EXPERIMENTAL RESULTS OF A FLUID ACTUATED MORPHING WINGLET TRAILING EDGE

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DLR

Experimental Results of a Fluid Actuated Morphing Winglet Trailing Edge

Outline

- Motivation
- Structutral Design
- Systems Design
- Experimental Results
- Conclusion and Outlook

Supported by the Clean Sky 2 Joint Undertaking (JU)

MANTA – „Movables for Next Generation Aircraft“

AEROMO2 – „Towards the application of Morphing Movables in Aerostructures“

The JU is financed by the Horizon 2020 Research-Programme of the European Union

Motivation
Application

Winglet-Tab

- Reduced induced drag, but increased load
- Reduction of load desirable → Potential for reduced weight
- Active load-reduction by integration of Winglet tab as control surface

- Small available volume, thin profiles
- Big distance from fuselage

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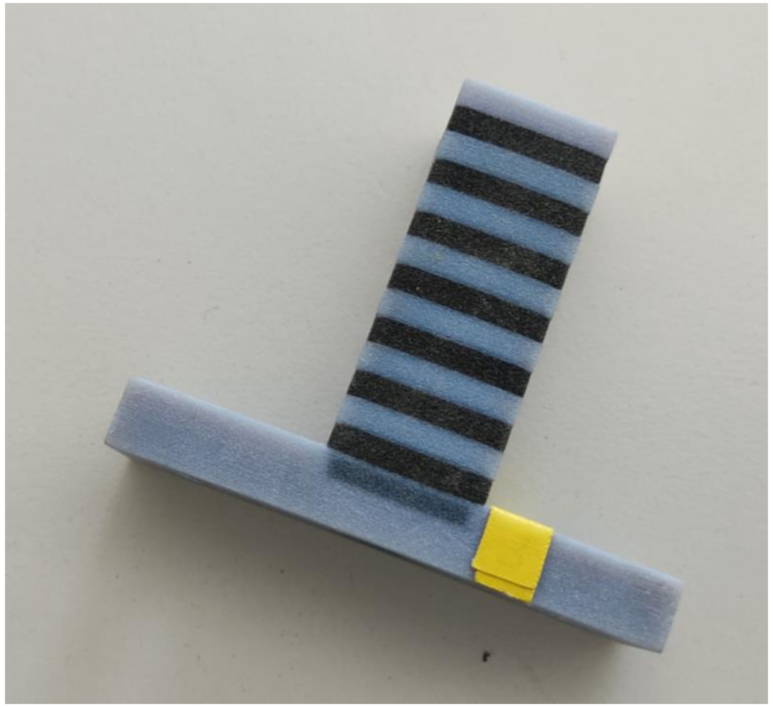
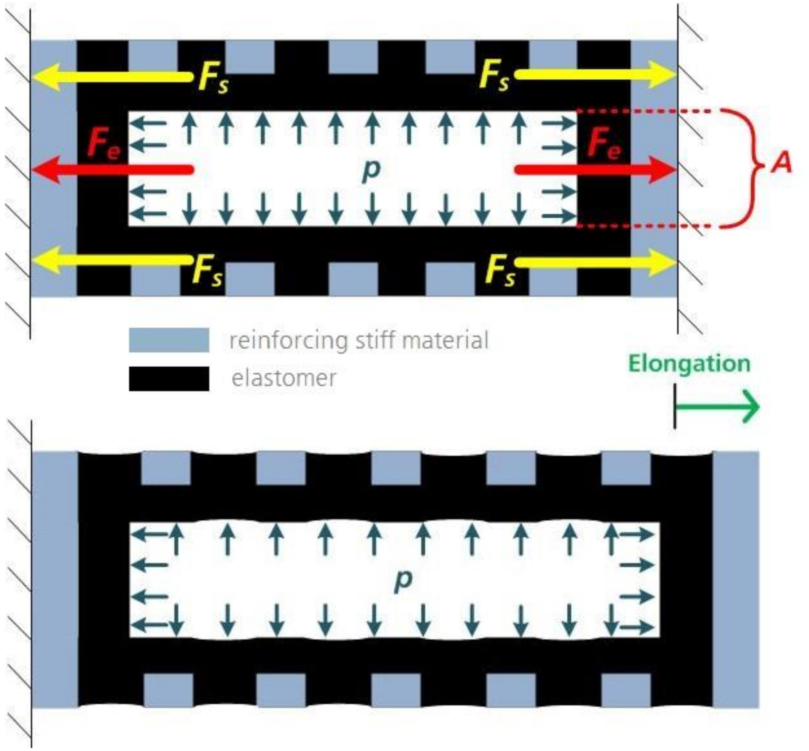
Motivation
Working Principle - Objectives

FAMoUS

- Fluid
  Actuated
  Morphing
  Unit
  Structures
- Look into feasibility
- Raise TRL
  - Starting at TRL 1
  - Goal: TRL 2-3
- Build structure
  AND system



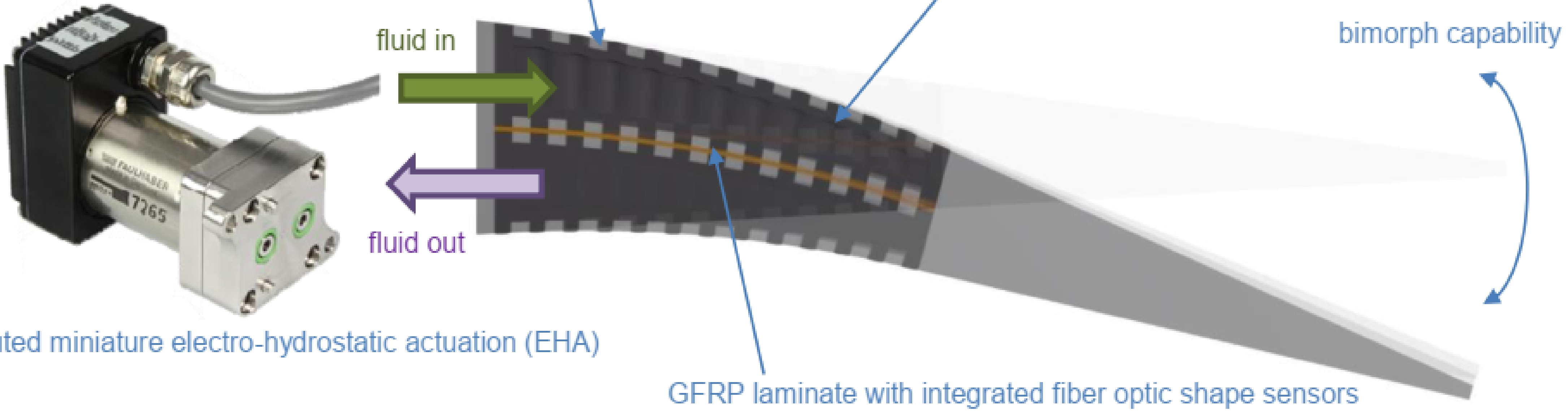


Motivation
Concept for Winglet tab

Challenges:

stretchable skin + flexible inner structure + fluid pressure:
integrated system contributing to both stiffness and flexibility

height only 45 mm



adequate moment authority & rate

clean surface:
no actuator protrusion, no fairings
(fluid pumps fit in the profile forward of the spar)

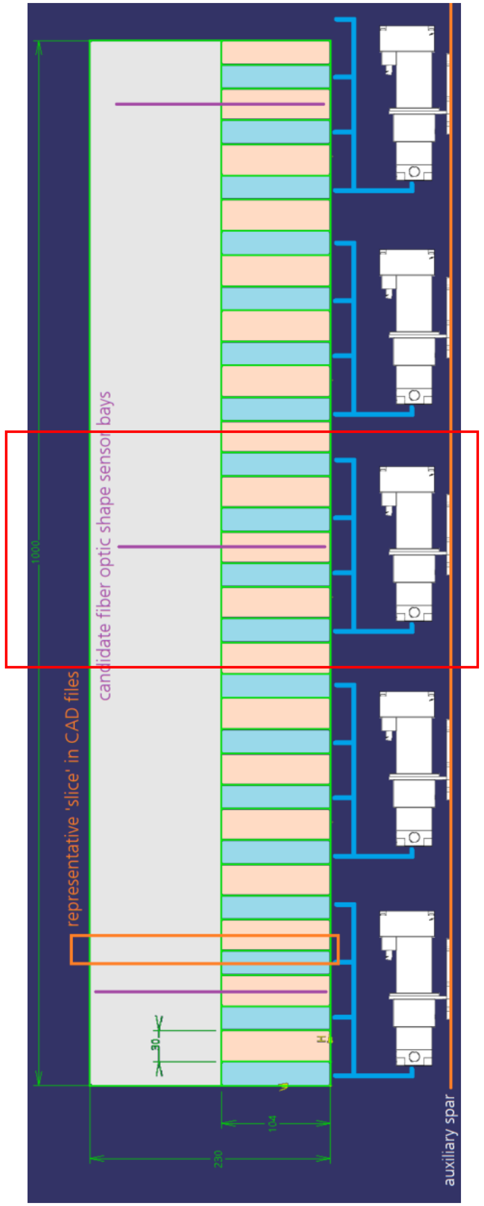
Motivation
Requirements

	1st Priority		2nd Step
Function	High Speed Performance	Maneuver load alleviation	Gust load alleviation
Deflection Range	+/- 10°	+/- 15°	+/- 15°
Deflection Speed	10°/s	20°/s	80°/s
Position Accuracy	+/- 0,1° Rationale: to ensure device position compliant with aerodynamic tolerance		
Design Assumptions	Either 2 actuators or 1 actuator and damper Rationale: Damper to avoid flutter in case of actuator failure		
System Architecture	Hydraulics is baseline, MEA (More Electric Actuation) as trade		

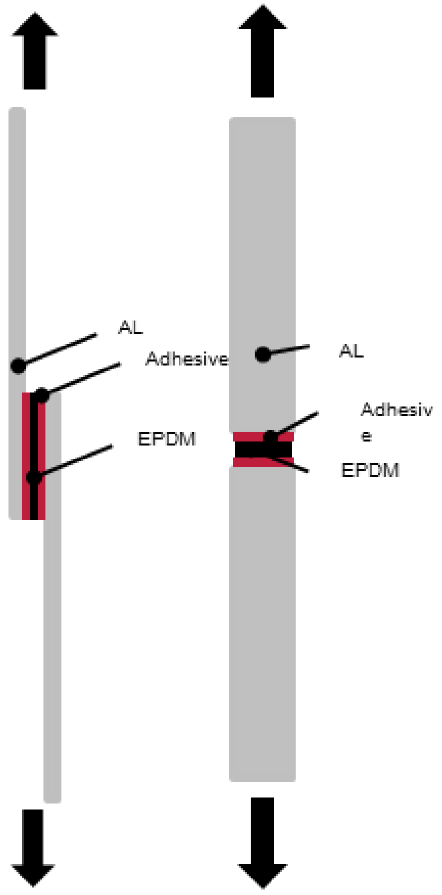
STRUCTURAL DESIGN

Structural Design
Design steps

1 m Demonstrator

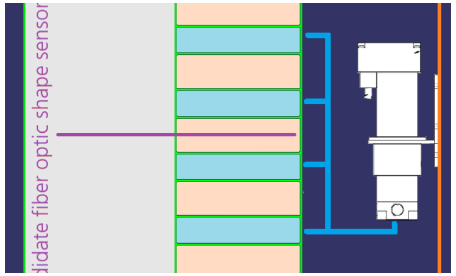


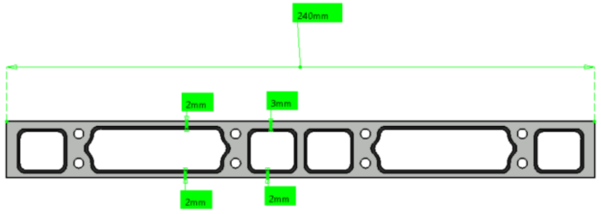
Coupon / Material



Singles Unit-Structure

Subsystem





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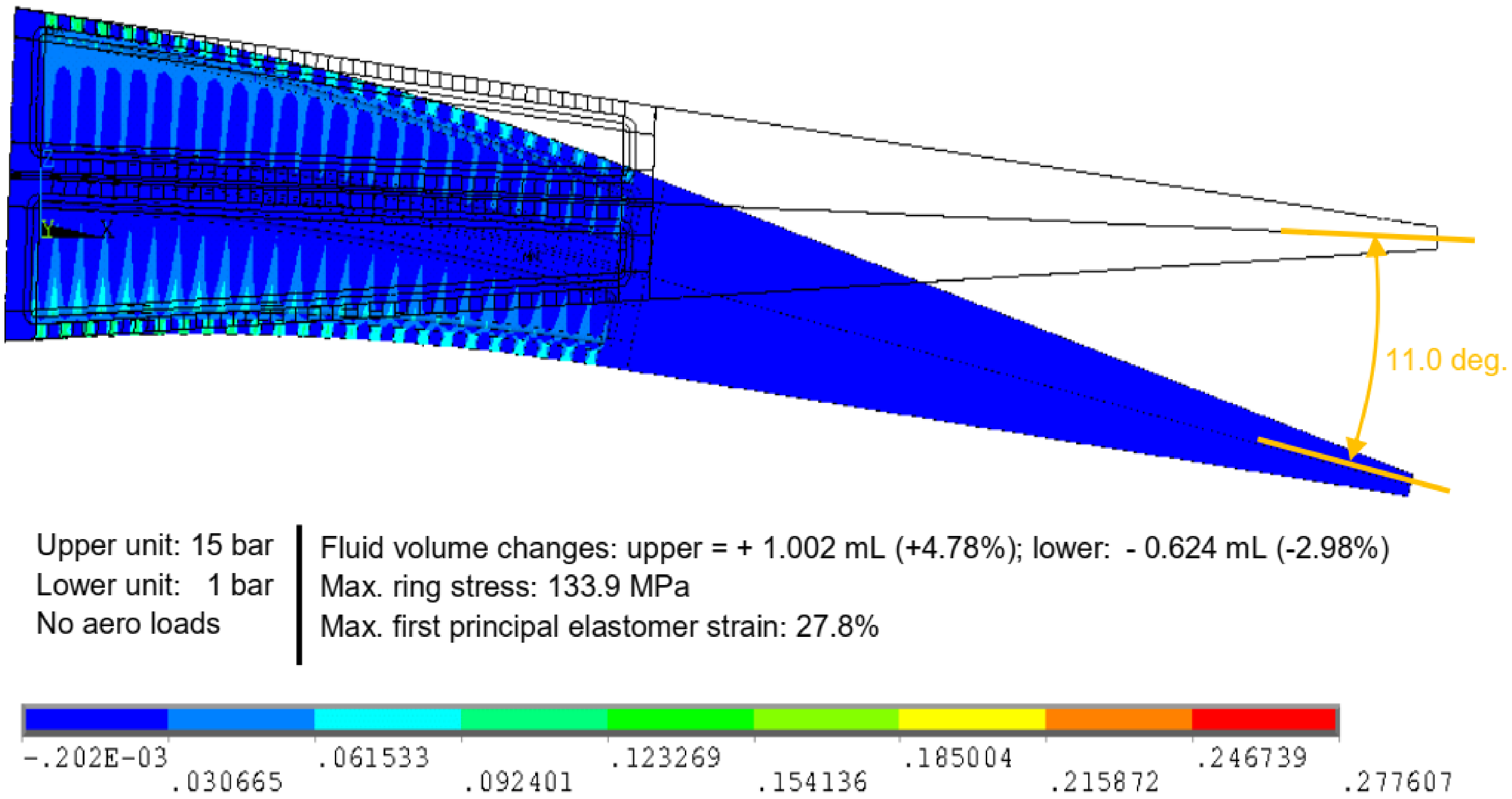
Structural Design
FE Model

Material Selection

- Aluminium
- EPDM

Resulting Parameters

- Fillet size 3 mm in stiffening rings
- Percentage of span comprising active units: 46.4%
- max ring stress = 110 Mpa
- Final TE angle = 16.08°
- 0,79°/bar deflection
- Fluid volume change for 15 bar differential pressure: +4.78% and -2.98%
- Thickness of EPDM and stiffening rings: 4 mm



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Structural Design
Manufacturing

- EPDM Bladders preventing leakage

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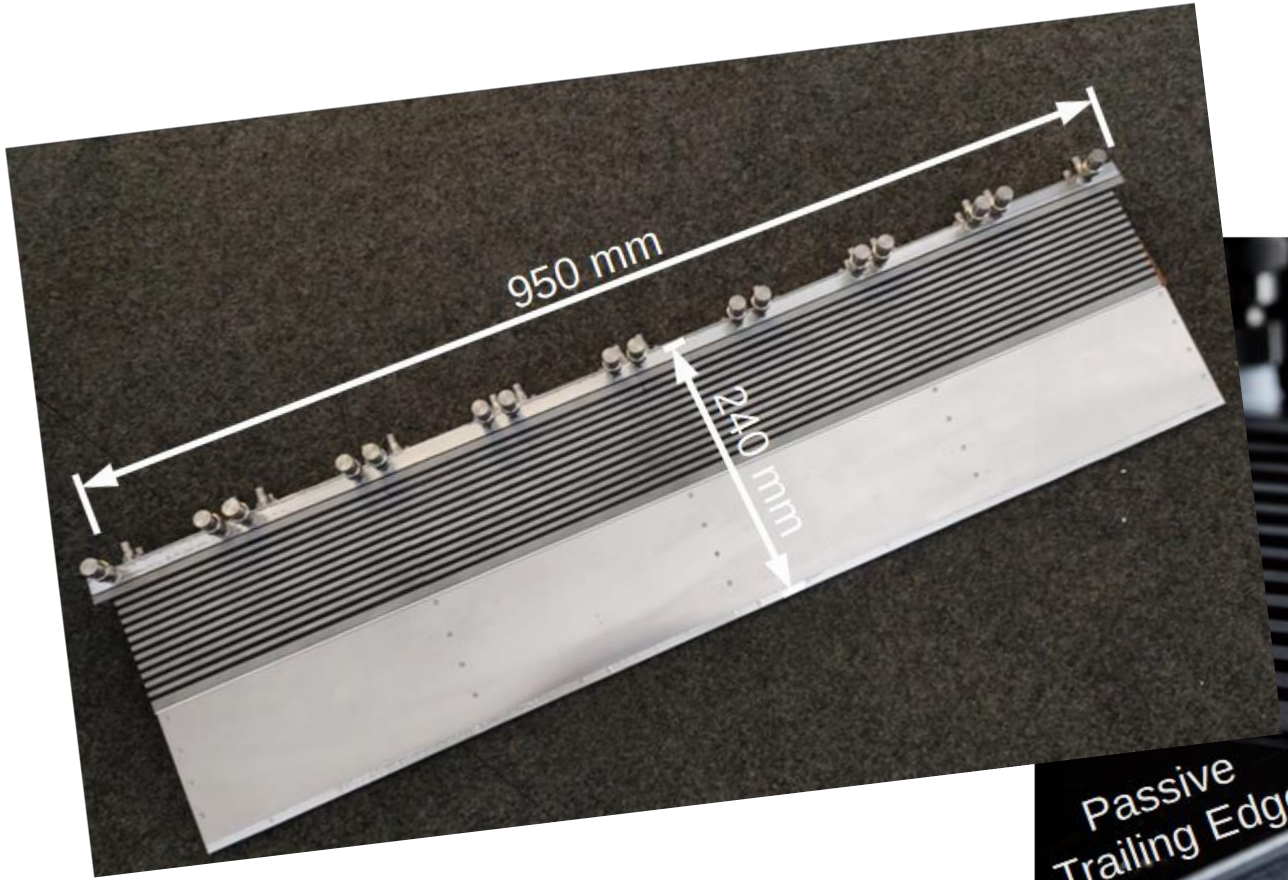
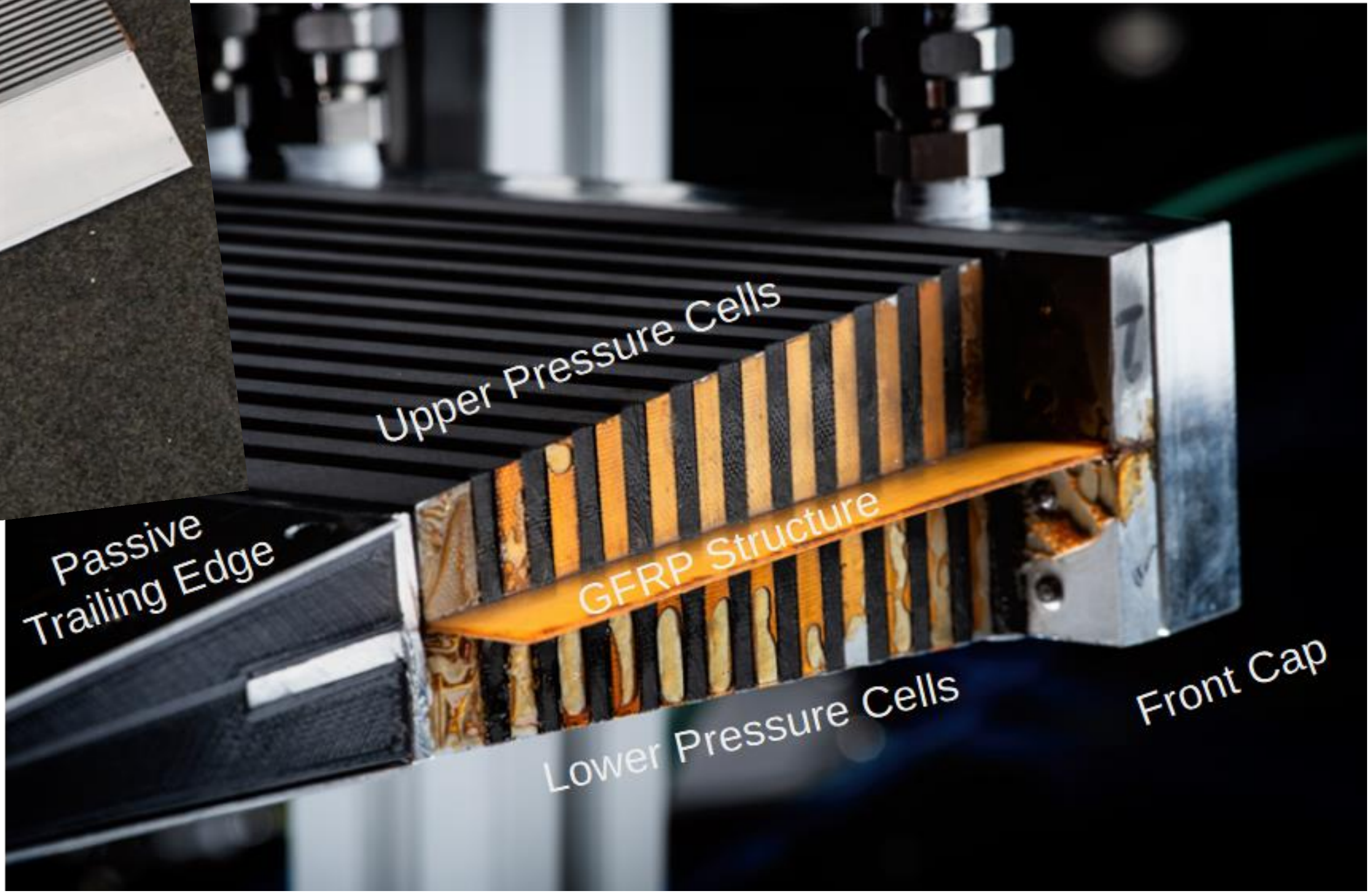
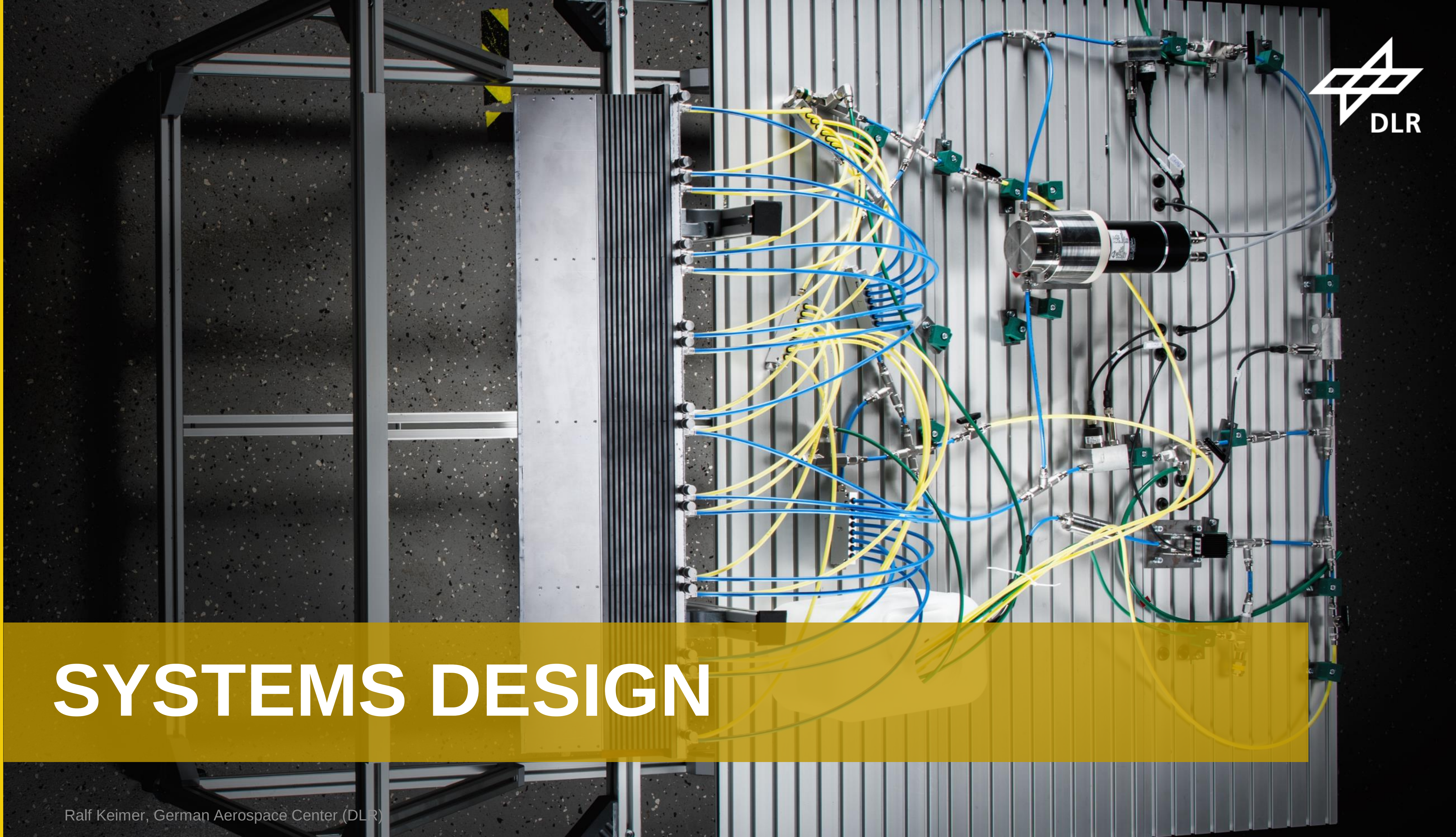
Structural Design
1m Morphing Structure







SYSTEMS DESIGN

Systems Design
Fluid Selection

- Pressure-cells can be driven with pneumatic or hydraulic systems
  - Pneumatic: lightweight medium – compressible
  - Hydraulic: heavy medium – incompressible

- High deflection rate is driver:
  → Hydraulic system

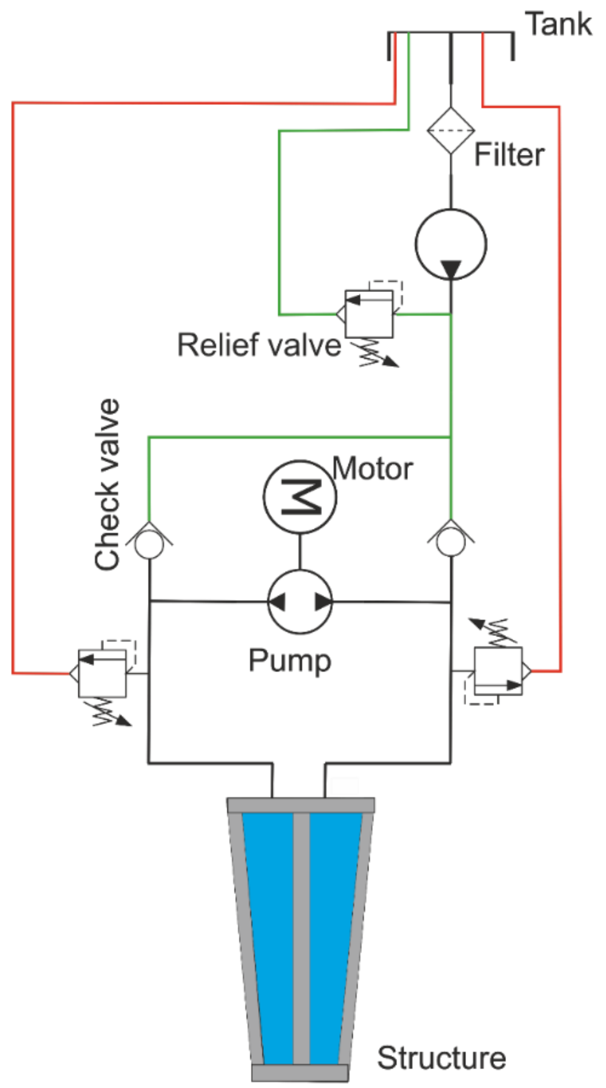
- Chemical Compatibility with EPDM:

  → mandates water-based fluid, selected fluid is able to work from -42°C to 60°C

Systems Design
Core Hydraulic System

- Simplified Electro Hydrostatic Actuator
- Water-based fluid (Lubesave-Fe-46-EAL-HFC)
- Pump moving Fluid Volume between upper and lower cells (black)
- Relieve Valves release Overpressure to Tank (red)
- Second Pump insures minimum Pressure in all Cells through Check Valves (green)

- Input: Direction and Speed of 1. Pump



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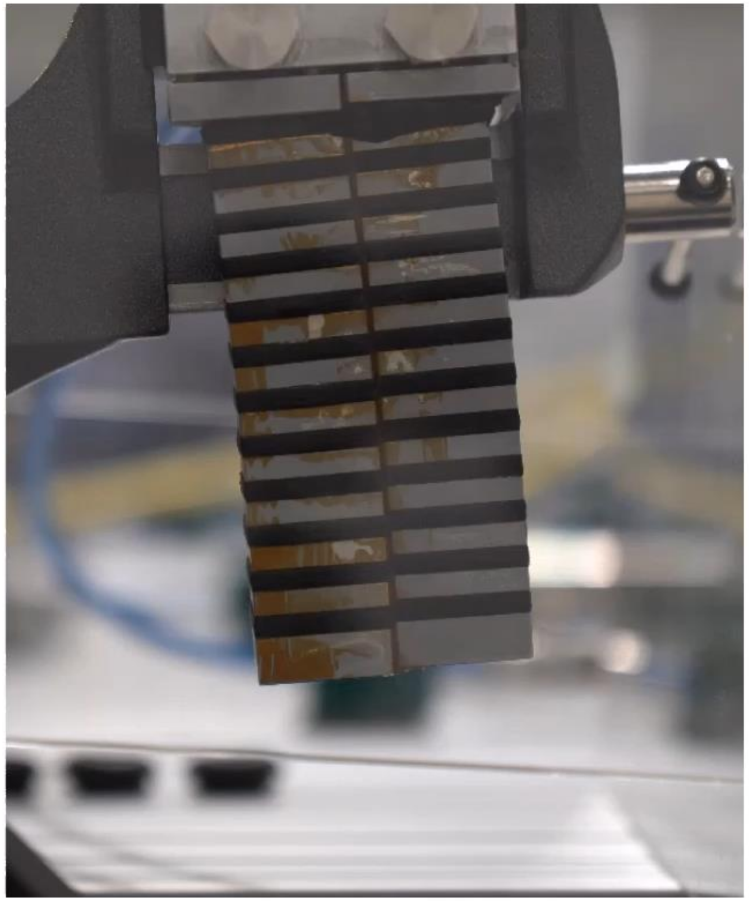
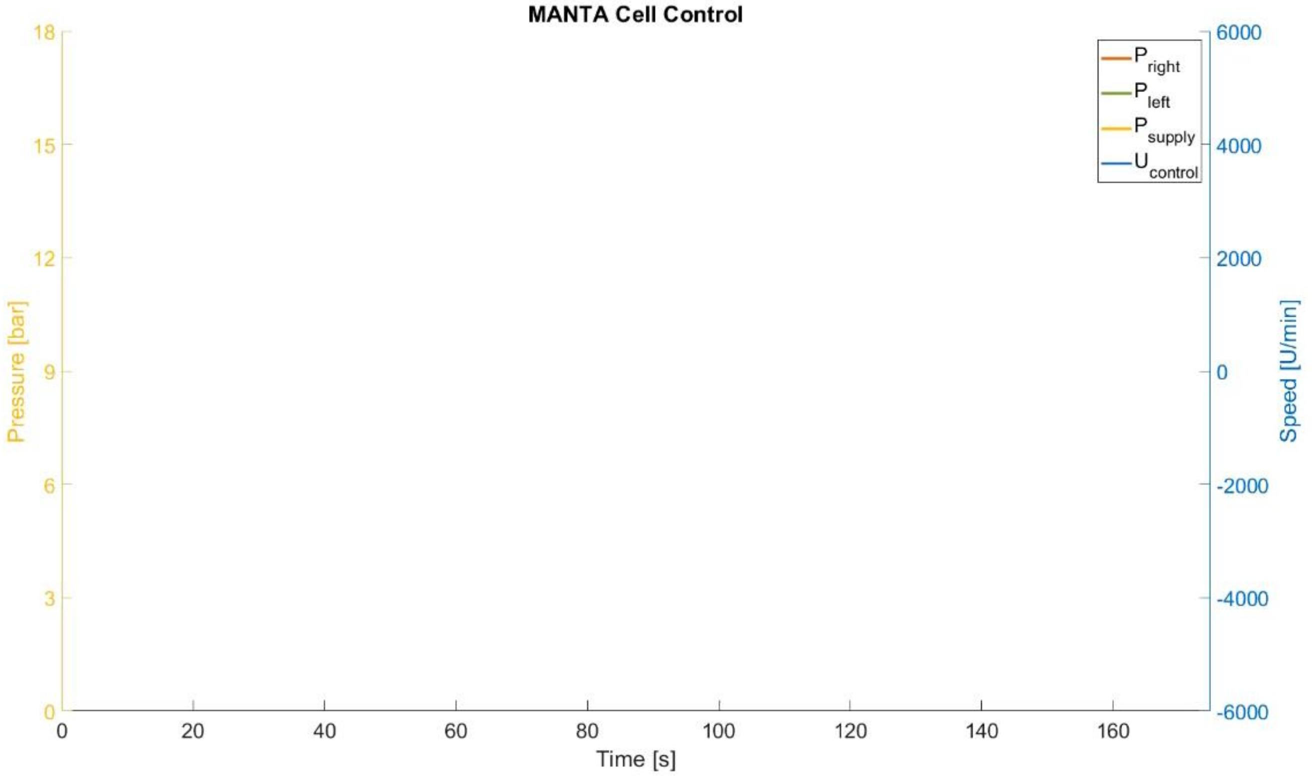
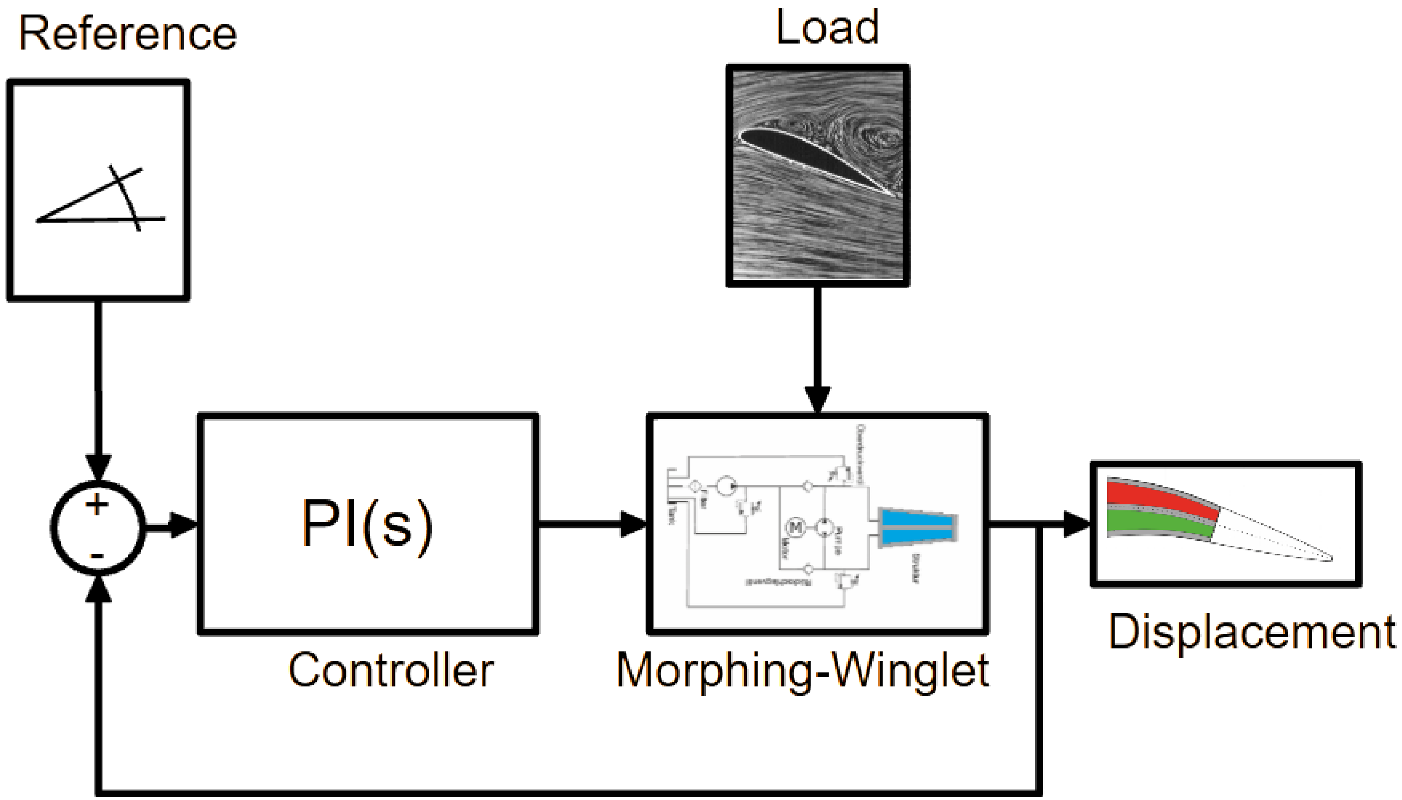
Systementwurf
Test Hydrauliksystem



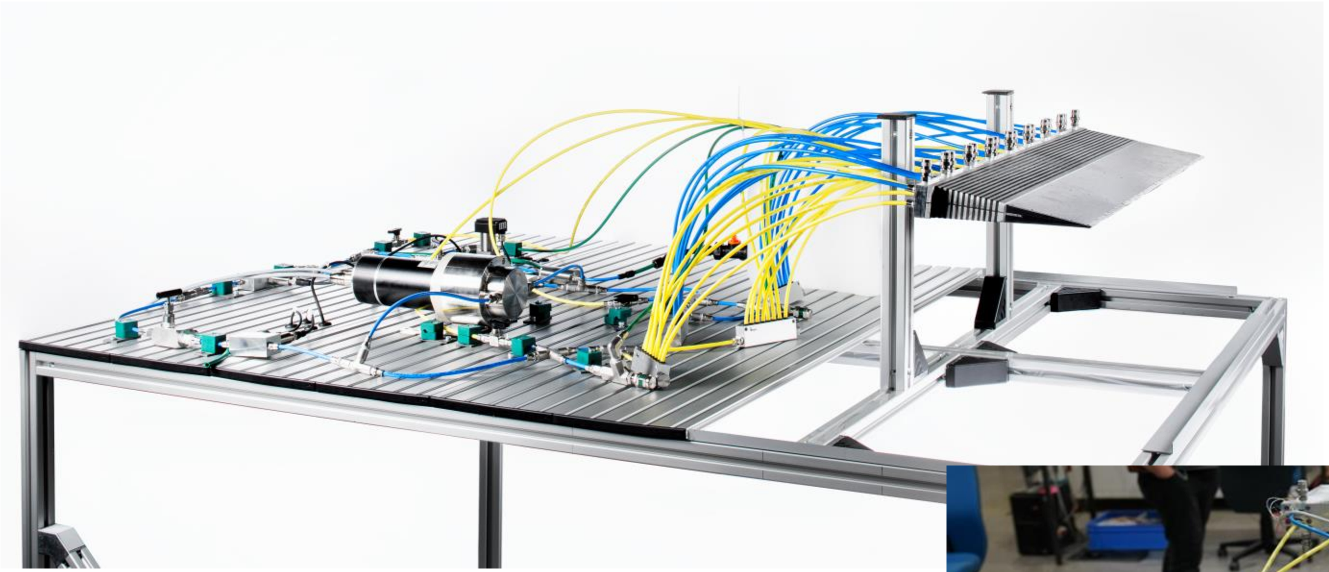


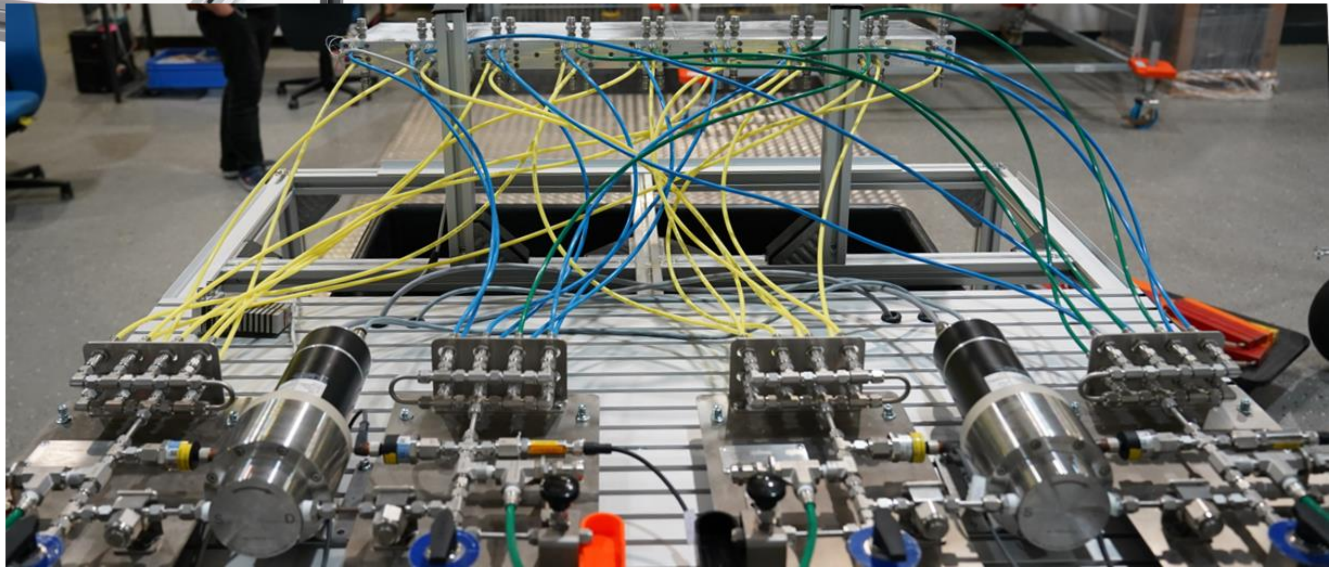
Systems Design
Closed Loop Control

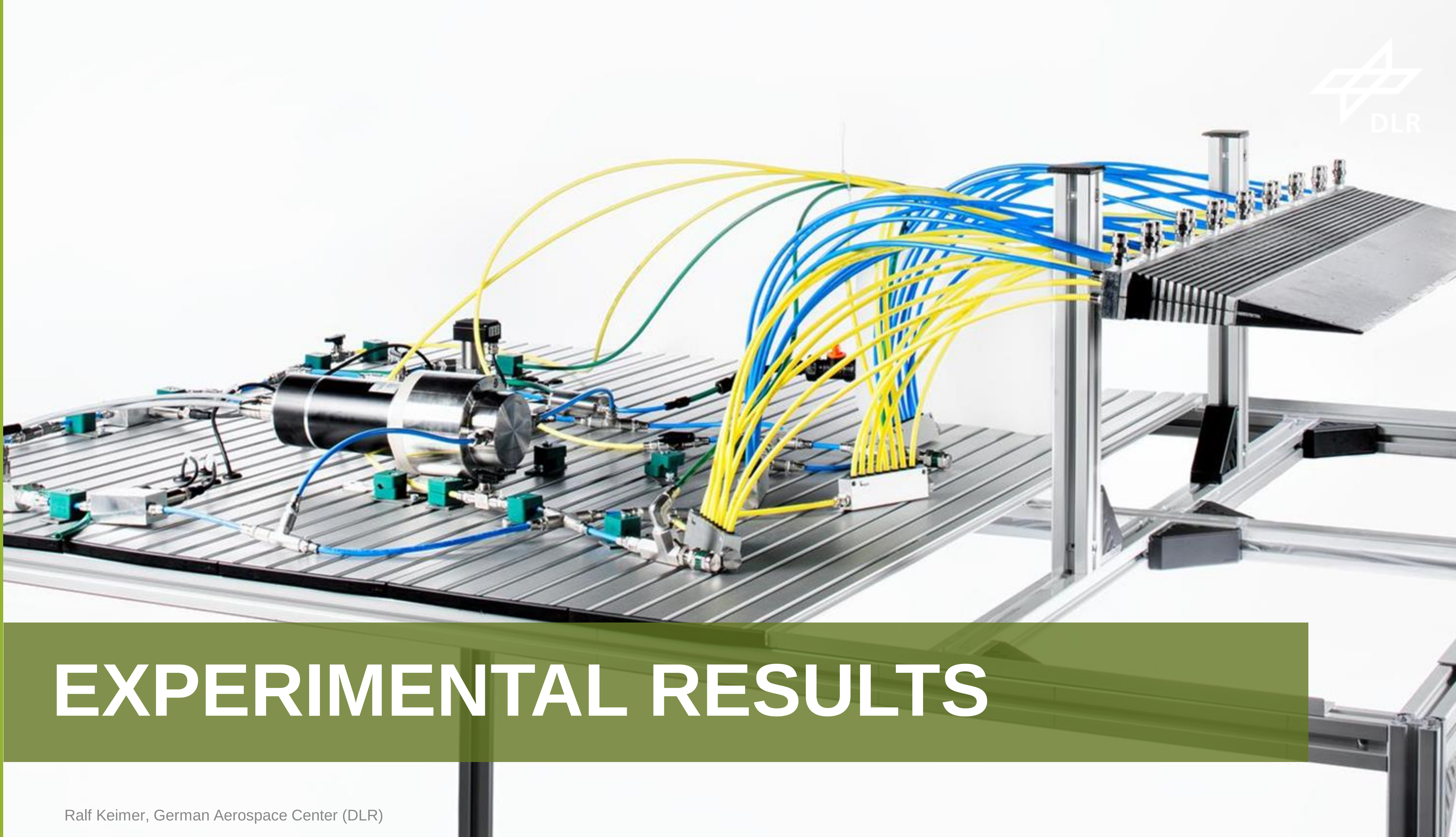
- Closed loop control needed, due to non-linearity of EPDM
- Sensors
  - Fibre optical sensors (Primary)
  - Strain-gages (Backup)



Systems Design
Redundancy







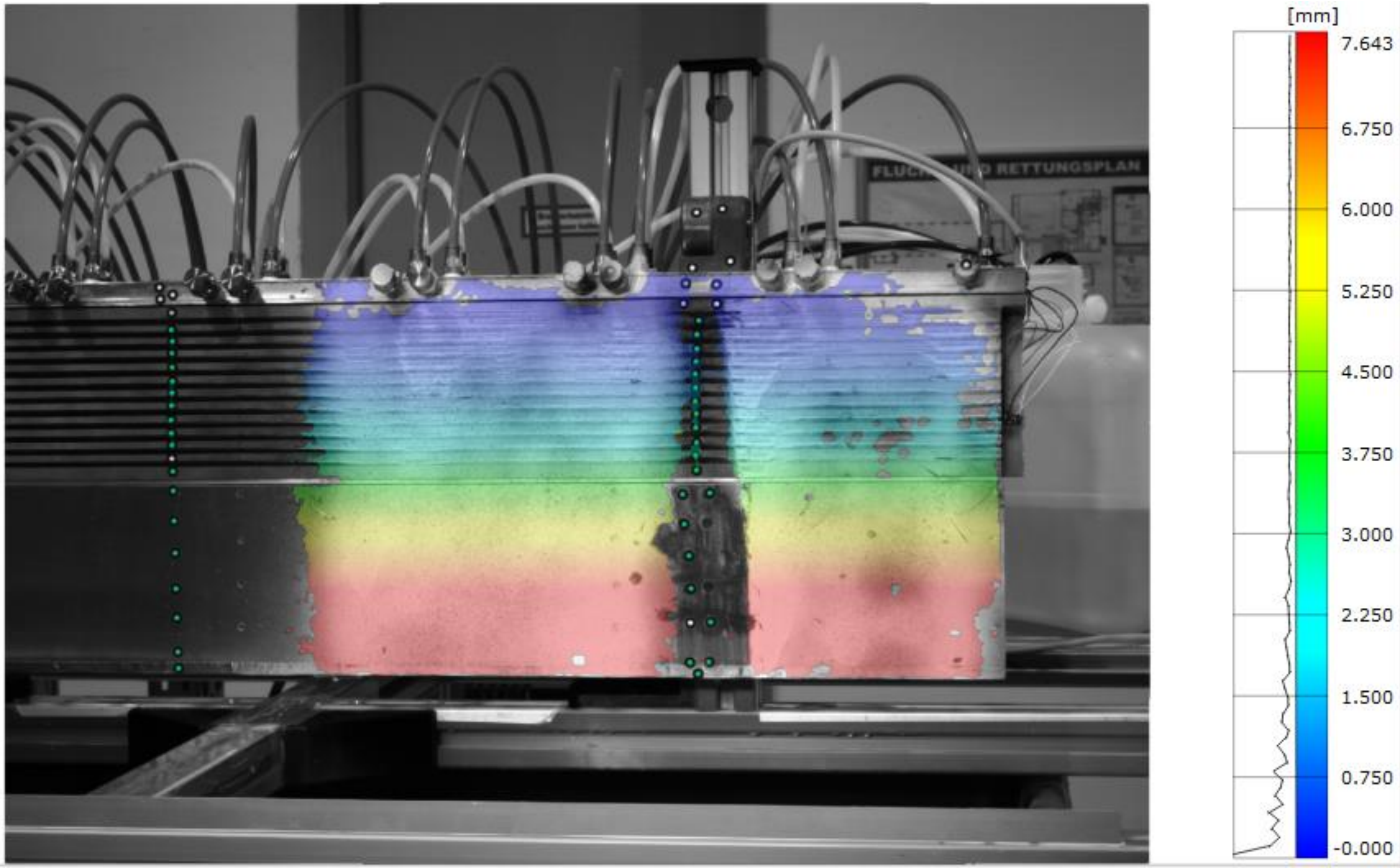
EXPERIMENTAL RESULTS

Experimental Results
Goals

- Calibrating closed-loop control sensors (feedback sensors)
- Static performance tests:
  - Angular deflection versus pressure → validate FE
  - Spanwise uniformity of angular deflection
- Dynamic performance tests:
  - Accuracy of deflection
  - Deflection rates

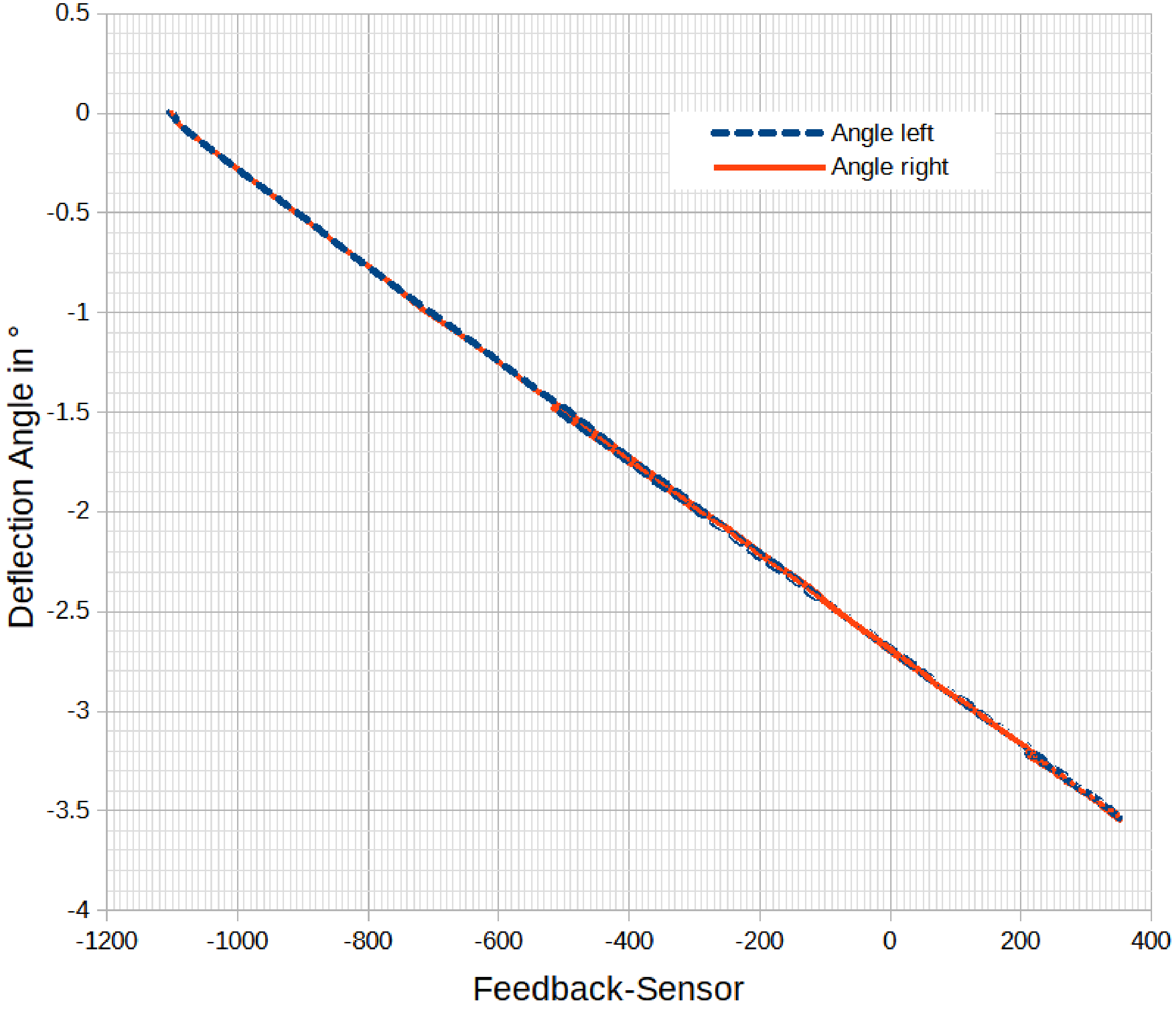
Experimental Results
Calibrating Closed-Loop Control Sensors

- Using external photogrammetry system



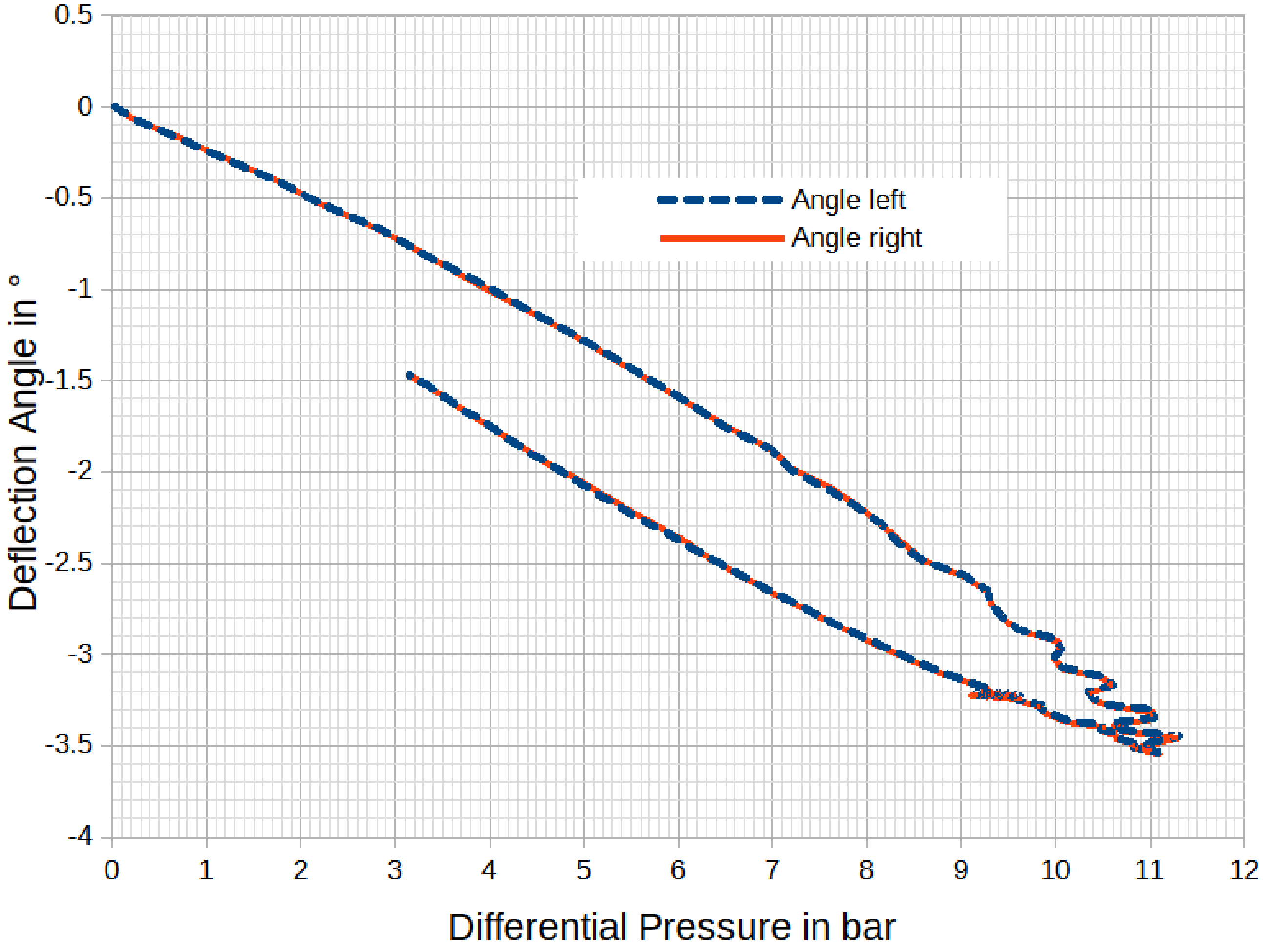
Experimental Results
Calibrating Closed-Loop Contraol Sensors

- Using external photogrammetry system
- Linear correlation between feedback-sensors and external system
- Spanwise uniformity of deflection



Experimental Results
Static Performance Tests

- Non-linear correlation between differential pressure and angular deflection
- Spanwise uniformity of deflection
- Discrepancy of angular deflection
  - FE 11° at 14 bar
    0,79°/bar
  - Test 3,5° at 11 bar
    0,32°/bar → **40%**



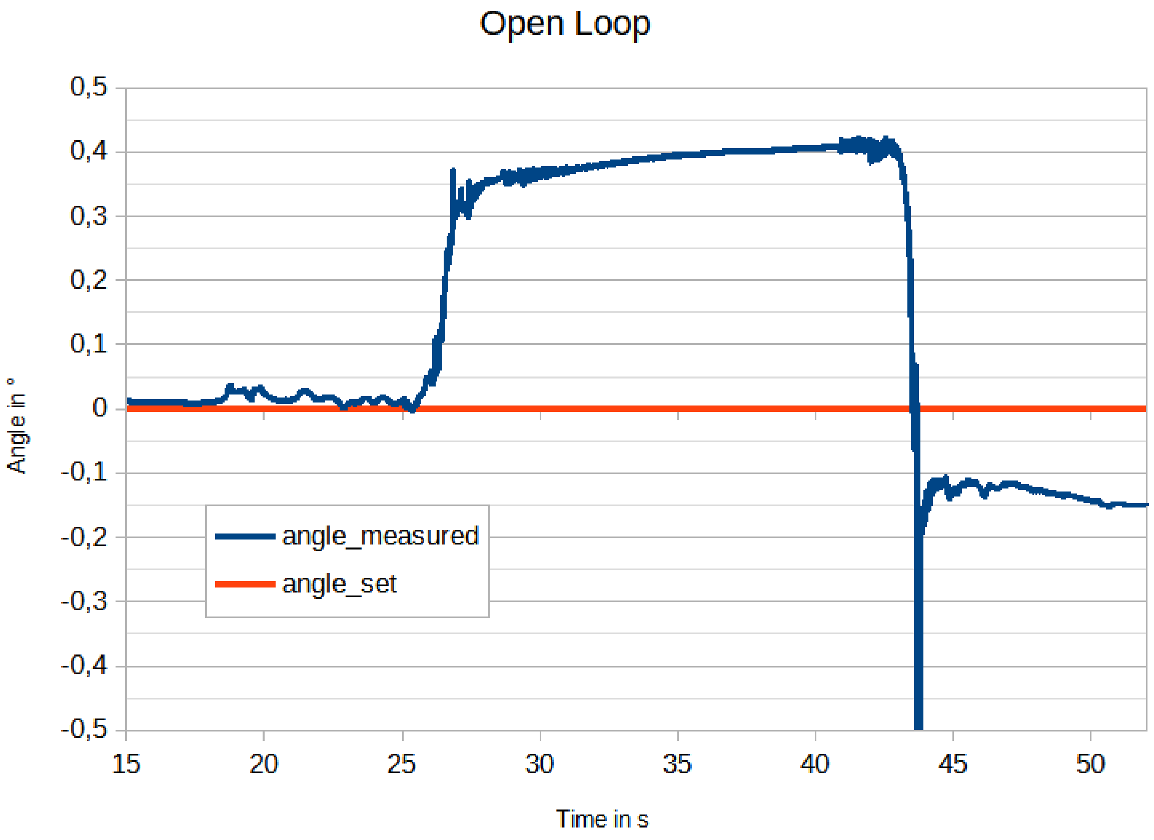
Experimental Results
Static Performance Tests

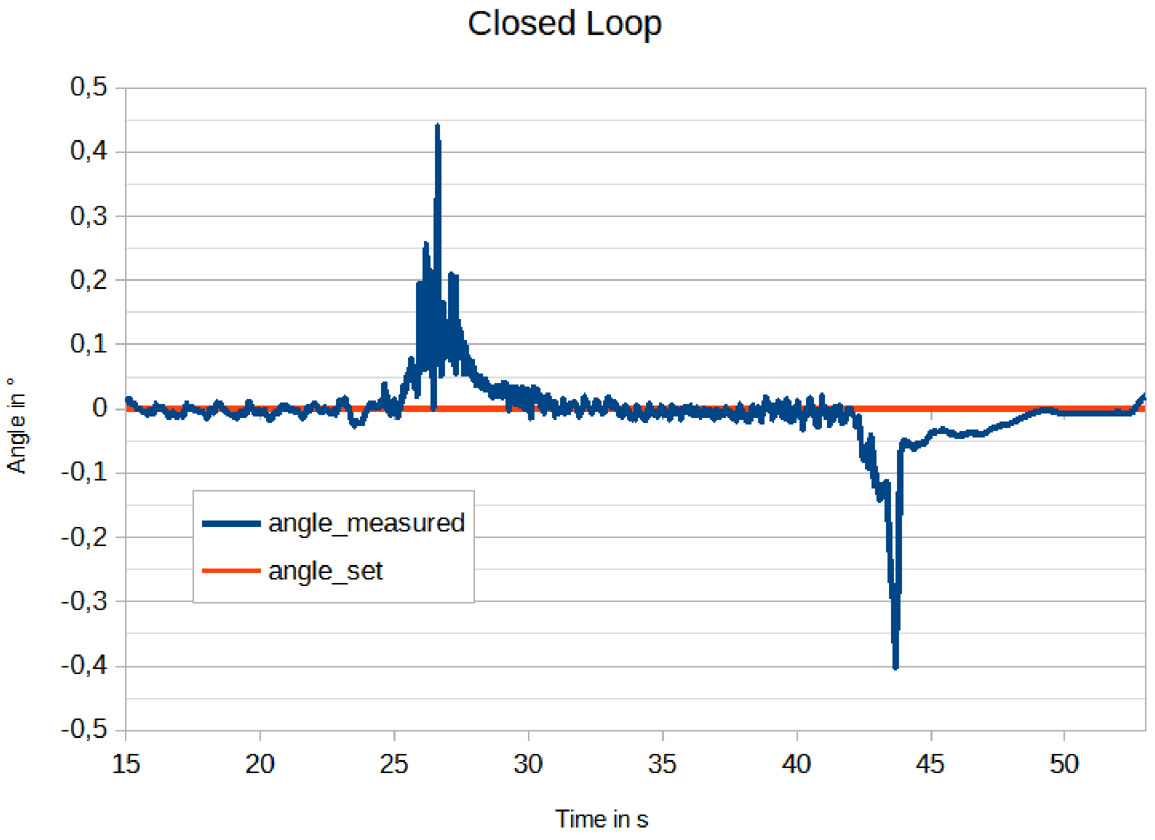
Accounting for Discrepancy

Model	FE
Measurement vs Original FE	40%
Bladders reducing Force 30%	58%
Active Passive Ratio decreased from 46.4% to 27%	95%

Experimental Results
Dynamic Performance Tests

Accuracy of Angular Deflection

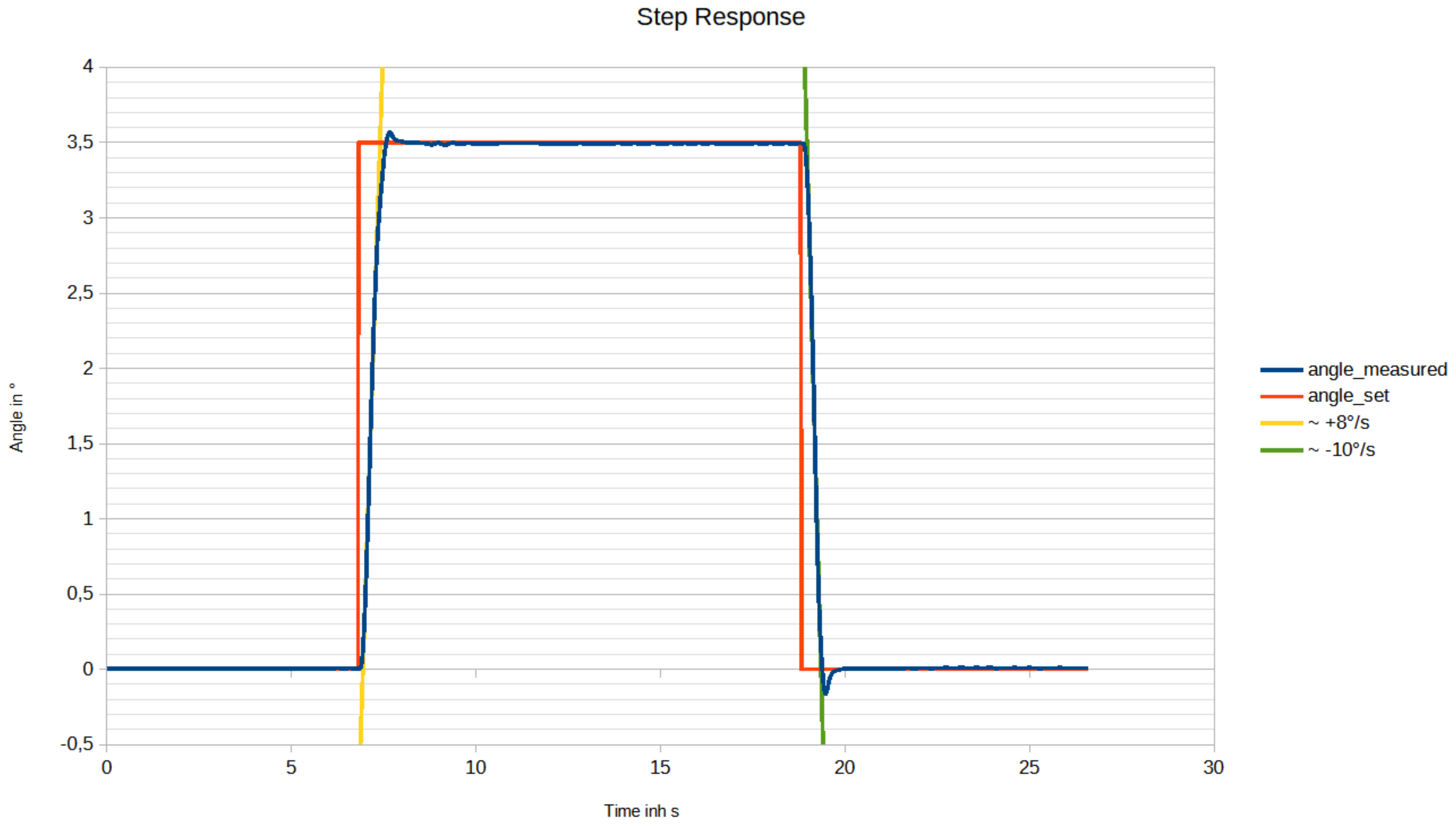




Experimental Results
Dynamic Performance Tests

Deflection Rates

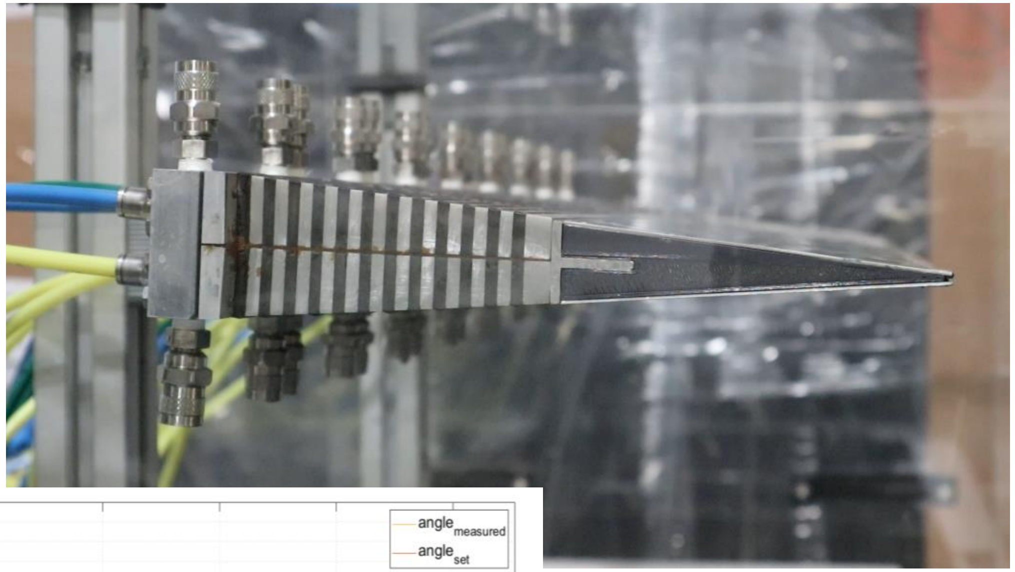
- Deflection rate sufficient for high speed performance

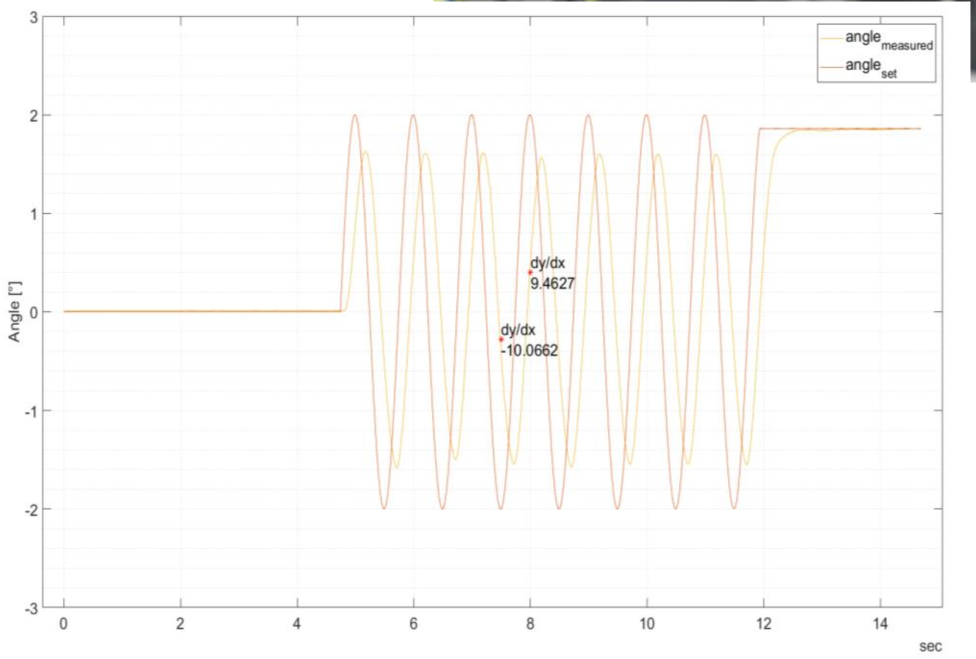


Experimental Results
Dynamic Performance Tests

Deflection

- Deflection rate sufficient for high speed performance
- Deviation of -3dB from set value





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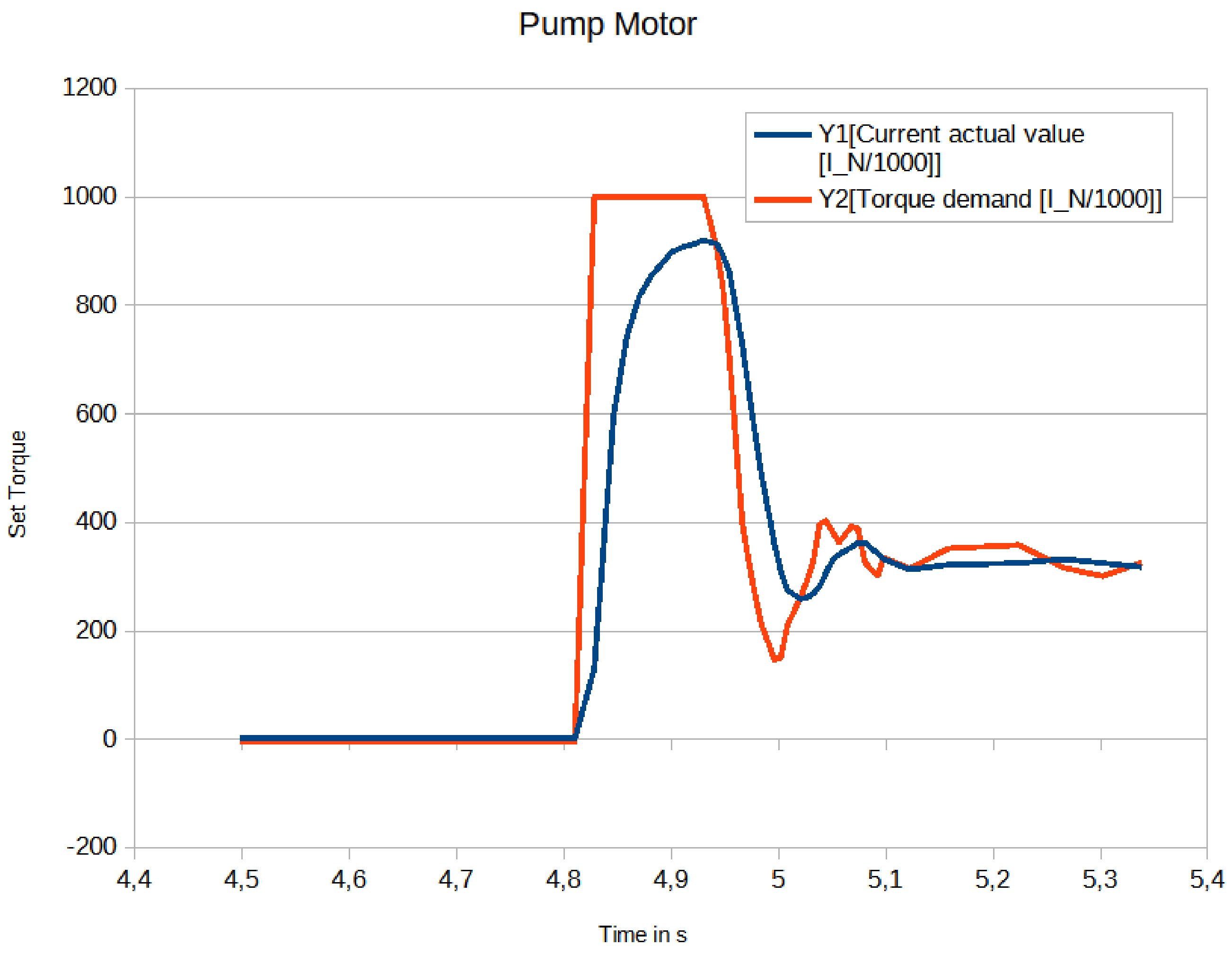

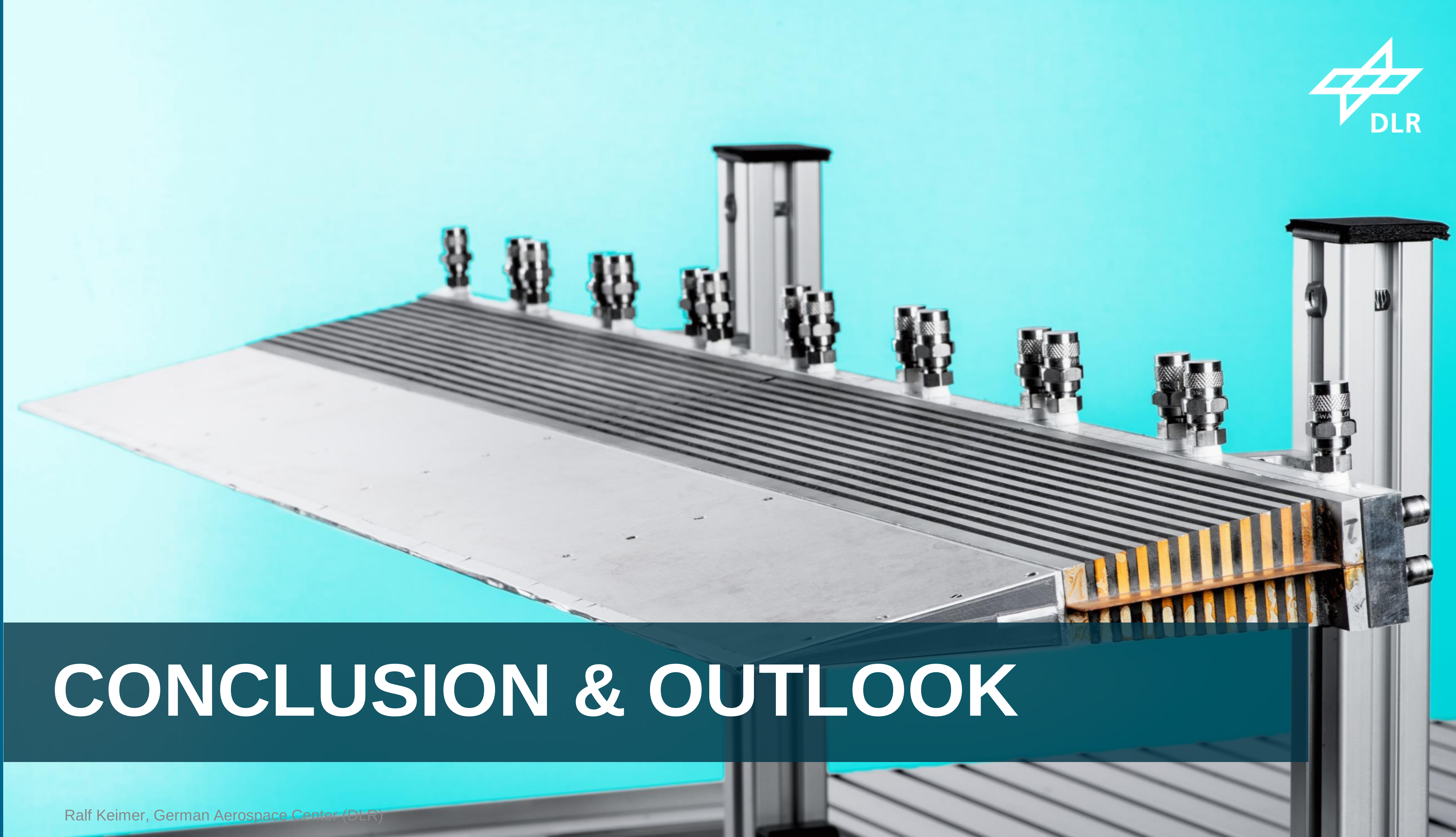

CONCLUSION & OUTLOOK

Conclusion & Outlook
Summary

- The main objective of this demonstrator to raise TRL to 2-3 is reached.

- An experimental proof of concept is done, analytical and experimental critical function and characteristics have been identified.

- 1 m spanwidth demonstrator is designed, manufactured and tested.
  This includes the morphing hardware, sensors, redundant hydraulic actuation system and a control-system
- The tests show that the requirements for size of deflection (+/- 15°) and control accuracy (better than 0.1°) are met, or can safely be assumed to be met in the next design due to validation of the design model.

- The requirement of deflection rate (> +/- 20°/s) is not yet reached, but a way forward is identified and will be tested going forward.

Conclusion & Outlook
Way Forward

- Control and Test
  - Tuning of control parameters
  - A deeper understanding of dynamic behavior of the pressure cells has to be assessed, especially separating control-parameters and material properties as cause
  - Testing the structure with simulated aero-loads
  - Testing under full range of temperatures is of interest
- Structural Design
  - Weight Optimization should be investigated in more detail
  - Account for observed failure-modes (e.g. as occasional leakage) in design
  - Aspects of Repairability should be taken into account.
- Material and Manufacturing
  - Reducing manufacturing complexity

FAMoUS Pressure Cells

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