DEVELOLPMENT OF THE HALF MODEL TESTING CAPABILITY AT ETW

Martin C.N. Wright
European Transonic Windtunnel GmbH
Ernst-Mach-Straße, D-51147 Köln, Germany

Keywords: *High Reynolds number, Transonic wind tunnel testing*

Abstract

The ETW facility is a high Reynolds number transonic wind tunnel with a partially slotted test section of 2.0 m x 2.4 m. It uses nitrogen as the test gas. With the combined effects of low temperatures and moderately high pressure, Reynolds numbers of up to 50 million at cruise conditions for full span models of large transport aircraft are regularly achieved. To extend the Reynolds number range up to 80 million ETW has developed a half model testing capability. The operational temperature range for both full and half model testing is 110 K to 313 K and the pressure range is 115 kPa to 450kPa. The Mach number range achieved during the initial half model development tests was 0.15 to 0.98.

The development of the half model capability at ETW has been driven by the requirements of the aerospace industry to achieve full scale flight conditions for future generation Very Large Aircraft in a ground based test facility. Considerable capital investment has been required to procure a model support system suitable for half model testing without compromising ETW's existing full model capability.

List of symbols

A_{TS}	Test section area
C	Local chord
C_{TS}	Chord based on $0.1*\sqrt{A_{TS}}$
M	Mach number
P_t	Stagnation pressure
Re	Reynolds number based on aerodynamic mean chord
T_t	Stagnation temperature
C_D	Drag coefficient
C_L	Lift coefficient
C_m	Pitching moment coefficient

1 Introduction

Following the start of wind tunnel operations in 1993 it became obvious that ETW needed to expand it's testing capabilities to include half models. A feasibility study was commissioned in 1994 to review the technical and financial aspects of developing a half model system and shortly after the option to modify one of the existing model carts was selected. Simultaneously, the specifications for the external balance and turntable were prepared and the decision to proceed with the project was taken. This paper provides a review of the various components that have been procured and the associated development activities that have been necessary to produce a fully operational system.

2 Model cart considerations

At present ETW has two model carts capable of supporting full models, Model Cart 1 has a large incidence range (-20° to +35°) suitable for combat aircraft testing whilst Model Cart 2 has an incidence capability from -10° to +20° which is dedicated to transport aircraft testing. The half model system comprises a new closed test section top wall equipped with a half model balance and has been designed to be exchangeable with the existing slotted (full model) top wall of Model Cart 1. The principal components of the system are shown schematically in Figure 1.

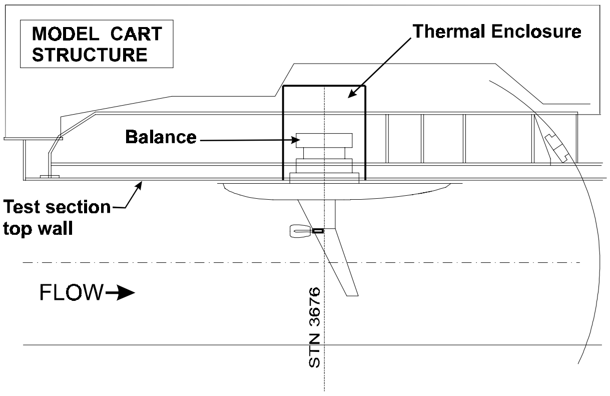

Figure 1 Half model schematic

In order to maintain ETW's capability for testing combat aircraft models a prerequisite for this system was the ability to perform the model cart configuration change from half model to full model and vice versa within a few working days. This aspect has been successfully achieved by installing lifting equipment in a dedicated model preparation area along with the design of matching electrical and pneumatic model cart top wall interfaces. Upon request, the exchange can be performed in a rapid, safe, and controlled manner. When the model cart is configured for half model testing the model loads are transmitted through the balance and turntable to the new top wall and from there to the cart structure.

3 Half model balance and turntable

The half model system uses a thermally conditioned balance attached to a dedicated turntable which, in turn, is connected to the top wall structure. A comprehensive thermal control system ensures that the balance is decoupled from ETW's variable temperature operating environment.

3.1 Half model balance

The balance has been designed for the combined static and dynamic loads listed in the following table. These loads are taken about the model reference position and in practice the balance capacity about the balance centre is much higher for the rolling moment and yawing moment components. The sixth balance component, side force, which is in the direction of model weight for the ETW half model system, is also measured by the balance, albeit at reduced sensitivity.

Balance Load Range and Sensitivities

Component	Load Range	Sensitivity (Each Bridge)
Normal Force	55,000 N	8 N/µV
Axial Force	5,500 N	0.9 N/µV
Pitching Moment	4,400 Nm	0.35 Nm/µV
Rolling Moment	33,000 Nm	0.7 Nm/µV
Yawing Moment	3,300 Nm	1.0 Nm/µV

The balance was manufactured from a single billet of Marval 18 Maraging steel and Figure 2 shows the bare balance structure being inspected just prior to the installation of the strain gauges. The finished balance has been fitted with thermal shields, which encapsulate the relatively thin flexures and help to minimize the convective flows in the region of the strain gauges.

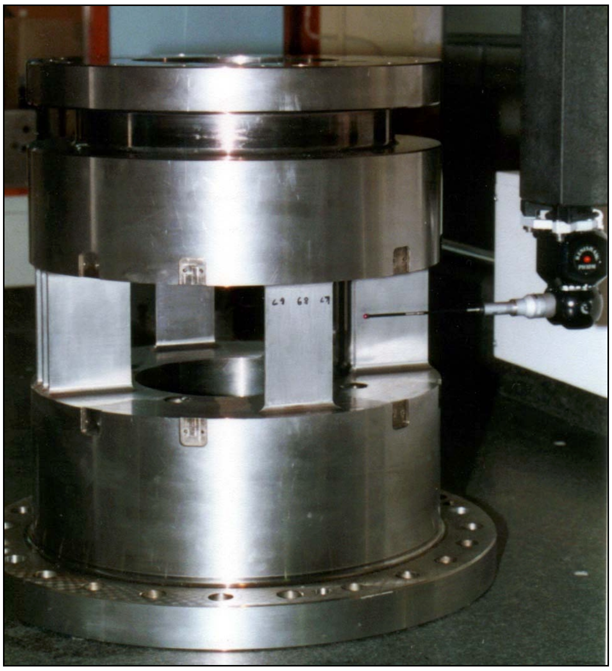

Figure 2 Half model balance

Accuracy is specified as a function of the combined operating loads. For normal force, axial force and pitching moment the accuracy is 0.1 % of the maximum load over 50 to 100 % of the range and 0.05 % below 50 %. For yawing moment and rolling moment the accuracy is 0.2% of the maximum operating load. The balance incorporates two independent gauge sets which have each been calibrated over the entire load range to produce independent calibration matrices.

3.2 Thermal protection

A comprehensive thermal control system has been developed by ETW to enable the half model balance and turntable to operate at stable conditions near to ambient temperature. The system has evolved during several design iterations and incorporates features to combat the cold conditions surrounding the half model balance and turntable. The schematic provided in Figure 3 shows the balance, turntable, and model cart structural components together with an indication of the heating concepts that have been used.

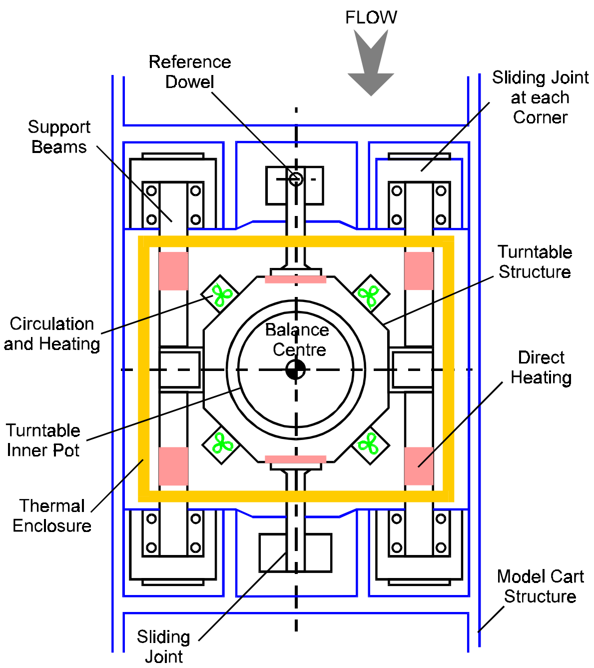

Figure 3 Heating concepts schematic

The balance and turntable are contained within a thermal enclosure, which is attached to the turntable structure, and all heating circuits are located within this enclosure. The enclosure has been fabricated from separate panels with each panel having a stainless steel outer skin filled with insulation material. Within the enclosure there are several separate systems which include a number of fan/heater combinations, several 'stirring' fans, a rapid response 'air-inlet' heater, and extensive wall heating. Figure 4 shows a view of some of the concepts employed within this enclosure.

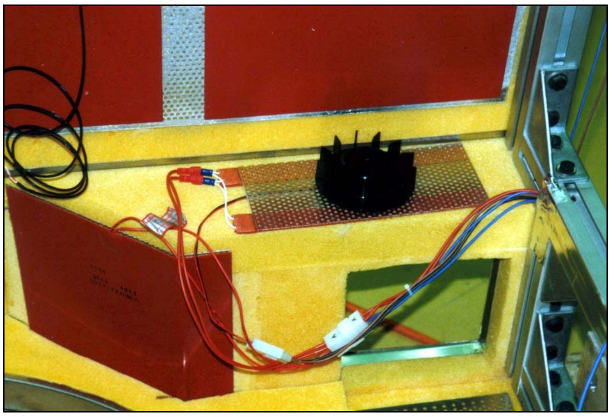

Figure 4 Enclosure internals

The structural interface components with the top wall are located outside the thermal enclosure as shown in Figures 3 and 5. To minimize the conductive heat losses through these relatively massive components a number of direct heating elements have been installed to act as thermal barriers. This has been combined with sliding joints to allow for the contraction of the top wall structure relative to the turntable structure when operating at reduced temperatures.

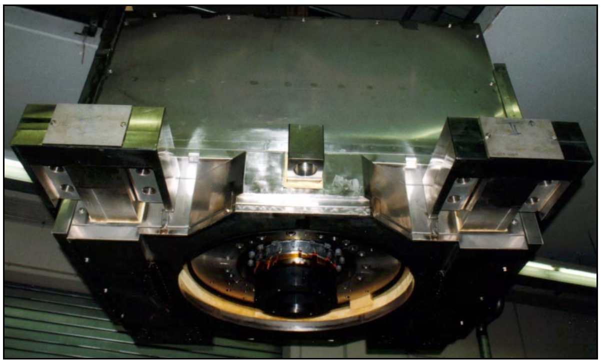

Figure 5 Enclosure externals

During initial trials with the half model system the critical area was identified as the area near to the base of the enclosure which is adjacent to the model mounting. In this area the complexity of heating has gradually increased and the final solution for the lower panel is shown in Figure 6. This panel rotates with the turntable and incorporates a combination of heat sinks and wall heating, with special attention to minimize gaps and associated leak paths.

The combination of concepts used within the thermal enclosure has been shown to apply heating in a diffused manner resulting in a uniform environment with almost no cold and/or hot spots. The balance temperature is then controlled to much closer tolerances near to the interface with the turntable attachment and between the balance structure and the model interface by low power direct heating.

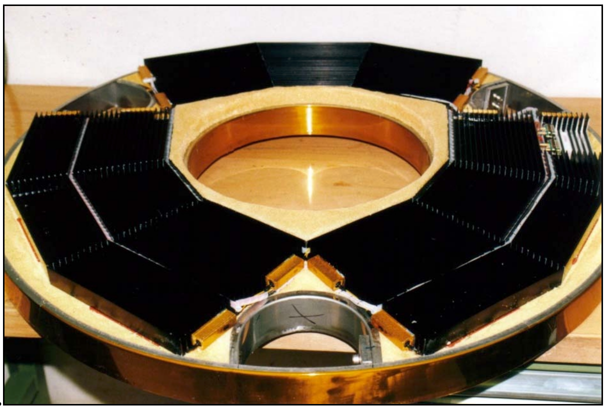

Figure 6 Enclosure lower panel

The heating systems described above are arranged as eight independent circuits with a total heat capacity of around 18 kW. Individual closed loop controllers are employed on each circuit. The controllers for each circuit are fully integrated in the overall data acquisition system and the control set points have been optimized during several trials at ETW over a range of conditions.

3.3 Turntable

During the development process severe problems were encountered with the rotating elements of the turntable and the drive system such that the initial concept had to be completely replaced. The drive system now incorporates a two stage worm screw drive system, as shown in Figure 7, which is capable of moving and positioning the test model under all load conditions.

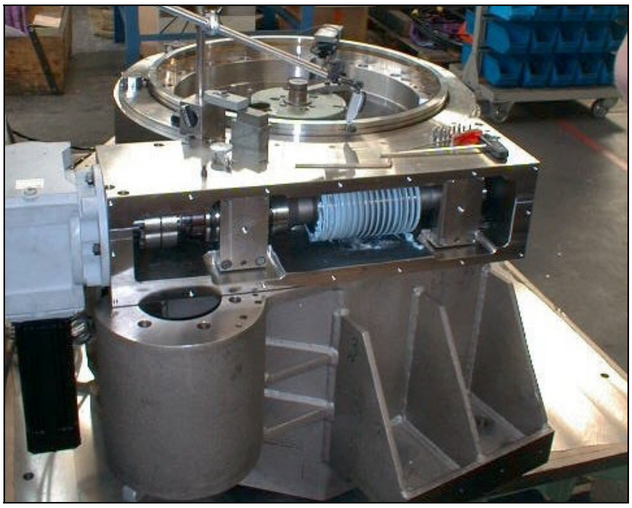

Figure 7 Turntable workshop trials

The turntable system has been designed for the following parameter ranges:

Drive System Performance	
Drive Torque	> 11 kNm
Incidence Range	- 45° to + 45°
Incidence Rate	0.05°/sec to 1°/sec
Incidence Acceleration	up to 0.5°/sec^2
Minimum Increment	0.01°
Movement Control	Pitch & Pause, Continuous
Positional Accuracy	± 0.005°

The turntable drive system is fully integrated into the existing model movement system such that the half model test sequences can be completed under automatic control. The incidence measurement system includes two digital signals and one analogue signal which are used for control, measurement and monitoring. The turntable drive mechanism also drives a set of rotating cover plates attached to the flow liner plate on the Model Cart. These cover plates are maintained on the earth side of the balance and rotate concentrically with the centre of the half model balance. The cover plates have been designed to enable a model Peniche (non-metric fuselage spacer) to be installed.

4 Balance calibration

The essential element of the half model concept is that the balance is maintained at constant ambient temperature throughout all wind tunnel operating conditions and therefore only a single calibration is required. Figure 8 shows the calibration rig installed in the balance calibration room at ETW. In this view the balance is installed in the turntable drum (removed from the initial drive system) which is attached to an earthed ‘yellow’ calibration frame whilst a live calibration frame is attached to the metric side of the balance.

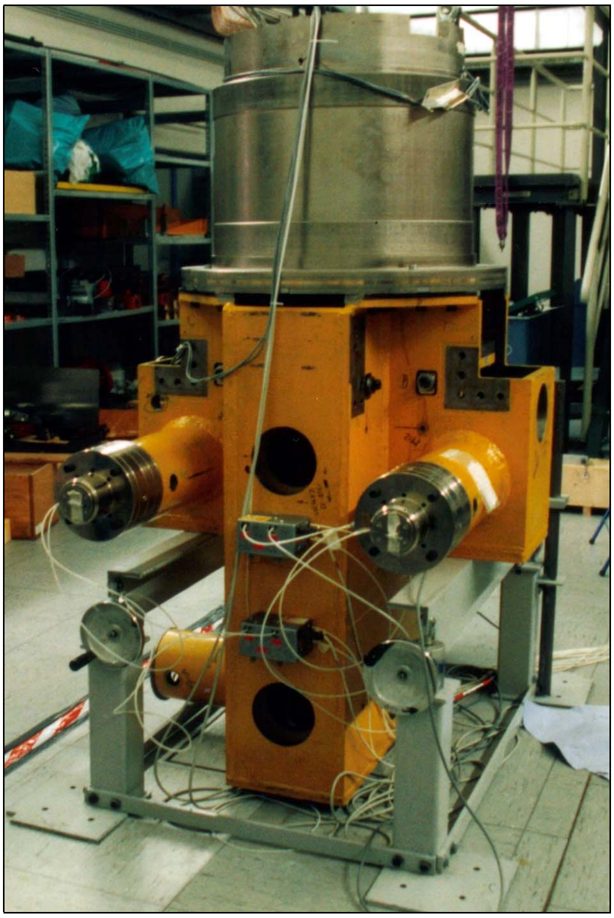

Figure 8 Balance calibration

The calibration loads are applied by using pneumatic force generators which can be installed at discrete locations on the calibration frames as shown schematically in Figure 9. In this figure two 50 kN capacity force generators are used to apply forces in the normal force direction and two 5 kN capacity force generators are used to apply forces either in the axial force direction or, as a couple, to apply a pitching moment. By using a combination of positive and negative loadings a substantial calibration envelope can be covered.

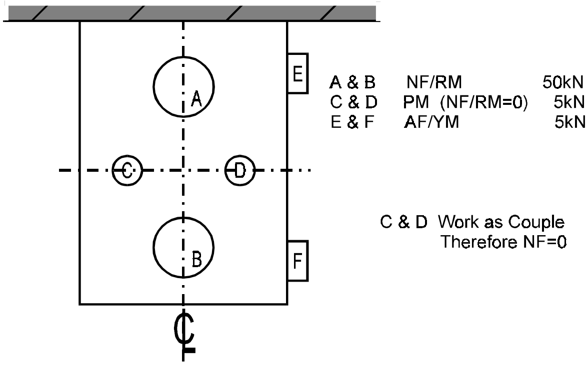

Figure 9 Loading frame schematic

A schematic of the force generator and loading train is shown in Figure 10. A precision controller is used to set the pressure on one side of the force generator piston and the applied load is measured directly by high quality load cells. The application of loads has been automated such that the force generators can be controlled by a PC to enable predefined loads to be applied with associated commands to trigger data acquisition.

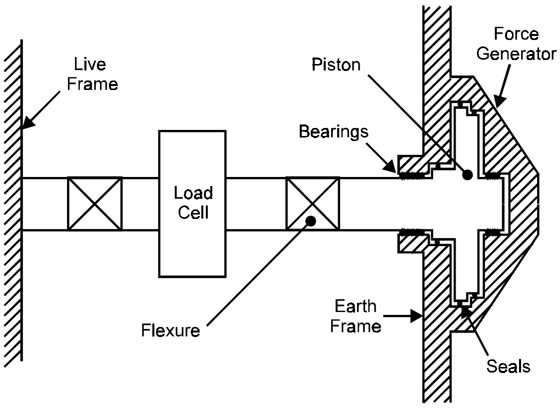

Figure 10 Calibration load train

During the initial calibration trials at ETW in late 1998 the loading system was found to function adequately during the application of individual loads but the loading concept introduced errors when combined loads were applied. A combination of axial force and normal force is always of prime interest for wind tunnel testing and an alternative force train concept had to be developed to resolve this shortcoming. The original force train system incorporated flexures incorporating spherical bearings / bushings which were compatible with loading in the positive and negative directions but introduced friction when combined loads were applied. An alternative load train was developed to enable 'pull' forces to be applied simultaneously in the normal force and axial force directions. This load train is shown in Figure 11 (upper) together with the original force train.

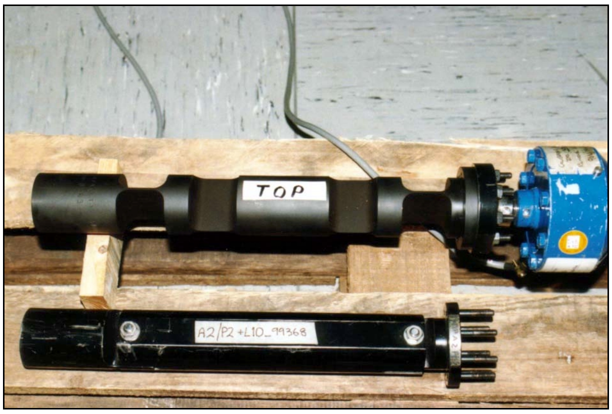

Figure 11 Force train development

During the final calibration in April 1999 with the new load trains a large number of loadings were applied to the balance and a balance matrix was derived for each gauge set. This initial calibration demonstrated compliance with the initial accuracy specification and based on the experience gained a reduced number of loadings will be incorporated in future calibrations.

5 Selection of half model test section

The test section in general is equipped with the capability of having all four walls slotted. For full model testing only the top and bottom walls are slotted in order to reduce the model blockage and minimize wall interference effects in the transonic Mach number region. During the early stages of the half model development a study was initiated to assist the selection of the most appropriate test section. The study reviewed the test sections shown in Figure 12 in terms of the 'empty' characteristics and also the correctability of test results when a model is installed.

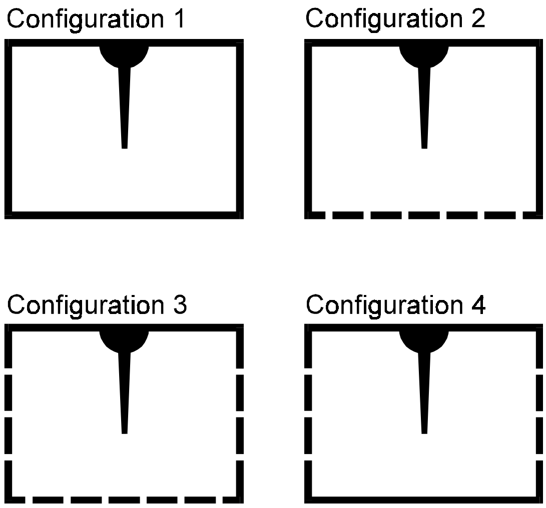

Figure 12 Wall configuration options

The study made use of the Pilot European Transonic Windtunnel (PETW) which is a 1/8.8-scale representation of ETW. The PETW test section was modified to include the required slot configurations and a representatively scaled pressure plotted half model was manufactured to be used as the reference device for the wall interference investigations. The model is shown installed on the top wall of the test section in Figure 13.

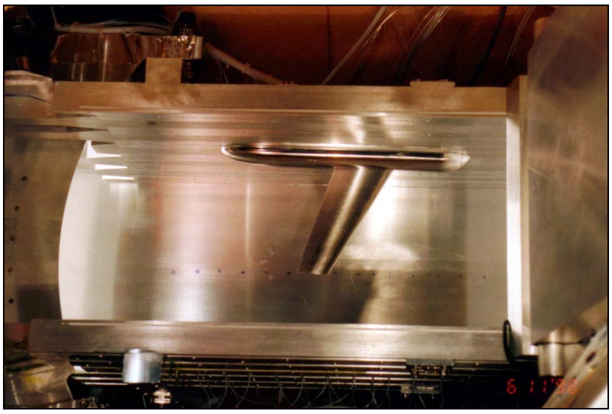

Figure 13 Half model in PETW test section

The technique used to determine the wall interference in the slotted-wall cases depended upon an initial test in a solid-wall version of the test section. A definitive set of results was obtained for the half model between solid walls by applying corrections using well-established methods. With no change to the model, the relative performance of the different slotted wall configurations was then assessed by direct comparison with the fully corrected solid wall datum. The analysis of the results [1] revealed that changing the slotted regions of the walls had a powerful effect. A summary of the Mach number increment due to blockage is provided in Figure 14 for each test section configuration. This demonstrates that wall interference could be practically eliminated over the Mach number range from 0.2 to 0.9 by using slots in the sidewalls. On the basis of this result, together with a similar conclusion from the analysis of wall constraint effects, the decision was taken to adopt this slot configuration for ETW. To realize this test section, a new set of slot inserts was fabricated in accordance with the results from the PETW study. When the slots are installed in the ETW test section the effective test section porosity is 4.6% for half model testing.

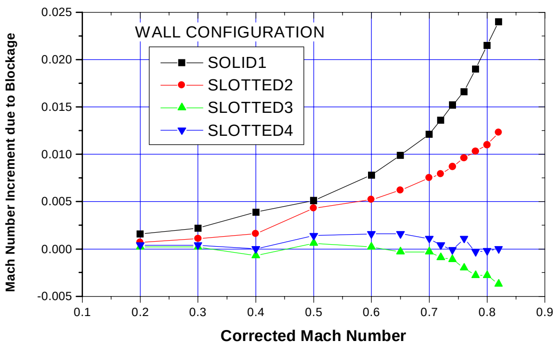

Figure 14 Effect of wall configuration

6 Commissioning and calibration

The half model system has been commissioned during several test campaigns utilizing both the ETW test section and the Variable Temperature Check-out Room (VTCR) facilities. The VTCR was used on several occasions to assess the performance of the enclosure and associated heating systems at several temperature conditions, including a prolonged soak at 120 K. The information obtained from these trials identified areas which required further improvement and in the first instance several significant shortcomings were identified. The enclosure was completely re-engineered to the present standard and the total heat capacity has been increased by more than 100% during the complete commissioning period.

The most significant experiences were gained in June 1999 when the first wind-on commissioning trials were completed in ETW. A simple symmetric Commissioning Half Model (CHM), which has been designed compatible with both the balance load envelope and the tunnel test envelope, was used for these trials. Figure 15 shows the CHM installed in the ETW test section. Several polars were recorded at test temperatures down to 180 K, which identified some further limitations of the thermal control system.

Figure 15 CHM in the ETW test section

The system was evaluated further during the empty test section calibration phase which was completed in August 1999. The calibration covered the Mach number range from 0.15 to 0.98 at temperatures from 280 K down to 115 K with resultant Reynolds numbers up to 70 million (based on C_{TS}=0.3098 m) as shown in Figure 16.

Following the test section calibration the lower part of the enclosure was modified with the addition of extra heating elements on the lower panel (Fig. 6) together with improvements to the sealing methods to reduce gas exchange.

The second CHM commissioning trials, completed in September 1999, successfully covered a large proportion of the test envelope.

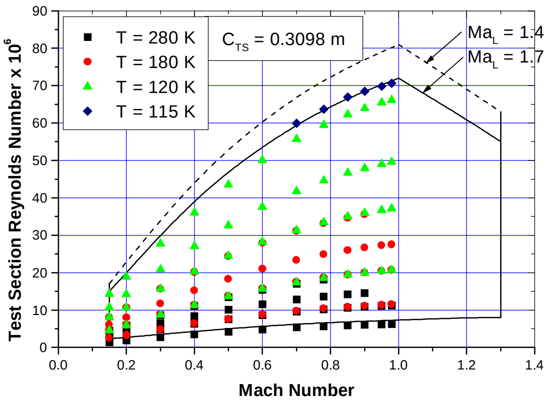

Figure 16 Half model calibration conditions

7 First test results

The crucial aspect of the thermally conditioned balance concept is the ability to condition the balance to a uniform temperature and then to control the temperature to close tolerances independent of ETW's variable temperature operating environment. In practice, this concept has been shown to work effectively and the resulting balance temperature stability is impressive, even at cryogenic conditions, as demonstrated in Figure 17.

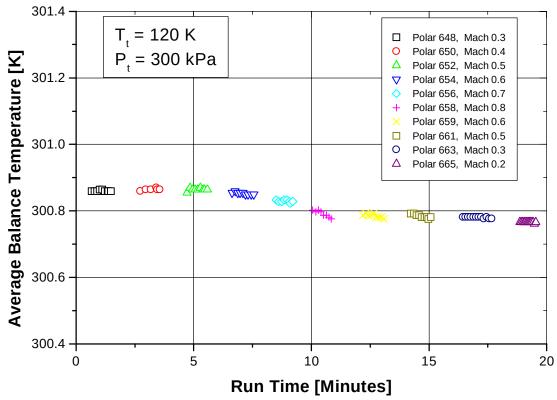

Figure 17 Balance temperature stability

These results show that during the execution of 10 transonic polars at cryogenic temperature the variation of the average balance temperature was less than 0.1 K. Although the total heat capacity of the system is substantial the power applied to the model adapter under the cryogenic conditions shown in Figure 17 was as low as 20 Watts. At these power levels any parasitic effect of heat flux into the model is minimal.

The results achieved with the new system have been very promising throughout the complete test envelope. An example of the short term repeatability is presented in Figure 18 for a Mach number of 0.6, a temperature of 120 K, and a total pressure of 300 kPa. Under these test conditions the standard deviation of the drag coefficient was well within 1 drag count. Similar levels have also been demonstrated for both medium term and long term repeatability.

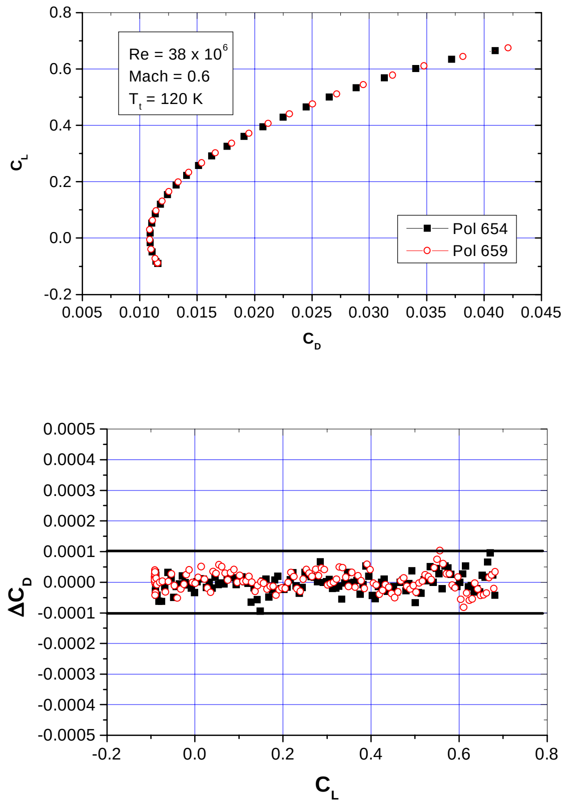

Figure 18 Short term repeatability

The half model system has also been used successfully at low speed and at reduced levels of dynamic pressure where balance stability strongly influences the quality of results. DaimlerChrysler Aerospace Airbus provided the model shown in Figure 19 for the purposes of validating the ETW half model system against their existing low speed database.

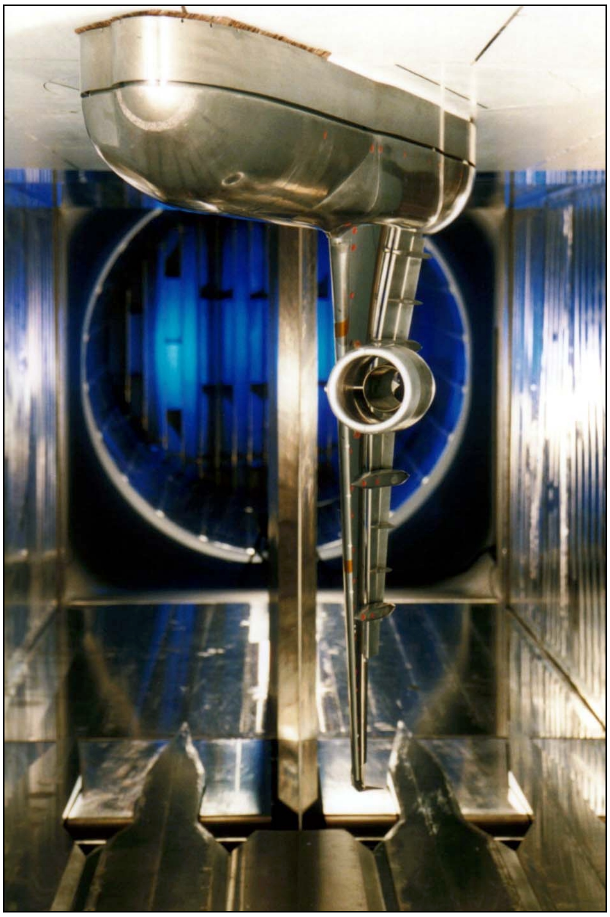

Figure 19 K3DY Half Model

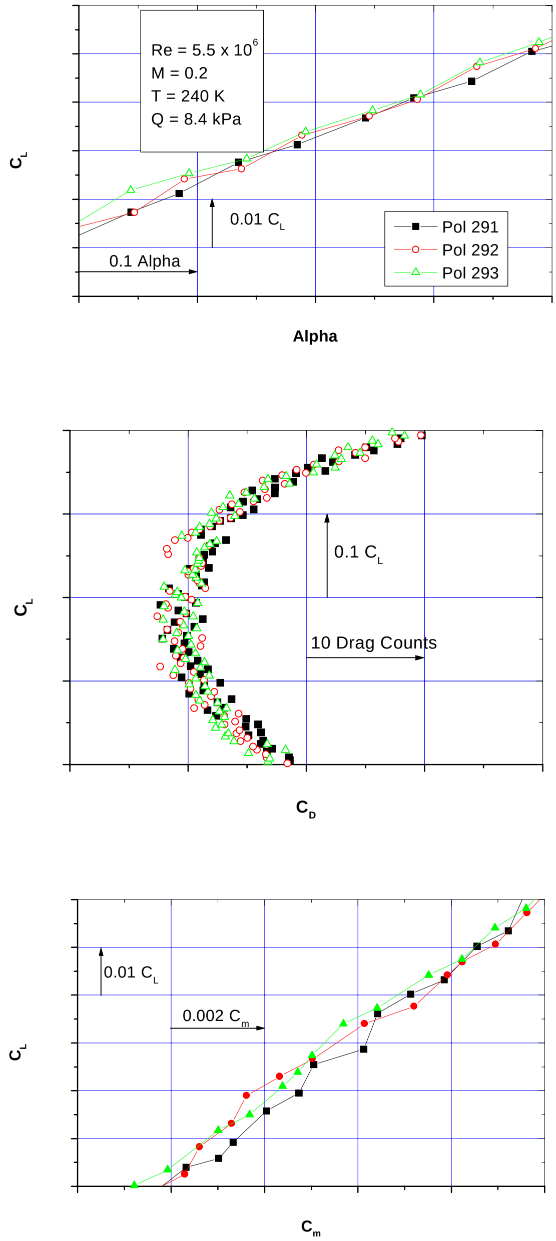

Figure 20 Low speed repeatability

During this initial validation series the model was tested at incidences up to and beyond maximum lift at low speed for a substantial Reynolds number range. Figure 20 presents the data from 3 consecutive polars to give an indication of the short-term repeatability. Different parts of the C_L versus alpha, C_D versus C_L, and C_m versus C_L curves have been expanded to show the distribution of the data points. The level of repeatability is considered excellent for this condition where the differences seen are close to the resolution of the balance. The achievement of these levels of repeatability give ETW a high level of confidence in the ability to test throughout the entire range of tunnel operating conditions.

8 Future development

Having demonstrated the basic capability for testing half models at ETW several additional activities are now underway. As previously noted the facility has been equipped with slotted sidewalls and a test series to derive the wall interference corrections has been planned for 2000. This test series will use a representative high speed model to derive corrections by using the solid test section configuration as a datum in a similar manner to both the PETW tests noted above, and also the existing corrections used for full model testing at ETW. Previous experience has indicated that this task is extremely difficult and it is only due to the high levels of confidence in the measuring systems that the programme is being initiated.

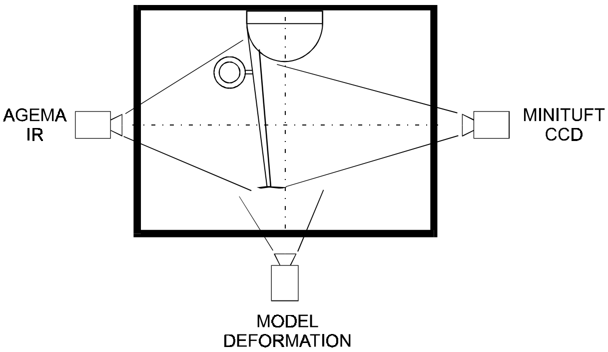

Figure 21 Test section systems

In parallel with the development of appropriate wind tunnel corrections a number of specialized measuring systems will be applied to the half model system as shown in Figure 21. The Infrared system, based on the AGEMA Thermovision camera which has been successfully used to visualize the condition of the boundary layer on full models [2] down to flow temperatures of around 220 K, will also be applied to half models. ETW has developed a cryogenic minituft technique for full model testing to enable clients to visualize flow features at flight Reynolds numbers. This technique will also be applied to half model testing at both high speed and low speed conditions. Finally, a model deformation measurement system is being developed for the half model system which uses a high quality CCD camera installed in the bottom wall of the test section to view specific parts of the model at discrete test conditions.

9 Conclusions

Following the extensive and costly development period the ETW half model system is now operational and is able to acquire high quality measurements over a range of test conditions that is unique in Europe. The balance, turntable, and supporting structure have been demonstrated to operate well within their initial specifications. Further developments are underway to enhance the half model capability by installing appropriate test systems.

Acknowledgements

The author wishes to thank the many organizations that have made positive contributions to this project. Thanks are also due to the dedicated staff at ETW who have contributed significantly to the successful integration and development of the half model system.

References

[1] Jordan R. *An investigation of wall interference on a half model in PETW - effect of wall configuration.* DERA/MSS4/CR990067/1.0, 1999

[2] Ansell D, Schimanski D. *Non-intrusive optical measuring techniques operated in cryogenic test conditions at the European Transonic Windtunnel.* 37th AIAA Aerospace Sciences Meeting and Exhibit, Reno, AIAA 99-0946, 1999.