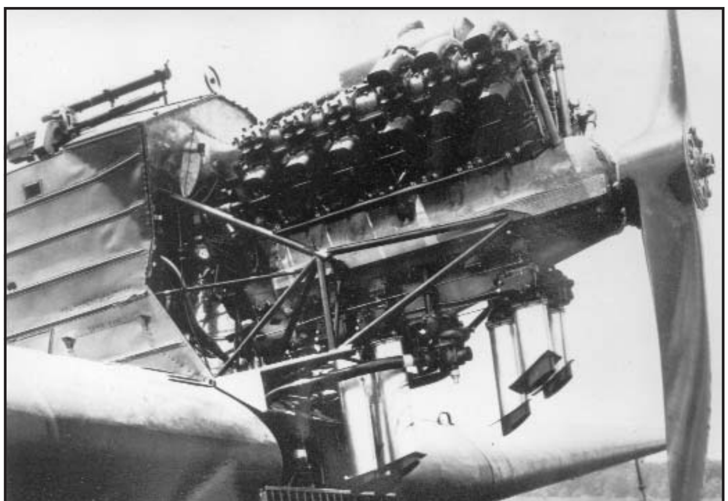


Gallaudet DB-1B

Engineering Division drawing of the DB-1B from the model wind tunnel test carried out at MIT. Plane statistics were listed as: Length - 41.4 feet; Wing span - 65.9 feet; Height - 13.2 feet; Weight fully loaded - 8, 600 pounds.



Boeing GA-2
Engineering Division drawing of the model wind tunnel test conducted at MIT. Plane statistics were listed as: Length - 37 feet; Wing span - 54 feet; Height - 11.83 feet, Weight fully loaded - 9,089 pounds.



This engine was to be shipped to Gallaudet for installation in the second DB-1, now called the DB-1B. The engine was urgently needed by Gallaudet so it was decided to ship it without rods or pistons, those to be shipped as soon as replacements could be obtained. This later testing had determined that not only were the bolts defective but the rods also. All were made by the New Britain Machine Co. of New Britain, Connecticut. The rods of AS 95058 were made by the same company and part of the same batch so an urgent message was sent to Boeing that under no circumstances should engine AS 95058 be flown until replacement rods were installed.

Engine AS 95060 (the fourth of this batch of six) was assembled and tested and eventually is recorded as having also been used in the testing of the second Boeing GA-2 (AS 64236). The fifth and sixth engines (AS 95061 & 95062) were most certainly assembled and used but I have found no record of them.

Gallaudet DB-1B AS 64239 P-304: Originally contracted as three DB-1 airplanes, the first item was found overweight and structurally weak. As a result a redesign was required and the DB-1B was the final item. The third plane was canceled. This plane is known to have been powered by W-1A engines AS 95059 and AS 22-24. Others may have been used as well. Delivered on May 26, 1923 and first flew on August 1. Flight testing was limited and the plane was surveyed on December 7, 1926.

Boeing GA-2 AS 64236 P-310: Originally contracted for three air planes, the third was canceled. The above is the second example delivered. It is known to have been powered by engines AS 95058 and 95060 and possibly others. The first example, AS 64235, was powered by engine AS 95012. It was surveyed on February 21, 1924, possibly following crash damage during testing. The above example was sent to Fairfield Air Intermediate Depot on April 14, 1925. Its history beyond that time is unknown to the author.

The NBL-1, NBL-2 and NBL-3

I have already mentioned the assignment of the Type XIII as the Night Bomber Long Distance class of aircraft and the fact that the Barling bomber had been given the designation of NBL-1, first of the class. Two were contracted on June 23, 1920. It was a huge airplane designed to be powered by six Liberty 12 engines giving it a total rated power of 2,400 HP.

After continual delays in completion and escalating costs, the second plane of the contract was canceled on January 31, 1922. The first plane was not in Army hands until October of 1922. It was so large it had to be delivered in sections to Wilbur Wright Field and stored until spring as there were no hangers large enough to assemble it in and that could not be done outdoors in winter weather. Assembly was not completed until July of 1923 and the first flight was made on August 23. Although it did set a few weight carrying records and was displayed to the public at several locations during its useful life (and a very impressive display it made because of its huge size), from a practical standpoint its range of only 170 miles when fully loaded was not impressive at all. Its service life was limited and it was scrapped in 1928.

NBL-2 Martin

In April of 1922 the Engineering Division had a competition for designs of heavy bombers and Technical Order 27 of July, 1922 noted there were three successful designs. Only one was awarded a contract. This was a biplane design by Glenn L. Martin to be powered by two W-1A engines. The contract to design and build two examples was signed on June 17, 1922.

The NBL-1 could carry about 5,000 pounds of bombs with a full load of fuel. The design specifications of the NBL-2 gave it about the same ability with a considerably smaller airplane and some 6,000 pounds less gross weight. Finally the W-1 was going to be put to its intended use it seems.

In Technical Bulletin 28 of September 1922 (the name of this publication was changed from Technical Order to Technical Bulletin at number 28) it was noted that the design and mock-up of the first airplane was under way at the Cleveland plant of the Glenn Martin Co. TB 29 of October 1922 contained further updates. It noted "The mock-up has been completed and inspected. Static tests are being made on various types of wing spars. Layouts of landing gear, fuel systems, and other assembly units are being made. The work is being done on a cost-plus-fixed-profit basis."

Further updates were contained in TB 30 of November 1922. First it was noted that "The work on the design—is progressing satisfactorily." That was followed by more detail. "The necessary changes in the mock-up which was recently inspected, will be made in accordance with instructions forwarded by the Engineering Division. The changes will also be incorporated in the design prior to beginning actual construction of the first airplane."

From this point there is no further mention of the project in the Technical Bulletins of the Engineering Division. Actual construction of an airplane apparently never began but a wind tunnel model was built and is currently in the collections of the National Air and Space Museum. We do not currently know why the project was halted or just when.

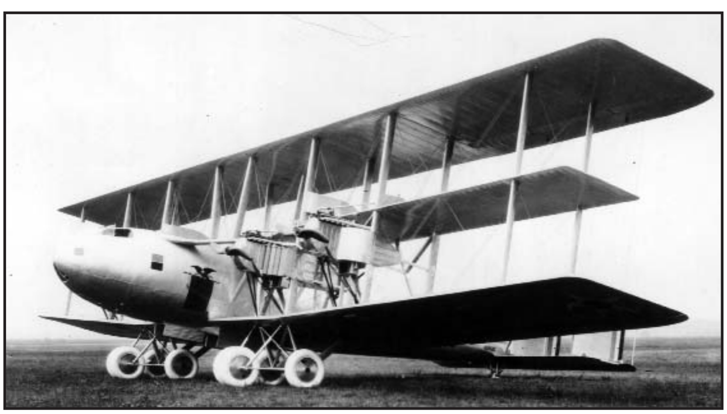
The reader will note that about a month after the two NBL-2 airplanes were contracted, ten production W-1A engines were ordered from Packard.

If we can take the construction of the Boeing GA-2 airplanes as an example, construction of an actual airplane might be expected to start within six to eight months of contract signing. Apparently the NBL-2 project never got to that point. The contract was thus either canceled or put on hold by or before January 1923. Although W-1 development must have reached the point of considerable discouragement by then, certainly there were as yet no plans in place to drop the engine. The NBL-1 was yet to make its first flight. That projects original estimate of cost for two airplanes had been $375,000. By this time the cost of the single airplane delivered had reached almost $525,000. Perhaps the NBL projects had just run out of current funds and by the time they were again available, development of the W-1 had been dropped.

The Engineering Division NBL-3

The Engineering Division made one more design proposal for a NBL class bomber. The design was announced in TB 38 of January - March 1924 with the following description:

"The Engineering Division has initiated preliminary designs for a large night bombardment airplane utilizing a centralized power plant. The general design embodies a single-bay, externally-braced biplane with an exceptionally long fuselage and a semi-biplane tail. The proposed bomber will have a wing span of 133 feet, an overall length of 85 feet, and a wing area of 4,000 square feet, all of which makes it larger dimensionally than the Barling Bomber. The centralized power plant will consist of four Liberty"12" engines



Engineering Division Bailing NBL-1. Contract for two executed on June 23, 1920; reduced to one on January 31, 1922. Delivered in October of 1922 it was not assembled until July of 1923. Powered by six Liberty 12 engines with a total of 2,400 hp. Length: 65 feet; Wing span: 120 feet; Height: 27 feet Weight: Empty - 27,703 pounds; Gross - 32,203 pounds. Range with 5,000 pounds of bombs - 170 miles.

Martin NBL-2. Contract for two on June 17, 1922. Design, mock-up and wind tunnel model were completed but the project was canceled prior to January of 1923. Powered by two W-1A engines with a total of 1,400 hp. Length: 53 feet; Wing span: 98 feet. Weight: Empty - 14,704 pounds; Gross - 26,198 pounds. Bomb load 5,000 to 8,000 pounds depending on fuel carried. Project never completed. Statistics are design and calculated.

driving a single 22-foot two-bladed propeller by means of a power transmission which permits the cutting-out of one or more engines as desired."

It went on to describe the structure, noting that the wing cellule and landing gear would be of similar design to that of the Douglas World Cruiser. Two wheels and tires were to be used on each side rather than the four of the Barling. Tire size would be the largest yet developed at 64x14 inches.

The crew of seven was described as: two pilots located aft of the engine room; three gunners, two in upper wing turrets and one in the tail; an engineer and a navigator.

It was noted that although the aggregate horsepower will be 800 less than the Barling Bomber (1,600 HP), the new bomber would have much less parasite area and be capable of carrying the same bomb load with the same endurance.

The design must have been well under way by this time as the Allison Engineering Co. of Indianapolis was shortly contracted to design and built the four-engine transmission system required. This they accomplished and it passed its 50-hour test in July-August of 1924. This transmission had a combined input of four Liberty engines and was arranged so that any one or more of the engines could be disconnected from the drive with a sliding-tooth clutch. In this manner the plane could continue flight while any engine was disconnected from the power train to allow repairs by the engineer on board.

The transmission also acted as a reduction gear with a ratio of 2.94:1. With this ratio, engines running at full rated RPM of 1,700 produced a speed of 577 RPM to the 22-foot propeller. Full details of the gear can be found on page 303 of *A Technical & Operational History of the Liberty Engine* by the author.

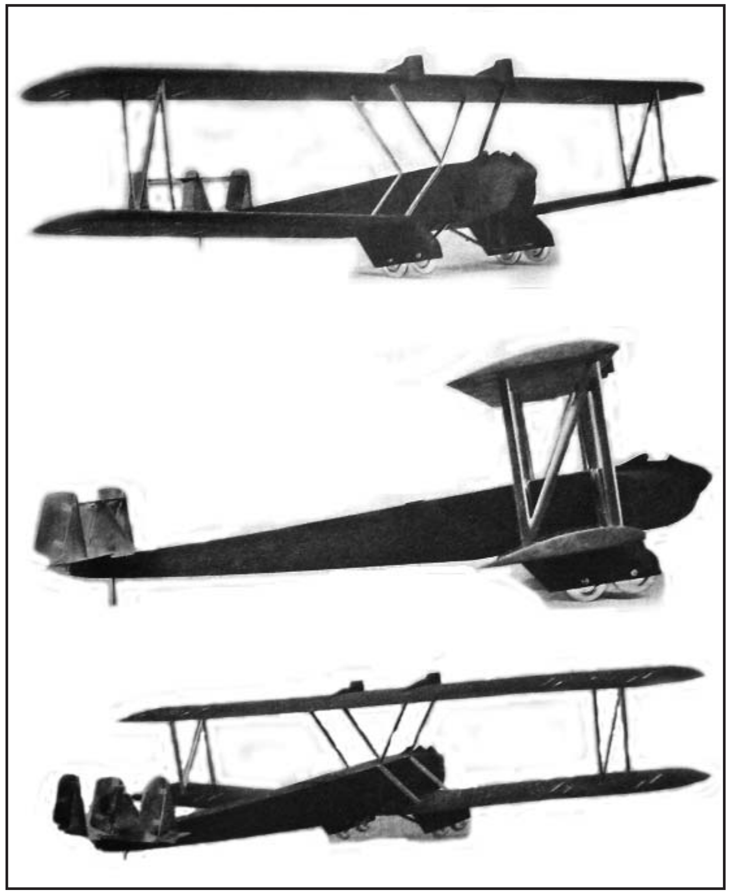
Design of the airplane reached the point of building and testing a wind tunnel model at MIT during September and October of 1924. Although considerable funds had been spent on the design and the gearbox by this time, it appears the project died by the end of 1924.

History of the 50-hour Tests

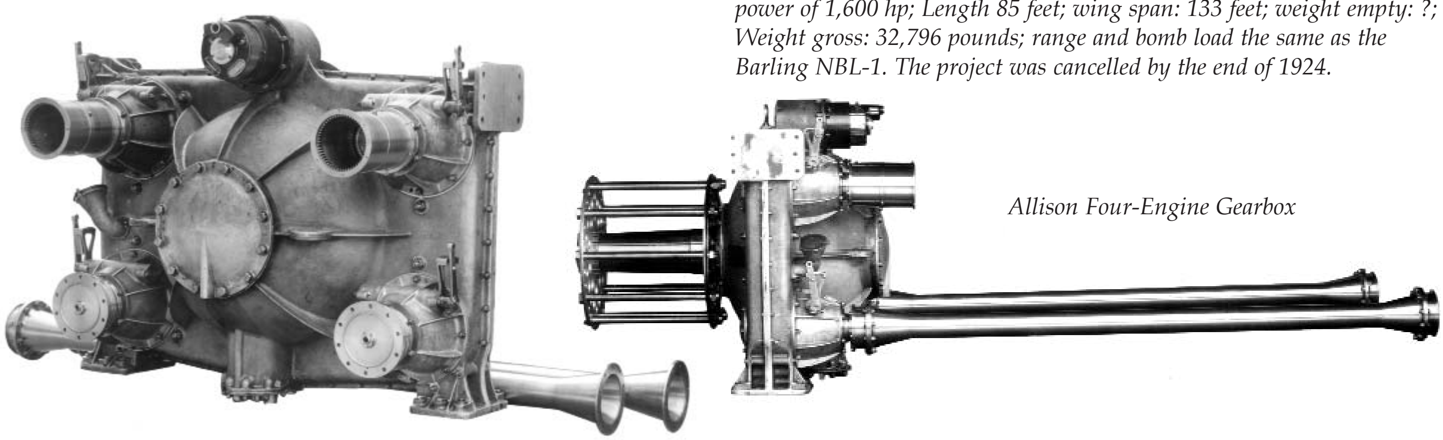
As I noted early in this article, the first 50-hour test showed numerous problems but the engineers still felt the engine had done well and had the potential of being a good production engine. Results of the following four 50-hour test were of a similar nature. As problems appeared resolutions were affected by redesign, new parts, or whatever was required. In other words, the design was perfected and failures reduced to acceptable limits in the usual fashion—with two exceptions. Cylinder water jacket leaks and breakage of valve springs seemed to be insurmountable problems. Just why they were so much of a problem on this engine is difficult to understand.

Cylinder Water-Jacket Leaks

Glenn Angle, in his August 3, 1923 *Aviation* magazine article, covered failures through the five 50-hour tests of the prototype engine (AS 94626) in some detail along with the various methods attempted to resolve the problem. He presented a chart of all the current production engines which used welded steel cylinders with similar water jacket construction. The implication was that the method, though certainly not failure-proof under very severe conditions, had been proven and there was no reason it could not be successful on the W-1A.



The Engineering Division NBL-3 design was proposed early in 1924 and was to be powered by four liberty 12 engines geared to a single 22 foot propeller. The gear would allow any engine to be disconnected from the drive for in-flight maintenance. The above wind tunnel model was built and tested. The gearbox was designed and 50-hour tested by Allison. Design Specifications: Powered by four Liberty engines with a total power of 1,600 hp; Length 85 feet; wing span: 133 feet; weight empty: ?; Weight gross: 32,796 pounds; range and bomb load the same as the Barling NBL-1. The project was cancelled by the end of 1924.



Allison Four-Engine Gearbox

Along with it was a bar type chart depicting the progress, or lack of it, of reducing water jacket leaks in the W-1A. Both are reproduced here because they give a good overall picture of the situation the Engineering Division was facing by late summer of 1923, almost four years after initiation of the project and two and one half years after the first engine ran.

Below I list all eight 50-hour tests the W-1A engine was subjected to along with significant problems encountered which proved difficult to correct. The first five tests were conducted on AS 94626.

First 50-hour - Mar - Oct 1921
Worn valve guides
56 broken valve springs
5 water jacket leaks
1 magneto failure

Second 50-hour - Nov 1921 - Jan 1922
Worn valve guides
Large number of broken valve springs (number not noted)
13 water jacket leaks
1 magneto failure

Third 50-hour - Feb - Mar 1922
79 broken valve springs
14 water jacket leaks
2 magneto failures

Fourth 50-hour - Apr - Jun 1922
59 broken valve springs
18 water jacket leaks

Fifth 50-hour - Oct - Dec 1922
36 broken valve springs
8 water jacket leaks
Delco replacement for magnetos tested successfully.
(Test halted at 18.75 hours to resolve problem of broken valve springs. After changing cam lobe design the test was resumed.)
18 broken valve springs
2 water jacket leaks
3 magneto failures
Test terminated because of failure of #6 master rod at 34.5 hours.
(In the process, a piston pin was thrown through the observation window.)

TABLE I. DATA ON ENGINES USING WELDED STEEL CYLINDERS

Engine	Rated Hp.	No. Cyl. & Type	Bore In.	Stroke In.	Displacement per hp.	B.m.e.p.	Compression Ratio
Benz	200	6-V	5.51	7.48	4.83	117.0	5.80
B.M.W.	185	6-V	5.91	7.09	5.86	96.4	6.51
Fiat "A12"	300	6-V	6.3	7.09	4.40	112.0	4.67
Fiat "A14"	650	12-Vee	6.69	8.27	5.36	98.9	4.98
Hall Scott "L6"	200	6-V	5.00	7.00	3.85	120.5	5.30
Liberty-6	200	6-V	5.00	7.00	3.57	130.5	5.42
Liberty-8	290	8-Vee	5.00	7.00	3.79	123.0	5.42
Liberty-12	400	12-Vee	5.00	7.00	3.92	119.4	5.42
Maybach	300	6-V	6.50	7.09	4.96	112.9	5.91
Mercedes	180	6-V	5.51	6.30	4.90	114.4	5.48
Mercedes	260	6-V	6.30	7.09	5.25	107.5	4.94
Napier "Lion"	450	12-W	5.50	5.125	3.24	127.0	5.53
Packard "744"	180	8-Vee	4.75	5.25	4.15	119.5	5.02
Packard "1116"	280	12-Vee	4.75	5.25	3.96	125.1	5.56
Packard "2025"	550	12-Vee	5.75	6.50	3.75	117.1	5.08
Rolls-Royce "Eagle VIII"	360	12-Vee	4.50	6.50	3.52	123.9	4.88
Rolls-Royce "Condor"	625	12-Vee	5.50	7.50	3.29	126.5	5.17
SPA 6A	210	6-V	5.31	6.69	4.24	113	5.30
USA Model W1A	800	18-W	5.50	6.50	3.47	127	5.40

Sixth 50-hour - Jan 1923
(Carried out on production engine 22-78)
34 broken valve springs
16 water jacket leaks
2 magnetos failed and 2 caused missing.

Seventh 50-hour - May - Sep 1923
(Carried out on production engine 22-79)
Delco battery ignition units replaced all magnetos in this test. Also the Allison stand-alone reduction gear was attached at the start for acceptance test.
18 broken valve springs (big improvement but not fixed)
21 water jacket leaks
No ignition failures of the Delco units.
Allison reduction gear was removed at 21.5 hours as accepted.

Eighth 50-hour Apr - May 1924
(Carried out on production engine 22-79 at 790 HP @ 1,800 RPM. All prior tests carried out at 700 HP @ 1,700 RPM. Also the engine had new type bearings to which the Engineering Design Branch was opposed, feeling they would fail.)
21 broken valve springs
8 water jacket leaks
Bearings failed at 18 hours and the test was terminated.

The conclusions stated at the end of the test was that "**neither spring failures nor water leaks are cured.**"

Although I have mentioned only those particular failing parts that persisted in giving problems, there were many that failed over the testing period. Fixes were found and applied in the usual manner. Various changes in magneto design were tried but none cured their problems. The Delco replacement units appeared to be the fix. A huge number of changes were applied in attempts to find springs which would not break (including the use of Liberty springs, which also broke) and methods of building cylinders

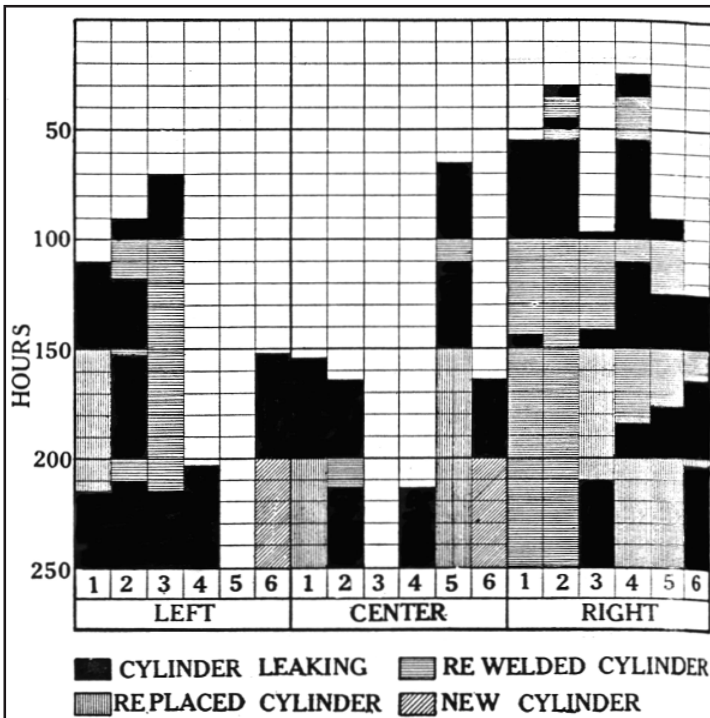


Chart showing Water Jacket Failures during the Endurance Tests on the Original Model W-1-A Engine whose water jackets would not leak. After more than three years of active engineering effort, water jacket leaks and valve spring failures were far from licked.

The eighth 50-hour test is the last one the author had access to. The production run of ten engines seems to have been divided into two groups. Engines noted as the first production group start at AS 22-78. As 22-79 is also noted as tested and 22-83 survives in the collection of the Air Force museum. Existing evidence seems to indicate that probably the first production group consisted of six engines, 22-78 through 22-83. The last four of the ten on order includes AS 22-24 (which was recorded as having been used in testing Gallaudet DB-1B AS 64239) and three others, obviously in a number range including 22-24 but I do not currently know what their numbers were.

This group of ten production engines incorporated some changes from the prior W-1A engines and are in some (but not all) references are called the W-1B models.

Planned Refinements

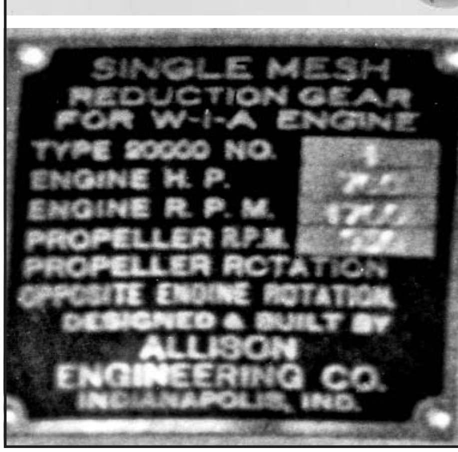
Delco Ignition - Early magneto failures soon prompted the engineers to have Delco design a replacement battery ignition system for the W-1. It was perfected sufficiently for a first unit to be installed in place of one of the four magnetos on AS 94626 for 50-hour test number 5 in October of 1922. It operated well and had no failures during the run, which lasted only 34.5 hours. The Delco unit weighed 8.5 pounds as compared to the 18 pounds of each Dixie magneto.

A full set was made up and installed on production engine 22-79 and tested during the seventh 50-hour run of May - September 1923. Weight of that engine when it underwent the sixth 50-hour test in January of 1923 was 1,831 pounds. Weight for the seventh test was 1,707 pounds. The Delco distributors went through the 50 hours without any failures but it was noted that they showed considerable ware in some areas and would certainly need further development. The eighth 50-hour used rebuilt Delco units and no failures were noted during the test. However, it was terminated at 18 hours because of bearing failures.

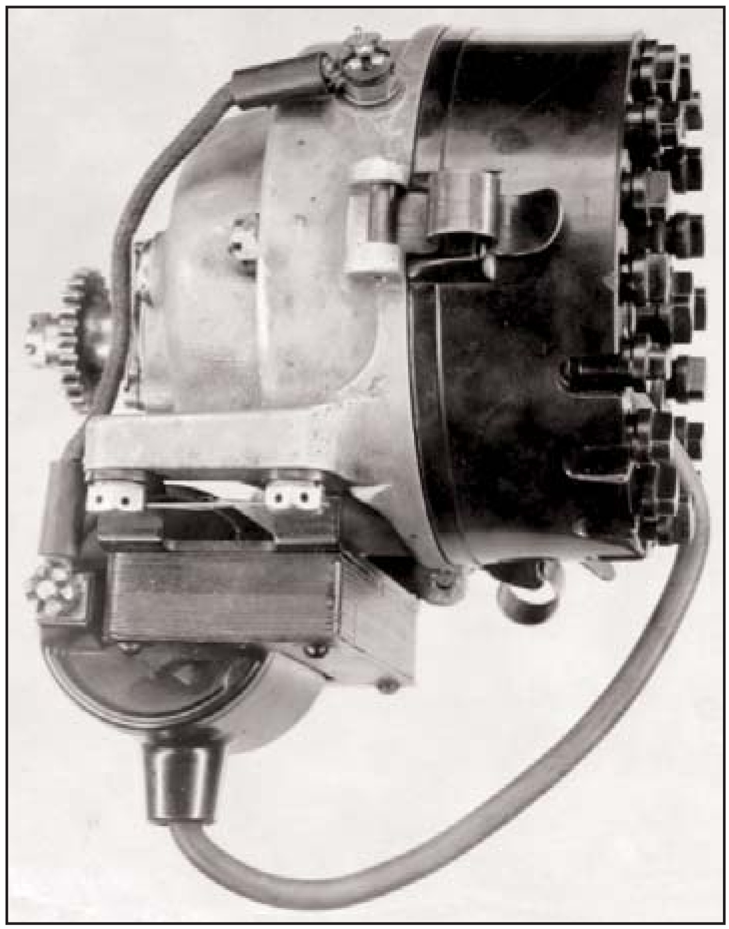
Engine 22-83 survives and is equipped with Dixie Magnetos. No information on the construction details of the last batch of four engines is currently known.

Aluminum Cylinder - Probably in about mid-1922 engineers initiated a project to design individual aluminum cylinders for the W-1 engine. A quick look at the results of the 50-hour tests of this period certainly point out the initiative for such a project—water jacket leaks.

Test reports for this project first show up in mid 1922 and Technical Bulletin No. 32 of February 1923 gives a brief, but significant, report of success to that time. This report (reproduced below in its entirety) pictured the cylinder and noted its performance



W-1A stand-alone reduction gear designed and built by the Allison Engineering Co. of Indianapolis under a contract initiated in early 1921. The gear passed acceptance in about June of 1923. It is not known to have ever been installed on an engine that flew.



The single Delco battery ignition distributor used for test during the fifth 50-hour test (EO 508-56) of W-1A 94626 in October - December 1922 as pictured in that report. It is not shown actually mounted on the engine but must have used some form of adapter. The full set tested during the seventh and eighth 50-hour tests on production engine 22 79 probably had a quite different appearance.

characteristics as being very good with fuel consumption of 0.50 lb/HP/hr, BMEP of 130 PSI and output of 46 HP @ 1,800 RPM (828 HP for a full engine).

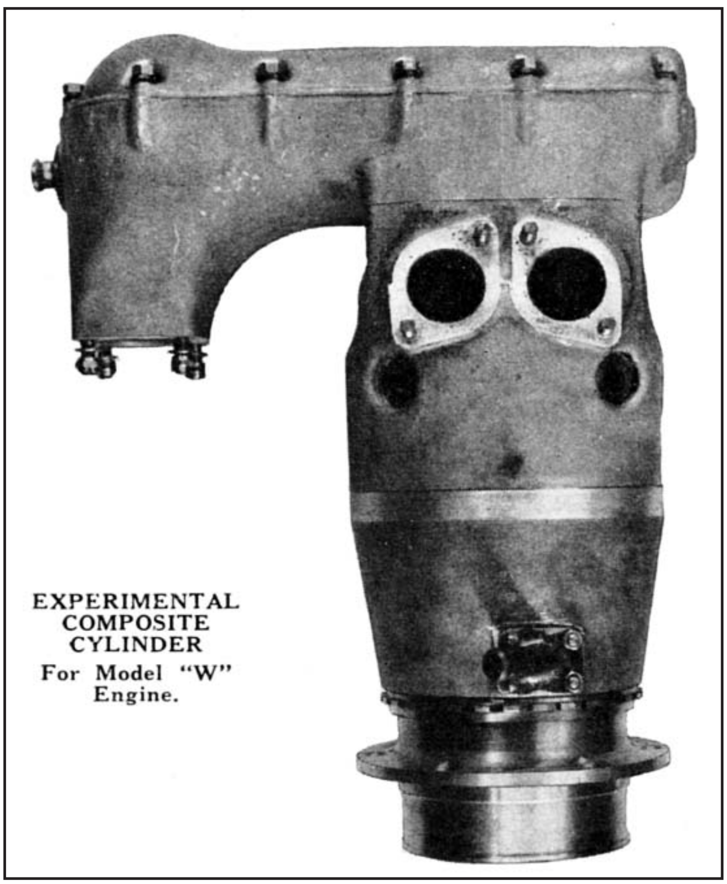
No more is heard of this project so we must assume they determined that carrying it into a full engine was not feasible.

Two-Valve Cylinder - Two test reports on “The development of two-valve cylinders for the W-1 engine” dated 1923 have turned up in the Aircraft Engine Historical Society effort to catalog the Engineering Division records in the National Archives. The author has not had the opportunity to study either report but they do indicate some effort was put into such development, though apparently a brief one.

Design and Test of Revised Carburetion - The last significant W-1 redesign project undertaken was an attempt to develop a system of manifolding to eliminate underneath carburetors. Under EO 508-65 such an effort was carried on between March and November of 1923.

They immediately encountered a space problem. There was not sufficient space between cylinder banks with 40° spacing to mount carburetors in the “V.” Carburetors thus had to be mounted at the end of the engine. Designs were executed to utilize both Stromberg NA-U6 and NA-S7 type carburetors with manifolds to allow either six or three cylinders to be fed from a branch. Best results were obtained by feeding only three cylinders from a branch and the best arrangement was with one carburetor feeding two sets of three cylinders through a “Y” manifold rather than a single carburetor feeding each set of three cylinders. Obviously the disadvantages of the long manifold pipes required with underneath carburetors were not much improved with the long pipes also required by the end-mounted carburetors in the above-engine arrangement.

By November of 1923 the division was close to letting a contract for the Packard 1A-2500. The successful testing of that engine was the last nail in the W-1 project coffin so there was certainly little incentive to carry the carburetor project any farther.



Aluminum Cylinder for Model "W" Engine. A single experimental cylinder of composite steel and aluminum construction, designed by the Engineering Division for the Model "W" 700-HP engine, was performance tested and produced 46 BHP @ 1,800 RPM with a BMEP of 130 psi and specific fuel consumption of 0.50 lb/HP/hr. The regular "W" cylinder had a bore of 5.5" and a normal BMEP of 126 psi.
The complete report was given in Technical Bulletin No. 32 of February 1923. This is the single-cylinder test unit and shows a great deal of work had been put into the project. Even though the report showed nothing but positive results, apparently continuing it to full engine status was not deemed feasible. Nothing more was heard of it.

W-2 Development

I noted earlier that the division had initiated the design of the W-2 before the first 50-hour test of the W-1 was even completed. Parts to build two complete engines were apparently ordered late in 1921 and before the end of the year tests were already being carried out on the W-2 water pump.

At least two different cylinder designs were tested on the universal test engine in 1922. A more advanced “split-head” type, derived from similar designs being tested for the W-1, was tested in 1923.

Also during 1922 work was being carried out on with manifold design and testing of NA-S7 type carburetors, using Packard 1A-2025 Manufacture No. 2 AS no 94558 as the test vehicle.

By June or July of 1923 the two sets of parts had arrived. It was decided to delay assembly and suspend further development work on this design because of the more urgent needs of W-1 development as well as work on other engines considered more important. Within seven months the W-1 project was in deep trouble with cylinder water leaks and valve spring breakage still not resolved. There is no evidence the two sets of parts were ever assembled into engines nor that any further development was undertaken. Drawings of the engine were obviously made but none have so far surfaced. They would be interesting to examine as some references indicate the design differed considerably from that of the W-1.

W-3 Development

The life of the W-3 engine project appears to have been very short. This was to have been a 1,500 HP engine but its specifications are currently unknown to the author. The only document the author has found containing significant information was a special Engineering Division report dated July 1923. In it was noted W-3 progress:

1) A new “W” type design is being undertaken based on experience gained with the W-1. It is expected the engine will show an increase in power and a decrease in weight as a result of incorporating the latest improvements in construction developed by the Division.

2) The general arrangement and type of construction has been determined.

3) A study is being made of a single cylinder set up for the Universal Test Engine.

4) A weight estimate and report on the construction of the engine is about to be prepared.

There is no current evidence that work progressed much beyond that indicated above. Certainly the project was dropped within a few months.

Conclusions

The project died a slow and hard death. Initial hopes were high and any reports published in official Engineering Divisions publications over its entire life were always quite positive. The brief announcement of its abandonment that appeared in Technical Bulletin No. 38 of January - March 1924, was typical and very positive regarding the engine. It consisted of the single paragraph reproduced below.

"The first step toward the development of a large water-cooled engine for use in bombardment airplanes was undertaken by the Engineering Division when the 700 horsepower, 18-cylinder engine known as the Model W-1 was designed, constructed and tested. This engine which was built along very conservative lines came up to its predicted performance in every respect and proved to be very satisfactory from the standpoints of reliability and length of service. However, before the engine could be gotten into service it appeared evident that equally satisfactory results could have been obtained with an engine of much lighter construction. For this reason, further development of this design has been abandoned."

Over the life of the project 20 W-1 and 2 W-2 engines were built (the 2 sets of W-2 parts were never assembled into complete engines). Ten of the W-1 engines were test, or experimental and ten were production. Three airplanes were designed around the engine, the Galludet DB-1, the Boeing GA-2 and the Martin NBL-2. Initial contracts for the respective airplanes were for three, three and two. This would have required ten production engines had all aircraft been built. As we now know, the order for three DB-1 airplanes was reduced to two, only one of which had an engine installed. The GA-2 order was reduced to two and both flew. The two-engine Martin NBL-2 airplanes were canceled before an actual plane was built.

The last two recorded 50-hour tests, the seventh of May through September 1923, and eighth of April through May of 1924, Both showed some mechanical problems under the 700-800 HP stress they were subjected to, but none that would have been considered serious. However, both tests still resulted in very excessive and unacceptable water jacket leaks and valve spring breakage. And to make matters worse, little progress had been made on these two problems after three years of work.

I have a feeling that the engineers working on the W-1 project were probably happy to see the Packard 1A-2500 come on the scene with its rating of 800 HP and weight of 1,120 pounds as compared to the W-1A and its rating of 700 HP and a weight of 1,851 pounds. The 1A-2500 finished off the W-1 project.

The Survivor

Of the 20 engines produced, one survives. It is production Packard engine 22-83 and could very well be the last production engine built. It is currently unrestored and in the storage area of the National Museum of the United States Air Force.

The 20 W-1 Engines Produced

Air Service numbers and comments for the 20 engines produced from three separate parts sets appear below:

First - four sets of parts, ordered from Packard Motor Car Co. in mid-1920 and assembled in 1921 and 1922

94626 - First engine assembled. Test serial No. 1765. This engine continued to be used as the principal test engine through 50-hour test No. 5 (50-hour test No. 4 of modified engine) even after the crankcase had been replaced more than once because of failures.

94627 - Probably the second engine assembled. No specific records available.

95011 - Probably the third engine assembled. No specific records available.

95012 - The fourth engine assembled. Reported in E. O. 508-41 Report serial No. 1899. Reason for test was to establish carburetor settings, determine heat rejection and engine weights prior to W-1 installations in airplanes. Report became Air Service Circular No. 361. Engine installed in the first GA-2 airplane, AS 64235.

Second - six sets of parts built primarily by Steel Products Engineering Co. Ordered in mid 1921 and assembled in late 1921 - early 1922.

95057 - Destroyed during initial acceptance tests. Remaining good parts used to build 95058.

95058 - Tested and sent to Boeing for installation in GA-2, AS 64236. Later held for new rods to be installed.

95059 - Tested for installation in Gallaudet DB-1B, AS 64239. Shipped and then held for new rods before installation.

95060 - Tested and later shipped to Boeing for installation in GA-2, AS 64236.

95061 - Assembled and tested but no current records of where used.

95062 - Assembled and tested but no current records of where used.

Third - ten sets of parts ordered from the Packard Motor Car Co. in 1922 and assembled in 1923.

22-24 - Although this is the lowest AS Number recorded of the batch of ten, 22-78 was noted as the first engine tested. Notes have been found indicating some design changes were made part way through production of these ten sets of parts. No complete records of engine numbers have been found but those which have indicate two batches of numbers were used as indicated here. 22-24 was eventually used in testing Gallaudet DB-1B, AS 64239.

22-25 - No records found.

22-26 - No records found.

22-27 - No records found.

22-78 - First engine tested. (January 1923.) Rejected for leaking water jackets, broken valve springs and cracks in crankcase and returned to builder for rework at 43 hours.

22-79 - Next test of production engine. New crankcase. First engine with all Delco ignition. Allison reduction gear acceptance test at same time.

22-79 - Continuation of testing of first production engines. Available test reports do not give engine number but indicate it is probably 22-79 again. Various new parts were used, including new type bearings of which the Engine Design Branch had no confidence. Early failure for this reason was expected, and occurred. Testing terminated at 15 hours.

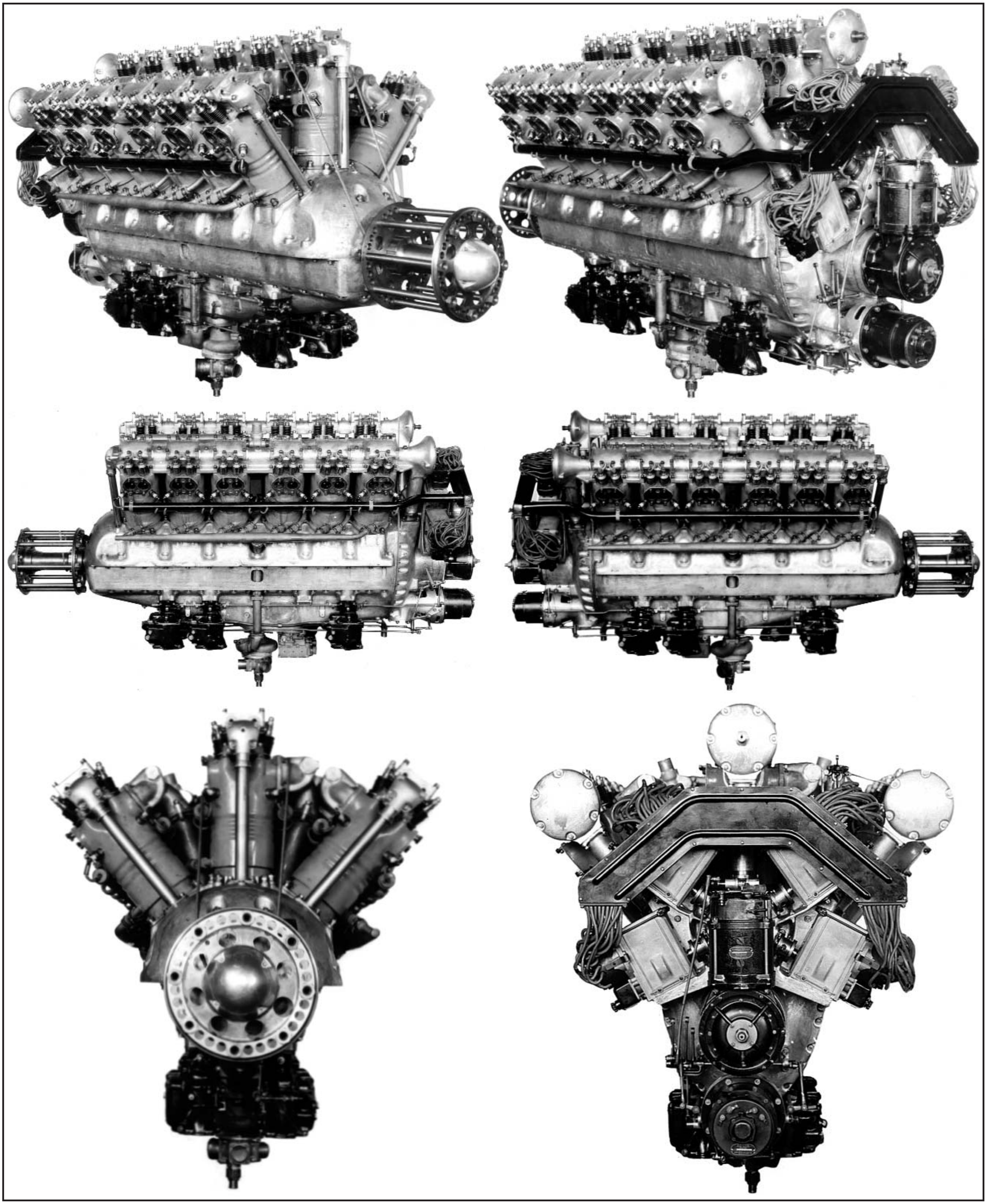
22-80 - No testing records available.

22-81 - No testing records available.

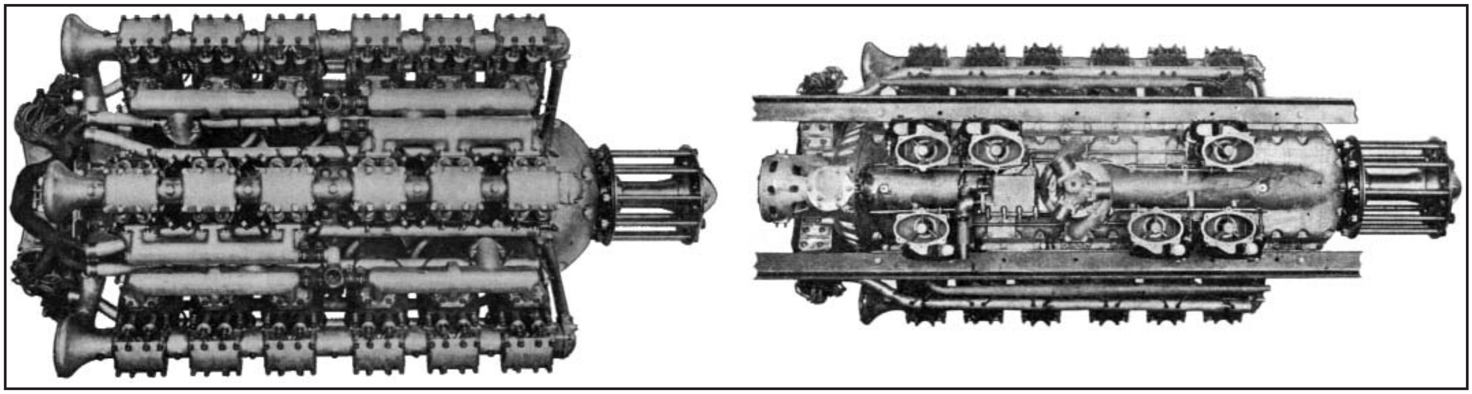
22-82 - No testing records available.

22-83 - Highest engine number recorded and is the lone surviving engine. Now in the National Museum of the United States Air Force inventory.

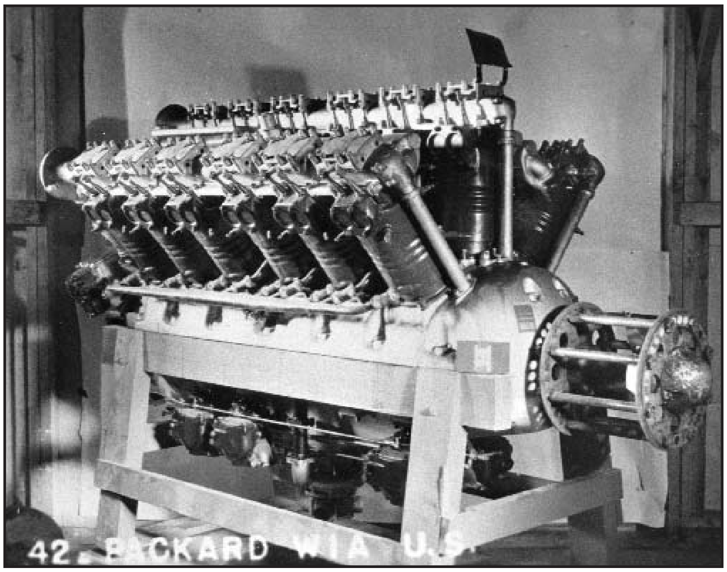
AEHS

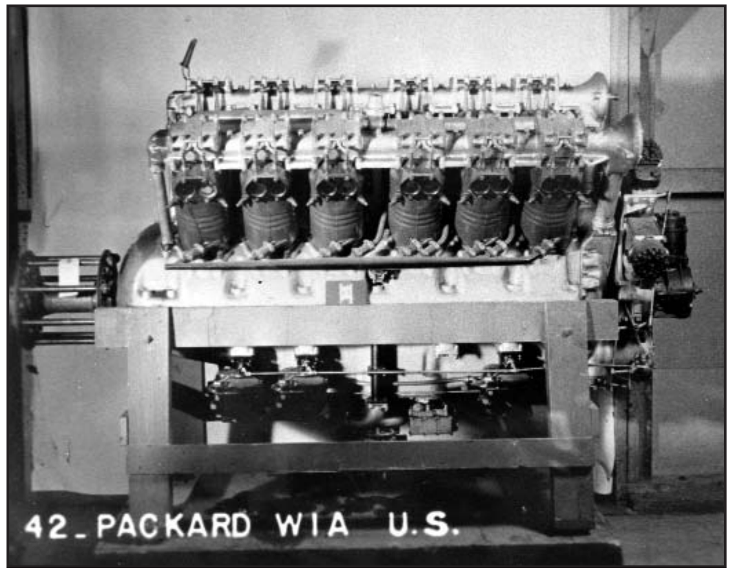


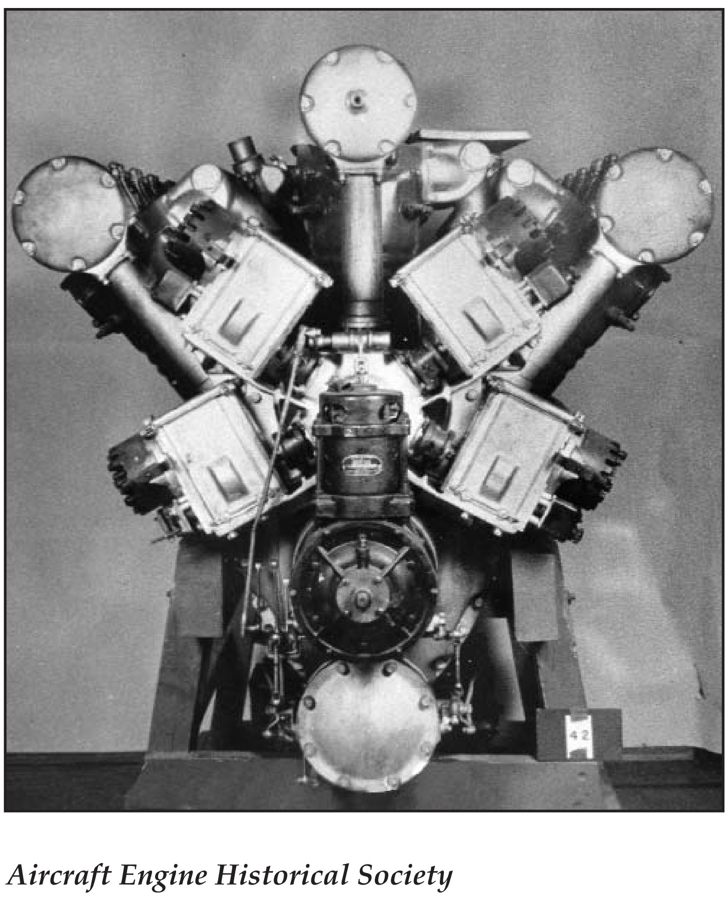
Views of XW-1 A AS 95057 from Test Report E. 0. 508-38. This engine was destroyed during testing; remaining good parts were used in AS 95058.



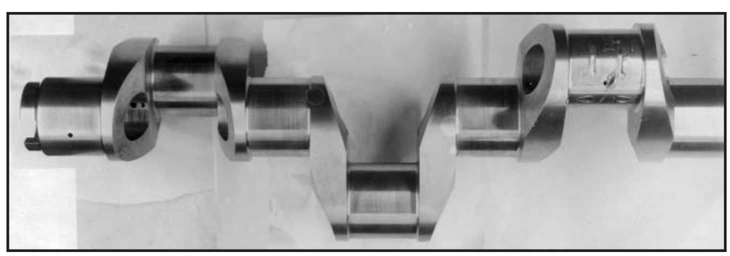
W-1A AS 95012 top and bottom views from report serial No. 1899 which became Air Information Circular No. 361.





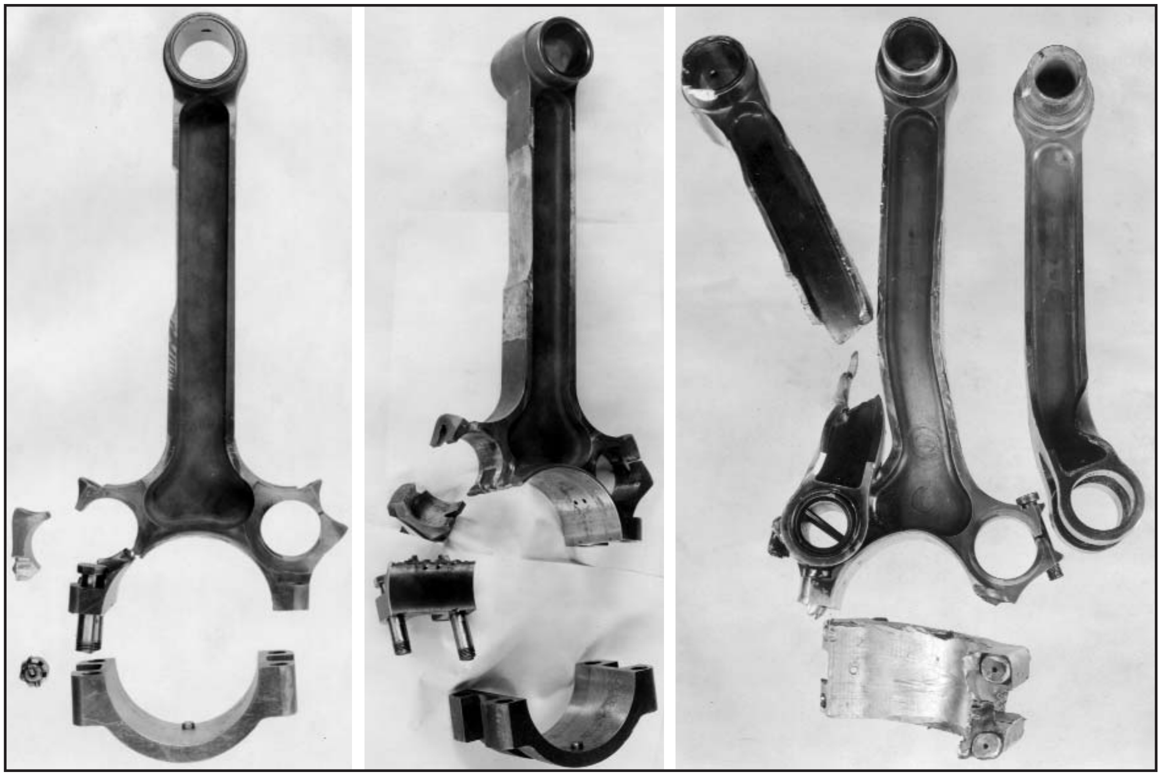


The only surviving W-1A engine, Packard production AS 22-83, is currently in collection of the National Museum of the United States Air Force. These photos were taken during an inventory of the Old Wright Field Museum collection some time in the 1930s. The engine was item number 42. As was common during this period, the engine was in fairly good condition but missing a number of minor parts, as if they had been removed from a museum engine to affect a repair on an in-use engine. In this case all of the valve springs and ignition wires had been removed.



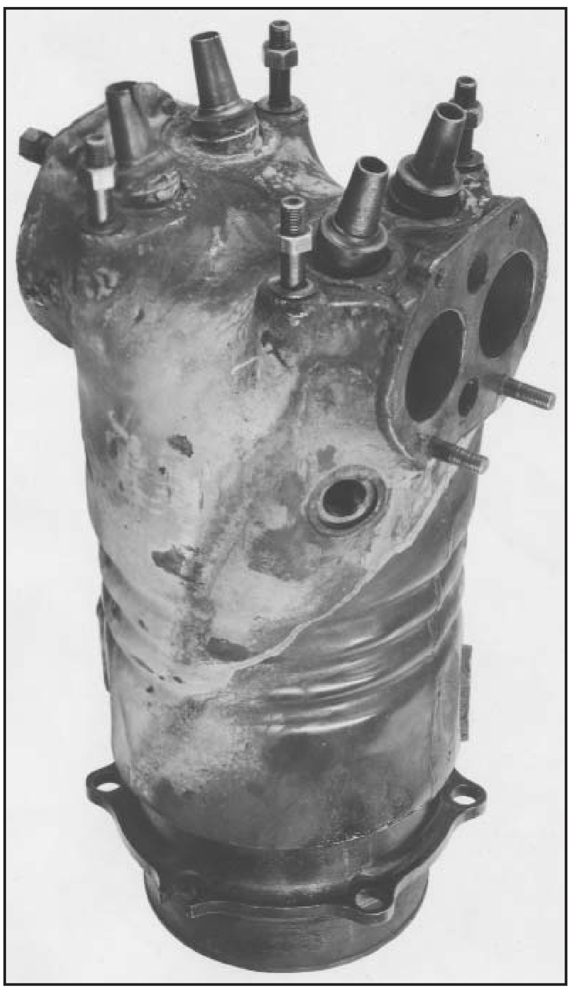
AS 95057 crankshaft showing No. 3 crankpin damage resulting from a failed master rod during an acceptance test run on June 29, 1922.

Connecting rod bolts from AS 95057 No. 3 master rod.

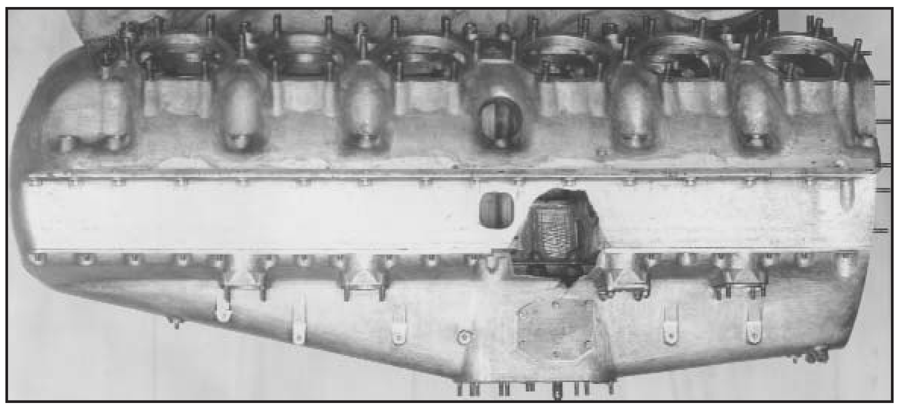


Mangled Master Rods. At left and center are views of the No. 3 master rod from AS 95057. On the right are No. 6 rods from AS 94626.

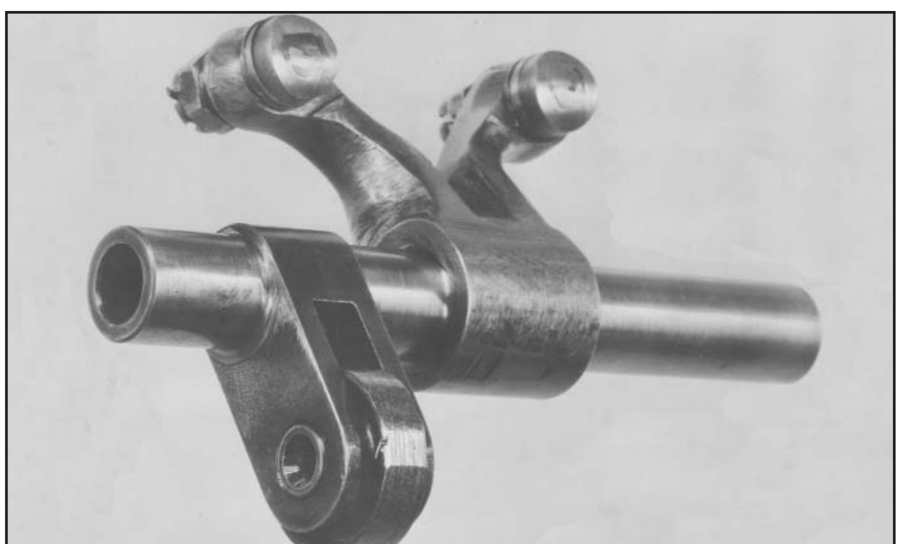
Burned Exhaust Valves from AS 95057



AS 95057 Cylinder after 50 Hour Endurance Test. Water leakage has deposited lime over the water jacket.



AS 95057 Crankcase. Note the hole left by broken No. 3 master rod.



Cylinder 4R Exhaust Rocker Arm from AS 94626. The roller is burned and scored.