



Large Low-Speed Facility (LLF)

A Modular Large-Scale Wind
Tunnel for Aerospace and
Automotive Applications



German-Dutch Wind Tunnels

www.dnw.aero

Large Low-Speed Facility (LLF)

Key Aspects at a Glance

Type of wind tunnel	Continuous, atmospheric, subsonic
Mach number	0 – 0.44
Test section size(s)	8 m x 6 m closed test section 6 m x 6 m closed test section 9.5 m x 9.5 m closed test section 8 m x 6 m open-jet 8 m x 6 m $\frac{3}{4}$ -open automotive test section
Total pressure	Ambient
Reynolds number (max, $l_{ref}=0.1 \sqrt{A}$)	6.15×10^6
Temperature range	Ambient
Contraction	9:1 (8 m x 6 m TS)
Drive power	~13 MW
Auxiliaries	Air supply: ~5.5 kg/s at 80 bar Power supply up to 1000 VDC

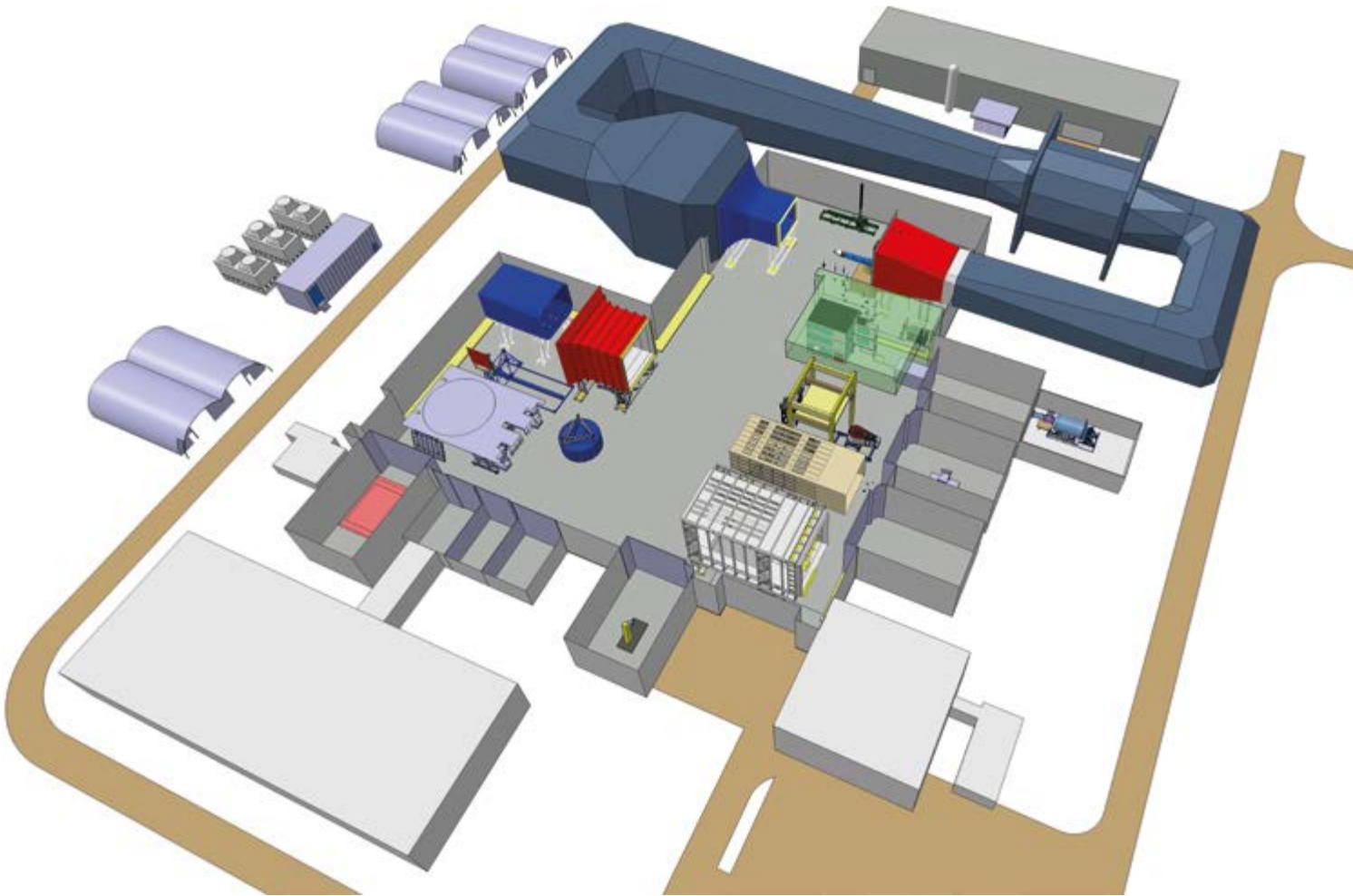


Illustration of DNW-LLF wind tunnel and its operational infrastructure

The Large Low-Speed Facility (LLF) is DNW's flagship atmospheric wind tunnel for large-scale aerodynamic and aero-acoustic testing.

The Large Low-Speed Facility (LLF) is DNW's flagship atmospheric wind tunnel for large-scale aerodynamic and aeroacoustic testing. As the largest low-speed wind tunnel in Europe, the LLF is designed to accommodate large complete aircraft configurations, large components and full-scale vehicles, while supporting the simultaneous application of advanced aerodynamic, aeroacoustic, propulsion and flow diagnostic techniques.

The facility primarily serves civil and military aerospace programmes as well as automotive OEMs, providing high-fidelity experimental data at representative Reynolds numbers with exceptional flow and acoustic quality.

Within DNW's facilities portfolio, the LLF represents the large-scale, low-speed validation capability, complemented by the LST as a development and pre-testing facility, the NWB for dedicated aero-acoustics and HST, TWG and SST for transonic and supersonic testing.

The LLF is a modular and reconfigurable wind tunnel, built around a common infrastructure with exchangeable test sections. This modularity enables DNW to support multiple industries and applications within a single facility while maintaining aerospace-grade accuracy, repeatability and experimental flexibility.

Why Large-Scale Low-Speed Testing

Large-scale low-speed testing is essential for understanding aerodynamic and aeroacoustic behaviour in regimes where Reynolds number effects, flow separation, installation interference, ground-effects, and unsteady phenomena play a dominant role.

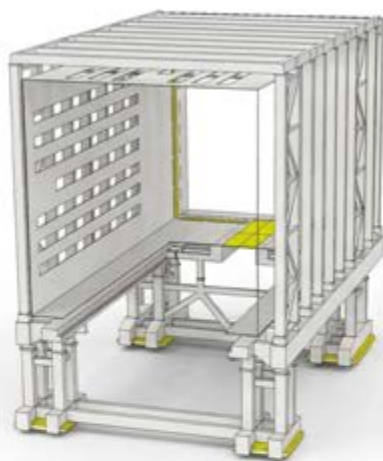
These effects become even more critical for modern aircraft and vehicles, which feature:

- Highly integrated propulsion systems
- Complex high-lift and flow-control devices
- Distributed propulsion concepts
- Open rotors and propellers
- VTOL concepts
- Noise-sensitive configurations
- Large, bluff body components

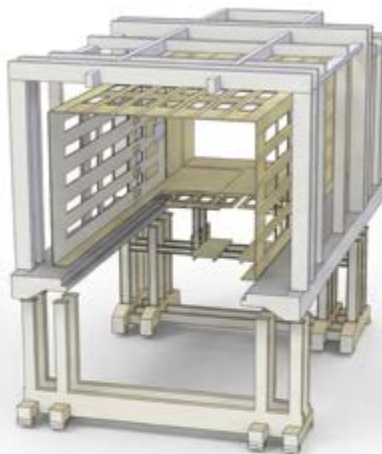
Large-scale testing at representative Reynolds numbers is therefore required to accurately capture:

- Aerodynamic performance and stability
- Flow separation and reattachment behaviour
- Wake interactions
- Aeroacoustic source mechanisms
- Propulsion-airframe interference effects
- Multidisciplinary couplings between aerodynamics, acoustics, and structural loads

The LLF is designed to address these challenges by enabling large models, allowing customers to move beyond isolated discipline testing toward truly integrated system-level understanding.



9.5 m x 9.5 m Test Section



8 m x 6 m Test Section (convertible to 6 m x 6 m)



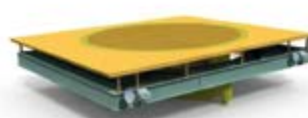
Automotive Test Section



Moving Belt Ground Plane (only 8x6)



Multi-Purpose Turn Table (incl. alpha cradle)



External Balance Turn Table

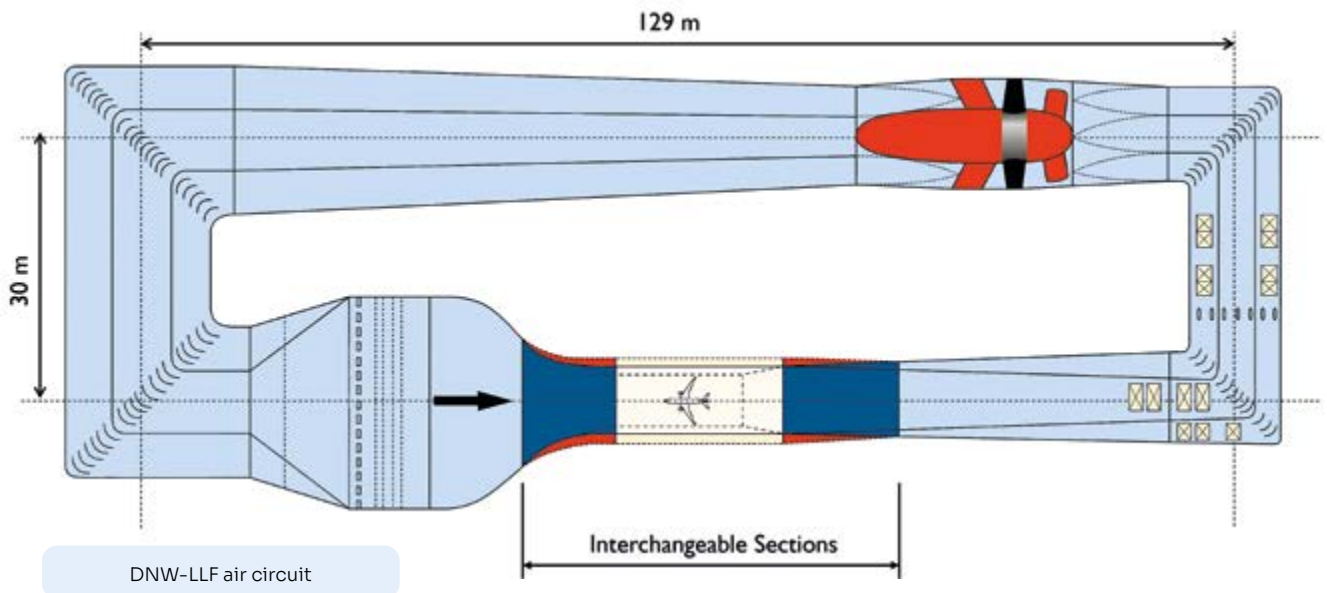


Slotted Floor Section

LLF modular test sections and floor elements

Wind Tunnel Configuration

The Large Low-Speed Facility (LLF) is a closed circuit, atmospheric, continuous wind tunnel.



A defining feature of the LLF is its set of exchangeable test sections, which allow the facility to be tailored to the specific needs of each test campaign.

Available configurations include:

- A 9.5 m × 9.5 m closed test section for large-scale aerodynamic and multidisciplinary testing
- An 8 m × 6 m closed test section, convertible to 6 m × 6 m, for simulation of common take-off and landing speeds
- An open-jet configuration using the 8 m × 6 m nozzle with a 9.5 m × 9.5 m transition section
- A semi-anechoic test hall for aero-acoustic investigations
- The 3/4-open Automotive Test Section (ATS); optimized for full-scale automotive testing with ground simulation. This test section is also suitable for simulating other in-ground applications.

This modular architecture enables rapid reconfiguration while maintaining consistent flow quality, measurement accuracy, and operational efficiency.

The facility is driven by a high-power fan system and supported by a large compressed air infrastructure shared with other DNW facilities, providing high flexibility in propulsion simulation and auxiliary air supply. In addition, there are provisions to accommodate electrically powered propulsion simulators, expanding the range of propulsion concepts that can be tested.

Large access doors, overhead cranes, and dedicated model handling systems allow the installation of very large and heavy test articles.

Key Flow Parameters & Operating Envelope

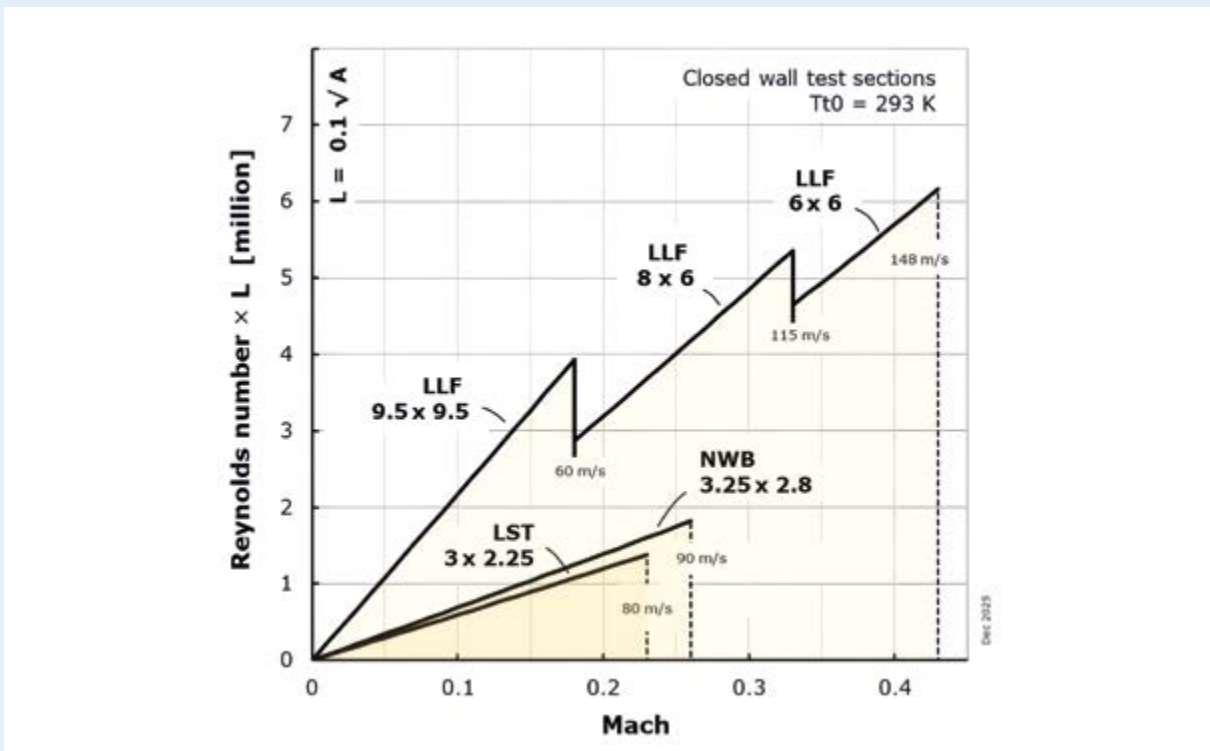
The LLF is designed to provide high-quality, low-turbulence flow at large scales and representative Reynolds numbers. Its operating envelope supports a wide variety of aerodynamic, aeroacoustic, and propulsion integration studies.

Typical flow characteristics include:

- Mach number range: approximately 0 – 0.44 (test section dependent)
- Mach number spatial uniformity: ± 0.001
- Reynolds number range (reference length $0.1 \sqrt{A}$) up to 6.15×10^6 ($\Delta Re \leq 0.005 \times 10^6$)
- Turbulence level at model centre:
 - Longitudinal: $\approx 0.02\%$
 - Lateral: $\approx 0.04\%$
- Flow angularity: $< 0.06^\circ$
- Flow uniformity: $\Delta cp \approx 0.001$ (≈ 5 Pa)
- Temperature uniformity: ± 0.2 K

These characteristics allow for highly repeatable test conditions and low background disturbances, which are essential for both aerodynamic force measurements and accurate aero-acoustic investigations.

The large cross-sectional areas of the test sections allow the use of large-scale models with realistic geometric detail, while minimising blockage effects and other forms of interference.



Mach-Reynolds envelope of DNW low-speed facilities

Model Support & Load Measurement Capabilities

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

Available support concepts include:

- Sting-mounted configurations (ventral, dorsal or rear), equipped with high-capacity internal strain-gauge balances (uncertainty $\leq 0.3\%$ FS per component)
- Underfloor external platform balance systems for large and heavy models, including full-scale road vehicles
- Semi-span and open-jet support configurations, enabling isolated component and installation-effect studies

These systems allow accurate measurement of aerodynamic forces and moments often including engine simulation, while minimising aerodynamic interference to correctable levels.

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

- Wingspan: ~4.2 m to 6.6 m (test section dependent)
- Maximum model mass: ~1500 kg
- Angle-of-attack range: up to 56°
- Yaw angle range: up to 50°
- Angular positioning accuracy: $\sim 0.02^\circ$

For propulsion-related testing, the LLF also supports the integration of rotary shaft balances, enabling the measurement of six-degree-of-freedom (6DoF) loads on rotating components such as propellers and fans.

Ground Proximity Simulation

Accurate simulation of ground proximity effects is a core capability of the LLF and is relevant for both aerospace and automotive applications.

For aerospace testing, the LLF is equipped with a high-speed moving-belt ground plane system, enabling realistic simulation of take-off and landing conditions. The current steel-belt system operates at speeds of up to 80 m/s and is equipped with suction and blowing systems to maintain belt flatness and boundary-layer control.

This capability allows detailed investigations of:

- Lift, drag and pitching moment variations during take-off and landing
- Ingestion and re-ingestion phenomena
- Jet-ground and wake-ground interactions

For automotive applications, moving-ground (road)

simulation is implemented within the Automotive Test Section and is fully aligned with WLTP-related test procedures and flow requirements, supporting realistic full-scale vehicle aerodynamics and driving-resistance measurements.

Business jet model in ground effect (PLAAT Clean Sky project)





Propulsion integration test
(L-CROR CTS Clean Sky project)

Propulsion Integration

Propulsion testing in the LLF is inherently multidisciplinary, combining aerodynamics, aero-acoustics and propulsion simulation within a single experimental environment. This integrated approach enables realistic assessment of installation effects and system interactions.

DNW has extensive experience in propulsion and engine–airframe integration testing, supporting both conventional and emerging propulsion concepts.

In addition to air-driven turbofan propulsion simulation, the LLF supports propeller simulation for fixed-wing aircraft, rotorcraft and advanced air mobility concepts, enabling detailed assessment of slipstream effects, noise generation and performance.

DNW is continuously advancing its propulsion simulation capabilities towards high power-dense, electrically driven propulsion simulators, supporting next-generation hybrid-electric and fully electric aircraft architectures.

Key propulsion-related capabilities include:

- Electrically driven or air-driven propulsion simulation
- Electrical power supply up to 1000 VDC

- Compressed air supply: up to 6 kg/s at 70 bar
- Suction-based intake simulation
- Interference-free thrust measurement using airline-balance bridge technology
- Rotary shaft balances enabling 6DoF load measurements
- In-house calibration and validation of propulsion simulators in the Engine Calibration Facility (ECF)

This integrated environment allows detailed assessment of:

- Engine installation effects
- Propulsion–airframe interactions
- Thrust and torque performance
- Unsteady loading
- Noise generation mechanisms

Propulsion testing at DNW is not treated as a standalone activity, but as part of a broader multidisciplinary experimental framework.

Aeroacoustics

The LLF is designed as a low-noise facility and supports high-fidelity aeroacoustic testing at large scales.

The background noise levels in the open test section, measured inflow and out-of-flow up to wind speeds of 70 m/s, are sufficiently low to realize accurate identification and characterisation of aerodynamic and propulsion-related noise sources.

Available aeroacoustic systems include:

- Fixed and traversing microphone arrays
- In-flow and out-of-flow phased array systems
- Advanced beamforming and deconvolution techniques

These systems enable both source localization and quantitative noise assessment for complex configurations, including:

- High-lift devices
- Propulsion systems
- Bluff bodies (e.g. landing gears)

The combination of large-scale testing and advanced acoustic diagnostics makes the LLF particularly well suited for configuration-level noise mitigation studies.

Rotor blade acoustics (STAR project)





Particle Image Velocimetry
(NIFTI Clean Sky 2 project)



3D Particle Tracking Velocimetry using Helium-Filled Soap Bubbles
(NEXTTRIP Clean Sky 2 project)

Measurements & Diagnostic Techniques

The LLF supports a comprehensive suite of advanced measurement and flow diagnostic techniques, enabling detailed characterisation of aerodynamic, aeroacoustic, and propulsion-related phenomena.

Many of these techniques are shared across DNW facilities, allowing consistent methodologies and direct comparison of results between tunnels.

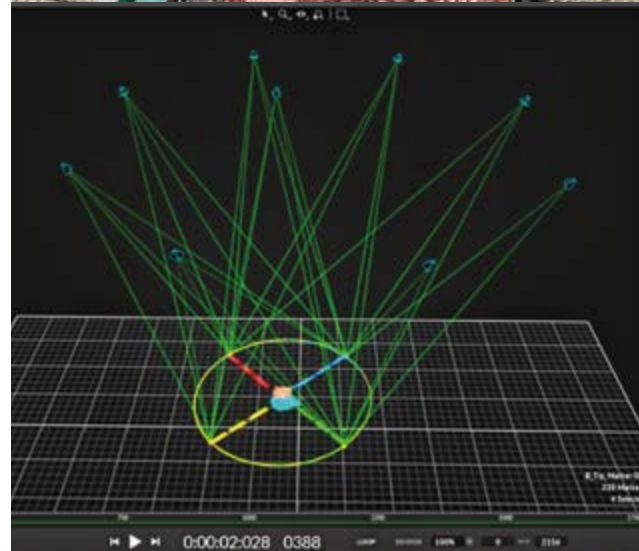
Available techniques include:

- High-accuracy force and moment balances (internal and external)
- High-density static and unsteady pressure measurement systems
- Stereoscopic pattern recognition (SPR) for model deformation and attitude measurement
- Infrared thermography (IRT) for transition detection
- Particle Image Velocimetry (2C and 3C-PIV)
- 3D Particle Tracking Velocimetry (by NLR)
- Laser light sheet visualisation
- Pressure-Sensitive Paint (PSP) and Temperature-Sensitive Paint (TSP) (by DLR)
- Tufts and smoke visualisation

These techniques can be applied simultaneously, allowing multi-physics datasets to be acquired within a single test campaign.

The use of common or closely related measurement systems across DNW facilities allows techniques developed and validated in one facility to be efficiently applied in others. This cross-facility consistency is a key element of DNW's experimental quality and portfolio synergy.

High testing productivity is enabled by DNW's GAIUS wind tunnel control, automation and data-acquisition system, which is deployed consistently across LLF, LST, ECF, HST and SST. GAIUS supports scripted test execution, continuous sweeps and synchronised data acquisition, ensuring data quality while reducing overall test time.



Stereoscopic pattern recognition (STAR project)



eVTOL model with electric ducted fans



Aero-elastically scaled, powered model
(ATTILA Clean Sky 2 project)



Open rotor performance and aero-acoustics

Aerospace Applications

The LLF supports a wide range of low-speed aerospace test programmes, focusing on flight phases and configurations where aerodynamic complexity, noise generation and installation effects are to be investigated.

Typical aerospace applications include:

- Aerodynamic configuration development and optimisation
- Aerodynamic database generation for fixed-wing aircraft, rotorcraft, and space vehicles
- High-lift system testing
- Take-off and landing performance assessment
- Ground effect investigations
- Engine–airframe integration studies
- Propeller and fan installation effects
- Aeroacoustic source identification and noise mitigation
- Wake interaction studies



WLTP testing on ATS

Automotive Applications

Using the same large-scale infrastructure and measurement philosophy applied in aerospace programmes, the LLF supports full-scale automotive testing across dedicated configurations tailored to vehicle class and regulatory purpose.

Typical automotive applications include:

- WLTP-compliant aerodynamic testing; wheelbases up to 4.75 m (ATS)
- WLTP-compliant driving resistance measurements (ATS)
- Aerodynamic drag reduction and environmental performance optimization studies
- Crosswind sensitivity and vehicle stability investigations
- Exterior aeroacoustic studies (9.5 m × 9.5 m CTS)
- Interior (cabin) aeroacoustic studies (9.5 m × 9.5 m CTS)
- Full-scale truck aerodynamic development (9.5 m × 9.5 m CTS)
- Tractor-trailer interaction studies (9.5 m × 9.5 m CTS)

Customer Value & DNW Portfolio Synergy

The LLF enables customers to perform large-scale, multidisciplinary testing under highly controlled conditions, reducing development risk and increasing confidence in both experimental and numerical results.

By combining large model capability, high-quality flow, and advanced diagnostics, the LLF allows customers to:

- Validate numerical simulations with high-quality experimental data
- Support regulatory approval with reliable, traceable experimental evidence
- Quantify installation and interference effects
- Identify multidisciplinary couplings
- Optimise complex configurations
- De-risk advanced configurations through early experimental assessment

Beyond the LLF 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.

Within this portfolio:

- LST serves as a readily accessible development and pre-testing facility for both HST and LLF
- NWB enables dedicated low-speed aero-acoustic 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 $M = 4$
- TWG offers highly flexible, smaller-scale continuous transonic and supersonic testing up to $M = 2.2$

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 LLF plays a central role within DNW's facility portfolio as the reference facility for large-model, complex-configuration and multidisciplinary low-speed testing.



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