Wind tunnel operations – personal lessons learned

Georg Eitelberg / 2023

Some background

Personal lessons learned

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Natural laboratory of the future – atmospheric boundary layers ☺

- TS - waves
- Very large Reynolds numbers
- Cheaper than flying

Who needs what in the present?

- Industry
  - Aircraft development
  - Design verification
  - Handling qualities
  - Future products
- Government
  - Access
  - Exploration
  - Force projection
- Research
  - Fundamental challenges
  - *Training*
- Operators
  - Upgrades/improvements
  - Skill base

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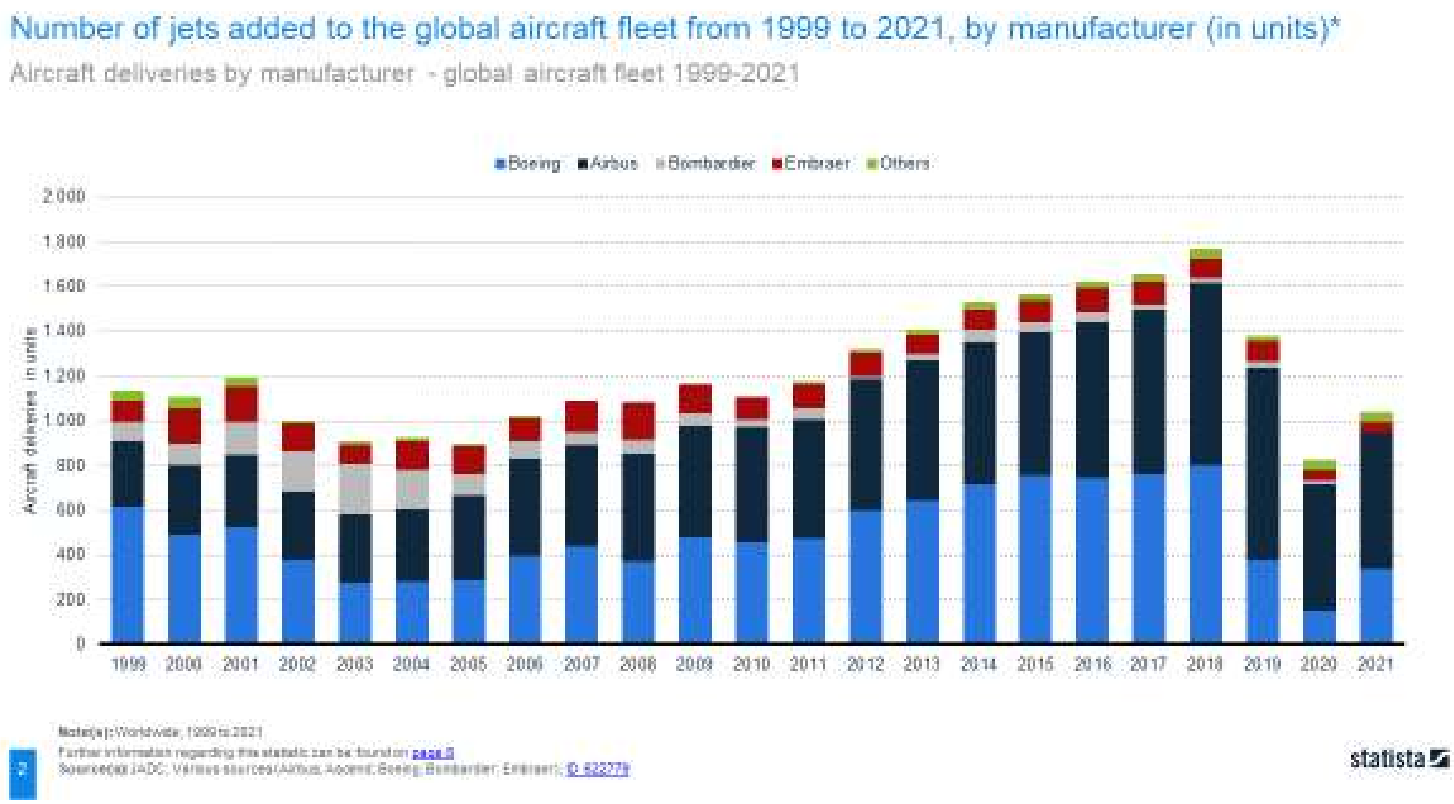
Industry global overview

- Airbus/Boeing duopoly



Industry position

Airbus website

	A300/A310	A220/A320	A330/A340/A350	A380	Total
Total orders	816	16997	3074	251	**21537**
Total deliveries	816	10624	2409	251	**14140**
Aircraft in fleet	283	9990	2153	240	**12696**

Orders – deliveries = future

Outstanding approximately 7500 aircraft

Annual production ca 700 aircraft

➔ 10 years delivery of known aircraft

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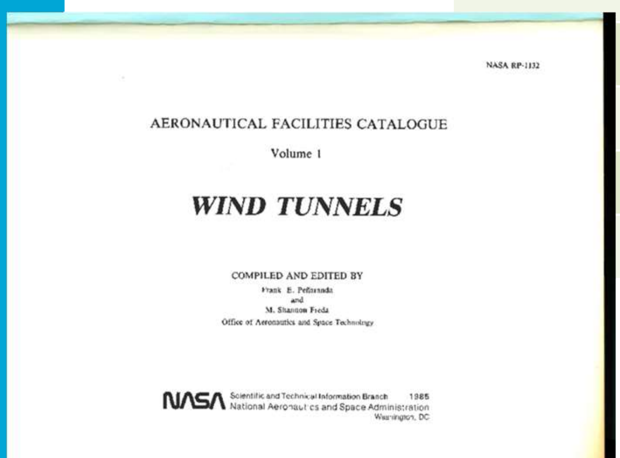
Compendium of **major** wind tunnels…

A generation ago

	Subsonic	Transonic
US	42	26
Foreign	34	22
Canada	*3*	*1*
FR	*5*	*6*
D	*4*	*4*
JN	*7*	*5*
NL	*2*	*1*
UK	*13*	*5*


NASA RP-1132

AERONAUTICAL FACILITIES CATALOGUE

Volume 1

WIND TUNNELS

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Office of Aeronautics and Space Technology

NASA Scientific and Technical Information Branch 1985
National Aeronautics and Space Administration
Washington, DC

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…of which **premier** capabilities

	EU	US
Subsonic	1 NL (DNW)	3 NASA
	1 UK (5m)	3 Industry
	1 FR (F1)	
Transonic	1 FR (S1)	1 AEDC
	1 D (TWG)	4+1 NASA (NTF)
	2 UK (Bedford, Wharton)	8 Industry

Note: HST and S2 not in this list

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DNW as a whole

Based on personal background

Locations of DNW

Business Unit NOP/ASD :

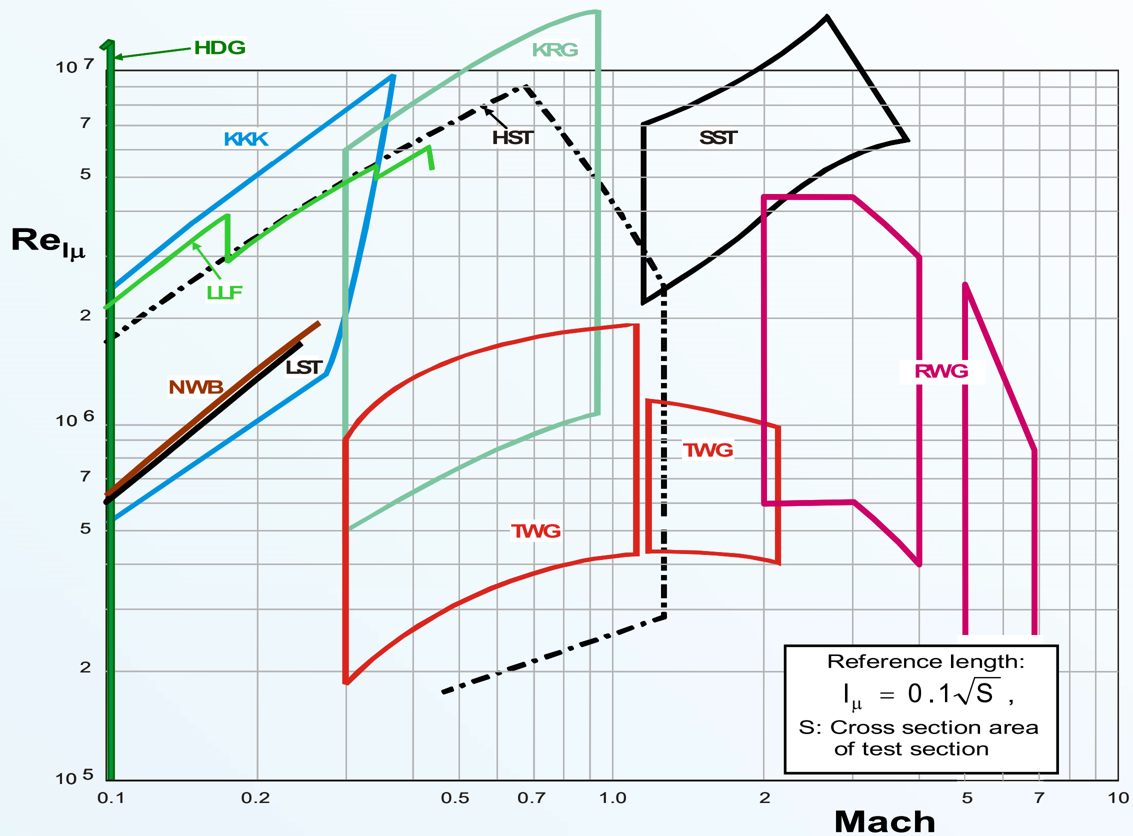
1) Marknesse(HQ) The Netherlands : LLF/LST/ECF
2) Amsterdam The Netherlands : HST/SST

Business Unit BGK :

3) Braunschweig Germany : NWB
4) Göttingen Germany : TWG, KRG, HDG, RWG
5) Köln Germany : KKK

German-Dutch Wind Tunnels

DNW *Mach-/Reynolds number spectrum*



German-Dutch Wind Tunnels

Evolution

- Foundation DNW established in 1976
- LLF operational in 1980
- Incorporated low speed wind tunnels (NWB and LST) from DLR and NLR in 1996
- Incorporated all aerodynamic wind tunnels of parent institutes in DNW 1998-2000
- Current insured value > 200M€

DNW operational model

- Bi-national distributed RI:
  - Formed by two national and institutional nodes
  - Part of international network
  - International character of governance
- Market-driven open access policy, based on agreement between user and DNW:
  - Fee for access
  - Potential limitations for IP rights (e.g. due to commercial sensitivity)
- Funding through full cost pricing, excl. depreciation on investments

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Funding through:

- Contract testing for operational cost recovery
  - Product development
    - European and non-European industry (competition)
  - Research programs
    - EU
    - National
- National support for expansion of capacity/capabilities by investment subsidies for
  - Noise testing
  - Propulsion efficiency (CO_2)
  - …

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Examples of frequently required technical capabilities

Wind tunnel operations

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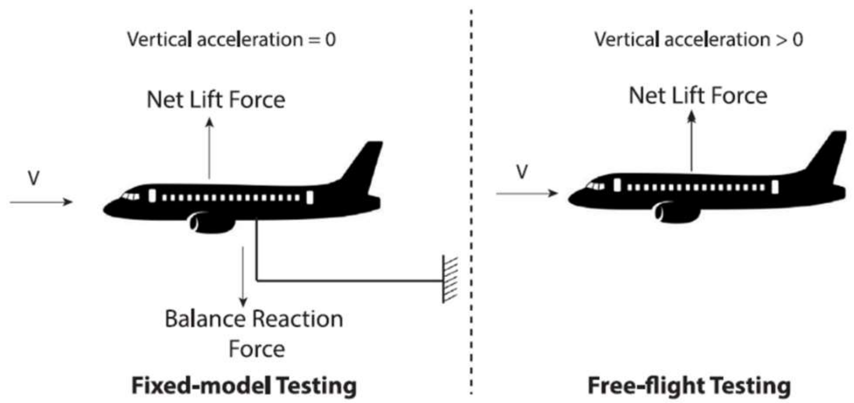
Reasonable scaling in WT vs. scaled flight

- Lift coefficient $c_L = 2\frac{W}{\rho_f u^2 L^2} = 2\frac{m_{AC}}{\rho_f L^3} \cdot \frac{Lg}{u^2}$ (aerodynamic efficiency)
- Two force ratios to be considered:
  - Gravity and inertia – Froude number
  - Weights of aircraft and displaced air – Archimedes number



In WT testing the independence is achieved by model mounting

In scaled flight testing off-scale manipulation is required

Figure; A. Raju Kulkarni, G. La Rocca, L.L.M. Veldhuis, G. Eitelberg

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Qualification of the WT
e.g., for transition studies

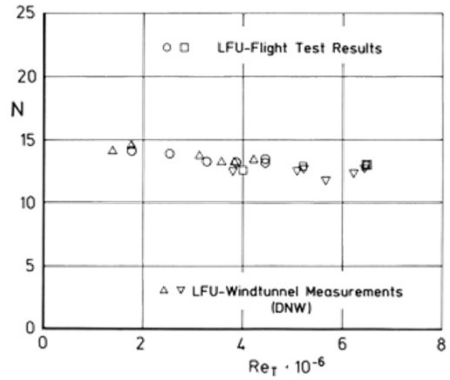
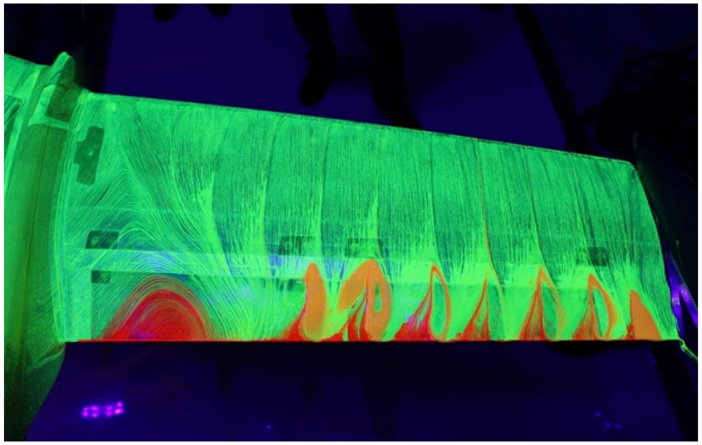


Fig. 3: Comparison of NTS factors from flight and wind tunnel measurements



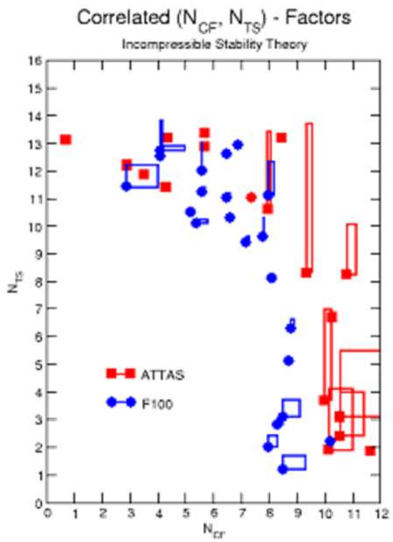


Fig. 8: ATTAS and F100 evaluated N-factors

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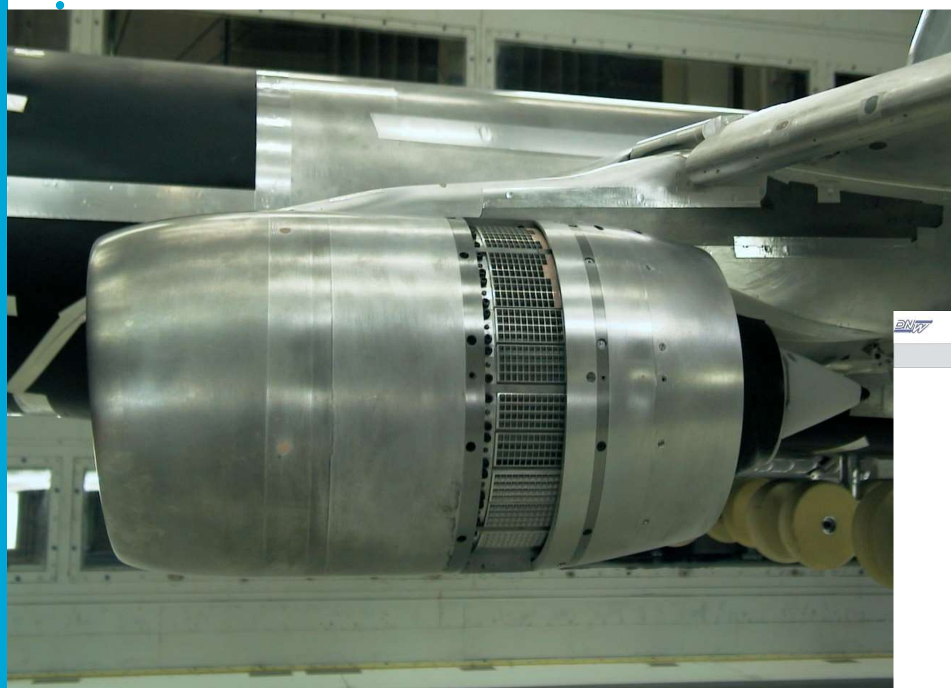
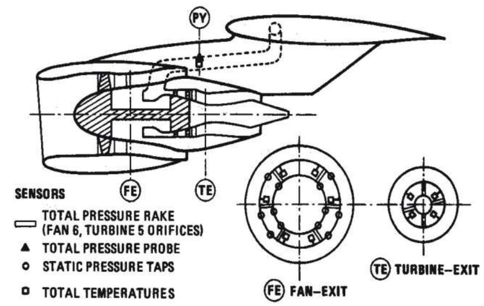
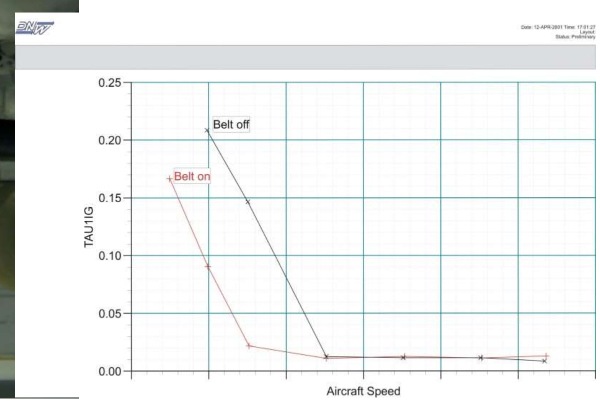
Engine Integration

- **Thrust reverser cascades**

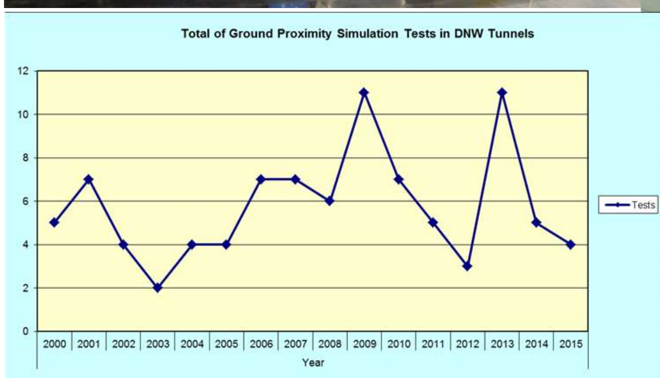






Ground proximity, stability and control

Nomination frequency

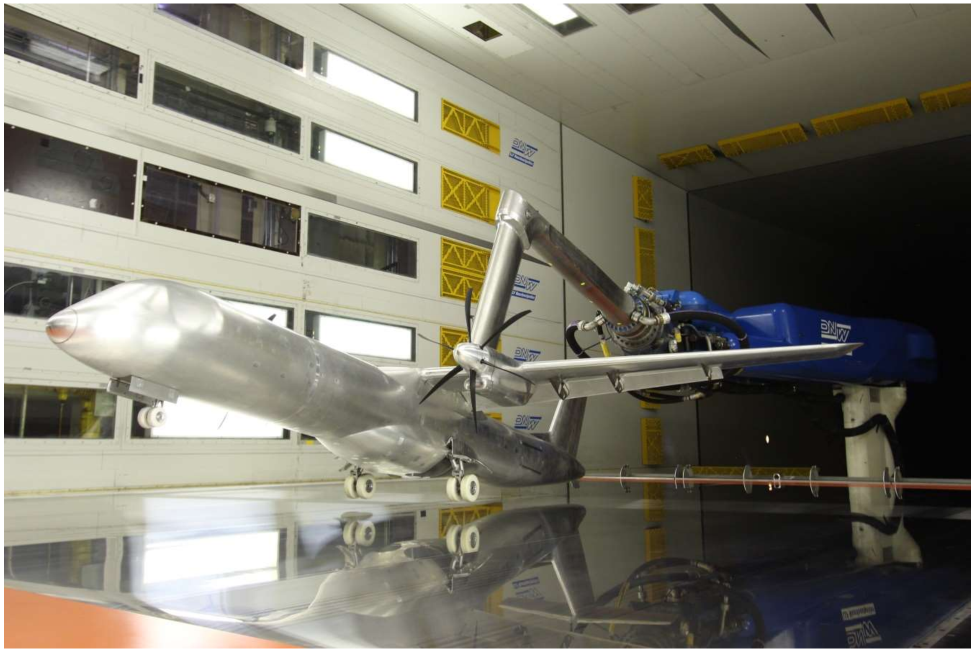


Fan simulation in ground proximity

Propeller tests

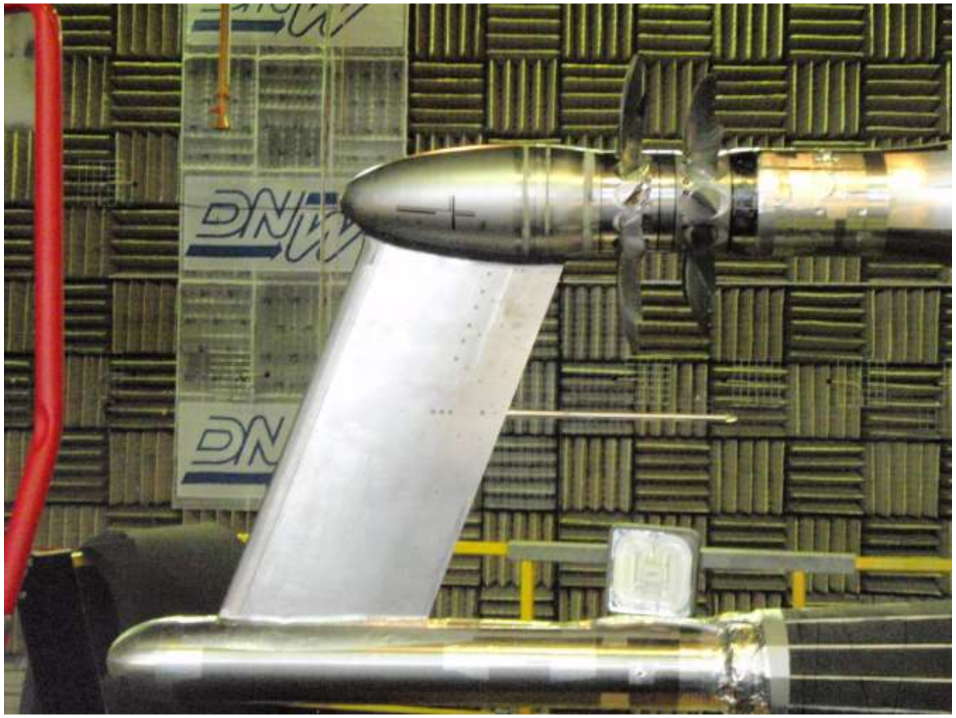
Objectives for propeller testing:

- Aerodynamics
- Acoustics

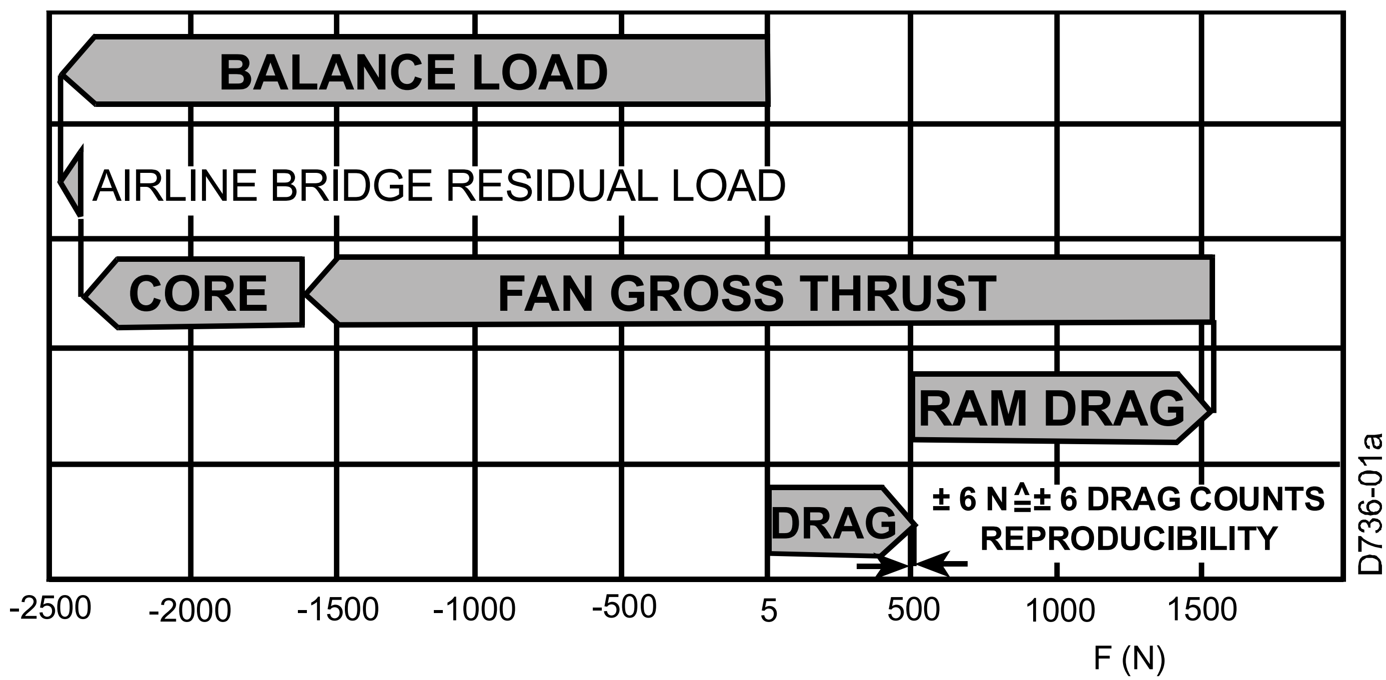


Illustrations

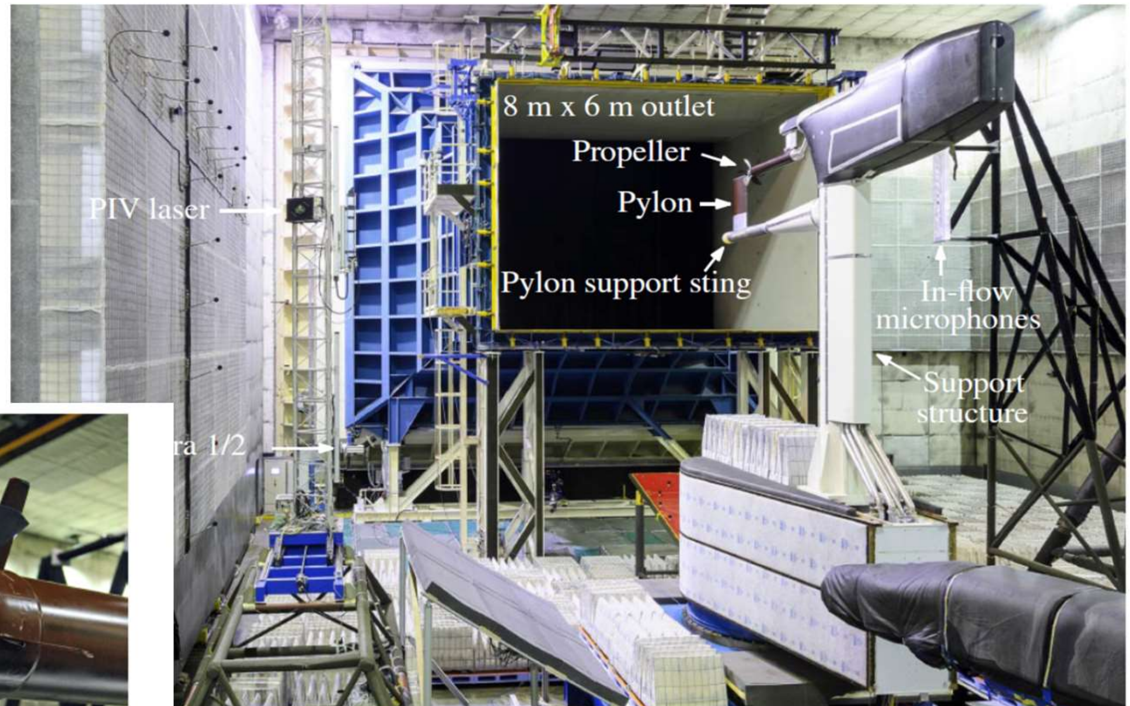
- CROR



Thrust / drag bookkeeping



Mounting and SRV effects on rotor performance



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Thrust correction for an open test section

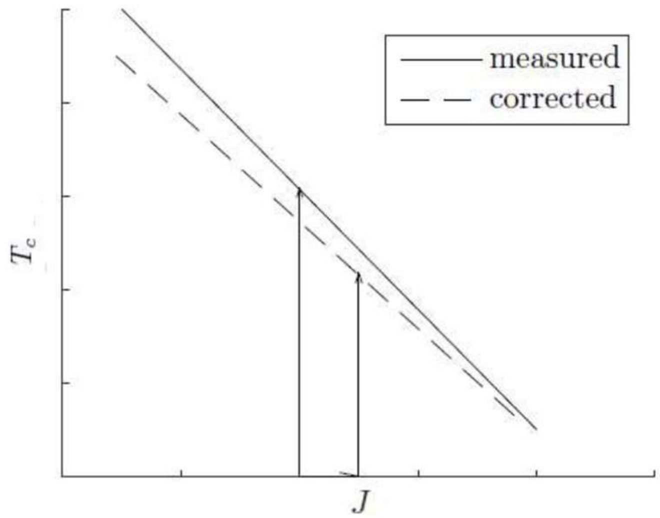

Figure 3.32: (T_c, J)-diagram for a propeller. (J = $\frac{u_\infty}{\omega D}$)

$$T = \dot{m}\Delta u\left(u_e - u_\infty \frac{1}{1 + \frac{S_p}{S_{tunnel}}\left(\sqrt{1 + \frac{8}{\pi}T_c} - 1\right)}\right)$$

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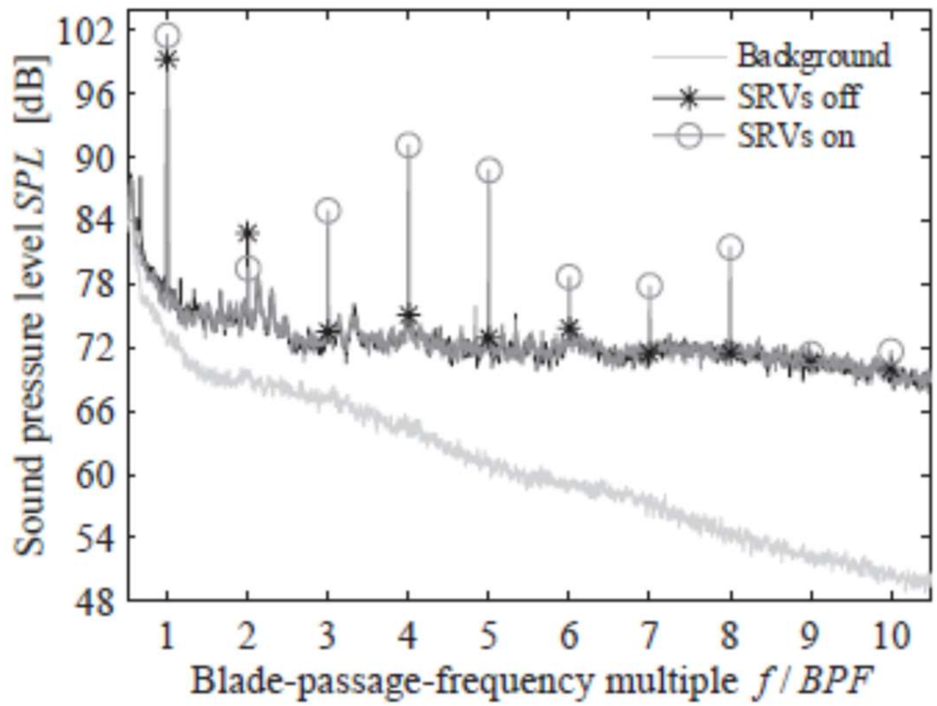
Acoustic testing environment

Effect of SRV on sound generation



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Wind tunnel corrections

Here for powered winged aircraft models

Total lift of the wing affected by n propellers with individual thrust

$$L = \int_{-\frac{b}{2}}^{\frac{b}{2}} c\, C_\ell q\, dy = \int_{-\frac{b}{2}}^{\frac{b}{2}} c\, C_\ell q_\infty dy + \sum_{i=1}^{n} \int_{Y_i}^{Y_i+D_i} c_i C_{\ell i} \left(q_i - q_\infty\right) dy$$

Lift coefficient

$$C_{LCT} = \frac{L}{A\, q_\infty} = \frac{1}{A} \int_{-\frac{b}{2}}^{\frac{b}{2}} c\, C_\ell q_\infty dy + \sum_{i=1}^{n} \int_{Y_i}^{Y_i+D_i} \frac{c_i C_{\ell i}}{A} \left(\frac{q_i}{q_\infty} - 1\right) dy$$

$$C_{L,CT} = C_{L,CT=0} \left[1 + \sum_{i}^{n} \frac{C_{\ell i} A_i}{C_{L,CT=0}} \left(\frac{q_i}{q_\infty} - 1\right)\right]$$

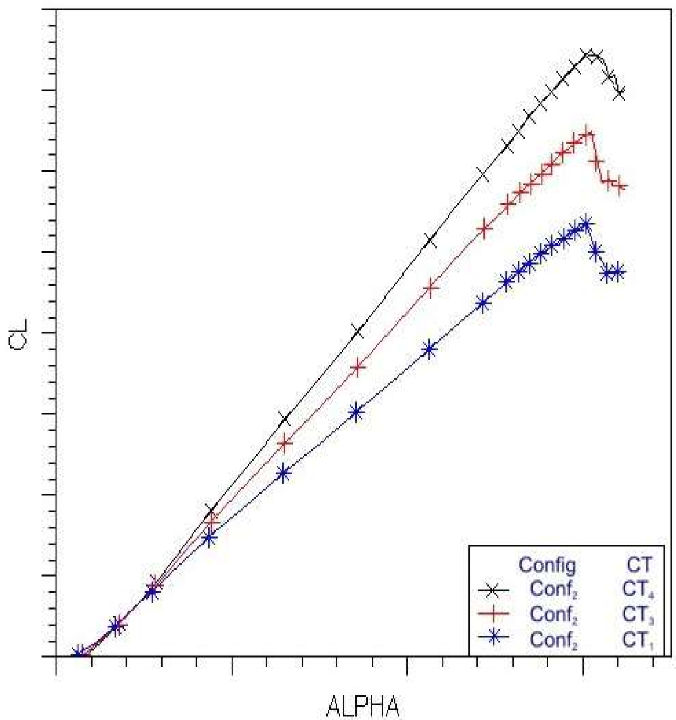
Thrust corrected Lift coefficient

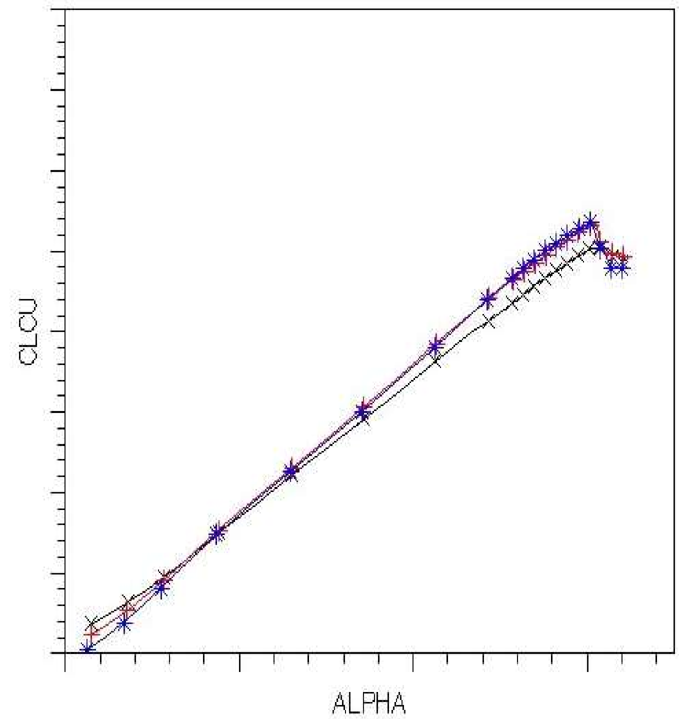
$$C_{L,CT=0} = \frac{C_{L,CT}}{\left[1 + k \frac{D_p}{b} \sum_{i=1}^{n} \frac{c_i}{c} \left(\left(\frac{\sqrt{1 + C_{T_i}} + 1}{2\sqrt{1 + C_{T_i}}}\right)^{\frac{1}{2}} C_{T_i}\right)\right]}$$

German-Dutch Wind Tunnels

WALL INTERFERENCE

Reduction of thrust effects on lift coefficients, example



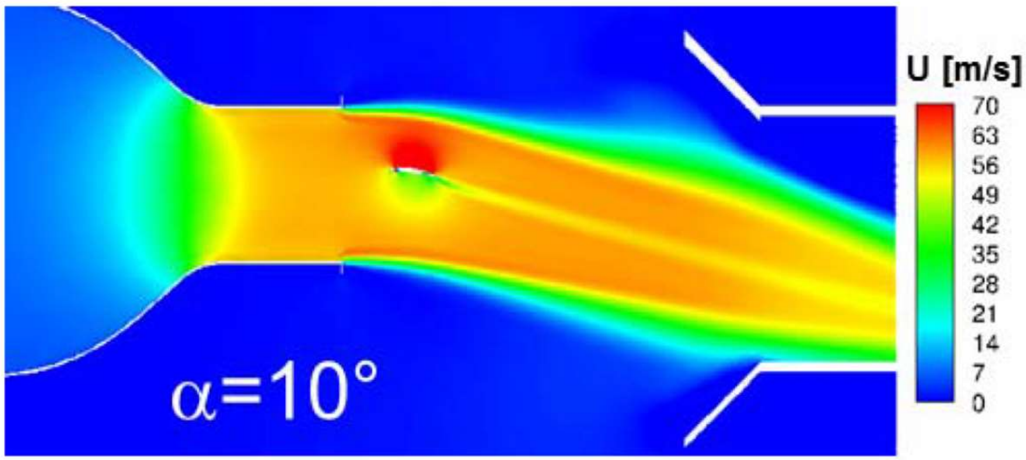


Correction procedure for OJ testing

Recurring myth downwash

- How about the downwash myth?

➢ *"Given how much grief I have been getting (and continue to get) on the equal time issue, I chickened out of this one…"* H. Babinski, U Cambridge



V. Ciobaca, M. Pott-Pollenske, S .Melber-Wilkending, and G. Wichmann, *Computational and experimental results in the open test section of the aero-acoustic wind tunnel Braunschweig,* International Journal of Engineering Systems Modelling and Simulation 47 **5**, 125 (2013).

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Economic indicators of wind tunnel operations

Visualization of a representative time scale

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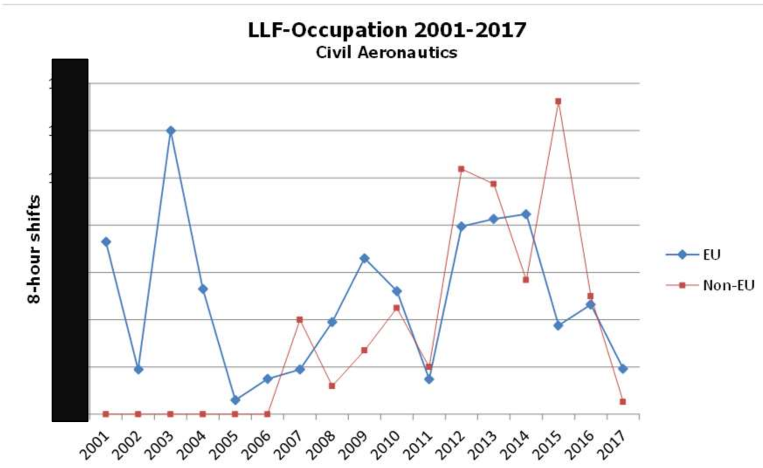
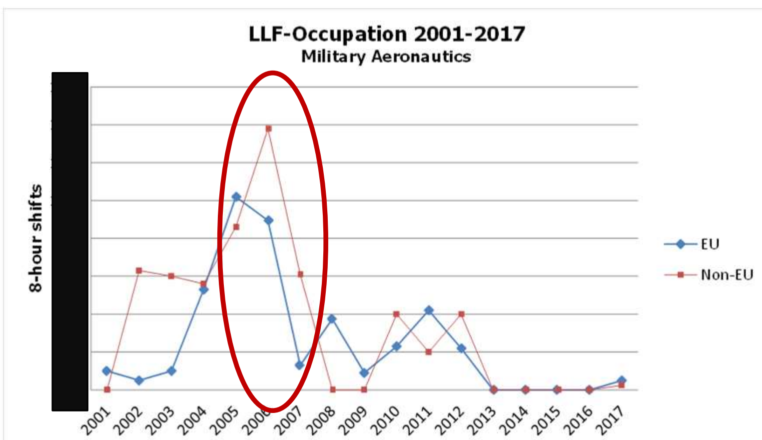
Stability of funding over a long period?





Volatility of the civilian and military markets in the low and high speed domain.

Stability only in the research market, approximately 15% of the total capacity.

Without some filling of the gaps, the skills will not be maintained.

Experimental research suffers from lead times longer than available for a thesis.

➔ Paper studies not verified; innovation hindered.

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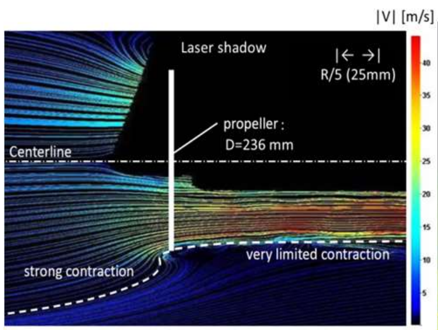
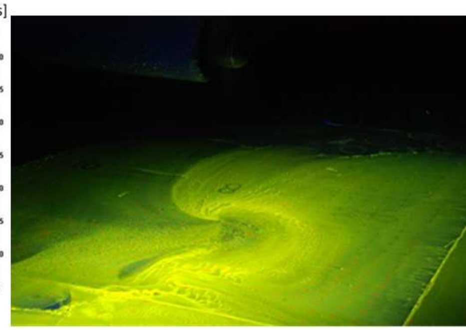
Effect of volatility

- Need to assure <u>survival</u> in the trough and <u>availability</u> during the next peak demand
  - Broaden customer base
    - ➢But: Broadening of customer base dilutes priorities
      - Priorities are required for competitiveness
- Strategic considerations are interfered with by survival strategies
  - ➢Continuous component of occupation required in order to maintain and generate skills
  - ➢Commitment needed from the strategic users

The need for continuous research access

- Long term preparation required for model and tunnel in research projects ➔ $T_{preparation} \geq T_{PhD\ thesis}$
- Need for skill developments at academic institutions
- Continuous and established access at European level will motivate academic involvement in skill development






➔ Support further TNA like in ESWIRP!

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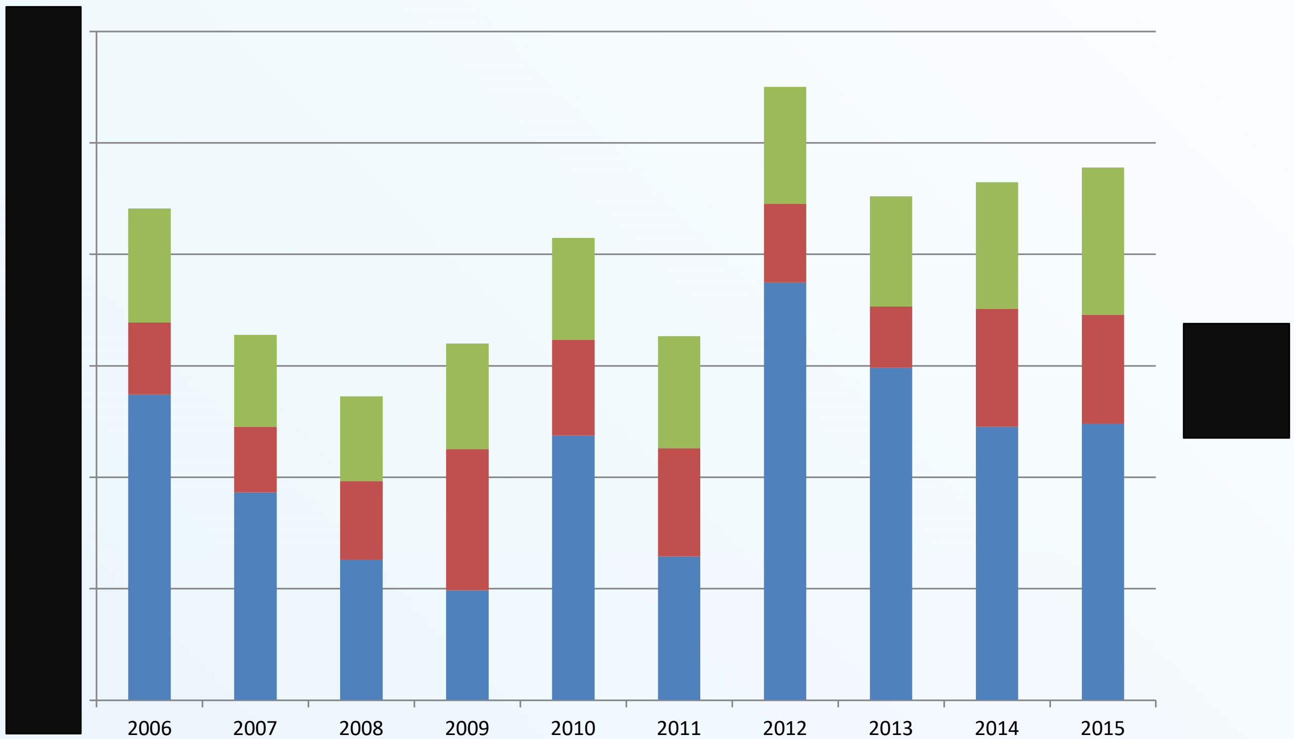
Revenue distribution between locations

up to year 2015



German-Dutch Wind Tunnels

Attraction of funding through users

- Europe has some of the most competitive wind tunnels world wide. For how long?
- Global attractiveness of DNW, high density of users from within the EU:

- Approach to user community not coordinated (competitive) with other national operators of infrastructure

DNW
German-Dutch Wind Tunnels

Some required skills

- Qualification of wind tunnel
  - Turbulence
  - N-factors
  - Uniformity
- Qualification of techniques
  - Resolution (spatial, temporal)
  - Availability
- Qualification of quality control
  - Certified quality of data
- Qualification of procedures
  - Planning reliability

Conclusions

As elements of retaining the usefulness and a globally competitive position of wind tunnels (and also of the European industry)

- Further deepening of specialization
- Involvement and commitment by the industry
- Continuous research involvement (e.g. through an institutionalized TNA)
- Continuous upgrades

are required

who will fund this strategy?

Thank you for your attention

Name

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