Back to basics

At Nasa's Langley Research Centre an extensive effort is under way to verify aerodynamics data produced by the very latest computer programs. **Chris Drewer** visited Norfolk, Virginia, to see the Nasa Basic Aerodynamics Research Tunnel.

With the advent of computational techniques which can accurately predict the flow over a complex shape such as a fighter aircraft, there is a growing need to make detailed experimental measurements in a flowfield to validate computed results.

The requirement for a comprehensive database of experimental results was recognized in the formative years of work on computational fluid dynamics (CFD). It was the subject of extensive discussions at a conference in 1980 at Stanford University in the USA, from which several recommendations resulted. The major one was that future experiments needed to be very well documented, with the inclusion of a clear statement about the experimental uncertainties. According to those present at the conference, this has critical implications for code validation. It is important when data from different windtunnel facilities is compared, and also when deciding whether to accept or reject data for validation. Another important recommendation was that experiments should be conducted in more than one facility, to enable problems produced by experimental techniques or facilities to be isolated. Factors such as the level of turbulence in a windtunnel can have marked effects on certain experiments.

In 1986 Nasa formed a committee to review computer code validation. This led to the formation, in

A Bart pitot pressure survey of the F-I8 shows vortex distribution in six cross-sectional planes

1987, of a "CFD validation workshop". During the review the committee arrived at a definition of validation "detailed surface and flowfield comparisons with experimental data to verify the code's ability to accurately model the critical physics of the flow". It was concluded that facilities were needed for the purpose of validation.

At Nasa's Langley Research Centre in Hampton, Virginia, the analytical methods branch (AMB) decided to develop a facility dedicated to the task of code validation. It would incorporate into its design as many of the recommendations of the 1980 Stanford conference as possible. In November 1984 a low-speed windtunnel was acquired by the AMB to perform basic aerodynamics research. It was chosen because it satisfied the AMB's requirements of size, flow velocity, and power consumption. Two research scientists, Bill Sellers and Scott Kjelgard, took up the challenge of setting up the facility to gather reliable data in sufficient detail to validate that produced using the latest computational fluid dynamics programs. The facility is called the Basic Aerodynamics Research Tunnel (Bart).

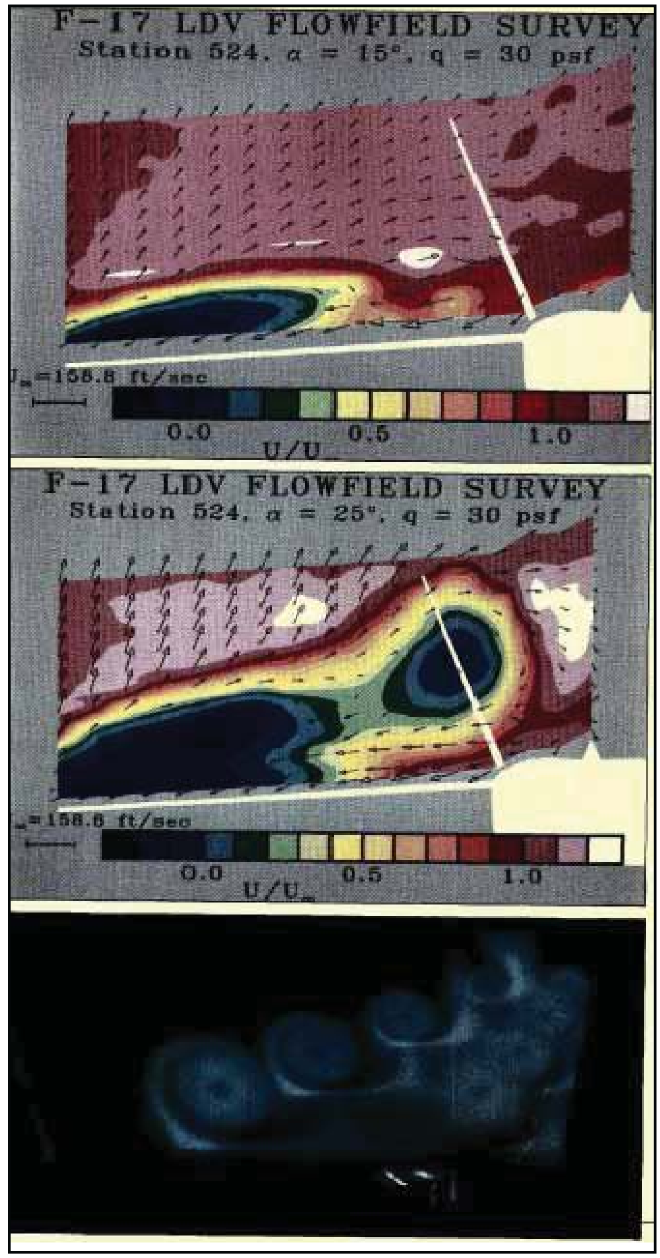
The Bart has evolved over the four-year period since its inception. In its current form it is an open-return windtunnel with a test section measuring 28in high by 40in wide by 10ft long. Air entering the test section passes through a honeycomb which improves the flow quality, and then through four antiturbulence screens. The honeycomb is 4in deep, and comprises cells 0-25in across.

Steady flow across the test section is achieved by accelerating it between the intake and the test section itself. In the Bart this is achieved with a contraction of 11:1 (the ratio between the intake area and the test section area). A 125 h.p. electric motor drives the fan which forces air through the tunnel, an electronic speed controller maintaining the fan speed to within 1 r.p.m. variation.

Flow in the tunnel can be kept at a maximum speed of 220ft/sec, corresponding to a Reynolds number of 1 • 4 million per foot. (The Reynold's number, which is nondimensional, must be based on a characteristic length measurement.)

The basic aerodynamics research tunnel is designed to provide a flow in the test section which is uniform across the section and has a low turbulence level.

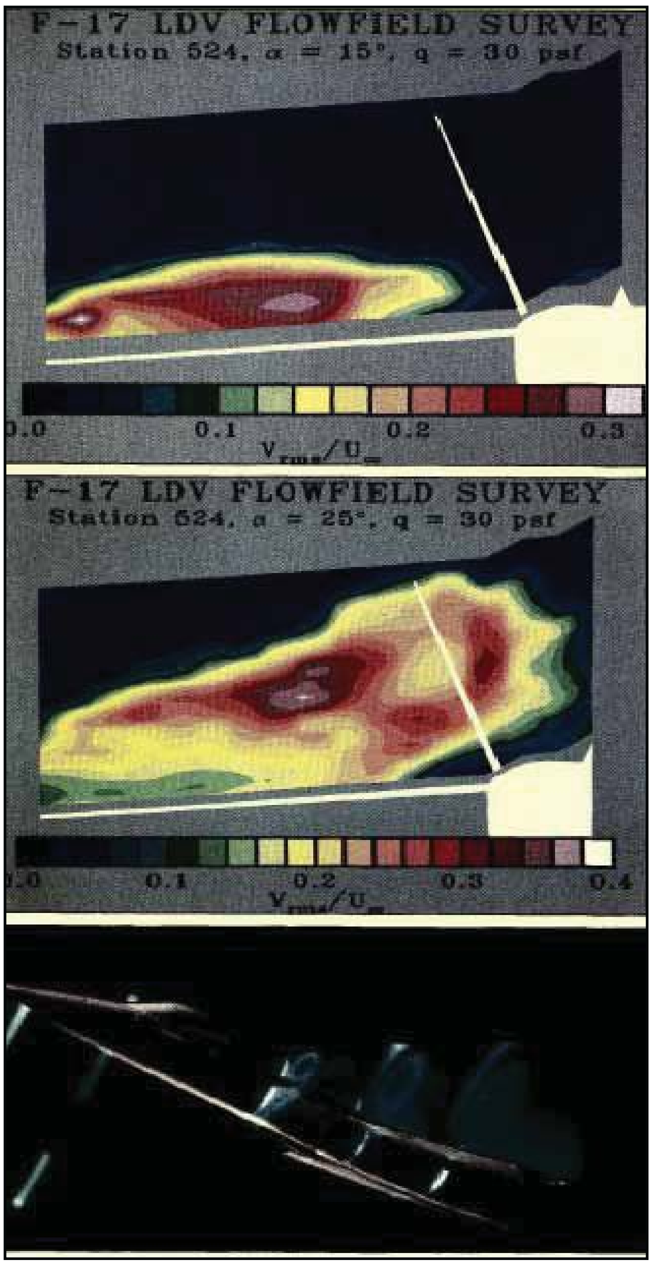
The Bart test section was designed to have excellent optical access. This was considered important



Comparative laser doppler velocimeter flowfields for an F-17 at 15° angle of attack (right and far right) and at 25° angle of attack (lower right and far right)

because optical systems could then be used both for qualitative work, such as flow visualisation, and for quantitative work, such as the latest laser techniques. The test-section walls have as much glass as structural considerations allow. The walls and the ceiling are made of Perspex, which is replaced by optical glass when laser techniques are being used.

Rapid data acquisition is a prime requirement of a facility dedicated to the validation of computer generated data. In the case of the Bart, this task is performed by two independent computer systems. A tunnel data acquisition and control (Tdac) computer handles data from the tunnel, and stores it on a desktop computer system, using 4 Megabytes of memory. The other system controls instrumentation which measures pressures and air speeds along all three components inside the test section.



Lasers make the vortices over a slender delta wing (far left) and an F-l 7 model (left) visible at several points along the line of flight

The conventional methods of measuring air speed in a windtunnel have been superseded in many new facilities, and the Bart is no exception. The five-hole probe has been used as an aerodynamics tool for many years. After lengthy calibration work, it measures flow angularity and velocity with a good degree of accuracy. Its major drawback, as with the pitot probe, is that it is intrusive. By its very nature, the probe changes the flowfield which it is designed to measure. A far more potent technique, the Laser Doppler Velocimeter (LDV), is used in the Bart.

The principle of the LDV is fairly simple. A laser beam is a very coherent light source, which means that it contains light of one specific wavelength. When two coherent light sources cross, interference fringes are created which are at known spacings. Particles are added to the air in the windtunnel, and when these cross the volume scanned by the laser beams they scatter the light from the lasers. The frequency of the scattered light is measured and, because the fringe spacings are known, the particle velocity can be easily determined.

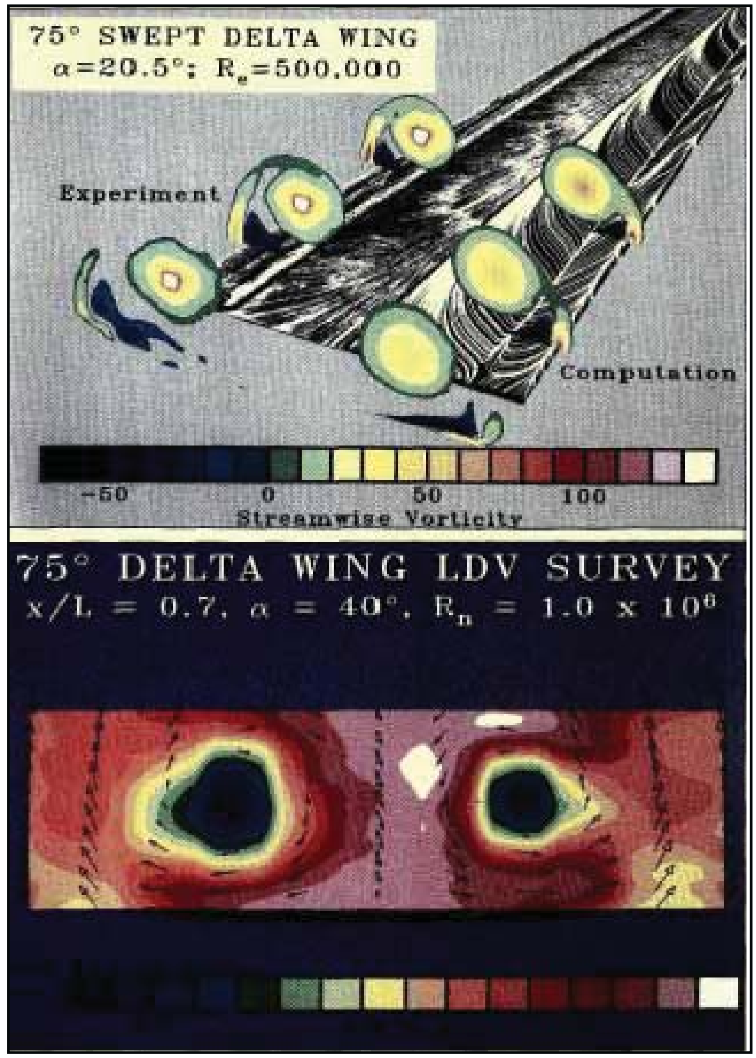
The Bart LDV is a three-component system using Argon ion lasers of three different wavelengths, one for the streamwise (u) direction, one for the lateral (v) direction, and one for the vertical plane (w). The u and w components are measured using four horizontal laser beams, while the v component uses two vertical beams. A spherical sample volume with a diameter of 150 microns is located at the intersection of the six beams.

The particles seeded into the flow are 0 • 8 micron-diameter latex microspheres. They are suspended in a mixture of water and alcohol, and are injected into the flow upstream of the honeycomb. During the early work on LDV instrumentation it was quickly learned that the size of particle has a significant effect on the accuracy of the technique. The particle must be the right size to follow closely the same path as an air molecule. This path is usually referred to as a streamline.

The LDV technique can map out a flowfield with great precision. Typically, several hundred velocity samples can be made at one point in the flowfield. Limiting factors are the data acquisition rate, and the rate at which particles can be seeded into the flow. The LDV system thus gives the experimental aerodynamicist the ability to obtain sufficient density of data to verify computed results.

When operating at high angles of attack, a modern figher aircraft such as the F-18 generates vortical flows which produce large increments of lift. Such vortices are typically shed by wing leading edges and slender fore-bodies, features of most modern aircraft. The high-angle-of-attack flight regime is becoming increasingly important, particularly in military aviation. Efforts to improve the manoeuvrability of fighters at high angle of attack are being made throughout the world. As well as having a beneficial effect, vortices can interact with an airframe to produce fatigue-related structural problems. They can also cause buffet problems when they impinge on critical parts of the aircraft. The development of theoretical methods of predicting aircraft buffet has largely been restricted by the lack of detailed data. Much of the data gathered in the past has been rather limited because there was no instrumentation to measure the velocity in the centre of a vortex. Quantitative data in the form of flow visualisation from water-tunnel tests has given an insight into vortex interactions. Work in the Bart in recent months, using LDV instrumentation, has vastly enlarged the database on vortices, and continuing tests will enhance this information further.

In the USA the F-15 and F-18 have encountered problems associated with vertical flows. For this reason a study was carried out in the Bart at Nasa Langley on the vortex flowfield over a twin-tailed fighter configuration. Velocity measurements were made using a laser doppler velocimeter, and a laser light sheet was used for surface-flow visualisation. The laser light sheet used a five-Watt argon-ion laser as its light source.



Top: Bart's experimental measurements on a 75° delta wing compared with Nasa Langley's computational study. Bottom: an LDV survey of the same wing model

The phenomenon of vortex bursting has been the subject of much research in the Bart. It can induce buffeting, which is clearly undesirable. When a vortex bursts, the velocity at the core drops and the core expands rapidly. After this expansion the flow changes significantly, and becomes highly turbulent.

The Bart study used a 3 per cent scale model of the Northrop YF-17. This aircraft was the prototype for the McDonnell-Douglas F-18 Hornet, and includes a swept wing (26-6°), twin fins, and a highly-swept leading-edge extension (Lex). The study concluded that, at 15° angle of attack, the vortices generated by the Lexs do not burst, and pass outboard of the base of the fins. However, at 25" angle of attack the Lex vortices burst in line with the fins. This was pinpointed as the cause of fatigue cracks in fins of F-18s. Flow visualisation using smoke confirmed this result. The region just ahead of the fins filled with smoke, indicating the breakdown of the vortex core.

A fundamental phenomenon of interest to all aerodynamicists concerns a highly-swept delta wing at high angles of attack, when it relies heavily on vortex flows to produce its lift. Anyone lucky enough to have flown on Concorde may have seen these vortices during takeoff or landing, when the low pressure at the core causes any moisture in the air to appear as a vapour.

At Nasa's Langley Centre a computational study of the flow over a delta wing was completed using a program called CFL3D. In parallel with this, an experimental investigation was conducted in the Bart. The model used was a 75in swept delta wing with a flat upper surface. Extensive flow visualization was performed both on the surface and in the off-body flow, and measurements were taken using a five-hole pressure probe and with the laser doppler velocimeter. The wing was tested at 20-5° angle of attack, and a comparison was made with computed results of the same configuration.

The comparison between predicted and measured results showed that the computation accurately predicted the flow over the wing. The position of the vortices and of the separation line in the experiment and in the computation compared well. The major differences occurred in the region of the core of the vortices shed from the wing leading edge. The experiment revealed higher levels of vorticity in the vortex core than did the computation. Errors as great as 35 per cent in this area were seen between experiment and computation. According to computational fluid dynamicists, this problem should be overcome by the use of a denser grid of points in the vortex centres.

At Nasa's Basic Aerodynamic Research Facility, close interaction between experimentalists and scientists working on computer codes, is in its infancy. The characteristics of the Bart meet the targets set by computational methods. It produces highly detailed flowfield data using state-of-the-art instrumentation, and satisfied the goals set by the Nasa committee on code validation.

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