The Concorde Accident: A Case Study

The Concorde airliner was a technical marvel that commercialized supersonic flight, for decades carrying wealthy passengers across the Atlantic Ocean at twice the speed of sound. But was the Concorde’s masterful design also its Achilles heel? Concorde Flight 4590 crashed shortly after takeoff from Charles de Gaulle Airport, killing all 109 on board and 4 on the ground. The investigation uncovered a confluence of improbabilities and miscalculations. Roger Forsgren, NASA Chief Knowledge Officer and Director of APPEL Knowledge Services, examines the radical engineering that made Concorde possible and the improbable chain of events that left investigators with an agonizing list of “what-ifs.”

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By Roger Forsgren

The Beginning of the End

In July 2000, at Houston’s George Bush Intercontinental Airport, airline mechanic John Taylor riveted a seventeen-inch wear strip he had fabricated to a DC-10’s General Electric CF6-50 engine. Taylor had difficulty positioning all the rivets and used aircraft mastic to help hold the wear strip in place.

A wear strip is a piece of sacrificial metal that acts both as a cushion as well as a tight seal for the engine’s thrust reverser cowling. Replacing a wear strip is routine aircraft maintenance and is not considered a safety issue affecting operation or flight. John Taylor did not follow the manufacturer’s recommendations when he fabricated it and decided to use a piece of titanium, presumably thinking that the much harder and stronger metal would last longer than the metal recommended by General Electric, the manufacturer.

At the time, he had no idea he would soon play a critical role in a chain reaction of catastrophic events. His titanium strip would be blamed for causing the world’s most famous jetliner, the Concorde, to crash half a world away, contributing to the end of twenty-seven years of commercial supersonic flight. Eight years after popping the last rivet in place, John Taylor would find himself facing manslaughter charges from a French court for the deaths of 113 people.

Overview of Concorde

The Concorde was a joint engineering and project management effort between two historic rivals, the British and the French. It was the first attempt to realize the dream of supersonic commercial flight and an enormous engineering achievement for the time, considering the design and development began in the early 1960s. The project became an object of national pride for both countries despite its agonizingly long development schedule and its enormous cost overruns. In 1976, when Concorde made its first commercial flight to New York’s JFK airport, the program was three years behind schedule and fifteen times over budget.
Supersonic flight was nothing new, even in the 1960s. What was new was the length of time Concorde would be required to fly at supersonic speeds. At the time, military aircraft had the capability to fly faster than sound but usually for only short intervals – to outrun an adversary or to dodge a missile. Concorde was designed to fly at twice the speed of sound for its entire flight. For the London to New York flight, that meant flying supersonic for almost three hours.

The Concorde was a technological marvel that, unfortunately, debuted its commercial service at exactly the wrong time. During her design, oil had been cheap but after the Arab oil embargo of 1973 airlines quickly changed their purchasing requirements from increased speed to efficiency, creating a market in which Concorde could never compete. Finding no buyers, the French and British governments, despite their enormous developmental investment, simply handed the fleet of fourteen planes to their national airlines.

Concorde became a symbol of grace and luxury. Its iconic drooping nose and wide delta wing holding its four massive engines made her the most striking and memorable plane in aviation history. It catered to the rich and famous, those who could afford the astronomical fare (at times charging as much as $12,000 round trip) for one of the one hundred seats on board, all of them first-class.

But many people came to view Concorde, not as a symbol of national pride and technological brilliance, but as a white elephant whose enormous developmental costs could never make commercial operation profitable. This brought public outcries that the poor were subsidizing the supersonic flights of the wealthy. Adding to this challenge, a new era of environmentalism began in the 1970s where Concorde’s engines, with their huge black clouds of exhaust and deafening roar brought out just as many protesters as admirers to watch it take off and land.

The Concorde Design

All engineering involves compromise, especially when designing anything that moves. The faster it goes, the more compromises are needed. The Concorde was certainly no exception.

In order to achieve supersonic speeds, the British and French designers chose a huge fixed delta wing configuration. As military jet designers knew, a delta wing presented a formidable compromise because, although it would be quite efficient at supersonic speeds, it was incredibly inefficient at the subsonic flight speeds required over land as well as for take offs and landings. The wing also had to be rigid without any ailerons or flaps for control because any extraneous flaps would cause drag or be simply torn off at supersonic speeds. To control the pitch of the airplane while in flight, designers pumped fuel from one tank to another to distribute weight similar to early submariners who were required to run to the bow of their vessel to make it dive or to the stern to make it rise.
The fixed delta wing also required a very high angle of attack in order to take off. The Concorde’s iconic stork-like stance placing the nose high above the tarmac was purposely designed in order to get the heavy aircraft with its fixed wing off the ground. The angle of attack was so steep that designers had to make the nose adjustable and swing downwards on takeoff and landings so the pilot could see the runway. They also had to install landing gear at the very rear of the fuselage so the tail didn’t scrape the runway.

Concorde was fitted with four Rolls Royce Olympus engines equipped with afterburners capable of producing a combined thrust of 152,000 pounds at takeoff. The designers developed an ingenious computerized system of air intakes that reduced incoming supersonic airflow into the engines from 1,350 mph to 550 mph to reduce the risk of engine surge.

In order to feed these hungry engines, the huge wing also had to hold almost 31,500 gallons of jet fuel at a weight of 209,000 pounds. On average, a Concorde burned almost four times as much fuel per passenger as a giant Boeing 747 consumed on a similar transatlantic flight. Required to fly at her inefficient subsonic speeds over populated areas to avoid creating sonic booms she burned half her fuel by the time she reached Mach 2 over the Atlantic. The Concorde’s four Rolls Royce engines could burn two tons of fuel just taxing from the gate to takeoff – as much fuel as a modern Airbus 320 would burn flying from London to Paris.

As she taxied down the runway, with her Olympus engines roaring and afterburners shooting flames, Concorde would move from 0-250 mph in forty seconds – faster than a Formula 1 race car. With its fuel tanks full and a hundred passengers strapped in and their baggage stowed, the tires for Concorde had to support the huge weight of the plane, as much as 408,000 pounds (204 tons), as well as higher than normal rotational speeds the Concorde delta wing required in order to get off the ground.
Once clearing land and heading over the ocean Concorde could finally make more efficient use of her delta wing and go supersonic at Mach 2 (1,354 mph) – faster than a rifle bullet. While over the Atlantic, Concorde needed to reduce aerodynamic drag and flew much higher than subsonic flights (30,000 feet) with her maximum altitude at 60,000 feet, almost 11.5 miles. At such an altitude her passengers could see the curvature of the Earth out the tiny windows that had grown warm from flying at Mach 2. At this height Concorde flew above the Jetstream and any storms providing an incredibly smooth flight without any turbulence. Because she burned fuel so quickly the airplane continually became lighter and the pilots had to re-direct the ballast fuel forward to keep her from continually climbing higher.

At such speeds Concorde fuselage, and particularly its nose cone, grew very hot. The entire plane could grow over nine inches during supersonic flight requiring the designers to equip her with expansion joints. The cabin floor was constructed on rollers to permit the expansion and contraction of the fuselage.

By the time Concorde arrived in New York’s busy airspace, she was seldom asked to go into any holding patterns and was usually given special treatment by air traffic controllers who knew at subsonic speeds she had to land ahead of others due to the inefficiencies inherent in her supersonic wing design.

The Concorde Disaster

Most engineering disasters, particularly those involving machinery with complex systems, seldom occur for just one major reason. Usually there are a series of factors involved leading to a cumulative catastrophic event. Such was the case on July 25, 2000 on Concorde Flight 4590 from Paris’ Charles de Gaulle (CDG) airport to New York’s JFK.

Flight 4590 was a chartered flight carrying a group of one hundred German passengers to New York where they were to catch a cruise ship for the Caribbean and South American ports. With an impeccable safety record, Christian Marty was one of Air France’s most talented pilots. But with today’s flight almost an hour late and knowing his passengers had to meet a cruise ship, the captain decided on expediency. Passengers on a chartered jet intending to go on an extended cruise are going to carry quite a bit of luggage. The investigative report later stated that the Concorde was slightly overweight, beyond the recommended maximum structural weight of 408,009 pounds for flight.

Rather than burn extra fuel, Christian Marty decided to pump fuel toward the rear of the plane in order to shift the center of gravity allowing the plane to get airborne and compensate for the additional weight.
When Air France Concorde Flight 4590 left the gate and taxied to runway 26 Right the flight controller told Marty that he had unfavorable tail winds at eight knots. For a plane on takeoff head winds are preferred because they provide added lift and this was particularly important for Flight 4590 because she was overweight. The extra weight along with the additional drag from head winds meant that Captain Marty would need most of the length of runway 26 Right during take off. But, in an attempt to get his passengers to their destination on time, Marty declined the opportunity to takeoff from another runway with a more favorable headwind.

As he was preparing the four Rolls Royce Olympus engines for full throttle Captain Marty did not know that a Continental Airlines DC-10 had recently taken off from the same runway. Just minutes before, the DC-10 dropped mechanic John Taylor’s makeshift wear strip on the same runway.

Typical runway maintenance at CDG called for three daily inspections to clean up any FOD (foreign object debris) that may have scattered on the runway. On this July afternoon the planned inspection was cancelled due to a routine fire drill.

As Captain Marty began to move the power levers to full throttle he, as all pilots who flew Concorde, was aware the sleek jetliner had a history of tire problems. Because of the extreme loads and speeds on takeoffs and landings, Concorde's tires were failing at a rate of one every 4,000 flying hours, 60 times more frequently than a typical airliner. In 1981 the U.S. National Transportation and Safety Board expressed its concern over Concorde’s recurring tire blowouts to Air France warning they could lead to “potentially catastrophic” results.
When Flight 4590 sped down the runway her tires encountered the titanium wear strip that had fallen from the DC-10. Titanium, a very strong and tough metal sliced like a razor into the tire on Concorde’s left side. When the tire burst, large pieces of rubber flew at more than 300 mph, hitting the underside of the delta wing and firing like flak into the landing gear compartment, slicing through exposed hydraulic lines and electrical wires.

The largest tire fragment, approximately four feet long and weighing more than ten pounds, struck the underside of the wing hitting fuel tank number 5, which was completely full. As the tank was hit with such a violent blow there was no empty air space in the tank to help absorb the hit. The tire fragment did not pierce the fuel tank but caused a hydrodynamic pressure surge within the overfilled fuel tank. With nowhere to go, the fuel from inside tank 5 blew out an aluminum panel measuring about one and a half feet square of the underbelly.

As fuel began pouring out of the ruptured wing the sparks from the torn electrical wires hanging from the wheel well ignited it. With Concorde moving down the runway at such a high rate of speed the fully engaged landing gear helped to slow down the flow of air causing an almost perfect ignition sequence as the slower air atomized the fuel and sent the flames toward the engines.

Inside the cockpit the fire sensors were blaring and instinctively the flight engineer shutdown both left engines. Captain Marty had reached the speed where there was no turning back, Concorde was running out of runway and he had to take it airborne. Desperately trying to pull her nose up and hoping to make an emergency landing at a nearby airport, the plane struggled with the additional drag of the landing gear as the pilots couldn’t retract it due to the hydraulic leaks.

With its undercarriage ablaze, Concorde never got above 200 feet. The pilots couldn’t keep the delta wing airborne at such slow speeds and she crashed less than two minutes after takeoff, barely six miles from CDG airport, hitting a hotel engulfing the area in flames. All one hundred passengers were killed along with Captain Marty, his co-pilot, his flight engineer, six flight attendants and four people on the ground at the hotel.
The Concorde Denouement

In many ways Concorde was ahead of its time. But with such a complex design, including so many innovative and pioneering features, it pushed the operational and safety boundaries of other critical subsystems. Her ingenious wing design allowed supersonic flight but with a compromise for the additional fuel and weight needed to fly her at subsonic speeds. The tire design during Concorde’s operations couldn’t reliably keep up with the demands for additional weight and the increased speeds required to get Concorde off the ground.

But Concorde Flight 4590 also suffered from an almost inconceivable chain of events that all compounded into a catastrophe. Without one event in the series happening, flight 4590 may have arrived safely at JFK that evening and its passengers may have gone onto their Caribbean cruise. Certainly, John Taylor’s decision to install a titanium wear strip was the easiest to blame but there were other events and decisions that all contributed to the tragedy. For example, what if the runway inspection had been conducted and the titanium strip found? What if the wear strip had fallen flat on the runway allowing the Concorde tire to crush it rather than falling and landing upwards, like a knife blade? Or, what if John Taylor’s wear strip had simply fallen a few inches to the right or left and Concorde’s tire would have missed it?

What if Captain Marty, realizing his plane was overweight had decided to burn off a ton or so of fuel while taxying? Or, what if he had selected another runway without such a strong headwind? If he had done either it’s very possible the Concorde would have been airborne before hitting John Taylor’s wear strip or had avoided it completely.

What if the NTBS or the British and French aviation safety commissions had placed the proper attention to Concorde’s continual tire problems and grounded the fleet forcing the airlines to work with manufacturers to develop a more reliable tire that could handle the speeds and loads.

Despite all the “what-ifs” perhaps Flight 4590 was doomed long before it took off for JFK. Perhaps the radical design of Concorde was an accident waiting to happen. In this relation perhaps the Concorde was similar in a way to the Space Shuttle, a vehicle that had always retained its designation as an experimental vehicle. Both were masterful designs and because of their radical design both carried significant risk.

Aftermath

After the crash of Flight 4590 all Concordes were grounded. British Airways and Air France made costly safety improvements such as lining all thirteen fuel tanks with Kevlar and developing stronger tires less prone to blowouts and shredding. Charles DeGaulle and Heathrow airports instituted more rigorous runway inspections.

On September 11th 2001, British Airways was conducting a test flight over the Atlantic when the World Trade Center Towers were hit by terrorists. The “9/11 effect” killed the Concorde for good as the world entered another economic slowdown and commercial travel, particularly business travel, came to a standstill.
Previous to Flight 4590, both British Airways and Air France boasted of the Concorde’s safety record of flying almost three decades without an accident. In reality, the Concorde’s safety record may not have been as stellar as advertised. The fleet of fourteen Concordes never came close to logging the hours and number of takeoffs and landings of other commercial jetliners. For instance, during the same period that Concorde flew, the huge international fleet of Boeing 737s would fly more hours in a week than the entire Concorde fleet did in their entire twenty-seven years of commercial service. Judging Concorde by the industry standard of “hull losses per million flights” the crash of Flight 4590 outside of Charles de Gaulle Airport places Concorde’s rating at, 11.6, by far the worst of any modern jet liner.

Concorde was pressed into service because of political pressure. The French and British governments were desperate to see it fly to justify its enormous developmental costs as well as to foster a feeling of national pride in the world’s only commercial supersonic airliner. But both British Airways and Air France were hampered by Concorde’s massive maintenance and operating costs and could never make a reliable profit from her tickets.

This Concorde is on display in the Boeing Aviation Hangar at the Steven F. Udvar-Hazy Center in Chantilly, VA. 
**Credit:** Smithsonian National Air and Space Museum

In its twenty-seven years of commercial service, the fleet of fourteen supersonic jetliners that had carried more than two million passengers on champagne filled flights across the Atlantic was now disbursed to museums around the world. In the U.S. there are Concordes on display at the Smithsonian’s Steven F. Udvar-Hazy Center near Dulles Airport, aboard New York’s Intrepid Sea, Air & Space Museum (along with the Space Shuttle Enterprise), and a third at Seattle’s The Museum of Flight.

In 2010, ten years after the crash, a French court found mechanic John Taylor and Continental Airlines guilty of involuntary manslaughter in the deaths of 113 people. Two years later a French appeals court exonerated Taylor, stating that the titanium wear strip did in fact lead to the accident but that Taylor’s poor workmanship was not criminal since no one could have predicted such devastating results. French Judge Michele Luga stated, “…he (Taylor) could never have imagined a scenario where this simple titanium blade could cause such a disaster.” Afterwards, Taylor mentioned to a newsman that the entire experience “…had ruined my life.”
Additional Resources:

The Aviation Administration’s Lessons Learned Air France 4590.
The French Bureau Enquêtes-Accidents Interim Report.