Concorde
Not Just a Commercial Failure - Also One of Engineering

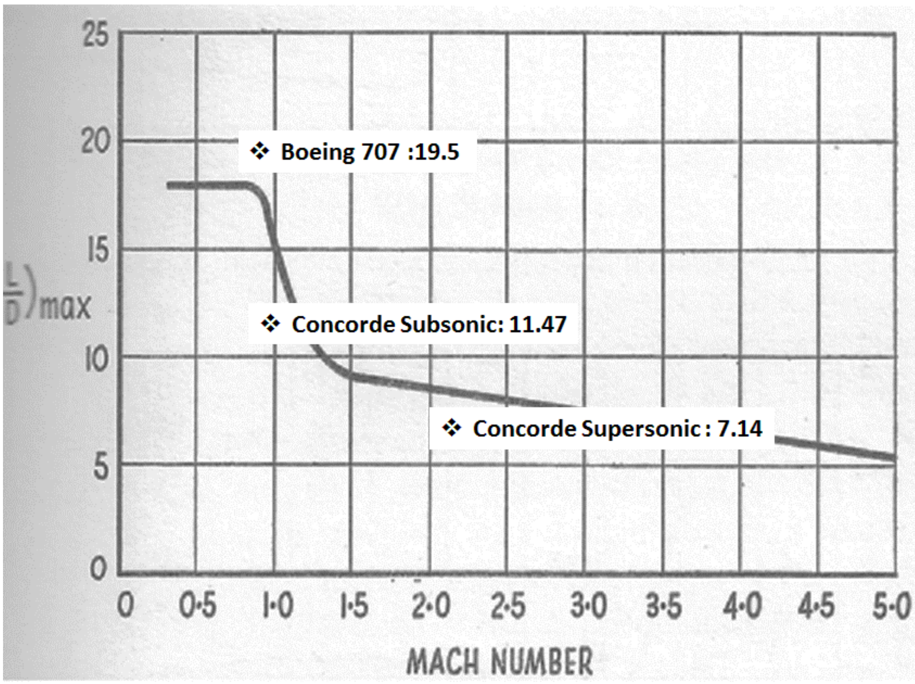
Introduction

No one could deny that Concorde is the most distinctive and beautiful aircraft to have flown. It certainly colours what we think of it. There was many a tear when the last three finally passed over London. There is, however, a grudging acknowledgement that Concorde was not a commercial success, a common view being that its sales potential was sabotaged by the Americans, infuriated by their own lack of success in building a supersonic transport.

But behind every prestige project that fails on a profit and loss account lurks an engineering "issue" which may not be so apparent. One thinks of the low efficiency of the engines of the Great Eastern. "Rusty bolts" breakaway corrosion which bedevilled the Advanced Gas Cooled Reactor. The unreliable tilting mechanism of the Advanced Passenger Train. What then of Concorde? Did it have an engineering Achilles heel? This short piece may give some surprises.

Doomed From the Start?

I would argue that Concorde was preordained to fail as the programme began without Britain having an engine of sufficient power. The shortage of thrust became ever more apparent as design and construction proceeded. It culminated in an aircraft which was so limited in range that London - New York was at the margin, and flights out of out of Washington meant a restriction on the number of passengers.



Variation of Lift to Drag Ratio with Mach No. Low values imply a need for high engine thrusts and high fuel consumption

Let's go back to basics. After Britain missed the bus in the market for swept wing jet transports of the Boeing 707 and DC8 type, the only option was true supersonic travel. Mach 2 and beyond. The critical issue, for a supersonic aircraft, compared to conventional jet transports, is that what is termed the "lift to drag ratio" halves. In a nutshell, even a well-designed Mach 2 airplane needs about twice as much thrust as those flying at 550 mph.

Twice the thrust implies twice the fuel consumption, in terms of pounds of fuel per hour. But a supersonic aircraft covers the ground more than twice as fast as a subsonic design. So the fuel load in each should be about the same. Hence that in itself should not be a problem. But there were other fundamental concerns. Travel at Mach 2 induces aerodynamic heating, which would have some effect on the strength of the airframe, which could only be compensated for by more sophisticated design and use of heavier gauge components. Finally, twice as much power requires bigger and heavier engines.

The graph shown above, based on a paper by Sutcliffe in 1961, shows the expected variation in L/D ratio (Lift to Drag) with Mach No for aircraft optimised to fly at the speed in question. The Boeing 707 is above the curve, one reason for its world beating performance. Later on, in this short account, it will be seen that Concorde, when it was finally flown, fell somewhat below the expected trend. In short it was a disappointment, aerodynamically. Furthermore when flying at Mach 0.93, the L/D ratio was well below that of the Boeing 707, implying that its range, at this speed was very poor.

Concorde: Beautiful shape, but an aerodynamic disappointment

Development of the Olympus Engine

Engines for supersonic flight have to be of the simple jet propulsion type, which by 1960 were becoming obsolete for commercial passenger transports. They were noisy, and, in terms of engine weight, a fairly lousy performance at take off. Fuel consumption is not so good. One can get round some of these shortcomings through innovative design. But a cash strapped

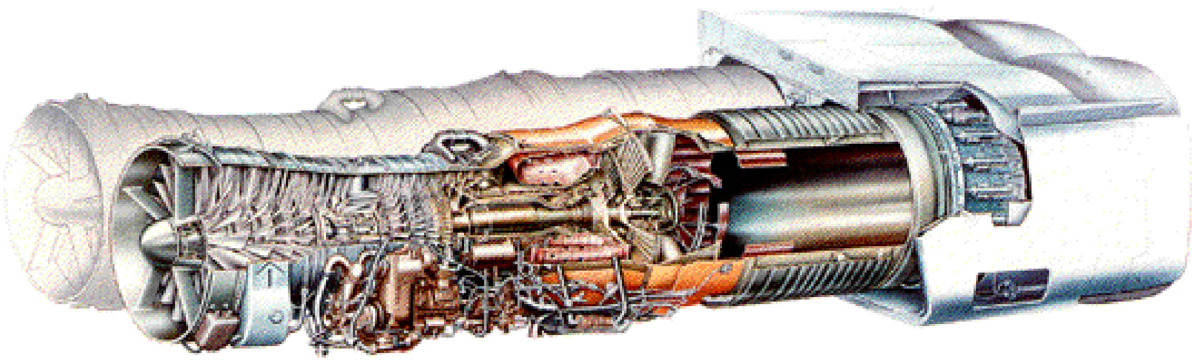
British Government was not going to underwrite a purpose built supersonic engine. In fact it had just cancelled one such, the De Havilland Gyron.

Fortunately, or unfortunately, if one wants to look at it this way, it was considered that the Bristol Olympus, although not ideal, but with some tweaking, might be made suitable In 1958 the engine was giving about 17000 lb thrust and could be expected to go to over 20000 lb with some modest development. But four such engines wouldn't be adequate for even a relatively small supersonic transport. Six would be needed. There was also the take off situation to consider. In some ways the critical issue. A delta winged aircraft of the Concorde type experiences a very large amount of "induced drag" at take off speeds. Engines have to be extra powerful to meet this need, especially in case of an engine failure. Six engines would have given some useful protection. Losing one on take off would only reduce power by 16%. In the real world, however, no airline would buy a six engined aircraft. Compared to four, maintenance costs would be 50% higher.

The Olympus 593

So the massive job of upgrading the Olympus had to begin, eventually resulting in the 593 version where something like 30000 lb of thrust was needed. Given that the Olympus started life with a thrust of around 10000 lb, this was quite a tall order. Changes would be needed to the compressor to increase the flow of air. Sophisticated cooling of the turbine blades would be essential; not an easy job when the cooling air was at 650°C.

Even so, the use of four highly developed Olympus engines was only feasible by opting for a fairly small aircraft carrying around 100 passengers. As the design proceeded the projected aircraft weight moved upwards. The initial proposal was for an aircraft weighing in at 262000 lb. John Davis in his book, which came out just as the prototypes took to the air in 1969, had been logging the increases, which by then had reached 367000 lb. But the actual production aircraft hit the scales at 412000 lb. One reason was the effort to extend the range. Another was an increase in certified passenger seating to 128, although in practice the number of seats provided was just 100.



The Olympus 593 plus reheat: A great engine, but giving insufficient thrust for the Concorde

What did this mean in terms of engine thrust? It is easy to show that given a constant take off distance, the thrust needed is proportional to the square of the aircraft weight. In the opinion of some people the line was crossed when reheat had to be specified for the take off requirement, with all the airport noise problems that implies. I live 25 miles from Heathrow and on some occasions I could hear Concorde when it took off in an easterly direction. The use of reheat had been on the cards since 1966, needing to get Concorde through the sound barrier and towards operating altitude. But it appears from the book by Davis, and from a 1972 RAeS paper, that it was the "supersonic reheat" installation which came to the rescue of the thrust requirements for take off. It also seems that reheat was viewed as a stop gap, until with more effort, time and money, more power could be obtained from the basic Olympus. Davis seems to think that the production engines would be providing 35080 lb without reheat, in fact all that was achieved was 31350 lb. So a lot of reheat was going to be needed.

The Downside of Reheat

Full reheat enabled the commercial versions of Concorde to get off the ground, both literally and metaphorically, but it had its drawbacks. The reheat installation added 7600 lb of weight to Concorde. In addition the pressure drop caused by the reheat burner nozzles, seem to have led to 1% drop in cruise thrust, and probably a similar increase in fuel consumption. But the main issue with reheat was the dramatic effect in fuel consumption. This more than doubled from 92500 to 198400 lb/hr, when it was in action. Despite reheat only being needed during take off and the in the supersonic acceleration phase, a conservative estimate is that it required an extra 15000 lb of fuel to be burned.

The Impact of the Increases in Weight

A heavier Concorde put more stress on the structure. It had to fly slightly slower, Mach 2.02 rather than 2.2 to reduce airframe temperatures. Slower meant a reduction in cruise altitude, down from 60 thousand to 55 thousand feet. The extra five minutes on a transatlantic crossing, was negligible as far as the passengers were concerned, but the extra time, plus the reduced flight altitude would have needed around an extra 5000 lb of fuel.

The End Game

Concorde was now carrying over half its weight in fuel, but the only destination it could easily reach from Paris or London was New York. Even Washington, just a little further on, meant that passenger numbers were restricted. To Paris from Washington, just 90 were permitted, to London a derisible 70. There was no prospect for flights from Frankfurt or Amsterdam to the USA, or even from places like Chicago to Europe. One by one the potential buyers dropped out. Concorde did not have the range.

There will be those who will think that this is not the most object of assessments. They should look at what was being proposed for a Mk 2 version of Concorde. There would be a partially redesign of the Olympus, which would have increased engine size, but the increased thrust would have eliminated the need for reheat on take off. There was also some hope that reheat during acceleration through the sound barrier could have been dispensed with. These changes plus some aerodynamic modifications, would have just about put Germany and Italy within range of New York. To me, it still looks marginal, which is how I would sum up the whole of the Concorde project.

References

René J Francillon **“**Concorde**:** Success and Controversy” pp 30-39 Air International December 2003

PL Sutcliffe Chapter 1 on “The General Problem” pp1-17 in “ Supersonic Engineering” edited by JT Henshaw, Heinemann 1962

John Davis “The Concorde Affair” pp 132 and 141-42, Leslie Freewin 1969

J. Devrise and PH. Young “Olympus in Concorde” pp 683-694 Aeronautical Journal Dec 1972

Dept of Transportation Federal Aviation Administration “Type Certificate Data Sheet No A45EU c.1980