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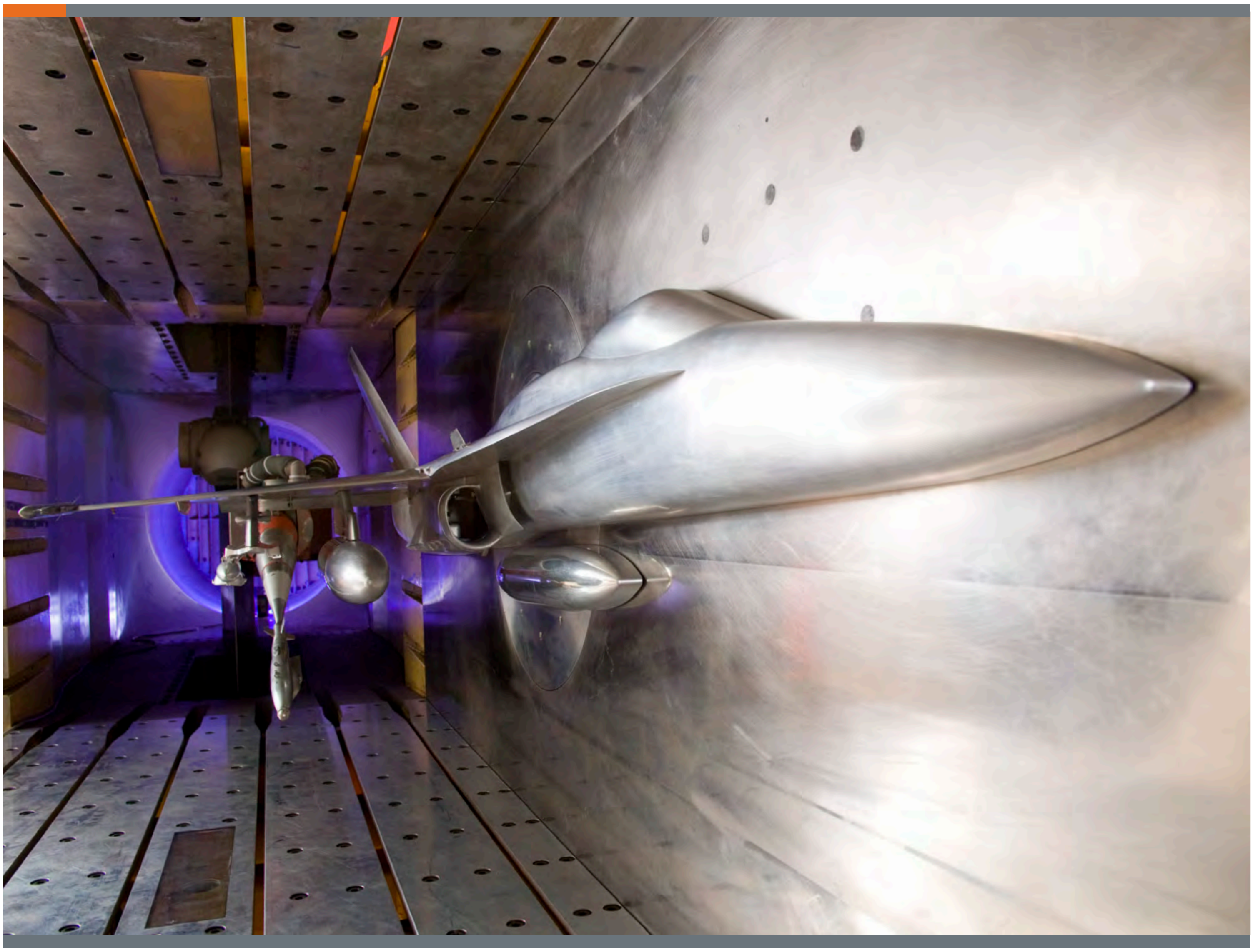
Defence Transonic Wind Tunnel Capability Overview



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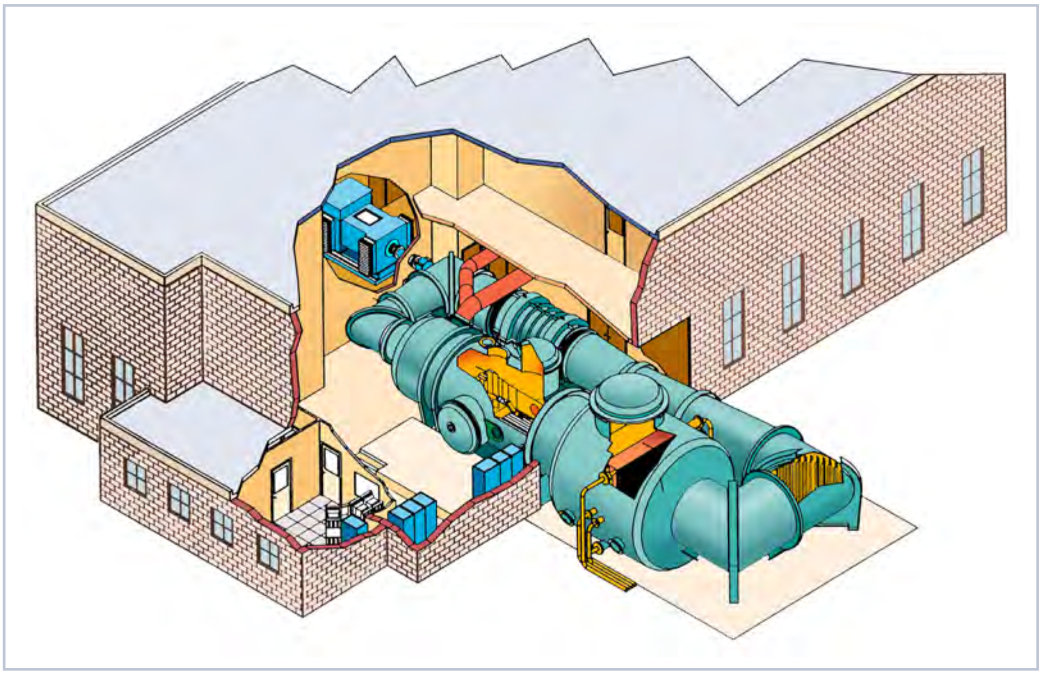

The Defence Science and Technology Group (DSTG) Transonic Wind Tunnel (TWT) in Melbourne was built in the late 1990s and commissioned in 2000. This facility has since been used in a variety of experimental aerodynamic test campaigns to support the Australian Defence Force (ADF), particularly associated with stores clearance and aerodynamic investigations of military aircraft and missiles. It is also used in partnership with industry and universities for collaborative testing and research and development in support of the ADF. This document provides basic details and capabilities of the facility.

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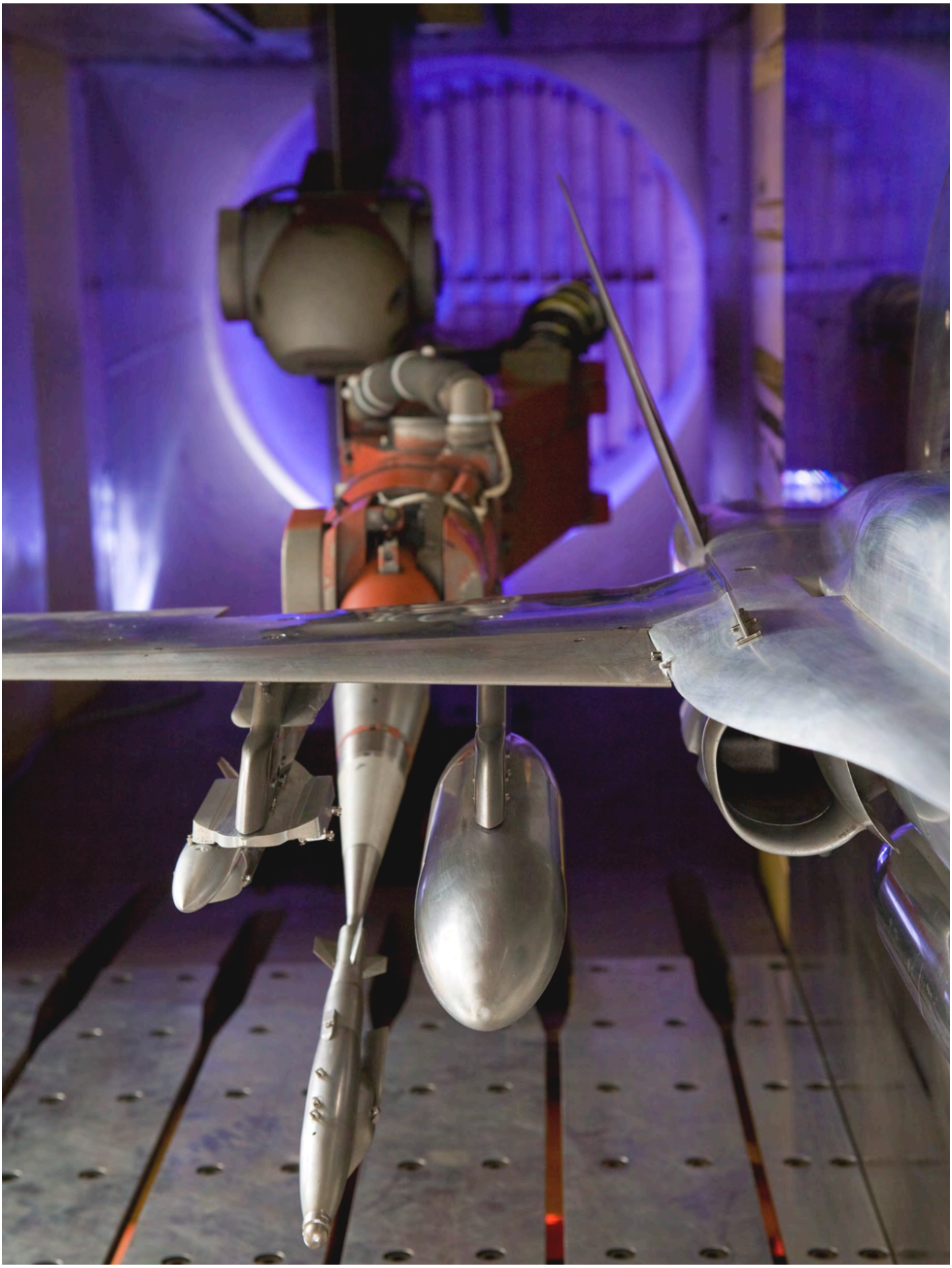


1. Aerodynamic Circuit and Operating Envelope

The Defence Science and Technology Group (DSTG) Transonic Wind Tunnel (TWT) is a closed return-circuit continuous flow tunnel designed and commissioned by the US supplier, Aero Systems Engineering (ASE) as the original end manufacturer (OEM). Flow is generated by a two-stage axial flow compressor powered by a 5.3 MW variable speed electric motor. The test section is 0.8 m wide by 0.8 m high and 2.7 m long with a slotted top and bottom walls and interchangeable solid or slotted sidewalls. The nominal operating envelope is provided in Figure 1.

A schematic drawing of the aerodynamic circuit and main components of the facility is shown in Figure 2 (next page). An auxiliary plenum evacuation system (PES) provides the capability for pressurisation, evacuation and an additional means for Mach number control. A regenerative air drier is integrated in the PES pipework to provide humidity control so that the air in the tunnel can be reduced to below 1000 ppmv prior to starting a test run.

A water-cooled heat exchanger in the settling chamber controls the air temperature in the test section to within ±2 °C of a set temperature which ranges from 30 to 40 °C. Turbulence conditioning screens and a 16:1 contraction are used to provide good quality flow.

The tunnel specifications are summarised below:

- Test section size: 0.806 m × 0.806 m
- Mach number range: 0.30 – 1.20, 1.40
- Pressure range: 30 – 200 kPa
- Max unit Reynolds number: 30 × 10^6 m^{-1}
- Circuit volume (inc. plenum): 280 m^3
- Further details on the main components of the TWT are provided in Section 2.

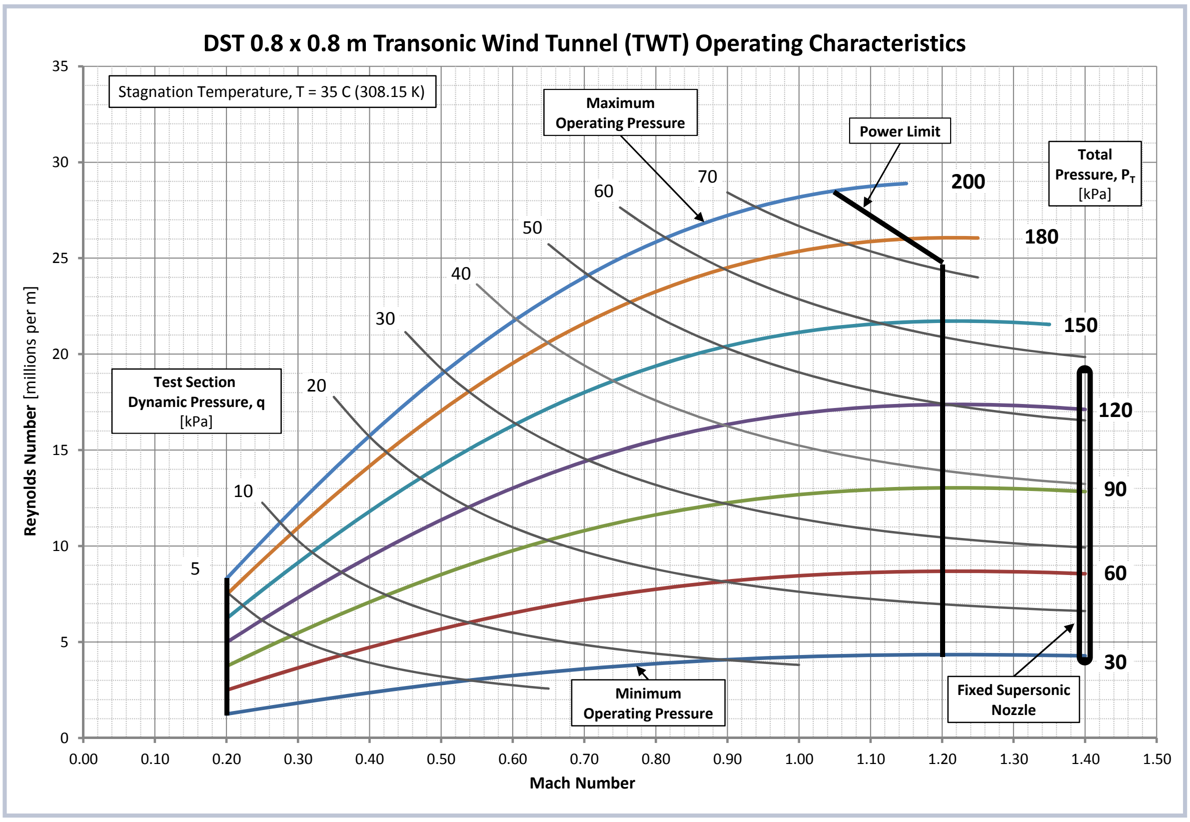


Figure 1: TWT operational envelope

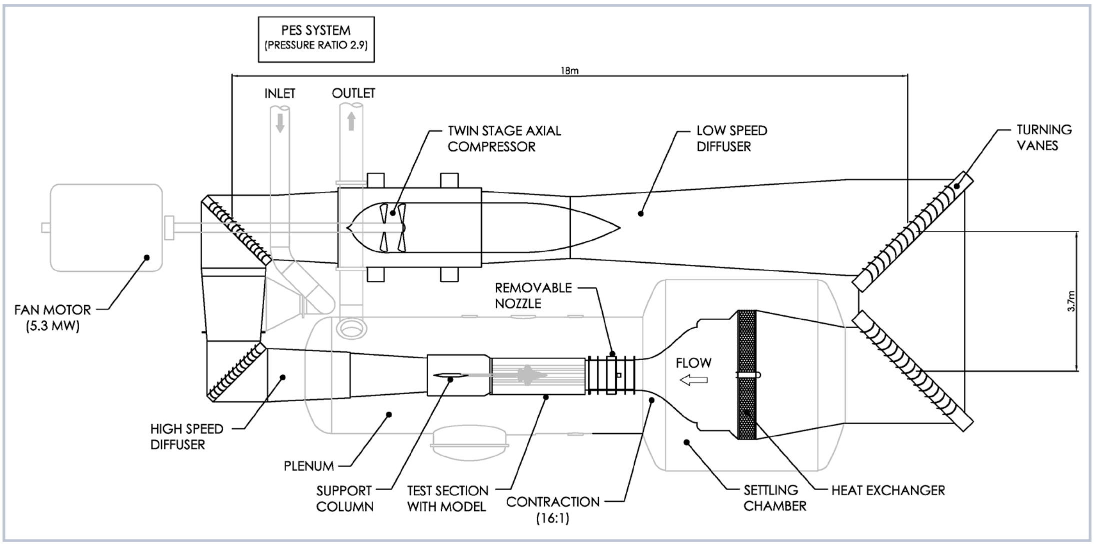


Figure 2: TWT aerodynamic circuit

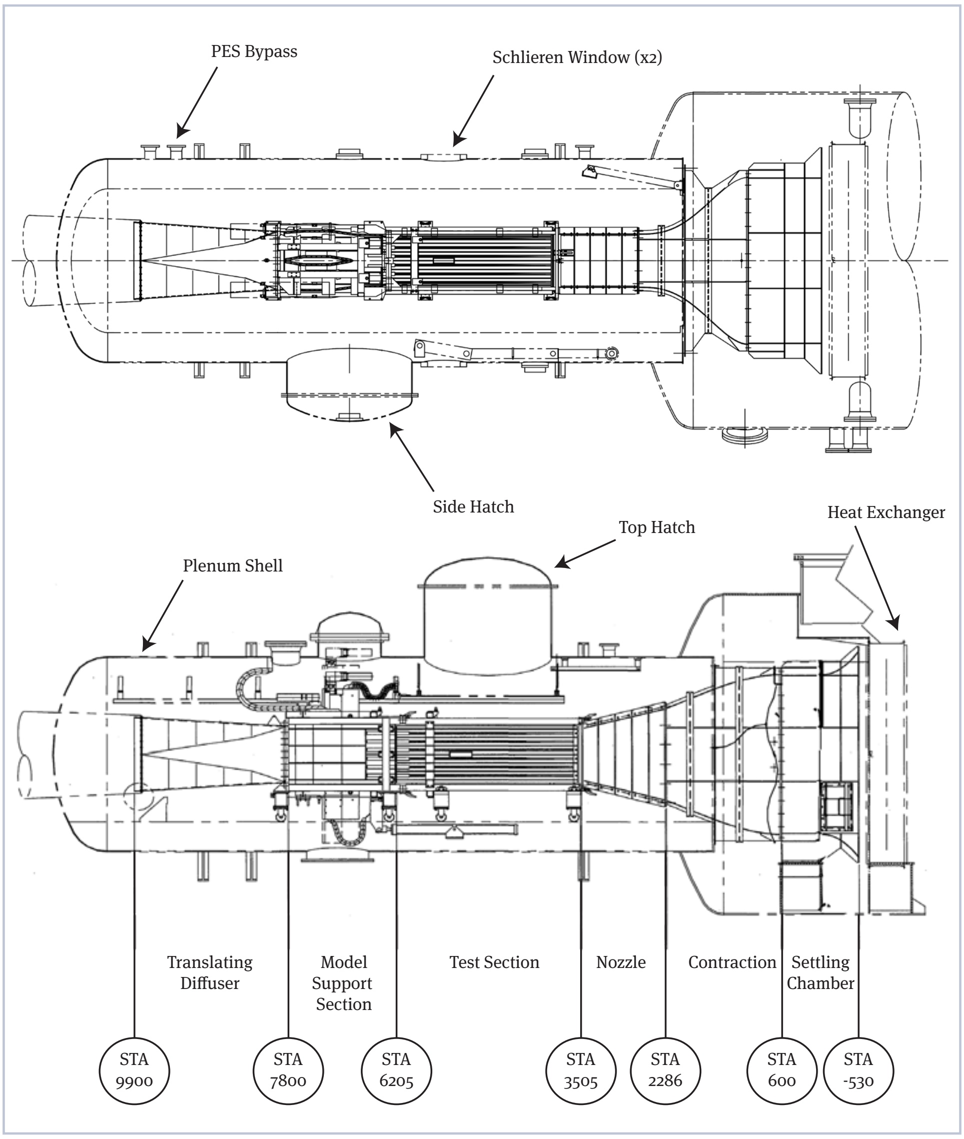


Figure 3: Test leg assembly and associated components

2. Description of Facility Components

2.1. Test section

The TWT test section is nominally 2700 mm long and 806 mm square. The test section nozzle interface is at station 3505 and test section model support interface is at station 6205. The high flow quality region extends ±400 mm from the nominal model centre at station 5257.

Figure 3 (previous page) shows the test section together with the other components which form the test leg.

The centreline static probe used for flow quality calibration is shown installed on the main model support in Figure 4.

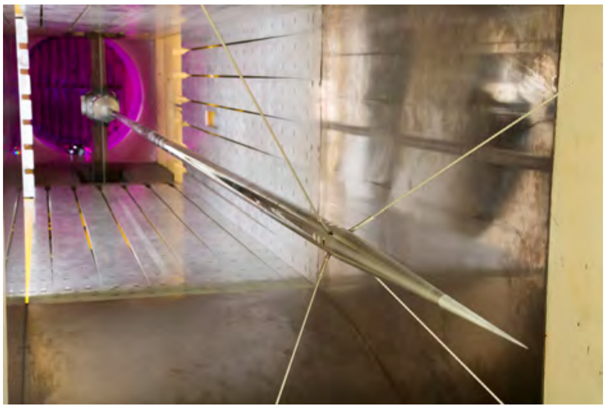


Figure 4: Centreline static probe in the test section

The test section slotted walls consist of six slots with a surface open area porosity of 4.97%. The sidewalls are interchangeable with solid walls. This results in a total open area ratio of 2.48% for solid sidewalls.

Sidewall removal and interchange is achieved through a manual translating rail system inside the plenum (Figure 5). The rail system is also used for storage of the unused sidewalls.

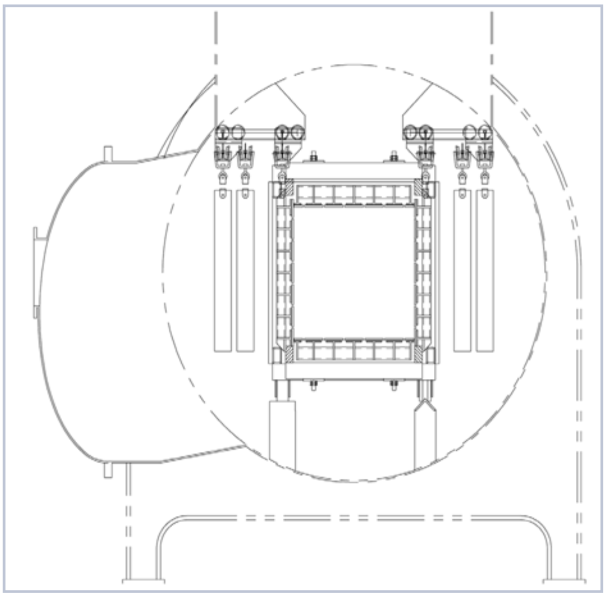


Figure 5: Sidewall storage rail system

The top and bottom wall angles are adjustable through a range of ±30 minutes of arc, nominally fixed at 20 minutes divergent during commissioning. Flexure strips provide a smooth flow transition from the nozzle.

The slotted walls incorporate a rectangular optical access window 300 mm long by 70 mm wide for model observation. The solid sidewalls have a circular cutout with removable BK-7 Schlieren grade optical windows with a diameter of 420 mm.

2.2. Model support section

The model support section is connected to the downstream end of the test section and the upstream end of the high speed diffuser. It comprises of a support column, adjustable top and bottom walls, and fixed sidewalls.

The main model support is integral with the support column. The store model support arm is attached to the side of the support column. Further details on model support systems are provided in Section 4.

The top and bottom model support section walls are adjustable from 0.0° (parallel top and bottom walls) to +0.85° (diverging).

The model support section sidewalls are fixed and contoured to allow the flow to pass around the support column.

The test section and model support section are mounted on wheels enabling part of the test leg to be retracted into the diffuser. Together with the removable sidewalls, this provides an alternative means of access to inside the test section. The test leg can be opened at either station 3505 or 6205.

2.3. High speed diffuser

The high speed diffuser downstream of the test section is constructed in two parts. The first is a translating section and incorporates the transition from a square cross section to circular. The translating diffuser telescopes into a fixed diffuser section to allow the translation of the test section and model support section. A seal at station 9900 seals the diffuser when it is in the test position.

2.4. Plenum

A plenum structure completes the pressure vessel around the test leg section. This structure is 3100 mm in diameter and has a design pressure from 0 to 220 kPa absolute.

A side access hatch (Figure 6) allows access to the plenum for personnel, tunnel equipment, and test equipment. The side hatch is 1900 mm in diameter and is sealed by an inflatable seal. It is mounted on a translation system to allow quick opening or closing. Translation is actuated by a pneumatic cylinder which is controlled from the control panel mounted next to the access hatch.

A top access hatch of 1830 mm diameter extends through the mezzanine floor to allow access to the plenum for installation or removal of the sidewall support and interchanging the nozzle.

The plenum has two top penetration hatches for cabling access. These penetrations can be accessed via panels on the mezzanine floor. An additional three penetrations exist on the inner side of the plenum for cabling access.

Three pairs of optical access windows are incorporated in the plenum. The main pair is at station 5257 and corresponds to the nominal model centre for schlieren imaging. Transparent covers can be mounted on the windows to protect them from damage when the schlieren system is not active for generable observation purposes. The other pairs of windows are for general observation.

A total of seven manway hatches are provided around the circuit for inspection and maintenance.

An outlet pipe inside the plenum provides a flow bypass through the PES via controllable valves.

2.5. First corner, cross-leg and second corner

Following the test leg a first corner directs the flow into a cross leg and a second corner directs the flow back into the return leg.

The cross leg continues diffusing and also incorporates an inlet pipe to re-inject the flow from the PES back into the tunnel circuit.

The corners are fitted with turning vanes which direct the flow around the corners of the tunnel circuit (Figure 7). This reduces pressure losses and improves flow quality by reducing flow angularity.

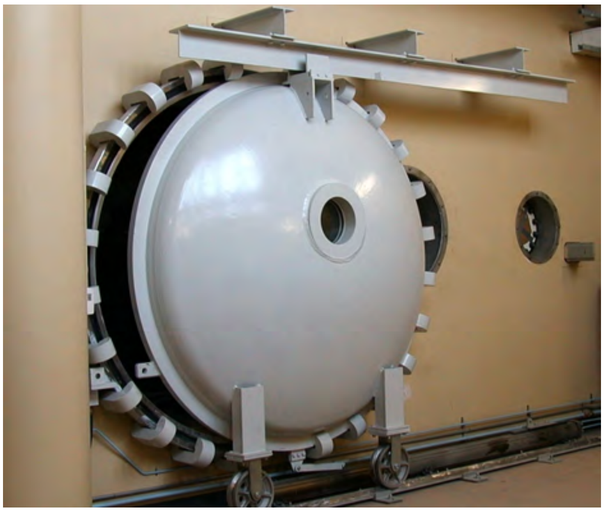


Figure 6: Plenum side hatch

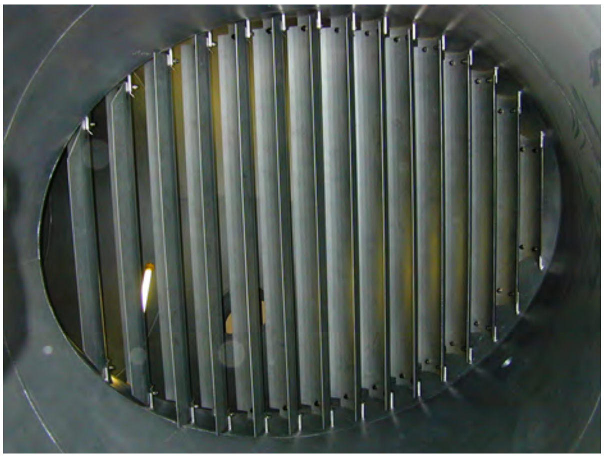


Figure 7: Corner turning vanes

2.6. Main fan and low speed diffuser

The main fan is located in the return leg after the second corner. The fan is a twin stage, axial flow compressor (Figure 8) powered by a 5.3 megawatt electric motor. Each stage comprises of 30 rotor blades and the fan speed can be driven to 1800 rpm. The blade positions are manually adjustable however have been fixed at predefined positions during tunnel commissioning.

The flow is further expanded downstream of the fan by the low speed diffuser.

2.7. Third corner, cross-leg and fourth corner

The third corner directs the flow into a cross leg and the fourth corner directs the flow back into the test leg. These corners are also fitted with turning vanes.

2.8. Wide angle diffuser

Following the fourth corner a wide angle diffuser expands the circuit cross section. A screen is installed to avoid boundary layer separation. This diffuser also incorporates the transition back to a rectangular cross section.

2.9. Heat exchanger and cooling system

A heat exchanger is located just downstream of the wide angle diffuser (Figure 9). This is designed to reject up to 5.3 MW of heat generated from the main compressor. This is achieved using up to a maximum of 150 litres per second of cooling water supplied from an external DSTG cooling tower system.

2.10. Settling chamber and contraction

Directly downstream from the heat exchange is the settling chamber and contraction (Figure 10).

The settling chamber incorporates two flow conditioning screens at station 50 and station 450. The screens are made of stainless steel wire mesh material with 10 wires per inch of 0.0189 inch diameter. This provides an open area ratio of 65.8%. This improves the flow quality by minimising turbulence.

Instrumentation used to measure the flow properties is installed in the settling chamber. This includes a high quality temperature and humidity sensor and four pitot probes to measure the total pressure.

The settling chamber feeds directly into a three dimensional 16:1 contraction.

Figure 9: Heat exchanger behind turbulence conditioning screens

Figure 8: Twin stage axial fan

Figure 10: Settling chamber casing and heat exchanger pipework

2.11. Nozzle

The nozzle is a four-piece assembly bolted together in each of the four corners. The top and bottom walls form a two-dimensional contoured nozzle shape to produce a high level of flow quality at the entrance to the test section. One set of top and bottom walls with a sonic (converging only) contour is provided for tunnel operation at Mach 1.2 and below. A second set with a supersonic (converging/diverging) contour is provided for operation at Mach 1.4.

2.12. Plenum evacuation system

The PES provides several functions critical to tunnel operation. Pressurisation up to 200 kPa occurs by allowing ambient air to enter the system on the suction side of the compressor. Evacuation down to 30 kPa occurs by discharging air to ambient from the discharge side of the compressor. Mach number control is affected by adjusting the amount of air removed from the plenum. It is also through the PES that drying of the air is achieved.

The principal component of the PES is a centrifugal compressor (Figure 11). This is a fixed geometry, fixed speed machine and is driven by a 2.6 MW induction motor and operates at a constant speed of 10840 rpm. The PES compressor consists of a 17 blade impellor (Figure 12).

The PES extracts air from the plenum, compresses it by a factor of approximately 2.9 and then re-injects the compressed air into the tunnel circuit downstream of the first corner. The effect that this has on the test section flow is equivalent to introducing a steady increase in cross-sectional area in the downstream direction.
The amount of air extracted is controlled by a variable control valve system.

2.12.1. Vacuum pumps and vent

Pressurisation and evacuation of the tunnel is controlled using vacuum pumps (Figure 13) and a vent integrated in the PES pipework.

These vacuum pumps consist of two 11 kW Becker Model VTLF2.500 carbon vane vacuum pumps units connected in parallel. Each vacuum pump has the capacity to pump 500 cubic metres of air per hour.

The purpose of the vacuum pumps during the initial PES starting up is to evacuate the pipe work to unload the compressor. After approximately one minute the vacuum pumps shut off and the PES continues its start-up sequence which takes approximately seven minutes.

Figure 11: PES motor and centrifugal compressor

Figure 12: PES compressor impellor

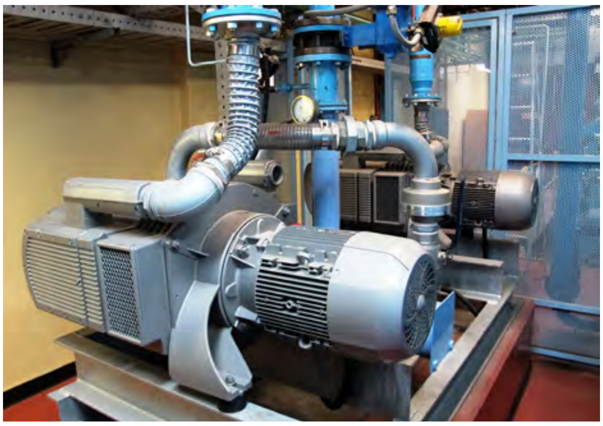


Figure 13: Vacuum pumps

During operation of the tunnel, the tunnel pressure will vary due to changes in pressure and Mach number. If the pressure is above what is required, the vacuum pumps switch on to obtain and hold the correct tunnel pressure. They are also used during conditioning of the tunnel for sub-atmospheric runs to evacuate the tunnel and PES pipework to the required pressure setpoint.

2.12.2. Air dryer

For transonic flow it is important that the test gas is kept dry so that condensation effects are negligible. This requires the dewpoint to be kept as low as possible.

Tunnel humidity is controlled using a Munters HCD-1125-EA dehumidifier integrated in the PES pipework. The dehumidifier is used prior to running the tunnel, working in conjunction with the PES to circulate tunnel air through the dryer to achieve the desired pre-set humidity in the circuit. Once the tunnel is in operation mode, the dryer is only activated during stages where the tunnel pressure needs to increase allowing only dried air to enter the tunnel circuit. During shut down and if the tunnel is below atmospheric pressure, the air enters the tunnel circuit via the dryer so that the incoming air is relatively dry.

Figure 14: DSTG cooling tower system

3. Tunnel Operation

The facility is remotely operated in a control room adjacent to the Plenum entrance room. This control room has a main control console consisting of five screens (three for display and two for operator input). The control console also includes a PES control panel and emergency interlock panel.

The tunnel control system automatically monitors the Mach number as measured by the ratio between the plenum static pressure and the settling chamber total pressure.

Flow acceptance tests were performed during tunnel commissioning using a centreline static pipe at selected test conditions. This data verified that the Mach number calculated from the plenum and settling chamber pressures was accurate to within ±0.002 for subsonic conditions and ±0.010 for supersonic conditions with slotted sidewalls along the high quality flow region ±400 mm from station 5257. The axial pressure distribution for these tests was typically within ±100 Pa over this range of 800 mm fur subsonic conditions.

Tests performed throughout the history of operation of the facility have demonstrated a high level of flow quality. A reference AGARD-B calibration model is tested intermittently to identify any change in flow characteristics. These tests have demonstrated good long term repeatability.

3.1. Modes of operation

The tunnel can be operated in four operational modes.

3.1.1. Mode A

The main fan speed is used in a closed loop control system to control Mach number. The PES bypass valves are set at fixed positions established from the acceptance test data. This extracts a constant amount of air from the plenum. The main fan speed is used to establish Mach number and compensate for changes in model attitude or requested test condition.

3.1.2. Mode B

The main fan speed is set to fixed speed established from the acceptance test data. PES bypass valves are used in a closed loop control system to establish Mach number and compensate for changes in model attitude.

3.1.3. Mode C

Selects Mode A if $M < 0.75$ or Mode B if $M > 0.75$.

3.1.4. Mode D

The PES is not used. Tunnel pressure is allowed to float. There is no plenum suction.

3.2. Temperature control

The heat generated by the main fan is rejected to atmosphere through the fin-tube heat exchanger located between the wide angle diffuser and settling chamber.

A constant flow of water from the DSTG cooling tower system (Figure 14, previous page) is delivered to the heat exchanger. A three-way bypass valve mixes water from the tower with heated water from the heat exchanger to maintain the tunnel setpoint temperature.

This system is able to control the air temperature in the test section to within ±2 °C of a set temperature which ranges from 30 to 40 °C.

4. Model Support Systems

The DSTG TWT includes three model support systems: a main model support system, an auxiliary store model support system, and a sidewall model support system.

The main model support system is permanently installed in the model support section of the test leg. The store model support is removable. When installed in the tunnel it is mounted to the vertical strut of the main model support. The sidewall model support is also removable. When installed in the tunnel it is located in the solid test section sidewall.

4.1. Main model support

The main model support (MS) system is located in the model support section of the test leg. It is capable of providing vertical, pitch, and roll motion. All motions can be coordinated and coordination of pitch and vertical motion allow the model centre to remain at the tunnel centreline. The MS pitch centre is Station 5257. The MS consists of a fixed strut, movable strut, pitch mechanism, removable roll drive, and sting.

Table 1: MS maximum model loads

Axial force	± 4000 N
Side force	± 4000 N
Normal force	± 8 000 N
Rolling moment	± 200 Nm
Pitching moment	± 1000 Nm
Yawing moment	± 500 Nm

Figure 15: AGARD-B calibration model on the main model support

A linear position transducer mounted in the fixed strut cavity provides vertical position feedback of the MS. Proximity switches mounted under the bottom wall define the vertical travel range limits.

An absolute encoder mounted to the starboard side of the movable strut and directly driven by the pitch arm provides the pitch position feedback. Limit switches mounted to the port side of the movable strut define when the pitch motion has reached the upper or lower limits of the pitch range.

The roll drive is a removable unit which mounts to the upstream end of the pitch pod. A resolver driven by an anti-backlash gear set and a torque tube attached to the sting socket provides roll position feedback. A rotary limit switch assembly driven by the torque tube defines when the roll motion has reached either end of the motion range.

The MS roll drive incorporates a 10 mm diameter internal passage as a provision for model instrumentation routing. The upstream end of the roll drive consists of a tapered socket and external threads allow a sting and sting nut to be attached.

Specifications for the main model support are provided in the Tables 1 and 2.

Table 2: MS motion specifications

	Range of motion	Motion rates	Position reading accuracy
Vertical translation	± 382.5 mm	0 to 130 mm/sec	± 0.1 mm
Roll angle	± 190º	0 to 10 º/sec	± 0.10º
Pitch angle	± 15º	0 to 5 º/sec	± 0.02º

4.2. Store model support

The auxiliary store model support system (SS) is a six degree of freedom model support capable of providing axial, lateral, vertical, roll, pitch and yaw motion (Figure 16). The SS is a removable fixture which mounts on the port side of the Main Model Support movable strut.

The SS mechanism consists of an axial drive, downstream yaw drive, upstream yaw drive, pitch drive, and a roll drive. All drives are all similar in that they include servomotors with encoders, harmonic drive gearing, and brakes. The axial drive also includesa ballscrew to convert rotary motion into linear motion. The servomotors are closed-loop controlled, brushless DC servomotors with encoders to provide velocity feedback.

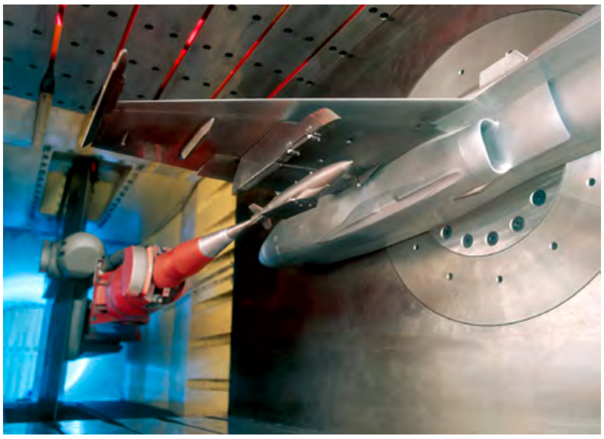


Figure 16: JDAM-ER model on the store model support

4.2.1. Roll drive

The roll drive includes the servomotor, encoder, harmonic drive gearing, and brake described for all the store support drives. In addition a resolver is coupled directly to the output shaft. End of travel stops are included. The centre shaft of the roll drive is a hollow 5 mm diameter passage to provide access for instrumentation cabling to and from the model.

4.2.2. Pitch drive

The pitch drive is located directly downstream of the roll drive. The pitch angle encoder is mounted directly at the pitch pivot with no intermediate gearing. Proximity switches define the limits of the pitch motion.

4.2.3. Yaw mechanisms

The SS has two yaw drive mechanisms. The yaw angle encoders are mounted directly to the yaw pivots with no intermediate gearing, thus providing very accurate position readout. Proximity switches define the limits of motion of each yaw drive.

4.2.4. Axial drive

The axial drive provides approximately 780 mm of axial translation to provide 500 mm of axial translation at the store model over the full range of lateral motion. A linear position transducer provides position feedback. Proximity switches define the limits of the axial motion.

Specifications for the store model support are provided in Tables 3 and 4.

Table 3: SS model limit loads

Axial force	± 100 N
Side force	± 200 N
Normal force	± 200 N
Rolling moment	± 4 Nm
Pitching moment	± 20 Nm
Yawing moment	± 20 Nm

Table 4: SS motion specifications

	Range of motion	Motion rates	Setting accuracy	Position reading accuracy
Axial translation	500 mm	0 to 20 mm/sec	± 0.3 mm	± 0.1 mm
Lateral translation	500 mm	0 to 20 mm/sec	± 0.6 mm	± 0.1 mm
Vertical translation	500 mm	0 to 20 mm/sec	± 0.2 mm	± 0.1 mm
Roll angle	± 190°	0 to 10 °/sec	± 0.50°	± 0.10°
Pitch angle	± 30°	0 to 5 °/sec	± 0.10°	± 0.01°
Yaw angle	± 30°	0 to 5 °/sec	± 0.10°	± 0.01°

NOTE: Vertical motion consists of 320 mm below and 180 mm above tunnel centreline.
Horizontal motion consists of 310 mm to the port side and 190 mm to the starboard side of tunnel centreline.
Axial motion consists of 250 mm upstream and 250 mm downstream of station 5257.

4.3. Sidewall turntable support

The sidewall model turntable support system (TS) is a single degree of freedom model support that typically mounts in the port sidewall of the test section. The TS is located at Station 5257 and provides pitch motion.

The TS is usually used to hold half models of an aircraft with a store attached to the SS arm for store release investigations (Figure 17). However it can also be used without the SS installed for measurements of the half model loads via the sidewall balance or for measurements of a store carriage loads. There is also the potential to use the TS for testing 2D models mounted across the test section.

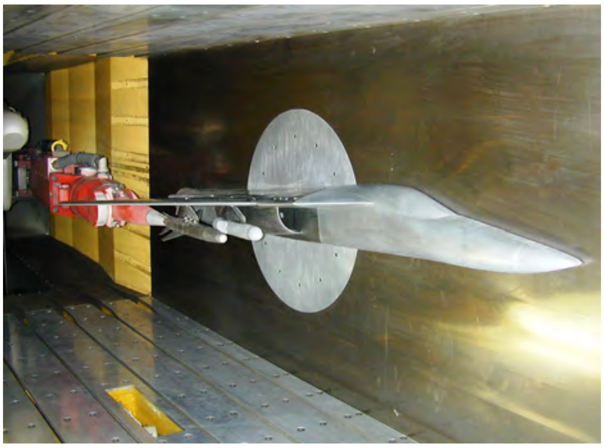


Figure 17: F-111 half-model on the sidewall support

The TS includes a brake and servo motor. A main drum provides a cavity for mounting a sidewall balance and a surface to mount the flow surface coverplate (Figure 18). An encoder coupled directly to the drum provides pitch position feedback. Proximity switches located on the housing define the ends of the pitch motion range.

Specifications for the sidewall support are provided in the Tables 5 and 6.

The turntable is 482 mm in diameter and coverplates mounts flush with the flow surface of the solid test Section sidewall at station 5257. The turntable is interchangeable and can be mounted in the port or starboard sidewall. When the turntable is not in use, the Schlieren windows can be fitted in the turntable cavities.

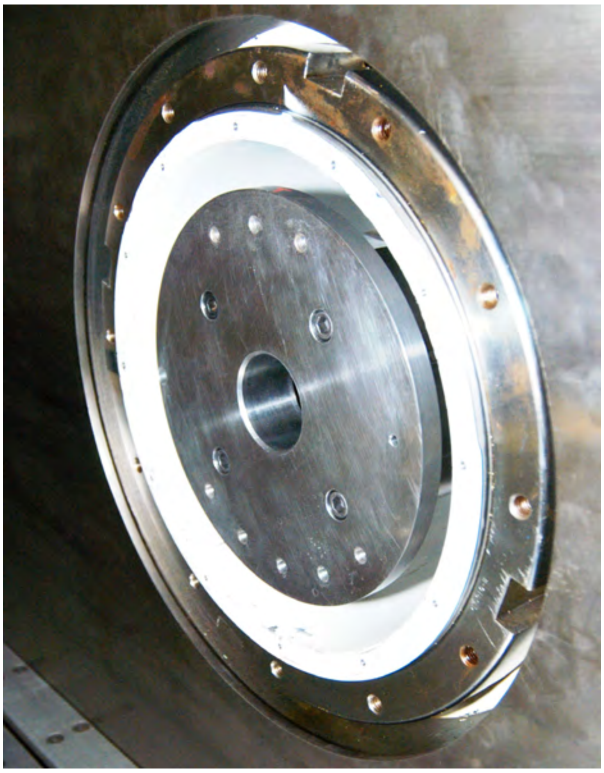


Figure 18: Turntable and sidewall balance interface

4.4. Support stings

DSTG have a number of stings compatible for mounting models either to the main model support or the store model support. These stings have typically been designed to mount the model centre so that it is in the nominal test section centre at station 5257.

Table 5: TS model limit loads

Axial force	± 6 000 N
Side force	n/a
Normal force	± 20 000 N
Rolling moment	± 10 000 Nm
Pitching moment	± 4 000 Nm
Yawing moment	± 2 000 Nm

Table 6: TS motion specifications

Pitch angle range	± 100°
Pitch rate	0 to 5 °/s
Setting accuracy	± 0.05°
Position reading accuracy	± 0.01°

5. Control and Data Acquisition System

A Dell Server 2950 (DACO), housed in the computer cabinet of the control room (Figure 19), hosts the software 'ASE2000LX' used for overall facility control, model support operation and data acquisition. A programmable logic controller (PLC) is used for data input/output and facility control. A VXI front end (data processing system) receives raw data and translates it into digital information. These three systems (DACO, PLC, and VXI) work in conjunction to control and monitor model test functions or related facility control functions: they process performance parameters or conditions for display on the main control console screens. All major operating components are connected via an Ethernet link designated as the 'control network'.

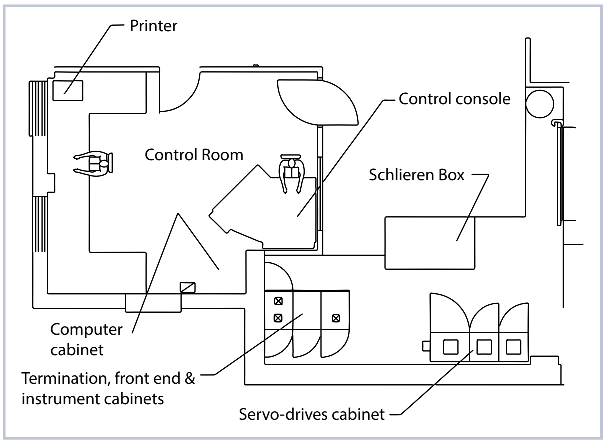


Figure 19: Plan view of the TWT control and test room

5.1. ASE2000LX DAC

The primary data acquisition and control system (DAC) for the facility is the software 'ASE2000LX' hosted on the DACO server. The usual interface to this system is through the five screen control console in the control room using keyboard and mouse input (Figure 20). Through this interface the operator is able to control the majority of the different activities required to run a test. This includes facility and subsystem functions, test parameters, model support positions, calibrations, checkout procedures, data monitoring and data acquisition.

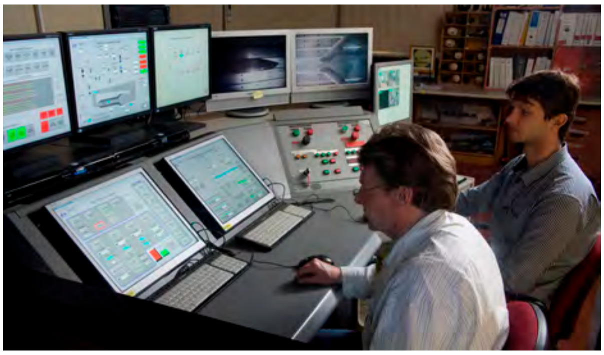


Figure 20: ASE control console

Most test sequences are automatically actuated using predefined test configurations and test plans. During test, the operator is able to intervene and modify a given test sequence if required.

The ASE2000LX DAC incorporates PID closed loop control algorithms for the main compressor command speed, PES valve position set-point, and model support position set-points. The software communicates with the PLC and VXI subsystems via the network (Figure 21) as required according to automatic operation through predefined configurations and test plans or by manual control.

ASE2000LX is structured using predefined configurations which detail all aspects of the control and data acquisition system. This includes hardware configuration, parameter definitions, acquisition settings, calibration curves, processing algorithms, display screens and controls. These configurations can be placed under version control so that any changes from the master configurations are traceable.

Predefined test plans are used in conjunction with an ASE2000LX configuration in order to conduct a test run. The test plans are created using an Excel workbook environment and define the matrix of test conditions and list of model traverse positions and orientations to step through. The test plan is also used to indicate a force-moment test or pressure test, including definition of the particular balance used and associated calibration matrix.

Typical operation of a test run using ASE2000LX using a predefined configuration and test plan consists of the following processes:

- Startup and operation of tunnel systems
- Condition tunnel to set-point conditions (humidity, temperature, pressure, mach number)
- Control movement of model to set-point position and orientation
- Maintain tunnel and model on set-point conditions
- Initiate and control data acquisition
- Perform preliminary data reduction for realtime monitoring

- Transition to new tunnel / model set-point conditions and repeat acquisition until test plan is completed
- Shutdown tunnel systems
- Produce raw data files.

5.2. PLC system

The PLC system, housed in the instrumentation cabinets, is a GE Rx3i series controller. This PLC is the front end for tunnel control and manages operation of the main compressor, PES compressor, lubrication system, valve control, facility pressure and temperature sensors, and model support interlocks. It also incorporates the PID control loop for cooling water control.

The PLC hardware consists of three racks. These racks are populated with a central processing unit, two 6/12-channel analogue input modules, two 8-channel analogue output modules, eight 16-channel digital input modules, six 8-channel digital output modules, two 6-channel RTD input modules, and one 12-channel thermocouple input module.

The software running on the PLC is a ladder logic program. Through this the PLC is able to operate the tunnel independently when the primary ASE2000LX DAC is not working.

Subsystems such as the main compressor, PES compressor, cooling water system, and high voltage supply system all have their own local control systems for standalone operation or low level diagnostics.

5.3. VXI system

The VXI system is effectively a self-contained data acquisition system. The series of cards installed perform most of the raw data acquisition and processing functions during a test sequence. The VXI system also provides digital inputs and outputs for control of various facility functions and model support control. The PID closed loop algorithms for model support position control are contained and run within the VXI system.

The VXI system comprises of a HP E1401A mainframe chassis populated with the following components:

- Embedded National Instruments computer
- HP1413 64-channel A/D card
- Tektronix VX4730 12-channel D/A card
- VBR 4-channel synchro-resolver serial input card
- SSEI ZST 16-channel synchronous serial encoder input card
- HP Z2404 64-channel digital input card
- HP E1463 5A Form-C switch.

The specifications for the 64-channel A/D card reading the primary signals for model performance parameters such as the strain gauge signals are shown in Table 7.

Table 7: VXI A/D card specifications

Range	± 62.5 mV to ± 16 V Full Scale
Resolution	16 bit
Max sampling rate	100 kS/s
Linearity	± 0.01 % FS
Offset error	Less than ± 0.01 % FS
Noise (3σ)	Less than ± 0.03 % FS

This A/D card incorporates signal conditioning plug-on (SCP) modules. An eight-channel VT1505A SCP current source module is installed for supply of excitation current for instrumentation such as RTDs. All other A/D channels are equipped with VT1502A SCPs which provides fixed low-pass filters with a 3 dB cutoff frequency of 7 Hz, gain is set to 1.

A front end program runs continuously on the VXI computer. This program reads all analogue and digital input channels and populates a shared memory area with the acquired values. In conjunction, the front end program updates all analogue and digital output channels if parameters on the shared memory area have changed.

5.3.1. Vishay 2310 Strain Gauge Amplifier

Six specialised Vishay 2310 strain gauge amplifier units are installed for dedicated signal conditioning of strain gauges associated with force balances to measure the forces and moments on a model. The analogue output readings of these units together with the sensed excitation are supplied directly to the VXI A/D card. The 2310 signal conditioning units provide precision high stability bridge completion resistors and dummy gages, and four shunt-calibration resistors for use with quarter, half and full bridges. Each amplifier contains a low-pass active two-pole Butterworth standard filter. Specifications are provided in Table 8.

Table 8: Signal conditioning amplifier specifications

Excitation	0.5, 0.7, 1, 1.4, 2, 2.7, 3.5, 5, 7, 10, 12 & 15 Vdc
Gain	1 to 11 000 cont. variable
Filter	10, 100, 1000 & 10 000 Hz
Analogue output	± 10 V (filtered & wideband)

5.3.2. Digiquartz

Two Digiquartz pressure transducers are connected in series to the VXI embedded computer via a serial port. These transducers are used to measure the tunnel total and static pressure measurements associated with calculating the flow conditions in the test section.

5.3.3. PSI-8400

A PSI-8400 system is used for multi-channel pressure measurements. This is typically used for acquiring test section flow pressures and/or model surface/cavity pressures. The PSI-8400 is connected to the VXI system via a GPIB interface.

5.4. Data acquisition settings

Digiquartz readings are read via serial communication on the VXI. With a nominal Digiquartz pressure integration period (PR) of 19, a data rate of approximately 10 Hz is achieved.

The VXI front end program samples and writes data to and from the A/D, D/A, and digital I/O cards at a rate of 40 Hz. The PLC front end program also has a fixed scan rate of 40 Hz.

The VXI A/D acquisition channels have a fixed low pass filter of 7 Hz and fixed gain of 1.

The Vishay 2310 signal conditioning amplifiers are usually set with a low-pass filter of 10 Hz. Excitation is normally set to 5 V however this can be dependent upon which balance is used. A gain of 1000 is typically used, however can be varied from 1 to 11 000.

The number of data records acquired by the ASE2000LX DAC for each data acquisition is configured according to test requirements.

The DAC scan rate of each parameter can be modified individually from 1 to 20 Hz with a default setting of 10 Hz. Each acquisition initiated from the DAC consists of a number of data records sampled at the selected rate from the VXI/PLC front end program. Each data record is averaged for the number of samples acquired by the VXI front end program. For example, with a VXI/PLC scan rate of 40 Hz and DAC scan rate of 10 Hz, the VXI/PLC front end program will sum the reading over 4 scans and divide the result by 4 before sending the value to ASE2000LX.

5.5. Peripheral equipment

Peripheral PCs and a printer, connected to the DACO server via a secondary network are also located in the control room. The peripheral PC's serve a number of functions including:

- Access to VXI PC and front end program.
- Access to the tunnel control PLC ladder logic and parameter states. This is used primarily for diagnostic

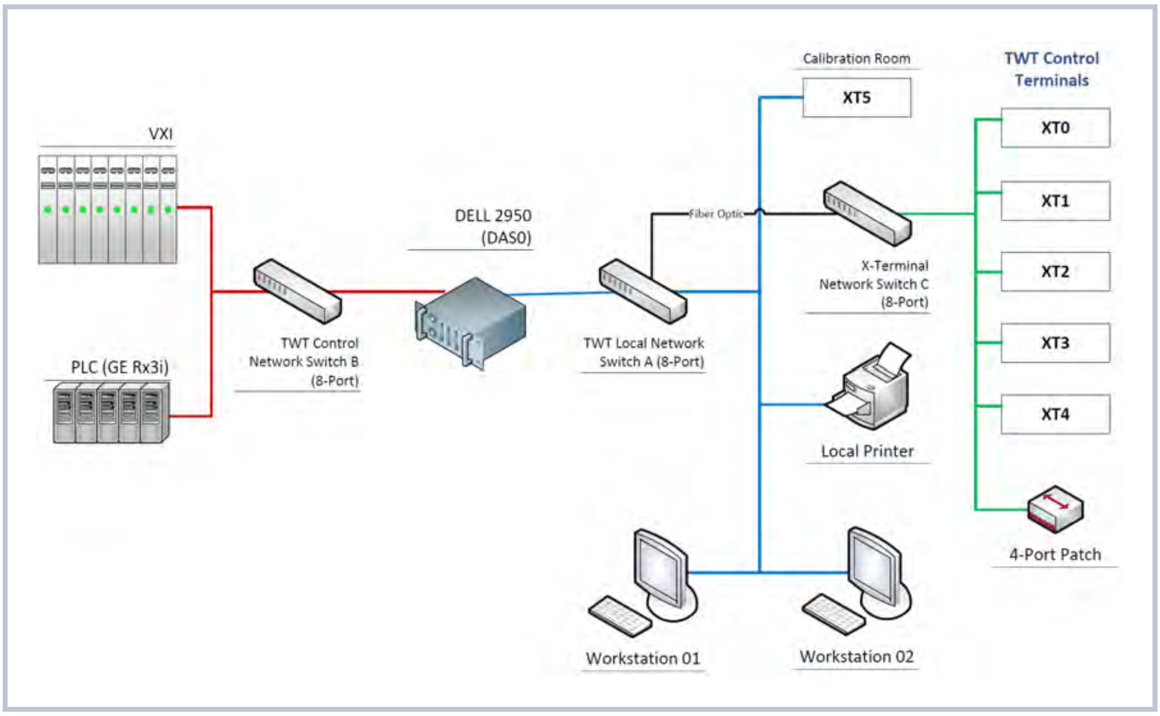


Figure 21: DAS network topology / schematic

purposes when experiencing faults or unusual behaviour with facility operation.

- Creation of predefined test plans using the ASE Testplan Excel software. These test plans define the test conditions and model attitudes to be conducted during a test. They are loaded by ASE2000LX and the test can be largely automated resulting in very efficient testing with a high level of productivity.
- Post processing data acquired during a test using the software WTDView. This data reduction includes post-test corrections and is used to produce and archive the final data sets for analysis and delivery to the client.
- Control and monitoring of facility observation cameras.

6. Instrumentation and Measurement Capabilities

This section provides details on instrumentation and measurement capabilities of the TWT. This includes calibration policies and methods, data reduction and corrections. Measurements are normally sampled in pitch-pause mode where the model is traversed to a discrete pitch/roll/yaw orientation and data acquired at fixed conditions.

6.1. Flow reference system

Several high precision transducers are used to measure the pressures and temperatures required to calculate the fundamental test section flow parameters such as Mach number (M), dynamic pressure (q), flow velocity (V), and Reynolds number (Re) with the required accuracy.

Three orifices in the plenum, approximately at station 3000, are open to static pressure. These orifices are teed to pneumatic tubing which is routed to and measured by a Paroscientific Digiquartz 30 psi absolute pressure transducer installed in the instrumentation cabinet at tunnel centreline. Four pitot probes located circumferentially around the settling chamber, approximately at station 700 sense the tunnel total pressure. These are pneumatic teed together and connected to a second 30-psia Digiquartz in the instrumentation cabinet.

The total temperature and humidity are acquired by a Vaisala HMT334 sensor consisting of a probe installed into the settling chamber at station 700.

The data acquired from these transducers are used to calculate the flow conditions in the test section using adiabatic equations. These parameters are then used both for tunnel control and data acquisition. The accuracy and resolution details of these flow reference system transducers are provided in Table 9.

Table 9: FRS parameter specifications

Parameter	Range	Accuracy	Resolution	Unit
P_T	0 to 206.8	± 0.020	± 0.003	kPa
P_S	0 to 206.8	± 0.020	± 0.003	kPa
T_T	0 to 60	± 0.5	± 0.1	°C
RH	0 to 100	± 2	± 0.1	%RH

A barometric pressure transducer is also installed in the instrumentation cabinet, however this is not used for flow reference parameter calculations.

6.2. Model attitude

Due to the limited size of most models installed in the TWT, the model attitude measurements are usually calculated from the model support system resolvers.

To accurately determine the model orientation the deflection of the sting and balance must be considered. The deflection characteristics of this system is determined during pre-test model setup and used to apply deflection corrections to the model support yaw, pitch and roll readings. The estimated accuracy for incidence measurement is ± 0.02 degrees on the main model support and ± 0.10 degrees on the store model support.

For a model with sufficient size a high precision inclinometer can be installed to directly measure the pitch of the model enabling an increased reading accuracy of the deflected incidence.

6.3. Forces and moments

Model forces and moments are typically determined using internal strain gauge balance for full models. Most of the balances utilise tapered ends to enable efficient fitting inside models with tight diameter size constraints. These balance measure up to six components: axial force, side force, normal force, rolling moment, pitching moment and yawing moment.

A side wall balance is available for measuring the forces and moments on half models.

Basic dimensions and load ranges for the balances available are provided in Appendix A.

6.4. Pressure

A PSI-8400 system is integrated with the TWT DAC for measurement of multiple pressure tappings. This can consist of base, cavity, surface, or flow pressure measurements.

A number of electronic differential scanner modules are available with pressure ranges varying from ±10” H2O (2.5 kPa) to ±10 psi (68.9 kPa). Each scanner has the capability of measuring up to 32 or 64 ports and up to four scanners can be connected to the PSI-8400 system. An accuracy of ±10 Pa is achievable for 5 psi scanners corresponding to 0.03% accuracy full scale. Three pressure calibration units (PCU) with various ranges are available for calibration of the scanner units in-situ during test.

Two 159 kPa absolute Digiquartz are also available for measurement of reference pressures. These have an accuracy of 0.01% of full scale range.

6.5. Temperature

Several transducers are integrated in the facility to measure temperatures of various plant equipment such as cooling water flow or motor bearing temperatures. These transducers are connected and measured by the PLC system.

Balance, model, and/or flow temperature transducers can also be integrated with the DAC for a given test program. These transducers are typically Pt-100 RTD sensors which are connected to the VXI system.

6.6. Dynamic data

A portable standalone high speed data acquisition system (HS-DAS) is available for measurement of dynamic signals such as those coming from accelerometers, Kulite pressure transducers, hot-wires, microphones, and other fast response sensors. Up to 32 channels can be measured at 24 bit precision with a simultaneous sampling rate of 200 kS/s/ch.

The HS-DAS provides a flexible configuration allowing signal conditioning modules to be installed and tailored to meet particular test requirements and channel count.

A number of accelerometer modules and Kulite pressure transducers are also available for use.

6.7. Calibrations

6.7.1. Facility

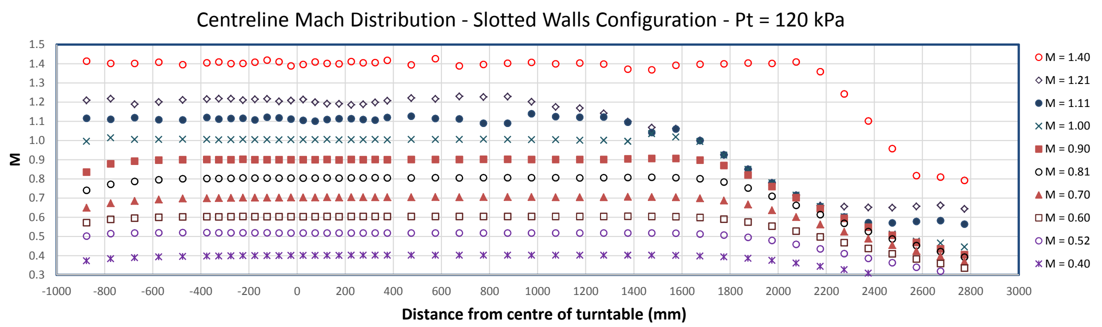
Acceptance tests were performed during tunnel commissioning in 2000 using a 25 mm diameter centreline static pipe. These measurements verified that the TWT Mach number calculation was accurately determined and that the axial pressure distribution was within acceptable limits.

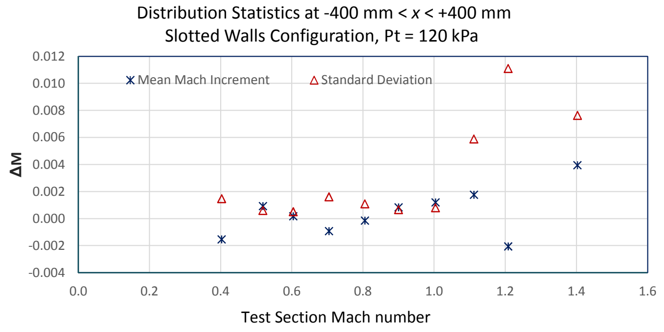
More comprehensive flow quality measurements in the test section were obtained in a 2017 calibration campaign using a 40 mm diameter centreline static probe with a typical result shown in Figure 22 (next page). This demonstrated a Mach number accuracy of ± 0.002 at a total pressure of 120 kPa.

Testing of the AGARD-B calibration model was also undertaken during commissioning and as part of the 2017 calibration campaign. This provided good comparison with measurements obtained in other established wind tunnels in the world. Results obtained validated the full process of wind tunnel testing at the DSTG TWT. This covers all elements that go into the final data produced including flow quality, instrumentation behaviour, data acquisition, and data reduction.

Internal strain gauge balances are calibrated on an as needed basis. This is determined in consideration of test requirements, date of last calibration, and results of check calibrations.

DSTG has a manually loaded calibration rig enabling first order balance calibrations. This can be sufficient for calibrating balances used for store separation testing and also for check calibrations of other balances. Where full second order calibrations are required, balances are sent to an accredited external calibration provider.





- Mean ΔM < ±0.002 for M < 1.0
- Mean ΔM < ±0.004 for M ≥ 1.0
- Standard Deviation < ±0.002 for M < 1.0
- Standard Deviation < ±0.012 for M ≥ 1.0

Figure 22: TWT centreline mach distribution (Pt = 120 kPa)

6.7.2. FRS (Digiquartz and Temperature)

The Digiquartz transducers used to measure the tunnel total and static pressure and the total temperature transducer are calibrated within three year intervals.

Calibrations can be performed in-house using a precision dead weight tester. Transducers can also be sent to NIST accredited calibration laboratories.

6.7.3. PSI-8400 equipment

The electronic scanner modules used to measure multiple model and/or flow pressures are calibrated in-situ during test using reference pressure calibration units (PCUs). The PCUs are calibrated within three year intervals using similar methods as the FRS Digiquartz.

6.7.4. Model support encoders

The model support encoders were fully calibrated during tunnel commissioning. Check calibrations are performed as needed with basic checks conducted prior to all test campaigns.

6.7.5. Electronic inclinometers

Inclinometers used to directly measure a model's orientation are calibrated on a tilt table against a reference inclinometer on an as needed basis.

6.7.6. Plant instrumentation

Pressure and temperature transducers and valves located around the plant for general operation purposes are checked periodically in accordance with standard TWT maintenance. Calibration of these sensors is performed on an as needed basis.

6.7.7. Data acquisition cards and signal conditioning units

The VXI A/D channels are calibrated prior to a test using internal onboard reference voltage sources. These reference voltages are calibrated annually using a precision multimeter.

6.8. Data reduction and corrections

Preliminary data reduction is performed during test by the ASE2000LX DAS so results can be monitored near realtime. This enables the operator to immediately identify any anomalous data and perform remedial action or change the test programme as necessary.

Final data reduction is performed using one of the peripheral PC's in the control room. This uses the ASE Excel VBA based program "WTDView" together with DSTG implemented algorithms to post process the data. This incorporates final data corrections and is used to produce the final data sets for provision to the client.

The main processes involved in producing the reduced data is described in the following sub-sections.

6.8.1. Flow parameters

The test section flow conditions are calculated from the reference transducers, settling chamber total pressure (Pt), total temperature (Tt), and plenum static pressure (Ps), using isentropic flow equations as detailed below.

Mach Number (M):

$$M = \sqrt{\frac{2}{\gamma - 1}\left[\left(\frac{P_s}{P_t}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

where ‘γ’ is the ratio of specific heats

Dynamic Pressure (q):

$$q = \frac{\gamma}{2} P_s M^2$$

Reynolds Number (Re):

$$\begin{aligned} \text{Re} &= \frac{\rho V d}{\mu} \\ &= \frac{M d}{\mu}\sqrt{\frac{\gamma}{R T_S}}\frac{P_T}{(1 + 0.2M^2)^{3.5}} \end{aligned}$$

where ‘ρ’ is the flow density

‘V’ is the flow velocity

‘d’ is the model reference diameter/length

‘R’ is the gas constant

‘Ts’ is the static temperature (calculated from the total temperature and Mach number)

‘μ’ is the dynamic viscosity (calculated from Sutherlands law)

6.8.2. Model position and orientation

Model position and orientation is calculated based on the support system readings taking into account offset/crank angles, model setting angles, and balance/sting system deflections.

For models with an inclinometer the orientation can be calculated directly from the inclinometer readings using the calibration taking into account any mechanical / electrical offsets for the inclinometer mounting.

6.8.3. Model loads

Balance readings are corrected for wind-off offsets. These corrected readings are then converted to gross balance loads using the balance calibration data. Loads are transferred to the model axes system taking into account translational and rotational offsets. This can include consideration of load dependant deflections between the balance and model axes. Aerodynamic loads are calculated taking into account the tare weight of the model including a component of the balance. These loads can also be translated into other axes systems as required. Loads are typically reduced to non-dimensional coefficients based on the dynamic pressure and model reference areas and lengths.

6.8.4. Model and flowfield pressures

Pressure tappings or orifices are pneumatically connected to scanners, with measurements acquired via the PSI-8400 system. These are normally non-dimensionalised to coefficient form using the dynamic pressure. Additional processing can be performed according to client requirements.

6.8.5. Corrections

Depending on test requirements the following data corrections can be applied:

- Flow angularity
- Base/cavity pressure.

Due to the high flow quality in the TWT and types of testing typically performed, the following corrections are not generally required:

- Test section static pressure
- Buoyancy
- Model blockage
- Wall interference
- Hydrostatic effects

6.8.6. Data provision

Parameter names for final results files can be defined by the client. Data can be provided to the client in the form of text files, spreadsheets, and/or graphical formats.

6.9. Specialised test techniques

6.9.1. Schlieren system

Schlieren flow visualisation techniques reveal the refractive density gradients in transparent media and find application in the visualisation of high speed compressible flows. A large field-of-view z-type Toepler Schlieren system has been designed and installed in the DSTG TWT to image the structures of high speed compressible flows within the test section and to aid in the interpretation of sensor-based data. The Schlieren system enables the identification of flow phenomena such as shockwave locations, expansion fans, and regions of boundary layer separation.

The DSTG system is capable of performing visualisation using the classic monochrome Schlieren method, tri-colour Schlieren method, and the direction-indicating dissection method (Figure 23). The dissection method is sensitive to gradient direction and captures all the important features of a compressible flow field in a single image. The monochrome and tri-colour filter methods detect the density gradient magnitude and are therefore complementary techniques to the direction-indicating method.

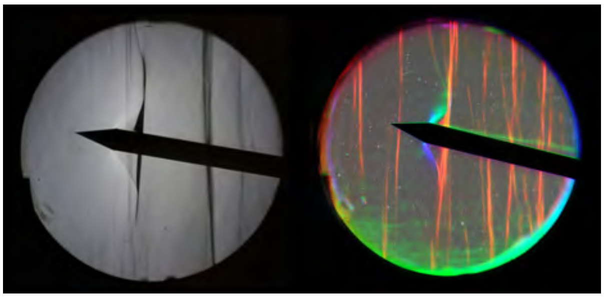


Figure 23: Schlieren flow over a cone-cylinder model – monochromatic (left), and direction indicating colour (right)

Optical layout of the Schlieren system is shown in Figure 24. The light source is installed between the plenum chamber and the tunnel return circuit, where space constraints dictated that the light path be folded using plane mirrors. Plane mirror (PM1) has a diameter of 100 mm and is used to direct the light beam to the collimating mirror SM1. The beam is then folded again using PM2, which has a diameter of 610 mm, and then traverses the test section before being focused using SM2. Both SM1 and SM2 have a parabolic surface profile and a diameter of 406 mm, while their focal lengths are 2517 mm and 2533 mm, respectively. Schlieren imaging requires the solid side walls to be installed. These sidewalls, and the plenum chamber walls, each house a 35 mm thick BK-7 high optical grade window, providing a 420 mm diameter clear aperture.

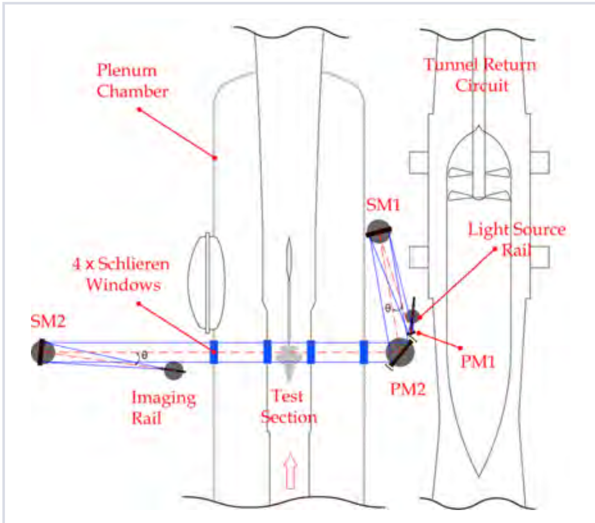


Figure 24: Schlieren system optical layout

The DSTG Schlieren light source is a high powered Light Emitting Diode (LED) driven by a Gardasoft RT820F-20 LED Lighting Controller. This unit offers eight independent constant current output channels, with currents of up to 2 amps continuous and 20 amps pulsed per channel. This enables the LED to be operated in continuous mode, or pulsed at high repetition rates, with pulse widths from 1 μs to 300 μs. DSTG has a range of camera equipment available enabling both high resolution and high speed flow fields to be captured.

6.9.2. Background – oriented schlieren

The z-type Toepler Schlieren system is limited to situations where direct optical access through the test section is available. The background-oriented Schlieren (BOS) method offers a viable solution to this limitation. As with the Schlieren system, BOS is a non-intrusive flow visualisation technique that reveals the density gradients in a flow. The experimental setup consists of a random-dot background pattern attached to the opposite wall of the test section, a light source and a camera. As the light travels from the background pattern through a density gradient, it is refracted by an angle equivalent to the integral of the refractive index along the path. In the image plane, this angular deflection causes an effective displacement of the dots in the background pattern that can be directly related to the density gradient. The displacement of dots is evaluated using the cross-correlation algorithm employed in processing PIV data (LaVision DaVis PIV software). Video capture is provided by high resolution 29 MP PIV cameras and four LED arrays.

6.9.3. Constant temperature anemometry

A constant temperature anemometer (CTA) system is available for signal conditioning of hot-wire measurements.

The CTA maintains the wire at constant temperature. The voltage measurement fluctuations output from the CTA are directly related to fluctuations in flow parameters, namely velocity, temperature, density.

Through characterisation of the heat transfer process and calibration of the hot-wire, measurements can be used to determine mean velocity, turbulence and spectra, Reynolds stresses and other cross correlations.

Use of the CTA system in the transonic regime is currently in development. The CTA system is typically used in conjunction with the HS-DAS for acquisition and digitisation of the hot-wire voltage readings.

6.9.4. Particle image velocimetry

Particle image velocimetry (PIV) is a quantitative laser diagnostic flow measurement technique providing the instantaneous velocity vector field over a plane within the flow. Typically, two velocity components (2C) or three velocity components (3C) with a stereoscopic arrangement can be measured. The technique is non-intrusive and requires the flow field to be seeded with small particles (~1 μm) which faithfully follow the flow. High resolution cameras capture images of particles that are illuminated with a high powered laser. PIV software is then used to determine the velocity of the particles. The result is a velocity field around the geometry of interest which provides much insight into the flow physics and can be used to obtain turbulent statistics which can aid in the validation of Computational Fluid Dynamics (CFD) simulations. Recently, long-distance high magnification PIV has been implemented and has allowed boundary layer profiles to be measured over models. This enhanced capability allows high resolution PIV to be used in regions of the flow around complex models that are inaccessible with probes, such as directly upstream of appendages and in regions of reverse flow or high flow angularity where probe measurements are generally invalid. The PIV system has been commissioned for use in the DSTG water tunnel and low speed wind tunnel facilities. A current project is in works to develop and deploy a PIV capability within the TWT.

6.9.5. Pressure sensitive paint

A pressure sensitive paint system, provided and operated by BAe UK, has been previously tested as a concept demonstrator in the TWT. This verified that pressure sensitive paint measurements can be successfully performed in the TWT.

6.9.6. Laser doppler anemometry

Laser doppler anemometry (LDA) is a non-intrusive optical technique used to measure flow velocity. A diode-laser based system supplied and operated by an Australian Defence Force Academy student was tested as part of a PhD in 2010, providing a proof of concept for this type of test technique.

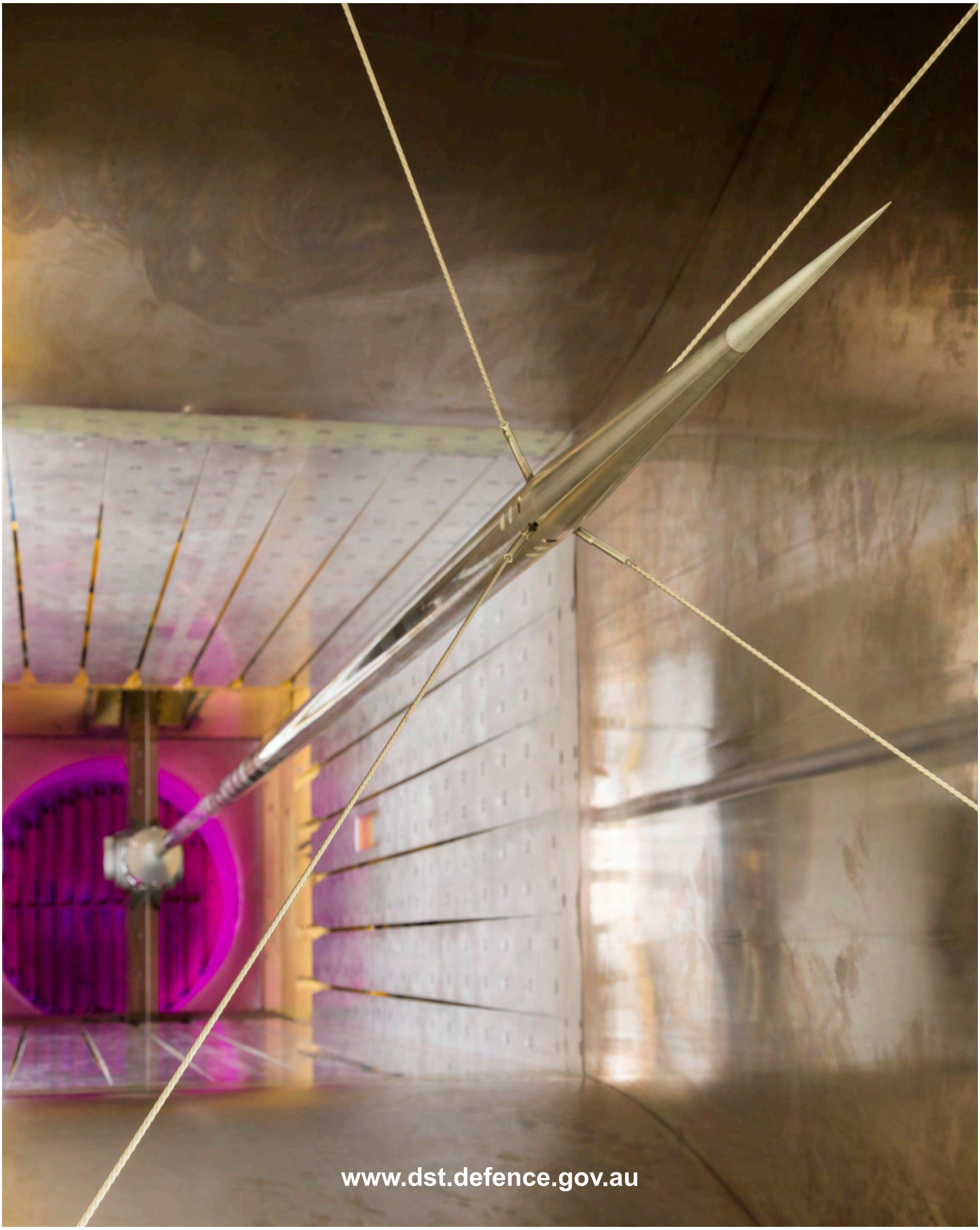
Appendix A. Balance Inventory

Name	Load Limits						Dimensions	
	Fx [N]	Fy [N]	Fz [N]	Mx [Nm]	My [Nm]	Mz [Nm]	Length [mm]	Diameter [mm]
DST-BAL-01	889	1557	3114	339	271	136	364.0	63.5
DST-BAL-02	1200	1600	3500	400	300	200	364.0	63.5
DST-BAL-03	1000	2000	5000	100	300	150	308.0	50.0
DST-BAL-04	100	1000	1000	12	50	50	178.0	25.0
DST-BAL-05	-	520	520	1.6	8	8	293.6	20.0
DST-BAL-06	-	260	520	1.6	8	8	114.4	20.0
DST-BAL-07	-	100	100	0.2	2	2	260.0	9.0
DST-BAL-08	-	150	150	0.4	2.6	2.6	333.8	8.0
DST-BAL-09	-	25	25	0.1	0.2	0.2	300.8	8.0
DST-BAL-10	-	-	2.5	-	0.02	-	285.8	8.0
DST-BAL-11	150	750	1500	15	60	40	200.0	20.0
DST-BAL-12	350	1200	2500	30	200	150	300.0	35.0
DST-SWB	3500	3000	18000	4000	1600	1600	TWT side-wall balance (half-models)	

NOTE: Limits specified for some balances are single component load limits. For other balances the load limits are defined by a rhombus with reduced allowable loads under combined loading. Further specifications can be discussed following a request for work or during model design when deciding on an appropriate balance.

Appendix B. Abbreviations and Nomenclature

A/D	Analogue to digital
ADFA	Australian Defence Force Academy
ASE	Aero Systems Engineering
BAE	British Aerospace Engineering
BOS	Background-oriented schlieren
CTA	Constant temperature anemometry
D/A	Digital to analogue
DAS	Data acquisition system
DSTG	Defence Science and Technology Group
FRS	Flow reference system
HS-DAS	High speed data acquisition system
I/O	Input / output
LDA	Laser doppler anemometry
M	Mach number
MS	Main model support
OEM	Original equipment manufacturer
PES	Plenum evacuation system
PID	Proportional–integral–derivative (controller)
PIV	Particle image velocimetry
PLC	Programmable logic controller
Ps	Static pressure
PSI	Pressure Systems Incorporated
PSP	Pressure sensitive paint
Pt	Total pressure
q	Dynamic pressure
Re	Reynolds number
RTD	Resistance temperature detector
SCP	Signal conditioning plug-on
SS	Store model support
TS	Sidewall turntable model support
Tt	Total temperature
TWT	Transonic Wind Tunnel
VXI	VME eXtensions for instrumentation


www.dst.defence.gov.au