ETW - A FACILITY FOR HIGH REYNOLDS NUMBER TESTING

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Abstract:

The European Transonic Windtunnel (ETW) at Cologne, Germany, is a cryogenic high pressure facility. It provides the capability for achieving full scale flight Reynolds numbers of transport aircraft by testing at pressures between 1.25 and 4.5 bars and at temperatures between 310 and 110 K. The tunnel started operation in 1994, and, after a phase of commissioning, calibration, and evaluation, it is available for productive testing. The report gives an overview of the tunnel design and the measuring techniques used, and presents some results on Reynolds number effects at low and transonic Mach numbers.

1. Facility Descriptions and Characteristics

1.1 Operating Characteristics

The ETW facility is a transonic windtunnel using nitrogen as test gas. High Reynolds numbers are achieved under the combined effects of low temperatures and moderately high pressures. Some characteristic data are listed in figure 1.

Test Section	***2.4 m x 2.0 m***
Mach Number Range	***0.15 - 1.3***
Pressure Range	***1.25 - 4.5 bar***
Temperature Range	***110 - 313 K***
Max. Reynolds number	***50 million***
Productivity	***3 to 6 Runs per day***

Figure 1 : ETW Specification

The test section size and the pressure and temperature ranges represent the best combination of parameters to meet the requirement from the aerospace industry to achieve a Reynolds number of 50 million at cruise conditions for large transport aircraft. This takes into account the limitations on minimum temperature (condensation effects) and maximum pressure (model loads). The operating range expressed as Reynolds number versus Mach number is presented in figure 2.

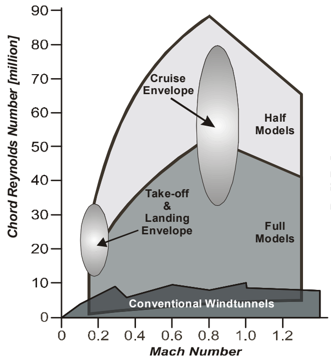


Figure 2: ETW Mach-Reynolds Number Envelope

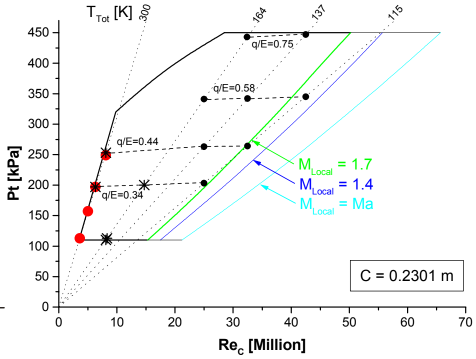


Figure 3: Typical Full Model Test Envelope at Mach = 0.85

The unique feature of a cryogenic wind tunnel is the controllability of the temperature which makes it possible to separate pure Reynolds number effects from model deformation effects. This is illustrated in figure 3 where a typical test programme for the investigation of these effects is shown. For a constant Mach number, the total pressures of test points versus Reynolds number are plotted with the temperature as a parameter. The temperature variation allows the Reynolds number to be changed at constant model loads (q/E = dynamic pressure / Youngs modulus = const) and, likewise, the investigation of aeroelastic effects at constant Reynolds number.

1.2 Aerodynamic Circuit

ETW has a closed aerodynamic circuit (figure 4) contained inside an internally insulated pressure shell. The two stage, fixed blade compressor is driven by a 50 MW synchronous motor. To achieve the desired low temperature of the test gas, liquid nitrogen is injected into the tunnel upstream of the compressor. The corresponding gaseous nitrogen exhaust upstream of the stilling chamber is controlled by valves for the accurate setting of the tunnel pressure. From the settling chamber with a honeycomb and two screens, the flow enters the test section via a fixed contraction and a flexible nozzle of overall contraction ratio 12. The test section has slots in the top and bottom wall for full span model tests and slotted side walls for half model tests.

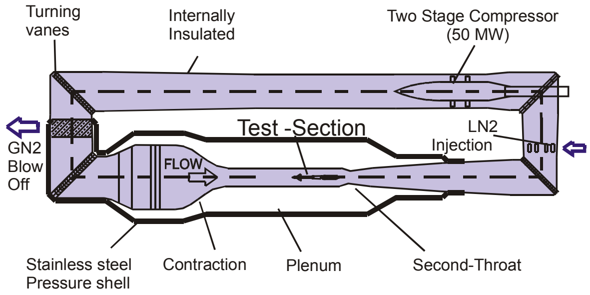


Figure 4 : Aerodynamic Circuit

The control of the Mach number can be done by three different concepts, i.e. the RPM of the compressor, the losses produced by trim flaps in the diffusor and by running the diffusor as a critical “second throat” controlling the critical area by the trim flaps. The Mach number stability is better than ∀ 0.0015 throughout a polar, the second throat control yielding the best result but, on the other hand, being the most expensive one because of the high losses.

1.3 Model Handling

As a consequence of using low temperature nitrogen as the test gas, two serious operational difficulties arise: The first problem is the accessibility of the model inside the test section for quick changes between runs, the second one is the danger of building up frost on the model surface in case the model temperature is below the dew point of the test gas. Furthermore, in todays economic climate not only must a windtunnel produce high quality aerodynamic data but it must achieve it at reasonable cost and on time for the client. In order to achieve this under the condition of strict confidence, a modular system adapted to cryogenic conditions has been designed (fig. 5).

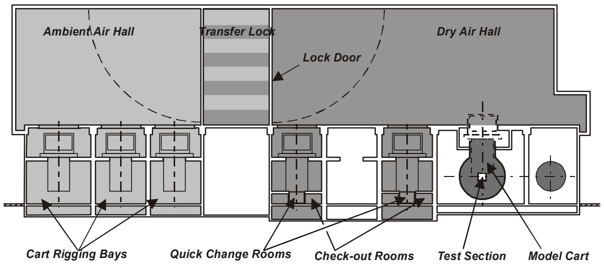


Figure 5: Section Through ETW Transfer Hall

After preparation of the model under ambient air conditions in a cart rigging bay, the whole set-up including model, model support, upper test section wall and instrumentation cabin is moved via a lock into an area of very dry air, where it can be checked out under cold conditions and be transported to the test section. For a quick change, the model needs to be moved from the test section into a “variable temperature check out room”. This system facilitates the preparation of another model on a second model cart in one of the cart rigging bays in parallel to the test being undertaken in the windtunnel.

2. Special Testing Capabilities and Equipment

The test arrangement most frequently used is the full span model mounted on a sting via an internal balance. ETW ownes a variety of balances which are calibrated at regular temperature intervals on the ETW automatic calibration machine [1]. The machine allows the conditioning of the balance to any temperature between ambient and 110K and an accurate calibration at this temperature. Inside the model, the cool down of the balance is accelerated by a special cold nitrogen system, shortening the conditioning time of the balance.

A disturbing phenomenon well known from conventional windtunnels is the dynamic behaviour of the model / support system. To attenuate model vibrations, ETW has developed an Anti Vibration System [2], which is sketched in figure 6a : An interface, the essential part of which is a set of annularly grouped piNzoceramic elements, is arranged between sting and balance.

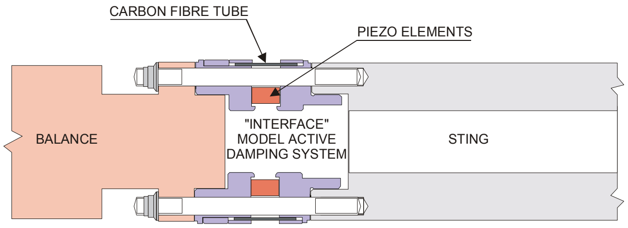


Figure 6a: Anti-Vibration System – Active Interface Schematic

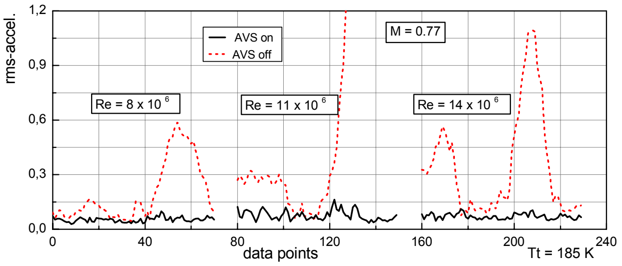


Figure 6b: RMS values

By exciting the elements, an elongation or contraction will be generated which results in movements in X, pitch and yaw direction. If this is done in counterphase to the model movements, an attenuation of the model vibrations will be achieved. The results are shown in figure 6b, where the RMS values of the z-accelerations during a polar are plotted for the AVS inactive and active.

Driven by the requirements of the aerospace industry to achieve full scale flight conditions for future generation Very Large Aircraft, ETW has developed a half model capability (figure 7) [3].

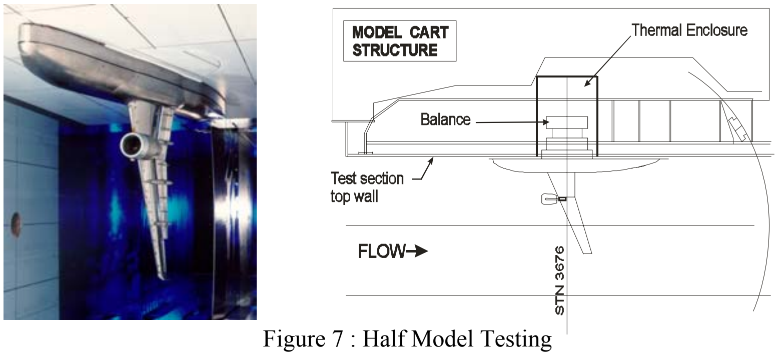


Figure 7 : Half Model Testing

The model is mounted to the external balance which is installed in the top wall of one of the two ETW model carts. The balance is located in an insulating enclosure which is kept under constant temperature above ambient for all test conditions by a carefully designed heating system. The balance is calibrated at this temperature. The load range is 55 kN for normal force, 33 kNm for rolling moment (reference is the intersection between the balance axes and the tunnel wall), 4.4 kNm for pitching moment and 5.5 kN for axial force.

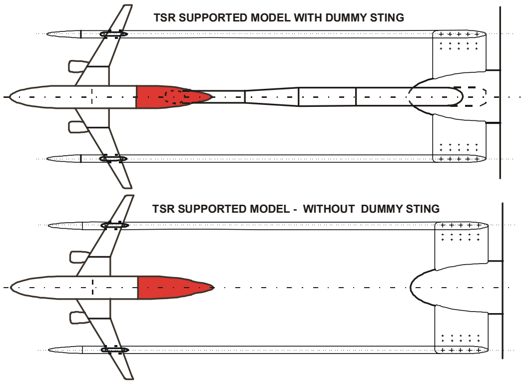


Figure 8 : Standard TSR Method

For sting interference measurements and afterbody investigations, ETW offers a Twin Sting Rig which is sketched in figure 8. The rig can be used in two modes: The version represented in figure 8 uses a split fuselage with an internal balance measuring the forces and moments on the afterbody. The second mode uses two balances mounted between the supporting booms and the wings measuring the forces and moments on the complete model.

3. Special Instrumentation

In addition to conventional instrumentation for force/moment and pressure measurements, ETW operates a variety of special instruments the most important of which are a set of infrared cameras and a Model Deformation Measurement System (MDMS) [4].

Two different infrared cameras can be used for transition detection at different temperature ranges: An "off the shelf" system is applicable for temperatures from ambient down to 220 K, a specially designed system is used down to 110 K. A series of images for a Reynolds number range between 3 million and 33 million at two different temperatures is presented in figure 9.

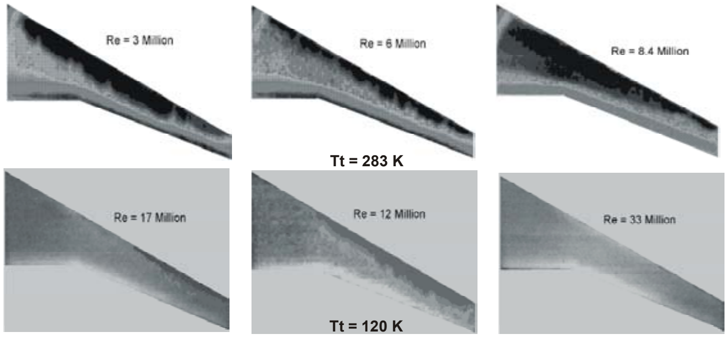


Figure 9 : Acquisition of IR Images – M = 0.785, C_L = 0.4°

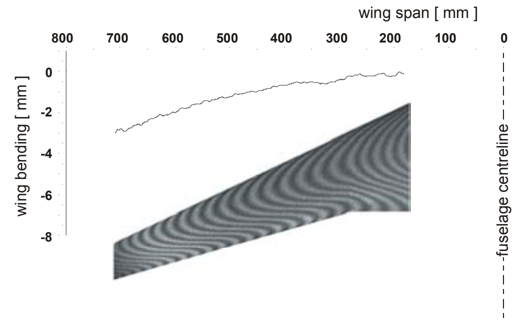
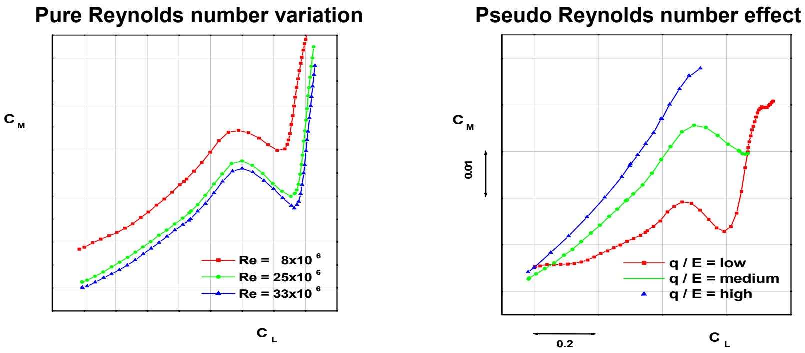


Figure 10 : Wing Bending Evaluated by MDMS-System

In order to fully exploit the unique capability of a cryogenic wind tunnel concerning Reynolds number variation at constant q/E, an exact measurement of the model deformation is of great interest. A system based on the Moiré principle has been developed providing wing deformation data which can be reduced to yield the bending and twist of the wing (figure 10**)**.
In addition, ETW has developed an approach to evaluate the effective wing twist from pressure measurements [5].

4. Some Results of High Reynolds Number Testing

It has been pointed out above that one advantage of a cryogenic wind tunnel is the elimination of pseudo Reynolds number effects by achieving different Reynolds numbers at different combinations of pressure and temperature. As an example, figure 11 shows pitching moment polars for three different Reynolds numbers [6]. In the left plot, the model loads, i.e. q/E, have been kept constant, in the right plot the temperature has been kept constant and the Reynolds number has been changed in the conventional way by varying the dynamic pressure. The plots show an opposite tendency for the two different ways of setting the Reynolds number, and only the left plot gives the correct answer.


Pure Reynolds number variation

Pseudo Reynolds number effect

Figure 11 : Reynolds Number Effect on Pitching Moment

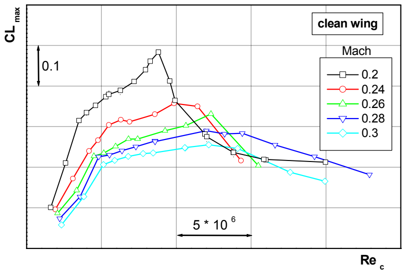


Figure 12 : Typical Reynolds Number Effects on Maximum Lift

ETW's capability to achieve flight Reynolds numbers at take off and landing conditions is more and more recognized by clients as flow phenomena at high lift are strongly Reynolds number dependent. Figure 12 shows the maximum lift as a function of Reynolds and Mach number for a clean configuration. Although the real Aircraft is not able to fly in this configuration at Mach numbers below ca. 0.28, the results are of high theoretical and practical interest regarding the steep drop of $C_{L\ max}$ for low M and the decrease of $C_{L\ max}$ with increasing Reynolds number at the area of flight conditions[7].

5. Summary

Apart from the unique Reynolds number capability, ETW offers additional features attributed to the variable temperature and its controllability. These are mainly the possibility of separating model deformation effects from Reynolds number effects, the application of infrared imaging and an excellent repeatability of test results. In addition, special devices like an external balance for half model testing, a twin sting rig, an anti-vibration system, and a model deformation measurement system are instruments for a great variety of tests at a large range of test conditions.

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