Handbook of

Propeller and Stealth Aircrafts

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Table of Contents

Chapter 1 - Propeller Aircraft

Chapter 2 - Contra-rotating Propellers and Counter-Rotating Propellers

Chapter 3 - Aeronca 11 Chief and Aeronca Sedan

Chapter 4 - Bell P-39 Airacobra

Chapter 5 - Bellanca CH-300, Bartel BM-4 and Bellanca Aircruiser

Chapter 6 - Caudron G.3 and Caudron C.714

Chapter 7 - Stealth Aircraft

Chapter 8 - Stealth Technology

Chapter 9 - Northrop Grumman B-2 Spirit

Chapter 10 - Lockheed Martin F-22 Raptor

Chapter 11 - Lockheed F-117 Nighthawk

Chapter 1

Propeller Aircraft

The feathered propellers of an RAF Hercules C.4

Aircraft propellers convert rotary motion from piston engines or turboprops to provide propulsive force. They may be fixed or variable pitch. Early aircraft propellers were carved by hand from solid or laminated wood with later propellers being constructed from metal. The most modern propeller designs use high-technology composite materials.

The propeller is usually attached to the crankshaft of a piston engine, either directly or through a reduction unit. Light aircraft engines often do not require the complexity of gearing but on larger engines and turboprop aircraft it is essential.

History

The twisted airfoil (aerofoil) shape of modern aircraft propellers was pioneered by the Wright brothers. They found that a propeller is essentially the same as a wing and so were able to use data collated from their earlier wind tunnel experiments on wings. They also found that the relative angle of attack from the forward movement of the aircraft was different for all points along the length of the blade, thus it was necessary to introduce a twist along its length. Their original propeller blades were only about 5% less efficient than the modern equivalent, some 100 years later.

Alberto Santos Dumont was another early pioneer, having designed propellers before the Wright Brothers (albeit not as efficient) for his airships. He applied the knowledge he gained from experiences with airships to make a propeller with a steel shaft and aluminium blades for his 14 bis biplane. Some of his designs used a bent aluminium sheet for blades, thus creating an airfoil shape. These are heavily undercambered because of this and combined with the lack of a lengthwise twist made them less efficient than the Wright propellers. Even so, this was perhaps the first use of aluminium in the construction of an airscrew.

Theory and design of aircraft propellers

A well-designed propeller typically has an efficiency of around 80% when operating in the best regime.Changes to a propeller's efficiency are produced by a number of factors, notably adjustments to the helix angle(θ), the angle between the resultant relative velocity and the blade rotation direction, and to blade pitch (where $\theta = \Phi + \alpha$) . Very small pitch and helix angles give a good performance against resistance but provide little thrust, while larger angles have the opposite effect. The best helix angle is when the blade is acting as a wing producing much more lift than drag.

A propeller's efficiency is determined by

$$\eta = \frac{\text{propulsive power out}}{\text{shaft power in}} = \frac{\text{thrust} \cdot \text{axial speed}}{\text{resistance torque} \cdot \text{rotational speed}}.$$

Propellers are similar in aerofoil section to a low drag wing and as such are poor in operation when at other than their optimum angle of attack. Control systems are required to counter the need for accurate matching of pitch to flight speed and engine speed.

The three-bladed propeller of a light aircraft: the Vans RV-7A

A further consideration is the number and the shape of the blades used. Increasing the aspect ratio of the blades reduces drag but the amount of thrust produced depends on blade area, so using high aspect blades can lead to the need for a propeller diameter which is unusable. A further balance is that using a smaller number of blades reduces interference effects between the blades, but to have sufficient blade area to transmit the available power within a set diameter means a compromise is needed. Increasing the number of blades also decreases the amount of work each blade is required to perform, limiting the local Mach number - a significant performance limit on propellers.

A propeller's performance suffers as the blade speed exceeds the speed of sound. As the relative air speed at the blade is rotation speed plus axial speed, a propeller blade tip will reach sonic speed sometime before the rest of the aircraft (with a theoretical blade the maximum aircraft speed is about 845 km/h (Mach 0.7) at sea-level, in reality it is rather lower). When a blade tip becomes supersonic, drag and torque resistance increase suddenly and shock waves form creating a sharp increase in noise. Aircraft with conventional propellers, therefore, do not usually fly faster than Mach 0.6. There are certain propeller-driven aircraft, usually military, which do operate at Mach 0.8 or higher, although there is considerable fall off in efficiency.

There have been efforts to develop propellers for aircraft at high subsonic speeds. The 'fix' is similar to that of transonic wing design. The maximum relative velocity is kept as low as possible by careful control of pitch to allow the blades to have large helix angles; thin blade sections are used and the blades are swept back in a scimitar shape (Scimitar propeller); a large number of blades are used to reduce work per blade and so circulation strength; contra-rotation is used. The propellers designed are more efficient than turbo-fans and their cruising speed (Mach 0.7–0.85) is suitable for airliners, but the noise generated is tremendous.

Forces acting on a propeller

Five forces act on the blades of an aircraft propeller in motion, they are:

Thrust bending force
: Thrust loads on the blades act to bend them forwards, opposite to the direction of flight.

Centrifugal twisting force
: Acts to twist the blades to a low or fine pitch angle.

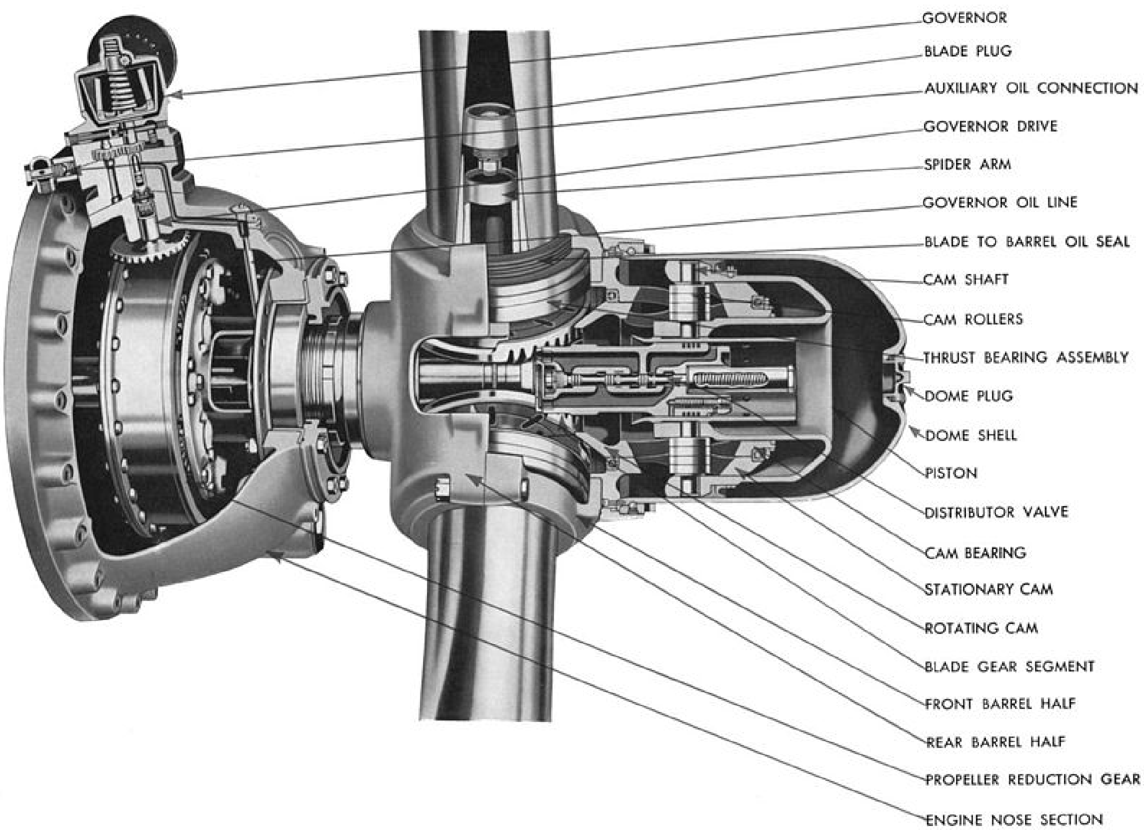
Aerodynamic twisting force
: As the centre of pressure of a propeller blade is forward of its centreline the blade is twisted towards a coarse pitch position.

Centrifugal force
: The force felt by the blades acting to pull them away from the hub when turning.

Torque bending force
: Air resistance acting against the blades, combined with inertial effects causes propeller blades to bend away from the direction of rotation.

Propeller control

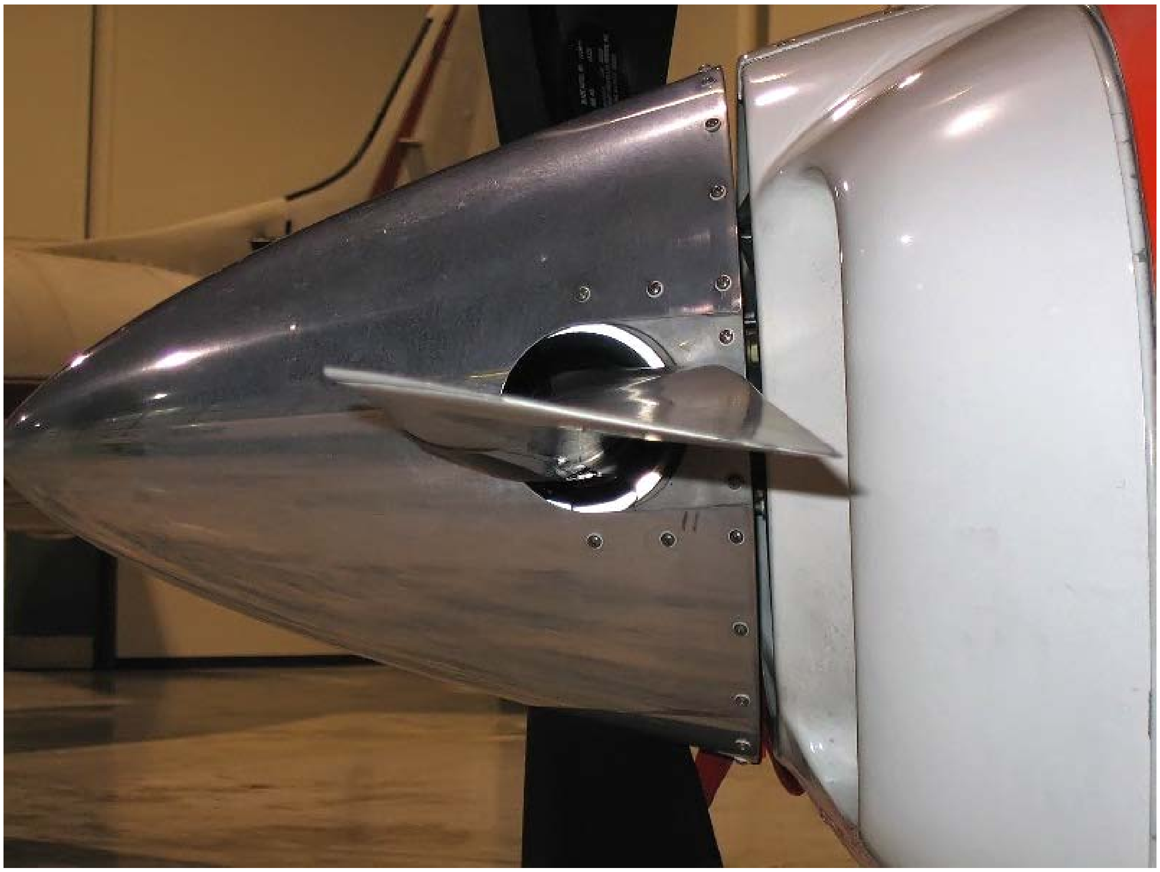
Variable pitch



Cut away view of a Hamilton Standard propeller. The engineers at Hamilton came up with a propeller design that was very reliable and maintenance friendly. With an auxiliary oil connection to feather the propeller in flight, gave multi-engined aircraft a huge safety factor. This type of propeller was used on most American fighters, bombers and transport aircraft of WWII.

The purpose of varying pitch angle with a variable pitch propeller is to maintain an optimal angle of attack (maximum lift to drag ratio) on the propeller blades as aircraft speed varies. Early pitch control settings were pilot operated, either two-position or manually variable. Following World War II, automatic propellers were developed to maintain an optimum angle of attack. This was done by balancing the centripetal twisting moment on the blades and a set of counterweights against a spring and the aerodynamic forces on the blade. Automatic props had the advantage of being simple, lightweight, and requiring no external control, but a particular propeller's performance was difficult to match with that of the aircraft's powerplant. An improvement on the automatic type was the constant-speed propeller. Constant speed propellers allow the pilot to select a rotational speed for maximum engine power or maximum efficiency, and a propeller governor acts as a closed-loop controller to vary propeller pitch angle as required to maintain the RPM commanded by the pilot. In most aircraft this system is hydraulic, with engine oil serving as the hydraulic fluid. However, electrically controlled propellers were developed during World War II and saw extensive use on military aircraft, and have recently seen a revival in use on homebuilt aircraft.

Feathering



A propeller blade in feathered position

On some variable-pitch propellers, the blades can be rotated parallel to the airflow to reduce drag in case of an engine failure. This is called feathering. Feathering propellers were developed for military fighter aircraft prior to World War II, as a fighter is more likely to experience an engine failure due to the inherent danger of combat. On single-engined aircraft, whether a powered glider or turbine powered aircraft, the effect is to increase the gliding distance. On a multi-engine aircraft, feathering the propeller on a failed engine reduces drag.

Most feathering systems for reciprocating engines sense a drop in oil pressure and move the blades toward the feather position, and require the pilot to pull the propeller control back to disengage the high-pitch stop pins before the engine reaches idle RPM. Turboprop control systems usually utilize a negative torque sensor in the reduction gearbox which moves the blades toward feather when the engine is no longer providing power to the propeller. Depending on design, the pilot may have to push a button to override the high-pitch stops and complete the feathering process, or the feathering process may be totally automatic.

Reverse pitch

Contra-rotating propellers of a modified
P-51 Mustang fitted with a Rolls-Royce Griffon.

In some aircraft (e.g., the C-130 Hercules), the pilot can manually override the constant speed mechanism to reverse the blade pitch angle, and thus the thrust of the engine (although the rotation of the engine itself does not reverse). This is used to help slow the plane down after landing in order to save wear on the brakes and tires, but in some cases also allows the aircraft to back up on its own. This is known as "Beta Range" operation.

Contra-rotating propellers

Contra-rotating propellers use a second propeller rotating in the opposite direction immediately 'downstream' of the main propeller so as to recover energy lost in the swirling motion of the air in the propeller slipstream. Contra-rotation also increases power without increasing propeller diameter and provides a counter to the torque effect of high-power piston engine as well as the gyroscopic precession effects, and of the slipstream swirl. However on small aircraft the added cost, complexity, weight and noise of the system rarely make it worthwhile.

Counter-rotating propellers

Counter-rotating propellers, are found on twin-, and multi-engine, propeller-driven aircraft and have propellers that spin in opposite directions. Generally, the propellers on both engines of most conventional twin-engined aircraft spin clockwise (as viewed from the rear of the aircraft). Counter-rotating propellers generally spin clockwise on the left engine, and counter-clockwise on the right. The advantage of counter-rotating propellers is to balance out the effects of torque and p-factor, eliminating the problem of the critical engine.

Aircraft fans

A fan is a propeller with a large number of blades. A fan therefore produces a lot of thrust for a given diameter but the closeness of the blades means that each strongly affects the flow around the others. If the flow is supersonic, this interference can be beneficial if the flow can be compressed through a series of shock waves rather than one. By placing the fan within a shaped duct, specific flow patterns can be created depending on flight speed and engine performance. As air enters the duct, its speed is reduced while its pressure and temperature increases. If the aircraft is at a high subsonic speed this creates two advantages: the air enters the fan at a lower Mach speed; and the higher temperature increases the local speed of sound. While there is a loss in efficiency as the fan is drawing on a smaller area of the free stream and so using less air, this is balanced by the ducted fan retaining efficiency at higher speeds where conventional propeller efficiency would be poor. A ducted fan or propeller also has certain benefits at lower speeds but the duct needs to be shaped in a different manner than one for higher speed flight. More air is taken in and the fan therefore operates at an efficiency equivalent to a larger un-ducted propeller. Noise is also reduced by the ducting and should a blade become detached the duct would contain the damage. However the duct adds weight, cost, complexity and (to a certain degree) drag.

Chapter 2

Contra-rotating Propellers and Counter-Rotating Propellers

Contra-rotating propellers

Contra-rotating propellers on a Rolls-Royce–Griffon–powered P-51 unlimited racer

Contra-rotating propellers, also referred to as coaxial contra-rotating propellers, apply the maximum power of usually a single piston or turboprop engine to drive two propellers in opposite rotation. Contra-rotating propellers are common in some marine transmission systems, in particular for medium to large size planing leisure craft. Two propellers are arranged one behind the other, and power is transferred from the engine via a planetary gear or spur gear transmission. Contra-rotating propellers should not be confused with counter-rotating propellers—airscrews on different engines turning opposite directions.

When airspeed is low the mass of the air flowing through the propeller disk (thrust) causes a significant amount of tangential or rotational air flow to be created by the spinning blades. The energy of this tangential air flow is wasted in a single-propeller design. To use this wasted effort the placement of a second propeller behind the first takes advantage of the disturbed airflow. The tangential air flow also causes handling problems at low speed as the air strikes the vertical stabilizer, causing the aircraft to yaw left or right, depending of the direction of propeller rotation.

If it is well designed, a contra-rotating propeller will have no rotational air flow, pushing a maximum amount of air uniformly through the propeller disk, resulting in high performance and low induced energy loss. It also serves to counter the asymmetrical torque effect of a conventional propeller. Some contra-rotating systems were designed to be used at take off for maximum power and efficiency under such conditions, and allowing one of the propellers to be disabled during cruise to extend flight time.

Contra-rotating propellers have been found to be between 6% and 16% more efficient than normal propellers. However they can be very noisy, with increases in noise in the axial (forward and aft) direction of up to 30 dB, and tangentially 10 dB. Most of this extra noise can be found in the higher frequencies. These substantial noise problems will limit commercial applications unless solutions can be found. One possibility is to enclose the contra-rotating propellers in a shroud. It is also helpful if the two propellers have a different number of blades (e.g. four blades on the forward propeller and five on the aft).

The efficiency of a contra-rotating prop is somewhat offset by its mechanical complexity. Nonetheless, coaxial contra-rotating propellers and rotors are moderately common in military aircraft and naval applications, such as torpedoes.

Significant aircraft

While several nations experimented with contra-rotating propellers in aircraft, only the United Kingdom and Soviet Union produced them in large numbers. The first aircraft to be fitted with a contra-rotating propeller to fly though was in the US when two inventors from Ft Worth, Texas tested the concept on an aircraft.

United Kingdom

Fairey Gannet AS.6 at the Imperial War Museum Duxford

Some of the more successful British aircraft with contra-rotating propellers are the Avro Shackleton, powered by the Rolls-Royce Griffon engine, and the Fairey Gannet, which used the Double Mamba Mk.101 engine.

Later variants of the Supermarine Spitfire and Seafire used the Griffon with contra-rotating props as well. In the Spitfire/Seafire and Shackleton's case the primary reason for using contra-rotating propellers was so as to increase the propeller blade-area, and hence absorb greater engine power, within a propeller diameter limited by the height of the aircraft's undercarriage. Whilst this also applied to the Gannet, in addition this aircraft's engine had two separate power-sections, each driving one propeller. The Short Sturgeon used 2 Merlin 140s with contra-rotating propellers.

The Bristol Brabazon prototype airliner used eight Bristol Centaurus engines driving four pairs of contra-rotating propellers, each engine driving a single propeller.

USSR

In the 1950s, the Soviet Union developed the Kuznetsov NK-12 turboprop. It drives an 8-blade contra-rotating propeller and, at 15,000 shp, it is the most powerful turboprop in the world. Four NK-12 engines power the Tupolev Tu-95 Bear, the only turboprop bomber to enter service, as well as one of the fastest propeller-driven aircraft. The Tu-114, an airliner derivative of the Bear, holds the world speed record for propeller aircraft. The Bear was also the first Soviet bomber to have intercontinental range, allowing it to strike North American targets from Asia. The Tu-126 AEW aircraft and Tu-142 maritime patrol aircraft are two more NK-12 powered designs derived from the Bear.

The NK-12 engine powers another well-known Soviet aircraft, the Antonov An-22 Antheus, a heavy-lift cargo aircraft. At the time of its introduction, the An-22 was the largest aircraft in the world and is still by far the world's largest turboprop-powered aircraft. From the 1960s through the 1970s, it set several world records in the categories of maximum payload-to-height ratio and maximum payload lifted to altitude.

Of lesser note is the use of the NK-12 engine in the A-90 Orlyonok, a mid-size Soviet ekranoplan. The A-90 uses one NK-12 engine mounted atop its T-tail, along with two turbojets nestled in its nose.

In 1994, Antonov produced the An-70, a heavy transport aircraft. It is powered by four Progress D-27 propfan engines driving contra-rotating propellers. The characteristics of the D-27 engine and its propeller make it a propfan, a hybrid between a turbofan engine and a turboprop engine.

United States

The U.S. worked with several prototypes, including the A2J Super Savage, the Boeing XF8B, the XP-56 Black Bullet and the tail-sitting Convair XFY and Lockheed XFV "Pogo" VTOL fighters and the Hughes XF-11 reconnaissance plane, but jet engine technology was advancing rapidly and the designs were deemed unnecessary.

Counter-rotating propellers

Opposite propeller blade section can be clearly seen on this Piper PA-44 Seminole

Counter-rotating propellers, found on twin- and multi-engine propeller-driven aircraft, spin in directions opposite one another.

The propellers on both engines of most conventional twin-engined aircraft spin clockwise (as viewed from the pilot seat). Counter-rotating propellers generally spin clockwise on the left engine and counter-clockwise on the right. The advantage of such designs is that counter-rotating propellers balance the effects of torque and p-factor, eliminating the problem of the critical engine.

In designing the Lockheed P-38, the decision was made to reverse the counter-rotation such that the "tops" of the propeller arcs move outwards, away from each other. Tests on the initial XP-38 prototype demonstrated greater accuracy in gunnery with the unusual configuration. The German World War II Henschel Hs 129 ground attack aircraft, Heinkel He 177 heavy bomber and Messerschmitt Me 323 transport's counter-rotating powerplants used the same rotational "sense" as the production P-38 did.

Drawbacks of counter-rotating propellers come from the fact that, in order to reverse sense of rotation of one propeller, a gearbox needs to be used or the engine or engine installation must be different. This may increase weight (gearbox), or maintenance and spare parts costs for the engines and propellers, as different spare parts need to be produced in lower numbers, compared to a conventional installation.

Counter-rotating propellers should not be confused with contra-rotating propellers that share common axes.

The following aircraft have counter-rotating propellers:

(Twin-engine, 1 engine per wing)

- The Wright Flyer
- de Havilland Hornet
- Lockheed P-38 Lightning
- Heinkel He 177 Greif (fourth prototype onwards)
- Piper PA-31 Navajo
- Piper PA-34 Seneca
- Piper PA-39 Twin Comanche
- Piper PA-40 Arapaho
- Piper PA-44 Seminole
- Cessna T303 Crusader
- Beech BE-76 Duchess

At least four engines, two or more on each wing :

- Messerschmitt Me 323 Gigant transport
- Airbus A400M - first plane with propellers that counter-rotate on each wing

Chapter 3

Aeronca 11 Chief and Aeronca Sedan

Aeronca 11 chief

Aeronca Chief

Role	Light utility aircraft
Manufacturer	Aeronca
Designed by	Raymond F. Hermes at Aeronca
First flight	1945
Introduced	1946
Produced	1946-1950
Number built	over 2,300
Variants	HAL Pushpak

Aeronca 11AC Chief, 1986

The **Aeronca Chief** is a single-engine, two-seat, light aircraft with fixed conventional landing gear, which entered production in the United States in 1945.

Designed for flight training and personal use, the Chief was produced in the United States between 1946 and 1950. The Chief was known as a basic gentle flyer with good manners, intended as a step up from the 7AC Champion which was designed for flight training.

Like many classic airplanes, it has a significant adverse yaw, powerful rudder and sensitive elevator controls. It had a well appointed cabin, with flocked taupe sidewalls and a zebra wood grain instrument panel. There was never a flight manual produced for the 11AC or 7AC series airplanes, as a simple placard system was deemed enough to keep a pilot out of trouble.

Production history

The model 11 Chief was designed and built by Aeronca Aircraft Corporation. While it shared the name "Chief" with the pre-war models, the design was not a derivative. Rather, the post-war 11AC Chief was designed in tandem with the 7AC Champion ("Champ")—the Chief with side-by-side seating and yoke controls, and the Champ with tandem seating and joystick controls. The intention was to simplify production and control costs by building a pair of aircraft with a significant number of parts in common; in fact, the two designs share between 70% and 80% of their parts. The tail surfaces, wings, ailerons, landing gear, and firewall forward—engine, most accessories, and cowling—are common to both airplanes. The Chief and the larger Aeronca Sedan also share selected parts, the control wheels, some control system parts, rudder pedals and control systems, so parts passed from plane to plane to save costs. Production costs and aircraft weights were tightly controlled and Aeronca was among the first to use a moving conveyor assembly line, with each stage taking about 30 minutes to complete.

The 11AC Chief entered production at Aeronca in early 1946, with upgraded versions introduced as the 11BC (also called the "Chief") and 11CC "Super Chief," in June 1947 and 1948, respectively. Aeronca was at the time headquartered at Middletown, Ohio, but production facilities there were heavily utilized with the 7AC Champion line; because of this, the model 11 aircraft were assembled at the Dayton Municipal Airport in Vandalia, Ohio. While the Vandalia location was first used only for the assembly of parts fabricated at Middletown, activities there later expanded to include some fabrication work. Only later, toward the end of production did the Chief line return to Middletown.

1946 model **Aeronca 11AC Chief** cockpit

Aeronca ceased all production of light aircraft in 1951. Production of the Chief, which had been outsold by its sibling the Champ by a margin of nearly 4 to 1, had already ended by 1950, with only a few planes produced in 1948-1949. This marked the last time the Chief design was built in the United States.

The design was sold in the mid-1950s to E. J. Trytek, who held the design until the late 1960s or early 1970s. The HUL-26 Pushpak, built by Hindustan Aeronautics between

1958 and 1968, was very similar to the Super Chief. Some sources say that the Pushpak was produced under license from Trytek, while others suggest that the Pushpak design resulted from reverse engineering. The Pushpak can be identified by the smaller rudder surface which is squared off at mid-fin and the larger vertical tail that is found on the 11CC.

Ownership of the Chief design passed to Bellanca Aircraft Corporation in the early 1970s, around the same time they acquired the 7 series Champion/Citabria and its derivative designs. In 1973 Bellanca considered producing an updated version of the Chief for flight training, but the aircraft never entered production. The model 11 designs are currently owned by American Champion Aircraft Corporation, which acquired them sometime before 1991. Ownership of the design in the period between Bellanca's liquidation in 1982 and the American Champion acquisition is unclear.

Design

Like the Taylorcraft B, Piper Vagabond, Cessna 120/140, and Luscombe 8 with which it competed, the Chief features side-by-side seating. As with many light aircraft of the time, including the Taylorcraft B and Piper Vagabond, the Chief's fuselage and tail surfaces are constructed of welded metal tubing. The outer shape of the fuselage is created by a combination of wooden formers and longerons, covered with fabric. The cross-section of the metal fuselage truss is triangular, a design feature which can be traced all the way back to the earliest Aeronca C-2 design of the late 1920s.

The strut-braced wings of the Chief are, like the fuselage and tail surfaces, fabric covered, utilizing aluminum ribs and wood spars. The landing gear of the Chief is in a conventional arrangement, with steel tube main gear which use an oleo strut for shock absorption, and a steerable tailwheel.

All of the models—11AC, 11BC, and 11CC—were approved as seaplanes, with the addition of floats and vertical stabilizer fins; the seaplane versions were designated the S11AC, S11BC, and S11CC, respectively.

Variants

Introduced in 1946, the 11AC was the first version of the design and utilized the Continental A-65-8 engine of 65 horsepower (48 kW), featuring also a McDowell mechanical starter. This McDowell starter was taken from the automotive industry and involved a spring loaded cam device that would spin the propeller through a compression stroke by a pull on a cabin floor mounted lever. The S11AC was a float plane. Also, Aeronca built a basic stripped down version of the 11AC called the "Scout," a trainer aircraft. The 11BC model, introduced in 1947, upgraded the engine to a Continental C-85-8F of 85 horsepower (63 kW); the design was otherwise substantially similar to the 11AC save for the addition of an extended dorsal fin in front of the vertical stabilizer for the purpose of increasing directional stability. The 11CC "Super Chief" of 1948 brought an upgraded interior, toe brakes on the pilot’s side, and balanced elevators.

In 1973 Bellanca built and flew a prototype trainer based on the model 11. The Bellanca Trainer featured a tricycle landing gear arrangement and appeared to share many parts with the 7ECA Citabria (a derivative of the Champ design). The Bellanca trainer's cowling, wings and struts, main gear, and horizontal tail surfaces all appeared to have come from the Citabria. The vertical stabilizer and rudder appeared similar, though shorter vertically in the prototype. They were extended to full size after flight testing. The fuselage of the trainer featured a rear window. The cabin had a taller modernized instrument panel and other furnishings. The design was never put into production after being shown to dealers in 1973.

1940 11AC Chief

1940 11AC Chief

Specifications (1946 11AC Chief)

General characteristics

- **Crew:** one pilot
- **Capacity:** one passenger
- **Length:** 20 ft 10 in (6.4 m)
- **Wingspan:** 36 ft 0 in (11 m)
- **Height:** 6 ft 10 in (2.1 m)
- **Wing area:** 175.5 ft² (16.3 m²)
- **Airfoil:** NACA 4412
- **Empty weight:** 725 lb (328.9 kg)
- **Loaded weight:** 1,250 lb (567 kg)
- **Useful load:** 525 lb (238.1 kg)
- **Max takeoff weight:** 1,250 lb (567 kg)
- **Powerplant:** 1× Continental A-65-8, 65 hp (48.5 kW)

Performance

- **Maximum speed:** 105 mph (169 km/h)
- **Cruise speed:** 95 mph (152.9 km/h)
- **Stall speed:** 40 mph (64.4 km/h)
- **Range:** 330 mi/550 mi with aux fuel tank (531.1 km)

- **Service ceiling:** 10,800 ft (3291.9 m)
- **Rate of climb:** 500 ft/min (2.54 m/s)
- **Wing loading:** 7.1 lb/ft² (34.8 kg/m²)
- **Power/mass:** 19.2 lb/hp (11.7 kg/kW)

Aeronca Sedan

15AC Sedan

Role	Light utility aircraft
Manufacturer	Aeronca Aircraft
First flight	1947
Introduced	1947
Produced	1948-1951
Number built	561

The **Aeronca 15AC Sedan** is a four-seat, fixed conventional gear light airplane which was produced in the United States between 1948 and 1951. Designed by Aeronca for personal use, the Sedan also found applications in utility roles including bush flying. The Sedan was the last design that Aeronca put into production and was the largest aircraft produced by the company.

Design and development

Like those of other Aeronca designs, the Sedan's fuselage and tail surfaces are constructed of welded metal tubing. The outer shape of the fuselage is created by a combination of wooden formers and longerons, covered with fabric. The cross-section of the metal fuselage truss is triangular, a design feature which can be traced back to the earliest Aeronca C-2 design of the late 1920s.

In a significant design departure from previous Aeronca aircraft, the strut-braced wings of the Sedan are all-metal assemblies. Such combinations of construction types were not common. While the Sedan mated a fabric-covered fuselage to all-metal wings, the contemporary Cessna 170 mated an all-metal fuselage to fabric-covered wings. Also unique to the Sedan, among Aeronca designs, are the single-piece wing struts.

The landing gear of the Sedan is in a conventional arrangement, with steel tube main gear, and a steerable tailwheel. Unlike its siblings the Champ and Chief, both of which employ oleo struts for shock absorption, the Sedan makes used of bungee cords to absorb landing and taxi loads.

The Sedan is powered by the Continental C-145-2 or Continental O-300-A engine of 145 horsepower (108 kW); the Franklin 6A4-165-B3 and Franklin 6A4-150-B3, of 165 and 150 horsepower (110 kW), respectively, are also approved for installation. The Sedan features an electrical system, including a starter, as standard equipment.

As it had with many of its other models, Aeronca certified a seaplane version of the Sedan, the model S15AC. While the standard Sedan was equipped with a single entry door on the right side, the seaplane version offered a left-side door as well.

Modifications

Modernized Sedan with 180 horsepower (130 kW) Lycoming O-360 engine

More than 50 Supplemental Type Certificate modifications are available for the Sedan, many of these intended to modernize the aircraft. One, sold by the current owner of the Sedan design, replaces many of the components ahead of the firewall with updated versions, including a Lycoming O-360-A1A engine of 180 horsepower (130 kW), a constant speed propeller, a new engine mount, and a fiberglass cowling. A second modification from the design holder allows the removal of the oil cooler, which can break and for which there are no replacements available.

Production history

Entering production in 1948, the 15AC Sedan was Aeronca's four-seat addition to its pair of two-seat airplanes, the Champ and Chief, both of which had entered production in 1946. The four-place design gave Aeronca a lineup similar to that of its competitors. Many other companies with two-place designs had been adding four-place versions. Among these four-place competitors were the Cessna 170, PA-14 Family Cruiser, Stinson 108, Taylorcraft 15 and the Luscombe 11A Silvaire Sedan.

The Aeronca Sedan was produced from 1948 until 1951, when Aeronca ceased all production of light aircraft. The Sedan production line shut down in 1950, but Sedans were still being assembled in 1951 from the remaining stock of parts. The last Sedan, which was also the last Aeronca-built airplane to fly, left the factory on October 23, 1951.

Though Aeronca sold a number of its other designs after ceasing production, the company long maintained ownership of the Sedan. The HAOP-27 Krishak, built by Hindustan Aeronautics, shows some similarities to the Sedan. Some sources say that the Krishak was produced under license from Aeronca, though the differences are significant enough to call this into question.

Aeronca finally parted with the design on 11 April 1991, selling it to (according to Federal Aviation Administration records) "William Brad Mitchell or Sandra Mitchell". On 10 July 2000, ownership of the design passed to Burl A. Rogers, owner of Burl's Aircraft of Chugiak, Alaska. Since 2000 Burl's Aircraft has provided parts and technical support to Sedan owners and operators.

Burl's Aircraft production

On February 21, 2008, Burl's Aircraft announced that the company was building new Sedan fuselages and a new style fuel valve. On December 8, 2009, Burl's Aircraft announced that they were commencing building new 15AC Sedans.

Since Aeronca still exists, but no longer holds the type certificate, the new production aircraft will be marketed by Burl A. Rogers and Burl's Aircraft LLC as the Rogers 15AC Sedan.

Operational history

The Sedan was designed to be a docile airplane but also a good performer. Pilots found that the Sedan, with its large interior, had plenty of room for baggage and passengers. With its large wing, it had good takeoff performance, and was capable of short takeoff and landing operations. It found a niche as a personal aircraft and in commercial bush flying roles; it could also be equipped for agricultural work. Though the commercial roles have been largely taken over by more modern designs, many Sedans remain in use as personal airplanes. Their ongoing operation is aided by the availability of support from the design owner.

Record flights

A Sedan was chosen by pilots Bill Barris and Dick Riedel for their attempt to set a time aloft record in 1949. Their flight was sponsored by the local chamber of commerce and the Sunkist growers association, the second sponsor accounting for the naming of the aircraft as the Sunkist Lady. (The accompanying support aircraft, also a Sedan, was called the Lady's Maid.) Departing from the Fullerton, California, Municipal Airport on March 15, the flight crossed the United States to Miami, Florida, where bad weather forced the pilots to circle for 14 days before making the return trip to Fullerton. Along the way, fuel and food were passed from vehicles on the ground to the pilots during low passes over airport runways. Having reached Fullerton on April 11, the pilots kept flying around the local area until April 26, finally landing at Fullerton Municipal Airport and setting a record of over 1,008 hours, or 42 days, in the air.

The Fullerton record was short lived. Inspired by the flight at Fullerton, later in 1949, Yuma, Arizona, decided to sponsor its own time aloft record attempt. The city needed publicity as it was experiencing economic hard times due to the 1946 closure of Yuma Army Air Field. Pilots Woody Jongeward and Bob Woodhouse piloted the City of Yuma, a Sedan borrowed from local owners, modified for the flight and painted with the slogan, "The City with a Future." The flight began on August 24, with the aircraft remaining in the Yuma area throughout, and ended after more than 1,124 hours, or nearly 47 days in the air, on October 10. In 1997, the record-setting airplane was located and returned to Yuma; made airworthy again, it flew on October 10, 1999, to commemorate the 50th anniversary of the end of the record flight. The "City of Yuma" airplane is now on display at a museum in Yuma.

Variants

Aeronca 15AC Sedan

Basic model, certified 23 September 1948 and produced 1948-1951. Specified engines are Continental C-145-2 or Continental O-300-A and Franklin 6A4-165-B3 or Franklin 6A4-150-B3 under a Maine Air Service Franklin Aeronca Conversion Kit.

Aeronca S15AC Sedan

Seaplane model, certified 23 September 1948. Same as the model 15AC except for float installation, larger elevator trim tab and fuselage reinforcements

Rogers 15AC Sedan

Proposed new version for production commencing 2010. The prototype aircraft, under construction in December 2009, will be equipped with Lycoming O-360-A1A 180 hp (134 kW) engine, 80 in (203 cm) constant speed propeller, vertically-arranged instrument panel, extended baggage compartment, large windows, dual seaplane-style doors, lightweight battery, starter, alternator and a 3200 series Alaskan Bushwheel tail wheel with a Pawnee-style tailwheel spring.

Specifications (1948 15AC Sedan)

General characteristics

- **Crew:** one pilot
- **Capacity:** three passengers
- **Length:** 25 ft 3 in (7.7 m)
- **Wingspan:** 37 ft 6 in (11.4 m)
- **Height:** 10 ft 4 in (3.1 m)
- **Wing area:** 200 ft² (18.6 m²)
- **Airfoil:** NACA 4412
- **Empty weight:** 1,170 lb (531 kg)
- **Loaded weight:** 2,050 lb (930 kg)
- **Useful load:** 880 lb (399 kg)
- **Max takeoff weight:** 2,050 lb (930 kg)
- **Powerplant:** 1× Continental C-145-2 piston engine, 145 hp (108 kW)

Performance

- **Never exceed speed:** 139 mph (224 km/h)
- **Maximum speed:** 120 mph (193 km/h)
- **Cruise speed:** 105 mph (169 km/h)
- **Stall speed:** 53 mph (85.3 km/h)
- **Range:** 400 mi (644 km)
- **Service ceiling:** 12,400 ft (3,780 m)
- **Rate of climb:** 650 ft/min (3.30 m/s)
- **Wing loading:** 10.3 lb/ft² (50 kg/m²)
- **Power/mass:** 14.1 lb/hp (8.6 kg/kW)

Chapter 4

Bell P-39 Airacobra

P-39 Airacobra

P-39Q-1BE 42-19447, **Saga Boy II** of Lt. Col. Edwin S. Chickering, CO 357th Fighter Group, July 1943

Role	Fighter
National origin	United States
Manufacturer	Bell Aircraft
First flight	6 April 1938
Introduced	1941
Status	Retired
Primary users	United States Army Air Forces Soviet Air Force Royal Air Force
Produced	1940-May 1944
Number built	9,584
Unit cost	50,666 USD in 1944
Variants	Bell XFL Airabonita Bell P-63 Kingcobra

The **Bell P-39 Airacobra** was one of the principal American fighter aircraft in service at the start of World War II. It was the first fighter in history with a tricycle undercarriage and the first to have the engine installed in the center fuselage, behind the pilot. Although its mid-engine placement was innovative, the P-39 design was handicapped by the lack of an efficient turbo-supercharger, limiting it to low-altitude work. The P-39 was used with great success by the Soviet Air Force, who scored the highest number of individual kills attributed to any U.S. fighter type. Other important users were the Free French and co-belligerent Italian air forces. Together with the derivative P-63 Kingcobra, these aircraft became the most successful mass-produced fixed-wing aircraft manufactured by Bell.

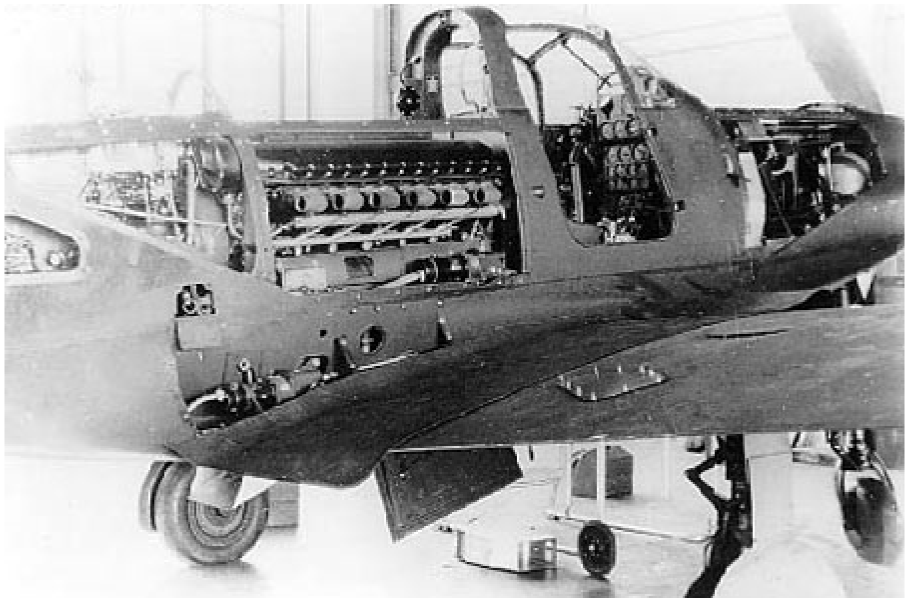
Design and development

In February 1937, Lieutenant Benjamin S. Kelsey, Project Officer for Fighters at the United States Army Air Corps (USAAC), issued a specification for a new fighter via **Circular Proposal X-609**. It was a request for a single-engine high-altitude "interceptor" having "the tactical mission of interception and attack of hostile aircraft at high altitude". Despite being called an interceptor, the proposed aircraft's role was simply an extension of the traditional pursuit (fighter) role, using a heavier and more powerful aircraft at higher altitude. Specifications called for at least 1,000 lb of heavy armament including a cannon, a liquid-cooled Allison engine with a General Electric turbo-supercharger, tricycle landing gear, a level airspeed of at least 360 mph (580 km/h) at altitude, and a climb to 20,000 ft (6,100 m) within 6 minutes; the toughest set of specifications USAAC had presented to that date. Although Bell's limited fighter design work had previously resulted in the unusual Bell YFM-1 Airacuda, the **Model 12** proposal adopted an equally original configuration with an Allison V-12 engine mounted in the middle of the fuselage, just behind the cockpit, and a propeller driven by a shaft passing beneath the pilot's feet under the cockpit floor.

The main purpose of this configuration was to free up space for the heavy main armament, a 37 mm (1.46 in) Oldsmobile T9 cannon firing through the center of the propeller hub for optimum accuracy and stability when firing. This happened because H.M. Poyer, designer for project leader Robert Woods, was impressed by the power of this weapon and he pressed for its incorporation though the original concept had been a 20–25 mm (.79–98 in) cannon mounted conventionally in the nose. This was unusual, because fighters had previously been designed around an engine, not a weapon system. Although devastating when it worked, the T9 had very limited ammunition, a low rate of fire, and was prone to jamming.

A secondary benefit of the mid-engine arrangement was to create a smooth and streamlined nose profile. Entry to the cockpit was through side doors (mounted on both sides of the cockpit) rather than a sliding canopy. Its unusual engine location and the long driveshaft caused some concern to pilots at first, but experience showed this was no more of a hazard in a crash landing than with an engine located forward of the cockpit. There were no problems with propshaft failure.

As originally designed, the XP-39 had a turbocharger with a scoop on the left side of the fuselage; both were deleted for production. The production P-39 retained a single-stage, single-speed supercharger with a critical altitude (above which performance declined) of about 12,000 feet (3,660 m) (3,658 m).



Bell P-39 Airacobra center fuselage detail with maintenance panels open

The XP-39 made its maiden flight on 6 April 1938 at Wright Field, Ohio, achieving 390 mph (630 km/h) at 20,000 ft (6,100 m), reaching this altitude in only five minutes. The Army ordered twelve YP-39s (with only a single-stage, single-speed supercharger) for service evaluation and one YP-39A. After these trials were complete, which resulted in detail changes including deletion of the external radiator, and on advice from NACA, the prototype was modified as the **XP-39B**; after demonstrating a performance improvement, the 13 YP-39s were completed to this standard, adding two .30 in (7.62 mm) machine guns to the two existing .50 in (12.7 mm) guns. Lacking armor or self-sealing fuel tanks, the prototype was one ton (900 kg) lighter than the production fighters.

After completing service trials, and originally designated **P-45**, a first order for 80 aircraft was placed 10 August 1939; the designation reverted before deliveries began.

Technical details

The P-39 was an all-metal, low-wing, single-engine fighter, with a tricycle undercarriage and an Allison V-1710 liquid-cooled V-12 engine mounted in the central fuselage, directly behind the cockpit.

The Airacobra was one of the first production fighters to be conceived as a "weapons system"; in this case the aircraft (known originally as the Bell Model 4) was designed around the 37mm T9 cannon. This weapon, which was designed in 1934 by the American Armament Corporation, a division of Oldsmobile, fired a 1.3 lb (610 g) projectile capable of piercing .8 in (2 cm) of armor at 500 yd (450 m) with armor piercing rounds. The 200 lb, 90 inch long weapon had to be rigidly mounted and fire parallel to and close to the centerline of the new fighter. It would be impossible to mount the weapon in the fuselage, firing through the propeller shaft as could be done with smaller 20mm cannon. Weight, balance and visibility problems meant that the cockpit could not be placed farther back in the fuselage, behind the engine and cannon. The solution adopted was to mount the cannon in the forward fuselage and the engine in the center fuselage, directly behind the pilot's seat. The tractor propeller was driven via a 10-foot-long (3.0 m) drive shaft which was made in two sections, incorporating a self-aligning bearing to accommodate fuselage deflection during violent maneuvers. This shaft ran through a tunnel in the cockpit floor and was connected to a gearbox in the nose of the fuselage which, in turn, drove the three or (later) four bladed propeller via a short central shaft. The gearbox was provided with its own lubrication system, separate from the engine; in later versions of the Airacobra the gearbox was provided with some armor protection. The glycol-cooled radiator was fitted in the wing center section, immediately beneath the engine; this was flanked on either side by a single drum shaped oil cooler. Air for the radiator and oil coolers was drawn in through intakes in both wing-root leading edges and was directed via four ducts to the radiator faces. The air was then exhausted through three controllable hinged flaps near the trailing edge of the center section. Air for the carburetor was drawn in via a raised oval intake immediately aft of the rear canopy.

The fuselage structure was unusual and innovative, being based on a strong central keel which incorporated the armament, cockpit and engine. Two strong fuselage beams to port and starboard formed the basis of the structure. These angled upwards fore and aft to create mounting points for the T9 cannon and propeller reduction gearbox and for the engine and accessories respectively. A strong arched bulkhead provided the main structural point to which the main spar of the wing was attached. This arch incorporated a fireproof panel and an armor plate separating the engine from the cockpit. It also incorporated a turnover pylon and a pane of bullet-resistant glass behind the pilot's head. The arch also formed the basis of the cockpit housing; the pilot's seat was attached to the forward face as was the cockpit floor. Forward of the cockpit the fuselage nose was formed from large removable covers. A long nose wheel well was incorporated in the lower nose section. The engine and accessories were attached to the rear of the arch and the main structural beams; these too were covered using large removable panels. A conventional semi-monocoque rear fuselage was attached aft of the main structure.

Because the pilot was above the extension shaft, he was placed higher in the fuselage than in most contemporary fighters, which, in turn gave the pilot a good field of view. Access to the cockpit was via sideways opening "car doors", one on either side. Both had wind-down windows; because only the right hand door had a handle both inside and outside this was used as the normal means of access. The left hand door could only be opened from the outside and was for emergency use, although both doors could be jettisoned. In service the cockpit was difficult to escape from in an emergency because the roof was fixed.

The complete armament fit consisted of the T9 with a pair of Browning M2 .50 caliber (12.7 mm) machine guns mounted in the nose. This would change to two .50 in (12.7 mm) and two .30 in (7.62 mm) guns in the XP-39B (P-39C, Model 13, the first 20 delivered) and two 0.50 in/12.7 mm and four 0.30 in/7.62 mm (all four in the wings) in the P-39D (Model 15), which also introduced self-sealing tanks and shackles (and piping) for a 500 lb (227 kg) bomb or drop tank.

Because of the unconventional layout, there was no space in the fuselage to place a fuel tank. Although drop tanks were implemented to extend its range, the standard fuel load was carried in the wings, with the result that the P-39 was limited to short range tactical strikes.

In September 1940, Britain ordered 386 P-39Ds (Model 14), with a 20 mm (.79 in) Hispano-Suiza HS.404 and six .303 in (7.7 mm), instead of a 37 mm (1.46 in) cannon and six 0.30 in (7.62 in) guns. The RAF eventually ordered a total of 675 P-39s. However, after the first Airacobras arrived at 601 Squadron RAF in September 1941, they were promptly recognized as having an inadequate rate of climb and performance at altitude for Western European conditions. Only 80 were adopted, all of them with 601 Squadron. Britain transferred about 200 P-39s to the Soviet Union.

Another 200 examples intended for the RAF were taken up by the USAAF after the attack on Pearl Harbor as the **P-400**, and were sent to the Fifth Air Force in Australia, for service in the South West Pacific Theatre.

A heavy structure, and around 265 lb (120 kg) of armor were characteristic of this aircraft as well. The production P-39's heavier weight combined with the Allison engine having only a single-stage, single-speed supercharger, limited the high-altitude capabilities of the fighter. The P-39's altitude performance was markedly inferior to the contemporary European fighters and, as a result, the first USAAF fighter units in the European Theater were equipped with the Spitfire V. However, the P-39D's roll rate was 75°/s at 235 mph (378 km/h)– better than the A6M2, F4F, F6F, or P-38 up to 265 mph (426 km/h).

Above the supercharger's critical altitude of about 12,000 ft (3,658 m), an early P-39's performance dropped off rapidly. This limited its usefulness in traditional fighter missions in Europe as well as in the Pacific, where it was not uncommon for Japanese bombers to attack at altitudes above the P-39's operational ceiling (which in the tropical hot air was lower than in moderate climates). The late production N and Q models, making up 75% of all Airacobras, could maintain a top speed of approximately 375 mph (604 km/h) up to 20,000 ft (6,100 m).

The weight distribution of the P-39 was supposedly the reason for its tendency to enter a dangerous flat spin, a characteristic Soviet test pilots were able to demonstrate to the skeptical manufacturer who had been unable to reproduce the effect. After extensive tests, it was determined the spin could only be induced if the aircraft was improperly loaded, with no ammunition in the front compartment. The flight manual noted a need to ballast the front ammunition compartment with the appropriate weight of shell casings to achieve a reasonable center of gravity. High speed controls were light, consequently, high speed turns and pull-outs were possible. The P-39 had to be held in a dive since it tended to level out, reminiscent of the Spitfire. Recommended dive speed limit (Vne) was 475 mph (764 km/h) for the P-39.

The rear-mounted engine made the aircraft ideal for ground attack since fire would be coming from the front-bottom quarter and was less likely to hit the engine and its cooling systems. The arrangement proved to be very vulnerable to attacks from above and behind and nearly any hit on the fuselage from an attacking enemy fighter was virtually guaranteed to disable the cooling system and lead to the prompt demise of the engine and thus the airplane. With its lack of high-altitude performance, the Airacobra was extremely vulnerable to any enemy fighter with decent high altitude performance.

By the time of the Pearl Harbor attack, nearly 600 had been built. When P-39 production ended in August 1944, Bell had built 9,558 Airacobras, of which 4,773 (mostly -39N and -39Q) were sent to the Soviet Union through the Lend-Lease program. There were numerous minor variations in engine, propeller, and armament, but no major structural changes in production types, excepting a few two-seat TP-39F and RP-39Q trainers. In addition, seven went to the U.S. Navy as radio-controlled drones.

Trials of a laminar flow wing (in the XP-39E) and Continental IV-1430 engine (the P-76) were unsuccessful. The mid-engine, gun-through-hub concept was developed further in the Bell P-63 Kingcobra.

A naval version with tail-dragger landing gear, the XFL-1 Airabonita, was ordered as a competitor to the F4U Corsair and XF5F Skyrocket. It first flew 13 May 1940, but after a troublesome and protracted development and testing period, it was rejected.

Operational history

The Airacobra saw combat throughout the world, particularly in the Southwest Pacific, Mediterranean and Russian theaters. Because its engine was only equipped with a single-stage, single-speed supercharger, the P-39 performed best below 17,000 feet (5,200 m) altitude. In both western Europe and the Pacific, the Airacobra found itself outclassed as an interceptor, its earliest proposed role, and the type was gradually relegated to other duties. It often was used at lower altitudes for such missions as ground strafing.

United Kingdom

Airacobra I AH589 L of 601 Squadron. The long-barrelled 20mm Hispano is clearly shown, as are the .303 wing guns.

In 1940, the British Direct Purchase Commission in the US was looking for combat aircraft; they ordered 675 of the export version Bell Model 14 as the "**Caribou**" on the strength of the company's representations on 13 April 1940. The performance of the Bell P-39 prototype and 13 test aircraft which were able to achieve a speed of 390 mph (630 km/h) at altitude was due to the installation of turbo-supercharging. The British armament was two nose mounted 0.50 in (12.7 mm) machine guns, and four 0.303 in (7.7 mm) Browning machine guns in the wings; the 37 mm gun was replaced by a 20 mm (.79 in) Hispano-Suiza.

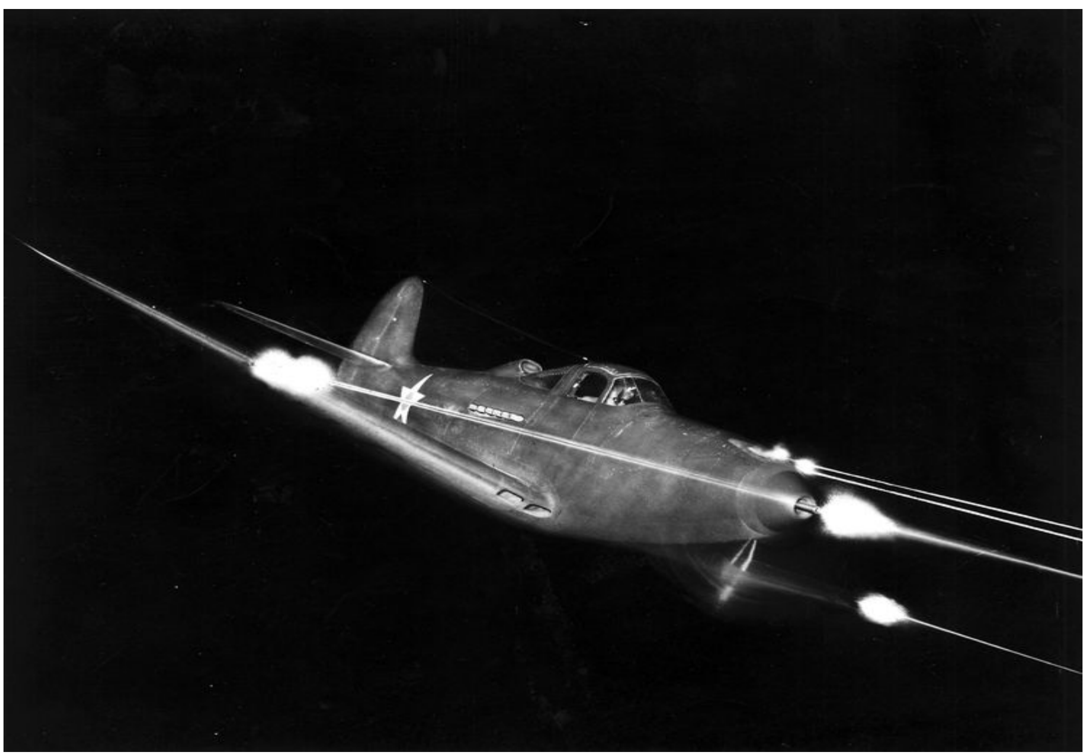
The British export models were renamed "**Airacobra**" in 1941. A further 150 were specified for delivery under Lend-lease in 1941 but these were not supplied. The Royal Air Force (RAF) took delivery in mid 1941 and found that performance of the non-turbo-supercharged production aircraft differed markedly from what they were expecting. In some areas, the Airacobra was inferior to existing aircraft such as the Hawker Hurricane and Supermarine Spitfire and its performance at altitude suffered drastically. Tests by the R.A.E at Boscombe Down showed the Airacobra reached 355 mph (571 km/h) at

13,000 ft (3,962 m). The cockpit layout was criticized, and it was noted that the pilot would have difficulty in baling out in an emergency because the cockpit roof could not be jettisoned. The lack of a clear vision panel on the windscreen assembly meant that in the event of heavy rain the pilot's forward view would be completely obliterated; the pilot's notes advised that in this case the door windows would have to be lowered and the speed reduced to 150 mph (241 km/h) On the other hand it was considered effective for low level fighter and ground attack work. Problems with gun and exhaust flash suppression and the compass could be fixed.

No. 601 Squadron RAF was the only British unit to use the Airacobra operationally, receiving their first two examples on 6 August 1941. On 9 October, four Airacobras attacked enemy barges near Dunkirk, in the type's only operational action with the RAF. The squadron continued to train with the Airacobra during the winter, but a combination of poor serviceability and deep distrust of this unfamiliar fighter resulted in the RAF rejecting the type after one combat mission. In March 1942, the unit re-equipped with Spitfires.

The Airacobras already in the UK, along with the remainder of the first batch being built in the US, were sent to the Soviet Air force, the sole exception being AH574, which was passed to the Royal Navy and used for experimental work, including the first carrier landing by a tricycle undercarriage aircraft on 4 April 1945 on HMS Pretoria Castle, until it was scrapped on the recommendation of a visiting Bell test pilot in March 1946.

U.S.



Bell P-39 Airacobra firing all weapons at night

The United States requisitioned 200 of the next part of the order as the P-400. The P-400 designation came from advertised top speed of 400 mph (644 km/h). After Pearl Harbor, the P-400 was deployed to training units, but some saw combat in the Southwest Pacific including with the Cactus Air Force in the Battle of Guadalcanal. Though outclassed by Japanese fighter planes, it performed well in strafing and bombing runs, often proving deadly in ground attacks on Japanese forces trying to retake Henderson Field. Guns salvaged from P-39s were sometimes fitted to Navy PT boats to increase firepower.

From September to November 1942 pilots of the 57th Fighter Squadron flew P-39s and P-38s from an airfield built on land bulldozed into Kuluk Bay on the barren island of Adak in Alaska's Aleutian Islands. They attacked the Japanese forces which had invaded Attu and Kiska islands in the Aleutians in June 1942. The factor that claimed the most lives was not the Japanese but the weather. The low clouds, heavy mist and fog, driving rain, snow and high winds made flying dangerous and lives miserable. The 57th remained in Alaska until November 1942 and then returned to the United States.

In North Africa, the Tuskegee Airmen were assigned P-39s in February 1944. They successfully transitioned and carried out their duties including supporting Operation Shingle over Anzio as well as missions over the Gulf of Naples in the Airacobra but achieved few aerial victories. By June they had transitioned to P-47 Thunderbolts and then P-51 Mustangs in July 1944.

While only one U.S. pilot, Lt. Bill Fiedler, became an ace in a P-39, many U.S. aces scored one or two of their victories in the aircraft.

USSR

P-39Q-15BE 44-2664
Aviation Museum of Central Finland

The most successful use of the P-39 was in the hands of the Soviet Air Force (VVS). They received the considerably improved N and Q versions of the Airacobra. The tactical environment of the Eastern Front did not demand the extreme high-altitude operations that the RAF and United States Army Air Forces (USAAF) employed with their big bombers. The low-speed, low-altitude turning nature of most air combat on the Russian Front suited the P-39's strengths: sturdy construction, reliable radio gear, and adequate firepower. Russian pilots appreciated the cannon-armed P-39 primarily for its air-to-air attack capability.

The usual nickname for the well-loved Airacobra in the VVS was Kobrushka, "little cobra", or Kobrastochka, a portmanteau of Kobra and Lastochka (swallow), "dear little cobra".

Soviet pilot Nikolai G. Golodnikov, in an interview with Andrei Sukhrukov, recalled:

"I liked the Cobra, especially the Q-5 version. It was the lightest version of all Cobras and was the best fighter I ever flew. The cockpit was very comfortable, and visibility was outstanding. The instrument panel was very ergonomic, with the entire complement of instruments right up to an artificial horizon and radio compass. It even had a relief tube in the shape of a funnel. The armored glass was very strong, extremely thick. The armor on the back was also thick. The oxygen equipment was reliable, although the mask was quite small, only covering the nose and mouth. We wore that mask only at high altitude. The HF radio set was powerful, reliable and clear."

The first Soviet Cobras had a 20 mm Hispano-Suiza cannon and two heavy Browning machine guns, synchronized and mounted in the nose. Later, Cobras arrived with the M-4 37 mm cannon and four machine guns, two synchronized and two wing-mounted. "We immediately removed the wing machine guns, leaving one cannon and two machine guns," Golodnikov recalled later. That modification improved roll rate by reducing rotational inertia. Soviet airmen appreciated the M-4 cannon with its powerful rounds and the reliable action but complained about the low rate of fire (three rounds per second) and inadequate ammunition storage (only 30 rounds). The Soviets used the Airacobra primarily for air-to-air combat against a variety of German aircraft, including Messerschmitt Bf 109s, Focke-Wulf Fw 190s, Junkers Ju 87s, and Ju 88s.

During the battle of Kuban River, the Soviet air force relied on P-39s much more than Spitfires and P-40s. Aleksandr Pokryshkin, from 16.Gv.IAP, claimed 20 air victories in that campaign. Pokryshkin, the third-highest scoring Allied ace (with a score of 53 air victories plus six shared) flew the P-39 from late 1942 until the end of the war (though rumors exist that he changed in late 1944 to a P-63 Kingcobra).

Grigoriy Rechkalov, second Soviet top-scoring ace (56 individual air victories plus 5 shared), occasionally his wingman while both in 16.Gv.IAP, scored 44 victories flying Airacobras. The majority of his kills were achieved on P-39N-0 number 42-8747 and P-39Q-15 number 44-2547. During the Great Patriotic War, he was awarded the Order of Lenin, the Order of the Red Banner (four times), the Order of Alexandr Nievskii, the

Order of Patriotic War 1st Class and the Order of the Red Star (twice). This is the highest score ever attained by any pilot with any American-made aircraft.

The United States did not supply M80 armor-piercing rounds for the autocannons of Soviet P-39s—instead, approximately 1,200,000 M54 high-explosive rounds were supplied, which the Soviets used for air-to-air combat and against soft ground targets. The VVS did not use the P-39 for tank-busting duties.

A total of 4,719 P-39s were sent to the Soviet Union, accounting for more than one-third of all U.S. and UK-supplied fighter aircraft in the VVS, and nearly half of all P-39 production.

USAAF P-39F-1BE 41-7224

Airacobra Soviet losses in 1941-45 were of 1,030 aircraft (49 in 1942, 305 in 1943, 486 in 1944 and 190 in 1945).

Australia

In early 1942, the Royal Australian Air Force (RAAF), experiencing Japanese air raids on towns in northern Australia, found itself unable to obtain British-designed interceptors or sufficient numbers of P-40s. US Fifth Air Force squadrons in Australia were already receiving the brand new P-39D-1. Consequently, in July 1942, older USAAF P-39s, which had been repaired at Australian workshops, were adopted by the RAAF as a stop-gap interceptor.

Seven P-39Ds were sent to No. 23 Squadron RAAF at Lowood, Queensland. Later, seven P-39Fs were operated by No. 24 Squadron RAAF at Townsville. In the absence of adequate supplies of P-39s, both squadrons also operated Wirraway armed trainers. However, neither squadron received a full complement of Airacobras, or saw combat with them. The home air defence role was filled first by P-40s, followed by Spitfires. Plans to equip two more squadrons with P-39s were also abandoned. 23 and 24 Squadrons converted to the Vultee Vengeance in 1943.

France

In 1940, France ordered P-39s from Bell, but because of the armistice with Germany they were not delivered. After Operation Torch, French forces in North Africa sided with the Allies, and were re-equipped with Allied equipment including P-39Ns. From mid-1943 on, three fighter squadrons, the GC 3/6 Roussillon, GC 1/4 Navarre and GC 1/5 Champagne, flew these P-39s in combat over the Mediterranean, Italy and Southern France. A batch of P-39Qs was delivered later, but Airacobras, which were never popular with French pilots, had been replaced by Republic P-47 Thunderbolts in front line units by late 1944.

Italy

In June 1944, the Italian Co-Belligerent Air Force (ICAF) received 170 P-39s, most of them -Qs, and a few -Ns (15th USAAF surplus aircraft stored in Napoli-Capodichino airfield) and also at least one -L and five -Ms. The P-39 N (without the underwing fairing for 12.7 machine guns) had engines with about 200 hours; a little newer than the P-39Q engines with 30–150 hours. A total of 149 P-39s would be used: the P-39N for training, while more modern Qs were used in the front line.

In June–July 1944, Gruppi 12°, 9° and 10° of 4° Stormo, moved to Campo Vesuvio airstrip to re-equip with the P-39s. The site was not suitable and, in three months of training, 11 accidents occurred, due to engine failures and poor maintenance of the base. Three pilots died and two were seriously injured. One of the victims, on 25 August 1944, was the "ace of aces", Sergente Maggiore Teresio Martinoli.

The three groups of 4° Stormo were first sent to Leverano (Lecce) airstrip, then in mid-October, to Galatina airfield. At the end of the training, eight more accidents occurred. Almost 70 aircraft were operational, and on 18 September 1944, 12° Group's P-39s flew their first mission over Albania. Concentrating on ground attack, the Italian P-39s proved to be suitable in this role, losing 10 aircraft to German flak in over 3,000 hours of combat.

By 8 May 1945, at the end of the war, 89 P-39s were still at the Canne airport and 13 at the Scuola Addestramento Bombardamento e Caccia (Training School for Bombers and Fighters), on Frosinone airfield. In 10 months of operational service, the 4° Stormo had been awarded with three Medaglia d'Oro al Valore Militare "alla memoria".

Portugal

Between December 1942 and February 1943, the Aeronáutica Militar (Army Military Aviation) obtained aircraft operated by the 81st and the 350th Fighter Groups originally dispatched to North Africa as part of Operation Torch. Due to several problems en route, some of the aircraft were forced to land in Portugal and Spain. Of the 19 fighter aircraft that landed in Portugal, all were interned and entered service that year with the Portuguese Army Military Aviation.

Though unnecessary, the Portuguese Government paid the United States US$20,000 for each of these interned aircraft as well as for one interned Lockheed P-38 Lightning. The US accepted the payment, and gave as a gift four additional crates of aircraft, two of which were not badly damaged, without supplying spares, flight manuals or service manuals. Without proper training, incorporation of the aircraft into service was plagued with problems, and the last six Portuguese Airacobras that remained in 1950 were sold for scrap.

Postwar

In 1945, Italy purchased the 46 surviving P-39s at 1% of their cost but in summer 1946 many accidents occurred, including fatal ones. By 1947, 4 Stormo re-equipped with P-38s, with P-39s sent to training units until the type's retirement in 1951. Only a T9 cannon survives today at Vigna di Valle Museum.

Racing Airacobras

The Airacobra was raced at the National Air Races in the United States after World War II. Famous versions used for racing included the twin aircraft known as "Cobra I" and "Cobra II," owned jointly between three Bell Aircraft test pilots, Chalmers "Slick" Goodlin, Alvin M. "Tex" Johnston, and Jack Woolams. These craft were extensively modified to use the more powerful P-63 Kingcobra engine and had prototype propeller blades from the Bell factory. "Cobra I" with its pilot, Jack Woolams, was lost in 1946, over the Great Lakes while he was flying from the National Air Races in Cleveland, Ohio back to the factory to get a fresh engine.

The "Cobra II" (Race #84) flown by famed test pilot "Tex" Johnston, beat out P-51 Mustangs and other P-39 racers, which were the favorites, to win the 1946 Thompson Trophy race. Cobra II raced again in the 1947 Thompson Trophy race, finishing 3rd. It raced yet again in the 1948 Thompson trophy race, but was unable to finish due to engine difficulties. Cobra II did not race again and was destroyed on 10 August 1968 during a test flight prior to a run on the world piston-engine speed record, when owner-pilot Mike

Carroll lost control and crashed. Carroll died and the highly-modified P-39 was destroyed.

Mira Slovak's "Mr. Mennen" (Race #21) P-39Q Airacobra was a very fast unlimited racer; a late arrival in 1972 kept this little 2,000 hp (1,491 kW) racer out of the Reno races, and it was never entered again. Its color scheme was all white with "Mennen" green and bronze trim. It is now owned and displayed by the Kalamazoo Air Zoo. The P-39Q (former USAAC serial no. 44-3908/NX40A), is painted as a P-400, "Whistlin' Britches."

Variants

XP-39

XP-39-BE
: Bell Model 11, one prototype 38-326 first flown 6 April 1939 . Powered by an Allison V-1710-17 (E2) engine (1,150 hp/858 kW) fitted with a B-5 two-stage turbosupercharger. Provision was made for two .50 in (12.7 mm) machine guns in the forward fuselage and one 25 mm (.98 in) cannon but aircraft remained unarmed. Later converted to XP-39B.

YP-39

YP-39
: Bell Model 12, service test version, V-1710-37 (E5) engine (1,090 hp/813 kW). First two aircraft delivered with armament, the remained with a M4 37 mm (1.46 in) autocannon with 15 rounds, 2 × .50 in (12.7 mm) machine guns with 200 rpg, and 2 × .30 in (7.62 in) machine guns with 500 rpg in the nose. wider vertical tail than XP-39B. 12 completed with the first flying 13 September 1940.

YP-39A
: One intended to have a high-altitude V-1710-31 engine (1,150 hp/858 kW), but was delivered as a regular YP-39.

XP-39B

XP-39B
: One conversion first flown 25 November 1939. Streamlined XP-39 based on NACA wind tunnel testing resulting in revised canopy and wheel door shape, oil and radiator intakes moved from right fuselage to wing roots, fuselage increased length (by 1 ft 1 in, to 29 ft 9 in) and decreased wingspan (by 1 ft 10 in, to 34 ft). Turbosupercharger replaced with single-stage geared supercharger, Allison V-1710-37 (E5) engine (1,090 hp/813 kW), carburetor air intake moved to fuselage behind canopy.

P-39C

P-39C-BE assigned to the 40th PS / 31st PG at Selfridge Field

P-39C
: Bell Model 13, first flown in January 1941 it was the first production version, identical to YP-39 except for V-1710-35 engine (1,150 hp/858 kW). Armed with 1 × 37 mm (1.46 in) cannon, 2 × .50 in (12.7 mm) & 2 × .30 in (7.62 mm) machine guns in the nose. Aircraft lacked armor and self-sealing fuel tanks. Twenty produced out of an order of 80 the remainder were redesignated P-39D

Airacobra I

Airacobra I
: Bell Model 13, Royal Air Force designation for three P-39Cs sent to United Kingdom England for testing.

Airacobra IA
: Bell Model 14. Briefly named **Caribou**. V-1710-E4 (1,150 hp/858 kW) engine, 1 × 20 mm (.79 in) cannon with 60 rounds & 2 × 0.50 in (12.7 mm) machine guns were mounted nose and four 0.303 in (7.7 mm) machine guns were mounted in the wings. IFF set removed from behind pilot. note: the designation IA indicates direct purchase aircraft; 675 built. The USAAF operated 128 former RAF aircraft with the designation P-400.

P-39D

P-39D-BE
: Bell Model 13, production variant based on the P-39C with 245 lb (111 kg) of additional armor, self-sealing fuel tanks. Armament increased to 1 × 37 mm/1.46 mm cannon (30 rounds), 2 × .50 in/12.7 mm (200 rpg) and 4 × wing mounted .30 in/7.62 mm (1,000 rpg) machine guns; 60 Produced.

P-39D-1
: Bell Model 14A, production variant fitted with a M1 20 mm (.79 in) M1 cannon. Specifically ordered for delivery under Lend-Lease; 336 produced

P-39D-2
: Bell Model 14A-1, production variant with a V-1710-63 (E6) engine (1,325 hp/988 kW) restored the 37 mm (1.46 in) cannon, provisions for a single 145 gal (549 l) drop tank or maximum 500 lb (227 kg) bomb under the fuselage; 158 produced.

P-39D-3
: 26 conversions from P-39D-1 to Photo Reconnaissance Configuration; K-24 and K-25 camera in rear fuselage, extra armor for oil coolers

P-39D-4
: 11 conversions from P-39D-2 to Photo Reconnaissance Configuration. Same modifications as D-3 aircraft.

XP-39E

XP-39E
: Bell Model 23. three P-39Ds modified for ground and flight testing first flown 21 February 1942. Intended for Continental I-1430-1 engine with (2,100 hp/1,566 kW) actually flown with Allison V-1710-47 (1,325 hp/988 kW) engine. Airframes were used to test various wing and different vertical tail surfaces. Fuselage was lengthened by 1 ft 9 in (53 cm). Used in the development of the P-63. The production variants, with the Continental engines were to be redesignated as P-76; there was no Bell XP-76 as such.

P-39F

P-39F-1
: Bell Model 15B, production variant with three-bladed Aeroproducts constant speed propeller, 12 exhaust stacks; 229 built.

TP-39F-1
: One P-39F converted as a two-seat training version with additional cockpit added in nose— no armament.

P-39F-2
: 27 conversions from P-39F-1 with additional belly armor and cameras in rear fuselage.

P-39G

P-39G

Bell Model 26, 1800 order and intended to be a P-39D-2 with an Aeroproducts propeller. Due to modifications during production no P-39G were actually delivered. Instead, these aircraft were designated P-39K, L, M and N.

P-39H

- Designation not used

P-39J

P-39J

Bell Model 15B, a P-39F with V-1710-59 (1,100 hp/820 kW) engine with automatic boost control; 25 built.

P-39K

P-39K-1

Bell Model 26A, a P-39D-2 with Aeroproducts propeller and V-1710-63 (E6) (1,325 hp/988 kW) engine. Vents added to nose; 210 built.

P-39K-2

Six conversion from P-39K-1 with additional belly armor and cameras in rear fuselage.

P-39K-5

One conversion with a V-1710-85 (E19) engine to serve as a P-39N prototype

P-39L

P-39L-1BE 44-4673
Lend-Lease to USSR

P-39L-1

Bell Model 26C, a P-39K with Curtiss Electric propeller, revised nose gear for reduced drag, provision for underwing rockets; 250 built.

P-39L-2

Eleven conversion from P-39L-1 with additional belly armor and cameras in rear fuselage.

P-39M

P-39M-1

Bell Model 26D, variant with a 11 ft 1 in Aeroproducts propeller, V-1710-67 (E8) (1,200 hp/895 kW) engine with improved high-altitude performance at the expense of low-altitude performance, 10 mph (16 km/h) faster than P-39L at 15,000 ft (4,600 m). Note: some P-39M-1BE were delivered with the V-1710-83 (E18) engine; 240 built.

P-39N

P-39N

Bell Model 26N, originally part of the P-39G order. V-1710-85 (E19) (1,200 hp/895 kW) engine. Aeroproducts propeller (10 ft 4 in diameter) & different propeller reduction gear ratio. Starting with the 167th aircraft, propeller increased to 11 ft 7 in & internal fuel reduced from 120 gal (454 l) to 87 gal (329 l); 500 built.

P-39N-1

Variant with internal changes to adjust center of gravity when nose guns were fired; 900 built.

P-39N-2

128 P-39N-1 converted with additional belly armor and cameras in rear fuselage.

P-39N-3B

35 P-39N converted with additional belly armor and cameras in rear fuselage.

P-39N-5

Variant with armor reduced from 231 lb (105 kg) to 193 lb (88 kg), Armor plate replaced the bulletproof glass behind the pilot, SCR-695 radio was fitted, and a new oxygen system was installed; 695 built.

P-39N-6

84 P-39N-5 converted with additional belly armor and cameras in rear fuselage.

P-39P

- Not used

P-39Q

- The final production variant last one built in August 1944.

P-39Q-1

Bell Model 26Q, variant with wing-mounted 0.30 in (7.62 mm) machine guns replaced with a single 0.50 in (12.7 mm) with 300 rounds of ammunition in a pod under each wing. Armor increased to the original 231 lb (105 kg) of armor of the P-39N-1BE; 150 built.

P-39Q-2

Five P-39Q-1s modified to carry cameras for photographic reconnaissance by adding K-24 and K-25 cameras in the aft fuselage.

P-39Q-6BE 42-19993
Brooklyn Bum
8th FG, 36th FS
The Fighter Collection

P-39Q-5

Production variant with reduced armor (193 lb/88 kg), fuel capacity increased (110 gal/l). Type A-1 bombsight adapters added; 950 built.

TP-39Q-5

One conversions to a two-seat training variant with additional cockpit added in nose - no armament. Enlarged tail fillet and a shallow ventral fin added.

P-39Q-6

148 P-39Q-5s modified to carry cameras for photographic reconnaissance by adding K-24 and K-25 cameras in the aft fuselage.

P-39Q-10

Variant with increased armor (228 lb/103 kg), fuel capacity increased (120 gal/454 l). Automatic Boost controls added and Throttle & RPM controls were coordinated. Winterization of oil systems and rubber mounts added to the engines; 705 built.

P-39Q-11
: Eight P-39Q-10s modified to carry cameras for photographic reconnaissance by adding K-24 and K-25 cameras in the aft fuselage.

P-39Q-15
: Production variant with reinforced inclined deck to prevent .50 in (12.7 mm) machine gun tripod mounting cracking, bulkhead reinforcements to prevent rudder pedal wall cracking, a reinforced reduction gearbox bulkhead to prevent cowling former cracking, and repositioning of the battery solenoid. Oxygen system reduced from four bottle to only two; 1,000 built.

P-39Q-20
: Production variant with minor equipment changes. The underwing 0.50 in (12.7 mm) machine gun pods were sometimes omitted in this version; 1,000 built.

P-39Q-21
: 109 P-39Q-20 fitted with a four-bladed Aeroproducts propeller.

RP-39Q-22
: 12 P-39Q-20s converted to two-seat trainers .

P-39Q-25
: Production variant similar to the P-39Q-21 but with a reinforced aft-fuselage and horizontal stabilizer structure; 700 built.

P-39Q-30
: Production variant that reverted back to the three-bladed propellor; 400 built.

XTDL-1
: United States Navy designation for two P-39Qs used as target drones. Assigned to NAS Cape May for test work. Later redesignated **F2L-1K**.

Other

P-45
: The P-45 was the initial designation of the P-39C or Model 13.

XFL-1 Airabonita
: One prototype for the United States Navy.

Operators

Australia

- Royal Australian Air Force

France

- Armée de l'Air

Italy

- Italian Co-Belligerent Air Force

Italy

- Aeronautica Militare

Portugal

- Esquadrilha Airacobra (Airacobra Squadron), later renamed Esquadrilha 4 (Squadron No. 4) — Aeronáutica Militar (Army Military Aviation)

Soviet Union

- Soviet Air Forces (Voyenno-Vozdushnye Sily or VVS)

United Kingdom

- Royal Air Force
- Royal Navy (Airacobra Mk 1 - test flight)

United States

- United States Army Air Corps / United States Army Air Forces

Survivors

Airworthy

- P-39N Airacobra, s/n 42-8740 is flightworthy and owned by Yanks Air Museum in Chino, California.
- P-39Q Airacobra, s/n 42-19597 is flightworthy and owned by the Commemorative Air Force in Midland, Texas.
- P-39Q Airacobra, s/n 42-19993 is flightworthy and owned by The Fighter Collection in Duxford, UK.

Display

- P-39D Airacobra, s/n 41-6951 is on display at the Beck Military Collection in Mareeba, Queensland.
- P-39N Airacobra, s/n 42-4949 is on display at the Military Aircraft Restoration Corporation in Chino, California.
- P-39N Airacobra, s/n 42-19027 is on display at the Planes of Fame in Chino, California.
- P-39N Airacobra, s/n 42-19039 is on display at the J. K. McCarthy Museum in Goroka, Papua New Guinea.
- P-39Q Airacobra, s/n 42-20000 is on display at the March Field Air Museum in Riverside, California.
- P-39Q Airacobra, s/n 42-20007 is on display at the Virginia Air & Space Center in Hampton, Virginia.

- P-39Q Airacobra, s/n 44-2664 is on display at the Aviation Museum of Central Finland in Tikkakoski, Finland.
- P-39Q Airacobra, s/n 44-3887 is on display at the National Museum of the United States Air Force in Dayton, Ohio.
- RP-39Q Airacobra, s/n 44-3908 is on display at the Kalamazoo Aviation History Museum in Kalamazoo, Michigan.
- P-39Q Airacobra, s/n 42-19995 is on display at the Buffalo and Erie County Naval & Military Park in Buffalo, New York.

Restoration

- P-39F Airacobra, s/n 41-7215 is under restoration by the Precision Aerospace Productions in Glenrowan, Victoria.
- P-39K Airacobra, s/n 42-4312 is under restoration by Fantasy of Flight in Tamiami, Florida.
- P-39N Airacobra, s/n 42-8784 is under restoration in Chino, California.
- P-39N Airacobra, s/n 42-18814 is under restoration by the Military Aircraft Restoration Corporation in Chino, California.
- P-39Q Airacobra, s/n 44-2485 is under restoration by Gary R. Larkins of Auburn, California.

Specifications (P-39Q)

Bell P-39Q Airacobra at the National Museum of the United States Air Force

General characteristics

- **Crew:** One
- **Length:** 30 ft 2 in (9.2 m)
- **Wingspan:** 34 ft 0 in (10.4 m)
- **Height:** 12 ft 5 in (3.8 m)
- **Wing area:** 213 sq ft (19.8 m²)
- **Empty weight:** 5,347 lb (2,425 kg)
- **Loaded weight:** 7,379 lb (3,347 kg)
- **Max takeoff weight:** 8,400 lb (3,800 kg)
- **Powerplant:** 1× Allison V-1710-85 liquid-cooled V-12, 1,200 hp (895 kW)

Performance

- **Maximum speed:** 376 mph (605 km/h) (Redline dive speed was 525 mph)
- **Range:** 525 miles on internal fuel (840 km)
- **Service ceiling:** 35,000 ft (10,700 m)
- **Rate of climb:** 3,750 ft/min (19 m/s)
- **Wing loading:** 34.6 lb/sq ft (169 kg/m²)
- **Power/mass:** 0.16 hp/lb (0.27 kW/kg)
- Time to climb: 15,000 in 4.5 min at 160 mph (260 km/h).

Armament

- **Guns:**
    - 1 x 37 mm M4 cannon with 30 rounds of HE ammo.
    - 2 x .50 cal (12.7 mm) machine guns. 200 rounds per nose-gun
    - 4 x .30 cal machine guns, wing mounted. 300 per wing-pod
- **Bombs:** Up to 500 lb (230 kg) of bombs externally

Chapter 5

Bellanca CH-300, Bartel BM-4 and Bellanca Aircruiser

Bellanca CH-300

CH-300 Pacemaker

Bellanca CH-300 CF-ATN Pacemaker Canada Aviation Museum

Role	Civil utility aircraft
Manufacturer	Bellanca
First flight	1929
Number built	approximately 35
Developed from	Bellanca CH-200
Variants	Bellanca CH-400

The **Bellanca CH-300 Pacemaker** was a six-seat utility aircraft built primarily in the United States in the 1920s and 1930s. It was a development of the Bellanca CH-200 fitted with a more powerful engine and, like the CH-200, soon became renowned for its long-distance endurance.

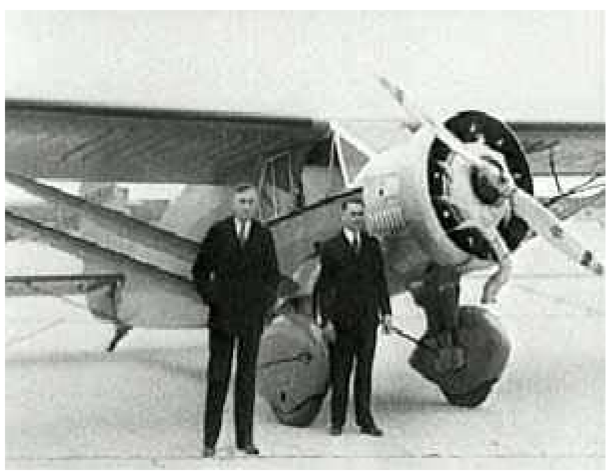
Design and development

Bellanca further developed the earlier CH-200 to create the CH-300 Pacemaker. The CH-300 was a conventional, high-wing braced monoplane with fixed tailwheel undercarriage. Like other Bellanca aircraft of the period, it featured "flying struts". While the CH-200 was powered by 220 hp Wright J-5 engines, the CH-300 series Pacemakers were powered by 300 hp Wright J-6s. Late in the series, some -300s were fitted with 420 hp Pratt & Whitney Wasps, leading to the CH-400 Skyrocket series.

Operational history

Pacemakers were renowned for their long-distance capabilities as well as reliability and weight-lifting attributes, which contributed to their successful operation throughout the world. In 1929, George Haldeman completed the first nonstop flight, New York to Cuba in 12 hours, 56 minutes, flying an early CH-300 (c. 1,310 miles, 101.3 mph). In 1931, a Bellanca fitted with a Packard DR-980 diesel, piloted by Walter Lees and Frederick Brossy, set a record for staying aloft for 84 hours and 33 minutes without being refuelled. This record was not broken until 55 years later.

In Alaska and the Canadian bush, Bellancas were very popular. Canadian-operated Bellancas were initially imported from the United States, but later six were built by Canadian Vickers in Montreal and delivered to the RCAF (added to the first order of 29 made in 1929), which used them mainly for aerial photography.



"Lituanica", a customized Bellanca CH-300

Record attempts

On June 3, 1932, Stanislaus F. Hausner flying a Bellanca CH Pacemaker named Rose Marie and powered by a 300-hp Wright J-6, attempted a transatlantic flight from Floyd Bennett Field, New York to Warsaw, Poland. The attempt failed when he made a forced landing at sea; he was rescued by a British tanker eight days later.

A CH-300 named Lituanica (registration NR688E) gained international fame when it was used by Steponas Darius and Stasys Girėnas in an attempt to fly non-stop from New York City to Kaunas, Lithuania. Departing on July 15, 1933, they spent 37 hours in the air, and flew 6,411 km before crashing in bad weather in Germany, 650 km from its final destination. A replica of Lituanica is in the Lithuanian Aviation Museum while the wreckage of the original is at the Vytautas the Great War Museum.

Survivors

Hawaiian Airlines owns the world's only CH-300 known to be in flying condition. The aircraft, which was acquired new in 1929 by Inter-Island Airways (which was renamed Hawaiian Airlines in 1941), was used for sightseeing flights over the island of Oahu for two years before being sold in 1933. Acquired from an aviation enthusiast in Oregon in early 2009, the aircraft was restored at the Port Townsend Aero Museum and was unveiled at the Honolulu International Airport on October 8, 2009.

One CH-300 Pacemaker is displayed at the Canada Aviation and Space Museum. This aircraft formerly served with Alaska Coastal Airlines. Another example is owned by the Virginia Aviation Museum, but this aircraft has been modified to CH-400 Skyrocket configuration and painted to resemble WB-2 Columbia, which made two pioneering transatlantic flights.

Variants

- **CH-300W** - CH-300 converted to use a Pratt & Whitney R-985 engine (one converted)
- **300-W** - Built with a Pratt & Whitney R-985 engine (seven built)
- **PM-300 Pacemaker Freighter** - Cargo version (two built)

Specifications

General characteristics

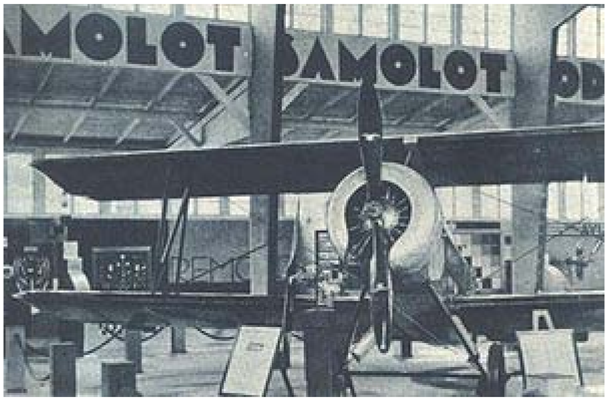
- **Crew:** one pilot
- **Capacity:** 5 passengers
- **Length:** 27 ft 9 in (8.5 m m)
- **Wingspan:** 46 ft 4 in (14.1 m)
- **Height:** 8 ft 4 in (2.5 m)
- **Empty weight:** 2,275 lb (1,032 kg)
- **Gross weight:** 4,072 lb (1,847 kg)
- **Powerplant:** 1 × Wright J-6 radial, 330 hp (246 kW)

Performance

- **Maximum speed:** 165 mph (266 km/h)
- **Range:** 675 miles (1,086 km)

Bartel BM-4

Bartel BM-4



BM-4 at exhibition in Poznan, 1929

Role	Primary trainer aircraft
Manufacturer	Samolot, PWS
First flight	20 December 1927
Introduced	1929
Retired	1939
Primary user	Polish Air Force
Produced	1928-1932
Number built	~75

The **Bartel BM-4** was a Polish biplane primary trainer aircraft used from 1929 to 1939 by the Polish Air Force and Polish civilian aviation, manufactured in the Samolot factory in Poznań. It was the first plane of Polish design put into production.

Design and development

The aircraft was designed by Ryszard Bartel in the Samolot factory in Poznań. It was a development of the Bartel BM-2, which did not advance beyond the prototype stage. Thanks to a lower weight than the BM-2, it could use lower-powered engines, so its performance was actually improved. Its performance was also superior to the Hanriot H.28, used by the Poles and licence-built by Samolot. The BM-4 prototype was flown on 20 December 1927 in Poznań. It had good handling and stability and was resistant to spinning. A distinguishing feature of all Bartels was an upper wing of a shorter span, because lower and upper wing halves were interchangeable (i.e. the lower wingspan included the width of the fuselage).

The first prototype was designated **BM-4b** and was fitted with 90 hp Walter Vega radial engine. The second prototype, flown on 2 April 1928, was designated **BM-4d** and fitted with the Polish experimental 85 hp WZ-7 radial engine, then refitted with 80 hp Le Rhône C rotary engine and redesignated **BM-4a**. The BM-4a became a production variant, because the Polish Air Force had a store of Le Rhône engines. 22 aircraft were ordered and built in 1928-1929. This variant had a cowled engine which made it different from all other BM-4s with radial engines.

Next several variants remained experimental. The **BM-4c** with a 125 hp Lorraine-Dietrich 5Pb radial engine, built as a one-off in 1928, was supposed to be used for long-distance flights to advertise the engines, but was finally used as the factory's aircraft. Three BM-4a's were converted to **BM-4e** of 1930 with the Polish experimental 85 hp Peterlot radial engine, the **BM-4f** of 1931 with the Polish experimental 120 hp Skoda G-594 Czarny Piotruś radial engine, and the **BM-4g** of 1931 with 100 hp de Havilland Gipsy I inline engine. The last one competed against the RWD-8 in a search for a standard trainer aircraft, but was not selected. After tests in 1932, all three were converted back with Le Rhône engines.

The second series variant became **BM-4h**, with 120 hp de Havilland Gipsy III or 120 hp Walter Junior 4 inline engines. Like late BM-4a's, they had a rounded tailfin and a modified undercarriage. Due to the Samolot factory's closure in 1930, the BM-4h was developed at the PWS (Podlaska Wytwórnia Samolotów) and built there in 1932 in a series of about 50 aircraft.

Operational history

BM-4a's were used in the Polish Air Force from 1929 - in pilots' school in Bydgoszcz. 6 burnt in September 1929 in the Samolot factory. BM-4h's were used in the Polish Air Force from 1932, in schools in Bydgoszcz and Dęblin. They only partly replaced Hanriot H.28s and were themselves replaced with the RWD-8. They had military numbers starting with 33.

In 1936 the Polish Air Force handed over their remaining 23 BM-4h's to civilian aviation - most to regional aero clubs, some to the Ministry of Communication. They received registrations SP-BBP - BBZ and from a range SP-ARB to ARZ. Several survived until the German invasion of Poland in September 1939. Several were used as liaison aircraft during the campaign. None survived the war.

Variants

BM-4a
: Powered by Le Rhône C, 9 cylinder rotary engine, 80 hp nominal power.

BM-4b
: Powered by Walter Vega, 5 cylinder radial engine, 90 hp take-of power, 85 hp nominal power.

BM-4c
: Powered by Lorraine-Dietrich 5Pb, 5 cylinder radial engine, 125 hp take-of power, 110 hp nominal power.

BM-4d
: Powered by Avia WZ-7, 7 cylinder radial engine, 85 hp take-of power, 80 hp nominal power.

BM-4e
: Powered by Peterlot, 7 cylinder radial engine, 85 hp take-of power, 80 hp nominal power.

BM-4f
: Powered by Skoda G-594 Czarny Piotruś, 5 cylinder radial engine, 120 hp take-of power, 100 hp nominal power.

BM-4g
: Powered by de Havilland Gipsy I, 4 cylinder straight engine, 100 hp take-of power, 90 hp nominal power.

BM-4h
: Powered by de Havilland Gipsy III, 4 cylinder straight engine, 120 hp nominal power or Walter Junior 4, 4 cylinder straight engine, 120 hp take-of power, 110 hp nominal power.

Operators

Afghanistan

- Afghan Air Force - The first prototype BM-4b was given to the king of Afghanistan Amanullah Khan during his visit to Poland in 1928.

Poland

- Polish Air Force

Specifications (BM-4h)

Description

Wooden construction biplane, conventional in layout. Fuselage rectangular in cross-section, plywood covered (engine section - metal covered). Rectangular two-spar wings, plywood and canvas covered. Crew of two, sitting in tandem in open cockpits, with individual windshields. Cockpits with dual controls, instructor's at rear. Fixed landing gear, with a rear skid. Two-blade wooden propeller 2.55 m diameter. Fuel tank in fuselage: 89.5 l.

General characteristics

- **Crew:** 2, student and instructor
- **Length:** 7.25 m (23 ft 9 in)
- **Wingspan:** 10.17 m (33 ft 4 in)
- **Height:** 2.93 m (9 ft 7 in)
- **Wing area:** 25 m² (269 ft²)
- **Empty weight:** 551 kg (1,212 lb)
- **Loaded weight:** 800 kg (1,760 lb)
- **Useful load:** 249 kg (548 lb)

- **Powerplant:** 1× de Havilland Gipsy III or Walter Junior 4 4-cylinder air-cooled straight engine, 90 kW (120 hp)

Performance

- **Maximum speed:** 138 km/h (74 knots, 86 mph)
- **Cruise speed:** 110 km/h (59 knots, 68 mph)
- **Stall speed:** 57 km/h (30 knots, 35 mph)
- **Range:** 275 km (149 nm, 170 mi)
- **Service ceiling:** 2,100 m (6,900 ft)
- **Rate of climb:** 1.8 m/s (350 ft/min)
- **Wing loading:** 31.6 kg/m² (6.54 lb/ft²)
- **Power/mass:** 0.11 kW/kg (0.068 hp/lb)

Bellanca Aircruiser

Airbus/Aircruiser

Bellanca Aircruiser under restoration at the Western Canada Aviation Museum, Winnipeg, 2006.

Role	Passenger/cargo aircraft
Manufacturer	Bellanca Aircraft Corporation
Designed by	Giuseppe Mario Bellanca
First flight	1930
Primary user	Private operators
Number built	23

The **Bellanca Aircruiser** and **Airbus** were high-wing, single engine aircraft built by Bellanca Aircraft Corporation of New Castle, Delaware. The aircraft was built as a "workhorse" intended for use as a passenger or cargo aircraft. It was available as land, sea or ski plane. The aircraft was powered by either a Wright Cyclone or Pratt and Whitney Hornet engine. The Airbus and Aircruiser served as both a commercial and military transport.

Design and development

The first Bellanca Airbus was built in 1930 as the **P-100**. An efficient design, it was capable of carrying 12 to 14 passengers depending on the cabin interior configuration, with later versions carrying up to 15. In 1931, test pilot George Haldeman flew the P-100 a distance of 4,400 miles in a time aloft of 35 hours. Although efficient, with a cost per mile figure of 0.08 cent per mile calculated for that flight, the first Airbus didn't sell due to its water-cooled engine.

In service

The next model, the **P-200 Airbus**, was powered by a larger, more reliable air-cooled engine. One version (P-200-A) came with floats and operated as a ferry service in New York City, flying between Wall Street and the East River. Other versions included a P-200 Deluxe model, with custom interiors and seating for nine. The **P-300** was designed to carry 15 passengers. The final model, the "Aircruiser," was the most efficient aircraft of its day, and would rank high amongst all aircraft designs. With a Wright Cyclone air-cooled supercharged radial engine rated at 715 hp, the Aircruiser could carry a useful load greater than its empty weight. In the mid-1930s, the Aircruiser could carry 4,000 lb payloads at a speed of between 145-155 mph, a performance that multi-engine Fokkers and Ford Trimotors could not come close to matching.

In 1934, US federal regulations outlawed single engine transports on US airlines, virtually eliminating future markets for the Aircruiser. Where the workhorse capabilities of the Aircruiser stood out was in Canada. Several of "The Flying W", as it was commonly dubbed in Canada, were used in northern mining operations, ferrying ore, supplies and the occasional passenger into the 1970s.

Variants

Airbus

P-100 Airbus
: 14-passenger monoplane powered by a 600 hp (447 kW) Curtis Conqueror engine, one built later converted into a P-200.

P-200 Airbus
: 12-passenger monoplane, nine built and one converted from P-100.

P-300 Airbus
: 15-seater monoplane powered by a Wright R-1820 Cyclone engine.

Y1C-27

United States Army Air Corps designation for four P-200 Airbuses powered by 550 hp (410 kW) Pratt & Whitney R-1860 Hornet engine. All later converted to C-27C.

C-27A Airbus
: Production version of the Y1C-27 powered by a 650 hp (485 kW) Pratt & Whitney R-1860 Hornet engine, ten built. One converted to a C-27B the rest converted to C-27Cs.

C-27B Airbus
: One C-27A re-engined with a 675 hp R-1820-17 engine.

C-27C Airbus
: Four Y1C-27s and nine of the C-27A re-engined with a 750 hp R-1820-25 engine.

Aircruiser

Aircruiser 66-67
: Improved structure modified from a P-200 with a 675 hp Wright SR-1820 Cyclone engine

Aircruiser 66-70
: An Aircruiser with a 710 hp Wright SGR-1820 Cyclone engine, five-built exported to Canada.

Aircruiser 66-75
: An Aircruiser with a 730 hp Wright Cyclone engine, three built.

Aircruiser 66-76
: A cargo-version of the Aircruiser with a 760 hp Wright Cyclone.

Aircruiser 66-80
: An Aircruiser with a 850 hp Wright Cyclone engine.

Operators

Canada

- Canadian Pacific Airlines (Aircruiser)
- Central Northern Airways (Aircruiser)
- Mackenzie Air Service (Aircruiser)

United States

- New York and Suburban Airlines (Airbus)
- United States Army Air Corps (Airbus)

Mexico
Philippines

Survivors

The last flying Aircruiser, "CF-BTW," a 1938 model, after serving in Manitoba, is now on display at the Tillamook Air Museum, in Tillamook, Oregon.

Another Bellanca Aircruiser, "CF-AWR" named the "Eldorado Radium Silver Express", built in 1935, is presently under restoration at the Western Canada Aviation Museum, Winnipeg.

Specifications (66-70 Aircruiser)

General characteristics

- **Crew:** one, pilot
- **Capacity:** 16 passengers
- **Length:** 43 ft 4 in (13.21 m)
- **Wingspan:** 65 ft 0 in (19.82 m)
- **Height:** 11 ft 6 in (3.51 m)
- **Wing area:** 520 ft² (48.3 m²)
- **Empty weight:** 6,072 lb (2,754 kg)
- **Loaded weight:** 10,000 lb (4,536 kg)
- **Powerplant:** 1× Wright R-1820 Cyclone 9 9-cylinder supercharged air-cooled radial engine, 710 hp (530 kW)

Performance

- **Maximum speed:** 144 knots (165 mph, 266 km/h)
- **Range:** 608 nm (700 miles, 1,130 km)
- **Service ceiling:** 22,000 ft (6,700 m)

Chapter 6

Caudron G.3 and Caudron C.714

Caudron G.3

Caudron G.3

Caudron G.3 displayed in the Musee de l'Air et de l'Espace at Le Bourget airport, Paris

Role	Reconnaissance aircraft
Manufacturer	Caudron
First flight	Late 1913
Introduced	1914
Primary users	Aéronautique Militaire US Army Air Service Finnish Air Force Polish Air Force
Developed from	Caudron G.2

The **Caudron G.3** was a single-engined French biplane built by Caudron, widely used in World War I as a reconnaissance aircraft and trainer. In comparison to its competitors, it had a better rate of climb and it was considered especially suitable in mountainous terrain.

Development

The Caudron G.3 was designed by René and Gaston Caudron as a development of their earlier Caudron G.2 for military use. It first flew in May 1914 at their Le Crotoy aerodrome.

The aircraft had a short crew nacelle, with a single engine in the nose of the nacelle, and twin open tailbooms. It was of sesquiplane layout, and used wing warping for lateral control, although this was replaced by conventional ailerons fitted on the upper wing in late production aircraft.

Following the outbreak of the First World War, it was ordered in large quantities. The Caudron factories built 1423 aircraft (2450 total were built in France) and it was built under licence in several other countries (233 were built in England and 166 were built in Italy). The Caudron brothers did not charge a licencing fee for the design, as an act of patriotism.

Usually, the G.3 was not equipped with any weapons, although sometimes light, small calibre machine guns and some hand-released small bombs were fitted to it.

It was followed in production by the Caudron G.4, which was a twin engined development.

Operational history

The G.3 equipped Escadrille C.11 of the French Aéronautique Militaire at the outbreak of war, and was well-suited for reconnaissance use, proving tough and reliable. As the war went on however, its low performance and the fact that it was unarmed made it vulnerable in front line service, and so the French withdrew it from front line operations in mid-1916. The Italians also used the G.3 for reconnaissance on a wide scale until 1917, as did the British RFC (continuing operations until October 1917),who also fitted some with light bombs and machine guns for ground attack.

It continued in use as a trainer after ceasing combat operations until after the end of the war. Caudron G.3 in Chinese hands, namely the air force of Fengtian clique warlords remained in service in training roles until the Mukden Incident, when most of them were captured by Japanese, and their eventual fate is unknown.

Variants

Most G.3s were the **A.2** model, used by various airforces for fire spotting on the West front, in Russia and in the Middle East. G.3 **D.2** was a two-seated trainer aircraft, equipped with dual controls and the **E.2** was a basic trainer. The **R.1** version, which had been developed from the basic version was used by France and by the USA for taxi training, with fabric removed from large areas of the wing to prevent its becoming airborne. The last version, the **G.3.12**, was equipped with a more powerful 100 hp Anzani 10 radial engine.

In Germany, Gotha built copies of the G.3 as the **LD.3** and **LD.4** (Land Doppeldecker - "Land Biplane").

Survivors

Caudron G.3s are displayed in several museums, including at the RAF Museum Hendon, the Musée de l'Air et de l'Espace, Paris, the Royal Army and Military History Museum, Brussels and the Aerospace Museum (Musal), Rio de Janeiro. One aircraft (1E.18) is currently being repaired at the Hallinportti Aviation Museum.

Operators

Caudron G3 in the Airspace Museum (Museu Aeroespacial) in Rio de Janeiro.

Argentina

Australia

- Mesopotamian Half Flight
- Central Flying School AFC at Point Cook, Victoria.

Belgium
Brazil
China
Colombia

Three aircraft only. The first military aircraft in the history of this country.

Denmark
El Salvador

Three aircraft only.

Finland

The Finnish Air Force purchased twelve aircraft from France in 1920. Six of these were built in Finland by Santahaminan ilmailutelakka (today a part of Patria Aviation) between 1921 - 1923. Two aircraft and spares were purchased from Flyg Aktiebolaget on April 26, 1923 (production numbers 6 and 4396) together with a Caudron G.4 for 100,000 Finnish markka. The aircraft was easy to fly and repair and thus very suitable as a trainer. The Finnish-constructed aircraft had worse flying characteristics than the French machines due to a bad wing profile. The FAF used a total of 19 Caudron G.3 aircraft, which carried the designation codes 2A.490 - 2A.495, later 1B.1 - 1B.7 and 1D.8 - 1D.12. Aircraft constructed in Finland carried designation codes 1D.12 and 1E.14 - 1E.18, and the one purchased from Flyg Aktiebolaget carried designation code 1B.19. The aircraft was called Tutankhamon in Finland. The G.3 was used by the FAF between 1920-1924.

Caudron G.3 replica in "Museo del Aire", Madrid

France

    operated by 38 escadrilles.

Greece

Italy

Japan

Peru

    One aircraft only.

Portugal

    Portuguese Air Force

Poland

Romania

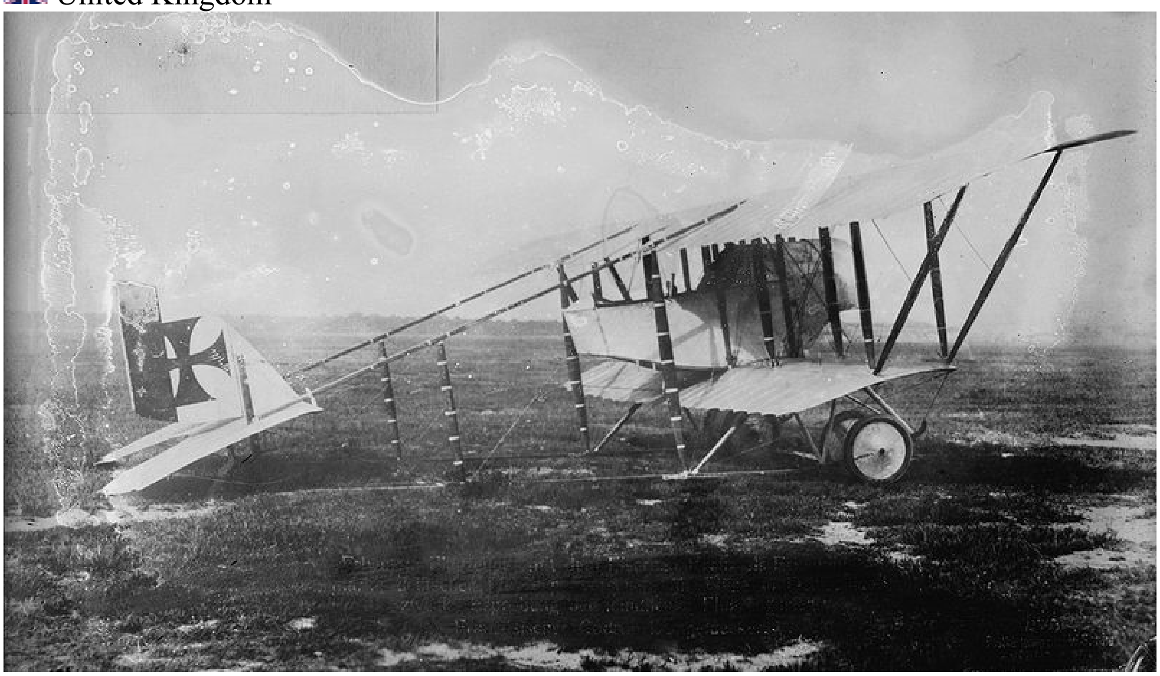
Russia

Serbia

Kingdom of Spain

    Spain purchased eighteen Caudron G.3 in June 1919. They were posted in flight schools in Getafe, Seville and Los Alcázares. These planes remained in service until they were replaced by Avro 504 K in 1924.

United Kingdom



Caudron captured

- Royal Flying Corps
    - No. 1 Squadron RFC
    - No. 4 Squadron RFC
    - No. 5 Squadron RFC
    - No. 19 Squadron RFC
    - No. 23 Squadron RFC
    - No. 25 Squadron RFC

- No. 29 Squadron RFC

United States
Venezuela

Specifications (G.3)

General characteristics

- **Crew:** 1
- **Length:** 6.40 m (21 ft 0 in)
- **Wingspan:** 13.40 m (44 ft 0 in)
- **Height:** 2.50 m (8 ft 3 in)
- **Wing area:** 27.00 m² (290 ft²)
- **Empty weight:** 420 kg (933 lb)
- **Max takeoff weight:** 710 kg (1,577 lb)
- **Powerplant:** 1× Le Rhone C rotary, 60 kW (80 hp)

Performance

- **Maximum speed:** 106 km/h (57 kn, 68 mph)
- **Service ceiling:** 4,300 m (14,110 ft)

Armament

One small calibre machine gun (optional) and some hand released bombs (optional)

Caudron C.714

Caudron C.714

Finnish C.714

Role	Fighter
Manufacturer	Caudron-Renault
Designed by	Marcel Riffard
First flight	18 July 1936 (C.710)
Introduced	1940
Retired	1941 (Finland)
Primary users	Polish Air Force in France Armee de l'Air Finland
Produced	1939-1940
Number built	approximately 90

The **C.710** were a series of light fighter aircraft developed by Caudron-Renault for the French Armée de l'Air just prior to the start of World War II. One version, the **C.714**, saw limited production, and were assigned to Polish pilots flying in France after the fall of Poland in 1939. A small number were also supplied to Finland.

Design and development

The original specification that led to the C.710 series was offered in 1936 in order to quickly raise the number of modern aircraft in French service, by supplying a "light fighter" of wooden construction that could be built rapidly in large numbers without upsetting the production of existing types. The contract resulted in three designs, the Arsenal VG-30, the Bloch MB-700, and the C.710. Prototypes of all three were ordered.

The original **C.710** model was an angular design developed from an earlier series of air racers. One common feature of the Caudron line was an extremely long nose that set the cockpit far back on the fuselage. The profile was the result of using the 336 kW (450 hp) Renault 12R-01 12-cylinder inline engine, which had a small cross section and was fairly easy to streamline, but very long. The landing gear was fixed and spatted, and the vertical stabilizer was a seemingly World War I-era semicircle instead of a more common trapezoidal or triangular design. Armament consisted of a 20 mm Hispano-Suiza HS.9 cannon under each wing in a small pod.

The C.710 prototype first flew on 18 July 1936. Despite its small size, it showed good potential and was able to reach a level speed of 470 km/h (292 mph) during flight testing. Further development continued with the **C.711** and **C.712** with more powerful engines, while the **C.713** which flew on 15 December 1937 introduced retractable landing gear and a more conventional triangular vertical stabilizer.

The final evolution of the 710 series was the **C.714 Cyclone**, a variation on the C.713 which first flew in April 1938 as the **C.714.01** prototype. The primary changes were a new wing airfoil profile, a strengthened fuselage, and instead of two cannons, the fighter had four 7.5 mm MAC 1934 machine guns in the wing gondolas. It was powered by the newer 12R-03 version of the engine, which introduced a new carburettor that could operate in negative g.

The Armée de l'Air ordered 20 C.714s on 5 November 1938, with options for a further 180. Production started at a Renault factory in the Paris suburbs in summer 1939

Other projected versions were the **C.720** trainer with a 75 or 164 kW (100 or 220 hp) engine, the **C.760** fighter with a 559 kW (750 hp) Isotta-Fraschini Delta engine, and the **C.770** fighter with an 597 kW (800 hp) Renault V-engine. None of these reached production.

Operational history

Deliveries did not start until January 1940. After a series of tests with the first production examples, it became apparent that the design was seriously flawed. Although light and fast, its wooden construction did not permit a more powerful engine to be fitted. The original engine seriously limited its climb rate and maneuverability with the result that the Caudron was withdrawn from active service in February 1940. In March, the initial production order was reduced to 90, as the performance was not considered good enough to warrant further production contracts. Eighty were diverted to Finland to fight in the Winter War. These were meant to be flown by French pilots. However, events in France resulted in only six aircraft being delivered, and an additional 10 were waiting in the harbour when deliveries were stopped. The six aircraft that arrived were assembled, tested and given registrations CA-551 to CA-556. The aircraft were found to be too unreliable and dangerous to use in Finnish conditions, and were not committed to combat. Two of the aircraft were damaged during a transport flight to Pori. Further, the Finnish pilots found that it was difficult to start and land the aircraft from the air bases at the front. The Finnish CR.714 aircraft were permanently grounded on 10 September 1940, and taken out of service in 1941.

On 18 May 1940, 35 Caudrons were delivered to the Polish Warsaw Squadron, the Groupe de Chasse polonais I/145, stationed at the Mions airfield. After just 23 sorties, adverse opinion of the fighter was confirmed by front line pilots who expressed concerns that it was seriously underpowered and was no match for contemporary German fighters.

On 25 May, only a week after it was introduced, French Minister of War Guy la Chambre ordered all C.714s to be withdrawn from active service. However, since the French authorities had no other aircraft to offer, the Polish pilots ignored the order and continued to fly the Caudrons. Despite flying a fighter hopelessly outdated compared to the Messerschmitt Bf 109E, the Polish pilots scored 12 confirmed and three unconfirmed victories in three battles between 8 June and 11 June, losing nine in the air and nine more on the ground. Interestingly, among the aircraft shot down were four Dornier Do 17 bombers, but also three Messerschmitt Bf 109 and five Messerschmitt Bf 110 fighters.

The Caudron fighter was also used by the Polish training squadron based in Bron near Lyon. Although the pilots managed to disperse several bombing raids, and although they did not score any kills, they did not lose any machines. By the end of June when France fell, only 53 production machines had been delivered (although the number varies, 98 is another common figure). Despite a larger number being diverted to Finland, only six Caudron C.714s were received in a semi-assembled state. An additional 10 were on the dockside at the time of France's Armistice with Germany, subsequently, further shipments were halted. After assembly, operations in Finland were limited to test flights and, in September 1941, combat flights with the fighters were prohibited. The aircraft were maintained on the roster until they were retired and scrapped on 30 December 1949. One example, CA-556 was transferred to the maintenance personnel school as an instructional airframe.

Operators

Wreckage of a Finnish C.714

Finland

- Finnish Air Force

France

- Armée de l'Air

Poland

- Polish Air Force in Exile

Survivors

One full CR.714 airframe as well as one additional fuselage were preserved in Finland. The fuselage was offered back to the Musée de l'Air et de l'Espace where it is currently undergoing restoration.

Specifications (Caudron C.714)

General characteristics

- **Crew:** One
- **Length:** 8.63 m (28 ft 3⅞ in)
- **Wingspan:** 8.97 m (29 ft 5⅛ in)
- **Height:** 2.87 m (9 ft 5 in)
- **Wing area:** 12.5 m² (135 ft²)
- **Empty weight:** 1,395 kg (3,075 lb)
- **Loaded weight:** 1,880 kg (4,145 lb)
- **Powerplant:** 1× Renault 12R 03 inverted V-12 inline piston engine, 373 kW (500 hp)

Performance

- **Maximum speed:** 460 km/h (249 kn, 286 mph) at 5,000 m (16,400 ft)
- **Range:** 900 km (486 nmi, 559 mi)
- **Climb to 4,000 m:** 9.66 min

Armament

- 4 × 7.5 mm MAC 1934 machine guns

Chapter 7

Stealth Aircraft

An F-117 Nighthawk stealth strike aircraft

Stealth aircraft are aircraft that use stealth technology to interfere with radar detection as well as means other than conventional aircraft by employing a combination of features to reduce visibility in the infrared, visual, audio, and radio frequency (RF) spectrum. Development of stealth technology likely began in Germany during WWII. Well-known modern examples of stealth aircraft include the United States' F-117 Nighthawk (1981–2008), the B-2 Spirit "Stealth Bomber", the F-22 Raptor, and the F-35 Lightning II While no aircraft is totally invisible to radar, stealth aircraft prevent conventional radar from detecting or tracking the aircraft effectively, reducing the odds of an attack. Stealth is accomplished by using a complex design philosophy to reduce the ability of an opponent's sensors to detect, track, or attack the stealth aircraft. This philosophy also takes into account the heat, sound, and other emissions of the aircraft as these can also be used to locate it.

Stealth is the combination of passive low observable (LO) features and active emitters such as Low Probability of Intercept Radars, radios and laser designators. These are usually combined with active defenses such as chaff, flares, and ECM.

Full-size stealth combat aircraft demonstrators have been flown by the United States (in 1977), Russia (in 2010) and China (in 2011).

Background

A World War I attempt to reduce the visibility of military aircraft resulted in the German, heavy bomber, the Linke-Hofmann R.I; this had a wooden structure convered with transparent material. The first true "stealth" aircraft may have been the Horten Ho 229 flying wing fighter-bomber, developed in Germany during the last years of World War II. In addition to the aircraft's shape, which may not have been a deliberate attempt to affect radar deflection, the majority of the Ho 229's wooden skin was bonded together using carbon-impregnated plywood resins designed with the purported intention of absorbing radar waves. Testing performed in early 2009 by the Northrop-Grumman Corporation established that this compound, along with the aircraft's shape, would have rendered the Ho 229 virtually invisible to Britain's Chain Home early warning radar, provided the aircraft was traveling at high speed (~550 mph) at extremely low altitude (50–100 feet).

In the closing weeks of WWII the US military initiated "Operation Paperclip", an effort by the US Army to capture as much advanced German weapons research as possible, and also to deny that research to advancing Soviet troops. A Horton glider and the Ho 229 number V3 were secured and sent to Northrop Aviation for evaluation in the United States, who much later used a flying wing design for the B-2 stealth bomber. During WWII Northrop had been commissioned to develop a large wing-only long-range bomber (XB-35) based on photographs of the Horton's record-setting glider from the 1930s, but their initial designs suffered controllability issues that were not resolved until after the war. Northrop's small one-man prototype (N9M-B) and a Horton wing-only glider are located in the Chino Air Museum in Southern California.

Modern stealth aircraft first became possible when Denys Overholser, a mathematician working for Lockheed Aircraft during the 1970s, adopted a mathematical model developed by Petr Ufimtsev, a Russian scientist, to develop a computer program called Echo 1. Echo made it possible to predict the radar signature an aircraft made with flat panels, called facets. In 1975, engineers at Lockheed Skunk Works found that an airplane made with faceted surfaces could have a very low radar signature because the surfaces would radiate almost all of the radar energy away from the receiver. Lockheed built a model called "the Hopeless Diamond", so-called because it resembled a squat diamond, and looked too hopeless to ever fly. Because advanced computers were available to control the flight of even a Hopeless Diamond, for the first time designers realized that it might be possible to make an aircraft that was virtually invisible to radar.

Reduced radar cross section is only one of five factors that designers addressed to create a truly stealthy design such as the F-22. The F-22 has also been designed to disguise its infrared emissions to make it harder to detect by infrared homing ("heat seeking") surface-to-air or air-to-air missiles. Designers also addressed making the aircraft less visible to the naked eye, controlling radio transmissions, and noise abatement.

The first combat use of purpose-designed stealth aircraft was in December 1989 during Operation Just Cause in Panama. On December 20, 1989, two USAF F-117s bombed a Panamanian Defense Force barracks in Rio Hato, Panama. In 1991, F-117s were tasked with attacking the most heavily fortified targets in Iraq in the opening phase of Operation Desert Storm and were the only jets allowed to operate inside Baghdad's city limits.

Limitations

B-2 Spirit stealth bomber of the U.S Air Force

Instability of design

Early stealth aircraft were designed with a focus on minimal radar cross section (RCS) rather than aerodynamic performance. Highly stealth aircraft like the F-117 Nighthawk and B-2 Spirit are aerodynamically unstable in all three axes and require constant flight corrections from a fly-by-wire system to maintain controlled flight. Most modern non-stealth fighter aircraft (F-16, Su-27, Gripen, Rafale) are unstable on one or two axes only. However, in the pursuit of increased maneuverability, most 4th and 5th-generation fighter aircraft have been designed with some degree of inherent instability that must be controlled by fly-by-wire computers.

Dogfighting ability

Earlier stealth aircraft (such as the F-117 and B-2) lack afterburners, because the hot exhaust would increase their infrared footprint, and breaking the sound barrier would produce an obvious sonic boom, as well as surface heating of the aircraft skin which also increased the infrared footprint. As a result their performance in air combat maneuvering required in a dogfight would never match that of a dedicated fighter aircraft. This was unimportant in the case of these two aircraft since both were designed to be bombers. More recent design techniques allow for stealthy designs such as the F-22 without compromising aerodynamic performance. Newer stealth aircraft, like the F-22 and F-35, have performance characteristics that meet or exceed those of current front-line jet fighters due to advances in other technologies such as flight control systems, engines, airframe construction and materials.

Electromagnetic emissions

The high level of computerization and large amount of electronic equipment found inside stealth aircraft are often claimed to make them vulnerable to passive detection. This is highly unlikely and certainly systems such as Tamara and Kolchuga, which are often described as counter-stealth radars, are not designed to detect stray electromagnetic fields of this type. Such systems are designed to detect intentional, higher power emissions such as radar and communication signals. Stealth aircraft are deliberately operated to avoid or reduce such emissions.

Current Radar Warning Receivers look for the regular pings of energy from mechanically swept radars while fifth generation jet fighters use Low Probability of Intercept Radars with no regular repeat pattern.

Vulnerable modes of flight

Stealth aircraft are still vulnerable to detection during, and immediately after using their weaponry. Since stealth payload (reduced RCS bombs and cruise missiles) are not yet generally available, and ordnance mount points create a significant radar return, stealth aircraft carry all armament internally. As soon as weapons bay doors are opened, the plane's RCS will be multiplied and even older generation radar systems will be able to locate the stealth aircraft. While the aircraft will reacquire its stealth as soon as the bay doors are closed, a fast response defensive weapons system has a short opportunity to engage the aircraft.

This vulnerability is addressed by operating in a manner that reduces the risk and consequences of temporary acquisition. The B-2's operational altitude imposes a flight time for defensive weapons that makes it virtually impossible to engage the aircraft during its weapons deployment. All stealthy aircraft carry weapons in internal weapons bays. New stealth aircraft designs such as the F-22 and F-35 can open their bays, release munitions and return to stealthy flight in less than a second.

Some weapons require that the weapon's guidance system acquire the target while the weapon is still attached to the aircraft. This forces relatively extended operations with the bay doors open.

Also, such aircraft as the F-22 Raptor and F-35 Lighting II Joint Strike Fighter can also carry additional weapons and fuel on hardpoints below their wings. When operating in this mode the planes will not be nearly as stealthy, as the hardpoints and the weapons mounted on those hardpoints will show up on radar systems. This option therefore represents a trade off between stealth or range and payload. External stores allow those aircraft to attack more targets further away, but will not allow for stealth during that mission as compared to a shorter range mission flying on just internal fuel and using only the more limited space of the internal weapon bays for armaments.

Reduced payload

In a 1994 live fire exercise near Point Mugu, California, a B-2 Spirit dropped forty-seven 500 lb (230 kg) class Mark 82 bombs, which represents about half of a B-2's total ordnance payload in Block 30 configuration

Fully stealth aircraft carry all fuel and armament internally, which limits the payload. By way of comparison, the F-117 carries only two laser or GPS guided bombs, while a non-stealth attack aircraft can carry several times more. This requires the deployment of additional aircraft to engage targets that would normally require a single non-stealth attack aircraft. This apparent disadvantage however is offset by the reduction in fewer supporting aircraft that are required to provide air cover, air-defense suppression and electronic counter measures, making stealth aircraft "force multipliers".

Sensitive skin

The B-2 Stealth Bomber has a skin made with highly specialized materials like Polygraphite.

Cost of operations

Stealth aircraft are typically more expensive to develop and manufacture. An example is the B-2 Spirit that is many times more expensive to manufacture and support than conventional bomber aircraft. The B-2 program costs the U.S. Air Force almost $45 billion.

Detection

Theoretically there are a number of methods to detect stealth aircraft at long range.

Reflected waves

Passive (multistatic) radar, bistatic radar and especially multistatic systems are believed to detect some stealth aircraft better than conventional monostatic radars, since first-generation stealth technology (such as the F117) reflects energy away from the transmitter's line of sight, effectively increasing the radar cross section (RCS) in other directions, which the passive radars monitor. Such a system typically uses either low frequency broadcast TV and FM radio signals (at which frequencies controlling the aircraft's signature is more difficult). Later stealth approaches do not rely on controlling the specular reflections of radar energy and so the geometrical benefits are unlikely to be significant.

Researchers at the University of Illinois at Urbana-Champaign with support of DARPA, have shown that it is possible to build a synthetic aperture radar image of an aircraft target using passive multistatic radar, possibly detailed enough to enable automatic target recognition (ATR).

In December 2007, SAAB researchers also revealed details for a system called Associative Aperture Synthesis Radar (AASR) that would employ a large array of inexpensive and redundant transmitters and a few intelligent receivers to exploit forward scatter to detect low observable targets. The system was originally designed to detect stealthy cruise missiles and should be just as effective against aircraft. The large array of inexpensive transmitters also provides a degree of protection against anti-radar (or anti-radiation) missiles or attacks.

Infrared (heat)

Some analysts claim Infra-red search and track systems (IRSTs) can be deployed against stealth aircraft, because any aircraft surface heats up due to air friction and with a two channel IRST is a CO_2 (4.3 μm absorption maxima) detection possible, through difference comparing between the low and high channel. These analysts also point to the resurgence in such systems in several Russian designs in the 1980s, such as those fitted to the MiG-29 and Su-27. The latest version of the MiG-29, the MiG-35, is equipped with a new Optical Locator System that includes even more advanced IRST capabilities.

In air combat, the optronic suite allows:

- Detection of non-afterburning targets at 45 km range and more;
- Identification of those targets at 8 to 10 km range; and
- Estimates of aerial target range at up to 15 km.

For ground targets, the suite allows:

- A tank-effective detection range up to 15 km, and aircraft carrier detection at 60 to 80 km;
- Identification of the tank type on the 8 to 10 km range, and of an aircraft carrier at 40 to 60 km; and
- Estimates of ground target range of up to 20 km.

Wavelength match

The Dutch company Thales Nederland, formerly known as Holland Signaal, have developed a naval phased-array radar called SMART-L, which also is operated at L-Band and is claimed to offer counter stealth benefits. However, as with most claims of counter-stealth capability, these are unproven and untested. True resonant effects might be expected with HF sky wave radar systems, which have wavelengths of tens of metres. However, in this case, the accuracy of the radar systems is such that the detection is of limited value for engagement. Any radar which can successfully match the resonant frequency of a type of stealth aircraft should be able to detect its direction. In practice this is difficult because the resonant frequency changes depending on how the stealth aircraft is oriented with respect to the radar system.

OTH radar (over-the-horizon radar)

Over-the-horizon radar is a design concept that increases radar's effective range over conventional radar. It is claimed that the Australian JORN Jindalee Operational Radar Network can overcome certain stealth characteristics. It is claimed that the HF frequency used and the method of bouncing radar from ionosphere overcomes the stealth characteristics of the F-117A. In other words, stealth aircraft are optimized for defeating much higher-frequency radar from front-on rather than low-frequency radars from above.

Use of stealth aircraft

USAF F-22 Raptor stealth fighter of the 27th Fighter Squadron

The F-35 Lightning II was developed by the United States

To date, stealth aircraft have been used in several low- and moderate-intensity conflicts, including Operation Desert Storm, Operation Allied Force and the 2003 invasion of Iraq. In each case they were employed to strike high-value targets that were either out of range of conventional aircraft in the theater or were too heavily defended for conventional aircraft to strike without a high risk of loss. In addition, because the stealth aircraft do not have to evade surface-to-air missiles and anti-aircraft artillery over the target they can aim more carefully and thus are more likely to hit the target and cause less collateral damage. In many cases they were used to hit the high value targets early in the campaign, before other aircraft had the opportunity to degrade the opposing air defense to the point where other aircraft had a good chance of reaching those critical targets.

Stealth aircraft in future low- and moderate-intensity conflicts are likely to have similar roles. However, given the increasing prevalence of Russian-built surface-to-air missile systems on the open market (such as the SA-10, SA-12 and SA-20 (S-300P/V/PMU) and SA-15 (9K331/332)), stealth aircraft are likely to be very important in a high-intensity conflict in order to gain and maintain air supremacy, especially to the United States who is likely to face these types of systems. It is possible to cover one's airspace with so many air defenses with such long range and capability that conventional aircraft would find it very difficult "clearing the way" for deeper strikes. For example, China license-builds all of the previously mentioned SAM systems in large quantities and would be able to heavily defend important strategic and tactical targets in the event of a conflict. Even if anti-radiation weapons are used in an attempt to destroy the SAM radars of such systems, or stand-off weapons are launched against them, these modern surface-to-air missile batteries are capable of shooting down weapons fired against them.

Stealth aircraft lost

The first (and to date only) case of a stealth aircraft being shot down happened on 27 March 1999, during Operation Allied Force. An Isayev S-125 'Neva-M' missile was fired at an American F-117 Nighthawk and successfully brought it down.

List of stealth aircraft

Manned

Fully stealth designs

In service

- **B-2 Spirit** - Northrop Grumman
- **F-22 Raptor** -Lockheed Martin / Boeing

Formerly in service

- **F-117 Nighthawk** - Lockheed Martin

Under development

- **Chengdu J-20** - Chengdu Aircraft Corporation
- **F-35 Lightning II (JSF)** - Lockheed Martin / BAE Systems / Northrop Grumman
- **FGFA** - Sukhoi/HAL
- **J-XX** - Shenyang Aircraft Corporation
- **PAK DA** - Tupolev
- **PAK FA** - Sukhoi

Cancelled

- **A-12 Avenger II** - McDonnell-Douglas / General Dynamics
- **Boeing X-32** - Boeing - lost to Lockheed for JSF
- **YF-23 Black Widow II** - Northrop / McDonnell Douglas - prototype built, but lost competition to YF-22
- **MBB Lampyridae** - West German stealth fighter prototype
- **RAH-66 Comanche** - Boeing Sikorsky

Technology demonstrators

- **BAE Replica** - BAE Systems
- **Boeing Bird of Prey** - Boeing
- **Have Blue** - Lockheed
- **Mitsubishi ATD-X** - Mitsubishi Heavy Industries
- **Northrop Tacit Blue** - Northrop
- **Northrop YB-49**

Reduced cross section designs

- **Chengdu J-10B** - "DSI/bump engine inlet which not only cuts weight but also reduces RCS"
- **SR-71 Blackbird** - Skunkworks Blackbirds were first production RCS aircraft; 1962 with CIA A-12, then later with SR-71, YF-12 and M-21 Blackbird series of aircraft
- **Tu-160** - Russian strategic bomber
- **Avro Vulcan** - British strategic bomber with delta wing and buried engines that gave an unplanned low radar cross-section
- **B-1B Lancer** - RCS to about 10 m2
- **Dassault Rafale** - RCS to about 0.75 m2
- **De Havilland Mosquito** - British light bomber and ground attack plane of wooden construction, low RCS against early radars.
- **Eurofighter Typhoon** - RCS to about 0.25-0.75 m2
- **F-16 Fighting Falcon** C/D and E/F - from Block 30 has got reduced RCS to about $1.2m^2$
- **F/A-18 Hornet** C/D - reduced RCS, believed be to similar to F-16C's
- **F/A-18E/F Super Hornet** - The F/A-18E/F's radar cross section was reduced greatly from some aspects, mainly the front and rear. RCS to about 0.75 m2
- **MiG 1.44** - Russian 5th generation fighter prototype
- **Mikoyan MiG-29K** - Due to special coatings Mig-29K radar reflecting surface is 4-5 times smaller than of basic MiG-29. RCS to about 0.60-0.75 m2
- **Sukhoi Su-47** - Russian technology demonstrator
- **Messerschmitt Me 163B** rocket-powered fighter aircraft.
- **PZL-230 Skorpion**
- **LCA(Tejas)**
- **Horten Ho 229** Flying wing turbojet fighter only 10% detected on radar, prototype test in 1944. Project cancelled in 1945 due to the worsening war situation.

Unmanned RCS designs

- **Boeing X-45** - Boeing - based on the manned Boeing Bird of Prey demonstrator (**technology demonstrator**)
- **BAE Taranis** - BAE Systems (**UCAV Technology Demonstrator**)
- **Dassault nEUROn - technology demonstrator**
- **EADS Barracuda** - EADS of Germany (**technology demonstrator**)
- **Rheinmetall KZO** - Rheinmetall (**tactical UAV**)

- **RQ-3 Dark Star** - Lockheed / Skunk Works (**cancelled**)
- **Armstechno NITI** - Armstechno, Bulgaria (**tactical UAV**)
- **RQ-170 Sentinel**
- **MiG Skat** - Mikoyan, Russia
- **X-47B** - Northrop Grumman, USA (**technology demonstrator**)

Chapter 8

Stealth Technology

F-117 stealth attack plane

Stealth technology also termed **LO technology** (**low observable technology**) is a sub-discipline of military tactics and passive electronic countermeasures, which cover a range of techniques used with personnel, aircraft, ships, submarines, and missiles, to make them less visible (ideally invisible) to radar, infrared, sonar and other detection methods.

Development in the United States occurred in 1958, where earlier attempts in preventing radar tracking of its U-2 spy planes during the Cold War by the Soviet Union had been unsuccessful. Designers turned to develop a particular shape for planes that tended to reduce detection, by redirecting electromagnetic waves from radars. Radar-absorbent material was also tested and made to reduce or block radar signals that reflect off from the surface of planes. Such changes to shape and surface composition form stealth technology as currently used on the Northrop Grumman B-2 Spirit "Stealth Bomber". The concept of stealth is to operate or hide without giving enemy forces any indications as to the presence of friendly forces. This concept was first explored through camouflage by blending into the background visual clutter. As the potency of detection and interception technologies (radar, IRST, surface-to-air missiles etc.) have increased over time, so too has the extent to which the design and operation of military personnel and vehicles have been affected in response. Some military uniforms are treated with chemicals to reduce their infrared signature. A modern "stealth" vehicle will generally have been designed from the outset to have reduced or controlled signature. Varying degrees of stealth can be achieved. The exact level and nature of stealth embodied in a particular design is determined by the prediction of likely threat capabilities.

History

In England, irregular units of gamekeepers in the 17th century were the first to adopt drab colours (common in the 16th century Irish units) as a form of camouflage, following examples from the continent.

Yehudi lights were successfully employed in World War II by RAF Shorts Sunderland aircraft in attacks on U-boats. In 1945 a Grumman Avenger with Yehudi lights got within 3,000 yards (2,700 m) of a ship before being sighted. This ability was rendered obsolete by the radar of the time.

One of the earliest stealth aircraft seems to have been the Horten Ho 229 flying wing. It included carbon powder in the glue to absorb radio waves. Some prototypes were built, but it was never used in action.

In 1958, the CIA requested funding for a reconnaissance aircraft, to replace U-2 spy planes in which Lockheed secured contractual rights to produce the aircraft. "Kelly" Johnson and his team at Lockheed's Skunk Works were assigned to produce the A-12 or OXCART the first of the former top secret classified Blackbird series which operated at high altitude of 70,000 to 80,000 ft and speed of Mach 3.2 to avoid radar detection. Radar absorbent material had already been introduced on U-2 spy planes, and various plane shapes had been developed in earlier prototypes named A1 to A11 to reduce its detection from radar. Later in 1964, using prior models, an optimal plane shape taking into account compactness was developed where another "Blackbird", the SR-71, was produced, surpassing prior models in both altitude of 90,000 ft and speed of Mach 3.3.

During 1970s, the U.S. Department of Defence then launched a project called Have Blue the project to develop a stealth fighter. Bidding between both Lockheed and Northrop for the tender was fierce to secure the multi-billion dollar contract. Lockheed incorporated in its program paper written by a Soviet/Russian physicist Pyotr Ufimtsev in 1962 titled Method of Edge Waves in the Physical Theory of Diffraction, Soviet Radio, Moscow, 1962. In 1971 this book was translated into English with the same title by U.S. Air Force, Foreign Technology Division (National Air Intelligence Center), Wright-Patterson AFB, OH, 1971. Technical Report AD 733203, Defense Technical Information Center of USA, Cameron Station, Alexandria, VA, 22304-6145, USA. This theory played a critical role in the design of American stealth-aircraft F-117 and B-2. The paper was able to find whether a plane's shape design would minimise its detection by radar or its radar cross-section (RCS) using a series of equations could be used to evaluate the radar cross section of any shape. Lockheed used it to design a shape they called the Hopeless Diamond, securing contractual rights to mass produce the F-117 Nighthawk.

The F-117 project began with a model called "The Hopeless Diamond" (a wordplay on the Hope Diamond) in 1975 due to its bizarre appearance. In 1977 Lockheed produced two 60% scale models under the Have Blue contract. The Have Blue program was a stealth technology demonstrator that lasted from 1976 to 1979. The success of Have Blue lead the Air Force to create the Senior Trend program which developed the F-117.

Principles

Stealth technology (or LO for "low observability") is not a single technology. It is a combination of technologies that attempt to greatly reduce the distances at which a person or vehicle can be detected; in particular radar cross section reductions, but also acoustic, thermal, and other aspects:

Radar cross-section (RCS) reductions

Almost since the invention of radar, various methods have been tried to minimize detection. Rapid development of radar during WWII led to equally rapid development of numerous counter radar measures during the period; a notable example of this was the use of chaff.

The term "stealth" in reference to reduced radar signature aircraft became popular during the late eighties when the Lockheed Martin F-117 stealth fighter became widely known. The first large scale (and public) use of the F-117 was during the Gulf War in 1991. However, F-117A stealth fighters were used for the first time in combat during Operation Just Cause, the United States invasion of Panama in 1989. Increased awareness of stealth vehicles and the technologies behind them is prompting the development of means to detect stealth vehicles, such as passive radar arrays and low-frequency radars. Many countries nevertheless continue to develop low-RCS vehicles because they offer advantages in detection range reduction and amplify the effectiveness of on-board systems against active radar guidance threats.

Vehicle shape

The F-35 Lightning II offers better stealthy features (such as this landing gear door) than prior American fighters, such as the F-16 Fighting Falcon

The possibility of designing aircraft in such a manner as to reduce their radar cross-section was recognized in the late 1930s, when the first radar tracking systems were employed, and it has been known since at least the 1960s that aircraft shape makes a significant difference in detectability. The Avro Vulcan, a British bomber of the 1960s, had a remarkably small appearance on radar despite its large size, and occasionally disappeared from radar screens entirely. It is now known that it had a fortuitously stealthy shape apart from the vertical element of the tail. In contrast, the Tupolev 95 Russian long range bomber (NATO reporting name 'Bear') appeared especially well on radar. It is now known that propellers and jet turbine blades produce a bright radar image; the Bear had four pairs of large (5.6 meter diameter) contra-rotating propellers.

Another important factor is internal construction. Some stealth aircraft have skin that is radar transparent or absorbing, behind which are structures termed re-entrant triangles. Radar waves penetrating the skin get trapped in these structures, reflecting off the internal faces and losing energy. This method was first used on the Blackbird series (A-11 / YF-12A / SR-71).

The most efficient way to reflect radar waves back to the emitting radar is with orthogonal metal plates, forming a corner reflector consisting of either a dihedral (two plates) or a trihedral (three orthogonal plates). This configuration occurs in the tail of a conventional aircraft, where the vertical and horizontal components of the tail are set at right angles. Stealth aircraft such as the F-117 use a different arrangement, tilting the tail surfaces to reduce corner reflections formed between them. A more radical method is to eliminate the tail completely, as in the B-2 Spirit.

In addition to altering the tail, stealth design must bury the engines within the wing or fuselage, or in some cases where stealth is applied to an extant aircraft, install baffles in the air intakes, so that the turbine blades are not visible to radar. A stealthy shape must be devoid of complex bumps or protrusions of any kind; meaning that weapons, fuel tanks, and other stores must not be carried externally. Any stealthy vehicle becomes un-stealthy when a door or hatch opens.

Planform alignment is also often used in stealth designs. Planform alignment involves using a small number of surface orientations in the shape of the structure. For example, on the F-22A Raptor, the leading edges of the wing and the tail surfaces are set at the same angle. Careful inspection shows that many small structures, such as the air intake bypass doors and the air refueling aperture, also use the same angles. The effect of planform alignment is to return a radar signal in a very specific direction away from the radar emitter rather than returning a diffuse signal detectable at many angles.

Stealth airframes sometimes display distinctive serrations on some exposed edges, such as the engine ports. The YF-23 has such serrations on the exhaust ports. This is another example in the use of re-entrant triangles and planform alignment, this time on the external airframe.

Shaping requirements have strong negative influence on the aircraft's aerodynamic properties. The F-117 has poor aerodynamics, is inherently unstable, and cannot be flown without a fly-by-wire control system.

Ships have also adopted similar methods. The Skjold class patrol boat was the first stealth ship to enter service, though the earlier Arleigh Burke class destroyer incorporated some signature-reduction features . Other examples are the French La Fayette class frigate, the German Sachsen class frigates, the Swedish Visby class corvette, the USS San Antonio amphibious transport dock, and most modern warship designs.

Similarly, coating the cockpit canopy with a thin film transparent conductor (vapor-deposited gold or indium tin oxide) helps to reduce the aircraft's radar profile, because radar waves would normally enter the cockpit, reflect off objects (the inside of a cockpit has a complex shape, with a pilot helmet alone forming a sizeable return), and possibly return to the radar, but the conductive coating creates a controlled shape that deflects the incoming radar waves away from the radar. The coating is thin enough that it has no adverse effect on pilot vision.

Non-metallic airframe

Dielectric composites are more transparent to radar, whereas electrically conductive materials such as metals and carbon fibers reflect electromagnetic energy incident on the material's surface. Composites may also contain ferrites to optimize the dielectric and magnetic properties of a material for its application.

Radar-absorbing material

Radar-absorbent material (RAM), often as paints, are used especially on the edges of metal surfaces. While the material and thickness of RAM coatings is classified, the material seeks to absorb radiated energy from a ground or air based radar station into the coating and convert it to heat rather than reflect it back.

Radar-absorbent material, or **RAM**, is a class of materials used in stealth technology to disguise a vehicle or structure from radar detection. A material's absorbency at a given frequency of radar wave depends upon its composition. RAM cannot perfectly absorb radar at any frequency, but any given composition does have greater absorbancy at some frequencies than others; there is no one RAM that is suited to absorption of all radar frequencies.

A common misunderstanding is that RAM makes an object invisible to radar. A radar absorbent material can significantly reduce an object's radar cross-section in specific radar frequencies, but it does not result in "invisibility" on any frequency. Bad weather may contribute to deficiencies in stealth capability. A particularly disastrous example occurred during the Kosovo war, in which moisture on the surface of an F-117 Nighthawk allowed long-wavelength radar to track and shoot it down. RAM is only a part of achieving stealth.

History

The earliest forms of RAM were the materials called Sumpf and Schornsteinfeger, a coating used by Germans during the World War II for the snorkels (or periscopes) of submarines, to lower their reflectivity in the 20-centimeter radar band the Allies used. The material had a layered structure and was based on graphite particles and other semiconductive materials embedded in a rubber matrix. The material's efficiency was partially reduced by the action of sea water.

Germany also pioneered the first aircraft to use RAM during World War II, in the form of the Horten Ho 229. It used a carbon-impregnated plywood that would have made it very stealthy to Britain's primitive radar of the time. However it is unknown if the carbon was incorporated for stealth reasons or because of Germany's metal shortage.

Types of RAM

Iron ball paint

One of the most commonly known types of RAM is iron ball paint. It contains tiny spheres coated with carbonyl iron or ferrite. Radar waves induce molecular oscillations from the alternating magnetic field in this paint, which leads to conversion of the radar energy into heat. The heat is then transferred to the aircraft and dissipated. The iron particles in the paint are obtained by decomposition of iron pentacarbonyl and may contain traces of carbon, oxygen and nitrogen.

A related type of RAM consists of neoprene polymer sheets with ferrite grains or carbon black particles (containing about 30% of crystalline graphite) embedded in the polymer matrix. The tiles were used on early versions of the F-117A Nighthawk, although more recent models use painted RAM. The painting of the F-117 is done by industrial robots with the plane covered in tiles glued to the fuselage and the remaining gaps filled with iron ball paint.

The United States Air Force introduced a radar absorbent paint made from both ferrofluidic and non-magnetic substances. By reducing the reflection of electromagnetic waves, this material helps to reduce the visibility of RAM painted aircraft on radar.

Foam absorber

Foam absorber is used as lining of anechoic chambers for electromagnetic radiation measurements. This material typically consists of a fireproofed urethane foam loaded with carbon black, and cut into long pyramids. The length from base to tip of the pyramid structure is chosen based on the lowest expected frequency and the amount of absorption required. For low frequency damping, this distance is often 24 inches, while high frequency panels are as short as 3-4 inches. Panels of RAM are installed with the tips pointing inward to the chamber. Pyramidal RAM attenuates signal by two effects: scattering and absorption. Scattering can occur both coherently, when reflected waves are in-phase but directed away from the receiver, or incoherently where waves are picked up by the receiver but are out of phase and thus have lower signal strength. This incoherent scattering also occurs within the foam structure, with the suspended carbon particles promoting destructive interference. Internal scattering can result in as much as 10dB of attenuation. Meanwhile, the pyramid shapes are cut at angles that maximize the number of bounces a wave makes within the structure. With each bounce, the wave loses energy to the foam material and thus exits with lower signal strength. Other foam absorbers are available in flat sheets, using an increasing gradient of carbon loadings in different layers.

Jaumann absorber

A Jaumann absorber or Jaumann layer is a radar absorbent device. When first introduced in 1943, the Jaumann layer consisted of two equally-spaced reflective surfaces and a conductive ground plane. One can think of it as a generalized, multi-layered Salisbury screen as the principles are similar.

Being a resonant absorber (i.e. it uses wave interfering to cancel the reflected wave), the Jaumann layer is dependent upon the $\lambda/4$ spacing between the first reflective surface and the ground plane and between the two reflective surfaces (a total of $\lambda/4 + \lambda/4$).

Because the wave can resonate at two frequencies, the Jaumann layer produces two absorption maxima across a band of wavelengths (if using the two layers configuration). These absorbers must have all of the layers parallel to each other and the ground plane that they conceal.

More elaborate Jaumann absorbers use series of dielectric surfaces that separate conductive sheets. The conductivity of those sheets increases with proximity to the ground plane.

Radar stealth countermeasures and limits

Low-frequency radar

Shaping does not offer stealth advantages against low-frequency radar. If the radar wavelength is roughly twice the size of the target, a half-wave resonance effect can still generate a significant return. However, low-frequency radar is limited by lack of available frequencies-many are heavily used by other systems, by lack of accuracy of the diffraction-limited systems given their long wavelengths, and by the radar's size, making it difficult to transport. A long-wave radar may detect a target and roughly locate it, but not identify it, and the location information lacks sufficient weapon targeting accuracy, or even to guide a fighter to the target. Noise poses another problem, but that can be efficiently addressed using modern computer technology; Chinese "Nantsin" radar and many older Soviet-made long-range radars were modified this way. It has been said that "there's nothing invisible in the radar frequency range below 2 GHz".

Multiple transmitters

Much of the stealth comes from reflecting the transmissions in a different direction other than a direct return. Thus, detection can be better achieved if the sources are spaced from the receivers, termed bistatic radar, and proposals exist to use reflections from sources such as civilian radio transmitters, including cellular telephone radio towers.

Moore's law

By Moore's law the processing power behind radar systems is rising over time. This will erode the ability of physical stealth to hide vehicles. However, that same level of improvement will boost the electronic warfare equipment of stealth vehicles, which will always have a quieter return signal to mask than a non-stealth craft would return.

Acoustics

Acoustic stealth plays a primary role in submarine stealth as well as for ground vehicles. Submarines use extensive rubber mountings to isolate and avoid mechanical noises that could reveal locations to underwater passive sonar arrays.

Early stealth observation aircraft used slow-turning propellers to avoid being heard by enemy troops below. Stealth aircraft that stay subsonic can avoid being tracked by sonic boom. The presence of supersonic and jet-powered stealth aircraft such as the SR-71 Blackbird indicates that acoustic signature is not always a major driver in aircraft design, although the Blackbird relied more on its extremely high speed and altitude.

Visibility

The simplest stealth technology is simply camouflage; the use of paint or other materials to color and break up the lines of the vehicle or person.

Most stealth aircraft use matte paint and dark colors, and operate only at night. Lately, interest in daylight Stealth (especially by the USAF) has emphasized the use of gray paint in disruptive schemes, and it is assumed that Yehudi lights could be used in the future to mask shadows in the airframe (in daylight, against the clear background of the sky, dark tones are easier to detect than light ones) or as a sort of active camouflage. The original B-2 design had wing tanks for a contrail-inhibiting chemical, alleged by some to be chlorofluorosulphonic acid, but this was replaced in the final design with a contrail sensor from Ophir that alerts the pilot when he should change altitude and mission planning also considers altitudes where the probability of their formation is minimized.

Infrared

An exhaust plume contributes a significant infrared signature. One means to reduce IR signature is to have a non-circular tail pipe (a slit shape) to minimize the exhaust cross-sectional volume and maximize the mixing of hot exhaust with cool ambient air. Often, cool air is deliberately injected into the exhaust flow to boost this process. Sometimes, the jet exhaust is vented above the wing surface to shield it from observers below, as in the B-2 Spirit, and the unstealthy A-10 Thunderbolt II. To achieve infrared stealth, the exhaust gas is cooled to the temperatures where the brightest wavelengths it radiates are absorbed by atmospheric carbon dioxide and water vapor, dramatically reducing the infrared visibility of the exhaust plume. Another way to reduce the exhaust temperature is to circulate coolant fluids such as fuel inside the exhaust pipe, where the fuel tanks serve as heat sinks cooled by the flow of air along the wings.

Ground combat includes the use of both active and passive infrared sensors and so the USMC ground combat uniform requirements document specifies infrared reflective quality standards.

Reducing radio frequency (RF) emissions

In addition to reducing infrared and acoustic emissions, a stealth vehicle must avoid radiating any other detectable energy, such as from onboard radars, communications systems, or RF leakage from electronics enclosures. The F-117 uses passive infrared and low light level television sensor systems to aim its weapons and the F-22 Raptor has an advanced LPI radar which can illuminate enemy aircraft without triggering a radar warning receiver response.

Measuring

The size of a target's image on radar is measured by the radar cross section or RCS, often represented by the symbol σ and expressed in square meters. This does not equal geometric area. A perfectly conducting sphere of projected cross sectional area 1 m^2 (i.e. a diameter of 1.13 m) will have an RCS of 1 m^2. Note that for radar wavelengths much less than the diameter of the sphere, RCS is independent of frequency. Conversely, a square flat plate of area 1 m^2 will have an RCS of $\sigma = 4\pi A^2 / \lambda^2$ (where A=area, λ=wavelength), or 13,982 m^2 at 10 GHz if the radar is perpendicular to the flat surface. At off-normal incident angles, energy is reflected away from the receiver, reducing the RCS. Modern stealth aircraft are said to have an RCS comparable with small birds or large insects, though this varies widely depending on aircraft and radar.

If the RCS was directly related to the target's cross-sectional area, the only way to reduce it would be to make the physical profile smaller. Rather, by reflecting much of the radiation away or absorbing it altogether, the target achieves a smaller radar cross section.

Tactics

Stealthy strike aircraft such as the F-117, designed by Lockheed Martin's famous Skunk Works, are usually used against heavily defended enemy sites such as Command and Control centers or surface-to-air missile (SAM) batteries. Enemy radar will cover the airspace around these sites with overlapping coverage, making undetected entry by conventional aircraft nearly impossible. Stealthy aircraft can also be detected, but only at short ranges around the radars, so that for a stealthy aircraft there are substantial gaps in the radar coverage. Thus a stealthy aircraft flying an appropriate route can remain undetected by radar. Many ground-based radars exploit Doppler filter to improve sensitivity to objects having a radial velocity component with respect to the radar. Mission planners use their knowledge of enemy radar locations and the RCS pattern of the aircraft to design a flight path that minimizes radial speed while presenting the lowest-RCS aspects of the aircraft to the threat radar. To be able to fly these "safe" routes, it is necessary to understand an enemy's radar coverage . Airborne or mobile radar systems such as AWACS can complicate tactical strategy for stealth operation.

Chapter 9

Northrop Grumman B-2 Spirit

B-2 Spirit

A USAF B-2 Spirit in flight

Role	Stealth bomber
National origin	United States
Manufacturer	Northrop Corporation Northrop Grumman
First flight	17 July 1989
Introduction	April 1997
Status	Active service: 20 aircraft
Primary user	United States Air Force
Number built	21
Program cost	US$44.75 billion (projected through 2004)
Unit cost	$737 million (1997 cost for each aircraft only, $1.01 billion today)

The Northrop Grumman **B-2 Spirit** (also known as the Stealth Bomber) is an American heavy bomber with "low observable" stealth technology designed to penetrate dense anti-aircraft defenses and deploy both conventional and nuclear weapons. Because of its considerable capital and operational costs, the project was controversial in the U.S. Congress and among the Joint Chiefs of Staff. During the late 1980s and early 1990s, the Congress slashed initial plans to purchase 132 bombers to just 21.

The cost of each aircraft averaged US$737 million in 1997 dollars ($1.01 billion today). Total procurement costs averaged US$929 million per aircraft ($1.27 billion today), which includes spare parts, equipment, retrofitting, and software support. The total program cost, which includes development, engineering and testing, averaged US$2.1 billion per aircraft (in 1997 dollars, $2.87 billion today).

Twenty B-2s are operated by the United States Air Force. Though originally designed in the 1980s for Cold War operations scenarios, B-2s were first used in combat to drop bombs on Serbia during the Kosovo War in 1999, and saw continued use during the wars in Iraq and Afghanistan. One aircraft was lost in 2008 when it crashed just after takeoff; the crew ejected safely.

The bomber has a crew of two and can drop up to 80 x 500 lb (230 kg)-class JDAM GPS-guided bombs, or 16 x 2,400 lb (1,100 kg) B83 nuclear bombs in a single pass through extremely dense anti-aircraft defenses. The B-2 is the only aircraft that can carry large air to surface standoff weapons in a stealth configuration. The program has been the subject of espionage and counter-espionage activity and the B-2 has provided prominent public spectacles at air shows since the 1990s.

Development

ATB project

The B-2 Spirit originated from the Advanced Technology Bomber (ATB) black project that began in 1979. The Cold War was long underway, and on the campaign trail in 1979 and 1980, candidate Ronald Reagan promised to restore American military strength. On 22 August 1980, the incumbent Carter administration publicly disclosed that the Department of Defense was working to develop stealth aircraft including the ATB. In 2007, it was revealed publicly that MIT scientists helped assess the mission effectiveness of the aircraft under classified contract during the 1980s.

The B-2's first public display in 1988

After the evaluations of the companies' proposals, the ATB competition was reduced to the Northrop/Boeing and Lockheed/Rockwell teams with each receiving a study contract for further work. Both teams used flying wing designs. The Northrop design was larger while the Lockheed design was smaller and included a small tail. The black project was funded under the code name "Aurora". The Northrop/Boeing team's ATB design was selected over the Lockheed/Rockwell design on 20 October 1981.

The Northrop design received the designation B-2 and the name "Spirit". The bomber's design was changed in the mid-1980s when the mission profile was changed from high-altitude to low-altitude, terrain-following. The redesign delayed the B-2's first flight by two years and added about US$1 billion to the program's cost. An estimated US$23 billion was secretly spent for research and development on the B-2 by 1989. At the program's peak, approximately 13,000 people were employed at a dedicated plant in Pico Rivera, California for the aircraft's engineering and portions of its manufacturing.

The B-2's first public flight in 1989

The B-2 was first publicly displayed on 22 November 1988, at Air Force Plant 42, Palmdale, California, where it was assembled. This initial viewing was heavily guarded and guests were not allowed to see the rear of the B-2. Its first public flight was on 17 July 1989 from Palmdale.

Procurement

A procurement of 132 aircraft was planned in the mid-1980s, but was later reduced to 75. By the early 1990s, the Soviet Union had disintegrated, which effectively eliminated the Spirit's primary Cold War mission. Under budgetary pressures and congressional opposition, in his 1992 State of the Union Address, President George H.W. Bush announced B-2 production would be limited to 20 aircraft. In 1996, however, the Clinton administration, though originally committed to ending production of the bombers at 20 aircraft, authorized the conversion of a 21st bomber, a prototype test model, to Block 30 fully operational status at a cost of nearly $500 million.

In 1995, Northrop made a proposal to the USAF to build 20 additional aircraft with a flyaway cost of $566 million each.

Espionage

In 1984 a Northrop employee, Thomas Cavanaugh, was arrested for trying to sell classified information to the Soviet Union, which apparently was smuggled out of the Pico Rivera, California factory. Cavanaugh was eventually sentenced to life in prison and released under parole in 2001.

Noshir Gowadia, a design engineer who worked on the B-2's propulsion system, was arrested in October 2005 for selling B-2 related classified information to foreign countries. His trial was initially scheduled for 12 February 2008, but he received a continuance. On 9 August 2010, Gowadia was convicted in the United States District Court for the District of Hawaii on 14 of 17 charges against him. Sentencing had been set for 22 November 2010.

Program costs

In a 1994 live fire exercise near Point Mugu, California, a B-2 drops forty-seven 500 lb (230 kg) class Mark 82 bombs, which is more than half of a B-2's total ordnance payload

The program was the subject of public controversy for its costs to American taxpayers. In 1996 the General Accounting Office disclosed that the USAF's B-2 bombers "will be, by far, the most costly bombers to operate on a per aircraft basis", costing over three times as much as the B-1B (US$9.6 million annually) and over four times as much as the B-52H ($US6.8 million annually). In September 1997, each hour of B-2 flight necessitated 119 hours of maintenance in turn. Comparable maintenance needs for the B-52 and the B-1B are 53 and 60 hours respectively for each hour of flight. A key reason for this cost is the provision of air-conditioned hangars large enough for the bomber's 172 ft (52.4 m) wingspan, which are needed to maintain the aircraft's stealthy properties, especially its "low-observable" stealthy skins. Maintenance costs are about $3.4 million a month for each aircraft.

The total "military construction" cost related to the program was projected to be US$553.6 million in 1997 dollars. The cost to procure each B-2 was US$737 million in 1997 dollars, based only on a fleet cost of US$15.48 billion. The procurement cost per aircraft as detailed in General Accounting Office (GAO) reports, which include spare parts and software support, was $929 million per aircraft in 1997 dollars.

The total program cost projected through 2004 was US$44.75 billion in 1997 dollars. This includes development, procurement, facilities, construction, and spare parts. The total program cost averaged US$2.13 billion per aircraft.

Opposition

In its consideration of the fiscal year 1990 defense budget, the House Armed Services Committee trimmed $800 million from the B-2 research and development budget, while at the same time staving off a motion to kill the bomber. Opposition in committee and in Congress more largely was broad and bipartisan, with Congressmen Ron Dellums (D-CA), John Kasich (R-OH), and John G. Rowland (R-CT) authorizing the motion to kill the bomber and others in the Senate such as Jim Exon (D-NE) and John McCain (R-AZ) also opposing the project.

The growing cost of the B-2 program, and evidence of flaws in the aircraft's ability to elude detection by radar, were among factors that drove opposition. At the peak production period specified in 1989, the schedule called for spending US$7 billion to $8 billion per year in 1989 dollars, something Committee Chair Les Aspin (D-WI) said "won't fly financially."

In 1990, the US Department of Defense accused Northrop of using faulty components in the flight control system. Efforts have also been made to reduce the probability of bird ingestion, which could damage engine fan blades.

In time, a number of prominent members of Congress began to oppose the program's expansion, including former Democratic presidential nominee John Kerry, who cast votes against the B-2 in 1989, 1991 and 1992 while a US Senator representing Massachusetts. By 1992, Republican President George H.W. Bush called for the cancellation of the B-2 and promised to cut military spending by 30% in the wake of the collapse of the Soviet Union.

In May 1995, on the basis of its 1995 Heavy Bomber Force Study, the DOD determined that additional B-2 procurements would exacerbate efforts to develop and implement long term recapitalization plans for the USAF bomber force.

In October 1995, former Chief of Staff of the United States Air Force, General Mike Ryan, and Former Chairman of the Joint Chiefs of Staff, General John Shalikashvili, strongly recommended against Congressional action to fund the purchase of any additional B-2s, arguing that to do so would require unacceptable cuts in existing conventional and nuclear-capable aircraft to pay for the new bombers, and because the military had much higher priorities on which to spend its limited procurement dollars.

Some B-2 advocates argued that procuring twenty additional aircraft would save money because B-2s would be able to deeply penetrate anti-aircraft defenses and use low-cost, short-range attack weapons rather than expensive standoff weapons. However, in 1995, the Congressional Budget Office (CBO), and its Director of National Security Analysis, found that additional B-2s would reduce the cost of weapons expended by the bomber force by less than US$2 billion in 1995 dollars during the first two weeks of a conflict, which is when the Air Force envisions bombers would make their greatest contribution. This is a small fraction of the US$26.8 billion (in 1995 dollars) life cycle cost that the CBO projected an additional 20 B-2s would cost.

In 1997, as Ranking Member of the House Armed Services Committee and National Security Committee, Congressman Ron Dellums (D-CA), a long-time opponent of the bomber, cited five independent studies and offered an amendment to that year's defense authorization bill to cap production of the bombers with the existing 21 aircraft. The amendment was narrowly defeated. Nonetheless, Congress did not approve funding for the purchase of any additional B-2 bombers.

Upgrades

In 2004, Northrop Grumman tested a new alternate high-frequency material (AHFM) for use as a Radar-absorbent material coating for the B-2.

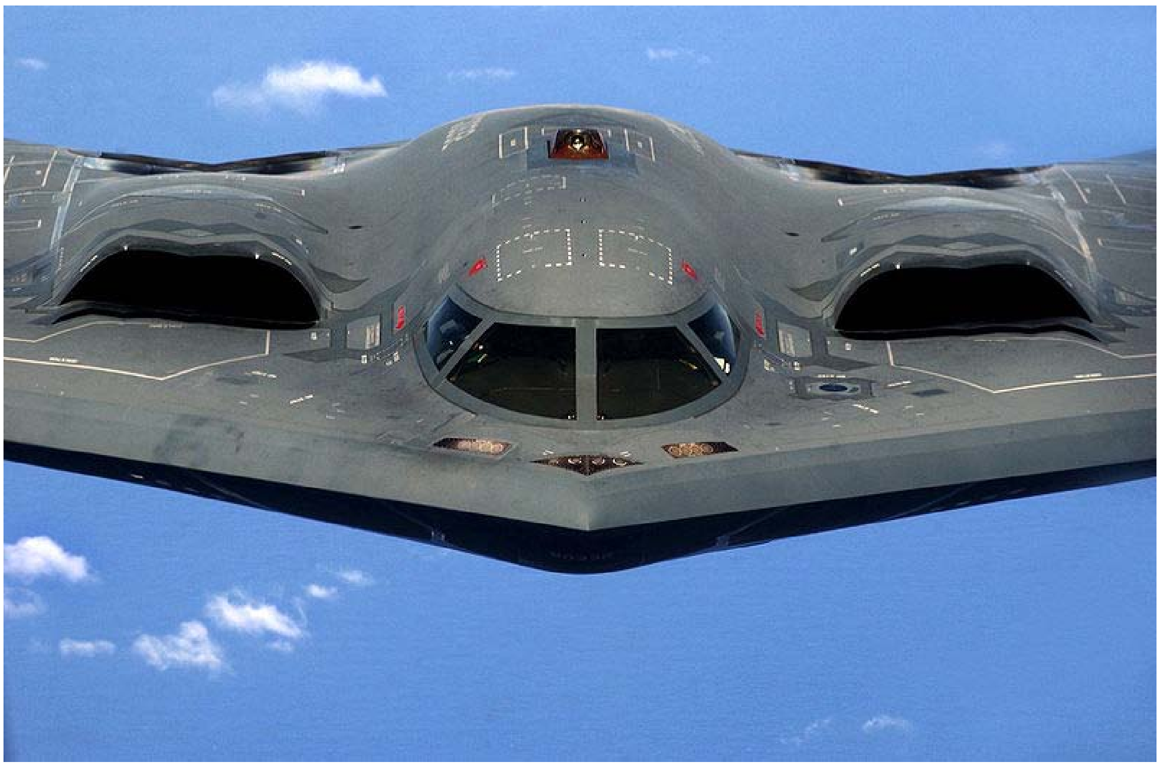
In 2008, the US Congress funded upgrades to the B-2s weapon control systems for hitting moving targets.

On 29 December 2008, Air Force officials awarded a production contract to Northrop Grumman to modernize the B-2 fleet's radar. The contract provides advanced state-of-the-art radar components, with the aim of sustained operational viability of the B-2 fleet into the future. The contract has a target value of approximately US$468 million. The award follows successful flight testing with the upgraded equipment. A modification to the radar was needed since the U.S. Department of Commerce required the B-2 to use a different radar frequency. It was reported on 22 July 2009 that the B-2 had passed the second of the two USAF audit milestones associated with this upgraded AESA radar capability.

On 28 April 2009, an Air Force/contractor team verified that the 30,000 pound Massive Ordnance Penetrator (MOP) would fit in the B-2's bomb bay.

The Air Force Research Laboratory has developed a new material to be used on the part of the wing trailing edge that is subject to engine exhaust to replace the current material that degrades.

Design



The B-2's engines are buried within its wing to conceal the induction fans and minimize their exhaust signature. The crew of two sit side-by-side in the cockpit.

The B-2's low-observable, or "stealth", characteristics give it the ability to penetrate an enemy's most sophisticated anti-aircraft defenses to attack its most heavily defended targets. The bomber's stealth comes from a combination of reduced acoustic, infrared, visual and radar signatures, making it difficult for opposition defenses to detect, track and engage the aircraft. Many specific aspects of the low-observability process remain classified. The B-2's composite materials, special coatings and flying wing design, which reduces the number of leading edges, contribute to its stealth characteristics. The Spirit has a radar signature of about 0.1 m^2. Each B-2 requires a climate-controlled hangar large enough for its 172-foot (52 m) wingspan to protect the operational integrity of its sophisticated radar absorbent material and coatings. The engines are buried within the wing to conceal the induction fans and hide their exhaust.

The blending of low-observable technologies with high aerodynamic efficiency and large payload gives the B-2 significant advantages over previous bombers. The U.S. Air Force reports its range as approximately 6,000 nautical miles (6,900 mi; 11,000 km). Also, its low-observation ability provides the B-2 greater freedom of action at high altitudes, thus increasing its range and providing a better field of view for the aircraft's sensors. It combines GPS Aided Targeting System (GATS) with GPS-aided bombs such as Joint Direct Attack Munition (JDAM). This uses its passive electronically scanned array APQ-181 radar to correct GPS errors of targets and gain much better than laser-guided weapon accuracy when "unguided" gravity bombs are equipped with a GPS-aided "smart" guidance tail kit. It can bomb 16 targets in a single pass when equipped with 1,000 or 2,000-pound (450 kg or 900 kg) bombs, or as many as 80 when carrying 500 lb (230 kg) bombs.

Vice President Dick Cheney sits inside the cockpit of a B-2 with pilot Capt. Luke Jayne during a visit to Whiteman AFB in 2006.

The B-2 has a crew of two: a pilot in the left seat, and mission commander in the right. The B-2 has provisions for a third crew member if needed. For comparison, the B-1B has a crew of four and the B-52 has a crew of five. B-2 crews have been used to pioneer sleep cycle research to improve crew performance on long sorties. The B-2 is highly automated, and, unlike two-seat fighters, one crew member can sleep, use a toilet or prepare a hot meal while the other monitors the aircraft.

As with the B-52 Stratofortress and B-1 Lancer, the B-2 provides the versatility inherent in manned bombers. Like other bombers, its assigned targets can be canceled or changed while in flight, the particular weapon assigned to a target can be changed, and the timing of attack, or the route to the target can be changed while in flight.

A B-2 during aerial refueling which extends its range past 6,000 miles to support intercontinental sorties

The prime contractor, responsible for overall system design, integration and support, is Northrop Grumman. Boeing, Raytheon (formerly Hughes Aircraft), G.E. and Vought Aircraft Industries, are subcontractors.

The original B-2 design had tanks for a contrail-inhibiting chemical, but this was replaced in the final design with a contrail sensor from Ophir that alerts the pilot when he should change altitude. Mission planning also considers altitudes where the probability of contrail formation is minimized.

Operational history

The first operational aircraft, christened Spirit of Missouri, was delivered to Whiteman Air Force Base, Missouri, where the fleet is based, on 17 December 1993. The B-2 reached initial operational capability (IOC) on 1 January 1997. Depot maintenance for the B-2 is accomplished by U.S. Air Force contractor support and managed at Oklahoma City Air Logistics Center at Tinker Air Force Base. Originally designed to deliver nuclear weapons, modern usage has shifted towards a flexible role with conventional and nuclear capability.

Into combat

An Air Force maintenance crew services a B-2 at Andersen AFB, Guam, 2004

The B-2 has seen service in three campaigns. Its combat debut was during the Kosovo War in 1999. It was responsible for destroying 33% of selected Serbian bombing targets in the first eight weeks of U.S. involvement in the War. During this war, B-2s flew non-stop to Kosovo from their home base in Missouri and back. The B-2 was the first aircraft to deploy GPS satellite guided JDAM "smart bombs" in combat use in Kosovo.

The B-2 has been used to drop bombs on Afghanistan in support of the War in Afghanistan. With the support of aerial refueling, the B-2 flew one of its longest missions to date from Whiteman Air Force Base, Missouri to Afghanistan and back.

During the War in Iraq, B-2s operated from Diego Garcia and an undisclosed "forward operating location". Other sorties in Iraq have launched from Whiteman AFB. This resulted in missions lasting over 30 hours and one mission of over 50 hours. The designated "forward operating locations" have been previously designated as Guam and RAF Fairford, where new climate controlled hangars have been constructed. B-2s have conducted 27 sorties from Whiteman AFB and 22 sorties from a forward operating location, releasing more than 1.5 million pounds of munitions, including 583 JDAM "smart bombs" in 2003.

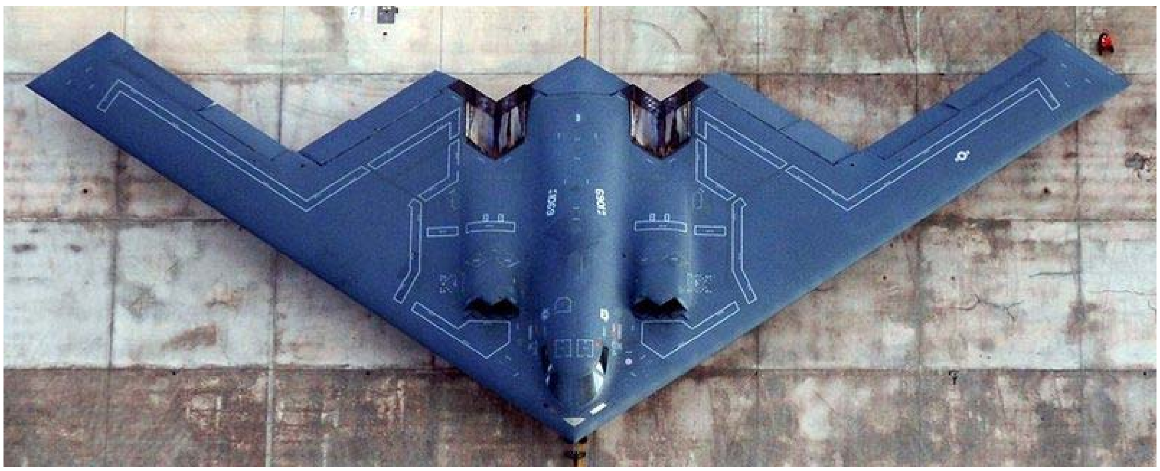
The B-2's combat use preceded a U.S. Air Force declaration of "full operational capability" in December 2003. The Pentagon's Operational Test and Evaluation 2003 Annual Report noted that the B-2's serviceability for Fiscal Year 2003 was still inadequate, mainly due to the maintainability of the B-2's low observable coatings. The evaluation also noted that the Defensive Avionics suite also had shortcomings with pop-up threats.

All B-2s, nuclear-capable B-52s, and nuclear intercontinental ballistic missiles have shifted to the nuclear-focused Air Force Global Strike Command set up on September 2009.

Replacement

When the B-2 is no longer able to penetrate enemy defenses the role of the manned nuclear armed penetration bomber will be taken up by the Lockheed Martin F-35 Lightning II, which also carries the B61 nuclear bomb, but as a tactical bomber is not covered by strategic arms limitation treaties such as New START.

Operators



The "Spirit of Indiana" sits on the ramp at Andersen AFB in Guam on 23 June 2006

B-2s are operated exclusively by the United States Air Force active units.

- United States Air Force
    - 509th Bomb Wing, Whiteman Air Force Base (currently has 19 B-2s)
        - 393d Bomb Squadron
        - 394th Combat Training Squadron
    - 131st Bomb Wing, Whiteman Air Force Base (Missouri Air National Guard)
        - 110th Bomb Squadron
    - 412th Test Wing, Edwards Air Force Base (currently has 1 B-2)
        - 419th Flight Test Squadron
    - 53d Wing, Eglin Air Force Base (former)
        - 72d Test and Evaluation Squadron, Whiteman Air Force Base
    - 57th Wing, Nellis Air Force Base (former)
        - 325th Weapons Squadron, Whiteman Air Force Base
        - 715th Weapons Squadron (inactivated)

Accident

The crashed B-2

On 23 February 2008, a B-2 crashed on the runway shortly after takeoff from Andersen Air Force Base in Guam. The Spirit of Kansas, 89-0127 had been operated by the 393rd Bomb Squadron, 509th Bomb Wing, Whiteman Air Force Base, Missouri, and had logged 5,176 flight hours. It was the first crash of a B-2. The two person crew ejected from the aircraft and survived the crash. The aircraft was completely destroyed, a hull loss valued at US$1.4 billion. After the accident, the Air Force took the B-2 fleet off operational status until clearing the fleet for flight status 53 days later on 15 April 2008.

Aircraft on display

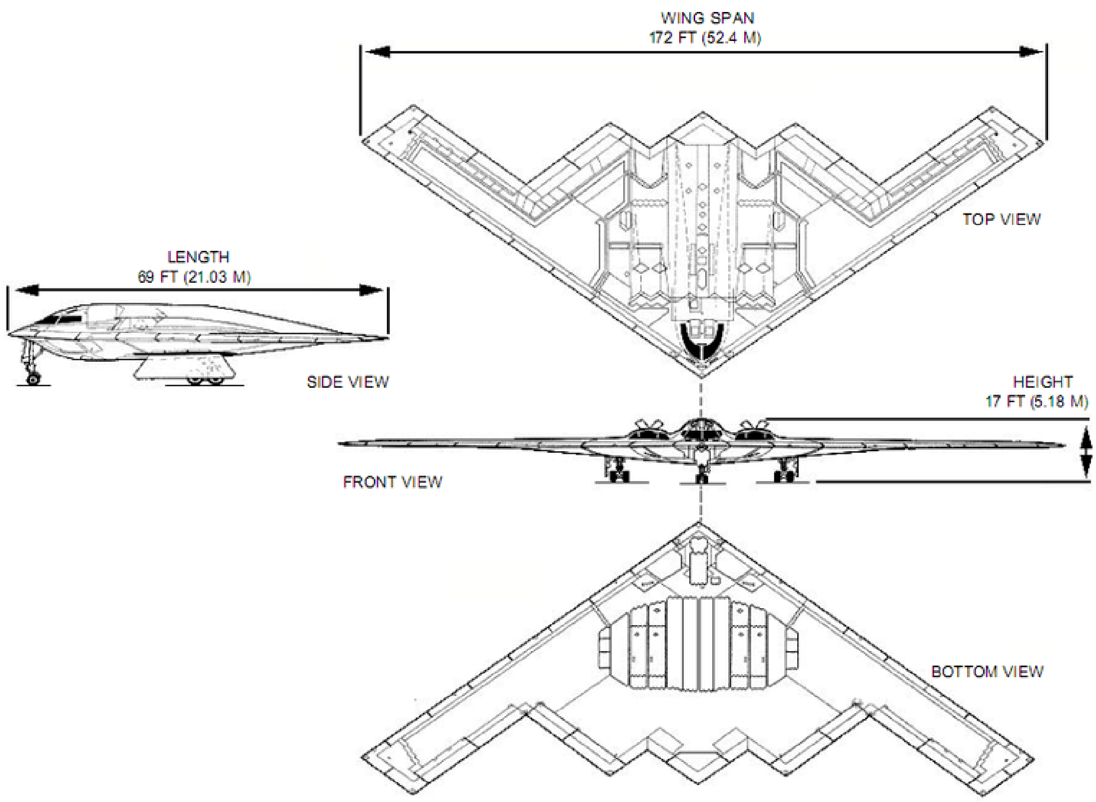
Mockup of a B-2 Spirit on display at the National Museum of the United States Air Force

Because of its high cost, strategic bombing role, and the still-classified aspects of its low observable coatings, no production B-2 has been placed on permanent display. However, B-2s have made periodic appearances on ground display at various air shows.

In 2004, one of the test articles (s/n AT-1000) built without engines or instruments for static testing was placed on display at the National Museum of the United States Air Force near Dayton, Ohio. The test article passed all structural testing. The Museum's restoration team spent over a year reassembling the fractured airframe.

From 1989 to 2004, the South Dakota Air and Space Museum located on the grounds of Ellsworth Air Force Base displayed the 10-short-ton (9-metric-ton) "Honda- Stealth", a 60% scale mock-up of a stealthy bomber which had been built by North American Honda in 1988 for an advertising campaign. Although not an actual replica of a B-2, the mock-up was close enough to the B-2's design to arouse suspicion that Honda had intercepted classified, top secret information, as the B-2 project was still officially classified in 1988. Honda donated the model to the museum in 1989, on condition that the model be destroyed if it was ever replaced with a different example. In 2005, when the museum received a B-1 Lancer for display (Ellsworth being a B-1 base), the museum destroyed the mock-up.

Specifications (B-2A Block 30)



General characteristics

- **Crew:** 2
- **Length:** 69 ft (21.0 m)
- **Wingspan:** 172 ft (52.4 m)
- **Height:** 17 ft (5.18 m)
- **Wing area:** 5,140 ft² (478 m²)
- **Empty weight:** 158,000 lb (71,700 kg)
- **Loaded weight:** 336,500 lb (152,200 kg)
- **Max takeoff weight:** 376,000 lb (170,600 kg)
- **Powerplant:** 4× General Electric F118-GE-100 non-afterburning turbofans, 17,300 lbf (77 kN) each

Performance

- **Maximum speed:** Mach 0.95 (525 knots, 604 mph, 972 km/h)
- **Cruise speed:** Mach 0.85 (470 knots, 541 mph, 870 km/h)
- **Range:** 6,000 nmi (11,100 km (6,900 mi))
- **Service ceiling:** 50,000 ft (15,200 m)

- **Wing loading:** 67.3 lb/ft² (329 kg/m²)
- **Thrust/weight:** 0.205

Armament

- 2 internal bays for 50,000 lb (23,000 kg) of ordnance.

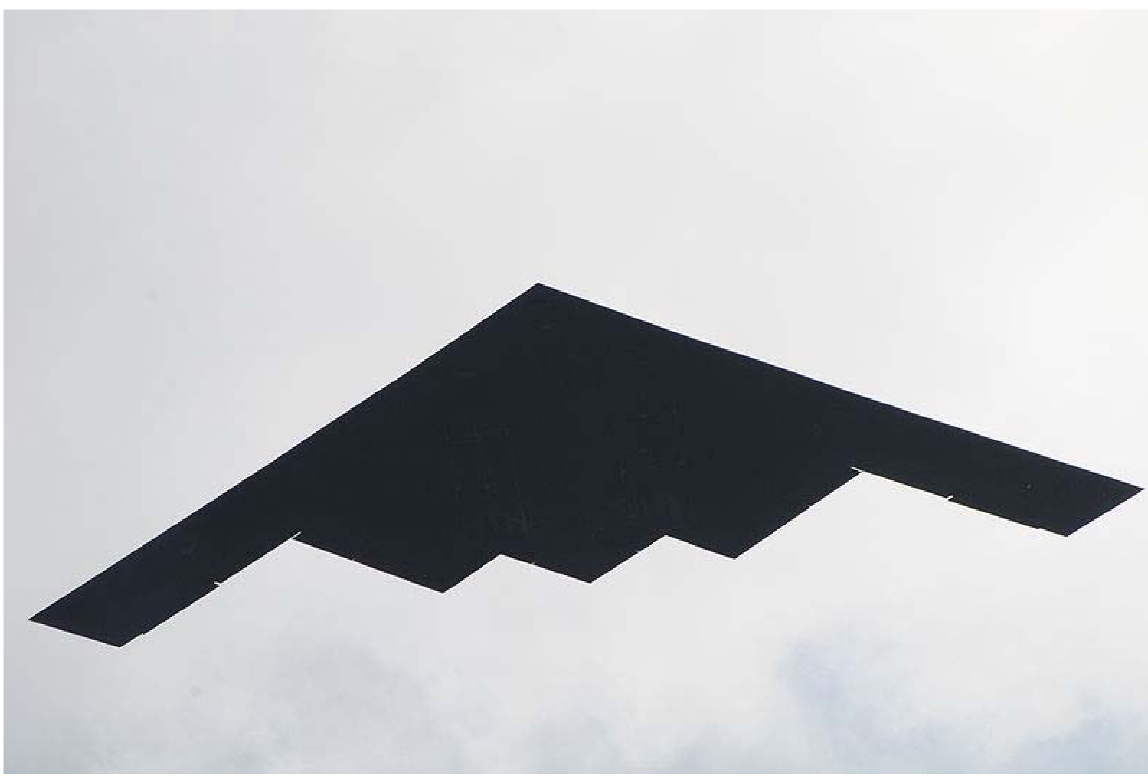
- 80× 500 lb class bombs (Mk-82) mounted on Bomb Rack Assembly (BRA)
- 36× 750 lb CBU class bombs on BRA
- 16× 2000 lb class weapons (Mk-84, JDAM-84, JDAM-102) mounted on Rotary Launcher Assembly (RLA)
- 16× B61 or B83 nuclear weapons on RLA

Later avionics and equipment improvements allow B-2A to carry JSOW, GBU-28, and GBU-57A/Bs as well. The Spirit is also designated as a delivery aircraft for the AGM-158 JASSM when the missile enters service.

List of B-2 bombers

Side view of a B-2 Spirit

B-2 in flight over the Mississippi River (St. Louis, Missouri) with the Gateway Arch and Busch Stadium in the background



B-2 from below

Air Vehicle No.	Block No.	USAF s/n	Formal name	Status
AV-1	Test/30	82-1066	Spirit of America	14 July 2000 — Active
AV-2	Test/30	82-1067	Spirit of Arizona	4 December 1997 — Active
AV-3	Test/30	82-1068	Spirit of New York	10 October 1997 — Active, Flight Test
AV-4	Test/30	82-1069	Spirit of Indiana	22 May 1999 — Active
AV-5	Test/20	82-1070	Spirit of Ohio	18 July 1997 — Active
AV-6	Test/30	82-1071	Spirit of Mississippi	23 May 1997 — Active
AV-7	10	88-0328	Spirit of Texas	21 August 1994 — Active
AV-8	10	88-0329	Spirit of Missouri	31 March 1994 — Active
AV-9	10	88-0330	Spirit of California	17 August 1994 — Active
AV-10	10	88-0331	Spirit of South Carolina	30 December 1994 — Active
AV-11	10	88-0332	Spirit of Washington	29 October 1994 — Active
AV-12	10	89-0127	Spirit of Kansas	17 February 1995 — 23 February 2008, Crashed
AV-13	10	89-0128	Spirit of Nebraska	28 June 1995 — Active
AV-14	10	89-0129	Spirit of Georgia	14 November 1995 — Active
AV-15	10	90-0040	Spirit of Alaska	24 January 1996 — Active
AV-16	10	90-0041	Spirit of Hawaii	10 January 1996 — Active
AV-17	20	92-0700	Spirit of Florida	3 July 1996 — Active
AV-18	20	93-1085	Spirit of Oklahoma	15 May 1996 — Active
AV-19	20	93-1086	Spirit of Kitty Hawk	30 August 1996 — Active
AV-20	30	93-1087	Spirit of Pennsylvania	5 August 1997 — Active
AV-21	30	93-1088	Spirit of Louisiana	10 November 1997 — Active
AV-22 through AV-165				Canceled

Chapter 10

Lockheed Martin F-22 Raptor

F-22 Raptor

F-22 Raptor

Role	Stealth air superiority fighter, multirole fighter
National origin	United States
Manufacturer	Lockheed Martin Aeronautics Boeing Integrated Defense Systems
First flight	YF-22: 29 September 1990 F-22: 7 September 1997
Introduced	15 December 2005
Status	In service
Primary user	United States Air Force
Number built	168 as of October 2010 (187 planned)
Program cost	US$65 billion
Unit cost	US$150 million (flyaway cost for FY2009)
Developed from	Lockheed YF-22
Developed into	X-44 MANTA FB-22

The **Lockheed Martin/Boeing F-22 Raptor** is a single-seat, twin-engine fifth-generation supermaneuverable fighter aircraft that uses stealth technology. It was designed primarily as an air superiority fighter, but has additional capabilities that include ground attack, electronic warfare, and signals intelligence roles. Lockheed Martin Aeronautics is the prime contractor and is responsible for the majority of the airframe, weapon systems and final assembly of the F-22. Program partner Boeing Defense, Space & Security provides the wings, aft fuselage, avionics integration, and all of the pilot and maintenance training systems.

The aircraft was variously designated **F-22** and **F/A-22** during the years prior to formally entering USAF service in December 2005 as the **F-22A**. Despite a protracted and costly development period, the United States Air Force considers the F-22 a critical component for the future of US tactical air power, and claims that the aircraft is unmatched by any known or projected fighter, while Lockheed Martin claims that the Raptor's combination of stealth, speed, agility, precision and situational awareness, combined with air-to-air and air-to-ground combat capabilities, makes it the best overall fighter in the world today. Air Chief Marshal Angus Houston, Chief of the Australian Defence Force, said in 2004 that the "F-22 will be the most outstanding fighter plane ever built."

The high cost of the aircraft, a lack of clear air-to-air combat missions because of the lengthy delays in the Russian and Chinese fifth generation fighter programs, a US ban on Raptor exports, and the development of the cheaper and more versatile F-35 resulted in calls to end F-22 production. In April 2009 the US Department of Defense proposed to cease placing new orders, subject to Congressional approval, for a final procurement tally of 187 Raptors. The US Senate and House each passed 2010 budget bill versions without F-22 production funding in July 2009. Congress worked to combine these versions into one bill, and President Obama signed the National Defense Authorization Act for Fiscal Year 2010 in October 2009, without funding for F-22 production.

Development

Origins

In 1981 the United States Air Force (USAF) developed a requirement for a new air superiority fighter, the Advanced Tactical Fighter (ATF), to replace the capability of the F-15 Eagle, primarily the F-15A, B, C and D variants. ATF was a demonstration and validation program undertaken by the USAF to develop a next-generation air superiority fighter to counter emerging worldwide threats, including development and proliferation of Soviet-era Su-27 "Flanker"-class fighter aircraft. It was envisioned that the ATF would incorporate emerging technologies including advanced alloys and composite materials, advanced fly-by-wire flight control systems, higher power propulsion systems, and low-observable/stealth technology.

A request for proposal (RFP) was issued in July 1986, and two contractor teams, Lockheed/Boeing/General Dynamics and Northrop/McDonnell Douglas were selected in October 1986 to undertake a 50-month demonstration/validation phase, culminating in the flight test of two prototype aircraft, the YF-22 and the YF-23. Each design team produced two prototypes featuring one of two engine options, one featuring thrust vectoring. The Pratt & Whitney F119 turbofan with vectored thrust was found to be worth the extra expense and complexity, as it permits a tighter turning radius, a valuable capability in dogfights.

During the development process in late 1980s, expected growth, the ATF's increasing takeoff weight and cost drove out many features. A dedicated Infra-red search and track (IRST) system was downgraded from multi-color to single color then deleted, the side-looking radars were deleted and the ejection seat requirement was downgraded to the McDonnell Douglas ACES II (in place of a fresh design able to cover the full flight envelope).

On 23 April 1991, the USAF ended the design and test flight competition by announcing Lockheed's YF-22 as the winner. It was anticipated at the time that 650 aircraft would be ordered.

Into production

The first operational F-22 Raptor is painted at the Lockheed Martin assembly plant at Marietta, Georgia

The YF-22 was modified for the production F-22. Several small design changes were made. The swept-back angle on the wing's leading edge was decreased from 48 degrees to 42 degrees, while the vertical stabilizer area was decreased 20%. To improve pilot visibility, the canopy was moved forward 7 inches (178 mm) and the engine intakes were moved rearward 14 inches (356 mm). The shape of the wing and stabilator trailing edges was refined to improve aerodynamics, strength, and stealth characteristics. Also, the vertical stabilizer was shifted rearward.

The production F-22 model was unveiled on 9 April 1997 at Lockheed Georgia Co., Marietta, Georgia. It first flew on 7 September 1997. The first production F-22 was delivered to Nellis Air Force Base, Nevada, on 14 January 2003 and "Dedicated Initial Operational Test and Evaluation" commenced on 27 October 2003. By 2004, 51 Raptors had been delivered.

In 2006, the Raptor's development team, composed of Lockheed Martin and over 1,000 other companies, plus the United States Air Force, won the Collier Trophy, American aviation's most prestigious award. The U.S. Air Force in 2006 sought to acquire 381 F-22s to be divided among seven active duty combat squadrons, and three integrated Air Force Reserve Command and Air National Guard fighter squadrons.

F-22 production was split up over many subcontractors across 46 states in an apparent strategy to increase congressional support for the program. The way the production was split up, and the number of new technologies used may have led to increased costs and production delays. Many essential capabilities were deferred to post-service upgrades, which reduced the initial cost, but increased the total project cost. Each F-22 required "1,000 subcontractors and suppliers and 95,000 workers" to build it.

Procurement

Two F-22s during flight testing, the upper one being the first EMD F-22, "Raptor 01"

The United States Air Force originally planned to order 750 ATFs, with production beginning in 1994; however, the 1990 Major Aircraft Review led by Defense Secretary Dick Cheney altered the plan to 648 aircraft beginning in 1996. The goal changed again in 1994, when it became 442 aircraft entering service in 2003 or 2004, but a 1997 Department of Defense report put the purchase at 339. In 2003, the Air Force said that the existing congressional cost cap limited the purchase to 277. By 2006, the Pentagon said it will buy 183 aircraft, which would save $15 billion but raise the cost of each aircraft, and this plan has been de facto approved by Congress in the form of a multi-year procurement plan, which allows for further orders later. The total cost of the program by 2006 was $62 billion.

In April 2006, the cost of the F-22 was assessed by the Government Accountability Office to be $361 million per aircraft. This cost reflects the F-22 total program cost, divided by the number of fighters the Air Force is programmed to buy; and which has so far invested $28 billion in the Raptor's research, development and testing. That money, referred to as a "sunk cost", is already spent and is separate from money used for future procurement. The Unit Procurement Cost was estimated at $177.6 million in 2006 based on a production run of 181 airframes.

By the time all 183 fighters have been purchased, $34 billion will have been spent on actual procurement, resulting in a total program cost of $62 billion or about $339 million per aircraft. The incremental cost for one additional F-22 is around $138 million; decreasing with larger volumes.

F-22 Raptors line up for refueling in their first official deployment, October 2005

On 31 July 2007, Lockheed Martin received a multiyear contract for 60 F-22s worth a total of US$7.3 billion. The contract brought the number of F-22s on order to 183 and extended production through 2011. Restarting production after production is shut down would greatly increase costs; building 75 more would cost an estimated $70 million extra per unit.

Ban on exports

No opportunity for export currently exists because the export sale of the F-22 is barred by American federal law. Most current customers for U.S. fighters are either acquiring earlier designs like the F-15, F-16, and F/A-18E/F Super Hornet, or else are waiting to acquire the F-35 Lightning II (Joint Strike Fighter), which contains technology from the F-22 but is designed to be cheaper, more flexible, and available for export from the start. The F-35 will not be as nimble as the F-22 or fly as high or as fast, but its radar and avionics will be more advanced.

The Japanese government reportedly showed interest in buying F-22s in its Replacement-Fighter program for the Japan Air Self-Defense Force (JASDF). If it were to occur, it would most likely involve a "watered-down" export variant while still retaining most of its advanced avionics and stealth characteristics. However, such a proposal would still need approval from the Pentagon, State Department and Congress. The Japanese Government sought to purchase the F-22 to decrease the number of JASDF's fighters to reduce cutting engineering costs and number of pilots. But some Japanese media raised concern that costs to buy and operate F-22s "would require a lifting of the popular 1 percent of GDP military budget ceiling in Japan." On 9 June 2009, Japanese Defense Minister Yasukazu Hamada said that Japan still seeks the F-22.

The US Congress upheld the ban on F-22 Raptor foreign sales during a joint conference on 27 September 2006. After talks in Washington in December 2006, the US DoD reported the F-22 would not be available for foreign sale.

Some Australian politicians and defense commentators have proposed that Australia purchase F-22s instead of the F-35. In 2006, the Australian Labor Party supported this proposal on the grounds that the F-22 is a proven, highly capable aircraft, while the F-35 is still under development. However, Australia's Howard government ruled out purchase of the F-22, on the grounds that it is unlikely to be released for export, and does not have sufficient ground/maritime strike capacity.

In 2007, the Australian government ordered a review of plans to procure the F-35 and F/A-18E/F Super Hornet. This review will include an evaluation of the F-22's suitability for Australia; moreover, then Defence Minister Joel Fitzgibbon stated: "I intend to pursue American politicians for access to the Raptor". In February 2008, U.S. Defense Secretary Robert Gates said he had no objection to sale of the Raptor to Australia, but Congress would have to change the law.

On 28 October 2009, President Barack Obama signed the 2010 defense authorization bill (H.R. 2647) which included provisions requiring the DoD to prepare a report on the costs and feasibility for an F-22 export variant and another report on the impact of F-22 export sales on the U.S. aerospace industry.

"The IAF would be happy to equip itself with 24 F-22s, but the problem at this time is the US refusal to sell the aircraft, and its $200 million price tag."

Israeli Air Force (IAF) chief procurement officer Brigadier-General Ze'ev Snir.

Thomas D. Crimmins of the Washington Institute for Near East Policy, who has written about a possible Israeli strike on Iran, stated in 2009 that the F-22 may be the only current aircraft that can evade the Russian S-300 air defense system which Russia may sell to

Iran. However, Lockheed Martin has expressed confidence in the ability of the F-35 to destroy S-300 systems and Russia has voted for United Nations sanctions that they say prevent the sale of S-300 systems to Iran.

End of procurement and production

Two F-22A Raptors in close trail formation

In 2006, David M. Walker, Comptroller General of the United States at the time, found that "the DOD has not demonstrated the need or value for making further investments in the F-22A program."

During the two-month grounding of nearly 700 older F-15s in November and December 2007, some US Senators demanded that Deputy Secretary of Defense Gordon England release three government reports that support additional F-22 Raptors beyond the planned 183 jets. The USAF has requested that the F-22 remain in production after the 183 planned fighters. This was believed at the time to have been a response to the grounding of F-15A-D fighters.

In January 2008, the Pentagon announced that it would ask Congress for funds to buy additional F-22s to replace other aircraft lost in combat, and proposed that $497 million that would have been used to shut down the F-22 line instead be used to buy four more F-22s, keeping open the production line beyond 2011 and providing the next Presidential administration the option to buy even more F-22s. The funds earmarked for the line shutdown, however, were directed by Pentagon Comptroller Tina W. Jonas on 17 December 2007, to be used to fund repairs to the F-15 fleet caused by the worldwide grounding of that aircraft in November 2007. This diversion had the same effect of postponing the decision to shut down the F-22 production line until at least 2009.

An F-22 executes a transonic flyby over the aircraft carrier USS John C. Stennis

An August 2008 RAND study showed that, as a land based aircraft, the F-22 would have little impact on a future conflict with China over Taiwan as its nearby bases would be shutdown by MRBMs and farther bases would require the assistance of tanker aircraft that would be quickly lost. The 2010 report by the United States-China Economic and

Security Review Commission indicated that the MRBM threat to American airbases had dramatically increased in just the last few years.

On 24 September 2008, US Congress passed a defense spending bill with funding for F-22 long lead items for future production. On 12 November 2008, the Pentagon released $50 million of the $140 million approved by Congress to buy parts for an additional four aircraft, thus leaving the Raptor program in the hands of the incoming Obama Administration. Additional funds to complete the four aircraft were provided in a war supplemental bill, for a total of 187 F-22s procured.

On 6 April 2009, as part of the 2010 Pentagon budget announcement, Secretary of Defense Gates called for production of the F-22 to be phased out by fiscal year 2011, leaving the USAF with 187 fighters. F-35 acquisition would be accelerated. On 17 June 2009 the House Armed Services Committee inserted $368.8 million in the budget markup as a down payment for a further 12 F-22s in FY 2011.

On 9 July 2009, General James Cartwright, Vice Chairman of the Joint Chiefs of Staff, explained to the U.S. Senate Committee on Armed Services his reasons for supporting termination of the F-22 production line. He believes, most importantly, that fifth-generation fighters need to be proliferated to all three services, a need that could only be met by shifting more resources to producing the 10-years more advanced, multi-service and multirole F-35. He further noted that one of the highest issues of concern of the combatant commanders was the ability to conduct electronic warfare (EW). Currently, the U.S. armed forces share only a single airborne EW platform, the EA-6B Prowler, which is being retired and partially replaced with the EA-18G Growler. Gen. Cartwright believes that keeping the F/A-18 production line "hot" offers the dual benefits of providing a fallback option should problems arise with the F-35 program, as well as leaving an option to purchase further Growlers, since the U.S. Navy currently plans to buy only enough for its own needs with no additional EW aircraft to support joint operations.

"Gates will prevail because the bottom line is, we ain’t got any money."

Statement from Loren Thompson of the Lexington Institute, on the termination of the F-22 production.

On 21 July 2009, the United States Senate voted in favor of ending F-22 production, in the face of intense lobbying by President Obama against funding the planes, and threats to sign what would have been his first veto. Secretary of Defense Robert Gates said that the decision to stop production of F-22s was taken in light of the capabilities of the F-35. A statement issued by Secretary Gates on 21 July 2009 said that "the Pentagon cannot continue with business as usual when it comes to the F-22 or any other program in excess of our needs."

On 29 July 2009, the director of the Air National Guard asked for "60 to 70" of the F-22s for air sovereignty missions, but that these fighters would not need the full ground attack capabilities of the upgraded F-22s. On 30 July 2009, The House agreed to remove funds for an additional 12 aircraft and so abide by the 187 cap. The two versions of the 2010 budget had to be resolved in conference before facing President Obama who had threatened to veto any additional F-22s and also if the final bill includes funds for certain other projects.

Gates had reduced the requirement from 243 to 187 aircraft by reducing the USAF requirement from two major regional conflicts to one, in line with the forces available from the other services. On 28 October 2009, President Barack Obama signed a defense bill that terminated some weapons projects and expanded war efforts for the current conflicts. The bill terminates production of the F-22.

RAND estimates that the cost of restarting the production line to build an additional 75 Raptors to be $17 billion or $227 million per aircraft. The RAND paper was produced as part of an USAF study to determine the costs of maintaining F-22 tooling for a future Service Life Extension Program (SLEP). The tooling for F-22 production will be documented in "80-plus" smartbooks (illustrated electronic manuals) and stored at the Sierra Army Depot.

On 17 July 2009, Secretary of Defense Robert Gates threatened Congress with a Presidential veto if Congress continued its plan to purchase more F-22s. Many Air Force generals expressed concern about Russia's and China's stealth fighter development, for example Gen. John Corley, head of the Air Combat Command, wrote in a 9 June 2009 letter to a senator, "In my opinion, a fleet of 187 F-22s puts execution of our current national military strategy at high risk in the near- to mid-term". But Gates commented "Nonsense". On 8 January 2011, Gates clarified that China's development of a fifth-generation fighter had been taken into account when setting the number of F-22s and that the United States would still have a vast advantage in stealth aircraft in 2025, even with recent F-35 delays.

On 11 January 2011, the China's J-20 stealth strike fighter made its first flight. Photographs show the J-20 is noticeably larger than the Raptor, allowing for a larger fuel and weapons load. This unexpected milestone for China might spur a movement to reactivate the F-22 production line.

Upgrades

On 5 January 2001, Raptor 4005 flew with the Block 3.0 software, which was the first combat-capable avionics version. In June 2009, Increment 3.1 was tested at Edwards Air Force Base. This provided the F-22 a basic ground attack capability through Synthetic Aperture Radar mapping, Electronic Attack and the GBU-39 Small Diameter Bomb. The F-22 Raptor Increment 3.1 Modification Team with the 412th Test Wing received the Chief of Staff Team Excellence Award for upgrading 149 Raptors. However, the software for the upgrade will not be completed before 2010 and it will not be operationally tested on the F-22A aircraft until late 2010.

"The current F-22A modernization plan will result in 34 Block 20 aircraft used for test and training, 63 combat-coded Block 30s fielded with Increment 3.1, 83 combat-coded Block 35s fielded with

Increment 3.2, and 3 Edwards AFB-test coded aircraft. Consideration is also being given to upgrade the 63 Block 30s to the most capable Block 35 configuration."

Extract from Congress dialogue upon the Air Force F-22 Fighter Program.

The next step will be Increment 3.2 with an advanced SDB capability, automatic ground collision avoidance system (Auto GCAS) to enable low level operations and the ability to use the AIM-9X Sidewinder and AIM-120D AMRAAM missiles. However, the F-22 will still lack a helmet mounted cueing system to allow the aircraft to take advantage of the AIM-9X's high off-boresight capability, they may integrate the JHMCS later on. Defense Daily reported that the Joint Helmet Mounted Cueing System was deferred on the F-22 because of maintenance overhead.

Upgrading the first 183 jets to the 3.2 upgrade is estimated to cost $8 billion. In May 2009, Gen. Norton A. Schwartz and Air Force Secretary Michael B. Donley gave testimony to Congress that this would be paid for through the early retirement of legacy fighters. The retirement of 254 fighters over the next year would have reduced the Air Force below the 2,250 fighter minimum requirement for national strategy, but the Fiscal 2010 defense appropriations bill prevented this. And only 249 fourth-generation fighters were retired during Fiscal Year 2010.

Increment 3.2 was expected to be fielded in FY15, and it may include the Multifunction Advanced Data Link that will tie together future U.S. penetration forces of stealth aircraft and unmanned platforms. In July 2009 the USAF announced that three business jets had been deployed with the interim Battlefield Airborne Communications Node (BACN) to allow communication between F-22s and other platforms, until MADL is installed. The USAF has accelerated software portions of the Increment 3.2 upgrade program with an expected completion date in FY 2013 with the rest to be completed later.

Lockheed Martin is working on an upgrade for the AN/AAR-56 Missile Launch Detector (MLD) system to provide situational awareness and defensive Infrared Search and Track along the same lines as the F-35's SAIRST, but with less resolution. The unfunded Increment 3.3 upgrade will include automatic target tracking and so bring the F-22 fleet to full fifth generation situational awareness. On 16 September 2009, Gates said "Our commitment to this aircraft is underscored by the 6 and-a half billion dollars provided over the next few years to upgrade the existing F-22 fleet to be fully mission-capable."

Lockheed Martin has also offered an upgrade that would give the F-22 some, but not all of the capabilities of the F-35.

Replacement

On 3 November 2010, the USAF issued a Materiel and Technology Concepts Search request for a Next Generation Tactical Aircraft (Next Gen TACAIR) to have an initial operational capability (IOC) of approximately 2030.

Design

Characteristics

F-22 Raptor displaying its F119-PW-100 engines on full afterburner during flight testing

The F-22 Raptor is a fifth generation fighter that is considered a fourth-generation stealth aircraft by the USAF. Its dual afterburning Pratt & Whitney F119-PW-100 turbofans incorporate pitch axis thrust vectoring, with a range of ±20 degrees. The maximum thrust is classified, though most sources place it at about 35,000 lbf (156 kN) per engine. Maximum speed, without external weapons, is estimated to be Mach 1.82 in supercruise mode, as demonstrated by General John P. Jumper, former US Air Force Chief of Staff, when his Raptor exceeded Mach 1.7 without afterburners on 13 January 2005. With afterburners, it is "greater than Mach 2.0" (1,317 mph, 2,120 km/h), according to Lockheed Martin; however, the Raptor can exceed its design speed limits, particularly at low altitudes, with max-speed alerts to help prevent the pilot from exceeding them. Former Lockheed F-22 chief test pilot Paul Metz stated that the Raptor has a fixed inlet. The absence of variable intake ramps generally limits speeds to approximately Mach 2.0. Such ramps would be used to prevent engine surge resulting in a compressor stall, but the intake itself may be designed to prevent this. Metz has also stated that the F-22 has a greater climb rate than the F-15 Eagle due to advances in engine technology, despite the

F-15's thrust-to-weight ratio of about 1.2:1, with the F-22 having a ratio closer to 1:1. The US Air Force claims that the Raptor cannot be matched by any known or projected fighter types, and Lockheed Martin claims that, "the F-22 is the only aircraft that blends supercruise speed, super-agility, stealth and sensor fusion into a single air dominance platform."

F-22 Raptor flight

The true top speed of the F-22 is unknown to the general public. The ability of the airframe to withstand the stress and heat is a further key factor, especially in an aircraft using as many polymers as the F-22. However, while some aircraft are faster on paper, the internal carriage of its standard combat load allows the aircraft to reach comparatively higher performance with a heavy load over other modern aircraft due to its lack of drag from external stores. It is one of only a handful of aircraft that can sustain supersonic flight without the use of afterburner augmented thrust (and its associated high fuel usage). This ability is now termed supercruise. This allows the aircraft to hit time-critical, fleeting or mobile targets that a subsonic aircraft would not have the speed to reach and an afterburner dependent aircraft would not have the fuel to reach.

A KC-10 Extender (top) refuels an F-22 Raptor

The F-22 is highly maneuverable, at both supersonic and subsonic speeds. It is extremely departure-resistant, enabling it to remain controllable at extreme pilot inputs. The Raptor's thrust vectoring nozzles allow the aircraft to turn tightly, and perform extremely high alpha (angle of attack) maneuvers such as the Herbst maneuver (or J-turn), Pugachev's Cobra, and the Kulbit, though the J-Turn is more useful in combat. The F-22 is also capable of maintaining a constant angle of attack of over 60°, yet still having some control of roll. During June 2006 exercises in Alaska, F-22 pilots demonstrated that cruise altitude has a significant effect on combat performance, and routinely attributed their altitude advantage as a major factor in achieving an unblemished kill ratio against other US fighters and 4th/4.5th generation fighters.

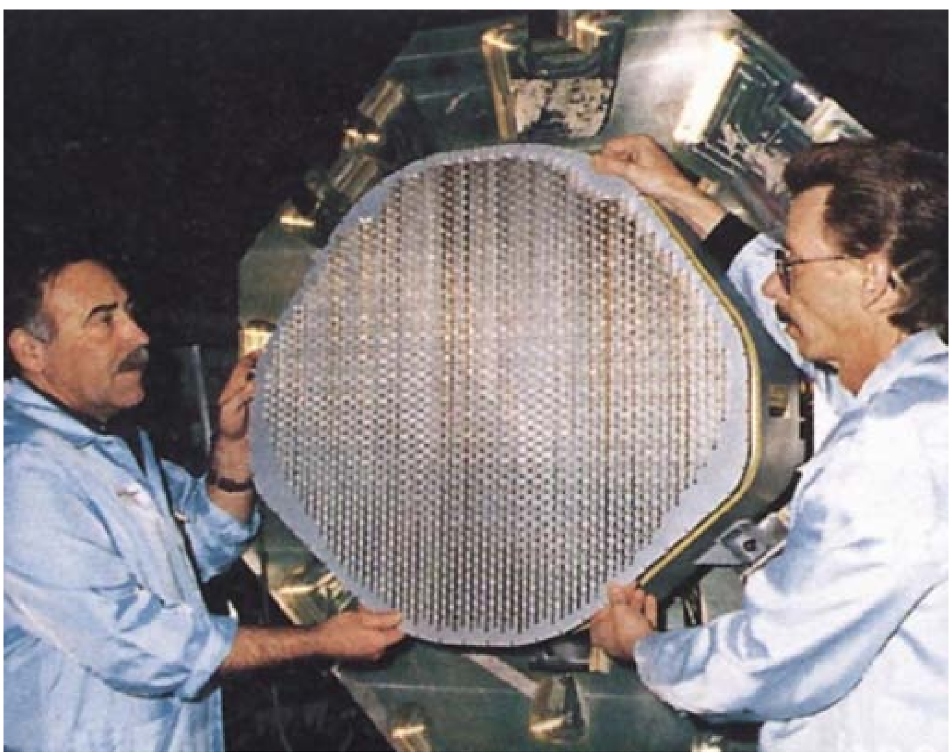
The F-22 is made out of materials that present significant health risks when handled and USAF technicians require eye protection, respirators and thick, industrial gloves to work with these materials.

Avionics

The F-22's avionics include BAE Systems E&IS radar warning receiver (RWR) AN/ALR-94, AN/AAR 56 Infra-Red and Ultra-Violet MAWS (Missile Approach Warning System) and the Northrop Grumman AN/APG-77 Active Electronically Scanned Array (AESA) radar. The AN/APG-77 has both long-range target acquisition and low probability of interception of its own signals by enemy aircraft.

The AN/ALR-94 is a passive receiver system capable of detecting the radar signals in the environment. Composed of more than 30 antennas smoothly blended into the wings and fuselage that provide all around coverage plus azimuth and elevation information in the forward sector, it is described by Tom Burbage, the former head of the F-22 program at Lockheed Martin, as "the most technically complex piece of equipment on the aircraft." With greater range (250+ nmi) than the radar, it enables the F-22 to limit its own radar emission to preserve its stealth. As a target approaches, the receiver can cue the AN/APG-77 radar to track the target with a narrow beam, which can be as focused down to 2° by 2° in azimuth and elevation.

The AN/APG-77 AESA radar, designed for air superiority and strike operations, features a low-observable, active-aperture, electronically-scanned array that can track multiple targets in any weather. The AN/APG-77 changes frequencies more than 1,000 times per second to reduce the chance of being intercepted. The radar can also focus its emissions to overload enemy sensors, giving the aircraft an electronic-attack capability.



The AN/APG-77 AESA radar

The radar's information is processed by two Raytheon Common Integrated Processor (CIP)s. Each CIP can process 10.5 billion instructions per second and has 300 megabytes of memory. Information can be gathered from the radar and other onboard and offboard systems, filtered by the CIP, and offered in easy-to-digest ways on several cockpit displays, enabling the pilot to remain on top of complicated situations. The Raptor's avionics software has some 1.7 million lines of code, written mostly in the DoD's Ada programming language. Most of the code concerns processing data from the radar. The radar has an estimated range of 125–150 miles, though planned upgrades will allow a range of 250 miles (400 km) or more in narrow beams. In 2007, tests by Northrop Grumman, Lockheed Martin, and L-3 Communications enabled the AESA system of a Raptor to act like a WiFi access point, able to transmit data at 548 megabits per second and receive at gigabit speed; this is far faster than the current Link 16 system used by US and allied aircraft, which transfers data at just over 1 Mbit/s.

The F-22 has several capabilities unique to an aircraft of its size and role. For instance, it has threat detection and identification capability on the order of that available on the RC-135 Rivet Joint. While the F-22's equipment is not as powerful or sophisticated, its stealth allows it to safely operate hundreds of miles closer to the battlefield, compensating for the reduced capability.

The F-22 is capable of functioning as a "mini-AWACS". Its radar is less powerful than those in dedicated aircraft such as the E-3 Sentry, but its forward presence again compensates. The F-22's system allows its pilot to designate targets for cooperating F-15s and F-16s, and even determine whether two friendly aircraft are targeting the same enemy aircraft. It is "sometimes [able to identify targets] many times quicker than the AWACS."

The F-22's low probability of intercept radar is being given a high-bandwidth data transmission capability, to allow it to be used in a "broadband" role to permit high-speed relaying of data between friendly transmitters and receivers in the area. The F-22 can already pass data to other F-22s, resulting in considerably reduced radio "chatter".

The IEEE-1394B data bus developed for the F-22 was derived from the commercial IEEE-1394 "FireWire" bus system, often used on personal computers. The same data bus is employed by the subsequent F-35 Lightning II fighter. Sensor fusion combines data from all onboard and offboard sensors into a common view to prevent the pilot from being overwhelmed.

In a critical article former Navy Secretary John Lehman wrote "[a]t least [the F-22s] are safe from cyberattack. No one in China knows how to program the '83 vintage IBM software that runs them."

Former Secretary of the USAF Michael Wynne blamed the use of the DoD's Ada "operating system" (Ada is actually a programming language) as part of the reason for cost overruns and schedule slippages on many major military projects, including the F-22 Raptor. The Raptor actually uses the INTEGRITY-178B operating system from Green

Hills Software. The same operating system is used on the F-35, several commercial airliners and the Orion Crew Exploration Vehicle.

Cockpit

Cockpit of the F-22, showing instruments and head up display

The F-22 cockpit is a glass cockpit design without any traditional analog flight instruments and represents a marked improvement on the cockpit design of previous advanced aircraft. The leading features of the F-22 cockpit include simple and rapid start-up, highly developed HMI, light helmet, large anthropometric accommodation and highly integrated warning system. Other main features include the large single-piece canopy, side stick and improved life support systems.

All internal displays are designed to be used with night vision goggles because the aircraft lacks optical or IR vision devices. The Integrated Caution, Advisory, and Warning (ICAW) system combines and filters all messages so that the pilot can be a tactician rather than a housekeeper.

Armament

An F-22 fires an AIM-120 AMRAAM

The Raptor has three internal weapons bays on the bottom and sides of the fuselage. It can carry six compressed carriage medium range missiles in the center bay and one short range missile in each of the two side bays. Four of the medium range missiles can be replaced with two bombracks that can each carry one medium-size bomb or four small diameter bombs each. Carrying missiles and bombs internally maintains its stealth capability and maintains lower drag resulting in higher top speeds and longer combat ranges. Launching missiles requires opening the weapons bay doors for less than a second, while the missiles are pushed clear of the airframe by hydraulic arms. This reduces the Raptor's chance of detection by enemy radar systems due to launched ordnance and also allows the F-22 to launch long range missiles while maintaining supercruise. The aircraft can also carry such air-to-surface weapons as bombs with the Joint Direct Attack Munition (JDAM) guidance system, and the new Small-Diameter Bomb (SDB), but cannot self-designate laser guided weapons as it lacks the F-35's stealthy designator. The Raptor carries an M61A2 Vulcan 20 mm rotary cannon, also with a trap door, in the right wing root. The M61A2 is a last ditch weapon, and carries 480 rounds; enough ammunition for approximately five seconds of sustained fire. The opening for the cannon's firing barrel is covered by a door when not in use to maintain stealth. The F-22 has been able to close to gun range in training dogfights without being detected, which can be necessary when missiles are depleted.

To maintain stealth, the F-22 carries its weapons in internal bays, shown here. The open doors for the center bay and smaller side bays are visible.

The Raptor's very high sustained cruise speed and operational altitude add significantly to the effective range of both air-to-air and air-to-surface munitions. These factors may be the rationale behind the USAF's decision not to pursue long-range, high-energy air-to-air missiles such as the MBDA Meteor. However, the USAF plans to procure the AIM-120D AMRAAM, which is reported to have a 50% increase in range compared to the AIM-120C. The Raptor launch platform provides additional energy to the missile which helps improve the range of air-to-ground ordnance. While specific figures remain classified, it is expected that JDAMs employed by F-22s will have twice or more the effective range of munitions dropped by legacy platforms. In testing, a Raptor dropped a 1,000 lb (450 kg) JDAM from 50,000 feet (15,000 m), while cruising at Mach 1.5, striking a moving target 24 miles (39 km) away. The SDB, as employed from the F-22, should see even greater increases in effective range, due to the improved lift to drag ratio of these weapons. The AIM-120 is the primary missile and the AIM-9 Sidewinder is the short-range missile.

An F-22 releases a JDAM from its center internal bay while flying at supersonic speed

While in its air-superiority configuration the F-22 carries its weapons internally, it is not limited to this option. The wings include four hardpoints, each rated to handle 5,000 lb (2,300 kg). Each hardpoint has a pylon that can carry a detachable 600 gallon fuel tank or a rail launcher that holds two air-air missiles. However, use of external stores compromises the F-22's stealth, and has a detrimental effect on maneuverability, speed, and range (unless external fuel is carried). The two inner hardpoints are "plumbed" for external fuel tanks. These hardpoints allow the mounting pylons to be jettisoned in flight so the fighter can regain its stealth after exhausting external stores. Research is currently being conducted to develop stealth ordnance pod and pylon. Such a pod would comprise a low observable shape and carry its weapons internally, then would open when launching a missile or dropping a bomb. The pod and pylon could be detached when no longer needed. This system would allow the F-22 to carry its maximum ordnance load while maintaining stealth without loss of maneuverability.

Stealth

F-22 with external pylons

Although several recent Western fighter aircraft are less detectable on radar than previous designs using techniques such as radar-absorbent material-coated S-shaped intake ducts that shield the compressor fan from reflecting radar waves, the F-22 design placed a much higher degree of importance on low observance throughout the entire spectrum of sensors including radar signature, visual, infrared, acoustic, and radio frequency.

The stealth of the F-22 is due to a combination of factors, including the overall shape of the aircraft, the use of radar absorbent material (RAM), and attention to detail such as hinges and pilot helmets that could provide a radar return. However, reduced radar cross section is only one of five facets that designers addressed to create a stealth design in the F-22. The F-22 has also been designed to disguise its infrared emissions to make it harder to detect by infrared homing ("heat seeking") surface-to-air or air-to-air missiles, including its flat (rather than round) thrust vectoring nozzles. Designers also made the aircraft less visible to the naked eye, and controlled radio and noise emissions. The Raptor has an under bay carrier made for hiding heat from missile threats, like surface-to-air missiles.

The F-22 apparently relies less on maintenance-intensive radar absorbent material and coatings than previous stealth designs like the F-117. These materials caused deployment problems due to their susceptibility to adverse weather conditions. Unlike the B-2, which requires climate-controlled hangars, the F-22 can undergo repairs on the flight line or in a normal hangar. Furthermore, the F-22 has a warning system (called "Signature Assessment System" or "SAS") which presents warning indicators when routine wear-and-tear have degraded the aircraft's radar signature to the point of requiring more substantial repairs. The exact radar cross section of the F-22 remains classified. In early 2009 Lockheed Martin released information on the F-22, showing it to have a radar cross section from certain critical angles of -40 dBsm — the equivalent radar reflection of a "steel marble". However, the stealth features of the F-22 require additional maintenance work that decreases their mission capable rate to approximately 62-70%.

The effectiveness of this emphasis on stealth characteristics during the F-22 design process is difficult to measure. While its radar cross-section is almost nonexistent, this is merely a static measurement of the aircraft's frontal or side area and is valid only for a radar source in a stationary location relative to the aircraft. As soon as the F-22 maneuvers, it exposes a different set of angles and a greater surface area to any radar, increasing its visibility. Furthermore, the use of stealth contouring and radar absorbent material are chiefly effective against high-frequency radars, the type usually found on other aircraft. Low-frequency radars, including weather radars and warning stations in areas of the former Soviet Union, are allegedly less affected by stealth characteristics and are more capable of detecting some of the aircraft employing them. The result of these low resolution and fleeting radar contacts will mean that while the defense may know that some sort of stealth aircraft has intruded into their airspace, they will be unable to vector defenses in to shoot down the aircraft, especially a high performance airframe like the F-22.

External lighting

The aircraft has integral position and anti-collision lighting (including strobes) on the wings, compatible with stealth requirements, supplied by Goodrich Corporation. The low voltage electroluminescent formation lights are located on the aircraft at critical positions for night flight operations (on both sides of the forward fuselage under the chin, on the tip of the upper left and right wings, and on the outside of both vertical stabilizers). There are similar air refueling lights on the butterfly doors that cover the air refueling receptacle.

Operational history

The 27th Fighter Squadron at Langley Air Force Base was the first squadron to receive the F-22

Designation and name changes

The YF-22 was originally given the unofficial name "Lightning II", after the World War II fighter P-38, by Lockheed, which persisted until the mid-1990s when the USAF officially named the aircraft "Raptor". The aircraft was also briefly dubbed "SuperStar" and "Rapier". The F-35 later received the Lightning II name on 7 July 2006. The production model was formally named F-22 "Raptor" when the first production-representative aircraft was unveiled on 9 April 1997.

In September 2002, Air Force leaders changed the Raptor’s designation to F/A-22. The new designation, which mimicked that of the Navy’s F/A-18 Hornet, was intended to highlight plans to give the Raptor a ground-attack capability amid intense debate over the relevance of the expensive air-superiority jet. This was later changed back to simply F-22 on 12 December 2005. On 15 December 2005, the F-22A entered service.

Testing

An F-22 refuels from a KC-135 during testing; the attachment on the back top is for a spin recovery chute

Flight testing of the F-22 began in 1997. Raptor 4001 was retired and sent to Wright-Patterson AFB to be fired at for testing the fighter's survivability. Usable parts of 4001 would be used to make a new F-22. Another engineering and manufacturing development (EMD) F-22 was also retired and likely to be sent to be rebuilt. A testing aircraft was converted to a maintenance trainer at Tyndall AFB.

On 3 May 2006, a report was released detailing a problem with a forward titanium boom on the aircraft that was not properly heat treated. Officials are still investigating the problem which was caused by the boom portion not being subjected to high temperatures in the factory for long enough, causing the boom to be less ductile than specified and potentially shortening the lives of the first 80 or so F-22s. Work is underway to restore them to full life expectancy. In April 2006, the F-22 fleet underwent modifications at Hill AFB, and at Edwards AFB near Palmdale, California.

Service history

On 15 December 2005 the USAF announced that the Raptor had reached its Initial Operational Capability (IOC).

During Exercise Northern Edge in Alaska in June 2006, 12 F-22s of the 94th FS downed 108 adversaries with no losses in simulated combat exercises. In two weeks of exercises, the Raptor-led Blue Force amassed 241 kills against two losses in air-to-air combat, and neither Blue Force loss was an F-22.

An F-22 observes as an F-15 Eagle banks left. The F-22 is slated to replace the F-15C/D

This was followed with the Raptor's first participation in a Red Flag exercise. Fourteen F-22s of the 94th FS supported attacking Blue Force strike packages as well as engaging in close air support sorties themselves in Red Flag 07-1 between 3 February and 16 February 2007. Against designed superior numbers of Red Force Aggressor F-15s and F-16s, it established air dominance using eight aircraft during day missions and six at night, reportedly defeating the Aggressors quickly and efficiently, even though the exercise rules of engagement allowed for four to five Red Force regenerations of losses but none to Blue Force. Further, no sorties were missed because of maintenance or other failures, and only one Raptor was adjudged lost against the virtual annihilation of the defending force. When their ordnance was expended, the F-22s remained in the exercise area providing electronic surveillance to the Blue Forces.

While attempting its first overseas deployment to the Kadena Air Base in Okinawa, Japan, on 11 February 2007, a group of six Raptors flying from Hickam AFB, Hawaii experienced multiple computer crashes coincident with their crossing of the 180th meridian of longitude (the International Date Line). The computer failures included at least navigation (completely lost) and communication. The fighters were able to return to Hawaii by following their tankers in good weather. The error was fixed within 48 hours and the F-22s continued their journey to Kadena.

An F-22 from Elmendorf AFB, Alaska intercepting a Russian Tupolev Tu-95 near Alaskan airspace

F-22A Raptors of the 90th Fighter Squadron performed their first intercept of two Russian Tu-95MS 'Bear-H' bombers in Alaska, on 22 November 2007. This was the first time that F-22s had been called to support a NORAD mission. Raptors have also shadowed Tu-160 'Blackjack' strategic bombers.

On 12 December 2007, General John D.W. Corley, USAF, Commander of Air Combat Command, officially declared the F-22s of the integrated active duty 1st Fighter Wing and Virginia Air National Guard 192d Fighter Wing fully operational, three years after the first Raptor arrived at Langley Air Force Base, Virginia. This was followed from 13 April to 19 April 2008 by an Operational Readiness Inspection (ORI) of the integrated wing in which it received an "excellent" rating in all categories while scoring a simulated kill-ratio of 221-0. The first pair of Raptors assigned to the 49th Fighter Wing became operational at Holloman Air Force Base, New Mexico, on 2 June 2008.

In December 2007, Secretary of the Air Force Michael Wynne requested that the F-22 be deployed to the Middle East, but Secretary of Defense Gates rejected this, and later requested the resignation of Wynne for the 2007 United States Air Force nuclear weapons incident.

F-22 Raptor

On 28 August 2008, an F-22 from the 411th Flight Test Squadron performed in the first ever air-to-air refueling of an aircraft using synthetic jet fuel. The test was a part of the wider USAF effort to qualify all of its aircraft to use the fuel, a 50/50 mix of JP-8 and a Fischer-Tropsch process-produced, natural gas-based fuel. For the tests, no modifications were made to the F-22 or the KC-135 Stratotanker which performed the refueling.

On 22 July 2009, the United States Senate voted to end F-22 production at 187 fighters. The extreme economic burden of the Raptor was cited, with arguments that since it is not used in Iraq or Afghanistan, the further costs are unnecessary. Defense Secretary Robert Gates announced in April that the military would shift more funding towards intelligence and personnel, rather than hardware only suitable for fighting major wars like the F-22, specifically stating that it is too expensive and does not have sufficient multi-mission capability for current military operations.

In February 2010 the entire fleet was grounded due to rusting ejection seat rods.

Maintenance

An F-22 near Langley AFB, Virginia in 2005

F-22 taxiing at Andrews AFB, Maryland in 2009

There have been several reports as to the F-22's overall mission ready rate and maintenance requirements.

Lockheed-Martin's F-22 spokesman says that the overall mission ready rate has improved from 62% in 2004 to 68% in 2009, and is "on track" to reach 85% by the time the fleet reaches 100,000 flight hours. The Washington Post says that between October 2008 and May 2009, just 55 percent of the deployed F-22 fleet has been available. Air Force Magazine reported that the Washington Post article's was incorrect and that mission capable rates have been climbing, and by June 2009 stood at 62.9%, compared to approximately 70% for the mature F-15 and F-16 aircraft. The Air Force Association states that the current mission capable rate for the entire F-22 fleet is 70%, which is in line with the 71.2 percent the even newer Super Hornet managed on its first wartime deployment.

In July 2009, the Air Force reported that the F-22 requires more than 30 hours of maintenance for every flight hour, with the total cost per flight hour of $44,000. The Office of the Secretary of Defense puts that figure at 34 hours of maintenance per single hour of flight at a cost of $49,808 per hour of flight. However, a Lockheed spokesman says that the variable cost per flight hour is only $19,000, with a direct maintenance man hours per flight hour of 18.10 in 2008 and 20.48 in 2009. The Pentagon requirement is for 12 hours of maintenance per flight hour. The F-22 also reportedly encountered a critical failure every 1.7 hours. The F-22 had required maintenance every 0.97 flight hours in 2004. This improved to 3.22 flight hours per maintenance event in production Lot 6 aircraft.

The aircraft's radar-absorbing metallic skin is the principal cause of its maintenance troubles, with skin repairs accounting for more than half of the maintenance. Another source of maintenance problems is that many components require custom hand-fitting and are not interchangeable. The canopy visibility has degraded more rapidly than expected, with refurbishments at 331 flight hours, on average, instead of the required 800 hours. Pentagon officials respond that measuring flying costs for aircraft fleets that have not reached 100,000 flying hours is premature. They say improvements have been made since 2008, and the F-22s are on track to meet key performance parameters by 2010.

During at least one exercise the F-22 maintained a high state of mission readiness. In January 2007, it was reported that the F-22 maintained a 97% sortie rate (flying 102 out of 105 tasked sorties) while amassing a 144-to-zero kill ratio during "Northern Edge" air-to-air exercises held in Alaska, the first large-scale exercise in which the Raptor participated. Lt. Col. Wade Tolliver, the squadron commander of the 27th FS from Langley AFB commented on the upkeep and reliability of the Raptor's RAM during simulated combat conditions, stating "the stealth coatings are not as fragile as they were in earlier stealth aircraft. It isn't damaged by a rain storm and it can stand the wear and tear of combat without degradation."

However, rain has caused "shorts and failures in sophisticated electrical components" when the Raptors were briefly posted to Guam.

Each Raptor requires a month-long packaged maintenance plan (PMP) after every 300 flight hours.

Variants

- **YF-22A** - Pre-production version used for ATF testing and evaluation. Two were built.
- **F-22A** - single-seat production version. Was designated "F/A-22A" in early 2000s.

Canceled

- **F-22B** - planned two-seat variant, but was dropped in 1996 to save development costs.
- Naval F-22 variant - a carrier-borne variant of the F-22 with swing-wings for the U.S. Navy's Navy Advanced Tactical Fighter (NATF) program to replace the F-14 Tomcat. Program was canceled in 1993.

Derivatives

The FB-22 was a proposed medium-range bomber for the USAF. The FB-22 was projected to carry up to 30 Small Diameter Bombs to about twice the range of the F-22A, while maintaining the F-22's stealth and supersonic speed. However, the FB-22 in its planned form appears to have been canceled with the 2006 Quadrennial Defense Review and subsequent developments, in lieu of a larger subsonic bomber with a much greater range.

The X-44 MANTA, or multi-axis, no-tail aircraft, was a planned experimental aircraft based on the F-22 with enhanced thrust vectoring controls and no aerodynamic backup. The aircraft was to be solely controlled by thrust vectoring, without featuring any rudders, ailerons, or elevators. Funding for this program was halted in 2000.

Operators

F-22A Raptor from Tyndall AFB, Florida cruising over the Florida Panhandle

An F-22 landing at Holloman AFB, New Mexico

An F-22 belonging to the 433rd Weapons Squadron at Nellis AFB, Nevada

An F-22, based at Elmendorf AFB, Alaska, over mountain terrain

The United States Air Force is the only operator of the F-22, with 168 aircraft in inventory as of May 2010. These are operated by the following commands:

- Air Education and Training Command
    - **325th Fighter Wing**, Tyndall Air Force Base, Florida
        - **43d Fighter Squadron** - The first squadron to operate the F-22 and continues to serve as the Formal Training Unit. Known as the "Hornets", the 43d was re-activated at Tyndall in 2002.

- Air Combat Command
    - **1st Fighter Wing**, Langley Air Force Base, Virginia
        - **27th Fighter Squadron** - The first combat F-22 squadron. Began conversion in December 2005 after and flew the first operational mission (January 2006 in support of Operation Noble Eagle).
        - **94th Fighter Squadron**
    - **49th Fighter Wing**, Holloman AFB, New Mexico
        - **7th Fighter Squadron**
        - **8th Fighter Squadron**
    - **44th Fighter Group**, Holloman AFB, New Mexico; Air Force Reserve Command (AFRC)
        - **301st Fighter Squadron** Associate AFRC squadron to the 49 FW.
    - **53d Wing**, Eglin Air Force Base, Florida
        - **422d Test and Evaluation Squadron** - The "Green Bats" are responsible for operational testing, tactics development and evaluation for the F-22 at Nellis Air Force Base, Nevada.
    - **57th Wing**, Nellis Air Force Base, Nevada
        - **433d Weapons Squadron**

- Air Force Materiel Command
    - **412th Test Wing**, Edwards Air Force Base, California
        - 411th Flight Test Squadron - Conducted competition between YF-22 and YF-23 from 1989-1991. Continues to conduct flight test on F-22 armaments and upgrades.

- Pacific Air Forces
    - **3d Wing**, Elmendorf Air Force Base, Alaska
        - **90th Fighter Squadron** - Converted from F-15Es; first F-22A arrived 8 August 2007.
        - **525th Fighter Squadron**
    - **477th Fighter Group**, Elmendorf AFB, Alaska. Air Force Reserve Command (AFRC) unit.
        - **302d Fighter Squadron** Associate AFRC squadron to the 3 WG.

- Air National Guard
    - **192d Fighter Wing** - Langley AFB, Virginia.
        - **149th Fighter Squadron** - Associate ANG squadron to the 1 FW.

- **154th Wing, Hickam AFB, Hawaii**
    - **531st Fighter Squadron**, Hickam AFB, Hawaii. Associate squadron to the 199th Fighter Squadron.
    - **199th Fighter Squadron, Hawaii Air National Guard**

Notable accidents

Because of the platform's relative immaturity due to its early operational status and low number of flight hours compared to legacy platforms (only 5 years for the F-22 compared to the longer lifetimes of the other aircraft), the F-22 currently has the highest accident rate of any USAF fighter aircraft currently in service. This rate is expected to go down as the Air Force gains more experience in operating the aircraft.

In April 1992, the first YF-22 crashed while landing at Edwards Air Force Base, California. The test pilot Tom Morgenfeld escaped without injury. The cause of the crash was found to be a flight control software error that failed to prevent a pilot-induced oscillation.

The first crash of a production F-22 occurred during takeoff at Nellis Air Force Base on 20 December 2004, in which the pilot ejected safely prior to impact. The crash investigation revealed that a brief interruption in power during an engine shutdown prior to flight caused a malfunction in the flight-control system; consequently, the aircraft design was corrected to avoid the problem. All USAF F-22s were grounded for two weeks after the crash, but resumed operations after a review was completed.

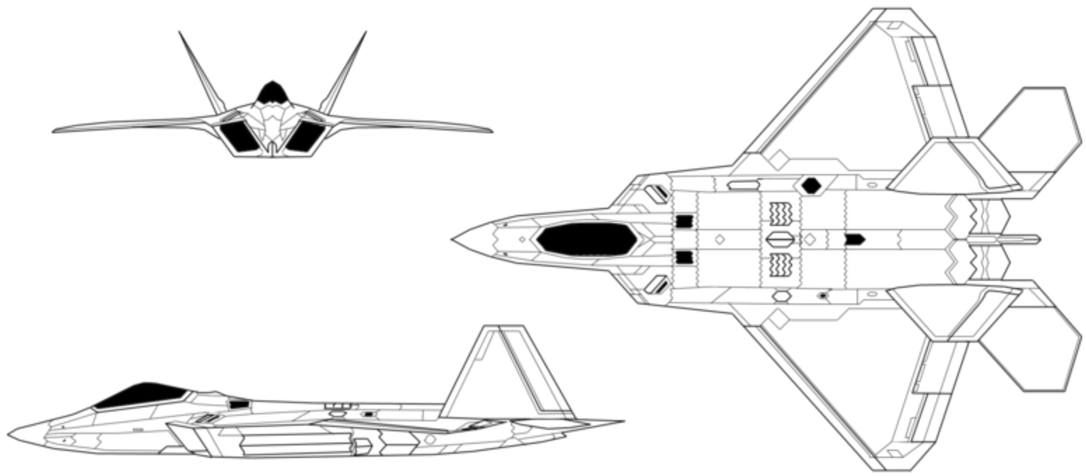
On 25 March 2009, an F-22 crashed 35 miles (56 km) northeast of Edwards Air Force Base during a test flight, resulting in the death of Lockheed test pilot David P. Cooley. The aircraft was from the 411th Flight Test Squadron. The Washington Post reported that the crash happened during a bombing test. An Air Force Materiel Command investigation found that Cooley momentarily lost consciousness during a high-G maneuver then ejected after finding himself too low to recover. Cooley was killed by blunt-force trauma during ejection because of the F-22's speed and the windblast. The investigation found no problems with the design or airworthiness of the F-22.

On 16 November 2010, an F-22 based at Elmendorf, AFB, Alaska, was reported overdue. ATC reportedly lost contact with the aircraft around 19:40 Alaska time. The crash site was found and search-and-rescue teams found conclusive evidence that the pilot, Air Force Captain Jeffrey Haney, did not survive the crash.

Aircraft on display

The National Museum of the United States Air Force, on 30 April 2007, announced that EMD Raptor 91-4003 would be put on display later in 2007 in the space being occupied by the YF-22. The Museum publicly unveiled its Raptor 91-4003 display on 18 January 2008.

Specifications

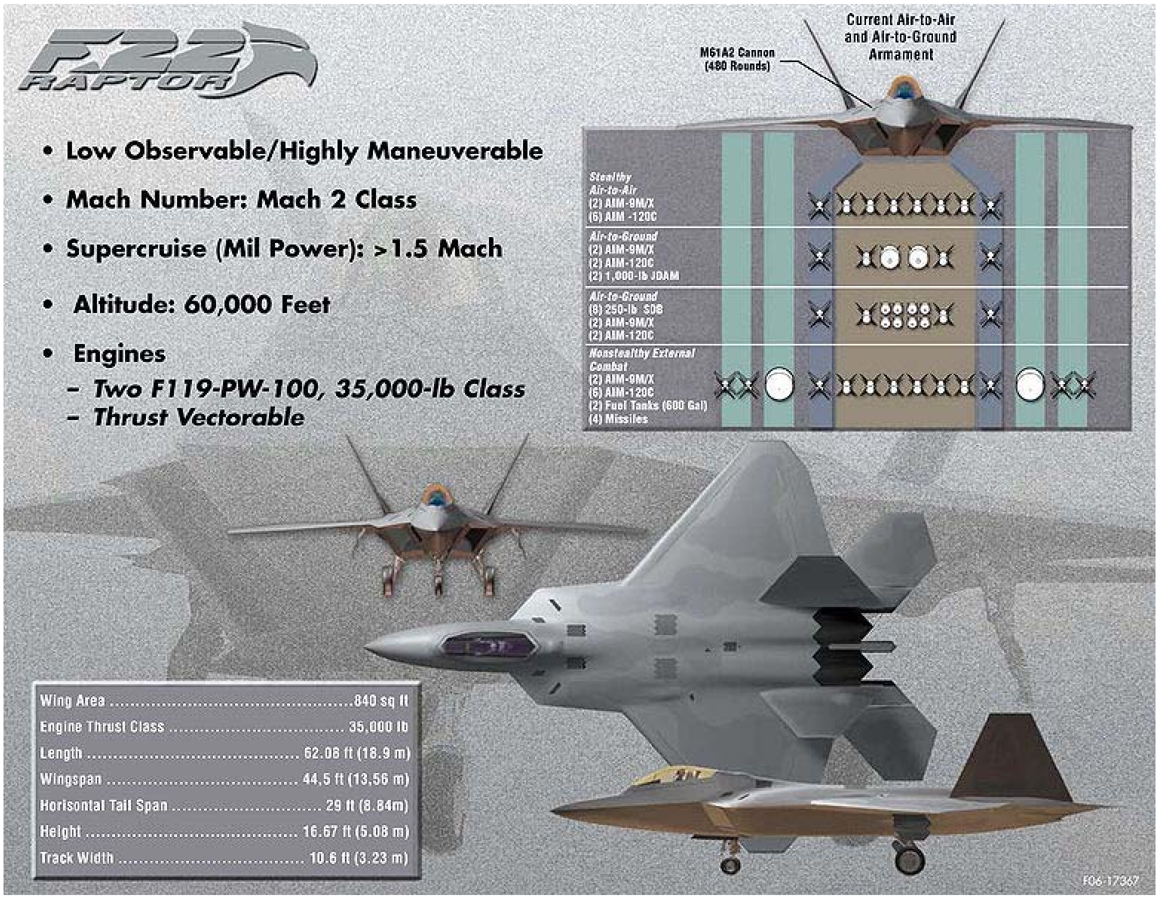


General characteristics

- **Crew:** 1
- **Length:** 62 ft 1 in (18.90 m)
- **Wingspan:** 44 ft 6 in (13.56 m)
- **Height:** 16 ft 8 in (5.08 m)
- **Wing area:** 840 ft² (78.04 m²)
- **Airfoil:** NACA 64A?05.92 root, NACA 64A?04.29 tip
- **Empty weight:** 43,430 lb (19,700 kg)
- **Loaded weight:** 64,460 lb (29,300 kg)
- **Max takeoff weight:** 83,500 lb (38,000 kg)
- **Powerplant:** 2× Pratt & Whitney F119-PW-100 Pitch Thrust vectoring turbofans
    - **Dry thrust:** 23,500 lb (104 kN) each
    - **Thrust with afterburner:** 35,000+ lb (156+ kN) each
- **Fuel capacity:** 18,000 lb (8,200 kg) internally, or 26,000 lb (11,900 kg) with two external fuel tanks

Performance

- **Maximum speed:**
    - **At altitude:** Mach 2.25 (1,500 mph, 2,410 km/h)
    - **Supercruise:** Mach 1.82 (1,220 mph, 1,963 km/h)
- **Range:** >1,600 nmi (1,840 mi, 2,960 km) with 2 external fuel tanks
- **Combat radius:** 410 nmi (471 mi, 759 km)
- **Ferry range:** 2,000 mi (1,738 nmi, 3,219 km)
- **Service ceiling:** 65,000 ft (19,812 m)
- **Wing loading:** 77 lb/ft² (375 kg/m²)
- **Thrust/weight:** 1.08 (1.26 with loaded weight & 50% fuel)
- **Maximum design g-load:** -3.0/+9.0 g



USAF poster overview of key features and armament

Armament

- **Guns:** 1× 20 mm (0.787 in) M61A2 Vulcan 6-barreled gatling cannon in starboard wing root, 480 rounds
- **Air to air loadout:**
    - 6× AIM-120 AMRAAM
    - 2× AIM-9 Sidewinder
- **Air to ground loadout:**
    - 2× AIM-120 AMRAAM and
    - 2× AIM-9 Sidewinder for self-protection, and one of the following:
        - 2× 1,000 lb (450 kg) JDAM or
        - 8× 250 lb (110 kg) GBU-39 Small Diameter Bombs
- **Hardpoints:** 4× under-wing pylon stations can be fitted to carry 600 US gallon drop tanks or weapons, each with a capacity of 5,000 lb (2,268 kg).

Avionics

- **RWR (Radar warning receiver):** 250 nmi (463 km) or more
- **Radar:** 125–150 miles (200–240 km) against 1 m^2 (11 sq ft) targets (estimated range)
- Chemring MJU-39/40 flares for protection against IR missiles.

Chapter 11

Lockheed F-117 Nighthawk

F-117 Nighthawk

Role	Stealth attack aircraft
National origin	United States
Manufacturer	Lockheed Corporation Lockheed Martin
First flight	18 June 1981
Introduced	15 October 1983
Retired	22 April 2008
Primary user	United States Air Force
Number built	64 (5 YF-117A, 59 F-117A)
Unit cost	US$42.6 M (flyaway cost) US$111.2 M (total program)
Developed from	Lockheed Have Blue

The **Lockheed F-117 Nighthawk** is a stealth ground attack aircraft formerly operated by the United States Air Force. The F-117A's first flight was in 1981, and it achieved initial operating capability status in October 1983. The F-117A was "acknowledged" and revealed to the world in November 1988.

A product of the Skunk Works and a development of the Have Blue technology demonstrator, it became the first operational aircraft initially designed around stealth technology. The F-117A was widely publicized during the Persian Gulf War of 1991.

The Air Force retired the F-117 on 22 April 2008, primarily due to the fielding of the F-22 Raptor and the impending fielding of the F-35 Lightning II.

Development

In 1964, Pyotr Ya. Ufimtsev, a Soviet/Russian mathematician, published a seminal paper, "Method of Edge Waves in the Physical Theory of Diffraction", in the Journal of the Moscow Institute for Radio Engineering, in which he showed that the strength of a radar return is related to the edge configuration of an object, not its size. Ufimtsev was extending theoretical work published by the German physicist Arnold Sommerfeld. Ufimtsev demonstrated that he could calculate the radar cross-section across a wing's surface and along its edge. The obvious conclusion was that even a large airplane could be made stealthy by exploiting this principle. However, the airplane's design would make it aerodynamically unstable, and the state of computer technology in the early 1960s could not provide the kinds of flight computers which allow aircraft such as the F-117, and B-2 Spirit to stay airborne. However, by the 1970s, when a Lockheed analyst reviewing foreign literature found Ufimtsev's paper, computers and software had advanced significantly, and the stage was set for the development of a stealthy airplane.

Senior Trend

F-117A painted in "Gray Dragon" experimental camouflage scheme.

The F-117 was born after combat experience in the Vietnam War when increasingly sophisticated Soviet surface-to-air missiles (SAMs) downed heavy bomber flights. It was a black project, an ultra-secret program for much of its life, until the late 1980s. The project began in 1975 with a model called the "Hopeless Diamond" (a wordplay on the Hope Diamond due to its appearance). In 1977 Lockheed produced two 60% scale models under the Have Blue contract. The Have Blue program was a stealth technology demonstrator that lasted from 1976 to 1979. The success of Have Blue led the Air Force to create the Senior Trend program which developed the F-117.

The decision to produce the F-117A was made on 1 November 1978, and a contract awarded to Lockheed Advanced Development Projects, popularly known as the Skunk Works, in Burbank, California. The program was led by Ben Rich. Rich called on Bill Schroeder, a Lockheed mathematician, and Denys Overholser, a computer scientist, to exploit Ufimtsev's work. They designed a computer program called Echo, which made it possible to design an airplane with flat panels, called facets, which were arranged so as to scatter over 99% of a radar's signal energy "painting" the aircraft.

The F-117 first flew in June 1981, only 31 months after the full-scale development decision. The first production F-117A was delivered in 1982, operational capability was achieved in October 1983. The Air Force denied the existence of the aircraft until 1988, when a grainy photograph was released to the public. In April 1990 two were flown into Nellis Air Force Base, Nevada, arriving during daylight and visible to a crowd of tens of thousands. Five Full Scale Development (FSD) aircraft built and were designated "YF-117A". A total of 59 production F-117s were delivered through July 1990.

F-117 taxiing

As the Air Force has stated, "Streamlined management by Aeronautical Systems Center, Wright-Patterson AFB, Ohio, combined breakthrough stealth technology with concurrent development and production to rapidly field the aircraft... The F-117A program demonstrates that a stealth aircraft can be designed for reliability and maintainability." The aircraft maintenance statistics are comparable to other tactical fighters of similar complexity. Logistically supported by Sacramento Air Logistics Center, McClellan AFB, California, the F-117A was kept at the forefront of technology through a planned weapon system improvement program located at USAF Plant 42 at Palmdale, California.

Several of the F-117s were painted with a gray camouflage pattern in an experiment to determine the effectiveness of the F-117's stealth during daylight conditions. 2004 and 2005 saw several mid-life improvement programs implemented on the F-117, including an avionics upgrade.

Designation

The operational aircraft had the official designation of "F-117A". Most modern U.S. military aircraft use post-1962 designations in which the designation "F" is usually an air-to-air fighter, "B" is usually a bomber, "A" is usually a ground-attack aircraft, etc. (Examples include the F-15, the B-2, and the A-6.) The F-117 is primarily a ground-attack aircraft so its "F" designation is inconsistent with the DoD system, but it is an inconsistency that has been repeatedly employed by the U.S. Air Force with several of its ground attack aircraft since the late 1950s (i.e., F-105, F-111, etc.).

The designation "F-117" seems to indicate that it was given an official designation prior to the 1962 U.S. Tri-Service Aircraft Designation System and could be considered numerically to be a part of the earlier "Century series" of fighters. The assumption prior to the revealing of the aircraft to the public was that it would likely receive the designation F-19 as that number had not been used. However there were no other aircraft to receive a "100" series number following the F-111. Captured Soviet fighters were given F-series numbers for their evaluation by U.S. test pilots, and with the advent of the Teen Series fighters, most often Century Series designations.

As with other exotic military aircraft types flying in the southern Nevada area, such as captured fighters, an arbitrary radio call of "117" was assigned. This same radio call had been used by the enigmatic 4477th "Red Hats/Red Eagles" unit that often had flown expatriated MiGs in the area, but there was no relationship to the call and the formal F-19 designation then being considered by the Air Force. Apparently, use of the "117" radio call became commonplace and when Lockheed released its first flight manual ("dash one"), F-117A was the designation printed on the cover.

A televised documentary quoted a senior member of the F-117A development team as saying that the top-notch fighter pilots required to fly the new aircraft were more easily attracted to an "F" plane, as opposed to a "B" or "A" aircraft.

F-117N "Seahawk"

In the early 1990s, Lockheed proposed an upgraded, carrier capable variant of the F-117 dubbed the "Seahawk" as an alternative to the canceled A/F-X program. The unsolicited proposal was received poorly by the Department of Defense, who had little interest in the single mission capabilities of such an aircraft, particularly as it would take money away from the Joint Advanced Strike Technology program (which evolved into the Joint Strike Fighter). The new aircraft would have differed from the land based F-117 in several ways, including the addition "of elevators, a bubble canopy, a less sharply swept wing and reconfigured tail". The "N" variant would also be re-engined to use General Electric F414 turbofans instead of the older General Electric F404s. Furthermore the aircraft would be optionally fitted with hardpoints, allowing for an additional 8,000 lb (3,600 kg) of payload, and a new ground attack radar with air-to-air capability. In that role the F-117N could carry AIM-120 AMRAAM air-to-air missiles.

After being rebuffed by the Navy, Lockheed submitted an updated proposal that included afterburning capability and a larger emphasis on the F-117N as a multimission aircraft, rather than just an attack aircraft. In efforts to boost interest, Lockheed also proposed an F-117B land-based variant that shared most of the F-117N capabilities. This variant was proposed to both the US Air Force and the RAF. This renewed F-117N proposal was also known as the A/F-117X. Neither the F-117N or the F-117B were purchased by any party.

Design

The front side of an F-117

The F-117 is shaped to deflect radar signals and is about the size of an F-15 Eagle. The single-seat Nighthawk is powered by two non-afterburning General Electric F404 turbofan engines, and has quadruple-redundant fly-by-wire flight controls. It is air refuelable. To lower development costs, the avionics, fly-by-wire systems, and other parts are derived from the F-16 Fighting Falcon, F/A-18 Hornet and F-15E Strike Eagle. The parts were originally described as spares on budgets for these aircraft, to keep the F-117 project secret. The F-117 Nighthawk has a radar signature of about 0.025 m^2.

F-117 with its canopy opened

Among the penalties for stealth are lower engine power thrust, due to losses in the inlet and outlet, a very low wing aspect ratio, and a high sweep angle (50°) needed to deflect incoming radar waves to the sides. With these design considerations and no afterburner, the F-117 is limited to subsonic speeds.

The F-117A is equipped with sophisticated navigation and attack systems integrated into a digital avionics suite. It carries no radar, which lowers emissions and cross-section. It navigates primarily by GPS and high-accuracy inertial navigation. Missions are coordinated by an automated planning system that can automatically perform all aspects of an attack mission, including weapons release. Targets are acquired by a thermal imaging infrared system, slaved to a laser that finds the range and designates targets for laser-guided bombs.

The F-117A's split internal bay can carry 5,000 lb (2,300 kg) of ordnance. Typical weapons are a pair of GBU-10, GBU-12, or GBU-27 laser-guided bombs, two BLU-109 penetration bombs, or two Joint Direct Attack Munitions (JDAMs), a GPS/INS guided stand-off bomb.

Operators

Three F-117s during maintenance

United States

United States Air Force

- 4450th Tactical Group - Tonopah Test Range Airport
  - 4450th Tactical Squadron (1981–1989)
  - 4451st Tactical Squadron (1981–1989)
  - 4453rd Test and Evaluation Squadron (1985–1989)
- 37th Tactical Fighter Wing - Tonopah Test Range Airport
  - 415th Tactical Fighter Squadron (1989–1993)
  - 416th Tactical Fighter Squadron (1989–1993)
  - 417th Tactical Fighter Training Squadron (1989–1993)
- 49th Fighter Wing - Holloman AFB
  - 7th Fighter Squadron (1991–2006)
  - 8th Fighter Squadron (1992–2008)
  - 9th Fighter Squadron (1993–2008)

Operational history

An F-117A during landing employing a drag-chute

During the program's early years, from 1984 to mid-1992, the F-117A fleet was based at Tonopah Test Range Airport, Nevada where it served under the 4450th Tactical Group. Because the F-117 was classified during this time, the 4450th Tactical Group was "officially" located at Nellis Air Force Base, Nevada and equipped with A-7 Corsair II aircraft. The 4450th was absorbed by the 37th Tactical Fighter Wing in 1989. In 1992, the entire fleet was transferred to Holloman Air Force Base, New Mexico, where it was placed under the command of the 49th Fighter Wing. The move eliminated the Key Air and American Trans Air contract flights, which flew 22,000 passenger trips on 300 flights from Nellis to Tonopah per month.

F-117 pilots called themselves "Bandits". Each of the 558 Air Force pilots who have flown the F-117 have a Bandit number, such as "Bandit 52", that indicates the sequential order of their first flight in the F-117.

The F-117 has been used several times in war. Its first mission was during the United States invasion of Panama in 1989. During that invasion two F-117A Nighthawks dropped two bombs on Rio Hato airfield.

F-117s in formation

During the Persian Gulf War in 1991, the F-117A flew approximately 1,300 sorties and scored direct hits on 1,600 high-value targets in Iraq over 6,905 flight hours. Only 2.5% of the American aircraft in Iraq were F-117s, yet they struck more than 40% of the strategic targets. F-117As dropped over 2,000 tons of precision-guided munitions and struck their targets with over an 80% success rate. "Although the 37th Tactical Fighter Wing Provisional and its 42 stealth fighters represented just 2.5 percent of all allied fighter and attack aircraft in the Persian Gulf, the F-117As were assigned against more than 31 percent of the strategic Iraqi military targets attacked during the first 24 hours of the air campaign."

F-117 Nighthawk

It was among the only U.S. or coalition aircraft to strike targets in downtown Baghdad. Among the aircraft with which the Nighthawk shared this distinction were the F-16s which attacked Baghdad during daylight on 19 January 1991 during the "Package Q" mission—the largest single sortie flown during the war.

Since moving to Holloman AFB in 1992, the F-117A and the men and women of the 49th Fighter Wing have deployed to Southwest Asia more than once. On their first trip, the crews flew non-stop from Holloman to Kuwait, a flight of approximately 18.5 hours – a record for single-seat fighters that stands today.

It has since been used in Operation Allied Force in 1999, Operation Enduring Freedom in 2001 and in Operation Iraqi Freedom in 2003.

Combat losses

One F-117 was lost in combat with the Army of Yugoslavia. On 27 March 1999, during the Kosovo War, the 3rd Battalion of the 250th Air Defence Missile Brigade under the command of Colonel Zoltán Dani, downed an F-117A, callsign "Vega 31", AF serial number 82-0806, with a Yugoslav version of the Soviet Isayev S-125 'Neva' (NATO name SA-3 'Goa') anti-aircraft missile system. According to NATO Commander Wesley Clark and other NATO generals, Yugoslav air defenses detected F-117s by operating their radars on unusually long wavelengths, making the aircraft visible to radar for brief periods. It is also possible that the aircraft was visible due to a disruption of its radar signature caused by open bomb-bay doors. This was the justification given by Colonel Dani in a 2007 interview.

Canopy of F-117 shot down in Serbia in March 1999 at the Museum of Aviation in Belgrade.

Reportedly, several SA-3s were launched from approximately 8 miles (13 km) out, one of which detonated near the F-117A, forcing the pilot to eject. Though still classified, it is believed that the F-117 has no radar warning indicator, so the pilot's first indication of an incoming missile was likely seeing its flame. At this distance and combined speed the pilot had about six seconds to react before impact. According to an interview, Zoltán Dani kept most of his missile sites intact by frequently moving them, and had spotters looking for F-117s and other NATO aircraft. He oversaw the modification of his targeting radar to improve its detection. The commanders and crews of the SAMs guessed the flight paths of earlier F-117A attacks from rare radar spottings and positioned their SAM launchers and spotters accordingly. It is believed that the SA-3 crews and spotters were able to locate and track F-117A 82-806 visually, probably with infra-red and night vision systems. He claimed that his battery shot down an F-16 as well.

The F-117 pilot survived and was later rescued by U.S. Air Force Pararescue personnel. The wreckage of the F-117 was not promptly bombed, due to possible media fallout from news footage of civilians around the wreckage. The Serbs are believed to have invited Russian personnel to inspect the remains, compromising the then 25-year old US stealth technology. The F-117's pilot was misidentified. While the name "Capt Ken 'Wiz'

Dwelle" was painted on the canopy, it was revealed in 2007 that the pilot was actually Lt Col Dale Zelko, USAF.

Some sources claim that a second F-117A was damaged during the same campaign, allegedly on 30 April. Although the aircraft returned to base, it supposedly never flew again.

Retirement

An F-117A parked at Langley AFB, Virginia.

Despite its productive combat service, the F-117 was designed with late 1970s technologies. Its stealth technology, while more advanced than that of any other aircraft except the B-2 Spirit and the F-22 Raptor, is maintenance intensive. Furthermore, the facet-based stealth design has been surpassed by newer technology. Program Budget Decision 720 (PBD 720), dated 28 December 2005, proposed retiring the entire fleet by October 2008 to permit buying more F-22As. PBD 720 called for 10 aircraft to be retired in FY 2007 and the remaining 42 aircraft in FY 2008 and stated there were more capable Air Force assets that could provide low observable, precision penetrating weapons capability including the B-2, F-22 and JASSM. The Air Force originally planned to retire the F-117 in 2011. The Air Force later decided to retire the F-117 sooner to shift funds to modernizing the rest of the fleet. This would save an estimated $1.07 billion.

In late 2006, the Air Force closed the F-117 formal training unit (FTU), and announced the retirement of the F-117. The first six aircraft to be retired made the last flight on 12 March 2007 after a ceremony at Holloman AFB to commemorate the aircraft's career.

Brigadier General David Goldfein, commander of the 49th Fighter Wing, said at the ceremony, "With the launch of these great aircraft today, the circle comes to a close — their service to our nation's defense fulfilled, their mission accomplished and a job well done. We send them today to their final resting place — a home they are intimately familiar with — their first, and only, home outside of Holloman."

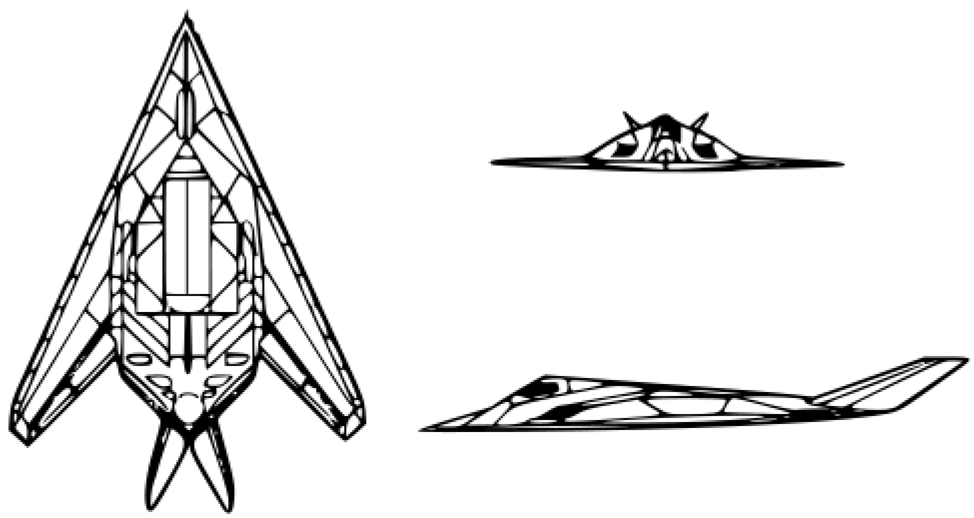
A pair of specially painted F-117 Nighthawks fly off from their last refueling by the Ohio Air National Guard's 121st Air Refueling Wing.

Unlike most other Air Force aircraft which are retired to Davis-Monthan AFB, the F-117s are being retired to the Tonopah Test Range Airport. At Tonopah, their wings will be removed and the aircraft will be stored in their original hangars. On 11 March 2008, it was reported that the last F-117s in service would touch down on 22 April 2008 in Tonopah Test Range Airfield in Nevada, the site of the F-117's first flight. The F-117 was retired during ceremonies at Palmdale and Tonopah on 22 April 2008. Four aircraft were kept flying beyond April by the 410th Flight Test Squadron at Palmdale for flight test. By the beginning of August, two were remaining, and the last F-117 left Palmdale to fly to Tonopah on 11 August 2008. With the last aircraft leaving for retirement, the 410th was deactivated in a ceremony on 1 August 2008.

Aircraft on display

- The first YF-117A is currently on pedestal display at Nellis Air Force Base, Nevada. (36°13′38.00″N 115°3′33.28″W / 36.22722°N 115.0592444°W)
- The second YF-117A is currently on static display at the National Museum of the Air Force at Wright-Patterson Air Force Base, Ohio.
- The third YF-117A built is on static display at Holloman Air Force Base, repainted to resemble the first F-117A used to drop weapons in combat.
- The fourth YF-117A built is currently on static display in the Blackbird Airpark at Air Force Plant 42 in Palmdale, California.
- The remains of the F-117A (s/n 82-0806) downed over Serbia are displayed at the Museum of Aviation in Belgrade close to Belgrade Nikola Tesla Airport.

Specifications



An F-117 conducts a live exercise bombing run using GBU-27 laser-guided bombs.

Nighthawk's left "ruddervator" or V-tail shown

General characteristics

- **Crew:** 1
- **Length:** 65 ft 11 in (20.09 m)
- **Wingspan:** 43 ft 4 in (13.20 m)
- **Height:** 12 ft 9.5 in (3.78 m)
- **Wing area:** 780 ft² (73 m²)
- **Empty weight:** 29,500 lb (13,380 kg)
- **Loaded weight:** 52,500 lb (23,800 kg)
- **Powerplant:** 2× General Electric F404-F1D2 turbofans, 10,600 lbf (48.0 kN) each

Performance

- **Maximum speed:** Mach 0.92 (617 mph, 993 km/h)
- **Cruise speed:** Mach 0.92
- **Range:** 930 NM (1720 km)
- **Service ceiling:** 45,000 ft (13,716 m)
- **Wing loading:** 65 lb/ft² (330 kg/m²)
- **Thrust/weight:** 0.40

Armament

- 2 × internal weapons bays with one hardpoint each (total of two weapons) equipped to carry:

- **Bombs:**
    - BLU-109 hardened penetrator
    - GBU-10 Paveway II laser-guided bomb
    - GBU-12 Paveway II laser-guided bomb
    - GBU-27 Paveway III laser-guided bomb
    - JDAM INS/GPS guided munition
    - B61 nuclear bomb

Nicknames

The aircraft's official name is "Night Hawk", however the alternative form "Nighthawk" is frequently used.

As it prioritized stealth over aerodynamics, it earned the nickname "Wobbly-Goblin" due to its alleged instability at low speeds; according to F-117 pilots, the nickname is undeserved. "Wobbly (or wobblin') Goblin" is likely a holdover from the early Have Blue / Senior Trend (FSD) days of the project when instability was a problem. In the USAF, "Goblin" (without wobbly) persists as a nickname because of the aircraft's appearance. Locals around Holloman Air Force Base call it the "Stealth".