Mach 2

Concorde magazine

Points of interest
What makes Concorde unique

Concorde watch
Aerospace Bristol

Tales of the unexpected
Overcoming challenges in flight

Issue 6
October 2016

Introduction

In this issue we focus on the technical aspects that made Concorde so special. Nigel Ferris explores the range of innovations incorporated into the airframe and systems, and discusses the solutions found to overcome some of the unique challenges of Concorde operation. Former Senior Engineering Officer Ian Kirby gives an insight into the awe-inspiring way in which Concorde and the flight crews overcame some serious technical and weather difficulties.

We also include an update on the new aviation heritage centre being built to house Concorde G-BOAF at Filton, as well as our occasional "tech log" feature in which Ian Kirby answers our readers' questions.

In this issue

Editor: Katie John

Contributing editor: Nigel Ferris

Fascinating facts

Nigel Ferris *follows Concorde through a flight from preparations to landing, considering the unique characteristics that the aircraft showed at each stage. He also looks at the test rig constructed to test performance through thousands of cycles.*

1 On the ramp, when the flight crew had completed their pre-flight check list, the flight engineer would contact ground and ask for "air to number 2 (or 3)" for start-up. The inner engine on the other side would then receive air for start. The outer two engines would not be started (by cross-feeding air) until the tug had been disconnected. This was because even at idle, the thrust from the Olympus 593 engines was such that to have all four running at idle could have caused the tow bar to bend, break, or push the tug backwards!

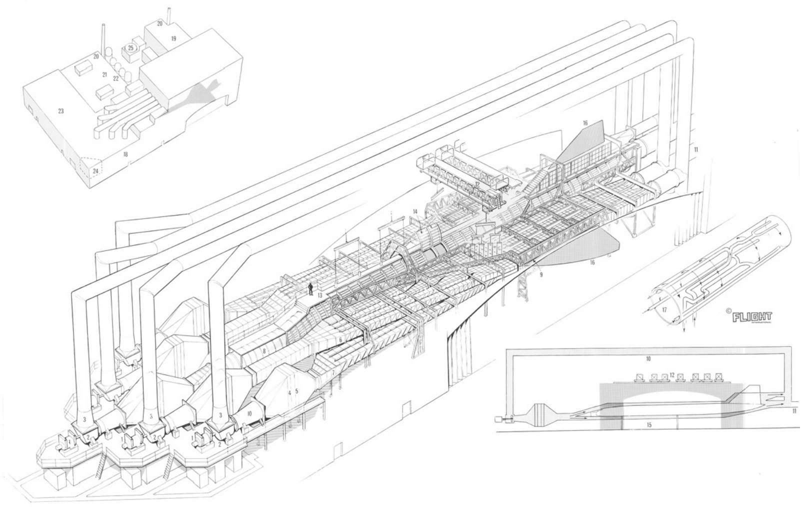
2 All swept-wing airliners have high lift devices on the wings – leading edge slats and trailing edge flaps, to increase lift on take-off and landing. Concorde had none of these, relying instead on the vortex lift developed by the wings, and the complicated landing procedure.

3 When Concorde was flying at supercruise across the Atlantic, she still had a pitch-up attitude of 1½ degrees to the horizontal to optimise the aerodynamic vortex lift and efficiency of the wing surfaces, and for low fuel burn.

4 Concorde was a naturally soft-landing aircraft. Due to the delta wing design, as she approached the runway, she would create a huge cushion of air under the wings: the 'ground cushion effect'. At 15 feet, when the throttles were retarded to idle, the pilot would select a small amount of back stick, to counteract the ground cushion tending to pitch the nose down. Landing Concorde was a balancing act, and it was essential this was achieved correctly, to ensure a 'positive' touchdown of the main wheels – i.e., not bouncing, so then the nose wheel could be landed and the main wheel brakes activated; prior to this they were inhibited until the nose wheel was travelling at the same speed as the main wheels. (Then when reverse thrust was selected, full forward stick would be selected to counteract the pitch-up attitude that reverse would initiate.)

Soft landing
Concorde G-BOAC in typical landing attitude as she comes in to runway 27L at Heathrow.
Photo © Jetinder Sira, 2003

5 In addition to the 20 airframes built and flown, there were also two complete structural specimens built – one for heating and cooling in a special rig, to simulate the cycles encountered in flight, and another for static load testing.



British test rig
The British test rig, shown here, was the sixth airframe to be built. Based at Farnborough, it was used for fatigue testing. The French airframe, the third to be built, was located at Toulouse and used for stress testing.
Artwork © FlightGlobal

It didn’t always go as expected

Ian Kirby, former Senior Engineering Officer on Concorde, British Airways

Concorde Flight Engineer Ian Kirby shares some “tales of the unexpected” – situations in which Concorde and her flight crew faced major challenges, from extra fuel demands to extreme weather. Yet the aircraft and flight crews rose to each occasion in perfect style.

Demanding a miracle

It was a normal flight to Washington Dulles. Well it was until we were in the area of the airport and under approach control. They sent us way south of the airport and when they turned us towards the airport they insisted we reduced to minimum approach speed. That speed of about 160 knots was still too fast for them so they gave us a massive dogleg. What had been plenty of fuel was now running low.

Eventually I advised the captain that it was likely we would arrive on the ground with below the minimum legal fuel level, known as the alternate reserve, of 6,500Kg. At that stage we declared a fuel emergency. We eventually landed with just a shade over the 6,500Kg. I should point out that the slower you fly a Concorde the more fuel you burn per mile, and at the low speed they expected of us the fuel flow was more than most aircraft at take-off.

Safely on the ground and parking at our normal position, we were visited by a representative of the FAA (Federal Aviation Authority), who came to see if we really had low fuel and then to reprimand us for not having sufficient fuel for our planned flight. The FAA rep made a bit of a long-winded pig’s ear of our reprimand – sufficient time for me to make a calculation that would demonstrate how badly we had been treated by air traffic control. When Mr FAA had finished I pointed out to him that if, instead of decelerating and landing at Washington, we had continued our flight, we could have flown on to Miami and landed with more fuel than we had when we arrived in Washington. I think he got the message.

“When it goes bump ...”

For this flight, we knew the weather in New York was not going to be great, but we had an aircraft with full Cat 3 automatic landing. The weather at our alternates was reasonable so we had no problems, or so we thought. As usual I had noted the weather reports from our destination and any likely alternates. We had entered the New York Kennedy area and were directed to a holding pattern. Then ATC dropped the bombshell: “Due to weather, JFK is closed with indefinite delays.”

A bit of a downer, so we requested a diversion to Bradley Field (now Bradley International Airport), Connecticut – our normal alternate. The weather was acceptable, so off we went. Approaching Bradley we were advised the temperature had risen and the visibility was virtually nil. That can happen when there is ice and snow on the ground and the temperature rises. With the conditions well below our limits we made a second diversion to Halifax. As all this was subsonic we were getting a bit low on fuel.

Approaching Halifax we received an emergency weather broadcast telling us the temperature had risen there and the visibility was near zero. We had no option. We did not

Tough conditions
Concorde G-BOAD on display in winter at the USS Intrepid museum, New York. While in service, Concorde coped with any extremes of weather, including heavy snow.
Photo: Jorge Láscar / Wikimedia Commons

have enough fuel to go anywhere else. There was no automatic landing available at Halifax due to the quality of their instrument landing system. We had no choice but to do a manual approach and landing at what was well below limits for a manual approach or probably any other approach.

About two miles out our jovial co-pilot asked what we were going to use as our landing limits. "When it goes bump", our captain replied. We could not see the runway, but the glow on both sides proved we were over the runway and just about on the centre-line. I think our captain saw the runway just about the same time as the main wheels touched down. We stopped safely and then had the very difficult task of finding our way to the parking gate; it took ages, but we were safe. Very well done, Captain.

Braving the storms
Concorde takes off into a stormy sky at Heathrow. Even in automatic pilot, Concorde showed she could overcome any challenge.
Photo © Jetinder Sira, 2003

Hurricane conditions

On another occasion we knew there was a hurricane approaching New York, JFK. We took plenty of fuel. British Airways, in its infinite wisdom, had cancelled all the other flights to JFK, so our Concorde was the only BA flight expected to land in the hurricane conditions.

I got the weather report and it was as bad as we had expected. When I passed the report to the captain he asked if I thought we would get in. I advised I considered we had a better than 50:50 chance of a successful landing. "OK, so what sort of approach do you suggest?" he asked. I suggested a full auto-land.

The captain pointed out the runway in use was not auto-land approved. I advised that I was aware of that but we were authorised to do automatic landings on unapproved runways if the visibility was good, and today it was good. He asked the co-pilot's view and he stated that "Ian knew the aircraft better than most" and if I thought it was worth a try then we should go for it. So that was decided.

We had a short discussion about how much to add to our target threshold speed due to the wind, and 10 knots was agreed as sensible. Although the wind at our altitude would require a larger increment, the wind reported on the ground was lower.

As we made our approach we could see a Boeing 747 ahead of us. They were all over the place – high, low, left, right, but seldom "in the slot". Our dear old Concorde went down the approach as if it was on rails, right down the middle of both the localiser and the glide slope. Despite the wind at about 40 knots, gusting 60 knots, with the gusts often some 20 to 30 degrees either side of the steady wind, the speed varied little, with the auto throttles holding us just a little fast due to the varying G the system was feeling.

We watched as the poor 747 ahead had enough, put power on and went round. We continued to a perfect auto-land with the system putting us correctly on the upwind side of the centre line. As we slowed and turned off the runway our co-pilot, who was a well qualified test pilot, stated, "That was very impressive."

As we taxied in, ATC asked us to phone the tower when we got to the office to discuss the approach and landing. "Your idea," our captain said to me, "you talk to them". As we continued to our gate a B747 that was behind us went round over the terminal, as they had not been able to land.

When I spoke to the tower about the approach and landing, they commented that we must have a good pilot. I told them the winds we had on the way down and advised them that it had been a fully automatic approach and landing. There was disbelieving silence from the tower supervisor. I discovered later, from the TV news, that we were the only aircraft to land in about a four-hour period when the winds were at their worst.

Concorde was a great bit of kit.

Outstanding Features

On these pages, Nigel Ferris *looks at some of the points that make Concorde unique in structure and performance.*

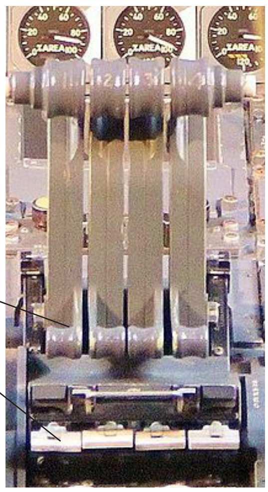
1 Cosmic radiation meter

Because Concorde flew so high, the flight deck included a solar radiation meter – an instrument not found on any other commercial aircraft. This meter showed the amount of radiation entering Earth's atmosphere, in millirems. In the event of solar flares, which could have exposed those on board to unwanted amounts of radiation, an alarm would sound, and Concorde would descend to a lower altitude where the atmosphere was thicker and would provide adequate protection for the passengers and crew. As far as I am aware, this situation never happened in 27 years of commercial service.

Concorde G-BOAC
Image: Emoscopes / Wikimedia Commons

2 Reheats

Concorde has four throttle levers (one for each engine), with further levers on the front to control the reverse thrust, and behind four 'piano' switches, to control the reheats (afterburners, thrust augmentation). Reheats would be selected in pairs (2 & 3, 1 & 4) for transonic acceleration – as the thrust provided by all four engines would cause a possible uncomfortable single 'push in the back' for the passengers. Instead, two smaller 'pushes' would be felt. But on take-off, all four would be selected to provide maximum power.

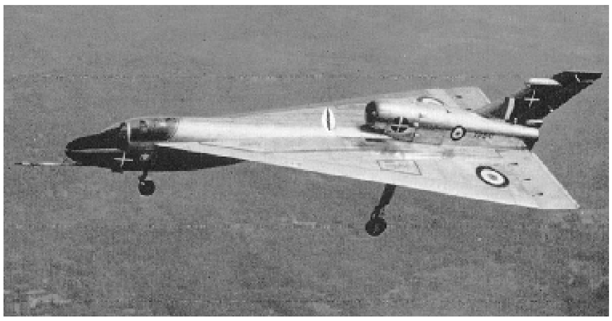


Throttles and reheats
Photo: Clemens Vasters / Wikimedia Commons

3 Wing shape

There is an ideal angle for the wing leading edges for high-speed flight – around 22° from the aircraft's centre line. The front portion of Concorde's wings were at roughly this angle – but if the entire wing had been like this, then Concorde would have been very much longer. Instead, the wings flared into a 'double delta' shape, with the leading edge forming an 'ogee' curve.

Test aircraft
The Handley Page HP.115 was used in developing Concorde, to test the action of a slender delta at low speeds.
Photo: Unknown source (no copyright)



4 Undercarriage

The main undercarriage on Concorde was especially tall, to minimise the risk of the exhaust secondary nozzles and the extreme end of the tail coming into contact with the runway on take-off.

The engine nacelles were positioned as far out as possible before the droop of the outer wings limited their position. This in turn dictated the undercarriage position. But on retraction, the undercarriage would have been too long to fit into the landing gear bays. A clever solution was employed by the use of a shortening jack in the mechanism, which reduced the length of the undercarriage by about 6 inches so that the wheels would fit into the bays.

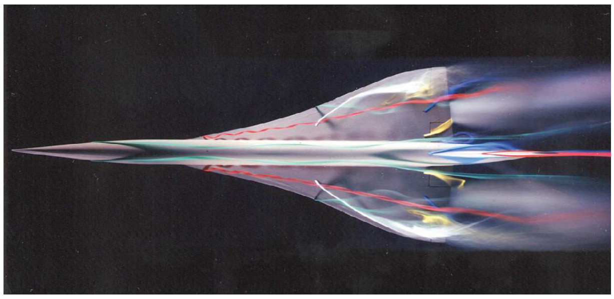
Telescopic structure
The undercarriage at its full extent. On take-off, the legs would shorten before retracting into the landing gear bays.
Photo: Mathieu Marquer / Wikimedia Commons

5 Engine nacelles

At the top edge of the engine nacelles, above the front lip of the intakes, is a small gap. This extends back over the length of the intake section, tapering out as a 'V' shaped wedge. This is designed to maintain boundary layer airflow on the wing undersurface, because the nacelles take up a fair amount of space.

Boundary layer airflow is where the air molecules 'stick' to the wing and help produce lift. There are two types. The laminar boundary layer is a very smooth flow, while the turbulent boundary layer contains swirls or 'eddies'. The laminar flow creates less skin friction drag than the turbulent flow, but is less stable.

Boundary layer flow over a wing surface begins as a smooth laminar flow. As the flow continues back from the leading edge, the laminar layer grows thicker. At some distance from the leading edge, the smooth laminar flow breaks down and transitions to a turbulent flow. In terms of drag, it is advisable to have the transition from laminar to turbulent flow as far aft on the wing as possible, or have a large amount of the wing surface within the laminar portion of the boundary layer.



Air flow over wing
A wind tunnel model of Concorde, showing the pattern of air flow over the upper wing.
Photo © H. Werlé / ONERA

Engine nacelles
Photo: Dockurt2k / Wikimedia Commons

Overcoming challenges

Concorde was both spectacular and safe, but as with any machine problems occasionally arise. Nigel Ferris *looks at two challenges unique to Concorde – engine surge at supersonic speeds, and the aftermath of the tragic crash in 2000. He shows the effective design solutions found to overcome these issues.*

Engine surge

This is a phenomenon experienced by jet engines, where the engine cannot cope with the amount of air entering, and the direction of this airflow is dramatically reversed, blowing out of the intake with accompanying combustion flames. This happens in a fraction of a second, and can go through several phases of reverse and normal direction – usually with large bangs. Disconcerting to passengers sitting in line with the engines. The worst result can be a multi-million pound engine being ejected onto the runway in thousands of pieces. Surge can be caused by various factors, including a worn engine, poor fuel supply control problems, or bad throttle commands.

Surprisingly, the loss of one or two engines on one side of Concorde at high Mach numbers would have a less detrimental effect on the aircraft's stability than it would do on a normal commercial airliner. In the event of surge, fire, or mechanical failure on a subsonic airliner, the air requirements of the engine become virtually nil, thereby creating a large amount of drag on the affected side, leading to possible uncontrollable yaw and loss of control. However, Concorde's very sophisticated digital electronic control intake design effectively dealt with such eventualities.

The pilot's procedure in a surge situation was to retard all throttles to idle, switch to alternative throttle control, and initiate emergency forward fuel transfer. (This procedure was not required in the event of an engine flame-out.) The automatic systems would lower the intake ramps to their full extent, lower than that required for supercruise; open the spill doors under the nacelles; and dump the air out and underneath. This diverted the incoming air from impacting on an ineffective engine, reducing the drag, and actually increasing the lift on that side, preventing its wing from dropping, which helped to counteract the loss of thrust.

Fuel tank penetrations

When the British and French were carrying out the modifications to their fleet after the Gonesse tragedy, there were many tests and performance checks that had to be completed and passed before the aircraft could regain their Certificate of Airworthiness, and be allowed to carry paying passengers.

Among these modifications was the installation of Kevlar liners in some of the fuel tanks. This was to prevent foreign objects penetrating the wing surfaces to the degree that occurred during that horrible accident.

The final test for the British was to fly out halfway across the Atlantic, turn around, and come back. The reason for this test was to ensure that the Kevlar liners did not have any detrimental effect on fuel flow, the fuel pump pick-ups were functioning correctly, and the cooling effect of the fuel on the aircraft skin around those tanks was not compromised.

"... the pilots would select a maximum of 20° bank and make the turn at Mach 2."

At the halfway point, at Mach 2, 1,350mph, the pilots would select a maximum of 20° bank and make the turn at Mach 2. Quite unbelievable – a civil airliner, with 100 passengers, travelling at twice the speed of sound making such a manoeuvre safely, under complete control and within the limits of its flight envelope.

The shadow of 9/11

British Airways carried out their final test flight after the Gonesse tragedy, with Concorde G-BOAF carrying passengers (BA employees) halfway across the Atlantic, on September 11th 2001.

When the aircraft returned to Heathrow, the full extent of the effect not only on Concorde but on airline traffic in general was realised. The fear was that Concorde would be badly affected, especially as the majority of her customers flew between New York and London. However, the fleet returned to service on this route, with Mayor of New York Rudy Giuliani coming on board the first flight to land at JFK, to welcome the passengers and congratulate BA for resuming the flights.

Sadly, around 40 of the people who died in the Twin Towers atrocity were regular passengers on Concorde. Following the 15th anniversary of the tragedy, we pay tribute here to those victims and their families.

Concorde watch

Concorde G-BOAF

British production aircraft

Location: Filton, UK
Reporter: Paul Evans
Date: 28 September 2016

The new building to house Concorde is coming along nicely. A ground-breaking ceremony was held in May; Alpha Fox is scheduled to be brought over early in the New Year, and the Aero Collection exhibits are nearly all ready to be moved into the restored WWI hangars. The museum is due to open in summer 2017.

Further details about the new aviation heritage centre can be found on the Aerospace Bristol website: http://www.aerospacebristol.org

Taking shape
Left: a line of attendees mark out the final location of Alpha Fox at the ground-breaking ceremony for the museum. Right: the metal structure of the new Concorde hangar comes together on the Filton airfield.
Photos: Aerospace Bristol

Latest progress
The photograph below, taken on 3 October, shows the cladding going up on the walls of the Concorde hangar.
Photo courtesy of Aerospace Bristol

Tech log

Q Is it true that, apart from pumping fuel across the aircraft for trim purposes, the outer wing tanks would have fuel pumped into them at high Mach speeds to increase the wing stiffness, or was some degree of flex desirable?
Nigel Ferris

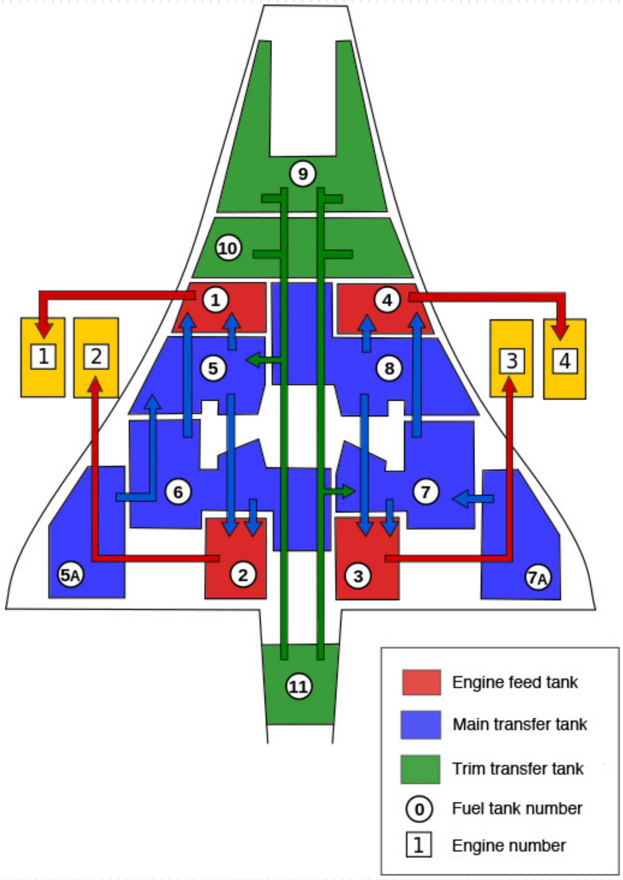
A **Ian Kirby replies:**
We used fuel from the fuel tanks outboard of the engines, tanks 5a and 7a, fairly soon. Due to the large surface area, high skin temperature and relatively low volume, a little over two tonnes of fuel in each, the fuel could have become unacceptably hot.

When fuel was being pumped from tanks 5a and 7a, aft of the centre of gravity, tanks 1 and 4, forward of the centre of gravity, were run to a low level of about 50%, known as aft trim, to keep the centre of gravity fairly constant.

It was not possible to pump fuel into tanks 5a and 7a in flight.

Stiffness of the Concorde wing was never a problem. It is a very stiff wing and moves very little even as it took up the lift as we rotated for take-off.

We seldom pumped fuel across the aircraft for trim as the Olympus engines burned fuel at a very even rate.



Concorde fuel tanks
Artwork: Steal88 / Wikimedia Commons