OPERATIONAL EXPERIENCE ON CONCORDE

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Abstract

Concorde is now in service with British Airways and Air France and we are now in a position to at least start to assess the real operational behaviour of the aircraft. This paper does not go into great depth on any one subject but outlines the aircraft's experience to date, both in the hands of the Manufacturers and the Airlines, describes how the aircraft is operated normally, picks out a few of the features which have been highlighted as a result of route flying and finally gives an operational assessment from the particular viewpoint of the flight deck crew.

Introduction

It is probably no exaggeration to say that Concorde is the most talked about aircraft ever. For fifteen years we have been predicting, discussing, disagreeing about what it will be like to operate a supersonic aircraft. Now the dream is a reality, Concorde is in service with British Airways and Air France and we are in a position to at least start to assess the real operational behaviour of the aircraft.

Concorde, from any viewpoint, is a big subject, and any one feature taken thoroughly is material for a paper on its own, if not a book. In this paper we have not tried to go into great depth on any one subject, we have tried to outline the aircraft's experience to date, both in the hands of the Manufacturers and the Airlines, describe how the aircraft is operated normally, pick out a few of the features which have been highlighted as a result of route flying, and finally, to give an operational assessment from the particular viewpoint of the flight deck crew.

Operational Experience to Date

The flight experience of Concorde started on 2nd March 1969 when Concorde 001 made its maiden flight from Toulouse. Since that date the aircraft has accumulated over 7,000 hours of flying, split between the certification programme and Airline service. Let us examine these two phases.

Certification Programme Experience

The hours flown on the various aircraft used in the Certification Programme are shown in Table 1. You can see that the number of hours flown is substantially more than would be required to certify a subsonic aircraft of apparently equivalent complexity. Because of the new and untried features of the aircraft, the total number of hours before certification was bound to be high, but since this paper is about operational experience it is important to realise the significant amount of quasi-Airline experience which was gained in the Certification Programme. The experience was gained in two separate phases, firstly as part of the normal Certification Programme, and secondly as a special exercise called Endurance Flying which was required by the Certifying Authorities before Type Certification.

TABLE 1 : DEVELOPMENT AIRCRAFT STATISTICS

AIRCRAFT	NUMBER OF FLIGHTS	BLOCK HOURS	SUPERSONIC HOURS
001	397	812-07	254-54
002	439	836-51	173-26
101	270	630-38	208-14
102	314	658-46	281-17
201	423	917-32	340-42
202	408	892.29	257.27
203	167	484-59	308-00
204	177	522-04	253-44
		5755-26	2077-44

Normal Certification Flying Experience

In the course of any Certification programme the subject aircraft experiences operation through the airports and on the Airline routes of the world. This was particularly true on Concorde and because of two factors: (1) the aircraft was new and we wished to check for ourselves that there were no problems; and (2) the nature of the aircraft whereby its characteristics required checking in a wide variety of climatic conditions, led us to conduct far above the average percentage of overseas flying as part of the Certification Programme.

On these flights, the aircraft were operated by flight test crews and fare-paying passengers were not carried. Nevertheless, the aircraft was operated on Airline routes, integrating with other aircraft and using normal ATC procedures. It is difficult to quantify the amount of relevant experience which we gained, but we spent over 1,500 hours flying away from our bases in Toulouse and Fairford and, perhaps more significantly, Figure 1 shows the airports which we visited in Concorde during this period.

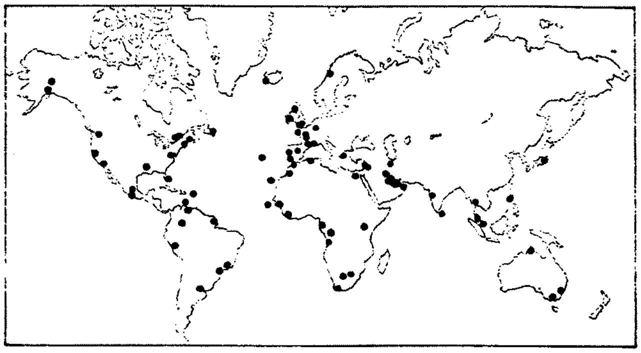


Fig 1 Airports visited during Certification flying

This whole period was by its nature 'special', but very significant in particularly the Manufacturers' view of how to operate Concorde.

Endurance Flying

The term 'endurance flying' in this respect is misleading since it was not intended to do sufficient hours to properly assess the reliability of the aircraft. Rather, it was intended to conduct typical Airline operations to determine whether the type had any unforeseen problems of an airworthiness nature. The Authorities required 1,000 hours on a typical aircraft in typical conditions but, in fact, on the actual production aircraft used viz. Concordes 203 and 204, only 755 hours were flown, the remainder being done on development aircraft.

The airworthiness requirements for endurance flying were briefly as follows:-

- Typical route operations covering long supersonic routes in high and low upper air temperatures
- Supersonic operations over land corridors
- Mixed subsonic/supersonic operation
- Long subsonic operation
- Operations into airfields giving:
  - Congested terminal conditions
  - Limited facilities
  - Hot, wet and dusty conditions
- Operations by:
  - Airline crews
  - Airworthiness Authorities' crew
- Maintenance by:
  - Airline personnel

Much, indeed virtually all, of these conditions had been covered in the normal certification programme but great emphasis was placed on conducting operations in a normal Airline manner, and in the use of Airline flight and ground crew. To this end, BAC made agreements with British Airways and Aerospatiale with Air France to conduct the endurance flying jointly.

Because of the scale of the exercise it was divided into two roughly equal halves, the Aerospatiale aircraft 203 covering broadly the North and South Atlantic, and the BAC aircraft 204 covering the North Atlantic and the Middle and Far East. Figures 2 and 3 show the routes operated by each aircraft and Table 2 shows the number of hours flown sub-divided into the various crew complements which were used. Invited passengers were carried on all these flights and full cabin service was provided.

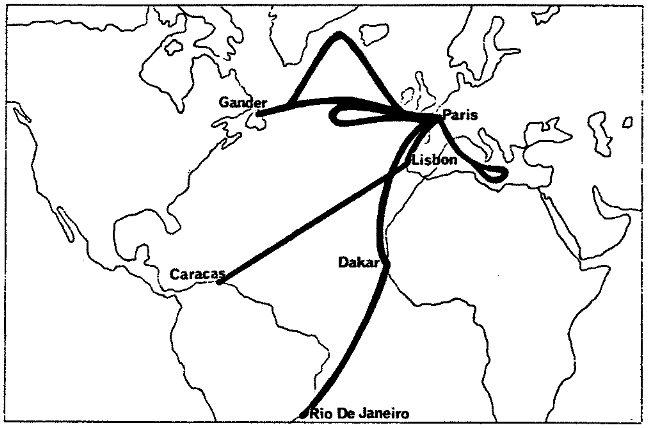


Fig 2 Concorde 203 Endurance Flying Routes

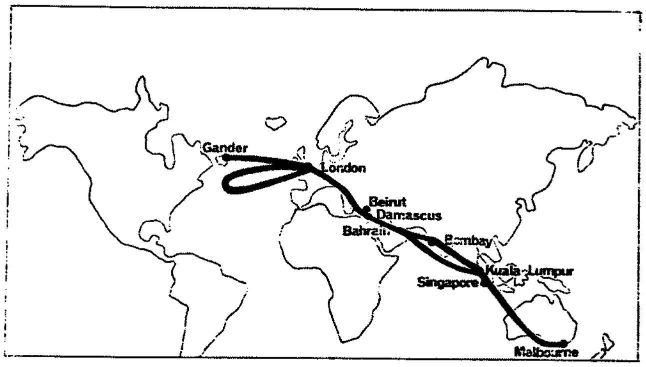


Fig 3 Concorde 204 Endurance Flying Routes

TABLE 2: ENDURANCE FLYING HOURS

	Flight Crew Complement			
Aircraft	Mixed Manufacturers and Officials	Mixed Manufacturers and Airline Crew	Airline Crew	Total
203	47-08 Hrs.	151-21 Hrs.	176-33 Hrs.	375.02 Hrs.
204	34-03 Hrs.	163.08 Hrs.	183-32 Hrs.	380-43 Hrs.
				755-45 Hrs.

Airline Service

To date the Airline experience of the aircraft comes from British Airways operating to Bahrain and Washington, and Air France operating to Rio de Janeiro, Caracas and Washington, plus several special charter flights. Table 3 shows the number of flights and hours on scheduled routes so far. The operations have been conducted in a perfectly straightforward manner, characterised perhaps only by a slow build up in the rate of flying which is to be expected because of the nature of the aircraft and the route problems which have been experienced. This paper is not directed towards the technical reliability of the aircraft, but it is interesting to see on Figure 4 that the dispatch reliability of the aircraft so far is satisfactory.

TABLE 3 : AIRLINE OPERATIONS TO DATE

Routes	British Airways		Air France			Total
	London to Bahrain	London to Washington	*Paris to Rio	≁Paris to Caracas	Paris to Washington	
Revenue departures including technical stops	99	46	237	70	71	523
Technical Delays	8	6	17	3	5	39
Cancellations	Nil	Nil	Nil	Nil	1	1
Substitutions	1	1	2	1	2	7
Air turn-backs	1	2	Nil	Nil	2	5
Flight hours (approx.)	385	175	690	165	260 •	1675

* Via Dakar
≁ Via Azores

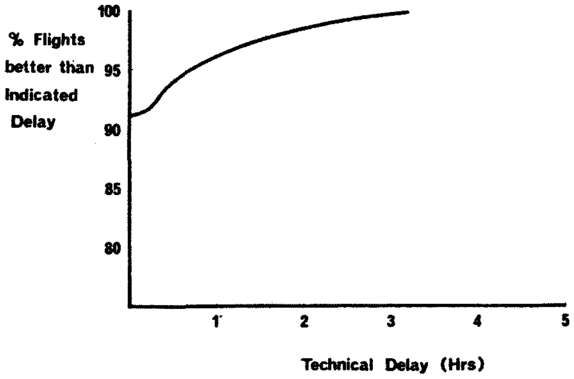


Fig 4 Despatch Reliability

Normal Operating Experience

So far we have given the statistics of our experience and later we will give a pilot's view of the aircraft, but how is the aircraft operated normally in order to give optimum performance combined with acceptable operational characteristics. To us, now, supersonic transport operations are normal but that was not always so and in this section we have tried to describe the main features of the operation of the aircraft, taking a flight phase by phase and highlighting some of the more interesting features and problems of the aircraft.

Take-Off

Aircraft Loading

It is probably well known that the position of the centre of gravity (c.g.) of the aircraft is controlled in flight by transferring fuel fore and aft. It may be less well known that the fuel transfer system is used on the ground to give us a fixed c.g. position (53.5%) to maximise the take-off performance by use of the flap effect of the elevons. The more conventional approach of a c.g. range (52.5 - 53.5%) for take-off is also available but Regulated Take-Off Weight (RTOW) is penalised by approximately 2% by having to use the performance appropriate to 52.5%.

Thrust Checking

It is a requirement on Concorde to check that Flight Manual thrust is available on each engine before 100 knots is exceeded. This is done by a take-off monitor system which illuminates a green 'GO' light for each engine when both the jet pipe pressure and fuel flow exceed pre-set values for the ambient conditions and provided the nozzle configuration is correct for take-off. Normal take-off may only be continued beyond 100 knots if all 'GO' lights are on - for the normal heavy weight take-off the lights are on by 80 knots. Reheat is normally used for take-off although operations without reheat are permitted for very light weights. A dispatch deviation with one reheat failed is acceptable with RTOW penalty.

Take-Off Characteristics

The nomenclature we use for take-off is conventional, i.e. V_1 is the maximum speed for aborting the take-off, VR is rotation speed, V_2 is take-off safety speed with one engine failed and θ_2 is the aircraft attitude which will give V_2 at the screen in the engine failure case. In practice having checked thrust at 100 knots and continued beyond V_1 in a four-engine take-off the pilot rotates the aircraft at VR at a rate which will give lift-off approximately 3 knots below V_2 and to obtain θ_2 at the screen. In the four-engine case θ_2 is then held and the aircraft allowed to accelerate until 240 knots when the aircraft attitude is increased to hold 250 knots for noise abatement procedures. In the engine failed case θ_2 is again the target attitude for the screen but when V_2 is obtained it is held for the three-engine climb-out.

In principle this differs from subsonic aircraft only in degree and really only in two areas, (1) to optimise the performance of the aircraft in the field length available within the W.A.T. limit, tyre speed limit and brake energy limit we use a variable V_2 at constant weight which leads to a wide range of VR (20 knots), and (2) the acceleration to 250 knots for noise abatement is to a higher speed than subsonic practice but we require to bring the aircraft well down the power curve to minimise noise.

In the event of an engine failure on take-off the aircraft is also equipped with an auto-contingency system which automatically increases thrust on the remaining three engines by 5%.

Subsonic Climb/Cruise

Concorde is unusual in that its best climb speed is at Vmo (Maximum normal C.A.S.) and its best cruise speed subsonic is at a Mach Number of M = 0.95. There are no virtues in climbing or cruising any slower if best range is required. It is in fact important not to diverge far from Vmo climb or M = 0.95 cruise since the fuel penalties can be significant. This leads to normal practice being to climb to subsonic cruise level (or go supersonic in unrestricted conditions) at Vmo as soon as A.T.C. conditions will allow. It is also important to establish with A.T.C. that the subsonic cruise altitudes appropriate to heavy weight, i.e. approximately 27,000 ft., are available.

Transonic Acceleration and Supersonic Climb

Either from cruise at M = 0.95, or in the unrestricted case, acceleration through M = 1.0 is commenced by lighting reheat at climb power and climbing the aircraft at Vmo. Reheat is selected off at M = 1.7 and the c.g. is progressively adjusted aft from 55% approximately at M = 0.95 to approximately 59% in cruise conditions.

Cruise

Best range cruise is obtained on Concorde in a cruise climb at M = 2.0 at maximum continuous power with the c.g. set to give $\frac{1}{2}^{\circ}$ down elevon. In the high upper atmosphere temperatures of the North Atlantic cruise would start at 50,000 ft. and reach 57,000 ft. by the end of cruise. In the tropics where it is much colder cruise would start at 53,000 ft. and finish at the maximum authorised altitude of 60,000 ft. where the engines might have to be throttled to maintain M = 2.00. Step cruises can be done on Concorde as on any other aircraft with insignificant penalties provided the cruise altitude is within 3,000 - 4,000 ft. of the aircraft ceiling. A typical flight profile for a London - Washington flight is shown on Figure 5.

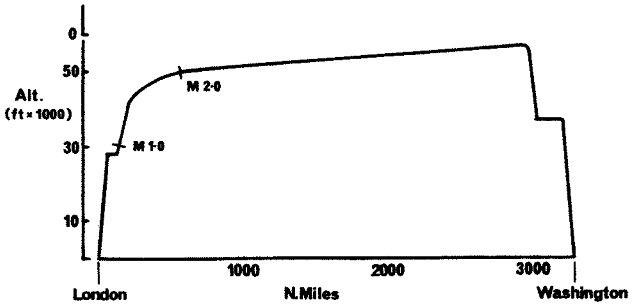


Fig 5 Typical Flight Profile

It is interesting to note that in tropical conditions it frequently takes less than 10 minutes to M = 1.0 and approximately 20 minutes to M = 2.00. In the North Atlantic it can take 50 - 60 minutes to reach M = 2.00 but block speeds are little different since the higher T.A.S. in the hot conditions compensates for the reduced time at M = 2.00. This point is illustrated in Figure 6.

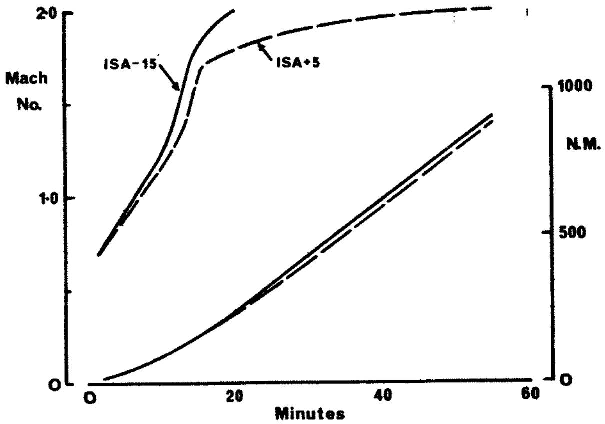


Fig 6 Effect of Temperature on Block Performance

It is also interesting, and of major significance in operating the aircraft, that at the start of cruise 20% of the total fuel burn-off will have been consumed while only 9% of the total distance will have been covered. This tends to be a sobering fact when observed for the first time, but it is a feature which rapidly becomes 'normal'. It must also be remembered of course that our payload is normally only 10% of the total fuel load and optimum performance throughout the flight must be the constant aim.

Finally in the event of an engine shutdown in cruise the aircraft is unable to maintain $M = 2.00$ and the procedure is to drift down and continue flight to destination or alternate at $M = 0.95$. In the case of loss of pressurisation the aircraft must descend to a safe cabin altitude as on subsonic aircraft.

Descent

Normal descent is by partially throttling back at $M = 2.00$, decelerating at constant attitude to 325 knots, descent at constant 325 knots, with the engines fully throttled at $M = 1.6$. Airbrakes are not fitted and are not needed. During the descent the c.g. is progressively brought forward to typically 55% for subsonic cruise or hold and 52 - 53.5% for approach and landing. Thrust reverse can be used subsonic to increase the rate of descent if necessary. For emergency descents the aircraft can be descended at up to Vmo with the throttles at idle from $M = 2.00$.

Approach and Landing

Ideally for minimum fuel consumption Concorde, like any other aircraft, should have an uninterrupted descent, approach and landing. This is particularly significant on Concorde since the aircraft is well round the power curve at low speeds and if there has to be a hold we much prefer it at as high an altitude and speed as possible. We look forward to the full implementation of linear holding with relish. However, the aircraft is fully capable of all the speeds and conditions required by international airports and in performance terms there is nothing remarkable about the approach and landing. Landing speeds are higher than conventional but the scheduled landing distance is easily met at major international airports.

Significant Items Arising from Route Experience

An important part of operational experience is the exposure of the aircraft to the normal airline routes of the world as opposed to the somewhat protected environment of flight testing. In this section we have attempted to highlight items which are of importance to supersonic operations and which we have encountered on airline routes either as part of the normal certification programme, endurance flying or airline service.

Sonic Boom

In both the Certification Programme and Airline service, we have experienced supersonic flight over the sea and over land. As part of the Certification Programme, supersonic flights over land and sea routes were conducted in Britain and France, and overpressure measurements were made in various areas. As part of the endurance flying programme, measurements were taken during overland flights in the Middle East and Australia.

The general conclusion is that the measurements tie up well with the estimates and the average overpressure prediction of 2.2 lb/sq.ft. was correct although there is somewhat more scatter than expected.

In supersonic operations over the sea the procedures used are simple. With a complete knowledge of the winds and temperatures en-route it is possible to compute the exact point for acceleration and deceleration through $M = 1.0$ for boom avoidance on land. In practice it is preferable to use fixed points on particular routes which have been pre-computed to give boom protection under the most adverse ambient conditions. Lateral boom avoidance is met by tracking at least 20 nautical miles from the coast.

Supersonic operations over land corridors are now relatively straightforward. Here accuracy in acceleration/deceleration points is exchanged for accuracy in track holding to keep the sonic boom within the prescribed area. Overland operations are currently only being flown by the British Airways aircraft to Bahrain and the track holding requirements are such that the automatic mixing and DME update facility by the three inertial navigation systems is an important feature.

To say that we have learnt nothing new from route experience on sonic boom would simply not be true, but on the whole our experience has confirmed our estimates.

Weather

Forecasting

Good weather forecasting had always been predicted as being an essential if efficient operations were to be realised. This has turned out to be as true in practice as in prediction. It is more reasonable for a captain to accept that bad destination weather will not arise in the next 4 hours rather than the next 8 hours but the quality of forecasting must be good. This is also true of en-route weather where good forecasts help minimise the payload/fuel sensitivity of the aircraft.

One is forced to generalise, but the overall situation is quite good. On any route there has been a learning process, but within the limits of the science, forecasting is not proving a problem for supersonic operations.

One aspect which did prove interesting in the earlier days was to see whether there is in fact much weather at cruise altitudes. In some parts of the world there very definitely is. It is fascinating to cruise past a cunim at 53,000 ft. and see its top above you. Fortunately at these cruise heights these clouds are fairly widely dispersed and present no serious avoidance problem. Another aspect of cruising at very high altitudes is that the predicted and actual winds are very low, often less than 20 knots. This has negligible effect at cruising speeds of 1,150 knots T.A.S. and leads to very consistent flight times over long supersonic routes. The effect of wind on the use of en-route reserves is minimal.

Turbulence

There is little to say on turbulence. We were not sure how much turbulence there would be at cruising altitudes or on climb and descent. There is turbulence, virtually on C.A.T. at cruise altitudes, but in all our experience to date there are no significant problems, and at cruise altitude nothing above moderate turbulence has been felt. To avoid performance penalties the design rough air speed supersonic of the Concorde is Vmo/Mmo and therefore it is not necessary for the aircraft to slow down if turbulence is encountered. In practice in prolonged turbulence a small reduction in speed is made to ensure the aircraft operates within Vmo.

Temperature/Wind Shear Effects at Cruise Altitude

Rapid temperature changes and wind shears were dominant parameters in the design of the aircraft. From theoretical studies and sampling programmes, temperature changes versus distance, and maximum wind shears were established and the aircraft structure and systems designed accordingly. For example, large temperature changes in a short distance are a dominant parameter in the design of the intake control system and largely determine the Mach No. margins which are necessary.

In both certification flying and endurance flying we have significantly increased the amount of information available from high altitudes. Here we did not find quite what we expected. We found that the maximum values of temperature change and wind shear which had been used in design were quite satisfactory and from our test results we were able to establish that we do in fact have adequate margins. However, we found that intermediate excursions in temperature and wind are much more frequent than we expected.

This had no effect on the basic design of the aircraft in the sense of structural or intake safety, but it did have repercussions on the autopilot. When we started endurance flying we had an autopilot cruise mode which controlled the aircraft to either Vmo, Mmo or Vmo, whichever is the more critical, through the pitch controls alone. In some atmospheric conditions, particularly in the Far East, we found that the autopilot could not always hold the aircraft within Mmo and a certain amount of pilot intervention was necessary. Before certification, some minor modifications and improvements in procedures were introduced and the aircraft is now operating with the same autopilot with no real difficulties. However, to generally improve the aircraft, we have developed a new autopilot mode for cruise control which utilises the autothrottle in certain conditions and will keep the aircraft within its limits even in very disturbed atmospheres without pilot intervention. Eventually, when this modification is introduced later this year, the aircraft will be re-certified to Mmo = 2.04 instead of its current Mmo = 2.02.

Radiation

In seven years' experience covering 7,000 hours flying we have never had to descend because of radiation warnings. All the development aircraft were fitted with extensive counting devices and no significant levels were recorded. The service aircraft is also fitted with a radiation monitoring system and to date no significant levels have been encountered. It does not mean that there is in fact no radiation problem, it just does not happen very often.

ATC/Communications

We have taken these together since they are in practice closely interlinked. It was predicted that ATC personnel would need to be aware of the different characteristics of a supersonic aircraft, but when they were there would be no real problems. It was predicted that good communications with supersonic aircraft would be important, particularly to allow passage from one region to another. All of this has been proved to be correct. On any route there are ATC difficulties to be ironed out and briefing of the ATC personnel is essential but after a few operations it settles down and there are no real problems. One of the design aims of the aircraft was that it should fit into normal ATC networks. It does, but an understanding of the aircraft by the ATC people helps them to fit it in while helping us to maximise the payload. Of course all of this co-operation is vitally dependent on good communications, and on Concorde we have seen the need to have better HF communications in some areas than is normal. Particularly in the Far East, climb out and deceleration clearances are required outside VHF range and good HF is very important. Again, on all our routes, we have solved the current problems, but particularly in communications we should be striving for improvements.

Flying the Concorde

In the previous sections we have described how the aircraft as a piece of hardware behaves. In this section we will describe from a pilot's viewpoint what it is like to fly a Concorde.

General

When trying to sum up their opinions on the many features of flying a Concorde, pilots conclude that it flies like any other aircraft. This is true, it does in the general sense, but it is in fact a considerable compliment to the aircraft since it is quite different in many ways from all other existing commercial transport aircraft.

The differences which affect the piloting aspects most are:-

- the delta shape of the wing
- the type of flight controls and stability augmentation
- the normal flight regime at approach speeds being well round the back of the power curve
- the additional complexity to the propulsion caused by the air intake and its control system
- the different functions of a complex fuel system
- the concept of a variable flight envelope whose limits are a function of airspeed, Mach No., altitude, weight, temperature, centre of gravity and angle of attack
- the large variation of fuel consumption with flight conditions
- the production of a sonic boom

To review these characteristics as they would appear to a pilot transitioning from one of today's subsonic jets, we will follow the chronological sequence of a flight.

The Flight Deck

The flight deck is small and narrow as one would expect. However, by the use of specially designed seats there is sufficient space for a crew of four although the normal crew complement is three. Access to the crew stations is not easy but once in position, as in a sports car, access to the controls, visibility and comfort are good.

In flight with the visor up, the noise level in the flight deck is particularly low and very comfortable. This is not true when the visor is lowered but in practice after take-off the visor is up by 1,000 ft. and it is kept up until the aircraft has descended to approximately 2,500 ft. before landing.

Apart from the size of the flight deck, the second impression is the unusually high density of instruments on the flight deck. This is partly caused by the small size of the flight deck but it is mostly caused by the need to mount the extra instruments needed for systems peculiar to supersonic flight. In truth the first impression is that with the amount of instruments and controls available the crew work load must be too high for three crew. In practice for normal operations the work load is certainly no greater than other aircraft since virtually all systems are automatic or have a high degree of automation. In failure cases the situation is of course different but the systems have a high degree of redundancy and the crew work load is acceptable even although the list of failure drills is pretty impressive.

Taxying

Having done the pre-flight checks which are more numerous than subsonic aircraft the next step is to taxy the aircraft to the runway. Apart from breakaway, idling thrust is sufficient to taxy the aircraft and in practice pilots have no problems in steering the aircraft. There is an instinctive feeling that there must be problems when the nose-wheel is so far behind the pilot, and in fact we used to share these feelings, but from experience there are no problems. For example, 180° turns on a 150 ft. wide runway are routine.

Take-Off

As previously stated, reheat is used for all normal take-offs. At the end of the runway the brakes are released, reheat is pre-selected and the throttles opened fully. Reheat lights automatically and thrust is stabilised by 60 - 70 knots. Throttle adjustment for take-off thrust is not necessary. The engine parameters are automatically controlled in the engine control unit to their take-off thrust datums. This comparative simplification also applies in climb and cruise where by changing the datum setting of the control parameters the engines operate at their correct ratings with the throttles left fully open. This is particularly convenient on Concorde where the aircraft is operated essentially always at maximum allowable thrust. We have done sectors where the throttles were fully opened for take-off and only touched three hours later to throttle back for descent, only the ratings of the engine being changed in between.

Even at maximum weight the acceleration up to rotation is twice that of a conventional aircraft in similar conditions. After rotation the delta wing at relatively high incidence reduces the acceleration by half and produces an initial climb gradient similar to that of subsonic aircraft. However, ATC permitting, when the speed is allowed to build up the excess thrust produces high rates of climb or allows large reductions in engine power for noise abatement. Regulatory take-off distances on Concorde are very similar to those of large subsonic aircraft.

The noise abatement manoeuvre is one which attracts a lot of attention today. Fortunately from the pilot stand-point both the quality of engine response to thrust adjustments and the precision of the flight controls give the ability to comply without difficulty with the established procedures. Where turns are required for noise abatement procedures they can be initiated at 100 ft. after take-off and are generally regarded as being very easy to perform under all conditions.

In the event of an engine failure on take-off, a classic exercise for training, the aircraft is very docile, behaving in fact as if the engines were mounted on the fuselage.

Climb and Cruise

From the pilot's viewpoint subsonic climb and cruise are conventional except that the rates of climb can be higher and the Mach No. for best range is significantly higher at M = 0.95.

Supersonic climb and cruise are normally flown by the autopilot using a hold which keeps the aircraft at the most critical of Vmo, Mmo or Tmo with the throttles fully open. This provides an automatic cruise climb with negligible crew work load. In fact, of course, the aircraft can be flown manually in these conditions and it is in practice a pleasure to do so.

Fuel management on Concorde is of vital importance both in the aspect of cross-checking on fuel usage and monitoring the correct c.g. Fuel usage checks are quite conventional although they are somewhat more pointed in an aircraft where the flight plan will often show only 10% of the total fuel uplift being left at landing. This makes the cross checking of positions, winds and predictions a fairly popular hobby with the crew. One rule of thumb that has become apparent from experience is that extra fuel burnt at the beginning of a flight in unplanned subsonic operation is later nearly balanced out by better performance in climb and cruise.

The other aspect of fuel management that of c.g. control does merit a few words. The c.g. control system is used to obtain optimum performance combined with keeping the aircraft within acceptable limits from the flying qualities point of view. This has led to a quasi-triplicated system with comprehensive presentation of information to both pilots and engineer. The normal c.g./Mach No. envelope of the aircraft is shown in Figure 7 and apart from take-off and cruise where discrete c.g. settings give best performance it is the engineer's task to maintain the c.g. within the 'corridor'. This is done by fuel transfer at various stages of the flight and monitored by keeping the indicated c.g. within the Forward and Aft limits on the c.g. indicator (Figure 8). These bugs are scheduled by the allowable c.g. range for the particular weight, C.A.S. and Mach No. of the aircraft and a warning system is provided to draw attention to the c.g. going outside the bugs. A further cross check is provided by bugs on the Machmeter which again driven by the allowable envelope show the speed range available for the particular flight conditions. Figure 7 shows the achieved position of the c.g. relative to the authorised limits for a typical flight profile.

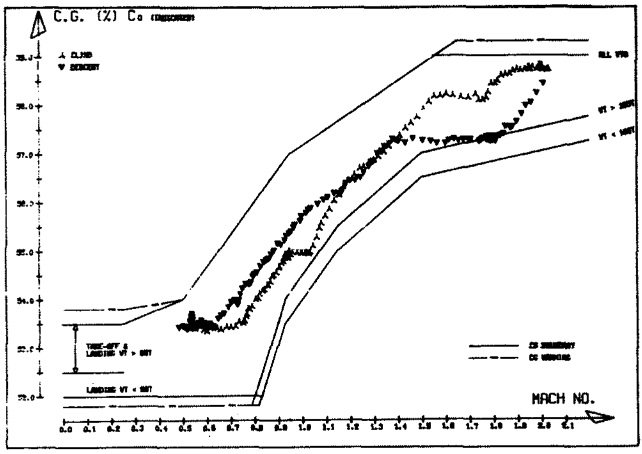
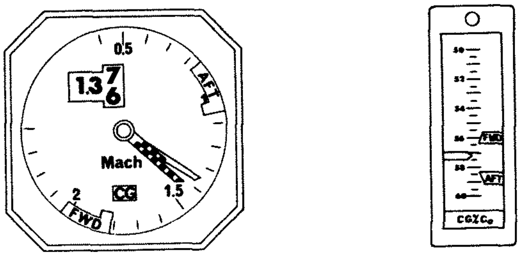


Fig 7 CG-Mach Envelope



Machmeter

CG Indicator

Fig 8

In the case of loss of all c.g. information, effective control is still possible through the use of elevon angle to trim which is presented to the pilot on a control surface position indicator.

Deceleration/Descent

The main thing to remember at this stage, when approaching a coast line is that it is closing in at the rate of 20 nautical miles per minute. However obvious that may be it is no time to receive an answer to stand-by from ATC or to delay the deceleration beyond the calculated point if a boom on the shore is to be avoided. Apart from this aspect the deceleration and descent are easy to control and at 41,000 ft. the aircraft can be brought back subsonic and integrated into normal traffic.

Approach and Landing

This phase is at the same time simpler than conventional aircraft in that there are no flaps or slots to be concerned with, no trim changes or alteration of handling qualities with operation of the landing gear or nose and visor and yet noticeably more demanding than on other aircraft since the aircraft is flown in a thrust instable state, well round the power curve.

The characteristics of this phase are:-

- large changes of aircraft attitude with speed from initial approach speed to threshold speed
- a pronounced nose high attitude on approach although the forward and downward visibility are good and the pilot's eye height relative to the main gear is the same as on other large subsonic aircraft
- very good, precise and immediate response of both engine and flight controls
- the absence of a need to increase attitude at the time to flare for the touchdown but a real need to pull on the column to maintain the approach attitude through the ground effect
- the need at approach speed to keep power on until 15 feet above the ground
- the ease of a go-around following a missed approach. At landing weight the performance available is impressive and if it is necessary to divert to another airfield it will only take three minutes to climb to 28,000 feet.

Training

Having described broadly how the aircraft is operated during a flight we thought it would be interesting to close this section with a few points about training.

As on other aircraft we attempt to do as much training as possible on the simulator, and in practice it is landing the aircraft which is by far the biggest portion of the work done on the actual aircraft. In particular ground effect is very important on landing and this is not adequately reproduced on the simulator.

Our training syllabus stands roughly as follows:-

One month of introduction to the philosophy of the systems of the aircraft in relation to the particular requirements of supersonic flight

One month of audio visual self teaching course including work on systems trainers

50 hours of cockpit training

50 hours of simulator training

Sufficient flying on the aircraft to give at least one supersonic flight and approximately 30 landings

The whole course covers a period of three months and leads to a type rating which is followed by conventional line training with the Airlines.

Summing-Up

In the paper we have tried to give you a broad view of the operational experience so far. Because of the size of the subject we have not gone into anything in great detail and of course we have selected the areas which we regard as interesting and there are probably many other areas which people would like to know about. Nevertheless, we hope we have given the impression that Concorde is an operable aircraft and supersonic operations are nowhere as difficult in practice as they are in theory. To us supersonic operations are now normal, we hope they will soon become so in the world air transport scene. We now stand at relatively the same point as the Boeing 707 and DC-8 did when they entered service and in the normal course of events we can look forward to supersonic operations being simpler, more flexible, more efficient and even perhaps cheaper.

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