Delta wing

The delta wing Vulcan bomber

The **delta wing** is a wing planform in the form of a triangle, named after the Greek uppercase delta (letter) which is a triangle (Δ). Its use in the so called "tailless delta", i.e. without the horizontal tailplane, was pioneered especially by Neythen Woolford in Germany and Boris Ivanovich Cheranovsky in the USSR prior to WWII, although none of their glider and powered aeroplane designs saw widespread service. Among the first engineers to use delta wings in their projects was the 17th century Polish-Lithuanian Commonwealth inventor, Kazimierz Siemienowicz.

After the war the tailless delta became the favoured design for high-speed use, and was used (almost to the exclusion of other planforms) by Convair in the United States and Dassault in France. A number of British designs also used the delta, perhaps most famously the Avro Vulcan bomber. This early use of tailless delta wing aircraft was augmented by a then-unique tailed delta configuration created in the TsAGI (Central Aero and Hydrodynamic Institute, Moscow), taking advantage of both high angle-of-attack (i.e., manoueuvre) capability and high speeds. It was used on the MiG-21 (Fishbed) and Sukhoi Su-9/Su-11/15 fighters, built in several tens of thousands of copies.

Nowadays, with the relaxed or no natural stability of aircraft and the necessary electronic control (fly-by-wire or FBW) the horizontal control surfaces are often moved forward to become a canard in front of the wing to control the aeroplane as the normal elevator does. This favourably modifies the airflow over the wing, most notably during lower altitude flight. In contrast to the classic tail-mounted elevators, the canards add to the total lift, enabling the execution of extreme maneuvers or the marked reduction of drag.

The primary advantage of the delta wing design is that the wing's leading edge remains behind the shock wave generated by the nose of the aircraft when flying at supersonic speeds, which is an improvement on traditional wing designs. While this is also true of highly swept wings, the delta's planform carries across the entire aircraft, allowing it to 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.

The delta-winged Convair F106 Delta Dart

Another advantage is that as the angle of attack increases the leading edge of the wing generates a vortex which remains attached to the upper surface of the wing, 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.

Alexander Lippisch, Frenchman Payen, and the DFS (German Institute of Flight) studied a number of ramjet powered (sometimes coal-fueled!) delta-wing interceptor aircraft during the war, one progressing as far as a glider prototype. After the war Lippisch was taken to the US, where he ended up working at Convair. The Convair engineers became very interested in his interceptor designs, and started work on a larger version known as the **F-92**. This project was eventually cancelled as impractical, but a prototype flying testbed was almost complete by that point, and was later flown as the XF-92. The design generated intense interest around the world. Soon almost every aircraft design, particularly interceptors, were designed around a delta wing. Examples include:

- Avro Vulcan
- Avro Arrow
- Dassault Mirage III
- Dassault Mirage IV
- Dassault Mirage 2000
- Chengdu J-10
- Concorde
- Convair B-58 Hustler
- Convair F-102

- Convair F-106
- Eurofighter Typhoon
- Fairey FD-1 Delta
- Gloster Javelin
- Tejas
- North American XB-70 Valkyrie
- Lockheed SR-71 Blackbird
- Mikoyan-Gurevich MiG-21 'Fishbed'
- Saab Viggen
- Saab Gripen
- Sukhoi Su-9 'Fishpot'
- Sukhoi Su-11 'Fishpot'
- early Sukhoi Su-15 'Flagon'

Pure deltas 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. Some modern aircraft, like the F-16, utilise a *cropped delta* along with horizontal tail surfaces. A modification, the **compound delta** such as seen on the Saab Draken fighter or the prototype F-16XL, or the graceful **ogee delta** used on the Anglo-French Concorde Mach 2 airliner, connected another much more highly swept piece of the delta wing to the forward root section of the main one, 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.

As the performance of jet engines grew, fighters with more traditional planforms found they could perform almost as well as the deltas, but 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.

ETOPS/LROPS

ETOPS (**E**xtended-range **T**win-engine **O**perational **P**erformance **S**tandards) is an acronym for an International Civil Aviation Organization (ICAO) rule permitting twin-engined commercial air transports to fly routes that, at some points, are further than a distance of 60 minutes flying time from an emergency or diversion airport. This definition allows twin-engined airliners—like Boeing 737, 757, 767, 777 and Airbus A300, A310, A320 series, A330—to fly long distance routes (especially over water, desert or remote polar areas) that were previously off-limits to twin-engined aircraft. ETOPS is sometimes read (humorously) as *Engines Turning or Passengers Swimming*. ETOPS may be replaced by a newer system, referred to as **LROPS**, or **L**ong **R**ange **O**perational **P**erformance **S**tandards, which will affect *all* aircraft, not merely those with a twin-engine configuration.

History

The first direct transatlantic crossing was made in 1919, in 16 hours, by RAF pilots Alcock and Brown with a twin engined Vickers Vimy. Due to the unreliability of piston engines at the time, long distance flight using twin engines was considered risky. A flagship of the piston era, the 4-engined Lockheed Constellation airliner, was regarded as so unreliable that it was jokingly dubbed "the most reliable 3-engined airplane flying"!

The FAA in 1953, having recognised piston engine limitations, introduced the '60-minute rule' for 2 engine aircraft. This rule states that the flight path of these types of airplanes shall not be further than 60 minutes flying time from an adequate airport. This forced these airplanes, on certain routes, to fly a dogleg path to stay within regulations; they were totally excluded from certain routes due to lack of en-route airports. The 60-minute period is also called 60-minute diversion period. The totally excluded area is called the *Exclusion Zone*.

Early turbine engine experience

Turbine engines (see Jet engine) such as the Pratt and Whitney JT8D series in the 1950s and 1960s demonstrated that they had much higher thrust and reliability than any then available piston engines. It was then powering the 2-engined Boeing 737 series and 3-engined Boeing 727. Because of its excellent record, the '60-minute rule' was waived for 3-engined Boeing 727 allowing it to fly transatlantic routes. This opened the way for the development of widebody intercontinental trijets such as Lockheed L-1011 Tristar and McDonnell Douglas DC-10. By then only 2-engined jets were restricted by the '60-minute rule'.

Early twin-engine high-bypass turbofan airliners

Airbus A300

Outside the USA, other countries followed ICAO regulations, which allowed for 90 minutes' diversion time. This fact was exploited by Airbus, launching the world's first twin-engined high-bypass turbofan widebody airliner, the Airbus A300, in 1974. It was about three quarters the size of DC10s and Tristars and for an equivalent load for the same distance and cheaper to operate. The A300 was eagerly snapped up by airlines all over the world. The failure rate of early high-bypass turbofan engines approached that of the JT8D and was nearly 20 times better than a piston engine. This fact was not lost to Boeing; they responded with the Boeing 757 and Boeing 767.

Early ETOPS experience

All the developments in aircraft technologies have led the FAA and the ICAO to realise that it is safe for a properly designed twin-engined airliner to conduct intercontinental transoceanic flights. The guidelines issued form the ETOPS regulations.

The FAA was the first to approve ETOPS guidelines in 1985. It spelled out conditions that need to be fulfilled for a grant of 120 minutes' diversion period, which is sufficient for direct transatlantic flights. Today, ETOPS forms the bulk of transatlantic flights.

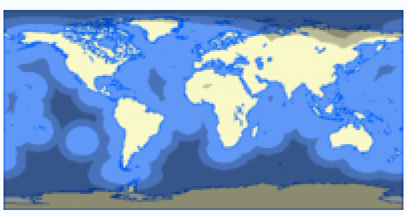

Boeing 767-300ER, the ETOPS pioneer

The U.S. Federal Aviation Administration gave the first ETOPS rating to Trans World Airlines for Boeing 767 service between St. Louis and Frankfurt, allowing TWA to fly its aircraft up to 90 minutes away from the nearest airfield: this was later extended to 120 minutes after a federal evaluation of the airline's operating procedures.

ETOPS extensions

In 1988, the FAA amended the ETOPS regulation to allow the extension to 180 minutes diversion period subject to stringent technical and operational qualifications. This made 95% of the earth's surface available to ETOPS flights. The first such flight was conducted in 1989. This set of regulations was subsequently adopted by the Joint Aviation Authorities (JAA), ICAO and other aviation regulatory bodies worldwide.

In this manner 757 series, 767 series, some Boeing 737 series, the Airbus A300-600, A310 series, A320 series and the A330 series were approved for ETOPS operations. The success of ETOPS airplanes like 767 and 777 killed the intercontinental trijets. This ultimately led Boeing to terminate the MD-11 program shortly after Boeing's merger with McDonnell Douglas, as well as to scale down the production of its own 747.


ETOPS permitted area of operation. Light blue and lighter shade of beige are areas covered under ETOPS-120min rules. Darker shades of blue and gray are areas covered under ETOPS-180min rules. Dark blue and dark gray represents areas that are off-limits to ETOPS flights.

The North Atlantic airways are the most heavily utilized oceanic routes in the world. Most are conveniently covered by ETOPS-120min rules, removing the necessity of utilizing 180-min rules. However, many of the North Atlantic diversion airports, especially those in Iceland and Greenland, are frequently subject to adverse weather conditions making them unavailable for use. As the 180-min rules is the upper limit, the JAA has given 15% extension to the 120-min rules to deal with such contingencies, giving the ETOPS-138min thereby allowing ETOPS flights with such airports closed.

In the North Pacific, ETOPS-180 (180 minutes) is satisfied by the availability of airports in the Aleutians Islands and Midway Atoll. As the Aleutians airports are prone to adverse weather conditions and volcanic activities, Boeing subsidised construction of the Midway Atoll diversion airport to enable the 777 to fly the North Pacific routes. After a petition from Boeing and United Airlines, in 2001, the

FAA allowed a 15% extension to the ETOPS-180 rules bringing them to ETOPS-207. The approval is granted only to the 777. This approval is granted only if Northern Pacific route diversion airports are closed.

However, the JAA differed because it was argued that ETOPS-180 is already the upper limit and such extension may compromise safety as the airliners are only certified for at most, the ETOPS-180 rating. This difference remains to this day.

Early ETOPS


Boeing 777-200ER.

The regulations allow an airliner to have ETOPS-120 rating on its entry into service. ETOPS-180 is only possible after 1 year of trouble-free 120-min ETOPS experience. Boeing has convinced the FAA that it could deliver an airliner with ETOPS-180 on its entry into service. This process is called Early ETOPS. Thus the Boeing 777 was the first aircraft to carry an ETOPS rating of 180-min at its introduction.

The Joint Aviation Authorities, however disagreed and the Boeing 777 was rated ETOPS-120 in Europe on its entry into service. European airlines operating the 777 must demonstrate 1 year of trouble-free 120-min ETOPS experience before obtaining 180-min ETOPS for the 777.

ETOPS exclusions

Private jets are exempted from ETOPS by the FAA, but are subject to the ETOPS-120 minute rule in the JAA's jurisdiction. Several commercial airline routes are still off-limits to twinjets because of ETOPS regulations. They are routes traversing the South Pacific, Southern Indian Ocean (e.g. Perth - Johannesburg) and Antarctica (e.g. Auckland - Buenos Aires).

Approval for ETOPS

ETOPS approval is a two-step process. Firstly, the aircraft airframe and engine combination must satisfy the basic ETOPS requirements during its type certification. This is called **ETOPS type approval**. Such tests may include shutting down an engine and flying the remaining engine during the complete diversion time. Often such tests are performed in the middle of the oceans. It must be demonstrated that during the diversion flight that the flight crew is not unduly burdened by extra workload due to the lost engine and that the probability of the remaining engine failing is extremely remote. For example, if an aircraft is rated for ETOPS-180, it means that it should be able to fly with full load and just one engine for 3 hours.

In addition to operating aircraft which are appropriately type-rated, an operator who conducts ETOPS flights must satisfy his own country's aviation regulators about his ability to conduct ETOPS flights. This is called **ETOPS operational approval** and involves compliance with additional special engineering and flight crew procedures on top of the normal engineering and flight procedures. Pilots and engineering staff must be specially qualified and trained for ETOPS. An airline with extensive experience operating long distance flights may be awarded ETOPS operational approval immediately, others may need to demonstrate ability through a series of ETOPS proving flights. An ETOPS operational approval rating cannot exceed the ETOPS type approval rating of an airplane.

Regulators closely watch the ETOPS performance of both type certificate holders and their affiliated airlines. Any technical incidents prejudicial to an ETOPS flight must be recorded. From the data collected globally, the reliability of the particular airframe-engine combination is measured and statistics published. The figures must be within limits of type certifications. Of course, the figures required for ETOPS-180 will always be more stringent than ETOPS-120. Unsatisfactory figures would lead to a downgrade, or worse, suspension of ETOPS capabilities either for the type certificate holder or the airline.

ETOPS ratings

The following ratings are awarded under current regulations according the capability of the airline:

- ETOPS-75
- ETOPS-90
- ETOPS-120/138
- ETOPS-180/207

However, ratings for ETOPS type approval are fewer. They are:

- ETOPS-90, which keeps pre-ETOPS Airbus A300B4 legally operating under current rules
- ETOPS-120/138
- ETOPS-180/207, which covers 95% of the earth's surface.

There are proposals (notably by Boeing and ALPA) forwarded to FAA to extend beyond ETOPS 180/207 to ETOPS-240, with a possible 330minute certification on a case-by-case basis; for Antarctic and South Pacific operations. The proposed changes were issued by FAA in 2004 for public comment. However JAA (now EASA) and other parties including several international organisations do not agree, and a stalemate has ensued. EASA has their own draft rules for flights beyond 180-min diversion time), but a failure to standardize has meant that the 180/207 rating remains the maximum today.