The Transonic Wind Tunnel Göttingen (TWG)

German-Dutch Wind Tunnels

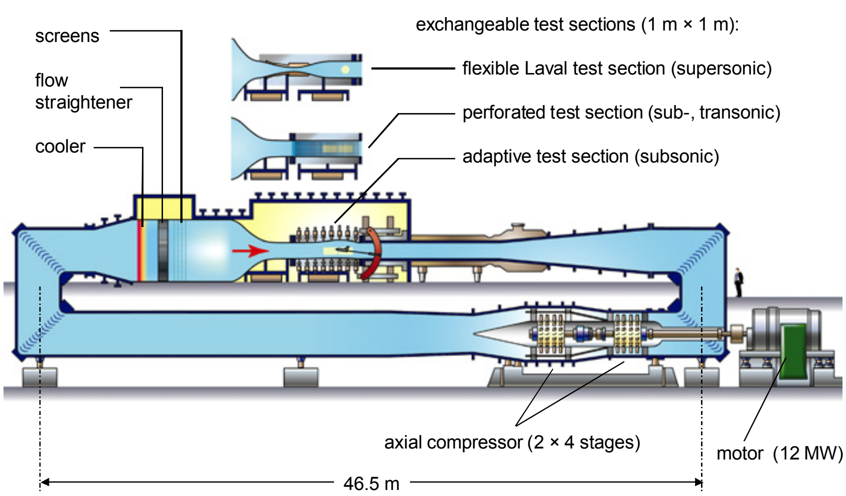
www.dnw.aero

The TWG is a closed circuit, 'Göttingen Type', wind tunnel for sub-, trans-, and supersonic flow research and development tests at air, space, and surface vehicle configurations and components.

Key Technical Parameters

Mach number		**Total pressure**	0.3 ÷ 1.5 × 10^5 Pa
Adaptive walls	0.3 ÷ 0.9	**Dynamic pressure** (max)	0.53 × 10^5 Pa
Perforated walls	0.3 ÷ 1.2	**Temperature range**	293 ÷ 315 K
Laval nozzle	1.3 ÷ 2.2		
Reynolds number		**Test section size**	1 m × 1 m × 4.5 m
(max, l_{ref}=0.1 m)	1.8 × 10^6	**Contraction**	16:1
		Drive power	12 MW

Figure 1



The eight-stage axial compressor with an electrical power supply of 12 MW allows for continuous flow in the test section. An auxiliary radial compressor with 3 MW is used as a suction plant, in the case that the test section with perforated walls is installed in the plenum chamber. The whole tunnel can be pressurized or evacuated, thus enabling variation of stagnation pressure and Reynolds number independently of the Mach number. An efficient air drying system guarantees humidity levels low enough to avoid condensation and flow disturbance in the whole speed range. The water cooling system is designed to keep the tunnel temperature constant in the specified range.

Since its commissioning in 1964 the TWG has been repeatedly upgraded. Major modifications have provided improved flow quality, extended test spectrum, and increased productivity in a new concept with three exchangeable test sections, exchangeable model supports, and excellent model access. The test section, model support, and model change logistics are enabled by an air cushion transport system. The plenum chamber can be accessed by a 10 m wide sliding door to the plenum. Inside the plenum, for free model access, the tunnel circuit can be opened by axially moving the contraction nozzle, together with the test section, several meters into the settling chamber. The tunnel components,

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the test runs, and the measurement and data acquisition are automatically controlled by an integrated hard- and software system.

Simulation Range

The Mach number range covered by the three test sections of the TWG is $0.3 \le M \le 2.2$. Between M=0.9 and 1.2 the flow simulation needs additional suction through the perforated walls and out of the plenum with re-injection behind the flexible diffuser. To vary the Reynolds number, the total pressure of the test gas can be varied in the range 0.3 ÷1.5 $\times 10^5$ Pa. This results in maximum Reynolds numbers of 1.8×10^6 based on a 3D model reference length of 0.1 m or 7.2×10^6 based on a maximum airfoil model chord length of 0.4 m.

Test Sections

Three exchangeable test sections with a cross section of 1 m × 1 m and a length of 4.5 m are designed with emphasis on different Mach number ranges.

Figure 2

Plenum (sliding door and test section opened).

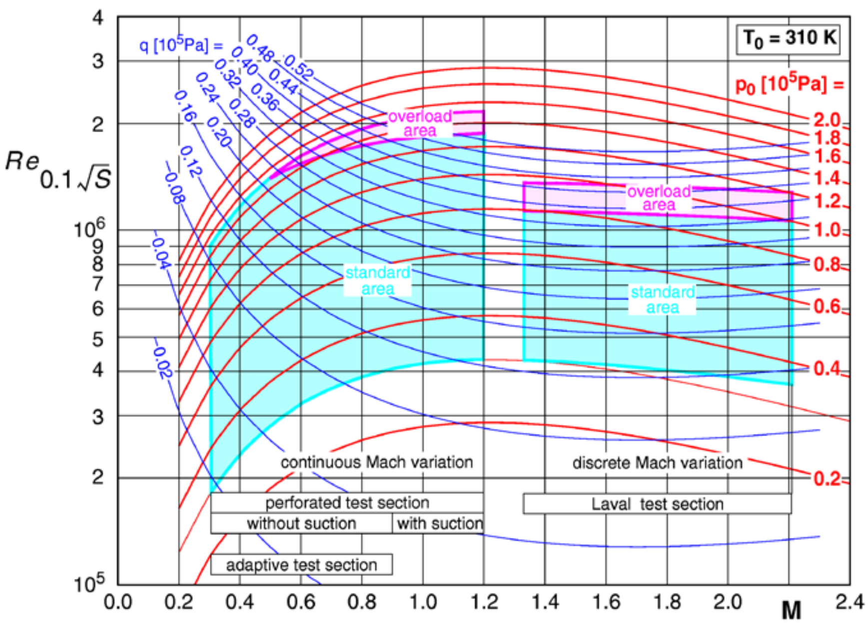

Figure 3

TWG simulation range.

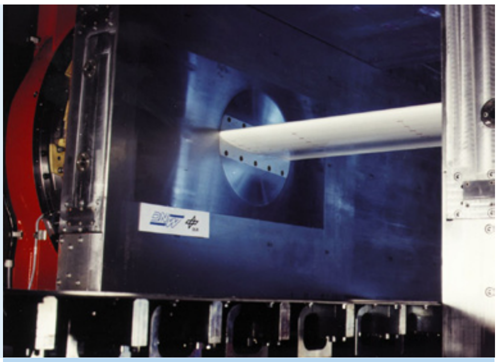

Figure 4
Model installation between side walls.

The transonic test section with conventionally perforated walls (6% open, 60° inclined, M_{design} = 1.05) can be operated with different suction rates in the range 0.3 ≤ M ≤ 1.2.

The second test section has flexible upper and lower walls allowing a 2D adaptation to the flow field. Thus, compared to conventional test sections, the wall interference is reduced and/or larger models can be used in the range 0.3 ≤ M ≤ 0.9. Using wall pressure distribution measurements a single-step algorithm, based on Cauchy´s integral formula for airfoil (2D) tests and on the Wedemeyer-Lamarche method for 3D models respectively, is applied to the adaptation. In case of 3D model testing the small residual wall interferences are calculated by Green´s integral formula and used for final correction.

The supersonic test section is a conventional Laval nozzle with flexible top and bottom walls calibrated for discrete Mach numbers in the range 1.3 ≤ M ≤ 2.2.

Model Supports

The flexibility of the TWG, especially the modular construction of the adaptive and the perforated test section, provides for the possibility to realize a variety of different model supports, depending on the special test requirements. Two classes of model supports are used.

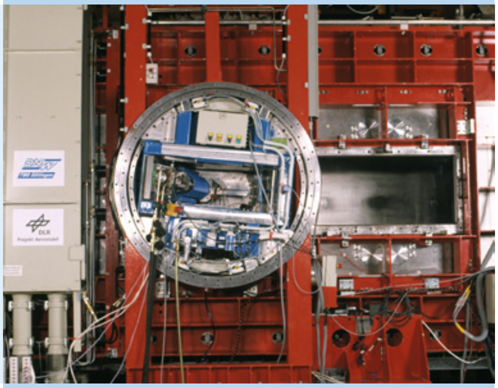

Figure 5
Dynamic half model support on the support portal.

Model Installation on or between the Side Walls

Airfoils are fixed between synchronized slewing rings on both sides of a portal support, surrounding the adaptive or the perforated walls test section. The walls are closed by turn tables. The remotely controlled pitch angle covers ± 15°,

Test Sections and Model Supports

which can be shifted by an offset installation. This support is placed upstream of the standard 3D model position in order to provide a better wake simulation, especially for 2D models.

The portal support is designed to support half models or side sting mounted models and to take up hydraulically driven pitch and heave oscillation and flutter test beds. This and other dynamic test beds, specifically adapted to the TWG, are operated by the DLR Institute of Aeroelasticity at Göttingen. In the supersonic test section (Laval nozzle) remotely controlled, synchronized half model supports can be installed in the side wall window frames.

Model Installation on the Downstream Sword

3D models are typically are supported on the sword, which can be rotated by = ± 17° and traversed vertically by Δ z= ± 100 mm and axially by Δ x=250mm. The center of rotation is 1500 mm in front of the sword leading edge. The sword, with models installed, can stay in the tunnel circuit, while the three test sections are exchanged. A special air cushion system allows to move the sword with the installed model out of the tunnel to a parking position in the wind tunnel hall. The integrated roll unit covers the range ϕ = ±100°. Model support stings can be flanged at arbitrary angles. The whole support system is designed to bear the following maximum loads acting in the rotational center of the sword (corresponding to the strongest standard internal strain gauge balance):

Forces:	Moments:
X ≤ 2000 N	L ≤ 500 Nm
Y ≤ 4000 N	M≤ 500 Nm
Z ≤ 8000 N	N ≤ 500 Nm

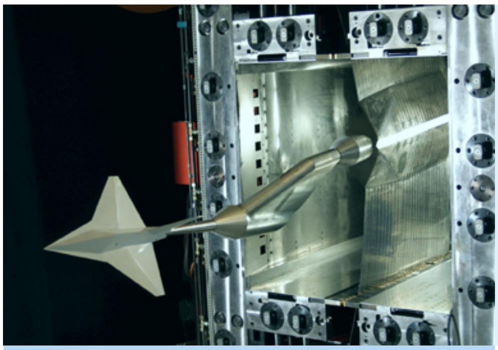

Figure 6
PSP coated model on a cranked roll adapter (used for direct sideslip simulation).

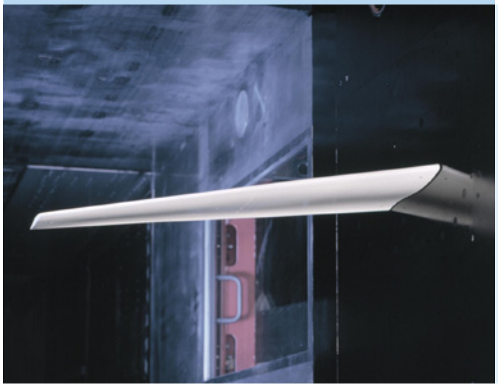

Figure 7
Elastic wing model on dynamic half model support.

Higher angles of incidence are realized by using adapters with appropriate crank angles. Some of them have a remote-controlled roll drive of their own and thus, in combination with the main roll device, allow direct sideslip simulation.
Several experiments with models rapidly rolling with the rear sting were realized with the help of specially designed fast rolling units, flanged to the sword. The rolling motion is either free (only aerodynamically driven) or forced by an electrical motor (constant, oscillatory, or transient).

A special sword with a hydraulically driven pitch mechanism is available to examine fast pitch maneuvers.

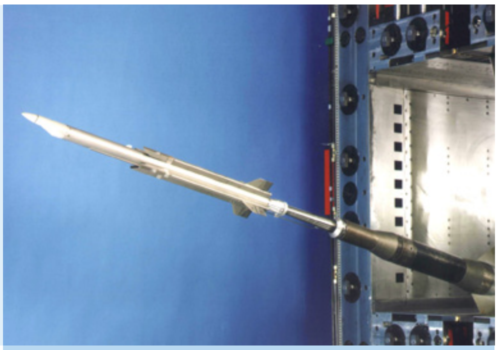

Figure 8
Missile model with trough flow ducts (throttle cone behind tail nozzle).

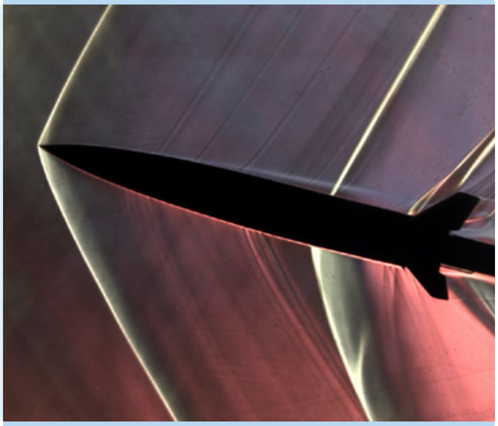

Figure 9
Schlieren picture of space vehicle.

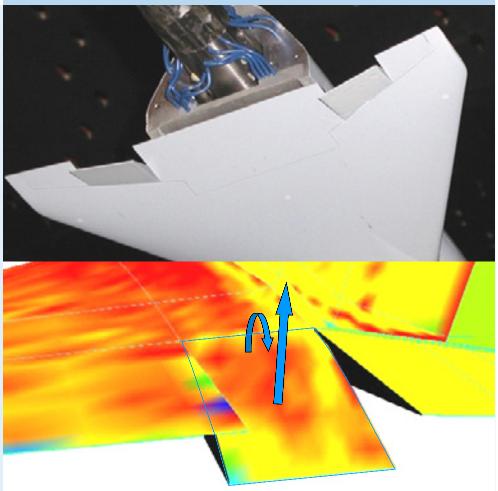

Figure 10
Measurement of loads on model components with Pressure Sensitive Paint (PSP).

Special Simulation Services

DNW-TWG offers flexible solutions for special simulation tasks, some with support of DLR-Institutes AS and AE:

- High precision Mach number tuning in steps of 0.001
- Continuous sweep measurement of pitch (0.5°/sec)
- Direct sideslip angle simulation (span direction horizontal)
- Efficient systems for suction and blowing (heated air) through model or tunnel walls
- Air intake simulation, drag bookkeeping by duct flow measurement
- Forced and free pitch and heave oscillation and flutter simulation of 2D and half-models
- Dynamically scaled models
- Rapidly rolling models (constant speed, oscillation, transient)
- Dynamically remote controlled control surfaces
- Upper and lower tunnel wall adaptation for $0.3 \leq M \leq 0.9$
- Weapon bay aero-acoustics

Measurement Techniques and Equipment

The DNW policy is to keep the measurement equipment on a high standard. Sharing of equipment between the DNW wind tunnel sites is a common practice. This allows meeting a large range of customer requirements. In addition, the available support on site by the German Aerospace Center DLR (Institute of Aerodynamics and Flow Technology Göttingen and Institute of Aeroelasticity) gives DNW access to a lot of particularly suitable and, for the purpose of development and improvement, most advanced measurement and simulation techniques. These techniques are partly developed in the TWG and therefore the installation of these techniques at

Simulation Services and Measurement Techniques

the wind tunnel is well prepared and includes the integration in the TWG data acquisition system.

Forces and Moments

For the measurement of static total forces and moments a wide range of internal strain gauge balances of different size and load range is available (most of them manufactured by TASK Able and the follow up company Aerophysics Research Instruments). Additional balances are used for half-model tests and for forces on model parts, respectively.

For unsteady force and moment measurements special piezo-electric balances (owned by DLR) can easily be operated in the TWG environment.

Pressures

For static pressure measurements PSI© Scanning Systems are operated. These allow the measurement of several hundred pressures accurately and fast, by using temperature compensated electronic pressure scanning modules. For highly accurate pressure measurement differential pressure transducers are available. For the evaluation of dynamic pressures a large number of Endevco© and Kulite© pressure transducers can be operated.

The combined analysis based on profile pressures and wake rake pressures allows lift, drag and pitching moment measurement.

Optical Measurement Techniques

A Schlieren system can provide black-and-white as well as colored Schlieren images. The images can either be recorded as single images with high resolution or as film with reduced resolution.

Flow visualization on the model surface is realized with colored oil film technique. The laminar-turbulent transition can be observed both with Temperature Sensitive Paint (TSP) or the infrared technique (owned by DLR).

The pressure sensitive paint (PSP) gives a more detailed and quantitative view on the surface pressure distribution. In addition to this, loads on particular model parts can be calculated.

In cooperation with the DLR several additional techniques can be provided:

- flow field measurement: Particle Image Velocimetry (PIV), Background Oriented Schlieren (BOS) and the Laser Light Sheet (LLS) technique
- deformation detection: the Moiré technique or the Image Pattern Correlation (IPC) technique
- model positioning: Optical Position Detection System (Posi).

Dynamic Data Acquisition

For dynamic data analysis a high precision data acquisition system, consisting of more than hundred channels, synchronized with the wind tunnel or model control system and connected to the static data acquisition system is available. DLR operates some optical measurement techniques (PIV, PSP, BOS, IPC) as dynamic systems for evaluating unsteady flow conditions or model motion.

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Wind Tunnels Operated by DNW

General Inquiries

Henri Vos
Business Development

Mobile: +31 6 12 97 52 82
Phone: +31 527 24 85 05
Fax: +31 527 24 85 82
E-mail: info@dnw.aero

NWB
Lilienthalplatz 7
38108 Braunschweig
Germany

Contact: A. Bergmann
Phone: +49 531 295 2450
Fax: +49 532 295 2829
E-mail: dnw-nwb@dnw.aero

KKK
Linder Höhe
51147 Köln
Germany

Contact: R. Rebstock
Phone: +49 2203 601 3700
Fax: +49 2203 695 961
E-mail: dnw-kkk@dnw.aero

HST, SST
Anthony Fokkerweg 2
1059 CM Amsterdam
The Netherlands

Contact: G.H. Hegen
Phone: +31 527 24 8519
Fax: +31 527 24 8582
E-mail: info@dnw.aero

TWG, HDG, KRG, RWG
Bunsenstraße 10
37073 Göttingen
Germany

Contact: K.-W. Bock
Phone: +49 551 709 2828
Fax: +49 551 709 2888
E-mail: dnw-guk@dnw.aero

LLF, LST, ECF
Voorsterweg 31
8316 PR Marknesse
The Netherlands

Contact: G.H. Hegen
Phone: +31 527 24 8519
Fax: +31 527 24 8582
E-mail: info@dnw.aero