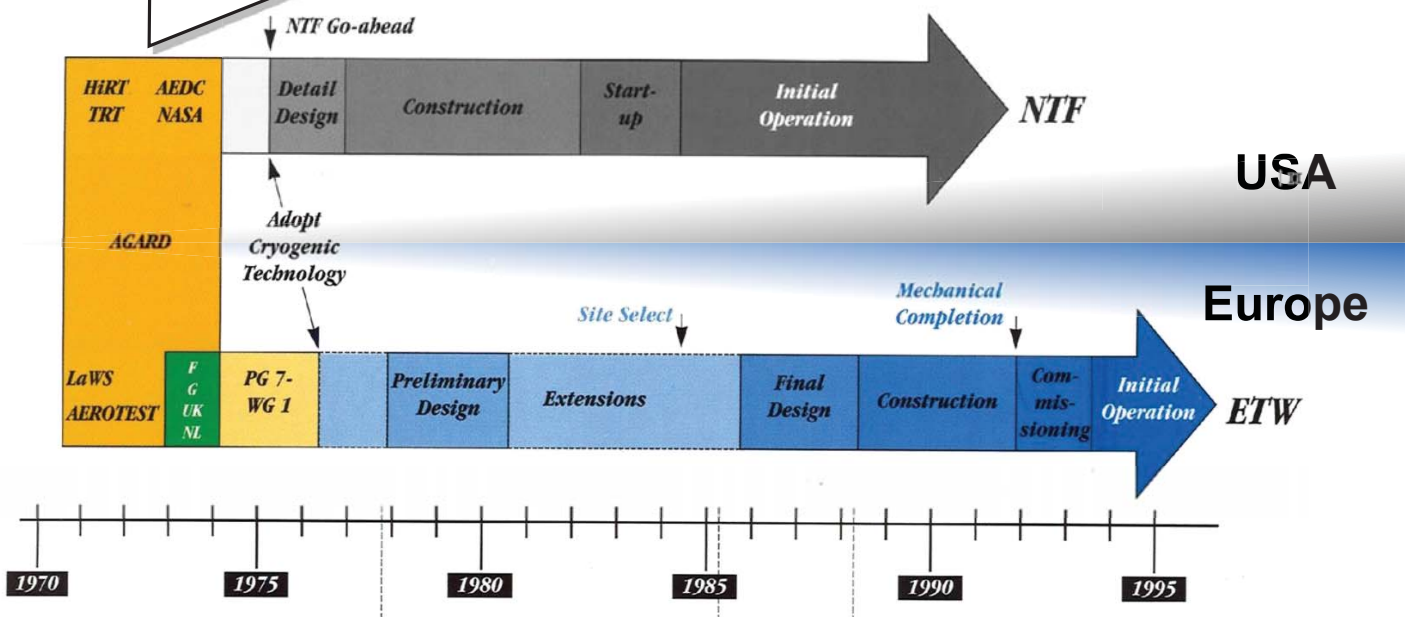
EUROPEAN TRANSONIC WINDTUNNEL

ETW – Bis an die Grenzen des Möglichen

Guido DIETZ
Managing Director

Chronology ETW and NASA-NTF (National Transonic Facility)

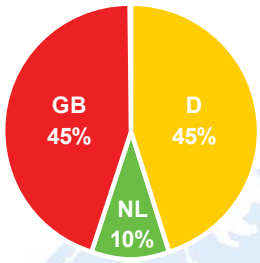
NATO-AGARD identified inadequacies of conventional wind tunnels based on C-141, C-5A experience, and recommended way forward



ETW at a Glance

- Conceptual design started 1977
- Erected 1988-1993, serving the world since 1995
- Limited-liability company / Non-Profit aiming for self-supporting operation
- Total investment > M€ 360 to date

Shareholders



Organisational Building Blocks

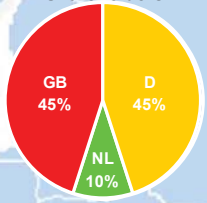
MoU & GmbH Statutes
limited-liability company according to German Law

World-Wide Sales at Equal Charges

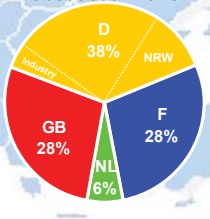
EUROPEAN TRANSONIC WINDTUNNEL

Aiming for Self-Supporting Ops, Non-Profit Policy
charging operation, maintenance, small preservation investments, no interest on invested capital, no depreciation of assets

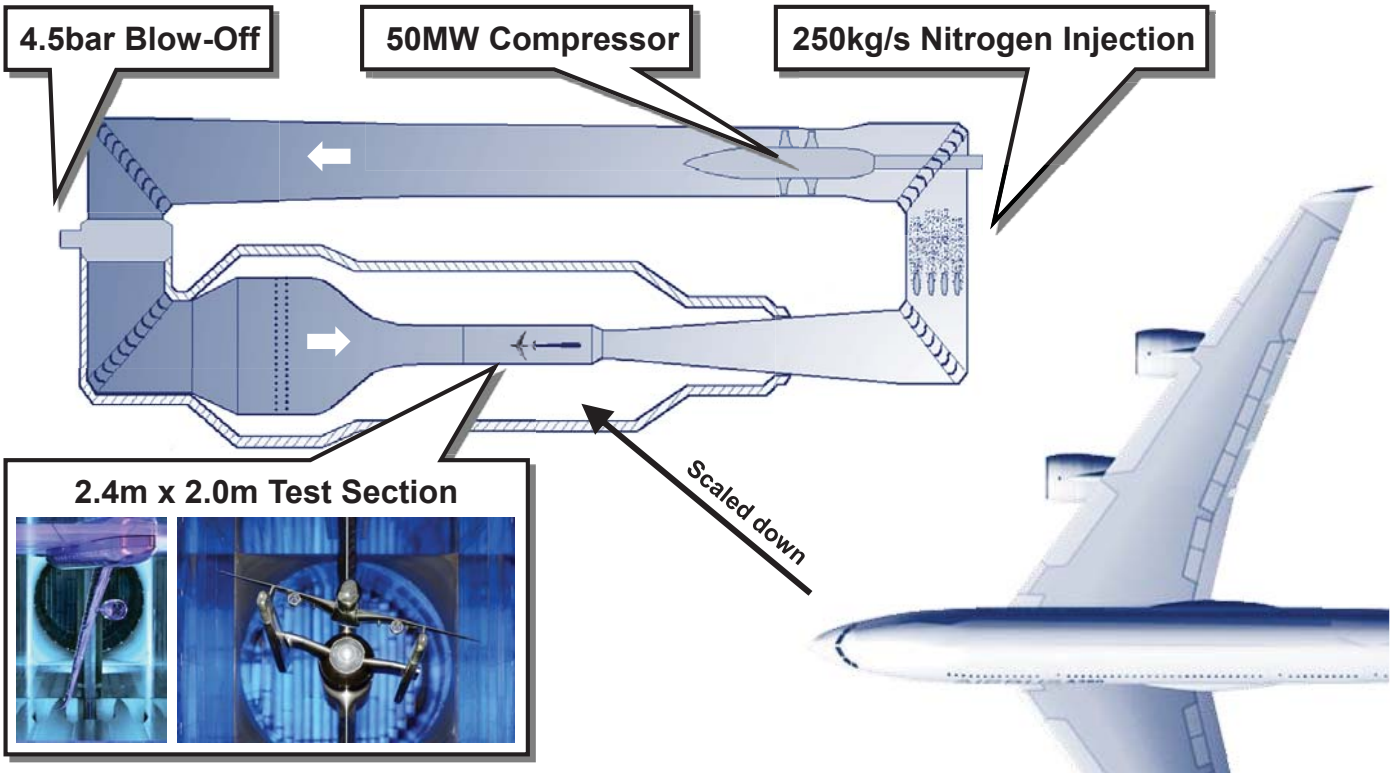
Shareholders



Construction Costs about 330 Mio. €



ETW's Tunnel Circuit

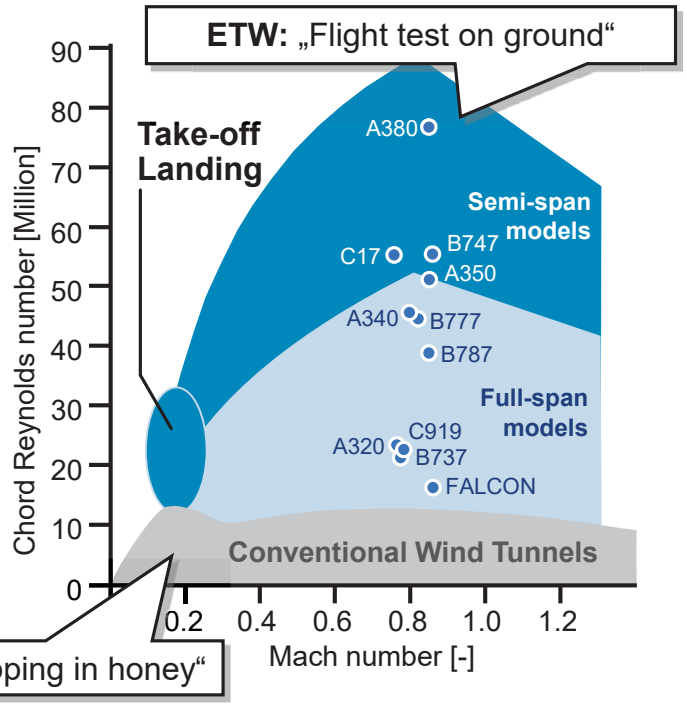


EUROPEAN TRANSONIC WINDTUNNEL

ETW's Key Characteristics & Capabilities

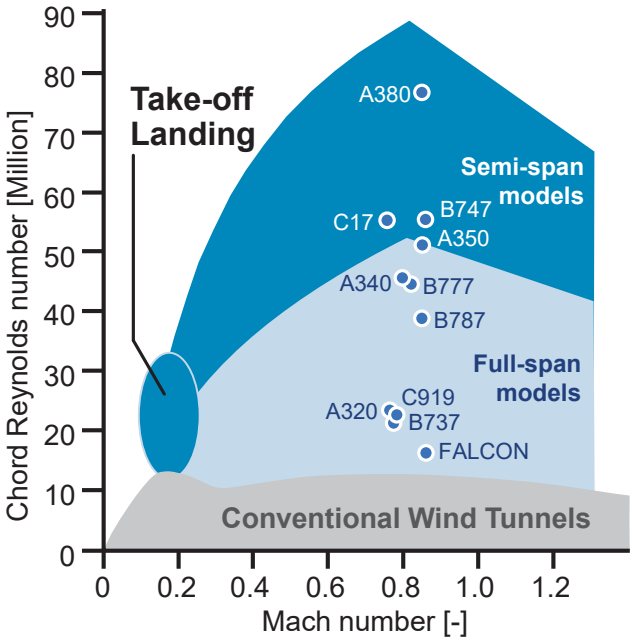
Aerodynamic similarity between real aircraft & wind-tunnel model:

- **Geometry**
- **Mach number**
  (Velocity per speed of sound)
- **Reynolds number**
  (Air inertia forces per friction)



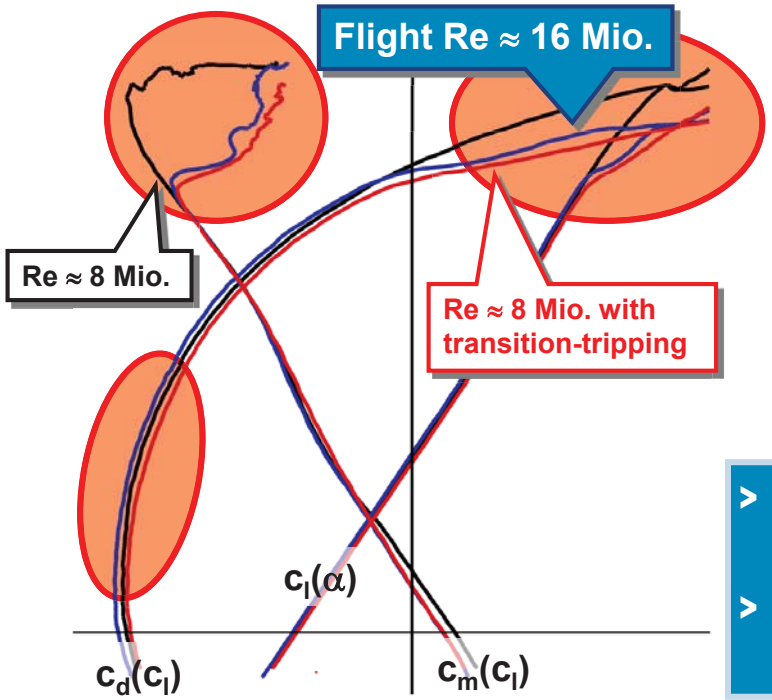
ETW's Key Capabilities & Characteristics

1. **Take-off, landing, cruise, off-design testing at flight Reynolds No**
   Mach numbers 0.15 - 1.35
   Stability ±0.0005 - ±0.0010
2. **Aeroelastic testing with independent Reynolds No & loads control**
   Total pressure 1.1 - 4.5 bar
   Stability ±0.1%
   Total temperature 110 K - 313 K
   Stability ± 0.25 K
3. **Laminar testing flow quality**
   close to free flight
4. **High cryo-testing productivity & costs efficiency**
5. **Security & client confidentiality**

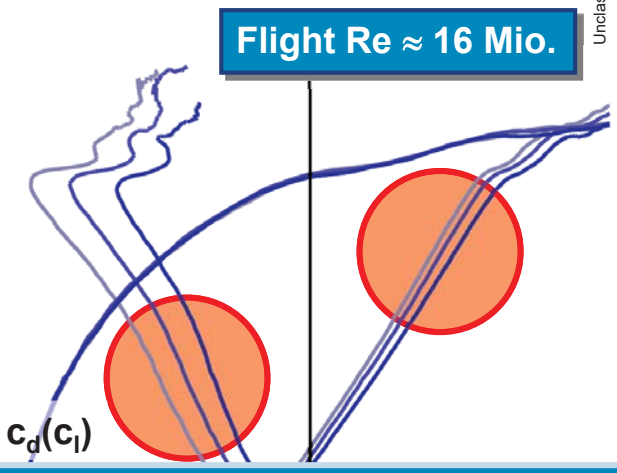


Lift, drag, pitching-moment characteristics Falcon 7X

Reynolds Variation at const. Airloads



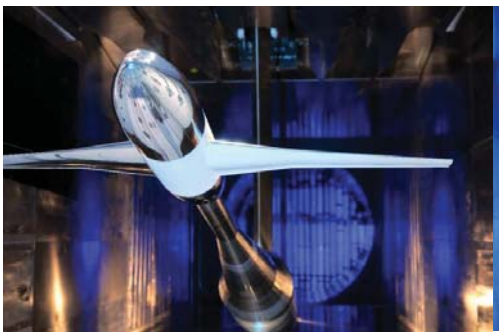
Airloads Variation at const. Reynolds

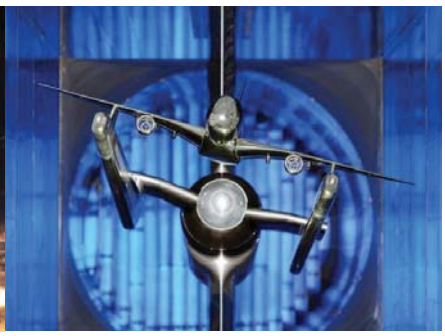


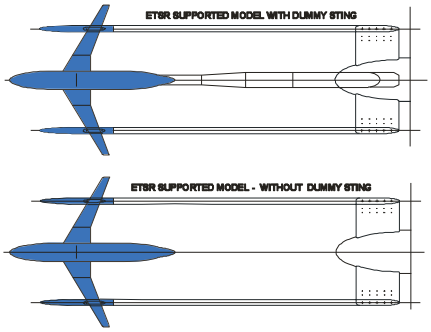
Unclassified

- Reynolds Number strongly affects aircraft performance
- Aeroelastic distortion strongly affects aircraft stability

Full-Span Model Data Corrections







Cost Optimized

- Performance data based on corrected low & high Reynolds data
- Single-sting data complete model / body alone plus deformation data
- Assessment of sting interference using CFD for the body alone config.
- Wind-tunnel calibration data & robust

Quality Optimized

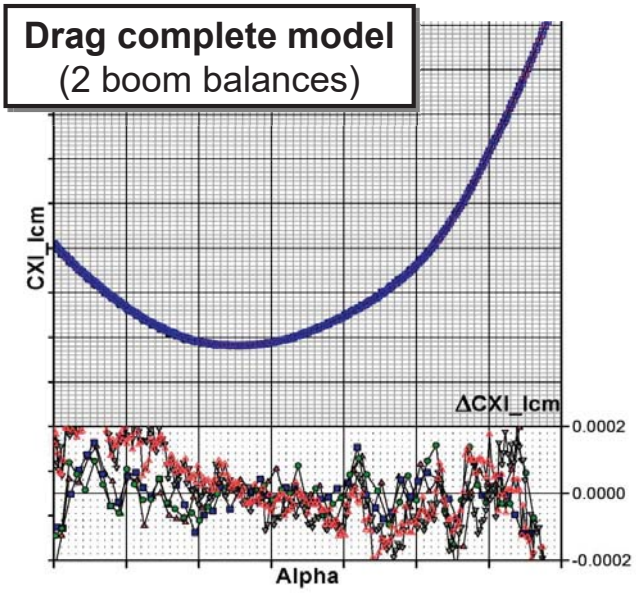
- Absolute performance data based on fully corrected high-Reynolds data
- **Lowest impact of sting correction method on final flight estimate**
- **Prediction of flight test data with an accuracy of better than 99%**

EUROPEAN TRANSONIC WINDTUNNEL

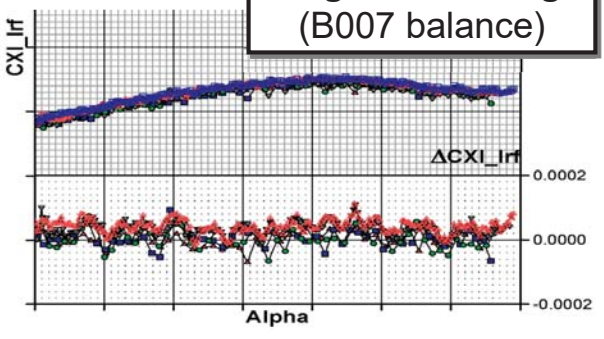
Long-Term Test Repeatability

- **4 years between tests**
- **Entire re-rigging of model & support**

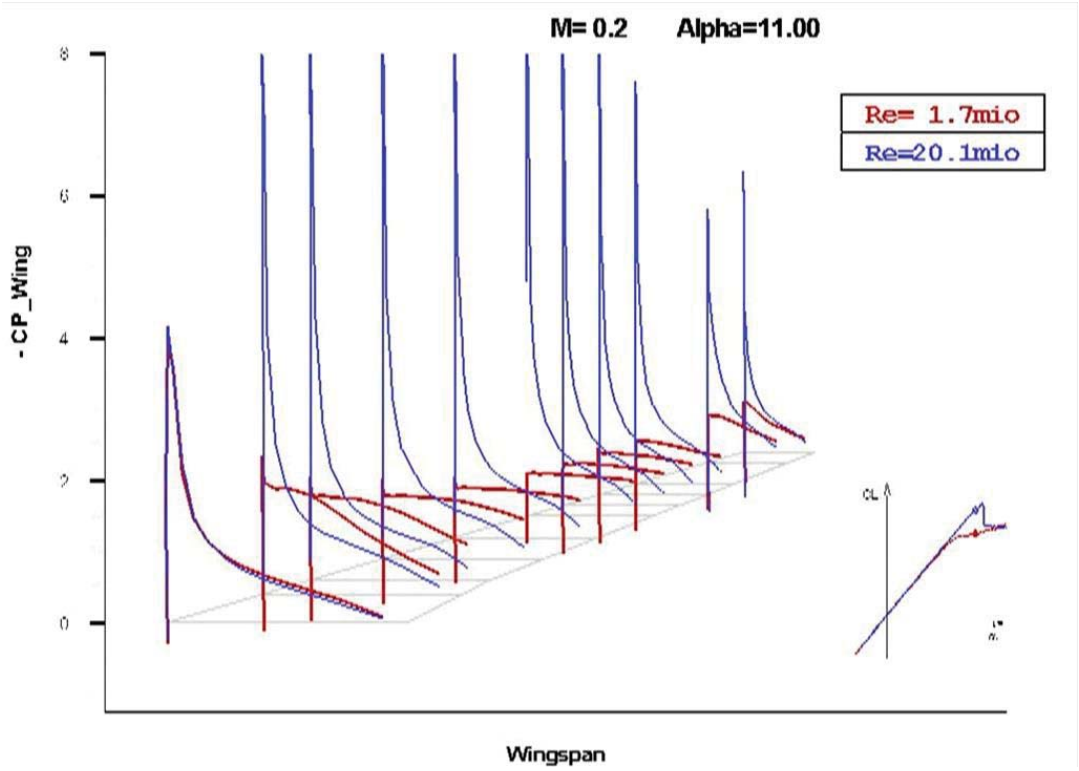
Drag complete model
(2 boom balances)



Drag rear fuselage
(B007 balance)

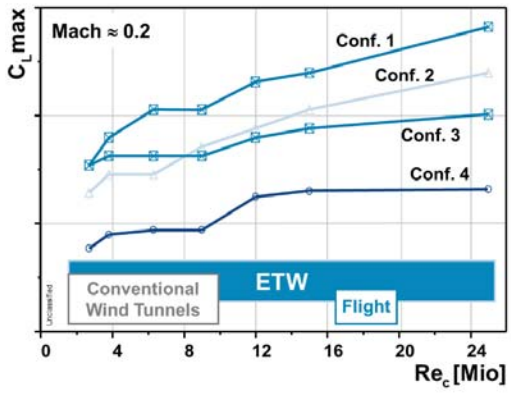


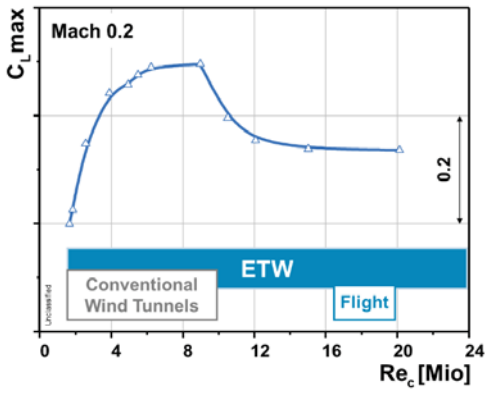
Reynolds-number Effect on Pressure Distribution



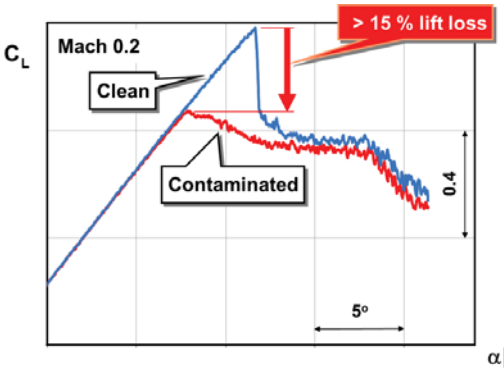
Unclassified

Reynolds-number Effect on Maximum Lift





- ETW provided aerodynamic performance & deformation data
- Particular configuration determines **$C_L$max dependency on Reynolds No**
- **Contamination may have strong impact**



Unclassified

ETW Complements the Aircraft Development Process
and enables better solutions faster at lower risks

Final check-out for cruise, off-design & high-lift performance

- Validate a final configuration by ETW tests

Computational Fluid Dynamics CFD / Aeroelasticity CAE validation

- Obtain flight-Reynolds-number ETW test data
  at high-lift, cruise, and off-design high-speed conditions
- Provide recommendations for appropriate modelling
- Validate / calibrate CFD / CAE tools
  by comparison of computational results with ETW (and flight-test) data

Aircraft design for flight Reynolds numbers

- Develop advanced aircraft by using validated / calibrated computational tools and complementing ETW tests
- Early verification & validation, exploiting physical limits
- **More simulation, less conventional but more specific testing**

EUROPEAN TRANSONIC WINDTUNNEL

ETW & CFD
Complement Each Other

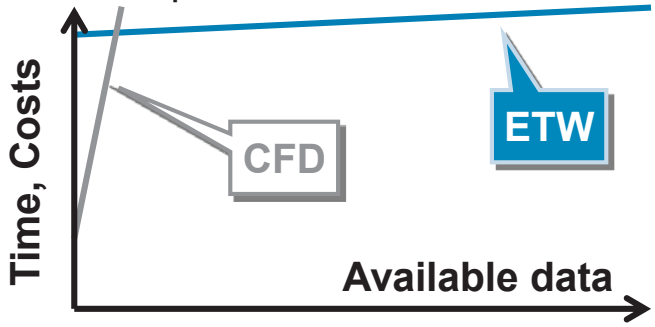
"There should not be an over-emphasis on what computers tell you, because they only tell you what you tell them to tell you."
(Joe Sutter to FlightGlobal, 2009)

ETW strengths:

- Real flow about complex configurations
- High productivity as soon as the test is set up
- Risks mitigation

CFD strengths:

- Responsive to shape changes
- Detailed flow field insights



⇒ **CFD optimizes the design by screening & refining,**
ETW discovers governing physics, validates & verifies

Note: Both share CI, maintenance, staff & electricity as cost drivers,
e.g. US DOE asks for 20-40 MW in 2020 for 1 exaflop, down from theoretical 200 MW with today's technology

Hamburger Aerospace Lecture Series: ETW – Bis an die Grenzen des Möglichen 19.10.2016

Benefits From ETW's Capabilities

$$\text{Range} = \frac{\text{Velocity}}{\text{Specific Fuel Consumption}} \cdot \frac{\text{Lift}}{\text{Drag}} \cdot \ln\left(1 + \frac{\text{Fuel Weight}}{\text{Load} + \text{Empty Weight}}\right)$$

Engines
- UHBR / OR

⇒ Engine Integration

Aerodynamics
- Flight-Re Design
- Lift-induced Drag
- Flow Control, e.g. Laminarity

Structures
- Lightweight

⇒ Aeroelastic Tailoring
- New configurations

⇒ Lack of Tool Calibration

Plus understanding/prediction of **cruise safety margins**

Vital need for ETW Capabilities in Research & Development

EUROPEAN TRANSONIC WINDTUNNEL

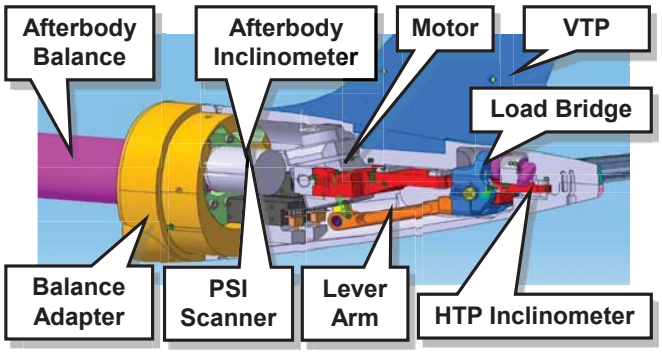
ETW Users' Demand Beyond The Horizon in the 70s/80s

- **Conditions beyond cruise at which Reynolds number similarity matters:** High-lift, off-design, handling-quality & laminar testing
- **CFD / CAE validation**
- Making use of **ETW as a design tool complementing CFD** rather than for experimental check-out only

Requiring:
- Significantly **enhanced productivity & value for money**
- **Low-interference supports** including **anti-vibration systems**
- **Deformation measurement**
- **Unsteady data acquisition & synchronisation of multiple techniques**
- **Flow visualisation** on the surface & in the flow field
- **Noise source localisation**
- Engine simulation

Currently, shareholders invest M€ 20 in developing the most urgent ones

Remotely Controlled Movables, e.g. HTP



Unclassified

- Avoid model-transport / -change, and -conditioning time
- **Abs. position accuracy ±0.1°, Rel. ±0.05° during polar**

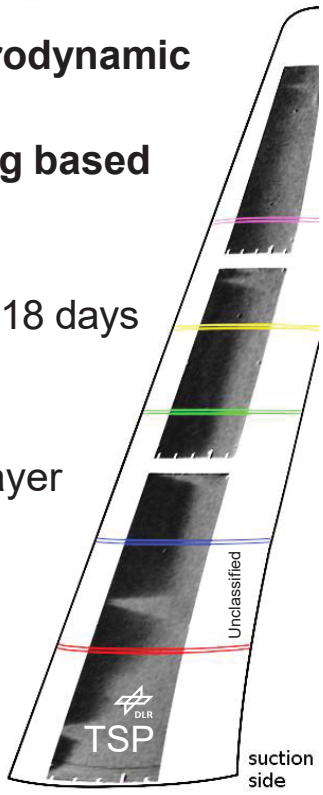
ETW HiLamBiz Testing in Clean Sky

Facility / test technique improvements

CLEANSKY
SEVENTH FRAMEWORK PROGRAMME

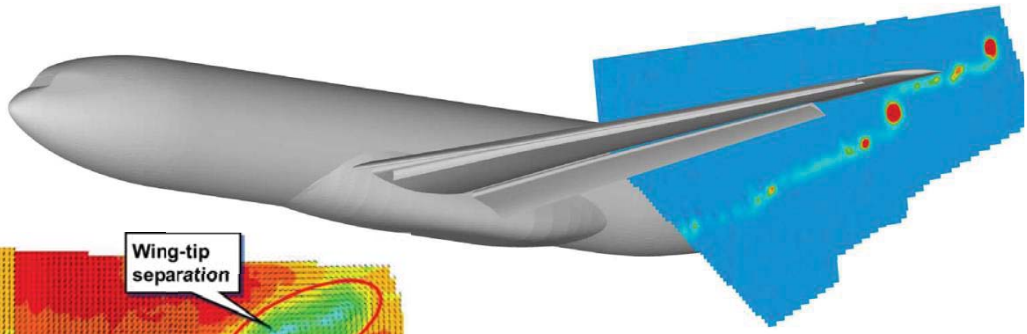
- **NLF high-speed full-span model test to assess its aerodynamic performance including the buffet boundaries**
- **Remotely controlled HTP with Stereo-Pattern-Tracking based close-loop control** to compensate aeroelastic torsion

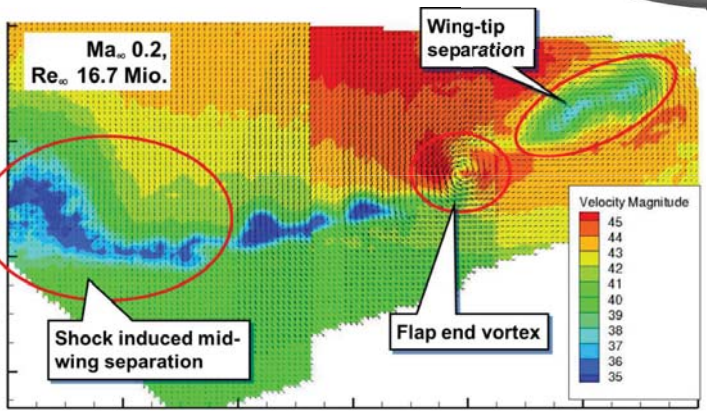
- **Rather productive testing:** 9 configs + 10 HTP settings in 18 days
- Laminar-turbulent boundary-layer detection by 4 TSP cameras

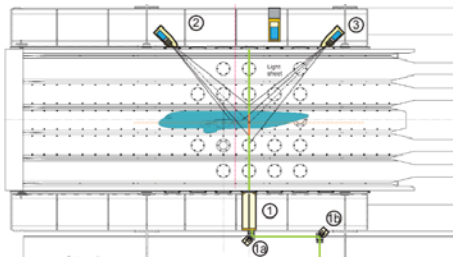


- **Tested up to Re 10M / 65M/m, and low amount of tunnel induced turbulent wedges occurred** due to:
  - Effective pre-test cleaning & operating procedures
  - Solimide protection & effective tunnel drying

Applying PIV to Understand Flow Topologies





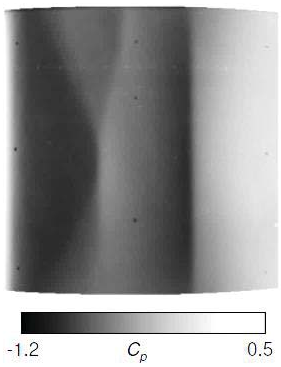


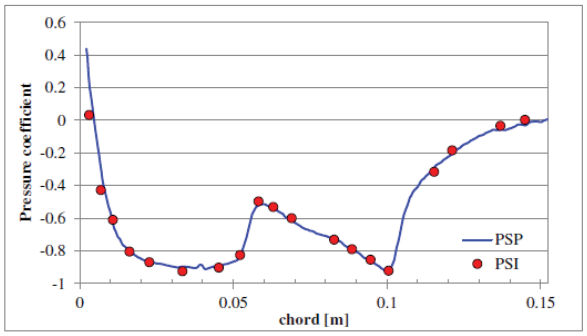
- Cryo-PIV applicable at flight-relevant Mach & Reynolds numbers
- Time resolve capability demonstrated up to 1 kHz sampling

Unclassified

EUROPEAN TRANSONIC WINDTUNNEL
DLR

Cryogenic PSP – LuFo Work in Progress





ΔCp - std	0.017	ΔCp - max	0.041

- Most hard- & software shared with TSP, integrated into ETW DAS
- Successful test entries in PETW in 2015 & 2016
- Aiming for further improvements on 0.2 µm surface roughness and PSP sensitivity
- ETW high-speed test planned for beginning 2017
- Suitable e.g. for wing regions or junctions

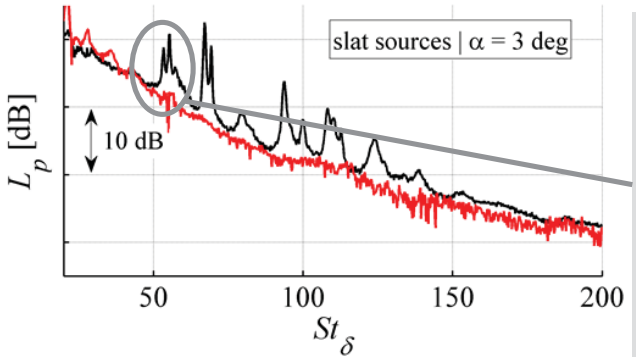
Unclassified

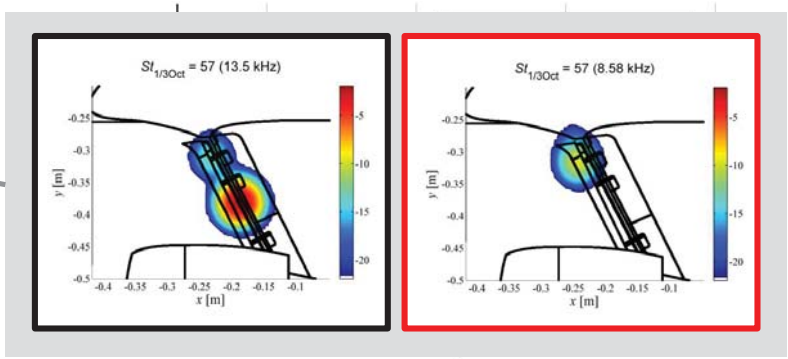
Localisation of flight-Re Relevant Noise Sources – Work in Progress

- **No-/low-cost add-on** piggyback to high-lift performance testing
- **Added value for dedicated acoustic testing** e.g. at DNW-LLF

$Re_\delta = 1.42 \cdot 10^6 \mid q/E = 1.55 \cdot 10^{-8}$

$Re_\delta = 20 \cdot 10^6 \mid q/E = 5.64 \cdot 10^{-8}$

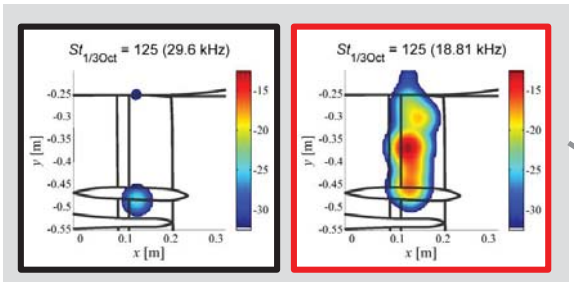


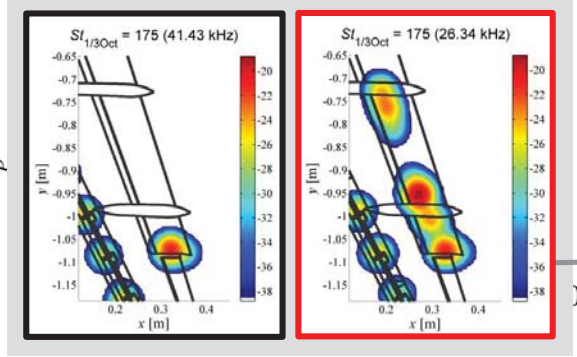


EUROPEAN TRANSONIC WINDTUNNEL
DLR

Localisation of flight-Re Relevant Noise Sources – Work in Progress

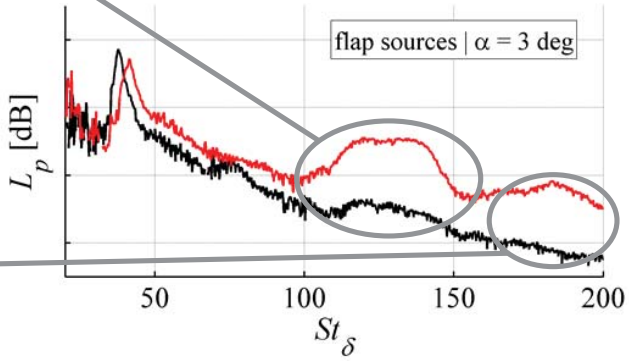
- **No-/low-cost add-on** piggyback to high-lift performance testing
- **Added value for dedicated acoustic testing** e.g. at DNW-LLF





$Re_\delta = 1.42 \cdot 10^6 \mid q/E = 1.55 \cdot 10^{-8}$

$Re_\delta = 20 \cdot 10^6 \mid q/E = 5.64 \cdot 10^{-8}$



Hamburger Aerospace Lecture Series: ETW – Bis an die Grenzen des Möglichen
19.10.2016 © ETW GmbH. All rights reserved.

Conclusion

ETW is a European strategic facility, bridging the gap between

- **Lab & Flight**, enabling flight-test prediction for low- & high speed
- **CFD & Reality**, advancing, validating & complementing numerical simulation
- **Research & Industry**, accelerating innovation from science to application

ca. 26% of all operating commercial aircraft benefited from ETW, additional ca. 6,900 are ordered, and more to come

ETW remains a permanent challenge, requiring

- **Sufficient workload from diverse users**
  - **To financially survive** despite cyclic demand
  - **To "train" the facility & its workforce**
- **Continuous improvement & investment**
  - **To adapt to the changing demand** of users
  - **To improve value for money**

More use by Academia would be mutually beneficial …