The Concorde: Pride and Treasure of the 20th Century and Beyond

The Concorde was a supersonic commercial aircraft jointly developed by Britain and France. It gave new meaning to commercial flight, giving passengers the opportunity to fly faster than the speed of sound. Despite the problems it faced, the Concorde still remains an engineering marvel that is loved by many. Using sophisticated leading-edge technology to power the Concorde, engineers set a high standard for future manufacturers of supersonic passenger aircraft to follow.

Introduction

A seven year old boy stood by the double glazed window that separated him from the outside world. As he licked his melting ice cream cone, a growing but sudden noise caught his attention. Glancing out the window, he shifted his eyes from one jumbo jet to another, but none of the airplanes he saw seemed to be the source of the noise. Then, he spotted an oddly shaped aircraft gaining considerable speed in the distance. As the aircraft lifted off with a thunderous boom, the boy pointed his finger at the airplane and asked his mother, "Mom, what *is* that? It looks like a swan!"

Source: http://www.aeroflight.co.uk/aircraft/types/aerospatialebac-concorde.htm

Figure 1. The Swan-like Concorde

The Swan-like Concorde is an engineering marvel that is loved and adored by people all over the world, both young and old. You do not have to be an airplane enthusiast to fall in love with it. For over 27 years, it was an everyday sight at London's Heathrow Airport, New York's JFK, and other major airports around the world. It shuttled passengers at speeds greater than the speed of sound, also known as supersonic. It is a flying machine that won the hearts of many for its sophisticated technology and elegant beauty. It was a dream fulfilled; a dream that became a reality.

However, the story does not and must not end here. We should take a step back and honor the engineers who made the Concorde dream a reality. Concorde is still considered to be technologically advanced, even by today's standards. Concorde set the bar high for future supersonic aircraft manufacturers to follow, in terms of the technology that was used. Current developments hint that the world will eventually see a comeback of supersonic commercial aircraft in the near future.

History of its Development

In 1956, the British government established the Supersonic Transport Aircraft Committee (STAC). As the name suggests, the STAC's purpose was to create passenger aircraft that could fly greater than the speed of sound [1]. Following the establishment of the STAC, a UK-based firm, Bristol Aeroplane Company, developed the Type 223 aircraft, a preliminary conceptual design of a supersonic aircraft. At the same time, a French aircraft company, Sud Aviation, shared the same vision and developed their own design, named the Super-Caravelle. However, the two concept aircraft never made to the development stage because both countries found their projects to be uneconomical and inefficient. To compensate for time and money, the two countries collaborated on 29 November 1962 to create their supersonic aircraft together, known as the Concorde [2]. Interestingly, the name "Concorde" was first used by president De Gaulle of France in 1963. The British initially spelled Concorde differently from the French, without the "e." However, the British eventually relented when their minister of technology, Tony Benn, decided to adopt the French way of spelling. In response to the angry British public, he claimed that the "e" stood for "Excellence, England, Europe, and Entente" [3].

Concorde can be considered as Britain and France's reaction to the heated space race between the United States and the Soviet Union in the 1950s and 1960s. Because of World War II, there was a spike in military aircraft production. As a result, military technology was integrated into commercial aircraft, improving their speed and power [4].

The combined efforts of the British and French government resulted in Concorde's first commercial flight, BA300, on 21 January 1976, nearly twenty years after its conception [3, 4]. As if being the first supersonic commercial aircraft was not enough, the Concorde also holds the title for the aircraft with the most number of hours of testing: a total of 5,335 flight hours, where more than 2,000 hours were spent testing at supersonic speeds. This achievement was made possible by the dedicated group of 250 British Airways engineers who worked diligently to ensure that the Concorde had undergone enough testing [3], [4].

After more than 27 years, Concorde retired. On 24 October 2003, thousands gathered at the London Heathrow Airport in anticipation to see flight BA002 make its final touchdown [4]. In total, 20 of these unique aircraft were manufactured: 14 were used for commercial purposes and six were used for development. More than 2.5 million passengers have experienced flying in a Concorde and they remain an elite group consisting of celebrities, singers, and highly ranked government officials, such as Queen Elizabeth II [4].

What's So Special About the Concorde?

The Concorde is special for its purposeful aesthetics and the technology it uses.

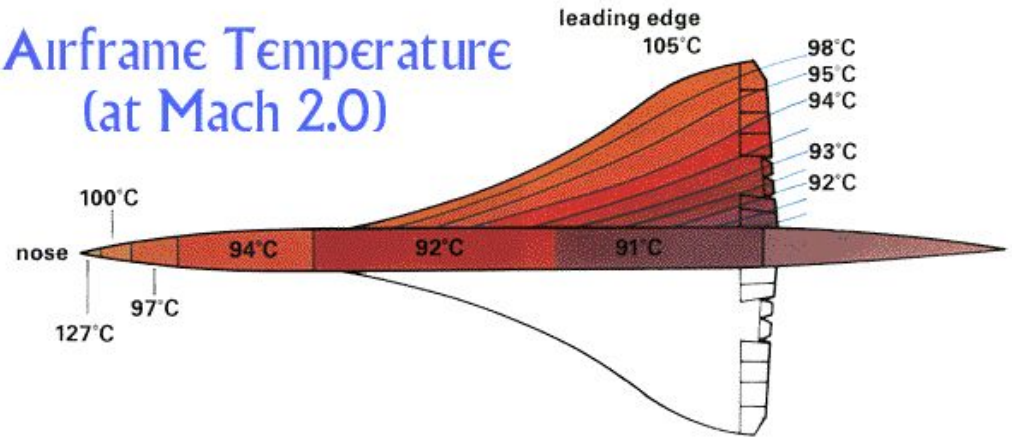
Aesthetics and Design

Flying greater than the speed of sound is no easy task, so Concorde has a streamlined body for this purpose. Intertwining engineering with beauty, a Concorde engineer once said that its narrow fuselage was a result of the laws of physics and not the result of artistic design [5]. A fuselage is the main body of an aircraft where passengers are seated. Slightly shorter than a Boeing 747 jumbo jet, the Concorde is 203 ft 9 in long, 37 ft 1 in high, and 9 ft 6 in wide [3]. Having a narrow fuselage mitigates the effects of drag experienced during supersonic flight. The aircraft also stretches between six and ten inches while flying due to thermal expansion of the aircraft body [3]. To reduce this expansion, engineers used lightweight and heat-resistant aluminium alloy to manufacture the Concorde [6].

Another striking feature of the Concorde is its Delta Wings. In the shape of a right angle triangle, it was the result of over 5,000 hours of testing by engineers and provides the right amount of lift for take off and landing, reduces drag, and provides enough stability for the aircraft [5], [6].

Technology

Beneath the Concorde's beauty are its leading-edge technology. On the surface, we see Concorde's airframe, which is the aircraft's body without its engines. The airframe can easily heat up when flying at supersonic speeds. Friction is produced when air molecules collide and rub against the surface of the airframe. Temperatures at the nose can climb as high as 260°F during a supersonic flight, as seen in Figure 2 [6]. Ordinary glass can break at such high temperatures, so engineers designed a visor that is installed at the nose of the aircraft. The visor is made from multiple layers of slightly tinted heat-resistant glass to protect pilots from extenuating heat [7]. Operated by a hydraulic system, the visor can slide up and down, much like a motorcycle helmet visor. Engineers also used highly-reflective white paint on the Concorde for effective reflection and dissipation of heat from the aircraft body to its surroundings [6].



Source: http://www.concordesst.com/performance.html

Figure 2. Surface temperature distribution of Concorde at Mach 2

The Mach number, as stated in Figure 2, is defined as the ratio of the speed of an object to the speed of sound. If a body travels at the speed of sound, its Mach number would be equal to a value of one. Supersonic refers to speeds between Mach 1 and Mach 5. The Concorde's cruising speed is Mach 2, which is equivalent to 1,350 mph, and cruises at 60,000 ft above sea level; nearly twice the altitude at which ordinary jumbo jets fly [3]. Passengers would experience little to no turbulence at this height. Plus, they can see the curvature of the Earth and the darkness of space.

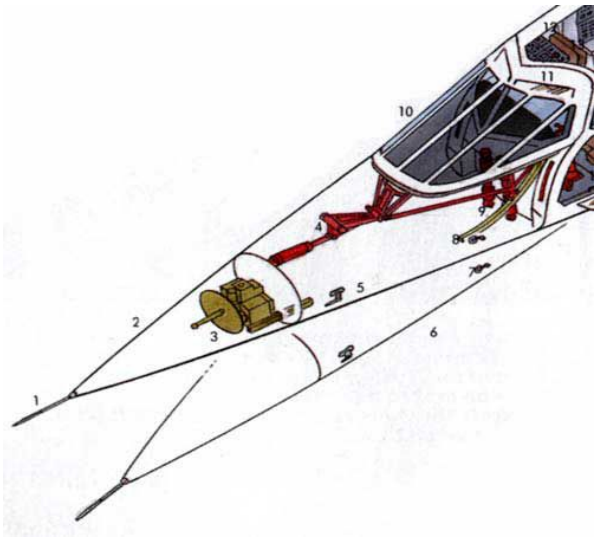
To generate that kind of speed requires a very powerful engine. Thrust is the amount of propulsive force that pushes an object forward. The four Rolls-Royce/SNECMA Olympus 593 turbojet engines deliver over 38,000 lbs of thrust and are attached to the underside of the wings [5]. They burn 6,771 gallons of fuel per hour, are two times more powerful than ordinary jet engines, and are capable of accelerating the aircraft from 0 to 225 mph in just 30 seconds [5], [6]. To reach supersonic speeds, the engines use afterburners to provide additional thrust. Afterburners are used in military fighter jets and are distinctive because they give out an orange glow, as depicted in Figure 3 [6].

Source: http://www.aviationtrivia.info/images/concorde.jpg

Figure 3. Afterburners at work

Attached to the front of the four Rolls-Royce turbojet engines are the air intakes. As an analogy to explain the importance of air intakes, imagine eating and swallowing food quickly without chewing. What you would get is an upset stomach, because the food is not chewed and swallowed at a moderate pace to allow proper digestion. Similarly, turbojet engines need time to properly "digest" air that flows through. The air intakes "chew" the air, reducing the speed of the air so that maximum performance is achieved [5]. Air flows into the intakes at 1,350 mph and is slowed down to less 300 mph before reaching the engines. This technology, although more than 40 years old, is still state-of-the-art [5].

To fly fast, an aircraft needs to have an aerodynamic nose. Concorde's distinctive Droop Nose does the job. Like the visor, the nose can be adjusted in two ways by means of a hydraulic system: in the downward position or horizontal position as illustrated in Figure 4. During take off and landing, pilots would tilt the nose downwards so that they can have a better view of the runway, and while in the air, the nose would be lifted up to increase the plane's aerodynamics and allow it to glide through the air more efficiently [5].



Source: http://www.concordesst.com/inside/1.jpg

Figure 4. Concorde's Droop Nose at horizontal and downwards position

Last but not least, the engineers implemented the state-of-the-art Automatic Flight Control System (AFCS). This system consists of the autopilot and autothrottle technology. Autopilot controls the trajectory of the aircraft, allowing human pilots to fly "hands free" through large portions of a flight. Autothrottle controls the speed of the plane and is able to maintain supersonic speeds even when the outside environment changes [5], [6]. Having such a system allows the human pilots to concentrate on other tasks while the computer takes care of basic chores.

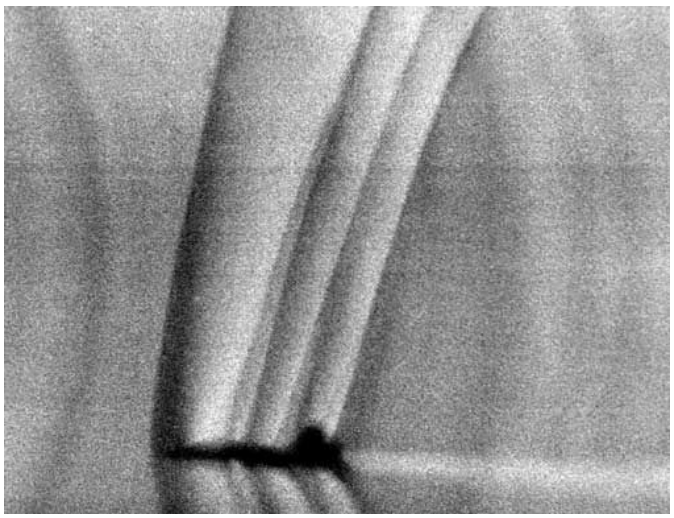
To put things into perspective, Concorde takes less than three and a half hours on average to travel from London to New York, whereas an ordinary airplane can take up to eight hours. The fastest recorded transatlantic flight by the Concorde from New York to London was on 7 February 1996, taking just 2 hours 52 minutes and 59 seconds [8]. Undoubtedly, an incredible feat. During its construction, the Concorde is said to be even more advanced than the spacecraft, Apollo 11, that brought astronauts Neil Armstrong and Buzz Aldrin to the Moon [9].

Setbacks

Despite the streak of success it enjoyed, Concorde also had its share of problems. A major contributor to Concorde's demise was the crash of Air France Flight 4590, which occurred on 25 July 2000 [10]. Bound from Paris to New York, the aircraft suffered a tire burst after hitting a titanium strip left by a Continental airplane that took off right before the Concorde. The blown

out rubber pieces flew up and fractured the fuel tank, leaking kerosene which eventually ignited into a fire. The Concorde crashed into a hotel only 60 seconds after take off, killing all 109 passengers and four people on the ground [10]. The accident severely tarnished Concorde's reputation. However, immediately casting doubts on Concorde's safety would be premature, because this was Concorde's first and only fatal incident. In addition, the accident was not caused by faulty parts or technical problems, but by a foreign debris. After the crash, engineers gave Concorde stronger tires, fitted the fuel tank with bulletproof Kevlar linings, and strengthened the wiring in the landing gear bay [11].

The sonic boom was another major issue that Concorde faced. When a supersonic airplane flies above an area of land and reaches the speed of sound, a thunderous noise as loud as a gunshot can be heard by people on the ground. When an aircraft surpasses the speed of sound, the air molecules surrounding the plane are not pushed away fast enough, causing an accumulation of molecules around the aircraft as shown in Figure 5. This accumulation is known as a shock wave, and can be heard as a very loud double-boom. The idea of air molecules being pushed away is analogous to water being cast aside when a boat rows across a river [12]. Sonic booms would shatter the windows of houses, set off car alarms, and were overall a major disturbance and annoyance to people. As a result, restrictions were placed on the number of countries Concorde could fly across, including the United States (excluding New York), Malaysia, and India. Other countries allowed Concorde to fly overland, but only at subsonic speeds, or speeds below Mach 1. [13].



Source: http://www.pbs.org/wgbh/nova/concorde/shoc-02.html

Figure 5. Shock waves produced as a result of an accumulation of air molecules

Unfortunately, Concorde also affected the environment. Concorde flew at around 60,000 ft above sea level as seen in Figure 6. This is an altitude that is in the vicinity of the ozone layer, which is a region where chemical reactions are more profound. Therefore, a fleet of Concorde aircraft can harm the ozone more than the total amount of chloroflourocarbons (CFCs) used globally [14]. Concorde uses a special type of fuel, A1 Jet Fuel, which causes the engines to release nitrogen oxides into the ozone layer [15]. The exhaust system also emits water vapor and hydroxyl radicals, and these emissions contribute to the greenhouse effect.

Source: http://www.rajcoaviation.com/Images/AircraftPerformanceOperatingAltitudes.jpg

Figure 6. Concorde flies near the ozone layer at 60,000 ft above sea level.

Less than two years into the Concorde project, the British and French governments expressed their concerns about the economic viability of the project. It has been said that "Concorde has always appealed far more to politicians and engineers than to administrators and economists" [16]. Concorde was expected to cost, in today's money, $3.1 billion in 1962; by 1975, total expenditure shot up exponentially to approximately $18 billion. Much of the investment went into developing the Droop Nose and tackling the sonic boom issue [16].

Concorde ticket prices were also tough on the wallet, since the entire fleet was first class and each aircraft could only take 100 passengers. On average, round trip tickets from London to New York cost $10,000, and from Paris to New York around $7,000 [17]. Evidently, average travelers could not afford such steep ticket prices.

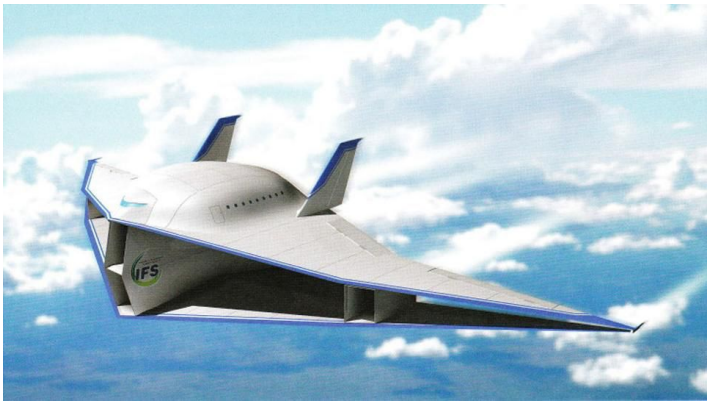
Paving the Way for the Future

The Concorde era may have come to an end, but hope is not lost for supersonic transportation. Concorde is only a stepping-stone to greater supersonic jets. In 1997, the National Research Council reported that the potential market for supersonic commercial aircraft is on the order of 1,000 jets [12]. As long as there is a demand for speed, which there always will be, supersonic transportation will certainly have a future.

Before formulating new ideas and improvements for the next supersonic aircraft, known problems must be dealt with first. As discussed earlier, the sonic boom phenomenon was a major issue for Concorde, and still stands today as a momentous obstacle that needs to be resolved. Aerospace giants including Boeing and Lockheed Martin are finding ways to reduce the loudness of sonic booms. NASA recently used wind tunnels to test new supersonic aircraft designs from the two manufacturers, and the results were promising: sonic booms can indeed be reduced to tolerable levels when flying overland [12].

Wing design is key when tackling the sonic boom. An assistant professor of aeronautics and astronautics at MIT, Qiqi Wang, has come up with a radical concept: using two layers of wings

on each side of an aircraft instead of one as seen in Figure 6. Called a biplane, the aircraft would fly with less of a sonic boom because the shock waves produced by each wing would cancel out one another. He credits his findings to late German engineer Adolf Busemann, who formulated the theory in the 1950s. Wang and his team determined that the optimum biplane wing shape is achieved by making the top edge of the higher wing and the bottom edge of the lower wing rounded. Doing so allows the plane to fly at supersonic speeds and experience drag two times lower than that of the Concorde. Wang predicts that "there may be a boom in the field in the coming years" [18].



Source: http://www.bbc.com/future/story/20120405-supersonic-jets-ready-to-take-off

Figure 6. A biplane with two layers of wing on each side of the aircraft

Wang is right. A team at Tohoku University in Japan is working on a biplane wing design based on Busemann's theory. Called the Misora, which stands for "Mitigated Sonic Boom Research Airplane," the biplane would have dynamic wings that can move and adjust itself at different speeds [19]. More and more aerospace companies have come up with new designs of supersonic aircraft, including Aerion Corporation, an aerospace company with its headquarters based in Reno, Nevada. Aerion predicts that by the year 2020, they could have one of their concept supersonic business jets, the Aerion SBJ, in service. The Japan Aerospace Exploration Agency, also known as JAXA, is currently developing their own commercial supersonic aircraft, and has high hopes that their project will come to fruition by the end of the 21st century [20].

Conclusion

Concorde was a success and a failure. What made it successful also contributed to its demise. It achieved supersonic speeds with ease, but at a cost of the sonic boom. It flew at an altitude that presented little to no turbulence, but there were concerns that it would drastically damage the ozone layer. Almost everyone loved Concorde, but only a few could afford the exorbitant tickets.

For an aircraft that was developed over forty years ago, the Concorde is still considered leading-edge today. Engineers and scientists have much to learn from their experience with Concorde. Technical issues such as the sonic boom will eventually be solved, because engineers are great problem solvers. While the economy viability of future projects remains unknown, one must keep in mind that there would always be a demand for speed. It is only a matter of time before the world sees a new generation of supersonic aircraft.

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