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FACTORS AFFECTING THE DESIGN OF A NEW TRANSONIC WIND TUNNEL FOR AUSTRALIA

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Abstract

An outline of the considerations leading to the specifications of the proposed new transonic wind tunnel for the Defence Science and Technology Organisation is presented.

1 Introduction

Considerable progress has now been made with a project to acquire a new transonic wind tunnel, at a total estimated cost of $38M (May 1989 prices), to support the operation of Australian Defence Force equipment. The proposed new tunnel would produce a major increase in Australian self reliance in defence aerodynamics and would also provide an important capability for the Australian aircraft industry. Present indications are that the project will proceed, with construction likely to be completed by the late 1990's. A tunnel becoming operational at that time will have the potential to remain in use for at least the first half of the next century. In selecting the type of tunnel and its specifications it was therefore necessary to carefully consider the current and projected future requirements. In this paper the considerations which led to the definition of the proposed tunnel are outlined.

2 Requirements

During the project approval process the defence requirements initially identified by Robinson (1982) and Pollock (1982) and the other national requirements which were identified in 1982 (Workshop Proceedings 1983) were reviewed and refined on a number of occasions. The final brief statement of the main test requirements for the transonic tunnel, in priority order, is:

1. Investigations of safe carriage and release of stores. These investigations would involve:
    - Safe store separation
    - Installed drag reduction
    - Flutter clearance

    related to Australian military aircraft.
2. Tests to produce data for use in studies of the flight behaviour of Australian military combat aircraft under all flight conditions likely to arise in coming decades.
3. Tests to investigate problems arising from the operation of Australian military aircraft, including the investigation of the flow over wings, fuselage and tail, separated flows and the performance of high-lift systems.
4. Static and dynamic tests on components of Australian military aircraft.
5. Similar testing to 1-4 above of locally developed aircraft, weapons, targets and other flight vehicles.
6. Two-dimensional testing of aerofoils.
7. Research investigations of flow phenomena at high angles of attack, including separated flows, vortex behaviour and flow interactions with other bodies eg., vortex bursting/impingement on tail surfaces.

3 Alternative Methods of Meeting Requirements

Before proceeding with a project of the cost of a new transonic wind tunnel it is necessary to determine whether there are any alternative approaches to obtaining the required aerodynamic data at lower cost. Since the mid 1960's Computational Fluid Dynamics (CFD) has been rapidly growing in capability and is the obvious challenger to the dominance of wind tunnels as a source of aerodynamic data. The initial work on the proposal for the new tunnel started in the same year that Chapman (1979) presented an influential review and projection of CFD capability which suggested that CFD would challenge wind tunnels in the area of aircraft testing in the mid 1990's. An independent assessment by ARL suggested that this projection was optimistic, at least for Australia, and that transonic wind tunnels would remain an important aerodynamic data source for the foreseeable future. A review by the American National Research Council (NRC 1983) reached the same conclusion. Since the paper by Chapman appeared, the United States Government has committed of the order of $500M to the construction of new wind tunnels and the upgrading of existing tunnels, which is not consistent with a belief in the imminent supremacy of CFD.

It is still not possible to project with any certainty when, or if, CFD will have capabilities comparable with wind tunnels. There is clear evidence that the Reynolds averaged Navier-Stokes equations with currently available turbulence models can not produce data of wind tunnel quality on complex aircraft configurations. It is yet to be demonstrated that direct simulation of large eddies using the complete time-dependent Navier-Stokes equations in combination with a simple subgrid turbulence model will prove adequate.

Wind tunnels and CFD are currently developing complementary roles and it is highly probable that this situation will continue until well into the next century.

4 Derivation of Tunnel Specifications

The specifications for the proposed new tunnel were derived directly from the defence requirements outlined in Section 2 above. The considerations which led to the specification are outlined below.

4.1 Basic Simulation Requirements

The basic non-dimensional parameters which govern compressible flows over aircraft are Mach number, Reynolds number (Re) and γ (the ratio of specific heats). The flow over typical aircraft configurations in the transonic speed range (the range where significant regions of subsonic and supersonic flow co-exist) is highly Mach number dependent. Mach number variations of as little as 0.001 can produce significant changes in aerodynamic behaviour (see for example Pollock et al. 1975). Mach number must therefore be reproduced exactly at model scale and Re can not be increased by testing at increased Mach number as is commonly done at low speed. If air is used as a test gas γ will be appropriate since it is only slightly affected by temperature and pressure and it has a relatively weak effect on aerodynamic behaviour. However some otherwise attractive alternative test gases, like Freon, have unacceptable γ deviations.

Reynolds number has a quite strong influence on transonic flows through its influence on shock-wave boundary-layer interactions and major simulation failures can result from an inadequate test Re. One well known, and very expensive, example which occurred on the C-141 aircraft is presented by Loving (1966). Throughout the 1960's and 1970's there was great emphasis placed on the importance of achieving flight values of Re. The ultimate result of this effort was the completion of the American National Transonic Facility (NTF) at NASA Langley and the commitment to construct the European Transonic Wind-Tunnel (ETW). Both these tunnels employ cryogenic Nitrogen as the test gas and achieve full scale flight Re. This approach was shown by Goodyer et al. (1973) to provide an economical approach to achieving high Re. The very significant operational problems experienced by the NTF suggest that cryogenic tunnels are only appropriate when extreme Re values are required. While tunnels with very high Re capabilities were being constructed, effective means of simulating flight Re in moderate Re wind tunnels were being refined. A recent review of these developments is presented by Elsenaar (1987).

The basic concept for simulating high Re results is to artificially induce boundary layer transition on the model further aft than it would occur in flight with the aim of obtaining the full scale non-dimensional turbulent boundary layer thickness at the foot of the shock or at the trailing edge. Reynolds number effects are dominated by the boundary layer thickness at the trailing edge for sub-critical flow and at the foot of the shock in supercritical flow. To obtain the necessary freedom to manipulate the transition location it is necessary for the natural transition point on the model in the wind tunnel to be well aft. It has recently become apparent that an excessively high, although still sub-full-scale, test Re does not allow this effective extrapolation technique to be used. The "aft-fixation" technique works very well in the Re range (based on model chord) 2×10^6 to 5×10^6. There are indications that for very high quality tunnels with low flow disturbances, aft-fixation can be effectively used up to Re values approaching 1×10^7. Test Re values between 1×10^7 and flight should be avoided due to the possibility of significant Re effects which can not be determined by current techniques.

4.2 Speed Range

Since significant Mach number effects are observed at speeds down to Mach 0.15 under high lift conditions (Fiddes et al. 1984) it is desirable that the lowest speed of a transonic tunnel extends down to the maximum speed of available low-speed tunnels. Practical problems limit the minimum Mach number of conventional solid wall supersonic tunnels to approximately Mach 1.4 and it is desirable for a transonic tunnel to operate at least up to this speed. At low supersonic speeds shocks reflected from the tunnel walls impinge on the model. A reasonable Mach number range above this shock reflection interference range is desirable to establish clear supersonic trends. A maximum Mach number of 1.6 allows this to be achieved.

4.3 Test Section Size

The investigation of the carriage and release of stores is a major Australian requirement. These investigations normally require the aerodynamic forces on a store to be measured while it is in close proximity to the parent aircraft. there are practical limits to the minimum size of multi-component force balance that can be constructed (approximately 5mm diameter and 50mm long) and this sets a minimum scale for the store model which must accommodate the balance internally. This also directly sets the scale of the parent aircraft model. Current transonic wind tunnel practice is to limit the maximum model blockage ratio (model frontal area/test section area) to 1% to avoid excessive wall interference effects. When the above limitations are considered along with current store dimensions, a minimum test section cross section size of 1.2m × 1.2m is obtained. It should be noted that a square test section shape is considered most appropriate for military aircraft testing. There are clear indications that stores are becoming more complex and that in the near future variable geometry features such as deployable aerodynamic surfaces will be common. To achieve a model scale where these features can be represented, a tunnel test section of at least 1.5m × 1.5m is necessary. Tunnel cost varies at a rate approaching the cube of the test section linear dimensions, so the minimum practical test section size tends to also be the maximum economic size. It is interesting to note that the last three transonic tunnels constructed worldwide, of the general type planned for Australia, have 1.5m × 1.5m test sections. These tunnels are located in Yugoslavia, Sweden and South Africa.

A 1.5m test section also permits models with some remotely controlled on-board control surface actuators to be accommodated. This has a very significant effect on tunnel productivity since it reduces the requirement for time consuming access to the model in the tunnel during a test programme.

4.4 Type of Tunnel, Operating Pressure and Drive Power

Early in the planning of the new tunnel the decision between a continuous compressor-driven closed circuit facility and an intermittent blowdown facility had to be made. This decision was made difficult by the fact that practical tunnels of either type, with the same test section size, had closely similar capital cost, but offered different advantages and disadvantages. The major differences were that the continuous facility offered virtually unrestricted testing time, a wider test Re range and superior flow quality while the intermittent facility offered a considerably higher maximum test Re and a low-cost development path to extend the maximum Mach number to 4 or 5. Considering the advantages and disadvantages of each facility *with respect to the specific Australian test requirements*, Pollock (1984) concluded that the continuous tunnel was more appropriate. A continuous tunnel of acceptable capital and operating cost could produce a maximum chord Re approaching 5×10^6 while a blowdown tunnel inherently produced maximum Re values exceeding 1×10^7 due to considerations of economic storage pressure and exhaust pressure. Most of the extra Re capability of the blowdown tunnel is therefore in an area of doubtful value as discussed in Section 4 above.

The selection of maximum operating pressure and drive power proceeded directly from the required maximum Re. The maximum available Re at any Mach number is directly proportional to the maximum operating pressure. However at higher Mach numbers, limitations on tunnel drive power arising from capital and running cost considerations will limit the usable pressure and Re. High operating pressures also have a significant impact on tunnel capital cost due to increased pressure shell thickness requirements. Since cost was a major concern in the design of the tunnel the operating pressure was selected so that a Re of 5×10^6 could be obtained at a moderate Mach number below the very sensitive transonic range, and therefore at all higher Mach numbers, given sufficient drive power. The power was selected such that the Re values which fell within the desirable range 2 to 5×10^6 were available at all Mach numbers up to 1.0. At supersonic speeds Re is of considerably lesser importance and no specific requirements were imposed.

4.5 Flow Quality

The static uniformity of flow variables in the volume occupied by the model, and to a lesser extent the remainder of the test section, directly affects the accuracy of aerodynamic measurements. Unsteadiness in the flow also has major effects. The basic aerodynamics of the test aircraft may be changed by movement of the boundary layer transition points due to flow turbulence and noise. The rate of data production is also dependent on flow steadiness. The time taken to make any measurement to a given level of precision depends on the magnitude of the superimposed random noise. Measurements of buffet and flutter are particularly sensitive to disturbance frequencies which coincide with model structural modes.

A high flow quality, but one that was achievable within the current state of the wind tunnel art, was specified. Particular attention was paid to the spectral content of flow unsteadiness at frequencies which could excite model structural modes.

4.6 Equipment

To meet the test requirements, comprehensive arrangements for mounting an aircraft model were needed along with a six degree-of-freedom auxiliary model support to position a store model in the vicinity of the parent aircraft model. It was considered to be highly desirable that the main and auxiliary model supports could be operated simultaneously to facilitate the investigation of store release from manoeuvring aircraft.

5 Specifications

The following specifications for the proposed tunnel were derived from the considerations outlined above.

5.1 Performance

- Speed Range - Mach Number 0.3 to 1.6.
- Test Section Size - 1.5m wide x 1.5m high x 4.5m long.
- Stagnation Pressure - 20kPa to 300kPa.
- Maximum Reynolds Number - 4.5x10^6 at Mach 0.6 with a desired upgrade path to 4.5x10^6 at Mach 1.0. (Fig. 1)
- Maximum Operating Total Temperature - 50°C.

5.2 Flow Quality

Air flow quality within central 75% of width and height and 50% of length of test section (this covers the volume normally occupied by a model) shall meet the following criteria:

- Spatial Mach Number Uniformity - $\Delta M \le \pm 0.005$.
- Spatial Flow Angularity - $\Delta\alpha \le \pm 0.3^\circ$.
- Spatial Total Temperature - $\le \pm 2^\circ C$.
- Maximum Water Content - 2500 PPMV.
- Temporal Static Pressure Variation - RMS $C_p \le 0.5\%$.
- Spectral Content of Static Pressure Variation - $\sqrt{n.f(n)} \le 0.005$ for $0.1 \le n \le 4.0$
  where: n = frequency × tunnel width / velocity
  and: f(n) = contribution to (RMS unsteady pressure)^2/(kinetic pressure)^2 in frequency band Δf
  (see Mabey (1971) for further details).

5.3 Test Section

- All four walls longitudinally slotted. Top and bottom walls parallel and sidewall divergence adjustable.
- 600mm diameter viewing ports in both sidewalls with optional glass and slotted steel fillers.
- Transparent sections of slat for lighting and video camera access.

5.4 Main Model Support

- Half sector type to provide mounting for models supported on a rear sting. Capable of being completely withdrawn from flow when not required.
- Pitch attitude range -10° to +30° and roll attitude range ±180°.

5.5 Sidewall Model Support

- Rotating mounting plate flush and parallel with tunnel wall, mountable in one of the 600mm windows.
- Pitch attitude range ±30°.

5.6 Captive Trajectory System-(Auxiliary Model Support)

- Six degree of freedom support. Capable of being used with parent model mounted on main or sidewall supports and capable of being completely withdrawn from flow when not required.

- Movement ranges: Vertical ±500mm, Lateral ±400mm, Axial ±500mm, Roll ±180°, Pitch ±45°, Yaw ±45°.

6 Conclusion

The rationale behind the specifications of the proposed new transonic wind tunnel for the Defence Science and Technology Organisation has been briefly described. A detailed description of the facility is presented by Pollock (1989).

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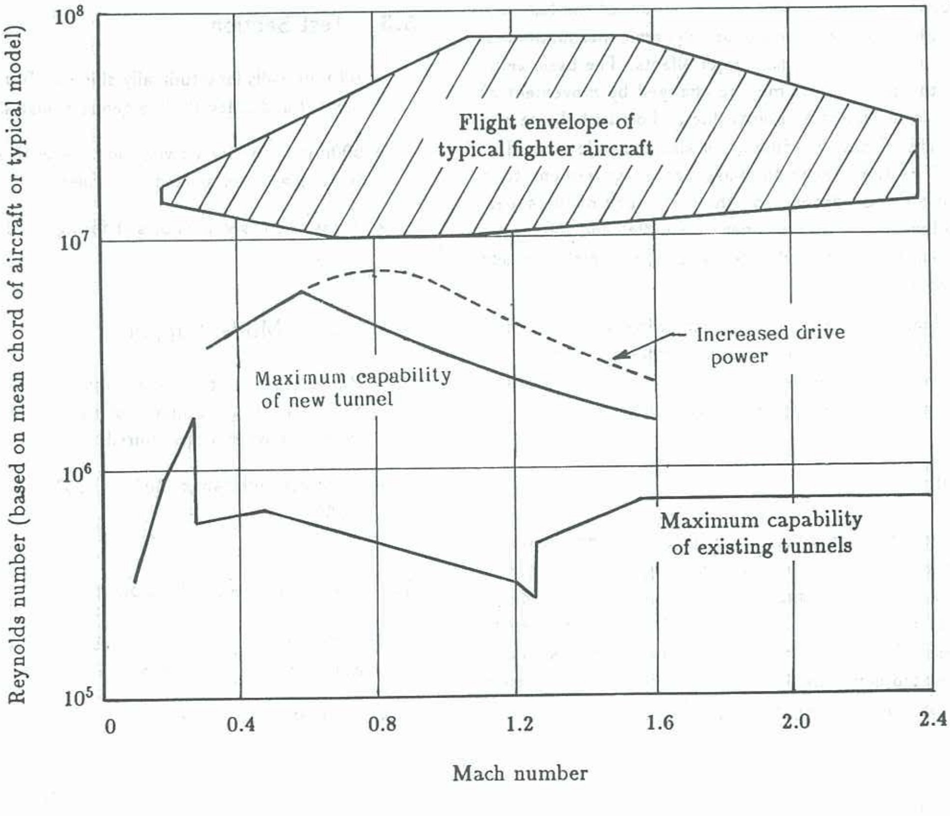

Figure 1. Operating envelope of tunnel.