

# Allison V-1710 Aircraft Engine



The Allison V-1710 was the only American built, liquid-cooled engine to see service during WW II. Originally developed to power dirigibles, the design was modified in 1935 for use in aircraft. It proved to be sturdy and reliable although its performance at high altitude limited its combat usefulness. Turbo-superchargers were added to a few engines, in particular those used on the Lockheed P-38.

Allison V-1710's were used to power the Lockheed P-38, Bell P-39 Aircobra, P-63 Kingcobra, Curtis P-40 Warhawk and early versions of the P-51 Mustang. The engine on display is the port engine from a P-38. Turbo-supercharged, it developed 1475 h.p.

## ***Specifications (V-1710-85)***

### **General characteristics**

- **Type:** 12-cylinder supercharged liquid-cooled 60° "Vee" piston aircraft engine
- **Bore:** 5.5 in (139.7 mm)
- **Stroke:** 6 in (152.4 mm)
- **Displacement:** 1,710.6 in<sup>3</sup> (28.03 L)
- **Length:** 98.53 in (2,502 mm)
- **Width:** 29.28 in (744 mm)
- **Height:** 41.18 in (1,046 mm)
- **Dry weight:** 1,445 lb (655 kg)

## Components

- **Valvetrain:** Two intake and two exhaust valves per cylinder with sodium-cooled exhaust valves, operated by a single gear-driven overhead camshaft per each bank of cylinders.
- **Supercharger:** Centrifugal-type, single stage, impeller 10.25 in (260 mm) in diameter with 15 vanes.
- **Fuel system:** Bendix Stromberg carburetor with automatic mixture control
- **Fuel type:** 100 octane
- **Oil system:** Dry sump with one pressure and two scavenge pumps.
- **Cooling system:** Liquid-cooled with a mixture of 70% water and 30% ethylene glycol, pressurized.

## Performance

- **Power output:** 1,325 HP at 3,000 RPM
- **Specific power:** 0.77 hp/in<sup>3</sup>
- **Compression ratio:** 6.65:1
- **Power-to-weight ratio:** 0.92 hp/lb

## History

The Allison Division of General Motors began developing the ethylene glycol-cooled engine in 1929 to meet a US Army need for a modern, 1000 hp (750 kW), engine to fit into a new generation of streamlined bombers and fighters. To ease production the new design could be equipped with different propeller gearing systems and superchargers, allowing a single production line to build engines for everything from fighters to bombers.

The U.S. Navy purchased the first V-1710s, the B model (the only V-1710 that did not have a gear driven supercharger) in 1931 and installed them on the airship aircraft carriers the Akron and Macon. The U.S. Army Air Corps purchased its first V-1710 in December 1932. The Great Depression slowed development, and it was not until December 14, 1936 that the engine next flew in the Consolidated XA-11A testbed. The V-1710-C6 successfully completed the Army *150 hour Type Test* on April 23, 1937 at 1000 hp (750 kW), the first engine of any type to do so. The engine was then offered to aircraft manufacturers where it powered the Curtiss X/YP-37. All entrants in the new pursuit competition were designed around it, powering the Lockheed P-38, Bell P-39 and Curtiss P-40. When North American Aviation was asked to build the P-40, they instead responded with an improved design, using the V-1710 in their P-51A.

The Army had earlier decided to concentrate on turbosuperchargers for high altitude boost, believing that further development of mechanical turbochargers would allow their engines to outperform European rivals using superchargers. Turbosuperchargers are powered by the engine exhaust and so do not draw power from the engine, whereas superchargers are connected directly by gears to the engine crankshaft. Superchargers as

a result require increasing proportions of engine power as altitude increases (the two-stage supercharger of the Merlin 60 series engines consumed some 230-280 horsepower at 30,000 ft). General Electric was the sole source for research and production of American turbosuperchargers.

Turbosuperchargers were indeed highly successful in U.S. bombers, which were virtually all powered by radial engines. The P-47 fighter had the same combination of radial engine (R-2800) and turbosupercharger and was also quite successful, apart from its large bulk, which was caused by the need for the ductwork for the turbosupercharger.

However, mating the turbosupercharger with the Allison V-1710 proved to be far more problematic. As a result, designers of the fighter planes that utilized the V-1710 were invariably forced to choose between the poor high altitude performance of the V-1710 versus the increased problems brought on by addition of the turbosupercharger. The fates of all of the V-1710 powered fighters of World War II would thus hinge on that choice.

The original XP-39 was built with a turbosupercharged V-1710. Numerous changes were made to the design of the production version (after a review by aerodynamicists at Langley Field), including a decision to drop the turbosupercharger. This decision came out of a combination of the severe teething problems encountered with the turbosupercharger mated to the V-1710, as well as the belief of the Army at that time that high altitude performance was not necessary in a fighter plane. The P-39 was thus stuck with poor high altitude performance and proved unsuitable for the air war in Western Europe, which was largely conducted at high altitudes. The P-39 was rejected by the British, used briefly by the U.S. in the early Pacific air war, and then was exiled by the USAAF to the Soviet Union under the Lend Lease program. The Soviets were still able to make good use of P-39s because of its excellent maneuverability and because the air war on the Eastern Front in Europe was largely short ranged, tactical, and conducted at lower altitudes.

The P-40, which also had only the single stage, single speed supercharger V-1710, would have similar problems with high altitude performance.

The P-38 would be the only fighter to make it into combat during World War II with turbosupercharged V-1710 engines. The operating conditions of the Western European air war - flying for long hours in intensely cold weather at 30,000 feet - unmasked several severe problems with the P-38's turbosupercharged V-1710. The V-1710 engines in these P-38s had a poor manifold fuel-air distribution and poor temperature regulation of the turbosupercharger air, which resulted in frequent engine failures (detonation occurred in certain cylinders as the result of persistent uneven fuel-air mixture across the cylinders caused by the poor manifold design). The turbosupercharger had additional problems with getting stuck in the freezing air in either high or low boost mode; the high boost mode could cause detonation in the engine, while the low boost mode would be manifested as power loss in one engine, resulting in sudden fishtailing in mid-flight. Specific details of the failure patterns of the P-38's turbosupercharged V-1710 were spelled out in a report by General Doolittle to General Spatz in January 1944 [p.188-189,

Ludwig. "P-51 Mustang: Development of the Long Range Escort Fighter"]. It was too late to correct these problems in the production lines of Allison or GE, and so the P-38s were steadily withdrawn from Europe until they were all gone by October 1944. It is not clear if all of the problems of the P-38 were ever fixed, as the Merlin-engined P-51 arrived at this same time and succeeded well enough to redirect attention to the more successful design. The P-38 had fewer engine failures in the Pacific Theater, where the weather was warmer, and the Japanese did not operate at such high altitudes.

When Packard started building Merlin V-1650 engines in America, certain American fighter designs using the Allison V-1710 were changed to use the Merlin. The Packard versions were not mere blueprint copies of the British Merlin. Packard's engineers contributed to the success of the Merlin throughout the war by making a number of modifications and design changes that were shared across the ocean with the British Merlins. Packard-Merlins were also manufactured to a far more uniform and rigorous standard, using standard U.S. mass production techniques, unlike the British Merlins which were hand fitted individually by craftsmen.

The P-40F, a Lend Lease export to Britain, was one of the first American fighters to be converted to a Packard-Merlin engine. However, the installed engine was the V-1650-1 series with slightly improved a single stage, two speed supercharger. And so the P-40F saw only some modest gains in performance.

The first production P-51A had the Allison V-1710 without turbosupercharger and thus, poor high altitude performance. But at low altitudes, the P-51A was substantially faster than the Spitfire, which very much impressed the British when they first received the plane; they quickly realized that the P-51 had an outstanding low drag airframe and the airplane could become one of the best of the war if the Allison V-1710 engine were replaced by the two-stage supercharger Merlin. Conversion of the P-51 to the Merlin thus proceeded on both sides of the Atlantic, with North American Aviation engineers making the definitive changes to the airframe to fully integrate the Packard-Merlin V-1650-3 into the P-51B. Ironically, because the P-51 was not originally an aircraft developed for the USAAF, this conversion was allowed to proceed rapidly with no input from the USAAF. A similar attempt to fix the problems of the P-38 by replacing its Allison engines with Merlins was quashed by the USAAF, after protests from Allison.

Starting with the V-1710-45 around 1943, Allison attached an auxiliary supercharger to some of its engines in an effort to improve high altitude performance, with limited success. Although described as a two-stage supercharger, it was essentially an afterthought and did not have all of the full refinements of the two stage Merlin, such as the pressure-altitude governed two-speed gearbox and the intercooling system. Various configurations of this auxiliary supercharger were used in production versions of the V-1710 that powered aircraft such as the Bell P-63 and North American P-82E/F/G series. P-82's performances never matched Merlin equipped P-51's. In addition, it was tried or studied as the powerplant for many experimental and test aircraft. Not much is known about the fate of the P-63 as almost all of these airplanes were sent to the Soviets.

The F-82 did see brief action in the Korean War, but the type was completely withdrawn from Korea by 1950. It had a very short service life that was probably due to a combination of factors: poor reliability from the G-series V-1710 engines, low numbers of F-82s produced, and the arrival of newer and better jet powered designs. The initial production P-82B had Merlin engines, but North American was forced to use the Allison V-1710 for the E/F/G models. According to Edgar Schmued, the designer of the P-51 and F-82, "The United States Air Force was tired of paying a \$6,000 royalty to England for each Merlin engine built in this country by Packard.....It was really pathetic to see a good design simply ruined by politics and the lack of cooperation by the Allison people in building a good engine."

In total, over 70,000 V-1710s were built by Allison during the war, all in Indianapolis, Indiana.

## Introduction

The Allison V-1710 was one of the most important large U.S. aero engines, with over 70,000 engines produced from the time of the first in 1931 to the last in 1948. The engine was produced in large quantities in the early 1940's for several important fighters of WWII including the P-38, P-39, P-40, P-51A, P-63, and P-82. While the debate over the merit of air-cooled -vs- liquid cooled engines had raged in the 1920's, each was recognized to have certain advantages. As the only liquid cooled U.S. designed engine of the second-world war (the Rolls-Royce licensed Merlin being the other significant liquid cool manufactured by Packard as the V-1650), the V-1710 exhibited the advantages inherent with liquid cooled engines. These advantages include low frontal area and high short-term peak power output thanks to the coolant heat-sink, higher power because of the greater heat rejection capability of liquid coolant, and packaging flexibility. The air-cooled engines advantages are primarily the weight savings and reliability inherent in eliminating the liquid cooling system.

Allison, which became a part of general motors in 1929, invested private funds in the development of a liquid-cooled V12 engine at the urging of Allison General manager Norm Gilman. While the U.S. Army Air Corp (U.S.A.A.C.) showed no interest, the Navy supported development of an experimental engine to test the basic design as a precursor to a reversible airship engine. The successful V-1710-A was test run in 1931 and delivered 650 hp at 2,400 RPM on 80-octane fuel. It featured the same 5.5" bore and 6.0" stroke as all succeeding V-1710's, weighed 1,010 lbs, had a 8.25" supercharger turning 7.3 times faster than the crankshaft, and had a compression ratio of 5.8:1. The engine featured a distinctive internal-spur gear propeller reduction drive (initial ratio was 0.66) which in late series models was replaced with more conventional external spur gearing. Modification were required half-way through the first 50 hr test run, and Allison took this opportunity to increase performance by increasing the supercharger gear ratio to 8.0:1. This engine completed its 50 hour test run in 1932 at a rating of 750 hp at 2,400 rpm.

Both the Navy and U.S.A.A.C. were now interested in the V-1710, the Navy placing the anticipated order for reversible airship engines designated V-1710-B and the U.S.A.A.C. designated V-1710-C. The Navy engine eliminated the supercharger (rotary induction blower) in favor of two carburetors placed in the Vee of the engine. The engine was designed to reverse from full power one direction to full power the opposite direction in less than 8 seconds, while driving a remote mounted propellers mounted on outriggers equipped with swiveling heads which allowed thrust to be directed vertically or horizontally. The engine power would be transmitted by 16' driveshafts to the remote transmission and gear arrangements in the swiveling heads. Allison had already designed such drive systems and transmissions for use in the Navy Airships USS *Akron* and USS *Macon*. The U.S.A.A.C. version was designated V-1710-C and featured a supercharger impeller enlarged to 9.5", a 2:1 propeller reduction drive in a longer nose casing, and a stiffened crankcase. Additional changes were required to overcome severe harmonic vibration problems caused by the long nose and change in reduction gearing which caused damage to crankshafts, reduction gears and cylinder blocks.

A significant redesign was undertaken by R.M. Hazen in 1936 which lead to an increased compression ratio of 6.0:1, improved combustion chambers which reduced the length of flame channel, improved piston and rings, and changed manifolds for better air-fuel distribution. This "C"-model passed its 150 hour type acceptance test in 1937, establishing a rating of 1,000 hp at 2,600 rpm at sea level. The definitive Allison which was the foundation for all future engines was now established -- penthouse-type combustion chambers with four valve per cylinder, overhead camshafts in each cylinder block with forked roller cam followers actuating pairs of valves in each cylinder, blade-and-fork connecting rods. Subsequent engines differing primarily in induction system and reduction gearing. A number of incremental improvements were made during the life of the "C"-model including increase in compression ratio to 6.65:1, eventually leading to "C"-models with takeoff ratings of 1,150 hp at 2,950 rpm and supporting 3,500 rpm for overspeed during dives.

The "D"-model featured a remote reduction gearbox in a pusher configuration for powering the Bell Aircraft XFM-1 Airacuda twin-engine fighter.

The power unit on the "E" and "F" engines were identical, with crankshafts, connecting rods, pistons, cylinder blocks, valve gear, and intake manifolds among other components completely interchangeable. The "E" featured a remote propeller reduction gearbox for the Bell P-39 Airacobra (and P-63 Kingcobra) driven with a 10 ft extension shaft turning at crankshaft speed between the engine and reduction gear. The "F" had a conventional integral tractor propeller reduction gear Lockheed P-38 Lightning and Curtiss P-40 Tomahawk. A turbocharged V-1710-F17L/-F17R engine equipped with ADI produced a WER of 2,300 bhp at 3,000 rpm with 90 in hg., developing a BMEP of 355 psi. The "E" and "F" engines were the bread & butter Allisons, with these engines used in large volume on several major fighter programs of WWII. A total of 66,658 "E" and "F" types were built -- 18,998 "E"-type extension shaft engines were shipped, mainly for P-39 and P-63 aircraft, and 47,660 "F" models were shipped, mainly for P-38 and P-40 airplanes.

The ultimate V-1710 was the "G" series which brought together all of Allison's design and manufacturing experience to produce an outstanding engine in almost all respects from earlier engines. The V-1710-G was incorporated a number of desired improvements identified in 1943 by Wright Field (U.S.A.A.F. engineering/procurement organization) and improve performance to 1,725 bhp at 3,400 rpm. To improve performance, the 12-counterweight crankshaft developed in late 1942 was used to increase the maximum rpm to 3,400, the induction path was improved to increase flow, and improvement were also made to the supercharger, cylinder heads, and accessories section. One interesting characteristic of the "G"-series was the large proliferation of features and configurations -- short-nose integral reduction gears or extension shafts, with and without auxiliary superchargers, both 9.5" and 10.25" engine supercharger impellers, one or two-speed supercharger drives, a range of supercharger drive ratio's, three compression ratio's, pressure (injection) carburetor, speed density injection, or port fuel injection, and both left and right hand rotation. These engines became the most desirable to racers, and tractor pullers because of the high-revving crankshafts and improved detail design. A total of 763 were produced -- a batch of 750 V-1710-G6R/-G6L consisted of virtually all the "G" series production. When this batch of engines were declared surplus in the 1950's by the Air Force, they were said to have been the engines which powered Unlimited Hydroplanes into the 1990's. This same source describes how the Unlimited Racers traded performance for engine life, modifying engines to deliver as much as 4,000 hp. These engines differed from other Allison's primarily in the areas of lower compression ratio, an auxiliary supercharger and speed/density fuel injection. The boat racers routinely increased the compression, and discarded the auxiliary supercharger and injection system.

The most remarkable engine was probably the V-1710-E27 experimental turbo-compound engine. This unique engine was the first turbo-compound or "power-feedback" engine and was way ahead of its time. Based on an E-22 power section with auxiliary stage supercharger, it used a General Electric CT-1 power turbine which was adapted from the exhaust turbine of a CH-5 turbosupercharger. The turbine drove the crankshaft through a 5.953 reduction gear. The engine compression was reduced to 6.0:1 to facilitate high supercharger boost pressure of 100 in hg (35 psig). Using 115/145 PN fuel with ADI injection, this engine was able to develop 2,980 hp at 3,200 rpm and 100 in hg boost from sea level to 11,000 feet. In addition to the remarkable power output, the engine demonstrated a 19% improvement in specific fuel consumption during cruise. Had the inlet exhaust temperature not been limited to 1750° F, it is certain even more power could have been developed. The temperature proved to be easily exceeded during full-power operation, so the engine was never placed into service with the P-63 as intended.

## Allison V-1710 Description

The V-1710 is a conventional overhead cam liquid cooled Vee-type engine with 4-valve pentagon roof combustion chambers using two 6-cylinder monoblocks bolted to a split crankcase. The engine has a propeller reduction gear or extension drive on the "grunt" of the engine as defined by Allison and an auxiliary case on the rear. Cylinders were numbered from the rear, with the bank to the left when viewed from the rear (auxiliary section) called the left bank and the other bank the right. Unlike automotive engines, the cylinders were numbered 1L to 6L on the left and 1R to 6R on the right, 1L being the the cylinder next to the auxiliary drive on the side of the coolant pump, the 1R cylinder being located next to the auxiliary section above the oil pump.

**Type:** 12 cylinder 60° Vee liquid cooled

**Cylinders:** Bore 5.5 in (139.7 mm), Stroke 6 in (152.4 mm), Displacement 1,710 cubic inches (28 liters). Compression ratio 6.0:1 (other versions typically use 6.65:1). Two cylinder blocks of six cylinders each comprising a cast aluminum-alloy cylinder head, six hardened steel cylinder barrels and a cast aluminum-alloy cooling jacket. Barrels held in head by a shrink-fit and are enclosed by coolant jacket. Jacket secured to head by studs and to cylinder by nut threaded over each barrel (and torqued to 2,200 ft-lbs!). Each cylinder-block secured to upper half of crankcase by 14 studs extending through the head. Combustion chamber has two intake and two exhaust valves and two diametrically opposed park plugs. Steel intake valve inserts, forged steel stellite-faced exhaust valve inserts.

**Pistons:** Machined from aluminum-alloy forgings. Three compression rings above piston pin -- one keystone ring in the top groove and two conventional rings, and two oil-control rings in a single groove below. Floating piston pin retained by snap-rings at each end.

**Connecting Rods:** Fork and blade type made from steel forgings machined and shot-peened. Connecting rod bearings consist of two flanged steel thin shells lined with nickel-silver-tin, and clamped in the forked end by two bearing caps. Center portion of the outside diameter of the bearing is covered with an overlay of nickel-silver-tin which acts as journal for the blade rod. Blade rod fits around the overlay and is held in place by a single steel cap. Bronze bearing pressed into the small end for the piston pin. Big-end bearings lubricated under pressure from crankshaft, small-end bearing lubricated by splash.

**Crankshaft:** Counter-balanced six-throw seven-bearing type. Each end of the shaft has a bolt flange which provide mountings at the front for a flexible splined coupling for driving the reduction gear pinion and at the rear for a dynamic torsional vibration balancer. Splined to the hub of the dynamic balancer is the outer member of a hydraulic damper. An inner member is connected to the outer rigid member by a flexible quill shaft and reacts against the outer member through a hydraulic fluid to minimize single-

node low frequency torsional vibration. This damper provides the driving connection between the accessories housing and the crankshaft.

**Crankcase:** Two aluminum castings split on horizontal centerline. Large studs on the face of the upper half pass through main bearing webs on lower-half to clamp the two halves over the bearing shells. All main bearings are steel flanged shells lined with nickel-silver-tin. Center main bearing provided with faced flanges which bear upon the center crank cheeks to provide axial location (and absorb thrust loads) for the crankshaft. Cast magnesium-alloy oil pan bolts to the bottom of the crankcase lower half. Oil is scavenged from front and rear of the oil pan.

**Valve Gear:** Two intake and two exhaust valves per cylinder. Stellite-faced sodium-cooled nichrome-alloy valves. The stems of the exhaust valves are parallel to each other and angled 22.5° with respect to the cylinder axis. The intake valves are also parallel to one another and angled 22.5°, the resulting angle between intake and exhaust valves being 45°. The exhaust valve seat was cut at a 45° angle to the valve stem, while the intake was cut at a 30° angle. Single camshaft operates six rocker arm assemblies top of each cylinder bank -- each rocker arm assembly consists of a two forked rocker arms pivoting on a plain bearing (one for the exhaust valves and the other for the intake valves), each with a single rolling cam follower which forks to actuate both intake or exhaust valves by means of articulated lash adjusting screws. Each camshaft is driven by bevel gears through separate inclined shafts from the accessory housing. Pressure lubrication to cam bearings supplied through hollow camshaft.

**Accessory Housing:** Accessory housing mounted directly to the rear of the crankcase and is driven from crankshaft through harmonic balancer/hydraulic vibration damper. Contains supercharger and auxiliary gearing, with drives for the engine supercharger impeller, auxiliary stage supercharger, camshafts, magneto, starter, oil pump, water pump, tachometer, fuel pump, generator and vacuum pumps. The housing also contains the supercharger and provides mounting provisions for the carburetor and those accessories listed above which are not contained within the engine.

**Supercharger:** The engine supercharger (second stage supercharger) is contained in the accessory housing and is driven from the flexible inner member of the hydraulic vibration damper. The impeller is 10.25" diameter with 15 vanes and includes a separate rotating reverse-curved inducer guide vane inlet guide, the relationship with the impeller being maintained by the common splined shaft. The diffuser is cast integrally with the supercharger cover, which also contains the inlet to which the injector throttle body mounts. The impeller is overhung, with the shaft supported by two floating lead-bronze steel backed bearings placed on both sides of the supercharger drive gear. The bearings are pressure lubricated with engine oil.

The auxiliary stage is contained in a separate assembly coupled to the engine accessory section. It is intended to provide a critical altitude of 25,000 ft by delivering air to the engine supercharger at pressures close to sea-level when at critical altitude. This requires large volume of low density air to be handled by the auxiliary supercharger -- because of

the density of the air at 25,000 ft the supercharger must move 2.23 times more air volume than the engine supercharger, and compress the air to about 2.7 times to deliver sea-level conditions. The auxiliary stage drive was obtained by a power-takeoff from the starter gear which connects to a driveshaft incorporating a universal joint, the driveshaft being contained in a tube coupling the engine accessory section with the remote auxiliary stage. The driveshaft hydraulic torque converter connected to the step-up gears contained in the auxiliary supercharger housing. The torque-converter provides variable speed for the supercharger by varying the amount of oil and therefore the coupling of the torque converter. The speed controlled by a boost-regulating system, permitting infinitely variable control of the speed of the auxiliary stage which was used to control manifold pressure so that power could be controlled while the throttle remains wide-open. The auxiliary supercharger consumes 490 hp from the crankshaft at the 2250 hp WER rating.

**Engine Models and Applications:** Because of the vast number of V-1710 derivatives which were generated, the following table is necessarily incomplete, but includes representative models from the major series. Many of these deviates stem from early development, for example the "C" series consists of 13 unique models with total production of 2,582, yet 2,550 of those engines belonged to one model type (and of the 32 remaining engine, 19 belonged to another model type!).

The total number of engines built for each series were:

A-series 2

B-series 3

C-series 2,582

D-series 44

E-series 18,998

F-series 47,660

G-series 763 (good rods)

Total 70,052 (note only 70,033 engines delivered because some prototypes were converted to later models)