DLR-F15 symposium, 7-9 December 2015, Braunschweig

Towards the investigation of unsteady control surface aerodynamics

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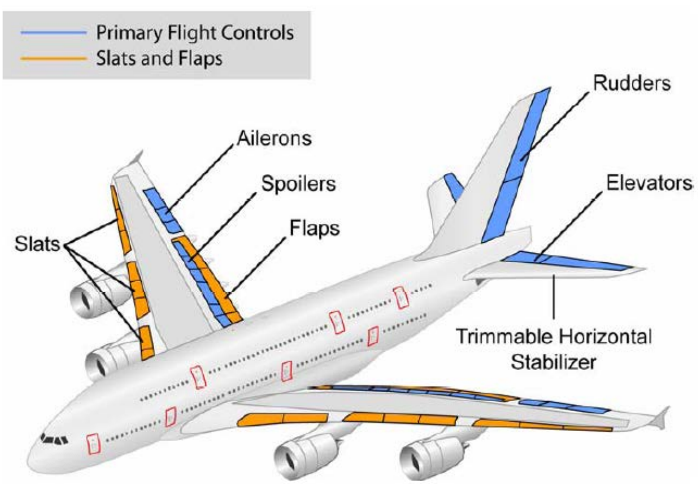
Outline

- Motivation, objectives and funding
- Spoiler aerodynamics
- Development of a wind tunnel model
- Outlook

Why focus on control surfaces?

- Long-term vision at DLR: **digital aircraft**, i.e. numerically simulate the aircraft within its entire flight envelope, including manoeuvres
  - Today CFD still mostly applied on cruise and high-lift configurations in steady conditions
  - Manoeuvre simulation requires geometrical representation of (all) control surfaces



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  - Today CFD still mostly applied on cruise and high-lift configurations in steady conditions
  - Manoeuvre simulation requires geometrical representation of (all) control surfaces
  - Accurate simulation of the time-dependent impact of control surface deflection on the overall aerodynamics of the aircraft required

→ Deeper insight into control surface aerodynamics and reliable validation data is of high priority!

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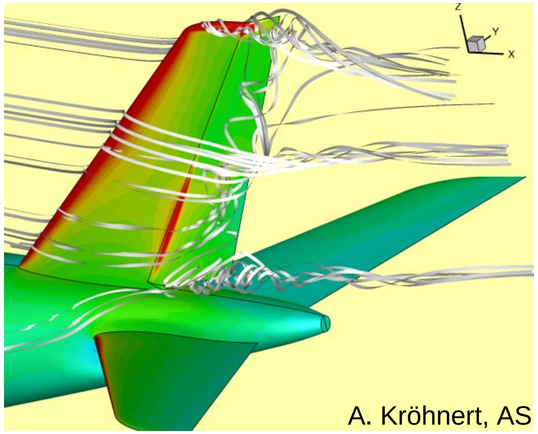
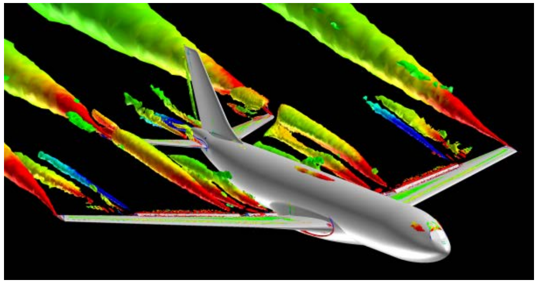
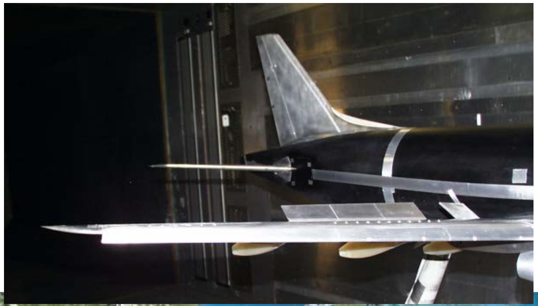
Where are we today?

- Growing interest in configurations with deflected control surfaces, both numerically and experimentally
- Examples:
  - High-lift
  - One engine inoperative
  - Emergency descent
  - Loads (re-)distribution
  - Control surface efficiency
- Predominantly static deflections, i.e. dynamic effects not considered yet
- Some control surfaces exhibit a non-linear behaviour, associated with time lags and adverse effects

Capture these effects and their impact on the aerodynamic behaviour of the configuration

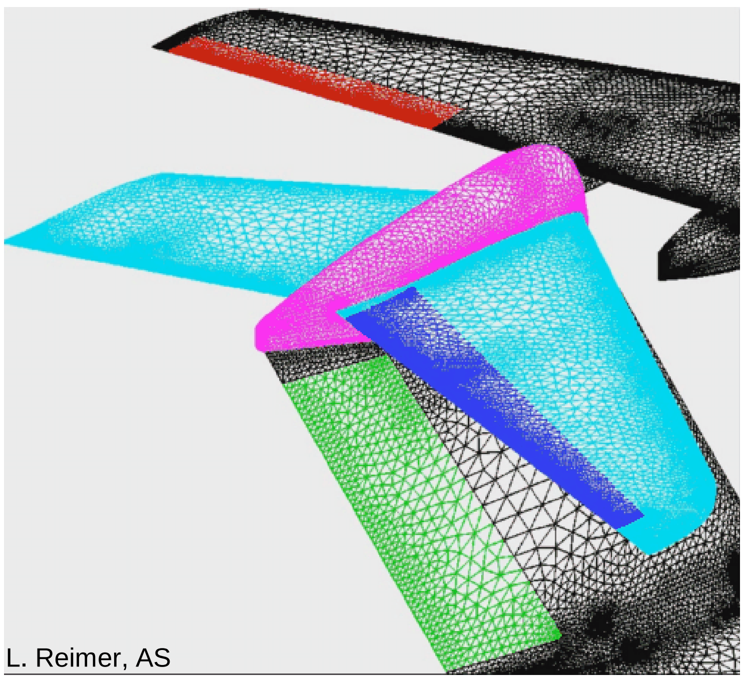


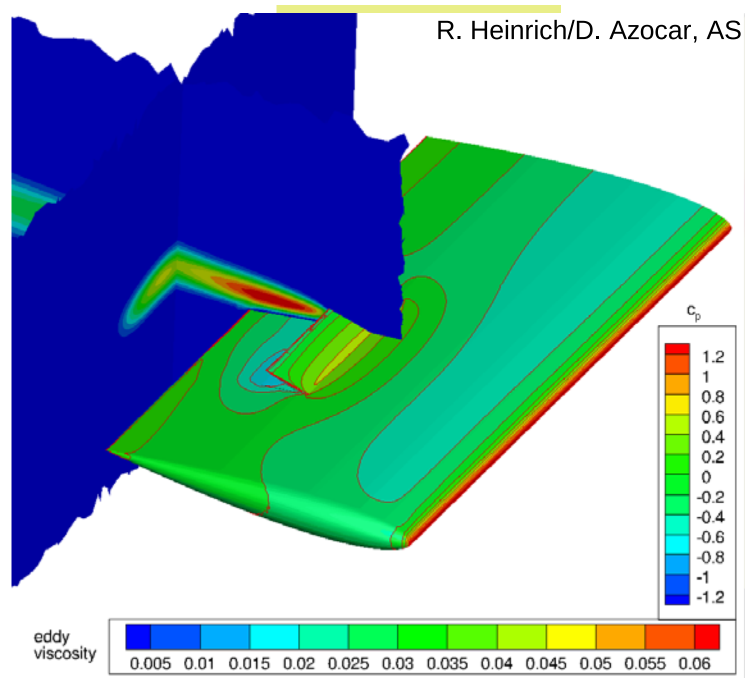




Where are we today?
Dynamic control surface modelling

- Mostly based on **mesh deformation**


L. Reimer, AS

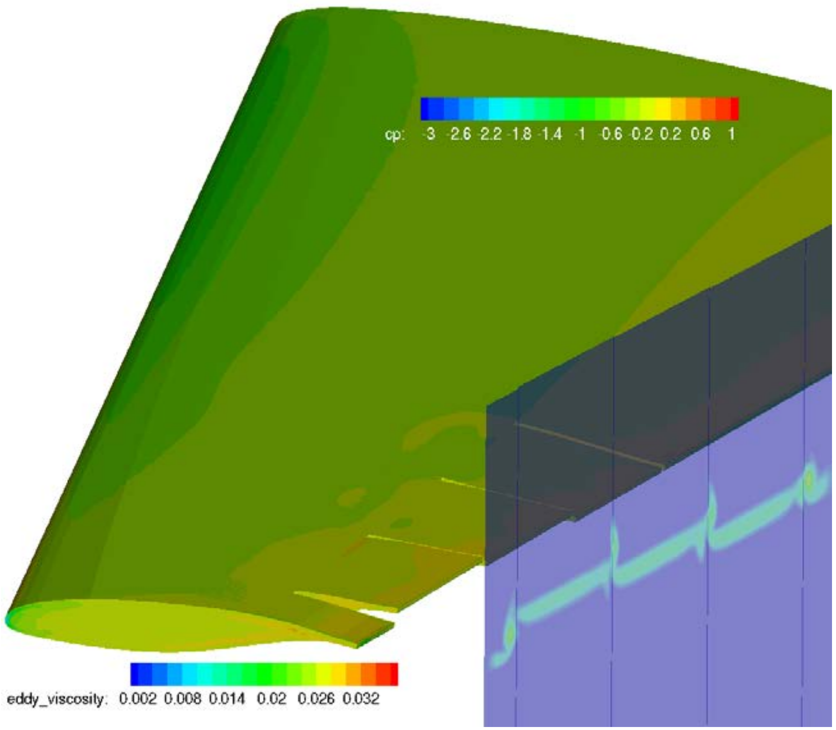


R. Heinrich/D. Azocar, AS

Where are we today?
Dynamic control surface modelling

- Mostly based on **mesh deformation** in combination with **patched grids**

Demonstration of A380 „aileron waltz“



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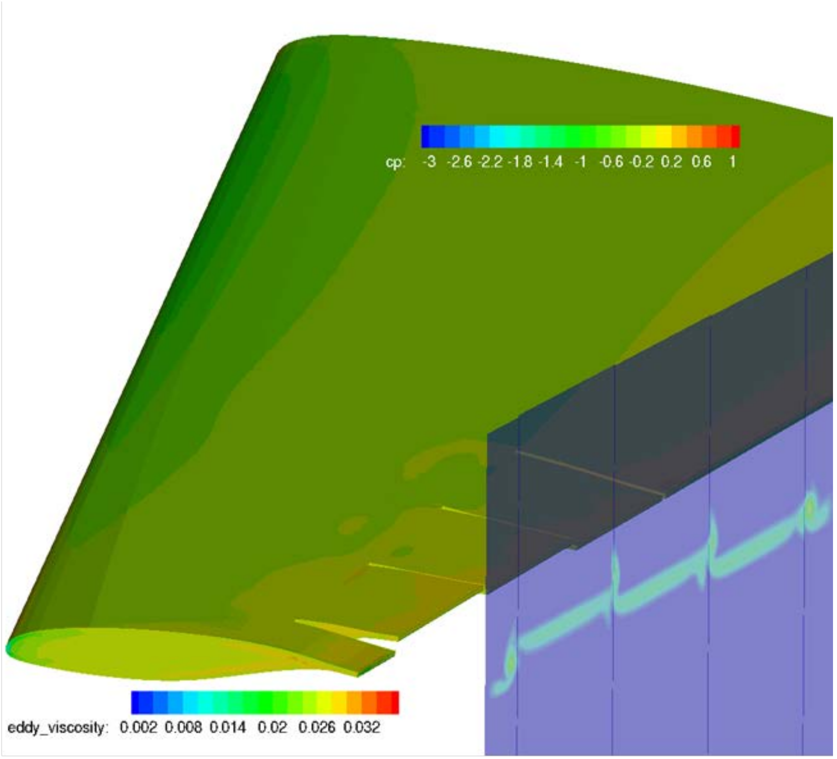
Where are we today?
Dynamic control surface modelling

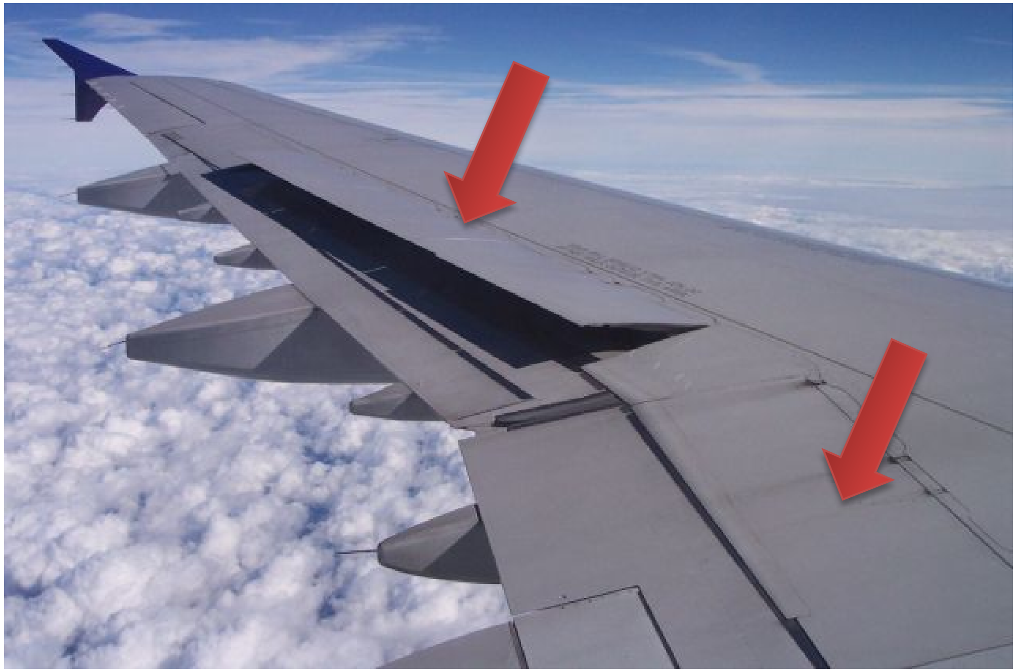
- Mostly based on **mesh deformation** in combination with **patched grids**
- Satisfying representation for most control surfaces…



R. Heinrich/D. Azocar, AS

Where are we today?
Dynamic control surface modelling

- Mostly based on **mesh deformation** in combination with **patched grids**
- Satisfying representation for most control surfaces…
  …apart from spoilers

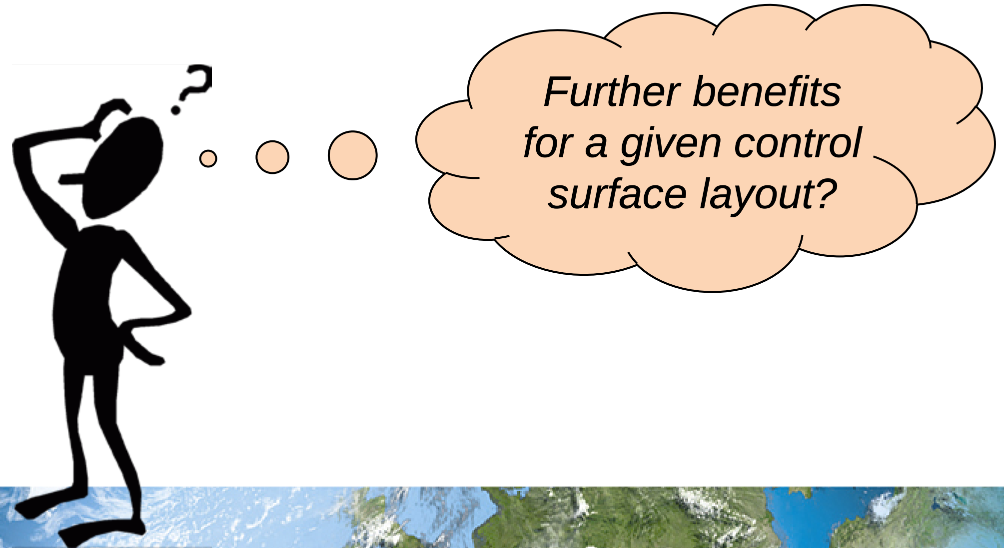


Objectives of this work

(1) Develop a wind tunnel setup to investigate the transient behaviour of a dynamic spoiler

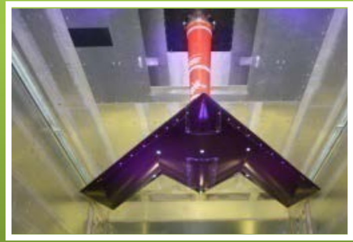
(2) Assess the impact of the relevant motion parameters such as deflection rate, deflection angle and type of deflection

(3) Verify and validate the DLR TAU code for configurations with a dynamic spoiler



Funding of this work

DLR project ***Mephisto***
2014 – 2018
Improving design capabilities of unmanned vehicles
including aerodynamics, aeroelastics, structures, propulsion, flight mechanics, radar/thermal/acoustic signature



Work package „Simulation“

- Determination of critical aero loads for wind tunnel model with deflected spoiler
- Verification and validation of the DLR TAU code
- CFD investigation of the unsteady aerodynamic behaviour during spoiler deployment

Work package „Experiments“

- Concept finding, construction and manufacturing of the new wind tunnel model
- 2 wind tunnel campaigns in 2016
- Provide validation data for the simulation

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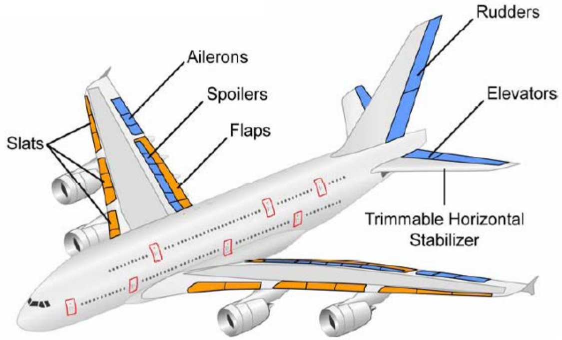
- **Spoiler aerodynamics**
- Development of a wind tunnel model
- Outlook

Why focus on spoilers?



- Truly multifunctional control surface
- High aerodynamic efficiency over the entire flight envelope (unlike ailerons)
- Induce favourable yawing moment (unlike ailerons)
- Use of spoilers allows for smaller aileron size, hence more space for the high-lift system

- Highly unsteady wake
- Significant time lag between spoiler deflection and aircraft response
- Hardly predictable by low-fidelity methods
- Very demanding to investigate with high-fidelity methods (grid generation, time scales)

Quotation of Mack et al. (Boeing, 1979)

„…the characteristics of spoilers are the most difficult to predict of any control surface due to strong non-linearities.“

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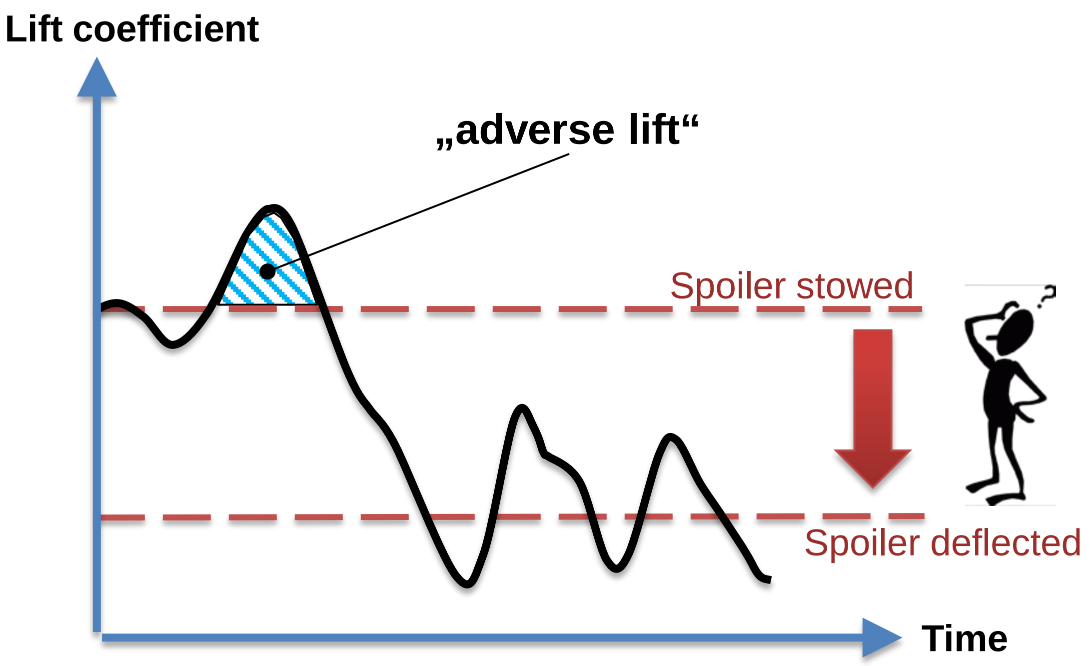
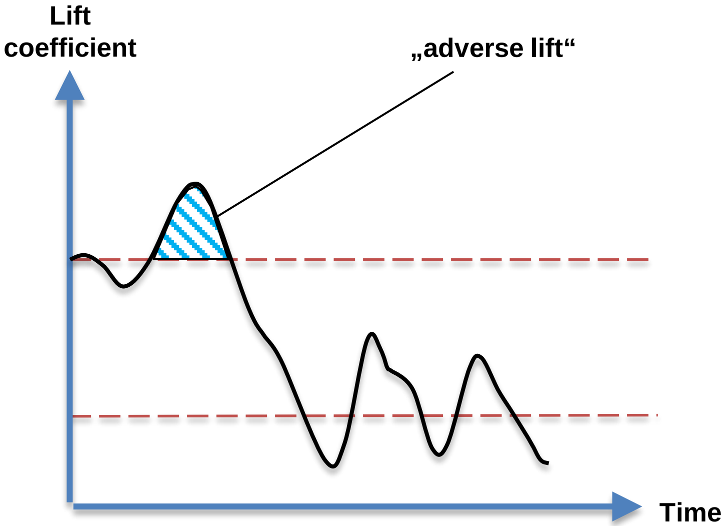
Spoiler aerodynamics
Non-linearities and adverse effects



Spoiler aerodynamics



- Adverse lift is a function of the deflection rate
- **Rapid spoiler** deflection leads to adverse lift
- Different definitions of what „rapid“ means
  - Mabey, 1983: $\dot{\delta} \geq 400\ deg/s$ (full scale)

    $t_{rise} = 5 * c/U_{\infty}$

Onflow velocity	Rise time
10 m/s	300 ms
90 m/s	33 ms

  - To comply with this definition at wind tunnel scale and at 90 m/s, a rapid spoiler deflection from **0°** → **30°** requires a mean deflection rate of **910 deg/s**
  - The chosen actuator is capable of 1250 deg/s

Outline

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- **Development of a wind tunnel model**
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Requirements for the wind tunnel model

The new wind tunnel model should…

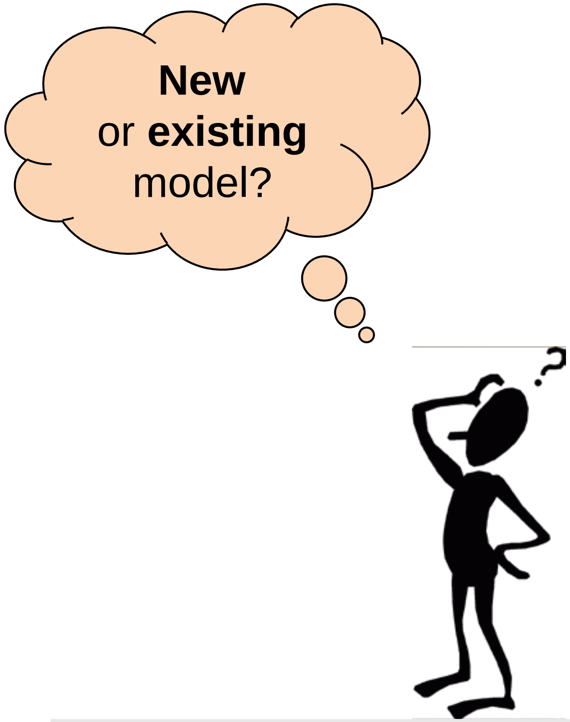
(1) …be 2D and yield a simple and well understood flow field

(2) …offer enough space to integrate the kinematics

(3) …include a moving spoiler, limited in spanwise direction, with deflection angles of up to 60° and …

(4) …have a spoiler drive allowing for variable deflection rates and different motion types

(5) ...allow for investigating sweep effects at a later stage



The DLR-F15 model with spoiler

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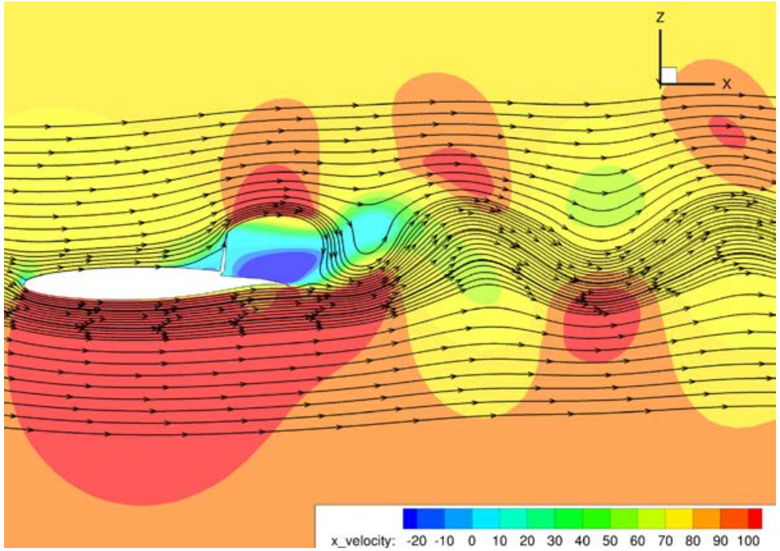
Determination of critical aerodynamic loads

Worst case conditions

- Spoiler chord length c_s: 0,09 m (15 % * c)
- Deployment angle: 90°
- Onflow velocity: 90 m/s
- Onflow Mach number: 0.265
- Reynolds number: 3,700,000 based on c_{ref}
- Angles of attack: -10° to + 10°



Grid generation and computation

- Unstructured 2D Centaur grids
- Unsteady TAU computations with $\Delta t = 0.16\,ms$

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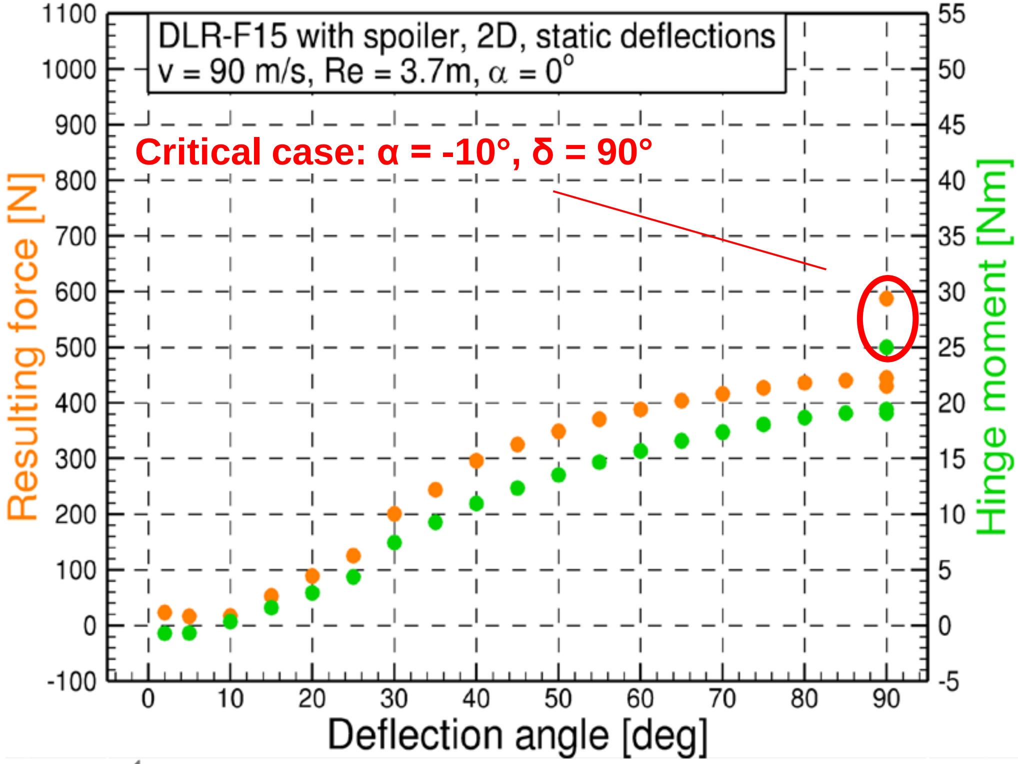
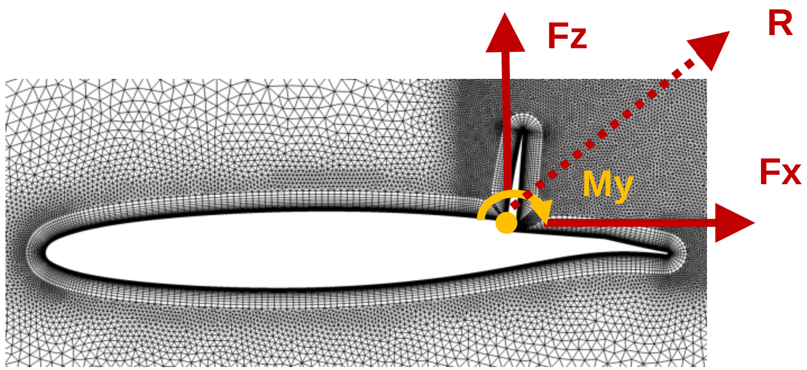
Determination of critical aerodynamic loads
Maximum hinge moment

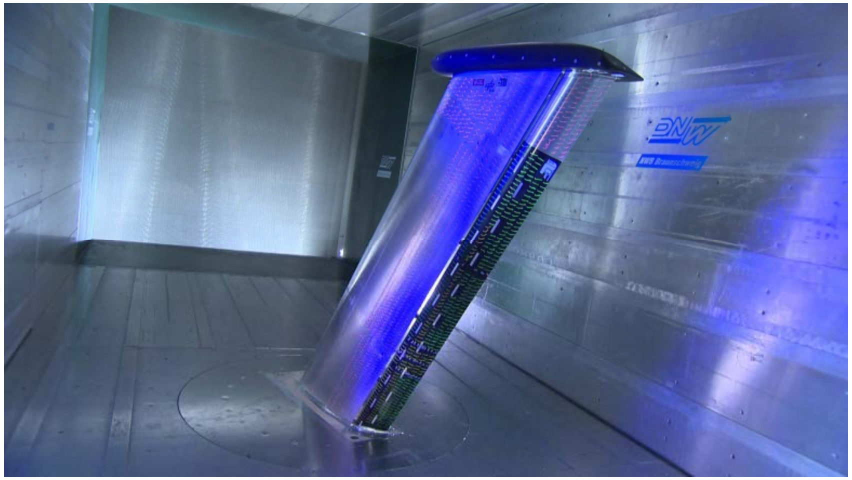




		α = 0° δ = 90°	α = -10° δ = 90°
Spoiler	R	445 N	**587 N**
	My	20 Nm	**25 Nm**

Spoiler kinematics

- Integration of spoiler drive within the model not possible due to lack of space
- Spoiler will be driven from one side only, i.e. through the floor of the test section to maintain the ability to vary the leading edge angle



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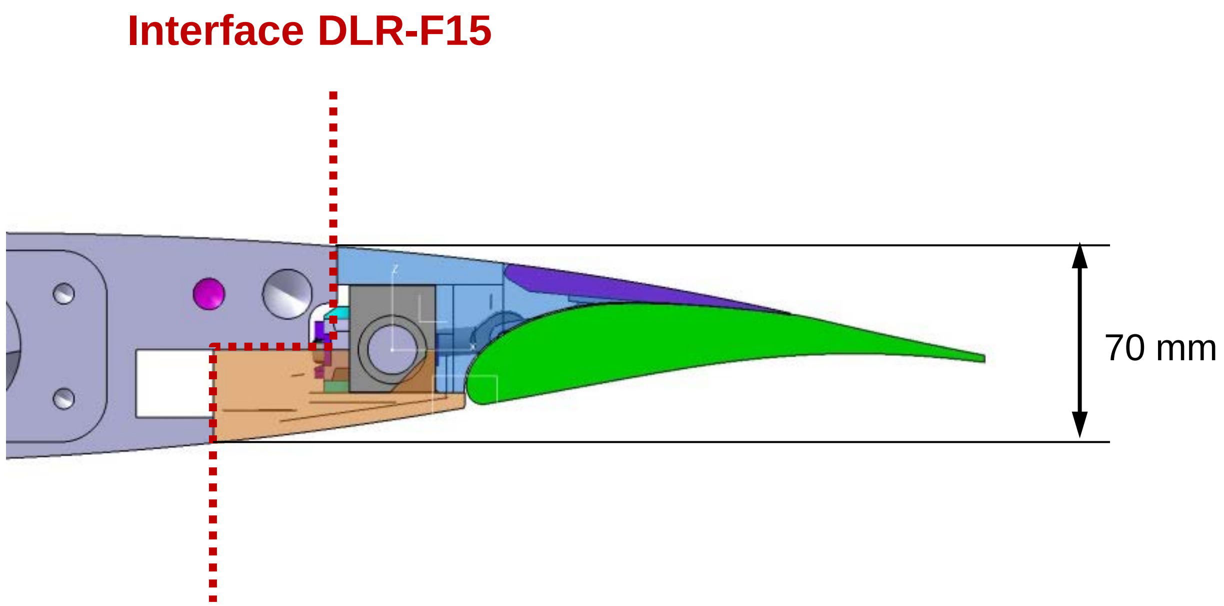
- Spoiler torque drive not feasible due insufficient torsional stiffness → push rod drive and lever kinematics instead



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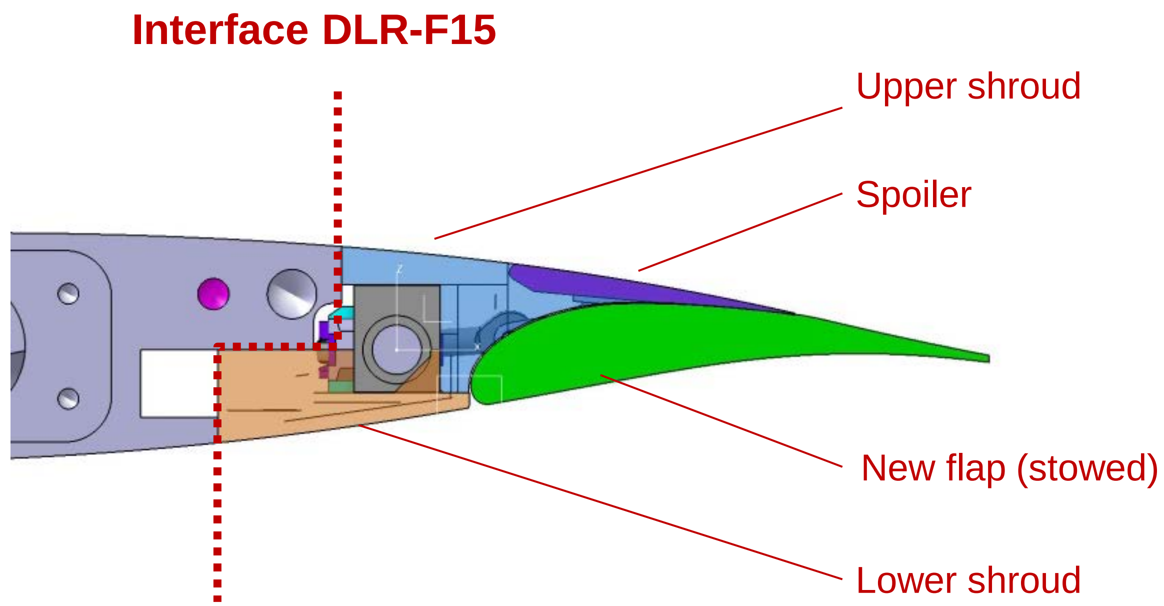

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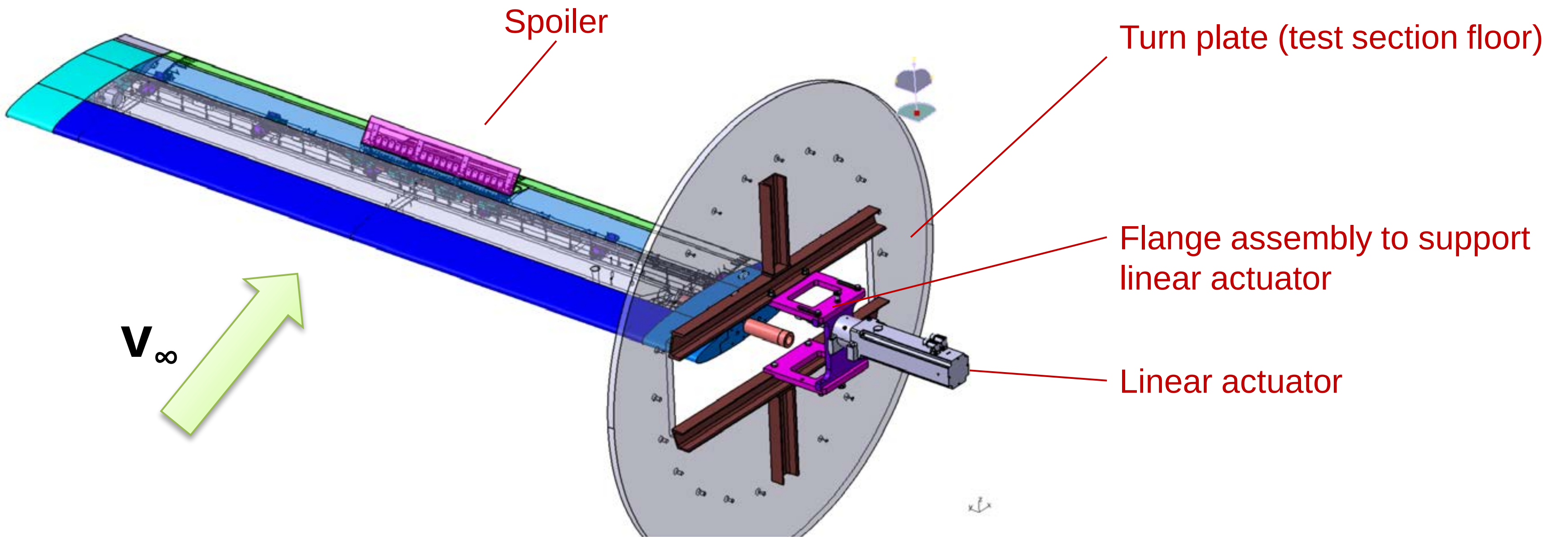

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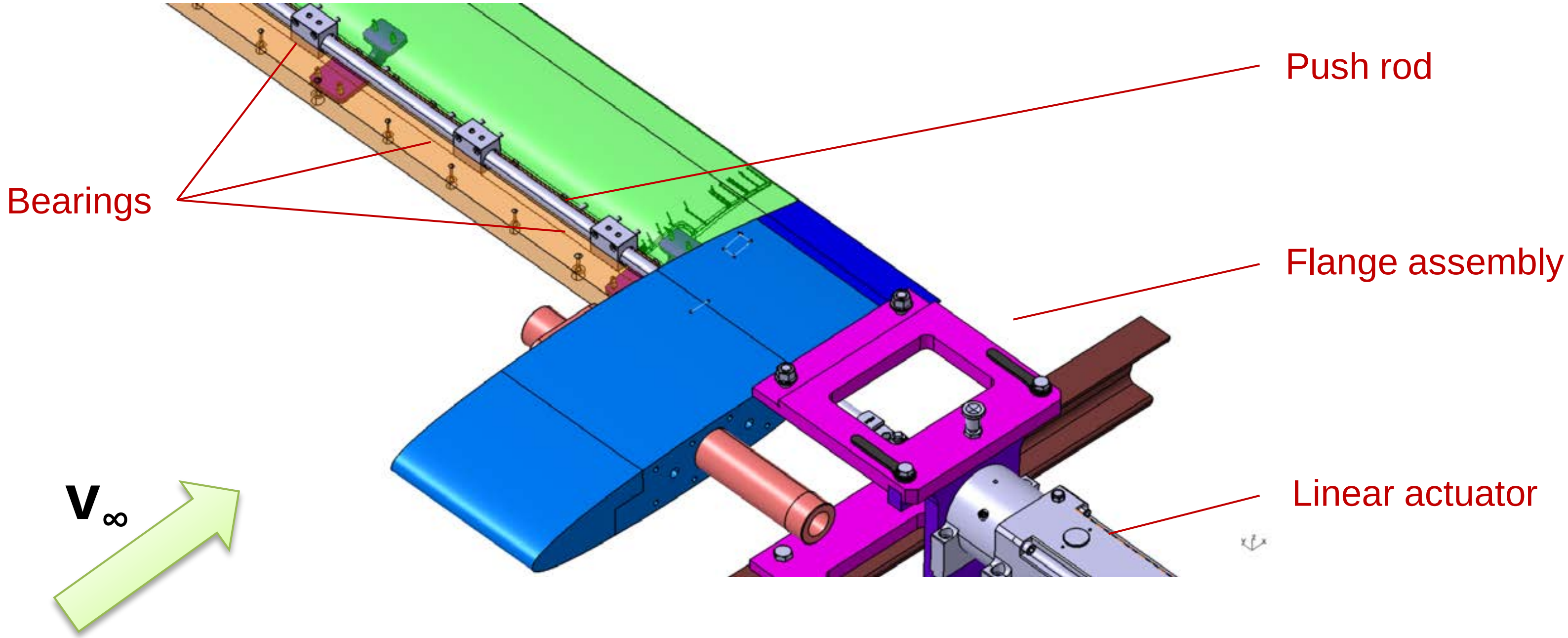

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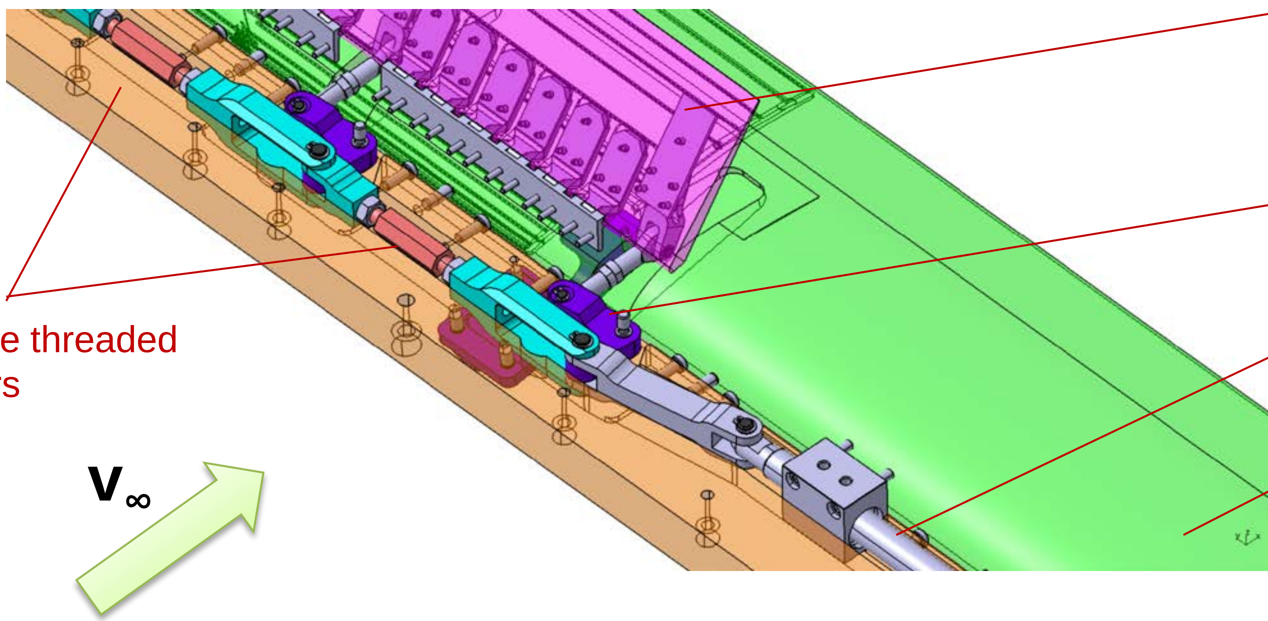

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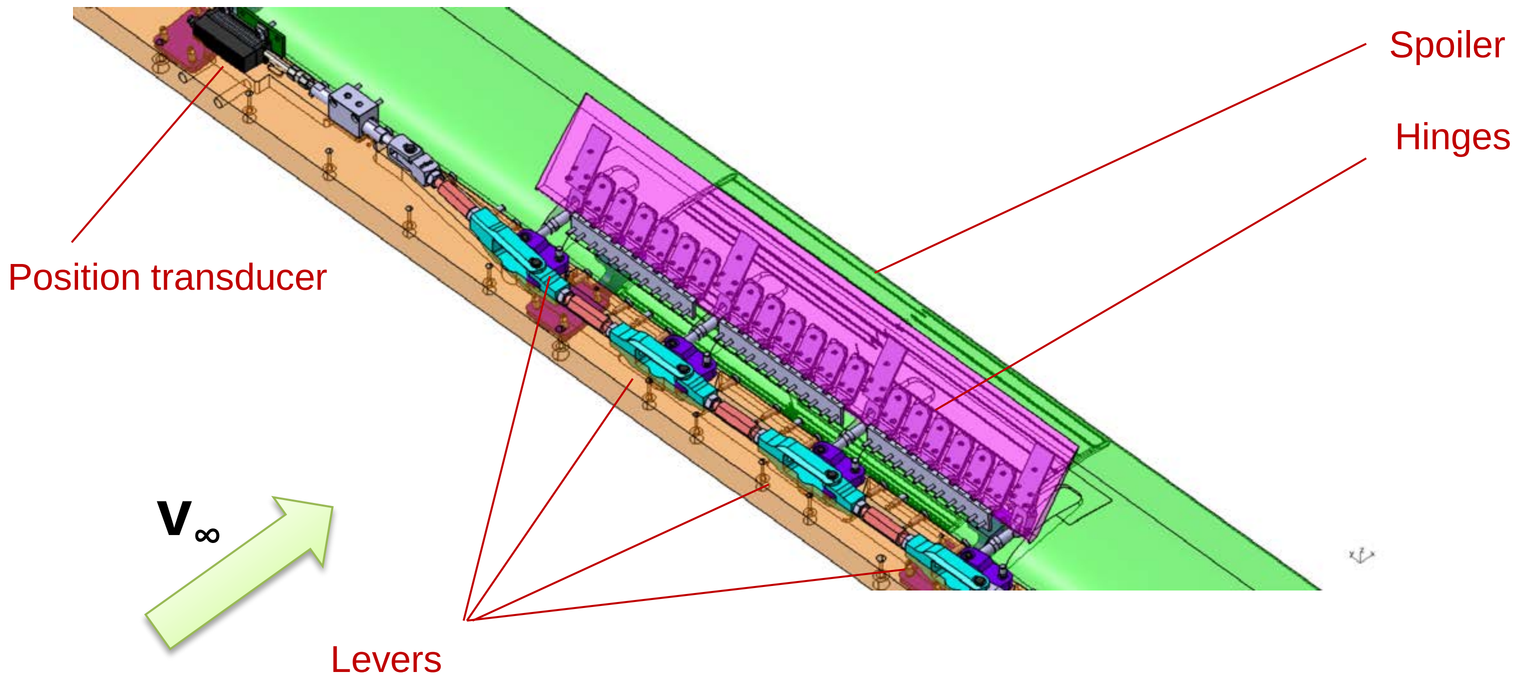

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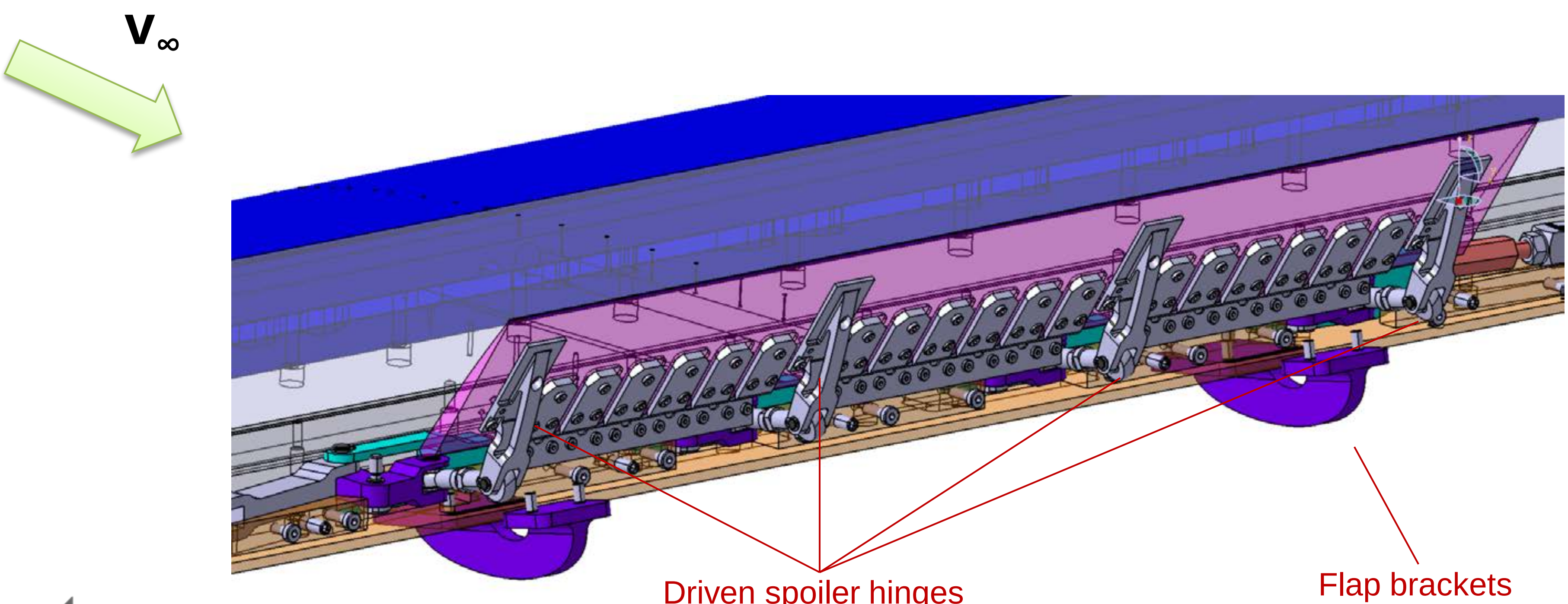
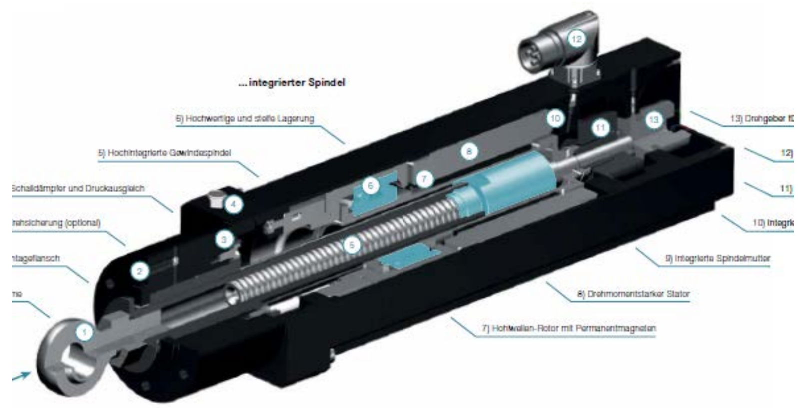
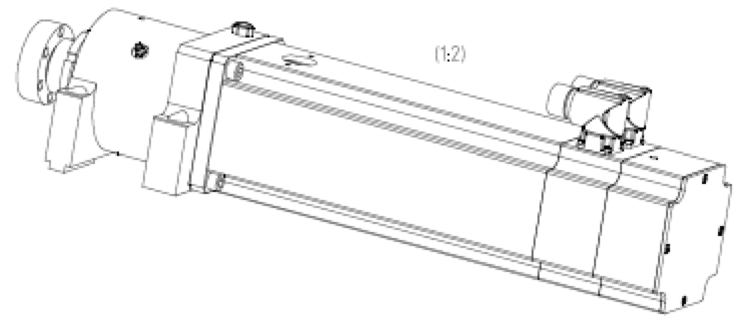


Spoiler actuator

- Electrically driven ball screw drive
- Fully integrated unit consisting of motor, ball screw, encoder and brake
- High forces and movement speed
- Challenge: very small travelling distances
  → deflection from 0° → 90° equals ~ 22 mm only
- Dimensions:
  Length 471 mm
  Diameter 100 mm x 100 mm





Stroke length	200 mm
Ball screw pitch	5 mm
Max. brake force	4000 N
Max. continuous force	6000 N
Max. force (temporary)	20000 N
Max. movement speed	300 mm/s

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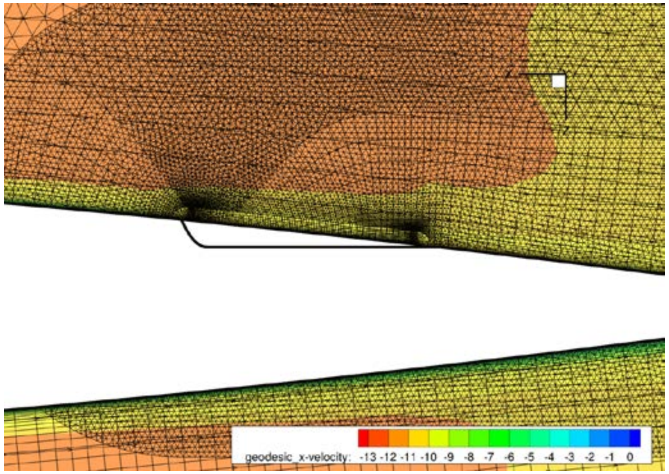
- **Outlook**

Outlook
Experiments

- Manufacturing has started in 11/2015
- The DLR-F15 model with spoiler will be capable to sustain cryogenic conditions
- Two wind tunnel campaigns in 2016 in the DNW-NWB facility in Braunschweig
    - Apr/May 2016: 10 days
        - Focus on steady and unsteady surface pressure information while investigating static and dynamic spoiler deflections
        - 2D setup
        - Optical monitoring of the spoiler position
    - Nov 2016: 10 days
        - Additional PIV measurements
        - 2D or 2.5D?
        - Additional flap deflections?

Outlook
Simulation

- Determination of critical loads completed
- Successfully verified and validated the DLR TAU code for a similar configuration
- Main work on dynamic simulations is beginning in mid 2016
- First attempts to simulate a deploying spoiler using a new, automatic hole cutting functionality of the DLR TAU code have already begun



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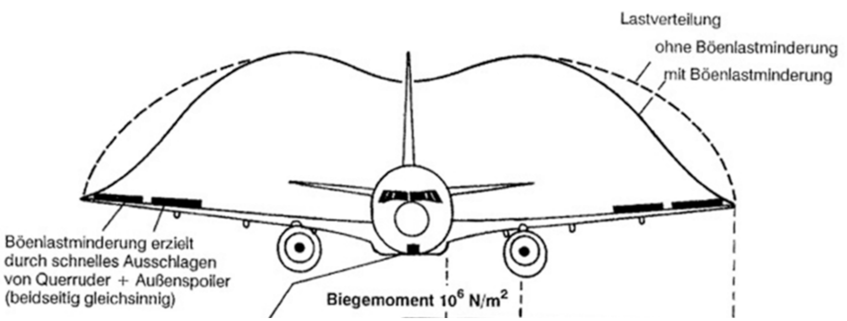
- Digital-X successor project VitAM (2016 – 2019) in which the modelling of a dynamic spoiler will also be addressed to virtually assess load alleviation systems



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Thank you!

Any questions?