Modeling of dynamically moving control surfaces for realistic aircraft configurations

20. STAB-Workshop

Larissa B. Streher[1,2] und Ralf Heinrich[2]

[1]Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence
 University of Groningen
 Nijenborgh 9, 9747 AG Groningen, The Netherlands

[2]Institute for Aerodynamics and Flow Technology
 German aerospace center
 Lilienthalplatz 7, 38108, Braunschweig, Deutschland

Knowledge for Tomorrow

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Motivation

- Virtual aircraft
- Simulate flight maneuvers over the entire flight envelope
- Consider gap between lifting and control surfaces
- Methods to simulation dynamically moving control surfaces
  - Mesh deformation + overset (Chimera) grids
    - AutoLap: automatic overlapping region generator
  - Mesh deformation + sliding interfaces
    - Sliding interfaces are considered as a Riemann problem, which is solved with a Riemann solver.
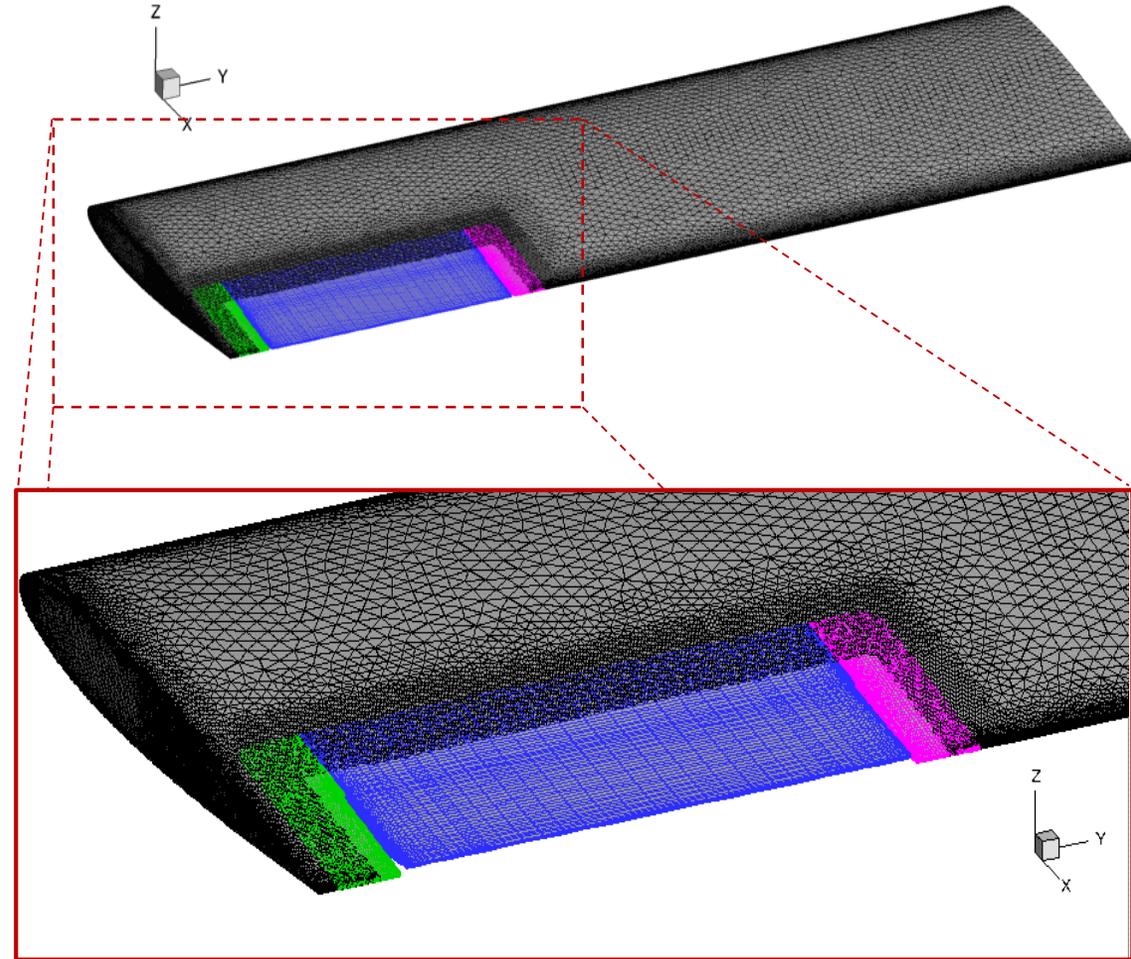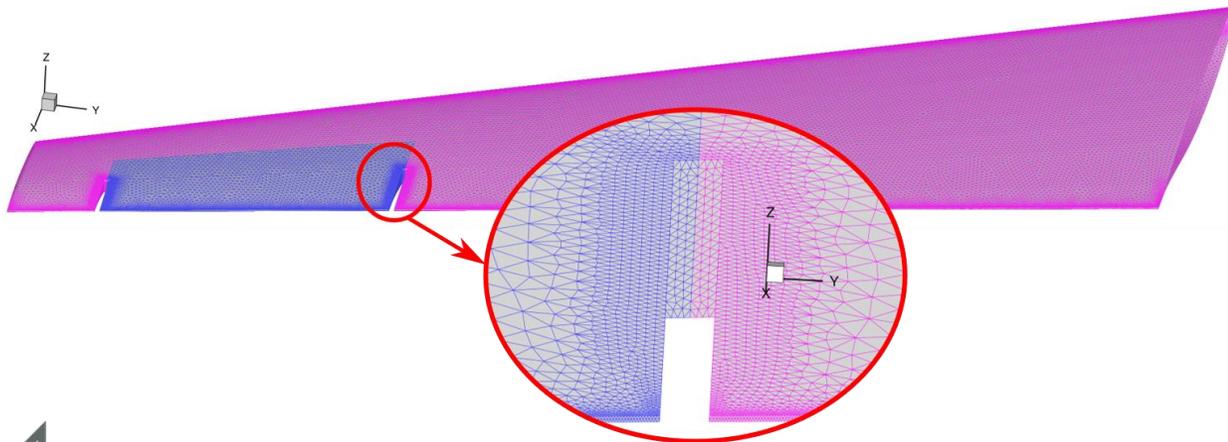
Control surface modeling
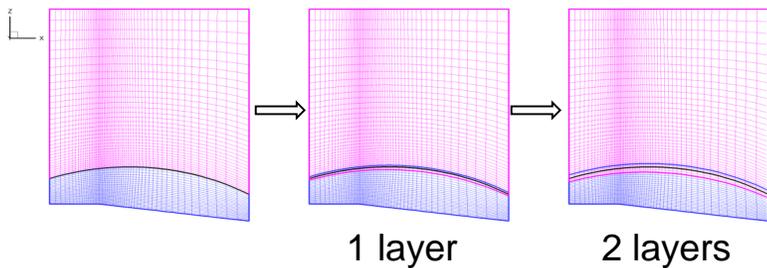## Combination of mesh deformation and overset grids

- Generating valid Chimera grids is often cumbersome
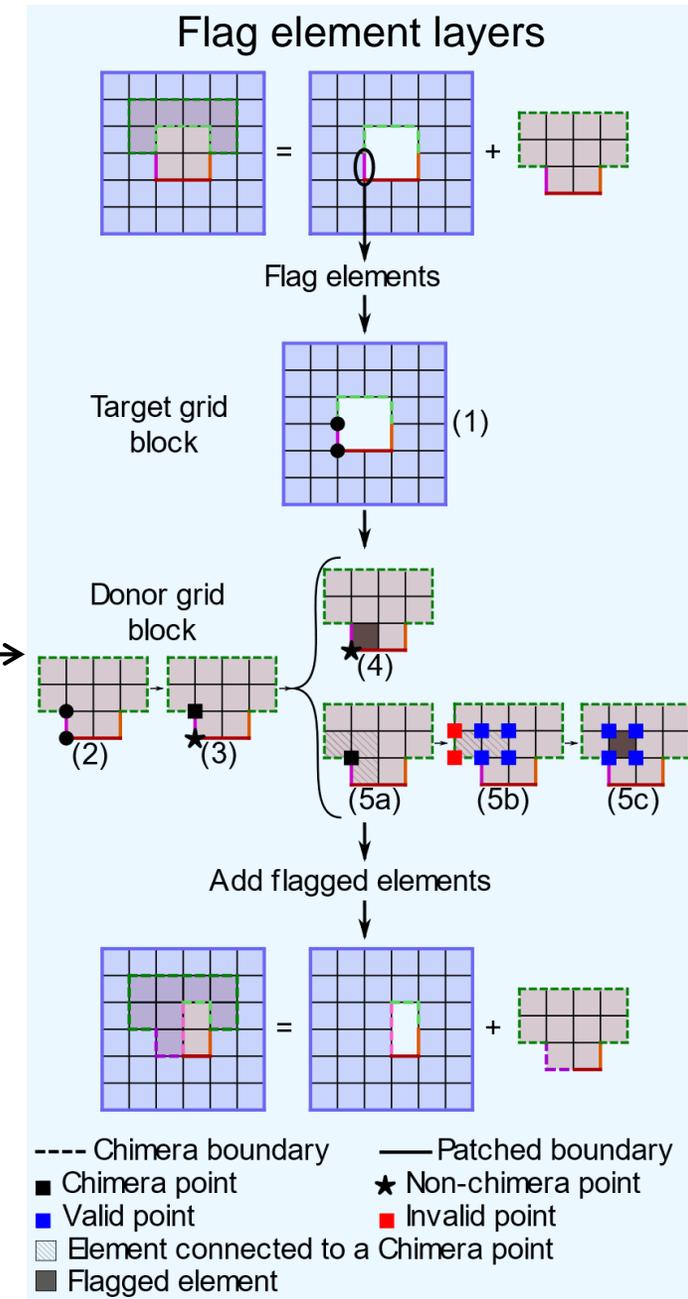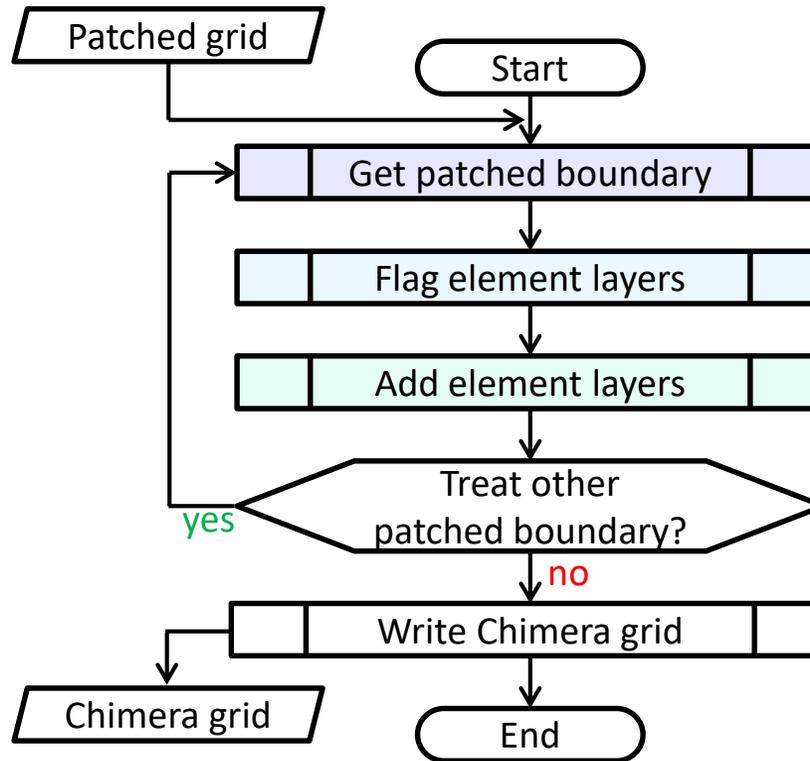- AutoLap was developed in order to facilitate the generation of these grids
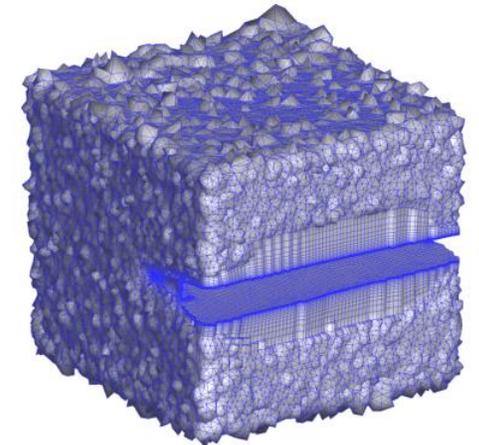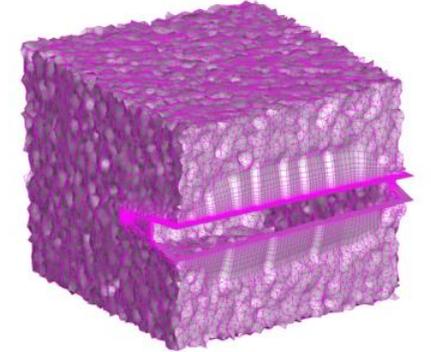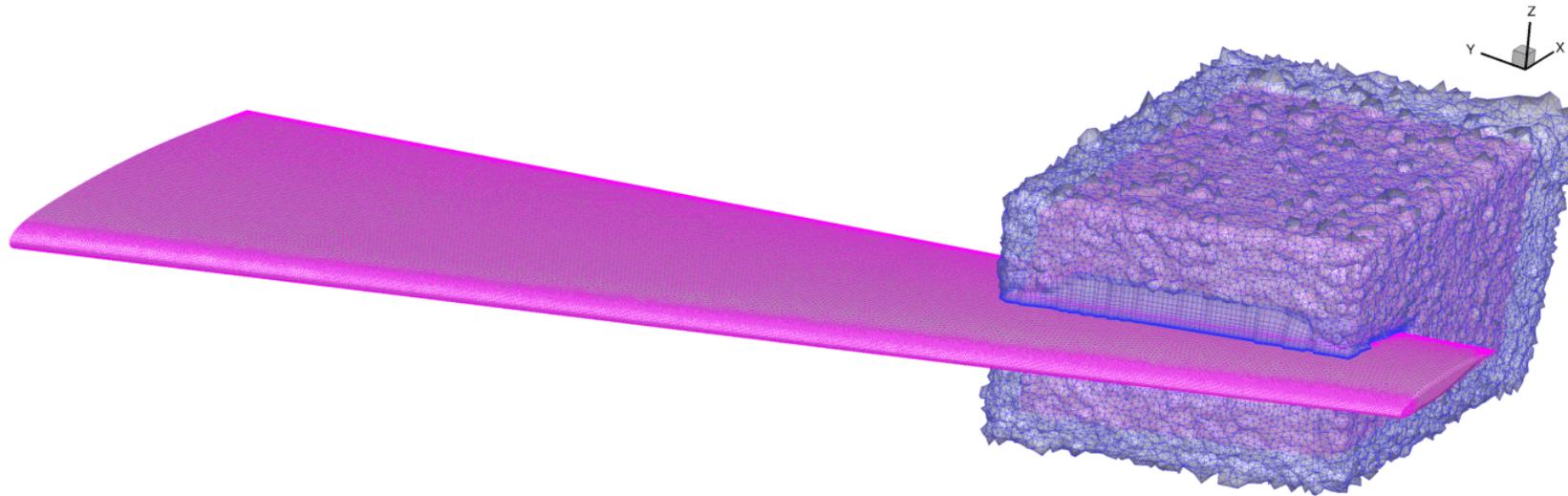
Control surface modeling
Combination of mesh deformation and overset grids - AutoLap

- AutoLap creates overlapping regions based on information available on the donor grid block.
- Elements are flagged layer by layer based on the neighboring elements.

1 layer   2 layers

- Boundary condition of the treated patched boundary changes to Chimera.

Flag element layers

---- Chimera boundary   ——— Patched boundary
■ Chimera point   ★ Non-chimera point
■ Valid point   ■ Invalid point
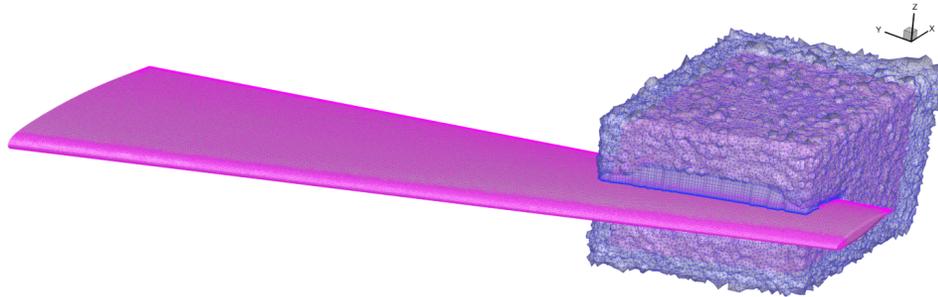▨ Element connected to a Chimera point
■ Flagged element

Control surface modeling
Combination of mesh deformation and overset grids - AutoLap
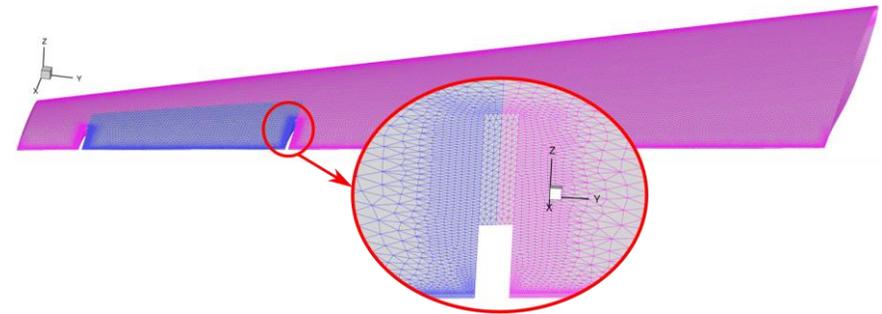
AutoLap - Advantages

- Mesh generation is facilitated

- User can easily chose the number of cell layers to be added to each patched boundary
- Fast to get configurations in which all donor points are found.

AutoLap - Disadvantages
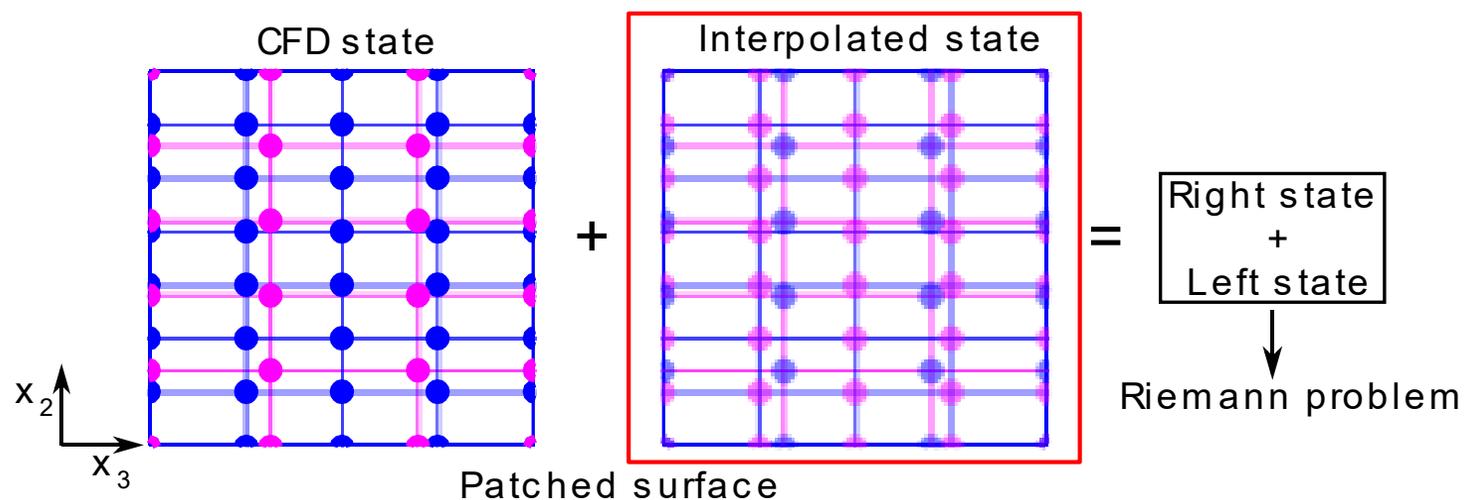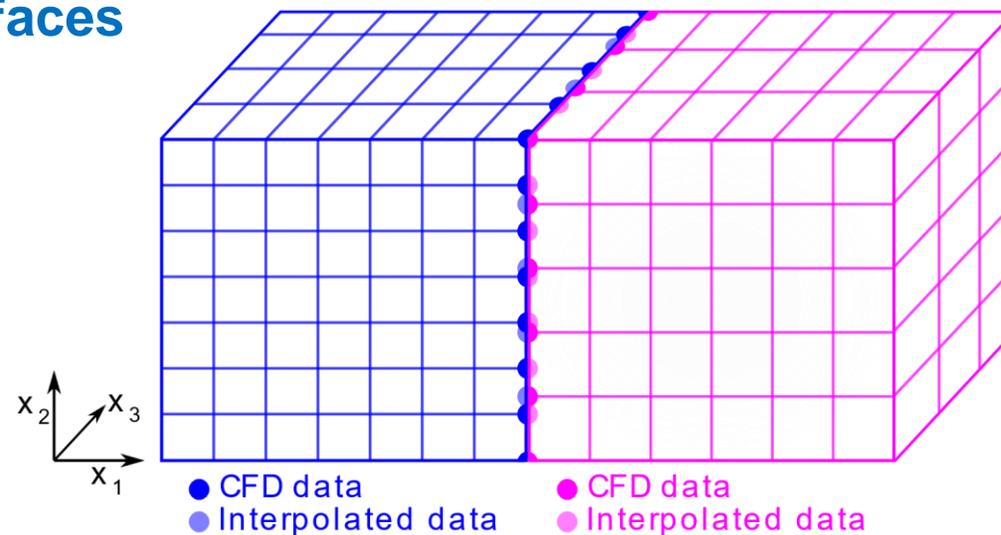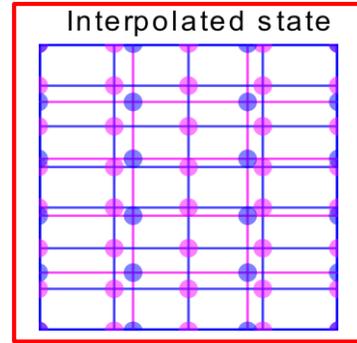
- Refinement of the spanwise gap region.

Control surface modeling
Combination of mesh deformation and sliding interfaces

Sliding interfaces in DLR CFD Solver TAU

- Sliding boundaries are treated as a Riemann problem
- Each cell vertex stores 2 states:
  - Current CFD solution
  - Interpolated state
- Flux is computed with a Riemann solver

x_2 x_3
x_1

● CFD data   ● CFD data
● Interpolated data   ● Interpolated data

CFD state   Interpolated state

x_2
x_3

Patched surface

+

=

Right state
+
Left state

Riemann problem

Control surface modeling
Combination of mesh deformation and sliding interfaces
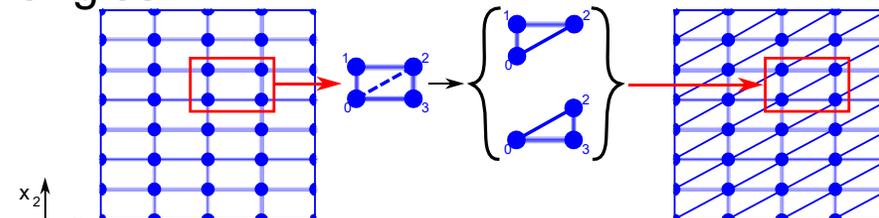

Interpolated state

Coarse grids

- Interpolated state
    - 0th order interpolation from the nearest neighbor located on the partner patched surface
    - k-d tree to find nearest neighbor

Interpolated state
& CFD state

k-d tree search

Donor surface point for the interpolated state of the target point
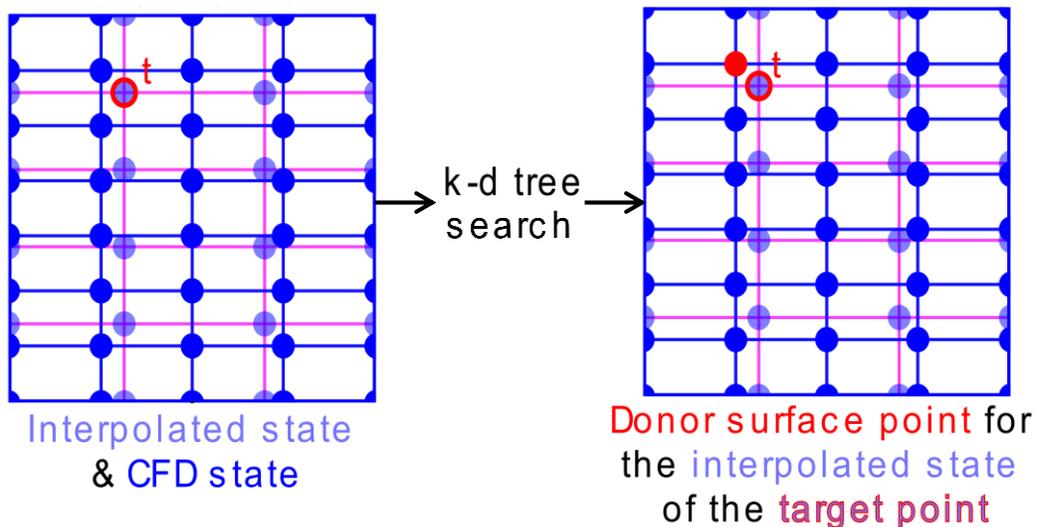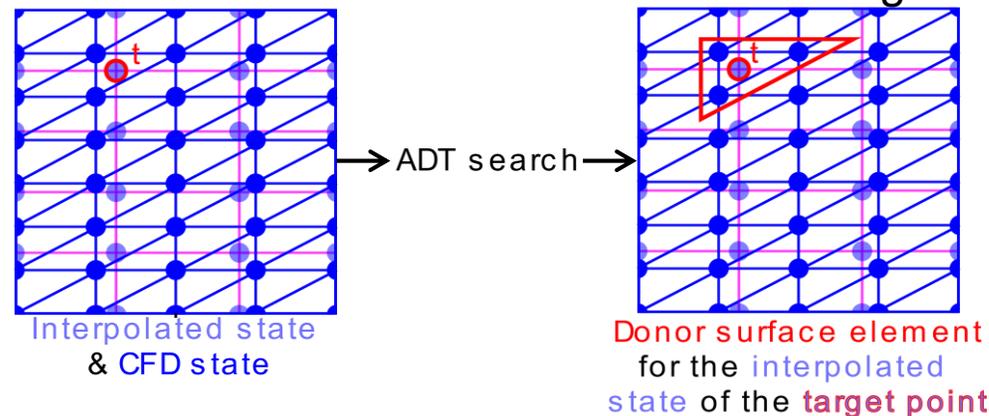
Fine grid

- Interpolated state
    - 1st order linear interpolation
    - Decomposition of all surface elements into triangles

- ADT to search for the donor surface triangle

Interpolated state
& CFD state

ADT search

Donor surface element for the interpolated state of the target point

Control surface modeling
Combination of mesh deformation and sliding interfaces

Linear interpolation – fine grid

- Unit normal vector of the surface triangle:

$$\vec{n}_{12} = \frac{\vec{v_1} \times \vec{v_2}}{\|\vec{v_1} \times \vec{v_2}\|}, \; \vec{n}_{23} = \frac{\vec{v_2} \times \vec{v_3}}{\|\vec{v_2} \times \vec{v_3}\|}$$

- Check whether $\vec{v_t}$ is orthogonal to $\vec{n}$:

$$\vec{n}_{12} \cdot \vec{v_t} = 0, \; \vec{n}_{23} \cdot \vec{v_t} = 0$$

  - Check whether the target point lies inside the surface triangle:

$$c_1\vec{v_1} + c_2\vec{v_2} = \vec{v_t}, \; c_2\vec{v_2} + c_3\vec{v_3} = \vec{v_t}$$
$$c_1 < 0, c_2 \geq 0 \; and \; c_1 + c_2 \leq 1$$
$$c_2 \geq 0, c_3 \geq 0 \; and \; c_2 + c_3 \leq 1$$

- Interpolate the primitive varibles:

$$u_t = u_0 + c_2(u_2 - u_0) + c_3(u_3 + u_0)$$
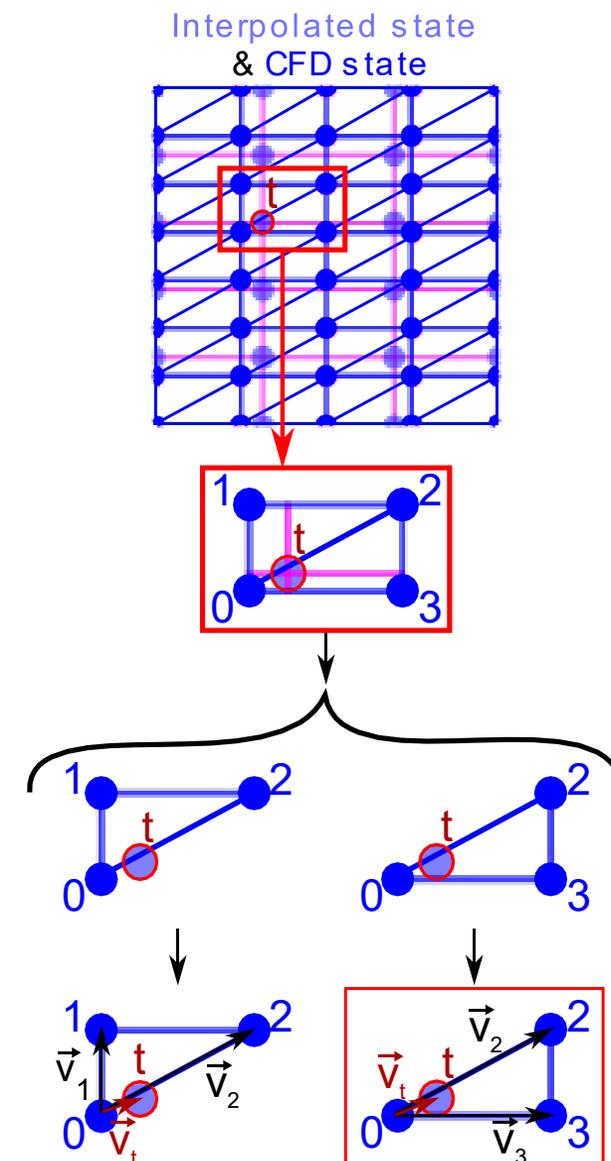
Test cases
NACA0012 Wing with a generic aileron

- Hybrid grids:
    - Wing grid (unstructured)
    - Inner gap grid (structured)
    - Outer gap grid (structured)
    - Aileron grid (structured)
    - Hole geometry
- Patched grid: 3 975 183 grid points
- Chimera grid: 4 046 039 grid points
- Free stream flow conditions:
    - $\mathrm{Ma}_\infty = 0.7$, $\mathrm{Re}_\infty = 7 \times 10^6$ und $\mathrm{Pr}_\infty = 0.72$, $\alpha = 5°$.
- 2nd order central discretization of the inviscid flux with added matrix dissipation
- Spalart-Allmaras turbulence model in the negative form.
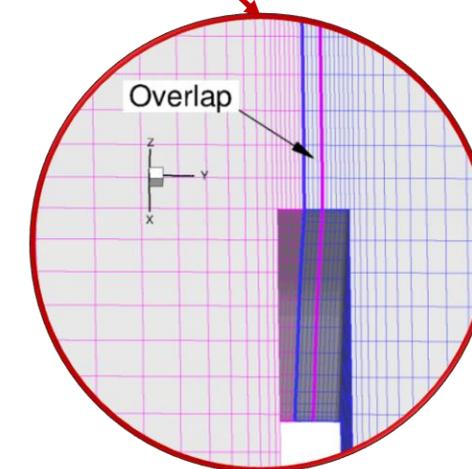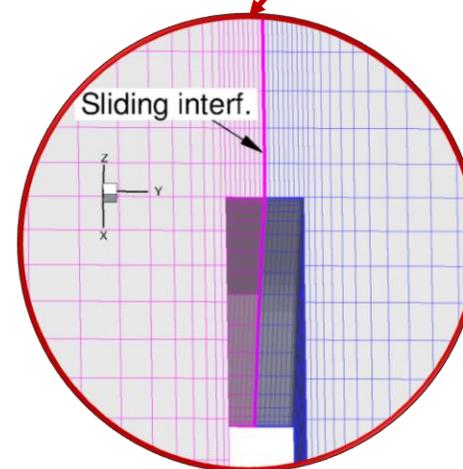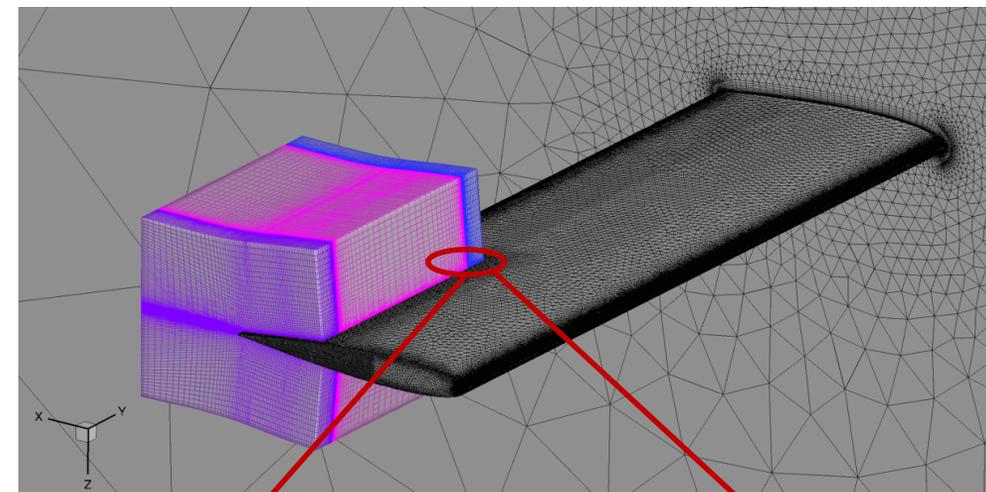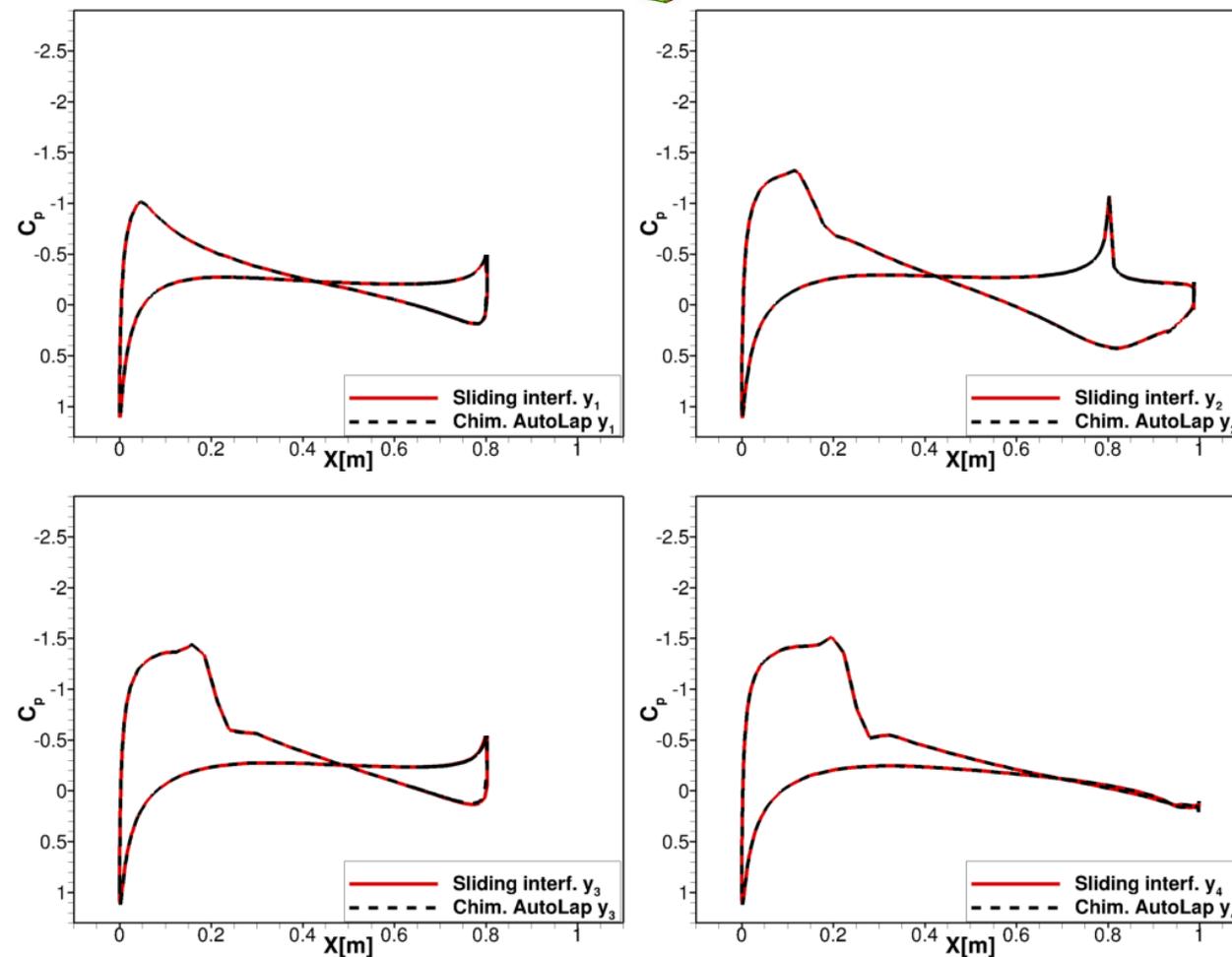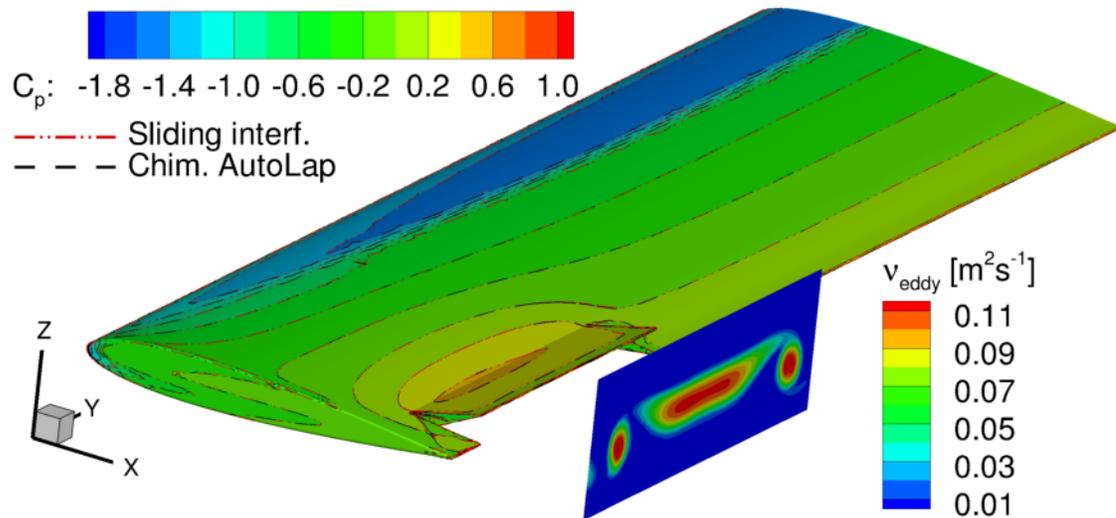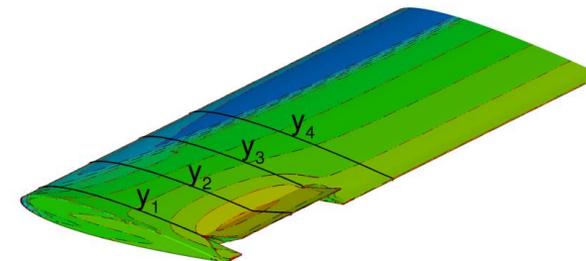
Test cases
NACA0012 Wing with a generic aileron

Aileron deployed by $\delta = -5°$
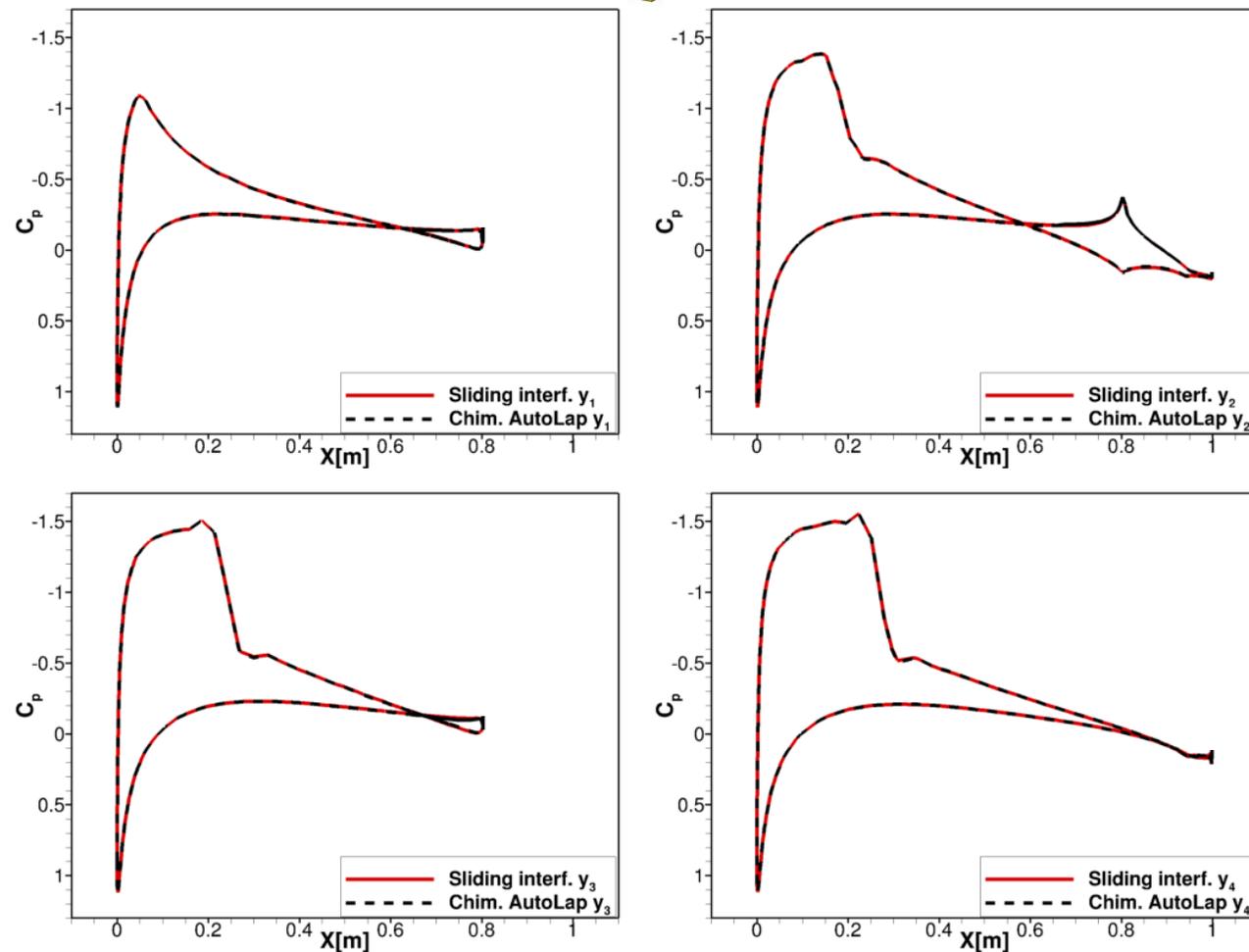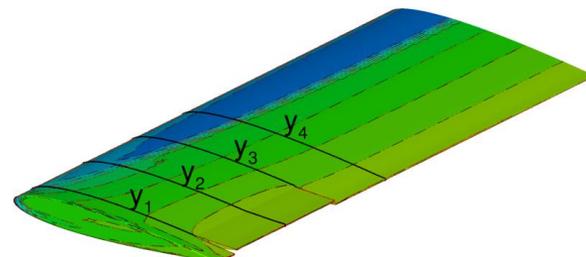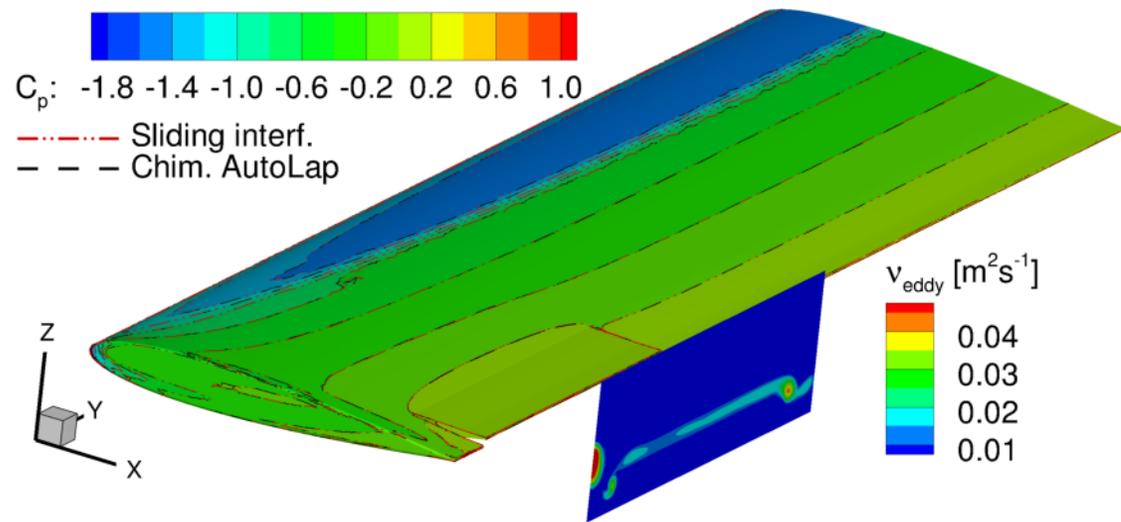
Test cases
NACA0012 Wing with a generic aileron
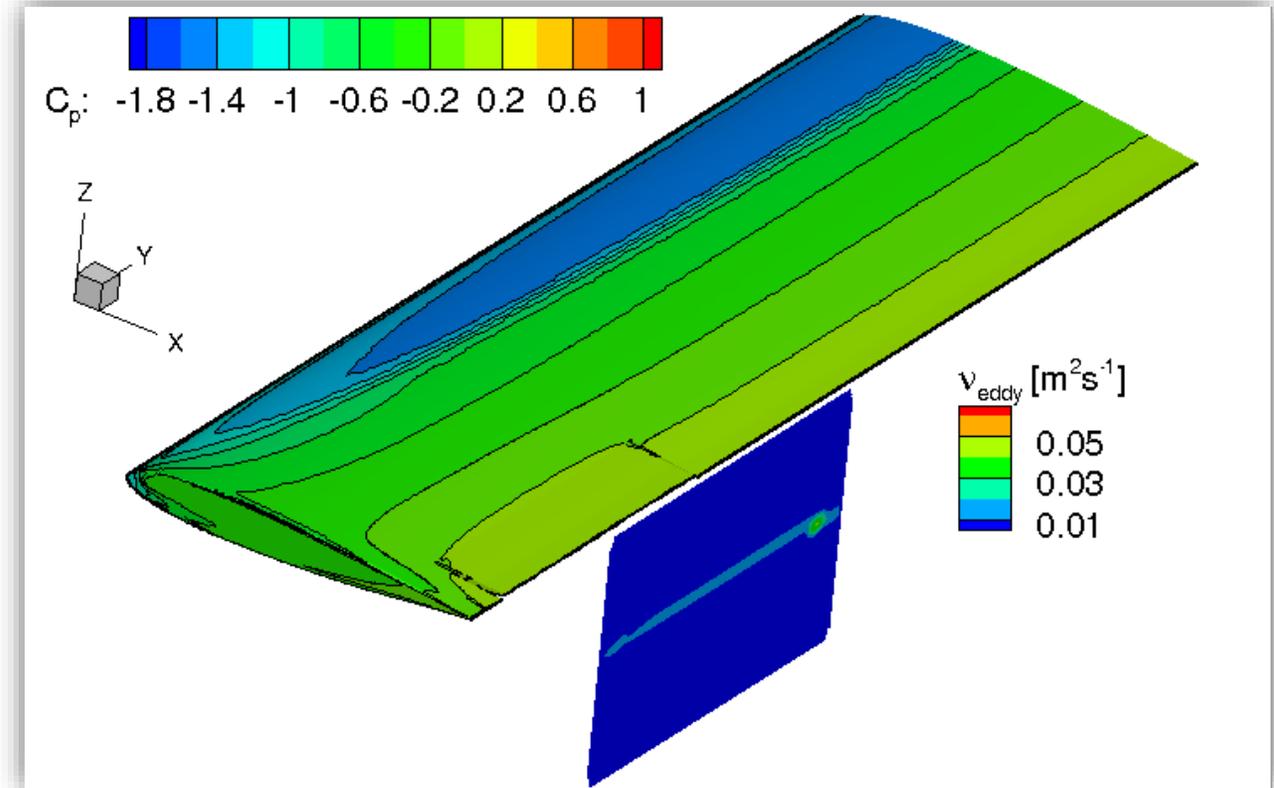
Aileron deployed by $\delta = -20°$

Test cases
NACA0012 Wing with a generic aileron

Dynamic aileron deployment

- Aileron oscillatory deployed by:

$$\delta = 20° \sin(2\pi t)$$

- Mesh deformation according to a thin-plate-spline algorithm

- 2nd oder dual time integration

Test cases
MULDICON configuration with inner and outer elevons

- Unstructured grids
  - Reference grid - 18 147 849 grid points
  - Patched grid - 18 241 885 grid points
  - Chimera grid - 18 610 306 grid points
- Patched and Chimera grids:
  - UCAV grid
  - Inner elevon
  - Outer elevon
- Free stream flow properties:
  - $\text{Ma}_\infty = 0.4$, $\text{Re}_\infty = 55.8 \times 10^6$ und $\text{Pr}_\infty = 0.72$, $\alpha = 2°$.
- 2$^{\text{nd}}$ order central discretization of the inviscid flux with added scalar dissipation
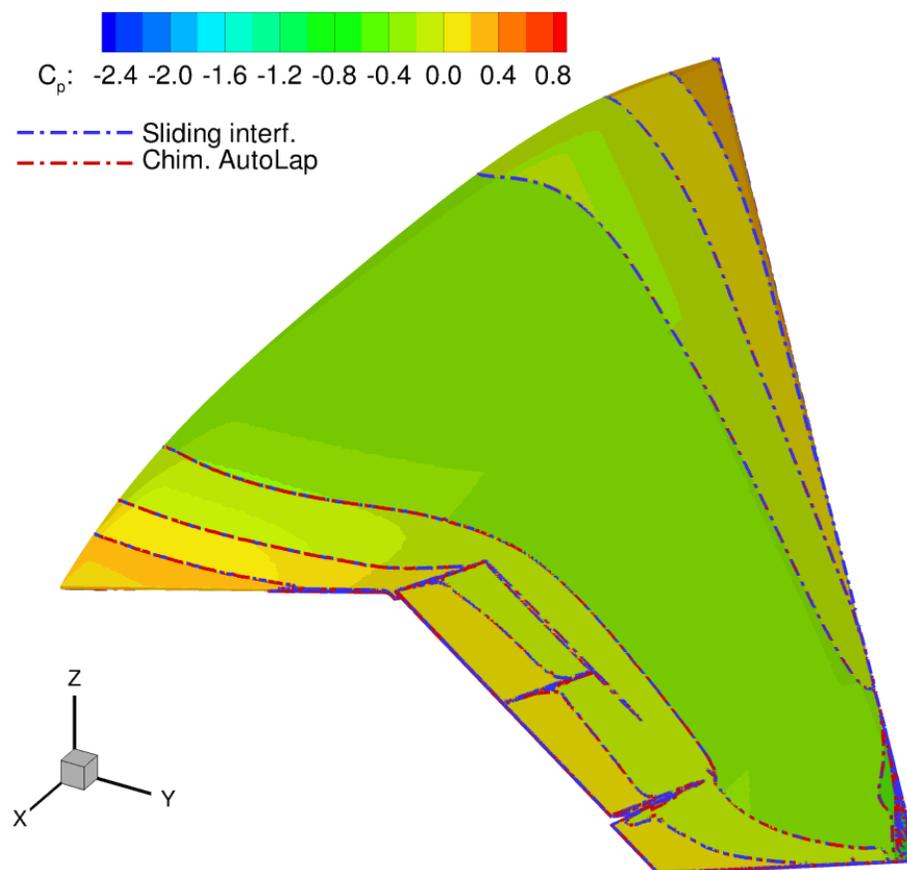- Spalart-Allmaras turbulence model in the negative form.
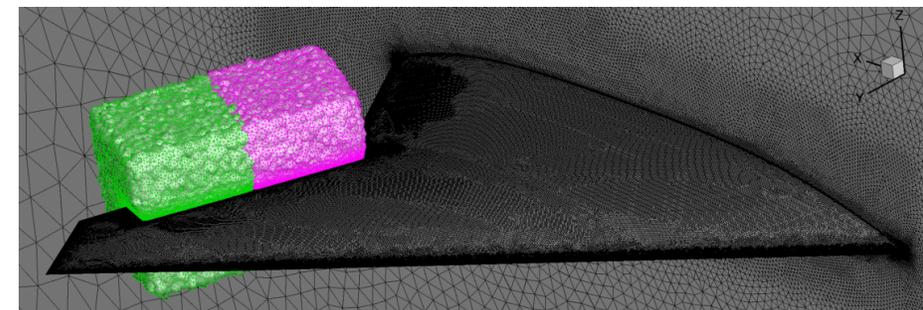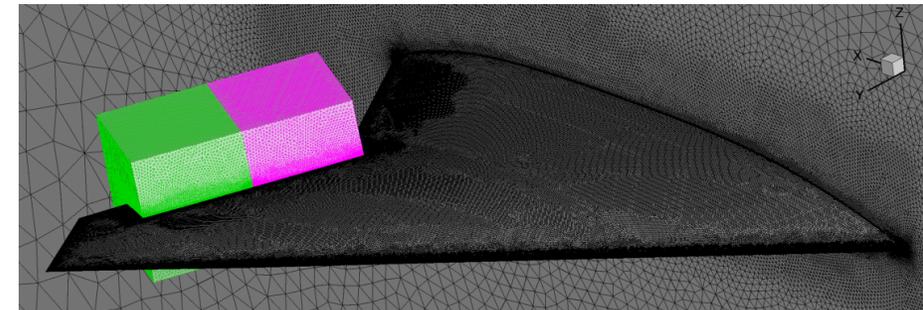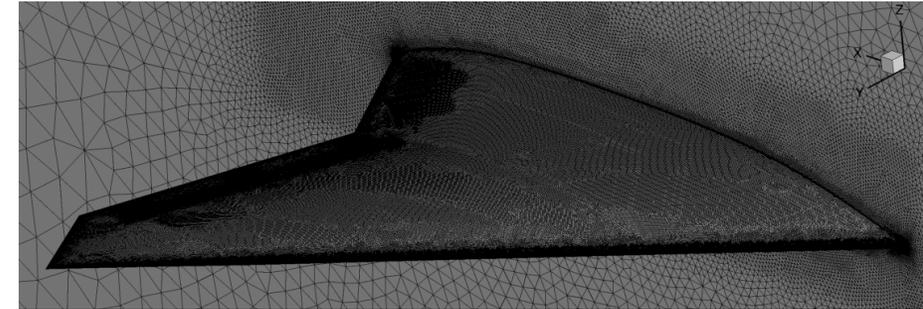
Test cases
MULDICON configuration with inner and outer elevons

Elevons not deployed
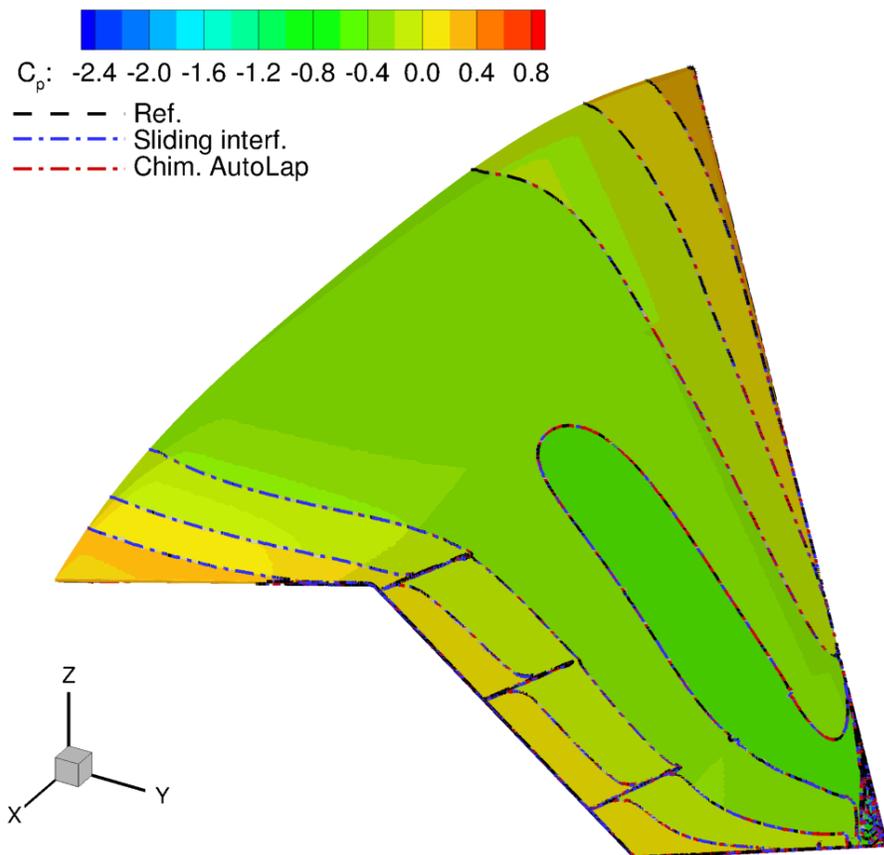
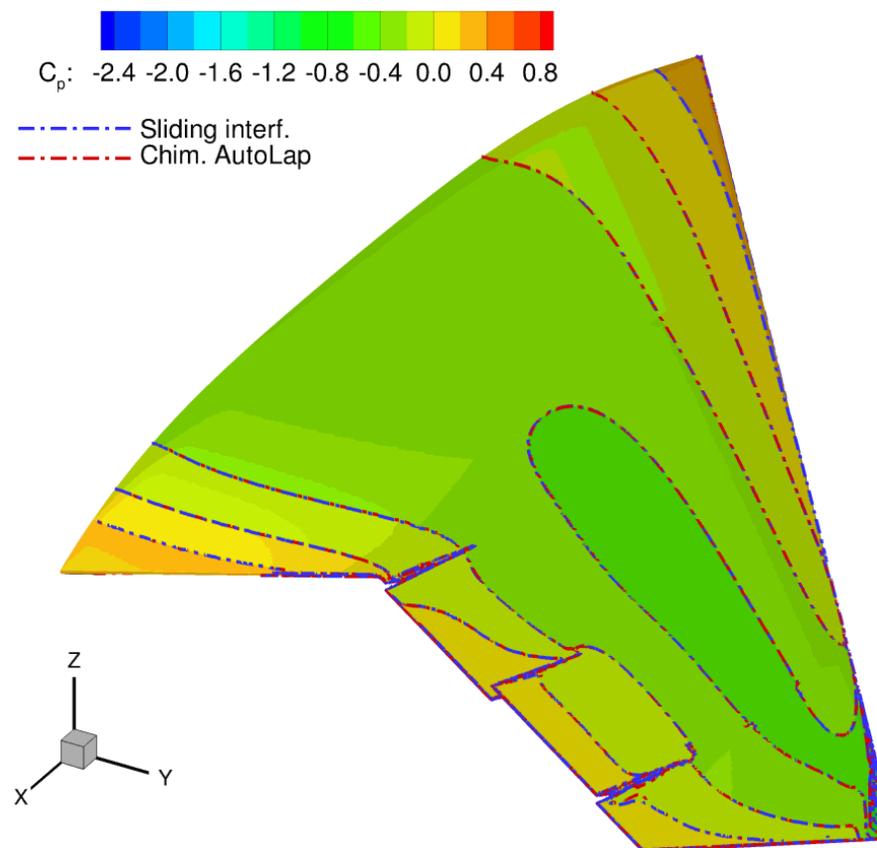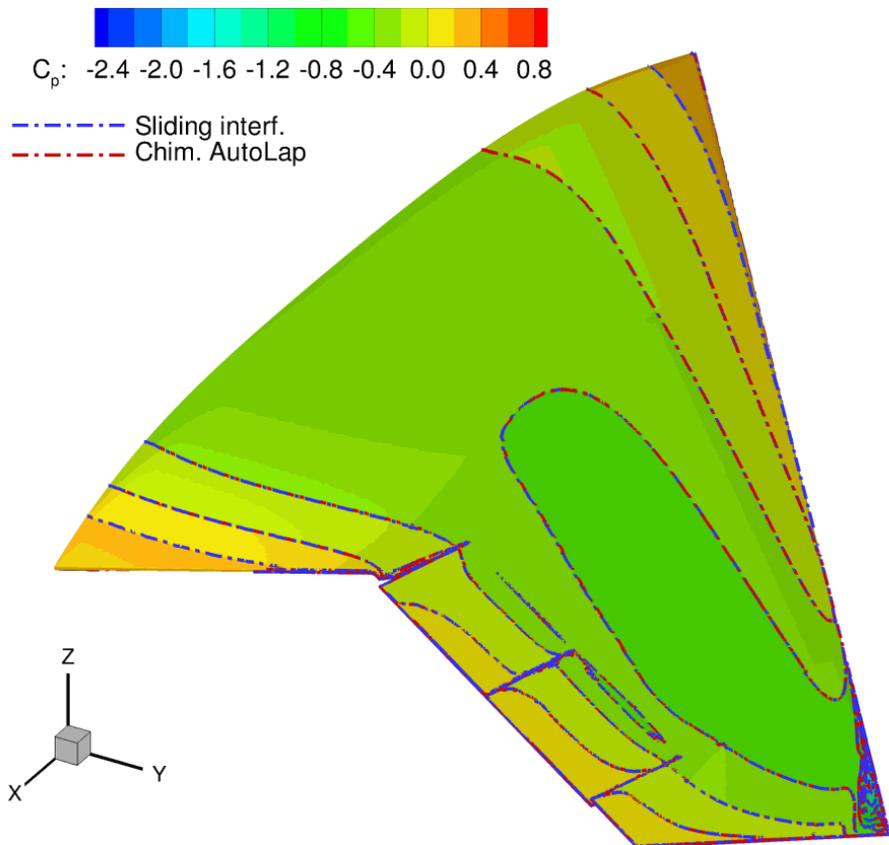**Elevons deployed by** $\delta_{RIB} = -5°$ **and** $\delta_{ROB} = -5°$

Test cases
MULDICON configuration with inner and outer elevons

Elevons deployed by $\delta_{RIB} = 5°$ and $\delta_{ROB} = 5°$

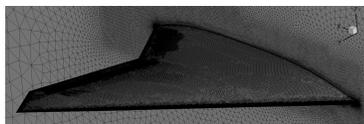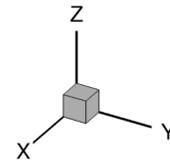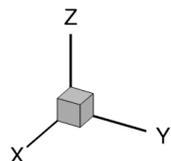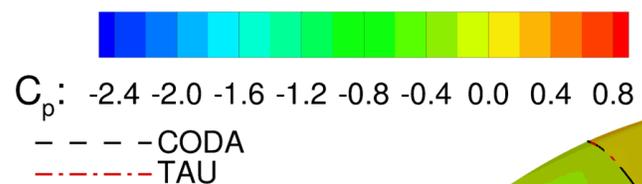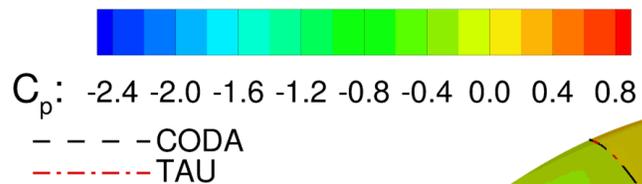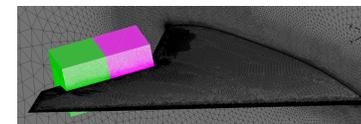**Elevons deployed by $\delta_{RIB} = 5°$ and $\delta_{ROB} = -5°$**

Sneak peek
Comparison between TAU and CODA for the control surface modeling

Conclusions and outlook

- The simulation of moving control surfaces is particularly challenging for realistic aircraft configurations.
- AutoLap was developed to facilitate the grid generation of overset grids.
- A new sliding interfaces algorithm has been implemented in TAU, eliminating the need for overlapping regions between the grid blocks.
- Both AutoLap and the sliding interfaces algorithm were successfully tested for two configurations.
- A first comparison between TAU and CODA was accomplished successfully.
- In the near future, the control surfaces of the MULDICON configuration and of the future fighter demonstrator (FFD) will be dynamically deployed with TAU and CODA.