Challenges in Aeroelastic Wind-Tunnel Testing

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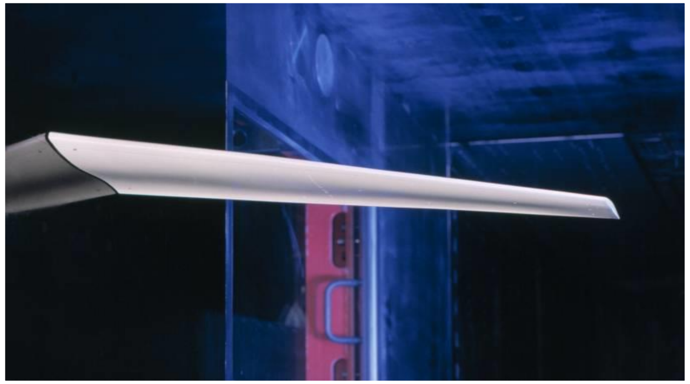
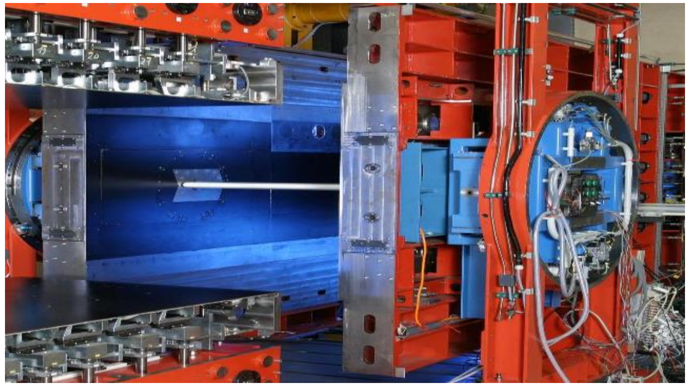
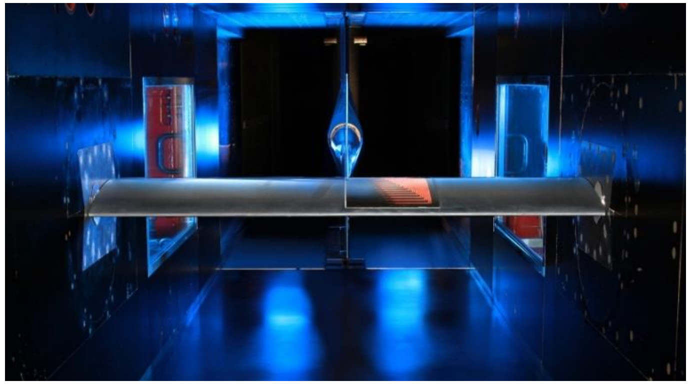
Overview

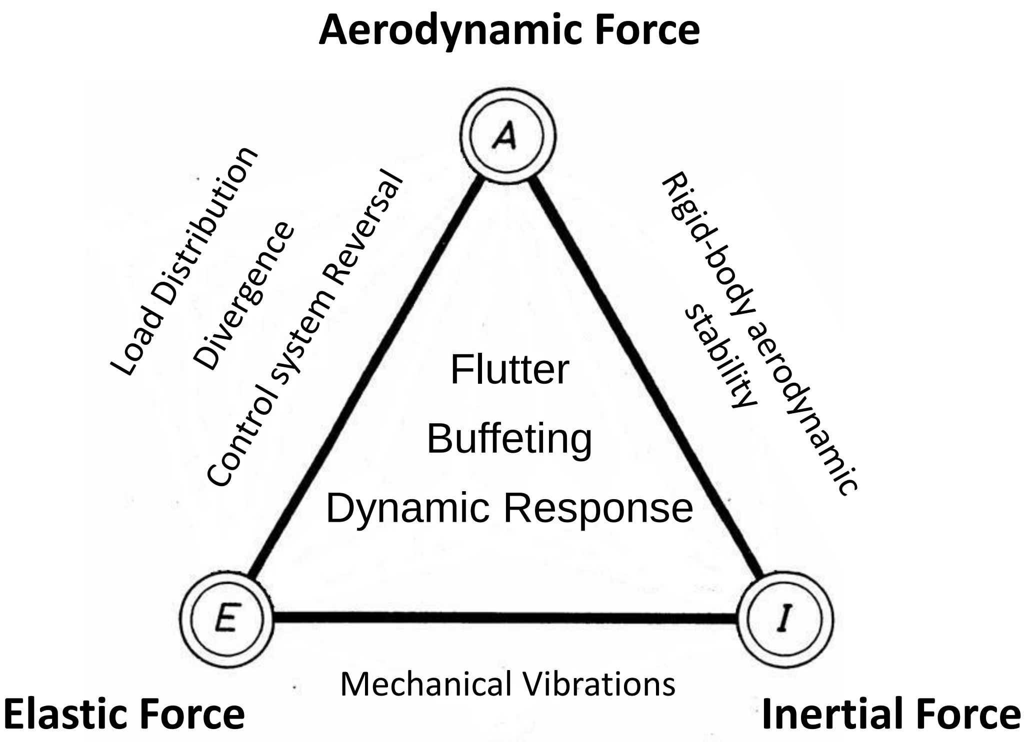
- Aeroelasticity
- Aeroelastic Wind-Tunnel Testing
- Past Challenges
- Future Challenges
- Requirements
- Outlook





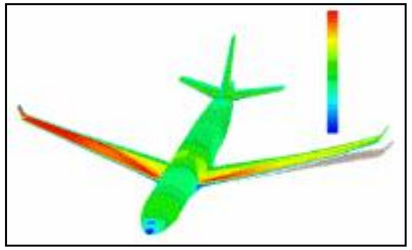


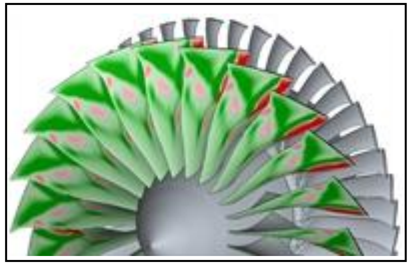
Aeroelasticity



Interaction of aerodynamic forces with elastic structures

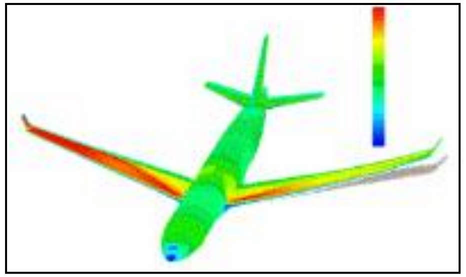
- Examples in nature:
  - Oscillation of trees, waving of grain in the wind
- Examples from engineering:
  - Wind-induced vibrations of television towers, cranes, bridge decks
- **Focus in the DLR aeronautical program:**
  - **Aeroelasticity of aircraft, helicopter and turbo machinery**
- **Aeroelasticity key enabler for the safe integration of new technologies**

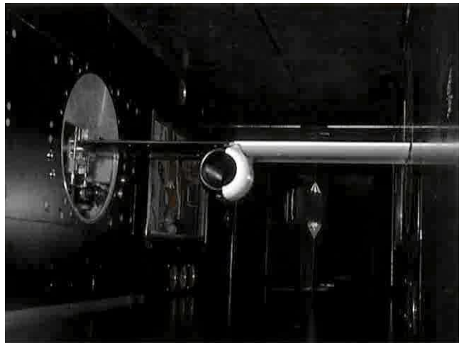


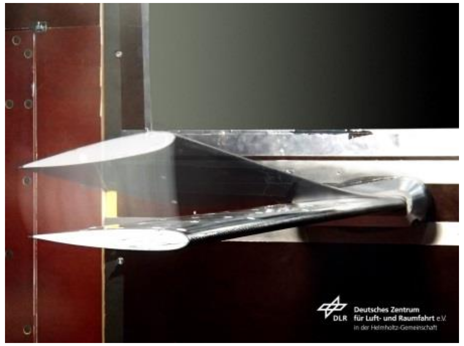


Aeroelastic (Wind-Tunnel) Experiments

- Since World War 1: Flutter investigated experimentally
- Experiments to proof aeroelastic stability of aircraft by using dynamically scaled models
- Today analytical and numerical methods are an essential part of aeroelastic analysis during the development and certification of aircraft: Determination of motion induced aerodynamic forces
- Need for validation experiments in the transonic regime, measurement of motion induced aerodynamic forces with forced motion models
- Steady deformation of models due to high dynamic pressures taken into account
- In contrast to that experiments with elastic models with a prescribed deformation behavior called aeroelastic validation experiments for validation of aeroelastic methods and fundamental experiments to improve physical understanding







Aeroelastic Wind-Tunnel Experiments

Objectives:

- Measuring of motion induced aerodynamic forces like pressure distributions or global forces and moments
    - using models as stiff as possible under prescribed motion
    - using elastic models that are excited at their eigenfrequencies
- Measuring of aeroelastic stability of elastic or elastically suspended models (flutter)
- Measuring of excitation by unsteady aerodynamics of fixed models (resonance, buffet)
- Measuring of dynamic response of elastic models as a result of gust or buffet (buffeting)
- Measuring of above effects at rotating, elastic rotor blades (helicopter, wind turbine)

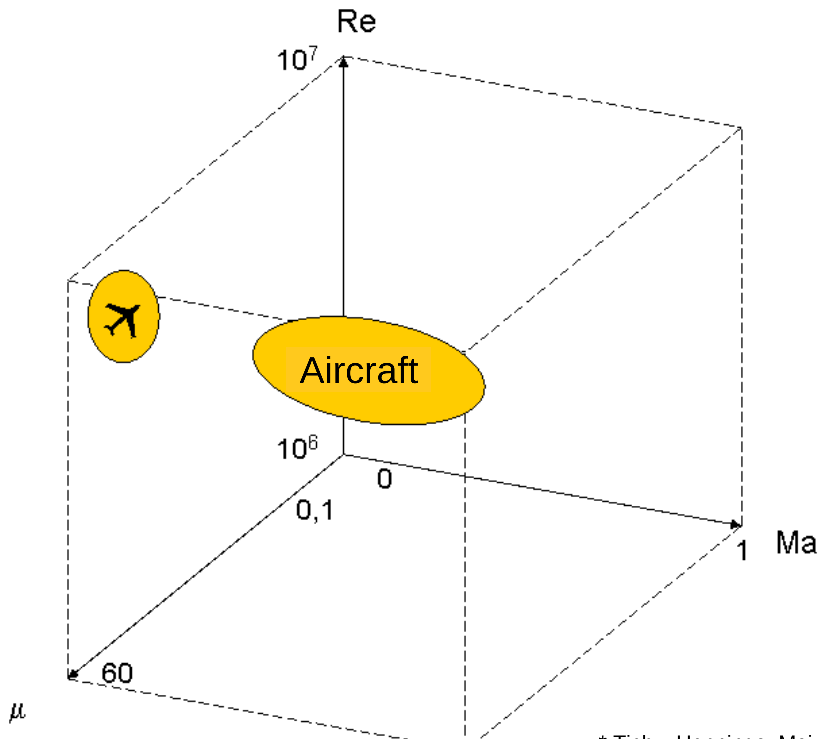
Similarity Rules in Aeroelastic Wind-Tunnel Testing

<u>Aerodynamic Wind-Tunnel Testing:</u>

- Ma (compressibility) and Re (friction) similarity

<u>Aeroelastic Wind-Tunnel Testing:</u>

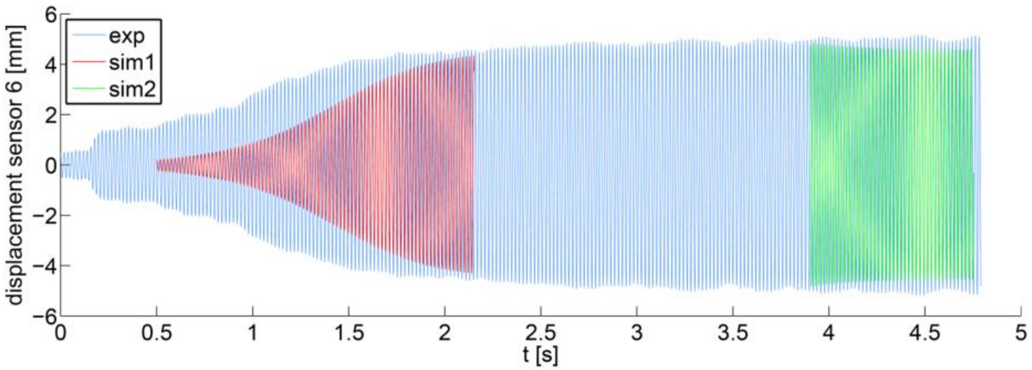
- Mass ratio: μ = (m* / π / 4 c*2 b*)) / ρ*∞
- Cauchy number: $Ca = \frac{\rho \cdot (\omega \cdot l)^2}{E}$
- Reduced frequency: $\omega^* = \frac{\omega \cdot l}{U_\infty}$



* Tichy, Hennings, Mai

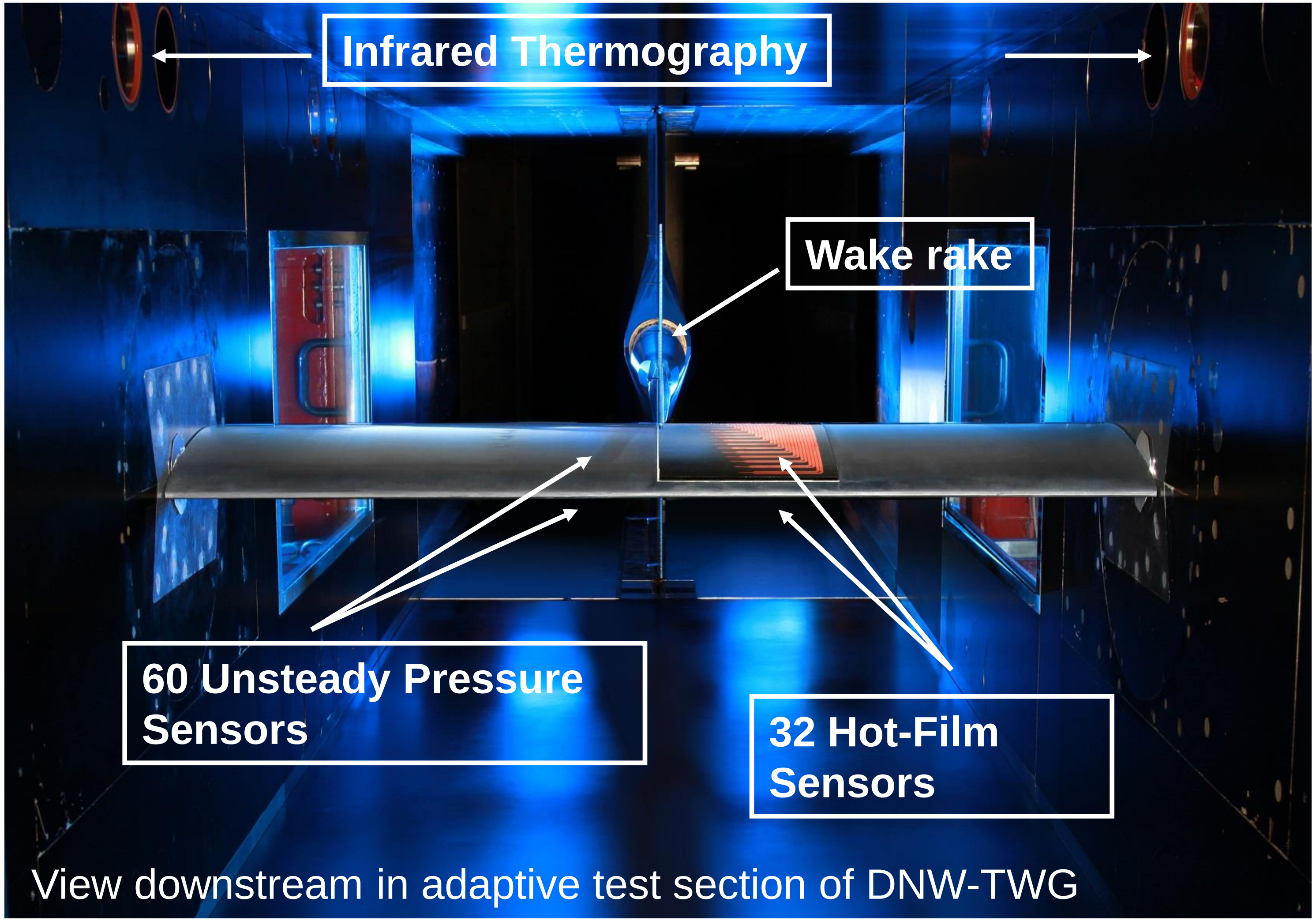
Project AEROSTABIL: Flutter of a flexible wing

- Ma = 0,865
- $\Delta\alpha \approx$ 10mm



* Stickan, Dillnger, Schewe (2014)

Project ALLEGRA: Aeroelastic Stability of a laminar Airfoil



Experiment ALF-3: Forced Pitch Oscillations

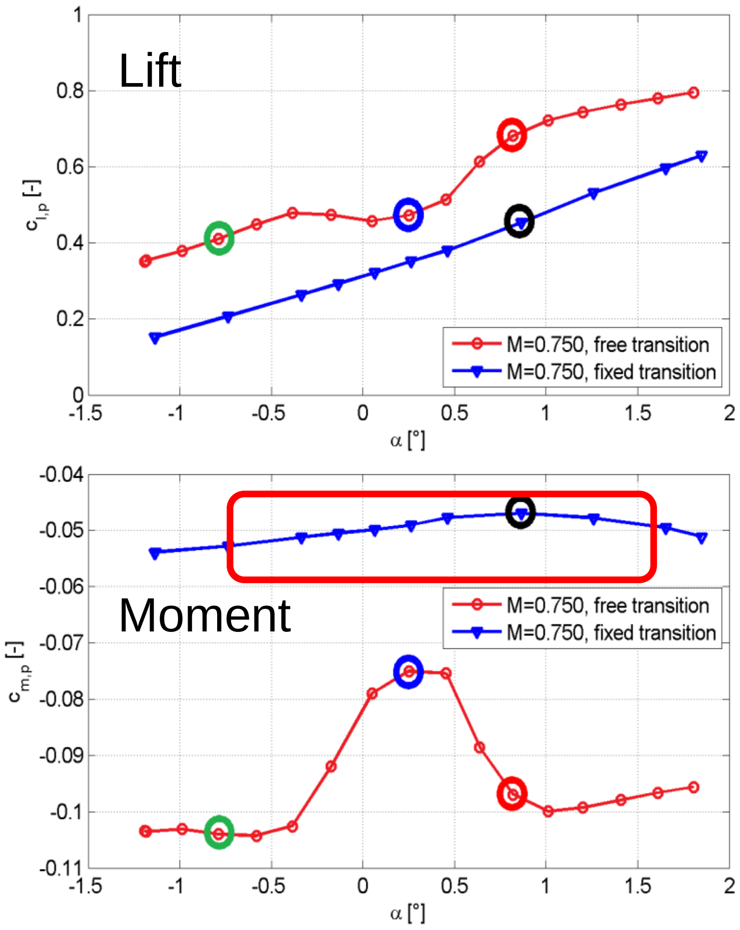
Ma = 0.750, Re = 2 mio.

Steady:

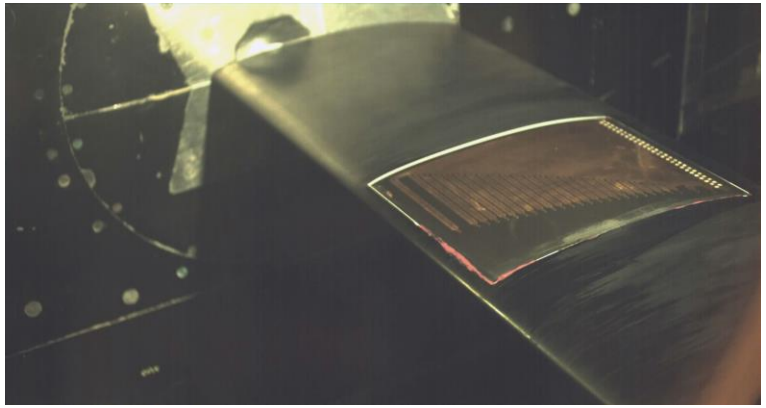
- Increased lift in laminar flow
- Non-linearity in lift and moment in transitional flow

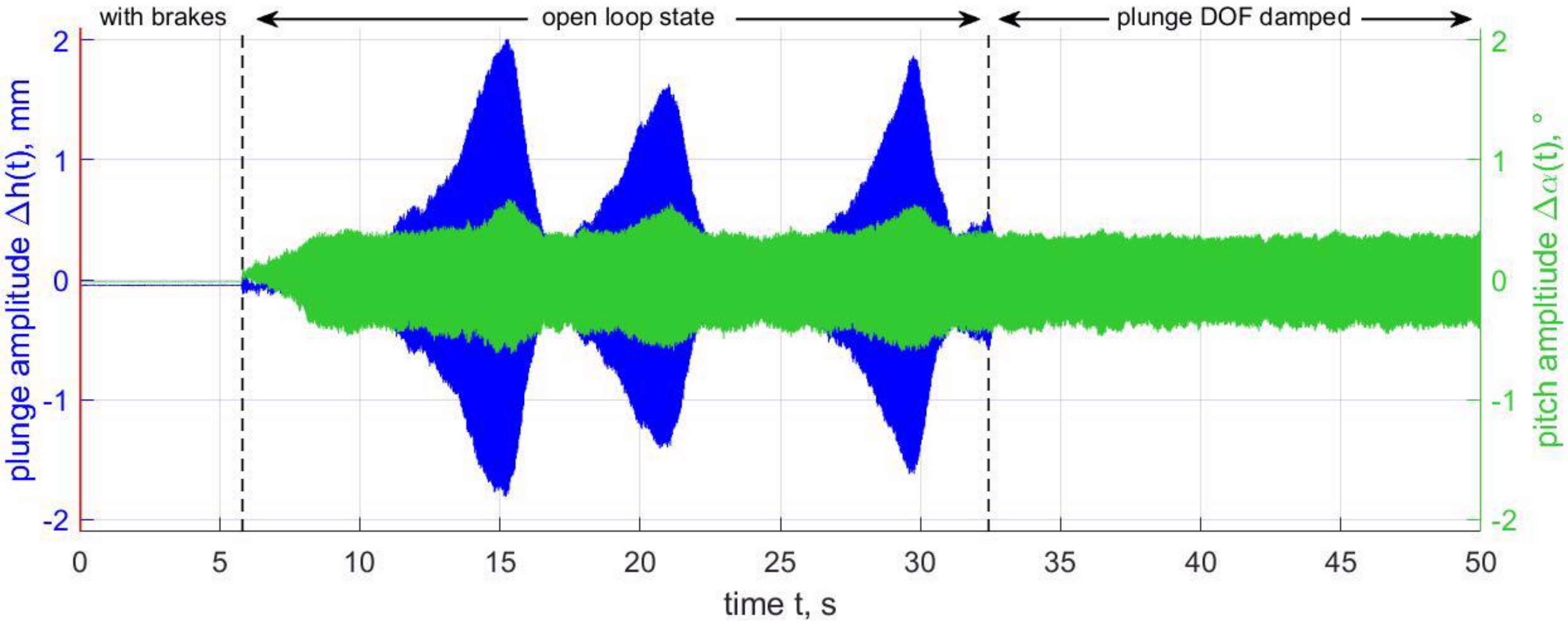
Unsteady:

- Lead in phase of moment derivative at α = 0.8°
  - Indicating 1 DOF flutter



Experiment ALF-7: 1 DOF Flutter of a laminar Airfoil

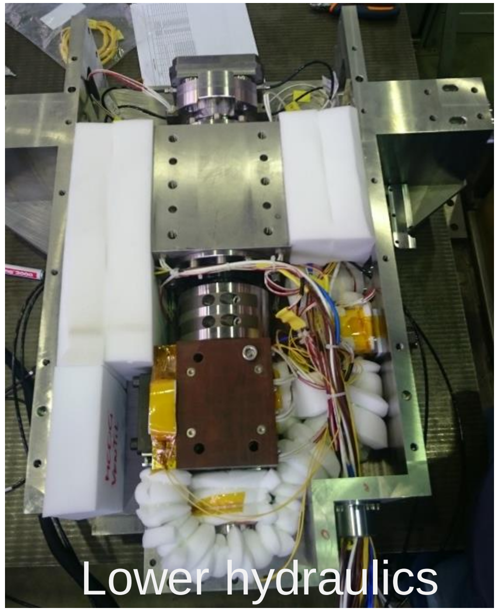




Aeroelastic Stability of a laminar Airfoil
at high Reynolds Numbers

- Realization of a hydraulic actuation at 100 Kelvin!
- CFRP model without linear thermal expansion
- Unsteady pressure transducers, accelerometer, hot-film sensors, optical position measurement under cryogenic conditions

Upper hydraulics

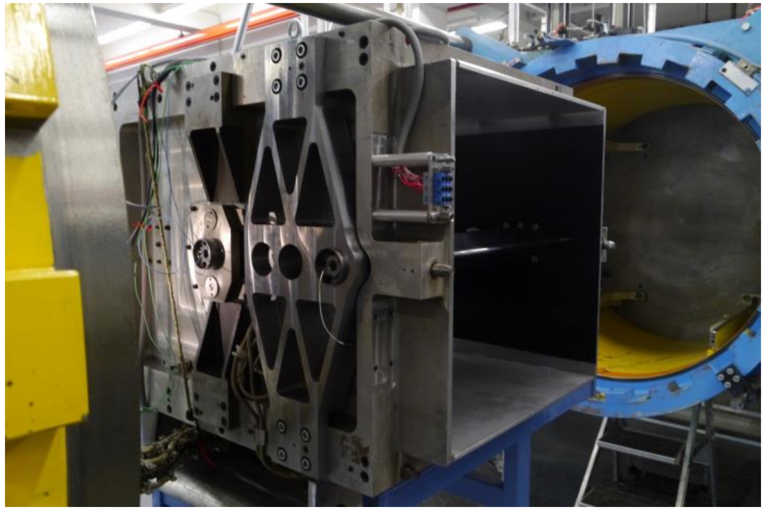


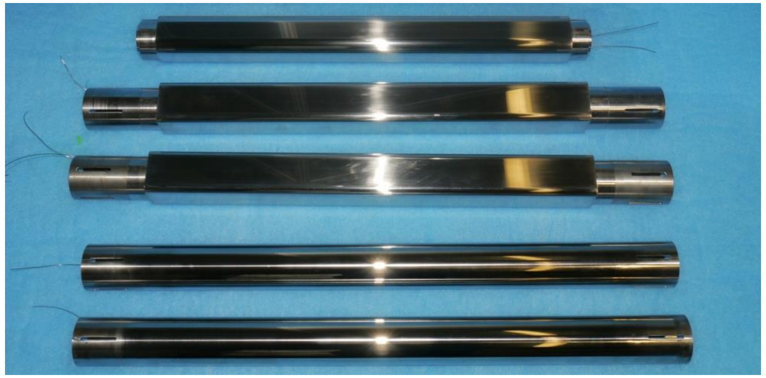
Lower hydraulics

Heating controler

High Reynolds number Testing: Vortex-induces Vibrations

- Motivation: strong vortex-induced motion of offshore platforms due to wave-pillar interaction
- Goal: gathering of experimental data at Re up to 10^7 for validation of numerical codes
- Experiment: unsteady aerodynamic forces, base pressure and wake profile as function of angle of incidence, corner radius, surface roughness and spacing for 2D cylinders in single and tandem configurations.





DLR

Challenges

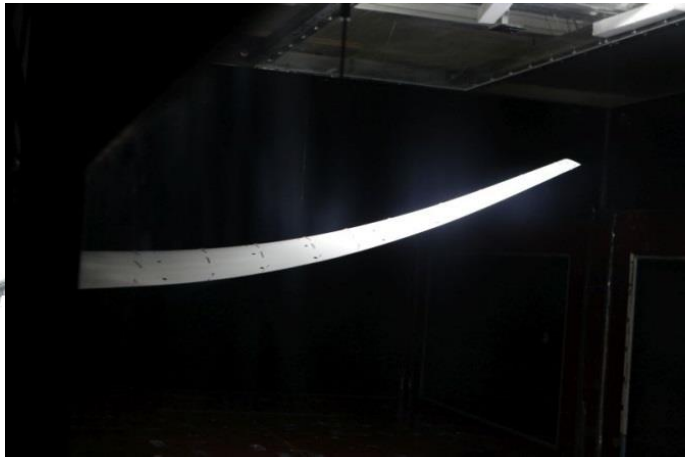

Larger Structures

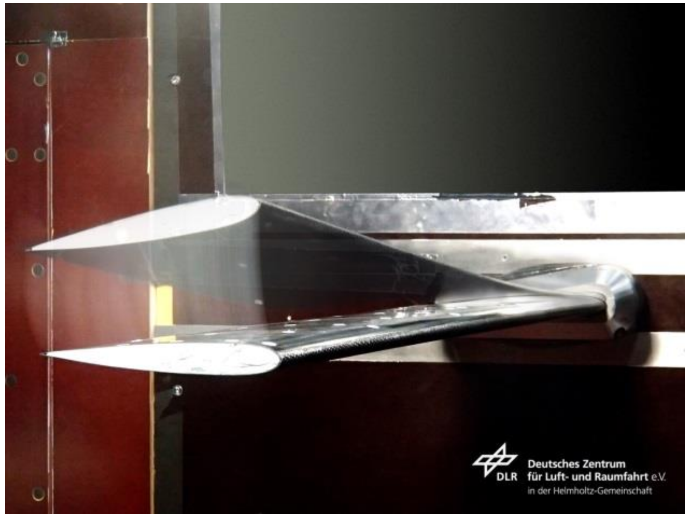

New Configurations


Green Aircraft:
Laminar Flow / Electrical Propulsion


Flexible Structures

Challenge: New Materials
Highly flexible Wing





What are the requirements?

- Optical Access
  - PIV
  - iPSP
  - Model position, motion, deformation
  - Infrared thermography
- Safety factors
  - Lightweight or highly flexible models
- Boundary conditions
  - Model mounting
  - Model excitation
  - Wall interference
  - Turbulence
  - Ma distribution
- Control of Boundary Conditions -> VICAS

VICAS - Validation and Integration Center for Aerodynamics and Structure Göttingen (AE, AS, DNW)

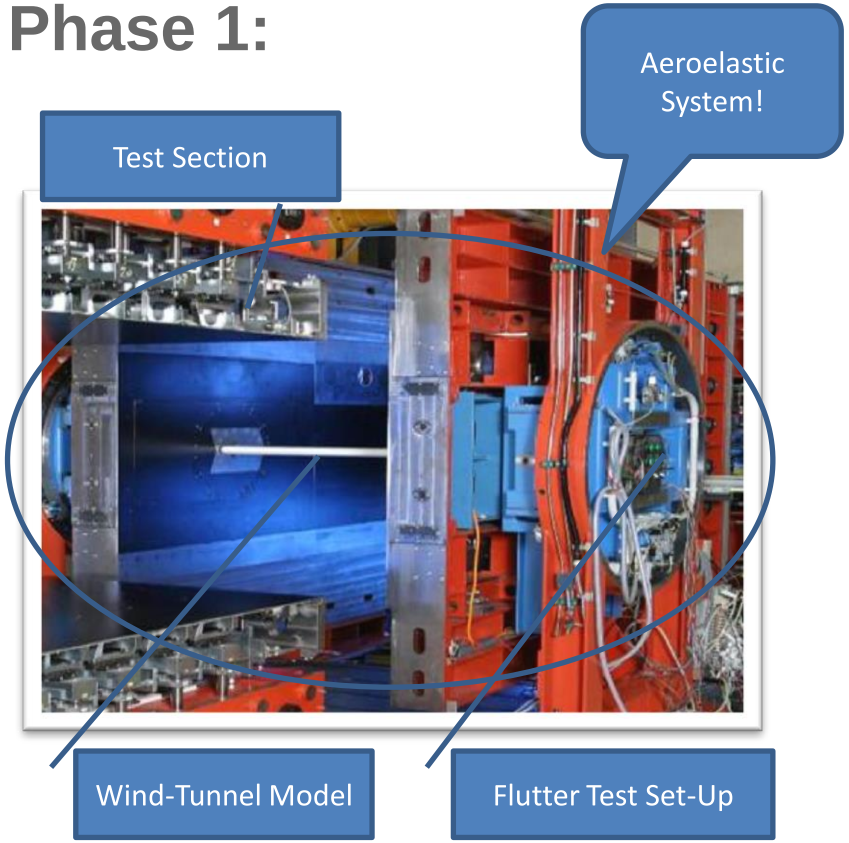
Objective:

- Establishment of an infrastructure for high-precision experimental validation of fluid-structure coupling methods in transonic regime:
    - Aeroelastic Stability, Dynamic Response, Simulation of Gust and Gust Load on highly flexible structures.
- Improvement of the physical understanding and assessment of new configurations and technologies by generic aeroelastic experiments

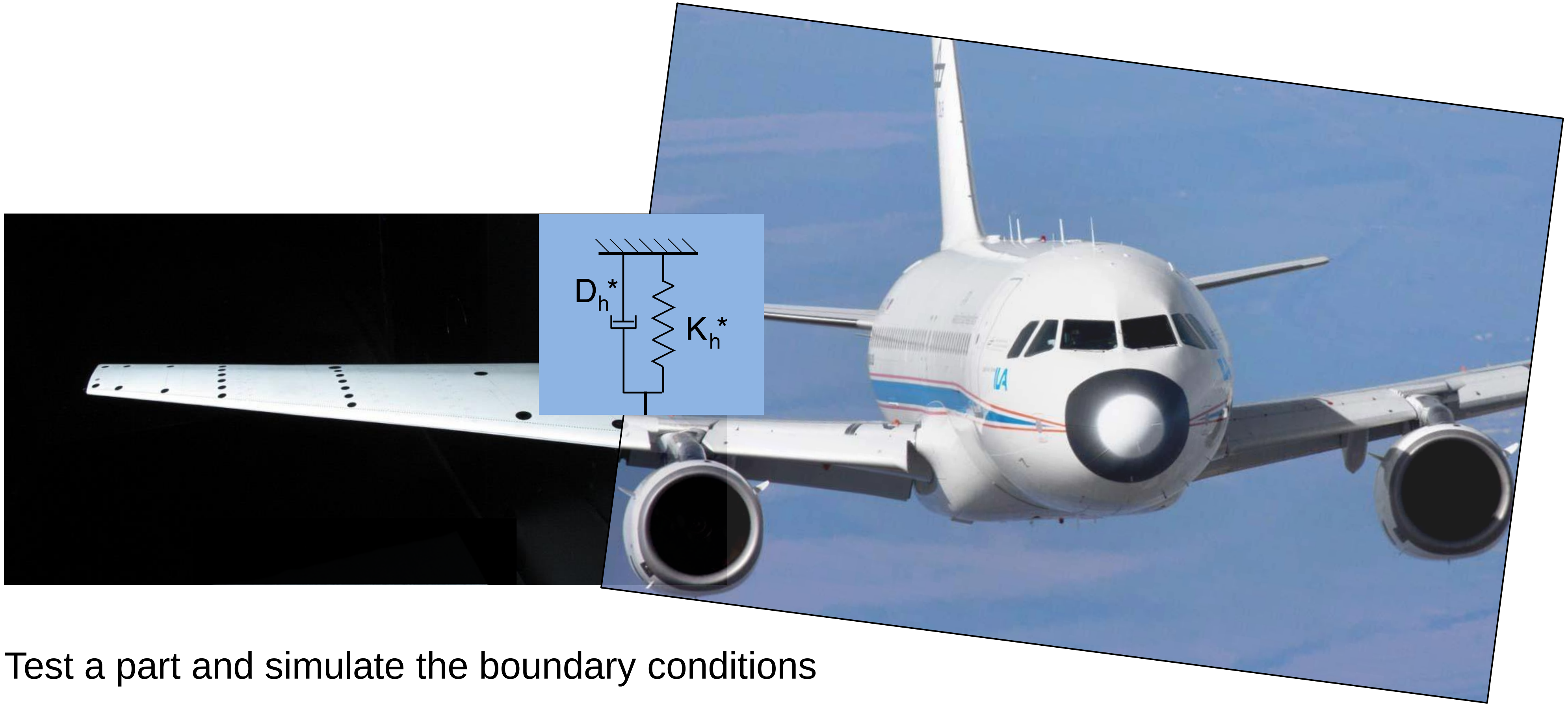
Roadmap:

- Phase 1: **vLab**: New lab for structural identification of structural boundary conditions outside of the wind tunnel.
- Phase 2: **vTest**: „Transparent test section". Maximum optical and mechanical access for new optical measuring techniques and model excitation.
- Phase 3: **vSim**: "Digital-analog hybrid wind tunnel". Direct integration of numerical simulation, digital twin, hardware-in-the-loop, virtualized hardware.

Phase 1:



VICAS Phase 2:
Control of (structural) Boundary Conditions

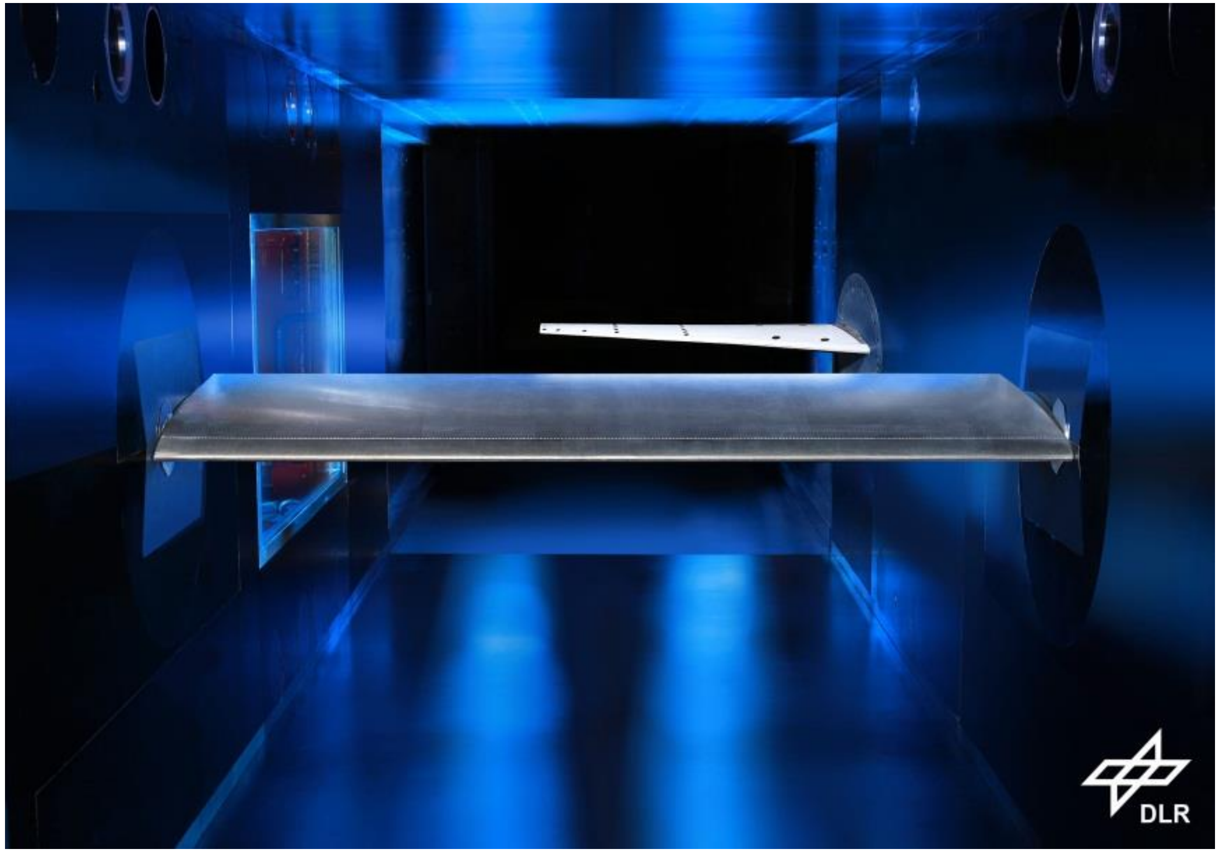


Test a part and simulate the boundary conditions

Validation Test Case Ma=0.750

VICAS Phase 3:
Digital-Analog Hybrid Wind Tunnel

Set-up in the adaptive test section of DNW-TWG



Summary

- Aeroelasticity makes challenging wind-tunnel tests
- Ma, Re, Ca, μ, ω^* similarities
- Experiments for modelling new physical effects for development and validation of methods
- Increased demand for aeroelastic methods in the future
- Driven by new materials and configurations challenging new tests
- Experimental simulation in wind tunnels and numerical simulation are complimentary
- Better and new methods for experimental simulation will be developed within VICAS