Unsteady High-Lift Aerodynamics - Unsteady RANS Validation

An Overview on the UHURA Project

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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

https://www.wired.com

Boeing 747

www.wikiwand.com

Boeing 707
“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
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

The DeSiReH project has received funding from the European Community's Seventh Framework Programme FP7 under grant agreement nº 233607
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.**
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

- **design**: Aero Design and Definition
- **tools**: Numerical Simulation, Experiment
- **validation**: Validation & Assessment

Management & dissemination
Background
DLR-F15-LLE airfoil shape

/laminar wing version of the DLR-F15 airfoil, leading edge designed by Dassault
/developed 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.
2. Limiting circle: centered in the hinge point and passing trailing edge position (guaranteed contamination shielding).

CIRA parameterization:
1. Krueger panel size fixed.
2. Shielding requirement for 9° impact angle.

DLR parameterization:
1. Front spar limit at 25%c.
2. 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: $C_L = 2.9$
   / $\alpha$-condition: $\alpha = 6^\circ$
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-implicit 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 Boltzmann method**
- Preliminary assessment of LBM for unsteady aerodynamics prediction of Krueger device
- WMLES mesh strategies studied for LBM
- LBM-WMLES preliminary verification with RANS
- Preliminary 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-F15S in DNW-NWB  DLR-F15LS in DNW-LLF
DLR-ONERA CRP LEAFCO  LuFo V project MOVE.ON  EC project OPENAIR

600 mm chord  2.4 m span (0°)  1200 mm chord  7 m span
2 m span (30°)
Wind tunnel experiments

ONERA-L1, closed test section, DLR-F15, 2D wall-to-wall: medium Reynolds number (approx. $2 \times 10^6$), 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. $6 \times 10^6$), 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
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