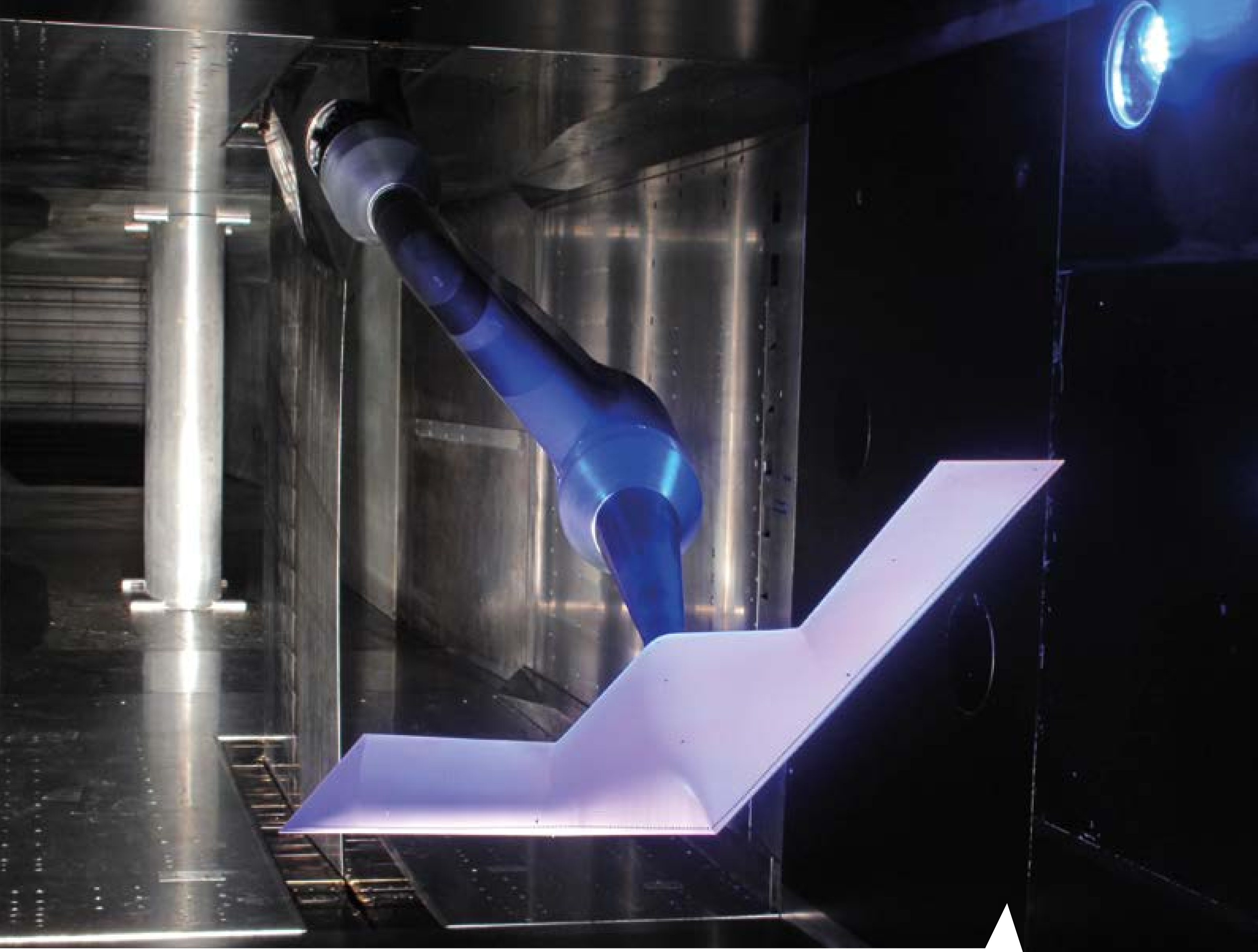


Transonic Wind Tunnel Göttingen (TWG)

A Flexible, High-Precision Transonic and Supersonic Facility for Aerospace Research and Technology Development

German-Dutch Wind Tunnels

www.dnw.aero

Transonic Wind Tunnel Göttingen (TWG)

Key Aspects at a Glance

Type of wind tunnel	Continuous, pressurised, closed circuit
Mach number	0.3 – 0.9 (adaptive TS)
	0.3 – 1.2 (perforated TS)
	1.3 – 2.2 (Laval nozzle)
Test section size(s)	1.0 m × 1.0 m at 4.5 m length
Total pressure	Adjustable between 30 kPa and 150 kPa
Reynolds number (max, l_{ref}=0.1 √A)	~ 1.8×10^6
Temperature range	293 - 315 K, actively stabilised
Contraction	16:1
Drive power	12 MW
Auxiliaries	Air supply: max. 150 bar
	Vacuum supply: min. 30 kPa

Cover picture - DLR Delta-Wing configuration coated with Pressure-Sensitive Paint in DNW-TWG, picture by DNW

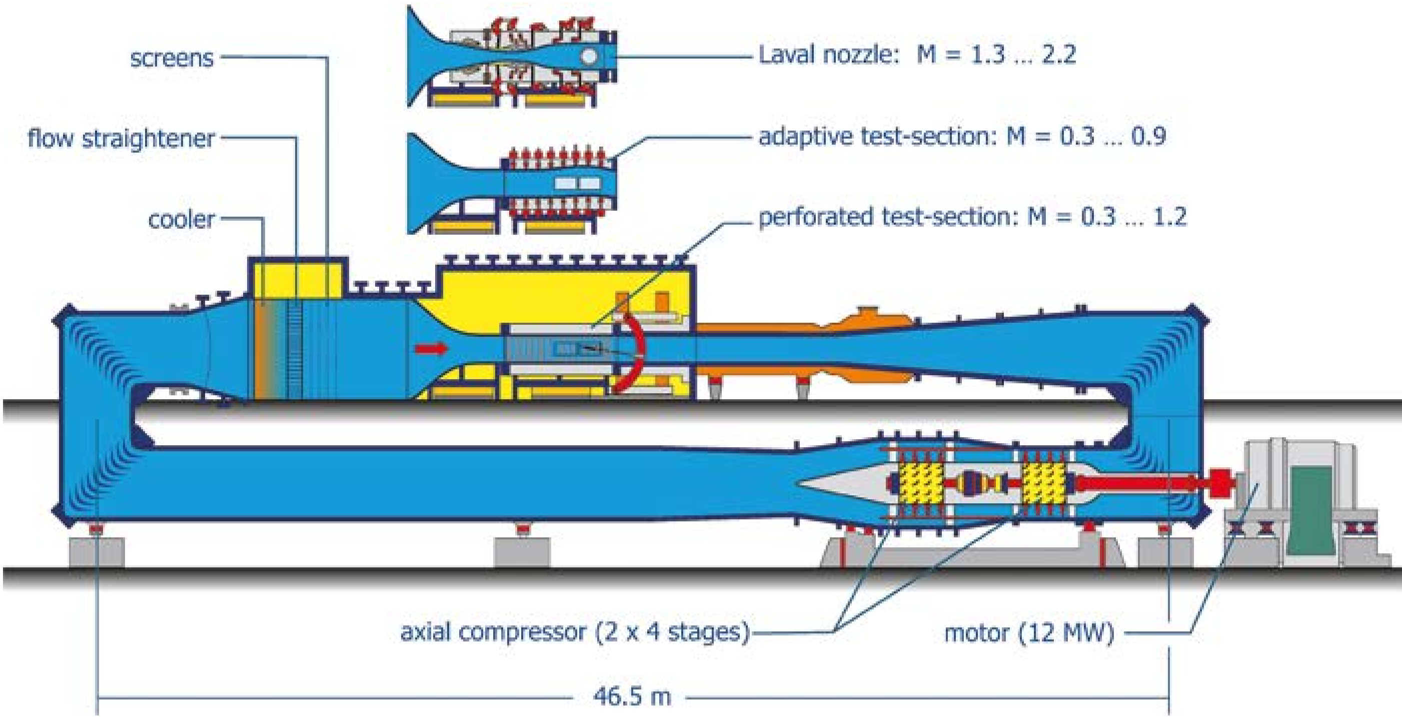


Illustration of the closed-circuit DNW-TWG with its three interchangeable test sections

The Transonic Wind Tunnel Göttingen (TWG) is a cornerstone of DNW's transonic and supersonic testing portfolio, serving as a unique, high-precision research facility for advanced aerodynamic and aeroelastic investigations.

It represents the facility with the widest Mach number range providing continuous operation in all regimes, extending from low subsonic speeds over the transonic range up to medium supersonic flow velocities. As the only transonic wind tunnel of its size and operating mode in Germany, the TWG provides valuable capabilities for the validation of numerical simulation methods and the verification of next-generation flight physics technologies under flight-like conditions. Nevertheless, the TWG also serves civil and military programmes providing high-fidelity experimental data to industrial partners.

The TWG's strategic location at the DLR site in Göttingen, in close proximity to the Institute of Aerodynamics and Flow Technology (AS), the Institute of Aeroelasticity (AE) and the Modelling Department (SHT), promotes efficient integration of experimental and numerical research. This includes the improvement of optical, non-intrusive measurement techniques expanding their capabilities into the unsteady regime as well as the development of advanced flutter control strategies and the investigation of nonlinear aeroelastic coupling phenomena.

View in open plenum with perforated test-section installed and adaptive and Laval test-section in wind-tunnel hall for preparation purposes

The TWG plays a central role in the DLR's transonic development chain, supporting the development and validation of high-fidelity CFD methods - most notably the future simulation platform CODA - while enabling the investigation of complex flow phenomena such as shock-boundary layer interactions, turbulent separation, laminar-turbulent transition, aeroelastic instabilities and unsteady flows. With its ability to operate continuously in the transonic and supersonic regimes, the TWG is uniquely positioned to address the challenges of future low-emission aircraft, including highly flexible wings and advanced flow control systems.

Within DNW's integrated facility portfolio, precisely the TWG's uniqueness complements DNW's capabilities in the transonic and supersonic regime also represented by the HST and SST facilities. For the subsonic speed range, the TWG features one of the largest adaptive wall test sections worldwide. Moreover, in Germany the TWG is currently the sole facility to support continuous testing at supersonic speeds up to M=2.2.

Typical example of method development. Global identification of flow separation and re-attachment for compressible, high Reynolds number flows using Temperature-Sensitive Paint (TSP) during DLR-Project VicToria

Why Medium-Scale Subsonic, Transonic & Supersonic Testing

Transonic and supersonic flight regimes present some of the most complex aerodynamic and aeroelastic challenges in aerospace engineering, where small changes in Mach number can lead to dramatic shifts in flow behaviour, including shock wave formation, boundary layer separation, and strong aeroelastic coupling. These phenomena are critical for the performance, stability, and safety of modern civil and military aircraft, particularly those featuring high aspect ratio wings, advanced propulsion integration, and lightweight, flexible structures.

For flow situations, where Reynolds number and Mach number dependencies are highly non-linear, high-fidelity testing at realistic flight conditions is essential to:

- Investigate aeroelastic instabilities such as flutter and buffeting
- Assess the performance of flow control and laminar flow technologies
- Characterise shock-induced separation and unsteady pressure fluctuations
- Validate and extend the accuracy of CFD methods for compressible flows
- Demonstrate the functionality of novel flight physics technologies under flight-like conditions

Numerical methods in aerodynamics nowadays allow complex aeroelastic problems to be described and analysed numerically using coupling methods to capture structural mechanics in addition to problems of fluid physics. However, highly accurate experimental reference data is still required for more complex flows, such as for investigations under detached, transitional or unsteady flows. In addition to obtaining measurement data for aircraft components, wind tunnel campaigns are therefore increasingly serving two other purposes. On the one hand, this is the validation of high-precision numerical methods in order to constantly expand the limits of their applicability. In this context the TWG is currently utilised as reference facility for the validation of numerical codes (CODA, TAU) involving the generation of a digital twin of the tunnel, which is continuously being developed including a very high level of detail, such as the more than 9600 perforation holes and the plenum chamber. On the other hand, this involves the verification of new technologies for flight-like conditions at the edge to supersonic speeds.

In the case of aeroelastic design the transonic speed range is of special interest investigating the boundaries of the unstable operation range of an airfoil.

The development of optical measurement techniques expands over the full Mach number range of the TWG. New techniques may start out at low subsonic speeds, whereas in later stages of the research, investigations focus on the transonic regime and unsteady flow fields with the ultimate goal to apply the methods in full-scale under free-flight conditions.

More specialised applications for example involve the cost-efficient aerodynamic probe calibration in full-scale over the full supported speed range or the investigation of supersonic missile models in a wide range of flight attitude conditions.

The TWG is uniquely equipped to address these challenges through its continuous operating mode, high flow quality, and advanced measurement capabilities, making it an indispensable tool.
Due to its modularity, the facility allows for cost efficient testing enabling comprehensive parameter studies with short turnaround times for model configurations, which is especially important in early development stages of new technologies.

Wind Tunnel Configuration

The TWG is a closed circuit, "Göttingen Type" wind tunnel designed for subsonic, transonic, and supersonic flow research. Its modular architecture enables flexible operation across a wide range of Mach numbers and test configurations supporting both, fundamental flow physics studies and applied technology development.

The facility is driven by a 12 MW axial compressor system and supported by a 3 MW auxiliary radial compressor used as a suction plant. The entire tunnel can be pressurised or evacuated, allowing precise control of stagnation pressure and Reynolds number independently from the Mach number.

An efficient air-drying system ensures humidity levels low enough to prevent condensation across the entire speed range, while a dedicated water-cooling system maintains the tunnel temperature within the specified range.

Key features of the TWG are its three interchangeable test sections, each optimised for a specific purpose or Mach number regime:

Test Section 1 (Adaptive Walls)

Features flexible upper and lower walls for 2D flow adaptation, reducing wall interference and enabling larger models in the range $0.3 \leq M \leq 0.9$. Wall corrections are applied using Cauchy's integral formula (2D) and the Wedemeyer-Lamarche method (3D), with residual interference calculated via Green's integral formula. Desired pressure gradients can be imposed by presetting wall contours predicted by numerical methods.

Test Section 2 (Perforated Walls)

Designed for Mach numbers $0.3 \leq M \leq 1.2$, with all-around conventionally perforated walls (6% opening, 60° inclined, $M_{design} = 1.05$). Variable suction is applied through the perforated walls starting at a Mach number of $M=0.85$ to suppress wall interference and to provide additional control for the Mach number.

Test Section 3 (Laval Nozzle)

The test section for the supersonic speed range is a conventional adjustable Laval nozzle with flexible top and bottom walls calibrated for discrete Mach-numbers in the range $1.3 \leq M \leq 2.2$.

Major upgrades of the TWG during 1991 to 1993 provided improved flow quality, an extended test spectrum and increased productivity deploying the new concept with three interchangeable test sections, featuring interchangeable model supports with an excellent model access. Currently an ongoing large investment program supported by DLR is installed in order to maintain and increase the operational reliability and the high standard of the facility.

The tunnel's plenum chamber is accessible via a 10 m wide sliding door, allowing full axial access to the tunnel circuit. The contraction nozzle and the test section can be moved several meters into the settling chamber, enabling free model access and simplified model installation and exchange. An air cushion transport system supports the rapid and safe movement of models, test sections, and support systems, enhancing operational efficiency.

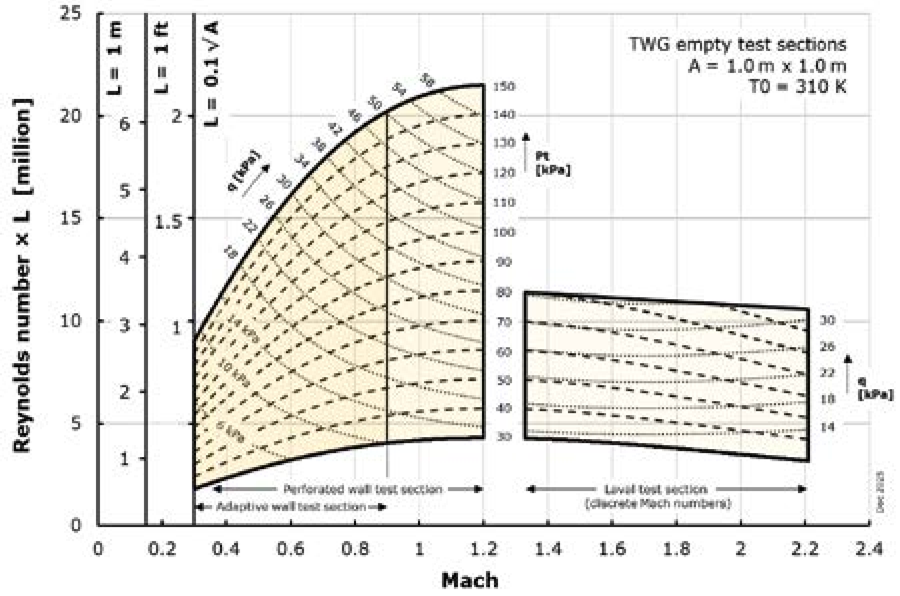
Key Flow Parameters & Operating Envelope

The TWG is designed to provide high-quality, continuous flow at small to medium scales in a wide Mach number range. Its operating envelope supports a variety of aerodynamic and aeroelastic studies as well as method development campaigns.

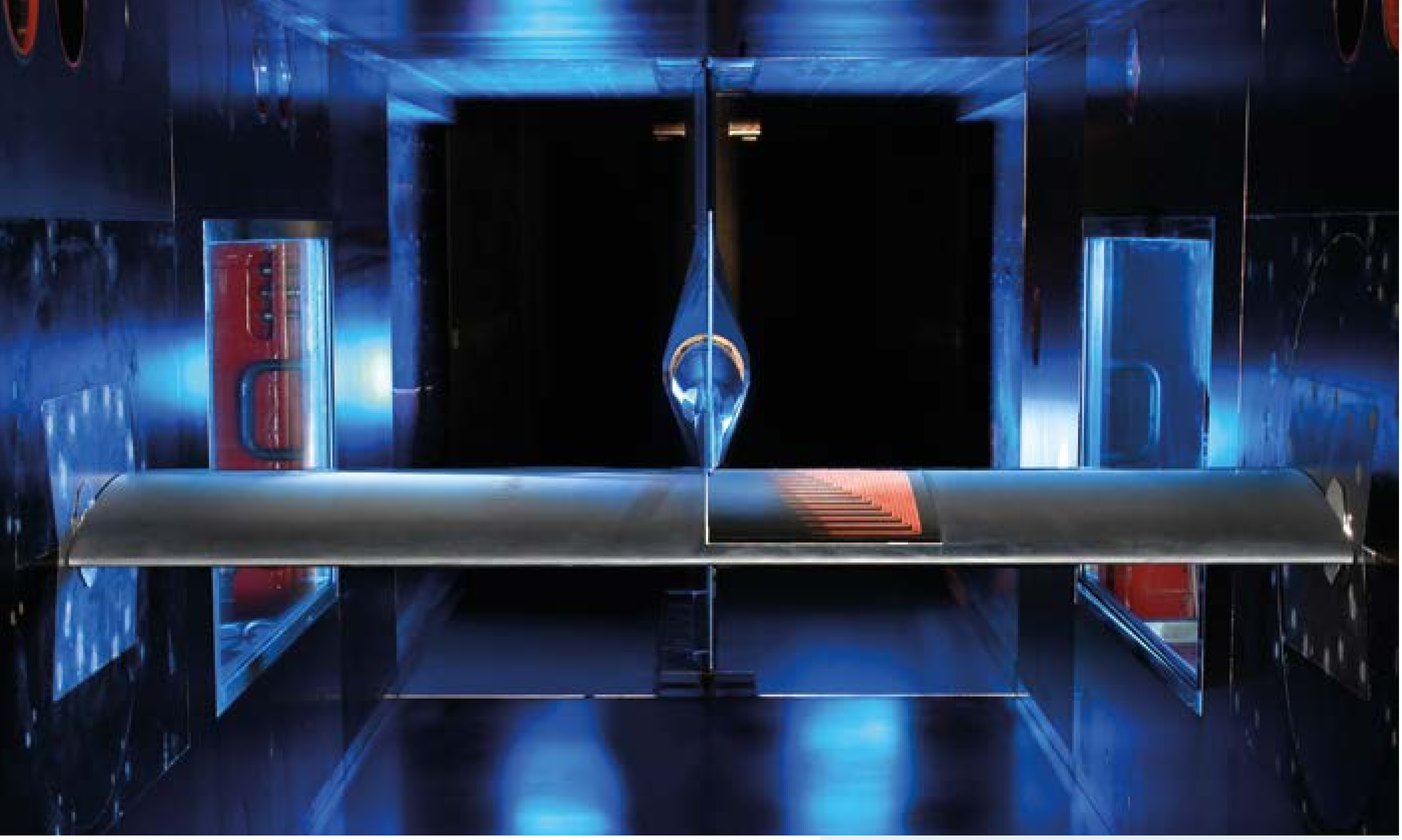
The TWG features independent variation of Reynolds number and Mach number. To vary the Reynolds number, the stagnation pressure within the closed circuit can be adjusted. In the transonic regime, the flow simulation uses additional active suction through the perforated walls, followed by the re-injection of the mass flux downstream of the second throat.

The TWG offers a comprehensive operating envelope covering subsonic, transonic and supersonic research needs:

- Mach number range:
    - Adaptive test section: 0.3 – 0.9
    - Perforated test section: 0.3 – 1.2
    - Flexible Laval Nozzle: 1.3 – 2.2 (discrete calibrated steps)
    - M>1.3 via flexible Laval-nozzle contour
- Total pressure range: adjustable between 30 kPa and 150 kPa
- Max. Reynolds number (2D, reference length 0.4 m): ~ 7.2 × 10^6
- Max. Reynolds number (3D, reference length 0.1 m): ~ 1.8 × 10^6
- Mach number repeatability: < ±0.01 (meas. acc. ±0.001)
- Maximum dynamic pressure: 53 kPa
- Stagnation temperature: 293 - 315 K, actively stabilised
- Test section cross-section: 1.0 m × 1.0 m at 4.5 m length
- Flow quality: High uniformity, negligible angularity
- Flow stability: Continuous operation with precise control over Mach number, Reynolds number and pressure conditions



Mach number - Reynolds number envelope of the DNW-TWG including all three interchangeable test sections



Two-dimensional profile with hotfilm array (front) and wake rake for drag prediction (background) mounted on the 2D portal support of the DNW-TWG

Model Support & Load Measurement Capabilities

The TWG offers a comprehensive range of model support systems and load measurement solutions.

The flexibility of the TWG, especially the modular design of the adaptive and the perforated test section, enables the implementation of a variety of different model supports tailored towards individual test requirements. Two primary support concepts are available:

2D Portal Support

This support is placed about 2 m downstream of the test-section entry, in order to allow for an improved wake simulation, especially important for investigations involving two-dimensional profiles. In this case the downstream model support can be equipped with a wake rake for accurate drag measurements.

The 2D portal support is also designed to mount semi-span models or side sting mounted models in three-dimensional configuration. The use of interchangeable wall segments enables the implementation of hydraulically driven dynamic testbeds to investigate pitch and heave oscillations as well as flutter phenomena. The DLR Institute of Aeroelasticity in Göttingen operates several of these dynamic model supports, specially adapted and integrated to the TWG, featuring high capacity, high accuracy piezo-electric balances covering forces and moments (six-degree-of-freedom).

In the supersonic test section (Laval nozzle) remote controlled half model supports can be installed in the side wall window frames.

3D Rear Sting Support

Three-dimensional models typically are mounted on the 3D rear sting support located at the end of the test section, but with support and model pivot point approx. 3 m downstream of the test section entry in order to minimize upstream flow interference. The support allows for the simultaneous adjustment of angle of attack, roll angle and sideslip angle.

In order to capture the forces and moments a large set of strain gauge balances with a wide load capacity range is available. The whole support system is designed to bear the following maximum loads acting in the rotational centre (corresponding to the largest standard internal strain gauge balance):

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

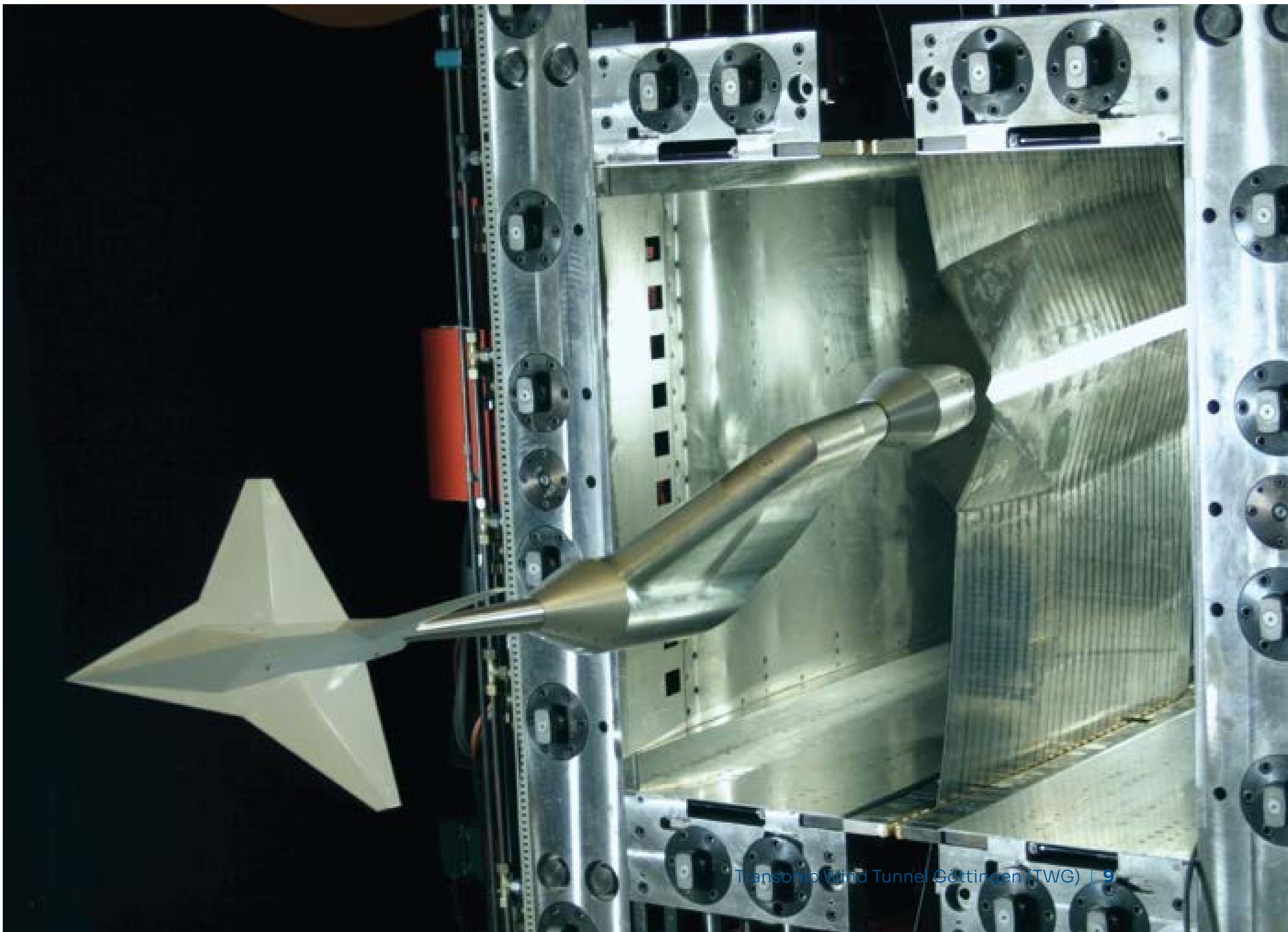
Typical operational ranges for full models mounted on a sting support include:

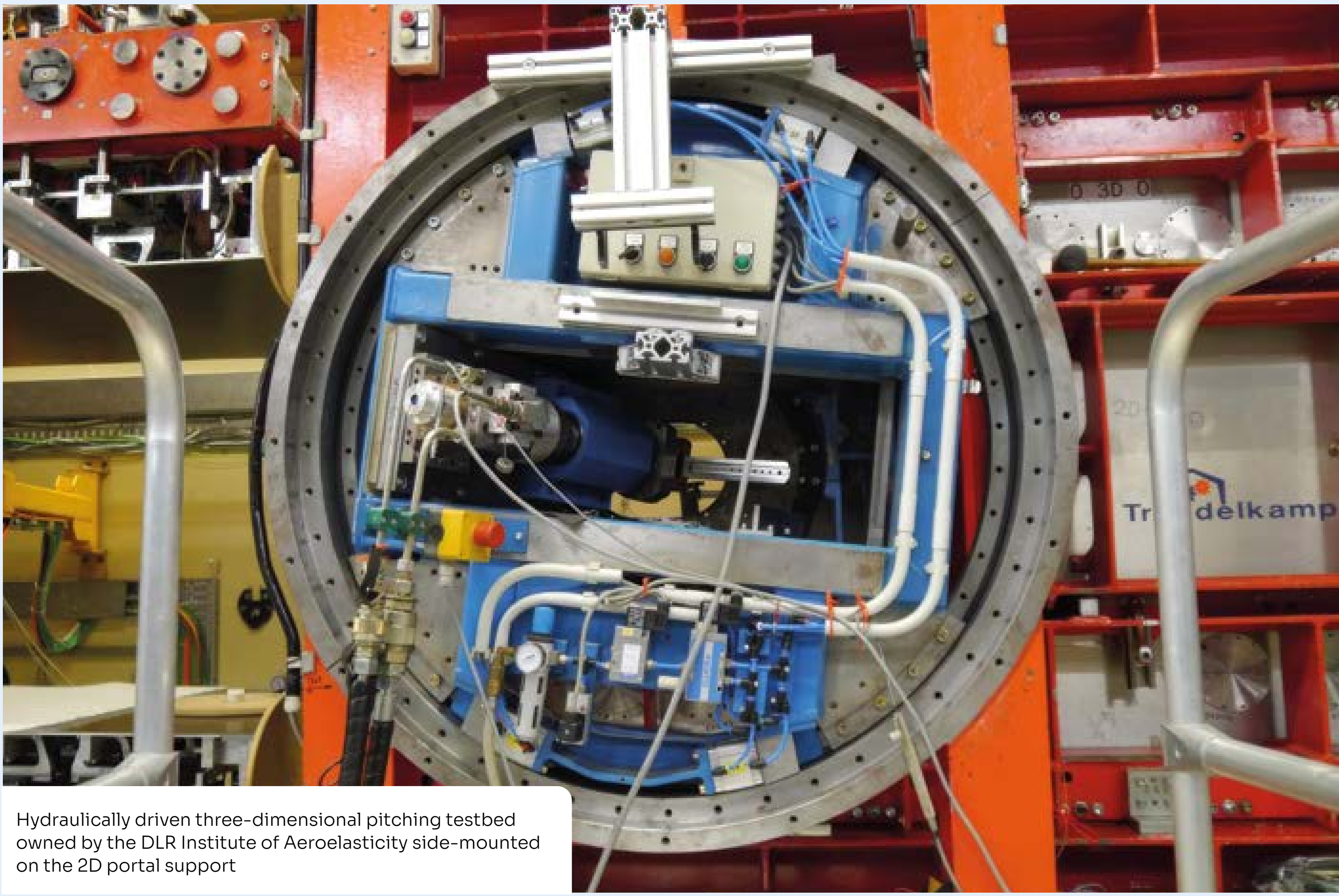
- Maximum wingspan: ~0.5 m
- Angle-of-attack range: up to ±15° (30° with offset, maximum 62°)
- Yaw angle range: up to ±15°
- Angular positioning accuracy: ~0.02°

Higher angles of incidence are accomplished 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 and roll simulation.

The availability of various two-dimensional and three-dimensional model supports, combined with interchangeable side wall panels and hydraulically driven options, makes the TWG particularly well suited for research-oriented projects, method development and aeroelastic airfoil design.

Delta wing model coated with Pressure-Sensitive Paint (PSP) mounted on the 3D rear sting support using a cranked roll adapter.





Hydraulically driven three-dimensional pitching testbed owned by the DLR Institute of Aeroelasticity side-mounted on the 2D portal support

Two-dimensional hydraulically driven profile mounted on the 2D portal support (front) used as a gust generator for a side-mounted three-dimensional wing (background)

Measurements & Diagnostic Techniques

The TWG supports a comprehensive suite of advanced measurement and flow diagnostic techniques, enabling detailed characterisation of aerodynamic, aeroelastic, and multidisciplinary phenomena.

A key strength of the facility is its ability to combine multiple diagnostic techniques within a single test campaign to link forces, pressures, flow fields, structural deformation and unsteady dynamics.

Thanks to a long-standing alliance with the Institute of Aerodynamics and Flow Technology (AS) and the Institute of Aeroelasticity (AE) of DLR Göttingen, DNW has local access to expert knowledge for a variety of advanced measurement and simulation techniques.

At the TWG some of these techniques are being further developed and are therefore integrated into the tunnel control and data acquisition system, which enables DNW to offer state-of-the-art measurement techniques to the customers in consultation with the onsite institutes.

In addition, it is possible to integrate customer devices, such as throttle cones for inlet flow investigations, into the tunnel control system either directly or via an industrial interface (OPC-UA) in order to enable highly automated and therefore time efficient parameter studies.

Available techniques include:

- High-accuracy internal and external force and moment balances:
    - A wide range of strain-gauge balances (TASK Able®, Aerophysics Research Instruments®, RUAG®) for static and unsteady measurements
    - Piezoelectric balances (owned by DLR) for high-frequency dynamic testing
- High-density static and unsteady pressure measurement systems:
    - PSI Scanning Systems for rapid, accurate acquisition of hundreds of pressure taps
    - Differential pressure transducers (Endevco®, Kulite®) for high-precision measurements
    - Synchronized high-precision data acquisition system (>100 channels) for dynamic analysis
- Schlieren imaging:
    - High-resolution black-and-white and coloured Schlieren systems for visualisation of shock waves and density gradients
    - Coloured Schlieren Video for compressible, dynamic flow phenomena
- Stereoscopic Pattern Recognition (SPR) for attitude control
- Coloured oil film for surface flow patterns visualisation

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

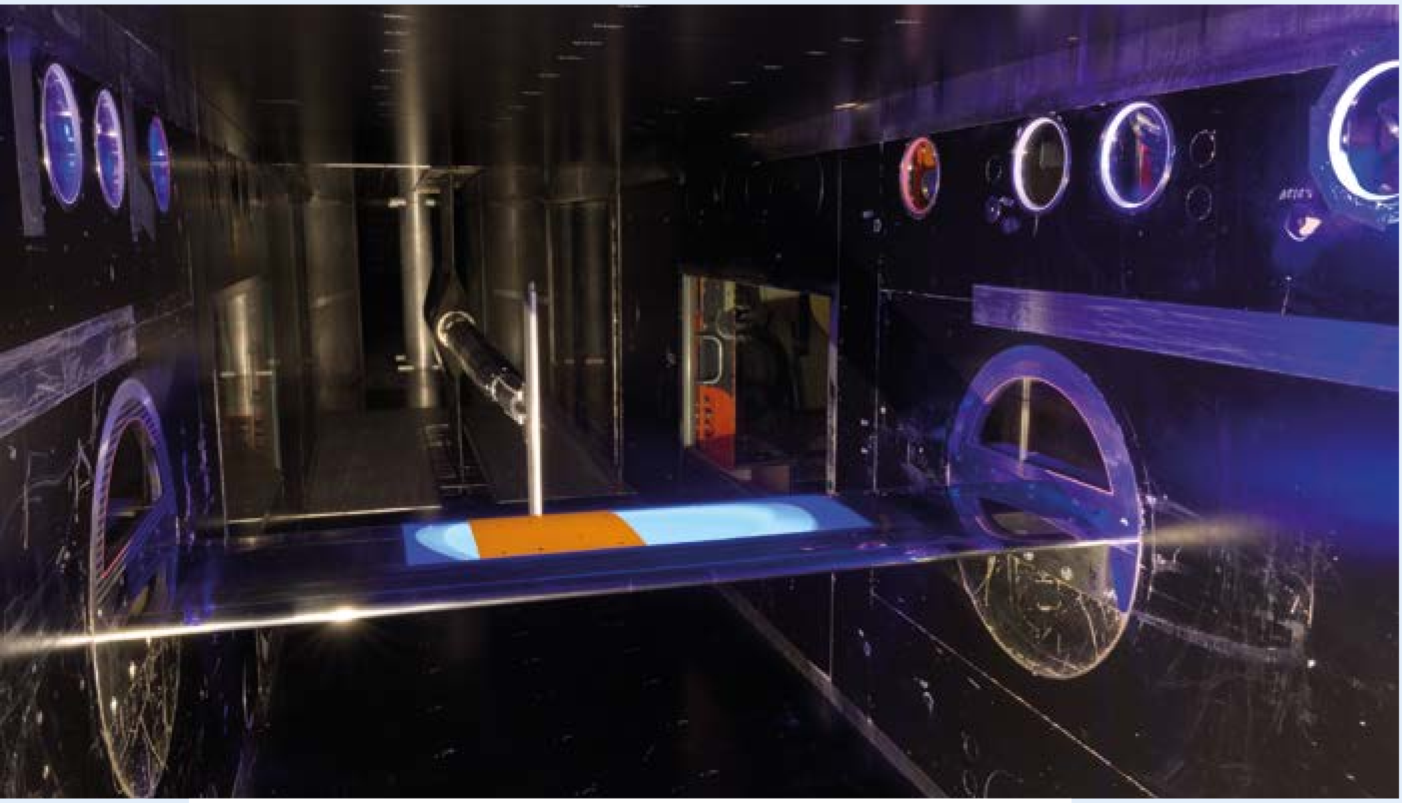
- Pressure-Sensitive Paint (PSP) and Temperature-Sensitive Paint (TSP) (steady and unsteady):
    - Full-field surface pressure and temperature mapping
    - Critical for validating separation/transition prediction models and assessing laminar flow control performance
- Particle Image Velocimetry (PIV):
    - 2C and 3C-PIV for time-resolved 2D and 3D flow field measurements
    - Shake-The-Box (STB): 3D-Particle-Tracking
- Laser Light Sheet Technique
- Infrared thermography (IRT):
    - Used e.g. in conjunction with PSP for temperature correction
    - Enables real-time monitoring of boundary layer development
- Image Pattern Correlation Technique (IPCT)
    - Time-resolved deformation analysis and attitude measurement
- Oil Film Interferometry (OFI)
- Hotwire and Hotfilm velocimetry

Special simulation services

The TWG offers additional solutions for special simulation tasks, some with support of DLR-Institutes:

- High precision Mach-number tuning in steps of 0.001
- Continuous sweep measurement of pitch (1.0°/s) and roll (5.0°/s)
- Direct sideslip angle simulation (span direction horizontal)
- Efficient systems for suction and exhaust on the model or through tunnel walls
- Air intake simulation, drag bookkeeping by duct flow measurement
- Forced and free pitch, 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
- Weapon bay aeroacoustics

High testing productivity is ensured by wind tunnel automation and a data-acquisition system, which is deployed consistently. The system supports automated test execution, continuous sweeps, synchronized data acquisition and real-time monitoring improving data quality while reducing overall test time.



2D model with aggressive adverse pressure gradient (AAPG) airfoil mounted in the DNW-TWG. Development of time-resolved Temperature-Sensitive Paint (iTSP) extending its operational range into the transonic regime during DLR-project ACTIVATE

DLR-F23-model in DLR project. PIV is conducted investigating the vortex formation on the upper side of the wing.

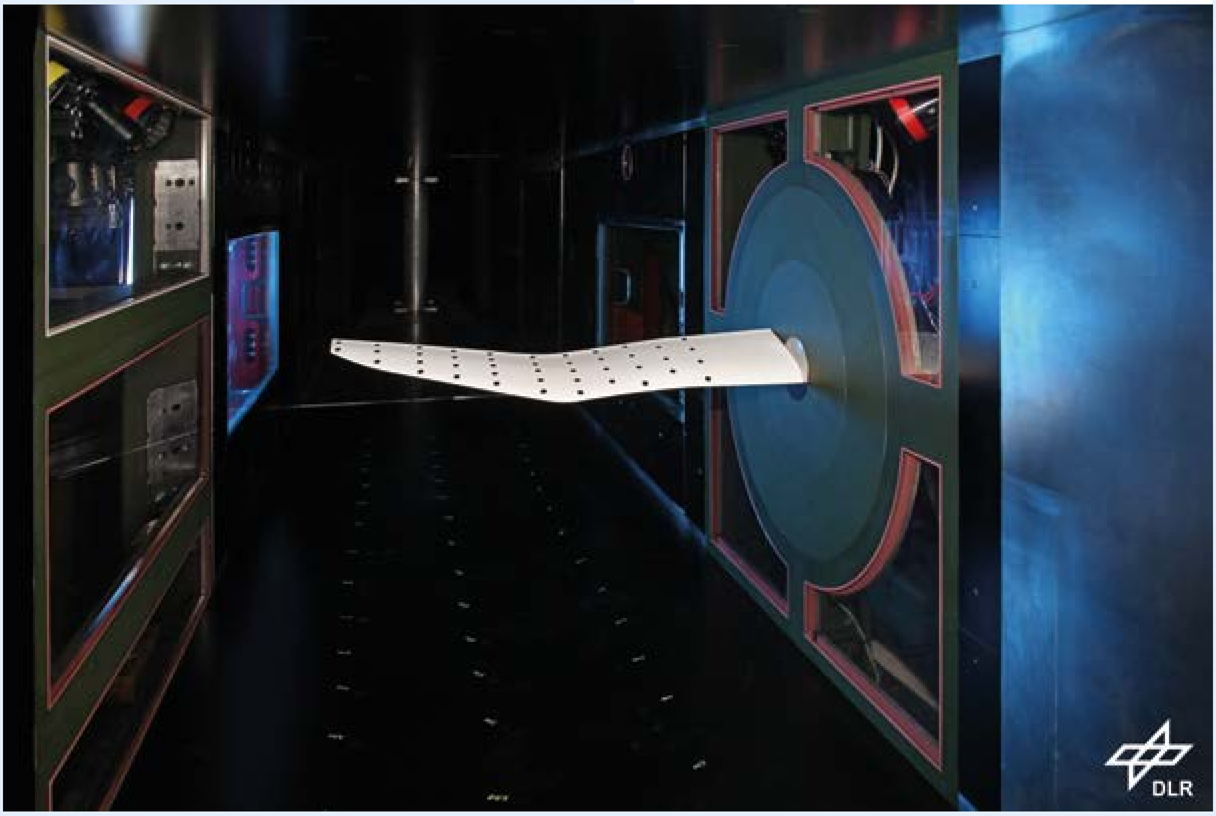
Typical Applications

The TWG supports a wide range of research and development programmes in both civil and military aerospace:

- Technology verification of novel flight physics concepts
- Validation of CFD methods (CODA, TAU)
- Support for digitalisation of aircraft development through high-fidelity experimental data
- Validation of coupled CFD-CSM methods for multidisciplinary design
- Development and testing of advanced measurement and simulation techniques
- Laminar flow control and flow management
- Flutter and buffeting prediction and control
- High aspect ratio wing development
- Multifunctional control surface concepts
- Missile and projectile aerodynamics
- Aerodynamic probe calibration in full scale

Notable success stories include the INROS project, where DLR-developed helicopter rotor profiles - validated in the TWG - were adopted in the Airbus Bluecopter (H135 and H145), as well as the DLR WingMates and ACTIVATE projects, where flow and flutter control technologies are developed in collaboration with industrial partners.

DLR-developed helicopter rotor profile side-mounted on hydraulic testbed owned by the DLR Institute of Aeroelasticity during Project INROS (shown with markers for Image Pattern Correlation Technique (IPCT)).



Customer Value & DNW Portfolio Synergy

The TWG’s unique combination of subsonic, transonic and supersonic capability, its modular design, the advanced diagnostics and the close collaboration with numerical simulation makes it an indispensable asset in the future of aerospace research and development.

As the digitisation of aircraft design accelerates, the TWG will continue to play a pivotal role in bridging the gap between virtual prediction and physical reality.

The TWG delivers exceptional value by enabling customers to:

- Gain highly accurate reference data for complex unsteady flow situations in the subsonic, transonic and supersonic regime
- Validate numerical simulations with high-fidelity experimental data at the limits of CFD reliability
- Demonstrate and verify novel technologies under flight-like conditions
- Reduce development risk through early detection of aeroelastic and flow instabilities
- Accelerate technology readiness level (TRL) through targeted, high-quality experiments
- Identify multidisciplinary couplings, e.g. in aeroelastic airfoil design
- Conduct cost efficient comprehensive parameter studies

Beyond the TWG itself, DNW operates a complementary portfolio of wind tunnel facilities in the Netherlands and Germany, covering subsonic, transonic and supersonic regimes. These facilities are managed as an integrated organisation.

German-Dutch Wind Tunnels

Within this portfolio:

- LLF provides large-scale, multidisciplinary low-speed testing
- LST serves as a readily accessible development and pre-testing facility for both HST and LLF
- NWB enables dedicated low-speed aeroacoustics and multidisciplinary investigations
- HST delivers high-Reynolds-number transonic validation up to M = 1.3
- SST extends testing seamlessly into the supersonic regime up to M = 4

This synergy of scales and speed regimes allows customers to execute coherent experimental programmes across multiple facilities, from early concept studies at smaller scale to large-scale high-fidelity validation.

This integrated approach differentiates DNW from isolated single-tunnel providers and enables customers to move from concept-level testing to large-scale validation within a single coordinated experimental ecosystem.

The TWG is a key asset within DNW’s integrated facility portfolio enabling continuous subsonic, transonic and supersonic testing for aerodynamic and aeroelastic studies providing high-fidelity experimental data to DLR and industrial partners, with a focus on method development, cost-efficient verification of new technologies and validation of next-generation simulation tools.

German-Dutch Wind Tunnels

+31 527 24 8520

info@dnw.aero

www.dnw.aero