ETW-Simulations of True Flight Behaviour

ABSTRACT

The capabilities of the European Transonic Windtunnel ETW to simulate flight conditions by testing at cryogenic temperatures are presented. The achieved flow quality and tunnel control form the basis for an excellent data repeatability and a high confidence level in the deliverables. Unique instrumentation has been developed to provide additional information about the test object and the surrounding flow field during tunnel entries. Typical samples of Reynolds number effects are shown. Productivity aspects are considered on the basis of recently performed test scenarios.

INTRODUCTION

The original motivation to build facilities for flight Reynolds number simulation of aircraft models was based on significant differences between wind-tunnel and flight, often leading to costly design changes after the first flight. Nowadays, with the availability of advanced CFD methods, some Re effects are better understood but so called indirect Re effects are still difficult to predict.

Striving for a capability to analyse such effects by experimental investigations on a wind-tunnel model, it is obvious to ask for :

a) an appropriate facility allowing the independent variation of single aerodynamic parameters and covering a wide Re-number range, ideally up to flight conditions,
b) extraordinary steady and dynamic flow quality to generate conditions comparable to flight
c) a high level of tunnel set point stability and repeatability.

THE FACILITY

The ETW facility is a high Reynolds number transonic wind tunnel of Eifel type, using nitrogen as the test gas. It can be operated in solid wall or partially slotted test section mode. The Mach number range is 0.15 to 1.35. By pressurisation, the total pressure can be varied between about 115 kPa to 450 kPa , while temperature variations are feasible over a range from 110 K to 310 K.

This available ability to independently control velocity, temperature and pressure provides unique capability for separating true Reynolds number effects from any pseudo Re-effects, induced by the model supporting system or the flow around the model.

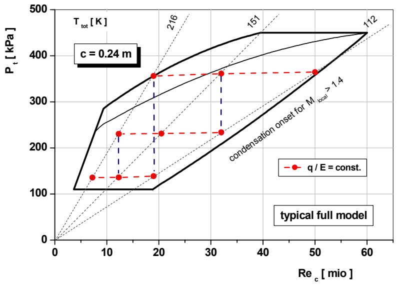

Figure 1 : Operating Envelope for Ma = 0.9

Additionally, effects of wing distortion may be investigated by a variation of dynamic head at constant Reynolds number. Figure 1 illustrates an eventual test scenario for a large transport aircraft model targeting for a coverage of the Reynolds number range up to flight conditions including a consideration of pure Reynolds as well as aeroelastic effects. Assuming a variation of Mach number in the order of eight per indicated condition allows to complete the presented scenario in one day for one model configuration.

FLOW QUALITY IN ETW

Extraordinary comprehensive experimental investigations to assess the steady state flow quality have been performed during two major phases undertaken during the mid 1990's. Homogeneities of total pressure of better than 0.15% total head and temperature (less than 0.25 K) could be documented at flight conditions by flow surveys in the model volume [1].

For the determination of the dynamic flow quality, hot-wires, hot-films, microphones, piezo-foils and KULITE pressure transducers have been committed. The central flow field as well as areas near the walls have been covered by measurements including wall mounted arrangements.

Corresponding rms-values in figure 2 demonstrate levels of 0.12% to 0.25% after integration up to a frequency of 20 kHz. The visible trend of decreasing levels with increasing Mach numbers is in good agreement with results achieved with other applied techniques.

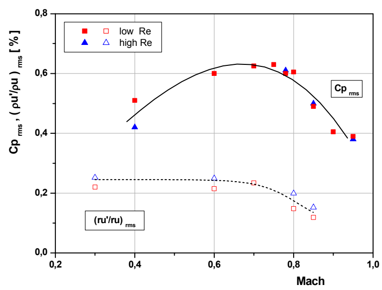

Figure 2 : pressure - & velocity fluctuation level

Corresponding normalised pressure fluctuations show the well known maximum to occur at a Mach number around 0.75.

CONTROLLABILITY & REPEATABILITY

In ETW, simultaneous direct control of stagnation pressure, total temperature and Mach number is feasible by combined setting of the blow off system, the injected liquid nitrogen flow and the compressor speed. Further improvement to Mach number stability during a polar can be achieved by activating the second throat. This technique allows the Mach number to be kept constant within better than +/- 0.0005 when pitching the model continuously with a rate of 0.25 degrees per second.

Typical deviations in Mach number are presented in figure 3, documenting the above stated quality. The indicated test conditions refer to Reynolds numbers covering the test capability from an ambient non-pressurised facility up to full scale flight condition. It should be emphasised that operating at pressure levels below 125 kPa is outside of the original ETW design specification.

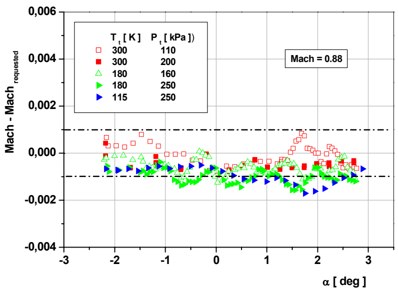

Figure 3 : Mach number variation during a polar

TEST ASSEMBLY STANDARDS

It is obvious that due to the reduced boundary layer thickness, wind tunnel testing at high Reynolds numbers requires a higher standard of model surface quality than ambient testing. As a consequence, for the first generation of models to be tested in ETW, mirror polished metallic surfaces with a roughness of better than Ra = 0.1 were regularly achieved.

The introduction of non–intrusive measuring techniques at cryogenic conditions requires the application of model coatings, either for reduction of thermal conduction in the case of applying the IR-technique for the detection of boundary layer transition, or to generate a diffuse non-reflective surface for the successful operation of the **M**odel **D**eformation **M**easurement **S**ystem **MDMS**, which is based on the Moiré technique.

Nowadays, the model wings can be machined providing a surface quality of Ra = 0.2. Manual polishing to improve the surface finish to Ra=0.1 is only applied over the first 20% of wing chord. Preparing the model for IR-imaging or MDMS measurements, 100µm thick white coating is sprayed onto the main part of the wing. Subsequent polishing keeps the upstream 3% chord in its original metallic condition, whilst a roughness of Ra = 0.15 can be achieved on the remaining surface. As a consequence, the leading edge area is more tolerant against particle impacts providing a major improvement in the confidence for aerodynamic data quality and boundary layer behaviour.

INSTRUMENTATION

One of the most essential quantities to be measured in aerodynamic testing refers to the incidence of the model. ETW have developed a concept, based on Q-flex incidence measurement, which is able to fulfil the challenging demands of accuracy, resolution and operational reliability.

The present ETW standard offers the specified accuracy in incidence measurements of 0.01 degree together with a resolution of 0.001 degree.

The test envelope of wind tunnel models in pressurised facilities is mostly restricted by load limits due to increased dynamic pressure levels. Further operational constraints may be caused by excessive vibrations of the model, generated by the supporting system or the test object itself.

To improve model safety in pitch–pause and continuous traverse mode with a simultaneous gain in aerodynamic data quality, an **A**nti **V**ibration **S**ystem (**AVS**) has been design and commissioned at ETW.

Generated amplifications can be exploited for the attenuation of the vibrations by counteracting the oscillations in a controlled way by an excitation produced by piezo elements.

The final set up of the complete system is installed between the flanges of the six-component strain gauge balance and the sting, in the support line of the wind tunnel.

Recently performed commissioning trials [2] have demonstrated the extraordinary capability of the device as given in figure 4. Running in continuous pitch without AVS (classical configuration), encountered vertical accelerations on the model exceeding gravity levels of 1g leading to a cancellation of the polar to protect the model and the balance.

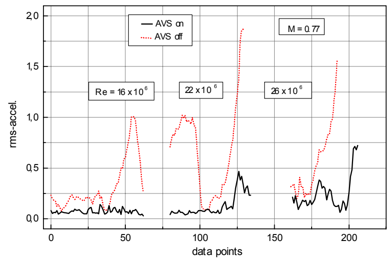

Figure 4 : Vertical acceleration with and without AVS

With the AVS system activated the vibration level could significantly be reduced allowing an extension of the pitch range.

To improve the understanding of results, additional information may be requested on flow development and behaviour. In this respect any knowledge about the characteristic of the boundary layer is of common interest. For such purpose ETW has selected the infrared imaging technique. This allows remote sensing of infrared radiation, emitted by the temperature patterns on the model surface. During the test, a step change in temperature is induced which causes different heat transfer rates to occur in the laminar and turbulent boundary layer for example.

Presently, two systems are owned : The standard AGEMA system which is operable down to about 210K and the so called CRYSTAL system, a complex unit which requires cooling by liquid Helium and a vacuum insulated housing. CRYSTAL can be operated down to 100K covering the flight Reynolds condition of most of the models.

TYPICAL REYNOLDS NUMBER EFFECTS

Direct Reynolds number effects such as skin friction follow defined scaling rules and can more easily be predicted. In this context the relation lift-pitching moment was declared as an indirect Re-number effect.

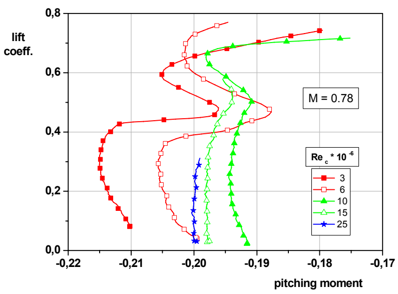

Figure 5 : Reynolds number effect on pitching moment

For the case presented in figure 5 natural transition is applied to the wing at design Mach number. In areas of dominating laminar flow, i.e. low Re and lift coefficients below 0.5, an increase of the Reynolds number from 3 to 10 million leads to a reduction in the pitching moment by about 0.02. A further increase of Re causes an opposite trend due to a downstream movement of the shock in a mainly turbulent flow environment.

Since the end of 1999 ETW has been in a position to offer a half model test capability to clients. A Mach number range from 0.15 up to about sonic conditions can be covered. As high lift model configurations to be tested at low speeds present an area of particular interest, relevant validation tests with a representative model have been performed at an early stage.

Figure 6 impressively documents the superior test range of the facility in comparison with conventional tunnels.

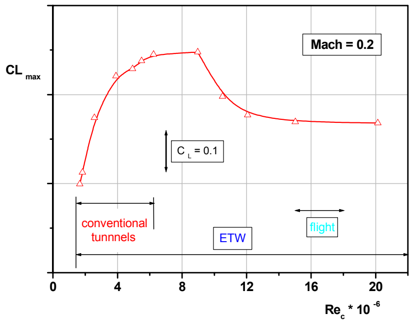

Figure 6: Reynolds number effect on maximum lift for a half model configuration

Classical scaling rules applied to results obtained in conventional tunnels may not accurately predict flight status as shown for the maximum lift behaviour. Challenging demands on the quality of pressure measurements have to be fulfilled for this type of testing, to ensure the accuracy of the dynamic head which is used to normalise the aerodynamic coefficients. Due to the low absolute Q-levels, small deviations in the static reference pressure can easily generate errors of a few lift counts.

PRODUCTIVITY ASPECTS

From a commercial point of view the target is always the minimisation of testing time. Operating in a cryogenic environment obviously requires more time than ambient investigations due to the limited accessibility to the model and the periods devoted to thermal conditioning of equipment to provide best data quality and high confidence in the aerodynamic results. Hence, the specific test requirements , such as configuration changes of the model, dominate a drafted test-scenario which is subsequently optimised time- and costwise by ETW in agreement with the client.

In half model testing, the temperature controlled 'warm' balance is not affected by any time consuming balance conditioning. Consequently, moderate test scenarios covering the full temperature envelope can be performed within one day. Figure 7 documents the setting of tunnel parameters required to complete a typical test programme with a half model.

The Mach number ranged from 0.17 to 0.3. For such tests, the maximum cool-down rate of 80 K/hour can be applied. If a pressurisation of the tunnel will be required (e.g. to investigate aeroelastic effects) , the experience gained recommends to run the polars at maximum requested tunnel pressure at first and then to

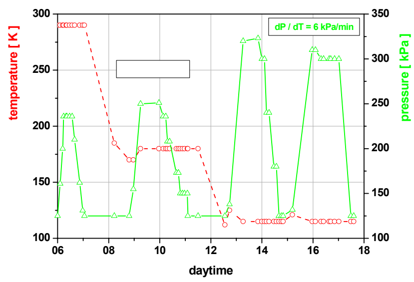

Figure 7 : Low speed test scenario for a half model

proceed to lower levels in a descending order for time saving reasons. The acceptable pressurisation rate may be dictated by stress limitations on the models which may be severe for high lift configurations.

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