Meshing and CFD strategies for large scale turboprop WT model integrating morphing high-lift devices

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Thanks to
Song Chen and Peter Eliasson, KTH

Traditional CFD approach

Wind-tunnel experiment

- Wind-tunnel model
  - Interchangeable modules
  - Control surface settings
  - Measurements (sensors, balance, …)
- Operation conditions
- Defined by a test matrix
- Generation of test database
  - Running the tests (computer controlled?)

CFD

- Geometry
- Meshing for fixed settings
- Operational conditions
- CFD
- Post processing
  - Comparison with test data
  - Possibly rerunning
- Collected in database

Test matrix CFD approach

Wind-tunnel experiment

- Wind-tunnel model
  - Interchangeable modules
  - Control surface settings
  - Measurements (sensors, balance, …)
- Operation conditions
- Defined by a test matrix
- Generation of test database
  - Running the tests (computer controlled?)

Numerical experiment (CFD)

- Parameterized meshing model
  - Interchangeable modules
  - Control surface settings
  - Monitors (Cp, forces, …)
- Operation conditions + CFD settings
- Defined by a CFD test matrix
- Generation of CFD database
  - Running the CFD (python controlled)

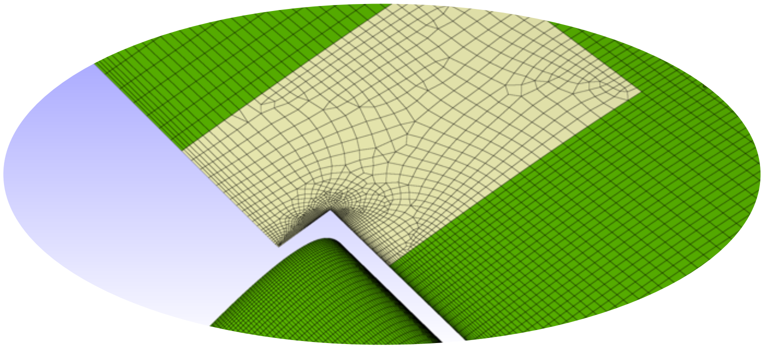
High-Fidelity meshing

Automatic meshing

- Specific geometry (one setting)
- Automatic meshing
  - Fast – remake for each setting
  - Triangular surface mesh
  - Prismatic layers
  - Refinement zones
  - Decent compromise accuracy - size

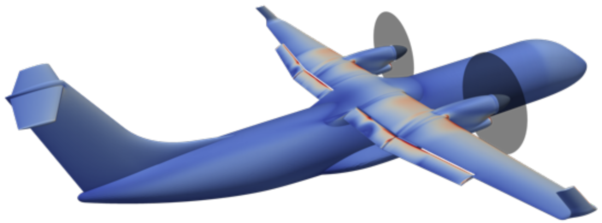
Hi-Fi parameterized meshing

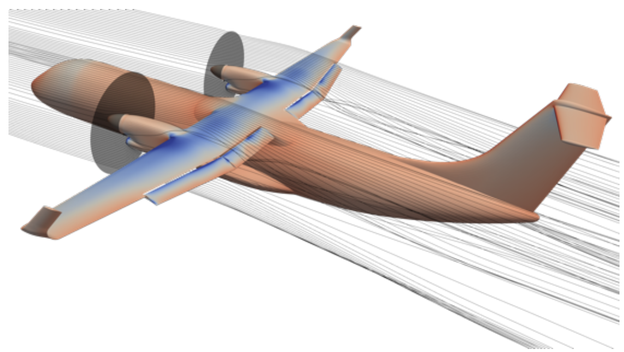
- Parameterised geometry (all settings)
- Meshing script
  - Manual work made once
  - Carefully designed surface mesh
  - Structured and unstructured patches
  - Parameterised mesh settings
  - Best accuracy - size



WTM-RECYCLE – CleanSky 2

- CleanSky-II EU project
  - Leonardo regional aircraft
  - 3 partners, KTH coordinator
- Large-scale turboprop WT model
  - Wing-propellers-fuselage-tail model
  - Natural Laminar wing design
  - Novel morphing high-lift devices
- WT model design and manufacturing
  - Large size ~5m
  - Modular devices and wing profiles
- WT testing at RUAG-LWTE
  - Running propellers
- CFD
  - Validation
  - Extrapolation to full scale





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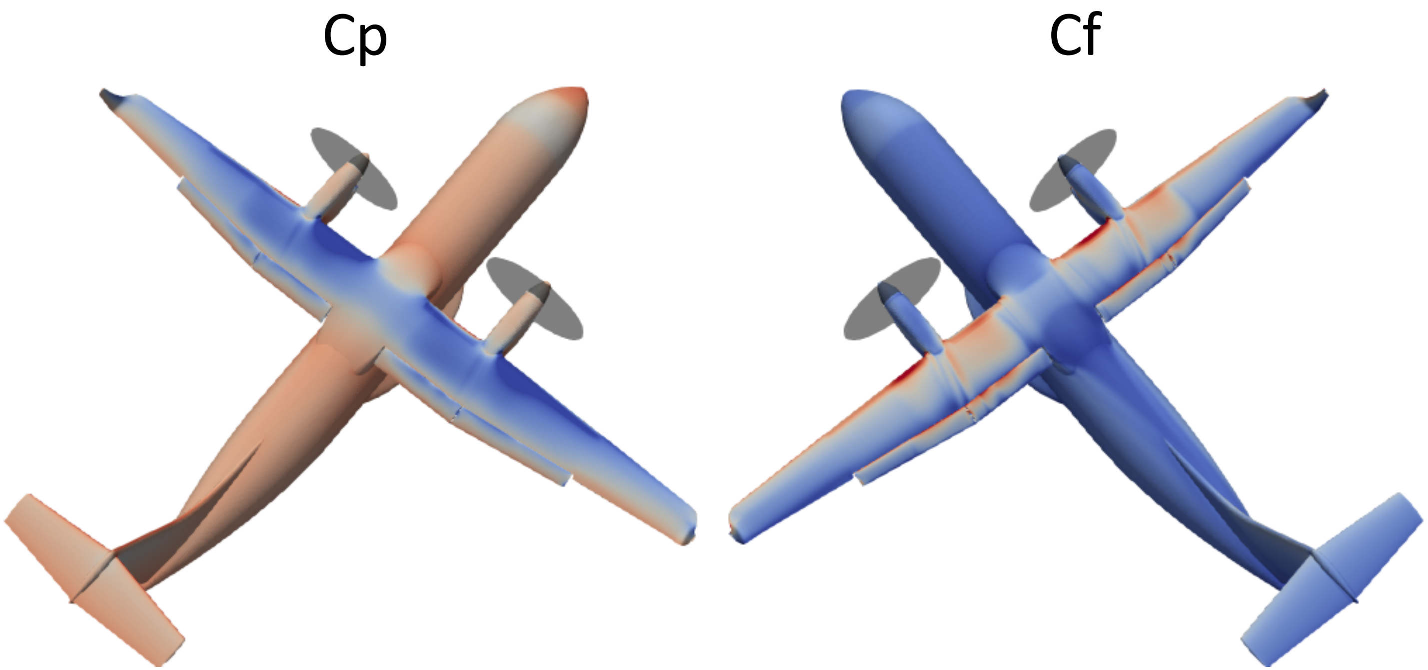
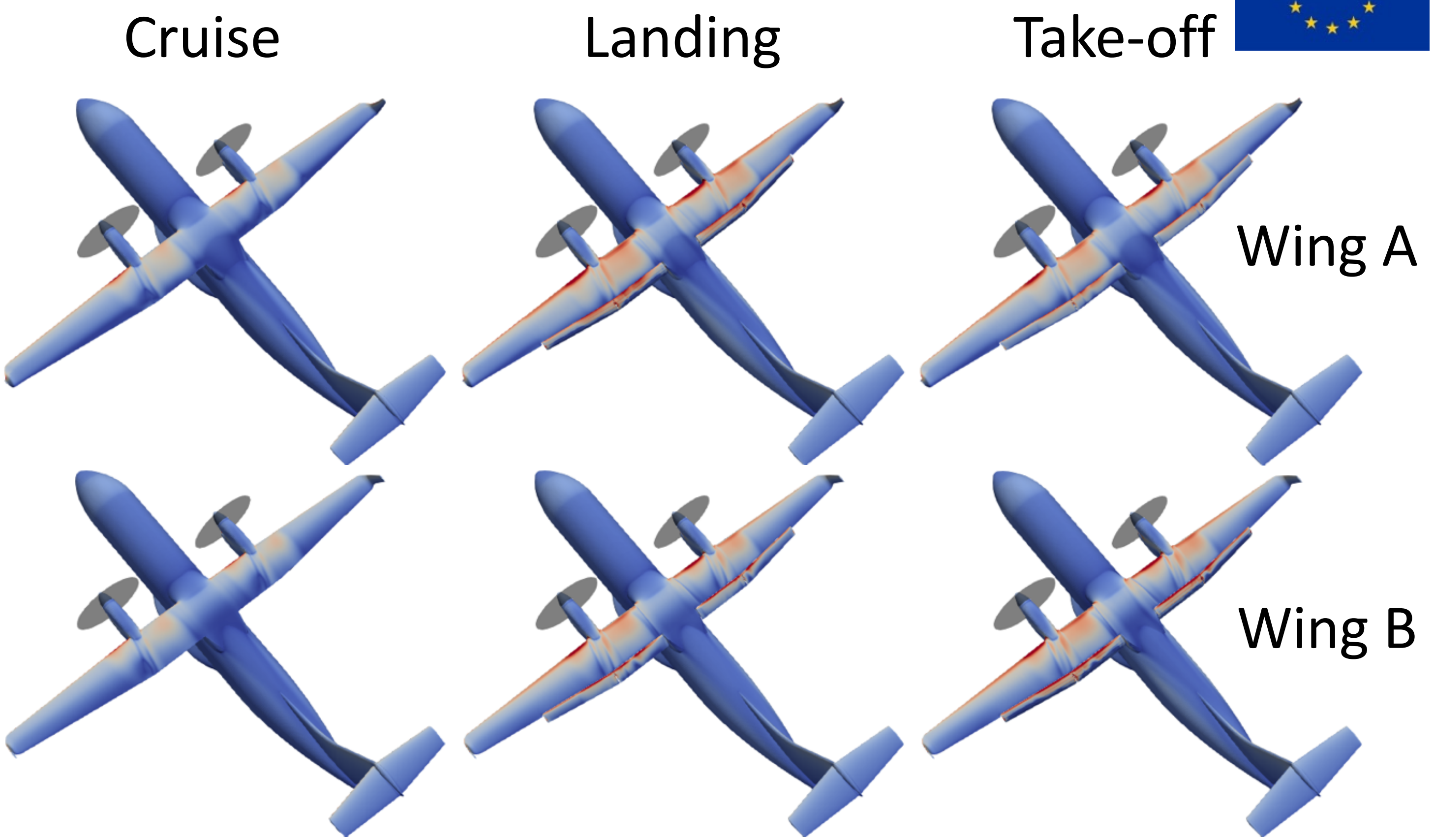
Example

- CFD
  - ~30M nodes
  - 2h on 128 cores
  - RANS EARSM model
  - Propeller disk model
- Take-off condition
  - Drooped nose
  - High propeller thrust
- Skin friction plot
  - Asymmetric
    - co-rotating props



Automatic CFD

- Automatic CFD
  - Python script
- Meshing model
  - Scripted
  - Pointwise software
- CFD test matrix
  - Geo modules
  - Ctrl surface settings
  - Propeller setting
  - Flow conditions
  - Etc



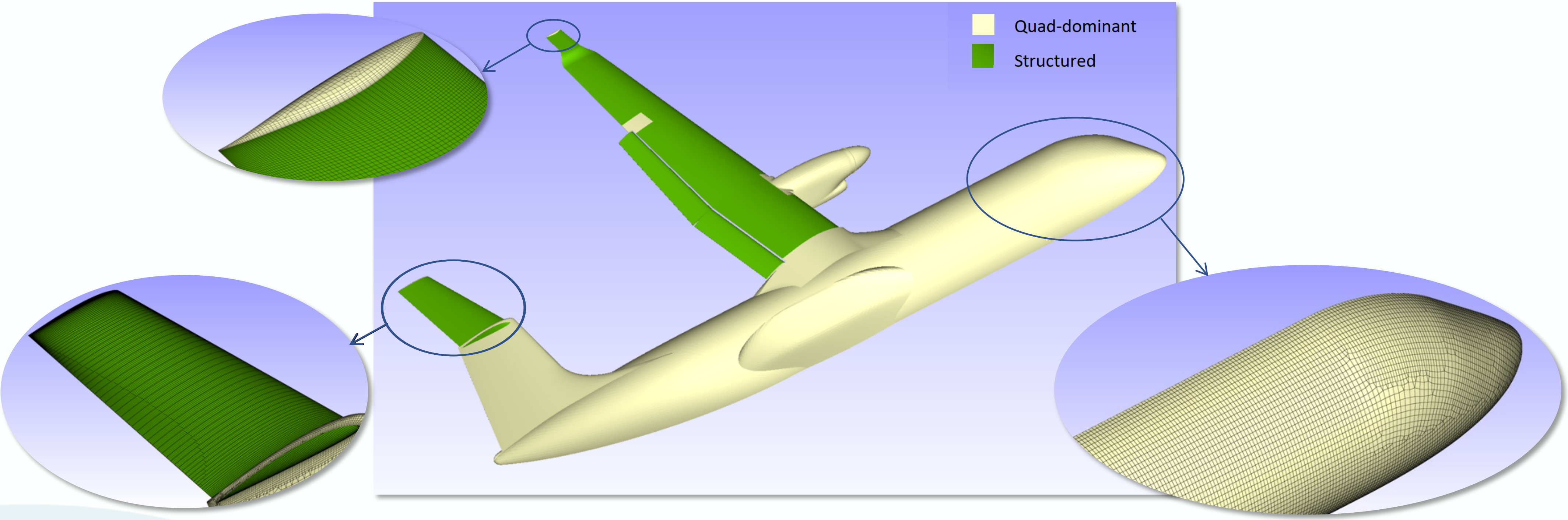
Meshing with Pointwise

Faranggis Bagheri

neptech

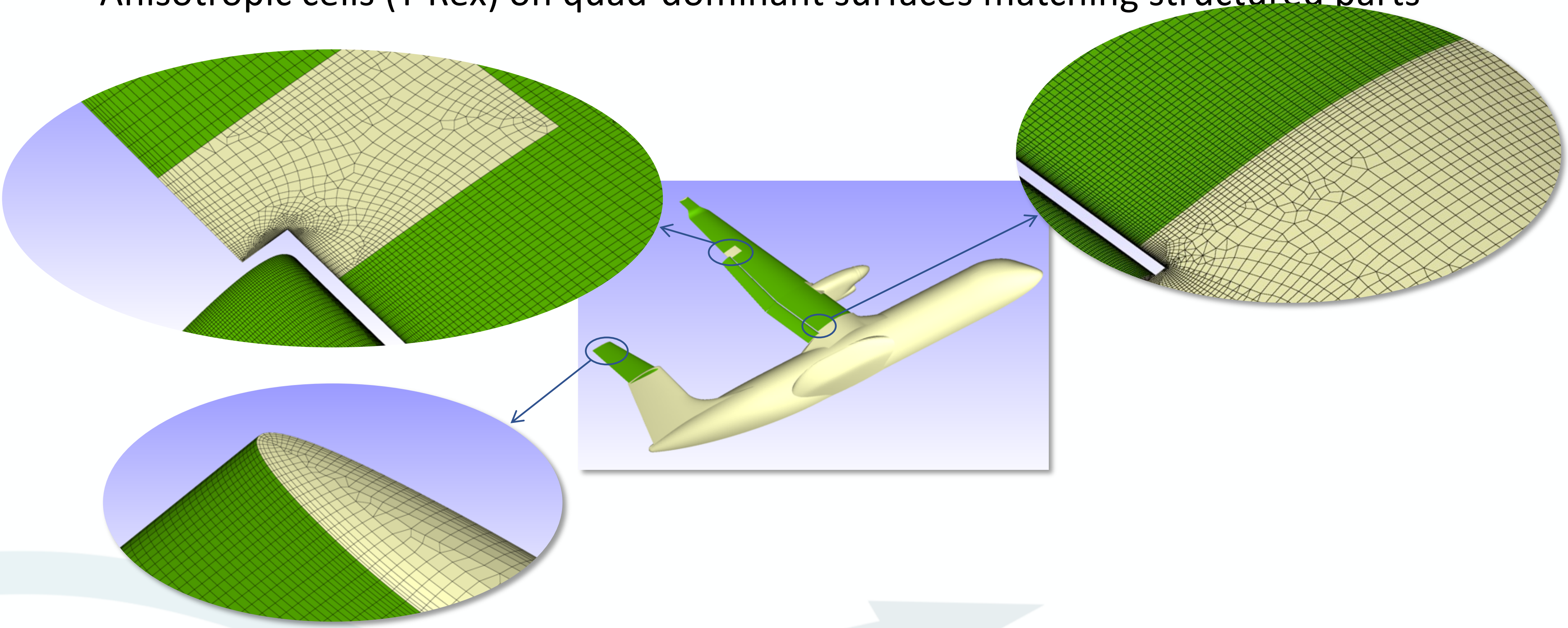
Surface Mesh

Structured mesh on important regions, quad dominant mesh on the remaining parts



Surface Mesh

Anisotropic cells (T-Rex) on quad-dominant surfaces matching structured parts



Volume Mesh

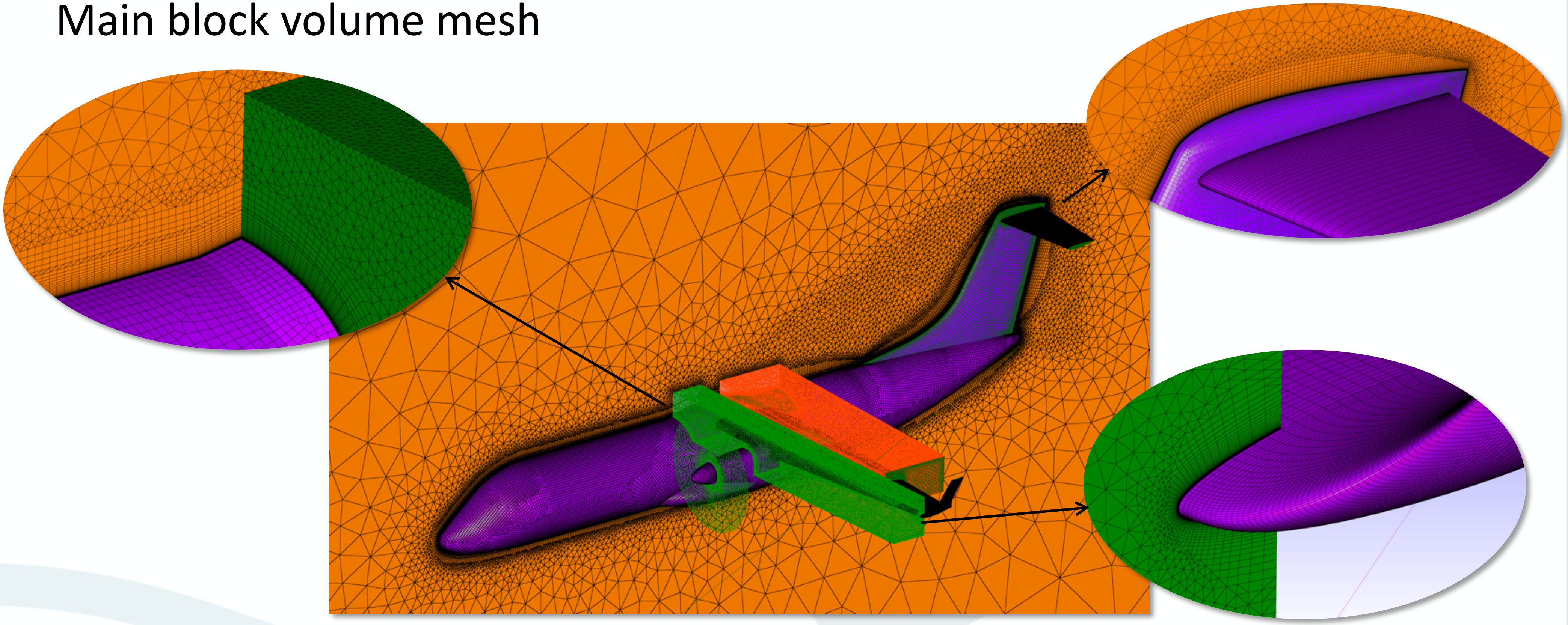
Use of scripting to automate creation of volume mesh

- TE and LE configurations
- First layer height
- Growth rate
- Pointwise volume mesh settings
- Matching the mesh of propeller with the given first layer height and growth rate

```
#
# This script loads the surface mesh file and generates the volume mesh
# export the mesh to Edge format.
#

# -------------------------------------------------------
# -- INITIALIZATION
# --
# -- Load Glyph package, initialize Pointwise, and
# -- define the working directory.
# --
# -------------------------------------------------------

# Load Glyph and Tcl Data Structure Libraries
package require PWI_Glyph

# Initialize Pointwise
pw::Application reset
pw::Application clearModified

# Define Working Directory
set scriptDir [file dirname [info script]]

# -------------------------------------------------------
# -- USER-DEFINED PARAMETERS
# --
# -- Define a set of user-controllable settings.
# --
# -------------------------------------------------------

set fileName        "SurfaceMesh.pw";  # Aircraft surface mesh filename
set droopedLE                      0;  # 0 for normal LE, 1 for drooped LE
set TEposition                     0;  # 0 for take off, 1 for cruise, 2 for landing
set initDs                     0.002;  # Initial wall spacing for boundary layer extrusion
set growthRate                  1.15;  # Growth rate for boundary layer extrusion
```

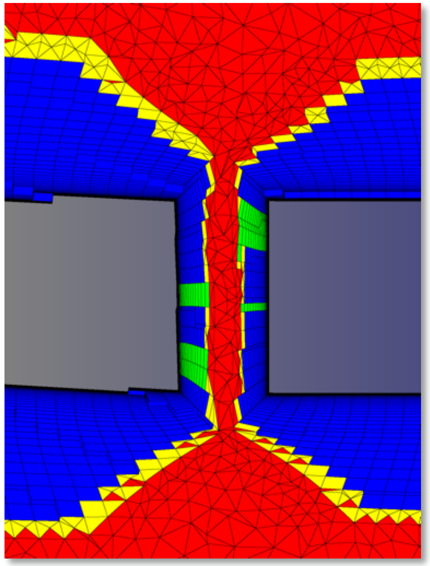
Volume Mesh

Main block volume mesh

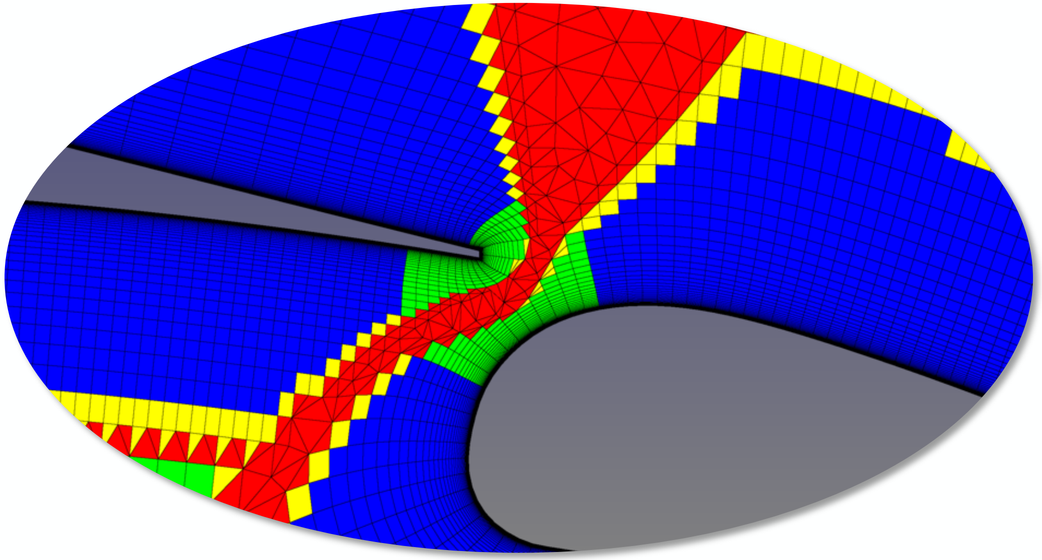


Volume Mesh

Volume mesh settings



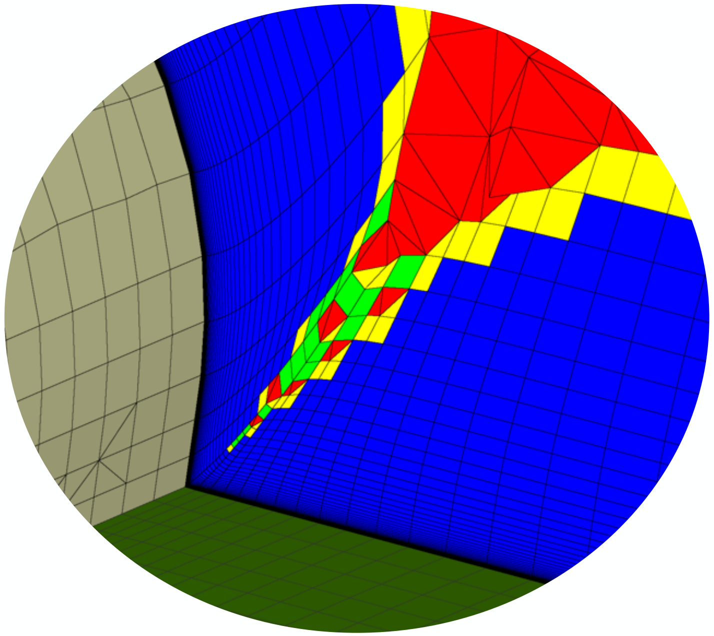
The gap between flaps

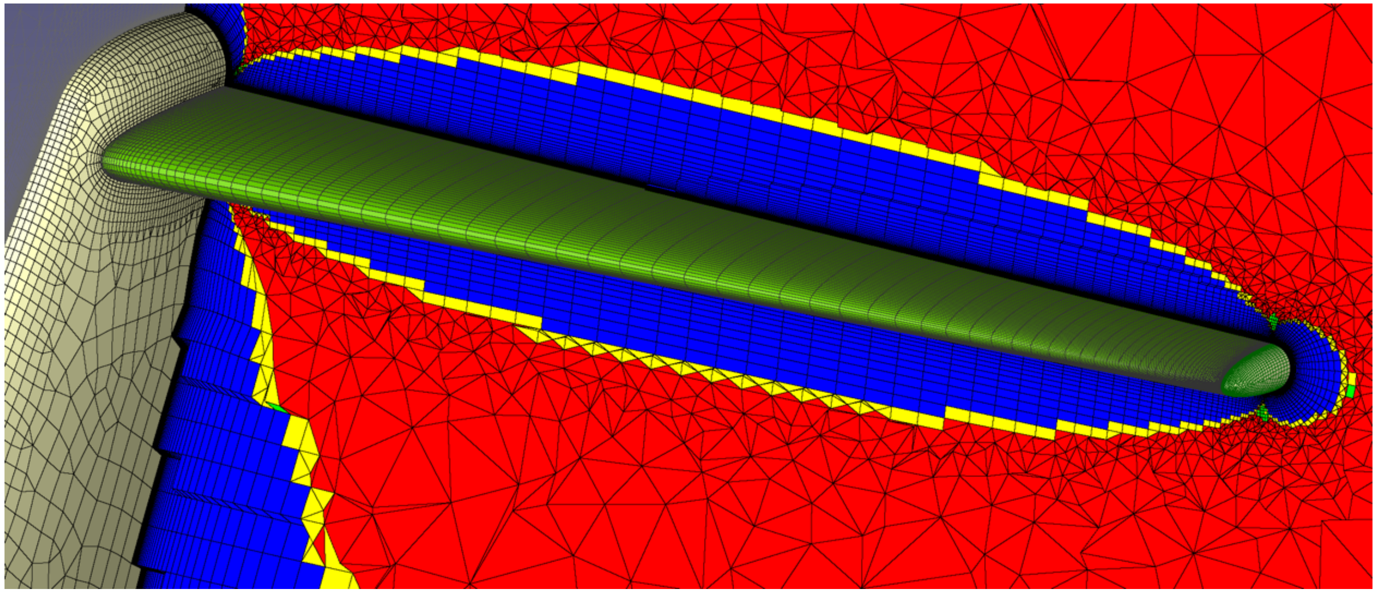


The gap between wing and flap

Volume Mesh

Volume mesh around the tail wing

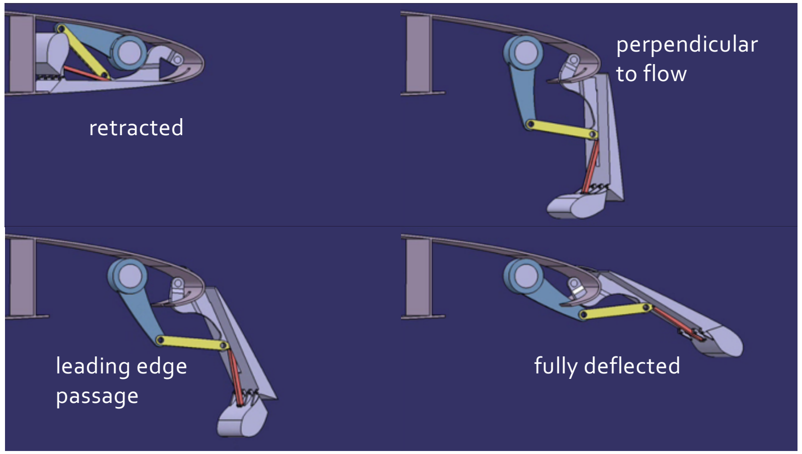




UHURA – H2020

- H2020 EU project
  - 12 partners, DLR coordinator
- Aerodynamics of Krueger device
  - Detailed experiments
  - CFD methodologies

- Quantification of aerodynamics
  - Still rather unknown
- Validation of CFD
  - Unsteady aerodynamics and dynamic loads
  - During deployment and retraction phase
- Qualification of impact on
  - handling qualities and certification



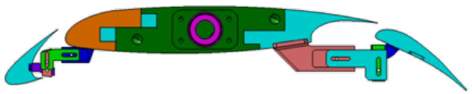
Deployment of vented folding bull-nose Krueger device developped in EC-FP7 funded project DeSiReH

UHURA – Validation wind-tunnel tests

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

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

DLR-F15L*S* in DNW-LLF
EC project OPENAIR

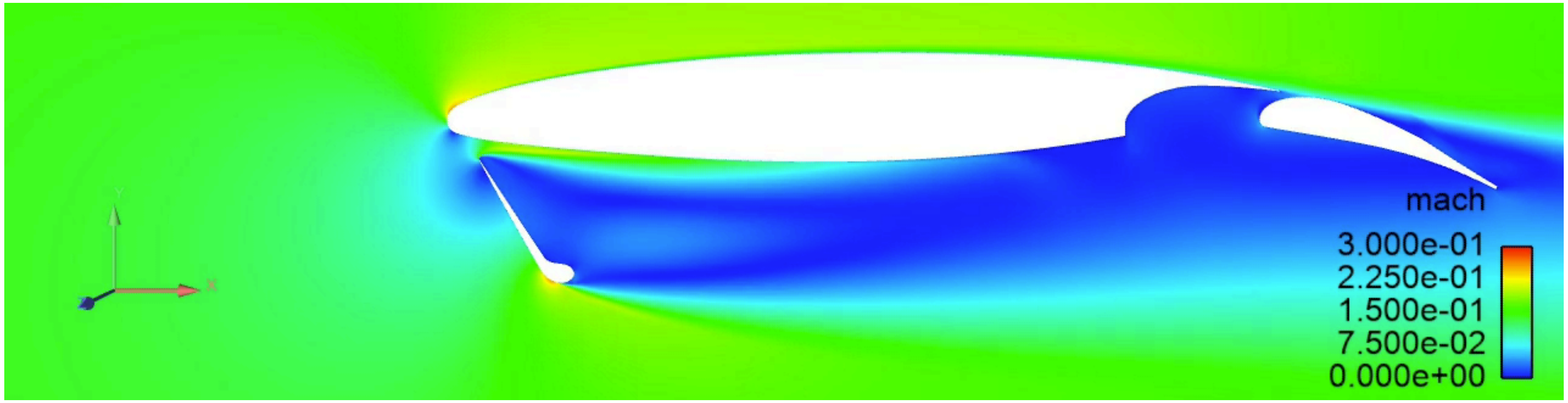


600 mm chord
2.4 m span (0°)
2 m span (30°)

1200 mm chord
7 m span

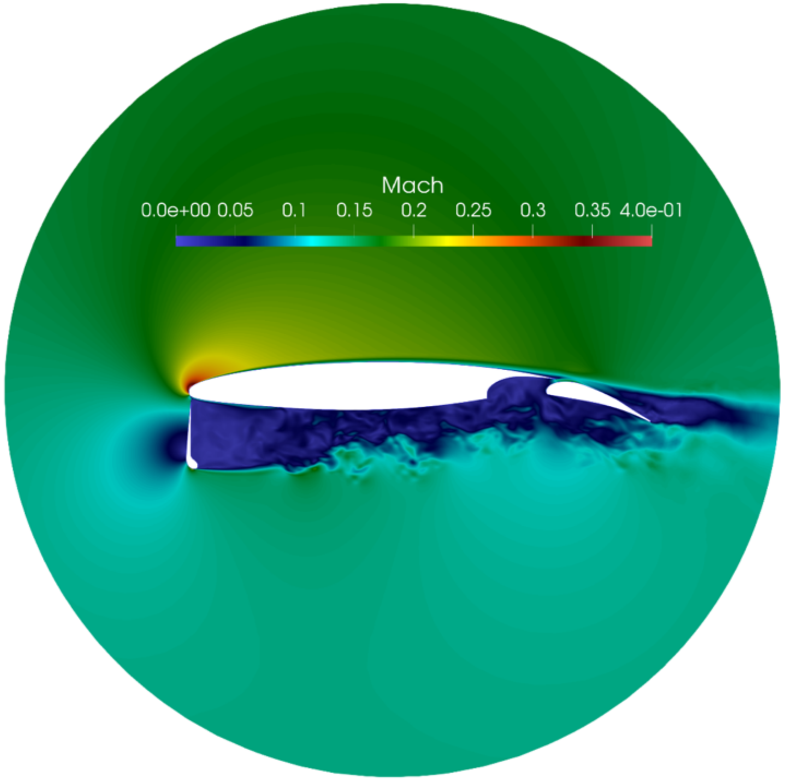
U-RANS of
Kruger flap deployment

- Mesh deformation
- Automatic remeshing using Pointwise script

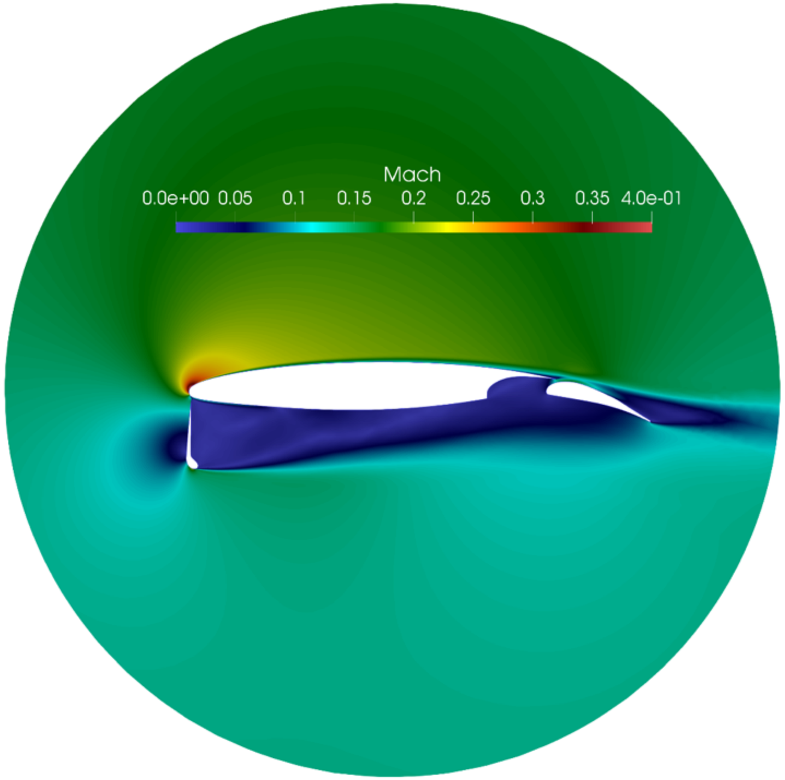


Hybrid RANS-LES

Instantaneous



Averaged



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Hybrid RANS-LES

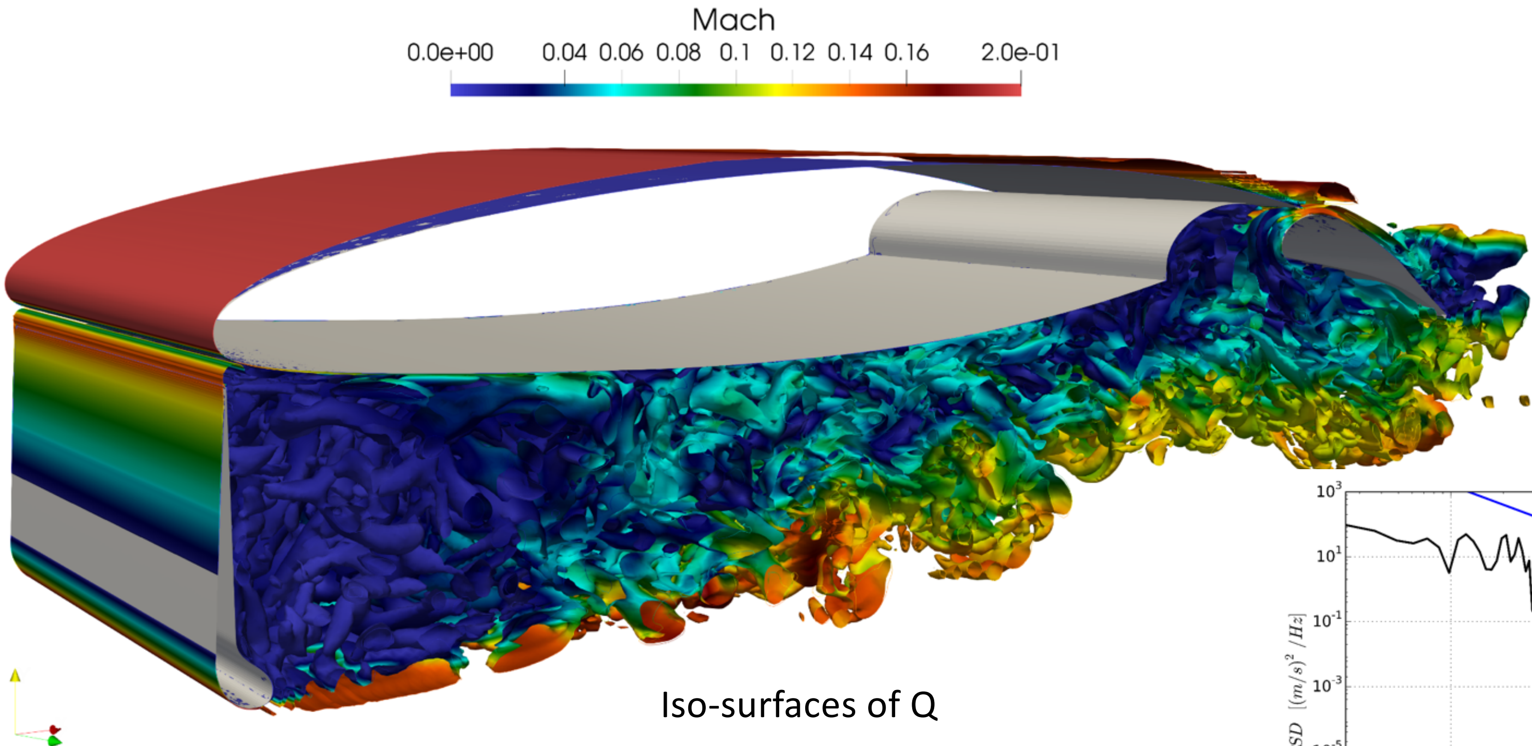
Mesh

- Spanwise: 2 Krueger flap chord length
  - Translational periodical boundaries
- Hybrid structure-unstructured grid
  - ~ 12 million cells

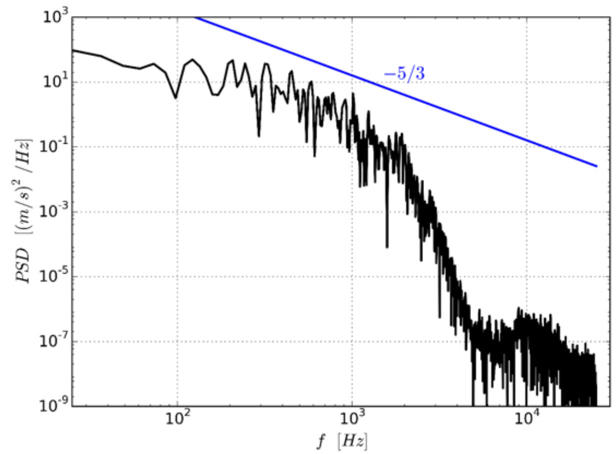
Numerical method

- Spalart-Allmaras DDES
- Central scheme with artificial dissipation in space
- Implicit scheme in time
  - CFL=0.2 in LES region
  - Explicit 4-stage Runge-Kutta within each time step
  - Multigrid + implicit residual smoothing

Hybrid RANS-LES computations



Iso-surfaces of Q



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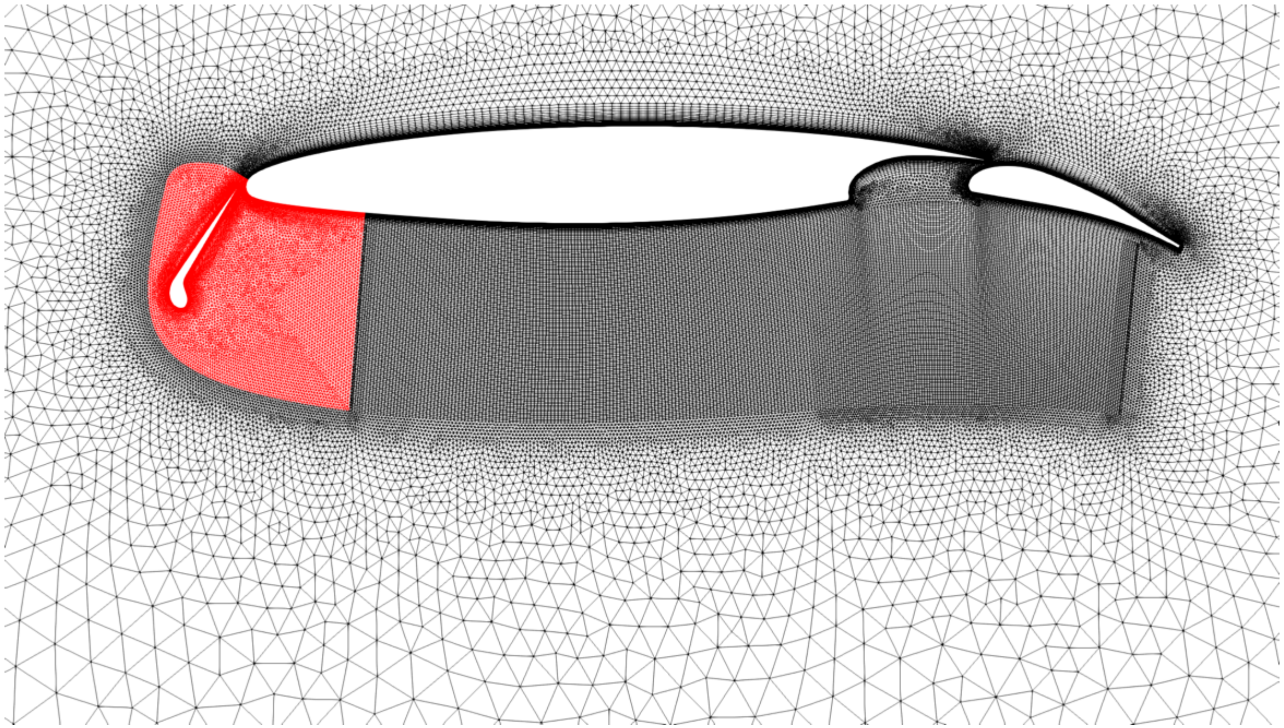
Meshing strategy

- Hybrid mesh strategy
- Structured zone
  - Equidistant
  - LES resolution
  - $(\Delta x, \Delta y, \Delta z) \approx (2, 1, 1)$
- Boundary layer mesh
  - RANS near-wall resolution
- Unstructured zones
  - Best compromise



Conclusions

- High-Fidelity CFD requires High-Fidelity meshing
  - Hybrid structured and unstructured surface mesh
  - Structured BL mesh and zones where high accuracy is needed
  - Automatic meshing models – corresponds to WT models
    - Contains all test settings and parts
    - Requires man work
    - Requires software with scripting capabilities – as e.g. Pointwise
- Test-matrix driven CFD
  - Automatic generation of CFD database
  - Setting and module variations through meshing script

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