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Research and Testing in the New Transonic Wind Tunnel at AMRL

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Abstract

Details of the new Transonic Wind Tunnel constructed recently at the Aeronautical and Maritime Research Laboratory (AMRL) are given in this paper. The tunnel was completed and handed over to AMRL in March 2000. Since that time, the tunnel has been used on a variety of projects to meet Defence needs. Details of some of the tests carried out to date are given, together with brief details of future research that is currently being planned.

Introduction

Major improvements in the transonic wind tunnel testing capability to meet future Australian Defence Force (ADF) needs for aerodynamic data at transonic speeds have been pursued for a considerable number of years. One of the main reasons for constructing this tunnel was to provide Australia with an independent capability for stores clearance tests for the ADF.

Initially, a new tunnel with a 1.5 m square test section, a Mach Number range of 0.3 to 1.6, operating at 3 atm. was considered, but this proved to be too costly at over A$50M in 1991. Alternatives were considered [1], which included upgrading an existing tunnel at AMRL. This tunnel was constructed in the late 1940s as a high-speed subsonic tunnel and converted to transonic operation in 1957. However, as the project progressed, it became clear that this would not be cost effective [2]. After considerable deliberation, it was decided to construct a new closed-circuit continuous flow tunnel with a test section around 0.8 m square.

In June 1995, a 'design and construct' contract was awarded to a Joint Venture consortium consisting of a specialist wind tunnel company 'Aero Systems Engineering Inc', in St Paul, USA, and a local construction and electrical company 'Kilpatrick Green Ltd' in Melbourne, Australia, to design and build this new tunnel.

The test section portion of the tunnel that was finally built is shown in Figure 1.

Figure 1. Test section of the new transonic wind tunnel

Details of the new transonic wind tunnel

A schematic drawing of the new transonic wind tunnel showing the main components, except for the plenum evacuation system plant, is given in Figure 2.

The new tunnel is a closed return-circuit continuous-flow tunnel,

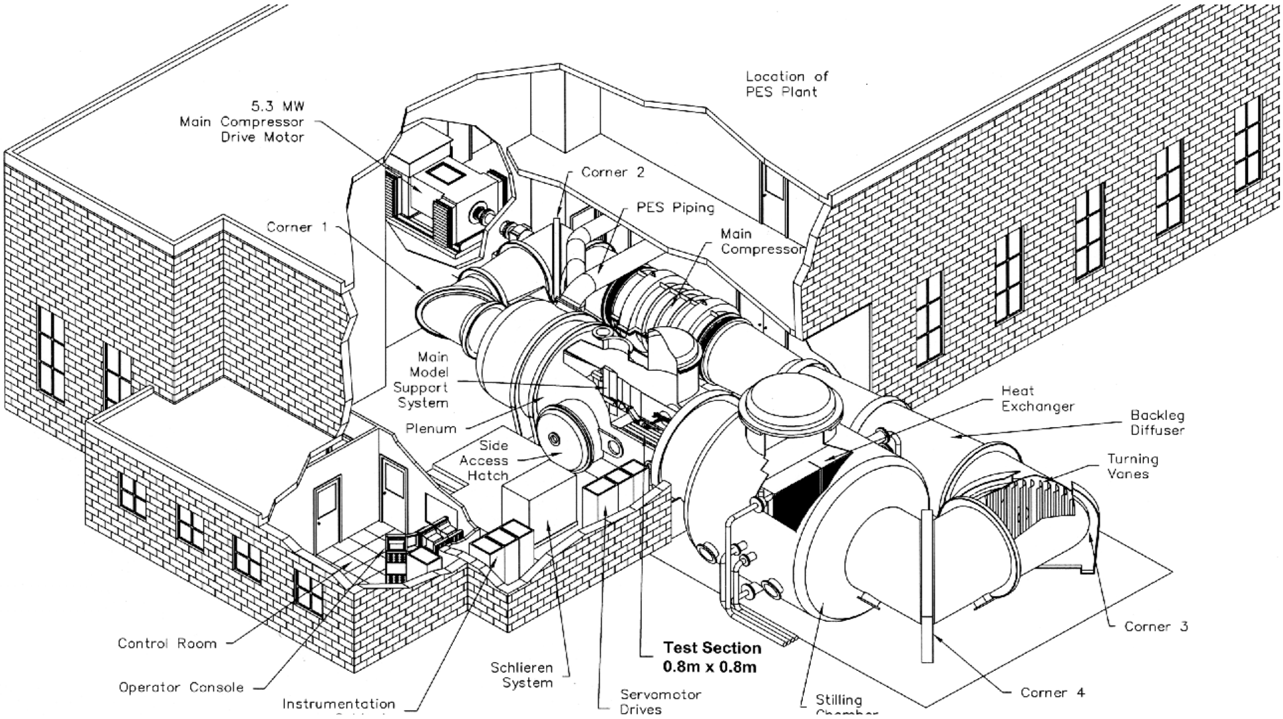

Figure 2. General view of the new transonic wind tunnel showing the layout of the main components

with a two-stage variable speed axial flow compressor powered by a 5.3 MW variable speed electric motor. It has a Mach number range from 0.3 to 1.2 in a continuously variable mode with a fixed nozzle, and Mach 1.4 with a different fixed nozzle. The tunnel can be pressurised to 200 kPa absolute or depressurised to 30 kPa absolute by a Plenum Evacuation System (PES), which has a single-stage centrifugal compressor driven by a 2.6 MW induction motor. A heat exchanger in the stilling chamber controls the air temperature in the test section to below 50ºC. Dry air within 1000 ppmv is provided in the circuit using a regenerative air drier. Coarse mesh and fine mesh screens, and a 16:1 contraction, are used to provide acceptable flow quality.

The test section is 0.806 meter wide, 0.806 meter high, and 2.7 meter long, with slotted (6 slots/wall) and solid interchangeable sidewalls, and slotted floor and ceiling. The PES provides controlled flow removal through the slotted test section walls. A 3.1 m diameter plenum surrounds the test section. Access to the model is provided by translating the model support downstream from the test section, or by removing the starboard sidewall.

There are three model supports, a vertical strut pitch-roll main model support, a sidewall model support (485 mm diameter turntable in the solid sidewall), and a 6 degree-of-freedom (6-DOF) store model support. All supports are operated remotely via a comprehensive control and data acquisition system that positions the model accurately during a test.

Construction

Following normal procedures for reasonably large construction projects, the major components of the tunnel were tested before they left the factory. The components were then assembled on site and the initial start-up and checkout of equipment commenced in January 1998. Commissioning of equipment proceeded gradually from February 1999 when the control system became operational. During this period a large number of difficulties were encountered, and final commissioning did not start until June 1999, some 9 months later than planned. Unfortunately, from June 1999, additional major problems were encountered which delayed the tunnel a further 8 months until acceptance and hand-over to AMRL on 15th March 2000.

Tunnel performance characteristics

There are 5 main performance parameters for the tunnel:

1. Mach number - pressure operating envelope.

The Mach number-pressure envelope for the tunnel with the slotted wall test section, and an AGARD Model-B calibration model with a wing span of 60% of the width of the test section under test at an angle of attack of 14º, is given in Figure 3.

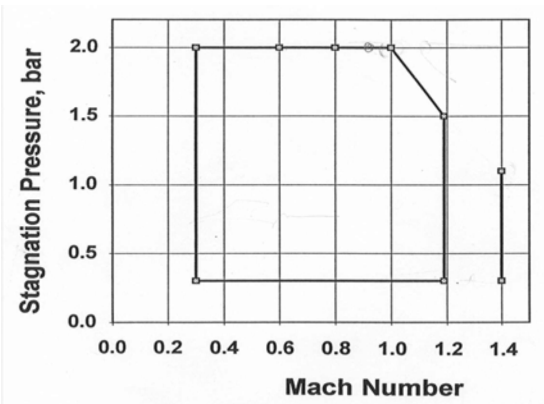

Figure 3. Mach number –pressure operating envelope

This envelope allows a wide range of models to be tested. The AGARD model is shown in the test section in Figure 1.

2. Mach number distribution along the test section centreline

The Mach number distribution achieved along the centerline of the test section met the following specification:

- Mach number uniformity defined in terms of standard deviation (σ_m) of the Mach number (M) along the tunnel centreline, 400 mm upstream and 400 mm downstream of the model pitch axis, at ~28 points for:
  - M = 0.5, 0.7, 0.9, σ_m was less than 0.002
  - M = 1.18 and 1.38, σ_m was less than 0.010

The Mach number distributions were taken using a 25 mm diameter centerline pipe with static pressure taps along its length. Data was taken with a PSI Model 8400 electronic pressure scanning system using +/- 5 psid ESP transducer modules. The transducers were scanned at 10 Hz. Ten data readings were taken over a 10 second period and averaged to provide one data point. An example of the Mach number distributions, which were within specification, is given in Figure 4 for the test condition of M=0.9 at a pressure of 129 kPa. Similar results were achieved at other Mach numbers and pressures.

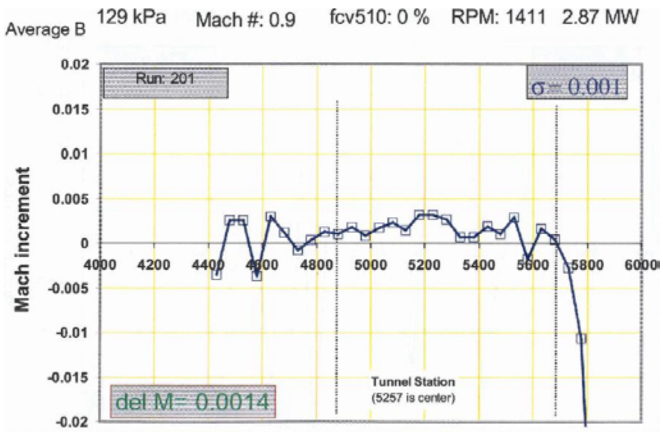

Figure 4. Mach number distribution along test section centreline at M=0.9 and a pressure of approx 1.3 atmosphere

3. Reynolds number

The test section size of 0.8 m x 0.8 m was a compromise between cost and model fidelity. It was the minimum needed to ensure store models could be made with sufficient fidelity to produce results with the accuracy needed. A Reynolds number (based on model chord) well in excess of $1.0x10^6$ over a Mach number ratio of at least 2 (M ~ 0.5 to 1.0) can be achieved. This is generally accepted as the minimum needed to simulate the flow about aircraft and predict performance with acceptable confidence [1]. For a model with an 80 mm wing chord, under test at M=1 and at 2 atm. pressure, the Reynolds number is $2.4x10^6$.

4. Model positioning ranges and accuracy.

The main model support could be pitched to ±15º to a position accuracy within ±0.02º and translated vertically to within ±0.1 mm. Similar position accuracy can be achieved with the six degrees of freedom store model support. The sidewall turntable model support has a pitch accuracy of ±0.05º. Appropriate motion ranges and speed ranges were provided for all supports.

5. Store model support operating envelope.

A store on the store model support is shown under test in the flowfield of a half-model aircraft mounted on the sidewall turntable in Figure 5.

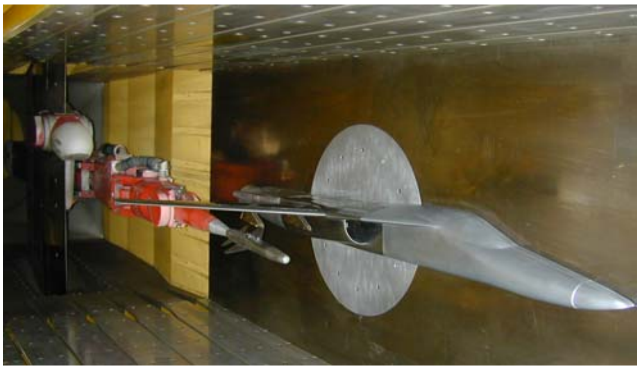

Figure 5. 6-DOF store model support with store (Number 1) under test in the flowfield of an aircraft half model

The store support operates over the central three-quarters of the test section width and height and over a length of ±250 mm. This envelope is achieved with a store model at up to 30º yaw and pitch for the Mach number pressure envelope in Figure 3.

Control and data acquisition systems

A new control and data acquisition system (DAS) controls all tunnel operations, test parameters, and model support movement, via touch screens and keyboards. Extensive plant monitoring and safety interlocks are included. The system allows the tunnel to be operated in a 'computer control' mode which steps through a test program automatically, or it can be operated manually. A DEC AlphaServer Model 1000 4/233 with a Digital Unix operating system and VXI modules forms the basis of the DAS. The tunnel is equipped with normal wind tunnel instrumentation including strain gauge balances, electronic pressure scanners and model position measuring systems. Extensive data reduction software provides reduced data in coefficient form in graphical or digital screen based or hard copy format in near real time.

AGARD Model Tests

The first tests were made on the AGARD Calibration Model-B, shown in Figure 1. The purpose of these tests was to check that the forces and moments measured using a strain gauge balance were comparable with those measured in other tunnels around the world. Examples of the drag and pitching moment coefficients obtained from the new tunnel, compared with the results from two other tunnels, are given in Figure 6 and 7. The run numbers correspond to tests in the AMRL tunnel, MSWT is the Medium Speed Wind Tunnel in South Africa, and PWT-4T is the 4 ft square propulsion wind tunnel at the Arnold Engineering Development Center, Arnold Air Force Base, Tennessee, USA. The results indicate that the tunnel produces force and moment data that compares very favourably with other high-class transonic tunnels in the world.

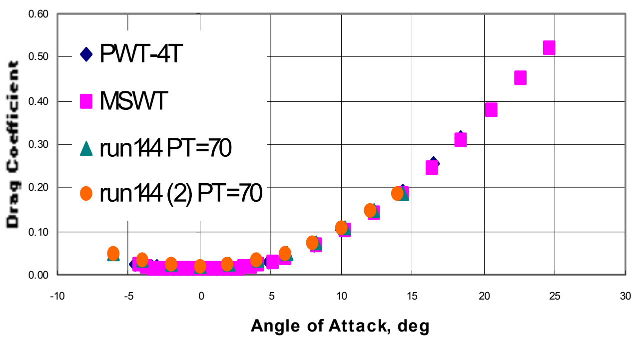

Figure 6. Drag Coefficients at M=0.8 for AGARD Model B

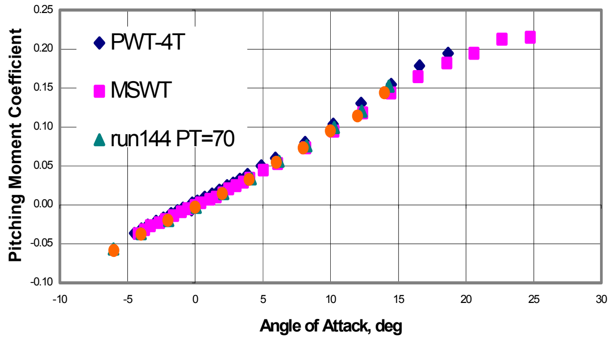

Figure 7. Pitching moment coefficients at M=0.8 for AGARD Model B

Stores release trajectory predictions

Tests to assess the safety of release of stores from Australian Defence Force (ADF) aircraft is one of the main types of test that will be carried out in the new tunnel. When external stores, which include bombs, racks, fuel tanks, and missiles, are released they usually encounter a highly non-uniform flow field produced by the parent aircraft, and this can cause inadvertent contact with the aircraft. Hazardous stores releases must be avoided as they can cause severe damage to equipment and injury to personnel.

The stores trajectory can be predicted using data from wind tunnel tests (or in some cases from CFD if the release is expected to be benign) and sophisticated computer programs. These codes solve the equations of motion at a large number of points as the store 'moves' through the flow field. There are two basic experimental methods to produce the data needed.

1. Captive trajectory system (CTS) method

In this method, the store is effectively 'flown' through its trajectory on a balance in the wind tunnel in near real time using a complex support system and computer codes.

2. Grid technique

Here, the loads on a store are again measured using a balance as the store is traversed over a range of pitch, yaw, and roll angles, at a set of 'grid' points in the region where the store could be expected to travel when it is released. These loads are then used in a computer program off-line to predict the trajectory.

The 'grid technique', is used in the new tunnel at AMRL for store trajectory predictions. The loads are then used in an in-house trajectory prediction code, known as 'DSTOres' (DSTO release evaluation suite). These codes also model other items such as racks and ejectors. The code output gives the store attitude and position in graphical (or numerical) format as a function of time for given release conditions, including Mach number, altitude, and incidence. Trajectories must be predicted for many combinations of these variables to determine the flight envelope under which the store can be released safely.

Stores tests in the new transonic wind tunnel

To date, the aerodynamic loads on models of two different stores traversed over a range of pitch, yaw, and roll angles, for a set of predetermined 'grid' points, and also in the freestream, have been determined from wind tunnel tests. To maximise accuracy, half models of the parent aircraft were used, as this increases Reynolds number and model fidelity compared with a full model. This data has been used in DSTOres to predict the trajectory of each store for release from under the wings of ADF aircraft.

Store number 1.

Freestream tests on a 15% scale model, which was approximately 680 mm long and 71 mm dia, and on a 6% model, were carried out on this store, over a range of Mach number, and pitch, yaw, and roll angles. The loads were also measured on the 6% store in the vicinity of the aircraft, as shown in Figure 5. The 15% scale store model under test in the freestream is shown in Figure 8.

Figure 8. Store number 1 under test in the freestream

Store number 2.
For Store No 2, freestream tests on a 25% scale model, which is 1160 mm long and 42 mm diameter, and on a 9% model, were made over a range of test conditions. The loads were also measured on the 9% store near the aircraft, as shown in Figure 9.

Figure 9. Store number 2 under test in the aircraft flowfield

The missile test results cannot be given at this stage. However, the DSTOres output showing the trajectory, in terms of position and attitude as a function of time, for a typical store is given in Figure 10. Similar outputs can be obtained for the stores above.

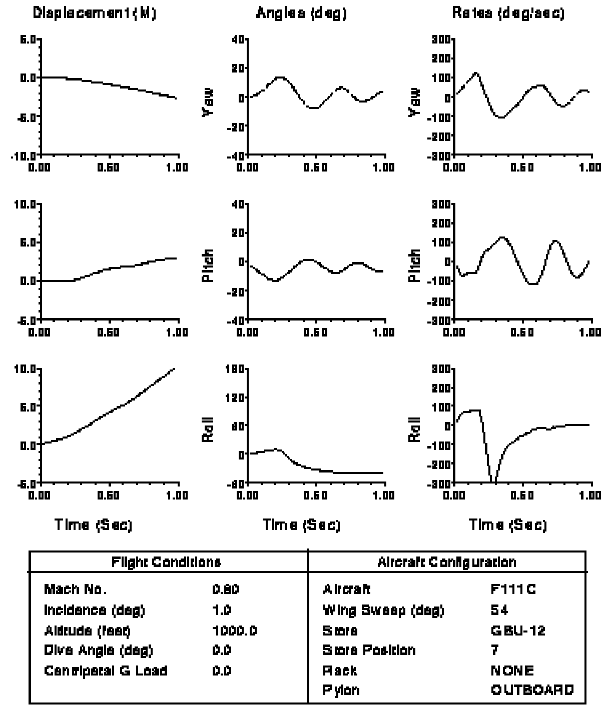

Figure 10. Typical DSTOres trajectory prediction output giving variation in the store position and attitude with time

Research investigations.

Nearly all the tests carried out have involved exploring some unexpected phenomena. Reynolds number effects and turbulence stimulation are two topics investigated, to a limited extent, so far.

Reynolds number effects and turbulence stimulation
The AGARD model tests were carried out without turbulence stimulation at a Reynolds number of 4.3×10^6**,** based on a wing chord at 50% span of 130 mm. More tests are planned to explore Reynolds number effects particularly with turbulence stimulation.

For Store No 1, freestream tests at M~1 on the 15% and 6% models, have shown minimal effects of Reynolds number from 0.5×10^6 to 1.1×10^6 for the 15% model (based on model diameter of 72 mm), and 0.15×10^6 to 0.30×10^6 for the 6% model. Tests were also made at lower Mach numbers ranging from M=0.7 to 0.9. At M=0.7, the Reynolds number was 0.11×10^6, which corresponds to a Reynolds number of 1.0×10^6 based on the 6% model length. The maximum test Reynolds number based on model length was 1.0×10^7 for the 15% model at M~1. Tests were done with and without a ballotine transition trip near the nose. The results were not significantly different.

Similarly, for Store No 2, freestream tests on a 25% scale model, which is approximately 1160 mm long and 42 mm diameter, and on a 9%, model indicate minimal effects of Reynolds number, although these tests are not complete yet.

Future research
In the near future, it is intended to carry out more definitive tests to determine the effects of Reynolds number and transition tripping devices on typical models that will be tested in the new tunnel. In addition, research on the effects of the slotted and solid sidewalls, shock reflections in the test section, and variations in flow quality, on the data produced from the tunnel, will be carried out as time permits.

Concluding remarks

The new transonic wind tunnel at AMRL is now complete and a number of test programs, mainly on the safe release of stores from ADF aircraft, have been carried out. While the tunnel was built to meet Defence requirements, it is potentially available to Universities and to Industry for research and development.

References

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[2] Link, Y, Y. & Matheson, N., Progress on Upgrading the Transonic Wind Tunnel at the Aeronautical and Maritime Research Laboratory, *International Aerospace Congress 97, Sydney, Australia*, 24-27 February, 1997, 431-438.