print | close

100 years of Aircraft engines

Machine Design
Stephen Mraz
Stephen J. Mraz
Thu, 2003-09-18 11:30

The 100th Anniversary of flight has us looking back at some evolutionary and revolutionary aircraft engines.

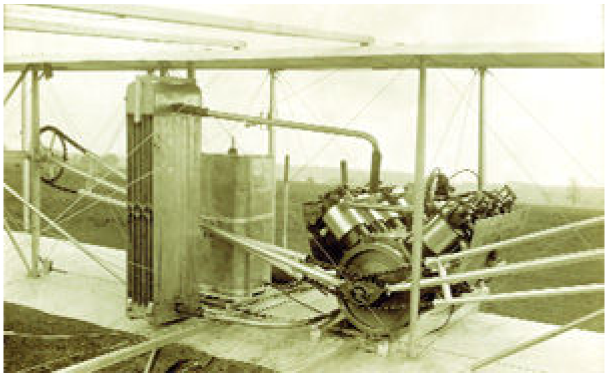
Like all good engineers, those designing aircraft engines are greedy. They always want more power, more durability, and more efficiency. They also want it in the smallest, lightest package possible. And it should be easy to manufacture and not cost too much.

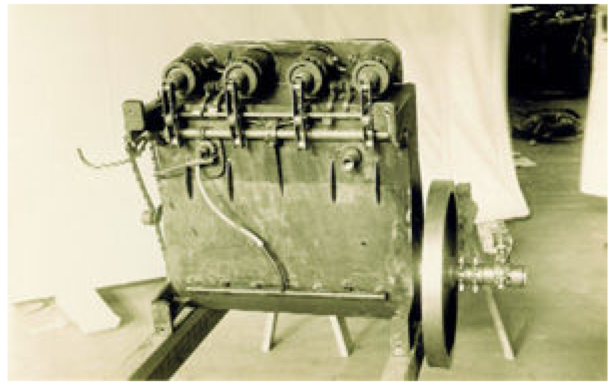
Aeronautical engineers have also been fortunate in that airplanes were quickly recognized as essential war machines. Two world wars, numerous "regional conflicts," and a 50-year Cold War, gave aerospace development several major boosts.

As a result, advances in aviation powerplants have been amazing. Here's a quick look at the strides made since Wilbur and Orville Wright took flight a century ago.

In next month's installment our three-part look at aviation's first 100 years, Machine Design will highlight some of the advances made in aerospace materials as the industry went from wood and fabric to metal and composites. And in December, we will trace some of the advances made in avionics, including radar, navigation, and autopilots.

In





1902, the Wright brothers sent out a request for bids to several engine makers for an 8-hp, "vibration-free," gas-fueled engine that would weigh no more than 200 lb. No one took them up on the offer. Having successfully built a one-cylinder, 3-hp, cast-iron engine the year before to power their machine shop, the brothers decided to design and build the engine for their aircraft as well. They finished it eight weeks later with the aid of Charles Taylor, a mechanic and machinist, but without drawings. The 12-hp, four-cylinder engine weighed 170 lb, including the radiator, water and fuel tanks, and 1.5 gallon of gas. It had no throttle. The four-stroke engine always ran at about 1,000 rpm. But output could be somewhat controlled by retarding or advancing the spark timing. Other engine features included:

- Noninterchangeable components. Each was hand fitted. A piston, for example, only fit in the cylinder it was built for.
- The crankcase, cylinder water jacket, mounting lugs, and part of the intake manifold were cast as a single piece of aluminum.
- Valves were cold-rolled steel and of the poppet type. Piston suction opened the inlets and exhaust valves operated on a bicycle chain and sprocket-driven camshaft.
- Fuel dripped into the intake manifold where it was vaporized by the hot water jacket and sucked through the inlet valve and into the cylinders.
- Time between overhauls was about 12 hr.

The brothers also had to design their own propeller. They initially thought they could use information on maritime props, but found little useful data. Besides, they needed a prop with 66% efficiency, and ship props were considered acceptable if they were 50% efficient. So the brothers developed a theory of prop design in which the prop is thought of as a rotating airfoil. They designed an 8.13-ft propeller that was later found to be 66% efficient.

Related

100 years of flight - Keep them flying : Avionics

100 years of flight - Keep them flying : Navigation

100 years of flight - Keep them flying : Safety

Carbon-Nanotube Coating Stops Icing on Aircraft

The Top 25

Curators at the San Diego Aerospace Museum have put together an exhibit celebrating historic aircraft engines. As part of the exhibit, they assembled a list of 25 engines that illustrates the development of major engine types used in military, commercial, and private aircraft. (Fo r more information, visit www.aerospacemuseum.org.)

Inline and horizontally opposed piston engines

1903 Wright Flyer (4-cyl): First engine to fly

1916 Lawrence A-3 (2-cyl): First U.S. opposed air-cooled engine
1926 Cirrus Mk III (4-cyl): British inline used for private aircraft
1930 Aeronca E-107 (2-cyl): First widely used U.S. opposed engine
1931 Continental A-40 (4-cyl): Ancestor of current opposed engines
1941 Ranger 6-440 (6-cyl): Final evolution of air-cooled inline engines
2003 Teledyne CAE IO-550-N (6-cyl): Latest opposed engine

V-type piston engines

1916 Curtiss OX-5 (8-cyl): Early US V-8.
1917 Liberty L-12 (12-cyl): First to fly the Atlantic, cross the U.S., and circle the globe
1932 Curtiss Conqueror (12-cyl): Typical V-12 of the 1930's
1939 Ranger SGV-770 (12-cyl): Rare U.S. inverted, air-cooled V-12
1940 Allison V-1710 (12-cyl): Most highly developed U.S. V-12

Radial and rotary piston engines

1911 Anzani (6-cyl): First two-row radial engine
1916 Le Rhone 9C9 (9-cyl): Rotary engine used in WW I fighters
1924 Wright J-4 Whirlwind (9-cyl): First successful U.S. radial
1950 Pratt & Whitney R-4360 (24-cyl): Largest U.S. radial
1958 Bristol Centaurus (18-cyl): Last large British radial

Gas turbine engines

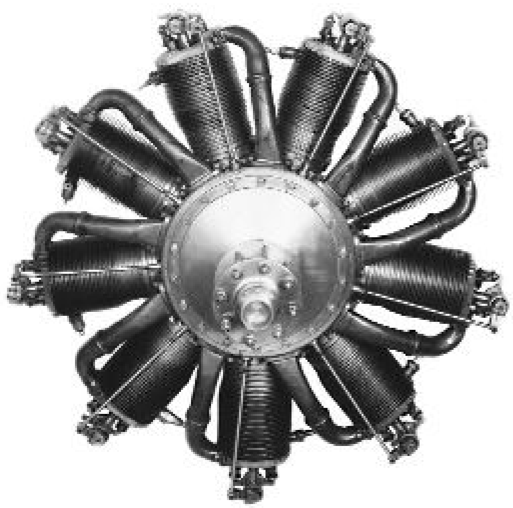
1943 Junkers Jumo 004 turbojet: First jet engine used in combat
1943 General Electric I-16 turbojet: First U.S. production jet engine
1947 General Electric J35 turbojet: First U.S. production axial-flow jet
1955 Klimov VK-1F turbojet: Last large centrifugal-flow engine
1965 Allison T63 turboshaft: Popular small gas turbine
1971 Pratt & Whitney TF30 turbofan: First afterburning turbofan
1974 Teledyne CAE J69 Turbojet: Ultra-compact cruise-missile engine
1975 General Electric TF34 turbofan: First mid-size high-bypass turbofan, still in production for regional jets

A rotating radial

The LeRhone C-9, a dependable French rotary radial, was initially rated at 80 hp, and was later increased to 130 hp. (The Oberursel engine made in Germany was almost an exact reproduction of the 110-hp LeRhone.) The air-cooled engine powered military planes in the first part of World War One. As a rotary radial, the engine and propeller spun around a crankshaft. By the end of the war, it had been surpassed in terms of power and put into trainers. It was also licensed for manufacturing in the U.S. by Union Switch and Signal in Pennsylvania.

TECH SPECS: LeRhone C-9
Date of manufacture: 1915
Power: 80 to 110 hp
Cylinders: 9
Size: 286 lb, 920 cu. In.

America's World War I engine

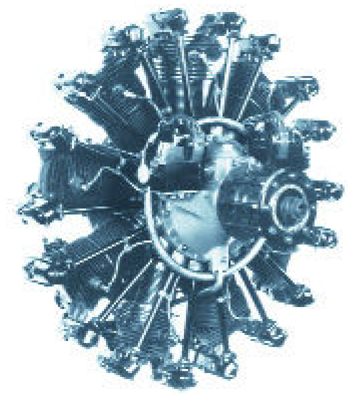


Some consider the Liberty 12-A the greatest technological contribution made by the U.S. to World War I. It was designed and built by the Dayton-Wright Airplane Co., but also manufactured by Packard, Lincoln, Ford, General Motors, Nordyke, and Marmon. They were used primarily in U.S. built Dehavilland DH-4s, the only U.S.-built plane to see combat in the first world war. Over 20,000 were made during the war. After the war, they powered the NC-4 in its series of flights across the Atlantic, a Fokker T-2 in the first transcontinental flight across the U.S., and the Martin planes that formed the U.S. Army's first bomber fleet. They were also put in everything from rum-running speedboats to Russian and British tanks in World War II.

The engine uses a coil ignition system, similar to those used in cars, because American companies could not build enough high-quality magnetos. And the angle between cylinder banks was 45¡ rather than the more conventional 60¡. This made the engine narrower, giving it a smaller cross section, and easier to shoehorn into airframes. The engine weighed 2 lb/hp, making it far more powerful than other mass-produced engines of the time.
Designers eventually turbocharged the Liberty, giving it 443 hp and more power and efficiency at higher altitudes. Turbosuperchargers use hot engine exhaust to power an air compressor, which sends dense, oxygen-rich intake air to the engine. It lets engines operate at high altitudes where air is thinner. At higher altitudes, turbocharging works better than supercharging, which uses a geared mechanism driven off the crankshaft to compress air. That's because hot exhaust gases expand more in thinner air, providing more power to turn the turbine.

TECH SPECS: Liberty 12-A
Date of manufacture: 1918
Power: 410 hp
Cylinders: V12, water cooled
Size: 786 lb, 1,649 cu in.

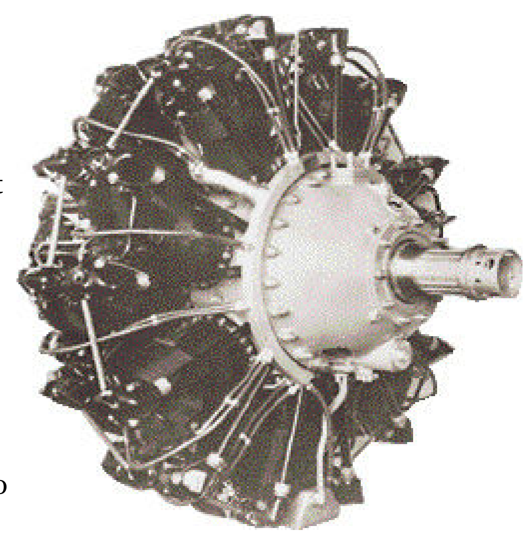
Lindbergh's choice



Charles Lindbergh wanted a single, reliable engine rather than two or more "dicey" engines powering his transatlantic flight. So he chose the Wright J-5 Whirlwind, even though America had been building air-cooled radials for only five years. The J-5 was a follow-on engine to the J-4 and sported a redesigned head and widely spaced valves. This let engineers use larger valves with more cooling fins and better airflow between the ports. Valves were machined from tungsten and their hollow stems filled with sodium and potassium salts for cooling. Rocker arms and push rods were fully enclosed, a first for U.S. air-cooled engines. And a new three-barrel carburetor solved mixture and distribution problems of previous models. (The original J-1 used three carburetors, each serving three cylinders.) As a result, the J-5 Whirlwind was the most reliable radial of its time and said to be everything a simple air-cooled engine can be, i.e., one without super or turbocharging, fuel injection, or reduction gearing for the prop. Its performance, power-to-weight ratio and reliability made it the engine of choice for world explorers, including Admiral Byrd.

TECH SPECS: J-5 Whirlwind
Date of manufacture: 1926
Power: 220 hp
Cylinders: 9, air-cooled
Size: 510 lb, 788 cu in.

The Twin Wasp



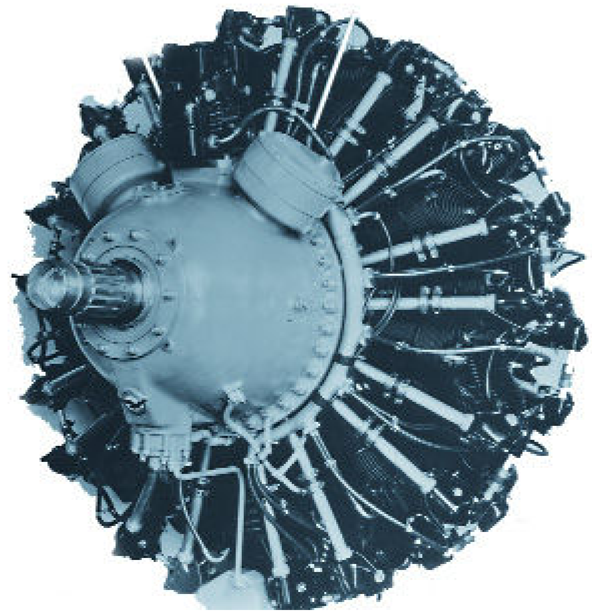
To make a bigger and better radial for the Navy, engineers at the Wright Co. left to form Pratt & Whitney. They effectively added a second row of seven cylinders to a seven-cylinder design to come up with the reliable and efficient Twin Wasp (R-1830). It has the highest production figures for any aircraft engine. Over 173,000 were made, including 13,000 for the C-47 transport plane alone.

It had a forged aluminum crankcase with a vibration damper, enclosed rocker arms with continuous lubrication, and a low-pressure blower for better performance at higher altitudes. It also had a higher compression ratio than other large radial engines, including the J-5 Whirlwind (6.1 and 6.5 compared to 5.4, respectively). When introduced, it generated 775 or 825 hp, depending on compression ratio. Designers discovered that to reach maximum power, however, they needed to use the highest octane gas available. With it, power reached 1,000 hp, and eventually 1,200 hp.

TECH SPECS: R-1830 Twin Wasp
Date of manufacture: 1932

Power: 1,200 hp
Cylinders: 14 in two rows, air cooled
Size: 1,467 lb, 1,830 cu in.

The Double Wasp

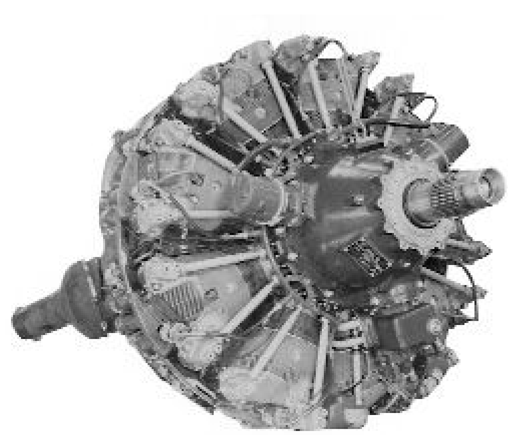


Pratt & Whitney's R-2800, the Double Wasp, was America's first 18-cylinder radial and much smaller than other 18-cylinder radials. Still, it was the most powerful engine of its kind when introduced in 1939, and stayed in production through 1960. But during design, overheating was a problem. Cast and forged cooling fins, which worked well on past radials, weren't enough to solve it. Instead, thin fins had to be machined from the solid metal of the head forgings using new machining technology. (Several automatically guided saws cut fins contoured about the head.) Engineers also had to devise a complex system of baffles to direct air around the cylinders. But the work led to an engine that generated 1 hp for every 1.4 cu in. An experimental model with fan cooling produced 2,800 hp.

The engine was put in fighters and medium bombers during World War II. It helped set a world record for high-speed military aircraft, 405 mph in level flight with an XF4U. After the war, designers used the engines in airliners such as the Martin 404 and the Douglas DC-6. Over 125,000 Double Wasp engines were built.

TECH SPECS: R-2800 Double Wasp
Date of manufacture: 1939
Power: 2,000 hp
Cylinders: 18 in two rows, air-cooled
Size: 2,350 lb, 2,800 cu in.

1950s engine of choice

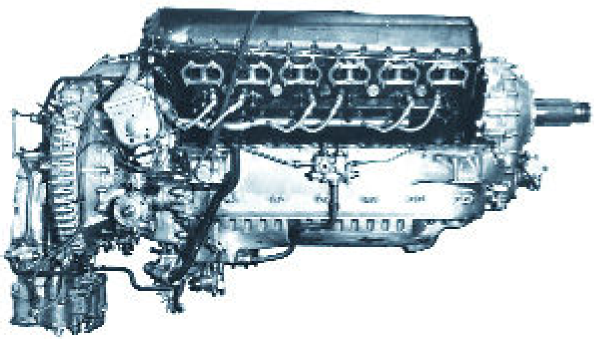


The twin-row, supercharged Cyclone engine, one of the most powerful radials ever built, powered military and commercial aircraft. Later versions were built as turbo compound versions, with three exhaust-driven turbines. The turbines drove a gearbox that added power to the engine crankshaft, boosting output to 3,500 hp, improving fuel consumption by 20%, and giving it the reputation as the most efficient gas-powered aircraft engine ever produced. In 1946, a P2V1 Neptune equipped with two of these modified engines set an unrefueled distance record of

11,236 miles. The engines eventually let Douglas DC-7s and Constellations cross the Atlantic Ocean nonstop.

TECH SPECS: Cyclone
Date of manufacture: 1940
Power: 2,800 hp
Cylinders: 18 in two rows, air-cooled
Size: 3,350 cu in., 2,279

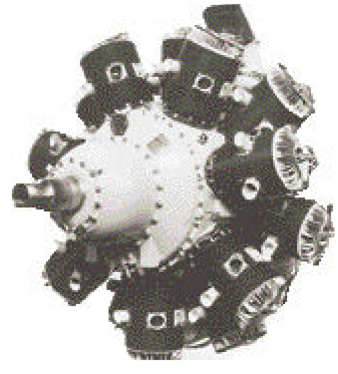
Spitfire and Mustang power



The Rolls Royce Merlin engine started out as a 790 hp V12 plagued by reliability problems, gear-train failures, and faulty water jackets. Adding a two-speed, two-stage supercharger boosted power but also heated incoming air so much it caused premature ignition. An air cooler between supercharger stages solved the ignition problem, and a fuel-injection system was also added. Horsepower climbed to 1,420. High-octane gas imported from the U.S. pushed it to 2,050 hp. Further refinements focused on improving the engine's reliability and ability to withstand abuse. Over 160,000 Merlin engines were built in 52 versions, including 16,000 built in the U.S. at the Packard Co.

TECH SPECS : Merlin
Date of manufacture: 1940
Power: 1,695 hp, and up to 2,640 hp for some models.
Cylinders: V12, liquid d-cooled
Size: 1,695 lb, 1,690 cu in.

British radial power



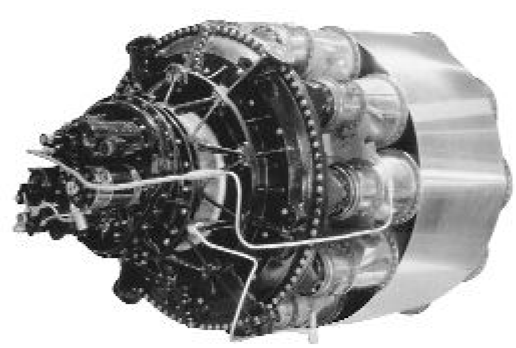
The Bristol Hercules radial engine used sleeve-valves rather than traditional poppet valves. Poppet valves get in the way of incoming gas, and hot exhaust valves limit compression and the octane rating of fuel an engine can use. Sleeve-valves use a ring or sleeve traveling up and down in the cylinder with the piston. A turning motion of the sleeve as it rises and falls aligns a hole in the sleeve wall with intake or exhaust ports and proper timing lets in gas and air, and lets out exhaust gases. The follow-on engine, the 18-cylinder Centaurus, was Britain's most powerful radial. The Mark VI version generated 2,500 hp.

TECH SPECS : Bristol Hercules
Date of manufacture: 1939
Power: 1,290 hp

Cylinders: 14 in two rows, air-cooled
Size: 1,680 lb, 2,364 cu in.

America's first turbojet

The General Electric I-16, also knows as the J-31, was the first jet engine produced in quantity in the U.S., and is said to be a close copy of the secret "Whittle" engine that had been developed in Britain. The engine's turbine was made of Hastelloy B, an alloy originally developed for forging turbocharger blades. Engine controls were based on those developed for steam turbines. When tests revealed that bearings were overheating, engineers increased the size of cooling-air blades on the turbine and redesigned the air diffuser. They also tried a new cooling-air inlet that took advantage of ram pressure.



The I-16 powered America's first jet, the Bell XP-59 Airacomet, but GE stopped production in 1945 after assembling 241 engines for the Army Air Corp.

TECH SPECS : I-16
Date of manufacture: 1943
Type: Single-stage centrifugal compressor and single-stage axial turbine
Thrust: 1,650
Weight: 850 lb

Prince of turbojets

The Jumo 004, built by the German Junkers company, was the first mass-produced turbojet. Volume deliveries of the engine began in late 1944, and more than 5,000 were produced before the end of World War II. They powered the twin-engine Me 262, the first operational jet fighter, and the Arada Ar 232 series of bomber-reconnaissance planes. Some of its unusual features and developments include hollow turbine blades, auxiliary fuel injection, and an afterburner.

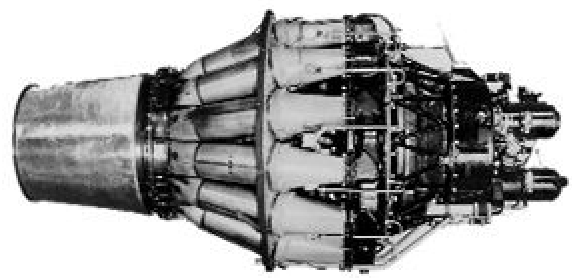
TECH SPECS : Junkers
Jumo 004
Date of manufacture: 1942
Type: Eight-stage, axial-flow compressor, six combustion chambers, a single turbine
Thrust: 1,980 lb
Weight: 1,600 lb

The improved turbojet

When the Army Air Corp wanted a more powerful jet engine, GE produced the I-40 (J-33). It powered the P-80 Shooting Star. It used a host of alloys, including Inconel for the combustion system, Stellite for the turbine nozzles, and Hastelloy B for the turbine bucket. By 1945, however, the recently formed U.S.

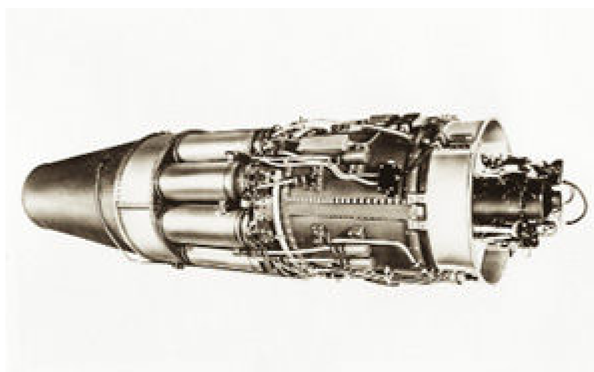
Air Force asked that production be moved to Allison, a division of General Motors. It eventually became the first jet engine to use water and alcohol injection to boost thrust, and be approved for commercial use.

TECH SPECS : I-40
Date of manufacture: 1944
Type: Single-stage centrifugal compressor, single-axle turbine, with 14 combustion chambers
Thrust: 4,000 lb, to 5,400 with water/alcohol injection
Weight: 1,850 lb



First U.S. axial-flow jet

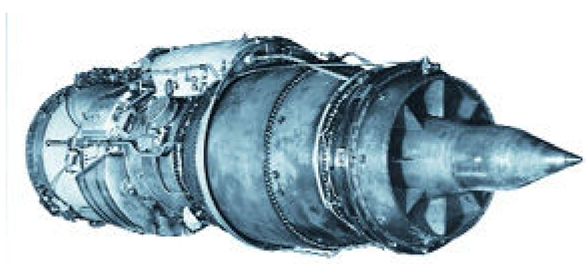
General Electric's TG-180, also known as the J-35, was developed from the TG-100/TG-31 turboprop. It was the Air Force's first jet with a straight-through (axial flow) compressor. Like GE's I-40, the TG-180 was turned over to Allison for production, and over 14,000 were built.



TECH SPECS : TG-180
Date of manufacture: 1946
Type: 11-stage axial flow compressor, single-stage turbine
Thrust: 5,600 lb, 7,400 lb with afterburner
Size: 2,850 lb, including afterburner

First engine with more than 10,000 lb thrust

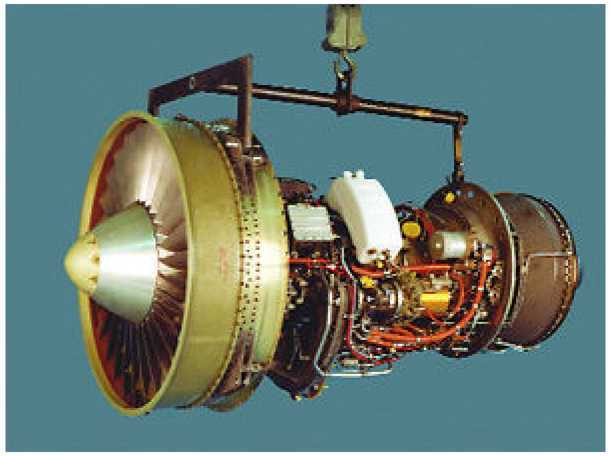
The Pratt & Whitney J-57, based on the JT-3, was the first to crank out more than 10,000 lb of thrust. (The JT-3 went on to power the Boeing 707 and Douglas DC-8). The J-57 used a dual rotor, axial flow compressor for lower fuel consumption over a wide operating range. The new design also helped eliminate the sluggish performance common to jet engines when asked to accelerate quickly. The engine has two compressors, a low-pressure section and a high-pressure section, each powered by its own turbine section. This requires concentric drive shafts connected to the low and high-pressure turbine sections. Production of the J-57 stopped in 1984.



TECH SPECS : J-57
Date of manufacture: 1953

Type: Dual rotor, axial flow compressor
Thrust: 10,700 lb, 16,900 with afterburner
Weight: 5, 215 lb

High bypass turbofan



The TF34 turbofan engine developed by General Electric was in response to the U.S. Navy's need for an antisubmarine aircraft. It was the first engine GE built with a forged combustor rather than one assembled out of sheet metal. The resulting engine was incredibly robust. It could operate while swallowing 120 gallon/min of water or breathing steam at 5.5 lb/min. It could also ingest ice, which let the engineers skip the addition of anti-icing systems. It also produces the highest thrust-to-weight ratio with the lowest specific fuel consumption in its class.

TECH SPECS : TF34
Date of manufacture: 1975
Type: High-bypass turbofan with dual rotors and axial combustion chamber
Thrust: 9,000 lb
Weight: 1,427 lb

The future of flight

Aircraft designers continue to look for new sources of power while they refine existing powerplants, mainly jet engines and some opposed internal-combustion engines. In some cases, they are waiting for strong, light, heat-resistant materials affordable enough to replace some of the metal in aviation engines. For example, Superior Air Parts, Coppell, Tex., recently developed a sump/induction system for piston aircraft engines. It is made of Ryton, a polyphenylene sulfide plastic from Chevron Phillips. The new sump weighs 8lb, half of the previous one. The key to replacing the metal in this case was finding a plastic that resists corrosion and exposure to all the fluids associated with piston engines.

While designers are free to replace older parts with lighter, easier-to-manufacture versions (if the FAA and other certifying bodies agree), they don't have as much leeway in making engines that increase aircraft speed. Most nations prohibit supersonic flight, a fact that probably contributed to the demise of the Concorde SST. Still, engineers are looking at new types of high-speed jet engines.

Pratt & Whitney, for example, just completed ground test at Mach 6.5 on a flight-weight, hydrocarbon-fueled scramjet. It burns standard JP-7 fuel, which is used to cool the 150-lb engine. Scramjets (supersonic combustion ramjet), have no moving parts. Combustion takes place as air moves supersonically through the engine. It's a mechanically simple design, but the aerodynamics needed to compress and discharge the air are complex. The engine will be used on high-speed, long-range missiles, though some might make it into less-expensive space launch vehicles and possibly commercial airliners and transport planes, legislation willing.

Another variation of the ramjet being explored is the pulsejet. It works like a scramjet, except it is limited to subsonic speeds, and airflow and combustion are intermittent and controlled by a series of valves ahead of the compression section. The German V-1, or buzz bomb, used a pulsejet that fired 40 times per second. Theoretically, pulsejets are more fuel-efficient since combustion is not constant, they can be built in different sizes for different levels of thrust, they are mechanically simple with few moving parts, and they have high thrust-to-weight ratios. On the downside, current technology limits efficiency, they are noisy, and vibrate too much. This confines them to small, nonpiloted aircraft.

In the past, hydrogen was the fuel commonly used on ram and scramjets. And it is still being considered as an aviation fuel. But most engineers believe it will have to be in the form of cryogenic slurry to give it the power density needed. Another possible fuel being explored is paraffin wax, but it is being looked at as a rocket fuel, not necessarily for airliners and Piper Cubs.

Make Contact
Image assistance provided by the Aircraft Engine Historical Society Inc., a nonprofit organization that fosters an appreciation of the people, science, and art of aircraft engine development, manufacture, and use. The AEHS publishes Torque Meter, the only journal dedicated to aircraft engine history. The AEHS also operates a web site with articles, images, and reference information on aircraft engines. (www.enginehistory.org)

Source URL: http://machinedesign.com/technologies/100-years-aircraft-engines