DLR’s Research in Morphing Structures for Aeronautics

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AIAC ‘19
September 19th 2019
Ankara, Turkey

DLR

Outline

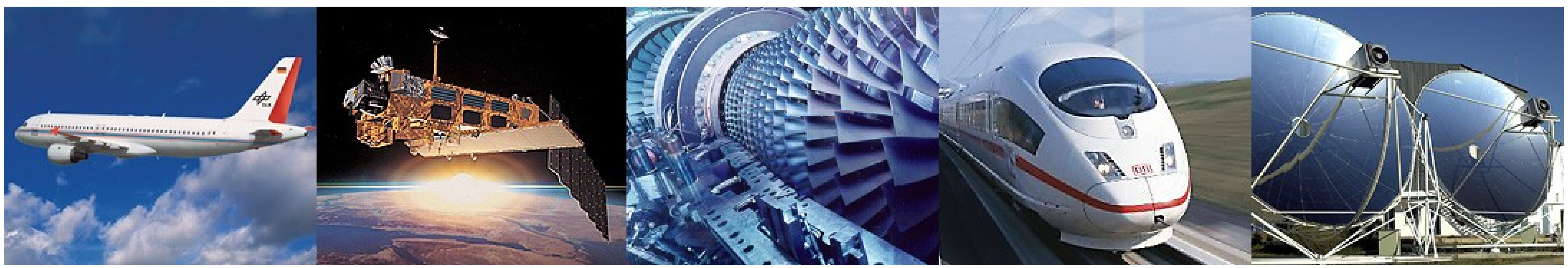
1. **DLR**
   - Who we are

2. **Morphing for Civil Aeronautics**
   - Motivation
   - Morphing Wings
   - Rotorcraft
   - Wind turbines

3. **Summary**

Who We Are

DLR
German Aerospace Center



- Research Institution
- Space Agency
- Project Management Agency

Research Areas

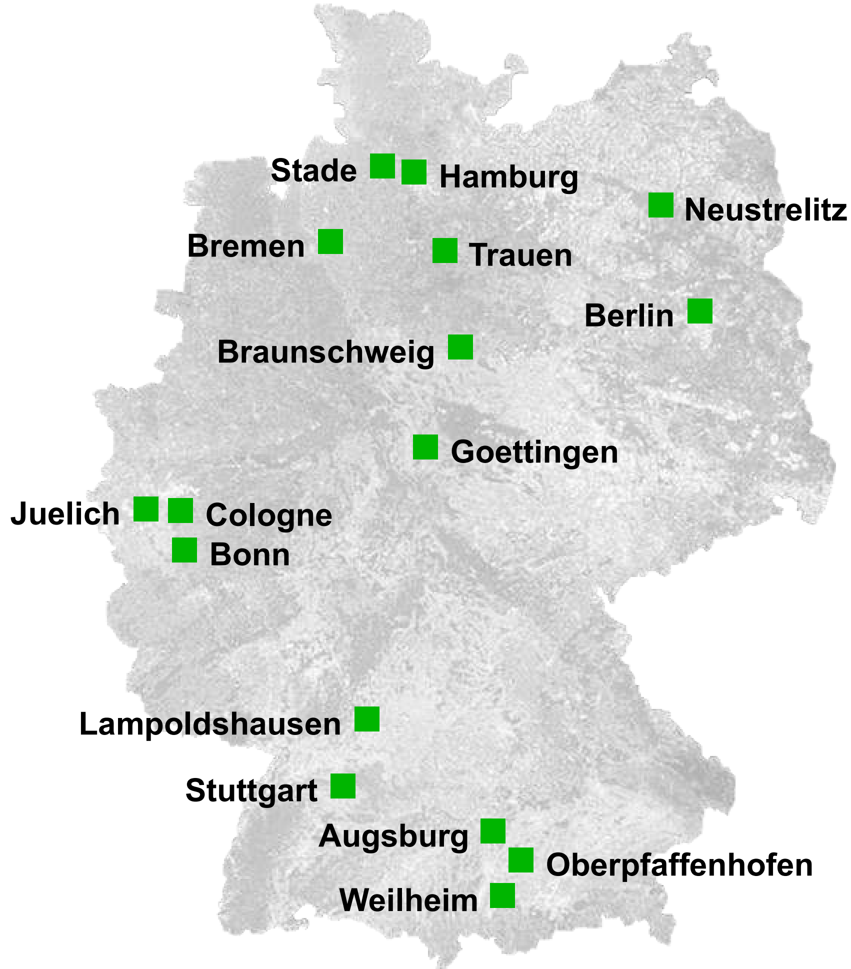
- Aeronautics
- Space Research and Technology
- Transport
- Energy
- Defence and Security
- Space Administration
- Project Management Agency

Locations and employees

Approx. 8000 employees across 33 institutes and facilities at

■ 16 sites.

Offices in Brussels, Paris, Tokyo and Washington.



Morphing Wings for Civil Aeronautics – Motivation

- Reduce emissions and fuel burn
- Improve high-lift performance
- Reduce airframe noise

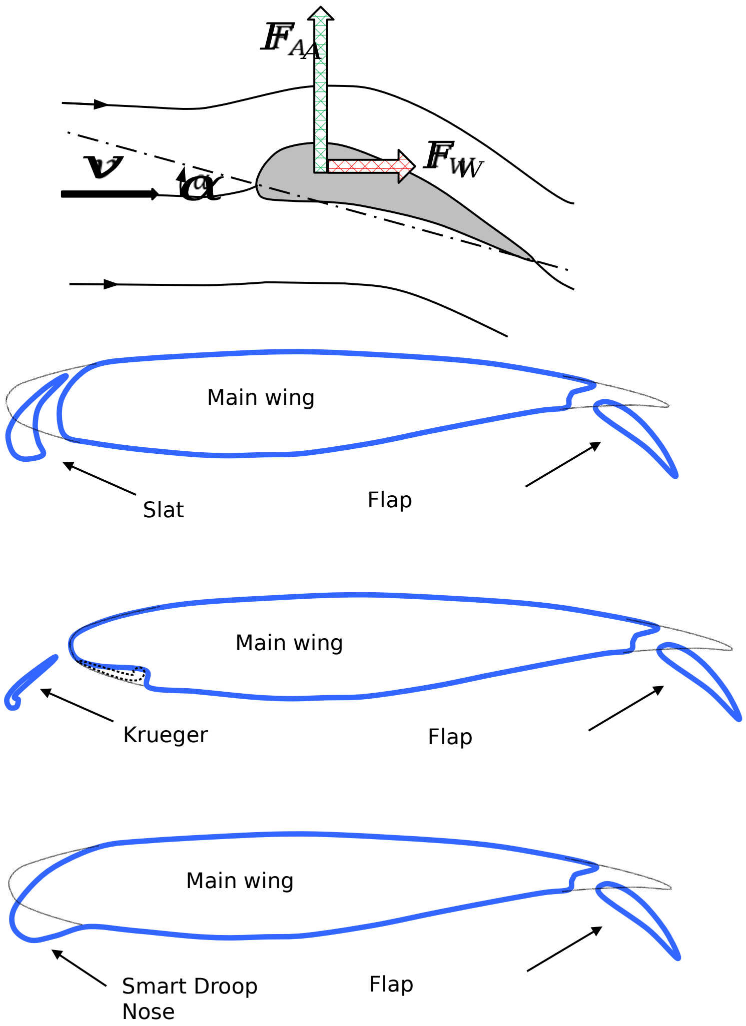
Morphing Wing Leading Edge Droop Nose – Laminarity

- High-Lift devices on leading and trailing edge for lift generation at low speed (take-off & landing)
- Common high-lift devices (Slat, Krueger) are highly effective ($c_{a,max}$) but exhibit slots, gaps and steps

→ Transition to turbulent flow on main wing due to steps and gaps

→ Drag due to steps and gaps

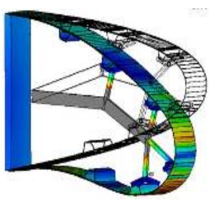
→ Primary source of airframe noise in approach/landing



Smart Droop Nose

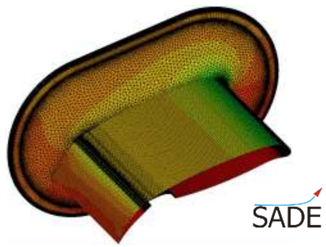
HIT High Lift Innovative Technologies SADE SARISTU SMART INTELLIGENT AIRCRAFT STRUCTURES

Morphing Droop Nose History at DLR



SmartLED
2007-2010

Ground Demonstrator, 3D, Feasibility

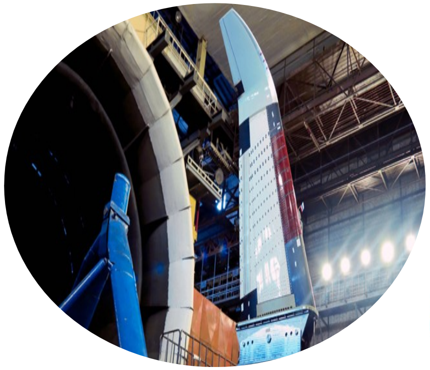


SADE
2008-2012

Wind Tunnel Model, 2D, Shape Control

JTI-SFWA
2009-2013

Ground Demonstrator, 2D, Kinematics, Fatigue



SARISTU
2011-2015

Wind Tunnel Model, 3D, Integration of Functionalities & Shape Control & Kinematics

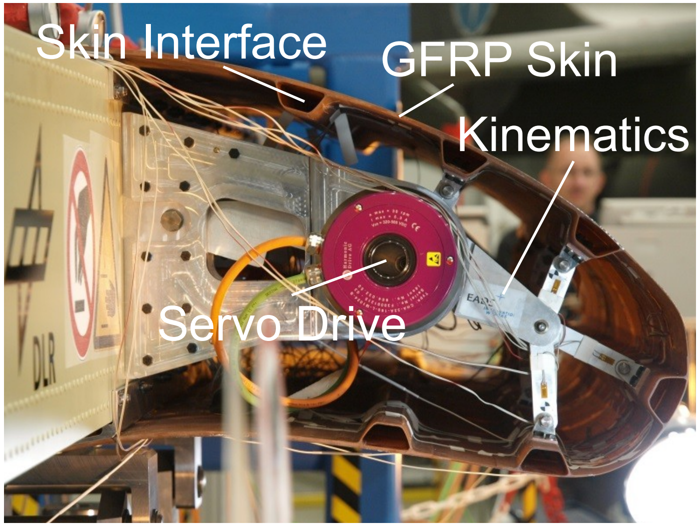
Hochauftrieb künftiger Verkehrsflugzeuge

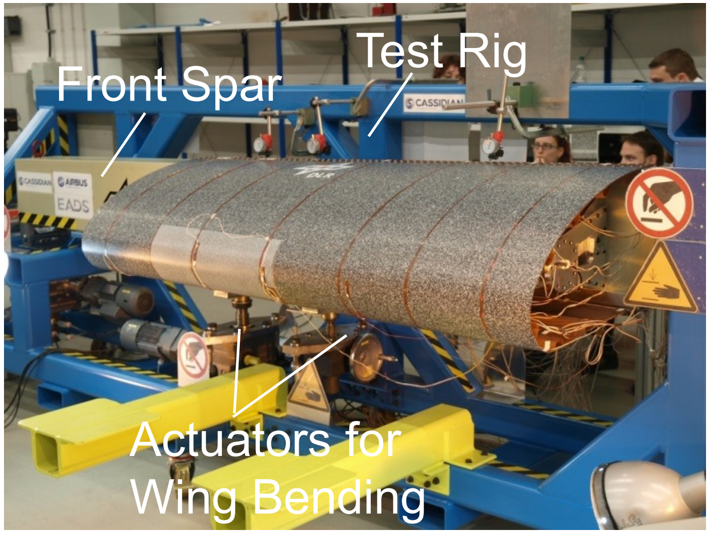
SFB880
2013-2019

High Droop nose

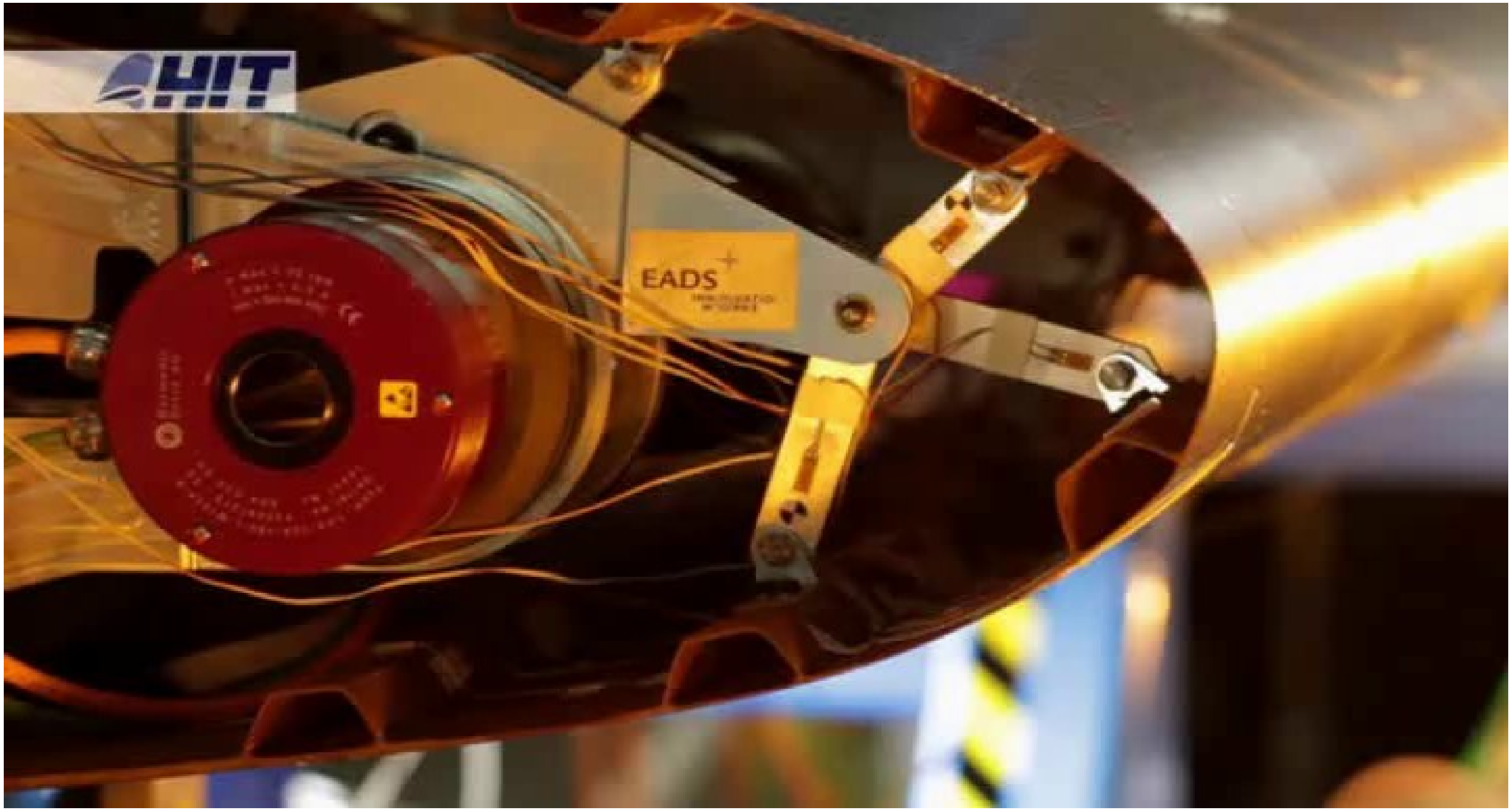
Ground Test Smart Leading Edge Device

- Full-scale 3D section of the leading edge for ground tests including wing bending, 2m span.
- Use of materials certified for aeronautics.
- Combined design process for kinematics and GFRP skin (HexPly 913).
- Investigation of strain and deformations under wing bending.

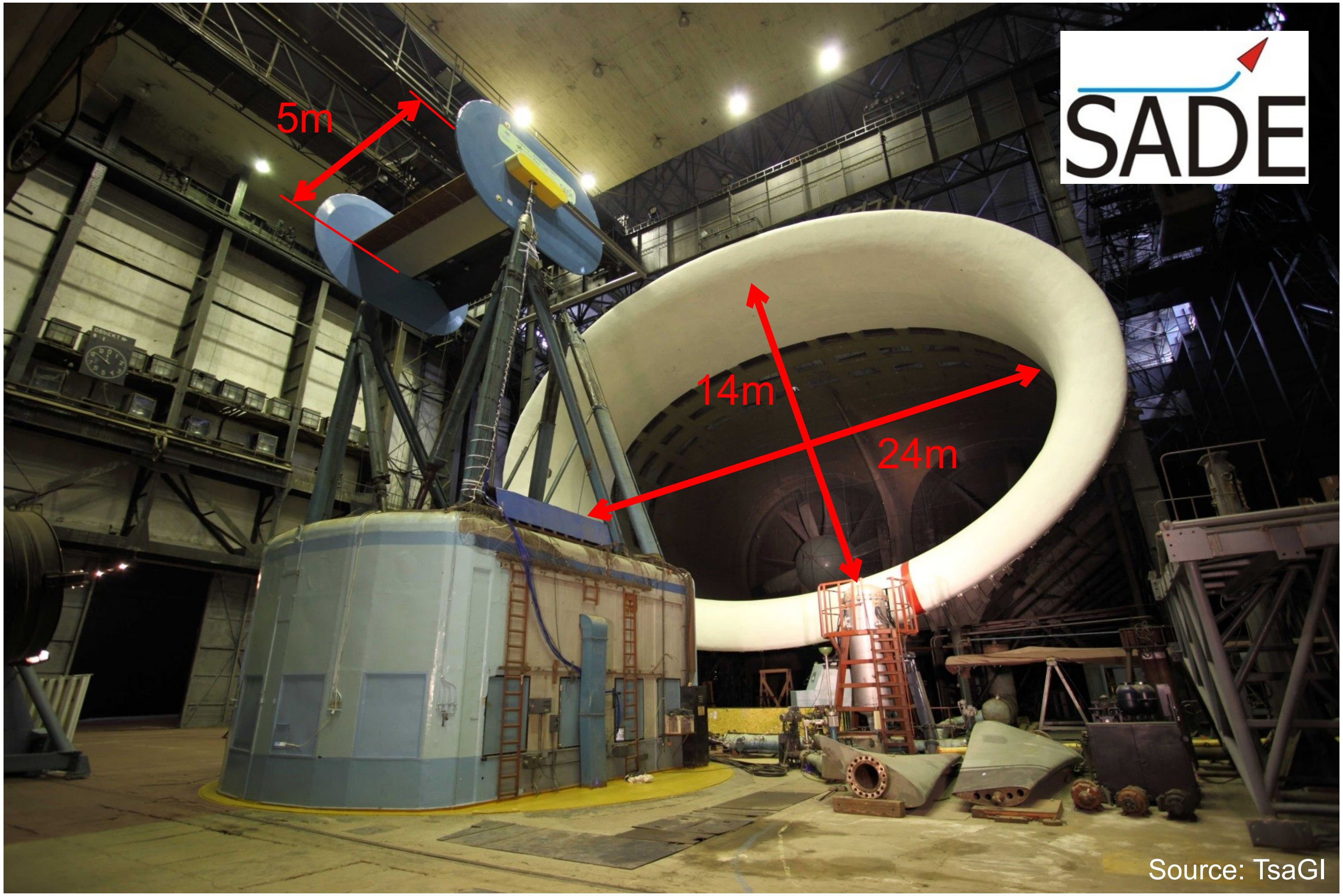




Smart Droop Nose Deployment, 18°



Wind Tunnel Test in T-101 at TsaGI



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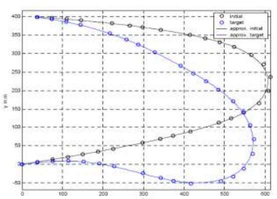
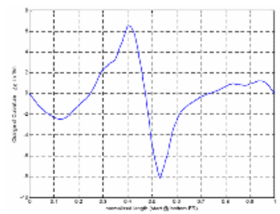
Flexible Skin Design

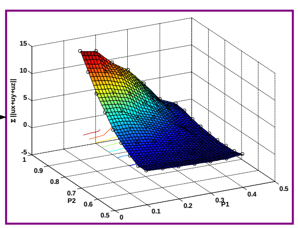
- Pre-Design of Skin and Kinematics (2D)



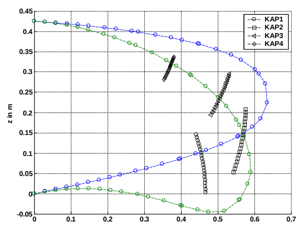
Aerod. Target Shape



Initial Skin Design

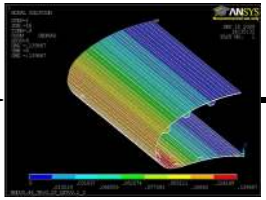


2D parametric FE,
Optimal Support Pos.

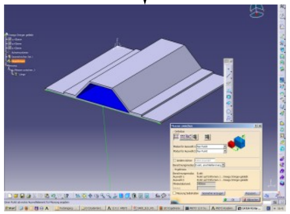


Kinematical Path, Strains, Deformations, Stresses

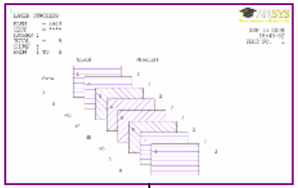
- Detailed Design (3D)



3D FE model



Optimization of the Design of Omega-Stringers wrt. stability and strength requirements

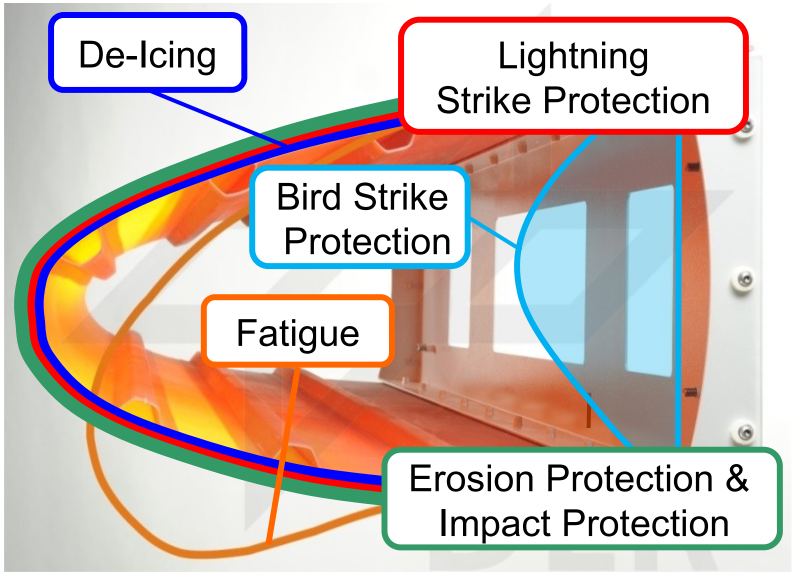


Optimization of layer stacking sequence/ laminate layup wrt. target shape, stability and strength requirements

Feedback data for other disciplines

Approaches for skin design – Additional Challenges

- Integration of additional functionalities into a ‚baseline' GFRP skin concept
  - Ice Protection System (IPS)
  - Lightning Strike Protection (LSP)
  - Erosion & Impact Protection
  - Bird Strike Protection
  - Improved Fatigue Behaviour



Bird Strike Protection

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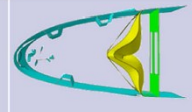
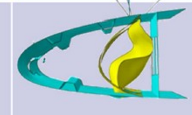
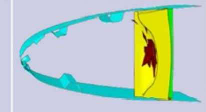
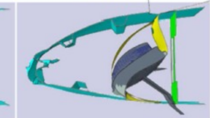
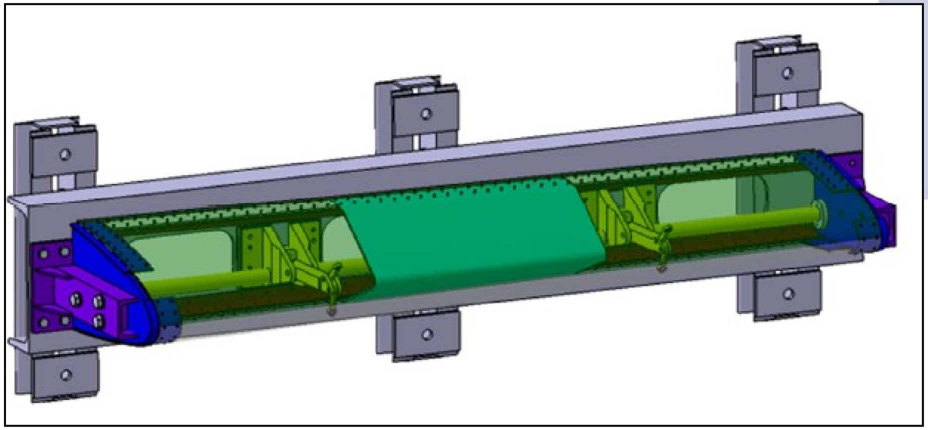
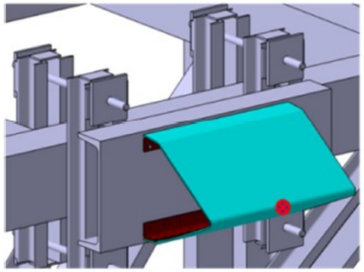
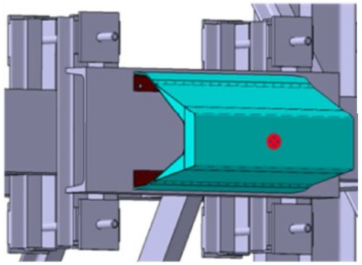
→Integration of bird strike protection and kinematics

- **Shot on morphing leading edge with integrated bird splitter and separate hybrid splitter concept**

	Concept 1	Concept 2	Concept 3	Concept 4
	Bird Splitter with a circular edge in the nose	Inner Dnose skin, designed to maximize the space allocation	Honeycomb panel attached to the subspar.	Combination of the inner Dnose and the honeycomb panel concept.
Final BSPS Damage				
BSPS masses	2.18 Kg	2.63Kg	3.19Kg	3.43 Kg
Spar protection	Not impacted	impacted	plastified	Not impacted
System Space allocation	Probably not sufficient	Better than concept 1	No space allocation	Better than concept 1
Scenario Description	• Nose skin perforated . • Acting as a bird splitter. • BSPS is higlhy deformed and locally torn. • bird is split and is flowing along the slopes of the BSPS, it leads to the bottom and top failure of the nose skin but the spar is protected.	• Nose skin perforated . • Bird is draging away the BSPS toward the subspar, the spar is finally impacted. • The BSPS is higlhy deformed and locally torn. • A part of the bird is flowing along the BSPS and perforate the nose skin.	• Bird stopped • Spar plastified	•Nose skin perforated • BSPS is higlhy deformed and plastified. • the majority of the bird kinetic energy is absorbed . •A part of the bird is flowing along the BSPS and perforate the nose skin but the spar is protected.







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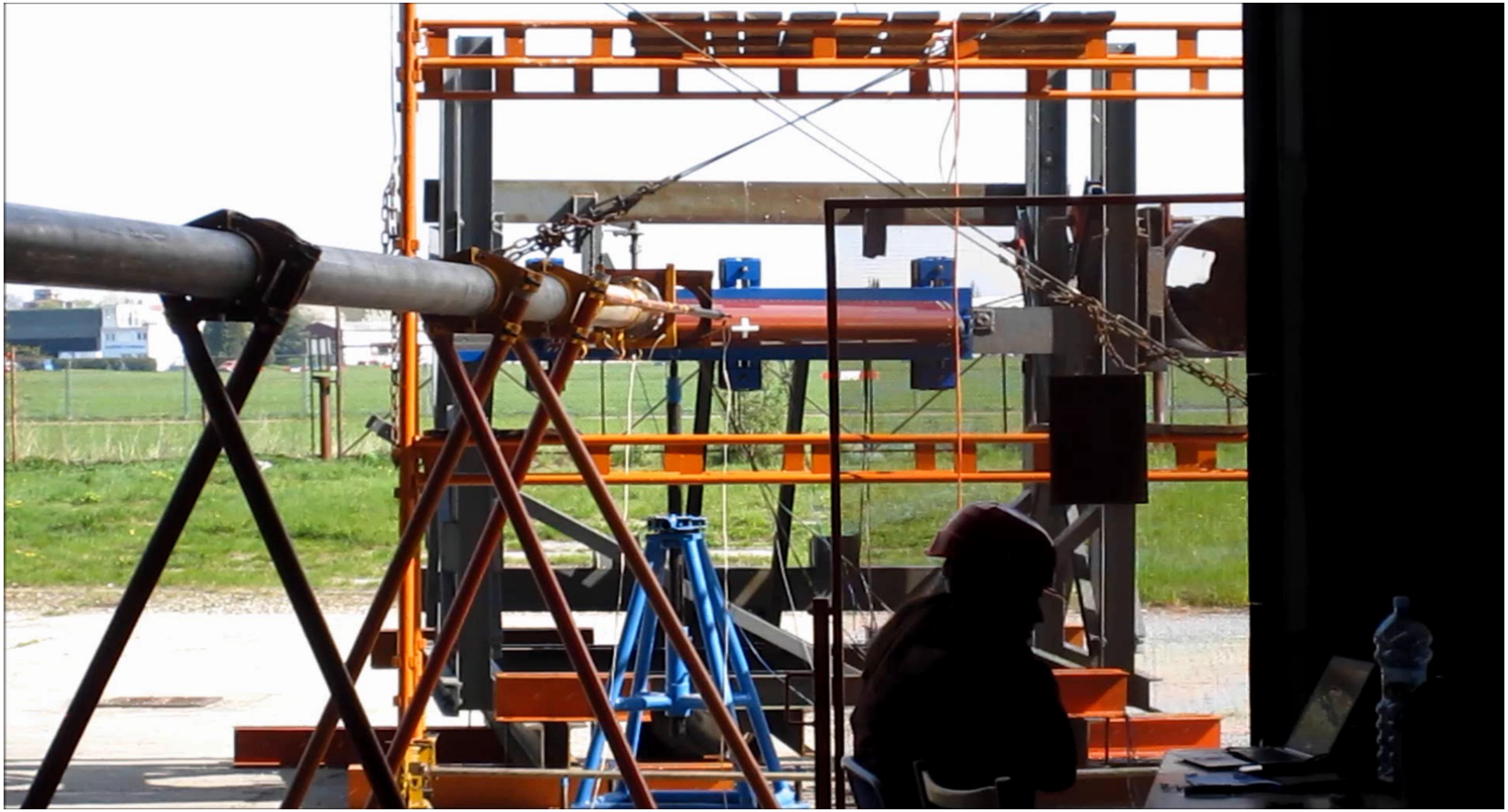
Bird Strike Protection



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Bird Strike Protection

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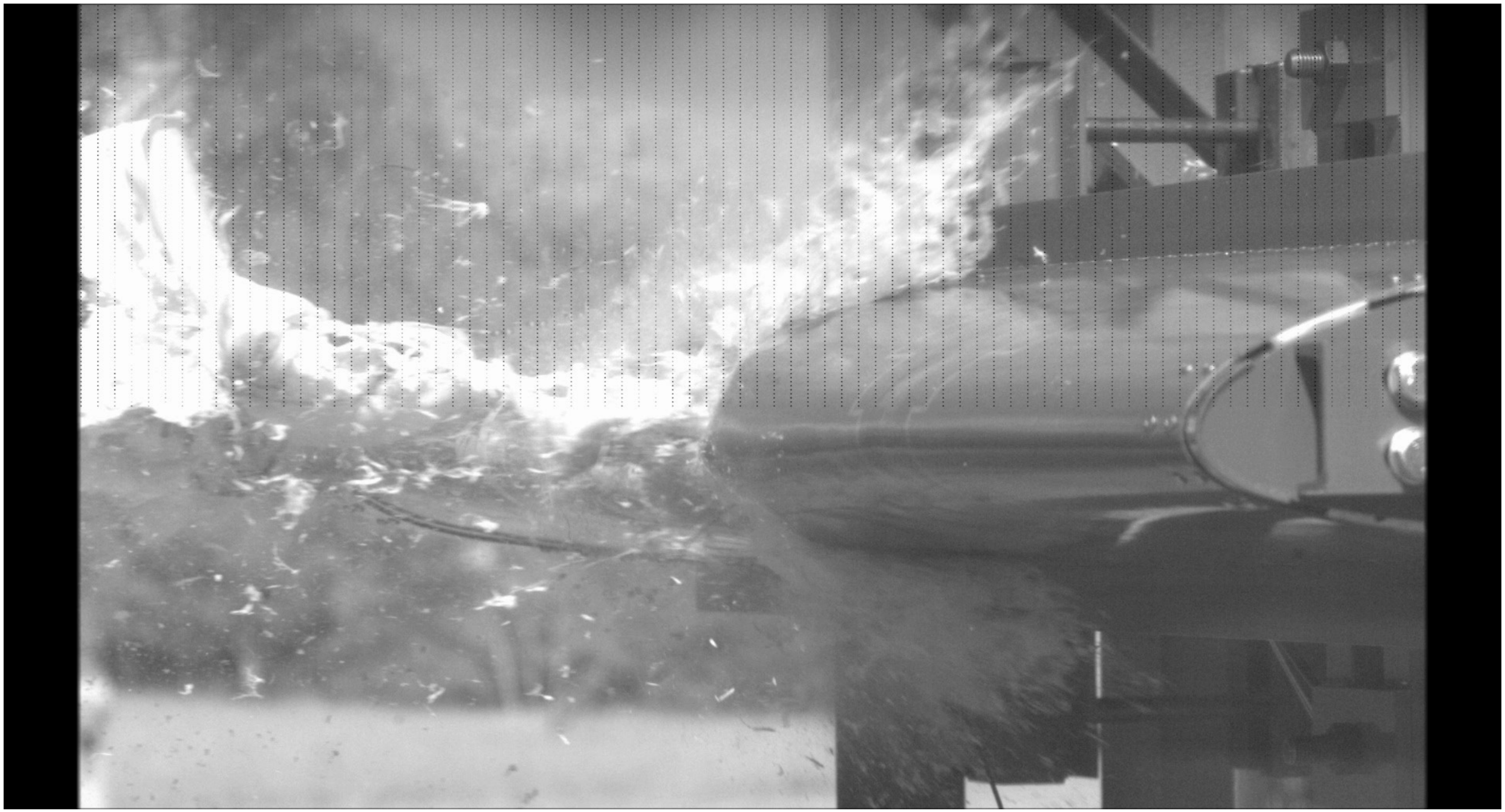

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Bird Strike Protection

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SMART INTELLIGENT AIRCRAFT STRUCTURES

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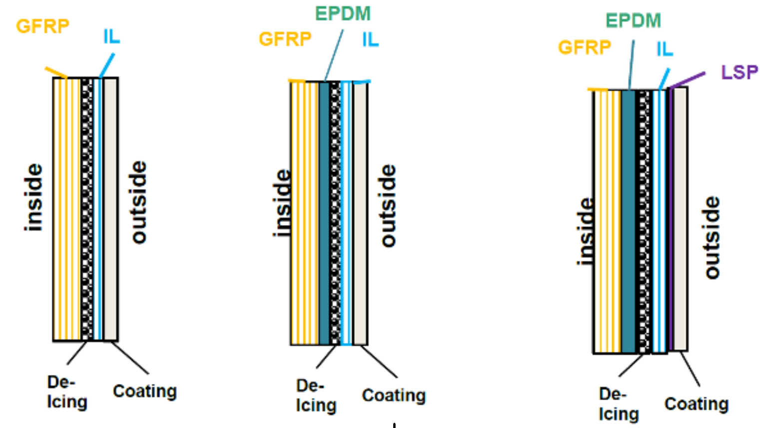
Approaches for skin design – Additional Challenges

"Integration of additional functionalities"

- Overall wing leading edge sections
- Integration concept of BSPS and kinematics
- **Integration concept of additional functional layers**
  - Surface Protection
  - De-/Anti- Icing
  - Impact Resistance
  - Lightning Strike Protection



Comparison of rain and solid particle erosion durability of different materials

	Metall	Paint	Rubber	Hard coating
Rain erosion (20 – 3000 impacts, 225 m/s, 2 mm drop size)				
Solid particle erosion (5 g silica sand 220 µm, 55 m/s, 2 g/min)	20° 90°	20° 90°	20° 90°	20° 90°

Approaches for skin design – Additional Challenges

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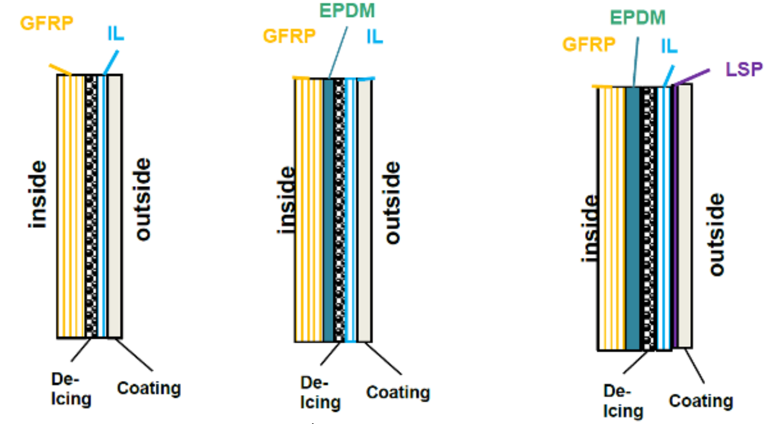
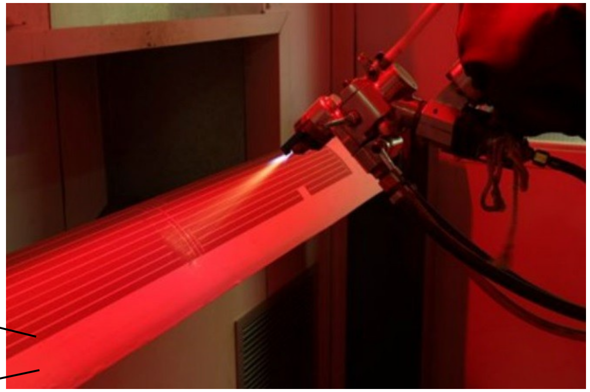
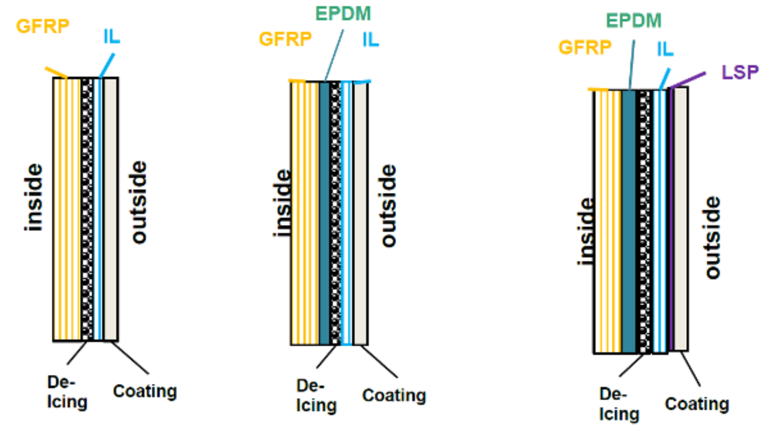




Source: GKN

Approaches for skin design – Additional Challenges

"Integration of additional functionalities"



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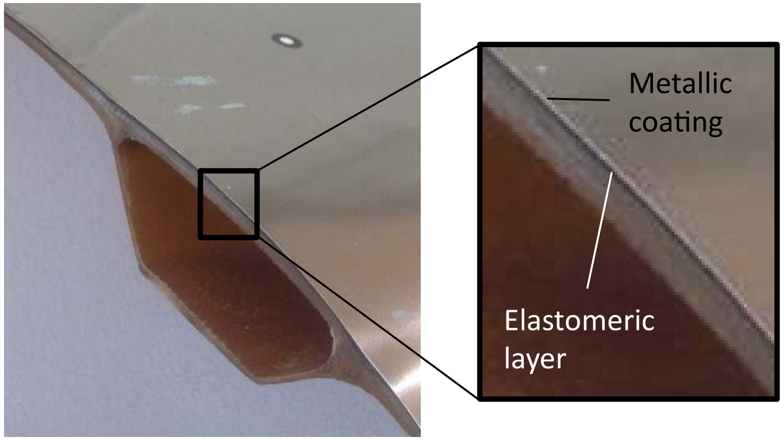
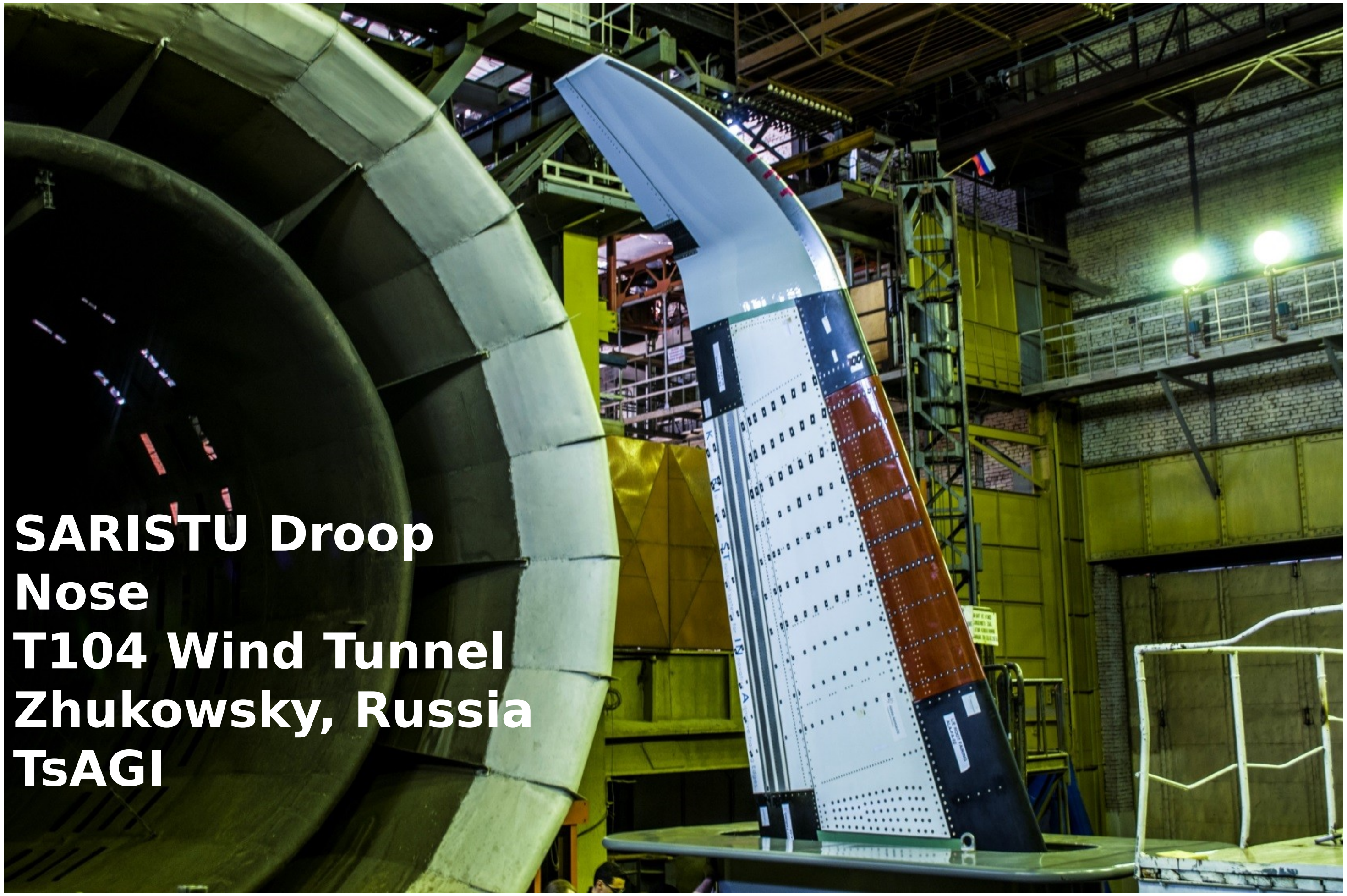
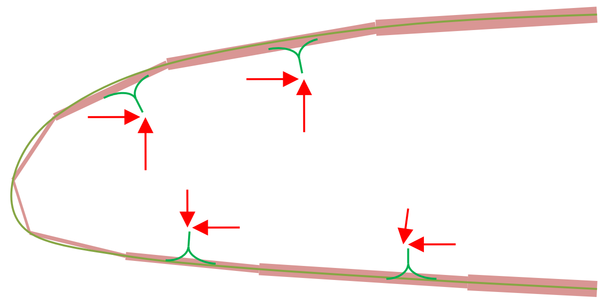


Wind Tunnel Testing – v2.0

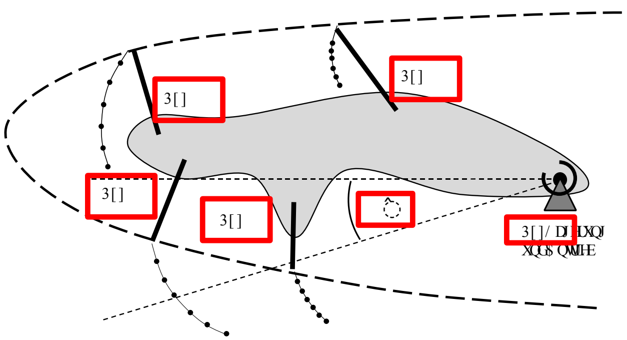


SARISTU Droop Nose
T104 Wind Tunnel
Zhukowsky, Russia
TsAGI

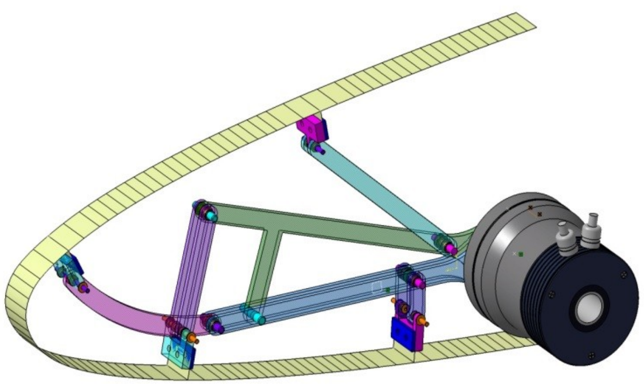
Kinematics Design



Optimization of the skin and skin-to-kinematic interfaces



Optimization of the inward kinematic

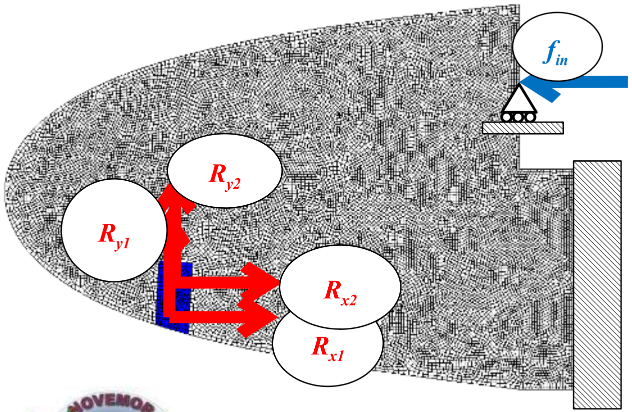


CAD-construction of the morphing leading edge

Compliant Mechanism Design

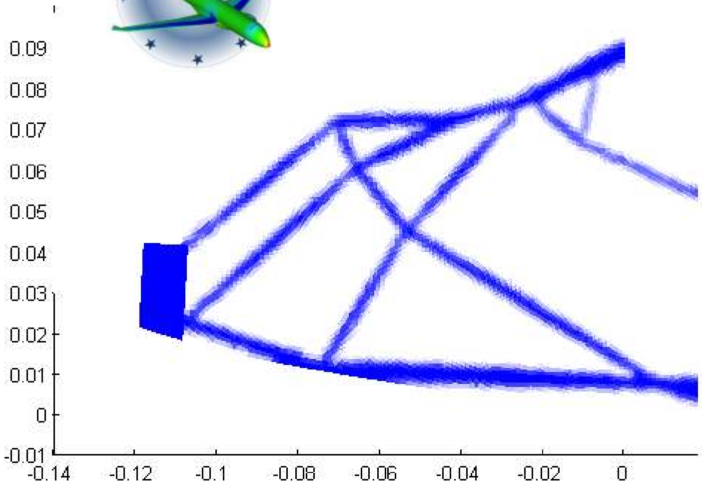
Advantages of Compliant Mechanisms

- lightweight structures
- reduced assembly complexity
- no backlash



Topology Optimization

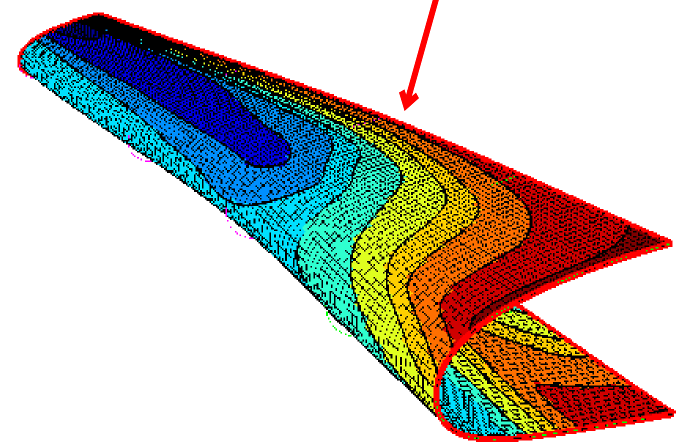
- find best structural layout starting from a “blank canvas”
- Shape control formulation: precision displacement

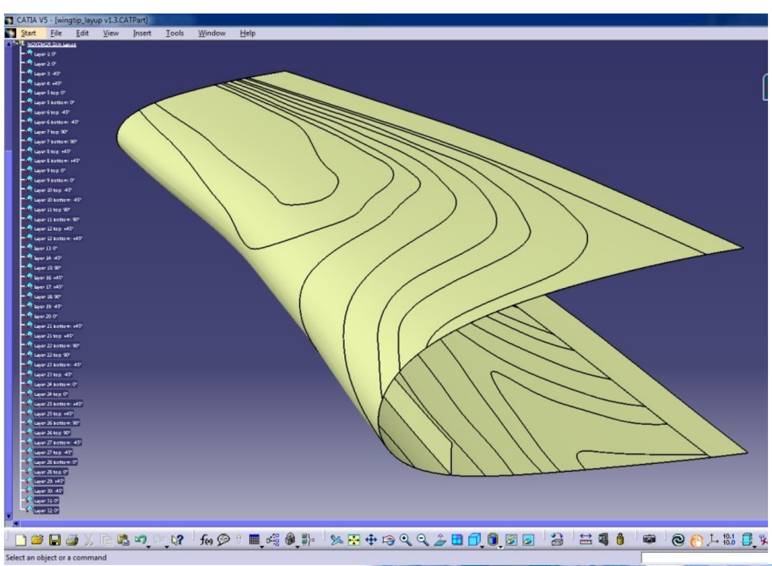


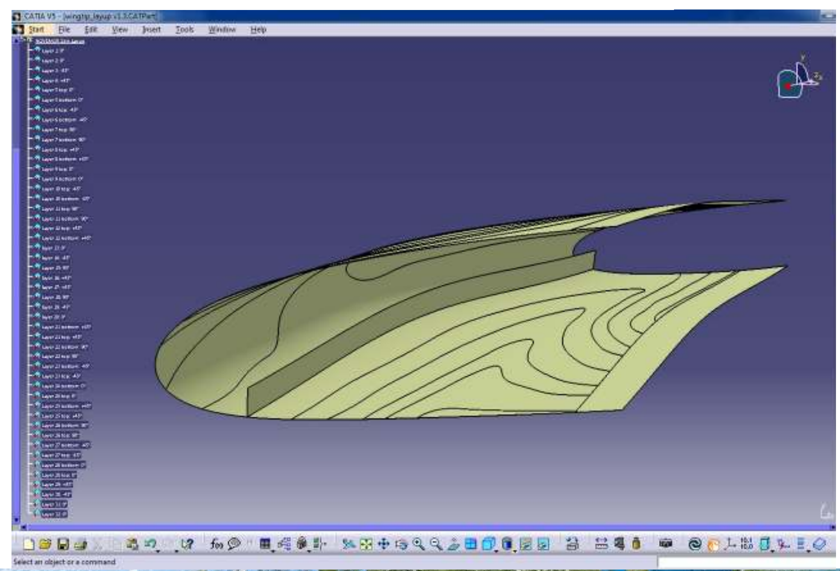
Wind Tunnel Testing – v3.0

Very 3D Skin Design

smooth contours

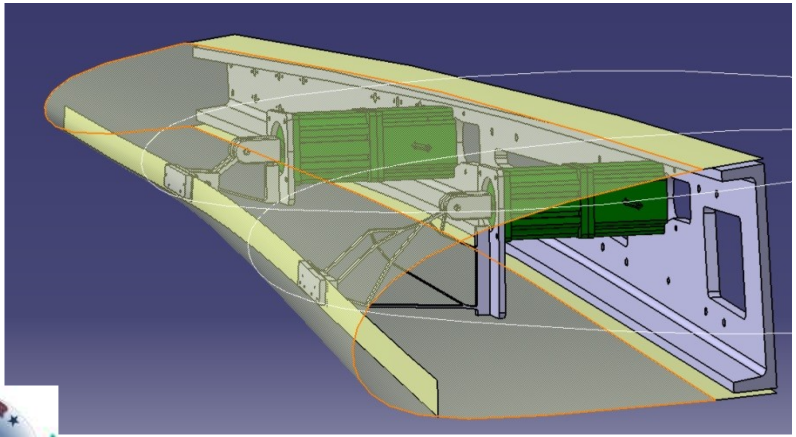


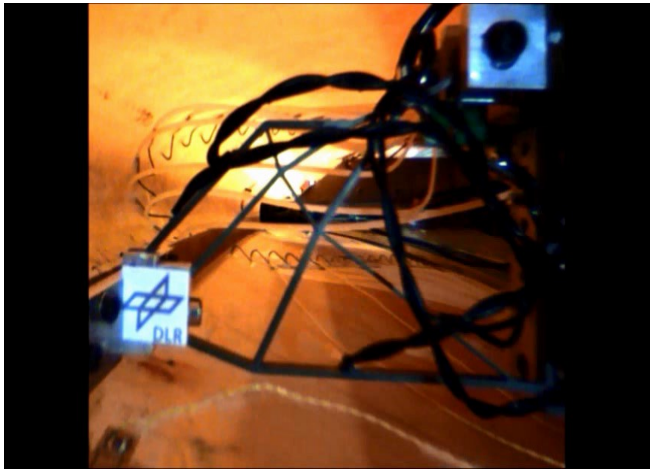




Compliant Mechanism Design

- Topology post-processed
- Superelastic nickel titanium (>2% strain)
- Manufactured by wire electrical discharge machining (EDM, 5 mm plate form)





Leading Edges with Large Displacement

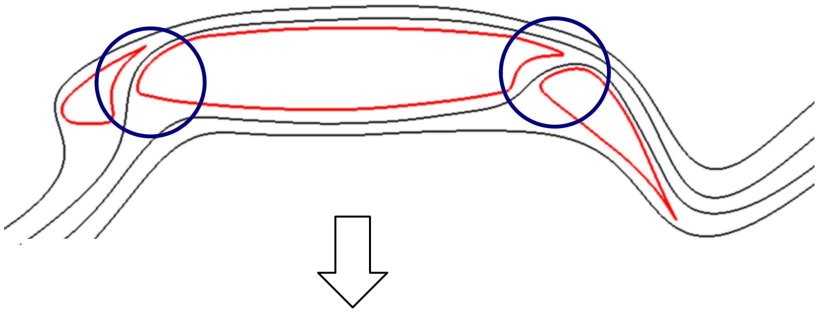
Hochauftrieb künftiger Verkehrsflugzeuge SFB 880

Technische Universität Braunschweig

IFL

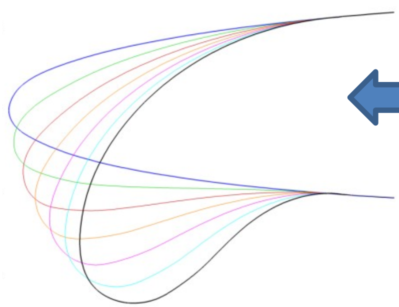
- Morphing leading edge for an active blown High-Lift system of a regional airliner
  - Gaps: noise and drag → Gapless active high lift system
  - Coanda effect is used for significantly increasing lift generation

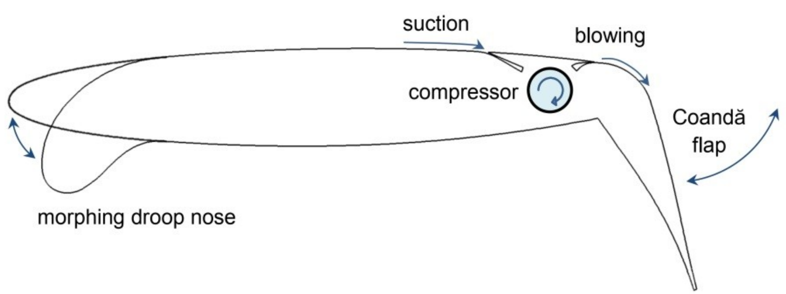
noise sources



Cruise position

High-Lift position





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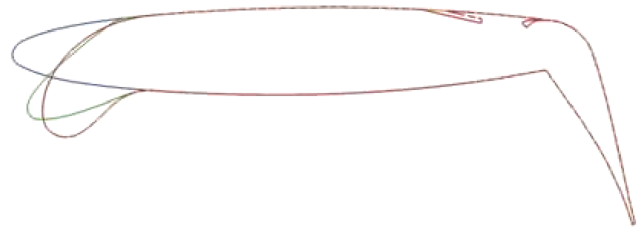
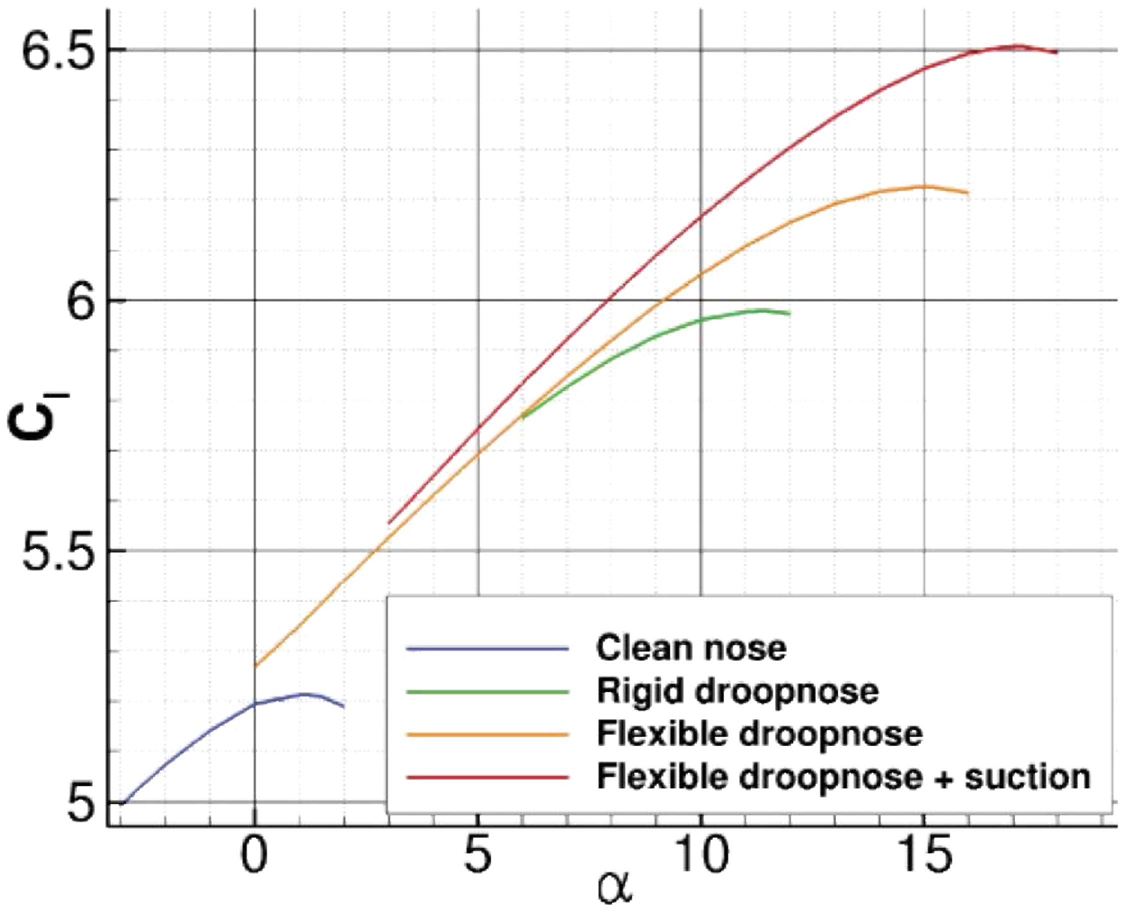
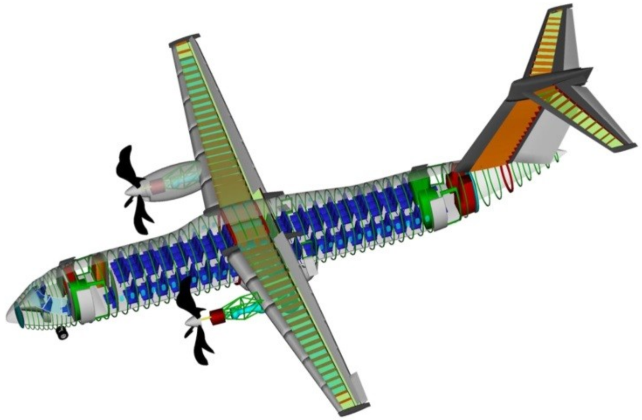
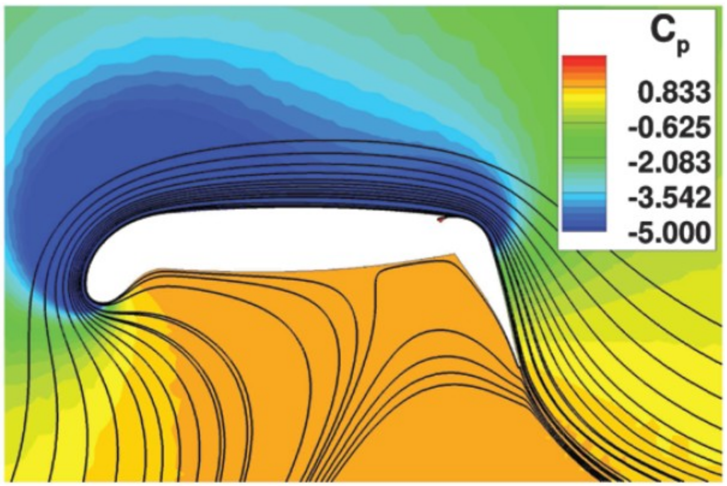
High-Lift



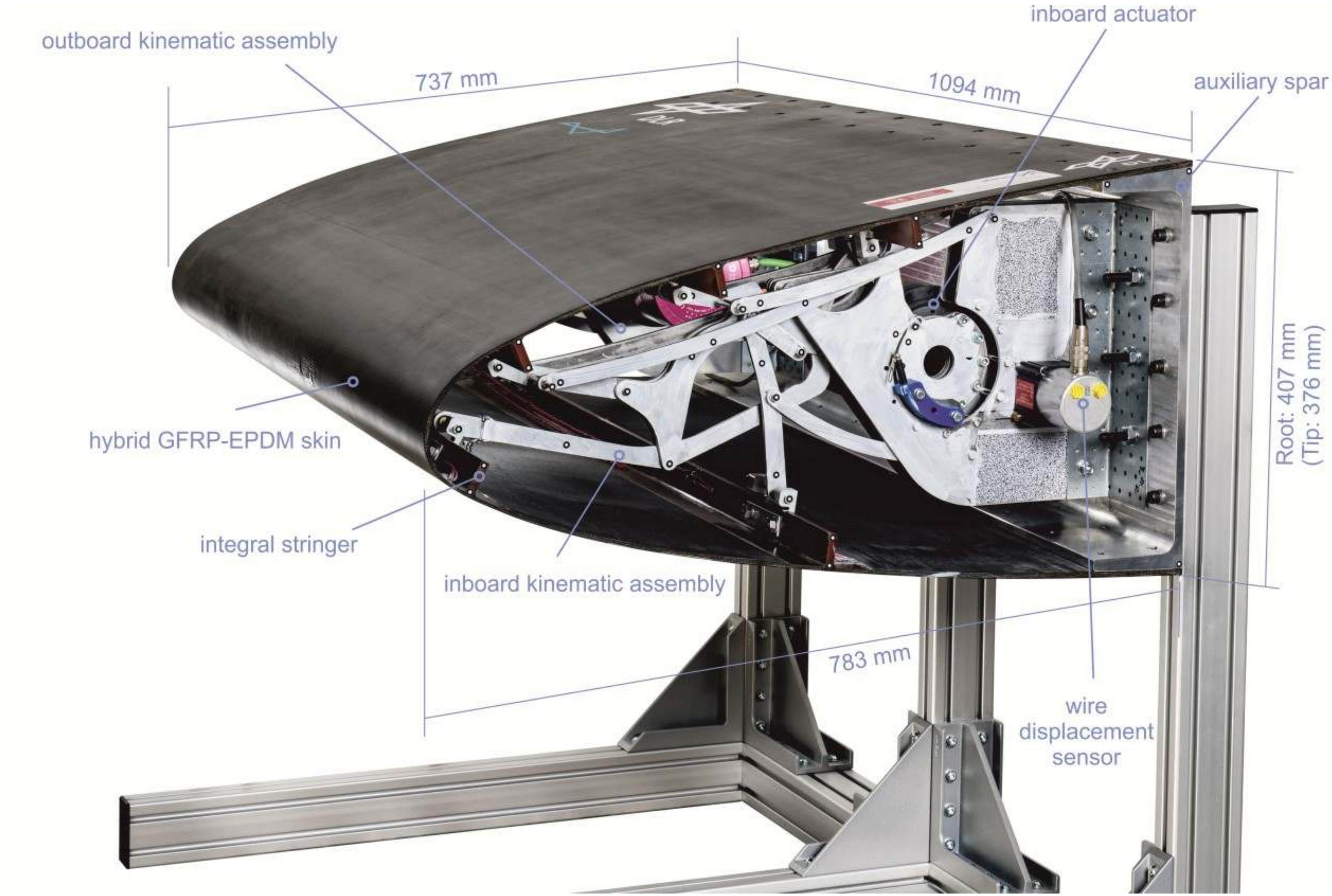




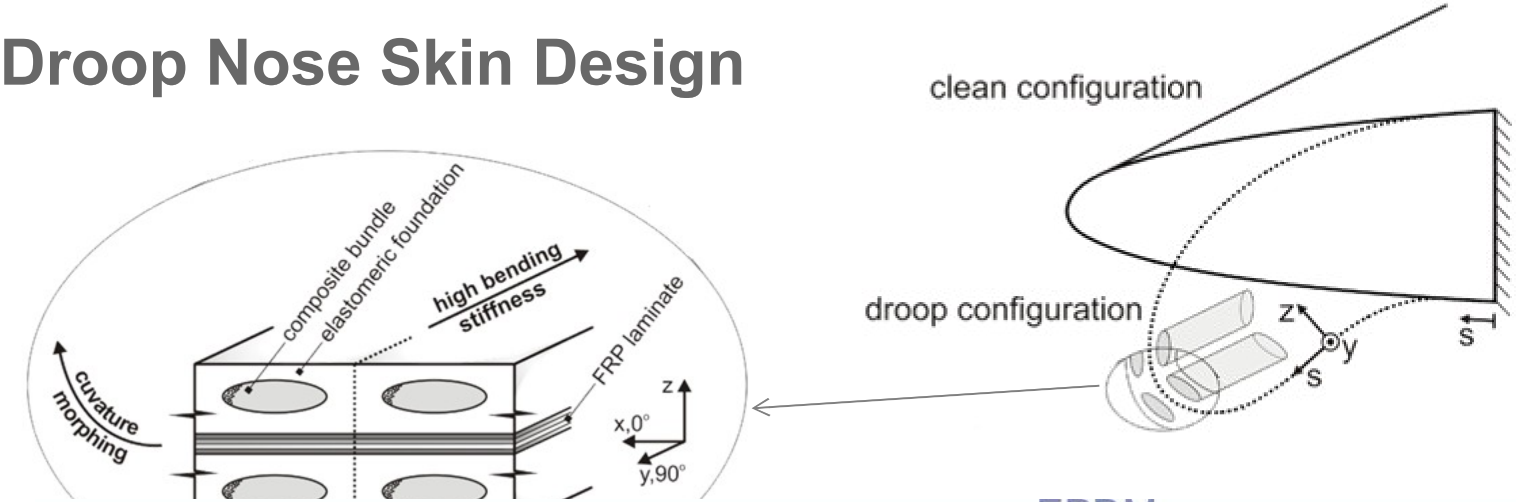


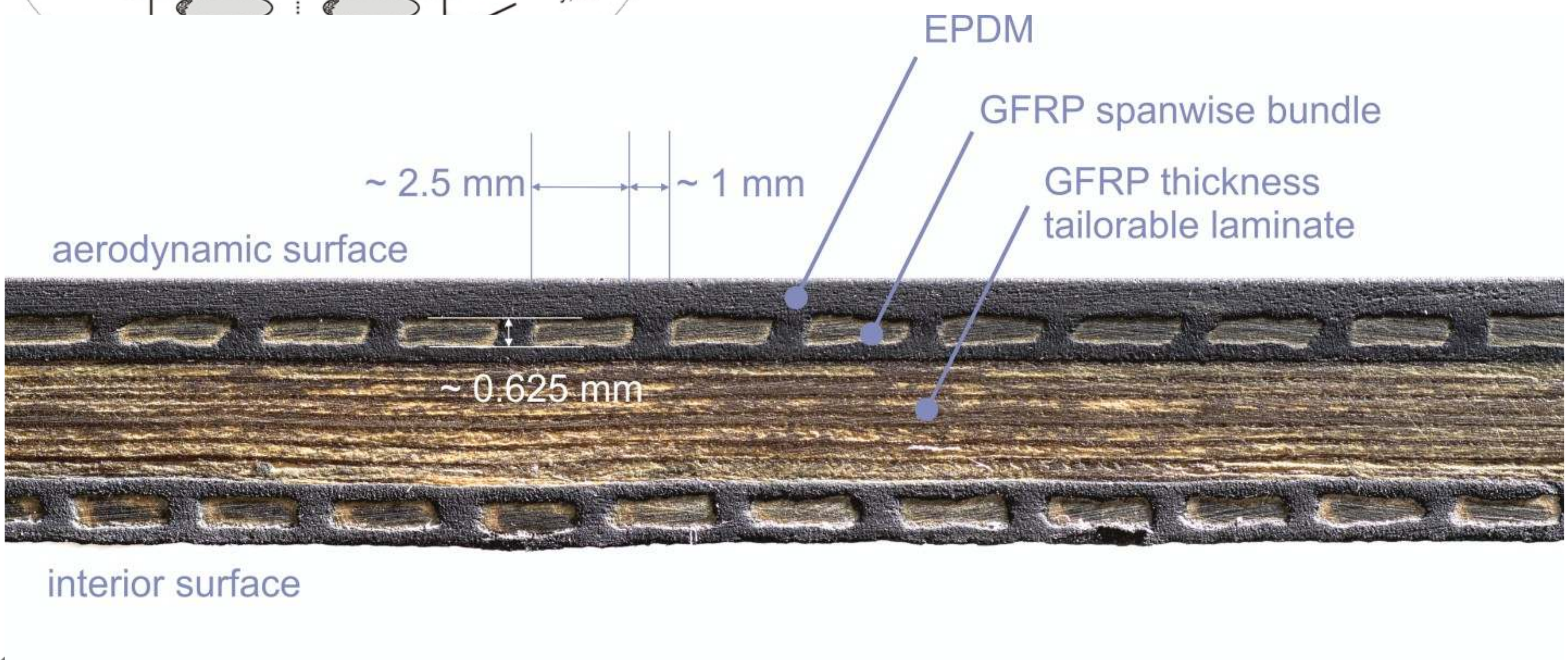
Source: Burnazzi & Radespiel, 2014

Large-displacement Morphing Droop Nose

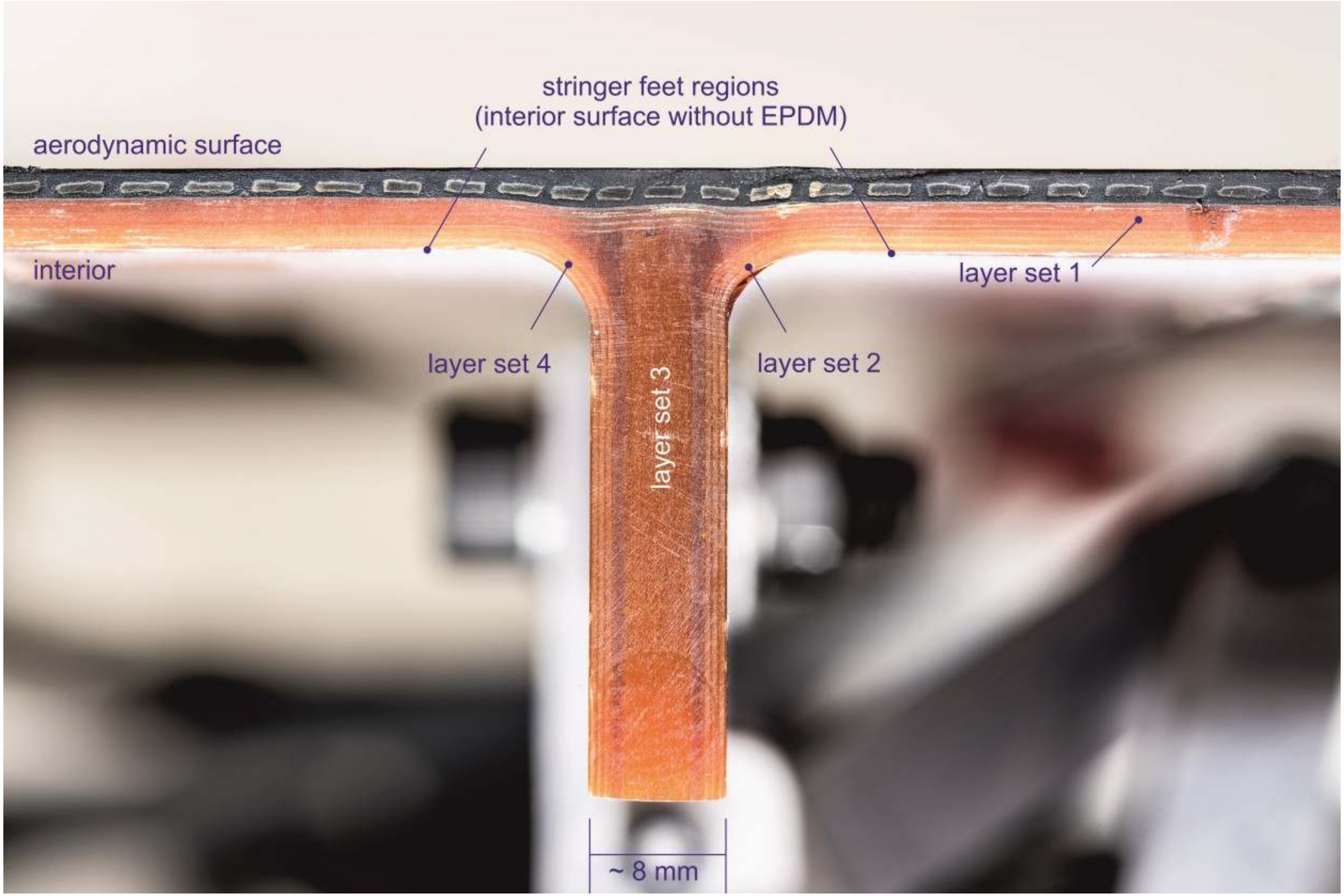


Droop Nose Skin Design

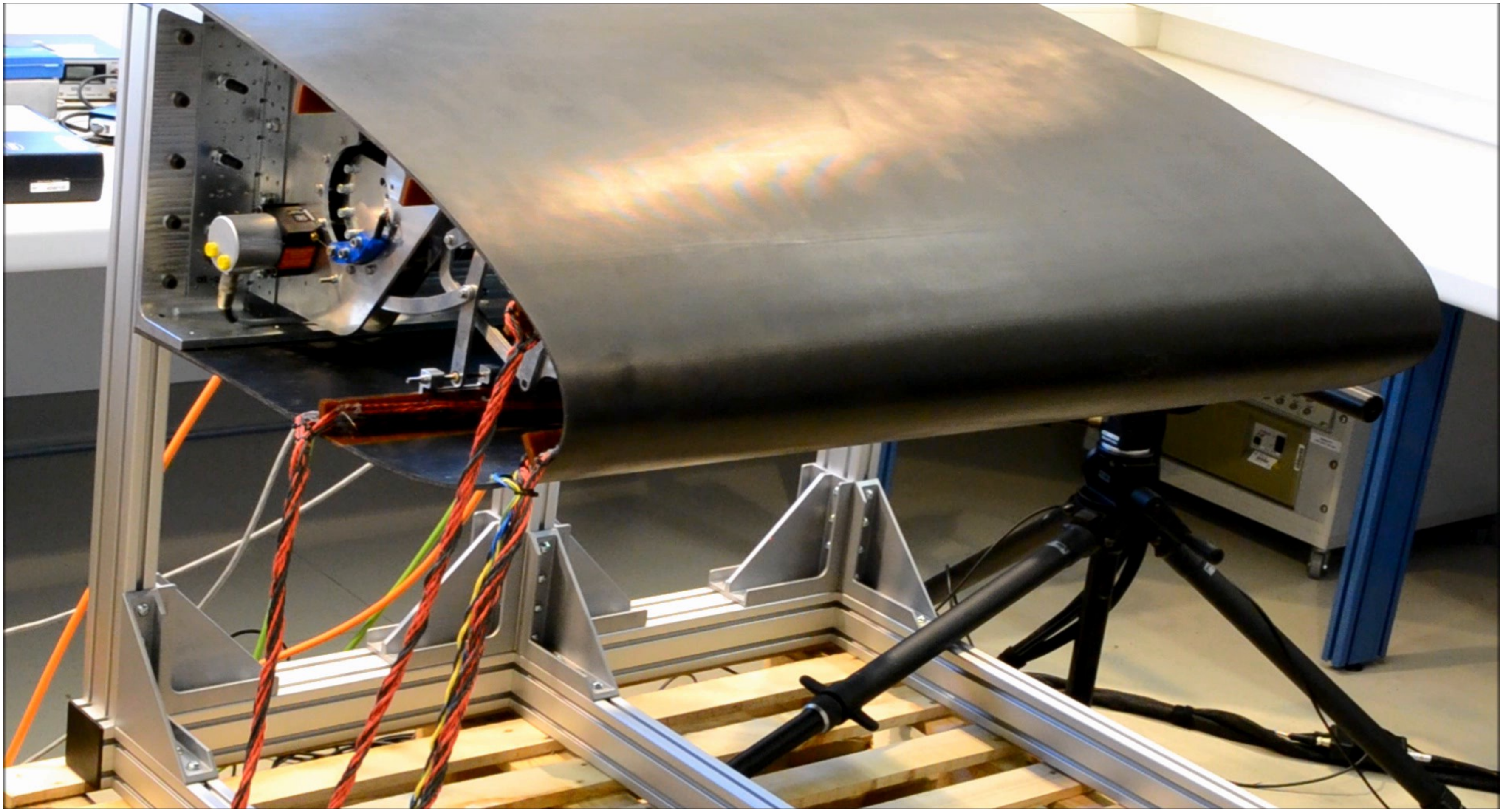




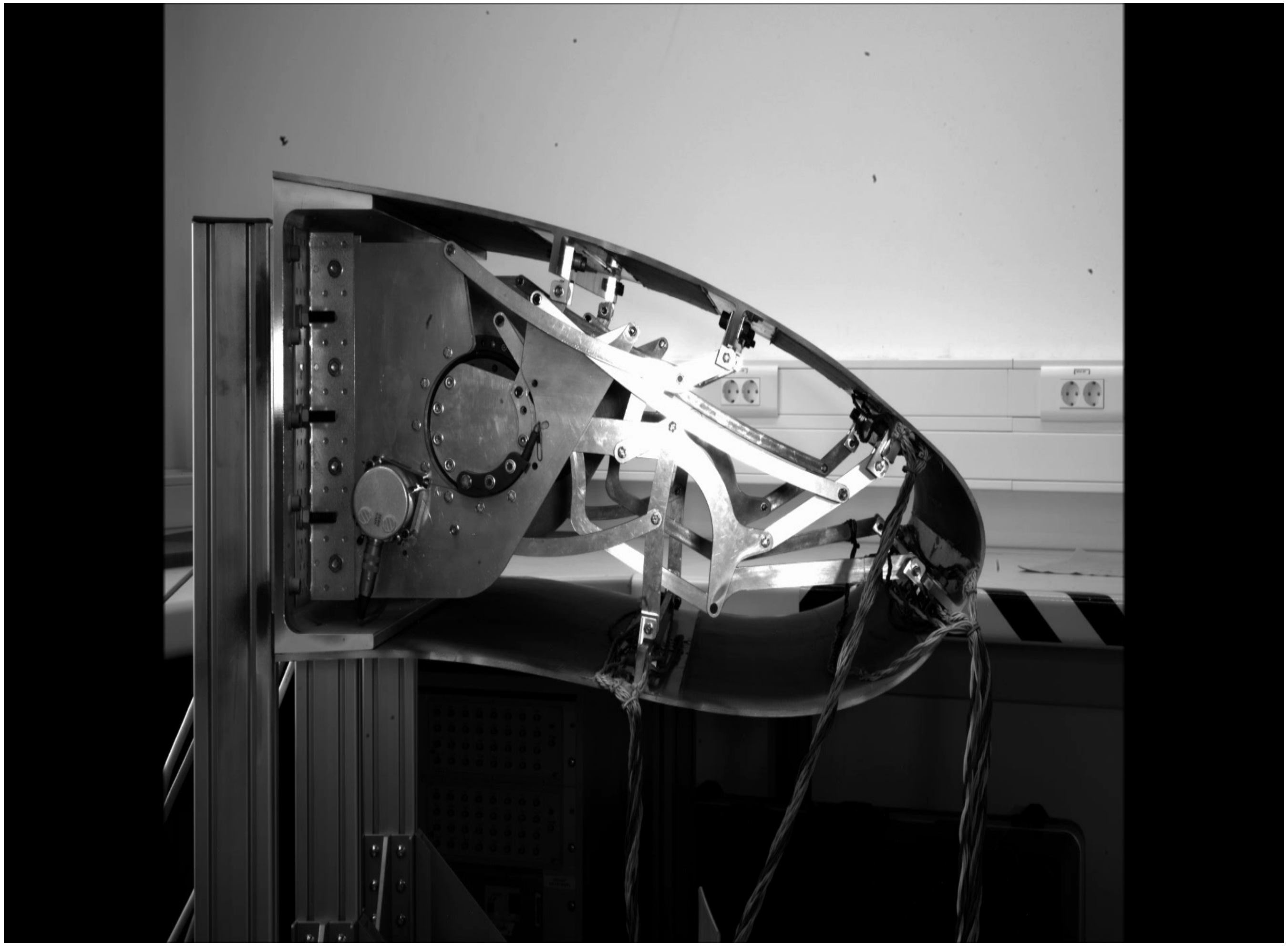
Integral Stringers



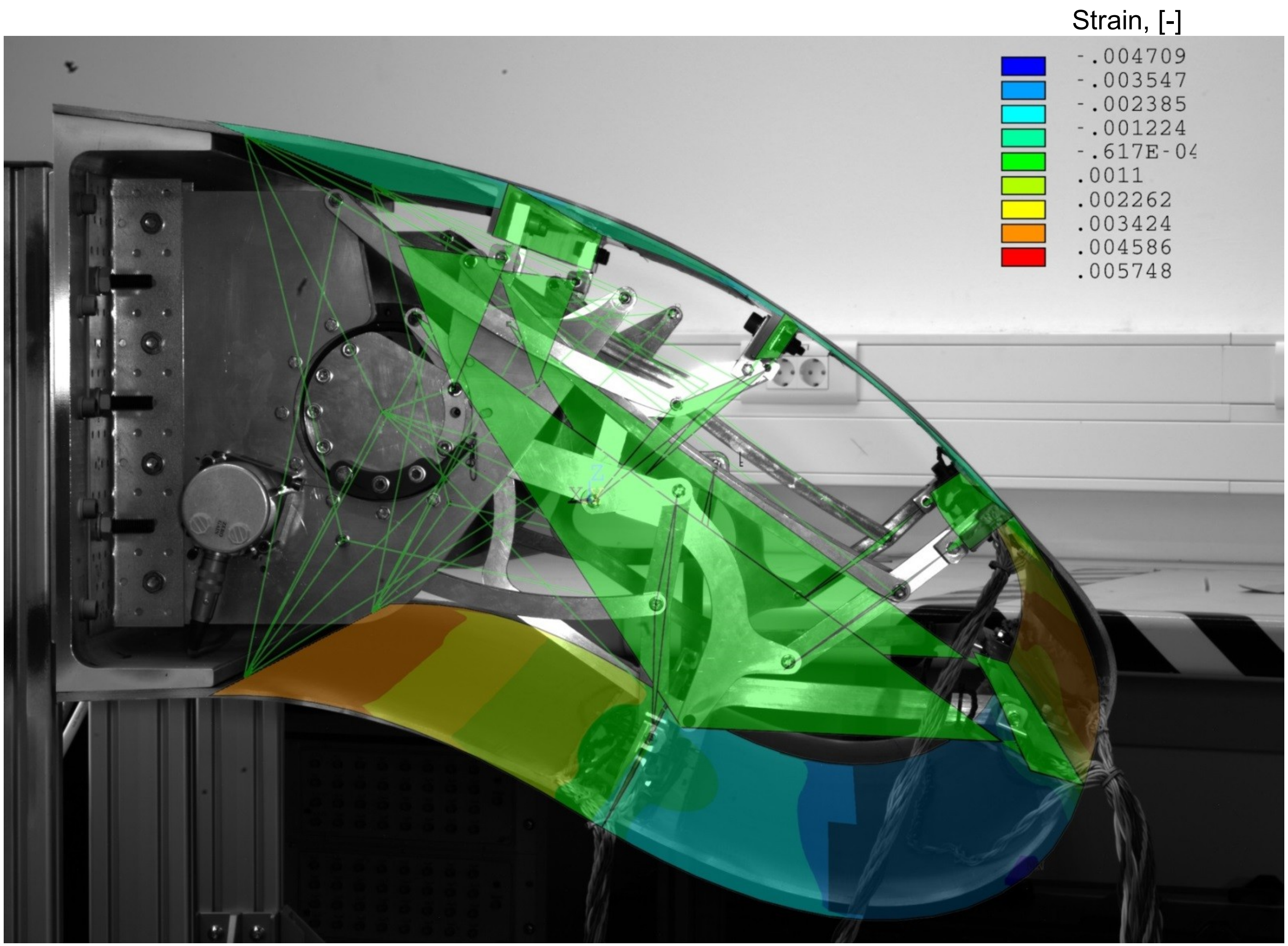
Hardware



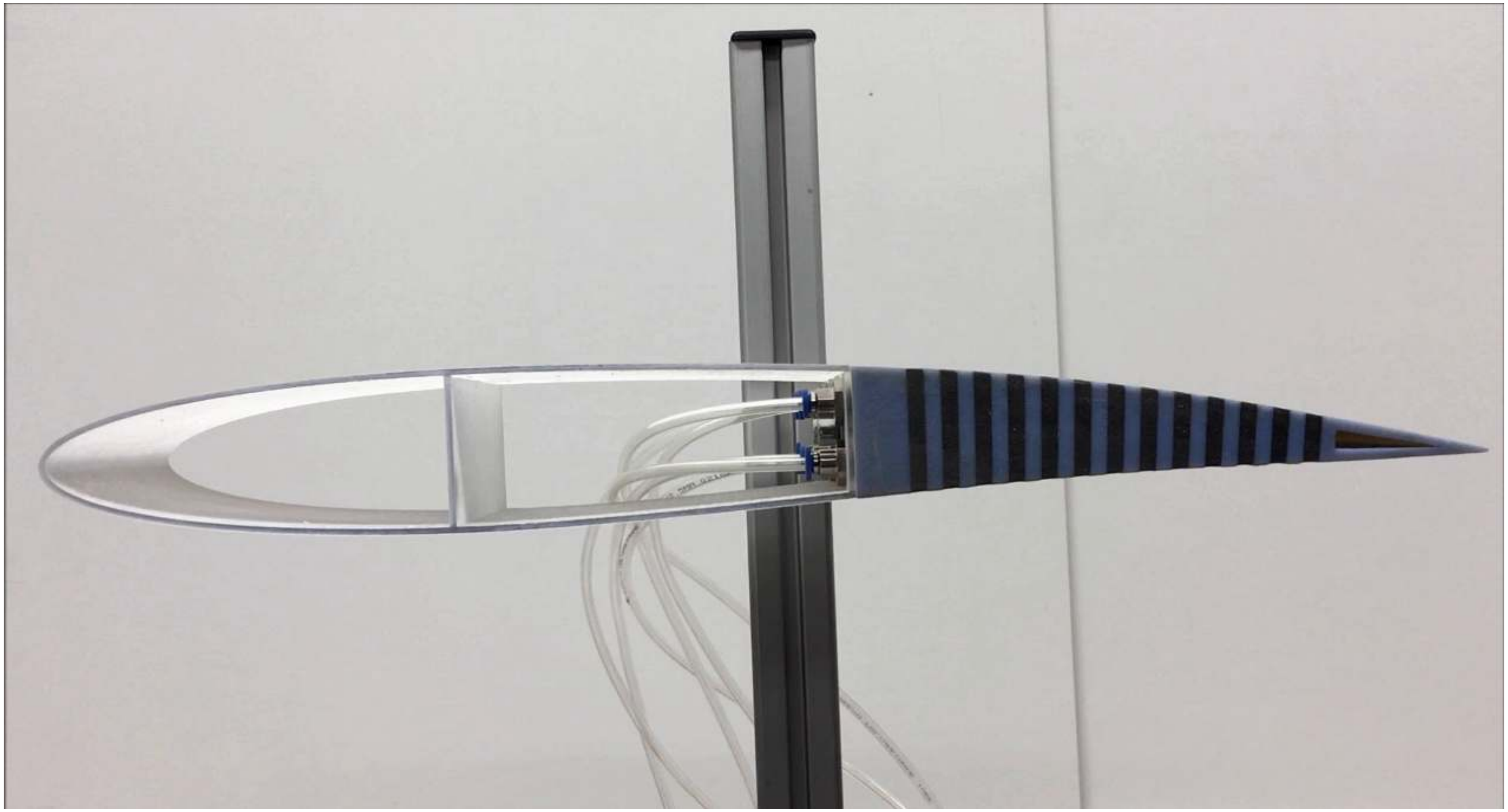
Hardware



Shape & Curvature Comparisons



Fluid Actuated Morphing Unit Structures (FAMoUS)



Fluid Actuated Morphing Unit Structures (FAMoUS)

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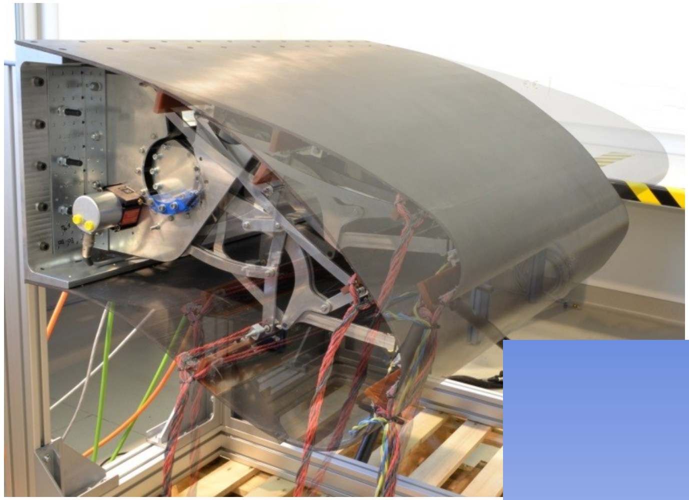
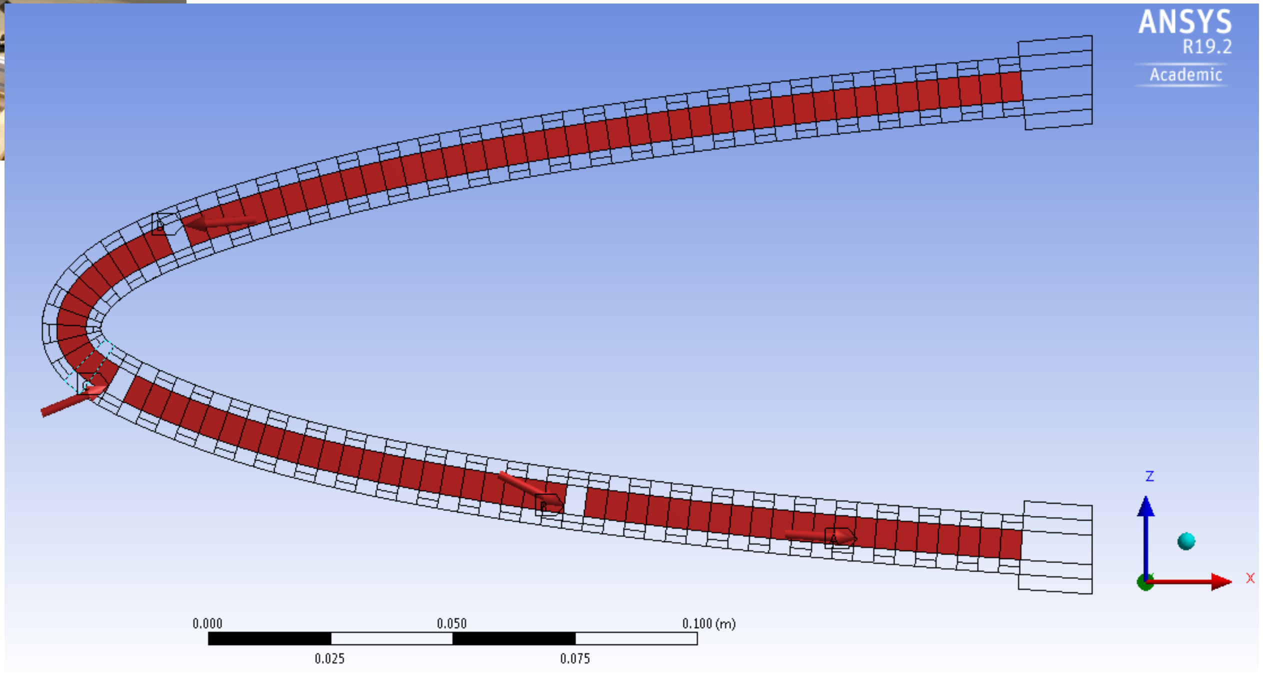
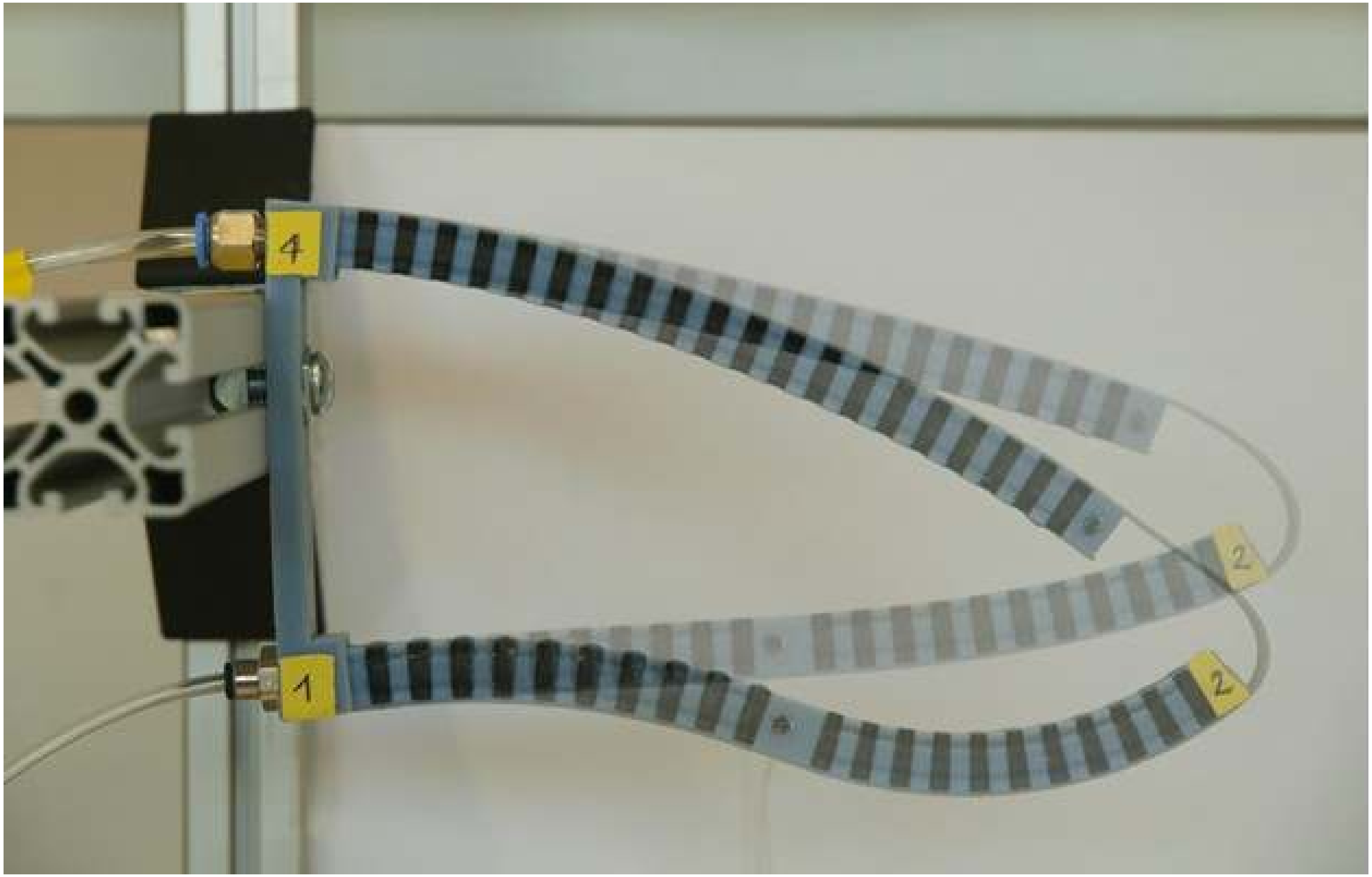


Morphing droop nose with conventional actuation

Morphing droop nose with FAMoUS

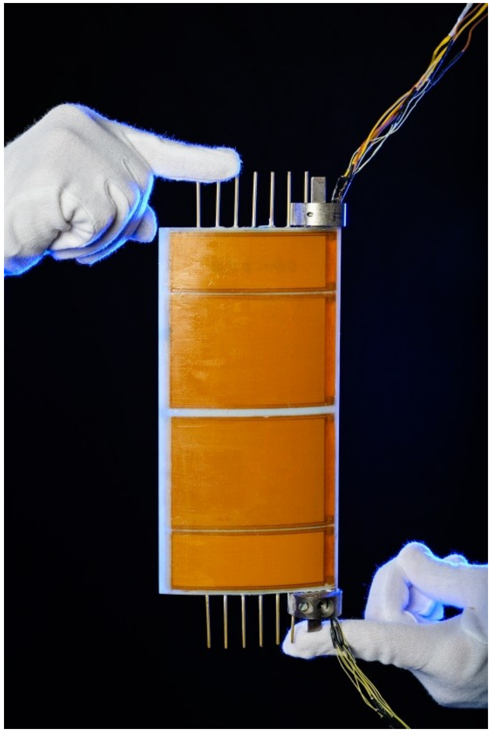


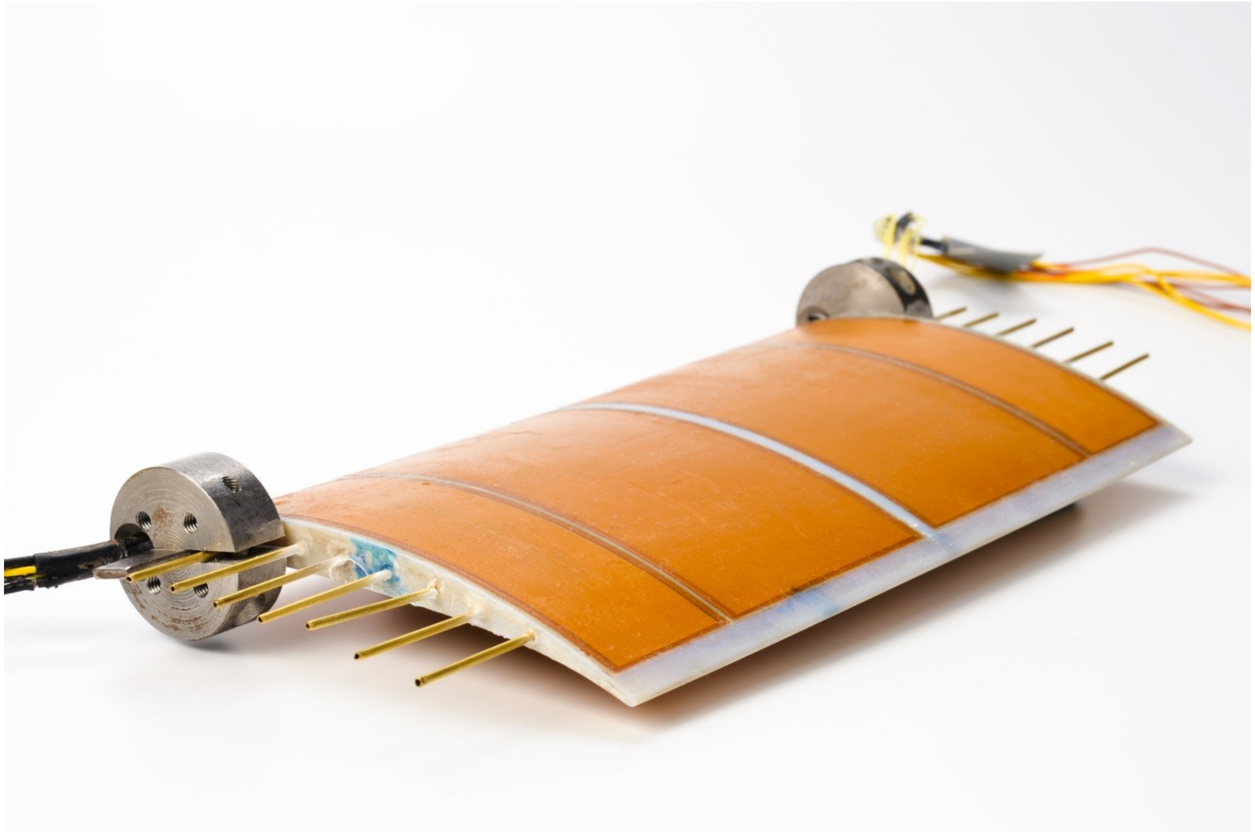
Fluid Actuated Morphing Unit Structures (FAMoUS)



Active Helicopter Rotorblades

Active Engine Fan & Compressor Blades

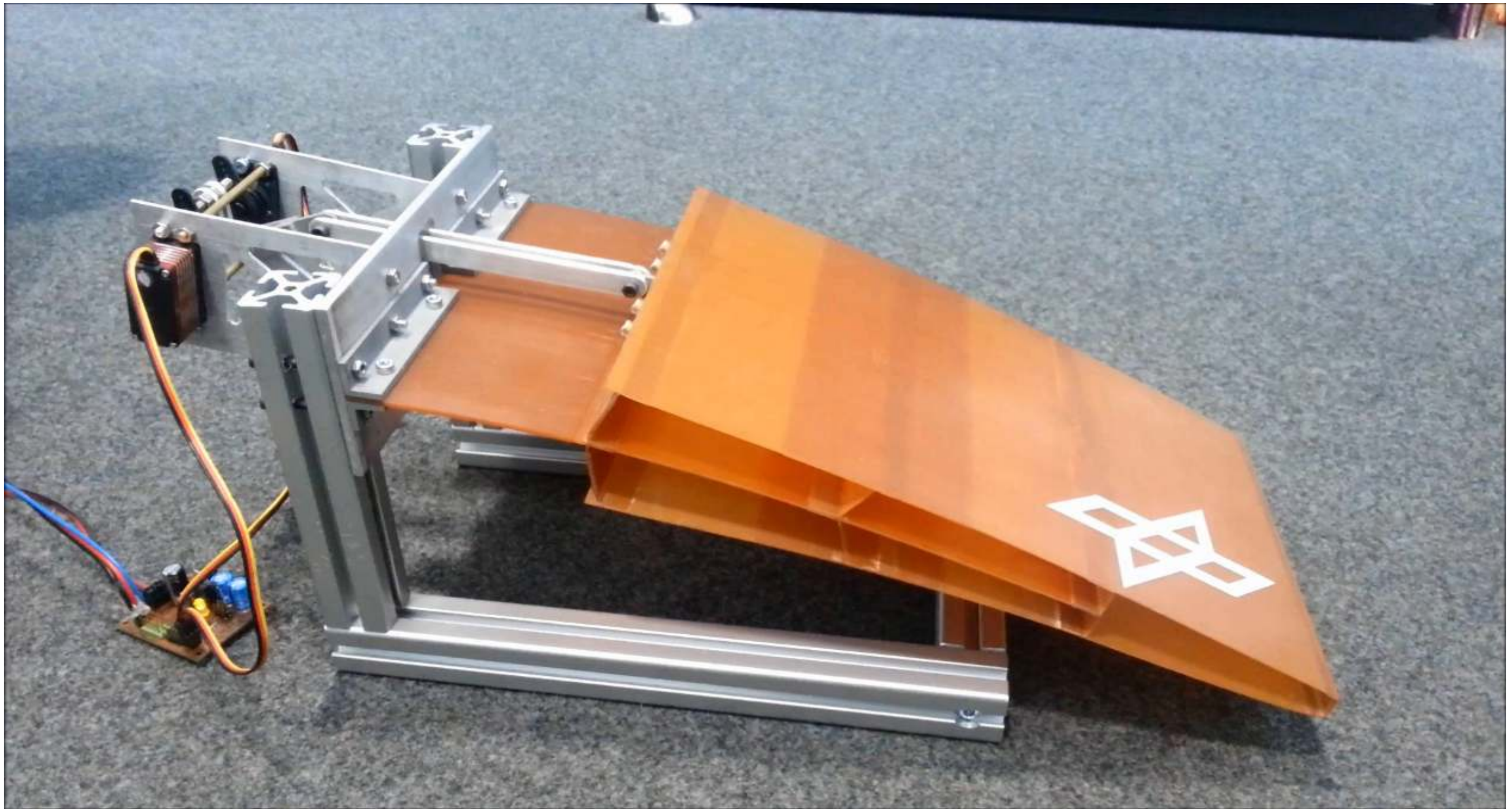




Adaptive Wind Turbine Blades

Design and manufacture of blades in Germany and testing at NREL, USA

Adaptive Wind Turbine Blades



Passive Morphing Ship Stabilizer

German Coastguard ship with stabiliser for low-speed (in service since 2014)

DLR

Summary

- Morphing structures enable many potential benefits
- Integrating skin, substructure, actuation → a big challenge!
- Stiffness vs flexibility → a careful balance
- Many applications
- Highly multidisciplinary

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Thank You & Questions