Supersonic Transport

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Chapter- 1

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.

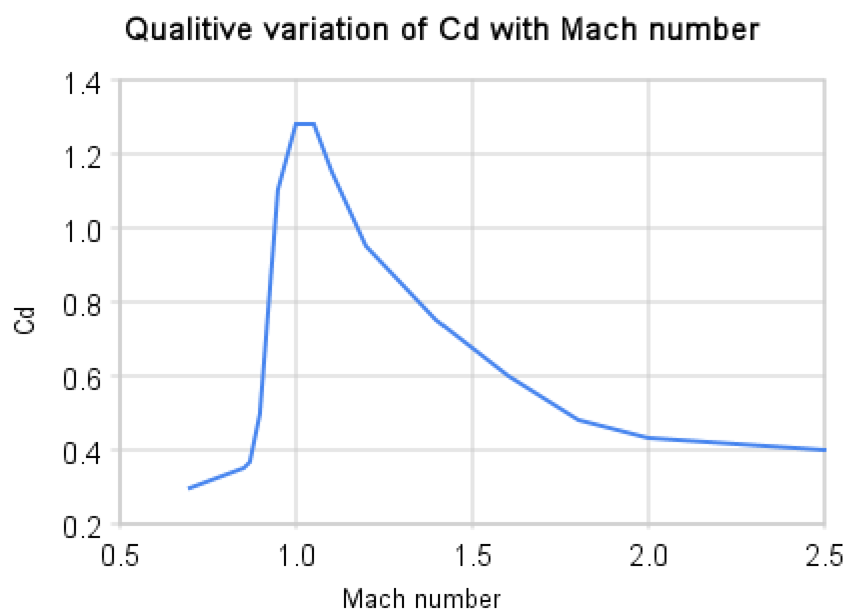
Supersonic airliners' greater speed and efficiency over their conventional counterparts have made them objects of numerous recent and ongoing design studies. Drawbacks and design challenges are excessive noise generation (due to sonic booms), high development costs, expensive construction materials,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

***Concorde* fuel efficiency comparison**

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

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 Concordes 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-engined 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.

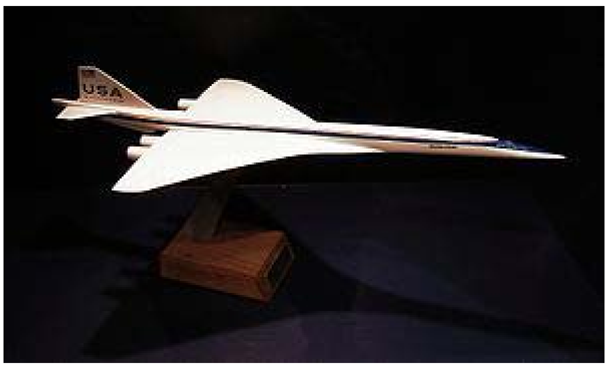
There is also a very long distance supersonic/hypersonic transport version of Skylon, the A2, being evaluated by the European Union as part of the LAPCAT project, which would travel at Mach 5 and would be capable of travelling Brussels to Sydney in 4.6 hours.

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

Chapter- 2

Boeing 2707

Boeing 2707



Model of a Boeing 2707-300.

Role	Supersonic transport
Manufacturer	Boeing Commercial Airplanes
Status	Cancelled
Number built	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 Shurcliff, 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

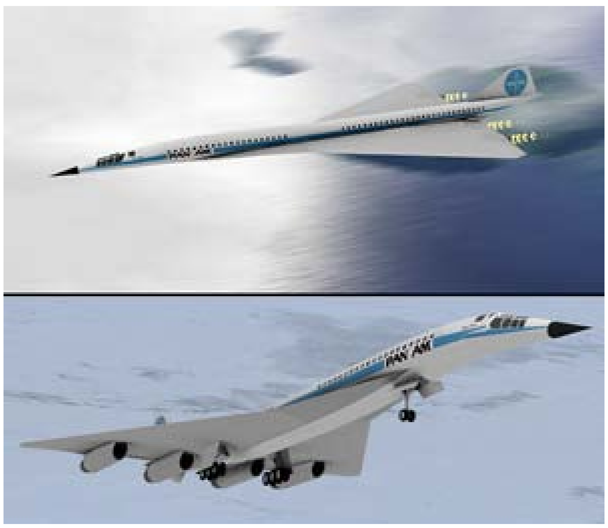
Model	Boeing 2707-200 SST
Wingspan	180 feet 4 inches (54.97 m) spread, 105 feet 9 inches (32.23 m) swept.
Length	306 feet 0 inches (93.27 m)
Height	46 feet 3 inches (14.10 m)
Takeoff length	5,700 feet (1,700 m)
Landing length	6,500 feet (2,000 m)
Fuselage max. external dimensions	Width 16 feet 8 inches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

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

Chapter- 3

Lockheed L-2000

Lockheed L-2000



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

Role	Supersonic transport
Manufacturer	Lockheed Corporation
Status	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 ft² (778 m²). 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 ft² (838.5 m²) 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 ft² (875 m²), 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 ft² (875 m²)
- **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^2 ()

Chapter- 4

Concorde

Concorde

Role	Supersonic airliner
Manufacturer	BAC (now BAE Systems) Aérospatiale (now EADS)
First flight	2 March 1969
Introduction	21 January 1976
Retired	26 November 2003
Status	Retired from service
Primary users	British Airways Air France Braniff International Airways Singapore Airlines
Number built	20 (including 6 non-airline aircraft)
Unit cost	£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 Concordes each. Other airlines in the order book included Panair do Brasil, Continental Airlines, Japan Airlines, Lufthansa, American Airlines, United Airlines, Air India, Air Canada, Braniff, Singapore Airlines, Iran Air, Olympic Airways, Qantas, CAAC, Middle East Airlines and TWA.

Naming

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

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

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

Testing

Construction of two prototypes began in February 1965: 001, built by Aerospatiale at Toulouse, and 002, by BAC at Filton, Bristol. Concorde 001 made its first test flight from Toulouse on 2 March 1969, piloted by André Turcat, and first went supersonic on 1 October. The first UK-built Concorde flew from Filton to RAF Fairford on 9 April 1969, piloted by Brian Trubshaw. 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.

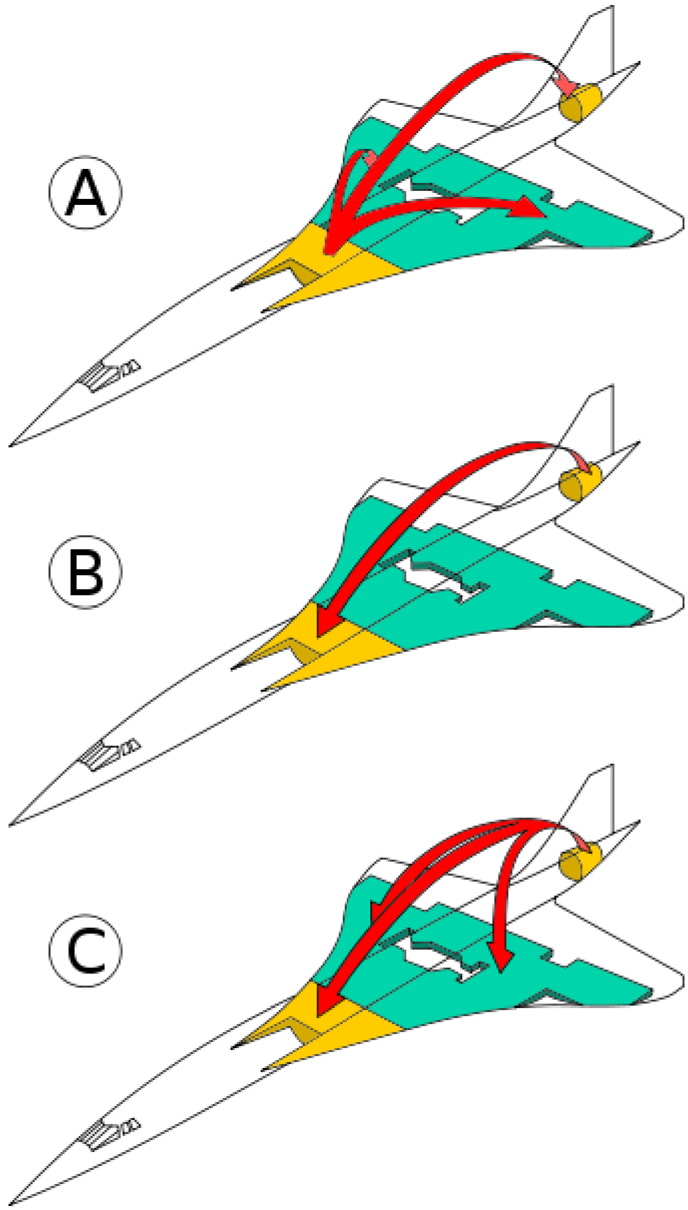
The United States cancelled the Boeing 2707, its supersonic transport programme, in 1971. Industry observers in France and the United Kingdom suggested that part of the American opposition to Concorde on grounds of noise pollution was orchestrated, or at least encouraged, by the United States Government, 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:

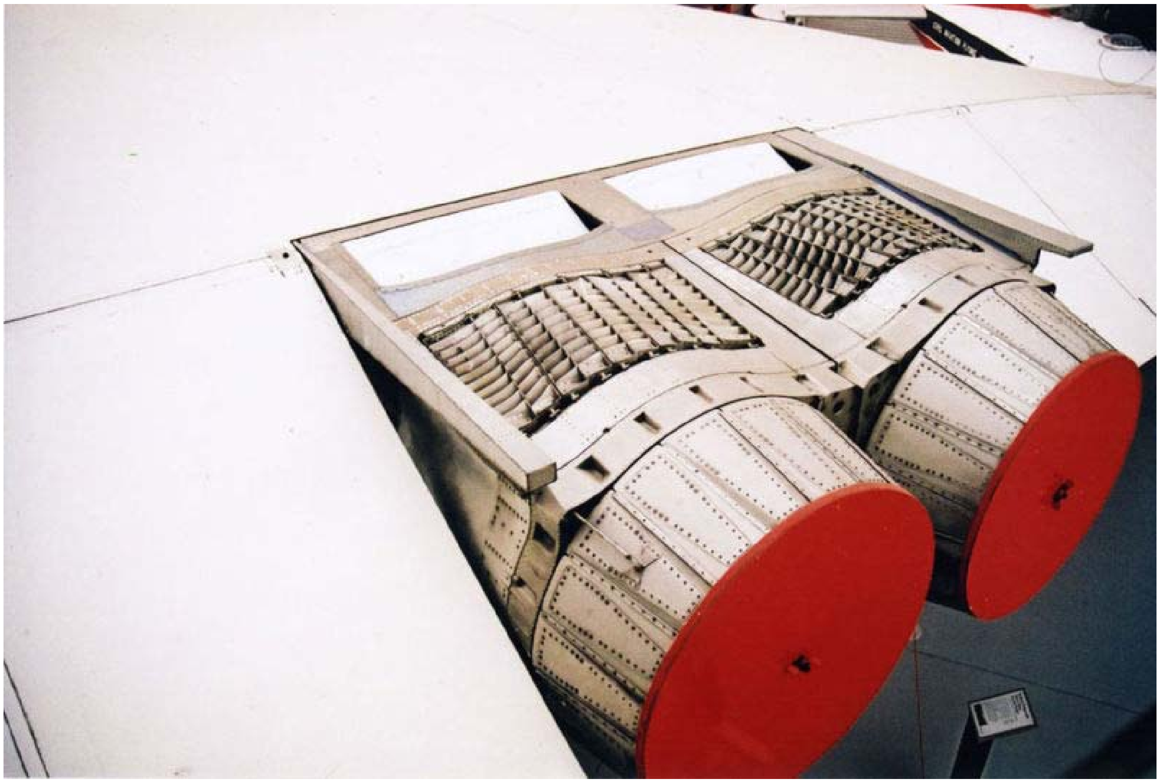
For high speed and optimisation of flight:

- 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/in²) for lighter hydraulic components
- Complex Air Data Computer (ADC) for the automated monitoring and transmission of aerodynamic measurements (total pressure, static pressure, angle of attack, side-slip).
- Fully electrically controlled analogue brake-by-wire system
- Pitch trim by shifting fuel around the fuselage for centre-of-gravity control
- Parts made using "sculpture milling" from single alloy billet, reducing the part-number count while saving weight and adding strength
- Lack of an auxiliary power unit, as Concorde would only visit large airports where a ground air start cart would be available.

Movement of centre of pressure

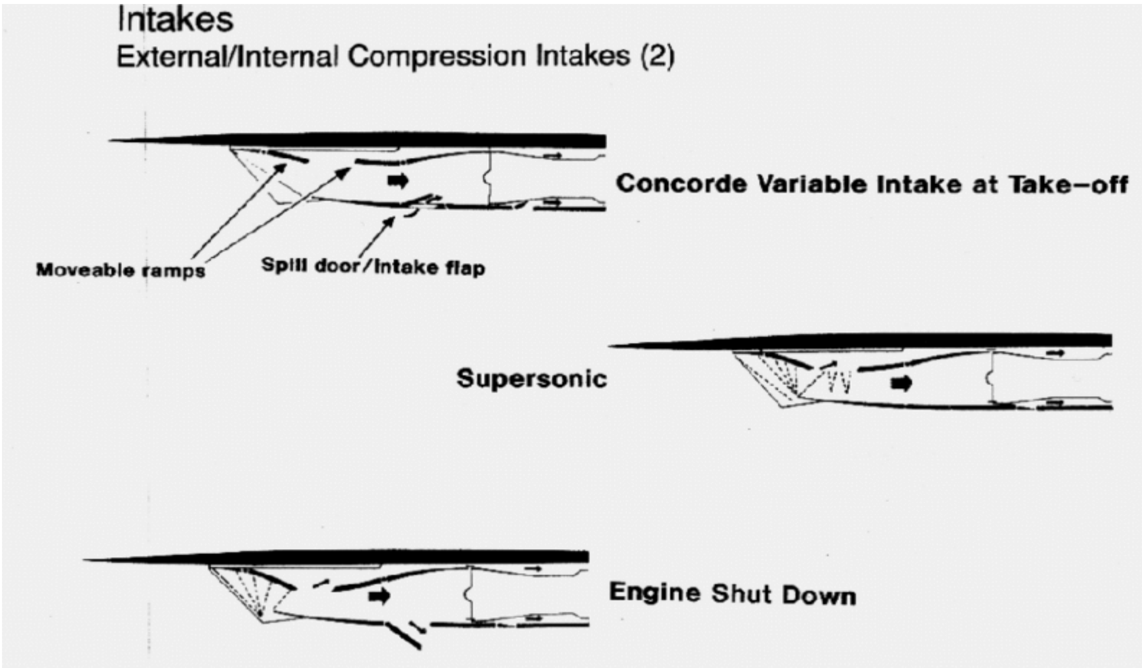


G-AXDN, Duxford, close up of pre-production engine nozzles. The nozzle/thrust reverser design was altered for the production Concordes.

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

Engines

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



Concorde's intake system schematics

Concorde's intake system

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

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

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

Heating issues

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

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

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

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

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

Structural issues

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

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

Brakes and undercarriage

Concorde tyres and brakes

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

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

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

Range

Concorde needed to travel between London and New York, or Washington, non-stop, and to achieve this the designers gave Concorde the greatest supersonic range of any aircraft. This was achieved by a combination of careful development of the engines to make them highly efficient at supersonic speeds (actually the world's most energy-efficient jet engine), by using a slender fuselage, 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.

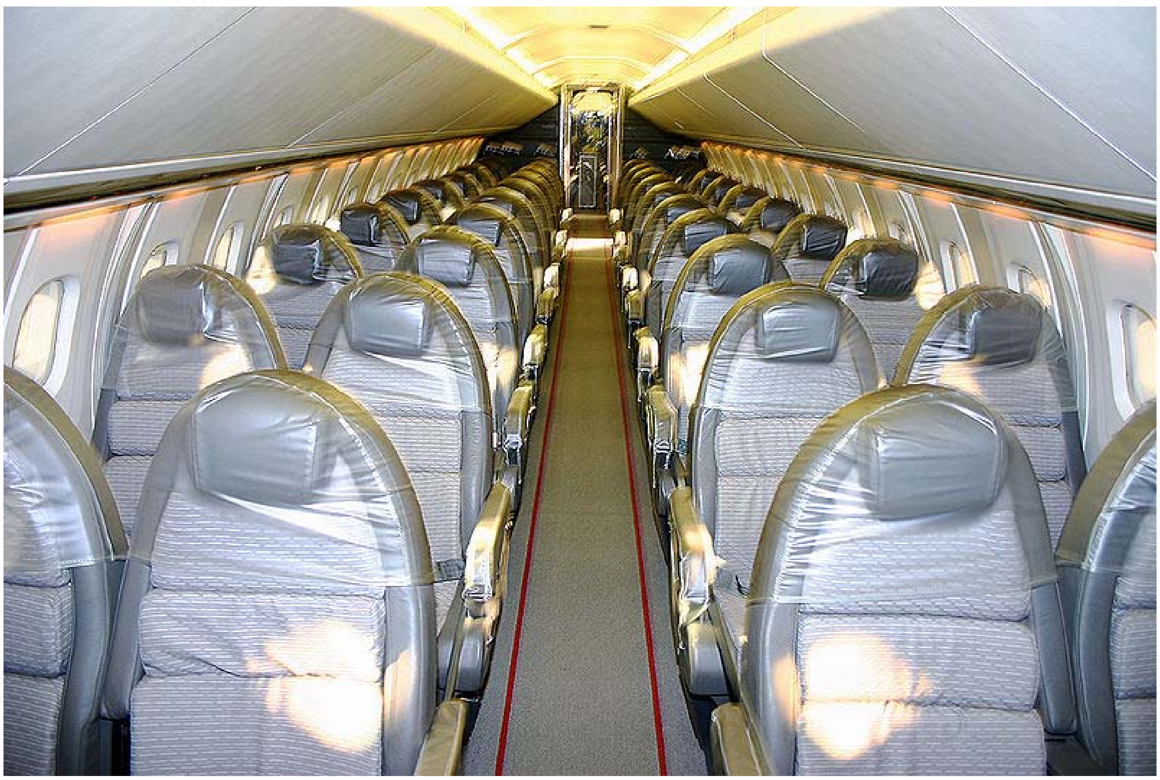
Nevertheless, soon after Concorde began flying, a Concorde "B" model was designed with slightly larger fuel capacity and slightly larger wings with leading edge slats to improve aerodynamic performance at all speeds. It featured more powerful engines with sound deadening and without the fuel-hungry and 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° below the standard horizontal position for taxiing and takeoff. Following takeoff and after clearing the airport, the nose and visor were raised. Shortly before landing, the visor was again retracted and the nose lowered to 12.5° below horizontal for maximum visibility. Upon landing, the nose was raised to the five-degree position to avoid the possibility of damage. On rare occasions, the aircraft could take off with the nose fully down.

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

Flight characteristics

Concorde performing a low-level flypast at an air show

While commercial jets take eight hours to fly from New York to Paris, the average supersonic flight time on the transatlantic routes was just under 3.5 hours. Concorde had a maximum cruise altitude of 18,300 metres (60,039 ft) and an average cruise speed of Mach 2.02, about 1155 knots (2140 km/h or 1334 mph), more than twice the speed of conventional aircraft.

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

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

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

Operational history

Scheduled flights

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

Concorde in 1977

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

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

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

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

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

BA buys its Concordes outright

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

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

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

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

Concorde Flight 4590 crash

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

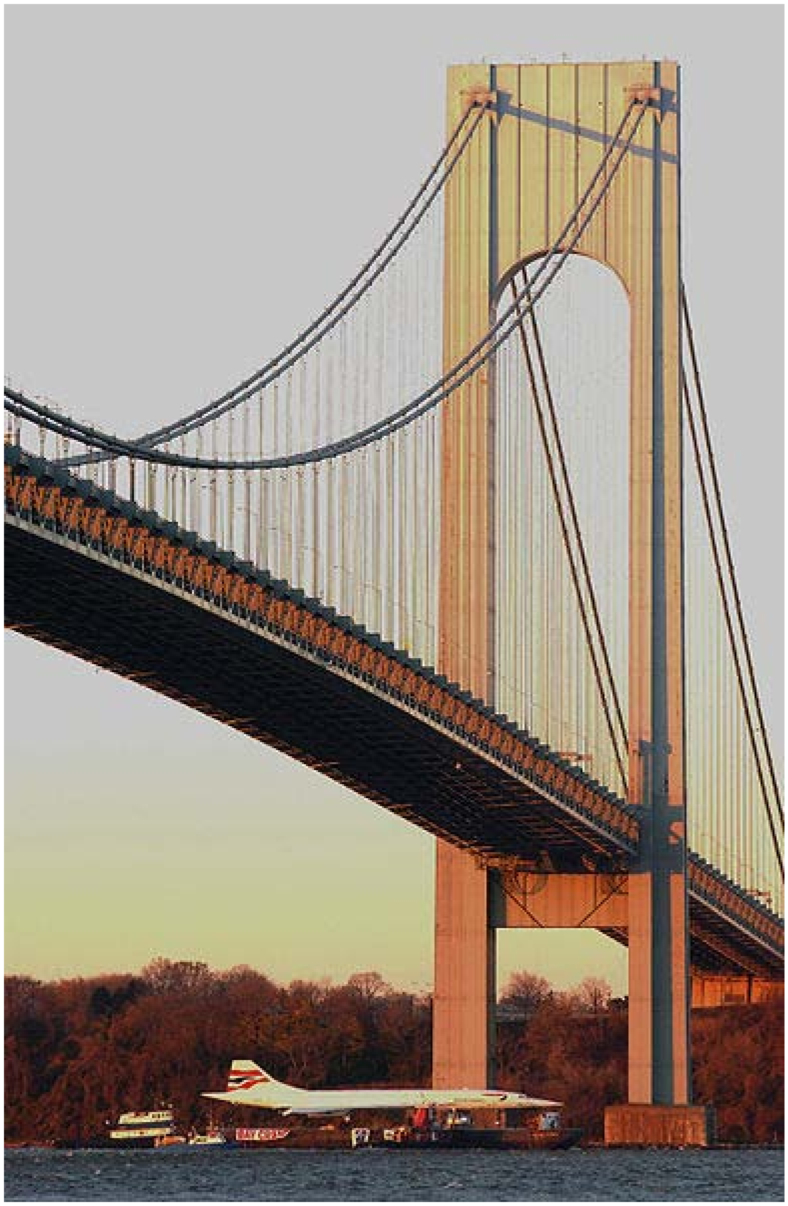
According to the official investigation conducted by the French accident investigation bureau (BEA), the crash was caused by a titanium strip that fell from a Continental Airlines DC-10 that had taken off minutes earlier. This metal fragment punctured a tyre on the Concorde's left main wheel bogie during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

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

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

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

Retirement



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

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

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

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

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

Air France

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

Air France Concorde at Paris-Charles de Gaulle Airport

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

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

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

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

British Airways

British Airways Concorde in the initial BA livery at Heathrow Airport

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

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

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

Mike Bannister (left) in the cockpit of BA002

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

British Airways retired its Concorde fleet on 24 October. G-BOAG left New York to a fanfare similar to that given for Air France's F-BTSD, while two more made round trips, G-BOAF over the Bay of Biscay, carrying VIP guests including former Concorde pilots, and G-BOAE to Edinburgh. The three aircraft then circled over London, having received special permission to fly at low altitude, before landing in sequence at Heathrow. All three aircraft spent 45 minutes taxiing around the airport before disembarking the last supersonic fare-paying passengers. The captain of the New York to London flight was Mike Bannister. G-BOAE (212) took its retirement flight on 17 November 2003 from Heathrow to Grantley Adams International Airport on Barbados, where the plane can still be seen daily.

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

Impact

Environmental

Prior to Concorde's flight trials, the developments made by the civil aviation industry were largely accepted by governments and their respective electorates. The opposition to Concorde's noise, particularly on the eastern coast of the United States, forged a new political agenda on both sides of the Atlantic, with scientists and technology experts across a multitude of industries beginning to take the environmental and social impact more seriously. Although Concorde led directly to the introduction of a general noise abatement programme for aircraft flying out of John F. Kennedy Airport, many found that Concorde was quieter than expected, partly due to the pilots temporarily throttling back their engines to reduce noise during overflight of residential areas. Even before the launch of revenue earning services, it had been noted that Concorde was quieter than several aircraft already commonly in service at that time.

***Concorde* fuel efficiency comparison**

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

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

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

Public perception

Parade flight at Queen’s Golden Jubilee

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

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

HM The Queen and HRH The Duke of Edinburgh disembark Concorde

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

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

Records

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

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

Comparison with other supersonic aircraft

Tu-144 as a research aircraft for NASA in 1997

The only other supersonic airliner in direct competition with Concorde was the Soviet Tupolev Tu-144, which was nicknamed "Concordski" by Western Europeans for its outward similarity to Concorde. Soviet espionage efforts had resulted in the theft of Concorde blueprints, ostensibly to assist in the design of the Tu-144. As a result of a rushed development programme, the first prototype of the Tu-144 was substantially different from the preproduction machines, but both were cruder and less refined than Concorde. The Tu-144*S* had a significantly shorter range than Concorde, due to its low-bypass turbofan engines. The vehicle had poor control at low speeds because of a simpler supersonic wing design; in addition the Tu-144 required parachutes to land while Concorde had sophisticated anti-lock brakes. The Tu-144 had two crashes, one at the 1973 Paris Air Show, and another during a pre-delivery test flight in the summer of 1978. Later production versions had retractable canards for better low-speed control, and a 126-seat research version used turbojet engines that gave them nearly the fuel efficiency and similar range to Concorde. With a top speed of Mach 2.35 it was potentially a more competitive aircraft – but was quickly taken out of service due to severe safety defects.

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

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

Replacements in development

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

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

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

In May 2008, it was reported that Aerion Corporation had $3 billion of pre-order sales on its Aerion SBJ supersonic business jet. 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^2 (358.25 m^2)
- **Empty weight:** 173,500 lb (78,700 kg)
- **Useful load:** 245,000 lb (111,130 kg)
- **Powerplant:** 4× Rolls-Royce/SNECMA Olympus 593 Mk 610 afterburning turbojets
  - **Dry thrust:** 32,000 lbf (140 kN) each
  - **Thrust with afterburner:** 38,050 lbf (169 kN) each
- **Maximum fuel load:** 210,940 lb (95,680 kg)
- **Maximum taxiing weight:** 412,000 lb (187,000 kg)

Performance

- **Maximum speed:** Mach 2.04 (≈1,350 mph, 2,172 km/h) at cruise altitude
- **Cruise speed:** Mach 2.02 (≈1,320 mph, 2,124 km/h) at cruise altitude
- **Range:** 3,900 nmi (4,500 mi, 7,250 km)
- **Service ceiling:** 60,000 ft (18,300 m)
- **Rate of climb:** 5,000 ft/min (25.41 m/s)

- **lift-to-drag:** *Low speed*– 3.94, *Approach*– 4.35, *250 kn, 10,000 ft*– 9.27, *Mach 0.94*– 11.47, *Mach 2.04*– 7.14
- **Fuel consumption:** 46.85 lb/mi (13.2 kg/km) operating for maximum range
- **Thrust/weight:** 0.373
- **Maximum nose tip temperature:** 260 °F (127 °C)

Chapter- 5

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	
Role	Experimental aircraft
National origin	United States
Manufacturer	Gulfstream Aerospace
Status	In development
Number built	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- 6

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

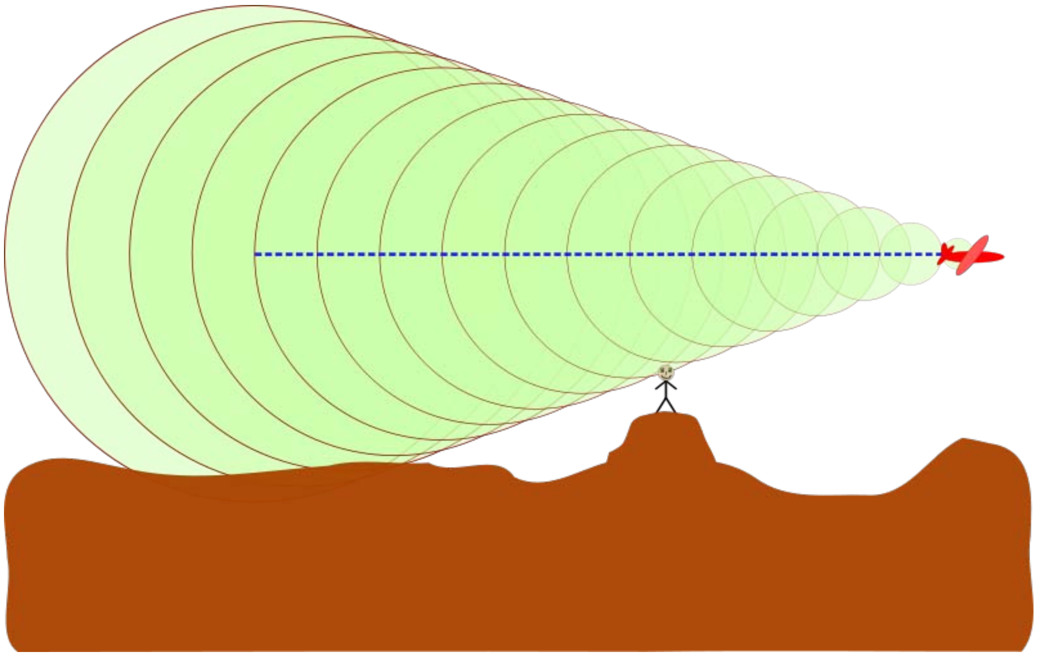
The Hungarian-born American scientist Theodore von Karman (May 11, 1881 – May 7, 1963) developed the theoretical background of supersonic flight and the analytical tools to study supersonic fluid flow, and as well as the swept wing. He is often called "the father of supersonic flight" due to his work 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.

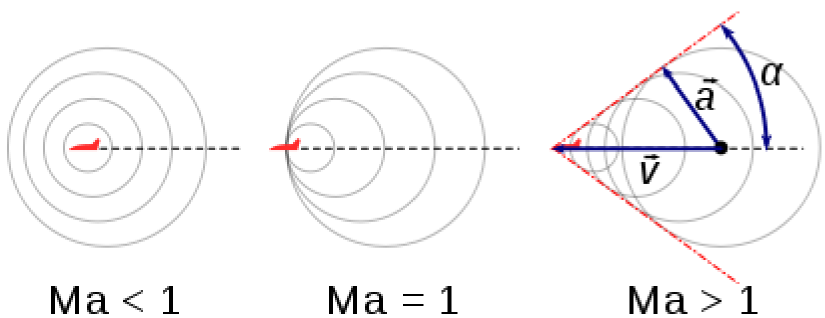
Chapter- 7

Sonic Boom

Rapid condensation of water vapor due to a sonic shock produced at sub-sonic speed creates a vapor cone (known as a Prandtl–Glauert singularity), which can be seen with the naked eye



A sonic boom produced by an aircraft moving at M=2.92, calculated from the cone angle of 20 degrees. An observer hears the boom when the shock wave, on the edges of the cone, crosses his or her location.



Mach cone angle

A **sonic boom** is the sound associated with the shock waves created by the supersonic flight of an aircraft. Sonic booms generate enormous amounts of sound energy, sounding much like an explosion. The crack of a supersonic bullet passing overhead is an example of a sonic boom in miniature.

Causes

When an object passes through the air, it creates a series of pressure waves in front of it and behind it, similar to the bow and stern waves created by a boat. These waves travel at the speed of sound, and as the speed of the object increases, the waves are forced together, or compressed, because they cannot "get out of the way" of each other, eventually merging into a single shock wave at the speed of sound. This critical speed is known as Mach 1 and is approximately 1,225 km/h (761 mph) at sea level and 20 °C (68 °F). In smooth flight, the shock wave starts at the nose of the aircraft and ends at the tail. Because directions around the aircraft's direction of travel are equivalent, the shock forms a Mach cone with the aircraft at its tip. The half-angle (between direction of flight and the shock wave) α is given by

$$\sin(\alpha) = \frac{v_{sound}}{v_{object}},$$

where $\frac{v_{object}}{v_{sound}}$ is the plane's Mach number. So the faster it goes, the finer, (more pointed) the cone.

There is a rise in pressure at the nose, decreasing steadily to a negative pressure at the tail, followed by a sudden return to normal pressure after the object passes. This "overpressure profile" is known as an N-wave because of its shape. The "boom" is experienced when there is a sudden change in pressure, so the N-wave causes two booms, one when the initial pressure rise from the nose hits, and another when the tail passes and the pressure suddenly returns to normal. This leads to a distinctive "double boom" from supersonic aircraft. When maneuvering, the pressure distribution changes into different forms, with a characteristic U-wave shape.

Since the boom is being generated continually as long as the aircraft is supersonic, it fills out a narrow path on the ground following the aircraft's flight path, a bit like an unrolling red carpet and hence known as the "**boom carpet**". Its width depends on the altitude of the aircraft. The distance from the point on the ground where the boom is heard to the aircraft depends on its altitude and the angle α.

For today's supersonic aircraft in normal operating conditions, the peak overpressure varies from less than 50 to 500 Pa (one pound per square foot to about 10 pounds per square foot) for a N-wave boom. Peak overpressures for U-waves are amplified two to five times the N-wave, but this amplified overpressure impacts only a very small area when compared to the area exposed to the rest of the sonic boom. The strongest sonic boom ever recorded was 7,000 Pa (144 pounds per square foot) and it did not cause injury to the researchers who were exposed to it. The boom was produced by a F-4 flying just above the speed of sound at an altitude of 100 feet (30 m). In recent tests, the maximum boom measured during more realistic flight conditions was 1,010 Pa (21 pounds per square foot). There is a probability that some damage — shattered glass for example — will result from a sonic boom. Buildings in good repair should suffer no damage by pressures of 11 pounds per square foot or less. And, typically, community exposure to sonic boom is below two pounds per square foot. Ground motion resulting from sonic boom is rare and is well below structural damage thresholds accepted by the U.S. Bureau of Mines and other agencies.

The power, or volume, of the shock wave is dependent on the quantity of air that is being accelerated, and thus the size and shape of the aircraft. As the aircraft increases speed the shock cone gets *tighter* around the craft and becomes weaker to the point that at very high speeds and altitudes no boom is heard. The "length" of the boom from front to back is dependent on the length of the aircraft to a factor of 3:2 . Longer aircraft therefore "spread out" their booms more than smaller ones, which leads to a less powerful boom which has a less "spread out" boom.

Several smaller shock waves can, and usually do, form at other points on the aircraft, primarily any convex points or curves, the leading wing edge and especially the inlet to engines. These secondary shockwaves are caused by the air being forced to turn around these convex points, which generates a shock wave in supersonic flow.

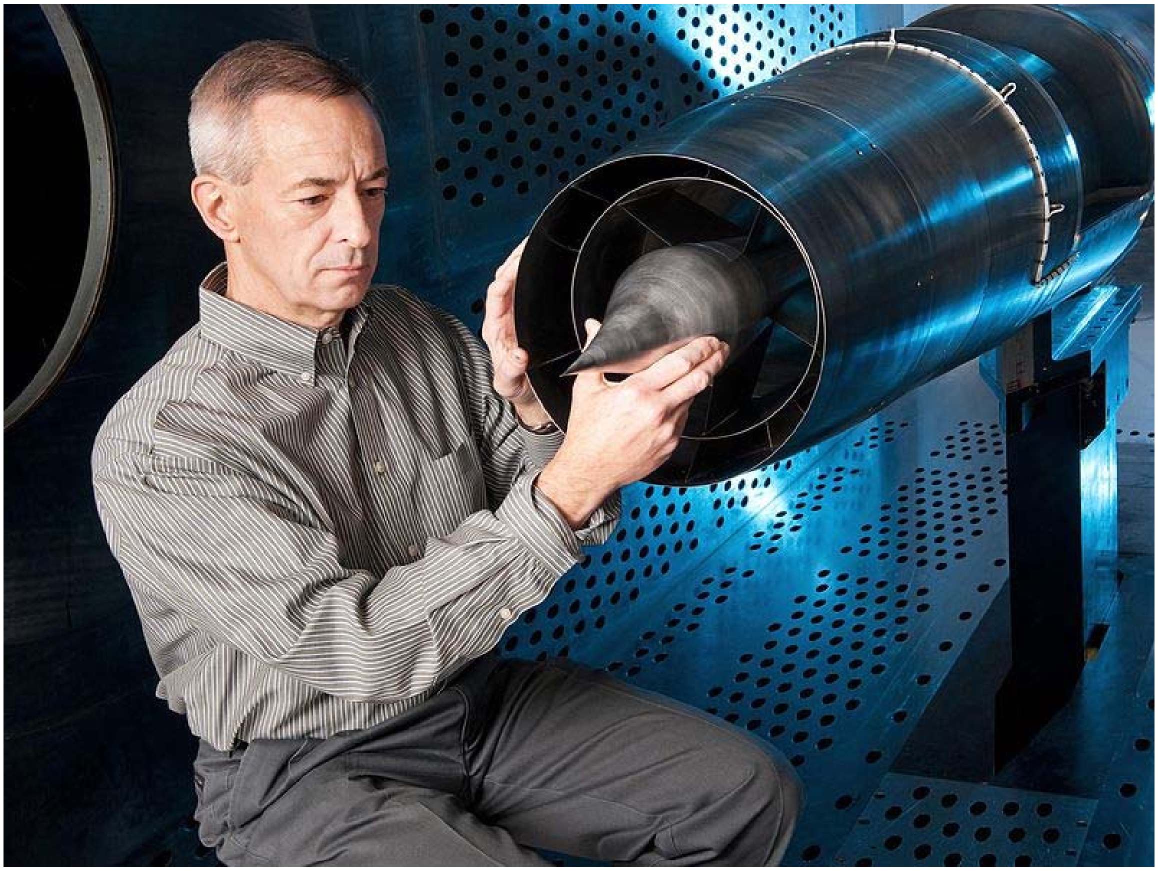
The later shock waves are somewhat faster than the first one, travel faster and add to the main shockwave at some distance away from the aircraft to create a much more defined N-wave shape. This maximizes both the magnitude and the "rise time" of the shock which makes the boom seem louder. On most designs the characteristic distance is about 40,000 feet (12,000 m), meaning that below this altitude the sonic boom will be "softer". However, the drag at this altitude or below makes supersonic travel particularly inefficient, which poses a serious problem.

Measurement and examples

The pressure from sonic booms caused by aircraft are often a few pounds per square foot. A vehicle flying at greater altitude will generate lower pressures on the ground, because the shock wave reduces in intensity as it spreads out away from the vehicle, but the sonic booms are less affected by vehicle speed.

Aircraft	speed	altitude	pressure (lbf/ft^2)	pressure (Pa)
SR-71	Mach 3	80,000 feet (24,000 m)	0.9	43
Concorde SST	Mach 2	52,000 feet (16,000 m)	1.94	93
F-104	Mach 1.93	48,000 feet (15,000 m)	0.8	38
Space Shuttle	Mach 1.5	60,000 feet (18,000 m)	1.25	60

Abatement



New research is being performed at NASA's Glenn Research Center that could help alleviate the sonic boom produced by supersonic aircraft. Testing was recently completed of a Large-Scale Low-Boom supersonic inlet model with micro-array flow control. A NASA aerospace engineer is pictured here in a wind tunnel with the Large-Scale Low-Boom supersonic inlet model.

In the late 1950s when supersonic transport (SST) designs were being actively pursued, it was thought that although the boom would be very large, the problems could be avoided by flying higher. This assumption was proven false when the North American B-70 *Valkyrie* started flying, and it was found that the boom was a problem even at 70,000 feet (21,000 m). It was during these tests that the N-wave was first characterized.

Richard Seebass and his colleague Albert George at Cornell University studied the problem extensively and eventually defined a "figure of merit" (FM) to characterize the sonic boom levels of different aircraft. FM is a function of the aircraft weight and the aircraft length. The lower this value, the less boom the aircraft generates, with figures of about 1 or lower being considered acceptable. Using this calculation, they found FMs of about 1.4 for Concorde and 1.9 for the Boeing 2707. This eventually doomed most SST projects as public resentment mixed with politics eventually resulted in laws that made any such aircraft impractical (flying only over water for instance). Another way to express this is wing span. The fuselage of even a large supersonic aircraft is very sleek and with enough angle of attack and wing span the plane can fly so high that the boom by the fuselage is not important. The larger the wing span, the greater the downwards impulse which can be applied to the air, the greater the boom felt. A smaller wing span favors small aeroplane designs like business jets.

Seebass and George also worked on the problem from another angle, trying to spread out the N-wave laterally and temporally (longitudinally), by producing a strong and downwards-focused (SR-71 Blackbird, Boeing X-43) shock at a sharp, but wide angle nosecone, which will travel at slightly supersonic speed (bow shock), and using a swept back flying wing or an oblique flying wing to smooth out this shock along the direction of flight (the tail of the shock travels at sonic speed). To adapt this principle to existing planes, which generate a shock at their nose cone and an even stronger one at their wing leading edge, the fuselage below the wing is shaped according to the area rule. Ideally this would raise the characteristic altitude from 40,000 feet (12,000 m) to 60,000 feet (from 12,000 m to 18,000 m), which is where most SST aircraft fly.

This remained untested for decades, until DARPA started the Quiet Supersonic Platform project and funded the Shaped Sonic Boom Demonstration (SSBD) aircraft to test it. SSBD used an F-5 Freedom Fighter. The F-5E was modified with a highly refined shape which lengthened the nose to that of the F-5F model. The fairing extended from the nose all the way back to the inlets on the underside of the aircraft. The SSBD was tested over a two year period culminating in 21 flights and was an extensive study on sonic boom characteristics. After measuring the 1,300 recordings, some taken inside the shock wave by a chase plane, the SSBD demonstrated a reduction in boom by about one-third. Although one-third is not a huge reduction, it could have reduced Concorde below the FM = 1 limit for instance.

As a follow-on to SSBD, in 2006 a NASA-Gulfstream Aerospace team tested the Quiet Spike on NASA-Dryden's F-15B aircraft 836. The Quiet Spike is a telescoping boom fitted to the nose of an aircraft specifically designed to weaken the strength of the shock waves forming on the nose of the aircraft at supersonic speeds. Over 50 test flights were performed. Several flights included probing of the shockwaves by a second F-15B, NASA's Intelligent Flight Control System testbed, aircraft 837.

There are theoretical designs that do not appear to create sonic booms at all, such as the Busemann's Biplane.

Perception and noise

The sound of a sonic boom depends largely on the distance between the observer and the aircraft shape producing the sonic boom. A sonic boom is usually heard as a deep double "boom" as the aircraft is usually some distance away. However, as those who have witnessed landings of space shuttles have heard, when the aircraft is nearby the sonic boom is a sharper "bang" or "crack". The sound is much like the "aerial bombs" used at firework displays. It is a common misconception that only "one" boom is generated during the subsonic to supersonic transition, rather, the boom is continuous along the boom carpet for the entire supersonic flight. As a former Concorde pilot puts it, "You don't actually hear anything on board. All we see is the pressure wave moving down the aeroplane - it gives an indication on the instruments. And that's what we see of Mach 1. But we don't hear the sonic boom or anything like that. That's rather like the wake of ship - it's behind us."

In 1964, NASA and the Federal Aviation Administration began the Oklahoma City sonic boom tests, which caused eight sonic booms per day over a period of six months. Valuable data was gathered from the experiment, but 15,000 complaints were generated and ultimately entangled the government in a class action lawsuit, which it lost on appeal in 1969.

There has been recent work in this area, notably under DARPA's Quiet Supersonic Platform studies. Research by acoustics experts under this program began looking more closely at the composition of sonic booms, including the frequency content. Several characteristics of the traditional sonic boom "N" wave can influence how loud and irritating it can be perceived by listeners on the ground. Even strong N-waves such as those generated by Concorde or military aircraft can be far less objectionable if the rise time of the overpressure is sufficiently long. A new metric has emerged, known as *perceived* loudness, measured in PLdB. This takes into account the frequency content, rise time, etc. A well known example is the snapping of your fingers in which the "perceived" sound is nothing more than an annoyance.

The energy range of sonic boom is concentrated in the 0.1–100 hertz frequency range that is considerably below that of subsonic aircraft, gunfire and most industrial noise. Duration of sonic boom is brief; less than a second, 100 milliseconds (0.1 second) for most fighter-sized aircraft and 500 milliseconds for the space shuttle or Concorde jetliner. The intensity and width of a sonic boom path depends on the physical characteristics of the aircraft and how it is operated. In general, the greater an aircraft's altitude, the lower the overpressure on the ground. Greater altitude also increases the boom's lateral spread, exposing a wider area to the boom. Overpressures in the sonic boom impact area, however, will not be uniform. Boom intensity is greatest directly under the flight path, progressively weakening with greater horizontal distance away from the aircraft flight track. Ground width of the boom exposure area is approximately 1 statute mile (1.6 km) for each 1,000 feet (300 m) of altitude (5 m/m); that is, an aircraft flying supersonic at 30,000 feet (9,100 m) will create a lateral boom spread of about 30 miles (48 km), or at 10,000 meters a spread of 50 kilometers. For steady supersonic flight, the boom is described as a carpet boom since it moves with the aircraft as it maintains supersonic speed and altitude. Some maneuvers, diving, acceleration or turning, can cause focusing of the boom. Other maneuvers, such as deceleration and climbing, can reduce the strength of the shock. In some instances weather conditions can distort sonic booms.

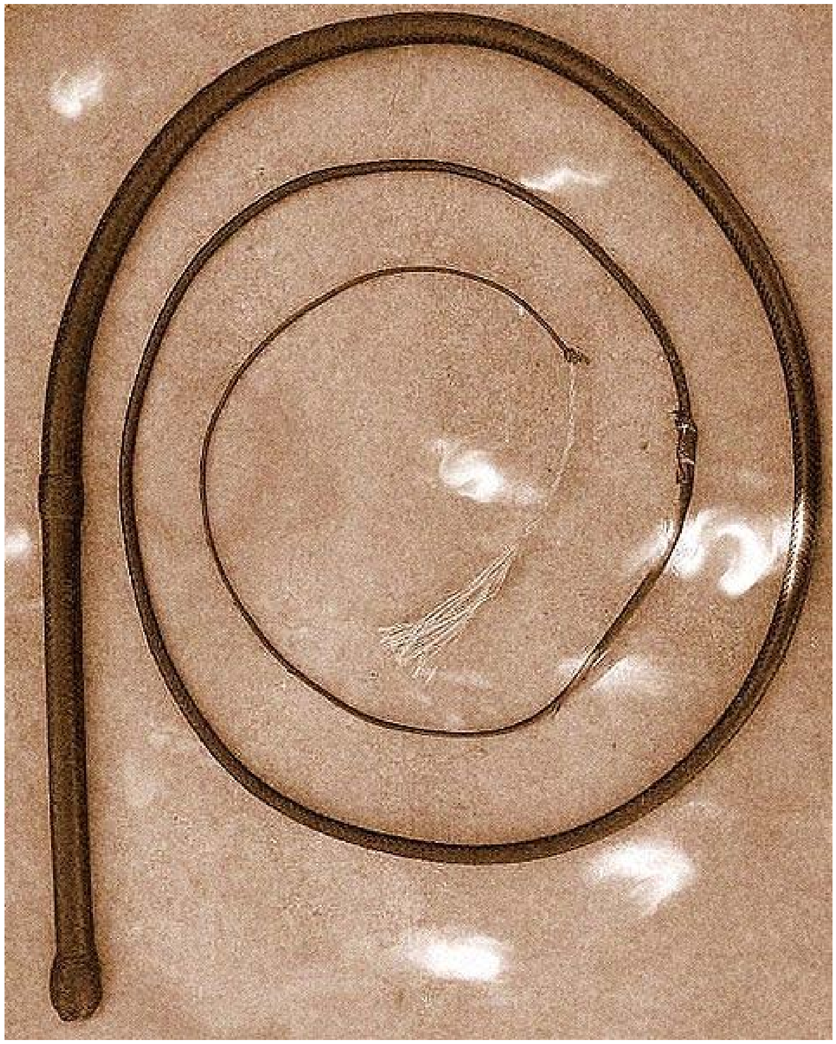
Depending on the aircraft's altitude, sonic booms reach the ground two to 60 seconds after flyover. However, not all booms are heard at ground level. The speed of sound at any altitude is a function of air temperature. A decrease or increase in temperature results in a corresponding decrease or increase in sound speed. Under standard atmospheric conditions, air temperature decreases with increased altitude. For example, when sea-level temperature is 59 degrees Fahrenheit (15 °C), the temperature at 30,000 feet (9,100 m) drops to minus 49 degrees Fahrenheit (−45 °C). This temperature gradient helps bend the sound waves upward. Therefore, for a boom to reach the ground, the aircraft speed relative to the ground must be greater than the speed of sound at the ground. For example, the speed of sound at 30,000 feet (9,100 m) is about 670 miles per hour, but an aircraft must travel at least 750 miles per hour (Mach 1.12, where Mach 1 equals the speed of sound) for a boom to be heard on the ground.

The composition of the atmosphere is also a factor. Temperature variations, humidity, atmospheric pollution, and winds can all have an effect on how a sonic boom is perceived on the ground. Even the ground itself can influence the sound of a sonic boom. Hard surfaces such as concrete, pavement, and large buildings can cause reflections which may amplify the sound of a sonic boom. Similarly grassy fields and lots of foliage can help attenuate the strength of the overpressure of a sonic boom.

Currently there are no industry accepted standards for the acceptability of a sonic boom. Until such metrics can be established, either through further study or supersonic overflight testing, it is doubtful that legislation will be enacted to remove the current prohibition on supersonic overflight in place in several countries, including the United States.

A sonic boom can sometimes be referred to as a sonic wave.

Bullwhip



An Australian bullwhip

The cracking sound a bullwhip makes when properly wielded is, in fact, a small sonic boom. The end of the whip, known as the *"cracker"*, moves faster than the speed of sound, thus creating a sonic boom. The whip was probably the first human invention to break the sound barrier.

A bullwhip tapers down from the handle section to the cracker. The cracker has much less mass than the handle section. When the whip is sharply swung, the energy is transferred down the length of the tapering whip. In accordance with the formula (if the work for whipping remains constant) for kinetic energy $E_k = mv^2 / 2$, the velocity of the whip increases with the decrease in mass, which is how the whip reaches the speed of sound and causes a sonic boom.

Chapter- 8

Supersonic Business Jet

A **supersonic business jet** (**SSBJ**) would be a small business jet, intended to travel at speeds above Mach 1.0. Typically intended to transport about ten passengers, SSBJs are about the same size as traditional subsonic business jets. Larger commercial supersonic transports such as the Aérospatiale/British Aerospace Concorde and Tupolev Tu-144 'Charger' had relatively high costs, and high noise, low range and some environmental concerns (although these problems were less evident in Concorde than the Tu-144).

Several manufacturers believe that many of these concerns can be dealt with at a smaller scale. In addition, it is believed that small groups of high-value passengers (such as executives or heads of state) will find value in higher speed transport.

No SSBJs are currently available, but several manufacturers are working on or have worked on designs, including but not limited to:

- Aerion SBJ
- Cessna design of unknown nature.
- Sukhoi-Gulfstream S-21
- Tupolev Tu-444
- Supersonic Aerospace International QSST
- NEXST

Several companies, including Gulfstream Aerospace continue to work on technologies intended to reduce or mitigate sonic booms. An example is the Quiet Spike.

Description of above Supersonic Business Jets:-

Aerion SBJ

Aerion SBJ

Artist's rendering of Aerion SBJ in flight

Role	Supersonic business jet
Manufacturer	Aerion Corporation
Status	Under development
Unit cost	US$80 million (target cost)

The **Aerion SBJ** is a concept for a supersonic business jet, designed by Aerion Corporation. If produced, it would allow practical non-stop travel from Europe to North America and back within one business day. The target price is $80 million (in 2007 dollars), with development costs ranging from $1.2 to $1.4 billion. Fifty deposits have been taken from customers, and entry into service is expected to be 2015.

Aerion reported positive results from aerodynamic flight tests in October 2010.

Specifications

General characteristics

- **Crew:** 2
- **Capacity:** 8-12 passengers
- **Length:** 135.6 ft (41.33 m)
- **Wingspan:** 64.2 ft (19.57 m)
- **Height:** 21.2 ft (6.46 m)
- **Wing area:** 1,200 ft² (111.5 m²)
- **Empty weight:** lb (kg)

- **Max takeoff weight:** 90,000 lb (40,823 kg)
- **Powerplant:** 2× Pratt & Whitney JT8D-219 turbofans, 19,600 lbf (87.19 kN) each

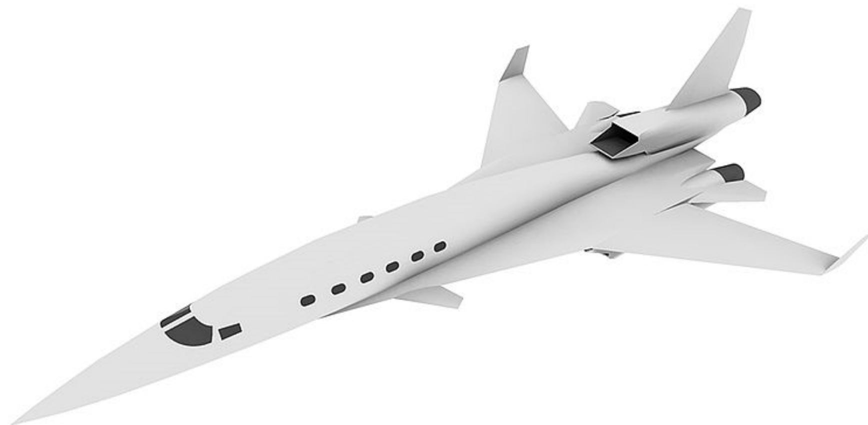
Performance

- **Maximum speed:** 1,030 knots (Mach 1.8, 1,186 mph, 1,909 km/h)
- **Cruise speed:** 966 knots (Mach 1.7, 1,112 mph, 1,790 km/h)
- **Range:**
  - **At Mach 0.95:** 4,600 nm (5,300 mi, 8,500 km)
  - **At Mach 1.40:** 4,200 nm (4,800 mi, 7,800 km)
- **Service ceiling:** 51,000 ft (16,000 m)

Sukhoi-Gulfstream S-21

S-21

Role	Supersonic business jet
Manufacturer	Sukhoi-Gulfstream



S-21 3D model

Sukhoi-Gulfstream S-21 was a projected Russian-American supersonic business jet.

In the early 1990s, Gulfstream Aerospace and the Sukhoi Design Bureau of Moscow began a joint effort to develop a supersonic small business jet, code named the S-21. Due to questionable market demand for commercial supersonic air travel, commitment to the project wavered and delays mounted.

Gulfstream eventually dissolved the partnership, although Sukhoi continued work on the S-21.

The S-21 would be capable of sustained cruise at Mach 2+ and much research and development has gone into the management of the troublesome transonic effects associated with near Mach 1 air speeds.

Specifications (S-21)

General characteristics

- **Crew:** 2
- **Capacity:** 6-10
- **Length:** 124.2 ft (37.86 m)
- **Wingspan:** 65.4 ft (19.93 m)
- **Wingsweep:** 32° unswept (68° swept)
- **Height:** 27.1 ft (8.26 m)
- **Empty weight:** 54,167 lb (24,570 kg)
- **Useful load:** 2,000 lb (907 kg)
- **Max takeoff weight:** 114,200 lb (51,800 kg)
- **Fuel:** 58,465 lb (26,519 kg)

- **Powerplant:** 3× Aviadvigatel D-21A1 turbofan, 16,535 lb_f (73.55 kN) each

Performance

- **Maximum speed:** 1,483 mph (2,386 km/h)
- **Cruise speed:** 1,483 mph (2,386 km/h)
- **Range:** 4,600 mi (7,403 km)
- **Range (1.4 Mach):** 2,715 mi (4,369 km)
- **Range (0.95 mach):** 4,600 mi (7,403 km)
- **Service ceiling:** 63,900 ft (19,477 m)
- **Thrust/weight:** 0.43

Tupolev Tu-444

Tu-444

The Tupolev Tu-444 supersonic business jet (sketch by Tupolev DB).

Role	Supersonic business jet
Manufacturer	Tupolev
Status	Concept - status unknown as of 2010

The **Tupolev Tu-444** is a concept for a supersonic business jet from the Russian firm Tupolev. Tupolev has had previous experience developing supersonic transport aircraft with projects such as the Tu-144, Tu-144LL and other experience with supersonic aircraft in the bombers Tu-22, Tu-22M and Tu-160.

Specifications (Tu-444)

General characteristics

- **Crew:** 2 pilots, 1 flight attendant
- **Capacity:** 6-10
- **Length:** 36 m (118 ft 1 in)
- **Wingspan:** 16.2 m (53 ft 1 in)
- **Height:** 6.51 m (21 ft 4 in)
- **Wing area:** 136 m² (1,460 ft²)

- **Empty weight:** 19,300 kg (42,550 lb)
- **Max takeoff weight:** 41,000 kg (90,400 lb)
- **Powerplant:** 2× NPO Saturn AL-32M turbofan, 95 kN (21,400 lbf) each

Performance

- **Cruise speed:** Mach 2, 2125 km/h (1,320 mph)
- **Range:** 7,500 km (4,660 mi)
- **Wing loading:** 300 kg/m² (29 lb/ft²)
- **Thrust/weight:** 0.48

Chapter- 9

Supercruise

The English Electric Lightning was the first aircraft capable of supercruise.

Supercruise is sustained supersonic flight of an aircraft with a useful cargo, passenger, or weapons load performed efficiently and without the use of afterburners ("reheat").

Due to its combination of decades long scheduled service and length of time spent at supersonic speeds, the main user of supercruise was Concorde, with more time spent in supersonic, largely supercruise flight, than all of the other aircraft put together.

Advantages

Most military aircraft use afterburners (or reheat) to travel at supersonic speeds. Afterburners are inefficient compared to conventional jet engine operation due to the low pressures typically found in the exhaust section. Therefore an aircraft that can supercruise has generally greater endurance at supersonic speeds than one which cannot. Furthermore, without a requirement to carry such a large quantity of fuel, a supercruise-capable aircraft can have a more favorable fuel fraction, the proportion of the plane's overall mass which is devoted to fuel. Supercruise is also an advantage for stealth aircraft, as an afterburner plume both reflects radar signals and creates a significant infrared signature.

History

Concorde routinely supercruised most of the way over the Atlantic

The first turbine-powered aircraft to exceed Mach 1 in level flight without afterburners was the P.1 prototype of the English Electric Lightning, on August 11, 1954. However, this early demonstration of supercruise was extremely limited; the Lightning could supercruise at approximately Mach 1.22 while later versions were able to achieve much higher speeds.

The British Aircraft Corporation Tactical Strike/Reconnaissance 2 (TSR-2), which first flew on September 27, 1964, was one of the first military aircraft specifically designed to cruise supersonically; one of the planned mission profiles was for a supersonic cruise at Mach 2.00 at 50–58,000 ft.. The TSR-2 used Bristol Olympus engines, a later version of which would also power Concorde.

Many of the fighters listed as capable of supercruise can only marginally exceed the speed of sound without afterburners and may only be able to do so without an external weapons load. In day-to-day operation the Tupolev Tu-144 and Concorde both used afterburners to accelerate quickly through the high-drag transonic flight regime before deactivating them to supercruise. Doing this minimized fuel use, even though afterburners are relatively inefficient. Both aircraft were capable of achieving supersonic flight without the use of afterburners; however, doing so meant that they spent much longer in the high-drag transonic flight envelope, and this made the short use of afterburners more fuel efficient over the whole flight.

Military use

The term supercruise was originally used to describe a fighter performance requirement set forth by USAF Col. John Boyd, Pierre Sprey, and Col. Everest Riccioni, designers of the F-16 Falcon. Following the entry into production of the F-16, they began work on an improved fighter design with the ability to cruise supersonically over enemy territory for a minimum of twenty minutes. As air combat is often the result of surprise, and the speed of the combat is determined by the speed of the surprising aircraft, this would have given a supercruise-capable design a worthwhile performance advantage in many situations. The postulated fighter would have had a top speed of just over Mach 1, and a fuel fraction in excess of 40%, the minimum required to successfully meet the twenty-minute requirement. Meeting the fuel fraction requirement necessitated a very austere design with few advanced electronics. The United States Air Force showed no interest in the proposal at that time, but years later revived the term and redefined it to apply to the requirements for the Advanced Tactical Fighter, which resulted in the F-22 Raptor.

The F-22 Raptor is capable of supercruise (but is seen here running afterburner)

The Eurofighter Typhoon is capable of supercruise at Mach 1.5

The F-22 Raptor's supercruise capabilities are touted as a major performance advantage over other fighters. Even so, supercruising uses much more fuel to travel the same distance than at subsonic speeds: The Air Force Association estimates that use of supercruise for a 100-nautical-mile (190 km) dash as part of a mission would cut the F-22's combat radius from about 600 nautical miles (1,110 km) to about 450 nautical miles (830 km). However, this is still unconfirmed as the altitude and flight profile are classified (as are most of the F-22's capabilities).

The F-22 has demonstrated supercruise speeds of at least Mach 1.7, a difference of 320 knots (593 km/h) indicated airspeed (KIAS) at 40,000 ft (12,000 m). Supercruise in militarily significant parlance is meant to imply a significant increase in effective combat speed with a full weapons load over existing types. Virtually all current and past jet fighters, prior to the F-22, cruise at approximately Mach 0.8–0.9 with a militarily significant weapons load. The F-22 represents a significant advance in cruise speed over previous types.

The key challenge in attaining supercruise is not simply attaining a high static thrust to weight ratio. Engine thrust and efficiency can vary greatly with speed and altitude. In order to achieve significant dry thrust at high supersonic speed, the engine (and airframe) must be purpose built with this goal in mind. Conversely, there is nothing special about being able to marginally exceed the speed of sound with a "regular" jet engine, as any supersonic engine is capable of surviving supercruise conditions, even if they may not provide enough dry power to maintain supersonic flight.

There are a few engines in production that are designed to facilitate tactically significant supercruise.

- The Pratt & Whitney F119 in combination with the F-22 Raptor
- The EJ200 engine built by EuroJet Turbo GmbH adds the supercruise capability in the Eurofighter Typhoon, and is capable of supercruising at Mach 1.5. Typhoon pilots have stated that Mach 1.3 is attainable in combat configuration with external stores.
- The General Electric F414G in JAS 39 Gripen NG is designed for supercruise and has been shown to achieve Mach 1.2.

The Pratt & Whitney F135 and the General Electric/Rolls-Royce F136 interchangeable engines for the Joint Strike Fighter each have a higher power output than the F119 they were derived from, and could in theory facilitate supercruise. However, the engines were not designed to supercruise in the F-35. NPO Saturn is developing a supercruise-capable derivative of its AL-41 engine for the Sukhoi PAK FA and the Indo-Russian Sukhoi/HAL FGFA. This is yet to bear fruit, but the stop-gap 117S engine, produced by this program, seems to achieve the supercruise goal already. It was recently announced that during testing of a Su-35BM fighter equipped with these engines it was traveling in the ~M1.1–1.2 airspeed range at nominal power and was still accelerating, thus suggesting that the supercruise was possible at even higher speed. Further testing will show the extent of this possibility.

All known supercruise aircraft can only do so at considerable altitude (where the air is thinner and so offers less resistance), which restricts the use of terrain mask and so makes any non-stealth aircraft very obvious.

Aircraft designed to cruise on afterburner

The Pratt & Whitney J58 engines of the Lockheed A-12 and SR-71 Blackbird were designed for sustained and efficient operation at supersonic speeds using afterburners with air that was diverted past the turbojet core of the engine. This gave a good compression ratio and higher efficiency simply due to the ram effect at the high operating speed of the aircraft. The afterburners acted essentially as ramjets and these types of engines achieve peak efficiency at around Mach 3.

In a somewhat similar vein, the XB-70A Valkyrie made use of specially designed turbojets (six General Electric YJ-93 engines) to sustain speeds in excess of Mach 3. Unlike the J58 engines powering the SR-71, the YJ-93 engines of the XB-70A did not require the use of special fuel, and did not radically modify the intake/exhaust geometry in order to achieve Mach 3 flight. The YJ-93 engines did operate in afterburner at Mach 3; however, the engines were specifically designed to be very efficient in afterburner, and the XB-70A AV-2 prototype sustained speeds in excess of Mach 3 for 32 minutes on one flight. Furthermore, the type was designed to operate at such speeds for periods of hours over intercontinental ranges.

Ramjets and Scramjets

Ramjet and scramjet powered aircraft have to date been mostly experimental (with exceptions such as the SR-71 and its turbojet/ramjet hybrid J58 engines, as noted above; and there have been numerous ramjet missiles), but these engines operate most efficiently at supersonic speeds and therefore would be theoretically ideal for an aircraft intended to spend long periods in supersonic flight. Due to the exotic nature of the engines, whether this would be considered "supercruise" is largely semantic.

Aircraft with supercruise

Aircraft with supercruise include:

- English Electric Lightning (The first aircraft capable of supercruise)
- Lockheed Blackbird (A-12, YF-12 and SR-71)
- Tupolev Tu-128
- Tupolev Tu-144
- Concorde
- BAC TSR-2
- Dassault Rafale
- Eurofighter Typhoon
- Gripen NG

- F-22 Raptor
- YF-23 Black Widow II
- Sukhoi Su-35BM
- F-16XL
- Saab Draken