German-Dutch Wind Tunnels

Large Low-speed Facility (LLF)

DNW - LLF

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About us

The Foundation DNW (German-Dutch Wind Tunnels) was established in 1976 by the Dutch National Aerospace Laboratory (NLR) and the German Aerospace Center (DLR), as a non-profit organization under Dutch law. DNW owns the largest low-speed wind tunnel in Europe, the LLF, and operates the aeronautical wind tunnels of DLR and NLR, which are fully integrated in the DNW organization.

The main objective of DNW is to provide its customers from the research community and aerospace industry with a wide spectrum of wind tunnel test- and simulation techniques, operated by one organization, providing the benefits of resource sharing, technology transfer, and coordinated implementation of research and development results.

Key Technical Parameters

Test section (m)	9.5x9.5	8x6 closed	8x6 open	6x6
Maximum velocity (m/s), empty test section	60	115	80	140
Maximum velocity (m/s), with model at sting support	55	105	80	130
Reynolds number (x 106 for reference length 1 m)	3.9	5.4	3.8	5.9

Mach number range
0.01 – 0.42

Pressure and temperature
ambient

Turbulence level (at model center)
lon: 0.02%, lat: 0.04%

Flow uniformity
Δ cp = 0.001 (5Pa)

Flow angularity
< 0.06°

Temperature uniformity
< 0.2°C

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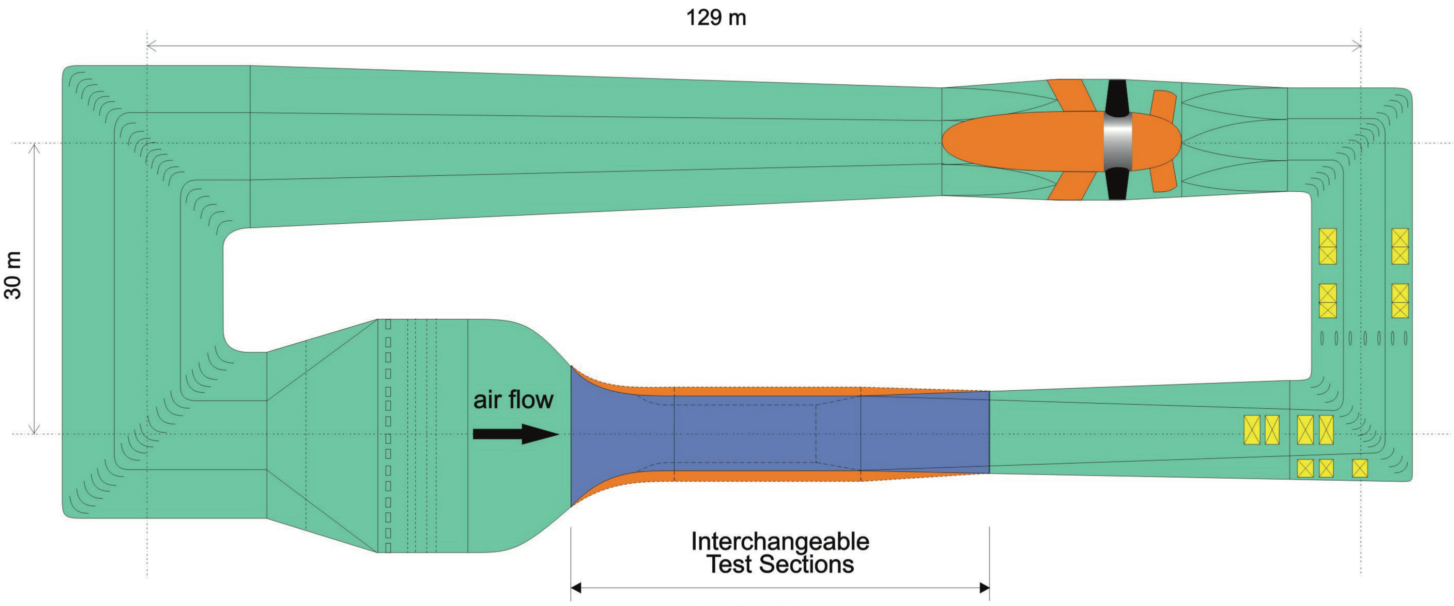
Figure 1
LLF wind tunnel circuit



The LLF (Figure 1) is a closed return circuit wind tunnel (with open and closed test sections) for industrial aerodynamic and aero-acoustic testing of complete aircraft configurations or its components. DNW offers wind tunnel testing techniques for the aerodynamic, aero-acoustic and aero-elastic simulation of aircraft models in a controlled environment with excellent air flow characteristics. The experimental capabilities of the LLF capture the essence of the issues to be investigated in the low speed regime, i.e. aircraft take-off and landing. Innovations and investments focus on aircraft safety (flight in ground proximity), environmental issues (noise hindrance) and engine integration related testing capabilities (saving fuel, reducing CO_2 emission).

Typical issues addressed during wind tunnel testing in the LLF cover aircraft configuration studies, aerodynamic database creation (civil and military transport aircraft, fighters, helicopters, spacecraft, cars and trucks), engine integration studies with turbine-powered simulators (turbofan and propeller) and engine air intake and exhaust jet and aeroacoustic investigations.

Customer Benefits

Low Noise Aircraft

Most of the noise generated in the vicinity of airports is produced by aircraft approaching or taking-off, taxiing along runways and by engine testing. DNW supports the strategy of the aviation industry to develop quiet aircraft in a continuous effort to limit aircraft noise impact, by offering an excellent test environment to reduce noise at source. DNW's state-of-the-art

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technologies for measuring aircraft noise and the related reduction mechanisms for full-size components (Figure 2) or full-span models reveal detailed knowledge of aircraft noise sources. The large open test section of the LLF and semi-anechoic test hall (50 m x 30 m x 20 m) are specifically qualified for aeroacoustic investigations due to their anechoic quality and very low background noise level.

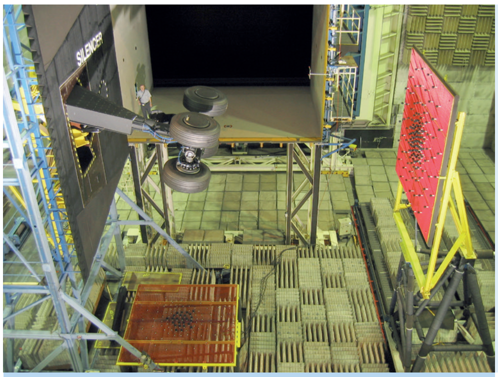

Figure 2
Landing gear acoustics
(EU SILENCE® project)

Safe Take-off and Landing

To realistically represent the influence of the ground proximity (Figure 3), especially during aircraft landing with wing flaps and slats fully deployed, the moving belt ground plane has been upgraded. The original flexible belt moving at speeds of up to 40 m/s was replaced by a steel belt system capable of running up to 80 m/s. A sophisticated suction/blowing system keeps the belt absolutely flat, also under large aerodynamic loading (when testing aircraft in ground proximity). A boundary layer removal system and reinjection scoop complement the test set-up.

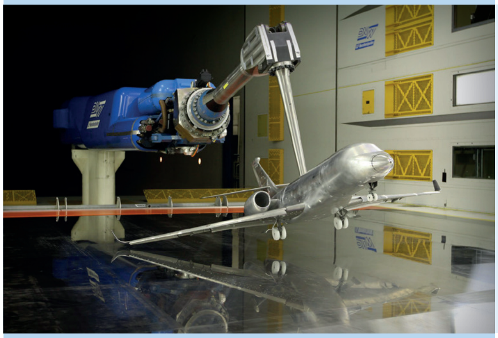

Figure 3
Business jet model
in ground effect
(EU CleanSky PLAAT project)

Efficient Engine

Aircraft – engine integration is of crucial importance for a successful aircraft design. DNW has specialized in providing simulation solutions to accurately assess the impact on engine inflow conditions, aircraft performance & stability and thrust reverser effectiveness. DNW owns several air–driven Turbofan Propulsion Simulators (TPS) units for different model scales, representing turbofan engines of all major engine manufacturers (Figure 4). The compressed air plant of the LLF delivers 4.7 kg/s (6.6 lb/s) continuously at 80 bar for powering TPS units. Application of a unique airline bridge design in the wind tunnel model allows for accurate and interference-free measurement of TPS thrust levels. Calibration of these systems can be done in-house in the Engine Calibration Facility ECF.

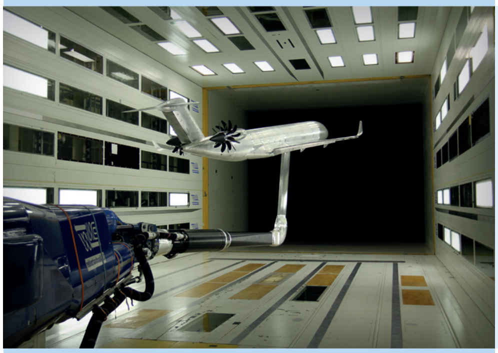

Figure 4
Counter rotating open
rotor model
(EU CleanSky Z08 project)

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Figure 5
MAN TGX truck testing

Wind Tunnel

Test Sections

The larger of the two closed test sections has a cross section of 9.5 m x 9.5 m and the smaller has a cross section of 8 m x 6 m (26.2 ft x 19.7 ft). This test section can be converted to 6 m x 6 m (19.7 ft x 19.7 ft). For the open jet arrangement the 8x6 nozzle is used together with the 9.5 m x 9.5 m transition. This open jet test section is part of the so-called test hall (50 m x 30 m 20 m), which is completely covered with sound-absorbing lining material during acoustic tests.

Model Support Systems

The flexibility of the LLF, especially its modular construction with a range of different test sections and model support systems, enables the realization of a variety of different test set-ups and wind tunnel speed ranges to suit the customer’s needs.

A typical aircraft model wing span is 4.5 m and the maximum tolerable model weight is 1500 kg. To optimize testing time, a range of remote controls for aircraft control surfaces is available for integration into the wind tunnel model.

The LLF offers model mounting capabilities on a sting support system (ventral or dorsal) via an internal balance (typical for aircraft and helicopter testing), an underfloor six-component external platform balance, e.g. used for full-size cars/trucks (Figure 5) and semi-span models, and different support systems for open jet testing. The sting support allows for 360°model roll angle variation for models of limited weight and has a 6.6 m vertical stroke. The model angle of attack setting range is 56°and the yawing angle is 50°(angle accuracy 0.02°).

The automated model control system allows for data acquisition in continuous measuring mode for aerodynamic model runs (data points at 0.4°) and in step-by-step mode for acoustic testing.

Auxiliary Systems

- Rotor test stand (owned and operated by DLR)
- Vacuum systems for engine air intake simulation (5 kg/s mass flow rate at 95 bar, that can be doubled with the use of nitrogen).

Simulation Techniques

The wall correction routine of LLF for lift interference and for solid blockage uses the definitions and formulation of the AGARDograph 109. For the wake blockage the Maskell-Vayssaire ideal-polar-method adopted for an on-line application is used.

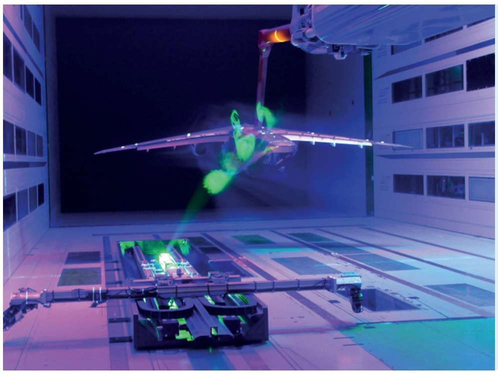


Figure 6
EMBRAER KC-390
optical measurements

Measurement Techniques

It's DNW's policy to keep measurement equipment at a high standard. Sharing of equipment between the various DNW wind tunnel sites is common practice. This allows meeting a large range of customer requirements. In addition, the support by both parent organizations (German Aerospace Center DLR and Netherlands Aerospace Center NLR) gives DNW access to experience, knowledge, innovations and new developments.

Forces and Moments

For the measurement of static forces and moments, a wide range of internal strain gauge load balances of different size and load range is available (length: 700 to 1250 mm, diameter: 150 to 220 mm). Of course also customer supplied balances can be applied.

Force range
6.500 – 50.000 N

Moment range
3.000 – 15.000 Nm

Uncertainty (3 sigma)
< 0.3%

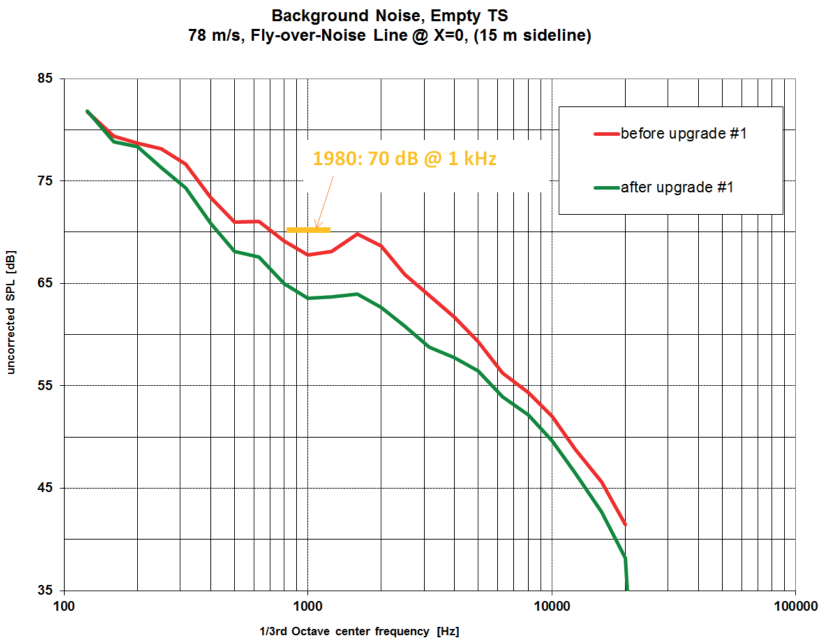
The external 7 m diameter platform balance has a load range of 20 – 65 kN / 20 – 40 kNm.

The on-board strain gauge measurement system is capable of measuring 80 auxiliary strain gauge balance components/signals.

Pressures

For static pressure measurements Scanivalve© Scanning Systems are operated. These allow the simultaneous measurement of 1500 pressures accurately and fast, by using temperature-compensated electronic pressure scanning modules (0,1% accuracy of the ZOC module range; ranges 1, 5, 15, 50 psi = 6.9, 34.5, 103, 345 kPa). For highly accurate pressure measurements, differential pressure transducers are available. For the evaluation of dynamic surface flow pressures up to 240 Endevco© and/or Kulite© transducers can be served by GBM Viper data acquisition systems.

Figure 7
Open test section background noise measurements



Flow Field

Instantaneous flow field images can be recorded by means of the Particle Image Velocimetry (PIV) technique in an arbitrary plane of the flow. One (for 2D) or two (for 3C) digital cameras take images of a plane in a laser light sheet (Figure 6). The light sheet is erected within the flow of a wind tunnel in order to illuminate tracer particles. These are seeded into the flow upstream of the flow phenomenon to be investigated.

The illuminated tracer particles within the light sheet window (30 x 40 cm) are recorded twice, allowing the calculation of particle displacement by cross correlation of a pair of images. A high productivity is achieved by mounting laser equipment and cameras on a traversing sledge in the tunnel circuit or outside, since the test section walls are equipped with large glass windows.

A stereoscopic point tracking technique is used to measure changes in the position (e.g. rudder deflection or rotor blade flapping) or shape of an object (wing bending, refueling hose). It measures marker positions on a (rotating) wind tunnel model component to derive its deformation or position. With two or more digital cameras, the spatial position of markers is determined. For a typical model scale of 5000 mm, the coordinate detection accuracy is approximately 0.3 mm or 0.1 degree in wing twist on a full span model.

Several other techniques can be applied like:
- Pressure Sensitive Paint (PSP) to quantify wind tunnel model surface pressure distribution
- Laser Light Sheet (LLS) to visualize flow field features
- Infrared (IR) technique to observe laminar-turbulent flow transition on a model surface
- Temperature Sensitive Paint (TSP)

Acoustics

The LLF was designed as a low noise facility. Faculty upgrades in the between 2010 and 2015 on corner vanes, flow straightener and the anechoic quality of the test hall reduced the background noise of the wind tunnel significantly to levels below 65 dB for frequencies above 800 Hz (Figure 7).

For acoustic measurements three independent microphone systems are available:

- 160 Far-field microphones at fixed positions on the walls and ceiling of the test hall (mostly of the electret type)
- 60 Microphones installed on traversing mechanisms, wall and floor of in the open test hall (½" free-field condenser microphone)
- Two out-of-flow microphone arrays of each 140 electret microphones installed in a fixed frame (4 m x 4 m)
- Two wall-installed in-flow microphone arrays with each 144 electret microphones installed in a fixed frame (1 m x 1 m) for application in a closed test section

Measurement techniques focus on the source and the nature of the noise and are capable of distinguishing between individual sources, thanks to diagnostic acoustic arrays consisting of multiple microphones. Correlation and phase analysis of the signals of these arrays enable the strength and location of relevant noise sources to be determined.

A phased array beamforming technique is applied to determine the locations and strength of individual sound sources (typical resolution is provided in the table below). CLEAN-SC deconvolution algorithms including convection and shear layer refraction corrections are applied.

Acoustic array results are typically graphically presented as contour plots, showing the measured noise sources on the model for different frequencies.

Data Acquisition

Dynamic data (including acoustics) are acquired by five 48-channel (16 bit, 200 kHz sampling rate per channel) high precision GBM Viper systems, synchronized with the wind tunnel or model control system and connected to the static data acquisition system.