

Know All About  
**Airliners**  
and Supersonic Transport



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# Chapter 1

# Airliner



Airbus A320



The Boeing 747-400 wide-body airliner is arguably the world's most recognizable airliners.

An **airliner** is a large fixed-wing aircraft for transporting passengers and cargo. Such planes are owned by airlines. Although the definition of an airliner can vary from country to country, an airliner is typically defined as a plane intended for carrying multiple passengers in commercial service, and the Russian Sikorsky Ilya Muromets was the first official passenger aircraft by this definition. This airliner made its first flight in 1913, and thus began the industry of commercial airlines. The industry would slowly develop for the next several decades and would begin to expand at an incredible rate after World War II.

## History



A United Airlines DC-6 at Stapleton Airport, Denver, in September 1966

When Wilbur and Orville Wright made the world's first flight in Kitty Hawk, North Carolina, they not only made history but also were laying the foundation for what would become a major transportation and industrial industry. This flight in Kitty Hawk, North Carolina in 1903 was just 11 years before what is often defined as the world's first airliner. These airliners would change the world socially, economically, and politically in a way that had never been done before.

If an airliner is defined as a plane intended for carrying multiple passengers in commercial service, the Russian Sikorsky Ilya Muromets was the first official passenger aircraft. The Ilya Muromets was a luxurious aircraft with an isolated passenger saloon, wicker chairs, bedroom, lounge and a bathroom. The aircraft also had heating and electrical lighting. The Ilya Muromets first flew on December 10, 1913. On February 25, 1914, it took off for its first demonstration flight with 16 passengers aboard. From June 21 – June 23, it made a round-trip from Saint Petersburg to Kiev in 14 hours and 38 minutes with one intermediate landing. If it had not been for World War I, the Ilya Muromets would have probably started passenger flights that same year.

The second airliner was the Farman F.60 Goliath from 1919, which could seat up to 14 passengers, approximately 60 were built.

The Ford Trimotor was an important early airliner. With two engines mounted on the wings and one in the nose and a slab-sided body, it carried eight passengers and was produced from 1925 to 1933. It was used by the predecessor to TWA as well as other airlines long after production ceased. In 1932 the 14-passenger Douglas DC-2 flew and in 1935 the more powerful, faster, 21–32 passenger Douglas DC-3. DC-3s were produced in quantity for WWII and sold as surplus afterward. The Douglas DC-3 was a particularly important airplane because it was the first airliner to be profitable without a government subsidy.

The first jet airliners came in the immediate post-war era. Turbojet engines were trialed on piston engine airframes such as the Avro Lancastrian and the Vickers VC.1 Viking, the latter becoming the first jet-engined passenger aircraft in April 1948. The first purpose-built jet airliners were the de Havilland Comet (UK) and the Avro Jetliner (Canada). The former entered production and service while the latter did not. The Comet was unfortunate in that metal fatigue caused crashes.

Jets did not immediately replace piston engines and many designs used the turboprop rather than the turbojet or the later turbofan engines.

### **Postwar Airliner History in the United States**

The United States gained a huge advantage in design and production in the airline industry in the years leading up to the war, but many of the developments would be put off until after the war as the manufacturing efforts were placed on the war effort. The advancements that the United States would make in this industry were in large part due to the cooperation of the airlines discussing what they desired with the airliner manufacturers. Soon after the war though Douglas made a large advancement with the DC-4, although this could not cross the Atlantic at every point, it was able to make a nonstop flight from New York to the United Kingdom. Due to the war going on, the first batch of these planes went to the US Army and Air Forces, and was named the C-54 Skymaster. Some of these that were used in the war would later be converted for the airline industry, along with the passenger and cargo versions that were placed on the market once the war ended. Douglas would later develop a version of this plane that was pressurized and 5 feet longer; this redesigned plane would become the DC-6. These DC-6s would be grounded for 6 months to rectify a few safety issues that were causing in-flight fires.

Soon after the DC-4, Lockheed developed the Constellation; this was a major development because it was the first airliner to have pressurization. This pressurization was very important because it allowed the planes to fly higher, and therefore further and faster than ever before. This had a fuselage that was about 127 inches wider than that of the DC-4. Like the DC-4 this plane also had a late entry to the civilian airline industry because they were used in the war and later converted for the airline industry. The Constellation did experience some safety concerns soon after it entered service, requiring it to be grounded for 6 months while the problems were investigated and repaired.

In 1947, an airliner from third company made its maiden voyage. The Boeing 377 Stratocruiser entered the industry with a completely different design than the planes from Douglas and Lockheed. This plane was based on the C-97 military transport plane, and had a double deck, and pressurized fuselage. This plane was known for the luxury that it had to offer as well as its ability to hold 100 passengers. There were only 55 Stratocruisers produced, but this plane was still incredibly important as nearly 900 of the C-97s were produced for the military.

The American companies had done a great job of advancing the status of transcontinental travel, but there was also the aging fleet of DC-3s that had to be addressed. Convair decided that they were going to address this market, and would begin producing the Convair 240 which was a 40 person fully pressurized plane. There were 566 of these planes that would fly, including 2 that were equipped with jet-assisted take off units. Convair would later develop the Convair 340, which was slightly larger and could accommodate between 44 and 52 passengers, and there were 311 of this model plane were produced. Finally Convair would create a Convair 440, which had small modifications including much better soundproofing than the previous models. Convair would experience a little bit of competition from the Martin 2-0-2 and Martin 4-0-4, but in general Convair was able to control this market, as the 2-0-2 was had safety concerns and was unpressurized, and the 4-0-4 only sold around 100 units.

The United States was dominant in this industry for several reasons including a large domestic market for these planes. The market would also work in the United States favor as the American companies began to build pressurized airliners. During the postwar years engines became much larger and more powerful, and safety features such as deicing, navigation, and weather were added to the planes. Lastly, the planes produced in the United States were more comfortable and had superior flight decks than those produced in Europe.

## **Postwar Airliner History in Great Britain**

Great Britain was in a very different position after the war than the United States. Unlike the United States, Great Britain had a small domestic market and almost all of the airplane construction that had take place domestically was for war. In December 1942 the British government had a committee put in place to set classifications for airplanes ranging from Non-Stop North Atlantic airplanes to Small Piston-engine airplanes for light traffic. These classifications were set up to encourage development of airliners of all types. In order to recover from the difficulties that this caused many of the postwar airliners were bombers that were converted to allow for commercial air travel, but this was not very economical as the planes could hold very few people. The first postwar program that was attempted in Great Britain was the Tudor airliner, however this was regarded as a failure due to safety concerns and few sales. The first successful British Airliner was a Vickers Armstrongs Viking. These were unpressurized and could hold between 21 and 27 people depending on the model. On April 6, 1948 one of these Viking airliners became the first jet-airliner to fly. The previous engines were now replaced with Rolls-Royce Nene Turbojets. In 1946 the Bristol 170 was the first transport aircraft to

receive a Certificate of Airworthiness from the British government. This plane remained in production for 12 years with 214 of the aircraft built. The British would also produce several smaller aircraft such as the Airspeed AS.57 Ambassador in 1947 and the Miles M.57 Aerovan in 1945. Most of the British planes produced in the postwar era were smaller planes that could hold less than 30 passengers, and did not sell as well as some of the planes produced in the United States, but these planes were enough to help the British airline industry from the lack of commercial production during the war.

### **Postwar Airliner History in France**

In the postwar years France developed a few significant airliners, some of these being planes that could land on water, part of the reason that the French companies were so focused on these flying boats is that in 1936 the French Air Ministry requested transatlantic flying boats that could hold at least 40 passengers. Only one model from this request would ever be put into service. The first set of these was 3 Latecoere 631's that Air France purchased and put into service in July 1947. However, two of these planes crashed, and the third plane was soon removed because of these safety concerns. There would later be a SNCASE SE.161 Languedoc build, which was a much more successful plane, and over 100 of these were built, with 40 of them being placed into service through Air-France. The French also developed the Breguet 763 Deux Ponts, which first flew in February 1949. This was a double-decker transport airliner that would end up being used for both people and cargo. This four-engine airliner would end up being used to hold massive amounts of cargo or 97 passengers.

### **Postwar Airliner History in the USSR**

Soon after the war most of the Soviet fleet of airliners consisted of DC-3s or the Lisunov Li-2. These planes were in desperate need of replacement, and in 1946 the Ilyushin Il-12 made its first flight. The Il-12 was very similar in design to American Convair 240, except was unpressurized. In 1953 the Ilyushin Il-14 would make its first flight, and this version was equipped with much more powerful engines. The main contribution that the Soviets made in regards to Airliners was the Antonov An-2. This plane is a bi-plane unlike most of the other airliners and sold more units than any other transport plane.

## Types



The Airbus A330 is a wide-body airliner

### Wide-body airliners

The largest airliners are *wide-body* jets. These aircraft are frequently called *twin-aisle aircraft* because they generally have two separate aisles running from the front to the back of the passenger cabin. Aircraft in this category are the Boeing 747, Boeing 767, Boeing 777, Airbus A300/A310, Airbus A330, Airbus A340, Airbus A380, Lockheed L-1011 TriStar, McDonnell Douglas DC-10, McDonnell Douglas MD-11, Ilyushin Il-86 and Ilyushin Il-96. These aircraft are usually used for long-haul flights between airline hubs and major cities with many passengers. Future wide-body models include the Boeing 787 and Airbus A350.

## Narrow-body airliners



The Boeing 757 is a narrow-body airliner

A smaller, more common class of airliners is the *narrow-body* or *single aisle* aircraft. These smaller airliners are generally used for medium-distance flights with fewer passengers than their wide-body counterparts.

Examples include the Boeing 717, 737, 757, McDonnell Douglas DC-9 and MD-80/MD-90 series, Airbus A320 family, Tupolev Tu-204, Tu-214, Embraer E-Jets 190&195 and Tu-334. Older airliners like the Boeing 707, 727, Douglas DC-8, Fokker F70/F100, VC10, Tupolev, and Yakovlev jets also fit into this category.

## Small airliners

Short haul airliners used by airlines and regional airlines



A JetBlue Airways Embraer 190 short haul airliner.



A PLUNA Bombardier CRJ900 short haul (regional) airliner taxiing.

*Regional airliners - Small (Regional) short haul airliners typically seat fewer than 100 passengers and may be powered by turbofans or turboprops.*



Direktflyg Jetstream 32 at Kristiansund Airport, Kvernberget

These airliners, though smaller than aircraft operated by most major carriers, legacy carriers, flag carriers, frequently serve customers who expect service, similar to that offered by the far larger airlines with their longer ranged larger jetliners. Therefore, these short haul airliners are usually equipped with lavatories, stand up cabins, pressurization, overhead storage bins, reclining seats, and have a flight attendant to look after the in-flight needs of the passengers upon point-to-point routes. Among some of earliest regional short haul airliners were the pre-airline deregulation Jetstream 31 aircraft.

**Feederliner aircraft used by regional airlines**



The Bombardier CRJ200



A Compass Airlines (North America) Embraer ERJ-170-200LR in the feederliner colors of Northwest Airlink

*Regional airliners - (Regional) Feederliners* typically seat fewer than 100 passengers and may be powered by turbofans or turboprops. These airliners, are the non mainline counterparts to the larger aircraft operated by the; major carriers, legacy carriers, and flag carriers and are used to feed traffic into the large airline hubs or focus cities. These particular routes may need the size of a smaller aircraft to meet the frequency needs and service levels, customers expect in the marketed product that is offered by larger airlines and their modern narrow and widebody aircraft. Therefore, most regional airliners are equipped with lavatories and have a flight attendant to look after the in-flight needs of the passengers, along with the features of a short haul regional airliner.

Typical aircraft in this category include the Bombardier CRJ and Embraer ERJ regional jets along with the "Q" (DASH-8) series, ATR 42/72 and Saab 340/2000 turboprop airliners. Airlines and their partners sometimes use these for flights between small hubs, or for bringing passengers to hub cities where they may board larger aircraft. Typically, these regional feederliners, are painted in the aircraft liveries and color schemes of the much larger airline partners so the regional airlines may offer and market a seamless transition between the larger airline to smaller airline.

## Commuterliner aircraft used by regional airlines and air taxi charter operators



The Beechcraft 1900 short range commuter aircraft

The lightest (light aircraft, list of light transport aircraft) of short haul regional feeder airliner type aircraft that carry 19 or fewer passenger seats are called *commuter aircraft*, *commuterliners*, *feederliners*, and *air taxis*, depending on their size, engines, how they are marketed, region of the world, and seating configurations. The Beechcraft 1900, for example, has only 19 seats. Depending on local and national regulations, a commuter aircraft may not qualify as an airliner and may not be subject to the regulations applied to larger aircraft. Members of this class of aircraft normally lack such amenities as lavatories and galleys and typically do not carry a flight attendant as an aircrew member.

Other aircraft that may fall into this category are the Fairchild Metro, Jetstream 31, and Embraer EMB 110 Bandeirante. The Cessna Caravan and Pilatus PC-12, are single-engine turboprops, sometimes used as a small airliner, although many countries stipulate a minimum requirement of two engines for aircraft to be used as airliners.

Twin piston-engined aircraft made by Cessna, Piper, Britten-Norman, and Beechcraft are also in use as short haul, short range commuter type aircraft.

## **Engines**

Until the beginning of the Jet Age, piston engines were common on propliners like the Douglas DC-3. Nearly all modern airliners are now powered by turbine engines, either turbofans or turboprops. Gas turbine engines operate efficiently at much higher altitudes, are more reliable than piston engines, and produce less vibration and noise. Prior to the Jet Age, it was common for the same or very similar engines to be used in civilian airliners as in military aircraft. In recent years, divergence has occurred so that it is now unusual for the same engine to be used on a military type as a civilian type. Usually military aircraft which share engine technology with airliners are transports or tanker types.

## **Airliner variants**

Some variants of airliners have been developed for carrying freight or for luxury corporate use. Many airliners have also been modified for government use as VIP transports and for military functions such as airborne tankers (for example, the Vickers VC10, Lockheed L1011, Boeing 707), air ambulance (USAF/USN McDonnell Douglas DC-9), reconnaissance (Embraer ERJ 145, Saab 340, Boeing 737), as well as for troop-carrying roles.

## **Layout**

Modern airliners are usually low-wing designs with engines mounted in underwing pods (usually two of them). For airliners, multi-engine design is mandated by some national regulations so that aircraft can continue to climb even in the worst case of power loss in one engine right after take-off. Another regulatory demand is that aircraft are able to fly a minimum specified amount of time after one engine fails in flight.

Mounting the engines underneath and to the fore of the wing moves weight from the fuselage to the wings, imposing less bending moment on them and allowing for a lighter wing structure. After this feature proved successful in military jets, Boeing introduced it to its 707 airliner design and it has been increasingly adopted since.

Mounting the engines in underwing pods also makes physical access for maintenance quicker and easier compared to tail-mounted engines.

Additionally, low wing design helps keep the engine nacelles and refueling valves closer to the ground to simplify access and the wing's surface acts as a barrier to prevent the engines' noise from reaching the fuselage in-flight.

Both Airbus and Boeing use this common layout for all of their current passenger aircraft and emerging manufacturers (e.g. Embraer and Sukhoi Superjet) follow the same scheme.

In a few special cases, where engine proximity to ground is detrimental (e.g. rural airfields with risk of foreign object damage or dirt), airliners will feature tail-mounted engines (e.g. MD-80 or Tu-334) or high-wing designs with underhung nacelles (e.g. BAe 146). These planes become rarer as almost all newly built airliners have underwing nacelles. Tail-engined designs are mostly used by business jet manufacturers.

Future airliners may feature innovative delta wing or lifting body outlines.

## Manufacturers



Assembly of a Boeing 757 airliner nose section

These include:

- Asia
  - China
    - Comac (includes Shanghai Aircraft Manufacturing Factory)
    - Shenyang Aircraft Corporation
    - Xi'an Aircraft Industrial Corporation
- Europe

- Airbus S.A.S. (formerly a multinational conglomeration of the largest European aerospace companies of France, Germany, Spain and the UK)
  - Czech Republic
    - Let Kunovice
  - France/Italy
    - ATR
  - Netherlands
    - Fokker (now defunct)
  - Russian companies (formerly Soviet-controlled)
    - Ilyushin
    - Sukhoi
    - Tupolev
    - Yakovlev
  - Sweden
    - Saab (no longer manufactures civilian aircraft)
  - Ukraine (formerly Soviet-controlled)
    - Antonov
  - United Kingdom
    - BAE Systems (formerly British Aerospace, no longer manufactures civilian aircraft)
    - Britten-Norman
- North America
  - Canada
    - Bombardier (includes the former De Havilland Canada and Canadair)
  - United States
    - Boeing (includes the former McDonnell Douglas company which itself included the Douglas Aircraft Company)
    - Lockheed Corporation (now part of Lockheed Martin, and no longer involved in civil aviation)
- South America
  - Brazil
    - Embraer

The international market for middle-sized and large-sized airliners is now divided between Airbus and Boeing, although Russian/former Soviet manufacturers still sell significant numbers of airliners to their traditional markets. Smaller-sized aircraft manufacturers include, in addition to these two, ATR, Embraer and Bombardier.

## Notable airliners



Notable airliners – a Boeing 747-400 "jumbo jet" of Qantas takes off



Notable airliners – an Airbus A380 "superjumbo" of Singapore Airlines takes off

- Boeing 247 – the first design to incorporate modern features such as all-metal construction and retractable landing gear
- Douglas DC-3 – still in service more than 70 years after its debut, it is generally regarded as one of the most significant transport aircraft ever made
- Douglas DC-6 – originally developed as a military transport, it was reworked for passenger service after World War II, a role it continues to perform today
- Boeing 377- Developed soon after World War 2, from the C-97 Stratofreighter, this was a luxurious double-decker airliner.
- Vickers Viscount – the first turboprop airliner to enter service
- Lockheed Constellation – a distinctive triple-tailed piston-engined airliner of the 1950s, it was one of the last large propeller-driven airliners
- De Havilland Comet – the world's first jetliner to reach mass production, its reputation was marred by a series of crashes due to structural failure
- Antonov An-2- Best selling transport airliner up to the point it was built.
- Sud Aviation Caravelle – one of the more successful European first-generation turbojet airliners
- Tupolev Tu-104 – the first turbojet airliner to provide sustained service, and the sole jetliner operating in the world between 1956 and 1958
- Boeing 707 – the first United States-built jetliner to enter production

- Douglas DC-8 – launched after the Boeing 707, it nevertheless established Douglas in the airliner market, and continues to serve as a cargo aircraft to this day
- Tupolev Tu-114 - long-range turbo-prop airliner and the world's largest and fastest passenger plane until 1968
- Tupolev Tu-154 - standard medium-range airliner for Russia (and others), carried half of all Soviet traffic since 1972 with 1015 built and the fastest airliner in service
- Ilyushin Il-62 - standard long-range airliner for Russia (and others) for three decades, first flight 1963 and still in service
- Boeing 727 – was the most produced commercial jet airliner in the world for over a decade, with 1,831 aircraft produced
- Douglas DC-9 – production of it and successive variants nearly reached 2,500
- Boeing 737 – currently the best selling civilian jet airliner
- Tupolev Tu-144 – the first supersonic transport aircraft constructed in Soviet Union
- Concorde – an Anglo-French supersonic transport, it remains the only supersonic aircraft to sustain a regular passenger service
- Boeing 747 "jumbo jet" – an iconic aircraft, it was the world's largest airliner between 1968 and 2005
- McDonnell Douglas DC-10 – a trijet competitor to the widebody 747
- Lockheed L-1011 TriStar – shared a similar configuration to the DC-10, but not its success, with only 250 produced
- Airbus A300 – the world's first twinjet widebody
- Airbus A320 – pioneered the use of fly-by-wire technology
- Airbus A340-600 - longest commercial airplane
- Boeing 777 – the first airliner designed entirely by computer, without physical mockups
- Airbus A380 "superjumbo" – the world's largest airliner from 2005 onwards
- Boeing 787 - the world's first jet airliner to make use of composite materials for most of its construction

## **Airliner recycling**

As airliners are very expensive, most are leased out for times typically from 20 to 40 years. Very few go back into service after a long lease is up because evolving aerospace technology leaves older airliners unable to compete against newer machines that can be operated at a lower cost. Many end-of-service airliners end up in the Mojave Desert, at the Mojave Air and Space Port (also known as "The Boneyard"). From this, the term "Mojave" has come to refer to the temporary storage of aircraft, e.g. during decreased demand for air travel and between short-term leases. Another airliner retirement location is Marana, Arizona.

While almost every airliner will be reduced to scrap (the exceptions end up as museum pieces or flown by collector groups) they may pass through many owners before they are retired. A well-maintained airliner can operate safely for decades, depending on how

often it is flown, its operating environment, and whether damage and wear and tear is properly repaired.

What may end an airliner's working life is a lack of spare parts, as the original manufacturer and third manufacturers may no longer provide or support them. Corrosion and metal fatigue are other issues that become more expensive to deal with as time goes on. Eventually, these factors and advances in aircraft technology lead to older airliners becoming too expensive or inefficient to operate.

To protect the environment, the Airbus company has set up a centre in France to decommission and recycle older aircraft. More than 200 airliners will finish active life each year, and will be dismantled and recycled under the newly established PAMELA Project.

## **Cabin configurations and features**



Interior of a Qatar Airways Airbus. Video systems (the vertical white panels) are visible above the very centre seats of the aircraft



Boarding an Airbus A380 at the Farnborough Airshow, 2006

An airliner will usually have several classes of seating: first class, business class, and/or economy class (which may be referred to as coach class or tourist class, and sometimes has a separate "premium" economy section with more legroom and amenities). The seats in more expensive classes are wider, more comfortable, and have more amenities such as "lie flat" seats for more comfortable sleeping on long flights. Generally, the more expensive the class, the better the beverage and meal service.

Domestic flights generally have a two-class configuration, usually first or business class and coach class, although many airlines instead offer all-economy seating. International flights generally have either a two-class configuration or a three-class configuration, depending on the airline, route and aircraft type. Many airliners offer movies or

audio/video on demand (this is standard in first and business class on many international flights and may be available on economy). Cabins of any class are provided with lavatory facilities.

## **Seats**

The types of seats that are provided and how much legroom is given to each passenger are decisions made by the individual airlines, not the aircraft manufacturers. Seats are mounted in "tracks" on the floor of the cabin and can be moved back and forth by the maintenance staff or removed altogether. Naturally the airline tries to maximize the number of seats available in every aircraft to carry the largest possible (and therefore most profitable) number of passengers.

Passengers seated in an **exit row** (the row of seats adjacent to an emergency exit) usually have substantially more legroom than those seated in the remainder of the cabin, while the seats directly in front of the exit row may have less legroom and may not even recline (for evacuation safety reasons). However, passengers seated in an exit row may be required to assist cabin crew during an emergency evacuation of the aircraft opening the emergency exit and assisting fellow passengers to the exit. As a precaution, many airlines prohibit young people under the age of 15 from being seated in the exit row .

The seats are designed to withstand strong forces so as not to break or come loose from their floor tracks during turbulence or accidents. The backs of seats are often equipped with a fold-down tray for eating, writing, or as a place to set up a portable computer, or a music or video player. Seats without another row of seats in front of them have a tray that is either folded into the armrest or that clips into brackets on the underside of the armrests. However, seats in premium cabins generally have trays in the armrests or clip-on trays, regardless of whether there is another row of seats in front of them. Seatbacks now often feature small color LCD screens for videos, television and video games. Controls for this display as well as an outlet to plug in audio headsets are normally found in the armrest of each seat.

## **Overhead bins**

The overhead bins are used for stowing carry-on baggage and other items. While the airliner manufacturer will normally supply a standard product, airlines may choose to have bins of differing size, shape, or color installed. Over time, these bins evolved out of what were originally overhead shelves used for little more than coat and briefcase storage. As concerns about falling debris during turbulence or in accidents increased, enclosed bins became the norm. Bins have increased in size in order to accommodate the larger carry-on baggage passengers may bring onto the aircraft. New bin designs may include a handrail, useful when moving through the cabin.

## **Passenger service units**

Above the passenger seats are Passenger Service Units (PSU). These typically contain reading lights, air vents, and a flight attendant call light. On most narrowbody aircraft (and some Airbus A300s and A310s), the flight attendant call button and the buttons to control the reading lights are located directly on the PSU, while on most widebody aircraft, the flight attendant call button and the reading light control buttons are usually part of the in-flight entertainment system. The units frequently have small "Fasten Seat Belt" and "No Smoking" illuminated signage and may also contain a speaker for the cabin public address system.

The PSU will also normally contain the drop-down oxygen masks which are activated if there is a sudden drop in cabin pressure. These are supplied with oxygen by means of a chemical oxygen generator. By using a chemical reaction rather than a connection to an oxygen tank, these devices supply breathing oxygen for long enough for the airliner to descend to thicker, more breathable air. Oxygen generators do generate considerable heat in the process. Because of this, the oxygen generators are thermally shielded and are only allowed in commercial airliners when properly installed – they are not permitted to be loaded as freight on passenger-carrying flights. ValuJet Flight 592 crashed on May 11, 1996 as a result of improperly loaded chemical oxygen generators.

## **Cabin pressurization**

Airliners developed since the 1940s have had pressurized cabins (or more accurately, pressurized hulls including baggage holds) to enable them to carry passengers safely at high altitudes where low oxygen levels and air pressure would otherwise cause sickness or death. High altitude flight enabled airliners to fly above most weather systems that cause turbulent or dangerous flying conditions, and also to fly faster and further as there is less drag due to the lower air density. Pressurisation is applied using compressed air, in most cases bled from the engines, and is managed by an environmental control system which draws in clean air, and vents stale air out through a valve.

Pressurization presents design and construction challenges to maintain the structural integrity and sealing of the cabin and hull and to prevent rapid decompression. Some of the consequences include small round windows, doors that open inwards and are larger than the door hole, and an emergency oxygen system.

To maintain a pressure in the cabin equivalent to an altitude close to sea level would, at a cruising altitude around 10,000 m (33,000 feet), create a pressure difference between inside the aircraft and outside the aircraft that would require greater hull strength and weight. Most people do not suffer ill effects up to an altitude of 1800–2500 m (6000–8000 feet), and maintaining cabin pressure at this equivalent altitude significantly reduces the pressure difference and therefore the required hull strength and weight. A side effect is that passengers experience some discomfort as the cabin pressure changes during ascent and descent to the majority of airports, which are at low altitudes.

## Cabin climate control

The air bled from the engines is hot and requires cooling by air conditioning units. It is also extremely dry at cruising altitude, and this causes sore eyes, dry skin and mucosa on long flights. Although humidification technology could raise its relative humidity to comfortable middle levels, this is not done since humidity promotes corrosion to the inside of the hull and risks condensation which could short electrical systems, so for safety reasons it is deliberately kept to a low value, around 10%.

## Baggage holds



An Airbus A320 baggage hold



Loading luggage onto a Boeing 747 at Boston Logan Airport, during a closure due to heavy snow



Boeing 747 front lower compartment. Note the rollers for ULDs on the floor and the partition labeled "Caution: Do Not Hit -- Potable Water Tank Inside".

Airliners must have space on board to store baggage that will not safely fit in the passenger cabin.

Designed to hold baggage as well as freight, these compartments are called "cargo bins", "holds", or occasionally "pits". Occasionally baggage holds may be referred to as **cargo decks** on the largest of aircraft. These compartments can be accessed through doors on the outside of the aircraft. Despite what is seen in many movies, access doors between passenger cabins and baggage holds are rare in modern airliners.

Depending on the aircraft, baggage holds are normally inside the hull and are therefore pressurized just like the passenger cabin although they may not be heated. While lighting is normally installed for use by the loading crew, typically the compartment is unlit when the door is closed.

Baggage holds on modern airliners are equipped with fire detection equipment and larger aircraft have automated or remotely activated fire-fighting devices installed.

## **Narrow-body airliners**

Most "narrow-body" airliners with more than 100 seats have space below the cabin floor, while smaller aircraft often have a special compartment separate from the passenger area but on the same level.

Baggage is normally stacked within the bin by hand, sorted by destination category. Netting that fits across the width of the bin is secured to limit movement of the bags. Airliners often carry items of freight and mail. These may be loaded separately from the baggage or mixed in if they are bound for the same destination. For securing bulky items "hold down" rings are provided to tie items into place.

## **Wide-body airliners**

"Wide-body" airliners frequently have a compartment like the ones described above, typically called a "bulk bin". It is normally used for late arriving luggage or bags which may have been checked at the gate.

However, most baggage and loose freight items are loaded into containers called Unit Load Devices (ULDs), often referred to as "cans". ULDs come in a variety of sizes and shapes, but the most common model is the LD3. This particular container has approximately the same height as the cargo compartment and fits across half of its width.

ULDs are loaded with baggage and are transported to the aircraft on dolly carts and loaded into the baggage hold by a loader designed for the task. By means of belts and rollers an operator can maneuver the ULD from the dolly cart, up to the aircraft baggage hold door, and into the aircraft. Inside the hold, the floor is also equipped with drive wheels and rollers that an operator inside can use to move the ULD properly into place. Locks in the floor are used to hold the ULD in place during flight.

For consolidated freight loads, like a pallet of boxes or an item too oddly shaped to fit into a container, flat metal pallets that resemble large baking sheets that are compatible with the loading equipment are used.

## Chapter 2

# Regional Airliner



A Flybe Bombardier Q400

A **regional airliner** or a **feederliner** is a small airliner designed to fly up to 100 passengers on short-haul flights, usually feeding larger carriers' hubs from small markets. This class of airliners are typically flown by the regional airlines that are either contracted by or subsidiaries of the larger airlines. Feederliner, commuter, and local service are all alternate terms for the same class of flight operations.

## History



The Douglas DC-3 first flew in 1935 and had a range of around 1,000 miles (1,625 kilometers.)

In the early days of aviation, most aircraft had a relatively short range so that all airlines were "regional" in nature. With the introduction of longer range aircraft, notably flying boats, these shorter range planes increasingly found their niche feeding the newer and longer range airliners by flying passengers to the mainline's airline hubs. Many of these smaller regional airlines were eventually bought by the larger flag carriers.

To keep these short routes economical, the airlines were generally unwilling to spend large amounts of money on new aircraft; they used what was available. Also, as new models slowly emerged, older aircraft were put into this service when they were replaced by progressively longer-range designs. In the immediate post-war era these were typically Douglas DC-3s, although even the De Havilland Dragon Rapide remained in service for some time. This "hand-me-down" process of supplying aircraft continued with designs like the Convair 440, Douglas DC-6 and Vickers Viscount also serving in this role while the first jets were introduced.

## Turboprop designs

By the mid-1950s, demand for even more economical designs led to the production of the first custom feederliners. These were almost always turboprops, which had fuel economy on par with piston engine designs, but had far lower maintenance costs. Often the time between engine overhaul periods was five times that of the best piston engines. Early examples of these designs include the Avro 748, Fokker F27 and Handley Page Dart Herald.

These designs were so successful that it was many years before newer designs bettered them enough to make it worthwhile to develop. There were a few exceptions, generally tailored to more specific roles. For instance, the Handley Page Jetstream (first flight in 1968) was intended for fewer passengers at much higher speeds, displacing smaller designs like the Beechcraft Queen Air. The Fairchild/Swearingen Metro (developed from the original Queen Air through a number of stages) filled a similar niche.



The De Havilland Dash 8-100

By the 1970s the first generation regional airliners were starting to wear out, but there had been little effort in producing new designs for this market. De Havilland Canada delivered its Dash 7 in 1978, but this was tailored more to the short-range and STOL

(Short Take-Off and Landing) role than as a regional airliner. Feedback from the airlines was fairly consistent, however, and De Havilland responded with the Dash 8 in 1984, which had economic benefits over the earlier generation machines, and was faster and quieter as well. Dash 8 sales were so strong that the company was unable to fund rebuilding the factory in order to meet demand, leading to a takeover by Bombardier.

In the early 1990's, the Dash 8's success sparked off development of a number of similar designs, including the ATR 42/72, Saab 340, Embraer Brasilia and Fokker F50. Consequently there were a relatively large number of aircraft offered by manufacturers in this sector of the market, pushing older 1950s designs from Fokker, Vickers and others into retirement. Due to the high level of competition, production of a number of these types ceased. Saab exited the civil aviation market and wrote its debts off, Daimler-Benz Aerospace "pulled the plug" on Dornier, and British Aerospace ended production of their BAe Jetstream 41 after 100 delivered. In 2006 only the ATR 42/72 models and the Dash 8 remain in production.

## Regional jets



A Bombardier CRJ700 in Delta Connection livery

Another reason for the downturn in the turboprop market was the introduction of the first regional jets. Although a number of small jets entered service in the 1950s and 60s, notably the Sud Aviation Caravelle, Fokker F28 and Yak-40, these could not compete in terms of cost of operation with the turboprop designs, and were suitable for routes with small numbers of passengers, as opposed to short routes where fuel economy was paramount. As engine technology improved, this difference continued to narrow, until the higher utilization factors due to higher cruising speeds erased any remaining advantage from lower operating costs.

The earliest example of a true short-range jet is the BAe 146, produced by BAE Systems. However, like the Dash 7 before it, the BAe 146 was tuned to a very specific market,

city-center to city-center service where low noise and excellent takeoff performance were paramount. Like the Dash 7, the market niche for this design proved to be fairly small, and its four engines meant it had higher maintenance costs than twin-engine designs. Unlike the Dash 7 example BAe did not respond by producing a twin-engine design that filled the same range requirements but offering lower operational costs.

This was addressed by Bombardier's twin-engine Canadair Regional Jet, which became a best-seller. The CRJ's range is enough to fill mid-range routes as well, routes previously served by larger aircraft such as the Boeing 737 and DC-9. These aircraft were originally intended to be used for direct airport-to-airport flights, bypassing hubs, and led to industry-wide discussions about the decline of the hub-and-spoke model. Although not as economical as the turboprop, by flying directly to and from smaller airports, they reduced the need for low-cost regional airliners. And although turboprops are quiet to outside observers, propwash makes them very noisy inside. Passengers greatly preferred jets, both for real and perception reasons.

As had happened with the turboprops of only a few years earlier, the success of the CRJ led to the introduction of a host of competitors. The only successful example is the Embraer ERJ 145, which has seen excellent sales and has competed strongly with the CRJ in most markets. Bombardier and Embraer have been locked in a series of counter-lawsuits over export taxes and subsidies ever since. The ERJ's success led to a totally new version, the Embraer E-Jets series, which Bombardier chose not to compete against until recently, with the announced Bombardier CSeries.

Other competitors have not been successful. Fairchild Dornier introduced the Fairchild Dornier 328JET to compete, but went bankrupt soon afterwards and the type did not enter large scale production. Their bankruptcy also ended development of the more competitive Fairchild-Dornier 728, which had attracted strong airline interest. The CRJ/ERJ also resulted in the end of the BAe 146 line.

The CRJ and ERJ success also played a minor part in the failure of Fokker, whose Fokker 100 found itself squeezed on both sides by new models of the Boeing 737 and Airbus A319 on the "large" side and the RJs on the "small side". Bombardier turned down the chance to purchase Fokker's assets, feeling that the 100-seat market was already saturated by designs like the A319.

The Sukhoi Superjet 100, a 60 to 95-seat jet developed by the Russian aerospace firm Sukhoi with assistance of Ilyushin and Boeing, is undergoing the certification process in 2010 so no commercial orders have been fulfilled yet. The Antonov An-148 entered service in 2009 but it remains to be seen if it will have any success in a market that has been fairly hesitant to adopt aircraft from the former Soviet Union.

## Recent changes



CityJet is a European regional airline operating services on behalf of its owner Air France. This is a British Aerospace 146-200.

In 2005, the "regional jet" boom suddenly collapsed, as increasing fuel prices and airline bankruptcies led to a rethinking of route structures. The high per-seat operational costs of the classic 50-seat regional jet have been exacerbated by an environment of ever-lowering fares. Furthermore, RJs increasingly were assigned to operate flights of two hours or more. This led to angry passengers, as their comfort and ergonomics compare unfavorably to the larger "mainline" jets which they replaced on these flights.

Further, the replacement of the hub-and-spoke model simply never took place. The economics and routing advantages of this mode of operation were simply too great. As the hub-and-spoke model has always been supported by low-cost regional airliners, turboprop designs once again became a major market. Improving their attractiveness in relation to the jets was the introduction of active noise-reduction systems, which reduced cabin noise to levels comparable, or even lower, than the RJ's. Bombardier found their Dash 8 to be in high demand once again, and shifted production to their latest model, the Bombardier Q400.

In late 2005, Bombardier suspended its CRJ-200 production line. The new trend is for larger aircraft with better economics, exemplified by Bombardier's 70-seat CRJ-700 and the 70-110-seat E-Jets series. The E-Jets in particular blur the line between "mainline" and "regional," as their cabin comfort is comparable or superior to traditional narrowbody jets like the Boeing 737 and Airbus A320 while offering ranges of over 2,000 miles. By

comparison, the original DC-9 jet aircraft were designed to seat approximately 75 passengers.

Regional airliners are also being blamed for flight delays in the US. According to the Wall Street Journal, 30% of flights in June 2007 were late by an average of 62 minutes. The delays are being blamed on an increased number of smaller aircraft, which the airlines are using in order to fill out schedules and provide more flights per day. This has led to the grounding of 385 larger aircraft and the adding of 1,029 regionals over the period from 2000 to 2006. The downside to this approach is that airports are running out of gates, causing delays as aircraft queue up for this limited resource.

## Features

Seating on regional airliners tends to be narrow and tight, and passengers typically are restricted from bringing on board carry-on items which would fit without difficulty in the overhead bins of larger aircraft. Often carry-on luggage is collected immediately prior to boarding and placed in the cargo hold, where it can be quickly retrieved by the ground staff while the passengers exit. While designed primarily for medium stage lengths, RJs may now be found supplementing major trunk routes alongside traditional larger jet aircraft. RJs allow airlines to open new "long, thin" routings with jet equipment which heretofore did not exist, such as Atlanta to Monterrey, Nuevo León. RJs have also meant a return of jet service to cities where full-size jet service had departed over a decade ago, such as Macon, Georgia, and Brownsville, Texas.

The notion that regional jet aircraft are less expensive (per seat mile) than traditional jets is a common misconception. On a seat-mile basis the RJ's cost is in fact higher. Regional jets are operated in the USA under a fee-per-departure payment structure. In this payment structure, a traditional airline contracts with a regional airline company on a per departure or per flight basis regardless of the number of passengers or the length of the flight. The traditional airline gets to keep all the revenue from the ticket sale and only pays the regional partner the agreed to amount. These contracts tend to be long term agreements, typically 10 year terms. The regional airline partner can then be relatively sure of the revenue side and only has to control cost in order to earn a modest return. However, these "regional airlines," now really "small jet providers" of contracted aircraft, have been squeezed by U.S. airline bankruptcies, fleet reductions and increasing operating costs. U.S. Legacy carriers have no longer been willing to shoulder burdensome losses from guaranteed-profit contracts with their small jet providers, and accordingly have played carrier against carrier in a low-bid game that has left hundreds of RJs idle and others potentially on their way to being laid up.

The idea that regional jets would provide point-to-point service and bypass the hub-and-spoke system may not be materializing as it was expected. As of January 2003, 90% of all regional jet flights in the United States had a hub or major airport at one end of that flight, and this number has been gradually increasing since 1995.

## Chapter 3

# Jet Airliner



A widebody jet airliner, the Boeing 777



Cutaway of an Airbus A300 jet airliner showing cabin and cargo deck

A **jet airliner** is an airliner that is powered by jet engines. This term is sometimes contracted to **jetliner** or jet.

In contrast to today's relatively fuel-efficient, turbofan-powered air travel, first generation jet airliner travel was noisy and fuel inefficient. These inefficiencies were addressed by the invention of turboprop and turbofan engines.

## Early history



Nene test-bed Lancastrian demonstrating in 1954 on the two jets with the two inner Merlins feathered

The first airliners with turbojet propulsion were experimental conversions of the Avro Lancastrian piston engined airliner, which were flown with several types of early jet engine, including the de Havilland Ghost and the Rolls-Royce Nene, however these retained the two inboard piston engines, the jets being housed in the outboard nacelles and these aircraft were therefore of 'mixed' propulsion. The first airliner with full jet power was the Nene-powered Vickers VC.1 Viking *G-AJPH*, which first flew on the 6 April 1948.

## First generation

The first purpose-built jet airliner was the de Havilland Comet which first flew in 1949 and entered service in 1952. Also developed in 1949 was the Avro Jetliner, and although it never reached production, the term jetliner caught on as a generic term for all passenger jet aircraft.

These first jet airliners were followed some years later by the Sud Aviation Caravelle, Tupolev Tu-104 (2nd in service), Boeing 707, Douglas DC-8, and Convair 880. National prestige was attached to developing prototypes and bringing these first generation designs

into service. There was also a strong nationalism in purchasing policy, such that the Boeing and Douglas products became closely associated with Pan Am, while BOAC ordered British made Comets.

These two airlines with strong nautical traditions of command hierarchy rank and chain of command, retained from their days of operations with flying boats, undoubtedly were quick to capitalize upon, with the help of advertising agencies, the linkings of the "speed of jets" with the safety and secure "luxury of ocean liners" among public perception.

Aeroflot used Soviet Tupolevs, while Air France introduced French Caravelles. Commercial realities dictated exceptions, however, as few airlines could risk missing out on a superior product: American airlines ordered the pioneering Comet (but later cancelled when the Comet ran into fatigue problems), Canadian, British and European airlines could not ignore the better operating economics of the Boeing 707 and the DC-8, while some American airlines ordered the Caravelle.



DH.106 Comet 1 of BOAC at London Heathrow on 2 June 1953

Boeing became the most successful of the early manufacturers. The KC-135 Stratotanker and military versions of the 707 remain operational, mostly as tankers or freighters. The basic configuration of the Boeing, Convair and Douglas aircraft jet airliner designs, with widely spaced podded engines under slung on pylons beneath a swept wing, proved to be the most common arrangement and was most easily compatible with the large-diameter high-bypass turbofan engines that subsequently prevailed for reasons of quietness and fuel efficiency.

The de Havilland and Tupolev designs had engines incorporated within the wings next to the fuselage, a concept that endured only within military designs while the Caravelle pioneered engines mounted either side of the rear fuselage.

## Second generation



Tupolev Tu-154M

In the 1960s, when jet airliners were powered by slim, low-bypass engines, many aircraft used the rear-engined, T-tail configuration, such as the BAC One-Eleven, Douglas DC-9 twinjets; Boeing 727, Hawker Siddeley Trident, Tupolev Tu-154 trijets; and the paired multi-engined Ilyushin Il-62, and Vickers VC10 whose engines were mounted upon the aft fuselage. This engine arrangement survives into the 21st century on numerous twin engined Douglas DC-9 derivatives plus newer short haul and range turbofan powered regional aircraft such as the "regional jet airliners" built by Bombardier, Embraer and, until recently, Fokker. However other "jetliner" developments, such as the concept of rocket assisted takeoffs RATO, and the briefly mentioned water-injection as used and tested upon first generation passenger jets, as well as trailing edge mounted powerplants, afterburners also known as reheat used upon supersonic jetliners (SSTs) such as Concorde and the Tupolev Tu-144, likewise have been relegated to the past.

For business jets, the rear-engined universal configuration pioneered by the turbojet powered early Learjet 23, North American Sabreliner, and Lockheed JetStar is common practice on smaller bizjet aircraft as the wing is too close to the ground to accommodate underslung engines. This is as opposed to early generation jet airliners, whose design engineers slung jet engines on the rear to increase wing lift performance and at the same time reduce cabin noise of the lower bypass "turbojet" engines.

## Present day



An Airbus A340-600 on final approach. Notice the fourth undercarriage under the fuselage belly.

Airliner descriptions are commonly broken down into the distinctions of the generally long-haul civilian passenger jumbo and, widebody jet airliners, and short-haul civilian passenger "jet" airliners. Among some of these categories included among the short-haul civilian passenger "jets" are both longer and shorter ranged "narrow-body jet and regional jet types." Semantically, the terms "civilian" "turbine powered" "jet" "passenger" "air" "liner" aircraft are routinely dropped from these various terms to accurately describe "jet aircraft" which can lead to confusion among those practicing language purity. It is also referenced in the Paul Pena song, "Jet Airliner (song)", made famous by the Steve Miller Band.

## Chapter 4

# Australian Airliners

## de Havilland Australia DHA-3 Drover

### DHA-3 Drover



DHA-3 Mk. 2 Drover

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<b>Role</b>	short-haul airliner
<b>Manufacturer</b>	de Havilland Australia
<b>First flight</b>	1948
<b>Introduced</b>	1949
<b>Status</b>	Four registered in Australia Royal Flying Doctor Service of
<b>Primary users</b>	Australia Qantas
<b>Produced</b>	1949-1953
<b>Number built</b>	20
<b>Unit cost</b>	£14,000
<b>Developed from</b>	de Havilland Dove

The **de Havilland Australia DHA-3 Drover** is a small transport aircraft that was built by de Havilland Australia (DHA) in the 1940s and 1950s. The aircraft had some similarities with the two-engine British-built de Havilland Dove but used a trimotor configuration.

## Design and development

Design work on the DHA-3 began in 1946 after DHA identified a need to replace the de Havilland Dragon biplane then in widespread use in Australia. Although the British parent company's Dove was being produced at the same time, DHA saw that the Dove was not entirely suitable for Australian conditions. Using the Dove as a starting point, DHA designed an aircraft with three four-cylinder Gipsy Major engines instead of the Dove's two Gipsy Queen six-cylinder engines and a fixed tailwheel undercarriage instead of the Dove's retractable tricycle undercarriage. Like the Dove the DHA-3 was sized to carry 8 to 9 passengers with a single pilot.

The result was an aircraft with the same wingspan as the Dove and a slightly shorter fuselage. The name 'Drover' was selected by Sir Geoffrey de Havilland after suggestions for a name were invited from DHA employees. Mr Thomas King from the Drawing Office came up with the winning name. The first **DHA-3 Mk. 1** Drover took to the air at Bankstown Airport on 23 January 1948 piloted by Brian (Black Jack) Walker, DHA's chief test pilot. The second aircraft did not fly until December 1949, while the first aircraft was delivered in October that year.

After entering service, by 1952 the type's shortcomings were becoming apparent. These included the aircraft's lack of power, especially in hot weather, and an unfortunate tendency for propellers to fail in-flight, resulting in the loss of two aircraft. The propeller problem was overcome by replacing the de Havilland variable-pitch propellers with Fairey Reed fixed-pitch propellers, modified aircraft being re-designated the **DHA-3 Mk. 1F**. All but the three aircraft that had crashed by that time were brought to this standard. The propeller change however did nothing to improve the type's performance. In a bid to improve lift all Mk. 1F aircraft were further modified with double slotted flaps in place of plain flaps, and were once again re-designated, this time as the **DHA-3 Mk. 2**.



A Mark 2 Drovver with Gipsy engines and fixed-pitch propellers



The Powerhouse Museum's DHA-3 Mk. 3a Drovver at Bankstown



Drover 3B, with Lycoming engines, at Bankstown in 1970

Sixteen aircraft had been delivered by the end of 1952, but the problems suffered by the type stalled further sales for several years. The last four of the twenty Drovers built were produced in 1953 but were not sold until 1955 and 1956. In another bid to rectify the type's poor performance DHA re-engined seven Mk. 2 aircraft with Lycoming O-360 horizontally-opposed engines driving Hartzell feathering constant-speed propellers. Changes were also made to the flap control system and the tail wheel assembly. The first modified aircraft, re-designated as a **DHA-3 Mk. 3**, was returned to its owner the Royal Flying Doctor Service of Australia (RFDS) on 4 June 1960. Three Mk. 3s were later further modified; two aircraft operated by the NSW Section of the RFDS were modified in 1962 as the **Mk. 3a** with the tailplane altered to have seven degrees of dihedral (14° according to one source) and the span increased by 2 ft (61 cm). The third was modified as a **Mk. 3b** with an increase in MTOW of 300 lb (137 kg) to 6,800 lb (3,087 kg).

## Operational history

### New aircraft deliveries

The type entered service with the Australian Department of Civil Aviation (DCA, now the Civil Aviation Safety Authority) in 1949, the DCA operating the first two aircraft. Qantas and the RFDS took delivery of their first aircraft in 1950, eventually receiving five and six new aircraft respectively. Qantas placed the Drover into service on its routes in what was then known as the Territory of Papua and New Guinea. Like many other

aircraft types before and since, the Drover was inadequate in the demanding operating conditions of the island and of the surviving four aircraft, three left Qantas service in 1954 and 1955. The last was retired by Qantas in 1960. The surviving DCA aircraft was also withdrawn and offered for sale in the latter 1950s and was sold at the end of 1959.

Trans Australia Airlines (TAA) briefly evaluated the prototype for a month in late 1950 and then received the first two of its eventual three new Drovers in 1952 (the third was delivered in 1956). TAA operated them on scheduled services in Queensland and as air ambulance aircraft, one of them as one of the six used by the RFDS. One aircraft crashed in January 1952 only five weeks after delivery and the other two were transferred to the RFDS in 1963 and 1964. The last main operators of new Drovers were the Australian Department of Health, which used two on outback aeromedical operations (one crashing in 1957); and Fiji Airways, which took delivery of two aircraft built for Qantas but refused by that company when the type's problems became apparent. The last aircraft built was delivered as a Mk. 2 to a private individual in July 1956.

### **Propeller problems**

On 16 July 1951 the third Drover built (registration VH-EBQ in service with Qantas), crashed off the coast of New Guinea (in the Huon Gulf near the mouth of the Markham River) after the centre engine's propeller failed. The pilot and the six passengers on board were killed. As of November 2008 this was the last fatal accident suffered by Qantas. At the time of the crash the aircraft was only ten months old.

The prototype Drover VH-DHA operated by the Australian Department of Civil Aviation was ditched in the Bismarck Sea between Wewak and Manus Island on 16 April 1952. The port propeller failed, a propeller blade penetrated the fuselage and the pilot was rendered unconscious; the ditching was performed by a passenger. On this occasion the three occupants survived the ordeal to be rescued.

A third aircraft (VH-EBS, also owned by Qantas) suffered a propeller failure while still on the ground in September the same year.

### **Later operations**

The RFDS had its Drovers modified to Mk. 3 standard in the early 1960s and operated the type until late in the decade when more modern aircraft such as the Beechcraft Queen Air were acquired. The seventh Mk. 3 was acquired second-hand from the Department of Health by the RFDS as a Mk. 2 and then modified. The RFDS Mk. 3s were configured to carry the pilot, two medical staff and two stretcher patients and were operated in the Northern Territory and outback New South Wales and Queensland.

The Drover became fairly well-travelled for an Australian design; apart from their initial use in Australia, New Guinea and Fiji already mentioned; second-hand Drovers were registered in the Western Pacific Islands (Solomon Islands) and operated by **New Hebrides Airways Ltd.** and **Air Melanesiae** in the New Hebrides, and others were

registered in New Zealand and the United Kingdom in addition to further examples making their way to Fiji.

By the end of the 1950s only nine Drovers were still in airline service worldwide. The last Drover to operate scheduled airline services was withdrawn from use by Mercury Airlines in New Zealand in the mid-1970s when it was replaced by a Cessna 207.

The final Drover built was modified in the late 1960s as an agricultural aircraft, flying for several years from Toowoomba, Queensland with a large hopper installed in the cabin. This Mk. 2 Drover is still airworthy in 2008 and is operated as VH-DHM from Illawarra Regional Airport by the **Historical Aircraft Restoration Society** on behalf of **Hawker de Havilland Aerospace**, now a part of Boeing.

Despite the small number produced the Drover survives in healthy numbers; in addition to VH-DHM already mentioned another three are on the Australian civil aircraft register as of November 2008 - a Mk. 3 and two Mk. 2s. Another Mk. 2, a composite of the 10th and 17th aircraft built, is on display at the RFDS Base at Mount Isa, Queensland while one of the Mk. 3a aircraft (owned by the Powerhouse Museum) can be seen at the **Australian Aviation Museum** at Bankstown Airport. The **Central Australian Aviation Museum** at Alice Springs has a Mk. 3 in its collection. Another Mk. 2 was in a museum at Lasham in England until its closure. It is now in 'storage' at Parkhouse Engineering in Booker nr. High Wycombe. and the **Queensland Air Museum** at Caloundra has two Mk. 3s.

## Variants

- **Drover Mk. 1:** Manufactured with variable-pitch propellers.
- **Drover Mk. 1F:** Modified with fixed-pitch propellers.
- **Drover Mk. 2:** Modified with double-slotted flaps.
- **Drover Mk. 3:** Re-engined with three Lycoming O-360-A1A horizontally-opposed engines.
  - **Mk. 3a:** Fitted with modified tailplane of increased span and dihedral.
  - **Mk. 3b:** MTOW increased to 6,800 lb (3,087 kg).

## Chapter 5

# Brazilian Airlines

## Embraer E-Jet family

### E-Jet family



An Air Canada E-175 departs Montréal-Pierre Elliott Trudeau International Airport

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<b>Role</b>	Airliner
<b>National origin</b>	Brazil
<b>Manufacturer</b>	Embraer
<b>First flight</b>	February 19, 2002
<b>Introduced</b>	March 2004, LOT Polish Airlines
<b>Primary users</b>	Republic Airways Air Canada JetBlue Airways Compass Airlines
<b>Number built</b>	713 (January 2011)
<b>Unit cost</b>	US\$28.5–40.0 million (2010)
<b>Variants</b>	Embraer Lineage 1000

The **Embraer E-Jets** are a series of narrow-body, twin-engine, medium-range, jet airliners produced by Embraer, a Brazilian aerospace conglomerate that produces

commercial, military, and corporate aircraft. Announced at the Paris Air Show in 1999, and entering production in 2002, the aircraft series has been a success. As of September 30, 2010, there is a backlog of 245 firm orders for the E-Jets and 747 options. The manufacturer reported that 671 units had been delivered by September 30, 2010, and predicted that by the end of 2016, more than 1,100 units would be delivered.

## **Design and development**



Interior of an Embraer E-170



Azul Brazilian Airlines E-195 at Campinas International Airport

The Embraer E-Jets line is composed of two main commercial families and a business jet variant. The smaller E-170 and E-175 make up the base model aircraft, with the E-190 and E-195 being stretched versions, with different engines and larger wing and landing gear structures. The 170 and 175 share 95% commonality, as do the 190 and 195. The two families share near 89% commonality, with identical fuselage cross-sections and avionics, featuring the Honeywell Primus Epic EFIS suite.

Although commonly referred to with simply an "E" prefix, the jets are technically still Embraer Regional Jets ("ERJ"s). Embraer dropped the ERJ prefix in its advertising early in production. The E-190/195 series of aircraft have similar capacities to the initial versions of the DC-9 and Boeing 737, which have always been considered mainline airliners. Embraer developed an innovative "double-bubble" design for its commercial passenger jet airplanes that provides stand-up headroom. Embraer E-Jets use four-abreast seating.

The launch customers for the aircraft were the French Régional Compagnie Aérienne Européenne with ten orders and five options for the E-170, and the Swiss Crossair with an order for 30 E-170s and 30 E-190s. The largest single order for any type of E-Jets has come from JetBlue with 100 orders for the E-190, and options for 100 more. JetBlue set the record for the longest flight of the E190 family on November 6, 2008, when aircraft N239JB made a non-stop flight from Anchorage, Alaska (ANC) to Buffalo, New York (BUF), a total of 2,694 nmi (4,989 km). This was an empty aircraft on a non-revenue

flight, the aircraft eventually returning to JFK after a two-month-long charter service with Vice Presidential candidate Sarah Palin.

## Variants

### E-170 and 175



Virgin Blue E-170



Embraer E-175, in company demonstrator colours, at Ottawa International Airport

The E-170/E-175 family is the smaller of the two E-Jet families. The E-170 and E-175 directly compete with the Bombardier CRJ-700 and Bombardier CRJ-900, respectively. They also loosely compete with the turboprop Bombardier Q400. It also seeks to replace the market segment occupied by earlier competing designs such as the BAe 146 and Fokker 70. The 170 and 175 are powered with GE CF34-8E engines of 14,200 pounds (62.28 kN) thrust each.

The Embraer 170 was the first version produced. The prototype was rolled out on 29 October 2001, with first flight 119 days later on February 19. The aircraft was displayed to the public in May 2002 at the Regional Airline Association convention. After a positive response from the airline community, Embraer launched the E-175. First flight of the stretched E-175 was on June 2003. Certification for the 170 took nearly 2 years after the public debut; delivery of the first E170 aircraft to the launch customer LOT Polish Airlines was in March 2004. The first E-175 was delivered to Air Canada and entered service in July 2005.

## E-190 and 195



Rollout of the Embraer 190 at Embraer's São José dos Campos plant on 9 February 2004



Flybe E-195

The E-190/195 family is a larger stretch of the E-170/175 family fitted with a new, larger wing and a new engine, the GE CF34-10E, rated at 18,500 lb (82.30 kN). These aircraft compete with the Bombardier CRJ-1000. In addition, being in the 100-seat range, it competes with smaller mainline jets including the Boeing 717-200, and 737-500/-600 the Airbus A318, and the upcoming Bombardier CSeries.

The first flight of the E-190 was on March 12, 2004, with the first flight of the E-195 on December 7 of the same year. The launch customer of the E-190 was New York-based low cost carrier JetBlue with 100 orders and 100 options. British low cost carrier Flybe launched the E-195 with 14 orders and 12 options.

As the 190/195 family is of mainline aircraft size, many airlines will operate them as such, fitting them with a business class section and operating them themselves, instead of having them flown by a regional airline partner. For example, Air Canada operates 45 E-190 aircraft fitted with 9 business-class and 84 economy-class seats as part of their primary fleet.

### **Embraer Lineage 1000**

On 2 May 2006, Embraer announced plans for the business jet variant of the E-190. This would have the same structure as the E-190, but with an extended range of up to 4,200 nm, and luxury seating for up to 19. The Argentine Air Force ordered one for its Presidential fleet. It was certified by the USA Federal Aviation Administration on 7 January 2009. The first two production aircraft were delivered in December 2008.

### **E-195X**

Embraer considered producing an aircraft which was known as the E-195X, a stretched version of the E-195. It would have seated approximately 130 passengers. The E-195X was apparently a response to American Airlines' request for a replacement for their MD-80s. Embraer abandoned plans for the 195X in May 2010, following concerns that its range would be too short.

## **Operators**

- **Embraer 170** (or EMB 170-100) - In October 2010 180 Embraer 170 aircraft (all variants) are in airline service, with 11 orders. Major operators include: Republic Airlines (48), Shuttle America (28), Saudi Arabian Airlines (15), EgyptAir Express (12), LOT Polish Airlines (10) and Australia's Virgin Blue (6). About 15 airlines operate the type in smaller numbers.
- **Embraer 175** (or EMB 170-200) - In October 2010, 130 Embraer 175 aircraft are in airline service, with 43 further orders. Major operators include Air Canada with 15 aircraft and LOT Polish Airlines with 12 aircraft. Major firm orders include 54 aircraft for Republic Airlines, which controls Frontier Airlines and Midwest Airlines, and 36 aircraft for Compass Airlines (a subsidiary of Delta Air Lines). Flybe, the British airline, ordered 35 Embraer 175 with options for an extra 60 and "purchase rights" for 40 more at the 2010 Farnborough airshow.
- **Embraer 190** (or EMB 190-100) — In October 2010, 301 Embraer 190 aircraft (all variants) are in airline service, with 156 orders. Operators include Air Canada with 45 aircraft (with options for 60 more), JetBlue Airways with 47 aircraft (104

firm orders), AeroMéxico Connect ordered 16 aircraft (with 15 options), Australia's Virgin Blue (14) and Nas Air (Saudi Arabia) (4). Other orders include 32 aircraft for US Airways and 20 for Austral Líneas Aéreas (Argentina).



Lufthansa Cityline E195LR

- **Embraer 195** (or EMB 190-200) — In October 2010 60 Embraer 195 aircraft (all variants) are in service and 35 firm orders. Major operators are Flybe (14), Lufthansa CityLine (15), Air Europa (5), Nas Air (2), Royal Jordanian (2). Azul Brazilian Airlines have 36 firm orders for the aircraft.

# Embraer ERJ 145 family

## ERJ 135/ERJ 140/ERJ 145



An **ERJ 145** of Air France Régional

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<b>Role</b>	Regional airliner
<b>Manufacturer</b>	Embraer
<b>First flight</b>	August 11, 1995
<b>Introduction</b>	December 1996
<b>Status</b>	In Service
<b>Primary users</b>	ExpressJet Airlines (As Continental Express) American Eagle Airlines
<b>Produced</b>	1989-present
<b>Number built</b>	1100+, 2009
<b>Developed from</b>	Embraer EMB 120 Brasilia
<b>Variants</b>	R-99 and P-99 Embraer Legacy 600

The **Embraer ERJ 145 family** is a series of regional jets produced by Embraer, a Brazilian aerospace company. Family members include the **ERJ 135** (37 passengers), **ERJ 140** (44 passengers), and **ERJ 145** (50 passengers), as well as the **Legacy** business jet and the **R-99** family of military aircraft. The ERJ 145 is the largest of the group. Each jet in the series is powered by two turbofan engines. The family's primary competition comes from the Bombardier CRJ regional jets.

# Development

## Early design

The ERJ 145 was launched at the Paris Airshow in 1989 as a stretched and turbofan-powered modification of the EMB 120 Brasilia. Key components of this design included:

- Straight wing (with winglets)
- Rear Fuselage-mounted engines
- Range of 2500 km
- 75% parts commonality with the EMB 120.

## Interim design



Embraer ERJ 145 of Air France Régional



Embraer ERJ-145 of Aeroméxico Connect



Embraer ERJ 145 of BMI in planform view



Embraer ERJ 145XR wing with winglet detail

By 1990, Embraer engineers found that results from wind-tunnel testing were less than satisfactory, and began considering a significantly different design from the EMB 120. The proposed modified design included a slightly ( $22.3^\circ$ ) swept wing with winglets, as well as engines mounted in underwing nacelles. This second design showed markedly better aerodynamic performance, but the combination of swept wings and wing-mounted engines required an unusually high (and therefore heavy) undercarriage.

### **Production design**

The design evolved until late 1991, at which time it was frozen. Though the aircraft went through many alterations before it was finalized, it did retain a few of the original influences of the EMB 120 such as the three abreast seating (2+1) configuration which was a similar configuration used for the Embraer/FMA CBA 123 Vector design which never reached production. The key features of the production design included:

- Rear fuselage-mounted engines
- Swept wings (no winglets)
- "T"-tail configuration
- Range of 2500 km

The company was seen to be at a disadvantage due to the delay in bringing the aircraft to service, partly because of the change in the aircraft's design. The first design was intended to retain as much commonality as possible with the EMB 120. However, the aircraft has sold well thus overcoming the initial setbacks. Embraer delivered 892 units of all variants through 2006, and predicts that another 102 units will be delivered in the 2007-2016 time period.

## **Derivatives**

The ERJ 140 is based on the ERJ 145 with 96% parts commonality and the same crew type rating. The only significant changes are a shorter fuselage, a slightly derated engine and an increased range. At launch, Embraer estimated the cost of an ERJ 140 to be approximately US\$15.2 million. The estimated cost of development of the ERJ 140 was US\$45 million. The ERJ 135, with a service entry date of 1999, has 95% parts commonality with the ERJ 145, but is 11.7 feet (3.6 m) shorter.

The ERJ 145 seats 50 passengers, the ERJ 140 seats 44, and the ERJ 135 seats 37. The ERJ 140 was designed with fewer seats in order to meet the needs of some major United States airlines, which have an agreement with the pilot union as to the number of 50-seat aircraft that can be operated in their mixed fleets.

In 2003, Embraer entered a partnership with the Harbin Aircraft Manufacturing Corporation of Harbin, China. The resulting company, Harbin Embraer, began producing the ERJ 145 for the Chinese market by assembling complete knock down kits premanufactured by other worldwide Embraer operations.

## **Operations**

The first flight of the ERJ 145 was on August 11, 1995, with the first delivery in December 1996 to ExpressJet Airlines (then the regional division of Continental Airlines). ExpressJet is the largest operator of the ERJ 145, with 270 of the nearly 1000 ERJ 145s in service. The second largest operator is American Eagle, with 206 ERJ 145 aircraft. Chautauqua Airlines also operates 95 ERJ 145s through its alliances with American Connection, Delta Connection, US Airways Express, Continental Express, United Express and Athens Airways .

By some accounts, the ERJ 145 has a cost of ownership of about \$2,500,000 per year.

In March 2007 ExpressJet entered into a short-term agreement to operate some regional routes for JetBlue Airways using its ERJ 145 aircraft.

The ERJ 140 was introduced in September 1999, first flew on June 27, 2000 and entered commercial service in July 2001. American Eagle Airlines, the regional jet subsidiary of American Airlines, operates the majority of the ERJ 140s built, including the first to be delivered, N800AE. Chautauqua Airlines also operate the ERJ 140.

As of early 2005, 74 ERJ 140s had been delivered.

This version is marketed as **ERJ 140**, but on the company's internal documents and on Federal Aviation Administration certification, the version is designated **EMB 135KL**.

## Variants

### Civilian models



City Airline Embraer ERJ 135



Embraer ERJ 145 of the Brazilian Federal Police

- **ERJ 135ER** - Extended range, although this is the Baseline 135 model. Simple shrink of the ERJ 145, seating thirteen fewer passengers, for a total of 37 passengers.
- **ERJ 135LR** - Long Range (increased fuel capacity and upgraded engines).
- **ERJ 140ER** - Simple shrink of the ERJ 145, seating six fewer passengers, for a total of 44 passengers.
- **ERJ 140LR** - Long Range (increased fuel capacity (5187 kg) and upgraded engines).
- **ERJ 145STD** - The baseline original
- **ERJ 145EU** - Model for European market. Same fuel capacity as 145STD (4174 kg) but an increased MTOW 19990 kg
- **ERJ 145ER** - Extended Range, although this is the Baseline 145 model.
- **ERJ 145EP** - Same fuel capacity as 145ER (4174 kg) but an increased MTOW 20990 kg.
- **ERJ 145LR** - Long Range (increased fuel capacity (5187 kg) and upgraded engines).
- **ERJ 145LU** - Same fuel capacity as 145LR (5187 kg) but an increased MTOW 21990 kg.
- **ERJ 145MK** - Same fuel capacity (4174 kg), landing weight (MLW) and MTOW as in the 145STD, but a changed MZFW (17700 kg).
- **ERJ 145XR** - Extra-long Range (numerous aerodynamic improvements, including winglets, strakes, etc. for lower cruise-configuration drag, a ventral fuel tank (aft location) in addition to the two main larger capacity wing tanks (same

- tanks as in the LR models), increased weight capacity, higher top speed and more powerful engines).
- **Legacy 600** - Business jet variant is a special variant based on the ERJ145.
  - Harbin Embraer ERJ145 - joint venture with Harbin Aircraft Manufacturing Corporation

MTOW - Maximum TakeOff Weight; MZFW - Maximum Zero Fuel Weight

The physical engines are the same (Rolls Royce Allison AE3007), however, the FADEC (Full Authority Digital Engine/Electronic Control) logic is what differs between the various models in regards to total thrust capability.

The extended range version, the ERJ-145ER, has Rolls Royce AE 3007A engines rated at 31.3 kN(7036 lb) thrust, with the option of more powerful AE 3007A1 engines. A, A1, A1P models are mechanically identical but differ in thrust due to variations in FADEC software. The A1E engine, however, has not only new software, but significantly upgraded mechanical components.

The long-range ERJ-145LR aircraft is equipped with Rolls Royce AE 3007A1 engines which provide 15% more power. The engines are flat rated at 33.1 kN (7440 lb) thrust to provide improved climb characteristics and improved cruise performance in high ambient temperatures.

The extra-long-range ERJ-145XR aircraft is equipped with Rolls-Royce AE 3007A1E engines. The high performance engines provide lower specific fuel consumption (SFC) and improved performance in hot and high conditions. The engines also yield a higher altitude for one-engine-inoperable conditions." ExpressJet is the sole operator of the ERJ 145XR.



Luxair Embraer ERJ 135LR

Despite the multiple variants, pilots need only one type rating to fly any variant of the ERJ aircraft. Companies like ExpressJet Airlines utilize this benefit with their mixed fleet of ERJ135ER/LR and ERJ145EP/LR/XR. Shared type ratings allows operators to utilize a single pilot pool for any ERJ aircraft.

## Chapter 6

# British Airliners

## BAe ATP

### BAe ATP



<b>Role</b>	Airliner
<b>Manufacturer</b>	British Aerospace
<b>First flight</b>	1986
<b>Introduced</b>	1988
<b>Produced</b>	1988-1996
<b>Number built</b>	64
<b>Developed from</b>	Hawker Siddeley HS 748

The **BAe ATP** was an airliner produced by British Aerospace, designed as an evolution of the Hawker Siddeley HS 748. The fuel crisis and increasing worries about aircraft noise led business planners at British Aerospace to believe that there was a market for a short-range, low-noise, fuel-efficient turboprop aircraft. By the time it entered the market, the segment was already well represented by designs such as the de Havilland Canada Dash 8 and ATR 42, and production was ended after only 64 examples.

## Design and development

The airframe of the HS 748 was redesigned with a lengthened 26.01 m body and a 30.62 m wing span. Minor modifications were made to the nose and tail shapes, as well as smaller windows on a shorter pitch. The twin Rolls-Royce Dart engines were replaced with Pratt & Whitney Canada PW126 fuel efficient engines. A custom-designed, slow-turning, six-blade propeller was developed by Hamilton Standard.

The aircraft first flew in August 1986 and entered service with British Midland in 1988. The type has an advanced EFIS Flight Deck, and has a good short-field performance. In addition to these virtues, it is also very quiet upon take off.

In total 64 aircraft were assembled at BAe's Woodford and Prestwick facilities with the manufacture of the airframe and wings undertaken at Chadderton. Production ended at Prestwick in 1996. The plane can accommodate between 64 and 72 passengers depending on the seat configuration. The biggest operators of the aircraft are British Airways CitiExpress and West Air Sweden.

In 2001 the **ATP Freighter** project allowed six ATPs to be converted in to cargo aircraft for West Air Sweden. Using a modification of the HS 748 freight door, the ATPF can carry 30% more cargo than its predecessor with a 10% increase in running costs. The ATPF made its first flight from West Air Sweden's facility in Lidköping on 10 July 2002.

In August 2006 a total of 32 ATP aircraft remain in airline service with West Air Sweden (11), First Flight Couriers (1), Atlantic Airlines (3), Emerald Airways (5), Enimex (1), SATA Air Açores (5) and West Air Luxembourg (5) NextJet Sweden (3).

## Variants

Several ATP variants were proposed and produced for civil and military use:

### Jetstream 61

The British Aerospace Jetstream 61 was an improved derivative of the ATP. It featured an interior based on the Jetstream 41 with innovative cabin wall armrests and an increase in capacity from 64-70 seats. In addition the airframe incorporated more powerful PW127 engines and increased weights and range.

The first flight was completed by the original prototype ATP (serial number 2001) reregistered G-PLXI (LXI being the Roman numeral for 61) on the 10th May 1994. Four airframes were subsequently produced as Jetstream 61's (2064–2067) before British Aerospace's regional operations were merged with ATR on the 26th January 1995. With the already highly successful ATR72 now part of the same product range the Jetstream 61 was immediately cancelled with all four airframes being scrapped at Woodford.

The original ATP and Jetstream 61 prototype is currently in storage at Woodford awaiting for a final move to the Jetstream Club at Liverpool.

### Maritime ATP

This was a variant for use in military naval operations, with a surveillance radar under the forward fuselage, nose-mounted FLIR and internal sonar buoys. A suite of special crew stations also featured, as did a choice of up to six weapon pylons under the wings and fuselage. The Maritime ATP was later known as the BAe P.132. None were built.

### ATP-AEW

The AEW was a 1986 proposal for an Airborne Early Warning aircraft for Australia, with two EMI Skymaster radars in nose and tail radomes, similar in appearance to the Nimrod AEW.3. None were built.

## **Notable accidents and incidents involving BAe ATP aircraft**

- On April 19, 1997 Merpati Nusantara Airlines Flight 106 lost control at 2000 feet on approach to Tanjung Pandan-Bulutumbang Airport in Indonesia. 15 people died and 43 survived the crash of Flight 106 the second worst air accident involving British Aerospace ATP aircraft.
- On December 11, 1999 SATA Air Açores Flight 530M crashed into mountain on the Sao Jorge Island, Açores, Portugal on a short haul flight. All 35 passengers and crew on board died in the crash. The accident was the worst air accident involving British Aerospace ATP.

# BAe Jetstream 41

## Jetstream 41



Eastern Airways BAe Jetstream 41

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<b>Role</b>	Regional airliner/Feederliner
<b>Manufacturer</b>	British Aerospace
<b>First flight</b>	25 September 1991
<b>Introduction</b>	1992
<b>Primary users</b>	Eastern Airways South African Airlink Yeti Airlines
<b>Produced</b>	1992–1997
<b>Number built</b>	100
<b>Developed from</b>	Jetstream 31



Jetstream 41 of now-defunct Origin Pacific Airways at Wellington International Airport in June 2004.

The **Jetstream 41** is a turboprop-powered feederliner and regional airliner, designed by British Aerospace as a "stretched" version of the popular Handley Page Jetstream. Intended to compete directly with 30-seat aircraft like the Embraer Brasilia, Dornier 328 and Saab 340, the new design eventually accommodated 29 passengers in a two-by-one arrangement like the Jetstream 31. Eastern Airways is the biggest operator of Jetstream 41s in the world, with 23 in the fleet.

## Design and development

The Jetstream 41's stretch added 16 feet (4.88 m) to the fuselage, consisting of an 8 foot 3 in (2.51 m) plug forward of the wing and a 7 feet 9 inches (2.36 m) plug to the rear; the fuselage design was all new and did not contain any parts of the old fuselage. The new design demanded a wing with increased span, which also included reworked ailerons and flaps. The wing was also mounted below the fuselage so that it did not carry through the cabin aisle, which also led to larger wing root fairings that increased baggage capacity.

The latest version of the Garrett TPE331 engines, the -14, now owned by Honeywell, delivered 1,500 shp (1,120 kW) and later 1,650 shp (1,232 kW) and were mounted in new nacelles with increased ground clearance. The flightdeck was improved with a modern EFIS setup, and a new windscreen arrangement. The J41 was the first turbo-prop certified to both JAR25 and FAR25 standards.

## **Operational service**

The J41 flew for the first time on 25 September 1991 and was certified on 23 November 1992 in Europe, and 9 April 1993 in the United States, with the first delivery, to Manx Airlines on 25 November 1992. In January 1996, the J41 became part of the Aero International (Regional) (AI(R)), a marketing consortium consisting of ATR, Aérospatiale (of France), Alenia (of Italy), and British Aerospace. Sales initially were fairly strong, but in May 1997 BAe announced that it was terminating J41 production, with 100 aircraft delivered.

## **Preservation**

Prototype Jetstream 41 G-JMAC is now preserved by the Jetstream Club on the former airside apron behind the Crowne Plaza Liverpool John Lennon Airport Hotel, which was the original terminal building of Liverpool Speke Airport.

## **Accidents and Incidents**

- On January 7, 1994, Atlantic Coast Airlines Flight 6291 crashed short of the runway at Port Columbus International Airport killing five people out of nine passengers and crew.
- On September 24, 2009, Airlink Flight 8911 crashed in the suburb of Merebank in Durban, South Africa, shortly after takeoff from Durban International Airport. The crew of three and one person on the ground was injured. The captain, Allister Freeman, died as a result of complications from his injuries on 7 October 2009.

## Chapter 7

# Canadian Airlines

## Bombardier CRJ200

### CRJ100 / CRJ200



A Cimber Air CRJ200 landing at London Heathrow Airport

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<b>Role</b>	Regional jet/Business jet
<b>Manufacturer</b>	Bombardier Aerospace
<b>First flight</b>	10 May 1991
<b>Introduction</b>	1992 (Lufthansa)
<b>Status</b>	Active Service
<b>Primary users</b>	SkyWest Airlines, MexicanaLink Pinnacle Airlines Atlantic Southeast Airlines Comair
<b>Number built</b>	1,021 as of July 31, 2010
<b>Unit cost</b>	US\$24-39.7m as of 2006
<b>Developed from</b>	Bombardier Challenger 600
<b>Variants</b>	CRJ700/900/1000

The **Bombardier CRJ100** and **CRJ200** are a family of regional airliner manufactured by Bombardier, and based on the Canadair Challenger business jet.

## Development



CRJ cockpit

The aircraft was based on the Canadair Challenger design, which was purchased by Canadair from Learjet in 1976.

The wide fuselage of the Challenger suggested early on to Canadair officials that it would be straightforward to stretch the aircraft to accommodate more seats, and there was a plan for a **Challenger 610E**, which would have had seating for 24 passengers. That lengthening did not occur, the effort being canceled in 1981, but the idea did not disappear.

In 1987, studies began for a much more ambitious stretched configuration, leading to the formal launch of the **Canadair Regional Jet** program in the spring of 1989. The "Canadair" name was retained despite the fact that Bombardier had bought out the company. The first of three development machines for the initial **CRJ100** performed its first flight on 10 May 1991, though one of the prototypes was lost in a spin mishap in

July 1993. The type obtained certification in late 1992, with initial delivery to customers late in that year.

## CRJ100



A Lufthansa CRJ100 landing

The CRJ100 was stretched 5.92 meters (19 feet 5 inches), with fuselage plugs fore and aft of the wing, two more emergency exit doors, plus a reinforced and modified wing. Typical seating was 50 passengers, the maximum load being 52 passengers. The CRJ100 featured a Collins ProLine 4 avionics suite, Collins weather radar, GE CF34-3A1 turbofans with 41.0 kN (4,180 kgp / 9,220 lbf), new wings with extended span, more fuel capacity, and improved landing gear to handle the higher weights. It was followed by the **CRJ100 ER** subvariant with 20% more range, and the **CRJ100 LR** subvariant with 40% more range than the standard CRJ100. The **CRJ 100 SE** sub-variant was produced to more closely meet the needs of corporate and executive operators.

## CRJ200



Air Nostrum CRJ200 ER

The CRJ200 is identical to the 100 model except for more efficient engines.

Pinnacle Airlines had operated some with 44 seats, designated as **CRJ440**, with closets in the forward areas of the passenger cabin though these were converted to 50 seat airplanes. These modifications were designed to allow operations under their major airline contract "scope clause" which restricts major airlines' connection carriers from operating equipment carrying 50 or more passengers to guard against usurpation of Air Line Pilots Association and Allied Pilots Association pilots' union contract. Similarly, Comair's fleet of 40-seat CRJ200s were sold at a discounted price to discourage Comair from purchasing the less expensive and smaller Embraer 135.

As of August 2006 a total of 938 CRJ100 and CRJ200 aircraft (all variants) are in airline service, with 8 further firm orders. Major operators include Comair (143), Pinnacle Airlines (121), SkyWest Airlines (136), Atlantic Southeast Airlines (110), Air Wisconsin (70), ALMA de Mexico (22), Air Canada Jazz (58), Mesa Airlines (60), Lufthansa CityLine (26), Air Nostrum (35, Plus 7 orders), PSA Airlines (35), Republic Airways Holdings (20) and Mesaba Airlines (19). Some 20 other airlines also operate smaller fleets of the type.

## Variants



CRJ-100SE corporate aircraft at Kenosha, Wisconsin in 1997



CRJ-200

Several models of the CRJ have been produced, ranging in capacity from 40 to 50 passengers. The **Regional Jet** designations are marketing names and the official designation is **CL-600-2B19**.

#### CRJ100

The CRJ100 is the original 50-seat version. It is equipped with General Electric CF34-3A1 engines. Operators include Air Canada Jazz, Comair and more.

#### CRJ200

The CRJ200 is identical to the CRJ100 except for its engines, which were upgraded to the CF34-3B1 model, offering improved efficiency.

#### CRJ440

Certified up to 44-seat, this version was designed with fewer seats in order to meet the needs of some major United States airlines.

#### Challenger 800/850

A business jet variant of the CRJ200

## Operators



Air Canada Jazz CRJ being fueled at La Guardia Airport

## Incidents and accidents

- On 16 December 1997, Air Canada Flight 646, a Bombardier CRJ-100, crashed on a go-around at Greater Fredericton Airport in Fredericton, New Brunswick. No fatalities were reported.

- On 22 June 2003, Brit Air Flight 5672 from Nantes to Brest, France, crashed 2.3 miles short and 0.3 miles to the left of the runway when attempting a landing at Brest's airport. The aircraft's captain was the sole fatality.
- On 14 October 2004, Pinnacle Airlines Flight 3701, a Bombardier CRJ-200, crashed on a repositioning flight from Little Rock, Arkansas to Minneapolis. The two pilots pushed the airplane to its service ceiling of 41,000 feet at much higher climb rates than the engines and airframe could handle. This caused both engines to flame out and possibly experience core lock. The aircraft did not have any passengers onboard because the plane was being ferried (moved from one location to another). The aircraft crashed about fifteen minutes later, in sight of the diversion airport; both pilots were killed.
- On 21 November 2004, China Eastern Airlines Flight 5210, a Bombardier CRJ-200LR, crashed shortly after takeoff, killing all 53 on board as well as two on the ground.
- On 27 August 2006, Comair Flight 5191, marketed as a Delta Connection flight, a Bombardier CRJ-100ER, crashed during takeoff from the wrong runway at Blue Grass Airport in Lexington, Kentucky. There were 49 fatalities, with only the severely injured first officer surviving.
- On 20 May 2007, an Air Canada Jazz Bombardier CRJ-100 which originated in Moncton, New Brunswick, was substantially damaged when its landing gear collapsed after landing at Toronto-Pearson International Airport, ON (YYZ). There were no injuries to any crew or passengers. Flight AC8911 departed Moncton (YQM) on a domestic flight to Toronto. The aircraft landed on runway 06R with a 90 degree crosswind from the left, gusting from 13 to 23 knots. The aircraft first contacted the runway in a left-wing-down sideslip. The left main landing gear struck the runway first and the aircraft sustained a sharp lateral side load before bouncing. Once airborne again, the flight and ground spoilers deployed and the aircraft landed hard. Both main landing gear trunnion fittings failed and the landing gear collapsed. The aircraft remained upright, supported by the landing gear struts and wheels. The aircraft slid down the runway and exited via the Delta 3 taxiway, where the passengers deplaned. There was no fire. There were no injuries to the crew; some passengers reported minor injuries as a result of the hard landing.
- On 16 December 2007, Air Wisconsin flight 758A, a Bombardier CRJ-200LR, departed the runway during landing at T. F. Green Airport in Providence, Rhode Island. No injuries or fatalities were reported.
- On 13 February 2008, Belavia Flight 1834, a Bombardier CRJ-100LR, crashed and flipped-over during takeoff at Zvartnots International Airport in Yerevan, Armenia. Most passengers suffered some burns, and four were taken to the hospital. No fatalities were reported.
- On 12 November 2009, RwandAir Flight 205, a Bombardier CRJ-100, crashed into a VIP terminal shortly after an emergency landing at Kigali International Airport, Rwanda; out of the ten passengers and five crew members, one passenger died.
- On 19 January 2010, PSA Airlines Canadair CRJ-200 N246PS overran the runway at Yeager Airport, Charleston, West Virginia following an aborted take-

off. The aircraft was stopped by the EMAS at the end of the runway, sustaining substantial damage to its undercarriage.

## Specifications

Variant	CRJ100 ER/LR	CRJ200 ER/LR
<b>Crew</b>	3 (2 pilots + flight attendant)	
<b>Seating capacity</b>	50	
<b>Length</b>	26.77 m (87 ft 10 in)	
<b>Wing span</b>	21.21 m (69 ft 7 in)	
<b>Height</b>	6.22 m (20 ft 5 in)	
<b>Engines (2x)</b>	GE CF34-3A1	GE CF34-3B1
<b>Takeoff thrust (2x)</b>	38.83 kN (8,729 lbf)	38.83 kN (8,729 lbf)
<b>Thrust APR (2x)</b>	41.01 kN (9,220 lbf)	41.01 kN (9,220 lbf)
<b>Max Zero Fuel Weight (ZFW)</b>	19,958 kg (44,000 lb)	
<b>Max payload weight</b>	6,124 kg (13,500 lb)	
<b>Max Take Off Weight</b>	24,091 kg (53,000 lb)	
<b>Maximum range</b>	ER: 3,000 km (1,864 mi, 1,620 nmi) LR: 3,710 km (2,305 mi, 2,003 nmi)	ER: 3,045 km (1,895 mi, 1,644 nmi) LR: 3,713 km (2,307 mi, 2,004 nmi)
<b>Basic cruising speed</b>	Mach .78 [503 mph, 437 knots] (593.74 mph ground, 516 knots ground)	
<b>Flight ceiling</b>	12,496 m (41,000 ft)	
<b>Number of Orders</b>	1054	
<b>Certification Date</b>	unknown	July 1992

### *CRJ200:*

#### **Dimensions:**

Wing area (net) 520.4 ft<sup>2</sup> 48.35 m<sup>2</sup>  
 Fuselage maximum diameter 8 ft 10 in 2.69 m  
 Turning Circle 75 ft 22.86 m

# Bombardier CRJ700

## CRJ700 / CRJ900 CRJ1000



A CRJ700 in Delta Connection livery

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<b>Role</b>	Regional jet
<b>National origin</b>	Canada
<b>Manufacturer</b>	Bombardier Aerospace
<b>First flight</b>	1999
<b>Introduction</b>	2001
<b>Status</b>	In production, in operation
<b>Primary users</b>	SkyWest Airlines Mesa Airlines Atlantic Southeast Airlines Mesaba Airlines
<b>Number built</b>	543 as of July 2010
<b>Unit cost</b>	US\$24-39.7m (2006)
<b>Developed from</b>	Bombardier CRJ200

The **Bombardier CRJ700**, **CRJ900**, and **CRJ1000** are regional airliners based on the Bombardier CRJ200. Final assembly of the aircraft is at Montréal-Mirabel International Airport in Mirabel, Quebec, outside Montreal, Canada.

## Development

Following the success of the CRJ100/200 series, Bombardier produced larger variants in order to compete with larger regional aircraft such as the Embraer E-Jets family, Fokker 70/100 series and the BAe 146/Avro RJ family.

## CRJ700



Horizon Air CRJ700 in Denver

The *CRJ700* is a stretched 66-78 seat derivative of the CRJ200, with 70 seats being the most common. The CRJ700 features a new wing with leading edge slats and a stretched and slightly widened fuselage, with a lowered floor. The aircraft is equipped with the General Electric CF34-8C1 engine. Maximum speed is Mach 0.85 (556 miles per hour) at a maximum altitude of 41,000 feet (12,500 m). Depending upon payload, the CRJ700 can travel up to 2,250 miles (3,620 km) with current engines, and a new variant with CF34-8C5 engines will be able to travel up to 2,895 miles (4,660 km).



Lufthansa CRJ701 ER

The CRJ700 comes in three versions: Series 700, Series 701, and Series 702. The 700 is limited to 68 passengers, the 701 to 70 passengers, and the 702 to 78 passengers. The CRJ700 also has three fuel/weight options: standard, ER, and LR. The ER version has an increase in fuel capacity as well as maximum weight, which in turn increases the range. The LR increases those values further.

Its first flight was in 1999 and it entered service in 2001. The aircraft's FAA Type Certificate designation is the **CL-600-2C10**. The first airline to fly a CRJ700 was Brit Air in 2001.

The CRJ-700 directly competes with the Embraer 170, which typically seats 70 passengers. However, the CRJ-700 is 10% more cost-effective to operate than the E-170.

In 2008, the CRJ700 was replaced with the CRJ700 NextGen, featuring improved economics and a revised cabin common to the CRJ900 NextGen and CRJ1000 NextGen.

In January 2011 SkyWest Airlines ordered four CRJ700 NextGen.

## **CRJ705**



Air Canada Jazz CRJ-705 at Regina International Airport

The *Series 705* is based on the CRJ900, with a business class and a reduced maximum seating capacity to allow operation with regional airlines. The Series 705 seat 75 passengers. Some regional airlines have contracts with their major airlines that limit the maximum passenger capacity of aircraft they operate. Air Canada Jazz was the launch customer for this aircraft in 2005 with 10 executive (business) class and 65 economy seats. The FAA Type Certificate designation of the CRJ705 is the **CL-600-2D15**. Air Canada Jazz operates 16 Series 705 aircraft.

## CRJ900



Lufthansa CityLine Bombardier CRJ900LR takes off. (2010)

The *CRJ900* is a stretched 76-90 seat version of the CRJ700. The aircraft features the GE CF34-8C5 engines, 13,360 lbf (59,400 N) thrust with APR, and added leading edge slats. Max GTOW is 84,500 pounds. The airplane is loosely based on the CRJ200 series with a few major improvements. The environmental packs have a target temperature instead of a hot-cold knob. The cabin has a recirculation fan which aids in cooling and heating. The engines are controlled by FADEC digital engine control instead of control cables and a fuel control unit. The cabin floor has been lowered 2 inches which gains outward visibility from the windows in the cabin as the windows become closer to eye level height. The APU is a General Electric unit which supplies much more air to the AC packs and has higher limits for starting and altitude usage. The wingspan is longer, the tail is redesigned with more span and anhedral. In typical service the CRJ900 can cruise 8-10,000 ft higher with a slightly higher fuel burn and an average true airspeed of 450-500 knots, a significant improvement over its predecessor. The FAA Type Certificate designation of the CRJ900 is the **CL-600-2D24**.



Scandinavian Airlines was a new customer of the CRJ900 in 2008

The first CRJ900 (C-FRJX) was modified from the prototype CRJ700 by adding longer fuselage plugs fore and aft; it was later converted into the prototype CRJ1000 by installing yet longer fuselage plugs. The CRJ900 competes with the Embraer 175, and is more efficient per seat-mile, according to Bombardier.

In 2007, Bombardier launched the CRJ900 NextGen to replace the initial version. The new model has improved economics and a new cabin common to the CRJ700 NextGen and CRJ1000 NextGen. Mesaba Aviation, operating at the time as Northwest Airlink (now Delta Connection), was the launch customer, and remains the largest operator of the CRJ900 NextGen. The Mesaba fleet of CRJ900 NextGen aircraft are configured in a two class seating configuration, with 12 first class seats and 64 coach seats.

Comair, flying as Delta Connection, has ordered 14 CRJ900s, with at least 6 in service as of Nov 2007. These are in a two class configuration, with 12 first class seats and 64 coach seats. This is due to a limitation in Delta's contract with its pilots which limits its regional carriers to flying 76-seat aircraft.

In July 2008 PLUNA received its fifth plane (from an eventual total of 7). Estonian Air ordered 3 new CRJ900 NextGen 90-seat aircraft. Also SAS ordered 13 of these in March 2008. Iraqi Airways has ordered six Bombardier CRJ900 NextGen airliners and options on a further four of the type.

In June 2010 Lufthansa ordered eight CRJ900 NextGen.

## CRJ1000



A CRJ1000 at Paine Field, Snohomish County, Washington

On 19 February 2007, Bombardier launched the *CRJ1000*, previously designated CRJ900X, as a stretched CRJ900, with up to 100 seats. Bombardier claims that it offers better performance and a higher profit per seat than the competing Embraer E-190. Brit Air and Air Nostrum are the launch customers for the CRJ1000. MyAir had ordered 15 CRJ900Xs that were converted to the CRJ1000, but the airline went bankrupt on 24 July 2009. Atlasjet also indicated interest in the new type.

The CRJ1000 successfully completed its first flight in 2008. Bombardier, however, stated that the introduction into service had been delayed until the first quarter of 2010. On 14 June 2009 Bombardier announced a new firm order for 15 CRJ1000 NextGen aircraft placed by Air Nostrum, for a total of 35 CRJ1000 NextGen aircraft. There are 49 firm orders and 4 options for the variant as of August 2009.

The variant completed its first production flight on 28 July 2009 in Montreal; the entry into service was planned then for the first quarter of 2010. A month after the first flight, however, a fault in the rudder controls forced the flight-test program to be grounded. The program was not resumed until February 2010, and deliveries were projected to begin by January 2011.

Bombardier Aerospace announced on 10 November 2010 that its 100-seat CRJ1000 was awarded Aircraft Type Certificates from Transport Canada and European Aviation Safety

Agency, clearing the way for deliveries to begin. On 14 December 2010, Bombardier began CRJ1000 deliveries to Brit Air and Air Nostrum. On 23 December 2010 it was announced that the Federal Aviation Administration had also awarded a type certificate, allowing the CRJ1000 to operate in US airspace.

## Operators



A comparison between Bombardier CRJ700 (top) and CRJ900 (bottom)

As of July 2010, 316 CRJ700 aircraft (all variants) and 229 CRJ900 aircraft (all variants) were in airline service. Operators for these aircraft are SkyWest Airlines (104), Mesa Airlines (58), Atlantic Southeast Airlines (49), Mesaba Airlines (41), Lufthansa CityLine (32), Comair (28), American Eagle Airlines (25), GoJet Airlines (25), and other operators with fewer aircraft of the type.

## Accidents and incidents

- On September 25, 2010, Delta Connection Flight 4951, a CRJ900, on a passenger flight from Atlanta, Georgia to White Plains, New York made a successful emergency landing at John F. Kennedy International Airport in New York City. The plane's right landing gear would not deploy and the right wing dragged along the runway during the landing. There were no injuries.

## Chapter 8

# Supersonic Transport



The Concorde supersonic transport had an ogival delta wing, a slender fuselage and four underslung Rolls-Royce/Snecma Olympus 593 engines.

A **supersonic transport (SST)** is a civilian supersonic aircraft designed to transport passengers at speeds greater than the speed of sound. The only SSTs to see regular service were Concorde and the Tupolev Tu-144. The last passenger flight of the Tu-144 was in June 1978, and Concorde's last flight was on November 26, 2003. Following the permanent cessation of flying by all Concorde, there are no SSTs in commercial service.

Supersonic airliners' greater speed and efficiency over their conventional counterparts have made them objects of numerous recent and ongoing design studies. Drawbacks and design challenges are excessive noise generation (due to sonic booms), high development

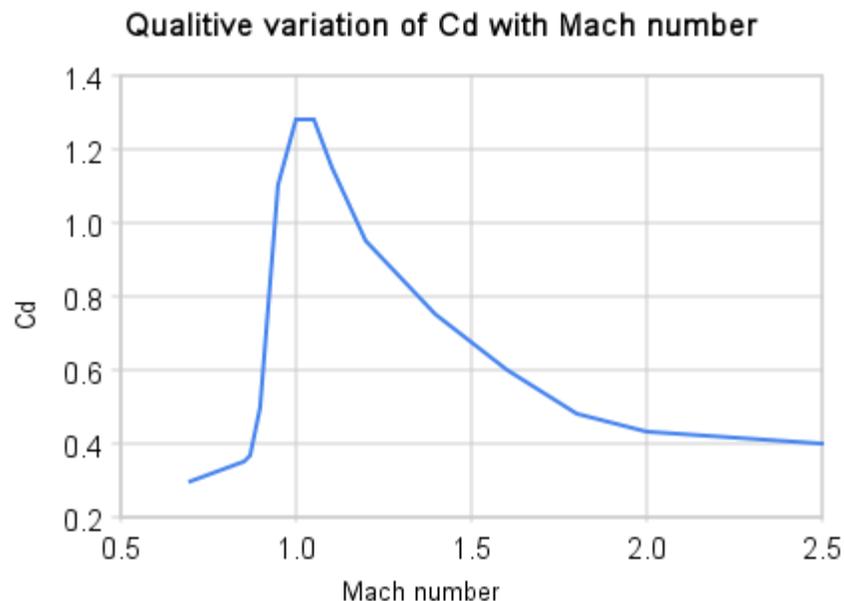
costs, expensive construction materials, great weight, and an increased cost per seat over subsonic airliners.

Despite these challenges, Concorde was operated profitably in a niche market for over 25 years.

## Challenges of supersonic passenger flight

### Aerodynamics

For all vehicles traveling through air, the force of drag is proportional to the coefficient of drag ( $C_d$ ), to the square of the airspeed and to the air density. Since drag rises rapidly with speed, a key priority of supersonic aircraft design is to minimize this force by lowering the coefficient of drag. This gives rise to the highly streamlined shapes of SST. To some extent, supersonic aircraft also manage drag by flying at higher altitudes than subsonic aircraft, where the air density is lower.



#### Qualitative variation in $C_d$ factor with Mach number for aircraft

As speeds approach the speed of sound, the additional phenomenon of wave drag appears. This is a powerful form of drag that begins at about Mach 0.8, and ends at about Mach 1.2, (transonic speeds). Between these speeds, the peak coefficient of drag can be up to four times that of subsonic drag. Above the transonic range, the coefficient drops dramatically again, although it remains 30 to 50% higher than at subsonic speeds. Supersonic aircraft must have considerably more power than subsonic aircraft require to overcome this wave drag, and although cruising performance above transonic speed is more efficient, it is still less efficient than flying subsonically.

Another issue in supersonic flight is the lift to drag ratio (L/D ratio) of the wings. At supersonic speeds, airfoils generate lift in an entirely different manner than at subsonic speeds, and are invariably less efficient. For this reason, considerable research has been put into designing planforms for sustained supersonic cruise. At about Mach 2, a typical wing design will cut its L/D ratio in half (e.g., the Concorde vehicle managed a ratio of 7.14, whereas the subsonic Boeing 747 has an L/D ratio of 17). Because an aircraft's design must provide enough lift to overcome its own weight, a reduction of its L/D ratio at supersonic speeds requires additional thrust to maintain its airspeed and altitude.

## Engines

Jet engine design shifts significantly between supersonic and subsonic aircraft. Jet engines, as a class, can supply *increased* fuel efficiency at supersonic speeds, even though their specific fuel consumption is greater at higher speeds. Because their speed over the ground is greater, this decrease in efficiency is less than proportional to speed until well above Mach 2, and the consumption per mile is lower.



A preserved ex-British Airways Concorde at Filton Aerodrome, Bristol, England shows the slender fuselage necessary for supersonic flight

When Concorde was being designed by Aérospatiale-BAC, high bypass jet engines ("turbofan" engines) had not yet been deployed on subsonic aircraft, and Concorde would have been more competitive. When these high bypass jet engines reached commercial service in the 1960s, subsonic jet engines immediately became much more efficient,

closer to the efficiency of turbojets at supersonic speeds. A bypass design is more fuel-efficient at subsonic speeds, as it generates the required thrust by accelerating a larger amount of air through a smaller velocity difference. On the other hand, this feature tends to reduce efficiency during supersonic cruise, where the smaller size of turbojet engines gives lower drag and better net efficiency. For example, the early TU-144S was fitted with a low bypass turbofan engine which was much less efficient than Concorde's turbojets in supersonic flight. The later TU-144D featured turbojet engines with comparable efficiency. The key advantage of turbojets is their smaller cross-sectional area which reduces inlet drag during cruise.

### Structural issues

Supersonic vehicle speeds demand narrower wing and fuselage designs, and are subject to greater stresses and temperatures. This leads to aeroelasticity problems, which require heavier structures to minimize unwanted flexing. SSTs also require a much stronger (and therefore heavier) structure because their fuselage must be pressurized to a greater differential than subsonic aircraft, which do not operate at the high altitudes necessary for supersonic flight. These factors together meant that the empty weight per seat of Concorde is more than three times that of a Boeing 747.

However, Concorde and the TU-144 were both constructed of conventional aluminum (duralumin), whereas more modern materials such as carbon fibre and Kevlar are much stronger in tension for their weight (important to deal with pressurization stresses) as well as, when mixed with polymers, being more rigid, so it's likely that considerable improvements could be made, far more so than with conventional aircraft.

### High costs

<i>Concorde fuel efficiency comparison</i>			
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

Higher fuel costs and lower passenger capacities due to the aerodynamic requirement for a narrow fuselage make SSTs an expensive form of commercial civil transportation compared with subsonic aircraft. Both Concorde and the Boeing 747 use approximately the same amount of fuel to cover the same distance, but the 747 can carry more than three times as many passengers.

Nevertheless, fuel costs are not the bulk of the price for most subsonic aircraft passenger tickets. For the transatlantic business market that SST aircraft were utilized for, Concorde was actually very successful, and was able to sustain a higher ticket price. Now that commercial SST aircraft have stopped flying, it has become clearer that Concorde made substantial profit for British Airways.

## **Sonic booms**

The sonic boom was not thought to be a serious issue due to the high altitudes at which the planes flew, but experiments in the mid-1960s such as the Oklahoma City sonic boom tests and studies of the USAF's North American XB-70 Valkyrie proved otherwise.

The annoyance of a sonic boom can be avoided by waiting until the aircraft is at high altitude over water before reaching supersonic speeds; this is the technique used by Concorde. However, it precludes supersonic flight over populated areas. Supersonic aircraft have poor lift/drag ratios at subsonic speeds as compared to subsonic aircraft (unless technologies such as swing wing are employed), and hence burn more fuel, which results in their use being economically disadvantageous on such flight paths.

Additionally, during the original SST efforts in the 1960s, it was suggested that careful shaping of the fuselage of the aircraft could reduce the intensity of the sonic boom's shock waves that reach the ground. One design caused the shock wave to interfere with each other, greatly reducing sonic boom. This was difficult to test at the time, but the increasing power of computer-aided design has since made this considerably easier. In 2003, a Shaped Sonic Boom Demonstration aircraft was flown which proved the soundness of the design and demonstrated the capability of reducing the boom by about half. Even lengthening the vehicle (without significantly increasing the weight) would seem to reduce the boom intensity.

If the intensity of the boom can be reduced, then this may make even very large designs of supersonic aircraft acceptable for overland flight.

## **Need to operate aircraft over a wide range of speeds**

The aerodynamic design of a supersonic aircraft needs to change with its speed for optimal performance. Thus, an SST would ideally change shape during flight to maintain optimal performance at both subsonic and supersonic speeds. Such a design would introduce complexity which increases maintenance needs, operations costs, and safety concerns.

In practice all supersonic transports have used essentially the same shape for subsonic and supersonic flight, and a compromise in performance is chosen, often to the detriment of low speed flight. For example, Concorde had very high drag (a lift to drag ratio of about 4) at slow speed, but it travelled at high speed for most of the flight. Designers of Concorde were forced to spend a massive 5000 hours optimizing the vehicle shape in wind tunnel tests to maximise the overall performance over the entire flightplan.

Some designs of supersonic transports possessed swing wings to give higher efficiency at low speeds, but the increased space required for such a feature produced capacity problems that proved ultimately insurmountable.

North American Aviation had an unusual approach to this problem with the XB-70 Valkyrie. By lowering the outer panels of the wings at high Mach numbers, they were able to take advantage of compression lift on the underside of the aircraft. This improved the L/D ratio by about 30%.

### **Takeoff noise**

One of the problems with Concorde and the Tu-144's operation was the high engine noise levels, associated with very high jet velocities used during take-off, and even more importantly flying over communities near the airport. SST engines need a fairly high specific thrust (net thrust/airflow) during supersonic cruise, to minimize engine cross-sectional area and, thereby, nacelle drag. Unfortunately this implies a high jet velocity, which makes the engines noisy which causes problems particularly at low speeds/altitudes and at take-off.

Therefore, a future SST might well benefit from a Variable Cycle Engine, where the specific thrust (and therefore jet velocity and noise) is low at take-off, but is forced high during Supersonic Cruise. Transition between the two modes would occur at some point during the Climb and back again during the Descent (to minimize jet noise upon Approach). The difficulty is devising a Variable Cycle Engine configuration that meets the requirement for a low cross-sectional area during Supersonic Cruise.

### **Skin temperature**

As a supersonic aircraft flies, it adiabatically compresses the air in front of the vehicle. This causes an increase in the temperature of the air resulting in heating of the aircraft.

Normal subsonic aircraft are traditionally made of aluminium. However aluminium, while being light and strong, is not able to withstand temperatures much over 127 °C; above 127 °C the aluminium gradually loses its temper and is weakened. This corresponds to an airspeed of about Mach 2.2.

For aircraft that fly at Mach 3, materials such as stainless steel (XB-70 Valkyrie) or titanium (SR-71) have been used, at considerable increase in expense, as the properties of these materials make the aircraft much more difficult to manufacture.

### **Poor range**

The range of supersonic aircraft can be estimated with the Breguet range equation.

The high per-passenger takeoff weight makes it difficult to obtain a good fuel fraction. This, together with the relatively poor supersonic lift/drag ratios, supersonic aircraft have

historically had relatively poor range. This meant that a lot of routes were non viable, and this in turn helped mean that they sold poorly with airlines.

### **Airline desirability of SSTs**

Airlines buy aircraft as a means of making money, and wish to make as much return on investment as possible from their assets.

Airlines potentially value very fast aircraft, because it enables the aircraft to make more flights per day, which allows for higher return on investment. However, Concorde's high noise levels around airports, time zone issues and insufficient speed meant that only a single return trip could be made per day, so the extra speed was not an advantage to the airline other than as a selling feature to its customers.

The American SSTs were intended to fly at Mach 3, partly for this reason. However, allowing for acceleration and deceleration time, this only would have cut 20 minutes off a transatlantic trip which would probably not have been enough to perform an extra roundtrip, and the aircraft would have been much more expensive for the airlines to purchase.

Since SSTs emit sonic booms at supersonic speeds and so they are rarely permitted to fly supersonic over land, and since, compared to subsonic aircraft they are inefficient at subsonic speeds, this reduces the routes that the aircraft can be used on, and this also reduces the desirability of such aircraft for most airlines.

Supersonic aircraft have higher per-passenger fuel consumption than subsonic aircraft; this makes the ticket price more sensitive to the price of oil.

Making investment for research and development work to design a new SST can be thought as an effort to push the speed limit of air transport. Generally, other than an urge for a technological achievement, the major driving force for such an effort is competition from other modes of transport. Competition between different service providers within a mode of transport, however, does not typically lead to such technological investments to increase the speed; the service providers rather prefer to compete in service quality and cost. The most apparent example to this phenomenon is the high - speed rail. The speed limit of rail transport had been pushed so hard in order to enable it to effectively compete with road and air transport. But this achievement was hardly done for different rail operating companies to compete between themselves. This phenomenon also reduces the airline desirability of SST's, because, in very long distances (a couple of thousands of kilometers), competition between different modes of transport is rather like a single - horse race; air transport does not have a significant competitor. The only competition is the one between the airline companies, and they would rather pay for reducing the cost and increasing the service quality than such an expensive speed increase attempt.

## History

Throughout the 1950s an SST looked possible from a technical standpoint, but it was not clear if it could be made economically viable. There was a good argument for supersonic speeds on medium- and long-range flights at least, where the increased speed and potential good economy once supersonic would offset the tremendous amount of fuel needed to overcome the wave drag. The main advantage appeared to be practical; these designs would be flying at least three times as fast as existing subsonic transports, and would be able to replace three planes in service, and thereby lower costs in terms of manpower and maintenance.



A Concorde landing

Serious work on SST designs started in the mid-1950s, when the first generation of supersonic fighter aircraft were entering service. In Europe, government-subsidized SST programs quickly settled on the delta wing in most studies, including the Sud Aviation Super-Caravelle and Bristol 223, although Armstrong-Whitworth proposed a more radical design, the Mach 1.2 M-Wing. Avro Canada proposed several designs to TWA that included Mach 1.6 double-ogee wing and Mach 1.2 delta-wing with separate tail and four under-wing engine configurations. Avro's team moved to the UK where its design formed the basis of Hawker Siddeley's designs. By the early 1960s, the designs had progressed to the point where the go-ahead for production was given, but costs were so high that Bristol and Sud eventually merged their efforts in 1962 to produce Concorde.

This development set off panic in the US industry, where it was thought that Concorde would soon replace all other long range designs. Congress was soon funding an SST design effort, selecting the existing Lockheed L-2000 and Boeing 2707 designs, to produce an even more advanced, larger, faster and longer ranged design. The Boeing design was eventually selected for continued work. The Soviet Union set out to produce its own design, the Tu-144, which was nicknamed the "Concordski."

In the 1960s environmental concerns came to the fore for the first time. The SST was seen as particularly offensive due to its sonic boom and the potential for its engine exhaust to damage the ozone layer. Both problems impacted the thinking of lawmakers, and eventually Congress dropped funding for the US SST program in 1971, and all overland commercial supersonic flight was banned.



Tupolev Tu-144LL

Concorde was now ready for service. The US political outcry was so high that New York banned the plane outright. This destroyed the aircraft's economic prospects — it had been built with the London-New York route in mind. However, the plane was allowed into Washington, DC, and the service was so popular that New Yorkers were soon complaining because they did not have it. It was not long before Concorde was flying into JFK after all.

Along with shifting political considerations, the flying public continued to show interest in high-speed ocean crossings. This started a second round of design studies in the US, under the name **AST**, for **Advanced Supersonic Transport**. Lockheed's **SCV** was a new design for this category, while Boeing continued studies with the 2707 as a baseline.

However by this time the economics of past SST concepts no longer made sense. When first designed, the SSTs were envisioned to compete with long-range aircraft seating 80 to 100 passengers such as the Boeing 707, but with newer aircraft such as the Boeing 747 carrying four times that, the speed and fuel advantages of the SST concept were washed away by sheer size.

Another problem was that the wide range of speeds over which an SST operates makes it difficult to improve engines. While subsonic engines had made great strides in increasing efficiencies through the 1960s with the introduction of the turbofan engine with ever-increasing bypass ratios, the fan concept is difficult to use at supersonic speeds where the "proper" bypass is about 0.45, as opposed to 2.0 or higher for subsonic designs. For both of these reasons the SST designs were doomed to higher operational costs, and the AST programs faded away by the early 1980s.

Concorde only sold to British Airways and Air France, with subsidized purchases that were to return 80% of the profits to the government. In practice for almost all of the length of the arrangement, there was no profit to be shared. After Concorde was privatised, cost reduction measures (notably the closing of the metallurgical wing testing site which had done enough temperature cycles to validate the aircraft through to 2010) and ticket price raises led to substantial profits.

Since Concorde stopped flying it has been revealed that over the life of Concorde, the plane did prove profitable, at least to British Airways. Concorde operating costs over nearly 28 years of operation were approximately £1 billion, with revenues of £1.75 billion.

The last regular passenger flights landed at Heathrow Airport on Friday, October 24, 2003 just past 4 p.m. – Flight 002 from New York, one from Edinburgh, Scotland, and the third which had taken off from Heathrow on a loop flight over the Bay of Biscay.

## Aircraft histories



The Sinsheim Auto & Technik Museum in Germany is the only place in the world where both the Concorde and the Tu-144 can be seen at the same time.

### Concorde

In total, 20 Concorde were built, six for development and 14 for commercial service.

These were:

- Two prototypes
- Two pre-production aircraft
- 16 production aircraft
  - The first two of these did not enter commercial service
  - Of the 14 that flew commercially, 8 were still in service in April 2003

All but two of these aircraft, a remarkably high percentage for any commercial fleet, are preserved; the two that are not preserved are F-BVFD (cn 211), parked as a spare-parts source in 1982 and scrapped in 1994, and F-BTSC (cn 203), which crashed in Paris on July 25, 2000.

## **Tupolev 144**

A total of 16 airworthy Tu-144s were built: the prototype Tu-144 reg 68001, a pre-production Tu-144S reg 77101, nine production Tu-144S reg 77102 – 110, and five Tu-144D reg 77111 – 115. A seventeenth Tu-144 (reg 77116) was never completed. There was also at least one ground test airframe for static testing in parallel with the prototype 68001 development.

## **Hypersonic transports**

While conventional turbo and ramjet engines are able to remain reasonably efficient up to Mach 5.5, some ideas for very high speed flight above Mach 6 are also sometimes discussed; with the aim of reducing travel times down to one or two hours anywhere in the world.

These vehicle proposals very typically either use rocket or scramjet engines; pulse detonation engines have also been proposed.

There are many difficulties with such flight, both technical and economic.

Rocket engined vehicles while technically practical (either as ballistic transports or as semiballistic transports using wings) would use a very large amount of propellant and operate best at speeds between about Mach 8 and orbital speeds. Rockets compete best with air breathing jet engines on cost at very long range, however even for antipodal travel, costs would be only somewhat lower than orbital launch costs.

Scramjets currently are not practical for passenger carrying vehicles.

Precooled jet engines are jet engines with a heat exchanger at the inlet that cools the air at very high speeds- these engines may be practical and efficient at up to about Mach 5.5, and this is an area of research in Europe and Japan.

## **Current research and development**

In April 1994, Aerospatiale, British Aerospace and Deutsche Aerospace AG (DASA) created the European Supersonic Research Program (ESRP) with plans for a second-generation Concorde to enter service in 2010. The plane was to be called the Avion de Transport Supersonique Futur. In parallel, SNECMA, Rolls-Royce, MTU München and Fiat started working together in 1991 on the development of a new engine. Investing no more than US\$12 million per year, mainly company funded, the research program covers materials, aerodynamics, systems and engine integration for a reference configuration. The ESRP exploratory study is based on a Mach 2, 250-seat, 5,500 nautical mile-range (10,186 km) aircraft, with the baseline design looking very much like an enlarged Concorde with canards.

Meanwhile NASA started a series of projects to study advances in the state of SST design. As part of the High Speed Civil Transport program a Tu-144 aircraft was re-engineered in order to carry out supersonic experiments in Russia in the mid-1990s, but development was ended in 1999.

Japan has a supersonic transport research program. In 2005, it was announced that a Japanese-French joint venture would continue research into a design the plane would be called Next Generation Supersonic Transport, JAXA hopes the Next Generation Supersonic Transport would be flying by 2015. An 11.5-meter model was successfully flight-tested in October 2005.

Another area that has seen research interest is the supersonic business jet (SSBJ). Some business jet customers are prepared to pay heavily for decreased travel times, and the noise issues are less serious in a smaller craft. Sukhoi and Gulfstream co-investigated such a craft in the mid-1990s, as did Dassault Aviation in the early 2000s. Aerion Corporation's Aerion SBJ, the SAI Quiet Supersonic Transport and Tupolev's Tu-444 are current SSBJ projects.

Another development in the field of engines is the pulse detonation engine. These engines, often referred to as PDEs, offer even greater efficiencies than current turbofan engines, while allowing for high speed use. NASA maintains a PDE research effort, with the baseline being a Mach 5 airliner. A PDE was test flown successfully in 2008.

At the most exotic, high supersonic designs like Reaction Engines Skylon would seem to be capable of reaching Mach 5.5 within the atmosphere, before activating a rocket engine and entering orbit. The design can later reenter the atmosphere and land back on the runway it took off from.

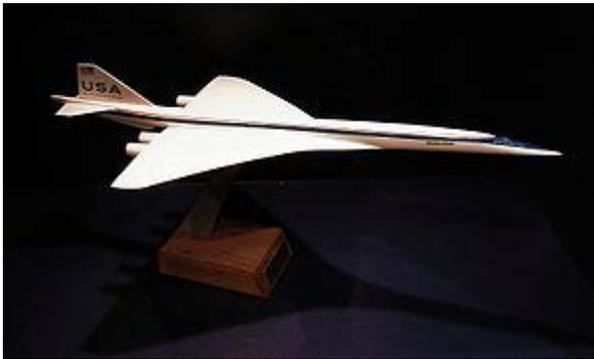
There is also a very long distance supersonic/hypersonic transport version of Skylon, the A2, being evaluated by the European Union as part of the LAPCAT project, which would travel at Mach 5 and would be capable of travelling Brussels to Sydney in 4.6 hours.

Tupolev plans to build the Tupolev Tu-244, although this SST may be canceled due to budget problems.

## Chapter 9

# Boeing 2707

### Boeing 2707



Model of a Boeing 2707-300.

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<b>Role</b>	Supersonic transport
<b>Manufacturer</b>	Boeing Commercial Airplanes
<b>Status</b>	Cancelled
<b>Number built</b>	0 completed

The **Boeing 2707** was developed as the first American supersonic transport (SST). After winning a competition for a government-funded contract to build an American SST, Boeing began development at its facilities in Seattle, Washington. Rising costs and the lack of a clear market led to its cancellation in 1971 before two prototypes had been completed.

## Development

### Early studies

Boeing had worked on a number of small-scale SST studies since 1952. In 1958, it established a permanent research committee, which grew to a \$1 million effort by 1960. The committee proposed a variety of alternative designs, all under the name **Model 733**. Most of the designs featured a large delta wing, but in 1959 another design was offered as an offshoot of Boeing's efforts in the swing-wing TFX project (which led to the purchase

of the General Dynamics F-111 instead of the Boeing offering). In 1960, an internal "competition" was run on a baseline 150-seat aircraft for trans-Atlantic routes, and the swing-wing version won.

By mid-1962, it was becoming clear that tentative talks earlier that year between the Bristol Aeroplane Company and Sud Aviation on a merger of their SST projects were more serious than originally thought. In November, the two companies announced that a design called "Concorde" would be built by a consortium effort. This set off something of a wave of panic in other countries, as it was widely believed that almost all future commercial aircraft would be supersonic, and it looked like the Europeans would start off with a huge lead.

### **National commitment**

On June 5, 1963, President John F. Kennedy formed the **National Supersonic Transport** program, which committed the government to subsidizing 75% of the development costs of a commercial airliner to compete with Concorde. The director of the Federal Aviation Administration, Najeeb Halaby, decided Concorde was too far ahead in development to bother building a direct competitor, and instead selected a more advanced standard as their baseline. The American SST was intended to carry 250 passengers (more than twice as many as Concorde), fly at Mach 2.7–3.0 (over M0.5 faster), and have an intercontinental range of 4,500 miles (7,200 km).

Concorde selected Mach 2 as its maximum speed deliberately. At the time British and European airframe engineers had no knowledge of, or experience in, fabricating airframe structures made out of anything other than aluminum alloys. At higher speeds the skin friction heating of an aircraft at Mach 2 was the maximum speed at which duralumin (an aluminum alloy) could be used before it would lose its temper and strength. Bristol engineers had considered using stainless steel in order to reach Mach 3, and built the Bristol Type 188 to test this sort of construction. However, the Type 188 proved to be extremely expensive (and well over weight for its size), and so plans then turned to using duralumin, and operating at lower maximum speeds.

The U.S. had an advantage, however, with the recent completion of the XB-70 Valkyrie. Originally designed as the next logical step in strategic bomber design, the B-70 was essentially a smaller SST, designed to cruise at Mach 3 for up to 7,000 miles (11,000 km), and built mostly of stainless steel. Its high-altitude bombing mission was rendered obsolete by new anti-aircraft missiles, but the program continued as a testbed for high-speed technologies.

Though the increase in speed of the proposed American aircraft seemed impressive, it in fact changed the point-to-point timing of a trans-atlantic trip almost not at all. Calculations later showed the speed increase would have only cut 20 minutes from a journey across the Atlantic compared to Concorde, due to acceleration times and similar issues.

Requests for Proposals were sent out to airframe manufacturers Boeing, Lockheed, and North American for the airframes; and Curtiss-Wright, General Electric and Pratt & Whitney for engines. The FAA estimated that there would be a market for 500 SSTs by 1990. In spite of not having even a selected design, orders from air carriers started flowing in immediately.

## **Design competition**

Preliminary designs were submitted to the FAA on January 15, 1964.

Boeing's entry was essentially identical to the swing-wing Model 733 studied in 1960; it was known officially as the **Model 733-197**, but also referred to both as the **1966 Model** and the **Model 2707**. The latter name became the best known in public, while Boeing continued to use 733 model numbers. The design resembled the future B-1 Lancer bomber, with the exception that the four engines were mounted in individual nacelles instead of the box-like system mounted in pairs on the four-engined Lancer.

The North American NAC-60 was, unsurprisingly, essentially a scaled-up B-70 with a less tapered fuselage and new compound-delta wing. The design retained the high-mounted canard and box-like engine area under the fuselage. The Lockheed CL-823 was essentially a scaled-up Concorde with a compound-delta wing (as opposed to the smoothed ogee of the Concorde), with individually podded engines.

A "downselect" of the proposed models resulted in the NAC-60 and Curtiss-Wright efforts being dropped from the program, with both Boeing and Lockheed asked to offer SST models meeting the more demanding FAA requirements and able to use either of the remaining engine designs. In November, another design review was held, and by this time Boeing had scaled up the original design into a 250-seat model, the **Model 733-290**. Due to concerns about jet blast, the four engines were moved to a position underneath an enlarged tailplane. When the wings were in their swept-back position, they merged with the tailplane to give a delta-wing planform.

Both companies were now asked for considerably more detailed proposals, to be presented for final selection in 1966. When this occurred, Boeing's design was now the 300-seat **Model 733-390**. Both the Boeing and Lockheed L-2000 designs were presented in September 1966 along with full-scale mock-ups. A lengthy review followed, and on December 31, 1966, Boeing was announced as the winner. The design would be powered by the General Electric GE4/J5 engines. Lockheed's L-2000 was judged simpler to produce and less risky, but its performance was slightly lower and its noise levels slightly higher.

## **Refining the design**

The -390 would have been an advanced aircraft even if it had been only subsonic. It was one of the earliest wide-body designs, using a 2-3-2 row seating arrangement in a fuselage that was considerably wider than aircraft then in service. The SST mock-up

included both overhead storage for smaller items with restraining nets, as well as large drop-in bins between sections of the aircraft. In the main 247-seat tourist-class cabin, the entertainment system consisted of retractable televisions placed between every sixth row in the overhead storage. In the 30-seat first-class area, every pair of seats included smaller televisions in a console between the seats. Windows were only 6" due to the high altitudes the aircraft flew at maximizing the pressure on them, but the internal pane was 12" to give an illusion of size.

Boeing predicted that if the go-ahead were given, construction of the SST prototypes would begin in early 1967 and the first flight could be made in early 1970. Production aircraft could start being built in early 1969, with the flight testing in late 1972 and certification by mid-1974.

A major change in the design came when Boeing added canards behind the nose—which added weight. Boeing also faced insurmountable weight problems due to the swing-wing mechanism. In October 1968, the company was finally forced to abandon the variable geometry wing. The Boeing team fell back on a tailed delta fixed wing. The new design was also smaller, seating 234, and known as the **Model 2707-300**. Work began on a full-sized mock-up and two prototypes in September 1969, now two years behind schedule.

A promotional film claimed that airlines would soon pay back the federal investment in the project, and it was projected that SSTs would dominate the skies with subsonic jumbo jets (such as Boeing's own 747) being only a passing intermediate fad.

## **Environmental concerns**

By this point, the opposition to the project was becoming increasingly vocal. Environmentalists were the most influential group, voicing concerns about possible depletion of the ozone layer due to the high altitude flights, and about noise at airports and from sonic booms.

The latter became the most significant rallying point, especially after the publication of the anti-SST paperback, "SST and Sonic Boom Handbook" edited by William Shureliff, which claimed that a single flight would "leave a 'bang-zone' 50 miles wide by 2,000 miles long" along with a host of problems that would cause. In tests in 1965 with the XB-70 near Oklahoma City, the path had a maximum width of 16 miles, but still resulted in 9,594 complaints of damage to buildings, 4,629 formal damage claims, and 229 claims for a total of \$12,845.32, mostly for broken glass and cracked plaster. As the opposition widened, the claimed negative effects became ever odder, including upsetting people who do delicate work (e.g. brain surgeons), harming persons with nervous ailments, and even inducing miscarriages.

Other concerns were also added to the list, although the evidence for them was essentially non-existent. One was that the water vapor released by the engines into the stratosphere would envelop the earth in a "global gloom". Presidential Adviser Russell Train warned that a fleet of 500 SSTs flying at 65,000 ft. for a period of years could raise stratospheric

water content by as much as 50% to 100%. According to Train, this could lead to greater ground-level heat and hamper the formation of ozone. Later, an additional threat to the ozone was found in the exhaust's nitrogen oxides, a threat that was later validated by MIT.

The cause was picked up by the Sierra Club, the National Wildlife Federation and the Wilderness Society. Supersonic flight over land in the United States was eventually banned, and several states added additional restrictions or banned the Concorde outright.

The project also suffered political opposition from the left, which disliked the government subsidizing the development of a commercial aircraft to be used by private enterprise. The anti-SST campaign was led by Democratic Senator William Proxmire (D-Wisconsin), who saw the campaign as a crusade against unnecessary spending by the federal government.

Halaby attempted to dismiss these concerns, stating "The supersonics are coming—as surely as tomorrow. You will be flying one version or another by 1980 and be trying to remember what the great debate was all about."

### **Government funding cut**

In March 1971, despite the project's strong support by the administration of President Richard Nixon, the U.S. Senate rejected further funding. A counterattack was organized under the banner of the "National Committee for an American SST", which urged supporters to send in \$1 to keep the program alive. Afterward, letters of support from aviation buffs, containing nearly \$1 million worth of contributions, poured in. Labor unions also supported the SST project, worried that the winding down of both the Vietnam War and Project Apollo would lead to mass unemployment in the aviation sector. AFL-CIO President George Meany suggested that the race to develop a first-generation SST was already lost, but the US should "enter the competition for the second generation —the SSTs of the 1980s and 1990s."

In spite of this newfound support, Congress also voted to end SST funding on 20 May 1971. The vote was highly contentious. Gerald Ford, then Republican Leader, shouted Meany's claims that "If you vote for the SST, you are insuring 13,000 jobs today plus 50,000 jobs in the second tier and 150,000 jobs each year over the next ten years." Sidney Yates, leading the "no" camp, demanded a public vote (at that time a newly introduced procedure) and eventually won the vote against further funding, 215 to 204.

At the time, there were 115 unfilled orders by 25 airlines; at the time, Concorde had 74 orders from 16 customers. The two prototypes were never completed. Due to the loss of several government contracts and a downturn in the civilian aviation market, Boeing reduced its number of employees by more than 60,000. The SST became known as "the airplane that almost ate Seattle." A billboard was erected in 1971 that read, "Will the last person leaving Seattle - turn out the lights"

## Legacy

The supercritical airfoil, developed for the SST, is now a standard feature of jet aircraft.

North American Rockwell's B-1 used a similar layout to the 733-197's. The B-1 is the only swing-wing aircraft still in service with US forces.

Seattle's NBA basketball team formed in 1968 was dubbed the Seattle SuperSonics or just "Sonics", a name inspired by the newly won SST contract. The team kept that name until its 2008 move to Oklahoma City, and Seattle holds the right to apply the name to any future NBA franchise there.

The Museum of Flight in Seattle parks its Concorde a few blocks from the building where the original mockup was housed in Seattle. While the Soviet Tu-144 had a short service life, Concorde was successful enough to fly as a small luxury fleet from 1976 until 2003, for the most part highly profitable for the airlines in the niche transatlantic market. As the most advanced supersonic transports became some of the oldest airframes in the fleet, they eventually fell due to rising maintenance costs.

Though many designs have been studied since, it is unlikely similar aircraft will be economically feasible in the foreseeable future. Concorde's model of cooperation paved the way for Airbus, Boeing's most formidable competitor. Seattle's economy is now more diverse, and 2007 made Boeing a leader in sales again. Boeing's Future of Flight museum has the story and models of all of its production jetliners and Concorde, but not the SST project.

One of the wooden mockups was displayed at the SST Aviation Exhibit Center in Kissimmee, Florida from 1973 to 1981. It is now on display at the Hiller Aviation Museum of San Carlos, California.

## Specifications

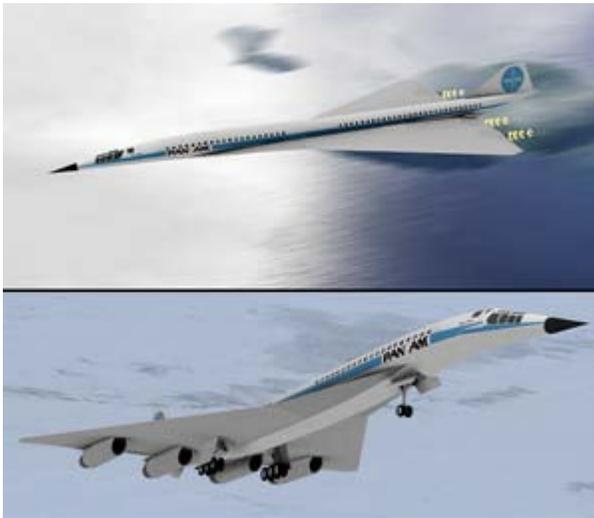
<b>Model</b>	<b>Boeing 2707-200 SST</b>
<b>Wingspan</b>	180 feet 4 inches (54.97 m) spread, 105 feet 9 inches (32.23 m) swept.
<b>Length</b>	306 feet 0 inches (93.27 m)
<b>Height</b>	46 feet 3 inches (14.10 m)
<b>Takeoff length</b>	5,700 feet (1,700 m)
<b>Landing length</b>	6,500 feet (2,000 m)
<b>Fuselage max. external dimensions</b>	Width 16 feet 8 inches (5.08 m), depth 15 feet 7 inches (4.75 m)
<b>Engines (4x)</b>	General Electric GE4/J5P turbojets, 63,200 lbf (281 kN) each, with augmentation.
<b>Empty operating weight</b>	International model: 287,500 pounds (130,400 kg)

<b>Max. ramp weight</b>	675,000 pounds (306,000 kg)
<b>Max. landing weight</b>	430,000 pounds (200,000 kg)
<b>Max. payload:</b>	75,000 pounds (34,000 kg)
<b>Normal cruising speed</b>	Mach 2.7: 1,800 miles per hour (2,900 km/h) at 64,000 feet (20,000 m)
<b>Range</b>	4,250 miles (6,840 km) with 277 passengers

## Chapter 10

# Lockheed L-2000

## Lockheed L-2000



Artist's concept of an L-2000 in Pan Am livery at altitude in full afterburner

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<b>Role</b>	Supersonic transport
<b>Manufacturer</b>	Lockheed Corporation
<b>Status</b>	Cancelled

The **Lockheed L-2000** was Lockheed Corporation's entry in a government-funded competition to build the United States' first supersonic transport (SST) in the 1960s. The L-2000 lost the contract to the Boeing 2707, but that competing design was ultimately canceled for political, environmental and economic reasons.

In 1961, President John F. Kennedy committed the government to subsidizing 75% of the development of a commercial airliner to compete with the Anglo-French Concorde then under development. The director of the Federal Aviation Administration (FAA), Najeeb Halaby, elected to improve upon the Concorde's design rather than compete head-to-head with it. The SST, which might have represented a significant advance over the Concorde, was intended to carry 250 passengers (a large number at the time), fly at Mach 2.7-3.0, and have a range of 4,000 nmi (7,400 km).

The program was launched on June 5, 1963, and the FAA estimated that by 1990 there would be a market for 500 SSTs. Boeing, Lockheed and North American officially responded. North American's design was soon rejected, but the Boeing and Lockheed designs were selected for further study.

## Development

### Early design studies

Like Boeing, Lockheed had done a number of "paper studies" on various SST designs, starting in 1958. Lockheed sought an airplane with cruise speeds of around 2,000 mph (3,219 km/h) with takeoff and landing speeds that compared to large subsonic jets of the same era. They also desired a plane whose center of pressure could be managed throughout the entire speed range. Lockheed knew a variable geometry, swing-wing design could accomplish this goal, but felt it was too heavy; however, they preferred a fixed-wing solution. In a worst-case scenario, they were willing to design a fixed-wing aircraft using fuel for ballast.

Early designs followed Lockheed's tapered straight wing much like the type used on the F-104 Starfighter, with a delta-shaped canard for aerodynamic trim. The problem was that in wind-tunnel tests the shift in the airplane's C/L was substantial. A delta wing was substituted which alleviated a portion of the movement, but it was not deemed sufficient. By 1962, Lockheed arrived at a highly swept, bat-wing design featuring four-engine pods buried in the wings and a canard. The improvement was closer to their goal, but still not optimal. By 1963, they extended the leading edge of the wing forward a bit to eliminate the need for the canard, and re-shaped the wing into a double-delta shape with a mild twist and camber. This, along with careful shaping of the fuselage, was able to control the shift in the center of pressure caused by the highly-swept forward part of the wing developing lift supersonically. The engines were shifted from being buried in the wings to individual pods slung below the wings.

### Later design studies

The new design was designated **L-2000-1** and was 223 ft (70 m) long with a narrow-body 132 in (335.2 cm) wide fuselage to meet aerodynamic requirements, allowing for passenger seating of five abreast seating in coach and a four-abreast arrangement in first-class seating. A typical mixed-class seating layout would equal around 170 passengers, with high-density layouts exceeding 200 passengers.

The L-2000-1 featured a long, pointed nose that was almost flat on top and curved on the bottom, which allowed for improved supersonic performance, and could be drooped for takeoff and landing to provide adequate visibility. The wing design featured a sharp forward inboard sweep of 80°, with the remaining part of the wing's leading edge swept back 60°, with an overall area of 8,370 ft<sup>2</sup> (778 m<sup>2</sup>). The high sweep angles produced powerful vortices on the leading edge which increased lift at moderate to high angles of attack, yet still retained stable airflow over the control surfaces during a stall. These

vortices also provided good directional control as well, which was somewhat deficient with the nose drooped at low speeds. The wing, while only 3% thick, provided substantial lift due to its large area, which, aided by vortex lift, allowed takeoff and landing speeds comparable to a Boeing 707. Additionally, a delta wing is a naturally rigid structure which requires little stiffening.

The plane's undercarriage was a traditional tricycle type with a twin-wheeled nose gear. Each of the two six-wheeled main gear utilized the same tires used on the Douglas DC-8, but which were filled with nitrogen and to lower pressures.

To provide an optimum entry date into service, Lockheed decided to use a beefed-up turbofan derivative of the Pratt & Whitney J58. The J58 had already successfully proven itself as a high-thrust, high-performance jet engine on the top-secret Lockheed A-12 (and subsequently on the Lockheed SR-71 Blackbird.) Due to its being a turbofan, it was deemed to be quieter than a typical turbojet at low altitude and low speed, required no afterburner for takeoff, and allowed reduced power settings. The engines were placed in cylindrical pods with a wedge-shaped splitter, and a squarish intake providing the inlet system for the aircraft. The inlet was designed with the goal of requiring no moving parts, and was naturally stable. To reduce the noise from sonic booms, rather than penetrate the sound barrier at a more ideal 30,000 ft (9,144 m), they intended to penetrate it at 42,000 ft (12,802 m) instead. It would not be possible on hot days, but on normal days this would be achievable. Acceleration would continue through the sound barrier to Mach 1.15, at which point sonic booms would be audible on the ground. The plane would climb precisely to minimize sonic boom levels. After an initial level-off at around 71,500 ft (21,793 m), the plane would cruise climb upwards, ultimately reaching 76,500 ft (23,317 m). Descents would also be performed in a precise way to reduce sonic boom levels until subsonic speeds were reached.

By 1964, the US Government issued new requirements regarding the SST Program which required Lockheed to modify their design, by now called the **L-2000-2**. The new design had numerous modifications to the wing; one change was rounding the front of the forward delta in order to eliminate the pitch-up tendency. To increase high-speed aerodynamic efficiency, the wing's thickness was reduced to 2.3%, the leading edges were made sharper, the sweep angles were changed from 80/60° to 85/62°, and substantial twist and camber were added to the forward delta; much of the rear delta was twisted upwards to allow the elevons to remain flush at Mach 3.0. In addition, wing/body fairings were added on the underside of the fuselage where the wings are located, allowing a more normally-shaped nose to be used. To retain low-speed performance, the rear delta was enlarged considerably; to increase the payload, the trailing edge featured a forward sweep of 10°. The new nose reduced the overall length to 214 ft (65.2 m) while retaining virtually the same internal dimensions. Wingspan was identical as before, and despite the thinner wing, the increased wing area of 9,026 ft<sup>2</sup> (838.5 m<sup>2</sup>) allowed the same takeoff performance. The airplane's overall lift-to-drag ratio increased from 7.25 to 7.94.

During the course of the L-2000-2's development, the engine previously selected by Lockheed was no longer deemed acceptable. During the time frame between the L-2000-

1 and L-2000-2, Pratt and Whitney designed a new afterburning turbofan called the JTF-17A, which produced greater amounts of thrust. General Electric developed the GE-4 which was an afterburning turbojet with variable guide-vanes, which was actually the less powerful of the two at sea level, but produced more power at high altitudes. Both engines required some degree of afterburner during cruise. Lockheed's design favored the JTF-17A over the GE-4, but there was the risk that GE would win the engine competition and Lockheed would win the SST contract, so they developed new engine pods that could accommodate either engine. Aerodynamic modifications allowed a shorter engine pod to be used and which utilized a new inlet design. This inlet featured minimal external cowl angles and was precisely contoured to allow a high-pressure recovery using no moving parts, and allowed maximum performance with either engine option. To allow additional airflow for noise-reduction, or to aid afterburner performance, a set of suck-in doors was added to the rear portion of the pod. To provide mid-air braking capability for rapid deceleration and rapid descents, and to assist ground braking, part of the nozzle could be employed as a thrust reverser at speeds below Mach 1.2. The pods were also repositioned on the new wing to better shield them from abrupt changes in airflow.

The additional thrust from the new engines allowed supersonic penetration to be delayed until up to 45,000 ft (13,716 km) under virtually all conditions. Since at this point the possibility of supersonic overland flight was still considered to be an option, Lockheed also considered larger, shorter-ranged versions of the L-2000-2B. All designs weighed exactly the same, with a new tail design, changes to the fuselage length, extensions to the forward delta, increased capacity, and variations in fuel capacity. The largest version featured capacity for 250 domestic passengers, while the medium version featured transatlantic capability with 220 passengers. Despite the fuselage length changes, there was no appreciable increase in the risk of the aircraft pitching upwards too far (over-rotation) on takeoff.

## **Design competition**

By 1966, the design took on its final form as the **L-2000-7A** and **L-2000-7B**. The L-2000-7A featured a re-designed wing and fuselage lengthened to 273 ft (83 m). The longer fuselage allows for a mixed-class seating of 230 passengers. The new wing featured a proportionately larger forward delta, with greater refinement to the wing's twist and curvature. Despite having the same wingspan, the wing-area was increased to 9,424 ft<sup>2</sup> (875 m<sup>2</sup>), with a slightly reduced 84° sweepback, and an increased 65° main delta wing, with reduced forward sweep along the trailing edge. Unlike previous versions, this aircraft featured a leading-edge flap to increase lift at low speeds, and to allow a slight down-elevon deflection. The fuselage, as a result of greater length, changes to the wing design, and attempts to further reduce drag, featured a slight vertical thinning in the fuselage where the wings were, a more prominent wing/body "belly" to carry fuel and cargo, a longer nose, and a refined tail. Since the airplane was not as directionally stable as before, the plane featured a ventral fin, located on the underside of the trailing fuselage. The L-2000-7B was extended to 293 ft (89 m), utilizing a lengthened cabin and a more pronounced upward-curving tail to reduce the chance of the tail striking the

runway during over-rotation. Both designs had the same maximum weight of 590,000 lb (267,600 kg), and the aerodynamic lift-to-drag ratio was increased to 8:1.

Full-scale mock-ups of the Boeing 2707-200 and L-2000-7 designs were presented to the FAA, and on December 31, 1966 the Boeing design was selected. The Lockheed design was judged simpler to produce and less risky, but its performance during takeoff and at high speed was slightly lower. Because of the JTF-17A, the L-2000-7 was also predicted to be louder as well. The Boeing design was considered more advanced, representing a greater lead over the Concorde and thus more fitting to the original design mandate. Ironically, Boeing eventually changed its advanced variable-geometry wing design to a simpler delta-wing similar to Lockheed's design, but with a tail. If Lockheed had built its simpler design, it might have flown by 1971. With technical problems, delays, cost overruns, and environmental and economic questions, the Boeing SST was ultimately canceled on May 20, 1971 after the US Congress stopped federal funding for the SST program on March 24, 1971.

## Specifications (L-2000-7A)

### General characteristics

- **Capacity:** 273 passengers
- **Length:** 273 ft 2 in (83.26 m)
- **Wingspan:** 116 ft (35.36 m)
- **Height:** ()
- **Wing area:** 9,424 ft<sup>2</sup> (875 m<sup>2</sup>)
- **Empty weight:** 238,000 lb (107,900 kg)
- **Max takeoff weight:** 590,000 lb (276,600 kg)
- **Powerplant:** 4× GE4/J5M or Pratt & Whitney JTF17A-21L

### Performance

- **Cruise speed:** Mach 3.0
- **Range:** 4,000 nmi (7,400 km)
- **Service ceiling:** 76,500 ft (23,317 m)
- **Wing loading:** 62.61 lbs/ft<sup>2</sup> ()

## Chapter 11

# Concorde

## Concorde



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

The **Aérospatiale-BAC Concorde** is 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 and Washington Dulles, 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 Britain and France. In Britain, 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**

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) for a transatlantic-ranged aircraft for about 100 people, while the French were intending to build a medium-range aircraft.



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.

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 Concorde's 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 Aérospatiale 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. 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.

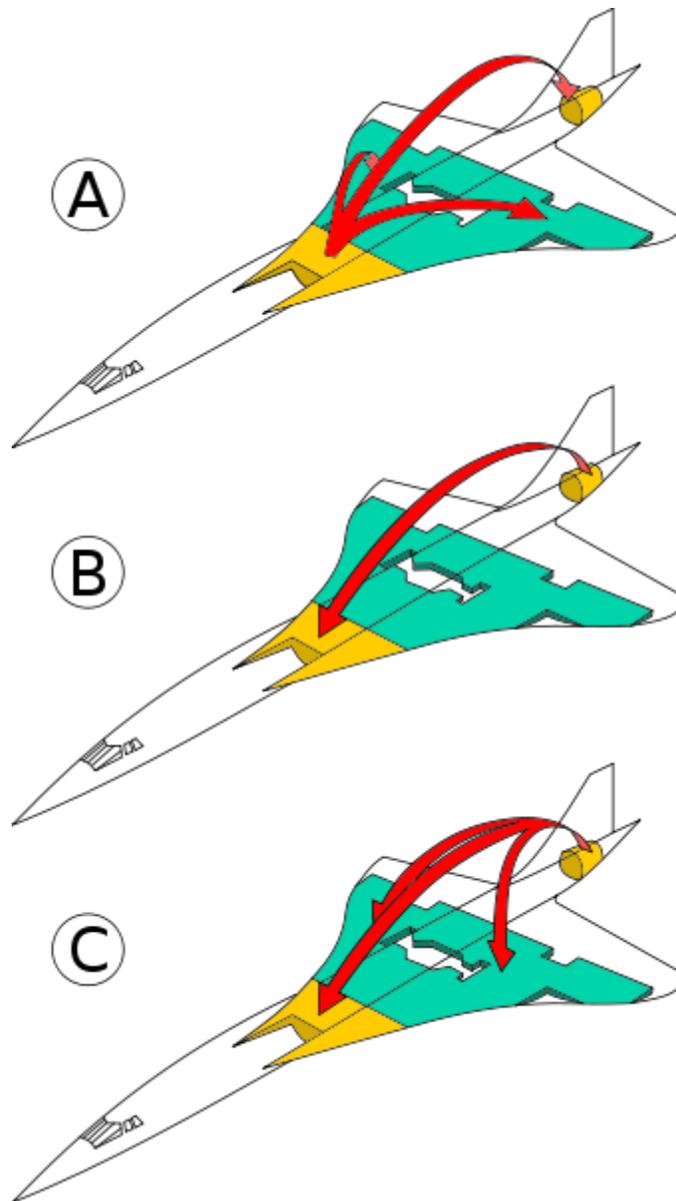
Demonstration and test flights were flown from 1974 onwards. The testing of Concorde set records that have not been surpassed; the prototype, pre-production and first production aircraft undertook 5,335 flight hours; 2,000 test hours were at supersonic speeds. Unit costs were £23 million (US\$46 million) 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:

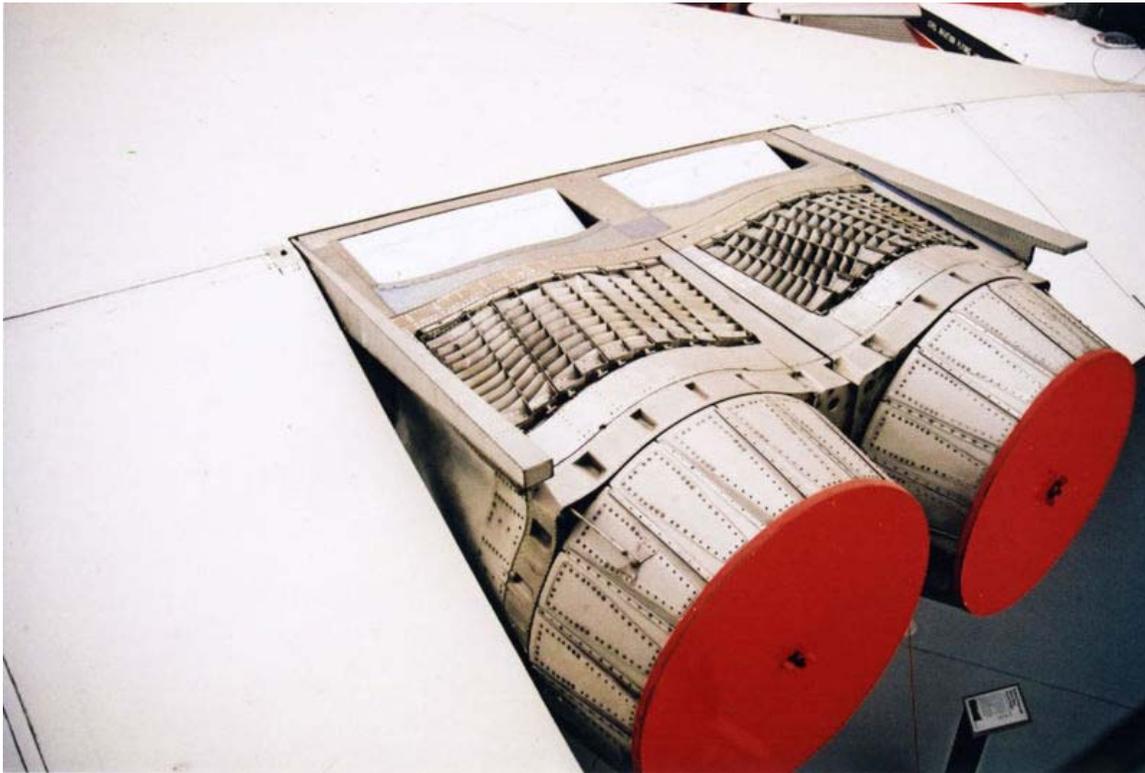
For high speed and optimisation of flight:

- 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/in<sup>2</sup>) 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

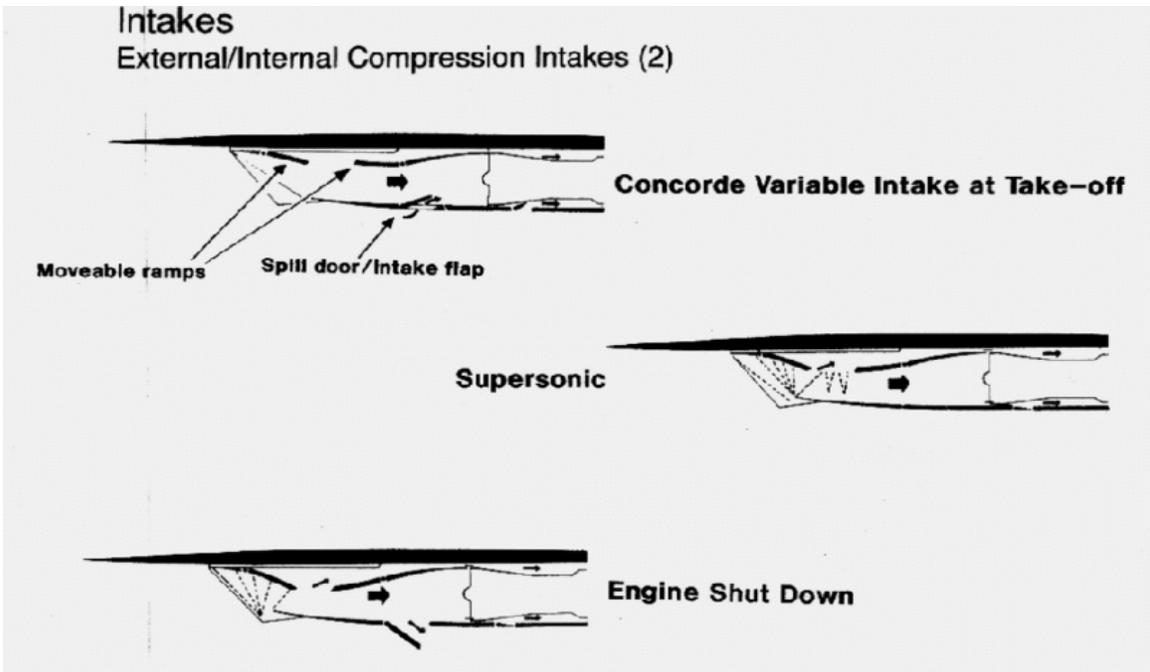


G-AXDN, Duxford, close up of pre-production engine nozzles. The nozzle/thrust reverser design was altered for the production Concorde.

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 Concorde's 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, 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

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. A cabin breach could even reduce air pressure to below the ambient pressure outside the aircraft due to the Venturi effect, as the air is sucked out through an opening. 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  $5^\circ$  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  $12.5^\circ$  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 Concorde 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 Concorde, 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 Concorde 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.

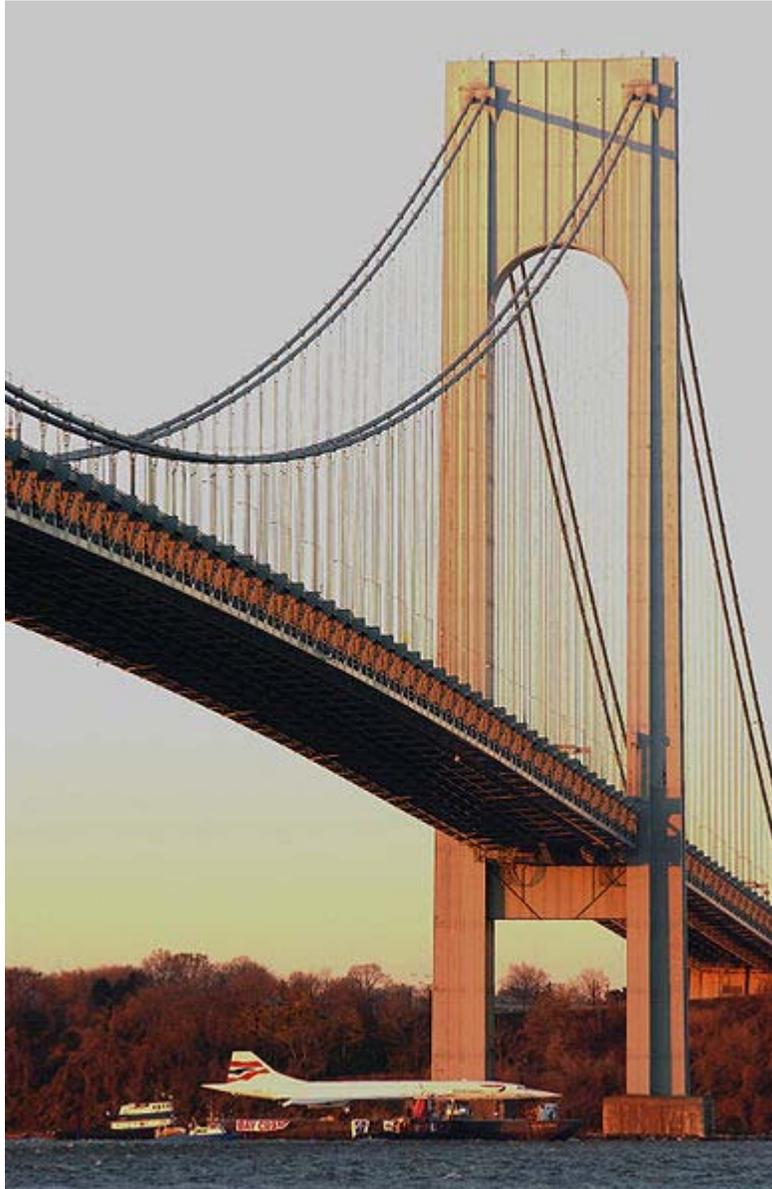
According to the official investigation conducted by the French accident investigation bureau (BEA), the crash was caused by a titanium strip that fell from a Continental Airlines DC-10 that had taken off minutes earlier. This metal fragment punctured a tyre on the Concorde's left main wheel bogie during 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 Concorde, 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, their airworthiness certificates withdrawn and drained of hydraulic fluid. 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 Concorde (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 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.

<b>Concorde fuel efficiency comparison</b>			
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-144S 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. As of 2010, the project continues but no progress has been made on developing a prototype.

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.

## 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<sup>2</sup> (358.25 m<sup>2</sup>)
- **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 12

# Other Supersonic Transports

## Bristol Type 223

The Bristol Aeroplane Company **Type 223** was an early design for a supersonic transport. In the late 1950s and early 1960s the company studied a number of models as part of a large British inter-company effort funded by the government. These models eventually culminated in the Type 223, a transatlantic transport for about 100 passengers at a speed around Mach 2. At about the same time Sud Aviation in France was developing the similar Super-Caravelle design, and in November 1962 the efforts were merged to create the Concorde project.

## Development

### Background

During the 1950s, the British lead in aircraft design was continually eroded by a series of technical and commercial disasters. The technically daunting Bristol Brabazon met all of its demanding performance requirements, but proved to be a commercial failure when customers felt the transatlantic market wasn't big enough to justify such a large and expensive aircraft. Meanwhile the de Havilland Comet suffered a series of mysterious and deadly accidents which cast a pall over the market for jet airliners, another area where the British technological lead might have proved decisive. In fact, the fatigue failures exposed in the Comet led to prolonged testing of other promising designs like the Bristol Britannia, which were so delayed that their production was eclipsed by US designs when they finally reached service. The leading US contender, the Boeing 707 series, gained much from the KC-135 Stratotanker project.

Throughout this period, the industry had been producing a series of advanced test aircraft however, and had extensively studied the problems of sustained high-speed flight. By the mid 1950s, two designs had been shown to have a lift-to-drag ratio suitable for supersonic cruise, a sharply swept "M-wing" pioneered at Armstrong-Whitworth for slightly-supersonic flight, and very slender delta wings suitable for a wide range of speeds. Higher speeds up to Mach 3 had been considered and found to be possible, but it appeared that a practical upper limit was Mach 2.2, above this speed the duralumin used

for most aircraft construction would start to go soft due to the heat of friction, and some new material would have to be used instead.

## STAC

By 1956 there was enough official interest in this research for the **Supersonic Transport Aircraft Committee**, or **STAC**, to be formed under Sir Morien Morgan to investigate the creation of a supersonic transport. Through the late 1950s, Bristol, Handley Page and Hawker Siddeley all conducted a series of studies into various delta wing designs under STAC.

At Bristol, Archibald Russell studied a number of variations under the generic **Type 198** label. Using RAE wind tunnel data, he concluded that a Mach 2 transatlantic machine was the only one worth building; at shorter ranges the added cost and complexity of supersonic flight would not reduce the flight times enough to be worthwhile. By 1958, the Type 198 had evolved into an eight-engined shoulder-wing delta of around 150 seats and a Mach 2 speed. In 1959, they received an additional £350,000 study contract to continue work on the design, and by the end of the year the 198 had evolved into a 136-seat aircraft cruising at Mach 1.8.

At the same time Russell started a parallel study on a similar sized but higher speed design built of stainless steel as **Type 213**. However this proved uneconomical when their own Bristol 188 design started into production that year. Although much of the problem can likely be traced to the novelty of the 188's steel construction, it cost many times more than conventional designs, and appeared to be impractical. From then on Russell was interested only in designs of Mach 2.2 or less, the upper limit for aluminium construction.

In March 1959, STAC recommended the UK build two supersonic designs, a long-range 150-seat aircraft to cruise at Mach 2 for the London to New York route, and a shorter-range aircraft to cruise at Mach 1.2 for use in Europe. On January 1, 1960, several British aerospace companies merged to form the British Aircraft Corporation, or BAC. Hawker Siddeley had also been working on the transatlantic version of the STAC designs, but the Bristol design was considered clearly superior.

However Russell soon started having second thoughts about the 150-seat sized version, and in 1961 started parallel work on a smaller design known as **Type 223**, of about 110-seats and with four engines, but otherwise similar to the low-wing version of the Type 198.

In 1961, Sud Aviation revealed their plans for the Super-Caravelle at the Paris Air Show. By this point STAC was looking at producing the Type 223, but the cost was going to be enormous. Throughout 1962 the two companies and their respective governments talked about forming a consortium to share development and production costs on similar parts. On November 29, 1962 an agreement was signed, and the Concorde project started. Originally two versions of the same basic design were going to be offered, a larger transatlantic version with a size about that of the Type 223, and a smaller short/medium

range version similar to the Super Caravelle. However as the group started talking to prospective customers, it soon became clear that the smaller version was not commercially interesting, and it was eventually dropped. The Bristol Olympus engine Mark No. designed for the cancelled short/medium range version was subsequently developed for use in the BAC TSR-2 strike aircraft.

## Gulfstream X-54

### X-54

<b>Role</b>	Experimental aircraft
<b>National origin</b>	United States
<b>Manufacturer</b>	Gulfstream Aerospace
<b>Status</b>	In development
<b>Number built</b>	0

The **Gulfstream X-54** is a research and demonstration aircraft, under development in the United States by Gulfstream Aerospace, that is planned for use in sonic boom and supersonic transport research.

### Development

Initiated during 2008, the X-54 project is intended to produce an experimental aircraft capable of supersonic speeds. The X-54A is intended to produce test data on sonic boom effects in support of future supersonic transport design and regulation. Current regulations prohibit supersonic flight over land areas in the United States; the X-54 is part of Gulfstream's efforts to have the regulations altered to allow for supersonic transports to be commercially viable.

The X-54A is being developed by Gulfstream Aerospace and is intended to be powered by two Rolls-Royce Tay turbofan engines. Although the aircraft has received an 'X' series designation in the U.S. Department of Defense's Mission Designation System at the request of NASA, neither the U.S. military nor NASA is currently involved in the project.

Although Gulfstream has made little comment about the X-54A project, at the 2008 National Business Aviation Association convention a Gulfstream executive stated that Gulfstream's work on advanced technologies for supersonic flight had been ongoing "for some time" and that a "complete airplane designed for low [sonic] boom" would possibly "have X-54 painted on the side of it."

The X-54A may be connected to Gulfstream's "Sonic Whisper" program, trademarked in 2005 as an aircraft design to "reduce boom intensities during supersonic flight." Some sources claim that the X-54A is based on the F-104 Starfighter; this conflicts with the description of the aircraft by the DOD.

## High Speed Civil Transport



The High Speed Civil Transport (HSCT)

The **High Speed Civil Transport (HSCT)**, also known as High-speed Research (HSR), was a NASA project to design a supersonic transport. It was to be a future Supersonic Passenger Aircraft, able to fly Mach 2, or twice the speed of sound. The project started in 1990 and ended during 1999. The goal was to employ up-to-date technologies.

It was intended to cross the Atlantic or the Pacific Ocean in half the time of a non-supersonic aircraft. It was to be fuel efficient, carry 300 passengers, and it would have allowed customers to buy tickets at a much lower price than that of a ticket on a Concorde. The goal for its maiden flight was within 20 years.

## Sud Aviation Super-Caravelle

The Sud Aviation **Super-Caravelle** was an early design for a supersonic transport. Unlike most competing designs which envisioned larger trans-Atlantic aircraft and led to the likes of the Boeing 2707, the Super-Caravelle was a much smaller, shorter range design intended to replace their earlier and very successful Caravelle. Design work

started in 1960 and was announced in 1961 at the Paris Air Show, but was later merged with similar work at the British Aircraft Corporation (originally the Bristol 223) to create the Concorde project in November 1962. After work had begun on designing Concorde, the Super Caravelle name was instead used on a lengthened version of the original Caravelle design, the SE-210B.

The Super-Caravelle looks very much like a smaller, two-engine version of Concorde. It used Concorde's unique ogive wing planform, and was otherwise similar in shape and layout with the exception of the nose area, which was more "conventional" and only the outermost section over the radar "drooped" for visibility on takeoff and landing. In normal use it was designed to carry 70 passengers between 2000 to 3000 km at about Mach 2. The size and range requirements were set to make the Super-Caravelle "perfect" for Air France's European and African routes.

Concorde was originally to be delivered in two versions, a longer-range transatlantic version similar to the Bristol 223 that was eventually delivered as Concorde, and a smaller version for shorter range routes similar to the Super-Caravelle. After consultations with prospective customers, the smaller design was dropped.

## Chapter 13

# Supersonic Speed



A United States Navy F/A-18E/F Super Hornet in transonic flight



U.S. Navy F/A-18 approaching the sound barrier. The white halo is formed by condensed water droplets which result from the shockwave shedding from the aircraft.

**Supersonic speed** is a rate of travel of an object that is larger than the speed of sound (Mach 1). For objects traveling in dry air of a temperature of 20 °C (68 °F) this speed is approximately 343 m/s, 1,125 ft/s, 768 mph or 1,236 km/h. Speeds greater than five times the speed of sound (Mach 5) are often referred to as hypersonic. Flight during which only some parts of the air around an object, such as the ends of rotor blades, reach supersonic speeds are called transonic. This occurs typically somewhere between Mach 0.8 and Mach 1.2.

Sounds are traveling vibrations in the form of pressure waves in an elastic medium. In gases, sound travels longitudinally at different speeds, mostly depending on the molecular mass and temperature of the gas, and pressure has little effect. Since air temperature and composition varies significantly with altitude, Mach numbers for aircraft may change despite a constant travel speed. In water at room temperature supersonic speed can be considered as any speed greater than 1,440 m/s (4,724 ft/s). In solids, sound waves can be polarized longitudinally or transversely and have even higher velocities.

Supersonic fracture is crack motion faster than the speed of sound in a brittle material.

## Supersonic objects

Most modern fighter aircraft are supersonic, but there have been supersonic passenger aircraft, namely Concorde and the Tupolev Tu-144. Both these passenger aircraft and some modern fighters are also capable of supercruise, a condition of sustained supersonic flight without the use of an afterburner. Due to its ability to supercruise for several hours and the relatively high frequency of flight over several decades, Concorde spent more time flying supersonically than all other aircraft put together by a considerable margin. Since Concorde's final retirement flight on November 26, 2003, there are no supersonic passenger aircraft left in service. Some large bombers, such as the Tupolev Tu-160 and Rockwell/Boeing B-1B are also supersonic-capable.

Most modern firearm bullets are supersonic, with rifle projectiles often travelling at speeds approaching and in some cases largely exceeding Mach 3.

Most spacecraft, most notably the Space Shuttle are supersonic at least during portions of their reentry, though the effects on the spacecraft are reduced by low air pressures. During ascent, launch vehicles generally avoid going supersonic below 30 km (~98,400 feet) to reduce air drag.

Note that the speed of sound decreases somewhat with altitude, due to lower temperatures found there (typically up to 25 km). At even higher altitudes the temperature starts increasing, with the corresponding increase in the speed of sound.

A wave traveling through a bull whip is also capable of achieving supersonic speeds.

## Supersonic flight

Supersonic aerodynamics are simpler than subsonic because the airsheets at different points along the plane often can't affect each other. Supersonic jets and rocket vehicles require several times greater thrust to push through the extra drag experienced within the transonic region (around Mach 0.85-1.2). At these speeds aerospace engineers can gently guide air around the fuselage of the aircraft without producing new shock waves but any change in cross sectional area further down the vehicle leads to shock waves along the body. Designers use the Supersonic area rule and the Whitcomb area rule to minimize sudden changes in size.

It should be kept in mind, however, that the aerodynamic principles behind a supersonic aircraft are often more complex than described above because such an aircraft must be efficient and stable at supersonic, transonic *and* subsonic flight.

One problem with sustained supersonic flight is the generation of heat in flight. At high speeds aerodynamic heating can occur, so an aircraft must be designed to operate and function under very high temperatures. Duralumin, the traditional aircraft material, starts to lose strength and go into plastic deformation at relatively low temperatures, and is

unsuitable for continuous use at speeds above Mach 2.2 to 2.4. Materials such as titanium and stainless steel allow operations at much higher temperatures. For example, the SR-71 Blackbird jet could fly continuously at Mach 3.1 while some parts were above 315°C (600°F).

Another area of concern for continued high-speed operation is the engines. Jet engines create thrust by increasing the temperature of the air they ingest, and as the aircraft speeds up, friction and compression heats this air before it reaches the engines. The maximum temperature of the exhaust is determined by the materials in the turbine at the rear of the engine, so as the aircraft speeds up the difference in intake and exhaust temperature the engine can extract decreases, and the thrust along with it. Air cooling the turbine area to allow operations at higher temperatures was a key solution, one that continued to improve through the 1950s and on to this day.

Intake design was also a major issue. Normal jet engines can only ingest subsonic air, so for supersonic operation the air has to be slowed down. Ramps or cones in the intake are used to create shock waves that slows the airflow before it reaches the engine. Doing so removes energy from the airflow, causing drag. The key to reducing this drag is to use multiple small oblique shock waves, but this was difficult because the angle they make inside the intake changes with Mach number. In order to efficiently operate across a range of speeds, the shock waves have to be "tuned."

An aircraft able to operate for extended periods at supersonic speeds has a potential range advantage over a similar design operating subsonically. Most of the drag an aircraft sees while speeding up to supersonic speeds occurs just below the speed of sound, due to an aerodynamic effect known as wave drag. An aircraft that can accelerate past this speed sees a significant drag decrease, and can fly supersonically with improved fuel economy. However, due to the way lift is generated supersonically, the lift-to-drag ratio of the aircraft as a whole drops, leading to lower range, offsetting or overturning this advantage.

The key to having low supersonic drag is to properly shape the overall aircraft to be long and skinny, and close to a "perfect" shape, the von Karman ogive or Sears-Haack body. This has led to almost every supersonic cruising aircraft looking very similar to every other, with a very long and skinny fuselage and large delta wings, cf. SR-71, Concorde, etc. Although not ideal for passenger aircraft, this shaping is quite adaptable for bomber use.

## History of supersonic flight

John Stack led the research on the "transonic gap" at NACA in the 1930s.



President Kennedy honors Dr. von Kármán

The Hungarian-born American scientist Theodore von Karman (May 11, 1881 – May 7, 1963) developed the theoretical background of supersonic flight and the analytical tools to study supersonic fluid flow, and as well as the swept wing. He is often called "the father of supersonic flight" due to his work on the stability of laminar flow, turbulence, airfoils in steady and unsteady flow, boundary layers, and supersonic aerodynamics, largely taking place in the 1940s through 60s.

The speed of sound was exceeded for the first time by a manned aircraft in controlled, level flight on October 14, 1947 in an American research project, using the experimental Bell X-1 research rocket plane, piloted by Charles "Chuck" Yeager. The first production plane to break the sound barrier was an F-86 Canadair Sabre with the first 'supersonic' woman pilot, Jacqueline Cochran, at the controls, although this aircraft was not designed with regular supersonic flights in mind.