Unsteady High-Lift Aerodynamics - Unsteady RANS Validation

An Overview on the UHURA Project

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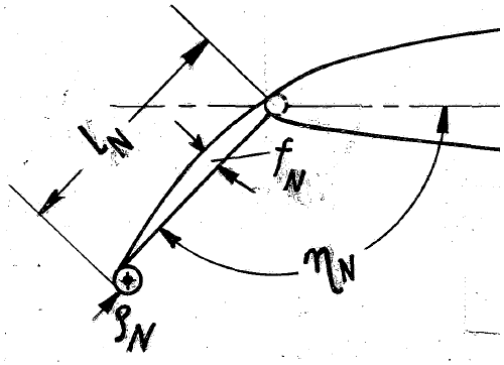
Horizon 2020
European Union funding
for Research & Innovation

What is a Krüger Device?

/nose split flap invented by W. Krüger (1943)

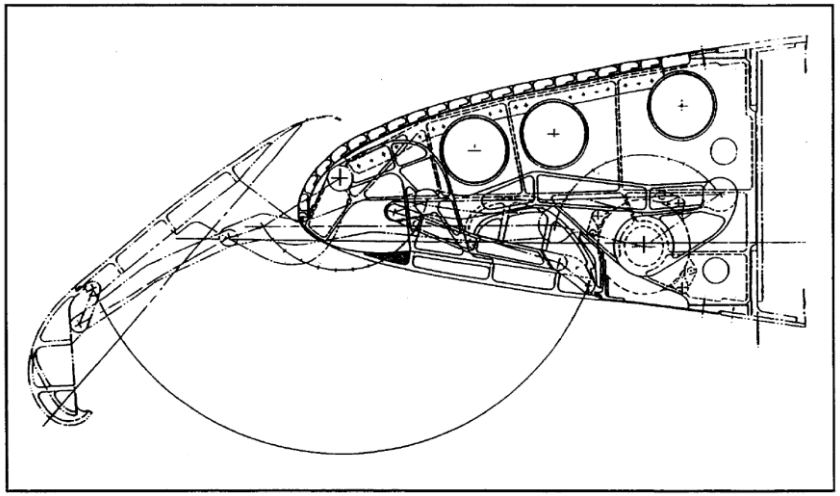
- High-lift leading edge device
- located at the leading edge
- deployed from the pressure side of the wing



W Krüger, Über eine neue Möglichkeit der Steigerung des Höchstauftriebes von Hochgeschwindigkeitsprofilen, AVA-Bericht 43/W/64, 1943

High-Lift System for B757-HLFC
vented folding bull-nose Kreuger device

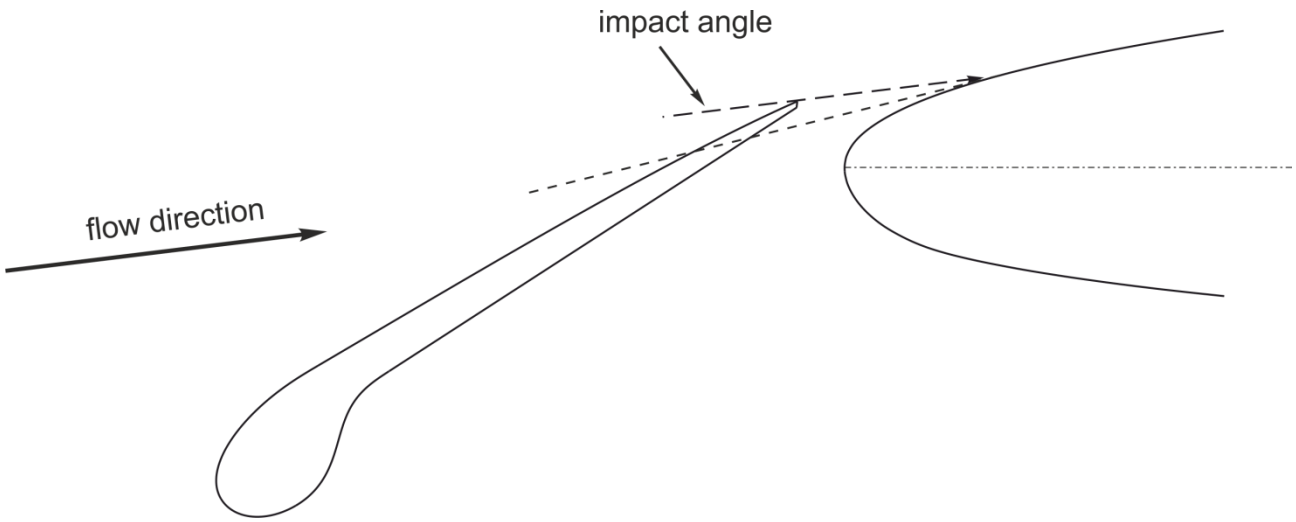
- "Folding, bull-nose (rigid) Krueger - The simple Krueger flap can be improved by adding a folding bull nose to it. [...] Because of the rounded bull nose, the folding, bull-nose Krueger is more tolerant to changes in angle of attack."
- "Fixed-camber Krueger - There has been no effort to develop the fixed-camber Krueger into a device that has characteristics similar to that of a slat, except for the work done on the 757 hybrid laminar flow experiment. Therefore, this area is one in which research could help the future implementation of hybrid or natural laminar flow concepts."



Why Krueger flaps for laminar wings?

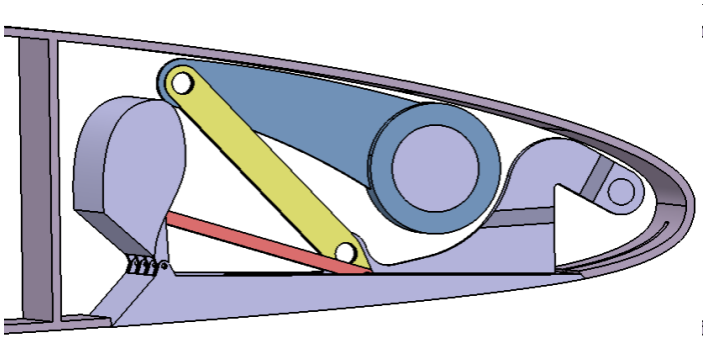
/ Requirements for laminar wing technology

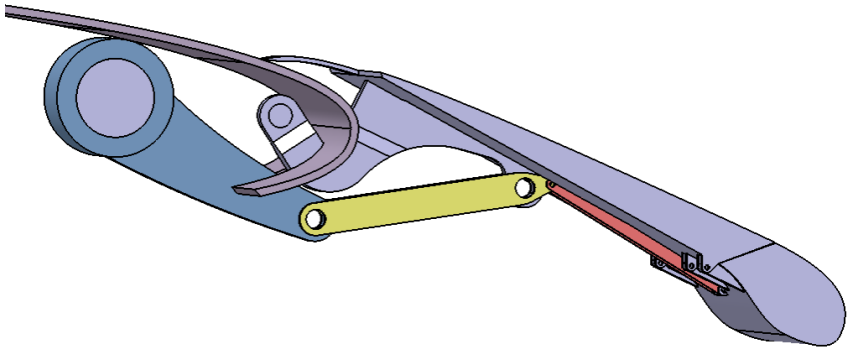
- / Avoid disturbance of wing upper side
- / Provide shielding of leading edge against contamination (insects, dust, moisture)



Aerodynamic design for a NLF wing
high-lift concepts for laminar wings

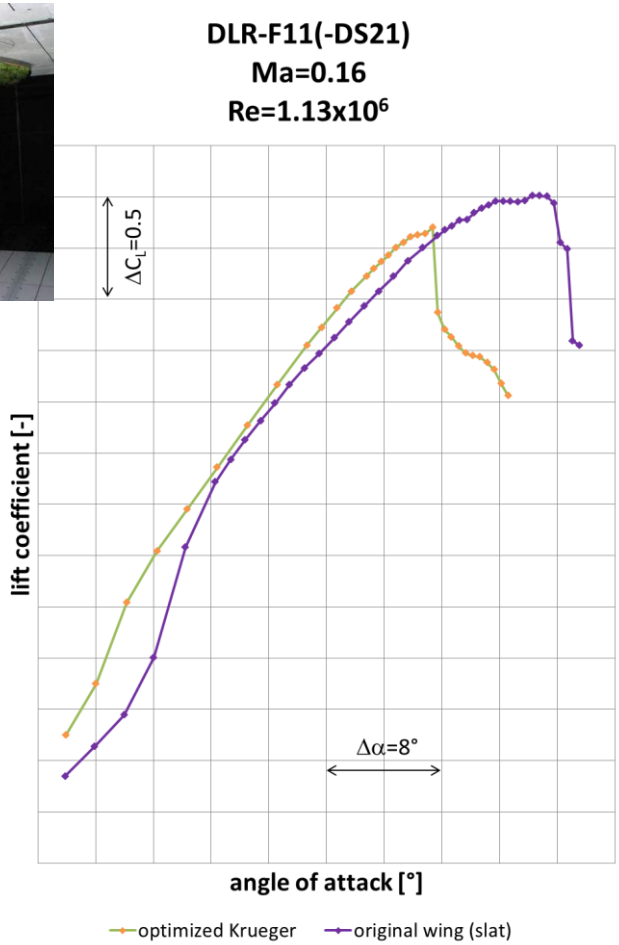
- analysis of different high-lift system concepts for compatibility with NLF wing requirements
  - high aerodynamic performance
  - guaranteed shielding against insect contamination
- select and design the compatible high-lift system including constraints from mechanical integration





The DeSiReH project has received funding from the European Community's Seventh Framework Programme FP7 under grant agreement n° -233607

Aerodynamic design for a NLF wing *performance assessment*



Key achievements

- designed Krueger device laminar wing closely comparable to turbulent wing with slat
- assessment of project achievements on Overall Aircraft Level (OAL) verified 4-7% fuel benefit of the high-lift enabled laminar wing aircraft
- assessment of project contributions to ACARE Vision 2020 targets shows significant contributions
- derivation of design strategy recommendations for industrial use of design optimization procedures
- formulations of testing guidelines for applying optical measurements at high Reynolds number testing

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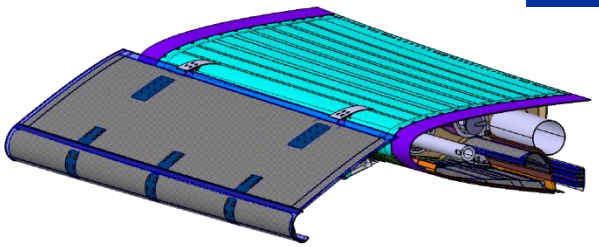
Aerodynamic design for an HLFC wing

wing integration



- **140° Krueger deflection**
  enabled by goose neck type kinematics
- **125° bullnose retraction angle**
  significantly benefits the space allocation in stowed position.
- **reduced actuation loads**
  due to late bullnose deployment
- **sealing foreseen for closing plate and Krüger**
  to enable cavity as suction camber
- **most forward position of opening/closing plate**
  behind stagnation line
- **in vertical position the Krüger panel is below the LE.**

The AFLoNext project has received funding from the European Community's Seventh Framework Programme FP7 under grant agreement n° 604013

Motivation

Identified issues

- deployment path critical in case of actuation failure/jamming
- deployment sequentially or in groups recommended

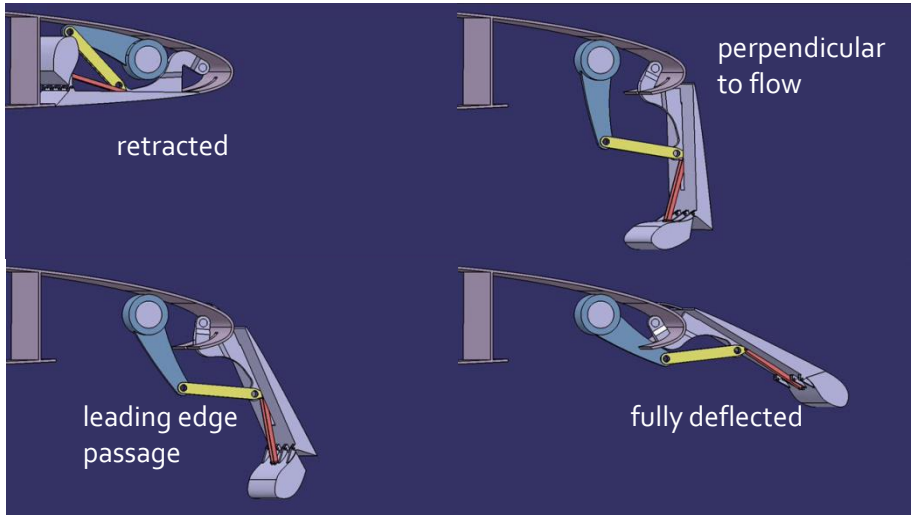
Challenges

- limited overall deployment time increases required deployment speed
- unsteady effects during deployments likely
- need for validated simulation methodology

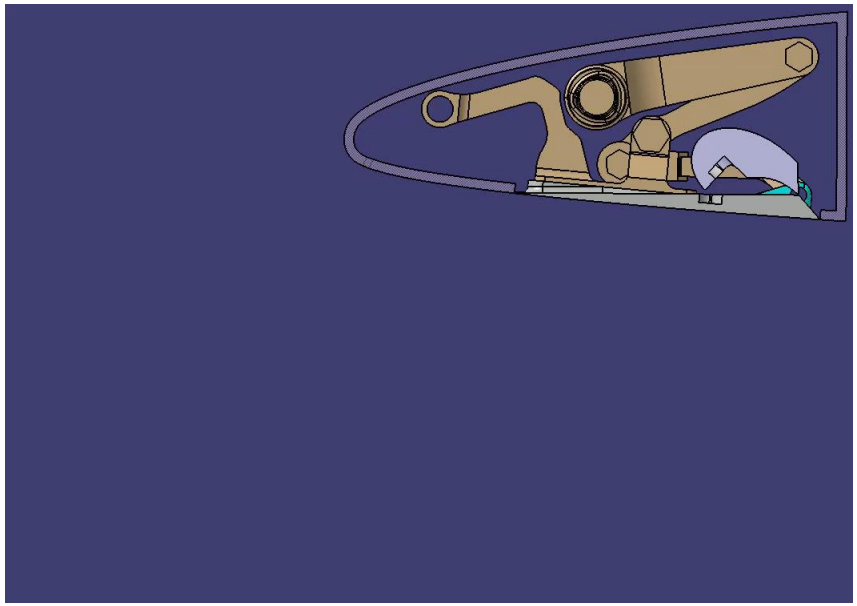
Source: airliners.net © Teemu Tuuri

Source: youtube.com © user/Jet3TV

Aerodynamic challenges

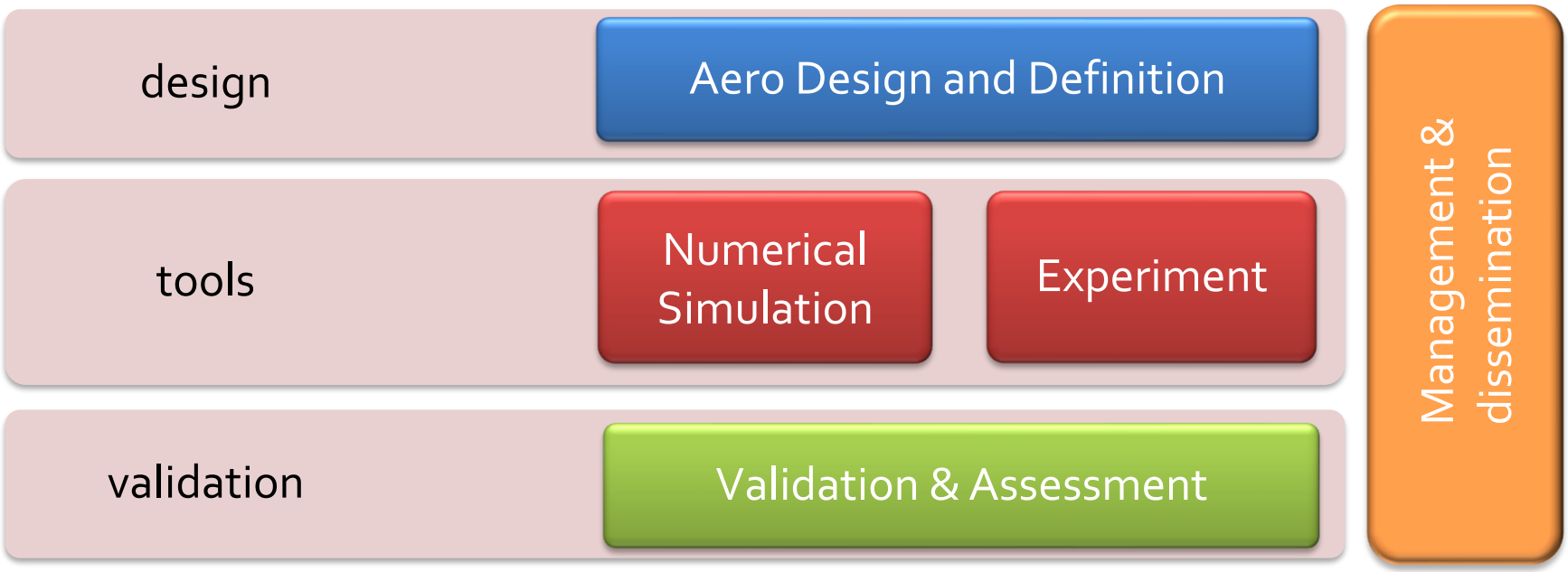


Specific critical conditions

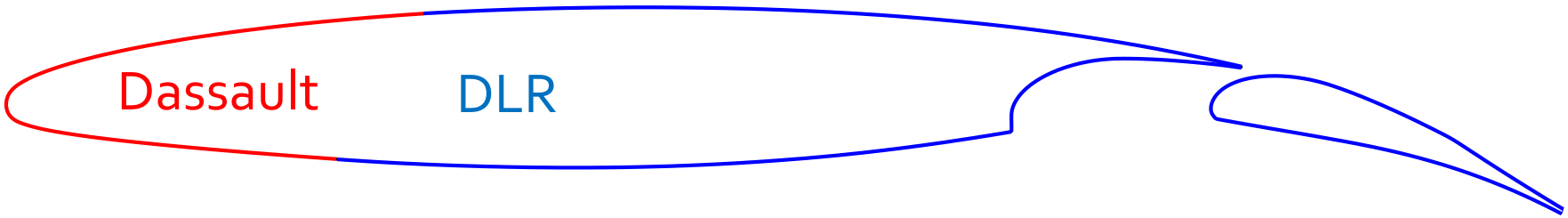


Targeted deployment time: 1s

Approach



Background
DLR-F15-LLE airfoil shape



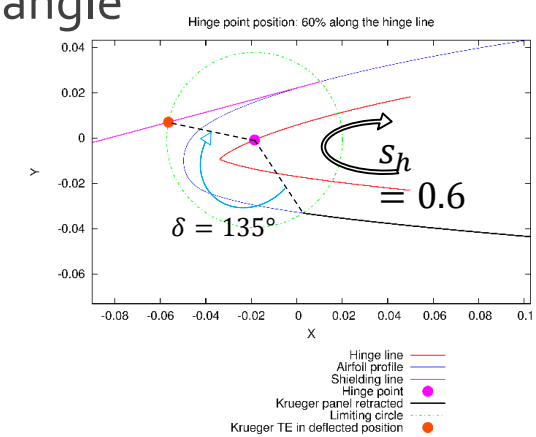
/ laminar wing version of the DLR-F15 airfoil, leading edge designed by Dassault

/ developped in CS2 Smart Fix Wing Aircraft

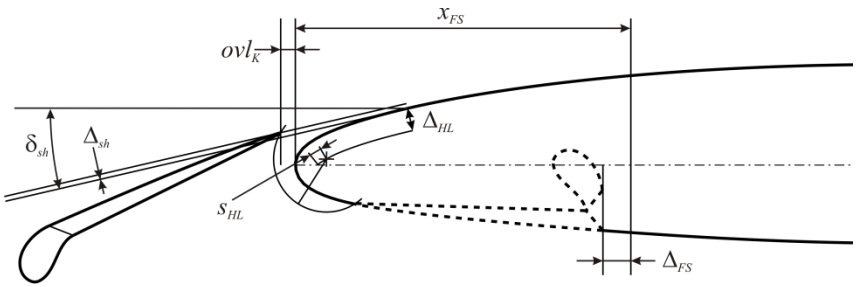
concurrent design optimization

- **Kinematics based coupling of size and position**
  - 1 curvilinear parameter: hinge point along offset from upper surface
  - limiting circle: centered in the hinge point and passing trailing edge position (guaranteed contamination shielding)
  - upstream cavity: intersection limiting circle/airfoil contour

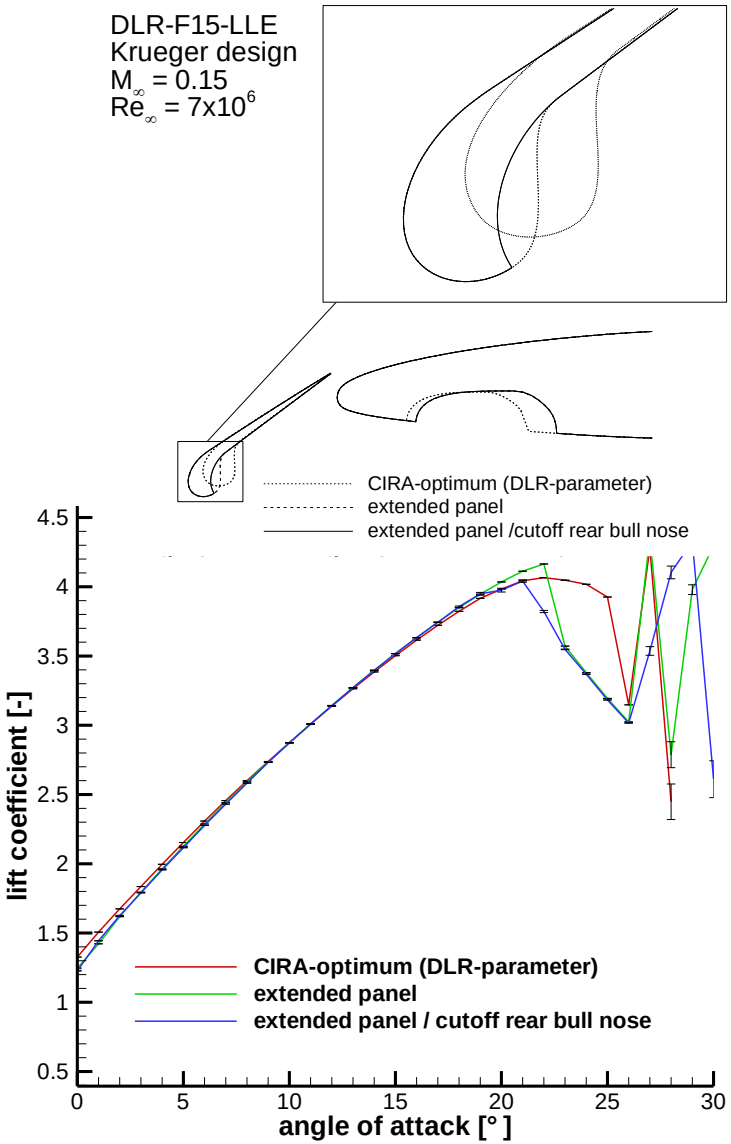
- **CIRA parameterization**
  - Krueger panel size fixed
  - shielding requirement for 9° impact angle



- **DLR parameterization**
  - front spar limit at 25%c
  - shielding requirement for 7° impact angle



kinematics compliant design

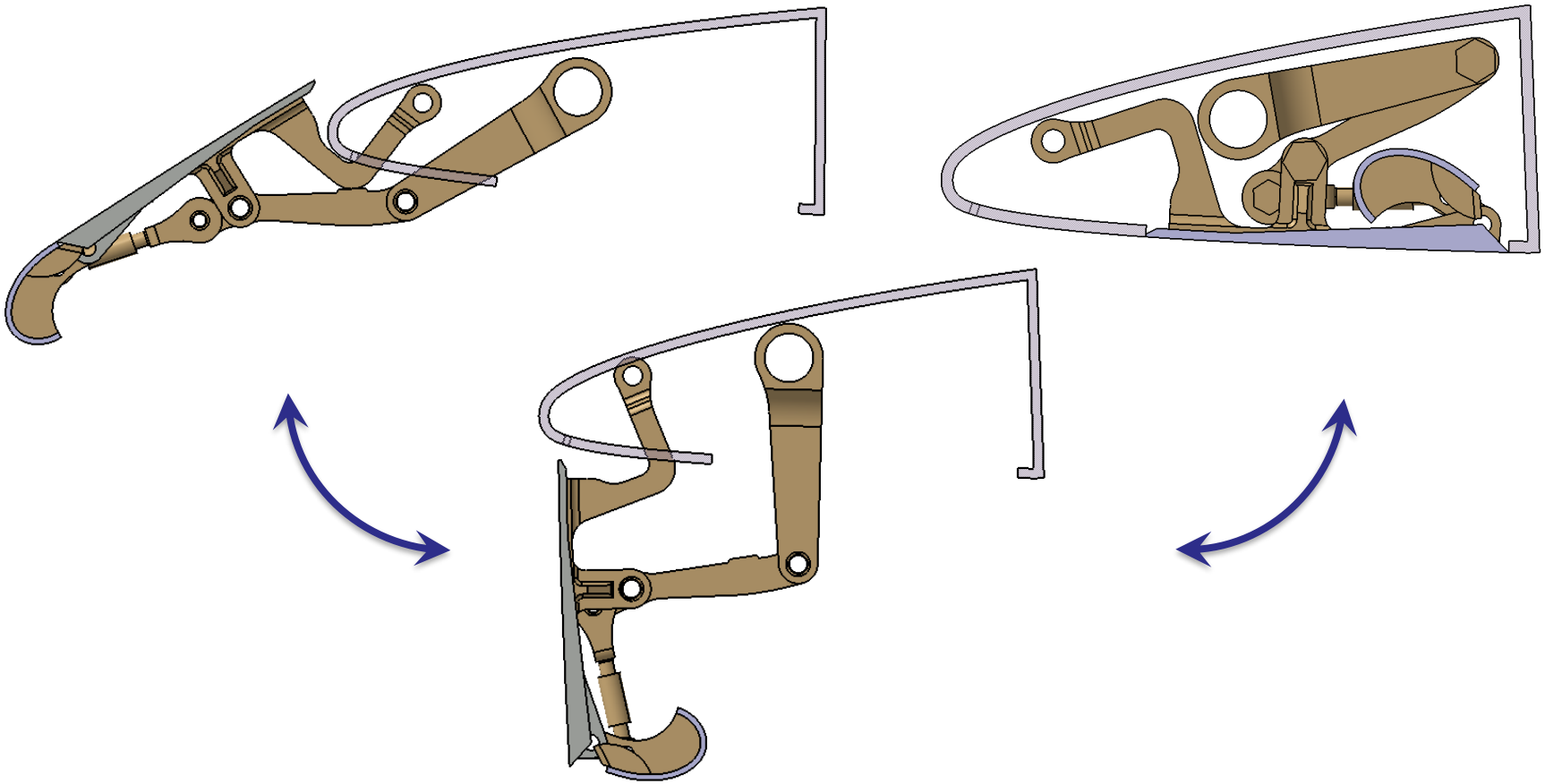


- respect requirements after first kinematics design loop
- extend rear cavity end for passing of kinematics levers
- cut rear bull nose shape allowing more compact folding

Kinematics design

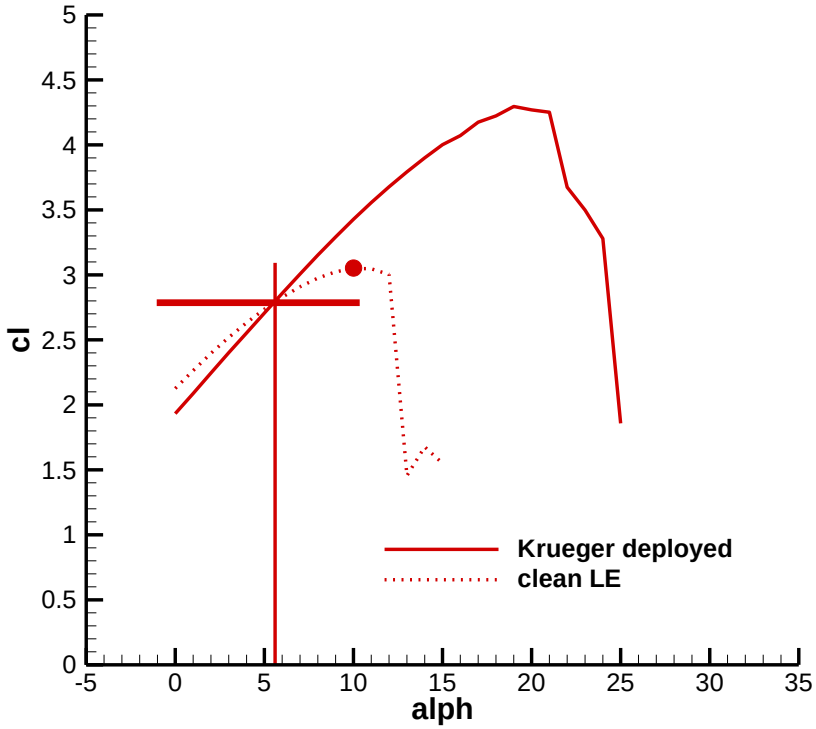
Gooseneck type kinematics

- compact design
- minimum number of moving parts
- fully stressed



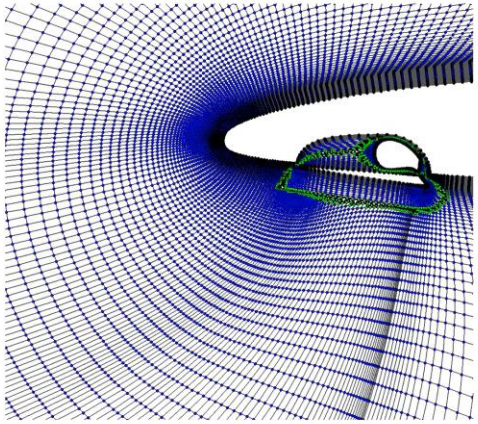
Krueger flap operation

- full dynamic deflection at maximum angle of attack is neither feasible nor required
- loads requirements:
  - full angle-of-attack range (up to stall) in steady mode only
  - dynamic mode only at reasonably low angles of attack
- for operating loads: choose angle of attack safe for Krueger retraction
  - C_L-condition: C_L = 2.9
  - α-condition: α = 6°

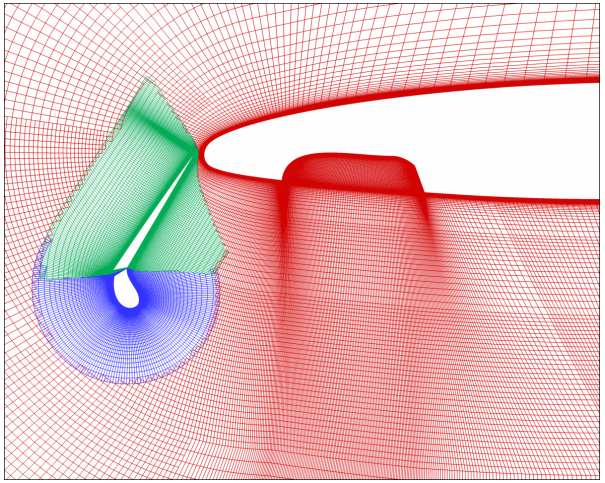


Improvement of CFD Meshing

- **Local reconnection**
  - Avoid interpolation in Chimera scheme
  - Reconnect mesh points in overlapping region
  - Only minor mesh quality degradation observed



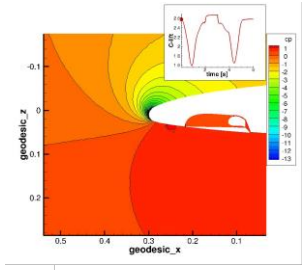
- **Local refinement**
  - Adjust mesh size in overlapping region
  - Improve Chimera interpolation accuracy
  - Automatic procedure on block structured meshes

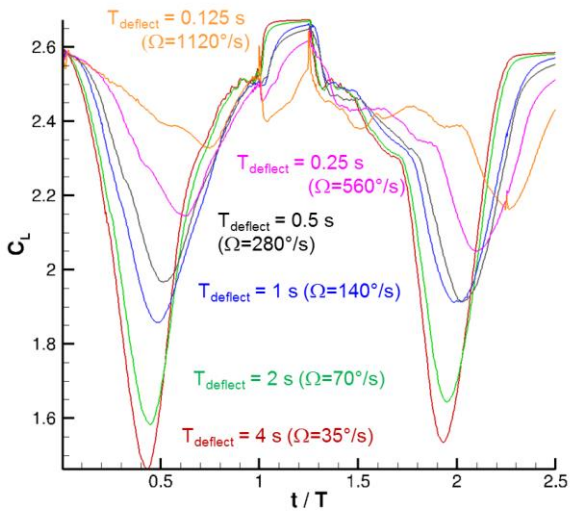


Improvement of CFD
RANS – uRANS – hybrid RANS/LES

RANS – uRANS by Chimera

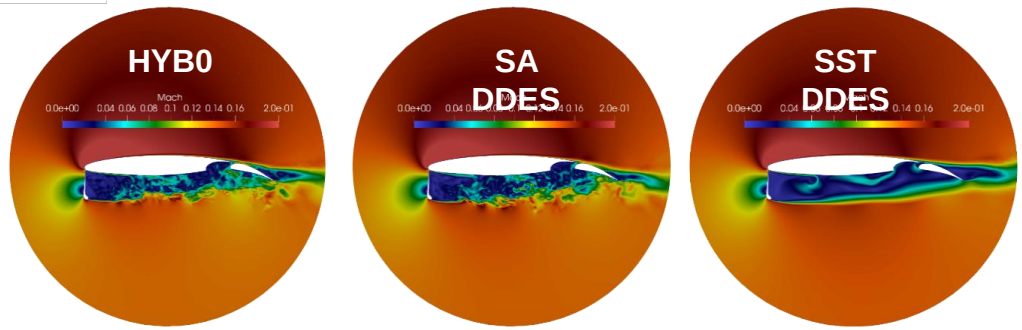
- Different proprietary Chimera implementations
- Provide stable setup
  - Adjustment of cell alignment
  - Mesh setup





Hybrid RANS/LES

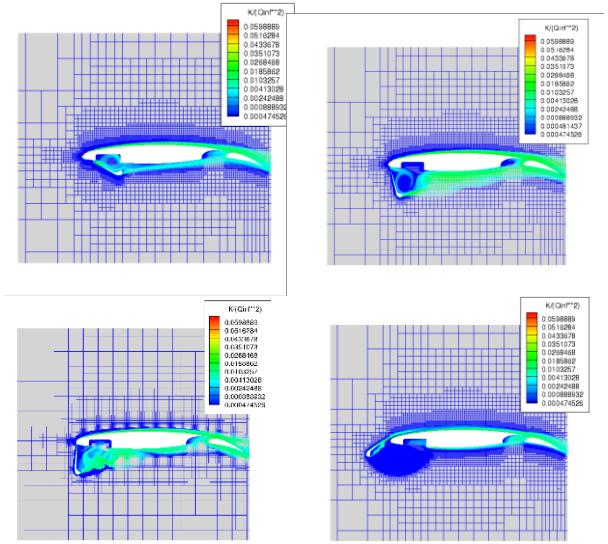
- Evaluation of different subscale models
- Balance of turbulence resolution and computational effort
- Acceleration by parallel line-implict solver



Improvement of CFD
alternative methods

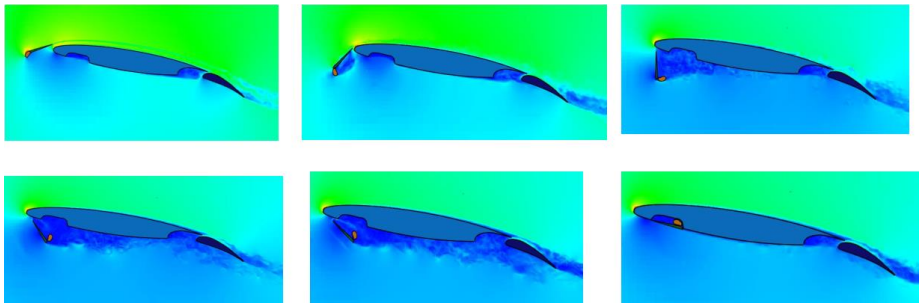
Immersed boundary method

- Dynamic IB method for moving/deforming objects
- CIRA-IBK interface between CFD and CSM meshes.
- Static and dynamic two-way FSI-coupling



Lattice Boltzman method

- Preliminary assessment of LBM for unsteady aerodynamics prediction of Krueger device
- WMLES mesh strategies studied for LBM
- LBM-WMLES preliminary verification with RANSPreliminary dynamic computations :
  - Affordable with limited available computational resources
  - Hysteresis due to numerical model



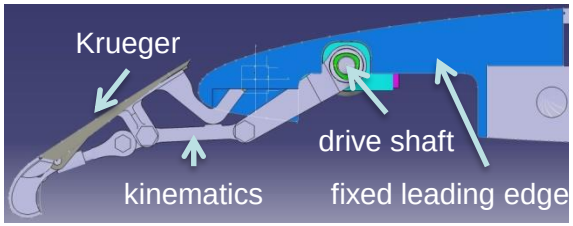
Wind tunnel experiments

/ DLR-F15 and DLR-F15LS wind tunnel models

DLR-F15-LLE in ONERA L1
DLR-ONERA CRP LEAFCO

DLR-F15*S* in DNW-NWB
LuFo V project MOVE.ON

DLR-F15LS in DNW-LLF
EC project OPENAIR



600 mm chord
2.4 m span (0°)
2 m span (30°)

1200 mm chord
7 m span

Wind tunnel experiments

ONERA-L1, closed test section, DLR-F15, 2D wall-to-wall: medium Reynolds number (approx. 2-3x10^6), detailed flow field with PIV, influence of deflection rate.

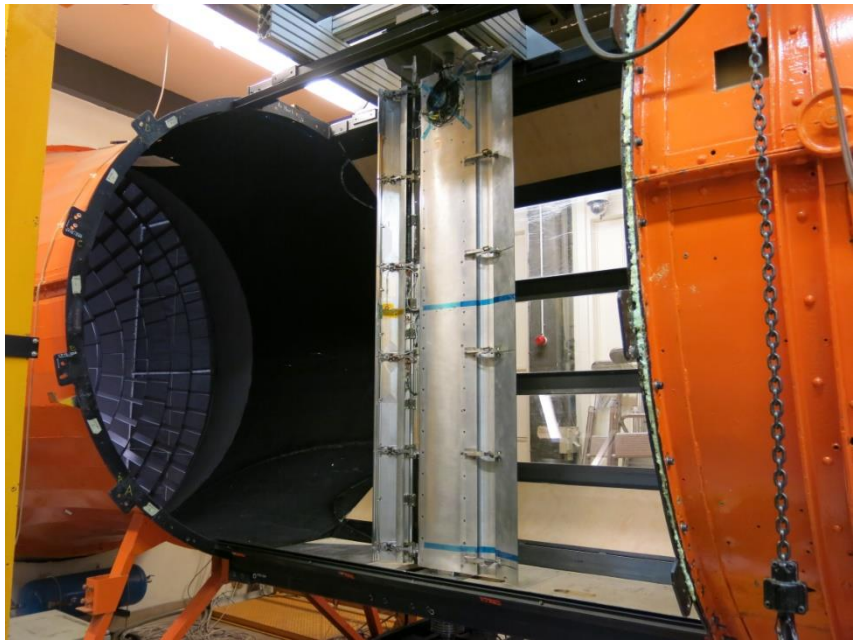
DNW-NWB, closed test section, DLR-F15S, 2,5D cantilever wing: influence of sweep, wake measurements (5-hole probe rake), possibly SPR

DNW-LLF, open test section, DLR-F15LS, 2D und 2.5D: realistic actuation & kinematics, effect of Reynolds number (ca. 6x10^6), effect of span loading, detailed flow field with PIV, force integration, Krueger flap deformation

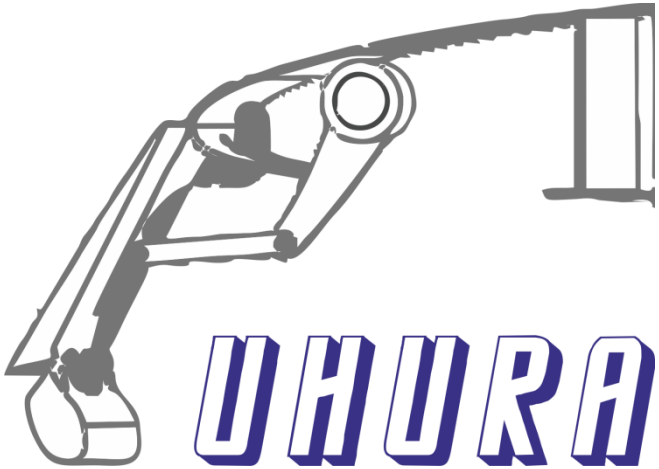
Conclusion

UHURA aims to provide

- Detailed understanding of unsteady high-lift flow field
- Detailed experimental data of unsteady Krueger flap movement
- Validated CFD methods for unsteady high-lift flows



DLR-F15 model with Krueger flap setup in ONERA L1 wind tunnel



The project leading to this presentation has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 769088

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