# Handbook of Tailless Aircrafts


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# Table of Contents

Chapter- 1

# Tailless Aircraft


The DH108 *Swallow*

A **tailless aircraft** (often **tail-less**) traditionally has all its horizontal control surfaces on its main wing surface. It has no horizontal stabilizer - either **tailplane** or **canard** foreplane (nor does it have a second wing in **tandem** arrangement). A 'tailless' type usually still has a vertical stabilising fin (vertical stabilizer) and control surface (rudder). However, NASA has recently adopted the 'tailless' description for the novel X-36 research aircraft which has a canard foreplane but no vertical fin.

The most successful tailless configuration has been the **tailless delta**, especially for combat aircraft.

## *Flying wings*

**Flying wings** are tailless designs which also lack a distinct fuselage, having the pilot, engines, etc. located directly in or on the wing.

## *Aerodynamics*

### Longitudinal stability

A tailless aeroplane has no separate horizontal stabiliser, either behind (Tailplane) or in front of (canard foreplane) the main lifting surface. Because of this the aerodynamic center of an ordinary wing would lie ahead of the aircraft's center of gravity, creating instability in pitch. Some other method must be used to move the aerodynamic center backward and make the aircraft stable. There are two main ways for the designer to achieve this:

- Sweep the wing leading edge back, either as a swept wing or delta wing, and reduce the angle of incidence of the outer wing section so that it acts rather like a conventional tailplane stabiliser. If this is done progressively along the span of the outer section, it is called **tip washout**. The outer section of the wing now acts as a conventional tailplane, and in level flight the aircraft should be trimmed so that the tips do not contribute any lift: they may even need to provide a small downthrust. This reduces the overall efficiency of the wing, but for many designs - especially for high speeds - this is outweighed by the reductions in drag, weight and cost over a conventional stabiliser. This method was developed by the English aeronaut J. W. Dunne in the early 20th century, but did not gain widespread use until the jet age. Since Dunne, this approach has been augmented by the use of low or null pitching moment airfoils, seen for example in the Horten series of sailplanes and fighters.

- Use a wing aerofoil section with reflex or reverse camber. With reflex camber the flatter side of the wing is on top, and the strongly curved side is on the bottom, so the front section presents a high angle of attack while the back section is more or less horizontal and contributes no lift, so acting like a tailplane or the washed-out tips of a swept wing. Reflex camber can be simulated by fitting large elevators to a conventional airfoil and trimming them noticeably upwards; the center of gravity must also be moved forward of the usual position. Due to the Bernoulli effect, reflex camber tends to create a small downthrust, so the angle of attack of the wing is increased to compensate. This in turn creates additional drag. This method allows a wider choice of wing planform than sweepback and washout, and designs have included circular (Arup) and straight wings. But the drag inherent in a high angle of attack is generally regarded as making the concept inefficient, and only a few types, such as the Fauvel and Marske Aircraft series of sailplanes, use it.

An alternative approach is to locate the main weight of the aircraft a significant distance below the wing center, so that gravity will tend to maintain the aircraft in a horizontal attitude and so counteract any aerodynamic instability. In practice this is not sufficient to provide stability on its own, and typically is augmented by sweepback and washout as described. A classic example is the Rogallo wing hang glider.

There is a trade-off between stability and maneuverability. A high level of maneuverability requires a low level of stability. Some modern hi-tech combat aircraft are aerodynamically unstable in pitch and rely on fly-by-wire computer control to provide stability. The Northrop B-2 *Spirit* flying wing is an example.

### Pitch control

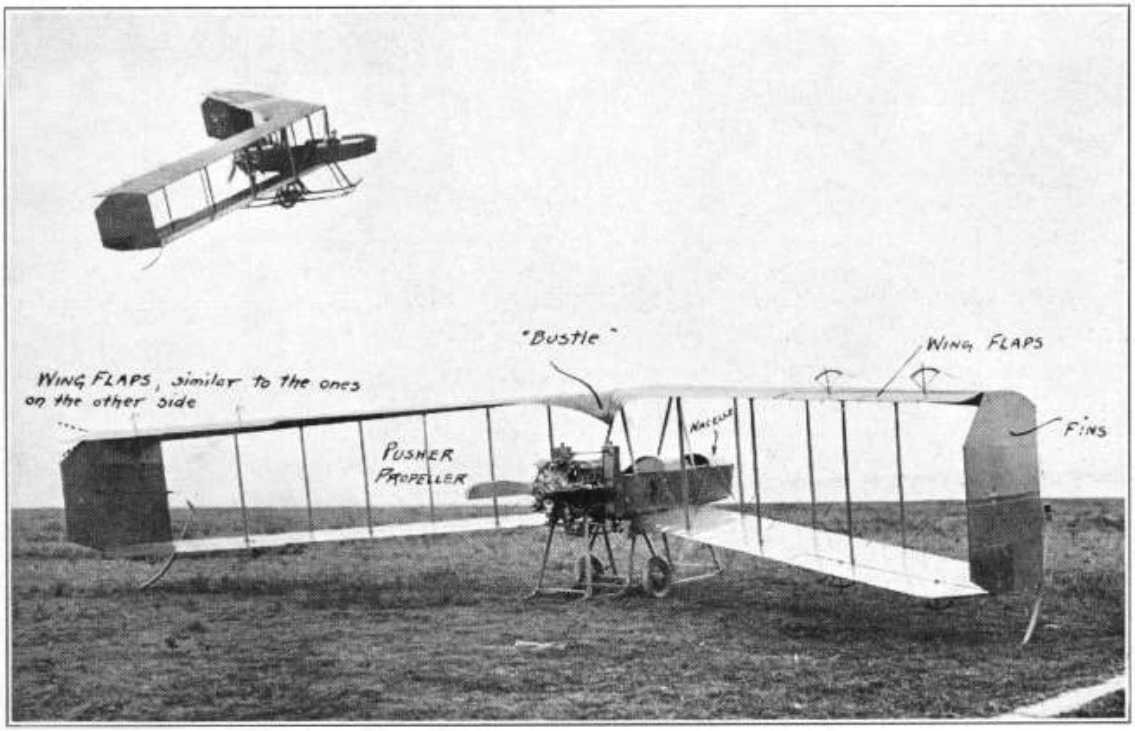
Many early designs failed to provide effective pitch control to compensate for the missing stabiliser. As a result, these aircraft could pitch up or down sharply and uncontrollably if they were not carefully handled. These gave tailless designs a reputation for instability. The original Dunne biplanes and the later success of the tailless delta configuration show that the problem was due as much to inadequate design, as to any problem inherent in the tailless configuration.

The solution usually adopted is to provide large elevator and/or elevon (combined elevator and aileron) surfaces on the wing trailing edge. These must generate large control forces, as their distance from the aerodynamic center is small. Consequently, when maneuvring, a tailless type may suffer higher drag than the conventional equivalent, even though it has less drag in level flight. High maneuvrability demands high control moments (force times "lever arm" distance), and the short lever arm inherent in tailless types means they are not as manoeuvrable as their conventional equivalents.

## *Notable examples*

The examples given here are in historical order.

## J. W. Dunne




THE U. S. ARMY DUNNE TYPE BIPLANE

A Dunne type biplane in the US Army of 1917.

During and shortly after the First World War, the English engineer J. W. Dunne developed a series of tailless aircraft characterised by having swept wings. In his book *An Experiment with Time* he claims that one of these was the first aeroplane ever to achieve natural stability in flight. Certainly, Dunne designed the first practical tailless aeroplanes. Few records of these aircraft remain.

Most of Dunne's designs were biplanes, typically featuring a fuselage nacelle between the planes, with rear-mounted 'pusher' propeller, and twin rudders between each pair of wing tips.

The D.6 monoplane of 1910 was a pusher type high-wing monoplane which featured turned-down wingtips with pronounced wash-out.

Many of Dunne's ideas on stability remain valid, and he is known to have influenced later designers such as John K. Northrop (father of the B-2 spirit stealth bomber).

Dunne gave some help initially to Geoffrey T. R. Hill who produced the Pterodactyl series of aircraft from 1920s onwards which were specifically designed to reduce the likelihood of stalling and spinning.

## Lippisch deltas

The German designer Alexander Lippisch produced the first tailless delta design, the Delta I, in 1931. He went on to build a series of ever-more sophisticated designs, and after the Second World War went to America to continue his work.

## Messerschmitt Me 163 *Komet*

During the Second World War, Lippisch worked for the German designer Willy Messerschmitt on the first tailless aircraft to go into production, the Me 163 *Komet*. It was a rocket-powered interceptor, and was the fastest aircraft to reach operational service during the war. Its rocket propulsion system was highly unsafe, especially the early versions. Landing was hazardous not only because the Komet had no wheels, but because sparks from the metal landing skid often flew up and ignited fuel vapours escaping from the propulsion system. More pilots were killed in takeoff and landing incidents than in combat.

## De Havilland DH 108 *Swallow*

In the 1940s, the English designer Geoffrey de Havilland made a few examples of a tailless jet-powered research aircraft called the DH108 *Swallow*, based on the forward fuselage of the de Havilland Vampire jet fighter. One of these was the first aircraft ever to break the sound barrier - it did so during a shallow dive, and the sonic boom was heard by several witnesses.

## Dassault *Mirage*

The French Mirage series of supersonic jet fighters were an example of the tailless delta configuration, and became one of the most widely produced of all Western jet aircraft. By contrast the Soviet Union's equivalent widely produced delta-winged fighter, the Mikoyan-Gurevich MiG-21, does have a tail stabiliser.

## Convair F2Y *Sea Dart*

In the 1950s, the Convair F2Y Sea Dart prototype became the only seaplane ever to exceed the speed of sound. Convair built several other successful tailless delta types.

## Supersonic airliners

The Anglo-French Concorde SST and its Soviet counterpart the Tupolev Tu-144 were tailless supersonic jet airliners, with gracefully curved *ogival delta* wings. The grace and beauty of these aircraft in flight were often remarked upon.

### Lockheed SR-71 *Blackbird*

The American Lockheed SR-71 Blackbird reconnaissance aircraft was the fastest known operational aircraft, achieving speeds above Mach 3.

### Northrop B-2 *Spirit*

The most recent tailless type to see operational service is the Northrop B-2 Spirit flying wing. It is unstable in flight and has artificial stability provided by a fly-by-wire system.

## *Other tailless aircraft*

- Avro 707 - research for Avro Vulcan, 1/3 scale of Vulcan
- Avro CF-105 Arrow - delta wing fighter
- Avro Vulcan - delta wing subsonic bomber
- Boulton Paul P.111 - delta wing research
- Convair B-58 Hustler - delta wing supersonic bomber
- Convair F-102
- Convair F-106
- Fauvel AV.36 and others by Charles Fauvel
- Douglas F-4D Skyray
- Vought F-7 Cutlass
- General Dynamics F-16XL
- Granger Archaeopteryx
- HAL Tejas
- Pterodactyl Pfledge — ultralight aircraft produced in large numbers
- Westland-Hill Pterodactyl
- X-44 MANTA

### Experimental

- Armstrong Whitworth A.W.52 - flying wing
- Short SB.1 (glider) and Short SB.4 Sherpa - tested aero-isoclinic wing
- Handley Page Manx -
- Handley Page HP.115 - low speed handling of delta wing
- Fairey Delta 2 - high speed delta design

**Chapter- 2**

# Flying Wing

Graphic rendering

A **flying wing** is a tailless fixed-wing aircraft which has no definite fuselage, with most of the crew, payload and equipment being housed inside the main wing structure.

A flying wing may have various small protuberances such as pods, nacelles, blisters, booms, vertical stabilizers (tail fins), or undercarriage. Some aircraft have no fuselage but

do have a separate horizontal stabilizer surface mounted on one or more booms; these are also commonly referred to as flying wings, although this is not strictly correct. An example of such a design is the Northrop X216H.

Theoretically the flying wing is the most efficient aircraft configuration from the point of view of aerodynamics and structural weight. It is argued that the absence of any aircraft components other than the wing should naturally provide these benefits. However in practice an aircraft's wing must provide for flight stability and control; this imposes additional constraints on the aircraft design problem. Therefore, the expected gains in weight and drag reduction may be partially or wholly negated due to design compromises needed to provide stability and control.

## *History*

Northrop YB-49 flying wing

The US-produced B-2 Spirit, a strategic bomber capable of intercontinental missions.

Tailless aircraft have been experimented with since the earliest attempts to fly. But it was not until the deep-chord monoplane wing became practicable after World War I that the opportunity to discard any form of fuselage arose and the true flying wing could be realised.

Hugo Junkers patented a wing-only air transport concept in 1910. He saw it as a natural solution to the problem of building an airliner large enough to carry a reasonable passenger load and enough fuel to cross the Atlantic in regular service. He believed that the flying wing's potentially large internal volume and low drag made it an obvious design for this role. In 1919 he started work on his "Giant" JG1 design, intended to seat passengers within thick wings, but two years later the Allied Aeronautical Commission of Control ordered the incomplete JG1 destroyed for exceeding post-war size limits on German aircraft. Junkers conceived futuristic flying wings for up to 1,000 passengers; the

nearest this came to realisation was in the 1931 Junkers G-38 34-seater *Grossflugzeug* airliner which featured a large thick-chord wing providing space for fuel, engines and two passenger cabins. However, it still required a short fuselage, ending in a double tail, and containing the crew and additional passengers.

The flying wing configuration was studied extensively in the 1930s and 1940s, notably by Jack Northrop and Cheston L. Eshelman in the United States, and Alexander Lippisch and the Horten brothers in Germany.

Soviet designers such as Boris Ivanovich Cheranovsky started research independently and in secret under Stalin after the 1920s. With significant breakthrough in materials and construction methods, aircraft such as the BICh-3, BICh-14, BICh-7A and so on became possible. Men like Chizhevskij and Antonov also came into the spotlight of the communist party by designing aircraft such as the tail-less BOK-5 (Chizhevskij) and OKA-33 (the first ever built by Antonov) which were designated as "motorized gliders" due to their similarity to popular gliders of the time. The BICh-11 by Cheranovsky in 1932 was competing with the Horten brothers H1 (and Adolf Galland) at the Ninth Glider Competitions in 1933, but did not demonstrate in the 1936 summer Olympics in Berlin. The BICh-26 was one of the first attempts at a supersonic jet flying-wing aircraft, ahead of its time in 1948 the airplane was not accepted by the military and the design died with Cheranovsky.

Early examples of true flying wings include:

- The Soviet Boris Ivanovich Cheranovsky built and tested tailless flying wings, from 1924 gliders, eventually also powered BICh-3.
- The French Charles Fauvel designed the AV3 glider, successfully flown in 1933, featuring a self-stabilizing airfoil on a straight wing.
- The German Horten H1 glider flown with partial success in 1933, and the subsequent H2 flown successfully in both glider and powered variants.
- The American Freel Flying Wing glider flown in 1937.
- The American Northrop N-1M of 1940
- The British Armstrong Whitworth A.W.52G of 1944, a glider test bed for the later Armstrong Whitworth A.W.52 jet-powered version.
- The German Horten Ho 229 of 1945 - the world's first twin jet engine pure flying wing

Several late-war German military designs were based on the flying wing concept (or variations of it) as a proposed solution to extend the range of the otherwise very short-range jet engined aircraft. Most famous of these would be the Horten Ho 229 fighter. This aircraft, first flown in 1944, combined a flying wing, or *Nurflügel*, design with twin jet engines. The surviving prototype remains in storage at the Smithsonian Institution in an unrestored state.

After the war, a number of experimental designs were based on the flying wing concept, but the known difficulties remained intractable. Some general interest continued until the

early 1950s, when the concept was proposed as a design solution for long range bombers. Such trends culminated in the Northrop YB-35 and YB-49, which did not enter production. Those designs did not necessarily offer a great advantage in range and presented a number of technical problems, leading to the adoption of "conventional" solutions like the Convair B-36 and the B-52 Stratofortress.

Interest in flying wings was renewed in the 1980s due to their potentially low radar reflection cross-sections. Stealth technology relies on shapes which only reflect radar waves in certain directions, thus making the aircraft hard to detect unless the radar receiver is at a specific position relative to the aircraft - a position that changes continuously as the aircraft moves. This approach eventually led to the Northrop B-2 Spirit stealth bomber. In this case the aerodynamic advantages of the flying wing are not the primary needs. However, modern computer-controlled fly-by-wire systems allowed for many of the aerodynamic drawbacks of the flying wing to be minimised, making for an efficient and stable long-range bomber.

Due to the practical need for a deep wing, the flying wing concept is most practical for designs in the slow-to-medium speed range, and there has been continual interest in using it as a tactical airlifter design. Boeing continues to work on paper projects for a Blended Wing Body Lockheed C-130 Hercules-sized transport with better range and about 1/3 more load, while maintaining the same size characteristics. A number of companies, including Boeing, McDonnell Douglas and de Havilland, did considerable design work on flying-wing airliners, but to date none have entered production.

## *Design issues*

A Northrop N-1M on display at the National Air and Space Museum's Steven F. Udvar-Hazy Center

A clean flying wing is theoretically the most aerodynamically efficient (lowest drag) design configuration for a fixed wing aircraft. It also offers high structural efficiency for a given wing depth, leading to light weight and high fuel efficiency.

Because it lacks conventional stabilizing surfaces or the associated control surfaces, in its purest form the flying wing suffers from the inherent disadvantages of being unstable and difficult to control. These compromises are difficult to reconcile, and efforts to do so can reduce or even negate the expected advantages of the flying wing design, such as reductions in weight and drag. Moreover, solutions may produce a final design that is still too unsafe for certain uses, such as commercial aviation.

Further difficulties arise from the problem of fitting the pilot, engines, flight equipment and payload all within the depth of the wing section. A wing that is made deep enough to contain all these elements will have an increased frontal area, when compared to a conventional wing and fuselage, which in turn results in higher drag and thus slower speed than a conventional design. Typically the solution adopted in this case is to keep the wing reasonably thin, and the aircraft is then fitted with an assortment of blisters, pods, nacelles, fins and so forth to accommodate all the needs of a practical aircraft.

## Directional stability

For any aircraft to fly without constant correction it must have directional stability in yaw.

Flying wings lack the long fuselage which provides a convenient attachment point for an efficient vertical stabilizer or fin. The fin must attach directly on to the rear part of the wing, giving a small moment arm from the aerodynamic center, which in turn means that to be effective the fin area must be large. This large fin has weight and drag penalties, and can negate the advantages of the flying wing. The problem can be minimized by increasing the leading edge sweepback, as for example in a low-aspect-ratio delta wing, but most flying wings have gentler sweepback and consequently have, at best, marginal stability. In the so called ruptured duck configuration, the wing tip sections are angled sharply downwards (anhedral), increasing the area at the rear of the aircraft when viewed from the side.

## Yaw control

In most flying wing designs, the stabilizing fins are so far forward that any control rudders mounted on them have little effect, thus alternative means for yaw control must be provided. The only practical solution is differential drag: the drag near one wing tip is artificially increased, causing the aircraft to yaw in the direction of that wing. Typical methods include:

- Split ailerons. The top surface moves up while the lower surface moves down, to create an air brake effect.

- Spoilers. A spoiler surface in the upper wing skin is raised, to disrupt the airflow and increase drag. This effect is generally accompanied by a loss of lift, which must be compensated for either by the pilot or by complex design features.
- Spoilerons. An upper surface spoiler which also acts to reduce lift (equivalent to deflecting an aileron upwards), so causing the aircraft to bank in the direction of the turn - the angle of roll causes the wing lift to act in the direction of turn, reducing the amount of drag required to turn the aircraft's longitudinal axis.

A consequence of the differential drag method is that if the aircraft manoeuvers frequently then it will frequently create drag. So flying wings are at their best when cruising in still air: in turbulent air or when changing course, the aircraft may be less efficient than a conventional design.

## *Borderline cases*

Some aircraft have no fuselage but do have a horizontal stabilizer mounted on one or more booms. Strictly, these are not flying wings although they are usually referred to as such. An example is the Northrop X-216H, which has a tail stabilizer mounted on two tail booms but is regarded as Northrop's first flying wing type.

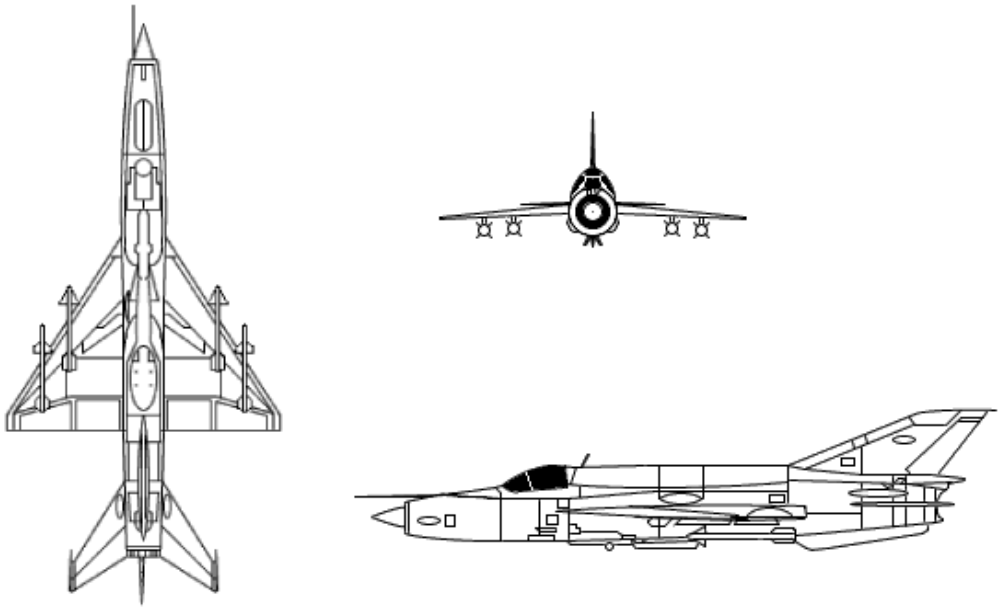
Many hang gliders and microlight aircraft are tailless. Although often referred to as flying wings, these types carry the pilot (and engine where fitted) below the wing structure rather than inside it, and so are not true flying wings.

An aircraft of sharply-swept delta planform and deep center section represents a borderline case between flying wing, blended wing body and/or lifting body configurations.

Chapter- 3

# Delta Wing

Eurofighter Typhoon of the German Luftwaffe has a tailless delta wing configuration



MiG-21 had a tailed delta wing configuration (it had a conventional tail)

The delta wing Avro Vulcan bomber

The **delta wing** is a wing planform in the form of a triangle. It is named for its similarity in shape to the Greek uppercase letter delta (Δ).

## *History*

### Delta-shaped stabilizers

Between 1529 and 1556 Conrad Haas wrote a book in which he described rocket technology, involving the combination of fireworks and weapons technologies. This manuscript was re-discovered in 1961, in the Sibiu public records (Sibiu public records Varia II 374). His work dealt with the theory of motion of multi-stage rockets, different fuel mixtures using liquid fuel, and also introduced delta-shaped stabilizers.

As the manuscript was discovered only in 1961 until recently the conception of such stabilizers and their name had been suggested in the 17th century by the Polish-Lithuanian military engineer Kazimierz Siemienowicz.

### Delta wing

The first practical uses of delta wing came in the form of so called "tailless delta", i.e. without the horizontal tailplane. In fact the designs were at the same time also the first flying wings. It could be argued if 1924 Cheranovsky designs, having one-of-a-kind parabolic planform, fit the category of delta wings. Nevertheless, a triangular wing was pioneered especially by Alexander Lippisch in Germany. He was first to fly tailless delta aircraft in 1931, followed by four improved designs. None of these was easy in handling at slow speeds, and none saw widespread service. During the war Lippisch studied a number of ramjet powered (sometimes coal-fueled) delta-wing interceptor aircraft, one progressing as far as a glider prototype.

After the war, Lippisch was taken to the United States of America, where he worked at the Convair company in California. Some high-ranking Convair engineers became quite interested in his interceptor designs, and they started work on a larger test version known as the Convair XF-92. The prototype—although never put into production—was extensively flight-tested, and its design generated a lot of interest of various airplane manufacturers in several countries. Soon many aircraft designs, particularly interceptors, would be designed around the delta wing. The tail-less delta became a favored design for high-speed use, and was used almost to the exclusion of other designs by Convair and by Dassault Aviation in France. Convair's F-102 was the first fighter with a tailless delta wing in service with any air force anywhere in the world.

Meanwhile, the British also developed aircraft based on the data from Lippisch, notably the Avro Vulcan strategic bomber and the Gloster Javelin fighter. The Javelin incorporated a tailplane in order to rectify some of the perceived weaknesses of the pure delta, to improve low-speed handling and high-speed manoeuvrability and to allow a greater center of gravity range.

The tailed delta configuration was again adopted by the TsAGI (Central Aero and Hydrodynamic Institute, Moscow), to take advantage of both high angle-of-attack flying capability and high speeds. It was used in the MiG-21 (Fishbed) and Sukhoi Su-9/Su-11/15 fighters, built by the tens of thousands in several different communist countries.

More recently, Saab AB used a close-coupled canard foreplane in front of the main wing of the Viggen fighter. The close coupling actively modifies the airflow over the wing, most notably during flight at high angles of attack. In contrast to the classic tail-mounted elevators, the canards add to the total lift, enabling the execution of extreme maneuvers, improving low-speed handling and lowering the landing speed. The design was copied in other aircraft, such as the Eurofighter Typhoon.

## *Aerodynamic advantages*

The primary advantage of the delta wing is that with a large enough angle of rearward sweep the wing’s leading edge will not contact the shock wave boundary formed at the nose of the fuselage as the speed of the aircraft approaches and exceeds transonic to supersonic velocity. The rearward sweep angle vastly lowers the airspeed normal to the leading edge of the wing, thereby allowing the aircraft to fly at high subsonic, transonic, or supersonic speed, while the over wing speed of the lifting air is kept to less than the speed of sound. The delta plan form gives the largest total wing area (generating useful lift) for the wing shape, with very low wing per-unit loading, permitting high maneuverability in the airframe. As the delta's platform carries across the entire aircraft, it can be be built much more strongly than a swept wing, where the spar meets the fuselage far in front of the center of gravity. Generally a delta will be stronger than a similar swept wing, as well as having much more internal volume for fuel and other storage.

Another advantage is that as the angle of attack increases the leading edge of the wing generates a vortex which energizes the flow, giving the delta a very high stall angle. A normal wing built for high speed use is typically dangerous at low speeds, but in this regime the delta changes over to a mode of lift based on the vortex it generates. The disadvantages, especially marked in the older tailless delta designs, are a loss of total available lift caused by turning up the wing trailing edge or the control surfaces (as required to achieve a sufficient stability) and the high induced drag of this low-aspect ratio type of wing. This causes delta-winged aircraft to 'bleed off' energy very rapidly in turns, a disadvantage in aerial maneuver combat and dogfighting.

Additional advantages of the delta wing are simplicity of manufacture, strength, and substantial interior volume for fuel or other equipment. Because the delta wing is simple, it can be made very robust (even if it is quite thin), and it is easy and relatively inexpensive to build - a substantial factor in the success of the MiG-21 and Mirage aircraft.

A canard-delta suffers from a smaller shift in the center of lift with increasing mach number than a wing and tail configuration, but requires a stronger wing in order to provide control inputs that a canard is less effective than a tail at providing.

When used with a T-tail as in the Gloster Javelin the large delta wing could give rise to a "deep stall"; at high angles of attack the wing blanked airflow over the tail and left the aircraft uncontrollable.

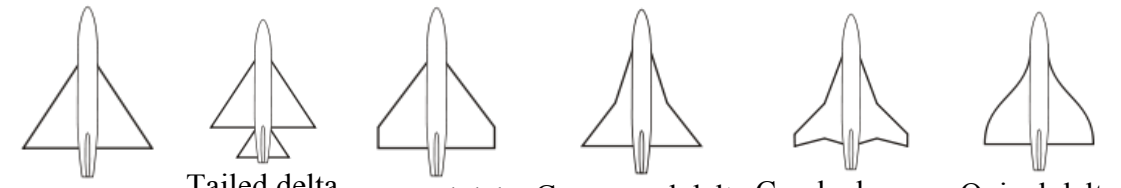
## *Delta-wing variations*

Pure delta-wings fell out of favour somewhat due to their undesirable characteristics, notably flow separation at high angles of attack (swept wings have similar problems), and high drag at low altitudes. This limited them primarily to high-speed, high-altitude interceptor roles.

Many modern fighter aircraft, such as the JAS 39 Gripen, the Eurofighter Typhoon and the Dassault Rafale use a combination of canards and a delta wing.

**Tailed delta** - adds a conventional tailplane (with horizontal tail surfaces), to improve handling. Popular on Soviet types such as the Mikoyan-Gurevich MiG-21. **Cropped delta** - tip is cut off. This helps avoid tip drag at high angles of attack. Used for example in F-16.

In another variant known variously as **compound delta**, **double delta** or **cranked arrow**, the inner part of the wing has a very high sweepback, while the outer part has less sweepback, to create the high-lift vortex in a more controlled fashion, reduce the drag and thereby allow for landing the delta at acceptably slow speed. This design can be seen on the Saab Draken fighter, the prototype F-16XL "Cranked Arrow" and in the High Speed Civil Transport study. The **ogee delta** (or **ogival delta**) used on the Anglo-French Concorde Mach 2 airliner is similar, but with a smooth 'ogee' curve joining the two parts rather than an angle.




As the performance of jet engines grew, fighters with other planforms could perform as well as deltas, and do so while maneuvering much harder and at a wider range of altitudes. Today a remnant of the compound delta can be found on most fighter aircraft, in the form of leading edge extensions. These are effectively very small delta wings placed so they remain parallel to the airflow in cruising flight, but start to generate a vortex at high angles of attack. The vortex is then captured on the top of the wing to

provide additional lift, thereby combining the delta's high-alpha performance with a conventional highly efficient wing planform.

## Chapter- 4

# Avro 707

## Avro 707

Avro 707B *VX790* at Farnborough in 1951.

| | |
|---|---|
| **Role** | Experimental aircraft |
| **Manufacturer** | Avro |
| **First flight** | 4 September 1949 |
| **Retired** | 1967 |
| **Status** | 3 aircraft survive in museums |
| **Primary users** | Avro<br>Royal Aircraft Establishment<br>Australian Aeronautical Research Council |
| **Number built** | 5 |

The **Avro 707** (also known as **Type 707**) was a British experimental aircraft built to test the tailless thick delta wing configuration chosen for the Avro 698 jet bomber, later named the Vulcan. In particular, the low-speed characteristics of such aircraft were not well known at the time. Aerodynamically, it was a ⅓-scale version of the Vulcan.

## *Design and development*

The 707 was a "proof-of-concept" delta design that was principally the work of Stewart D. Davies, Avro Design Office leader. The diminuative experimental aircraft initially incorporated a wing with about 50° sweep, without a horizontal tail on a fin with trailing edge sweep. The trailing edge of the wing carried two pairs of control surfaces: inboard elevators and outboard ailerons. Retractable airbrakes were provided above and below the wings. The prototypes were ordered by the Air Ministry to Specification E.15/48. The aircraft were produced quickly using a few components from other aircraft including the first prototype utilizing a Gloster Meteor canopy. The 707 programme provided valuable insights into the Vulcan's flight characteristics, most of the information coming from the second and third prototypes which flew before the Vulcan. All 707s were powered by a single Rolls Royce Derwent centrifugal turbojet. The air intake on the first prototype and later 707B was located on the upper rear fuselage.Five 707s were built altogether.

## *Operational history*

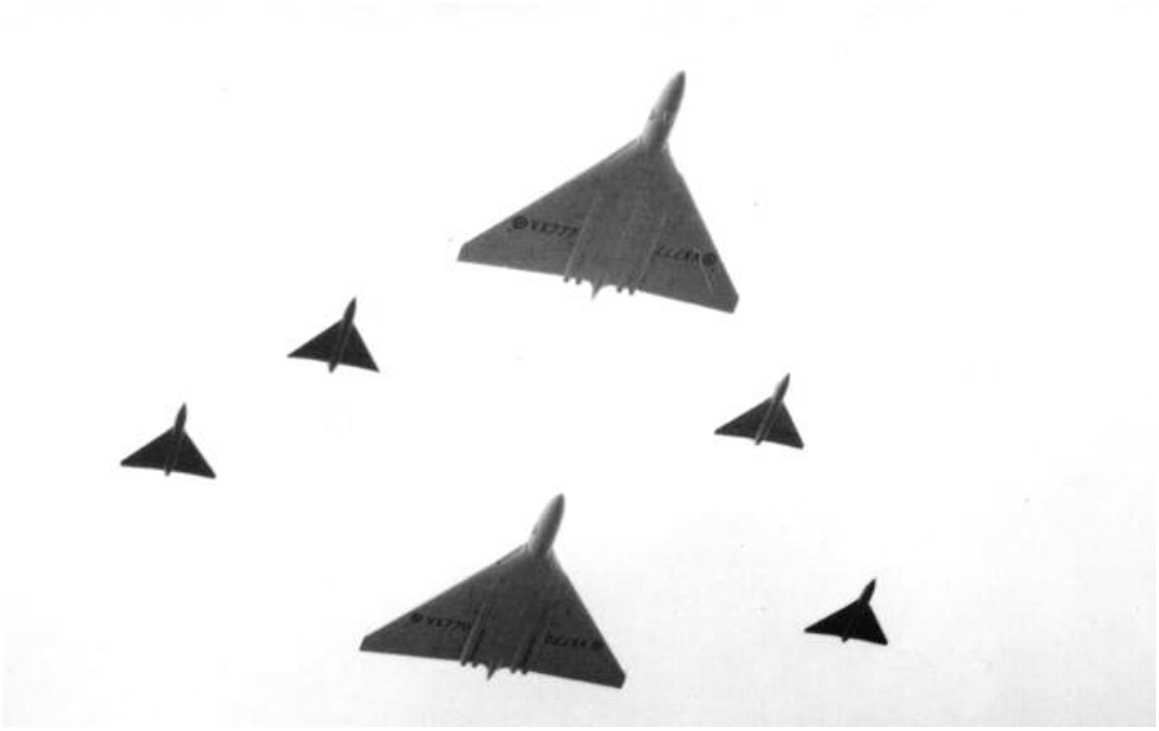

The second Avro 707A *WZ736* displayed next to an Avro Shackleton at the Museum of Science & Industry in Manchester in 1985

The first, the Avro **707**, *VX784* first flew from Boscombe Down on 4 September 1949 with S.E. "Red" Esler, at the controls. The prototype crashed less than a month later, on 30 September, near Blackbushe. The next prototype, *VX790*, renamed the **707B**, had a longer nose, different cockpit canopy, a wing of different (51°) sweep and a longer nose wheel leg to provide the high angle of incidence required by deltas for landing and take off. The 707B was given the same dorsal engine intake as the 707, although this was later

modified to a N.A.C.A design. It first flew on 6 September 1950. Both these aircraft were built to test low speed characteristics.

The third aircraft, designated **707A**, *WD280* was built for higher speed testing. Experience with the dorsal intake of the earlier 707 and 707B had shown that as speed increased, the cockpit induced turbulence which interrupted the intake airflow, so the intakes were moved to the wing roots. When the Vulcan appeared, it looked very much like an enlarged 707A. Later, this 707A was used to test the compound leading edge sweep subsequently used on all Vulcans. Although the first Vulcan prototype was already flying, a second 707A *WZ736* was built to speed the development programme, making its maiden fight on 20 February 1953.

The final variant was the two-seat **707C**; originally four examples were ordered by the RAF for use in orientation training revolving around flying aircraft with delta wing configurations. The 707C had "side-by-side" seating with dual-controls but the production order was cancelled with only the sole prototype, *WZ744* built. The 707C had its maiden flight on 1 July 1953 and was ultimately employed in other research that did not involve Vulcan development.



Two Avro 707As, 707B and 707C with Vulcan prototypes at SBAC Farnborough Show, September 1953

Even after the Vulcan development phase was over, the four surviving 707s, resplendent in individual bright blue, red, orange and silver (natural metal) colour schemes, continued in use as research aircraft. After the compound sweep investigation and a period with the Royal Aircraft Establishment (R.A.E) carrying out handling trials with powered controls,

the first 707A went to the Aeronautical Research Laboratories in Australia for low-speed delta wing airflow measurements. The second 707A was also at the R.A.E from June 1953 for aerodynamic and later, automatic control investigations.

The Avro 707B joined the R.A.E. in September 1952 and was one of the aircraft used by the Empire Test Pilots School from January to September 1956, when it was damaged on landing, and broken up at R.A.E. Bedford. The two-seat 707C joined the R.A.E. January 1956; perhaps its most substantial research contribution was to the development of fly-by-wire control systems, one of the first of their kind, and fitted with a side stick controller. This aircraft was flying with the R.A.E. until September 1966.

The Avro 707s made public appearances at the Farnborough Airshows in both September 1952 and 1953; in 1952, the first prototype Vulcan flew with the 707s A and B and in 1953, the four surviving 707s flew alongside the first two Vulcan prototypes.

## *Survivors*

No 707s are now airworthy. Both examples of the Avro 707A variant survive. One, *WZ736* is preserved at the Museum of Science and Industry in Manchester, the other, *WD280* at the RAAF Museum in Point Cook, Victoria. *WZ744*, the single 707C is displayed at the RAF Museum, Cosford near Wolverhampton.

## *Operators*

Australia

- Royal Australian Air Force
- Australian Aeronautical Research Council

United Kingdom

- Aeroplane and Armament Experimental Establishment
- Royal Aircraft Establishment

## *Specifications (707C)*

### General characteristics

- **Crew:** 2 instructor/pupil
- **Length:** 42 ft 4 in (12.90 m)
- **Wingspan:** 34 ft 2 in (10.41 m)
- **Height:** 11 ft 7 in (3.53 m)
- **Wing area:** 420 ft² (39 m²)
- **Empty weight:** lb (kg)
- **Loaded weight:** 10,000 lb (4,535 kg)
- **Powerplant:** 1× Rolls-Royce Derwent 8 turbojet, 3,600 lbf (16 kN)

## Performance

- **Maximum speed:** 406 kn (467 mph, 747 km/h)
- **Wing loading:** 22.6 lb/ft² (110 kg/m²)
- **Thrust/weight:** 0.38

Chapter- 5

# Convair XB-53 and de Havilland DH 108

## Convair XB-53

### XB-53

1946 design then designated XA-44

| | |
|---|---|
| **Role** | Attack aircraft |
| **Manufacturer** | Convair |
| **First flight** | n/a |
| **Status** | Cancelled in 1949 |
| **Primary user** | United States Air Force |
| **Number built** | 0 |

The **Convair XB-53** was a proposed jet powered medium bomber aircraft, designed by Convair for the United States Army Air Force. With a radical tailless, forward-swept wing design, the aircraft appeared futuristic, however the project was cancelled before either of the two prototypes were completed.

## *Design and development*

The project was originally designated **XA-44** in 1945 under the old "attack" category. An unusual forward-swept wing-design powered by three J35-GE turbojets, the project was developed in parallel with Convair's XB-46. It would have a wing with a 30° forward-sweep and 8° dihedral that borrowed from German wartime research. The swept-forward configuration would give the aircraft a greater climb rate and maneuverability. It looked promising enough at one point that the Army Air Force considered cancelling the XB-46 in favor of the XA-44 since there was not enough funding for both.

Classified as a medium bomber, the XB-53 would have carried up to 12,000 pounds of bombs as well as 40 High Velocity Aerial Rockets (HVAR) mounted on underwing pylons.

Convair argued for completion of the XB-46 prototype as a flying testbed sans armament and other equipment and substitution of two XA-44s for the other two B-46 airframes on contract. The Air Force ratified this in June 1946 but the project did not progress, nor were additional B-46s built. The XA-44 was redesignated XB-53 in 1948 when the "attack" category was dropped but the project was cancelled before the two prototypes were completed. The XA-44 program was reinstated in February 1949 but only for a short while.

## *Specifications (XB-53)*

### General characteristics

- **Crew:** 4
- **Length:** 79 ft 6 in (24.2 m)
- **Wingspan:** 80 ft 7 in (24.6 m)
- **Height:** 23 ft 8 in (7.22 m)
- **Wing area:** 1,370 ft² ()
- **Empty weight:** 31,760 lb ()
- **Loaded weight:** 60,000 lb ()
- **Max takeoff weight:** 60,000 lb (27,000 kg)
- **Powerplant:** 3× General Electric J35 turbojets, 4,000 lbf (18 kN) each

Performance (estimated)

- **Maximum speed:** 580 mph (500 knots, 930 km/h)
- **Range:** 2,000 mi (1,700 nm, 3,200 km)
- **Service ceiling:** 44,000 ft (13,400 m)
- **Rate of climb:** Unknown ()
- **Wing loading:** Unknown ()
- **Thrust/weight:** Unknown

### Armament

- **Bombs:** 12,000 lb (5,400 kg)

# de Havilland DH 108

## DH 108 "Swallow"


The first DH 108 built – *TG283*. The torpedo-shaped objects on the wing tips are containers for anti-spin parachutes.

| | |
|---|---|
| **Role** | experimental |
| **Manufacturer** | de Havilland |
| **Designed by** | John Frost |
| **First flight** | 15 May 1946 |
| **Introduced** | Experimental programme only |
| **Status** | Cancelled |
| **Primary user** | Royal Aircraft Establishment |
| **Produced** | 1946–1947 |
| **Number built** | Three |

The **de Havilland DH 108 "Swallow"** was a British experimental aircraft designed by John Carver Meadows Frost in October 1945. The DH 108 featured a tailless, swept wing with a single vertical stabilizer, closely resembling the layout of the wartime German Messerschmitt Me 163 *Komet* rocket-powered point-defense interceptor. Initially designed to evaluate swept wing handling characteristics at low and high subsonic speeds for the proposed early tailless design of the Comet airliner, three examples of the DH 108 were built to the Air Ministry specifications E.1/45 and E.11/45. With the adoption of a conventional tail for the Comet, the aircraft were used instead to investigate swept wing handling up to supersonic speeds. All three prototypes were lost in fatal crashes.

## Design and development

Employing the main fuselage section and engine of the de Havilland Vampire mated to a longer fuselage with a single tail fin and swept wings, the de Havilland DH 108 was proposed in 1944 as a test "mule" for the DH 106 Comet which had initially considered a tailless, swept-wing concept. Despite the Comet design taking on more conventional features, the value of testing the unique configuration to provide basic data for the DH.110 spurred de Havilland to continue development of the DH 108. Selecting two airframes from the English Electric Vampire F 1 production line, the new aircraft had unmistakable similarities to its fighter origins, especially in the original forward fuselage which retained the nose, cockpit and other components of the Vampire. The Ministry of Supply named the DH 108 the "Swallow", a name that was never officially adopted by the company.

The new metal wing incorporating a 43˚ sweepback was approximately 15% greater in area than the standard Vampire wing. Control was based on the conventional rudder in combination with elevons that were part elevator and ailerons, fitted outboard of the split trailing edge flaps. Although the Vampire fuselage was retained, as development continued, a revised nose and streamlined, reinforced canopy were incorporated.

## Testing

The first DH 108 prototype, *TG283,* utilising the Vampire fuselage and a 43° swept wing, flew on 15 May 1946. Designed to investigate low-speed handling, it was capable of only 280 mph (451 km/h). De Havilland Chief Test Pilot Geoffrey de Havilland Jr., son of de Havilland company owner-designer Geoffrey de Havilland, gave a display flight in the DH 108 during the 1946 Society of British Aircraft Constructors (SBAC) airshow at Radlett. In later low-speed testing designed to clear the rear fuselage at high angles of attack, the first prototype was fitted with longer Sea Vampire landing gear.

The second, high-speed prototype, *TG306,* with a 45° swept wing incorporating automatic leading-edge Handley Page slats and powered by a de Havilland Goblin 3 turbojet, flew soon after in June 1946. Modifications to the design included a more streamlined, longer nose and a smaller canopy (framed by a strengthened metal fairing) facilitated by lowering the pilot's seat. While being used to evaluate handling characteristics at high-speed, on 27 September 1946 *TG306* suffered a catastrophic structural failure that occurred in a dive from 10,000 ft (3,050 m) at Mach 0.9 and crashed in the Thames Estuary. The pilot, Geoffrey de Havilland Jr., was killed in the accident. Early wind tunnel testing had pointed to potentially dangerous flight behaviours, but pitch oscillation at high-speed had been unexpected. The subsequent accident investigation centred on a structural failure that occurred as air built up at Mach 0.9, pitching the aircraft into a shock stall that placed tremendous loads on the fuselage and wings. The main spar cracked at the roots with the wings immediately folding backwards.


*VW120* in flight, about 1949

After the loss of the second prototype, *VW120* became the third and final prototype based on the newer Vampire F.5 fighter built at Hatfield. It differed from the first test aircraft in that it featured an even more streamlined pointed nose and smaller reinforced canopy (lowering the pilot's seat allowed for a more aerodynamic canopy shape to be employed). Power-boosted elevators had been specified as a means to control the pitch oscillations at the root of the earlier disaster. A more powerful Goblin 4 of 3,738 lbf (16.67 kN) thrust had the potential to push the DH 108 into the supersonic range. *VW120* first flew on 24 July 1947 flown by John Cunningham, the wartime nightfighter ace.

Considered an important testbed for high-speed flight, *VW120* was readied for an attempt at the World Speed Record then held by a Gloster Meteor at 616 mph (991 km/h). The second prototype, *TG306*, was a "back up" for the attempt before it fatally crashed. On 12 April 1948, *VW120* established a new World Air Speed Record of 604.98 mph (974.02 km/h) on a 62 mile (100 km) circuit. Then, on 9 September 1948, John Derry is thought to have probably exceeded the speed of sound in a shallow dive from 40,000 ft (12,195 m) to 30,000 ft (9,145 m).

In 1949, *VW120* put on an aerial display at Farnborough and scored third place in the Society of British Aircraft Constructors Challenge Trophy Air Race before being turned over to the Ministry of Supply and test flown at RAE Farnborough. It was destroyed on 15 February 1950 in a fatal crash near Brickhill, Buckinghamshire, killing its test pilot, Squadron Leader Stuart Muller-Rowland. Accident investigation pointed to a faulty oxygen system that incapacitated the pilot.

Finally, on 1 May 1950 during low-speed sideslip and stall tests the first prototype, *TG283*, was lost in a crash at Hartley Wintney killing the pilot Sqn Ldr George E.C. Genders AFC DFM, when, after abandoning the aircraft at low altitude in an inverted

spin, his parachute failed to open in time. In all, 480 flights had been made by the three Swallows.

## *Legacy*

The DH108 established a number of "firsts" for British aircraft: it was the first British swept-winged jet aircraft and the first British tailless jet aircraft; it was the first British aircraft to exceed Mach 1, one of the first jet-powered aircraft in the world to achieve this landmark speed. The XP-86 (the prototype for the F-86 Sabre) had also broken the sound barrier in a test flight on 26 April 1948. Two of the aircraft which earlier had exceeded the speed of sound, the Bell X-1 and the Douglas Skyrocket, were both rocket-powered.

## *Operators*

United Kingdom

- Royal Aircraft Establishment

## *Specifications (DH 108* VW120*: third prototype)*

### General characteristics

- **Crew:** one, pilot
- **Length:** 26 ft 10 in (8.17 m)
- **Wingspan:** 39 ft 0 in (11.89 m)
- **Height:** 14 ft 0 in (4.27 m)
- **Wing area:** 327.86 ft² (30.47 m²)
- **Loaded weight:** 8,940 lb (4,064 kg)
- **Powerplant:** 1× de Havilland Goblin-4 turbojet, 3,738 lbf (16.67 kN)

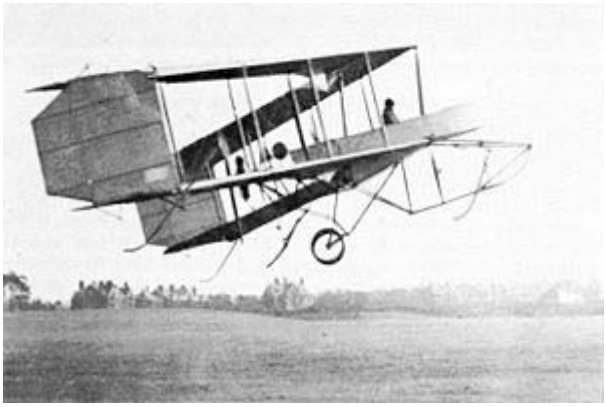
### Performance

- **Maximum speed:** 580 kn (677 mph, 1,090 km/h)
- **Range:** 634 nmi (730 mi, 1,175 km)
- **Service ceiling:** 35,425 ft (10,800 m)
- **Wing loading:** 27 lb/ft² (133 kg/m²)
- **Thrust/weight:** 0.42

## Chapter- 6

# Dunne D.8

### D.8



Dunne D.8 at Farnborough, 11 March 1914

| | |
|---|---|
| **Role** | Experimental aircraft |
| **National origin** | United Kingdom |
| **Manufacturer** | Blair-Atholl Syndicate Ltd, London |
| **Designed by** | J. W. Dunne |
| **First flight** | June 1912 |
| **Status** | original aircrafts lost or destroyed; 1 replica exists in Canada |
| **Primary users** | Royal Flying Corps<br>US Signal Corps<br>United States Navy<br>Canadian Aviation Corps |
| **Produced** | 5 |
| **Number built** | 5 |
| **Developed** | Dunne D.5 |

**from**

The **Dunne D.8** of 1912 was one of a series of tailless swept wing biplanes, designed by J. W. Dunne to have inherent stability. One of the few built was the only Dunne aircraft to fly, albeit very briefly, with the Royal Flying Corps (RFC). Others were used by the US Signal Corps and United States Navy and the short-lived Canadian Aviation Corps. It was the latter's first and only warplane.

## *Design and development*

J. W. Dunne's first swept biplane wing aircraft, designed to have automatic stability, dated from his employment at the Balloon (later) Aircraft Factory at Farnborough during 1906–09. To preserve military secrecy testing was done at Blair Atholl in Scotland. After leaving Farnborough, Dunne set up a private company, the Blair-Atholl Syndicate Ltd. Its first aircraft was the Dunne D.5. When this crashed in 1911 it was rebuilt as the D.8. The two models shared very similar wings and the same engine, but the D.8 had a single pusher propeller instead of the chain-driven pair of the D.5. Their fuselages and undercarriages were also different.

The D.8 was a tailless four bay unstaggered biplane with its wings swept at 32°. Its constant chord wings were built up around two spruce spars, the forward one forming the leading edge. To help achieve stability the incidence and interplane gap decreased outboard, the former becoming negative. This washout on tips well behind the centre of gravity provided longitudinal stability in the same way as a conventional tailplane, set at lower incidence than the wings. Camber increased outwards. Simple, near parallel, pairs of interplane struts joined the spars. The outer interplane struts were enclosed with fabric, forming fixed side curtains that provided directional (yaw) stability. Wing tip elevons were used for control, operated by a pair of levers, one either side of the pilot. The D.8 initially used just a pair of these, mounted on the upper wing, a rectangular cutout in the side curtains allowing for their movement as on the D.5. Large parts of the aircraft were built by Short Brothers.

The D.8's water cooled 4-cylinder, 60 hp (45 kW) Green engine directly drove a four-bladed pusher propeller, saving weight compared with the D.5's chain drive. Though it is not certain when the propeller was changed, most photographs show the Green engine driving a two bladed airscrew. As a consequence of the propeller position the fuselage was shortened at the rear; it was also extended in the nose. This first D.8 seems to have been a single seater like its D.5 predecessor, the pilot sitting at mid chord.

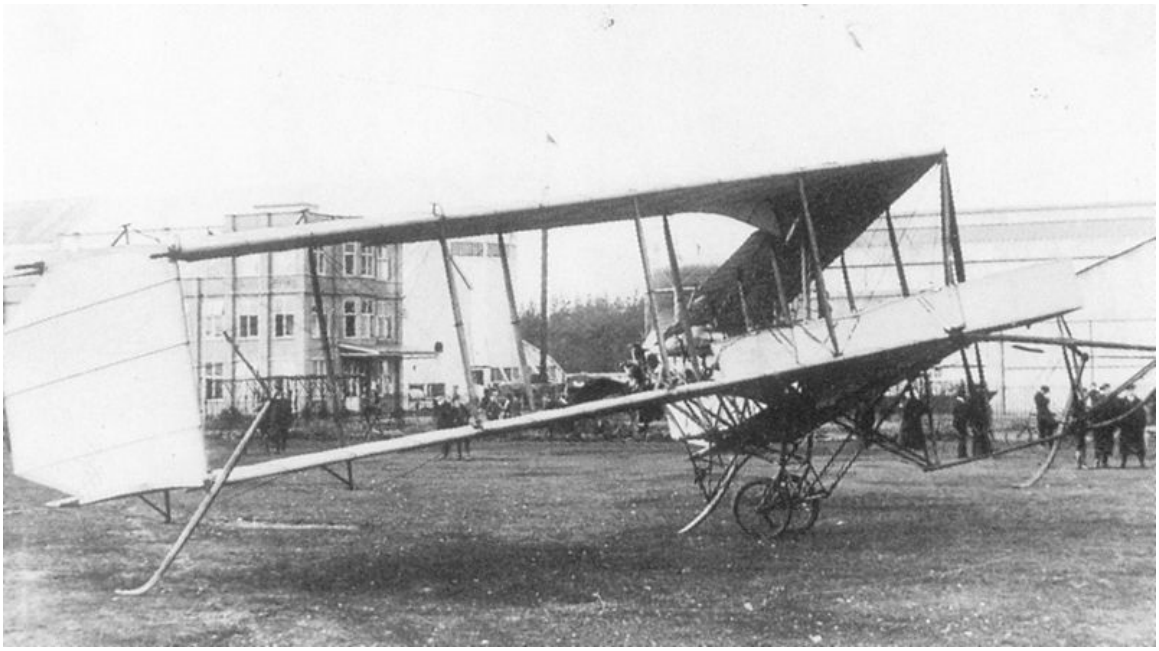
Contemporary sources remarked on the complexity of the D.8's undercarriage, which combined a narrow track pair of sprung wheels pair with wingtip skids. Part of its complication came from opposing springing in the absence of dampers, and part from an elaborate anti-noseover skid.

In this form the D.8 first flew in June 1912 at Eastchurch. It attended the Larkhill Military trial in August 1912, though it did not take part in the competition. It flew

regularly at Eastchurch through 1911 and 1912 and was still active there in November 1912. Despite the two handed arrangement of the D.8's controls, the one-handed Capt. A.D. Carden gained his Royal Aero Club Aviator's Certificate on it in June 1912.

It is not known if this machine was later modified aerodynamically, but by August 1913 the Green engine had been replaced by an 80 hp (60 kW) 7-cylinder Gnôme rotary engine. This much shorter engine also powered the second aircraft, which was a two seater with the pilot placed just ahead of the wing leading edge and the passenger (who had dual control) at the trailing edge. There were now control surfaces on both upper and lower wings, the side curtains having a pair of tapered notches to allow them to move. Each of the upper wings carried a pair of elevons, nearly doubling the control surface area, though it is not certain if these moved as one or differentially. It first flew, with Felix at the controls, on 18 October 1913.

In August 1913 Commandant Felix piloted a D.8 across the English Channel from Eastchurch to Villacoublay. Nieuport had obtained a licence to build the D.8 and Felix gave demonstration flights in France on their behalf.A Nieuport-built Dunne appeared at the Paris Aero Salon in December 1913. Like the second D.8 it was a Gnôme powered two seater, but with significant differences both aerodynamically and structurally. It combined the double upper wing elevons into a single surface and had very rounded rear wingtips. The fuselage was slightly modified and built around steel tubes rather than wood. The interplane struts were streamlined steel tubes. It also had a strikingly simplified undercarriage.



Dunne D.8 at Farnborough, 11 March 1914

Dunne had obtained a War Office order for two D.8s, though one was cancelled because of late delivery. One, possibly the machine flown in October 1913 and certainly similar to

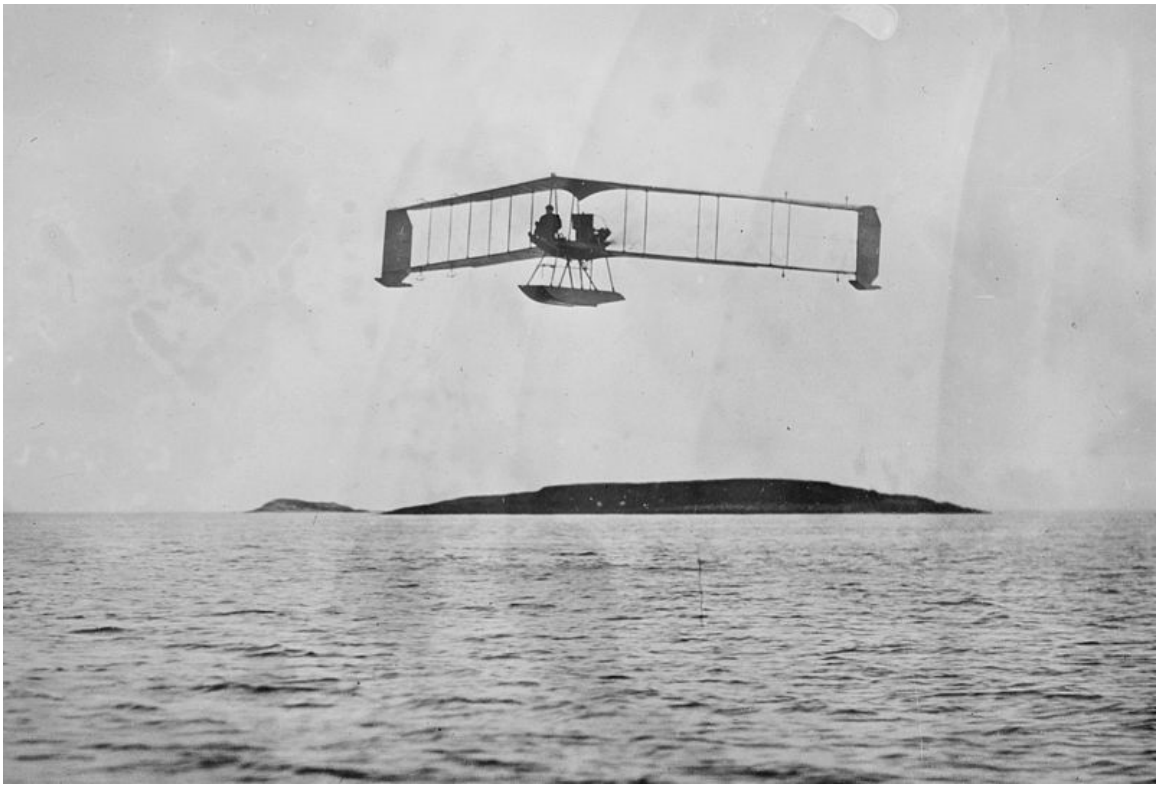
it, was delivered to Farnborough on 3 March 1914. It made several flights on 11 March piloted by N.S.Percival, who had flown the first D.8 many times at Eastchurch and was now a RFC officer. Though it carried the RFC number 366, there is no record of it flying again though it may have survived until at least the summer of 1914. The general judgement was that in the search for balance between stability and controllability, the Dunne design overemphasised the former.

## *Variants*

- **D.10** A shorter span (45 ft, 13.7 m) two seat Gnôme powered version, later converted to D.8.

- **Burgess-Dunne** The Burgess Company and Curtiss, based in Marblehead, Mass, USA gained the US manufacturing rights and built a series of aircraft based on the D.8. They became known as Burgess-Dunne machines and were mostly single-float planes. The first flew in March 1914, piloted by Clifford Webster. Apart from wingtip floats the wings were identical to those of the D8, but the fuselage was revised with a distinct nacelle containing a more enclosed cockpit. The aircraft was a single seater, with the heavier 100 hp (75 kW) Curtiss OXX2 water cooled engine moved forwards, shortening the fuselage and with its radiator placed between engine and pilot. The single float was 17 ft 8 in long (5.38 m), shallow and flat bottomed viewed from in front, with a single step. The prototype behaved well in the air and on the water. The second machine was very similar to the first, but room was made for a second seat by replacing the single fuselage mounted radiator with a pair fixed to the rear float struts.

  The second machine was bought by the Canadian government for the Canadian Aviation Corps and was their first military aircraft. It was shipped to Europe for service in World War I, but was seriously damaged in transit and not used. The third machine, another two seater but powered by a Salmson M-9 radial providing 135 hp (100 kW), was delivered to the US Signal Corps in either 1914 or 1915. Two were also delivered to the US Navy as type AH-7, fitted with a 90 hp (60 kW) Curtiss engine and AH-10 with the 100 hp Curtiss. The latter set a US altitude record of 10,000 fft (3,050 m) on 23 April 1915. One Burgess-Dunne was configured as a landplane for a time.



The first Burgess-Dunne floatplane at Marblehead in 1914

The Dunne-Burgess types were

- BDI - as the prototype.
- BD - as the second aircraft, first aimed at the military market then as a sports plane.
- BDH - a two seater with a 140 hp (104 kW) Sturtevant V-8 engine and a slightly increased span (46 ft, 14.0 m).
- BDF - a three seat, flying boat variant with the Curtiss engine but a span increased to 53 ft (16.2 m).

There is a full scale, non-flying replica of a Burgess-Dunne in the RCAF Memorial Museum, CFB Trenton, Ontario, largely built by Barry D. MacKeracher.

## *Specifications (second aircraft)*

### General characteristics

- **Crew:** 1
- **Length:** 25 ft 9 in (7.85 m)
- **Wingspan:** 46 ft 0 in (14.02 m)
- **Wing area:** 545 sq ft (50.6 $m^2$)
- **Empty weight:** 1,400 lb (635 kg)

- **Gross weight:** 1,900 lb (862 kg)
- **Powerplant:** 1 × Gnôme 7-cylinder rotary, 80 hp (60 kW)

## Performance

- **Maximum speed:** 56 mph (90 km/h; 49 kn)
- **Rate of climb:** 500 ft/min (2.5 m/s)

Chapter- 7

# Fauvel AV.36, Kayaba Ku-2 and Kayaba Ku-3

## Fauvel AV.36

### AV.36

Fauvel AV 36 at the French Air & Space Museum.

| | |
|---|---|
| **Role** | Flying wing glider |
| **Manufacturer** | Homebuilt |
| **Designed by** | Charles Fauvel |
| **First flight** | December 31 1951 |
| **Number built** | over 100 |

The **Fauvel AV.36** was a single-seat tailless glider designed in France in the 1950s by Charles Fauvel. Although the "AV" in *AV.36* stands for *Aile Volante* (Flying Wing), it was not a true flying wing: it featured two large fins mounted on stubby tailbooms extending back from the wing's trailing edge, and accommodated the pilot within a stubby fuselage. The aircraft was designed to be quickly disassembled for road transport, with the nose detaching, and the fins able to fold back against the trailing edge of the

wing. A refined version with a slightly longer wingspan, the **AV.361** was introduced in 1960.

The AV.36 lent itself to easy motorisation, with some builders installing an engine at the rear of the cockpit pod to drive a pusher propeller turning between the tail fins, and the Bölkow factory manufactured some aircraft in this configuration as the **AV.36 C11**.

Plans for the AV.36 have not been available in France since Fauvel's death in 1979, but as of 2007 they are still available from a Canadian supplier.

### *Specifications (AV.36)*

#### General characteristics

- **Crew:** one pilot
- **Length:** 3.17 m (10 ft 5 in)
- **Wingspan:** 11.95 m (39 ft 2 in)
- **Wing area:** 14.2 m² (153 ft²)
- **Empty weight:** 120 kg (265 lb)
- **Gross weight:** 225 kg (496 lb)

#### Performance

- **Maximum speed:** 180 km/h (112 mph)
- **Maximum glide ratio:** 26:1
- **Rate of sink:** 0.9 m/s (180 ft/min)

# Kayaba Ku-2

**Ku-2**

| | |
|---|---|
| **Role** | Research glider |
| **National origin** | Japan |
| **Manufacturer** | Kayaba |
| **Designed by** | Hidemasa Kimura |
| **First flight** | October 1940 |
| **Number built** | 1 |

The **Kayaba Ku-2** was a glider built in Japan in 1940 to investigate the possibilities of tailless aircraft. It was developed as part of an Imperial Japanese Army contract that had

been offered to designer Hidemasa Kimura following the successful flights of his HK-1 tailless glider over the previous years.

Developed with the help of the Kayaba company's chief designer Shigeki Naito, the Ku-2 had a swept wing with two vertical fins at the end of the wings. The Ku-2 flew 262 test flights between October 1940 and May 1941 before being damaged beyond repair in a crash.

### *Specifications*

#### General characteristics

- **Crew:** One pilot
- **Length:** 3.04 m (10 ft 0 in)
- **Wingspan:** 9.80 m (32 ft 2 in)
- **Wing area:** 14.5 m² (156 ft²)

#### Performance

- **Maximum speed:** 75 km/h (47 mph)

# Kayaba Ku-3

| Ku-3 | |
|---|---|
| **Role** | Research glider |
| **National origin** | Japan |
| **Manufacturer** | Kayaba |
| **Designed by** | Hidemasa Kimura and Joji Washimi |
| **First flight** | February 1941 |
| **Number built** | 1 |

The **Kayaba Ku-3** was a glider built in Japan in 1941 to investigate the possibilities of tailless aircraft. Building on the success of the Ku-2 design of the previous year, the Ku-3 was a substantially larger aircraft with several novel features. The small vertical fins of the Ku-2 were abandoned, leaving the Ku-3 with no vertical control surfaces. The wing was a cranked delta design, with three pairs of control surfaces on the trailing edge. The outer, less-swept wing sections had a greater dihedral than the inner sections.

The prototype crashed after 67 flights, when the test pilot was unable to recover from a spin.

Chapter- 8

# Lippisch P.13 and Nike PUL 9

# Lippisch P.13

**P.13**

| | |
|---|---|
| **Role** | Bomber |
| **National origin** | Nazi Germany |
| **Manufacturer** | Messerschmitt |
| **Designed by** | Josef Hubert |
| **Number built** | 0 |

The **Lippisch P.13** was a 1942 design for a high-speed bomber aircraft by Josef Hubert. Of highly unconventional configuration, it was a tail-less, swept-wing design with an engine and propeller mounted at both the front and rear of the aircraft. A large ventral fin gave it an almost cruciform cross-section.

At the time of the P.13's design, Hubert was working in Dr Alexander Lippisch's department at Messerschmitt; when Lippisch left the firm in April 1943, the department was dissolved and its designs (including the P.13) were abandoned.

The similarly-named Lippisch P.13a and P.13b were completely unrelated projects, undertaken after Lippisch's relocation to Vienna.

## *Specifications (P.13, as designed)*

### General characteristics

- **Crew:** one, pilot
- **Length:** 9.40 m (30 ft 10 in)
- **Wingspan:** 12.80 m (42 ft 0 in)
- **Height:** 5.10 m (16 ft 9 in)

### Performance

### Armament

- 1 × bomb

# Nike PUL 9

| PUL 9 | |
|---|---|
| **Role** | Experimental tailless aircraft |
| **National origin** | Argentina |
| **Manufacturer** | Nike Aeronautica srl |
| **Designed by** | Reimar Horten & Siegfried Panek |
| **First flight** | 22 July 1990 |
| **Number built** | 1 |

The **Mike PUL 9** is an Argentine experimental tailless aircraft powered by a Rotax 447 engine.

## *Design and development*

The PUL 9 had its origins in Argentina, the home of the German flying wing pioneer Reimar Horten since 1948. In late 1989 a collaboration between Horten and Siegfried Panek produced a design for a single seat, single pusher engine tailless aircraft. The name was an acronym of Panek UltraLight, with 9 the span in metres. Construction began near Frankfurt, Germany in January 1990 but was transferred to the Italian company Nike Aeronautica in the Spring. The PUL 9 first flew on 22 June 1990.

It had 30° of sweep on the leading edges of its thick (thickness/chord ratio 20%), symmetric aerofoil, wings, built using carbon fibre and Kevlar with glassfibre for the spars. The wingtips were rounded, with washout. Elevons controlled both pitch and roll; there was no vertical stabilizing surface, rudder or separate tailplane.

Like some of Horten's tailless gliders, the I.Ae. 34 Clen Antú for example, the PUL 9 had a well defined, though short, fuselage or pod. This was a deep steel tube structure starting about mid-chord and extending well behind the trailing edge, with a single seat open cockpit at the front and a 42 hp (31 kW) Rotax 447 two cylinder two-stroke engine in pusher mode behind. The main wheels of the PUL 9's fixed tricycle undercarriage were

also mounted on the steel frame, with the nosewheel attached near the leading edge. The undercarriage used rubber cord shock absorbers and drum brakes.

The PUL 9 is reported to have flown several times and handled well. By the end of 1991 attention had turned to a two seat version, the PUL 10.

## *Specifications*

### General characteristics

- **Crew:** 1
- **Length:** 3.90 m (12 ft 10 in)
- **Wingspan:** 9.00 m (29 ft 6 in)
- **Height:** 1.60 m (5 ft 3 in)
- **Wing area:** 11.60 $m^2$ (124.9 sq ft) approximate
- **Empty weight:** 150 kg (331 lb)
- **Max takeoff weight:** 300 kg (661 lb)
- **Powerplant:** 1 × Rotax 447UL 2-cylinder inline two-stroke, 31.3 kW (42.0 hp)
- **Propellers:** 3-bladed Arplast 148GAM adjustable pitch pusher, 1.48 m (4 ft 10 in) diameter

### Performance

- **Maximum speed:** 225 km/h (140 mph; 121 kn) at sea level
- **Cruising speed:** 140 km/h (87 mph; 76 kn) economical, at sea level
- **Stall speed:** 55 km/h (34 mph; 30 kn)
- **Rate of climb:** 5.08 m/s (1,000 ft/min)

Chapter- 9

# Payen Pa 49 and Saab 35 Draken

## Payen Pa 49

### Pa 49 Katy


The sole Pa 49 Katy on display at the 1957 Paris Air Show wearing French military markings

| | |
|---|---|
| **Role** | Experimental tailess delta |
| **National origin** | France |
| **Manufacturer** | Payen-Aviation, Juvisy, Seine et Oise |
| **Designed by** | Roland Payen |
| **First flight** | 22 January 1954 |
| **Retired** | 1958 |
| **Number built** | 1 |

The **Payen Pa 49 Katy** was a small experimental French turbojet powered delta wing aircraft, first flown in 1954, was the first French aircraft of this kind and the smallest jet aircraft of its day.

## *Design and Development*

Roland Payen was a pioneer of tailess and delta winged aircraft, building two designs, a light aircraft and a fighter, before the second world war. The Pa 49 Katy was his first post-war design.

The all wood Katy was a true tailess aircraft, in the sense that it had no separate horizontal stabiliser. The wing leading edge was swept at about 55° but, unlike the classic delta with its straight trailing edge, the Katy's was swept at about 30° with each trailing edge carrying full span control surfaces, elevators inboard and ailerons outboard.

At its root, the wing merged gently into the fuselage with small air intakes for the 1.47 kN (330 lbf) Turboméca Palas engine built into the leading edge. The cockpit was placed just aft of the intakes and the long straight-edged fin, swept at about 75° and initially as wide as the cockpit, began immediately behind it, narrowing to a slightly swept trailing edge carrying a full depth rudder. Images recorded before the first flight show the Katy with a low bicycle undercarriage with wing tip skids but, by the time of the flight itself, this was replaced by a fixed, un-faired tricycle undercarriage.

## *Operational History*


The Pa 49 Katy has been in the Musée de l'Air at Le Bourget since 1958

The first flight of what was now the Pa 49A took place on 22 January 1954 at Melun-Villaroche flown by Tony Ochsenbein, a comparatively inexperienced pilot, who had previously logged only 30 minutes on jets. Ten hours of manufacturer's testing was

followed, in April 1954, by assessment at the Centre d'Essais en Vol (CEV), Brétigny-sur-Orge. The aerobatic ability of the Pa 49 was established. At the CEV it was fitted with a split rudder airbrake; the two surfaces of the rudder separated from just below the tip, driven via faired external links near the bottom, into a V at the hinge for braking, rotating together for yaw control. This airbrake was designed by Fléchair SA, a company founded by Payen. At the time of its appearance at the 12th Salon International d'Aeronautique at Paris, in 1957, the undercarriage legs were faired and the main wheels enclosed in spats and the aircraft renamed the Pa 49B. For a time the nosewheel was also spatted. There were plans for a version with a retractable undercarriage, but this did not come about.

When the flight testing programme ended in 1958 Payen gave the aircraft to the Musée de l'Air at Paris - Le Bourget Airport. He continued to design delta winged aircraft and the Payen Pa 71 and Pa 149 projects of the 1970s were direct developments of the Katy.

## *Specifications*


The Pa 49 at le Bourget

### General characteristics

- **Crew:** 1
- **Length:** 5.10 m (16 ft 9 in)
- **Wingspan:** 5.16 m (16 ft 11 in)
- **Height:** 2.50 m (8 ft 2 in)

- **Empty weight:** 457 kg (1,008 lb)
- **Gross weight:** 650 kg (1,433 lb)
- **Powerplant:** 1 × Turboméca Palas centrifugal turbojet, 1.5 kN (330 lbf) thrust

### Performance

- **Maximum speed:** 500 km/h (310 mph; 270 kn)
- **Cruising speed:** 350 km/h (220 mph; 190 kn)
- **Range:** 450 km (280 mi; 243 nmi)
- **Service ceiling:** 8,500 m (27,887 ft)
- **Rate of climb:** 5.8 m/s (1,140 ft/min) initial

# Saab 35 Draken

## Saab 35 Draken

An Austrian Air Force Draken in a special paint scheme.

| | |
|---|---|
| **Role** | Fighter |
| **National origin** | Sweden |
| **Manufacturer** | Saab |
| **First flight** | 25 October 1955 |
| **Introduced** | 8 March 1960 |
| **Retired** | 1993 Denmark<br>1999 Swedish Air Force<br>2000 Finland<br>2005 Austria |
| **Status** | Retired from military service |
| **Primary users** | Swedish Air Force<br>Austrian Air Force |

| | |
|---|---|
| | Finnish Air Force<br>Royal Danish Air Force |
| **Produced** | 1955–1974 |
| **Number built** | 644 |
| **Developed from** | Saab 210 |

The **Saab 35 Draken** is a Swedish fighter aircraft manufactured by Saab between 1955 and 1974. The Draken was built to replace the Saab J 29 Tunnan and, later, the fighter variant (J 32B) of the Saab 32 Lansen. The indigenous J 35 was an effective supersonic Cold War fighter that was also successfully exported to Austria, Denmark and Finland.

## *Design and development*

As the jet era started, Sweden foresaw the need for a jet fighter that could intercept bombers at high altitude and also successfully engage fighters. Although other interceptors such as the US Air Force's F-104 Starfighter were being conceived during the same period, Saab's "Draken" would have to undertake a combat role unique to Sweden. Other demanding requirements were the capability to operate from reinforced public roads used as part of wartime airbases, and for refuelling/rearming to be carried out in no more than ten minutes, by conscripts with minimal training. In September 1949, the Swedish Defence Material Administration issued a request for a fighter/interceptor aircraft, and work began at Saab the same year.

A line-up of J 35As.

Draken's design incorporated a distinctive "double-delta" configuration, with one delta wing within another larger delta. The inner wing has an 80° angle for high speed performance, while the outer 60° wing gives good performance at low speeds. Propulsion was provided by a single Svenska Flygmotor RM 6B/C turbojet (Rolls-Royce Avon 200/300). A ram turbine, under the nose, provided emergency power and the engine had a built-in emergency starter unit. The Draken could deploy a drag chute to reduce its landing distance.

The double-delta shape was so revolutionary that it warranted the only sub-scale test aircraft built in Sweden: the Saab 210, unofficially nicknamed "Lilldraken" (the little kite). The Saab 210 tested the concept of the double delta, first flying on 21 January 1952. The 210's successful testing results led to an order for three full-size Draken prototypes. The first prototype, not fitted with an afterburner, made its maiden flight on 25 October 1955. The second prototype, equipped with an afterburner, unintentionally broke the sound barrier on its first flight while climbing.

## *Operational history*

Although not designed to be a dogfighter, the J 35 Draken proved to have good instantaneous turn capability and was a very capable fighter. It entered service in 1960 with the Swedish Air Force; 644 Saab Drakens were built for Sweden as well as other European nations. Sweden's Draken fleet came in six different variants while two Draken models were offered for export. The early models were intended purely for air defence. The last model built was the J 35F, the final variant to remain in Swedish service. These aircraft were retired in the 1990s and replaced by the Saab Gripen.

Ex-RDAF RF-35XD N217FR operated by the National Test Pilot School takes off from the Mojave Spaceport.

The J 35 Draken design underwent several upgrades. The last was the J 35J version, in the late 1980s, although by then, the Draken had been almost totally replaced by the Saab 37 Viggen in Swedish service. The J 35J was a service-life extension program since the delivery of the new Saab JAS 39 Gripen was still in the development stage and suffering from delivery delays. The extension program was to keep the Draken flying into the 2000s, but due to cutbacks and high maintenance costs the Draken was eventually phased out. The Swedish Drakens were officially retired in December 1998, although the type remains in limited numbers in both military and civilian versions. Export customers included Denmark and Finland. In 1985, the Austrian Air Force purchased 24 J 35D s reconditioned by Saab, designated J 35Ö.

All Drakens are interceptors with limited air-to-ground capability, with the sole exception of the Danish Drakens, which are strike aircraft capable of carrying AGM-12 Bullpup missiles, advanced "jammers", and increased internal and external fuel stores. The Danish Drakens are so far the heaviest of the series to have been in service. Danish F-35 aircraft were retired in 1993.

Finland updated its 35XS fleet with new avionics, cockpit displays, navigational/attack systems and electronic countermeasures during the 1990s but finally retired the Draken in 2000.

Austria was the last country to operate the Draken in military service. They bought refurbished J 35D which was the last Austrian Air Force fighter with two internal cannons due to the restriction in the Austrian State Treaty of 1955 of not being allowed to carry air-to-air missiles. This restriction was dropped in 1993 due to airspace violations from the nearby Yugoslavian internal conflict on its southern border, AIM-9 Sidewinder missiles were purchased. These Drakens were retired in 2005, when they were replaced by former Swiss Tiger IIs, while waiting for new Eurofighters.

In the United States, the National Test Pilot School (NTPS) owns six Drakens that were formerly in Danish service; of these, two TF-35XD s and one RF-35XD are operational, based at the Mojave Spaceport.

## *Variants*

### Proof of concept

Saab 210 Draken

(also known as **Lilldraken**) - A scaled-down, "proof of concept" experimental aircraft to evaluate the double-delta wing configuration, not specifically a Draken variant but included here for sequence purposes.

### Full-size Drakens

J 35A

Fighter version, total production: 90. The J 35As were delivered between 1959-1961. The tail section was lengthened after the 66th aircraft to house a new afterburner for additional thrust. This forced the installation of a retractable tail-

wheel. The two versions were nicknamed *Adam kort* (Adam short) and *Adam lång* (Adam long).

J 35B

Fighter version, built and delivered between 1962–1963, total production: 73. This variant had improved radar and gun sights, and was also fully integrated into the Swedish STRIL 60 system; a combat guidance and air surveillance system.

SK 35C

25 J 35As with short tail sections rebuilt into a twin-seated trainer version. The minor modification meant that the aircraft could easily be converted back to a J 35A standard if necessary. The trainer version lacked armament.

J 35D

Fighter version, delivered between 1963–1964, total production: 120. The aircraft had a new and more powerful Rolls-Royce Avon 300 (RM 6C), which could deliver 77.3 kN thrust when using its afterburner. This was also the fastest Draken version, capable of accelerating until out of fuel. It was also the last Draken to carry two cannons.

S 35E

Reconnaissance version, total production: 60. The radar and the armament had been removed and several cameras (of ortho and oblique types) fitted. The aircraft was unarmed but was fitted with a countermeasure system to increase its survivability. A total of 28 aircraft were re-built J 35Ds.

J 35F

Fighter version, delivered between 1965 and 1972, total production: 230. This variant had improved electronics and avionics, e.g. integrated radar, aim and missile systems. The aircraft's main armament were IR and SARH versions of the Hughes Falcon missile originally intended for the J 35D, but one of the cannon was removed to make space for more avionics. The **J 35F2** was a J 35F, produced with a Hughes Aircraft Company N71 infra red sensor, a so-called IR seeker. This was a change in the production line from the no. 35501 airframe.

J 35J

In 1985 the Swedish government decided to modify 54 J 35F2s to J 35J standard. In 1987, 12 more modifications were ordered. Between 1987 and 1991, the aircraft were given a longer lifespan, more modern electronics, a modernized cannon, an additional two sidewinder pylons under the air intakes and increased fuel capacity. The final operative J 35J flew for the last time in 1999.

Saab 35H

Proposed export version for the Swiss Air Force; none sold or delivered.

Saab 35XD

Danish export versions: **F-35** single-seat Strike Aircraft, **TF-35** two-seat trainer and **RF-35** reconnaissance aircraft. The type was heavily modified to make it into a strike aircraft compared the Swedish versions.

Saab 35XS

Fighter version for the Finnish Air Force; built by Saab and assembled under licence by Valmet in Finland.

Saab 35BS

Used J 35Bs sold to Finland.

Saab 35FS
: Used J 35F1s sold to Finland.

Saab 35CS
: Used SK 35Cs sold to Finland.

Saab 35Ö
: In the mid-1980s, Saab purchased back 24 J 35D aircraft from the Swedish Air Force and converted them into the J 35Ö version (also called **J 35OE** in English literature). These were later exported to Austria.

## Proposed modifications

Before it was decided to develop the JAS 39 Gripen in the late 1970s, an intensive study was undertaken on an AJ 35 modification for the remaining S 35E and J 35F variants. The main goal was to give the aircraft strike capability while waiting for a replacement for the AJ 37 Viggen.

35 MOD Level 4
: The most ambitious modification in the program. The proposed modifications were; new outer wing, additional weapon stations, RBS 15 capability, the addition of canard wings by the air intakes for increased maneuverability and maximum take-off weight increased to 15 000 kg.

35 MOD Level 1b
: Essentially the aircraft that became the J 35J.

The total number of Drakens produced and delivered: 644.

## *Operators*

former Saab 35 Draken Operators in red

The Saab 35 Draken was withdrawn from military use in 2005. Several aircraft fly in the civil circuit, mainly in the USA.

Austria

- Austrian Air Force, 24 aircraft:
  - Fliegerregiment 2
    - Staffel 1
    - Staffel 2

Denmark

- Royal Danish Air Force, 51 aircraft:
  - No. 725 Squadron
  - No. 729 Squadron

Finland

- Finnish Air Force, 50 aircraft:
  - Fighter Squadron 11
  - Fighter Squadron 21

Sweden

- Swedish Air Force
  - F 1 Hässlö
  - F 3 Malmslätt
  - F 4 Frösön
  - F 10 Ängelholm
  - F 11 Nyköping
  - F 12 Kalmar
  - F 13 Norrköping
  - F 16 Uppsala
  - F 17 Kallinge
  - F 18 Tullinge
  - F 21 Luleå

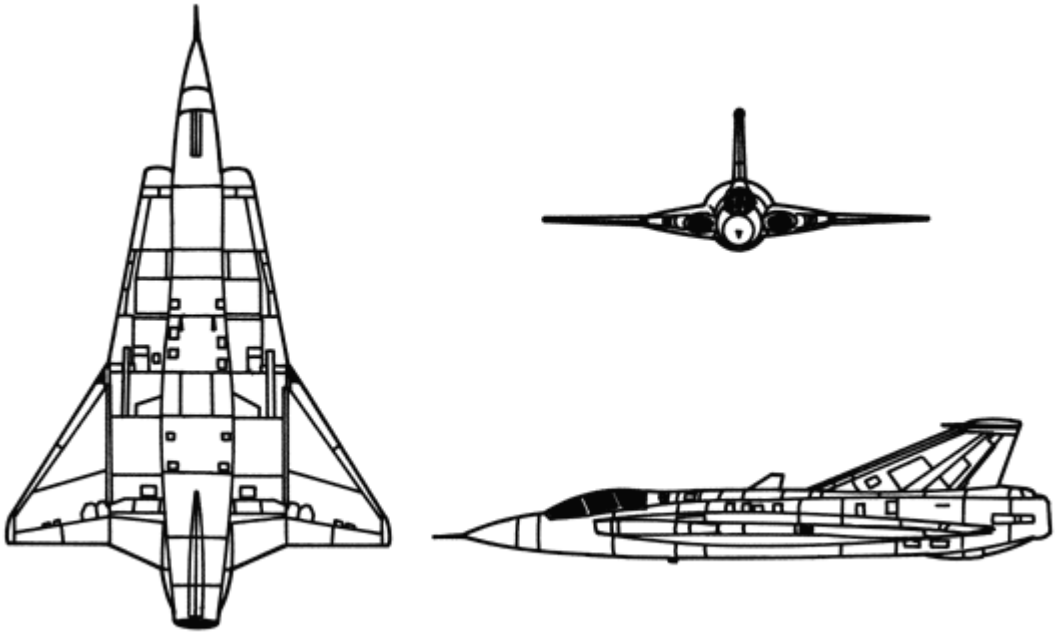
United States

- National Test Pilot School (6)

## *Survivors*

- J 35J, 35556 in the Swedish Air Force Museum at F 14 Halmstad, Sweden Only airworthy Saab J 35 in Sweden
- J 35J, 35630 at the at the Angelholms Flyg Museum on the former Scandia Air Force Wing F 10 Ängelholm

## *Specifications (J 35F Draken)*



### General characteristics

- **Crew:** One
- **Length:** 15.34 m (50 ft 4 in)
- **Wingspan:** 9.42 m (30 ft 10 in)
- **Height:** 3.89 m (12 ft 9 in)
- **Wing area:** 49.22 m² (529.82 ft²)
- **Empty weight:** 7,865 kg (17,340 lb)
- **Loaded weight:** 11,400 kg (25,132 lb)
- **Max takeoff weight:** 16,000 kg (35,273 lb)
- **Powerplant:** 1× Volvo Flygmotor RM 6C afterburning turbojet
    - **Dry thrust:** 56.5 kN (12,787 lbf)
    - **Thrust with afterburner:** 78.4 kN (17,637 lbf)

### Performance

- **Maximum speed:** Mach 2+, 2,120 km/h (1,317 mph) at 11,000 m (36,100 ft)
- **Range:** 3,250 km (2,020 mi) with external drop tanks
- **Service ceiling:** 20,000 m (65,600 ft)
- **Rate of climb:** 175 m/s (34,450 ft/min)
- **Wing loading:** 231.6 kg/m² (47.4 lb/ft²)
- **Thrust/weight:** 0.70
- **Takeoff roll:** 650 m (2,133 ft)

## Armament

- **Guns:** 1x 30 mm M-55 ADEN cannon with 100 rounds (2x 30 mm M-55 ADEN cannon with 90 rounds each in earlier models)
- **Hardpoints:** for fuel tanks or ordnance with a capacity of 2,900 kg (6,393 lb) and provisions to carry combinations of:
    - **Rockets:** 2x 75 mm air-to-air rocket pods ventrally or 12x 135mm rockets on six underwing pylons
    - **Missiles:** Rb 24, Rb 27 and Rb 28 air-to-air missiles
    - **Bombs:** 55, 220, 500, and 1,000 pound bombs

Chapter- 10

# Vought F7U Cutlass

## F7U Cutlass


An F7U-3 Cutlass on the ramp at Naval Air Station Jacksonville.

| | |
|---|---|
| **Role** | Naval multirole fighter |
| **Manufacturer** | Chance Vought |
| **First flight** | 29 September 1948 |
| **Introduced** | July 1951 |
| **Retired** | 2 March 1959 |
| **Primary user** | United States Navy |
| **Produced** | 1948-1955 |
| **Number built** | 320 |

The **Vought F7U Cutlass** was a United States Navy carrier-based jet fighter and fighter-bomber of the early Cold War era. It was a highly unusual, semi-tailless design, allegedly based on aerodynamic data and plans captured from the German Arado company at the end of World War II, though Vought designers denied any link to the German research at

the time. The F7U was the last aircraft designed by Rex Beisel, who was responsible for the first fighter ever designed specifically for the US Navy, the Curtiss TS-1 of 1922.

Regarded as a radical departure from traditional aircraft design, the Cutlass suffered from numerous technical and handling problems throughout its short service career. The type was responsible for the deaths of four test pilots and 21 other U.S. Navy pilots. Over one quarter of all Cutlasses built were destroyed in accidents. The poor safety record was largely the result of the advanced design built to apply new aerodynamic theories and insufficiently powerful, unreliable engines.

## *Design and development*


The first F7U-1 launching from the *USS Midway* in 1951

The Cutlass was Vought's entry to a U.S. Navy competition for a new carrier capable day fighter opened on 1 June 1945. The requirements were for an aircraft that was able to fly at 600 mph (966 km/h) at 40,000 ft (12,192 m). The design featured broad chord, low aspect ratio, swept wings, with twin wing-mounted tail fins either side of a short fuselage. The cockpit was situated well forward to provide good visibility for the pilot during aircraft carrier approaches. The design was given the company type number of V-346 and then the designation F7U when it was announced the winner of the competition.

Pitch and roll control was provided by elevons, though Vought called these surfaces "ailevators" at the time. Slats were fitted to the entire span of the leading edge. All controls were hydraulically-powered. The very long nose landing gear strut required for high angle of attack takeoffs was rather weak, and a collapse could seriously jeopardize the pilot's safety. The F7U was also largely let down by its underpowered Westinghouse turbojets, an engine which some pilots wryly observed put out less heat than the same company's toasters. Naval aviators referred to the F7U as the "gutless cutlass" or, in kinder moments, as the "praying mantis".

## *Operational history*

Vought F7U-3 Cutlass

Ramp strike of a VF-124 F7U-3 on the USS *Hancock* on 14 July 1955 resulting in the death of the pilot but only relatively minor injuries to deck crew.

Three prototypes were ordered in 1946, with the first example flying on 29 September 1948, piloted by Vought's Chief Test Pilot, J. Robert Baker. The maiden flight took place from Naval Air Station Patuxent River and was not without its problems. During testing one of the protypes reached a maximum speed of 625 mph (1,058 km/h)

Production orders were placed for the **F7U-1** in a specification very close to the prototypes, and further developed **F7U-2** and **F7U-3** versions with more powerful engines. Because of development problems with the powerplant, however, the F7U-2 would never be built, while the F7U-3 would incorporate many refinements suggested by tests of the -1. The first 16 F7U-3s had non-afterburning Allison J35-29 engines. The -3 with its Westinghouse J46-WE-8B turbojets would eventually become the definitive production version, with 288 aircraft equipping 13 U.S. Navy squadrons. Further development stopped once the F8U Crusader flew.

The F7U bore the fleet nickname of the *Gutless Cutlass* in reference to its lack of engine thrust; consequently its carrier landing and takeoff performance was notoriously poor. The J35 was actually known to flameout in the rain, a very serious fault.

The first fleet squadron to receive F7Us was VF-81 in April 1954; the last with Cutlasses was VA-66 in November 1957. Few squadrons made deployments with the type, and most "beached" them during part of the cruise owing to operating difficulties. Those units known to have taken the type to sea were:

VF-124, USS *Hancock* (CVA-19), August 1955 - March 1956; VF-81, USS *Ticonderoga* (CVA-14), November 1955 - August 1956; VF-86, USS *Forrestal* (CVA-59), January - March 1956; VF-83, USS *Intrepid* (CVA-11), March - September 1956; VF-212, USS *Bon Homme Richard* (CVA-31), August 1956 - February 1957.

VC-3 and VX-4 also operated Cutlasses at sea for evaluation purposes.

## Blue Angels

The Navy Flight Demonstration Squadron, the Blue Angels, flew two F7U-1 Cutlasses as a side act during their 1953 show season in an effort to promote the new aircraft, but did not use them as part of their regular formation act. Both the pilots and ground crews found the aircraft generally unsatisfactory and it was apparent that the type was still experiencing teething troubles.

During the Blue Angels' first airshow appearance in 1953, pilot LT Edward "Whitey" Feightner, the former program manager for the F7U, experienced a total loss of hydraulics on a full afterburner takeoff and steep climb. While trying to gain enough altitude for ejection he was able to stay with the aircraft until the back up system came on. He clipped trees on the end of the runway, causing the left engine to flame out. With hydraulic fluid streaming back in a bright flame, he made a hard turn and got the plane back on the runway, much to the excitement of the crowd. Later, while traveling to the airshow at Naval Air Station Glenview in Chicago, Blue Angel pilot LT Harding MacKnight experienced an engine flameout in his Cutlass, forcing him to make an emergency landing at Glenview. Traveling with him, "Whitey" Feightner was redirected to make his landing at Chicago's former Orchard Airpark, which had been expanded and renamed O'Hare Airport. The runway had just been completed and was covered with peach baskets to prevent aircraft from landing until it was opened. LT Feightner was told to ignore the baskets and land on the new runway. As a result, LT Feightner's F7U became the first aircraft to land on the new runway for Chicago's O'Hare Airport.

Following these incidents the two F7U were deemed unsuitable for demonstration flying and were flown to Naval Air Station Memphis, Tennessee, where they were abandoned to become aircraft maintenance instructional airframes for the Naval Technical Training Center.

## *Variants*

XF7U-1

: Three prototypes ordered on 25 June 1946. First flight, 29 September 1948, all three aircraft were destroyed in crashes.

F7U-1

The initial production version, 14 built. Powered by two J34-WE-32 engines.

F7U-2

Proposed version, planned to be powered by two Westinghouse J34-WE-42 engines with afterburner, but the order for 88 aircraft was cancelled.

XF7U-3

Designation given to one aircraft built as the prototype for the F7U-3. First flight: 20 December 1951.

F7U-3

The definitive production version, 192 built.

F7U-3P reconnaissance aircraft

F7U-3P

Photo-reconnaissance version, 12 built. With a 25 in longer nose and equipped with photo flash cartridges none of these aircraft saw operational service, being used only for research and evaluation purposes.

F7U-3M

This version was armed with the AIM-7 Sparrow air-to-air missile, 98 built. A total of 48 F7U-3 existing airframes were upgraded to F7U-3M standard. An order for 202 aircraft was cancelled.

A2U-1

Designation given to a cancelled order of 250 aircraft to be used in the ground attack role.

## Operators


A VF-83 F7U-3M launches from the *USS Intrepid* in 1954

United States
- United States Navy
  - Attack Squadron 12 (VA-12)
  - VA-34
  - VA-35
  - VA-66
  - VA-83
  - VA-86
  - VA-116
  - Fleet Composite Squadron 3 (VC-3)
  - Fighter Squadron 124 (VF-124)
  - VA-126**VA-155**VF-83
  - VF-81
  - VF-84
  - VF-122
  - VF-151
  - VF-212
  - Test and Evaluation Squadron 4 (VX-4)

## Survivors

Seven F7U Cutlass aircraft are known to have survived.

F7U-3 BuNo 128451

Formerly at the Fred E. Weisbroad Aviation Museum/International B-24 Museum in Pueblo, Colorado. It was unrestored and incomplete, in poor condition. It is now at the USS Midway (CV-41) Museum in San Diego, California, to be combined with BuNo 129565 to make one complete aircraft.

F7U-3 BuNo 129554

Purchased by Len Berryman from Geiger Field, Washington in May 1958 and displayed outside the Berryman War Memorial Park in Bridgeport, Washington from 1958 until 1992. In June 1992 it was sold to Tom Cathcart of Ephrata, Washington for restoration to eventual flying condition. This aircraft is currently undergoing restoration at the Museum of Flight in Everett, Washington.

F7U-3 BuNo 129565

Was undergoing restoration for display at the USS Hornet (CV-12) Museum at the former NAS Alameda in Alameda, California. Has now been transferred to USS Midway (CV-41) Museum in San Diego, California for final restoration and display.

F7U-3 BuNo 129622

Ex VA-12 aircraft that sustained crash-landing damage at NAS Glenview, Illinois; was moved to the Oakdale Elementary School for playground use, and was subsequently dissected and sold for its engines. Forward fuselage was part of Earl Reinart's collection in Mundelein, Illinois, while the rest of the aircraft went to J-46 dragster builder Fred Sibley. Its components are currently reunited in the collection of noted F7U historian Al Casby of Phoenix, Arizona.

F7U-3M at the National Museum of Naval Aviation at NAS Pensacola, Florida

F7U-3 BuNo 129642

On display at the Wings of Freedom Aviation Museum at the Naval Air Station Joint Reserve Base Willow Grove, Pennsylvania. The aircraft belonged to Attack Squadron 12 (VA-12} and was flown to NAS Willow Grove in May 1957 to take part in an air show. Upon arrival the aircraft was stricken from active duty. It was given to the Navy Reserve as a ground training aircraft, and eventually placed as a gate guard in front of the base on US Route 611. The airframe has only 326.3 hours total time.

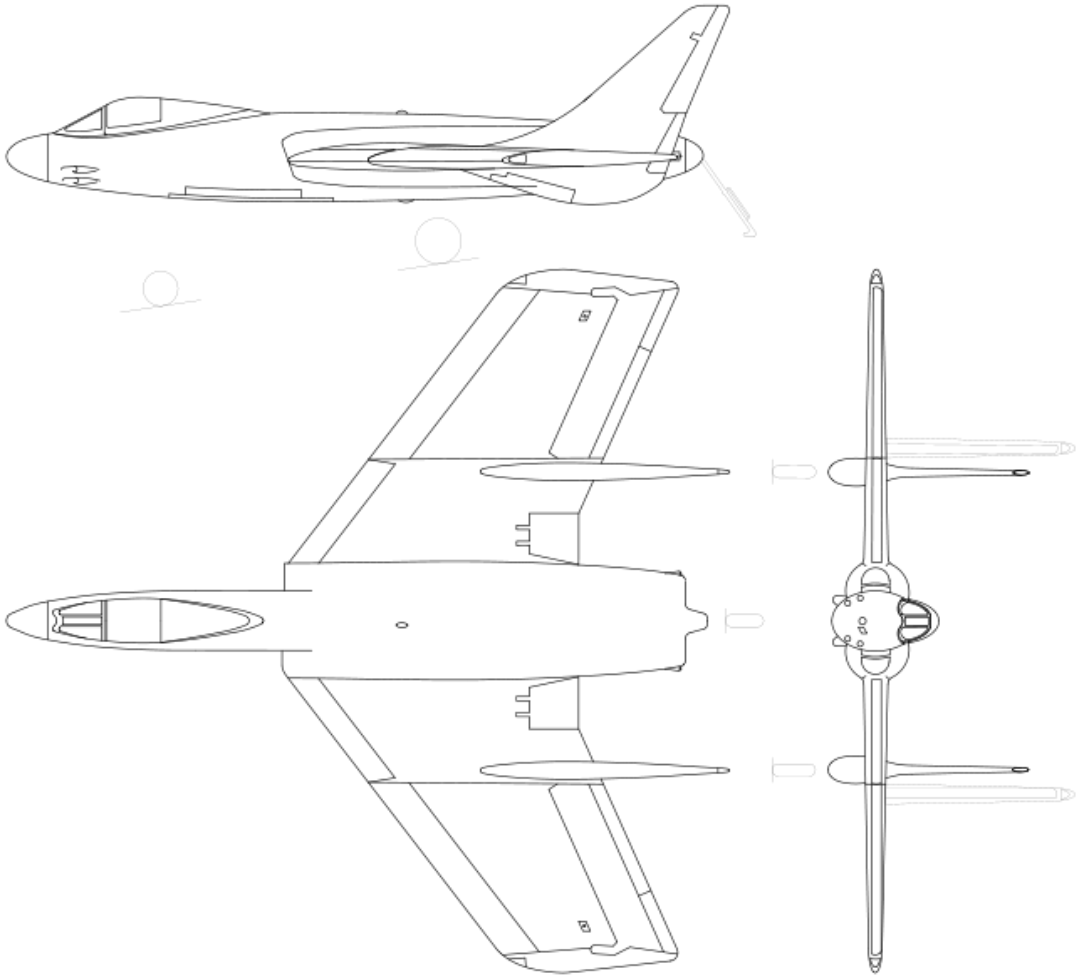
F7U-3 BuNo 129655

Although marked as an F7U-3M, this aircraft on display at the National Museum of Naval Aviation at NAS Pensacola, Florida is in reality an F7U-3 which was factory upgraded to F7U-3M standards. Formerly displayed at Griffith Park, California.

F7U-3 BuNo 129685

Located for many years at the aircraft collection of Walter Soplata in Newbury, Ohio. Like most aircraft on this famous farm, the aircraft appears complete, though it is exposed to the elements and unrestored.

## *Specifications (F7U-3M)*



## General characteristics

- **Crew:** 1
- **Length:** 44 ft 3 in (13.49 m)
- **Wingspan:** 38 ft 8 in (11.79 m)
- **Height:** 14 ft 0 in (4.27 m)
- **Wing area:** 496 ft² (46.1 m²)
- **Empty weight:** 18,210 lb (8,260 kg)
- **Max takeoff weight:** 31,642 lb (14,353 kg)
- **Powerplant:** 2× Westinghouse J46-WE-8A turbojets, 4,600 lbf (20.46 kN) each

## Performance

- **Maximum speed:**
  - **Clean:** 680 mph (590 kn, 1,095 km/h)
  - **With missiles:** 648 mph (562 kn, 1,040 km/h)
- **Range:** 660 mi (570 nmi, 1,060 km)
- **Service ceiling:** 40,000 ft (12,000 m)
- **Rate of climb:** 13,000 ft/min (67 m/s)
- **Wing loading:** 64 lb/ft² (312 kg/m²)
- **Thrust/weight:** 0.29

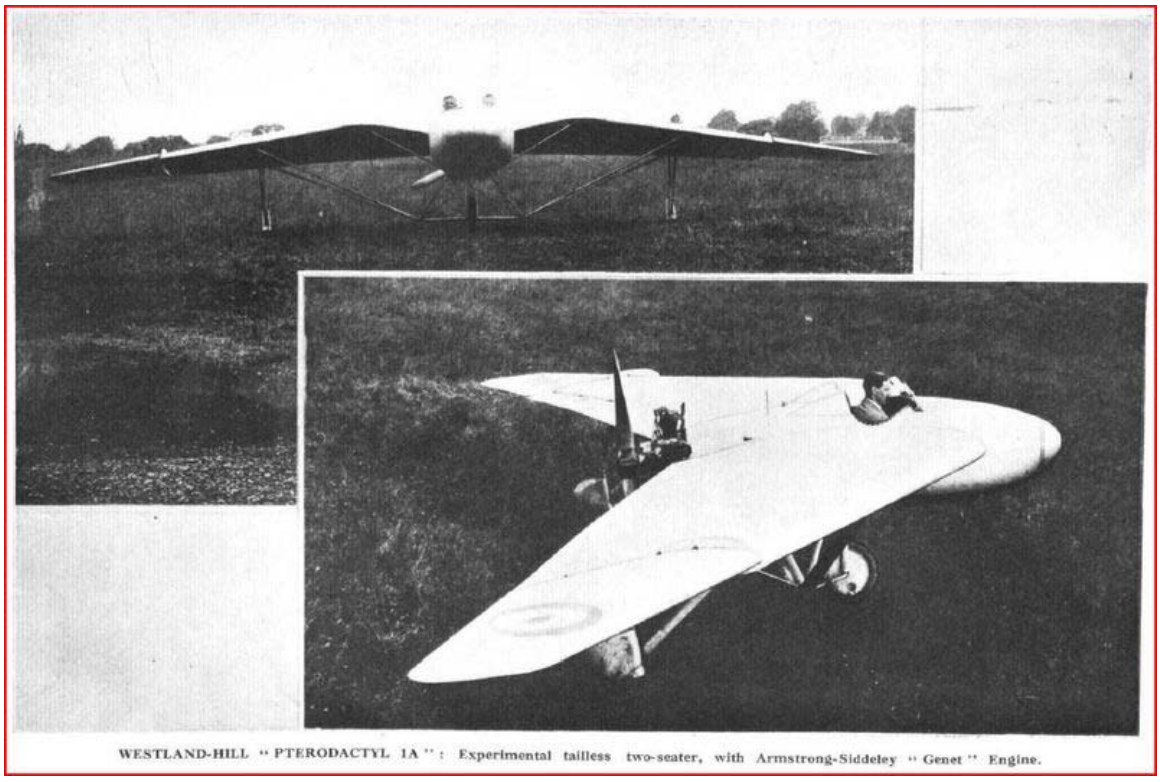
## Armament

- **Guns:** 4× 20 mm (0.787 in) M3 cannons above inlet ducts, 180 rounds/gun
- **Hardpoints:** 4 with a capacity of 5,500 lb (2,500 kg) and provisions to carry combinations of:
  - **Missiles:** AIM-7 Sparrow air-to-air missiles

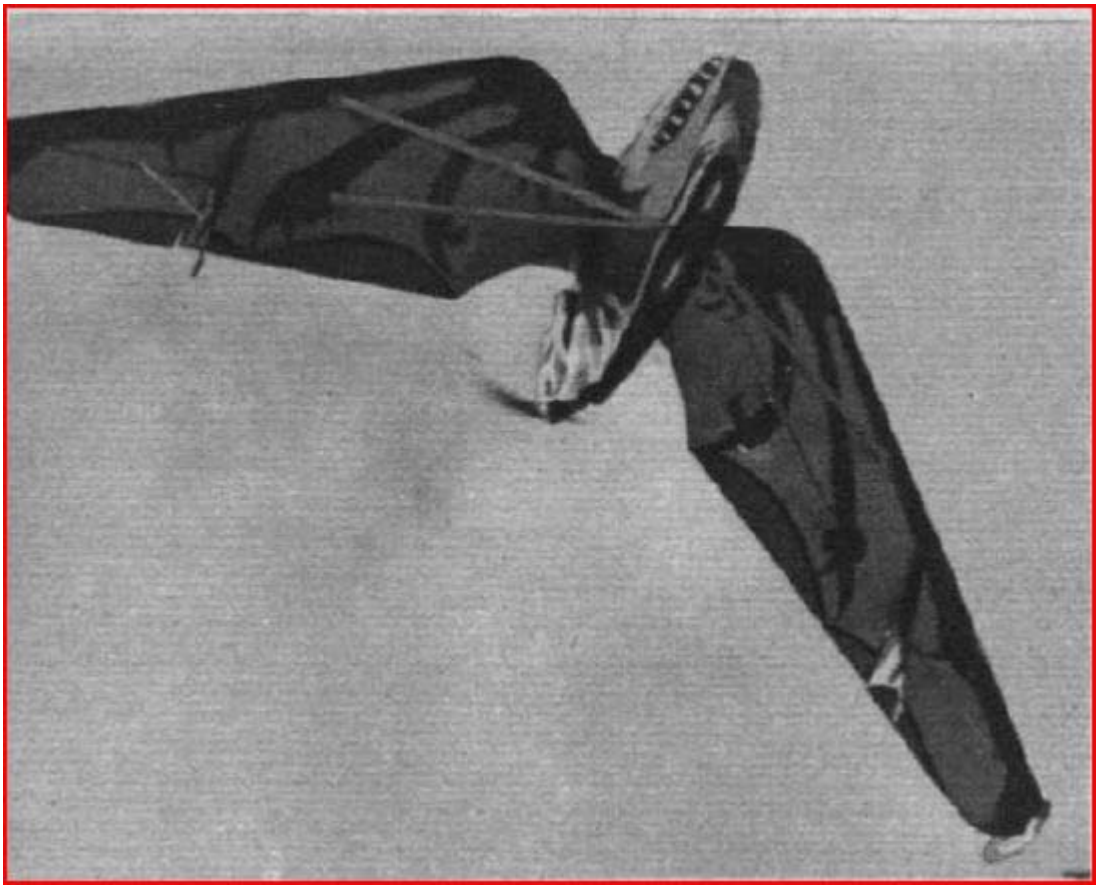
Chapter- 11

# Westland-Hill Pterodactyl and Boeing X-45

## Westland-Hill Pterodactyl




caption=Pterodactyl version 1A (Flight international 1928)



caption=Pterodactyl version 1A shot from below (Flight international 1928)

The **Westland-Hill Pterodactyl** was a series of experimental tailess or flying wing aircraft designs starting in the 1920s named after the Pterosaur.

They were designed by Geoffrey T. R. Hill and built by Westland Aircraft, having their first flights from RAF Andover. The first (Pterodactyl lA and lB) were high wing tailess monoplanes with fully moving wingtips for control built to overcome the issue of stalling and spinning. In some designs the monoplane wing was supported by struts from a stubby lower wing giving them some of the appearance of an unequal span biplane (sesquiplane). Later designs included fighter and transport aircraft.

The designs were credited as being inspired by observation of seagulls and used fully moving outer wingtips for control. If both tips were moved in the same way they functioned as elevators, in opposite ways then as ailerons

The pioneer tailless aircraft designer John William Dunne assisted Hill with the early designs.

## Aircraft

- Pterodactyl I

  Glider, built by G T R Hill in 1924; fitted with engine as Mk.IA in 1925

- Pterodactyl IA

  Bristol Cherub engine

- Pterodactyl IB

  Armstrong Siddeley Genet

- Pterodactyl IV

  Three seat cabin monoplane of 44 ft 4 in span and 19 ft 6 in length. Pitch and roll control by elevons.

- Pterodactyl V

  Fighter design with a 600 hp Rolls-Royce Goshawk engine and 2 Vickers machine guns.

- Pterodactyl VI.

  Designed to Specification F.5/33 for a 2 seater fighter aircraft with front mounted turret. Pusher engine design with powered, front-mounted, gun turret.

- Pterodactyl Mk VII

  Designed to Specification R1/33. Flying boat with two tractor and two pusher engines

- Short Brothers-Hill Pterodactyl VIII

  Proposed Flying wing transatlantic passenger aircraft with 5 pusher Rolls-Royce Griffon engines.

## Related Work

The Pterodactyl V gained some unexpected interest when it featured in an assignment for the module Materials in Design (MME4008), an elective study unit taken by students in their final year of a four year course which leads to the much coveted degree of a mechanical engineer from the University of Malta. The assignment which carried 30% of the global mark required students to make a material selection exercise on the various

components of the Pterodactyl V model which ranged from rudder pedals to internal mudguard.

### *On display*

The Pterodactyl 1A of 1925 is held by the Science Museum London.

# Boeing X-45

## X-45


Boeing X-45A

| | |
|---|---|
| **Role** | Unmanned Combat Air Vehicle |
| **Manufacturer** | Boeing Integrated Defense Systems |
| **First flight** | 22 May 2002 |
| **Primary user** | United States Air Force |
| **Number built** | 2 |
| **Variants** | Phantom Ray |

The **Boeing X-45** unmanned combat air vehicle is a concept demonstrator for a next generation of completely autonomous military aircraft, developed by Boeing's Phantom Works. Manufactured by Boeing Integrated Defense Systems, the X-45 was a part of DARPA's J-UCAS project.

### *Development*

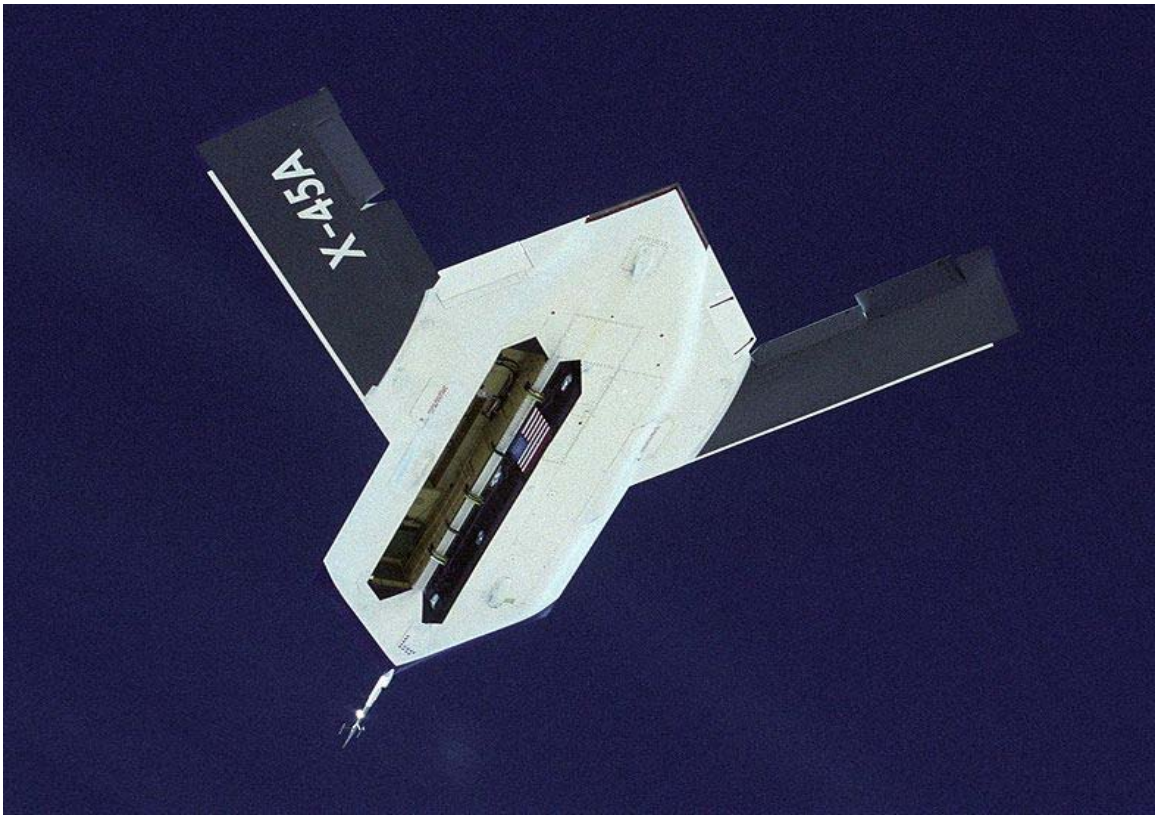
Boeing developed the X-45 from research gathered during the development of the Bird of Prey. The X-45 features an extremely low-profile dorsal intake placed near the leading edge of the aircraft. The center fuselage is blended into a swept lambda wing, with a small exhaust outlet. It has no vertical control surfaces — split ailerons near each wingtip function as asymmetric air brakes, providing rudder control, much as in Northrop's flying wings.

Removing the pilot and its associated facilities dramatically reduces the aircraft's cost. Operators may remotely command the aircraft, but the actual piloting is autonomous.

## *Variants*

### X-45A

Boeing built two of the model X-45A; both were scaled-down proof-of-concept aircraft. The first was completed by Boeing's Phantom Works in September 2000. The goal of the X-45A technology demonstrator program was to develop the technologies needed to "conduct suppression of enemy air defense missions with unmanned combat air vehicles." The first generation of unmanned combat air vehicles are primarily planned for air-to-ground roles with defensive air-to-air capabilities coupled with significant remote piloting.




X-45A underside with weapons bay door open

The X-45A had its first flight on May 22, 2002, and the second vehicle followed in November of that year. On April 18, 2004, the X-45A's first bombing run test at Edwards Air Force Base was successful; it hit a ground target with a 250-pound inert precision-guided munition. On August 1, 2004, for the first time, two X-45As were controlled in flight simultaneously by one ground controller.

On February 4, 2005, on their 50th flight, the two X-45As took off into a patrol pattern and were then alerted to the presence of a target. The X-45As then autonomously determined which vehicle held the optimum position, weapons (notional), and fuel load to properly attack the target. After making that decision, one of the X-45As changed course and the pilot-operator allowed it to attack the simulated antiaircraft emplacement. Following a successful strike, another simulated threat, this time disguised, emerged and was subsequently destroyed by the second X-45A. This demonstrated the ability of these vehicles to work autonomously as a team and manage their resources, as well as to engage previously-undetected targets, which is significantly harder than following a predetermined attack path.

After the completion of the flight test program, both X-45As were sent to museums, one to the National Air and Space Museum, and the other to the National Museum of the United States Air Force at Wright-Patterson Air Force Base, where it was inducted on November 13, 2006.

## X-45B/C

The newer, larger X-45C

X-45C from the side

The larger X-45B design was modified to have even more fuel capacity and three times greater combat range, becoming the X-45C. Each wing's leading edge spans from the nose to the wingtip, giving the aircraft more wing area, and a planform very similar to the B-2 Spirits'. The first of the three planned X-45C aircraft was originally scheduled to be completed in 2006, with capability demonstrations scheduled for early 2007. By 2010 Boeing hoped to complete an autonomous aerial refueling of the X-45C by a KC-135 Stratotanker. Boeing has displayed a mock-up of the X-45C on static displays at many airshows.

The X-45C portion of the program received $767 million from DARPA in October 2004, to construct and test three aircraft, along with several supplemental goals. The X-45C included an F404 engine. In July 2005 DARPA awarded an additional $175 million to continue the program, as well as implement autonomous Aerial Refueling technology.

As of March 2, 2006, the US Air Force has decided not to continue with the X-45 project. However, Boeing submitted a proposal to the Navy for a carrier based demonstrator version of the X-45, designated the X-45N.

## X-45N

The X-45N was Boeing's proposal to the Navy's Unmanned Combat Air Systems demonstration project. When it became known that the US Air Force would end funding to the Joint Unmanned Combat Air System program (which included the X-45 and X-47), the US Navy started its own UCAS program. Requirements were defined over the summer of 2006, and proposals were submitted in April 2007.

The first flight of the X-45N was planned for November 2008, had Boeing won the contract. The contract was eventually awarded to Northrop Grumman's proposed naval X-47, thus ending the X-45 program.

The software Boeing developed to allow the X-45N to land and takeoff autonomously on aircraft carriers has recently been installed on the first F/A-18F, which has used it to perform autonomous approaches. All autonomous approaches ended with a wave-off by design. This Super Hornet is expected to be able to hook the carrier's arrester cables autonomously by the 2009 timeframe, setting the stage for carrier-borne UAV operations.

## Phantom Ray

Boeing plans to develop and demonstrate an unmanned flying test bed for advanced air system technologies. The internally funded program, called Phantom Ray, will use the X-45C prototype vehicle that Boeing originally developed for the Defense Advanced Research Projects Agency (DARPA)/U.S. Air Force/U.S. Navy Joint-Unmanned Combat Air System (J-UCAS) program. The UAV is not aimed at any particular program or competition.

## *Specifications (X-45A)*

### General characteristics

- **Crew:** 0
- **Length:** 26 ft 6 in (8.08 m)
- **Wingspan:** 33 ft 10 in (10.3 m)
- **Height:** 6 ft 8 in (2.14 m)
- **Empty weight:** 8,000 lb (3,630 kg)
- **Powerplant:** 1× Honeywell F124-GA-100 turbofan

### Performance

- **Maximum speed:** Mach 0.75 (571 mph, 919 km/h)
- **Range:** 1,300 nmi (2,405 km)
- **Combat radius:** 375 miles (600 km)
- **Service ceiling:** 40,000 ft (13,200 m)

### Armament

- **Hardpoints:** 8 - 2 weapon bays with 4 in each - and provisions to carry combinations of:
    - **Bombs:** JDAM, Small diameter bomb

## Chapter- 12

# Concorde

## Concorde

| | |
|---|---|
| **Role** | Supersonic airliner |
| **Manufacturer** | BAC (now BAE Systems)<br>Aérospatiale (now EADS) |
| **First flight** | 2 March 1969 |
| **Introduction** | 21 January 1976 |
| **Retired** | 26 November 2003 |
| **Status** | Retired from service |
| **Primary users** | British Airways<br>Air France<br>Braniff International Airways<br>Singapore Airlines |
| **Number built** | 20 (including 6 non-airline aircraft) |
| **Unit cost** | £23 million in 1977 |

The **Aérospatiale-BAC Concorde** was a turbojet-powered supersonic passenger airliner, a supersonic transport (SST). It was a product of an Anglo-French government treaty,

combining the manufacturing efforts of Aérospatiale and the British Aircraft Corporation. First flown in 1969, Concorde entered service in 1976 and continued commercial flights for 27 years.

Among other destinations, Concorde flew regular transatlantic flights from London Heathrow (British Airways) and Paris-Charles de Gaulle Airport (Air France) to New York JFK, profitably flying these routes at record speeds, in less than half the time of other airliners.

With only 20 aircraft built, their development represented a substantial economic loss, in addition to which Air France and British Airways were subsidised by their governments to buy them. As a result of the type's only crash on 25 July 2000 and other factors, its retirement flight was on 26 November 2003.

Concorde's name reflects the development agreement between the United Kingdom and France. In the UK, any or all of the type—unusual for an aircraft—are known simply as "Concorde". The aircraft is regarded by many as an aviation icon.

## *Development*

### Concept

Concorde's final flight, G-BOAF from Heathrow to Bristol, on 26 November 2003. The extremely high fineness ratio of the fuselage is evident.

Concorde on takeoff

Pre-production Concorde 101 on display at the Imperial War Museum Duxford, UK.


Concorde G-BOAB in storage at London Heathrow Airport following the end of all Concorde flying. This aircraft flew for 22,296 hours between its first flight in 1976 and its final flight in 2000.

In the late 1950s, the United Kingdom, France, United States, and Soviet Union were considering developing supersonic transport. The British Bristol Aeroplane Company and the French Sud Aviation were both working on designs, called the Type 223 and Super-Caravelle, respectively. Both were largely funded by their respective governments. The British design was for a thin-winged delta shape (which owed much to work by Dietrich Küchemann, then at the Royal Aircraft Establishment) for a transatlantic-ranged aircraft for about 100 people, while the French were intending to build a medium-range aircraft.

The designs were both ready to start prototype construction in the early 1960s, but the cost was so great that the British government made it a requirement that BAC look for international co-operation. Approaches were made to a number of countries, but only France showed real interest. The development project was negotiated as an international treaty between the two countries rather than a commercial agreement between companies and included a clause, originally asked for by the UK, imposing heavy penalties for cancellation. A draft treaty was signed on 28 November 1962. By this time, both companies had been merged into new ones; thus, the Concorde project was between the British Aircraft Corporation and Aérospatiale. At first the new consortium intended to produce one long range and one short range version. However, prospective customers showed no interest in the short-range version and it was dropped. The consortium secured orders (i.e., non-binding options) for over 100 of the long-range version from the major airlines of the day: Pan Am, BOAC and Air France were the launch customers, with six Concordes each. Other airlines in the order book included Panair do Brasil, Continental Airlines, Japan Airlines, Lufthansa, American Airlines, United Airlines, Air India, Air Canada, Braniff, Singapore Airlines, Iran Air, Olympic Airways, Qantas, CAAC, Middle East Airlines and TWA.

## Naming

Reflecting the treaty between the British and French governments which led to Concorde's construction, the name *Concorde* is from the French word *concorde*, which has an English cognate, *concord*. Both words mean *agreement*, *harmony* or *union*.

The aircraft was initially referred to in the UK as *Concorde*, with the French spelling, but was officially changed to *Concord* by Harold Macmillan in response to a perceived slight by Charles de Gaulle. In 1967, at the French roll-out in Toulouse the British Government Minister for Technology, Tony Benn announced that he would change the spelling back to *Concorde*. This created a nationalist uproar that died down when Benn stated that the suffixed ‹e› represented "Excellence, England, Europe and Entente (Cordiale)." In his memoirs, he recounts a tale of a letter from an irate Scotsman claiming: "[Y]ou talk about 'E' for England, but part of it is made in Scotland." Given Scotland’s contribution of providing the nose cone for the aircraft, Benn replied, "[I]t was also 'E' for 'Écosse' (the French name for Scotland) — and I might have added 'e' for extravagance and 'e' for escalation as well!"

Concorde also acquired an unusual nomenclature for an aircraft. In common usage in the United Kingdom, the type is known as *Concorde* (without an article) rather than ***the*** *Concorde* or ***a*** *Concorde*.

## Testing

Construction of two prototypes began in February 1965: 001, built by Aerospatiale at Toulouse, and 002, by BAC at Filton, Bristol. Concorde 001 made its first test flight from Toulouse on 2 March 1969, piloted by André Turcat, and first went supersonic on 1 October. The first UK-built Concorde flew from Filton to RAF Fairford on 9 April 1969, piloted by Brian Trubshaw. Both prototypes were presented to the public for the first time on 7–8 June 1969 at the Paris Airshow. As the flight programme progressed, 001 embarked on a sales and demonstration tour on 4 September 1971, which was also the first transatlantic crossing of Concorde. Concorde 002 followed suit on 2 June 1972 with a tour of the Middle and Far East. Concorde 002 made the first visit to the United States in 1973, landing at the new Dallas/Fort Worth Regional Airport to mark that airport's opening. These trips led to orders for over 70 aircraft, but a combination of factors led to order cancellations: the 1973 oil crisis, financial difficulties of airlines, a spectacular Paris Le Bourget air show crash of the competing Soviet Tupolev Tu-144, and environmental concerns such as the sonic boom, takeoff-noise and pollution. By 1976 four nations remained as prospective buyers: Britain, France, China, and Iran. In the end only Air France and British Airways (the successor to BOAC) took up their orders, with the two governments taking a cut of any profits made. In the case of BA, 80% of the profit was kept by the government until 1984, while the cost of buying the aircraft was covered by a state loan.

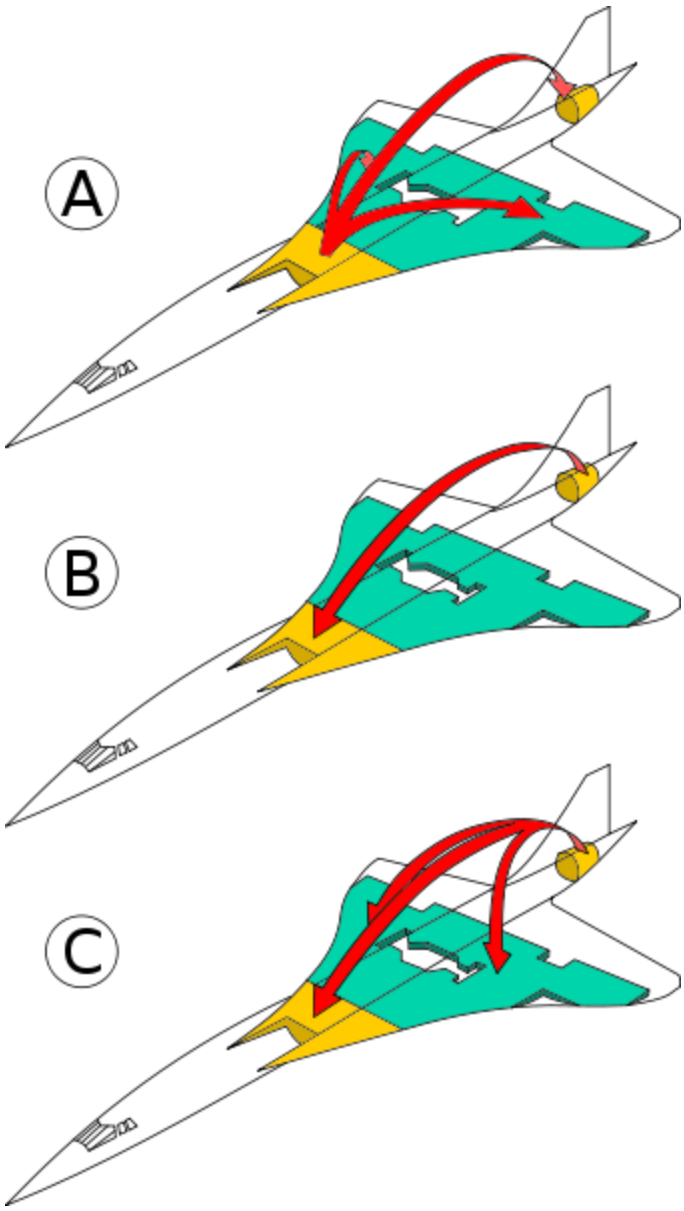
The United States cancelled the Boeing 2707, its supersonic transport programme, in 1971. Industry observers in France and the United Kingdom suggested that part of the American opposition to Concorde on grounds of noise pollution was orchestrated, or at least encouraged, by the United States Government, out of spite at not being able to propose a viable competitor, despite President John F. Kennedy's impassioned 1963 statement of commitment. Other countries, such as India and Malaysia, ruled out Concorde supersonic overflights stating noise concerns.

Demonstration and test flights were flown from 1974 onwards. The testing of Concorde set records that have not been surpassed; the prototype, pre-production and first production aircraft undertook 5,335 flight hours; 2,000 test hours were at supersonic speeds. During one such test flight, on 7th of November 1974, 001 performed the fastest civil flight across the North Atlantic, record still valid today. Unit costs were £23 million (US$46 million) in 1977, and development costs were six times the projected amount.

## *Design*

### General features

Concorde cockpit layout




Fuel pitch trim

Concorde is an ogival (also "ogee") delta-winged aircraft with four Olympus engines based on those originally developed for the Avro Vulcan strategic bomber. Concorde was the first airliner to have an (in this case, analogue) fly-by-wire flight-control system; the avionics of Concorde were unique because it was the first commercial aircraft to employ hybrid circuits. The principal designer for the project was Pierre Satre, with Sir Archibald Russell as his deputy.

Concorde pioneered the following technologies:

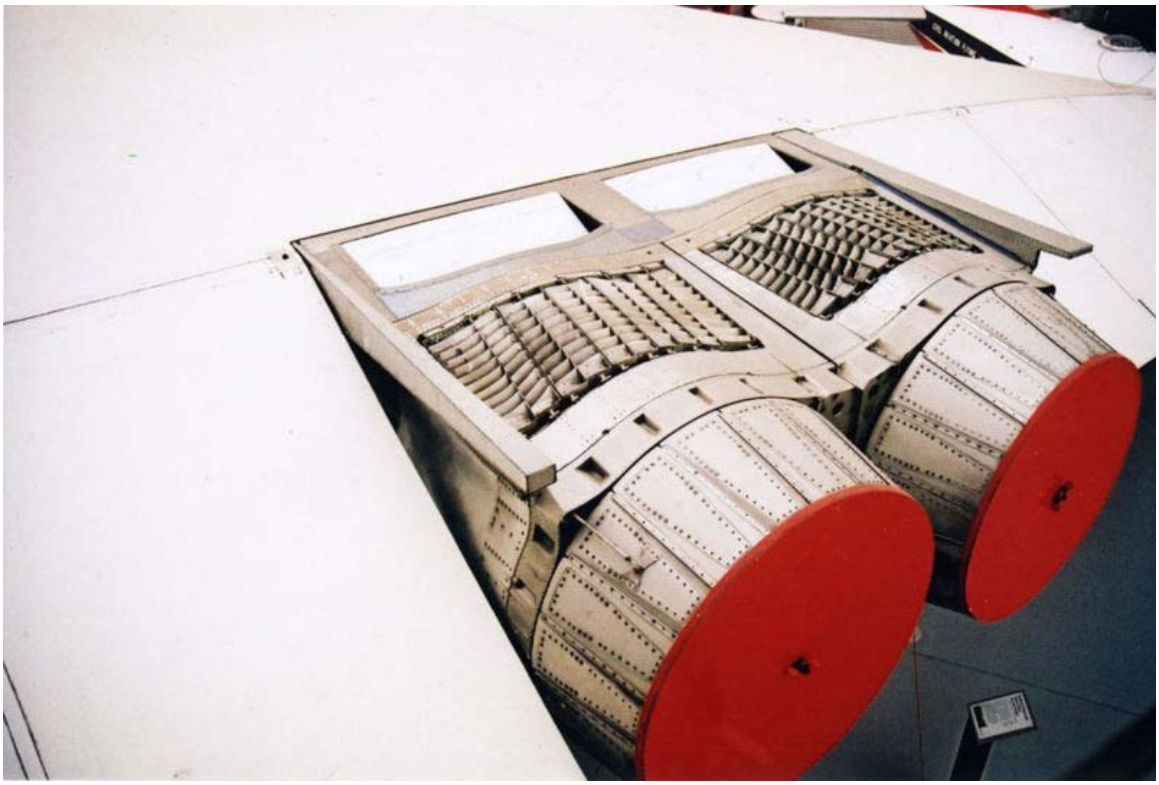
For high speed and optimisation of flight:

- Double-delta (ogee/ogival) shaped wings
- Variable engine air intake system controlled by digital computers
- Supercruise capability
- Thrust-by-wire engines, predecessor of today's FADEC-controlled engines
- Droop-nose section for better landing visibility

For weight-saving and enhanced performance:

- Mach 2.04 (~2,170 kilometres per hour / 1,350 mph) cruising speed for optimum fuel consumption (supersonic drag minimum although turbojet engines are more efficient at higher speed)
- Mainly aluminium construction for low weight and conventional manufacture (higher speeds would have ruled out aluminium)
- Full-regime autopilot and autothrottle allowing "hands off" control of the aircraft from climbout to landing
- Fully electrically controlled analogue fly-by-wire flight controls systems
- High-pressure hydraulic system of 28 MPa (4,000 lbf/in²) for lighter hydraulic components
- Complex Air Data Computer (ADC) for the automated monitoring and transmission of aerodynamic measurements (total pressure, static pressure, angle of attack, side-slip).
- Fully electrically controlled analogue brake-by-wire system
- Pitch trim by shifting fuel around the fuselage for centre-of-gravity control
- Parts made using "sculpture milling" from single alloy billet, reducing the part-number count while saving weight and adding strength
- Lack of an auxiliary power unit, as Concorde would only visit large airports where a ground air start cart would be available.

## Movement of centre of pressure

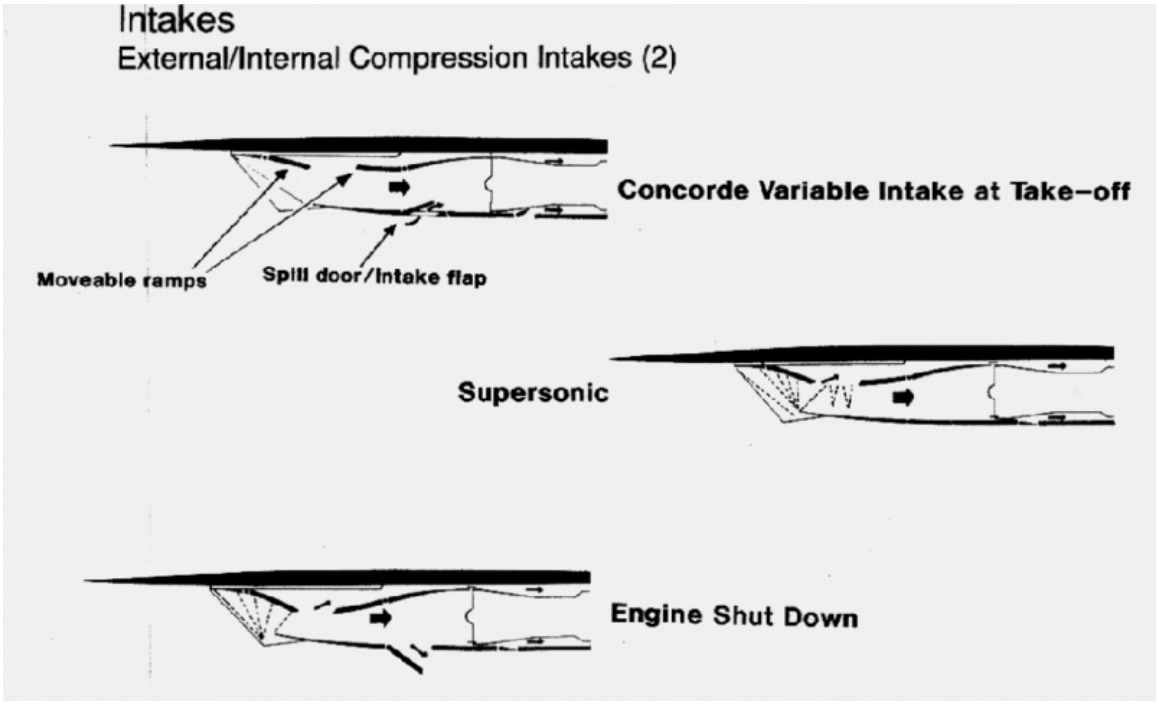


G-AXDN, Duxford, close up of pre-production engine nozzles. The nozzle/thrust reverser design was altered for the production Concordes.

When any aircraft passes the critical mach of that particular airframe, the centre of pressure shifts rearwards. This causes a pitch down force on the aircraft, as the centre of mass remains where it was. The engineers designed the wings in a specific manner to reduce this shift. However, there was still a shift of about 2 metres. This could have been countered by the use of trim controls, but at such high speeds this would have caused a dramatic increase in the drag on the aircraft. Instead, the distribution of fuel along the aircraft was shifted during acceleration and deceleration to move the centre of mass, effectively acting as an auxiliary trim control.

## Engines

To be economically viable, Concorde needed to be able to fly long distances, and this required high efficiency. For optimum supersonic flight, turbofan engines were considered, but rejected, due to their larger cross-section which would cause excessive drag. Turbojets were found to be the best choice of engines. The engine developed was the twin spool Rolls-Royce/Snecma Olympus 593, a development of the Bristol engine first used for the Avro Vulcan bomber, and developed into an afterburning supersonic variant for the BAC TSR-2 strike bomber.




Concorde's intake system schematics


Concorde's intake system

The intake design for Concorde's engines was critical. All conventional jet engines can take in air at only around Mach 0.5; therefore the air has to be slowed from the Mach 2.0 airspeed that enters the engine intake. In particular, Concorde needed to control the shock waves that this reduction in speed generates to avoid damage to the engines. This was done by a pair of intake ramps and an auxiliary spill door, whose position was moved during flight to slow the air down. The ramps were at the top of the engine compartment and moved down and the auxiliary spill door moved both up and down allowing air to flow in or out. The effectiveness of the intake system is such that, during supersonic flight, 63% of the aircraft's thrust is attributed to the intakes whilst the exhaust nozzles generate 29% and the engines just 8% of the thrust.

Engine failure causes problems on conventional subsonic aircraft; not only does the aircraft lose thrust on that side but the engine creates drag, causing the aircraft to yaw and bank in the direction of the failed engine. If this had happened to Concorde at supersonic speeds, it could theoretically cause a catastrophic failure of the airframe. However, during an engine failure, air intake needs are virtually zero, so in Concorde, the immediate effects of the engine failure were countered by the opening of the auxiliary spill door and the full extension of the ramps, which deflected the air downwards past the engine, gaining lift and streamlining the engine, minimising the drag effects of the failed engine. Although computer simulations predicted considerable difficulties, in practice Concorde was able to shut down both engines on the same side of the aircraft at Mach 2 without any of the predicted control problems. Concorde pilots were routinely trained in simulators to deal with a double engine failure.

The aircraft used reheat (afterburners) at takeoff and to pass through the transonic regime (i.e., "go supersonic") between Mach 0.95 and Mach 1.7, and were switched off at all other times. Due to jet engines being highly inefficient at low speeds, Concorde burned two tonnes of fuel (almost 2% of the maximum fuel load) taxiing to the runway. To conserve fuel only the two outer engines were run after landing. The thrust from two engines was sufficient for taxiing to the ramp due to low aircraft weight upon landing at its destination.

## Heating issues

Beside engines, the hottest part of the structure of any supersonic aircraft is the nose. The engineers wanted to use duralumin, an aluminium alloy, throughout the aircraft due to its familiarity, cost and ease of construction. The highest temperature that aluminium could sustain over the life of the aircraft was 127 °C, which limited the top speed to Mach 2.02.

Concorde went through two cycles of heating and cooling during a flight, first cooling down as it gained altitude, then heating up after going supersonic. The reverse happened when descending and slowing down. This had to be factored into the metallurgical modelling. A test rig was built that repeatedly heated up a full-size section of the wing, and then cooled it, and periodically samples of metal were taken for testing.

Owing to the heat generated by compression of air as Concorde travelled supersonically, the fuselage would extend by as much as 300 mm (almost 1 ft), the most obvious manifestation of this being a gap that opened up on the flight deck between the flight engineer's console and the bulkhead. On all Concordes that had a supersonic retirement flight, the flight engineers placed their hats in this gap before it cooled, where the hats remain to this day.

To keep the cabin cool, Concorde used the fuel as a heat sink for the heat from the air conditioning, the same method also cooled the hydraulics. During supersonic flight the surfaces forward from the cockpit became heated, a visor was used to deflect much of this heat from directly reaching the cockpit.

Concorde also had restrictions on livery; the majority of the surface had to be painted with a highly reflective white paint to avoid overheating the aluminium structure due to heating effects from supersonic flight at Mach 2. In 1996, however, Air France briefly painted F-BTSD in a predominantly blue livery (with the exception of the wings) as part of a promotional deal with Pepsi Cola. In this paint scheme, Air France were advised to remain at Mach 2 for no more than 20 minutes at a time, but there was no restriction at speeds under Mach 1.7. F-BTSD was chosen for the promotion because the aircraft was not then scheduled to operate any long flights that required extended Mach 2 operations.

## Structural issues

Due to the high speeds at which Concorde travelled, large forces were applied to the aircraft's structure during banks and turns. This caused twisting and the distortion of the aircraft's structure. In addition there were concerns over maintaining precise control at supersonic speeds; both of these issues were resolved by active ratio changes between the inboard and outboard elevons, varying at differing speeds including supersonic. Only the innermost elevons, which are attached to the stiffest area of the wings, are active at high speed.

Additionally, the narrow fuselage meant that the aircraft flexed. This was visible from the rear passengers' viewpoints.

## Brakes and undercarriage


Concorde tyres and brakes

Tail bumper of Concorde G-BOAG at the Museum of Flight in Seattle

Due to a high average takeoff speed of 250 miles per hour (400 km/h), Concorde needed upgraded brakes. Like most airliners, Concorde has anti-skid braking – a system which prevents the tyres from losing traction when the brakes are applied for greater control during roll-out. The brakes, developed by Dunlop, were the first carbon-based brakes used on an airliner. They could bring Concorde to a stop from an aborted takeoff within one mile (1600 m) when weighing up to 185 tons (188 tonnes) and travelling at 190 miles per hour (310 km/h). This braking manoeuvre brought the brakes to temperatures of 300–500 °C, requiring several hours for cooling.

Another issue uncovered during development was the undercarriage. Because of the way Concorde's delta-wing generated lift, the undercarriage had to be unusually strong. At rotation, Concorde would rise to a high angle of attack, about 18 degrees. Prior to rotation the wing generated almost no lift, unlike typical aircraft wings. Combined with the high airspeed at rotation (199 KIAS), this unexpectedly increased the stresses on the rear undercarriage and during the development required a major redesign. Due to the high alpha needed at rotation, a small set of wheels were added aft to prevent tailstrikes. The rear main undercarriage units swing towards each other to be stowed but due to their great height also need to retract telescopically before swinging in order to clear each other when stowed.

## Range

Concorde needed to travel between London and New York, or Washington, non-stop, and to achieve this the designers gave Concorde the greatest supersonic range of any aircraft. This was achieved by a combination of careful development of the engines to make them highly efficient at supersonic speeds (actually the world's most energy-efficient jet engine), by using a slender fuselage of high fineness ratio, and very careful design of the wing shape to give a good lift to drag ratio, by having a modest payload and high fuel capacity, and by moving the fuel to trim the aircraft without introducing any additional drag.

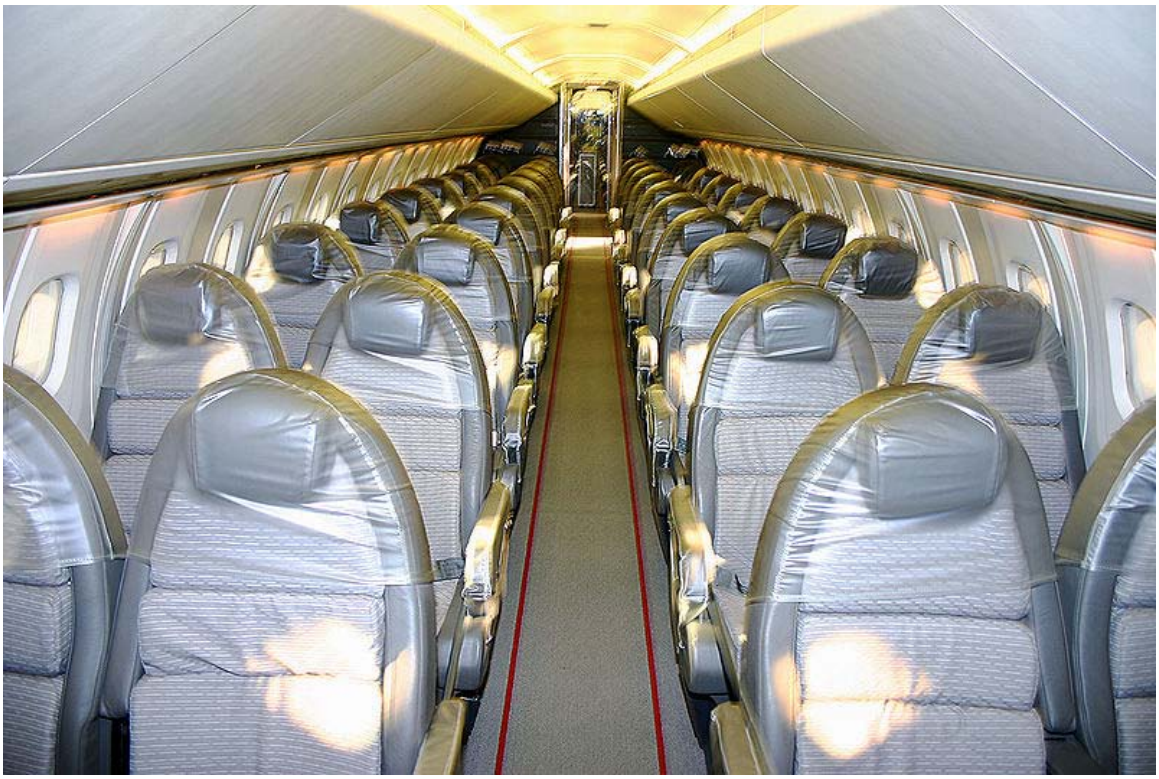
Nevertheless, soon after Concorde began flying, a Concorde "B" model was designed with slightly larger fuel capacity and slightly larger wings with leading edge slats to improve aerodynamic performance at all speeds. It featured more powerful engines with sound deadening and without the fuel-hungry and noisy reheat. It was speculated that it was reasonably possible to create an engine with up to 25% gain in efficiency over the Rolls-Royce/Snecma Olympus 593. This would have given 500 mi (805 km) additional range even with greater payload, and would have made new commercial routes possible. This was cancelled due in part to poor sales of Concorde, but also to the rising cost of aviation fuel in the 1970s.

## Increased radiation exposure

Concorde fuselage

The high altitude at which Concorde cruised meant passengers received almost twice the flux of extraterrestrial ionising radiation as those travelling on a conventional long-haul flight. Upon Concorde's introduction, it was speculated that this exposure during supersonic travels would increase the likelihood of skin cancer. However, due to the proportionally reduced flight time, the overall equivalent dose would normally be *less* than a conventional flight over the same distance. Unusual solar activity might lead to an increase in incident radiation. To prevent incidents of excessive radiation exposure the flight deck had a radiometer and an instrument to measure the rate of decrease of radiation. If the radiation level became too high, Concorde would descend below 47,000 feet (14,000 m).

## Cabin pressurisation



British Airways Concorde interior before 2000. The narrow fuselage needed for efficient supersonic flight permitted only 4 seats across the aircraft, and gave limited headroom and locker space.

Airliner cabins were usually maintained at a pressure equivalent to 6,000–8,000 feet (1,800–2,400 m) elevation. Concorde's pressurisation was set to an altitude at the lower end of this range, 6,000 feet (1,800 m). Concorde's maximum cruising altitude was 60,000 feet (18,000 m); subsonic airliners typically cruise below 40,000 feet (12,000 m). Above 50,000 feet (15,000 m), the lack of air pressure would give a "time of useful consciousness" in even a conditioned athlete of no more than 10–15 seconds. A sudden reduction in cabin pressure is hazardous to all passengers and crew. At Concorde's altitude, the air density is very low; a breach of cabin integrity would result in a loss of

pressure severe enough so that the plastic emergency oxygen masks installed on other passenger jets would not be effective, and passengers would quickly suffer from hypoxia despite quickly donning them. Concorde, therefore, was equipped with smaller windows to reduce the rate of loss in the event of a breach, a reserve air supply system to augment cabin air pressure, and a rapid descent procedure to bring the aircraft to a safe altitude. The FAA enforces minimum emergency descent rates for aircraft and made note of Concorde's higher operating altitude, concluding that the best response to a loss of pressure would be a rapid descent. Pilots had access to Continuous Positive Airway Pressure (CPAP) which used masks that forced oxygen at higher pressure into the crew's lungs.

## Droop nose

Concorde with droop nose in fully down position during rollout after landing.

Concorde's drooping nose was a compromise between the need for a streamlined design to reduce drag and increase aerodynamic efficiency in flight and the need for the pilot to see properly during taxi, takeoff, and landing operations. A delta-wing aircraft takes off and lands with a high angle of attack (a high nose angle) compared to other wing planforms, due to the way the delta wing generates lift. The pointed nose would obstruct the pilots' view of taxiways and runways, so Concorde's nose was designed to allow for different positioning for different operations. The droop nose was accompanied by a moving visor that was retracted into the nose prior to the nose being lowered. When the nose was raised back to horizontal, the visor was raised ahead of the front cockpit windscreen for aerodynamic streamlining in flight.

A controller in the cockpit allowed the visor to be retracted and the nose to be lowered to 5° below the standard horizontal position for taxiing and takeoff. Following takeoff and after clearing the airport, the nose and visor were raised. Shortly before landing, the visor was again retracted and the nose lowered to 12.5° below horizontal for maximum visibility. Upon landing, the nose was raised to the five-degree position to avoid the possibility of damage. On rare occasions, the aircraft could take off with the nose fully down.

A final position had the visor retracted into the nose but the nose in the standard horizontal position. This setup was used for cleaning the windscreen and for short subsonic flights. The two prototype Concordes had two fixed "glass holes" on their retractable visors. The US Federal Aviation Administration objected to that restrictive visibility and demanded a different design before it would permit Concorde to serve US airports, which led to the redesigned visor used on the production aircraft and the four "pre-production" aircraft (101, 102, 201, and 202).

## Flight characteristics

Concorde performing a low-level flypast at an air show

While commercial jets take eight hours to fly from New York to Paris, the average supersonic flight time on the transatlantic routes was just under 3.5 hours. Concorde had a maximum cruise altitude of 18,300 metres (60,039 ft) and an average cruise speed of

Mach 2.02, about 1155 knots (2140 km/h or 1334 mph), more than twice the speed of conventional aircraft.

With no other civil traffic operating at its cruising altitude of about 56,000 ft (17,000 m), dedicated oceanic airways or "tracks" were used by Concorde to cross the Atlantic. Due to the nature of high altitude winds, these SST tracks were fixed in terms of their co-ordinates, unlike the North Atlantic Tracks at lower altitudes whose co-ordinates alter daily according to forecast weather patterns. Concorde would also be cleared in a 15,000-foot (4,600 m) block, allowing for a slow climb from 45,000 to 60,000 ft (18,000 m) during the oceanic crossing as the fuel load gradually decreased. In regular service, Concorde employed an efficient *cruise-climb* flight profile following take-off.

During a landing approach Concorde was on the "back side" of the drag force curve, where raising the nose would increase the sink rate. The delta-shaped wings allowed Concorde to attain a higher angle of attack than conventional aircraft, as it allowed the formation of large low pressure vortices over the entire upper wing surface, maintaining lift. The normal landing speed was 170 miles per hour (274 km/h).

BA flights flown by Concorde added "*Concorde*" in addition to the standard "*Speedbird*" callsign to notify air traffic control of the aircraft's unique abilities and restrictions.

## *Operational history*

### Scheduled flights

Scheduled flights began on 21 January 1976 on the London–Bahrain and Paris–Rio (via Dakar) routes. The Paris-Caracas route (via Azores) began on 10 April of the same year. The US Congress had just banned Concorde landings in the US, mainly due to citizen protest over sonic booms, preventing launch on the coveted transatlantic routes. However, the US Secretary of Transportation, William Coleman, gave permission for Concorde service to Washington Dulles International Airport, and Air France and British Airways simultaneously began service to Dulles on 24 May 1976.


Concorde in 1977

When the US ban on JFK Concorde operations was lifted in February 1977, New York banned Concorde locally. The ban came to an end on 17 October 1977 when the Supreme Court of the United States declined to overturn a lower court's ruling rejecting efforts by the Port Authority and a grass-roots campaign led by Carol Berman to continue the ban. In spite of complaints about noise, the noise report noted that Air Force One, at the time a Boeing VC-137, was louder than Concorde at subsonic speeds and during takeoff and landing. Scheduled service from Paris and London to New York's John F. Kennedy Airport began on 22 November 1977.

In 1977, British Airways and Singapore Airlines shared a Concorde for flights between London and Singapore International Airport via Bahrain. The aircraft, BA's Concorde G-BOAD, was painted in Singapore Airlines livery on the port side and British Airways livery on the starboard side. The service was discontinued after three return flights because of noise complaints from the Malaysian government; it could only be reinstated on a new route bypassing Malaysian airspace in 1979. A dispute with India prevented Concorde from reaching supersonic speeds in Indian airspace, so the route was eventually declared not viable and discontinued in 1980.

During the Mexican oil boom, Air France flew Concorde twice weekly to Mexico City's Benito Juárez International Airport via Washington, DC, or New York City, from September 1978 to November 1982. The worldwide economic crisis during that period resulted in this route's cancellation; the last flights were almost empty. The routing between Washington or New York and Mexico City included a deceleration, from Mach

2.02 to Mach 0.95, to cross Florida subsonically and avoid unlawfully creating a sonic boom over the state; Concorde then re-accelerated back to its original speed to cross the Gulf of Mexico. On 1 April 1989, on an around-the-world luxury tour charter, British Airways implemented a new version of this routing that allowed G-BOAF to maintain Mach 2.02 by passing around Florida to the east and south. From time to time, Concorde came back to the region on similar chartered flights to Mexico City and Acapulco.

From 1978 to 1980, Braniff International Airways leased 10 Concordes, five each from Air France and British Airways. These were used on subsonic flights between Dallas-Fort Worth and Washington Dulles International Airport, flown by Braniff flight crews. Air France and British Airways crews then took over for the continuing supersonic flights to London and Paris. The aircraft were registered in both the United States and their home countries; the European registration was covered for the hours it was being operated by Braniff, retaining the full AF/BA liveries. The flights were not profitable and were usually less than 50% booked, forcing Braniff to end its tenure as the only US Concorde operator in May 1980.

## BA buys its Concordes outright

By around 1981 in the UK, the future for Concorde looked bleak. The British government had lost money operating Concorde every year, and moves were afoot to cancel the service entirely. A cost projection came back with greatly reduced metallurgical testing costs because the test rig for the wings had built up enough data to last for 30 years and could be shut down. Despite this, the government was not keen to continue. In late 1983, the managing director of BA, Sir John King, convinced the government to sell the aircraft outright to (the then state owned, later privatised) BA for £16.5 million plus the first year's profits.


An Air France Concorde at John F. Kennedy International Airport in 1987

Sir John King realised that he had a premier product that was underpriced, and after carrying out a market survey, British Airways discovered that their target customers thought that Concorde was more expensive than it actually was. They progressively raised prices and service quality to match these perceptions. It is reported that British Airways then ran Concorde at a profit, unlike their French counterpart. British Airways's profits have been reported to be up to £50 million in the most profitable years, with a total revenue of £1.75 billion, before costs of £1 billion.

Between 1984 and 1991, British Airways flew a thrice-weekly Concorde service between London and Miami, stopping at Washington's Dulles International Airport. Until 2003, Air France and British Airways continued to operate the New York services daily. Concorde also visited Barbados's Grantley Adams International Airport during the winter holiday season. Until the Air France Paris crash ended virtually all charter services by both AF and BA, several UK and French tour operators operated charter flights to European destinations on a regular basis; the charter business was viewed as lucrative by British Airways and Air France.

## Concorde Flight 4590 crash

On 25 July 2000, Air France Flight 4590, registration F-BTSC, crashed in Gonesse, France, killing all 100 passengers and nine crew members on board the flight, and four people on the ground. It was the only fatal incident involving Concorde.

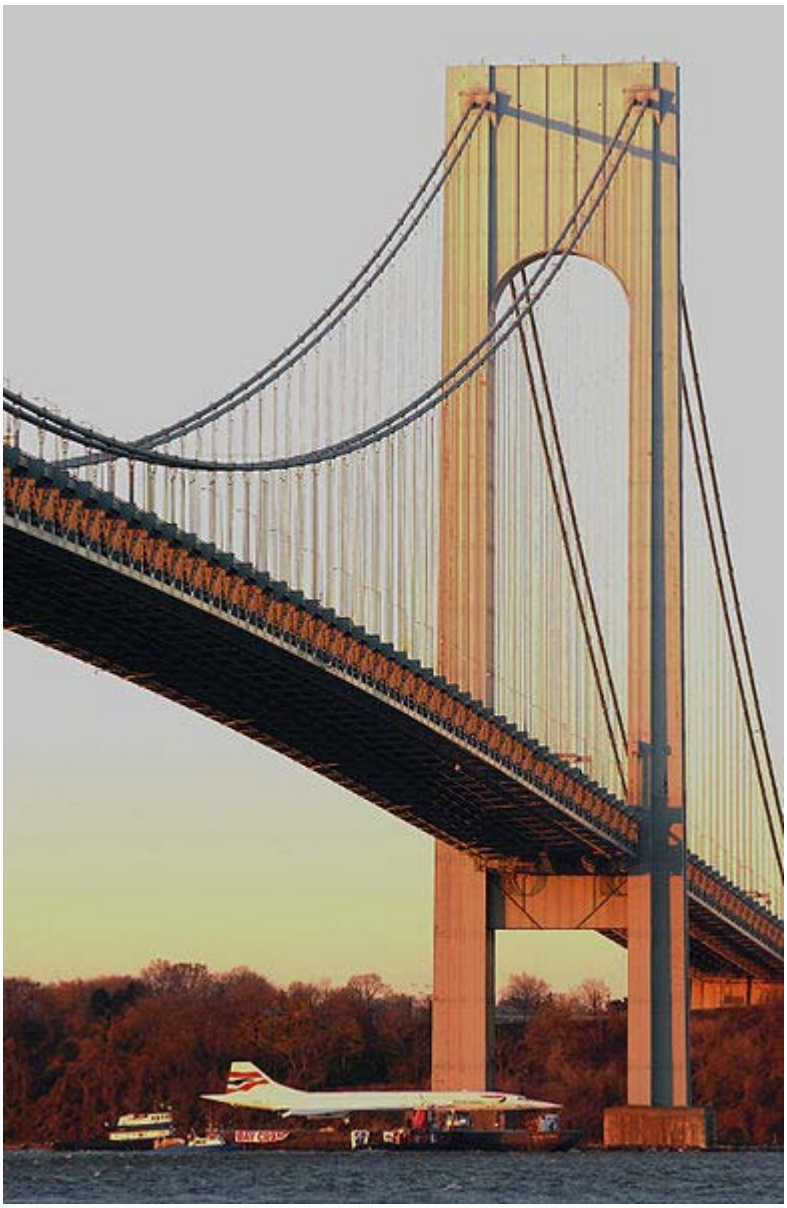
According to the official investigation conducted by the French accident investigation bureau (BEA), the crash was caused by a titanium strip that fell from a Continental Airlines DC-10 that had taken off minutes earlier. This metal fragment punctured a tyre on the Concorde's left main wheel bogie during takeoff. The tyre exploded, a piece of rubber hit the fuel tank, and while the fuel tank was not punctured, the impact caused a shock-wave which caused one of the fuel valves in the wing to burst open. This caused a major fuel leak from the tank, which then ignited due to sparking electrical landing gear wiring severed by another piece of the same tyre. The crew shut down engine number 2 in response to a fire warning, and with engine number 1 surging and producing little power, the aircraft was unable to gain height or speed. The aircraft entered a rapid pitch-up then a violent descent, rolling left and crashing tail-low into the Hotelissimo Hotel in Gonesse. On 6 December 2010, Continental Airlines and John Taylor, one of their mechanics, were found guilty of involuntary manslaughter.

Prior to the accident, Concorde had been arguably the safest operational passenger airliner in the world in terms of passenger deaths-per-kilometres travelled with zero, but with a history of tyre explosions 60 times higher than subsonic jets. Safety improvements were made in the wake of the crash, including more secure electrical controls, Kevlar lining to the fuel tanks and specially developed burst-resistant tyres.

The first flight after the modifications departed from London Heathrow on 17 July 2001, piloted by BA Chief Concorde Pilot Mike Bannister. During the 3-hour 20-minute flight over the mid-Atlantic towards Iceland, Bannister attained Mach 2.02 and 60,000 ft (18,000 m) before returning to RAF Brize Norton. The test flight, intended to resemble the London–New York route, was declared a success and was watched on live TV, and by crowds on the ground at both locations. Another BA assessment flight carrying passengers took place on 11 September 2001, and landed just before the 11 September 2001 attacks in the United States. This was not a revenue flight, as all the passengers were BA employees.

Normal commercial operations resumed on 7 November 2001 by BA and AF (aircraft G-BOAE and F-BTSD), with service to New York JFK, where passengers were welcomed by the mayor Rudy Giuliani.

## Retirement



Concorde G-BOAD on a barge beneath the Verrazano Narrows Bridge in New York City in November 2003, bound for the Intrepid Sea-Air-Space Museum

On 10 April 2003, Air France and British Airways simultaneously announced that they would retire Concorde later that year. They cited low passenger numbers following 25 July 2000 crash, economic effects and the slump in air travel following 11 September 2001, and rising maintenance costs. Although Concorde was a technological marvel when introduced into service in the 1970s, 30 years later its cockpit, cluttered with analogue controls and dials, looked dated, as there had been little commercial pressure or reason to upgrade Concorde due to a lack of competing aircraft, unlike other airliners of the same vintage, for example the Boeing 747. By its retirement, it was the last aircraft in

British Airways' fleet that still had a flight engineer; other aircraft, such as the modernised 747-400, had eliminated that role.

On the same day, Sir Richard Branson offered to buy British Airways' Concorde fleet at their "original price of £1" for service with his Virgin Atlantic Airways. Branson claimed this to be the same token price that British Airways had paid the British Government, but BA denied this and refused the offer. The real cost of buying the aircraft was £26 million each but the money for buying the aircraft was lent by the government (which in turn took 80% of the profits). Subsequently BA bought two aircraft for a book value of £1 as part of the £16.5 million buy out in 1983. Branson wrote in *The Economist* (23 October 2003) that his final offer was "over £5 million" and that he had intended to operate the fleet "for many years to come". Any hope of Concorde remaining in service was further thwarted by Airbus's unwillingness to provide maintenance support for the aging airframes.

It has been suggested that Concorde was not withdrawn for the reasons usually given, but that it became apparent during the grounding of Concorde to the airlines that they could make more revenue carrying first class passengers subsonically. Rob Lewis suggested that the Air France retirement of its Concorde fleet was the result of a conspiracy between Air France Chairman Jean-Cyril Spinetta and Airbus CEO Noel Forgeard, and stemmed as much from a fear of being found criminally liable under French law for future AF Concorde accidents as from simple economics. On the British Airways side, a lack of commitment to Concorde by then-Director of Engineering Alan MacDonald was cited as undermining BA's resolve to continue operating Concorde from within.

## Air France

Air France made its final commercial Concorde landing in the United States in New York City from Paris on 30 May 2003. During the following week, on 2 June and 3 June 2003, F-BTSD flew a final round-trip from Paris to New York and back for airline staff and long-time employees in the airline's Concorde operations. Air France's final Concorde flight took place on 27 June 2003 when F-BVFC retired to Toulouse.


Air France Concorde at Paris-Charles de Gaulle Airport

An auction of Concorde parts and memorabilia for Air France was held at Christie's in Paris on 15 November 2003; thirteen hundred people attended, and several lots exceeded their predicted values.

French Concorde F-BVFC was retired to Toulouse and kept functional after the end of service, including engine runs, for a short while, in case taxi runs were required in support of the French judicial enquiry into the 2000 crash. The aircraft is now fully retired and no longer functional.

French Concorde F-BTSD has been retired to the "Musée de l'Air et de l'Espace" at Le Bourget (near Paris) and, unlike the other museum Concordes, a few of the systems are being kept functional, so that, for instance, the famous "droop nose" can still be lowered and raised. This led to rumours that they could be prepared for future flights for special occasions.

French Concorde F-BVFB currently rests at the Auto & Technik Museum Sinsheim at Sinsheim, Germany, after its last flight from Paris to Baden-Baden, followed by a spectacular transport to Sinsheim via barge and road. The museum also has a Tu-144 on display – this is the only place where both supersonic airliners can be seen together.

## British Airways


British Airways Concorde in the initial BA livery at Heathrow Airport

British Airways conducted a North American farewell tour in October 2003. G-BOAG visited Toronto Pearson International Airport on 1 October 2003, after which it flew to New York's John F. Kennedy International Airport as part of the tour. G-BOAD visited Boston's Logan International Airport on 8 October 2003, and G-BOAG visited Washington Dulles International Airport on 14 October 2003. Misleading claims were made that G-BOAD's flight to Boston set a record for the fastest transatlantic flight from east to west, making the trip from London Heathrow in 3 hours, 5 minutes, 34 seconds. However the fastest transatlantic flight was from London Heathrow to New York JFK airport on 7 February 1996 which took 2 hours, 52 minutes, 59 seconds from takeoff to touchdown. This flight was also made by G-BOAD.

In a week of farewell flights around the United Kingdom, Concorde visited Birmingham on 20 October, Belfast on 21 October, Manchester on 22 October, Cardiff on 23 October and Edinburgh on 24 October. Each day the aircraft made a return flight out and back into Heathrow to the cities, often overflying them at low altitude.


Concorde G-BOAC at the Manchester International Airport Aviation Viewing Park (meanwhile a hall has been constructed to accommodate it)

Mike Bannister (left) in the cockpit of BA002

On 22 October, Heathrow ATC arranged for the inbound flight BA9021C, a special from Manchester, and BA002 from New York to land simultaneously on the left and right runways respectively. On the evening of 23 October 2003, the Queen consented to the illumination of Windsor Castle as Concorde's last west-bound commercial flight departed London overhead, an honour normally reserved for major state events and visiting dignitaries.

British Airways retired its Concorde fleet on 24 October. G-BOAG left New York to a fanfare similar to that given for Air France's F-BTSD, while two more made round trips,

G-BOAF over the Bay of Biscay, carrying VIP guests including former Concorde pilots, and G-BOAE to Edinburgh. The three aircraft then circled over London, having received special permission to fly at low altitude, before landing in sequence at Heathrow. All three aircraft spent 45 minutes taxiing around the airport before disembarking the last supersonic fare-paying passengers. The captain of the New York to London flight was Mike Bannister. G-BOAE (212) took its retirement flight on 17 November 2003 from Heathrow to Grantley Adams International Airport on Barbados, where the plane can still be seen daily.

All of BA's Concorde fleet have been grounded,drained of hydraulic fluid and their airworthiness certificates withdrawn . Jock Lowe, ex-chief Concorde pilot and manager of the fleet estimated in 2004 that it would cost £10–15 million to make G-BOAF airworthy again. BA maintain ownership and have stated that they will not fly again as Airbus ended support of the aircraft in 2003.

On 1 December 2003, Bonhams held an auction of British Airways' Concorde artefacts, including a nose cone, at Kensington Olympia in London. Proceeds of around £750,000 were raised, with the majority going to charity. In March 2007, BA announced they would not renew their contract for the prime advertising spot at the entrance to Heathrow Airport where, since 1990, a 40% scale model of Concorde was located. The Concorde model was removed and placed on display at the Brooklands Museum.

### Restoration

Although only used for spares after being retired from test flying and trials work in 1981, Concorde G-BBDG was dismantled and transported by road from Filton then restored from essentially a shell at the Brooklands Museum in Surrey.

One of the youngest Concordes (F-BTSD) is on display at Le Bourget Air and Space Museum in Paris. In February 2010, it was announced that the museum and a group of volunteer Air France technicians intend to restore F-BTSD so it can taxi under its own power. On 29 May 2010, it was reported that a group comprising the British Save Concorde Group and the French Olympus 593 had begun work on inspecting the engines of a Concorde at Le Bourget Air and Space Museum, with the intent to restore the plane to be able to fly again in demonstrations and air shows. Flying in the opening ceremony for the 2012 London Olympics is also a goal.

## *Impact*

### Environmental

Prior to Concorde's flight trials, the developments made by the civil aviation industry were largely accepted by governments and their respective electorates. The opposition to Concorde's noise, particularly on the eastern coast of the United States, forged a new political agenda on both sides of the Atlantic, with scientists and technology experts across a multitude of industries beginning to take the environmental and social impact

more seriously. Although Concorde led directly to the introduction of a general noise abatement programme for aircraft flying out of John F. Kennedy Airport, many found that Concorde was quieter than expected, partly due to the pilots temporarily throttling back their engines (known as "noise abatement" - spoken by the pilots as the command "Noise" during take off) to reduce noise during overflight of residential areas. Even before the launch of revenue earning services, it had been noted that Concorde was quieter than several aircraft already commonly in service at that time.

***Concorde* fuel efficiency comparison**

| Aircraft | Concorde | Gulfstream G550 business jet | Boeing 747-400 |
|---|---|---|---|
| passenger miles/imperial gallon | 17 | 19 | 109 |
| passenger miles/US gallon | 14 | 16 | 91 |
| litres/passenger 100 km | 16.6 | 14.8 | 2.6 |

Concorde produced nitrogen oxides in its exhaust, which, despite complicated chemical interactions with other ozone-depleting chemicals, are understood to produce a net degradation to the ozone layer at the stratospheric altitudes it cruised. It has been pointed out that other, lower-flying, airliners produce ozone during their flights in the troposphere, but vertical transit of gases between the two is highly restricted. The small fleet size meant that any net ozone-layer degradation caused by Concorde was for all practical purposes negligible.

Concorde's technical leap forward boosted the public's understanding of conflicts between technology and the environment as well as the awareness of the complex decision analysis processes that surround such conflicts. In France, the use of acoustic fencing alongside TGV tracks might not have been achieved without the 1970s controversy over aircraft noise. In the UK, the CPRE have issued tranquillity maps since 1990.

## Public perception

Parade flight at Queen's Golden Jubilee

Concorde was normally perceived as a privilege of the rich, but special circular or one-way (with return by other flight or ship) charter flights were arranged to bring a trip within the means of moderately well-off enthusiasts. It is a symbol of great national pride to many in the UK and France; in France it was thought of as a French aircraft, in the UK as British.

The aircraft was usually referred to by the British as simply "Concorde", whilst in France it was known as "le Concorde" due to "le", the definite article, being used in French grammar to introduce the name of a ship or aircraft, and the capital being used to distinguish a proper name from a common noun of the same spelling. In French, the common noun *concorde* means "agreement, harmony, or peace", Concorde's pilots and British Airways in official publications and videos often refer to Concorde both in the singular and plural as "she" or "her".


HM The Queen and HRH The Duke of Edinburgh disembark Concorde

As a symbol of national pride, an example from the BA fleet made occasional flypasts at selected Royal events, major air shows and other special occasions, sometimes in formation with the Red Arrows. On the final day of commercial service, public interest was so great that grandstands were erected at London's Heathrow Airport to afford a view of the final arrivals. Crowds filled the boundary road around the airport and there was extensive media coverage.

Thirty-seven years after her first test flight, Concorde was announced the winner of the Great British Design Quest organised by the BBC and the Design Museum. A total of 212,000 votes were cast with Concorde beating design icons such as the Mini, mini skirt, Jaguar E-type, Tube map and the Supermarine Spitfire.

## Records

The fastest transatlantic airliner flight was from London Heathrow to New York JFK on 7 February 1996 by British Airways' G-BOAD in 2 hours, 52 minutes, 59 seconds from takeoff to touchdown. Concorde also set other records, including the official FAI "Westbound Around the World" and "Eastbound Around the World" world air speed records. On 12–13 October 1992, in commemoration of the 500th anniversary of Columbus' first New World landing, Concorde Spirit Tours (USA) chartered Air France Concorde F-BTSD and circumnavigated the world in 32 hours 49 minutes and 3 seconds, from Lisbon, Portugal, including six refuelling stops at Santo Domingo, Acapulco, Honolulu, Guam, Bangkok, and Bahrain.

The eastbound record was set by the same Air France Concorde (F-BTSD) under charter to Concorde Spirit Tours in the USA on 15–16 August 1995. This promotional flight circumnavigated the world from New York/JFK International Airport in 31 hours 27 minutes 49 seconds, including six refuelling stops at Toulouse, Dubai, Bangkok, Andersen AFB in Guam, Honolulu, and Acapulco. By its 30th flight anniversary on 2 March 1999 Concorde had clocked up 920,000 flight hours, with more than 600,000 supersonic, much more than all of the other supersonic aircraft in the Western world combined.

## Comparison with other supersonic aircraft

Tu-144 as a research aircraft for NASA in 1997

The only other supersonic airliner in direct competition with Concorde was the Soviet Tupolev Tu-144, which was nicknamed "Concordski" by Western Europeans for its outward similarity to Concorde. Soviet espionage efforts had resulted in the theft of Concorde blueprints, ostensibly to assist in the design of the Tu-144. As a result of a rushed development programme, the first prototype of the Tu-144 was substantially different from the preproduction machines, but both were cruder and less refined than Concorde. The Tu-144*S* had a significantly shorter range than Concorde, due to its low-bypass turbofan engines. The vehicle had poor control at low speeds because of a simpler

supersonic wing design; in addition the Tu-144 required parachutes to land while Concorde had sophisticated anti-lock brakes. The Tu-144 had two crashes, one at the 1973 Paris Air Show, and another during a pre-delivery test flight in the summer of 1978. Later production versions had retractable canards for better low-speed control, and a 126-seat research version used turbojet engines that gave them nearly the fuel efficiency and similar range to Concorde. With a top speed of Mach 2.35 it was potentially a more competitive aircraft – but was quickly taken out of service due to severe safety defects.

The American designs, the Boeing 2707 and the Lockheed L-2000 were to have been larger, with seating for up to 300 people. Running a few years behind Concorde, the winning Boeing 2707 was redesigned to a cropped delta layout; the extra cost of these changes helped to kill the project. The operation of US military aircraft such as the XB-70 Valkyrie and B-58 Hustler had shown that sonic booms were quite capable of reaching the ground, and the experience from the Oklahoma City sonic boom tests led to the same environmental concerns that hindered the commercial success of Concorde. The American government cancelled the project in 1971, after having spent more than $1 billion.

The only other large supersonic aircraft comparable to Concorde are strategic bombers, principally the Russian Tupolev Tu-22/Tu-22M and Tu-160 and the American B-1B Lancer.

## Replacements in development

The desire for a second-generation supersonic aircraft has remained within some elements of the aviation industry, and several concepts emerged quickly following the retirement of Concorde.

In November 2003, EADS—the parent company of the Airbus aircraft manufacturing company—announced that it was considering working with Japanese companies to develop a larger, faster replacement for Concorde. In October 2005, JAXA, the Japan Aerospace eXploration Agency, undertook aerodynamic testing of a scale model of an airliner designed to carry 300 passengers at Mach 2 (working name *NEXST*). If pursued to commercial deployment, it would be expected to be in service around 2020–2025.

The British company Reaction Engines Limited, with 50% EU money, has been engaged in a research programme called *LAPCAT*, which examined a design for a hydrogen-fuelled plane carrying 300 passengers called the *A2*, potentially capable of flying at Mach 5+ non-stop from Brussels to Sydney in 4.6 hours. The follow-on research effort, *LAPCAT II* began in 2008 and is to last four years.

In May 2008, it was reported that Aerion Corporation had $3 billion of pre-order sales on its Aerion SBJ supersonic business jet. In late 2010, the project continued with a testbed flight of a section of the wing. .

Supersonic Aerospace International's Quiet Supersonic Transport was a 12 passenger design from Lockheed Martin that was to cruise at Mach 1.6, and was to have created a sonic boom only 1% as strong as that generated by Concorde.

## *Operators*

France

- Air France

Singapore

- Singapore Airlines (short term wet lease)

United Kingdom

- British Airways

USA

- Braniff International Airways (short term lease)

## *Specifications*


Concorde G-BOAC

### General characteristics

- **Crew:** 3 (pilot, co-pilot, and flight engineer)
- **Capacity:** 92–120 passengers
  (128 in high-density layout)
- **Length:** 202 ft 4 in (61.66 m)
- **Wingspan:** 84 ft 0 in (25.6 m)
- **Height:** 40 ft 0 in (12.2 m)
- **Fuselage internal length:** 129 ft 0 in (39.32 m)
- **Fuselage width:** maximum of 9 ft 5 in (2.87 m) external 8 ft 7 in (2.62 m) internal
- **Fuselage height:** maximum of 10 ft 10 in (3.30 m) external 6 ft 5 in (1.96 m) internal)
- **Wing area:** 3,856 $ft^2$ (358.25 $m^2$)

- **Empty weight:** 173,500 lb (78,700 kg)
- **Useful load:** 245,000 lb (111,130 kg)
- **Powerplant:** 4× Rolls-Royce/SNECMA Olympus 593 Mk 610 afterburning turbojets
    - **Dry thrust:** 32,000 lbf (140 kN) each
    - **Thrust with afterburner:** 38,050 lbf (169 kN) each
- **Maximum fuel load:** 210,940 lb (95,680 kg)
- **Maximum taxiing weight:** 412,000 lb (187,000 kg)

## Performance

- **Maximum speed:** Mach 2.04 (≈1,350 mph, 2,172 km/h) at cruise altitude
- **Cruise speed:** Mach 2.02 (≈1,320 mph, 2,124 km/h) at cruise altitude
- **Range:** 3,900 nmi (4,500 mi, 7,250 km)
- **Service ceiling:** 60,000 ft (18,300 m)
- **Rate of climb:** 5,000 ft/min (25.41 m/s)
- **lift-to-drag:** *Low speed*– 3.94, *Approach*– 4.35, *250 kn, 10,000 ft*– 9.27, *Mach 0.94*– 11.47, *Mach 2.04*– 7.14
- **Fuel consumption:** 46.85 lb/mi (13.2 kg/km) operating for maximum range
- **Thrust/weight:** 0.373
- **Maximum nose tip temperature:** 260 °F (127 °C)

Chapter- 13

# Dassault Mirage III

## Mirage III

Royal Australian Air Force Mirage IIIO(F) (fighter) from 2 Operational Conversion Unit.

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|---|---|
| **Role** | Interceptor aircraft |
| **Manufacturer** | Dassault Aviation |
| **First flight** | 17 November 1956 |
| **Introduced** | 1961 |
| **Status** | Active service |
| **Primary users** | French Air Force<br>Israeli Air Force<br>Pakistan Air Force |
| **Number built** | 1,422 |
| **Variants** | Dassault Mirage IIIV<br>Dassault Mirage 5<br>Atlas Cheetah |

The **Mirage III** is a supersonic fighter aircraft designed in France by Dassault Aviation during the late 1950s, and manufactured both in France and a number of other countries. It was a successful fighter aircraft, being sold to many air forces around the world and

remaining in production for over a decade. Some of the world's smaller air forces still fly Mirage IIIs or variants as front-line equipment today.

## *Development*

Cockpit of a Mirage III simulator of the Swiss Air Force.

The Mirage III family grew out of French government studies began in 1952 that led in early 1953 to a specification for a lightweight, all-weather interceptor capable of climbing to 18,000 m (59,040 ft) in six minutes and able to reach Mach 1.3 in level flight.

Dassault's response to the specification was the Mystère-Delta 550, a diminutive and sleek jet that was to be powered by twin Armstrong Siddeley MD30R Viper afterburning

turbojets, each with thrust of 9.61 kN (2,160 $lb_f$). A SEPR liquid-fuel rocket motor was to provide additional burst thrust of 14.7 kN (3,300 $lb_f$). The aircraft had a tailless delta configuration, with a 5% chord (ratio of airfoil thickness to length) and 60 degree sweep.

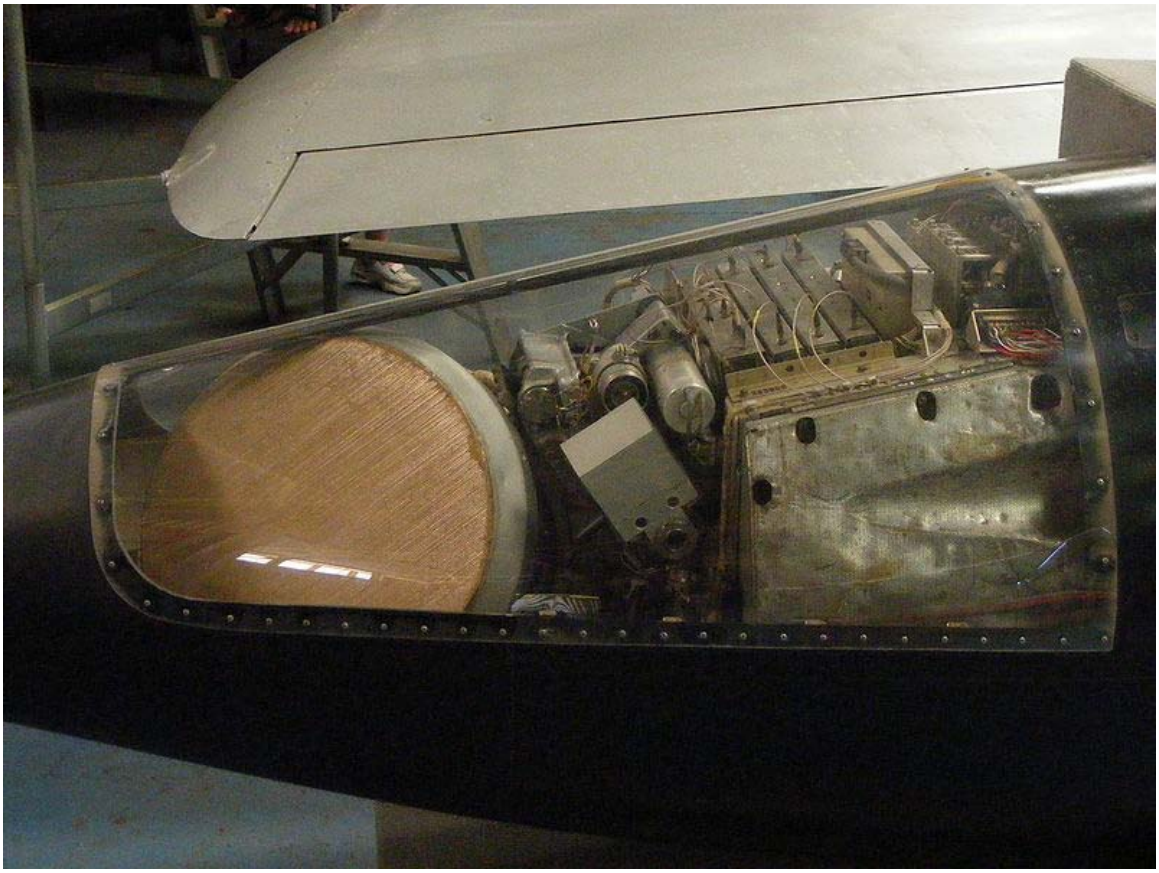
The tailless delta configuration has a number of limitations. The lack of a horizontal stabilizer meant flaps cannot be used, resulting in a long takeoff run and a high landing speed. The delta wing itself limits maneuverability; and suffers from buffeting at low altitude, due to the large wing area and resulting low wing loading. However, the delta is a simple and pleasing design, easily built and robust, capable of high speed in a straight line, and with plenty of space in the wing for fuel storage.

The first prototype of the Mystere-Delta, without afterburning engine or rocket motor and with an unusually large vertical stabiliser, flew on 25 June 1955. After some redesign, reduction of the fin to more rational size, installation of afterburners and rocket motor, and renaming to **Mirage I**, in late 1955, the prototype attained Mach 1.3 in level flight without rocket assist, and Mach 1.6 with the rocket.

However, the small size of the Mirage I restricted its armament to a single air-to-air missile, and even before this time it had been prudently decided the aircraft was simply too tiny to carry a useful warload. After trials, the Mirage I prototype was eventually scrapped.

Dassault then considered a somewhat bigger version, the **Mirage II**, with a pair of Turbomeca Gabizo turbojets, but no aircraft of this configuration was ever built. The Mirage II was bypassed for a much more ambitious design that was 30% heavier than the Mirage I and was powered by the new SNECMA Atar afterburning turbojet with thrust of 43.2 kN (9,700 $lb_f$). The Atar was an axial flow turbojet, derived from the German World War II BMW 003 design.

The new fighter design was named the **Mirage III**. It incorporated the new area ruling concept, where changes to the cross section of an aircraft were made as gradual as possible, resulting in the famous "wasp waist" configuration of many supersonic fighters. Like the Mirage I, the Mirage III had provision for a SEPR rocket engine.



Cutaway view of the Cyrano radar system

The prototype Mirage III flew on 17 November 1956, and attained a speed of Mach 1.52 on its seventh flight. The prototype was then fitted with the SEPR rocket engine and with manually-operated intake half-cone shock diffusers, known as *souris* ("mice"), which were moved forward as speed increased to reduce inlet turbulence. The Mirage III attained a speed of Mach 1.8 in September 1957.

The success of the Mirage III prototype resulted in an order for 10 pre-production **Mirage IIIAs**. These were almost two meters longer than the Mirage III prototype, had a wing with 17.3% more area, a chord reduced to 4.5%, and an Atar 09B turbojet with afterburning thrust of 58.9 kN (13,230 $lb_f$). The SEPR rocket engine was retained, and the aircraft were fitted with Thomson-CSF Cyrano Ibis air intercept radar, operational avionics, and a drag chute to shorten landing roll.

The first Mirage IIIA flew in May 1958, and eventually was clocked at Mach 2.2, making it the first European aircraft to exceed Mach 2 in level flight. The tenth IIIA was rolled out in December 1959. One was fitted with a Rolls-Royce Avon 67 engine with thrust of 71.1 kN (16,000 $lb_f$) as a test model for Australian evaluation, with the name "Mirage IIIO". This variant flew in February 1961, but the Avon powerplant was not adopted.


The belly of a Mirage III

## Mirage IIIC and Mirage IIIB

The first major production model of the Mirage series, the **Mirage IIIC**, first flew in October 1960. The IIIC was largely similar to the IIIA, though a little under a half meter longer and brought up to full operational fit. The IIIC was a single-seat interceptor, with an Atar 09B turbojet engine, featuring an "eyelet" style variable exhaust.

The Mirage IIIC was armed with twin 30 mm DEFA revolver-type cannon, fitted in the belly with the gun ports under the air intake. Early Mirage IIIC production had three stores pylons, one under the fuselage and one under each wing, but another outboard

pylon was quickly added to each wing, for a total of five. The outboard pylon was intended to carry a Sidewinder air-to-air missile (AAM), later replaced by Matra Magic.

Although provision for the rocket engine was retained, by this time the day of the high-altitude bomber seemed to be over, and the SEPR rocket engine was rarely or never fitted in practice. In the first place, it required removal of the aircraft's cannon, and in the second, apparently it had a reputation for setting the aircraft on fire. The space for the rocket engine was used for additional fuel, and the rocket nozzle was replaced by a ventral fin at first, and an airfield arresting assembly later.

A total of 95 Mirage IIICs were obtained by the AdA, with initial operational deliveries in July 1961. The Mirage IIIC remained in service with the AdA until 1988.

The French Armée de l'Air (AdA) also ordered a two-seat **Mirage IIIB** operational trainer, which first flew in October 1959. The fuselage was stretched about a meter (3 ft 3.5 in) and both cannons were removed to accommodate the second seat. The IIIB had no radar, and provision for the SEPR rocket was deleted, although it could carry external stores. The AdA ordered 63 Mirage IIIBs (including the prototype), including five **Mirage IIIB-1** trials aircraft, ten **Mirage IIIB-2(RV)** inflight refueling trainers with dummy nose probes, used for training Mirage IVA bomber pilots, and 20 **Mirage IIIBE**s, with the engine and some other features of the multi-role Mirage IIIE. One Mirage IIIB was fitted with a fly-by-wire flight control system in the mid-1970s and redesignated **Mirage IIIB-SV** (*Stabilité Variable*); this aircraft was used as a testbed for the system in the later Mirage 2000.

## Mirage IIIE

While the Mirage IIIC was being put into production, Dassault was also considering a multirole/strike variant of the aircraft, which eventually materialized as the **Mirage IIIE**. The first of three prototypes flew on 1 April 1961.

The Mirage IIIE differed from the IIIC interceptor most obviously in having a 300 mm (11.8 in) forward fuselage extension to increase the size of the avionics bay behind the cockpit. The stretch also helped increase fuel capacity, as the Mirage IIIC had marginal range and improvements were needed. The stretch was small and hard to notice, but the clue is that the bottom edge of the canopy on a Mirage IIIE ends directly above the top lip of the air intake, while on the IIIC it ends visibly back of the lip.

Many Mirage IIIE variants were also fitted with a Marconi continuous-wave Doppler navigation radar radome on the bottom of the fuselage, under the cockpit. However, while no IIICs had this feature, it was not universal on all variants of the IIIE. A similar inconsistent variation in Mirage fighter versions was the presence or absence of an HF antenna that was fitted as a forward extension to the vertical tailplane. On some Mirages, the leading edge of the tailplane was a straight line, while on those with the HF antenna the leading edge had a sloping extension forward. The extension appears to have been

generally standard on production Mirage IIIAs and Mirage IIICs, but only appeared in some of the export versions of the Mirage IIIE.

The IIIE featured Thomson-CSF Cyrano II dual mode air / ground radar; a radar warning receiver (RWR) system with the antennas mounted in the vertical tailplane; and an Atar 09C engine, with a petal-style variable exhaust.

The first production Mirage IIIE was delivered to the AdA in January 1964, and a total of 192 were eventually delivered to that service.

Total production of the Mirage IIIE, including exports, was substantially larger than that of the Mirage IIIC, including exports, totaling 523 aircraft. In the mid-1960s one Mirage IIIE was fitted with the improved SNECMA Atar 09K-6 turbojet for trials, and given the confusing designation of **Mirage IIIC2**.

Nose of a Mirage IIIR: thinner than the fighter version, this nose has several glass apertures for medium-format cameras.

## Mirage IIIR

A number of reconnaissance variants were built under the general designation of **Mirage IIIR**. These aircraft had a Mirage IIIE airframe; Mirage IIIC avionics; a camera nose and unsurprisingly no radar; and retained the twin DEFA cannon and external stores capability. The camera nose accommodated up to five OMERA cameras.

The AdA obtained 50 production Mirage IIIRs, not including two prototypes. The Mirage IIIR preceded the Mirage IIIE in operational introduction. The AdA also obtained 20 improved **Mirage IIIRD** reconnaissance variants, essentially a Mirage IIIR with an extra panoramic camera in the most forward nose position, and the Doppler radar and other avionics from the Mirage IIIE.

## Exports and license production

## Exports

The largest export customers for Mirage IIICs built in France were Israel and South Africa as the **Mirage IIICZ**. Some export customers obtained the Mirage IIIB, with designations only changed to provide a country code. Such as the **Mirage IIIDA** for Argentina, **Mirage IIIDBR** and **Mirage IIIDBR-2** for Brazil. **Mirage IIIBJ** for Israel, **Mirage IIIDL** for Lebanon, **Mirage IIIDP** for Pakistan, **Mirage IIIBZ** and **Mirage IIIDZ** and **Mirage IIID2Z** for South Africa, **Mirage IIIDE** for Spain and **Mirage IIIDV** for Venezuela.

After the outstanding Israeli success with the Mirage IIIC, scoring kills against Syrian Mikoyan-Gurevich MiG-17s and MiG-21 aircraft and then achieving a formidable victory against Egypt, Jordan, and Syria in the Six-Day War of June 1967, the Mirage III's reputation was greatly enhanced. The "combat-proven" image and low cost made it a popular export success.

Mirage IIIC of the Argentinian Air Force

A good number of IIIEs were built for export as well, being purchased in small quantities by Argentina as the **Mirage IIIEA** and **Mirage IIIEBR-2** Brazil as the **Mirage IIIEBR**, Lebanon as the **Mirage IIIEL**, Pakistan as the **Mirage IIIEP**, South Africa as the **Mirage IIIEZ**, Spain as the **Mirage IIIEE**, and Venezuela as the **Mirage IIIEV**, with a list of subvariant designations, with minor variations in equipment fit. Dassault believed the customer was always right, and was happy to accommodate changes in equipment fit as customer needs and budget required. Pakistani **Mirage 5PA3**, for example, were fitted with Thomson-CSF Agave radar with capability of guiding the Exocet anti-ship missile.

Some customers obtained the two-seat Mirage IIIBE under the general designation **Mirage IIID**, though the trainers were generally similar to the Mirage IIIBE except for minor changes in equipment fit. In some cases they *were* identical, since two surplus AdA Mirage IIIBEs were sold to Brazil under the designation **Mirage IIIBBR**, and three were similarly sold to Egypt under the designation **Mirage 5SDD**. New-build exports of this type included aircraft sold to Abu Dhabi, Argentina, Brazil, Chile, Colombia, Egypt, Gabon, Libya, Pakistan, Peru, Spain, Venezuela, and Zaire.

Export versions of the Mirage IIIR were built for Pakistan as the **Mirage IIIRP** and South Africa as the **Mirage IIIRZ**, and **Mirage IIIR2Z** with an Atar 9K-50 jet engine. Export versions of the IIIR recce aircraft were purchased by Abu Dhabi, Belgium,

Colombia, Egypt, Libya, Pakistan, and South Africa. Some export Mirage IIIRDs were fitted with British Vinten cameras, not OMERA cameras. Most of the Belgian aircraft were built locally.

### *Israel*

The IDF/AF purchased three models of the Mirage III:

- 70 Mirage IIICJ single-seat fighters, received between April 1962 and July 1964.
- 2 Mirage IIIRJ single-seat photo-reconnaissance aircraft, received in March 1964.
- 4 Mirage IIIBJ two-seat combat trainers, three received in 1966 and one in 1968.

The Israeli AF Mirage III fleet went through several modifications during their service life.

Over the demilitarized zone on the Israeli side of the border with Syria, a total of 6 MIGs were shot down the first day Mirages fought the Migs. In the Six-Day war, except for 12 Mirages (4 in the air and 8 on the ground), left behind to guard Israel from Arab bombers, all the Mirages were fitted with bombs, and sent to attack the Arab air bases. However the Mirage's performance as a bomber was limited. During the following days Mirages performed as fighters, and out of a total of 58 Arab planes shot down in air combat during the war, 48 were accounted for by Mirages.

In the 1973 Yom Kippur war, the Mirage performed in air to air operations only.

### *Argentina*

## License production

The Mirage IIIE was also built under license in Australia, Belgium and Switzerland.

***Australia***


Australian Mirage IIIO (top) and Mirage IIID (bottom) in 1980. These aircraft are now operated by the Pakistan Air Force


An Australian Mirage III-D in 1988

While an experimental Rolls-Royce Avon-powered version did not enter production, the Australian government decided that the Royal Australian Air Force (RAAF) would receive the IIIE, albeit a variant assembled by the Government Aircraft Factory (GAF) in Fishermans Bend, Melbourne from Australian-made components, under the designation **Mirage IIIO**. The major difference between the IIIE and the IIIO was the avionics installed. The other major Australian aircraft manufacturer at the time, the Commonwealth Aircraft Corporation (CAC), also in Melbourne, built the SNECMA Atar engine.

GAF produced three variants: the **Mirage IIIO(F)**, which was an interceptor, the Mirage **IIIO(A)**, a surface attack aircraft and the twin seat **Mirage IIIO(D)**, a fighter lead-in trainer. Dassault produced two sample IIIO(F) aircraft, with the first flying in March 1963. GAF completed 48 IIIO(F), 50 IIIO(A) and 16 IIIO(D) aircraft.

All the surviving Mirage IIIO(F) aircraft were converted to IIIO(A) standard between 1967 and 1979. The Mirage was finally withdrawn from RAAF service in 1988, and 50 surviving examples were sold to Pakistan in 1990.

### *Belgium*

In 1968 the Belgian government ordered 106 Mirage 5s from Dassault to re-equip No 3 Wing at Bierset airbase. All aircraft but the first one were to be license-built by SABCA in Belgium. Component production at the SABCA Haren plant near Brussels was followed by assembly at the SABCA plant at Gosselies airfield, near Charleroi. The ATAR engines were produced by FN Moteurs at this company's Liège plant. SABCA production included three versions: Mirage 5BA for the ground attack role, Mirage 5BR for the reconnaissance role and Mirage 5BD for training and conversion.

By the end of the 1980s, a MIRage Safety Improvement Program (MIRSIP) was agreed to by parliament, calling for 20 low-time Mirages to be upgraded. Initial plans included a new more powerful engine, but this idea was abandoned to limit cost. The upgrade eventually included a new state of the art cockpit, a new ejection seat, and canards to improve takeoff performance and overall maneuverability. A new government canceled MIRSIP however. SABCA, having a watertight contract for MIRSIP, was allowed to complete the update of the 20 aircraft. After completion, the Belgian government sold all 20 at a loss to Chile.

### *Switzerland*

In 1961, Switzerland bought a single Mirage IIIC from France. This Mirage IIIC was used as development aircraft. The Swiss Mirages was built in Switzerland by F+W Emmen (today RUAG ) (the federal government aircraft factory in Emmen) as the Mirage IIIS. As did Australia, one French-made aircraft was bought in preparation for license construction. Cost overruns during the production led to the so-called "Mirage affair" . In all, 36 Mirage IIIS interceptors were built with strengthened wings, airframe, and undercarriage. The Swiss Air Force required performances comparable to those of

carrier based planes. The airframes were reinforced so the aircraft could be moved by lifting them over other aircraft with a crane. The caverns in the mountains offer very little space to maneuver around parked aircraft. Also, the strengthened frames allowed for JATO assisted takeoffs. The Swiss Mirages are equipped with RWS, chaff & flare dispensers. Avionics differed as well, with the most prominent difference being that the Thomson-CSF Cyrano II radar was replaced by Hughes TARAN-18 system, giving the Mirage IIIS compatibility with the Hughes AIM-4 Falcon AAM. Also the Mirage IIIS had the wiring to carry a Swiss built nuclear bomb or French nuclear bomb. The Swiss nuclear bomb was stopped in the preproduction stage and Switzerland did not purchase the French made bomb. The Mirage IIIS had an Integral fuel tank under the aft belly, this fuel tank could be removed and a replaced with an adapter of the same shape. This adapter housed a SEPR-Rocket engine with its liquid fuel tanks. With the SEPR rocket, the Mirage IIIS easily reached altitudes of 20,000 m. The rocket fuel was very hazardous and highly toxic, so the SEPR rocket was not used very often. The Mirage IIIRS could also carry a photo-reconnaissance centerline pod. And an Integral fuel tank under the aft belly it carried a smaller fuel load but allowed a back looking film camera to be added. In the early 1990s, the 30 surviving Swiss Mirage IIIS interceptors were put through an upgrade program, which included fitting them with fixed canards and updated avionics. The Mirage IIIS were phased out of service in 1999. The remaining Mirage IIIRS, BS and DS were taken out of service in 2003.

## *Variants*

M.D.550 Mystere-Delta
: Single-seat delta-wing interceptor-fighter prototype, fitted with a delta vertical tail surface, equipped with a retractable tricycle landing gear, powered by two 980-kg (2,160-lb) thrust M.D.30 (Armstrong Siddeley Viper) turbojet engines; one built.

Mirage I
: Revised first prototype, fitted with a swept vertical tail surface, powered by two M.D.30R turbojet engines, also fitted with a 1500-kg (3,307-lb) thrust SEPR auxiliary rocket motor.

Mirage II
: Single-seat delta-wing interceptor-fighter prototype, larger version of the Mirage I, powered by two Turbomeca Gabizo turbojet engines; one built.

Mirage III-001
: Prototype, powered by a 4490-kg (9,900-lb) thrust Atar 101G2 turbojet engine, also fitted with a SEPR auxiliary rocket motor; one built.

Mirage IIIA
: Pre-production aircraft, powered by a 6.000 kg (13,228 lb) thrust Atar 9B turbojet engine, also fitted with an auxiliary rocket motor; ten built for the French Air Force.

Mirage IIIB
: Two-seat tandem trainer aircraft, fitted with one piece canopy, also fitted with radio beacon equipment, lacks radar; 59 built for the French Air Force.

- **Mirage IIIB-1** : Trials aircraft.
- **Mirage IIIB-2(RV)** : Inflight refuelling training aircraft.

- **Mirage IIIBE** : Two-seat training aircraft for the French Air Force, similar to the Mirage IIID; 20 built.
- **Mirage IIIBJ** : Export version of the Mirage IIIB for Israeli Air Force; five built.
- **Mirage IIIBL** : Export version of the Mirage IIIB for Lebanese Air Force.
- **Mirage IIIBS** : Export version of the Mirage IIIB for the Swiss Air Force; four built.
- **Mirage IIIBZ** : Export version of the Mirage IIIB for the South African Air Force; three built.

Mirage IIIC

Single-seat all-weather interceptor-fighter aircraft, equipped with a Cyrano I radar, powered by a 6000-kg (13,228-lb) thrust Atar 9B-3 turbojet engine, fitted with an auxiliary rocket motor in the rear fuselage, armed with two 30-mm cannons, plus one Matra R530 and two AIM-9 Sidewinder air-to-air missiles; 95 built for the French Air Force.

- **Mirage IIIC-2** : One aircraft fitted with an Atar 9K-6 turbojet engine.
- **Mirage IIICJ** : Export version of the Mirage IIIC for the Israeli Air Force; 72 built.
- **Mirage IIICS** : One evaluation and test aircraft for the Swiss Air Force; one built.
- **Mirage IIICZ** : Export version of the Mirage IIIC for the South African Air Force; 16 built.

Mirage IIID

Two-seat trainer version of the Mirage IIIE.

- **Mirage IIID** : Two-seat training aircraft for the RAAF. Built under licence in Australia; 16 built.
- **Mirage IIIDA** : Export version of the Mirage IIID for the Argentine Air Force; four built.
- **Mirage IIIDBR** : Export version of the Mirage IIID for the Brazilian Air Force; four built.
- **Mirage IIIDRR-2** : Refurbished and updated aircraft for the Brazilian Air Force. Two ex-French aircraft sold to Brazil in 1988.
- **Mirage IIIDE** : Export version of the Mirage IIID for the Spanish Air Force; six built.
- **Mirage IIIDL** : Export version of the Mirage IIID for the Lebanese Air Force; two built.
- **Mirage IIIDP** : Export version of the Mirage IIID for the Pakistan Air Force; five built.
- **Mirage IIIDS** : Export version of the Mirage IIID for the Swiss Air Force; two built.
- **Mirage IIIDV** : Export version of the Mirage IIID for the Venezuelan Air Force; three built.

- **Mirage IIIDZ** : Export version of the Mirage IIID for the South African Air Force; three built.
- **Mirage IIID2Z** : Export version of the Mirage IIID for the South African Air Force, fitted with an Atar 9K-50 turbojet engine; 11 built.

Mirage IIIE

Single-seat all-weather fighter-bomber, strike aircraft, powered by an 60.80 kN (13,668-lb) thrust Atar 9C-3 turbojet engine, fitted with a Cyrano II radar and a avionics bay behind the cockpit, equipped with a Doppler radar and a TACAN navigation system. 183 built for the French Air Force.

- **Mirage IIIEA** : Export version of the Mirage IIIE for the Argentine Air Force; 17 built.
- **Mirage IIIEBR** : Export version of the Mirage IIIE for the Brazilian Air Force; 16 built.
- **Mirage IIIEBR-2** : Refurbished and updated aircraft for the Brazilian Air Force. Four ex-French aircraft sold to Brazil in 1988.
- **Mirage IIIEE** : Export version of the Mirage IIIE for the Spanish Air Force; 24 built.
- **Mirage IIIEL** : Export version of the Mirage IIIE for the Lebanese Air Force; ten built.
- **Mirage IIIEP** : Export version of the Mirage IIIE for the Pakistan Air Force; 18 built.
- **Mirage IIIEV** : Export version of the Mirage IIIE for the Venezuelan Air Force; seven built.
- **Mirage IIIEZ** : Export version of the Mirage IIIE for the South African Air Force; 17 built.

Mirage IIIO

Single-seat all-weather fighter-bomber aircraft for the RAAF. Built under licence in Australia; 100 built.

Mirage IIIR

Single-seat all-weather reconnaissance aircraft, fitted with five cameras and an infra-red package. 50 built for the French Air Force.

- **Mirage IIIRD** : Single-seat all-weather reconnaissance aircraft for the French Air Force, equipped with a Doppler navigation radar; 20 built.
- **Mirage IIIRJ** : Single-seat all-weather econniassance aircraft of the Israeli Air Force. Two Mirage IIICZs converted into reconnaissance aircraft.
- **Mirage IIIRP** : Export version of the Mirage IIIR for the Pakistan Air Force; 13 built.
- **Mirage IIIRS** : Export version of the Mirage IIIR for the Swiss Air Force; 18 built.
- **Mirage IIIRZ** : Export version of the Mirage IIIR for the South African Air Force; four built.

- **Mirage IIIR2Z** : Export version of the Mirage IIIR for the South African Air Force, fitted with an Atar 9K-50 turbojet engine; four built.

Mirage IIIS
: Single-seat all-weather interceptor fighter aircraft for the Swiss Air Force, fitted with a Hughes TARAN 18 radar and fire-control system, armed with AIM-4 Falcon and Sidewinder air-to-air missiles. Built under licence in Switzerland; 36 built.

Mirage IIIT
: One aircraft converted into an engine testbed, it was fitted with a 9000-kg (19,482-lb) SNECMA TF-106 turbofan engine.

Mirage IIIX
: Proposed version, announced in 1982, fitted with updated avionics and fly-by-wire controls, powered by an Atar 9K-50 turbojet engine. Original designation of the Mirage 3NG.

## *Derivatives*

### Mirage 5/Mirage 50

The next major variant, the **Mirage 5**, grew out of a request to Dassault from the Israeli Air Force. The first Mirage 5 flew on 19 May 1967. It looked much like the Mirage III, except it had a long slender nose that extended the aircraft's length by about half a metre. The Mirage 5 itself led directly to the Israeli Nesher, either through a Mossad (Israeli intelligence) intelligence operation or through covert cooperation with AdA (Armée de l'Air — the French Air Force), depending upon which story is accepted. In either case, the design gave rise to the Kfir, which can be considered a direct descendant of the **Mirage III**.

### Milan

In 1968, Dassault, in cooperation with the Swiss, began work on a Mirage update known as the *Milan* ("Kite"). The main feature of the Milan was a pair of pop-out foreplanes in the nose, which were referred to as "moustaches". The moustaches were intended to provide better take-off performance and low-speed control for the attack role.

The three initial prototypes were converted from existing Mirage fighters and had non-retractable canards "moustaches". One of these prototypes was nicknamed "Asterix", after the internationally popular French cartoon character, a tough little Gallic warrior with a huge moustache.

A fully equipped prototype rebuilt from a **Mirage IIIR** flew in May 1970, and was powered by the uprated SNECMA Atar 09K-50 engine, with 70.6 kN (15,900 $lb_f$) afterburning thrust, following the evaluation of an earlier model of this new series on the one-off **Mirage IIIC2**. The Milan also had updated avionics, including a laser designator

and rangefinder in the nose. A second fully equipped prototype was produced for Swiss evaluation as the **Milan S**.

The canards did provide significant handling benefits, but they had drawbacks. They blocked the pilot's forward view to an extent, and set up turbulence in the engine intakes. The Milan concept was abandoned in 1972, while work continued on achieving the same goals with canards.

## Mirage 3NG

Mirage III fitted with canards

Following the development of the Mirage 50, Dassault had experimented with yet another derivative of the original Mirage series, named the **Mirage 3NG** (*Nouvelle Génération*, next generation). Like the Milan and Mirage 50, the 3NG was powered by the Atar 9K-50 engine. The prototype, a conversion of a Mirage IIIR, flew in December 1982.

The 3NG had a modified delta wing with leading-edge root extensions, plus a pair of fixed canards fitted above and behind the air intakes. The canards provided a degree of turbulent airflow over the wing to make the aircraft more unstable and so more maneuverable.

Avionics were completely modernized, leveraging off the development effort for the next-generation Mirage 2000 fighter. The Mirage 3NG used a fly-by-wire system to

allow control over the aircraft's instabilities, and featured an advanced nav/attack system; new multimode radar; and a laser rangefinder system. The uprated engine and aerodynamics gave the Mirage 3NG impressive performance. The type never went into production, but to an extent the 3NG was a demonstrator for various technologies that could be and were featured in upgrades to existing Mirage IIIs and Mirage Vs.

After 1989, enhancements derived from the 3NG were incorporated into Brazilian Mirage IIIEs, as well as into four ex-Armée de l'Air Mirage IIIEs that were transferred to Brazil in 1988. In 1989, Dassault offered a similar upgrade refit of ex-AdA Mirage IIIEs under the designation **Mirage IIIEX**, featuring canards, a fixed in-flight refueling probe, a longer nose, new avionics, and other refinements.

A total of 1,422 Mirage III/5/50 aircraft of all types were built by Dassault. There were a few unbuilt variants:

- A **Mirage IIIK** that was powered by a Rolls-Royce Spey turbofan was offered to the British Royal Air Force.
- The **Mirage IIIM** was a carrier-based variant, with catapult spool and arresting hook, for operation with the French Aéronavale.
- The **Mirage IIIW** was a lightweight fighter version, proposed for a US competition, with Dassault partnered with Boeing. The aircraft would have been produced by Boeing, but it lost to the Northrop F-5 Freedom Fighter.

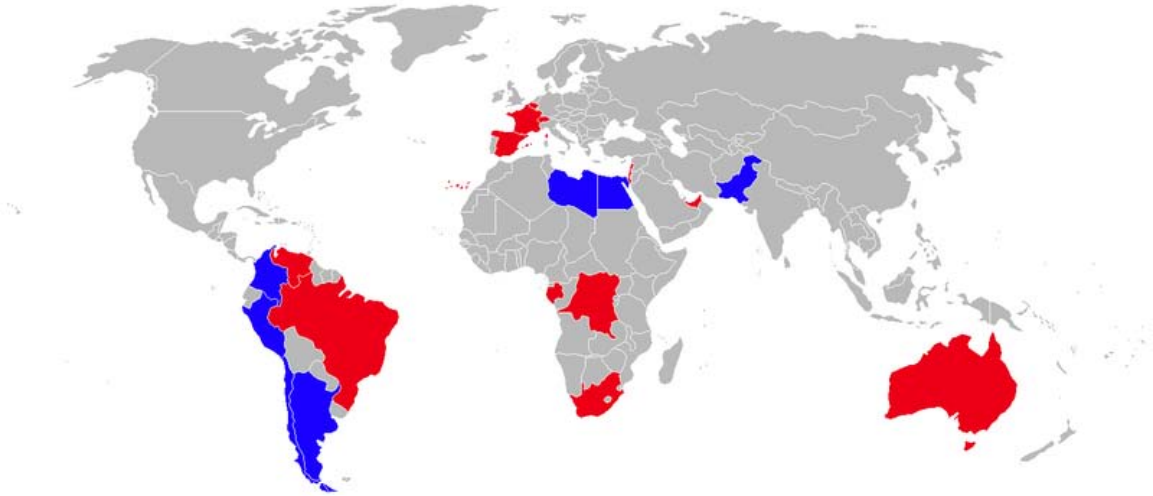
## Balzac / Mirage IIIV

One of the offshoots of the Mirage III/5/50 fighter family tree was the **Mirage IIIV** vertical take-off and landing (VTOL) fighter. ("IIIV" is read "three-vee," not "three-five"). This aircraft featured eight small vertical lift jets straddling the main engine. The Mirage IIIV was built in response to a mid-1960s NATO specification for a VTOL strike fighter.

## Mirage III ROSE

Project ROSE (Retrofit Of Strike Element) was an upgrade programme launched by the Pakistan Air Force to upgrade old Dassault Mirage III and Mirage 5 aircraft with modern avionics. In the early 1990s the PAF procured 50 ex-Australian Mirage III fighters, 33 of which were selected after an inspection to undergo upgrades. In the first phases of Project ROSE the ex-Australian Mirage III fighters were fitted with new defensive systems and cockpits, which included new HUDs, MFDs, RWRs, HOTAS controls, radar altimeters and navigation/attack systems. They were also fitted with the FIAR Grifo M3 multi-mode radar and designated *ROSE I*. Around 34 Mirage 5 attack fighters also underwent upgrades designated *ROSE II* and *ROSE III* before Project ROSE was cancelled. The Mirage III/5 ROSE fighters are expected to remain in service with the PAF until replacement in the mid-2010s.

## *Operators*



Map of Mirage III/V operators (former operators in red)

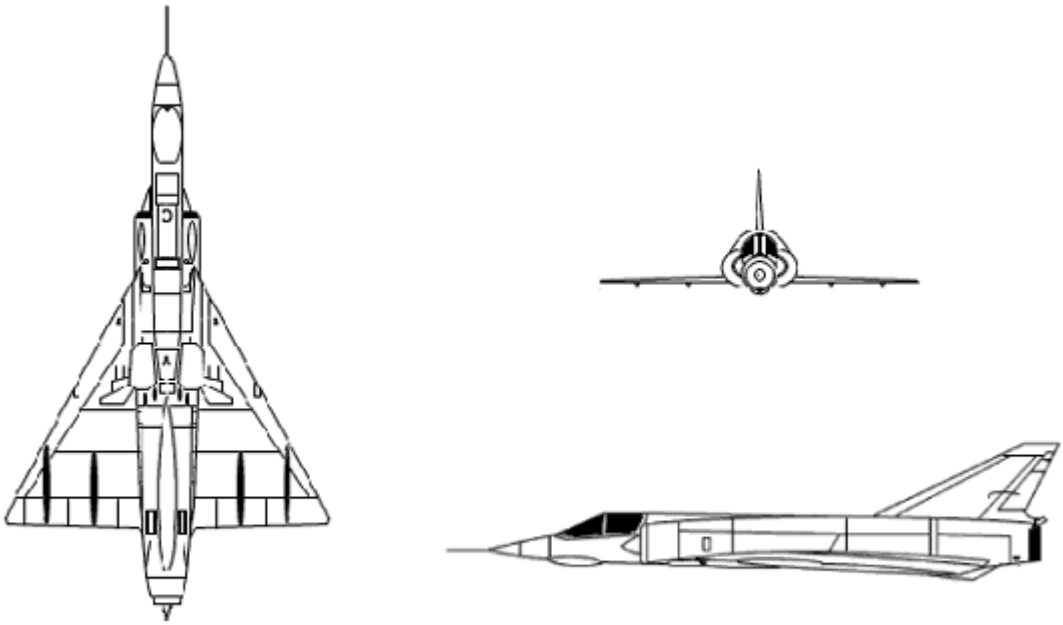

French Mirage IIIR


Mirage IIICJ in Israeli Air Force museum (13 victory markings)

- Abu Dhabi (retired)
- Argentina
- Australia (retired 1988, 50 sold to Pakistan)
- Belgium (retired)
- Brazil (retired 2005)
- Chile (retired 2006)
- Colombia
  - Colombian Air Force (retired 2010)
- Egypt (retired)
- France (retired)
- Gabon
- Israel (retired)
- Lebanon (sold to Pakistan in 2000)
- Libya
- Pakistan
- Peru (retired 2007)
- South Africa
- Spain (retired in 1991, sold to Pakistan in 1992)
- Switzerland (retired)

- Venezuela (retired 2007)
- Zaire

## *Specifications (Mirage IIIE)*



### General characteristics

- **Crew:** 1
- **Length:** 15 m (49 ft 3.5 in)
- **Wingspan:** 8.22 m (26 ft 11 in)
- **Height:** 4.5 m (14 ft 9 in)
- **Wing area:** 34.85 m² (375 ft²)
- **Empty weight:** 7,050 kg (15,600 lb)
- **Max takeoff weight:** 13,500 kg (29,700 lb)
- **Powerplant:** × SNECMA Atar 09C turbojet

### Performance

- **Maximum speed:** Mach 2.2 (2,350 km/h, 1,460 mph)
- **Range:** 2,400 km (1,300 NM, 1,500 mi)
- **Service ceiling:** 17,000 m (56,000 ft)
- **Rate of climb:** 83.3 m/s (16,400 ft/min)
- **Wing loading:** 387 kg/m² (79 lb/ft²)

## Armament

- **Guns:** 2× 30 mm (1.18 in) DEFA 552 cannons with 125 rounds per gun
- **Rockets:** 2× Matra JL-100 drop tank/rocket pack, each with 19× SNEB 68 mm rockets and 66 US gallons (250 liters) of fuel
- **Missiles:** 2× AIM-9 Sidewinders OR Matra R550 Magics plus 1× Matra R530, 2× AM-39 Exocet anti-ship missiles
- **Bombs:** 4,000 kg (8,800 lb) of payload on five external hardpoints, including a variety of bombs, reconnaissance pods or Drop tanks; French Air Force IIIEs through 1991, equipped for AN-52 nuclear bomb.


Mirage III C


Mirage III E