BAHG Newsletter

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Special Issue – RAE Bedford's Contribution to Concorde

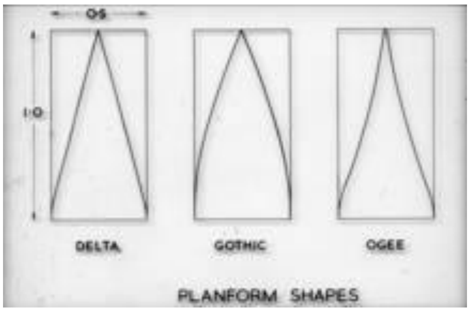
British prototype Concorde 002 G-BSST visiting RAE Bedford, Jan 1972, in acknowledgement of Bedford's contribution to the project (neg B3090)

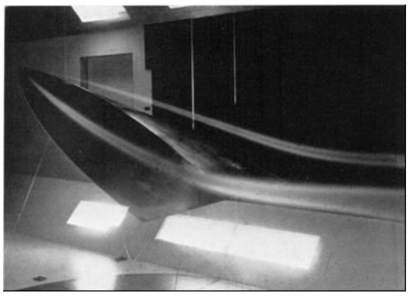
BAC 221 showing Concorde-like ogee wing shape (neg B2495C)

Commemoration On the occasion of the 50th anniversary of Concorde's first flight, this special issue, larger than usual, outlines RAE Bedford's contribution, through its research, to the technical success of the Concorde project. Much of the material here is based on an article also contributed to the Farnborough Air Sciences Trust newsletter.

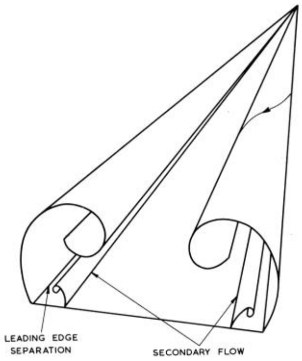
The Higgins Bedford BAHG is delighted to announce that we have been able to mount a display, now open, in Bedford's museum, The Higgins, to convey to a wider public what RAE Bedford did as part of the Concorde project. The Higgins in Bedford (www.thehigginsbedford.org.uk) is open Tuesday to Saturday 11AM to 5PM and Sunday 2-5PM. Admission is free. The exhibition will be on display at least to the end of 2019.

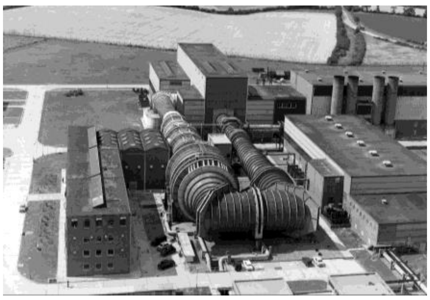
RAE Bedford and Concorde Fifty years ago, on 9 April 1969, Concorde 002, the British prototype, took to the air for the first time, at Filton. Some 22 minutes later it landed at Fairford, Gloucestershire, its base for future test flights. The French prototype, 001, had already flown, at Toulouse, on 2 March. These flights were the culmination of many years' research for the Concorde project that began in the 1950s. The Royal Aircraft Establishment overall laid the foundations for Concorde and conducted research in many areas. RAE Bedford made major contributions to this research (not always recognised), through its world-class wind tunnels and its flight research.





The Slender Wing The fundamental wing shape that enables an airliner to cruise efficiently at twice the speed of sound (Mach 2), known as a "slender wing", was first proposed by aerodynamicists led by Dr D Kuchemann at RAE Farnborough. Such a slender wing is defined as one that fits inside a box with a width to length ratio of 0.5 (slenderness = 0.25). A variety of wing shapes can fit inside such a box: a simple delta, a gothic wing or an ogee, as shown in the diagram above (*neg M296*).

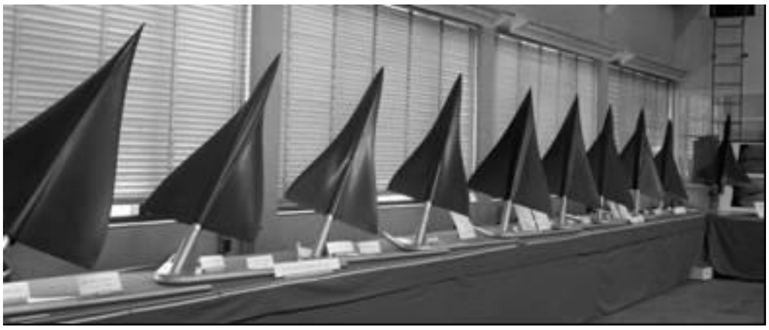




A crucial property of a slender wing is its sharp leading edge that was predicted to produce an air flow with a strong and stable vortex over the upper wing surface. Flow visualisation tests made in the 13x9 tunnel using smoke (picture left, *neg M359*) confirmed this occurred as predicted. A schematic of the vortex flow over a slender wing (*neg M360*) is also shown, based on the tunnel tests. Later, this flow was visualised with the HP115 aircraft, to confirm that it really worked in full scale flight.

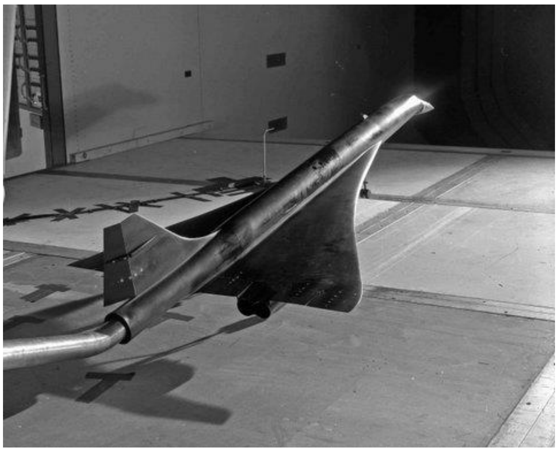
Wind Tunnels One of RAE Bedford's major tasks was to test the aerodynamic properties of the wing planforms derived from theoretical ideas and refine them to a practical wing shape, using Bedford's main wind tunnels, the 3x3 supersonic tunnel (the first tunnel at Bedford to start research, in 1954), the 8x8 supersonic tunnel (picture above left, *neg B10289-Bk1A*) and the 13x9 low-speed tunnel (picture right, *neg B3433-Bk1A*). (Note: 3x3, 8x8 and 13x9 refer to the dimensions of the tunnel working section, in feet.)

Several hundred wind tunnel models, manufactured in the workshops at RAE Bedford, were designed and tested, in thousands of hours of tunnel runs. (To operate the 8x8 supersonic tunnel required 60MW, more electricity than the whole of Bedford town.) The picture below (*neg B5557-Bk1A*) shows a small selection of models used in the 8x8 tunnel. After evaluating the results of these tests, the ogee wing shape was selected for detailed refinement at low speeds and supersonically.



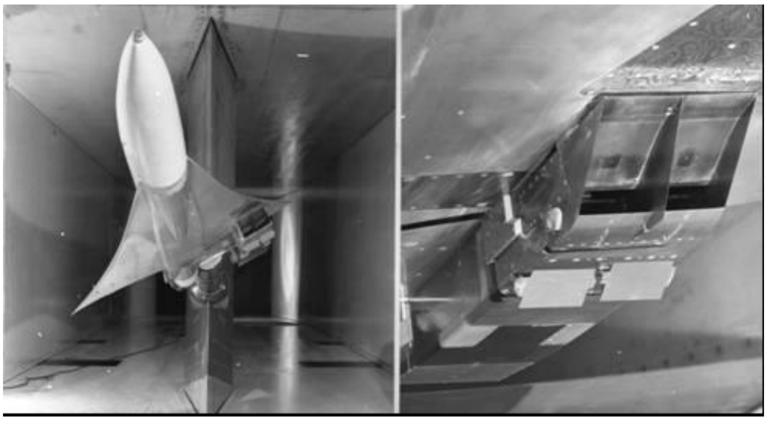
After the signing of the collaboration treaty between the British and French governments in 1962, the companies involved (at that time British Aircraft Corporation and Aerospatiale) produced a design which was then tested extensively in RAE Bedford's wind tunnels, at supersonic speeds (picture below, left) and also at low speeds (picture below, right). Measurement of ground effect in the 13x9 tunnel was of crucial importance to the assessment of landing performance.

Concorde model in 8x8 supersonic tunnel (*neg B9777-Bk1A*)



Ground effect tests on Concorde model in 13x9 tunnel (*neg C10687*)

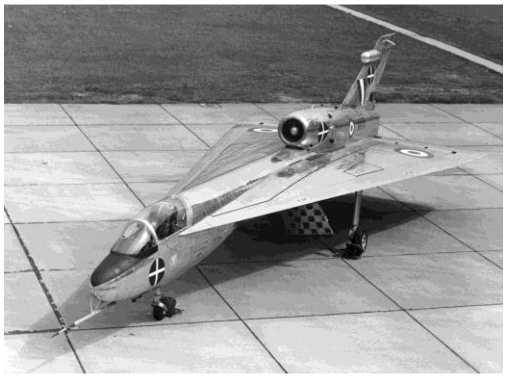
A critical aspect of Concorde's design, and a topic which consumed nearly as many tunnel hours as wing aerodynamics, concerned the engine air intakes and their contribution to the aircraft's supersonic cruising efficiency. A jet engine requires the air it receives to be at subsonic speeds (about 0.5 Mach). The task of the intake is to slow the incoming air from Mach 2 and to do so efficiently. Pressure measurement data from extensive tests in the 8x8 supersonic tunnel on a model of the twin-nacelle intakes (see picture, *neg TS4026*) were used to develop the complex schedule for the safe automatic control of the variable-geometry air intake throughout the flight envelope. Tests in the 3x3 tunnel established the detailed design of the air intake geometry to minimise interference to the air flow to one engine following a failure of the other in a twin-engine nacelle.



Flight Research The second major theme of RAE Bedford's contribution to Concorde was its flight research programme. This used specially designed research aircraft, free-flying drop models, and flight simulation. The properties of the atmosphere at Concorde cruising altitudes were also measured.

Prior to the Concorde programme, RAE Bedford had devoted many years of research to the challenges of supersonic flight, using such aircraft as the two Fairey FD2 delta wing aircraft (seen here at Bedford, *neg C5534*). The SST project really got under way with the publication of the report of the Supersonic Transport Aircraft Committee (STAC) in 1959. The STAC report recommended the development of a Mach 2 supersonic transport with supporting research. Two unique research aircraft were commissioned: the Handley Page HP115, and the British Aircraft Corporation BAC 221. Their roles were to explore the behaviour in full-scale flight of a slender wing, at low speeds (HP115) and supersonically (BAC 221).

The HP115, the first "slender wing" aircraft in the world, made its maiden flight at RAE Bedford's Thurleigh airfield on 17 August 1961, flown by Bedford test pilot Flt Lt Jack Henderson. The picture (*neg C6616*), shows the aircraft just before its first flight. Its primary purpose was to confirm that the slender wing concept and its associated vortex air flow, as proposed for Concorde, actually worked in real life. The aircraft was predicted to be sensitive to atmospheric turbulence and to have an unstable lateral oscillation mode at high angles of incidence. These crucial areas were explored and shown not to pose the problems anticipated. Indeed, the principal test pilot, Jack Henderson, described the HP115 as "a pilot's aircraft". It was flown to higher angles of incidence (24 deg) and lower flying speeds (60kt) than was ever expected to be possible.



The HP115 aircraft was a great success, making more than 1000 test flights, and was flown by more than 60 pilots. Among the non-RAE pilots to fly the aircraft were Brian Trubshaw, Concorde's chief UK test pilot, Godfrey Auty, later to make the first flight of the BAC 221, several French test pilots, and Astronaut Neil Armstrong.

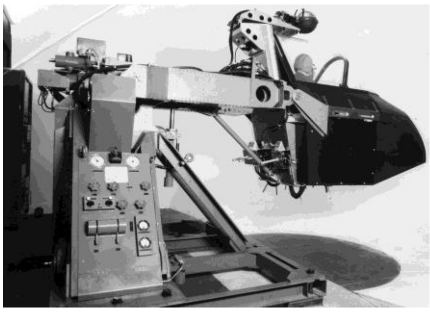
The HP115 contributed greatly to confidence in the flying behaviour of the Concorde slender wing design at low speeds. The HP115 made its last research flight in August 1973 and can be seen today in the Fleet Air Arm museum at Yeovilton, Somerset, alongside Concorde 002.

The BAC 221 was re-built from the Fairey FD2 WG774, with a new wing of "ogee" planform, much more like the ultimate shape used for Concorde – see BAC 221-FD2 comparison in picture right (*neg M313*). After its maiden flight at Filton, Bristol on 1 May 1964, the BAC 221 was delivered to Bedford on 20 May 1966 by RAE test pilot Flt Lt Clive Rustin (below left, after arrival, *neg B1925C*). In its 7 year research life at Bedford (1966-73), it made 288 flights. The BAC 221 also can be seen today at the Fleet Air Arm museum, Yeovilton.

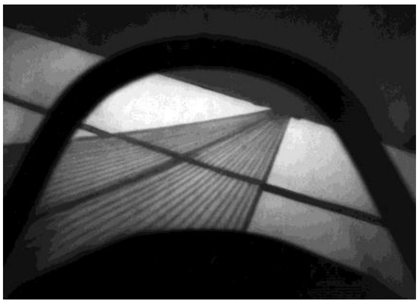
Measurements made on the BAC 221 in flight of lift and drag, and of various stability and control parameters, were compared with the results of tests in the 13x9 low speed wind tunnel, and in the 8x8 supersonic wind tunnel. Good agreement gave great confidence to Concorde's designers.

RAE Bedford's flight research involved more than just the slender wing research aircraft. Experiments using free-flying drop models enabled the stability and control behaviour of slender wing aircraft at high angles of incidence to be investigated safely using flying models released from a helicopter. Models, typically one quarter scale, of the HP115, BAC 221 and Concorde itself were tested (picture of Concorde drop model on ground, *neg CL139B*).

Flight Simulation By 1960, when the supersonic transport research programme began in earnest, the use of flight simulation technology in research was in its infancy, but starting to prove itself as a useful tool in aircraft handling qualities studies. At RAE Bedford, Aero Flight Division's first flight simulator had a single seat cockpit on a small motion system (picture), with a very basic visual scene using shadow projection techniques. A new technology using closed-circuit TV with a scale model terrain improved the capability, and enabled landing and take-off to be simulated with more realism.



Simulator single-seat cockpit (neg C6705)



Simulated shadow runway (neg B961)

Simulator cockpit showing runway using TV technology (neg B3029)

Early simulator-based studies, in 1962 and again in 1963, looked at SST handling qualities during landing. Several further simulations of landing and take-off behaviour of a Concorde-like aircraft followed, enabling potentially difficult or dangerous manoeuvres to be explored. Bedford's research aircraft, the HP115 and BAC 221, were also simulated, which enabled the validity of the simulator to be assessed. The safety-critical subject of minimum flying speeds was also explored through piloted simulation, which led to the recommendation, subsequently adopted, that "zero rate of climb" speed be used as a practical alternative to stall speed for slender-wing aircraft.

Atmospheric properties Concorde was designed to cruise at altitudes around 60000 ft, much higher than conventional jet airliners. Very little was known about the properties of the atmosphere at such altitudes. Flight tests were undertaken to make appropriate measurements of high altitude atmospheric turbulence and air temperature. RAE Canberra WH793 flew to the Far East in 1968, being based in Tengah alongside a USAF RB-57 (picture, *neg M318*).

Concorde Optimum Climb Profile An unusual task was to assess how accurately a pilot could fly the required Concorde climb profile to cruise altitude. An English Electric Lightning XN725 supersonic aircraft was used (picture, *neg B3345G*). The flights concluded that autopilot assistance was required to achieve the necessary consistency and accuracy.

Achievements RAE Bedford's research for Concorde, in the wind tunnels, in flight research and in flight simulation, contributed significantly to the project. Some specific achievements included…

- Refinement of the wing shape through wind tunnel tests to identify the best solution for flight at Mach 2 and yet also be suitable for take-off and landing
- Definition through wind tunnel tests of the engine intake geometry for efficient flight at supersonic cruise speeds
- Demonstration in full-scale flight of the effectiveness of the slender wing concept proposed for Concorde, both at low speeds (HP115, *neg B2636P*, 1969) and supersonically (BAC 221)
- Exploration through flight simulation of the flying behaviour of the Concorde in landing and take-off prior to first flight, to evaluate and ensure its safety, including identification of the "zero rate of climb" speed as a suitable alternative to the conventional stall speed
- Measurement of atmospheric properties at relevant cruise altitudes

All those who worked at RAE Bedford at this time can be proud of the establishment's major contribution to the technical success of Concorde, an iconic aircraft.