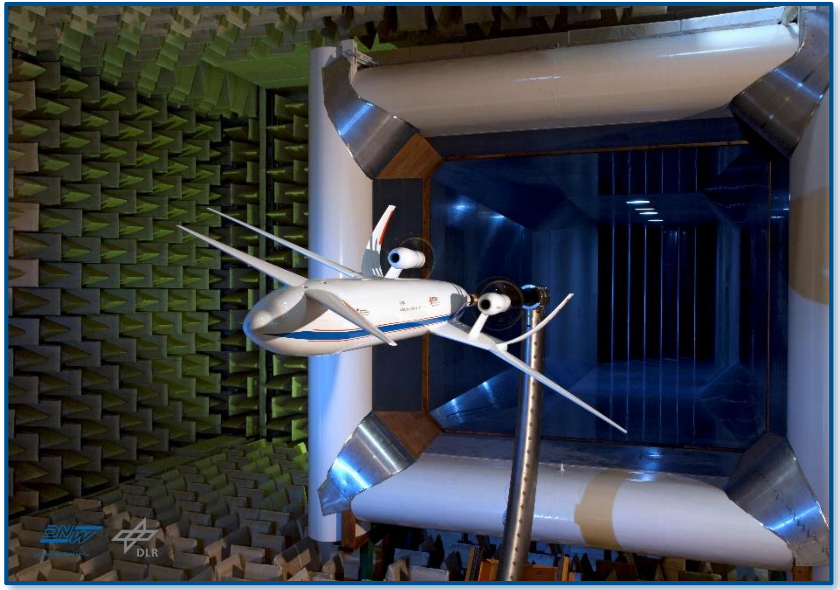

Challenges, capabilities and future developments at the German-Dutch Wind Tunnels DNW

German-Dutch Wind Tunnels

Dr. C. Lenfers 2025/04/02 NWTF conference 2025, Birmingham

Content

- The DNW foundation & organization
- Challenges
  - DNW's market
  - Customer expectations & demands
- Capabilities
  - DNW's mission statement & key assets
  - DNW's facilities
- (Recent &) future developments
  - Electric propulsion simulation
  - Automotive testing according to WLTP
  - Accuracy upgrade of αβ-support at DNW-NWB
  - Performance upgrade of DNW-HST
- Conclusion

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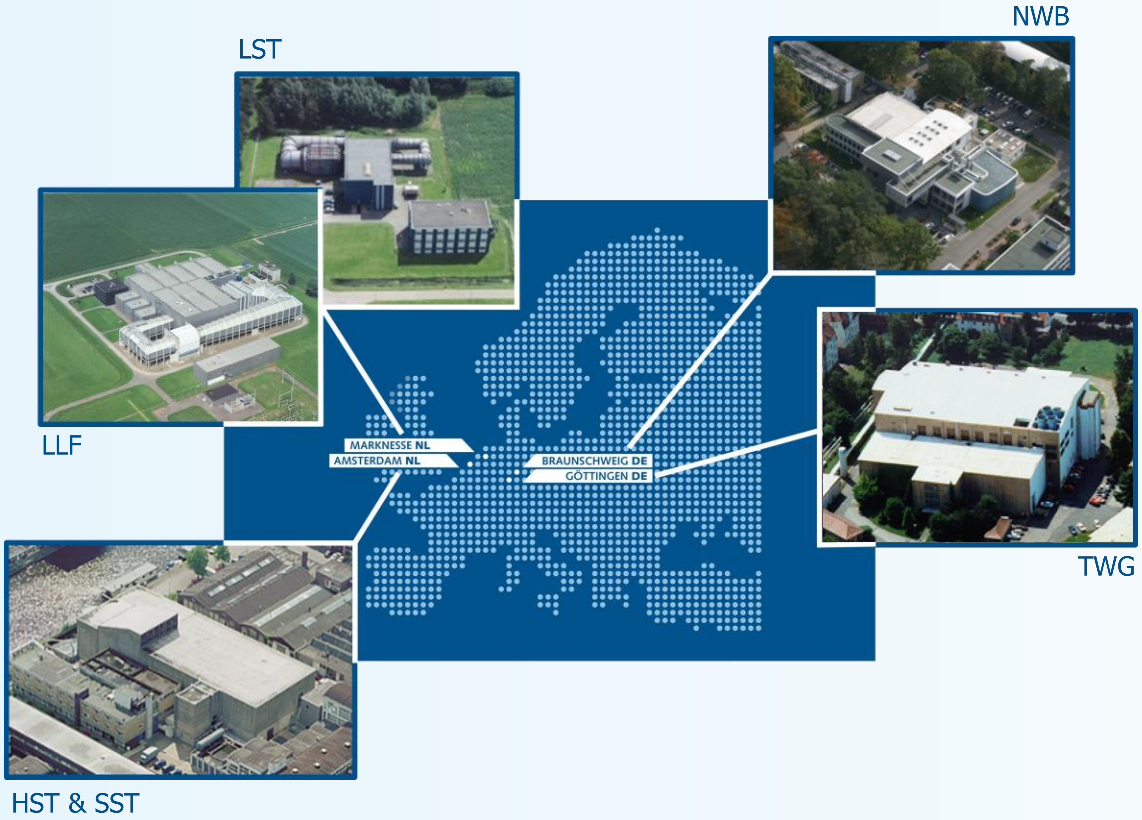
German-Dutch Wind Tunnels

The DNW foundation & organisation

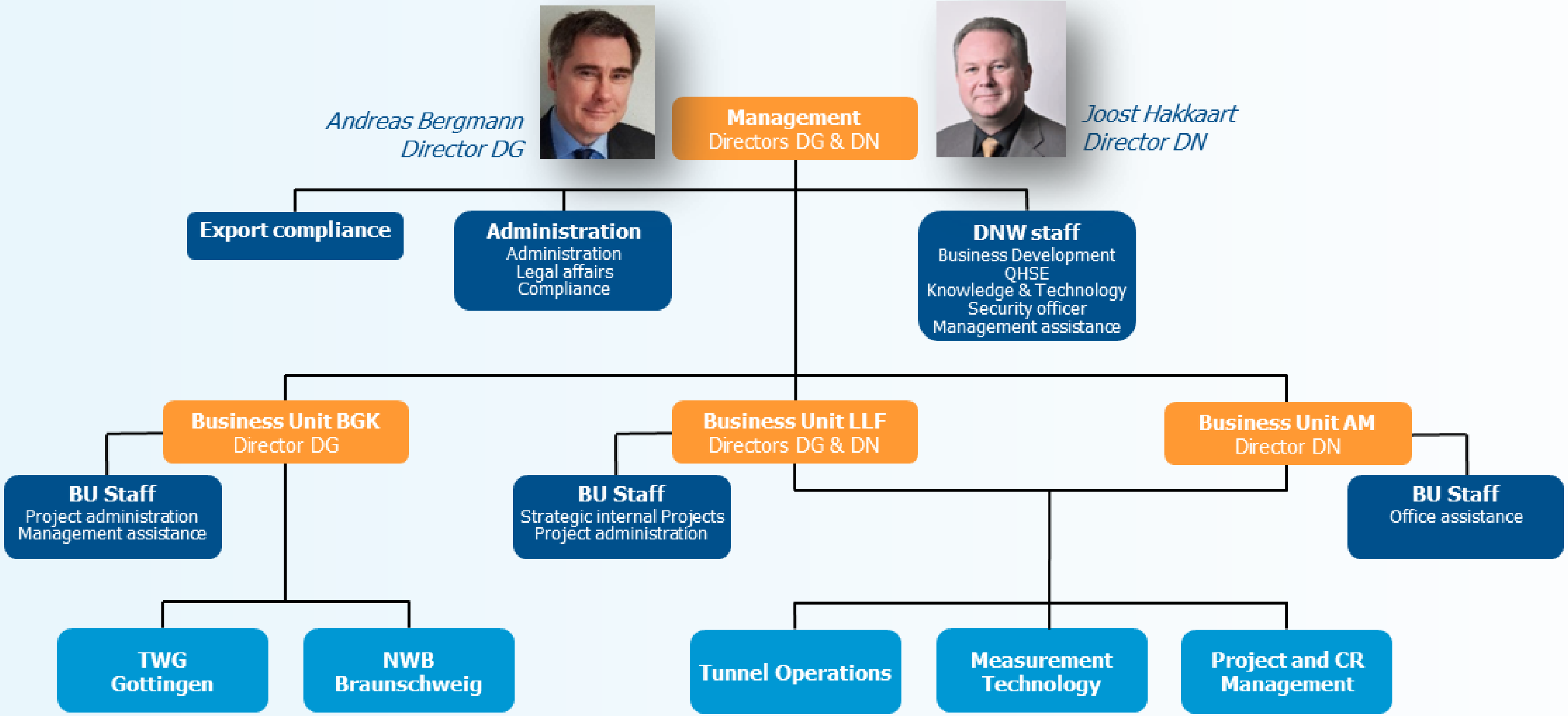


- DNW as independent foundation established in 1976 by DLR and NLR (HQ in Marknesse NL)
- LLF operational in 1980
  - First Airbus commercial contract in 1981
- Currently includes all (5) industrial wind tunnels of DLR and NLR and together with LLF, operates 6 wind tunnels in total
- All staff seconded by DLR and NLR
- DLR and NLR share the financial cost/surplus

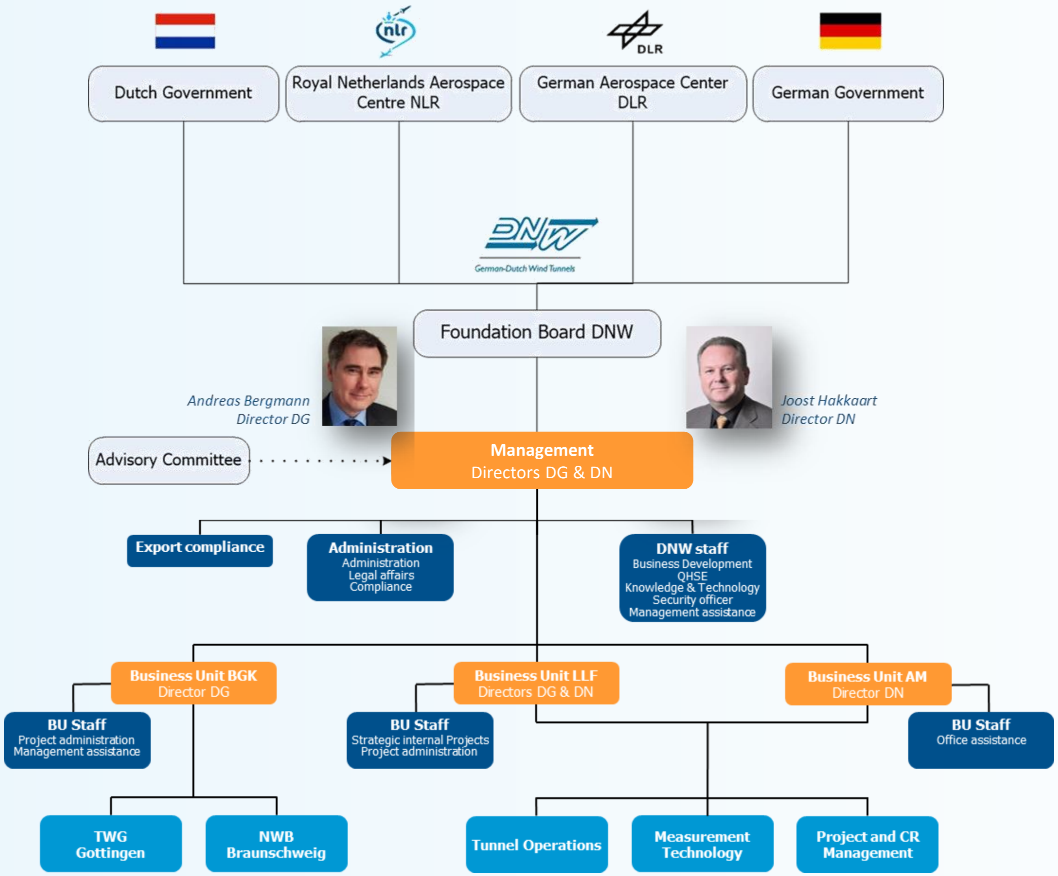
DNW is a non-profit organization without own direct government funding

German-Dutch Wind Tunnels

The DNW foundation & organisation



The DNW foundation & organisation



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Challenges – DNW's market

Civil Aerospace

- Net zero European aviation
  - adv. propulsion concepts
    - electric, distributed, hybrid, hydrogen,…
  - adv. wing configurations
    - BWB, strut braced, high aspect ratio, elastic, …
- Advanced air mobility concepts, E-VTOL

Military Aerospace

- Operational support for 5th generation fighters (e.g. Eurofighter)
- Development of 6th generation fighters (manned/unmanned, e.g. FCAS NGF)
- Missile development (isolated, store separation)

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Challenges – DNW’s market

Automotive

- Aerodynamic testing according to WLTP (certification support)
- Cost efficient alternative to coast down test
- Collaboration/synergetic approach with MITC

Civil Engineering

- Wind turbine industry
- 2D aerodynamic and aero-acoustic performance testing

Space

- Air-launched systems
- High speed separation testing

German-Dutch Wind Tunnels

Challenges – Customer expectations & demands

- General:
  - High availability of DNW's facilities
  - Reliable and high productive facilities
  - Common but flexible data format for all facilities
- Civil aerospace:
  - Versatile and precise model supports to accommodate (powered) w/t models of unconventional aircraft configurations
  - Tests of w/t models at high level of integration (e.g. engines, movables)
  - High aspect ratio wings require aero-elastic testing
  - Handling of big datasets due to the simultaneous and time resolved acquisition of different measurement techniques (e.g. MEMS, optical meas. techniques, time resolving pressure transducers, aux. balances)
- Military aerospace:
  - Focus on productivity (double shift operation) and reliability of high speed facilities
  - Need for captive trajectory testing (military & space market)

German-Dutch Wind Tunnels

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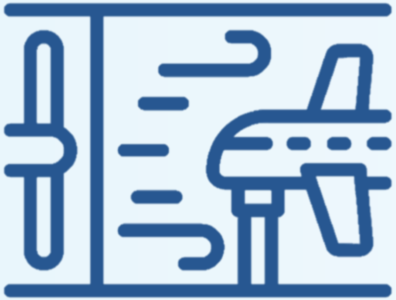
German-Dutch Wind Tunnels

Capabilities - DNW's mission statement & key assets

DNW's mission is to support the development of sustainable, safe and secure aviation by providing high quality aerodynamic and aero-acoustic wind tunnel data.

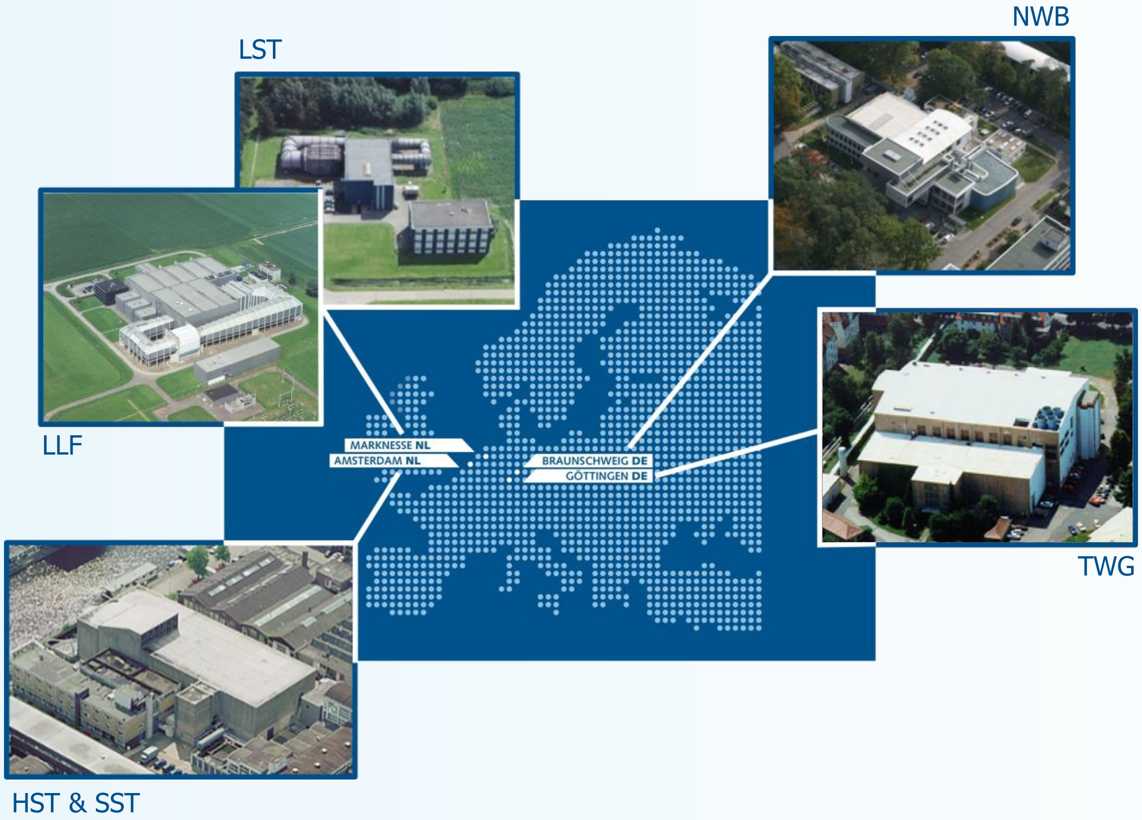


Portfolio of complementary facilities, covering a large Re-/Ma-number range

Access to knowledge and innovation of parent institutes NLR/DLR

Proactive, qualified and experienced staff offering high flexibility and service level, willingness to innovate

Capabilities – DNW's facilities



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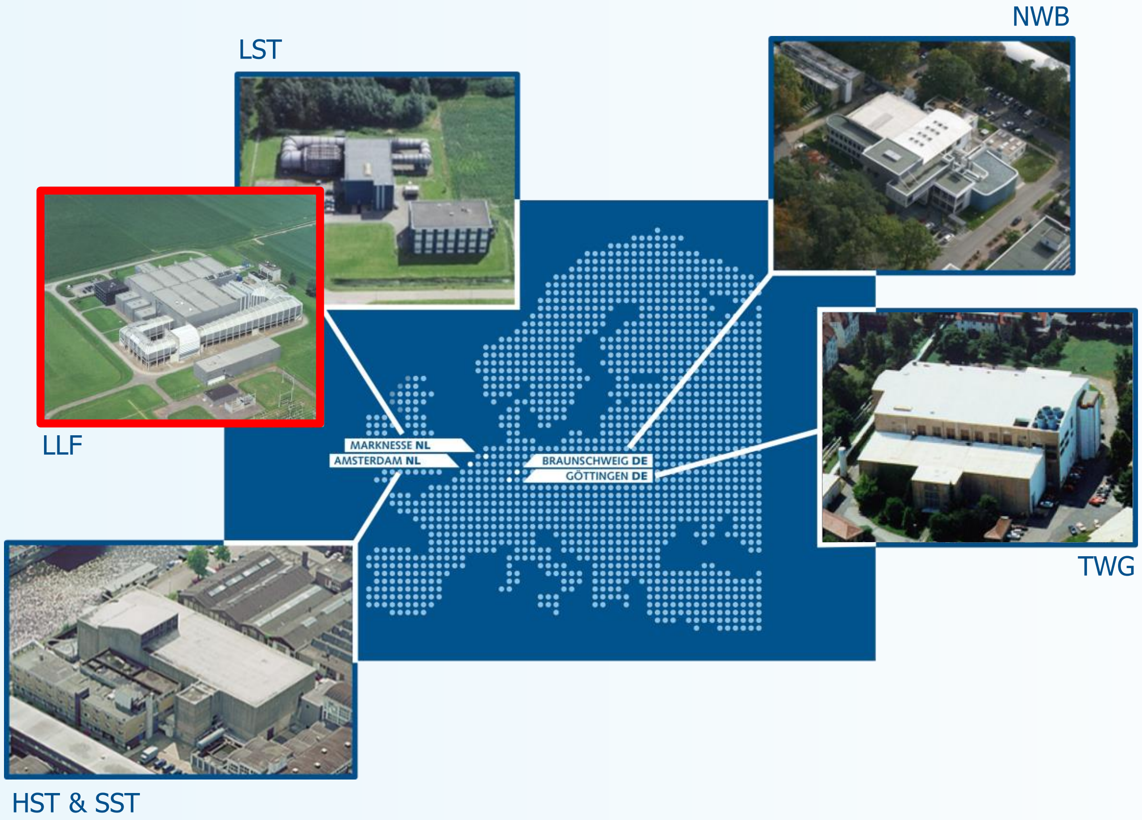
Capabilities – DNW’s facilities

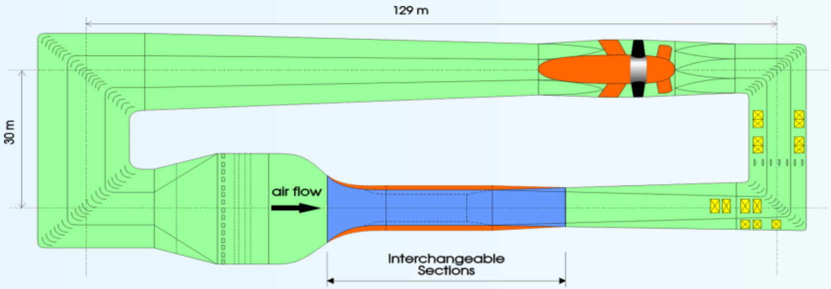


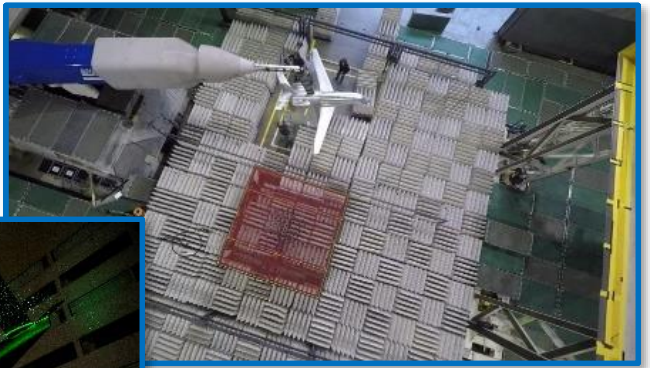
German-Dutch Wind Tunnels

Capabilities – DNW’s facilities – DNW-LLF

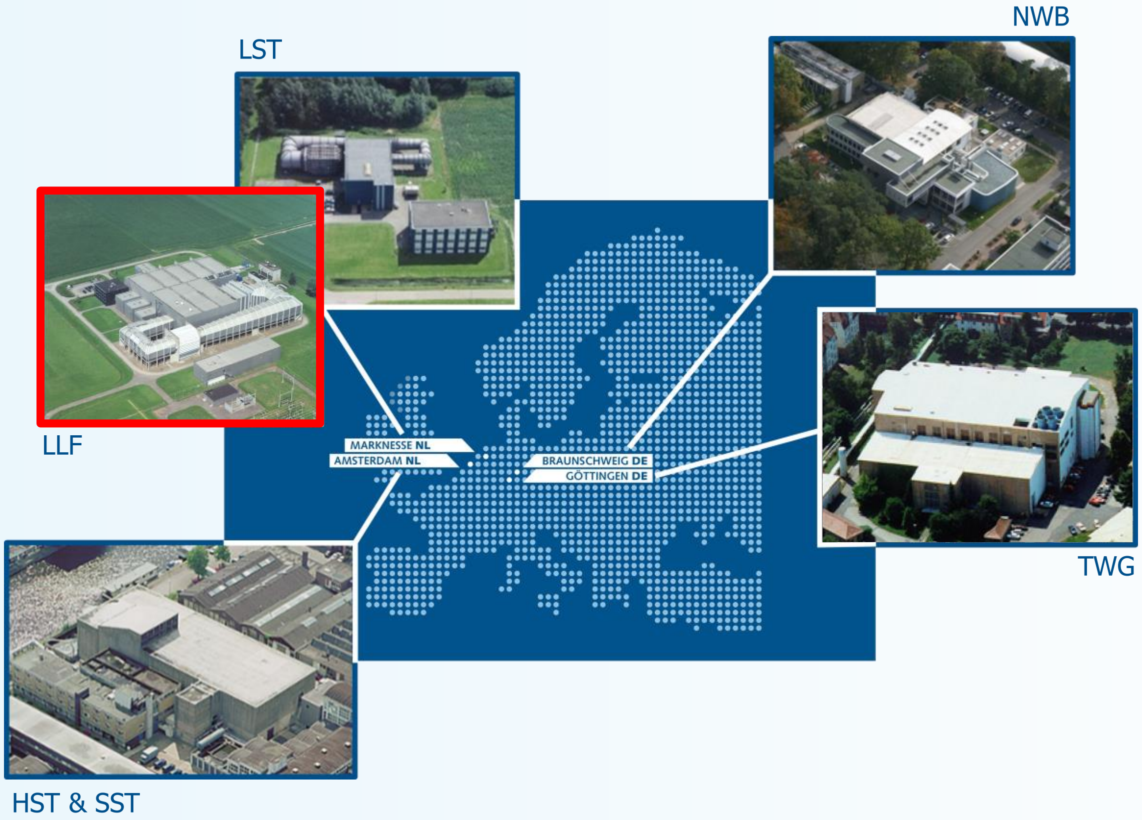
- Test sections and operating range
  - 9.50 m x 9.50 m $v_\infty \leq 62$ m/s
  - 8.00 m x 6.00 m $v_\infty \leq 116$ m/s
  - 8.00 m x 6.00 m $v_\infty \leq 68$ m/s (open jet)
  - 6.00 m x 6.00 m $v_\infty \leq 152$ m/s

- Key Test Capabilities:
  - Aerodynamics and Aeroacoustics
  - Ground proximity testing
  - Propulsion simulation



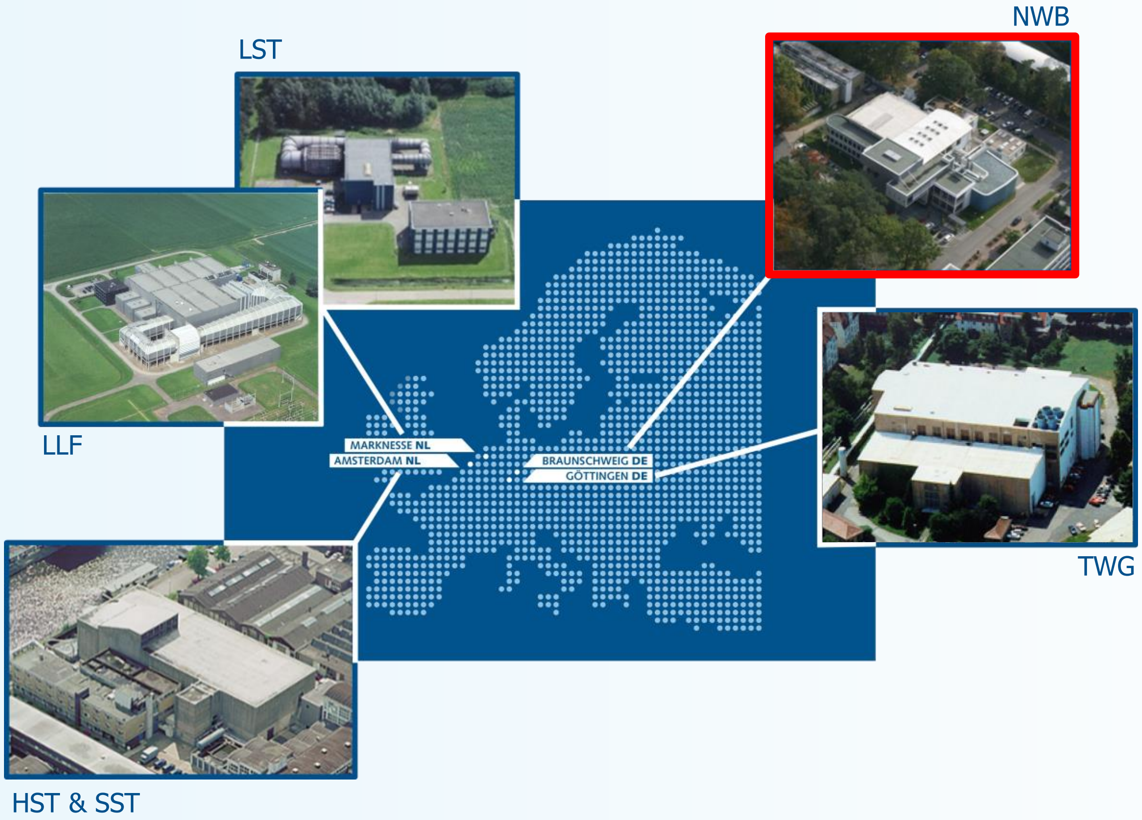


Capabilities – DNW's facilities



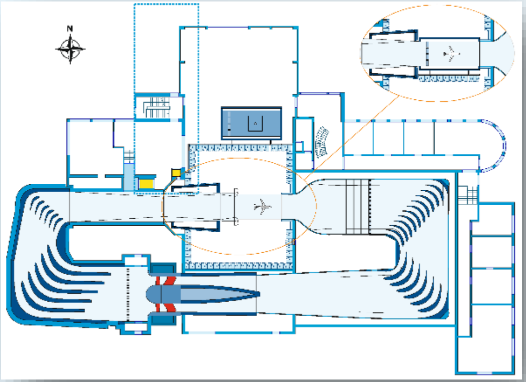
German-Dutch Wind Tunnels

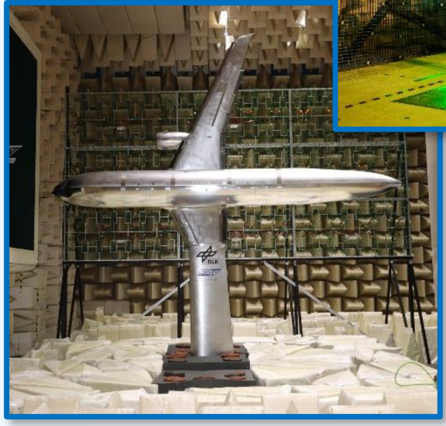
Capabilities – DNW's facilities



Capabilities – DNW's facilities – DNW-NWB

- Test sections and operating range
  - 3.25 m x 2.80 m $v_\infty \leq 90$ m/s (closed)
  - 3.25 m x 2.80 m $v_\infty \leq 80$ m/s (open jet)
  - 3.25 m x 2.80 m $v_\infty \leq 80$ m/s (3/4 open jet)

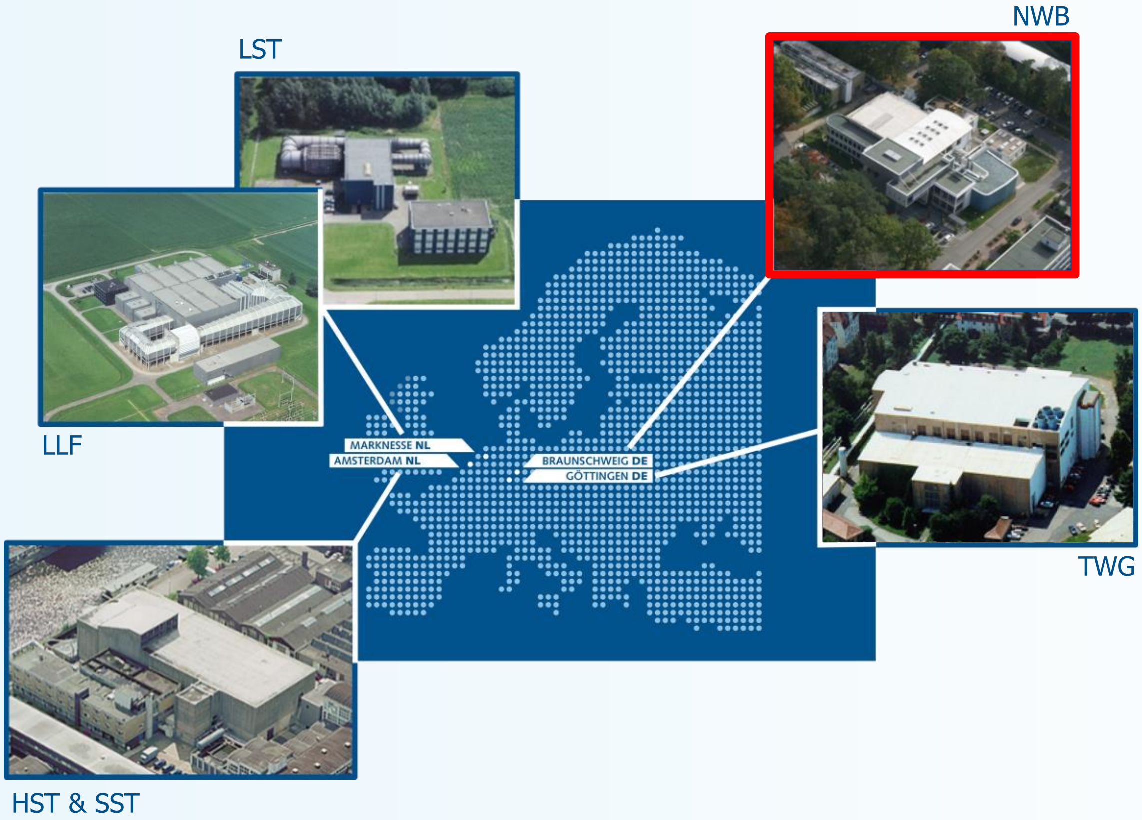




- Key Test Capabilities:
  - Aerodynamics and Aeroacoustics
  - Dynamic derivative testing using 6 DoF parallel kinematic (MPM)
  - Fixed ground plane & scoop for automotive testing

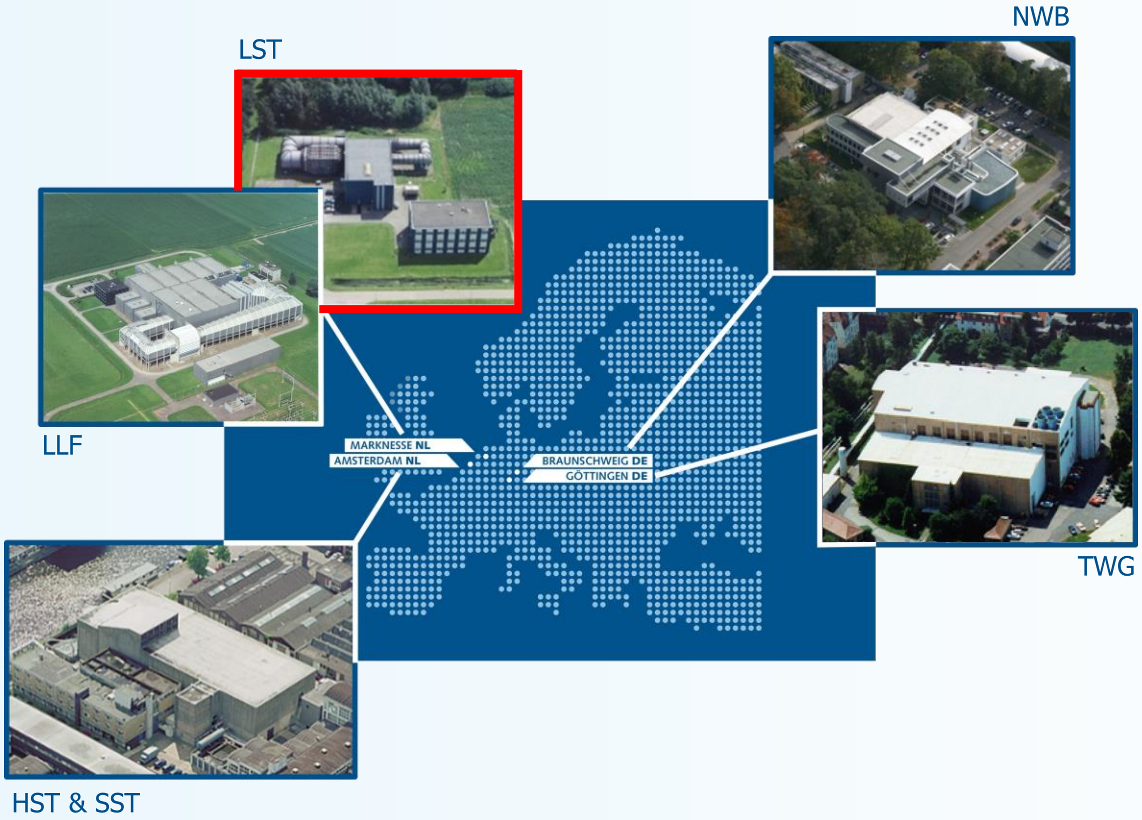
German-Dutch Wind Tunnels

Capabilities – DNW’s facilities



German-Dutch Wind Tunnels

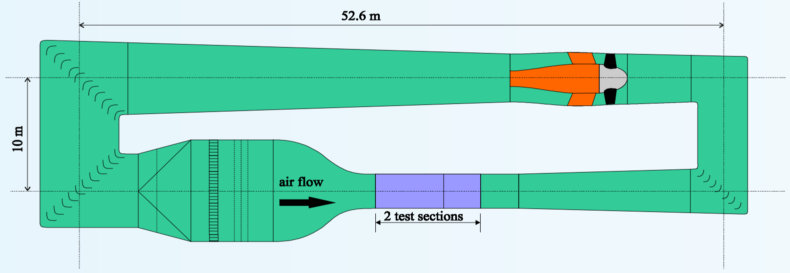
Capabilities – DNW's facilities

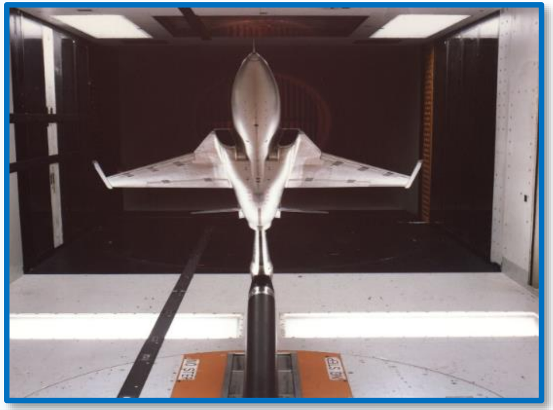


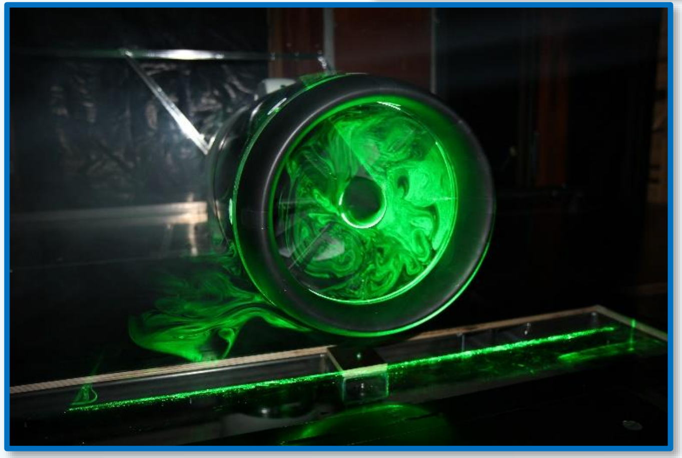
German-Dutch Wind Tunnels

Capabilities – DNW's facilities – DNW-LST

- Test sections and operating range
  - 3.00 m x 2.25 m $v_\infty \leq 80$ m/s
- High Flow Quality
  - Flow angularities: < 0.10°
  - Turbulence levels: $Tu_x = 0.02$ %, $Tu_y = Tu_z = 0.03$ %
- Key test capabilities:
  - Aerodynamics
  - Propulsion simulation

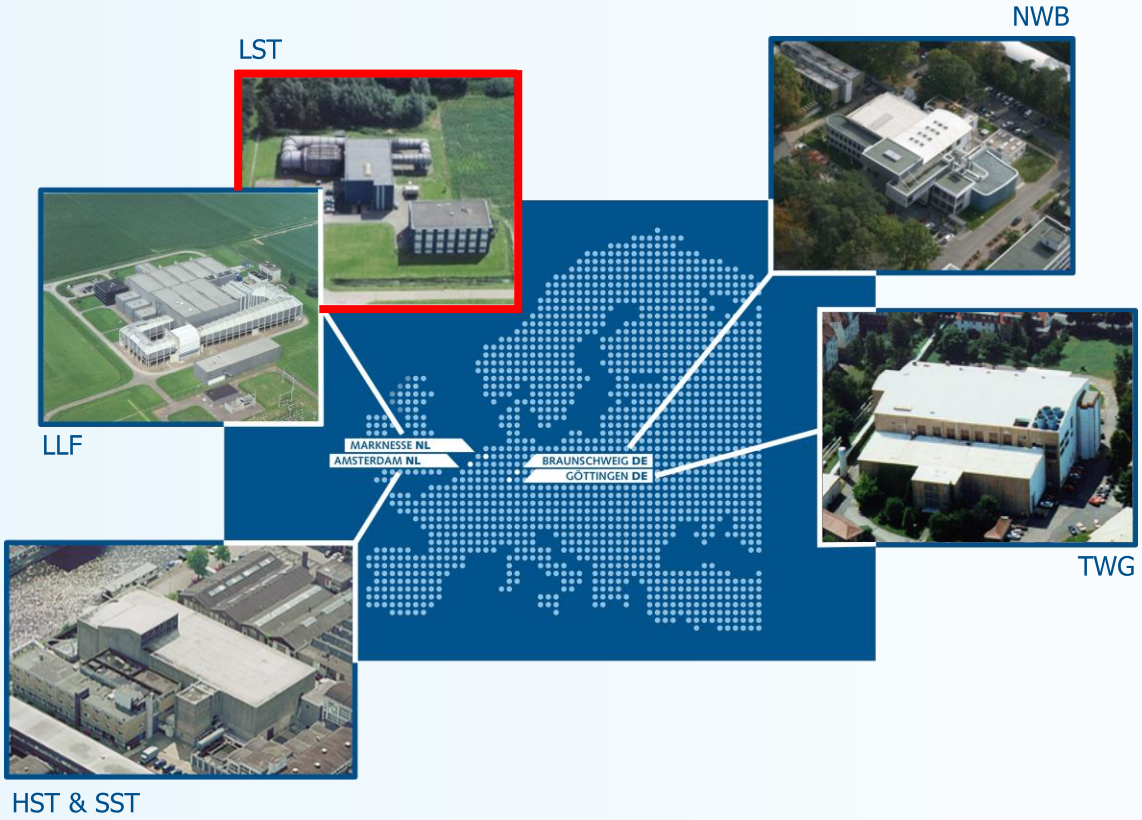






German-Dutch Wind Tunnels

Capabilities – DNW's facilities



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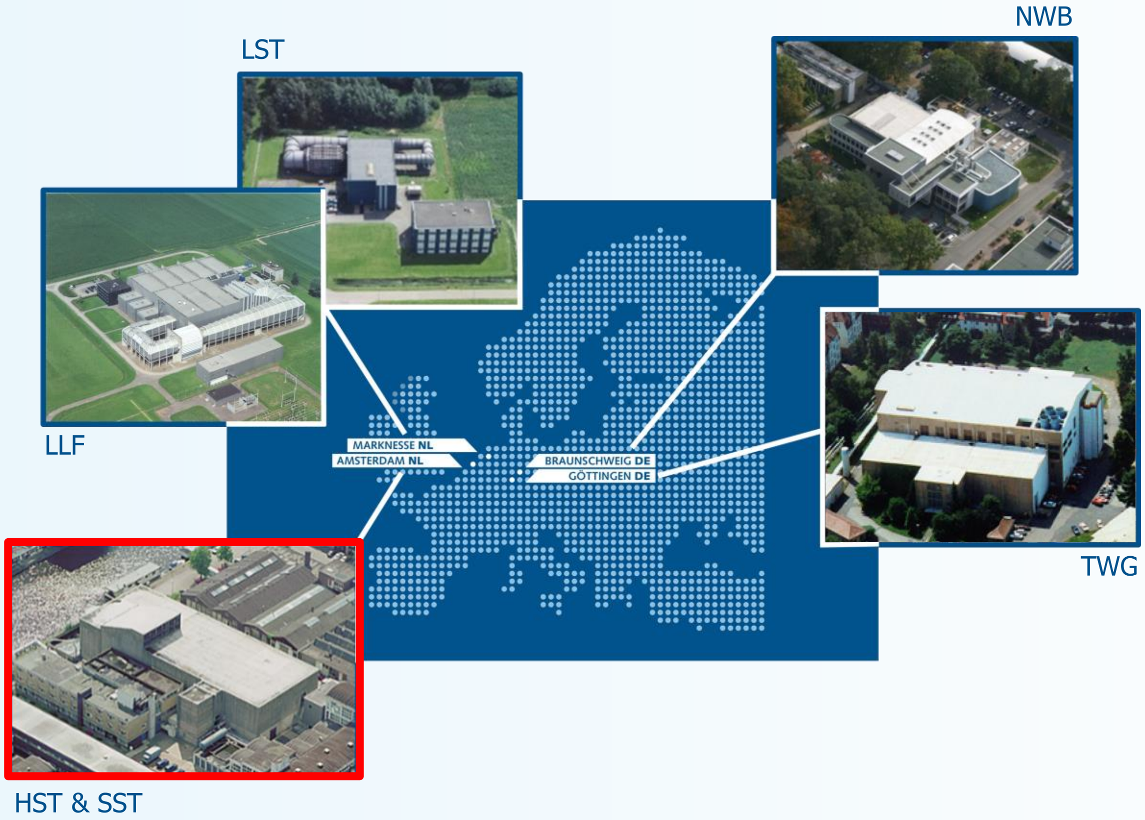
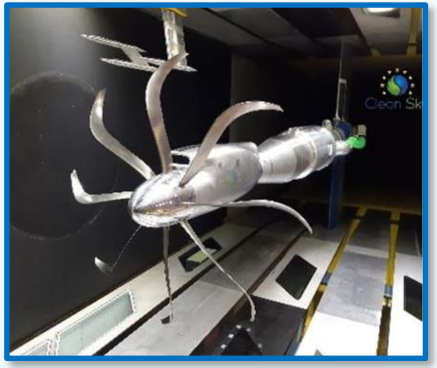
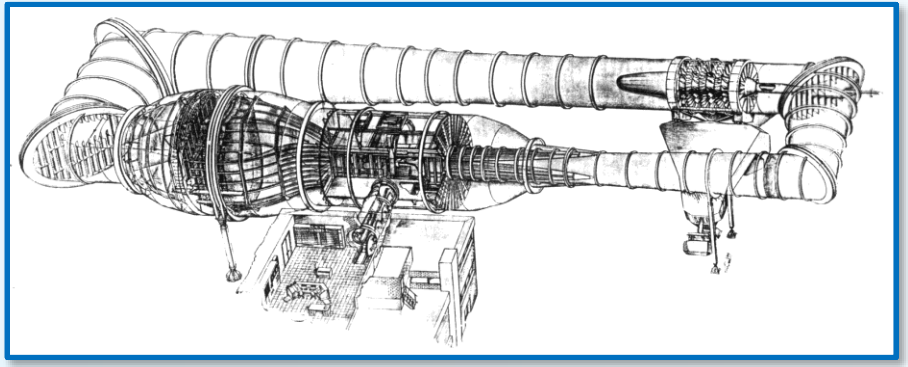
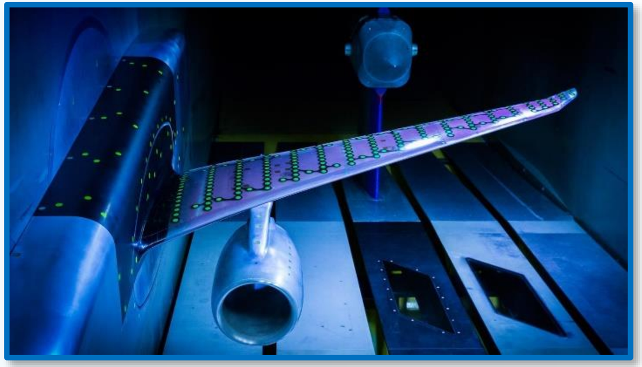


Capabilities – DNW's facilities – DNW-HST

- Test sections and operating range
  - 2.00 m x 1.60 m or 2.00 x 1.80 m
  - $0.15 \leq M_{\infty} \leq 1.3$
  - $0.25 \text{ bar} \leq p_{\infty} \leq 3.9 \text{ bar}$
  - $Re_{\,0.1 \times \sqrt{(S)}} < 9.00 \times 10^{6}$
- Key Test Capabilities:
  - Aerodynamics
  - Propulsion simulation

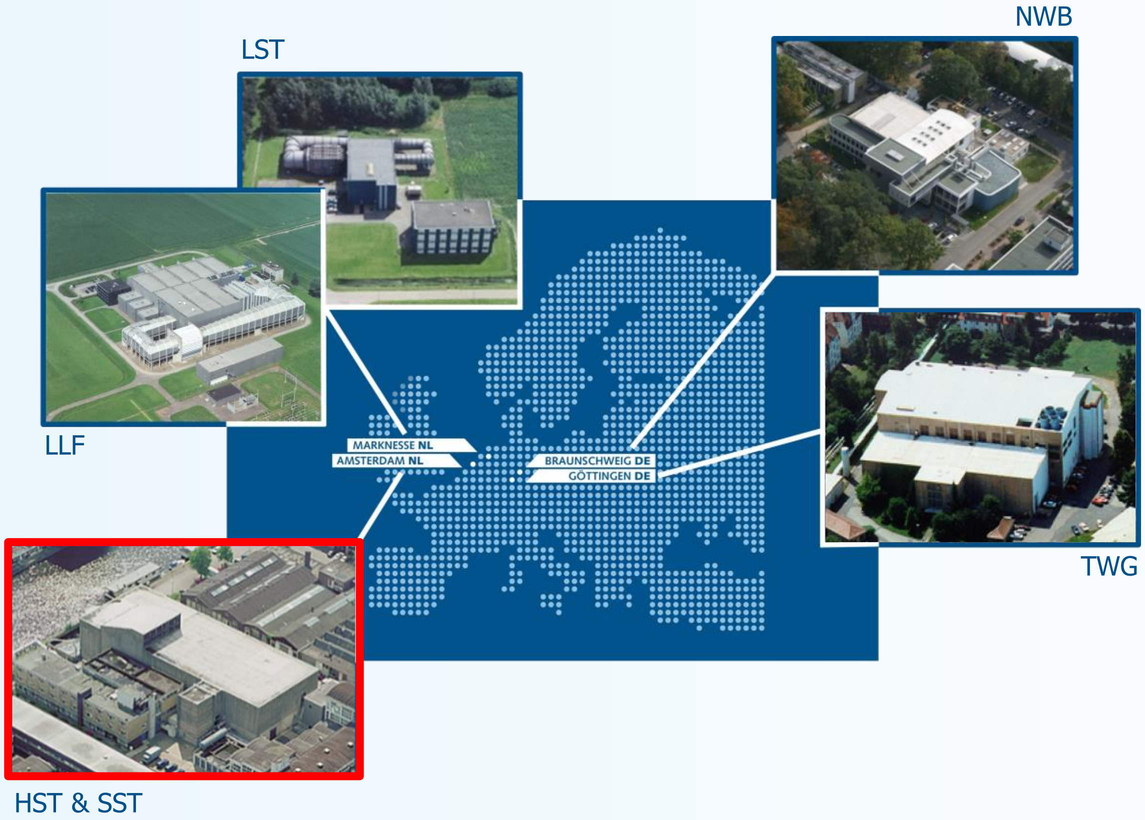






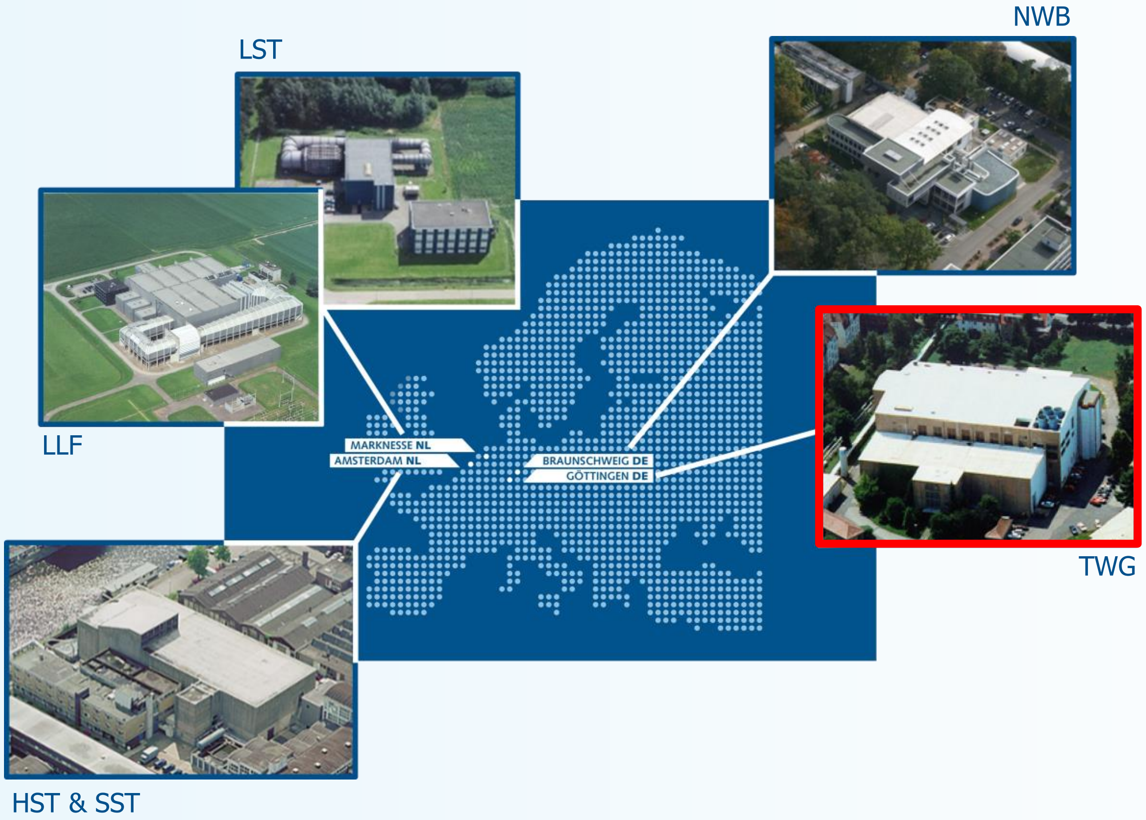
German-Dutch Wind Tunnels

Capabilities – DNW's facilities



German-Dutch Wind Tunnels

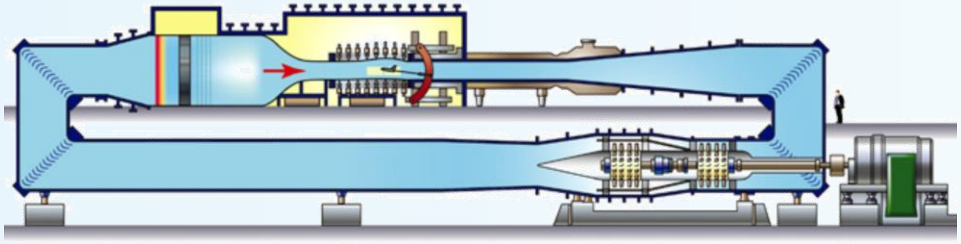
Capabilities – DNW's facilities

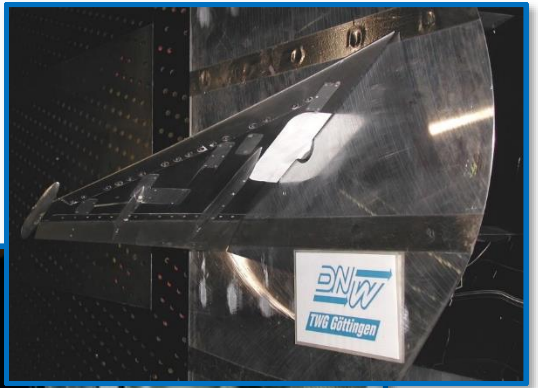


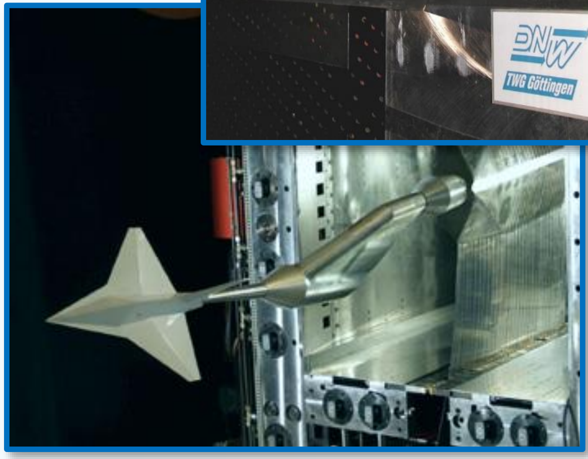
German-Dutch Wind Tunnels

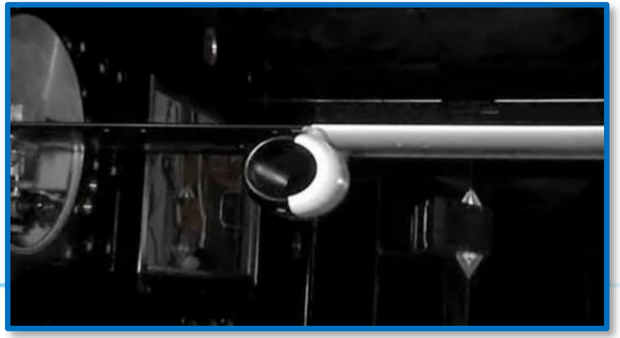
Capabilities – DNW's facilities – DNW-TWG

- Test sections and operating range
  - 1.00 m x 1.00 m
  - <u>0.30</u> $\leq M_\infty \leq$ 0.9 adaptive walls
  - 0.30 $\leq M_\infty \leq$ 1.2 perforated walls
  - 1.30 $\leq M_\infty \leq$ <u>2.2</u> flexible Laval nozzle
  - 0.30 bar $\leq p_\infty \leq$ 1.5 bar
- Key Test Capabilities:
  - Aerodynamics
  - Aeroelastic testing (with DLR institute for Aeroelasticity)









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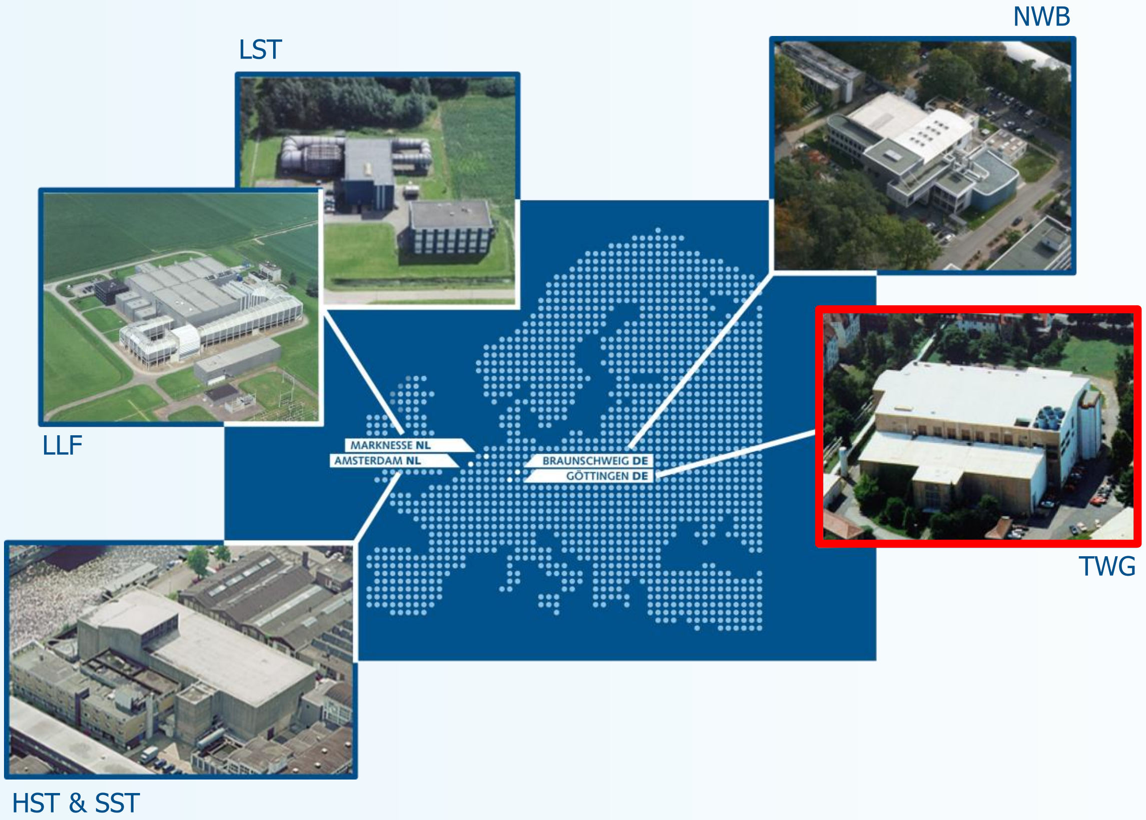
Capabilities – DNW's facilities

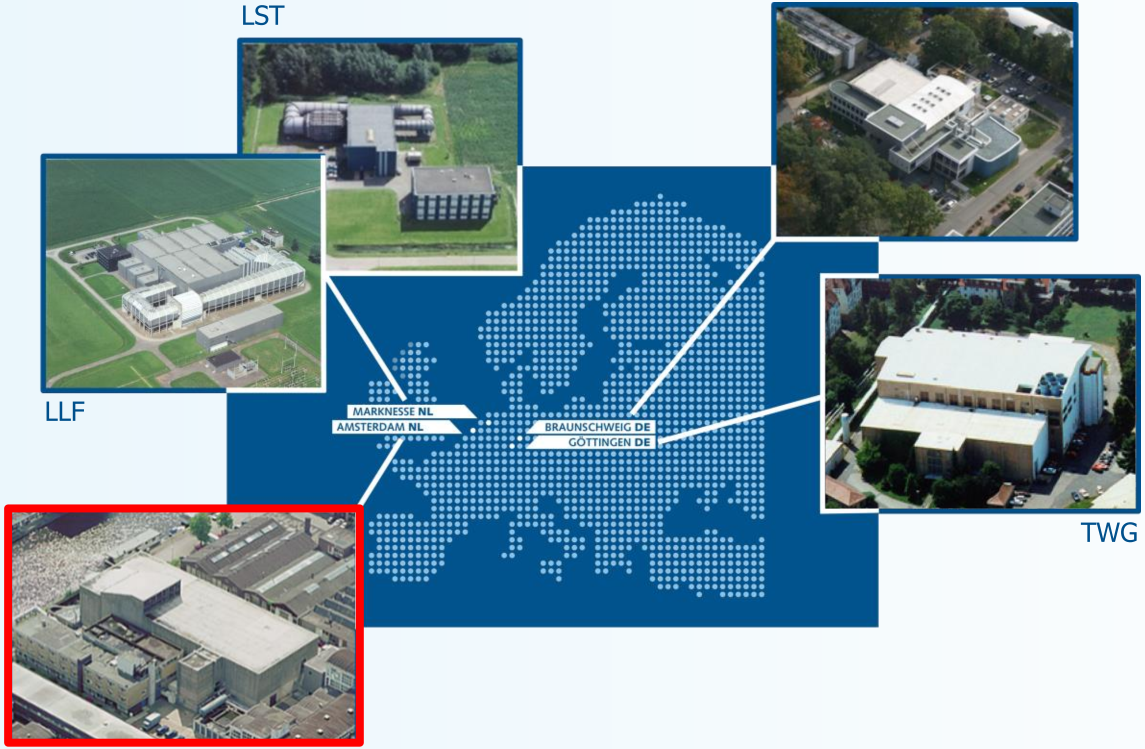


German-Dutch Wind Tunnels

Capabilities – DNW’s facilities

LST

NWB



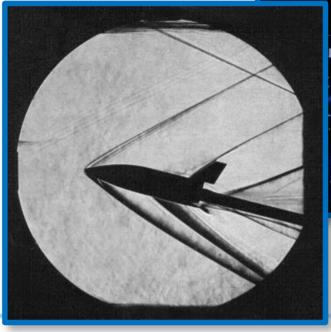
LLF

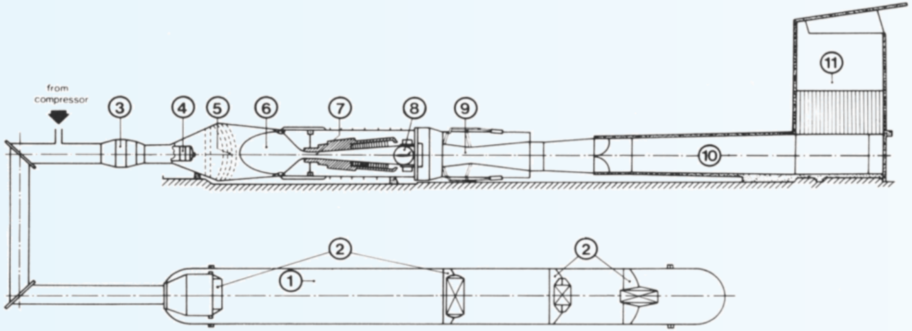
TWG

HST & SST

Capabilities – DNW's facilities – DNW-SST

- Test sections and operating range
  - 1.20 m x 1.20 m
  - $1.30 \leq M_{\infty} \leq 4.0$
  - Blow down facility:
    - Run time depends on Mach number and pressure level and is maximally about 50 seconds *(sufficient for an upward and downward incidence sweep)*
- Key Test Capabilities:
  - Fast and easy model setup change between SST and HST
    - Identical mechanical and electrical interfaces





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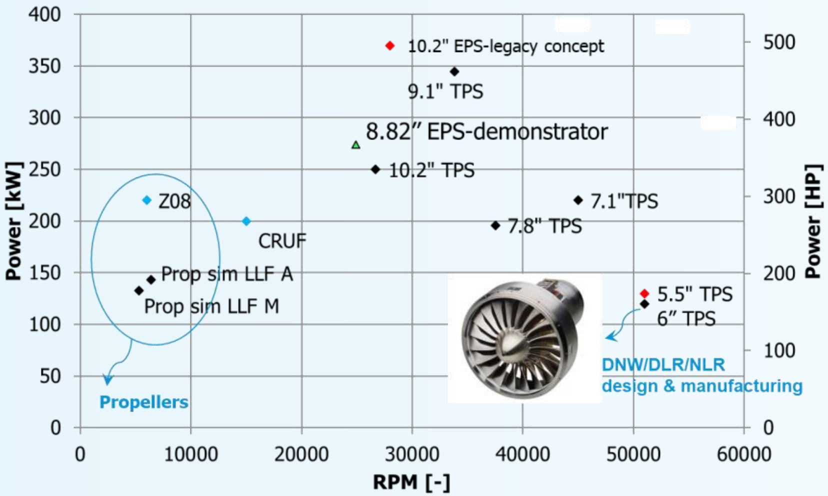
Electric Propulsion Simulation

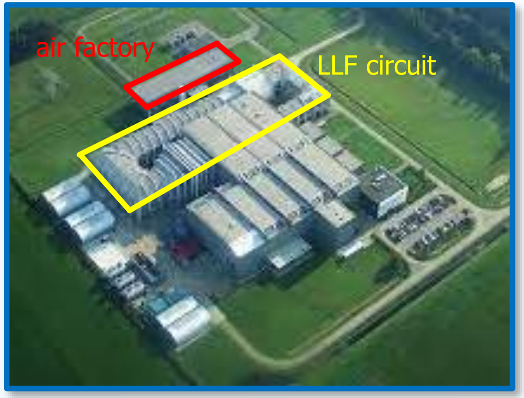
- Motivation:
  - Current technology: turbine powered simulation (TPS)
  - Possible enhancements of (installed) engine simulation via electric powered simulation (EPS)
- Specifications for EPS design
- Current status of the project

Electric Propulsion Simulation - Motivation

Turbine Powered Simulation:

- Long history at DNW in providing engine simulation (isolated & installed at airframe) using TPS
- Compressed air driven machinery of high power density (ca. 100 kW/litre)
- Requires "air factory" (compressor plant)
  - Ca. 5 MW electrical powered required for 500 kW shaft power at TPS (η = 0.10)

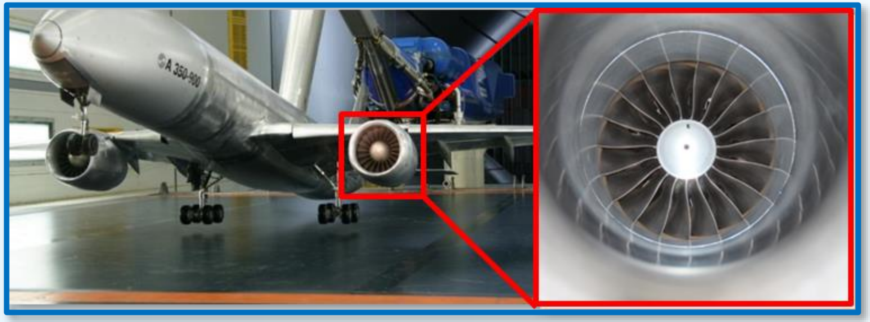


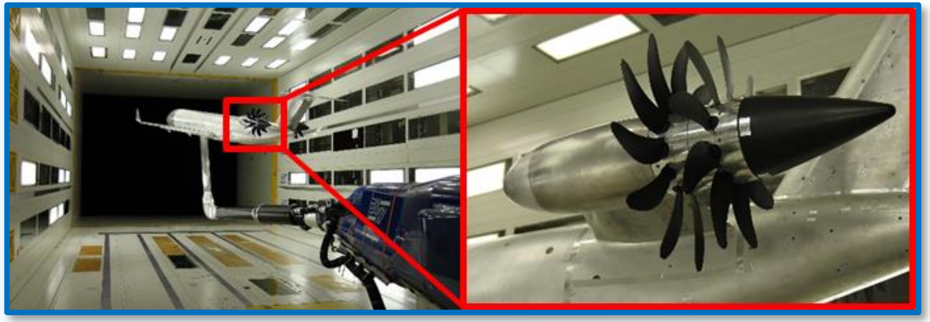


Electric Propulsion Simulation - Motivation

Turbine Powered Simulation:

- Large specification range of engine simulators available at DNW and DNW's customers (drive units, propeller & fan simulators)





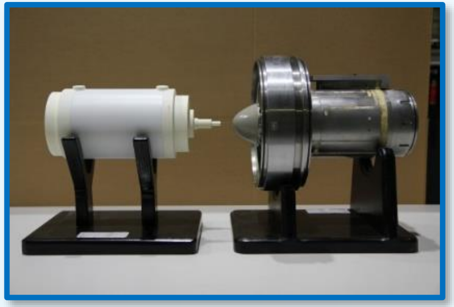
- Typically, with TPS-units, internal geometries are not scaled, instead "boundary conditions" are replicated:
  - Duplication of average fan pressure ratio over fan stage
  - Scaled (bypass) exhaust area

    → Produces correct (bypass) mass flux
  - TPS-core can be source of similarity-destruction due to shock structures and low exhaust temperature

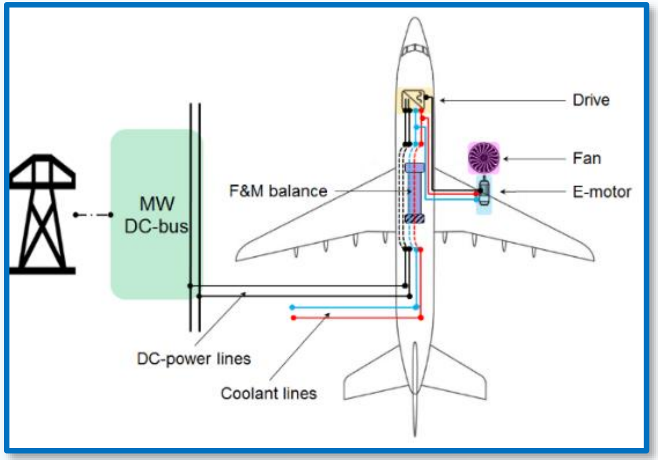
Electric Propulsion Simulation - Motivation

Electric Powered Simulation:

- Could enable integrated simulation of engine aerodynamics and aeroacoustics (fan noise)
- Flexible installation
- Efficient ($\eta > 0.90$) and economic operation
- Relatively easy (compared to TPS) transportable between different DNW sites
- Needed technology available:
  - High power density, compact solid state electronics and electric motors
  - High power electrical infrastructure
  - Electronic controls



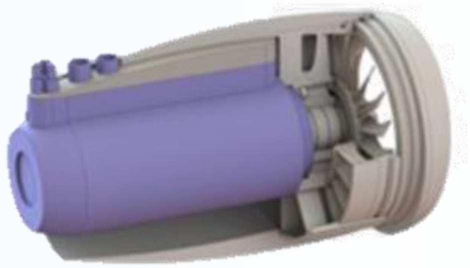
E-motor dummy and TPS unit of comparable power



Electric Propulsion Simulation – Design Target & Specs

- With the EPS unit we attempt to take the similarity further:
  - Maintain:
    - Fan stage geometry (shape, blade count, …)
    - Rotor speed
    - Separate core channel
  - This should automatically replicate:
    - Fan pressure ratio → M-distribution, mass flux, jet speed, …
    - Acoustics → Fan noise

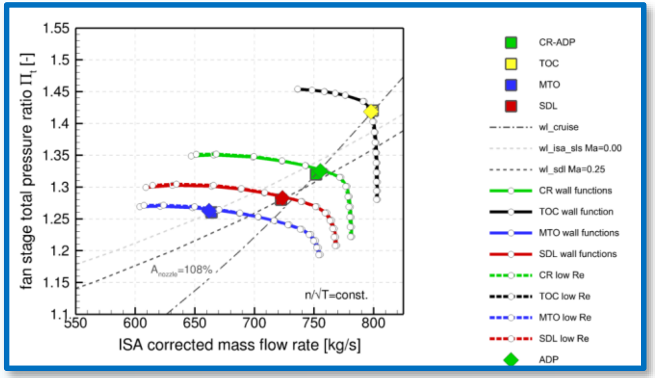
- EPS project specifications:
  - A320-like narrow-body aircraft
  - Low fan pressure ratio, high flow capacity, high bypass ratio
  - Technology level EIS 2035+
  - Scaling:
    - half model setup = one engine in DNW-NWB
    - full model setup = two engines in DNW-LLF

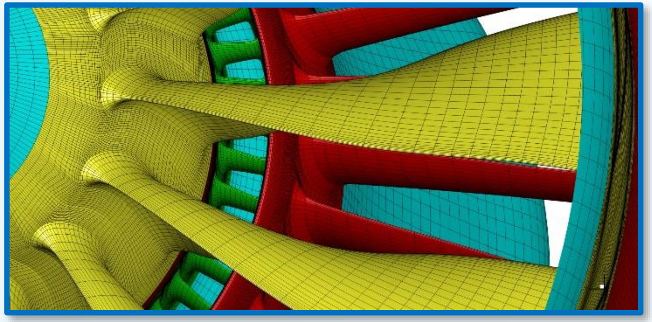


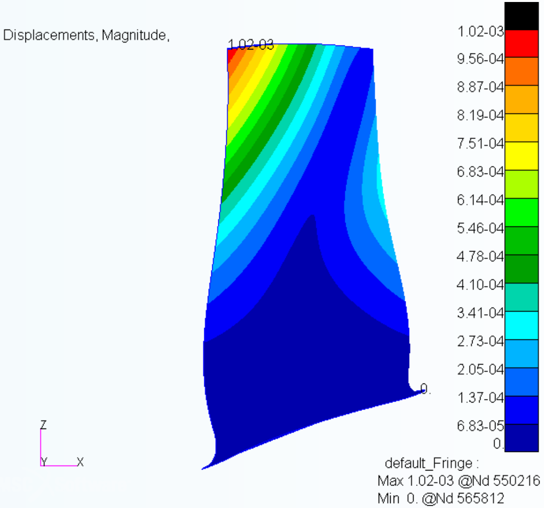
German-Dutch Wind Tunnels

Electric Propulsion Simulation – Current status

- Fan stage design (by DLR M. Menniken / R. Schnell):
  - Fan stage designed to meet specs in full scale
  - Fan stage scaled to model size (9.31”)
  - Max. thrust at TOC = approx. 850 N @ 25.500 rpm
- Rotor Stress analysis (by NLR J. Aalbers / R. van Enkhuizen):
  - “hot to cold” analysis performed
  - Tip gap clearance checked (< 0.15 mm)
- Fatigue Analysis (by NLR J. Aalbers / R. van Enkhuizen):
  - Infinite Life Expected (SF = 1.5)
  - Material Selection: Ti-6Al-4V



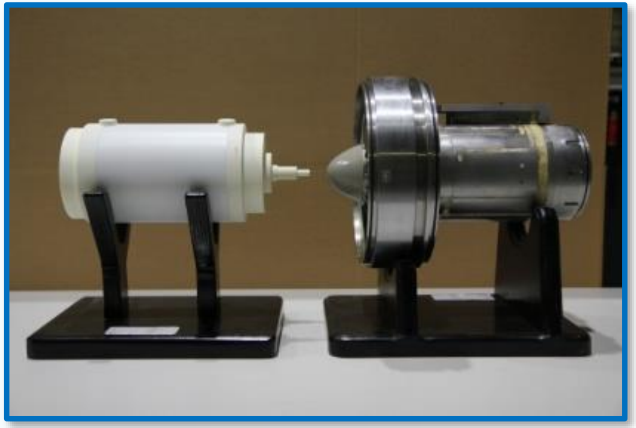




German-Dutch Wind Tunnels

Electric Propulsion Simulation – Current status

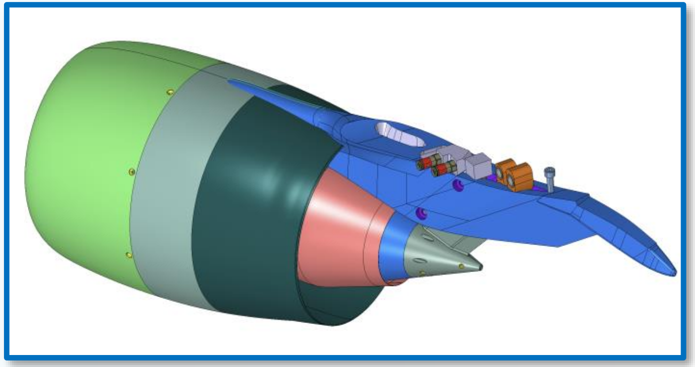
- Design of E-Motor and Inverter finished
  - Motor diameter = 110 mm
  - Motor length = 300 mm
  - Continuous power rating at 25.500 rpm = 327 kW
  - Water cooled:
    - Rotor cooling: 1.5 lpm
    - Stator cooling: 30 lpm
- Fabrication if e-motor and inverter ongoing
- Factory acceptance test (FAT) expected end of May 2025

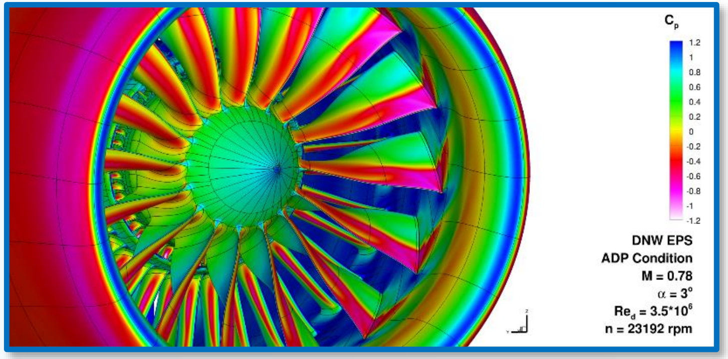


German-Dutch Wind Tunnels

Electric Propulsion Simulation – Current status

- Nacelle aero design finished (by NLR M. Laban)
  - Isolated engine
  - Investigation of installation by DLR in 2027
- Bearing design and analysis finished (by NLR A. Wiegmink / B. Noordman, B. de Wit)
  - Sufficient lifetime, regular inspection needed
- Mechanical design in progress (by NLR K. van de Wetering)
  - Conceptual design finished
  - Instrumentation design ongoing
    - Total pressure rakes
    - Surface pressure taps
- Manufacturing expected to start mid 2025
- Commissioning expected in q1/2026
  - Isolated aero & acoustic tests in DNW-LST/NWB





German-Dutch Wind Tunnels

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  - DNW’s facilities
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  - Automotive testing according to WLTP
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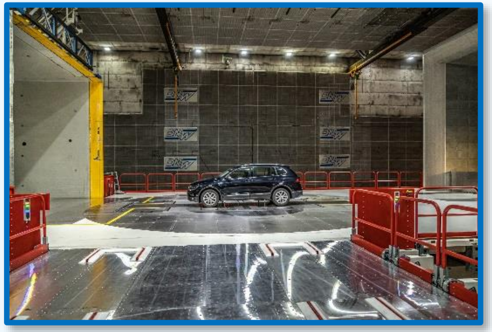
German-Dutch Wind Tunnels

Automotive testing according to WLTP

- All new passenger cars (since Sept. 2018) and all commercial vehicles (since Sept. 2019) in the European Union have to be tested according to WLTP
- WLTP:
  - Worldwide Harmonised Light Vehicle Test Procedure
  - Test methodology to accurately measure the aerodynamic and rolling resistance
  - Test methodology takes optional vehicle equipment and weight class into account
  - Measured resistance used to reliably derive exhaust gas emissions
- Automotive Test Section (ATS) at LLF officially opened on December 10th,2024
- ATS certified for WLTP and CE by German TÜV and Kraftfahrtbundesamt (KBA) and fully operational and available for industry



German-Dutch Wind Tunnels

Automotive testing according to WLTP

<u>ATS features:</u>

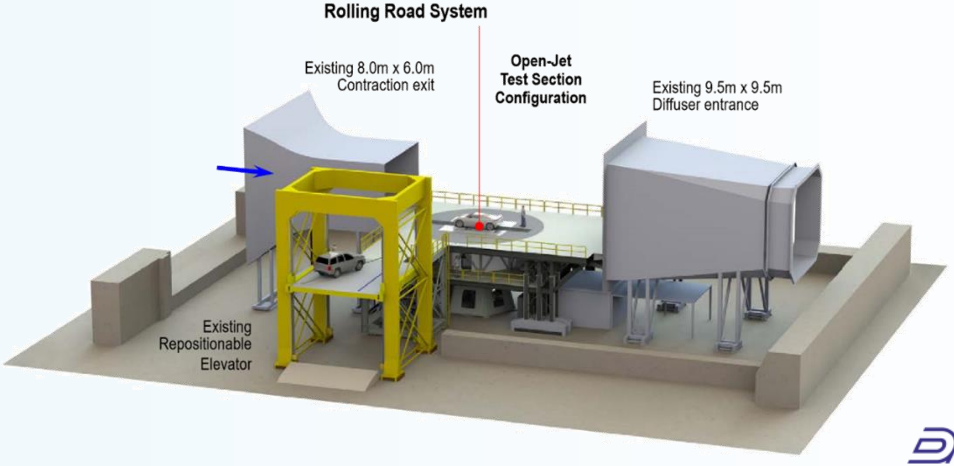
- Six-component balance
- Turntable Diameter: 12m
- Five steel belts:
  - Belt speed: 75 m/s
  - Centre belt: 9 m length, 0.9 m or 1.1m width
  - Wheel drive units:
    - 280 – 480 mm
    - 80 kW
    - Measurement of F_x

<u>Vehicle size:</u>

- Maximum load per wheel: 1500 kg
- Wheel base: 1900 – 4650 mm
- Wheel track: 1230 – 1840 mm

<u>Wind tunnel:</u>

- Nozzle exit area: 8.00 x 6.00 m²
- Test section length: 19 m



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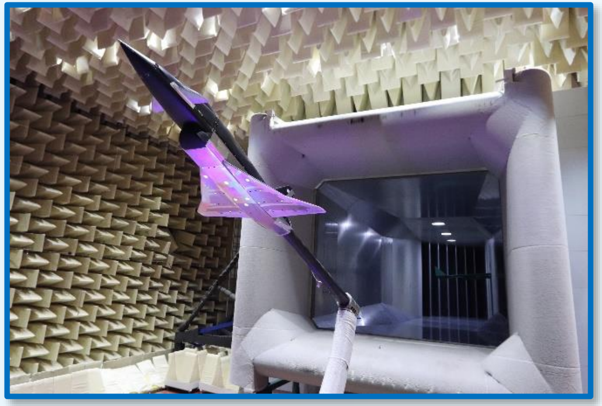
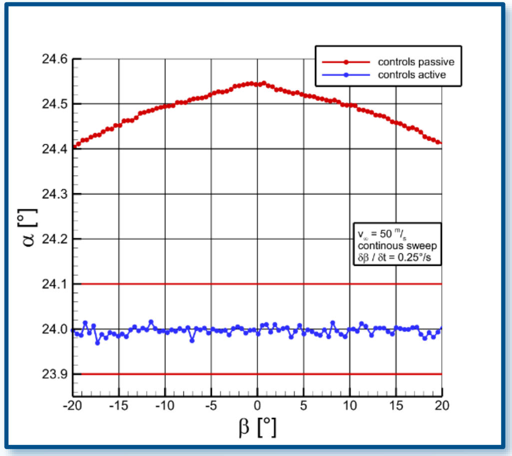
Accuracy upgrade of alpha-beta support at DNW-NWB

- Efficient production of accurate stability and control datasets require precisely controlled model attitude
  - Especially needed for highly manoeuvrable aircraft (fighter/UCAV configurations, highly swept wings)
- Precise control of model attitude while model encounters (unsteady) aerodynamic loads (e.g. vortex breakdown)
- Enable compensation for balance and sting deformation

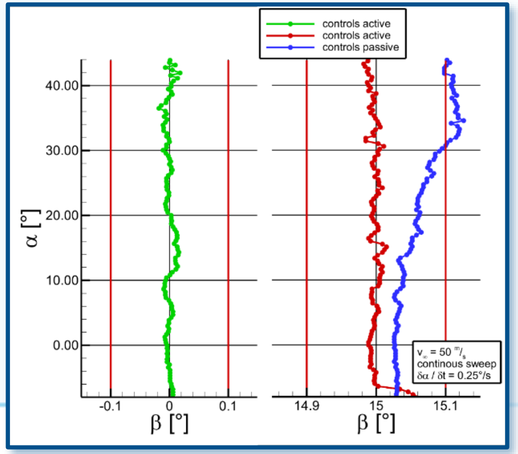
→ Stereo optical system & in-the-loop-control



X31 model mounted on rear sting



AoS run at AoA = 24° w/ and w/o in-the-loop-control



AoA run at AoS = 0° and AoS = 15° w/ and w/o in-the-loop-control

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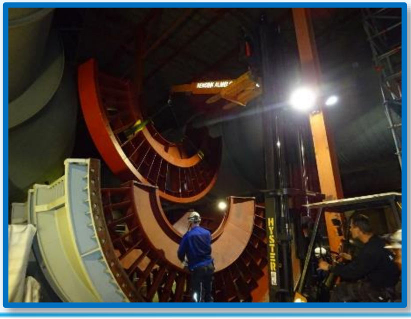
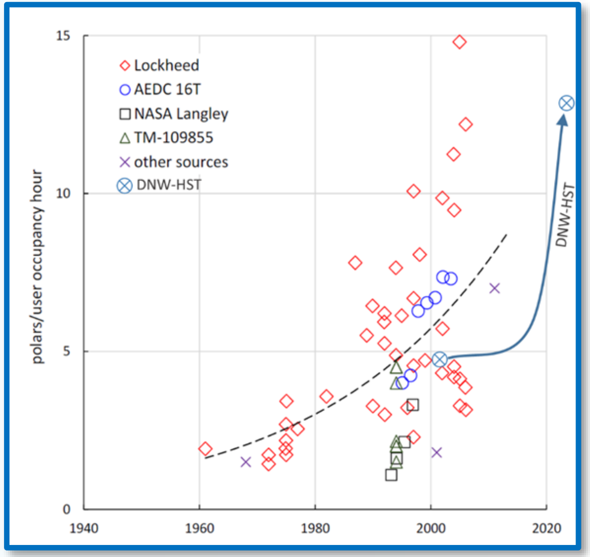
Performance upgrade of DNW-HST

- Increased quality, productivity & test envelope for military testing
- Perforated (top & bottom) walls
  - reducing shock wave interference effects for high angle of attack test conditions near Ma=1
- Control upgrade
  - Model control speed increased
  - Mach control speed increased
- Compressor capacity
  - installation of additional compressor blades stage, to improve performance at supersonic conditions





From: The Aeronautical Journal, "Transonic industrial wind tunnel testing in the 2020s"

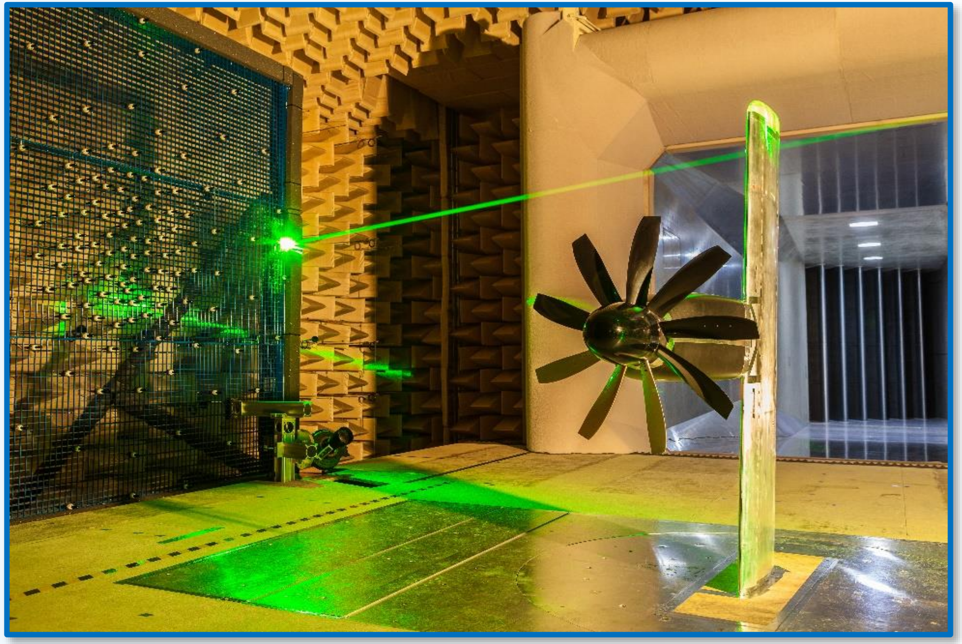
Conclusion

- DNW‘s market area is subject to global trends such as …
  - … sustainable (towards zero emission) aviation and new advanced air mobility,
  - … the need for understanding of contemporary air power as affect of the global political developments,
  - ... continuous ambition of the automotive industry to lower the CO_2-emssions of all kinds of vehicles (WLTP).
- DNW provides wind tunnel facilities forming a one-stop shop by covering a huge range of Mach and Reynolds number and offering state-of-the-art simulation techniques since the beginning of the 1980s
- DNW assures the sustainability and continuous development of its facilities by facilitating the support of its parent institutes DLR and NLR.

Thank you.

Thank you for your attention!

Looking forward to your comments and questions.



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