Overset Grids Technology in STAR-CCM+: Methodology and Applications

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  - Launching of lifeboats, missiles etc.
  - Relative motion of vessels with crossing paths
  - Store separation
  - Other devices with moving parts…
- Future development

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About STAR-CCM+, I

- What distinguishes STAR-CCM+ most from other codes?
  - User interface (everything under one roof…)
  - Meshing tools:
    - Surface wrapping
    - Surface remeshing
    - Surface repair
    - Automatic volume meshing and mesh design
  - Process automation
  - Some physics and numerics features...

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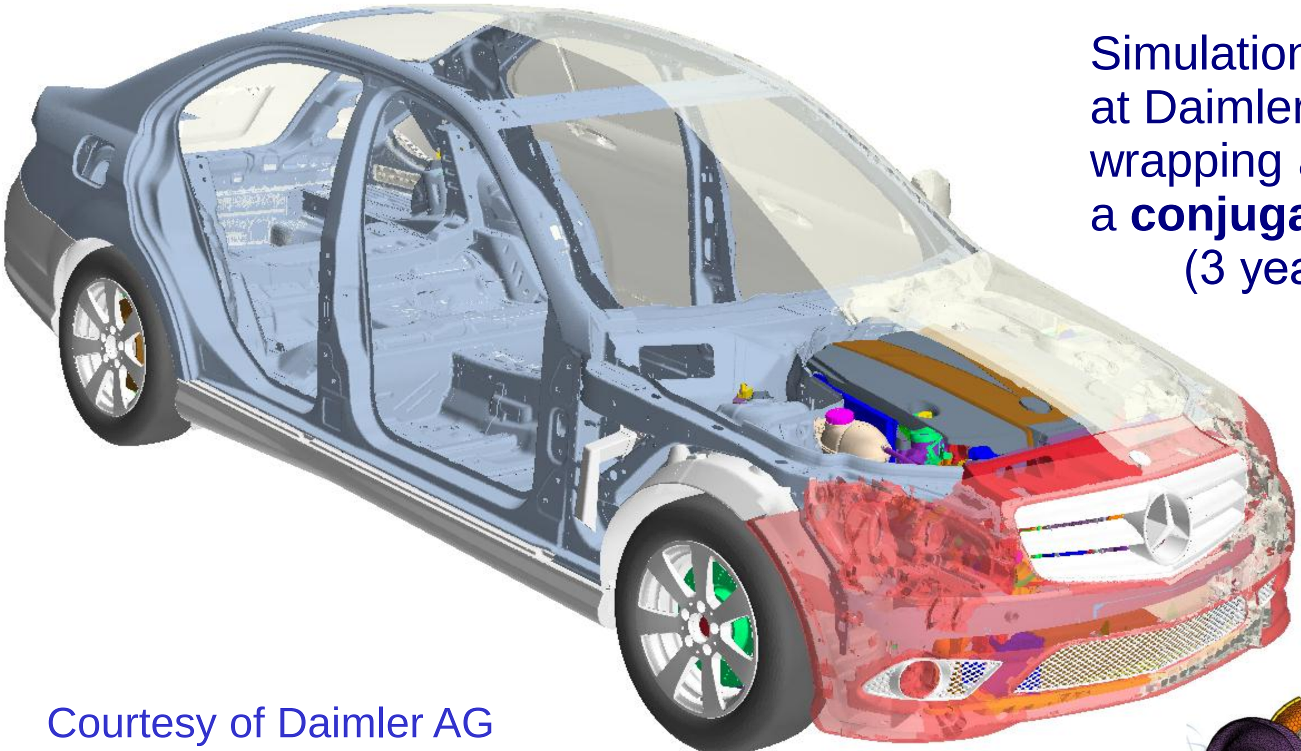
About STAR-CCM+, II

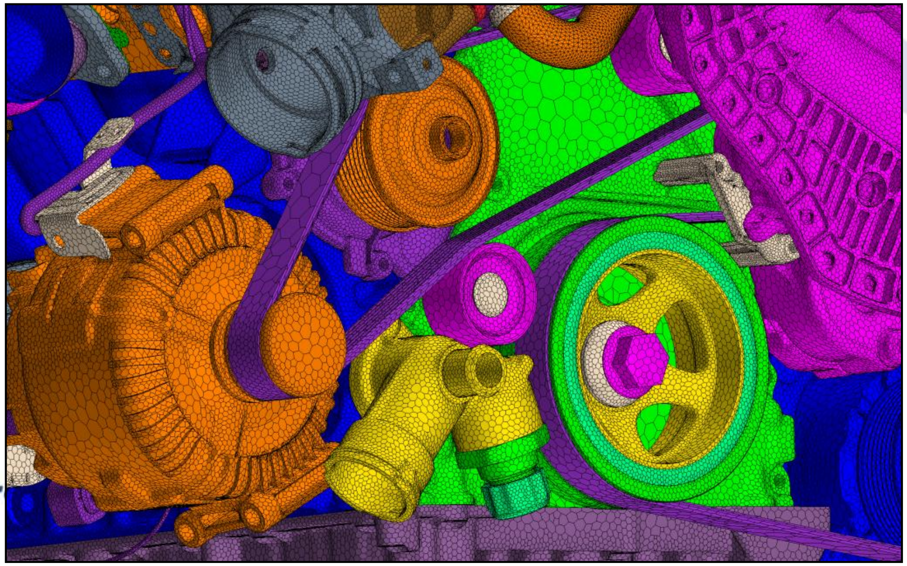


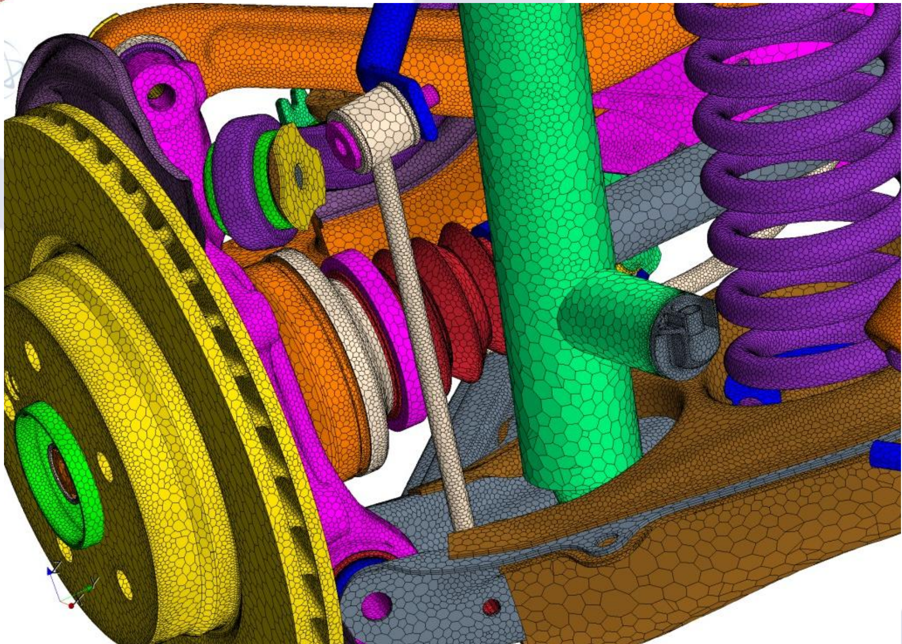
Simulation of vehicle thermal management at Daimler AG: 777 solid parts, surface-wrapping and automatic mesh generation for a **conjugate heat transfer analysis** (3 years ago…).

Mesh size: ca. 30 millions cells
Meshing time: ca. 100 minutes

High geometric fidelity…

Courtesy of Daimler AG



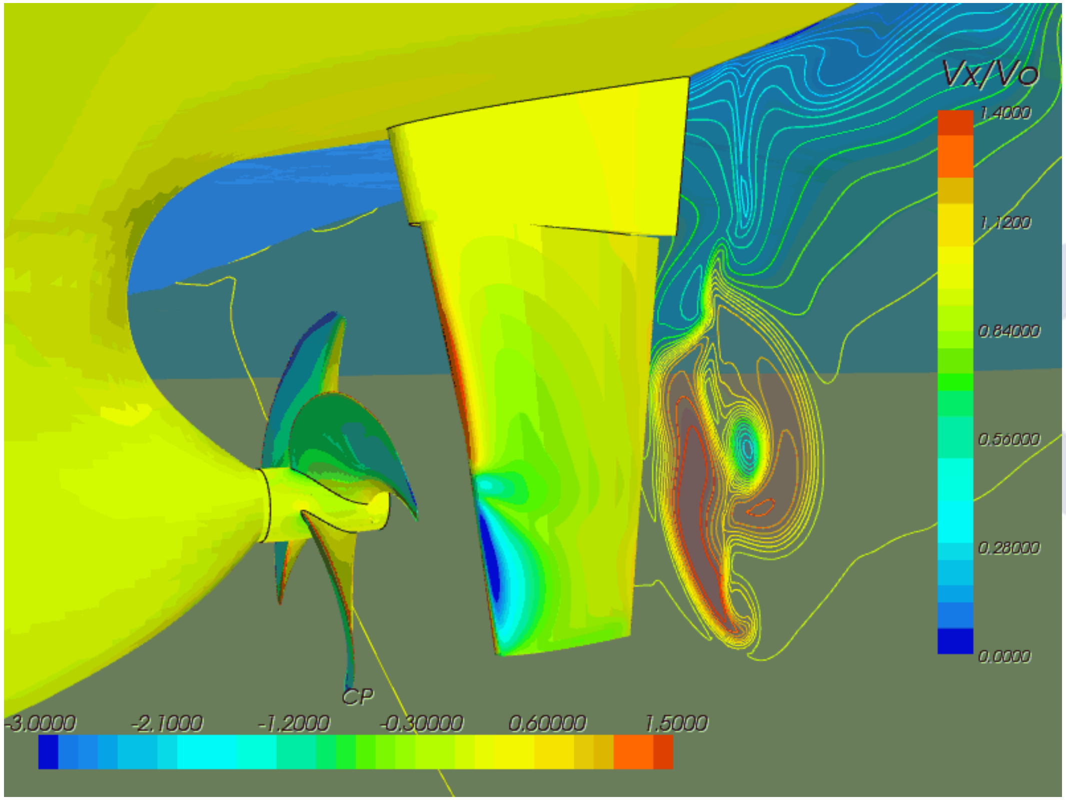


About STAR-CCM+, IV

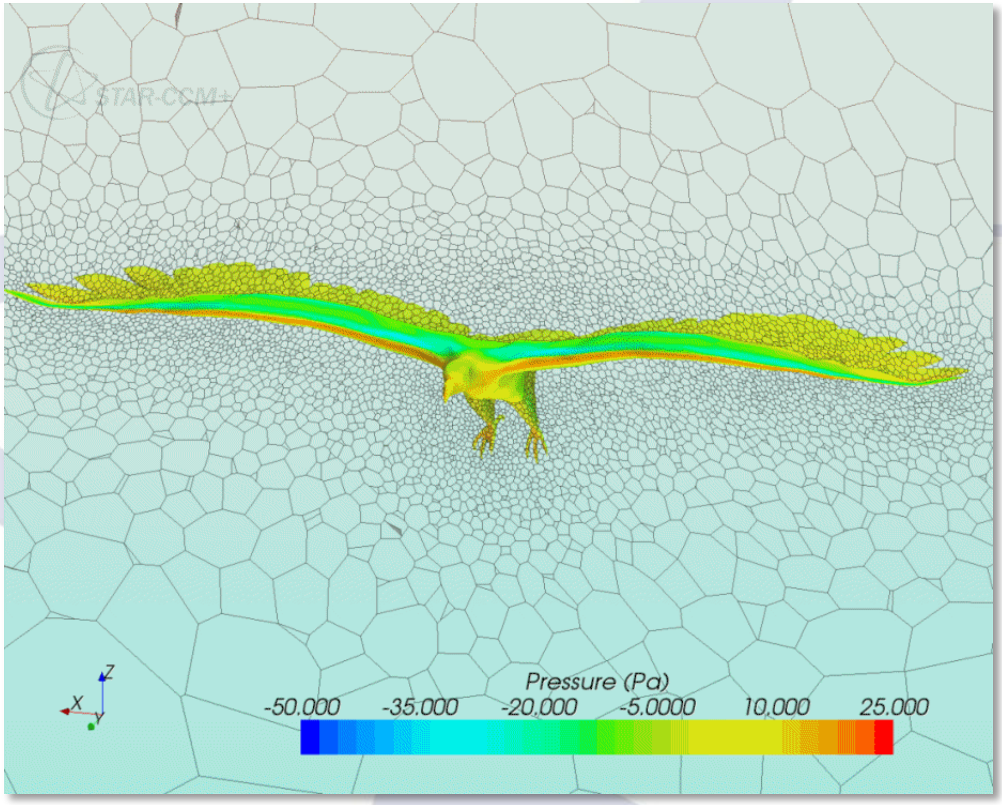
Many kinds of problems can be solved without overset grids…

Overset grids are needed for:

- Easy parametric studies
- Extreme or constrained motions…



Sliding grid (cylinder surface)



Morphing grid

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Overset Grids Method in STAR-CCM+, I

- Control volumes are labelled as:
  - **Active** cells, or
  - **Passive** cells.
- In active cells, regular discretized equations are solved.
- In passive cells, no equation is solved – they are temporarily or permanently de-activated.
- Active cells along interface to passive cells refer to **donor** cells at another grid instead of the passive neighbours on the same grid...
- The first layer of passive cells next to active cells are called **acceptor** cells...

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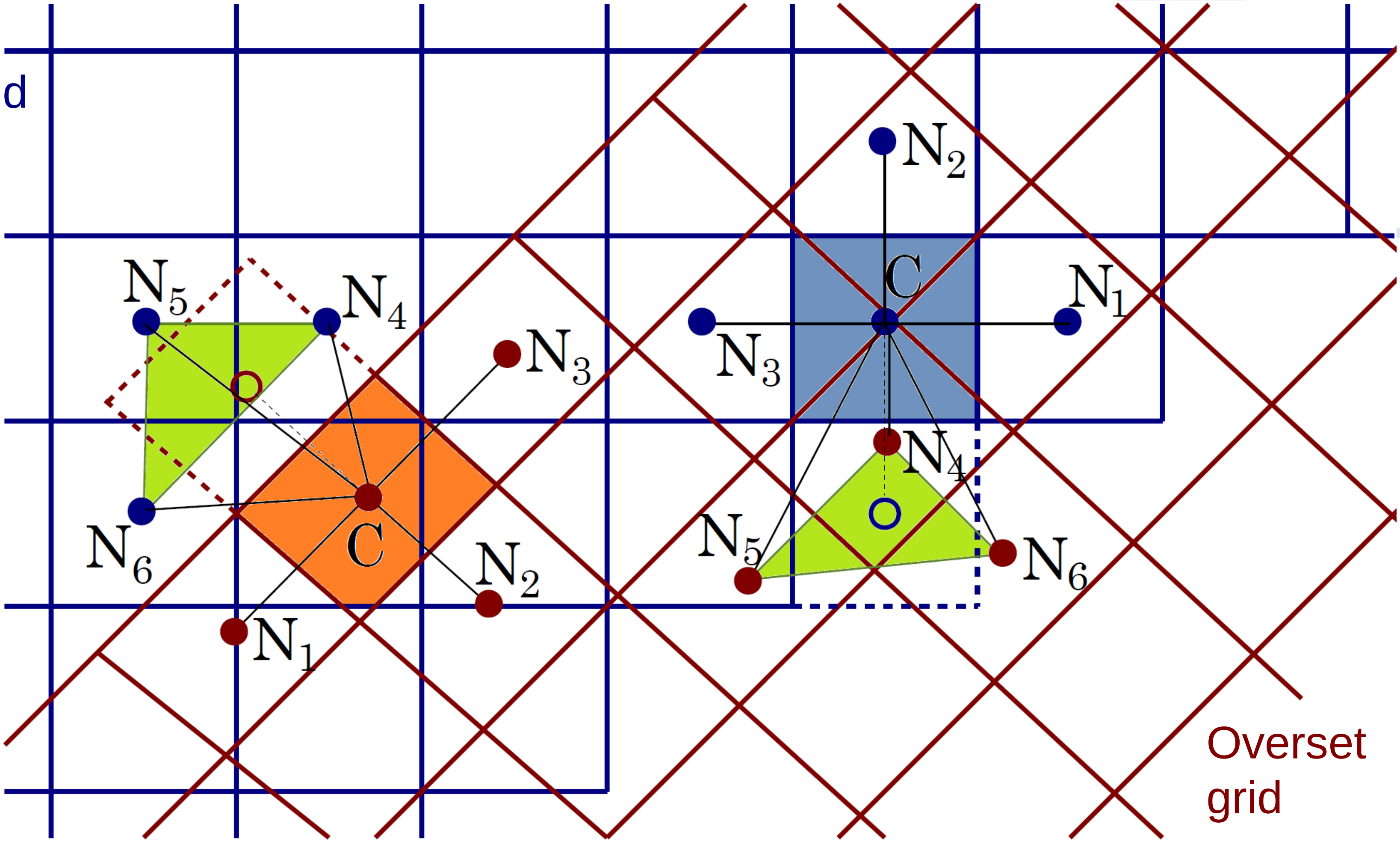
Overset Grids Method in STAR-CCM+, II

- Currently, triangular (2D) or tetrahedral (3D) interpolation elements are used, with either distance-weighted or linear interpolation... Other (higher-order) interpolations will come…

Background grid

N_1, N_2, N_3 – Neighbors from the same grid;

N_4, N_5, N_6 – Neighbors from the overlapping grid.



Overset grid

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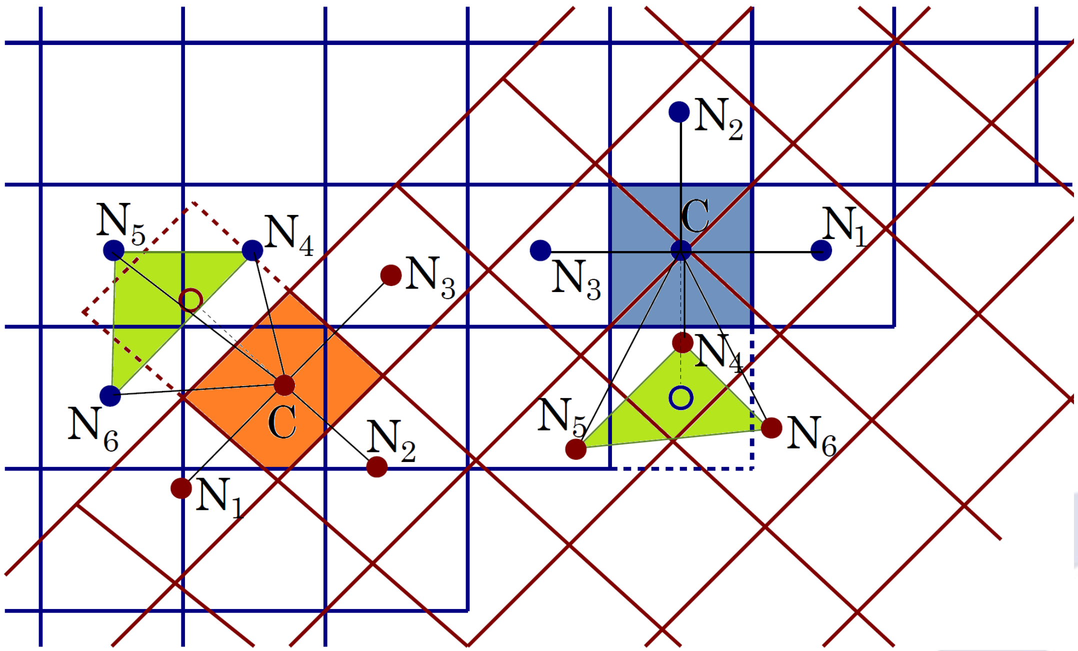
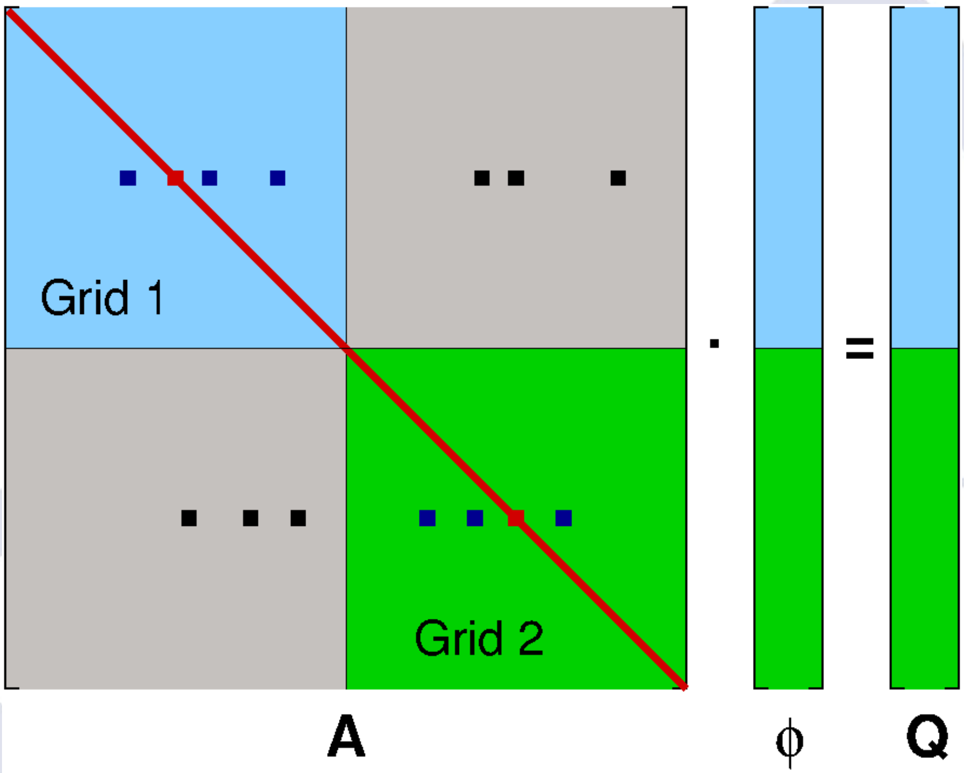
Overset Grids Method in STAR-CCM+, III



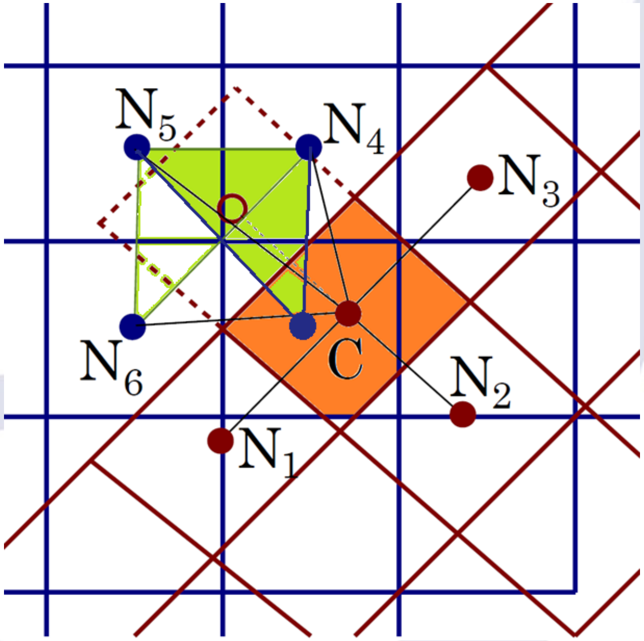


- No explicit interpolation of solution is performed…
- Solution is computed on all grids simultaneously – grids are implicitly coupled through the linear equation system matrix...

Overset Grids Method in STAR-CCM+, IV

- Different interpolation functions can be used to express values at acceptor cells via values at donor cells (different interpolation elements)…

Interpolation elements are not unique – when grids move, continuity is important…



- Donor cells must be active cells.

- The change of cell status is controlled by the solver and happens automatically.

- The user can visualize the cell status as a scalar field (this can help in case of problems – mostly due to inadequate grids)...

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Overset Grids Method in STAR-CCM+, V

- Overset grids usually involve:
  - One background mesh, adapted to environment (can be fixed or moving);
  - One or more overset grids attached to bodies and overlapping the background mesh and/or each other.
- Each grid represents a separate *region*.
- Both background and overset mesh(es) can be generated in the usual way (or imported) as in the case of a single region.
- Each grid can also deform (e.g. in a coupled fluid-structure interaction simulation).
- Overset grid can fall out of solution domain (cut-out by boundary surface).

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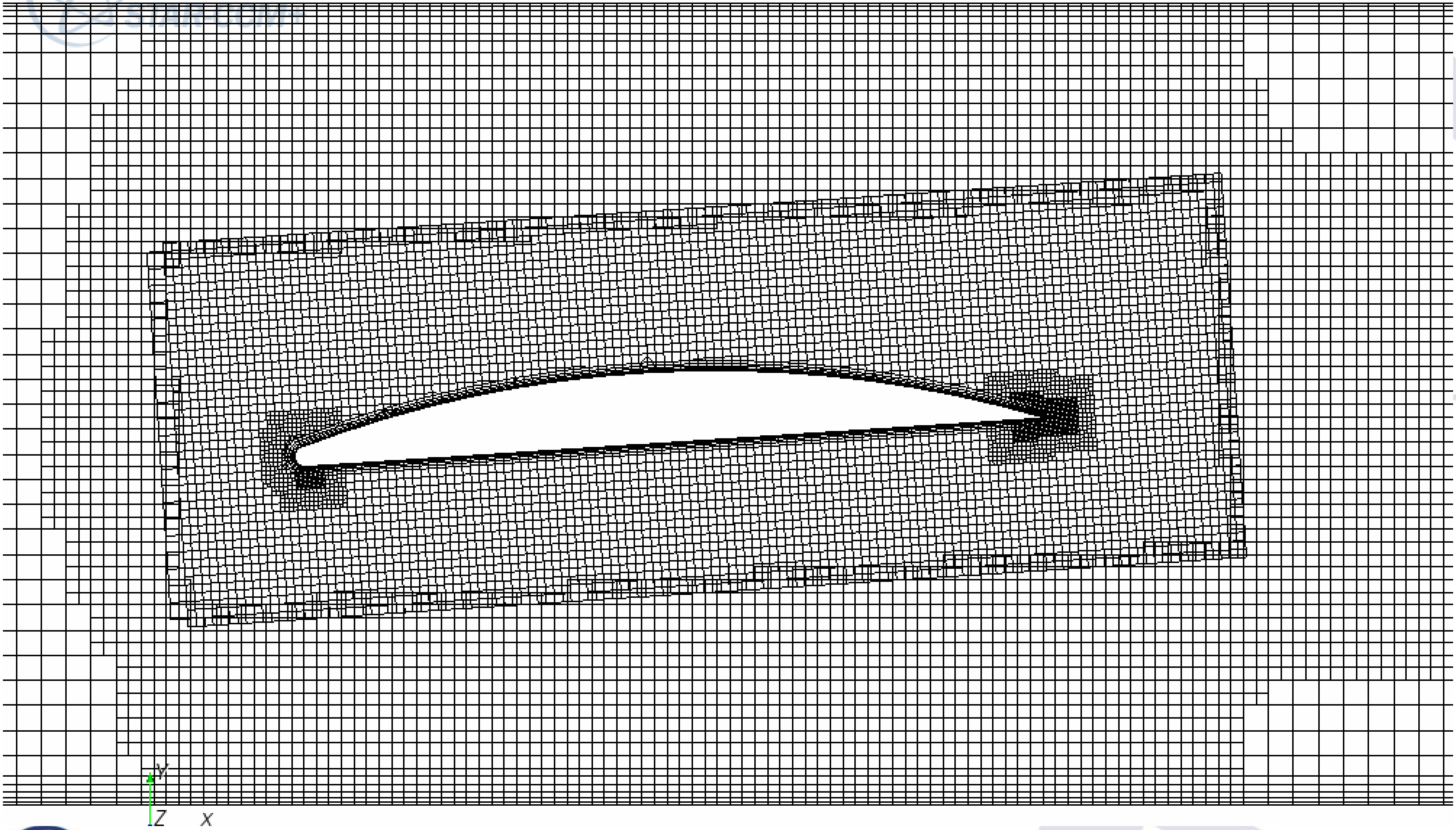
Example: Pitching Foil

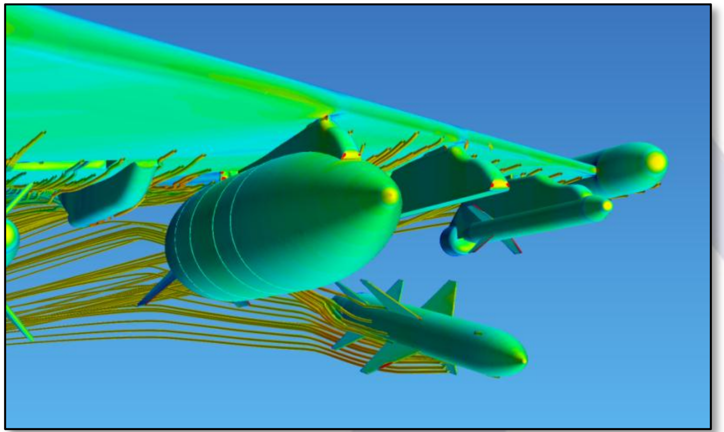


Overlapping grid can fall outside solution domain...

Overset Grids Method in STAR-CCM+, VI

- In the overlapping zone, cells should be of comparable size in both meshes *(recommendation)*:
  - Interpolation errors in the coupling equation should be of the same order as when computing convective and diffusive fluxes (interpolation over half a cell);
  - The coarser of the two coupled meshes determines the error level.
- Between two body walls, at least 4 cells on both background and overset grid are needed to couple them *(requirement)*.
- The overset grid should not move more than one cell per time step in the overlapping zone *(recommendation)*.

Working with Overset Grids, I



- No compromises on usability:
  - Any grid type can be used
  - Most physics models can be applied
  - Processing pipeline (meshing, solving, analysing) unaffected
  - Minimum on additional set-up steps:
    - New region interface (with interface options)
    - New boundary condition
- Using STAR-CCM+ infrastructure for interfaces
- New intersector-module added (searches for donors, defines interpolation factors, cuts holes etc.) – solver almost unaffected…

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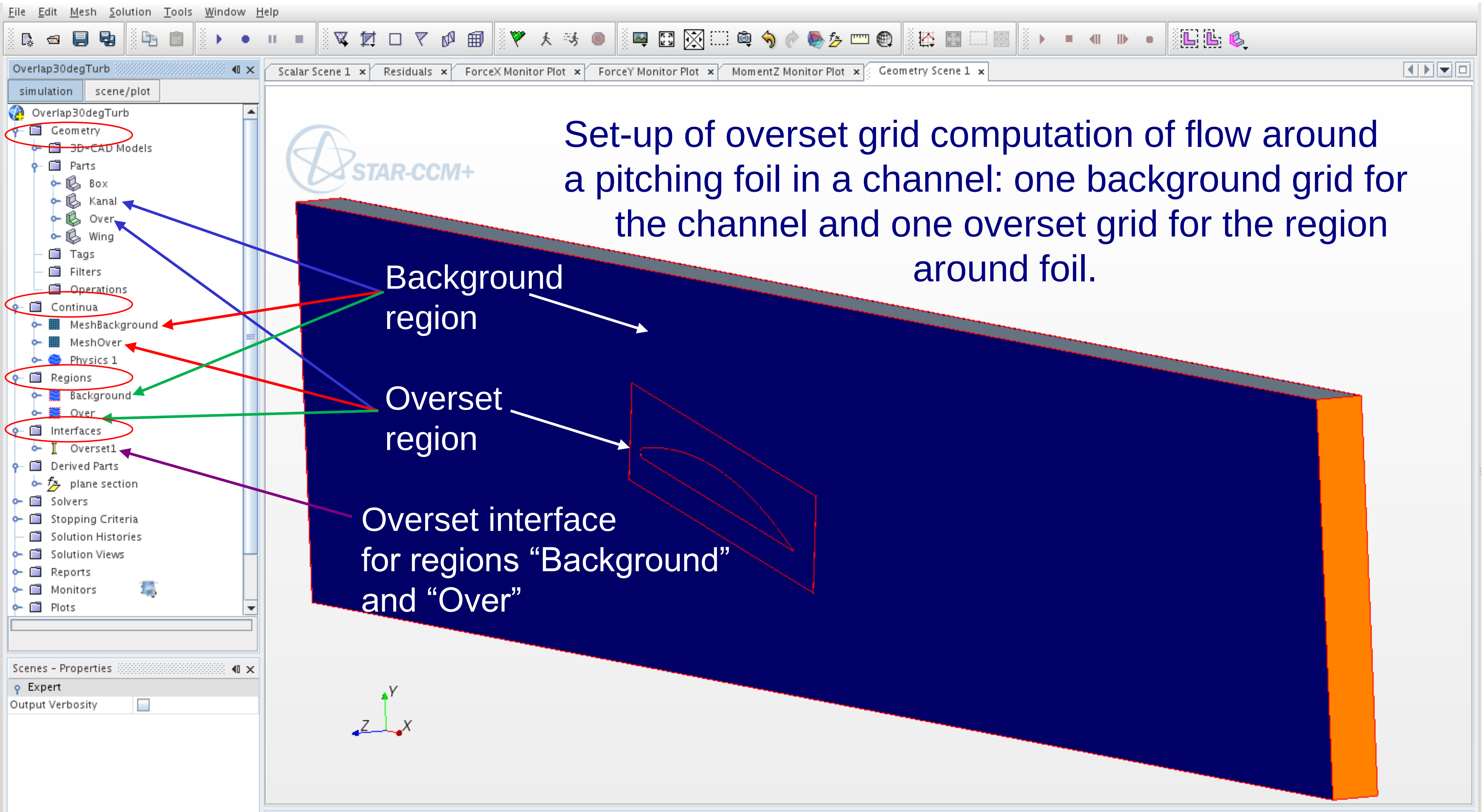
Working with Overset Grids, II



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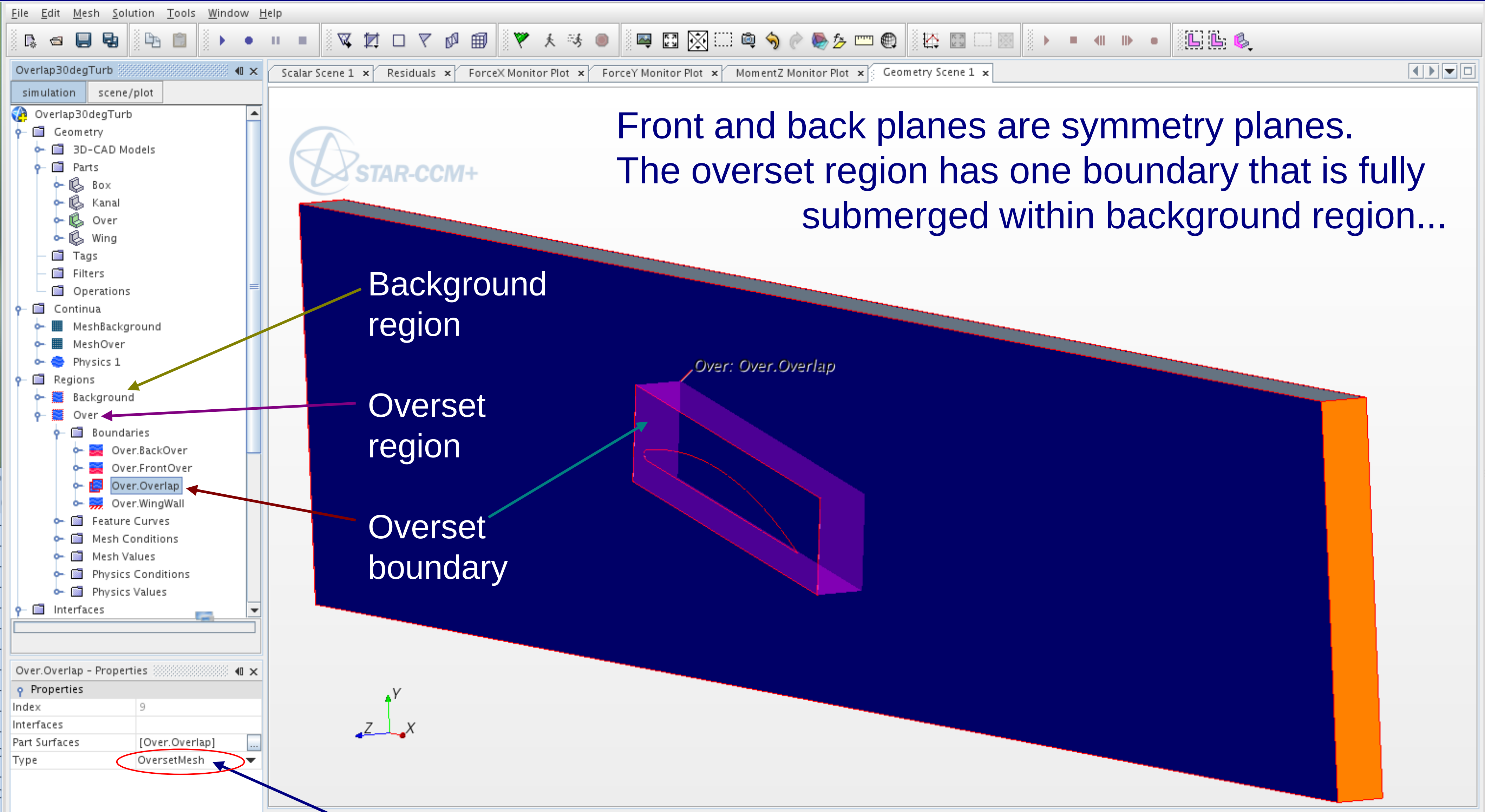
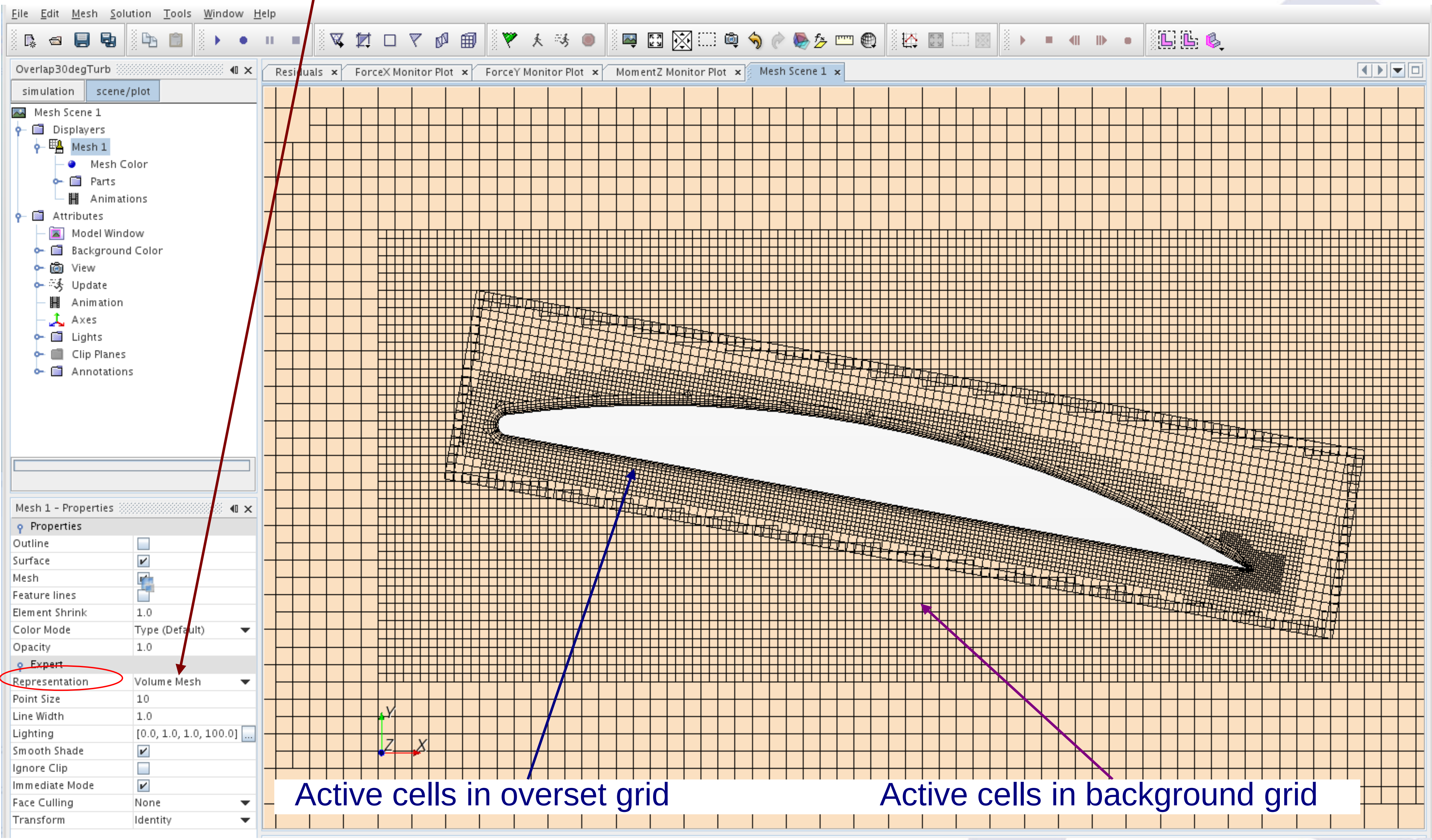
Working with Overset Grids, III



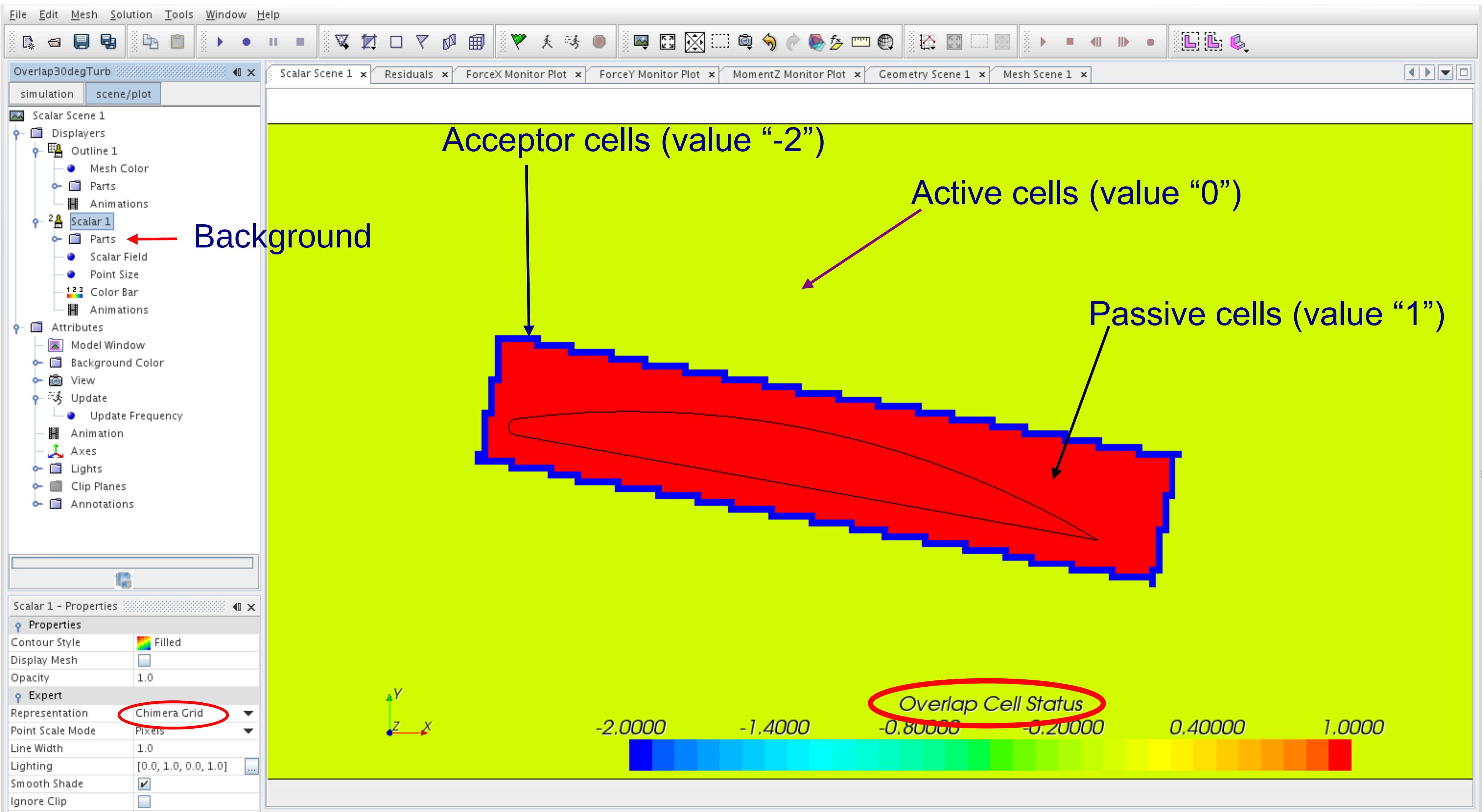
Overset grid surface has boundary type “OversetMesh”

Working with Overset Grids, V

"Volume Mesh Representation" includes active cells – used to plot results...

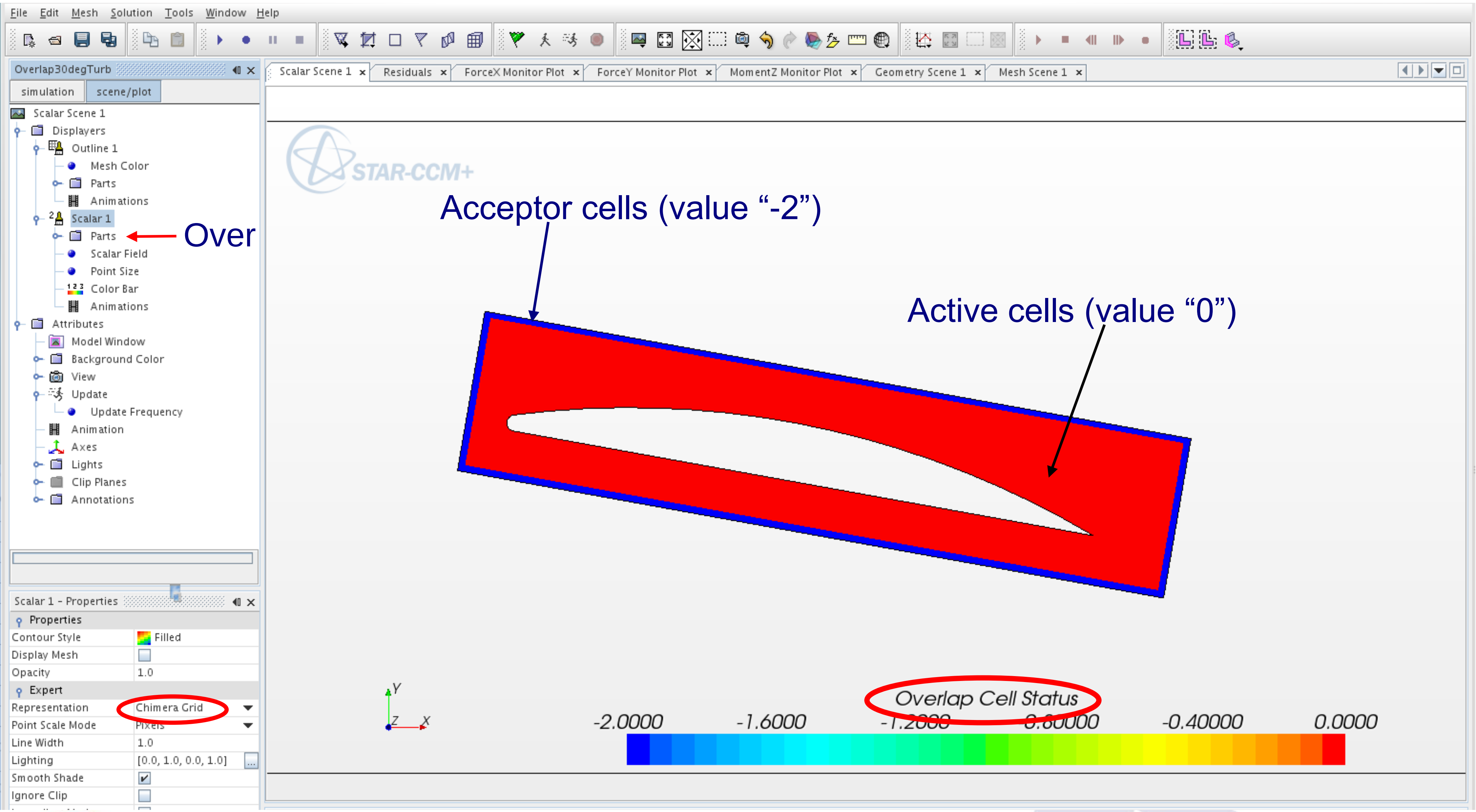


Working with Overset Grids, VI



Checking "Overlap Cell Status" (scalar field): acceptor cells must separate active and passive cells – direct contact is not allowed...

Working with Overset Grids, VII



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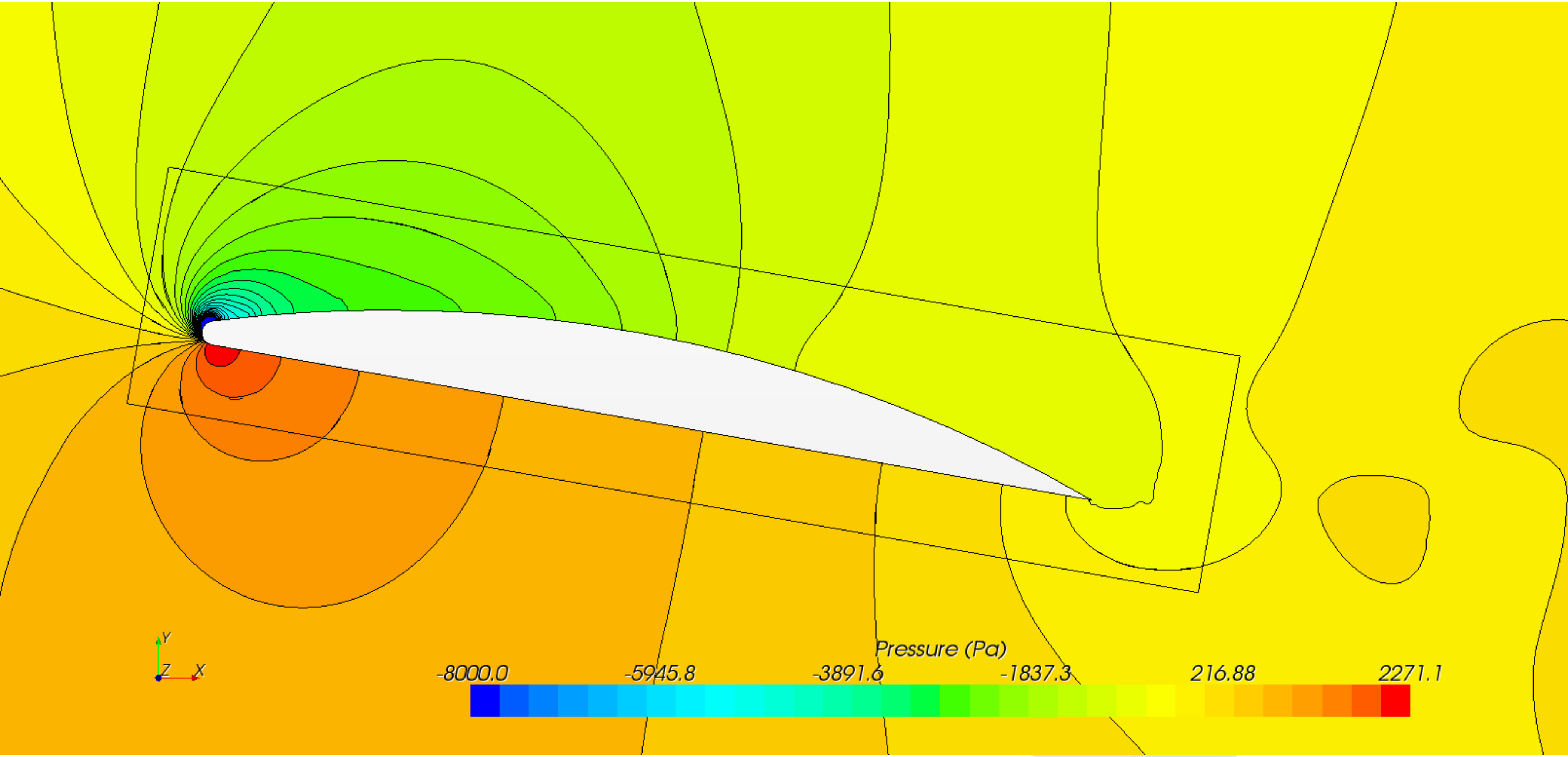
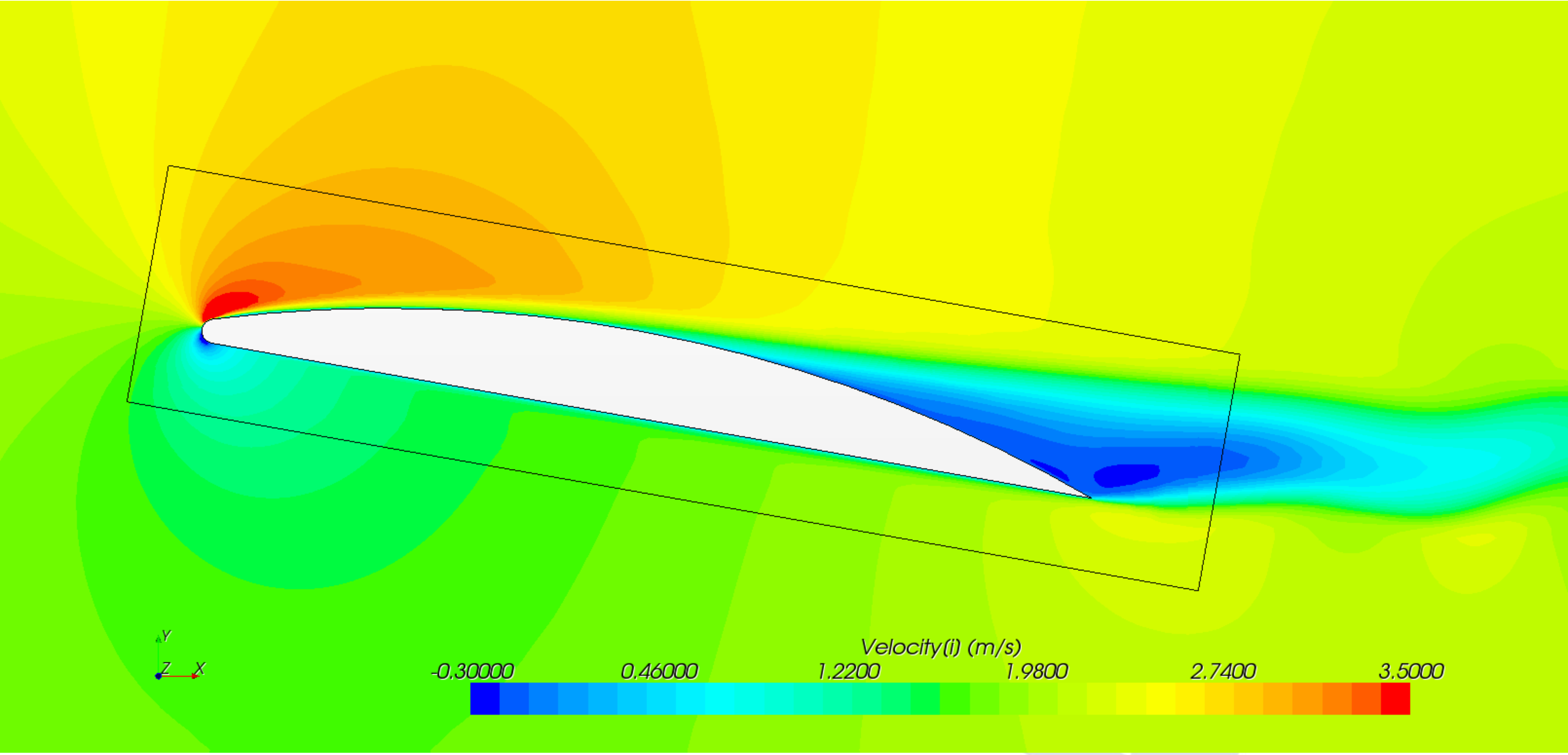
Checking "Overlap Cell Status" (scalar field): the overset grid here contains only active and acceptor cells...

Pressure Contours



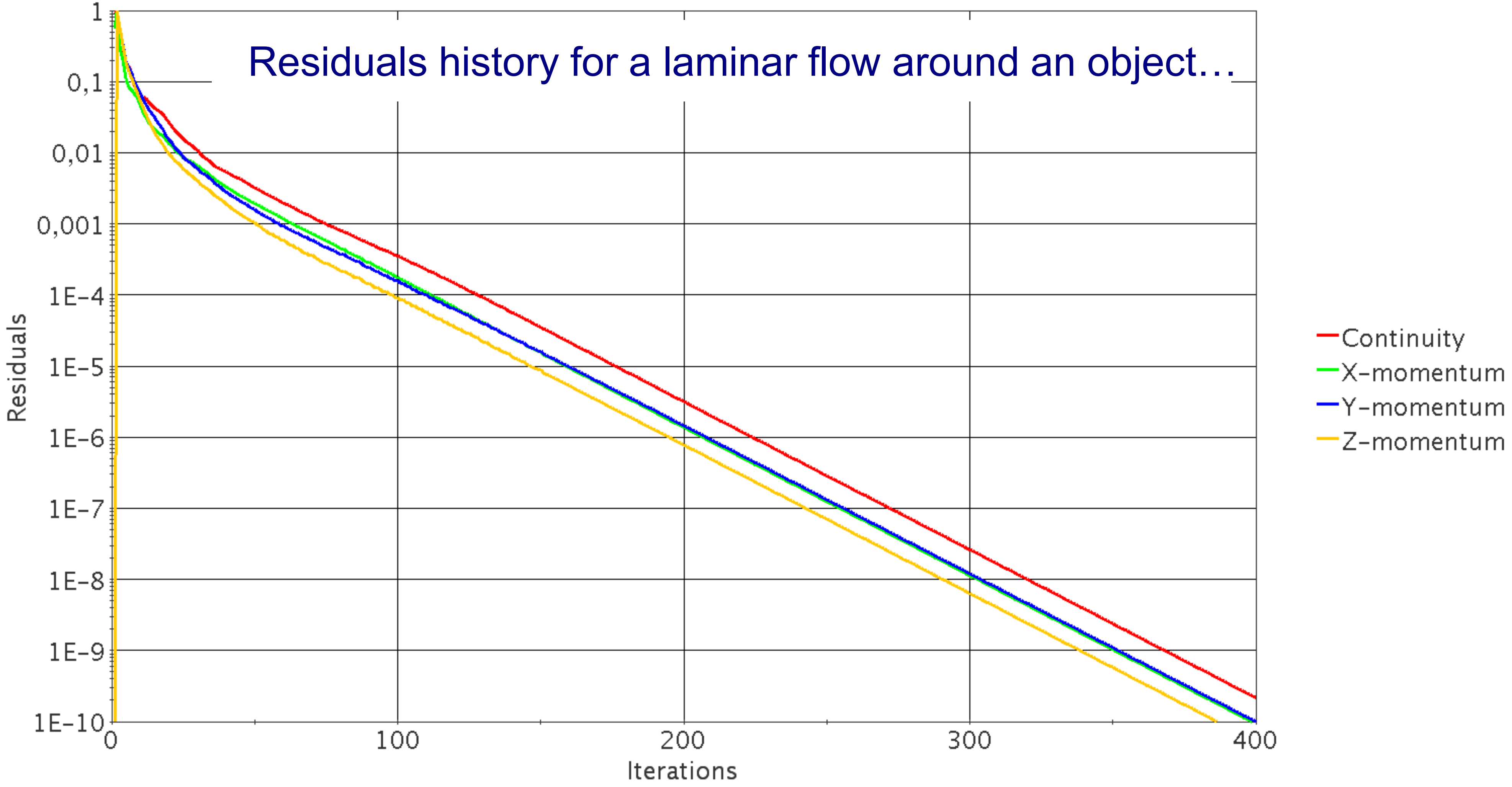
Pressure contours with lines: small imperfections (two lines visible within overlap zone) visible only at few locations – most contours are almost perfectly continuous (grid from previous slides)

Velocity Contours



Velocity contours without lines: hardly any imperfection visible – contours appear almost perfectly continuous (grid from previous slides)

Convergence of Iterations



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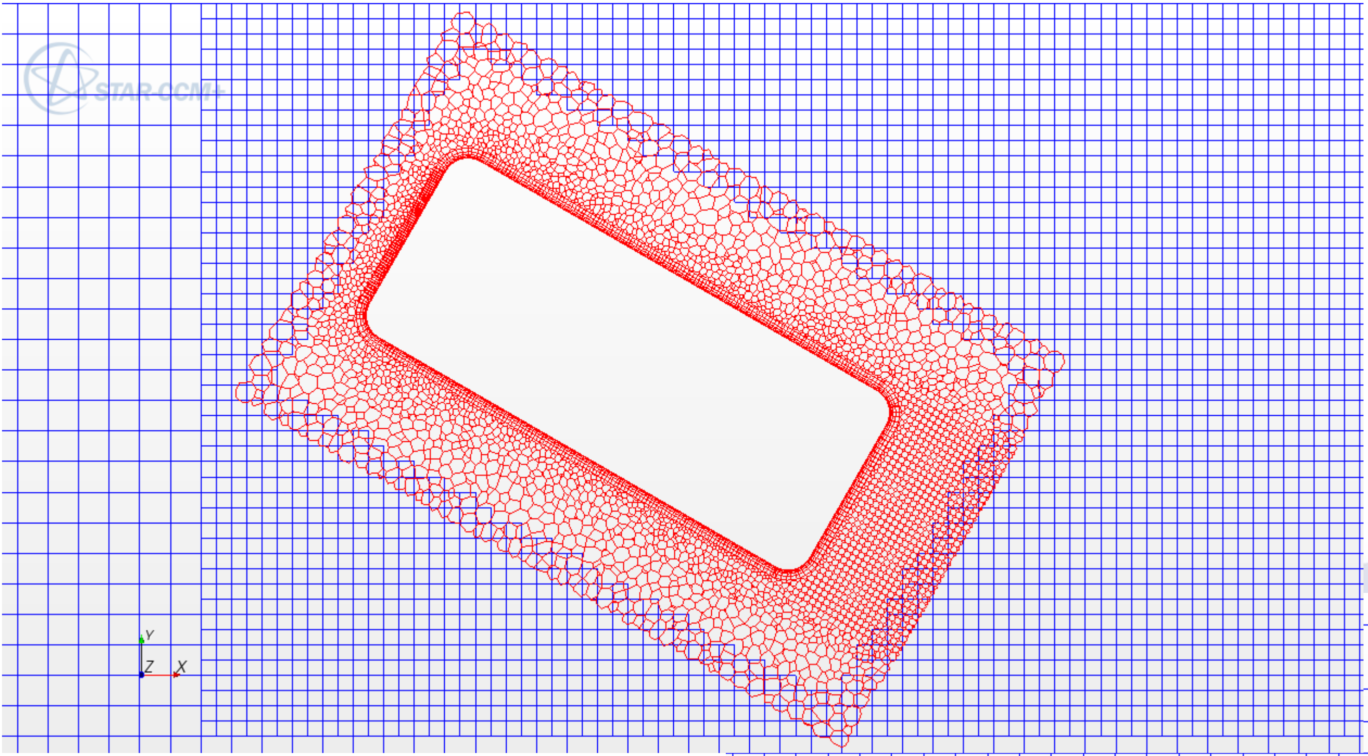
Implicit coupling of grids allows convergence to round-off level of residuals…

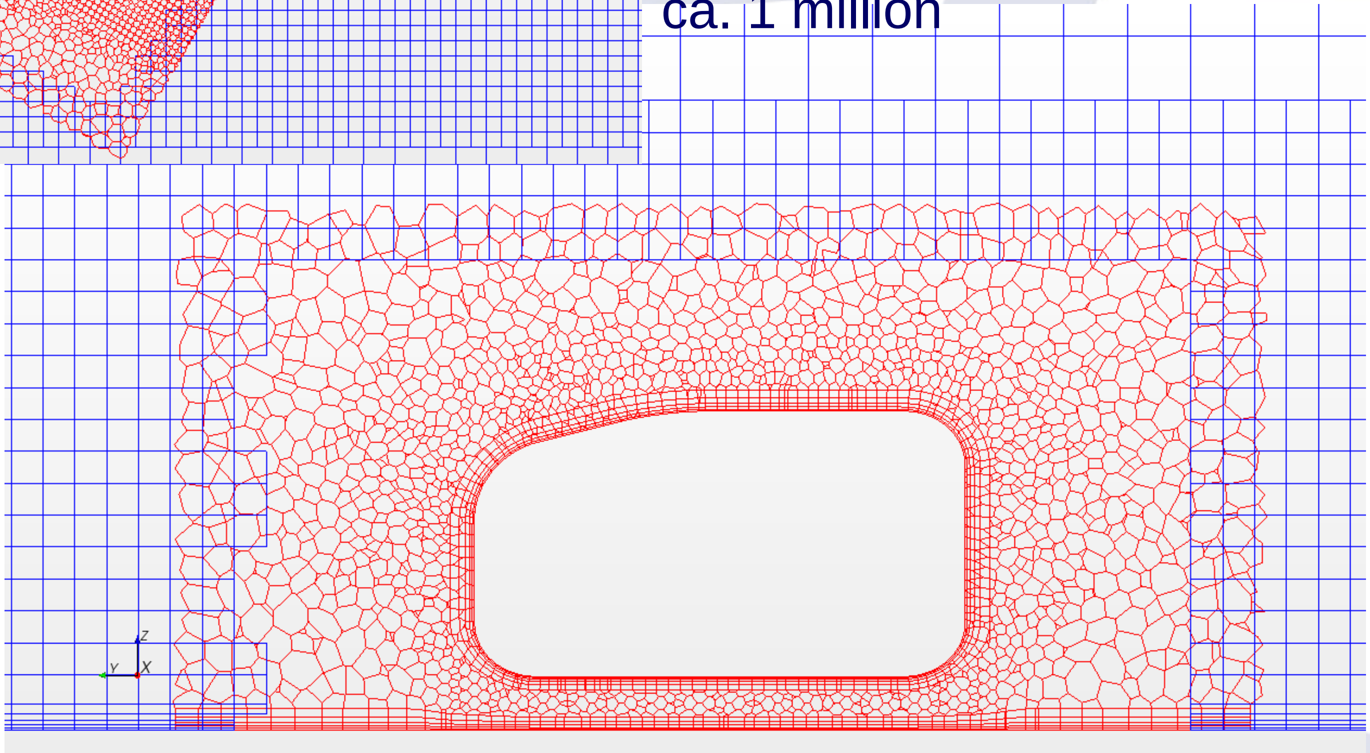
Application to Parametric Studies, I



Flow around a car at different angles of attack

A horizontal section through both grids (only active cells are shown).

Total number of cells:
ca. 1 million



Vertical section through the two grids (only active cells are shown).

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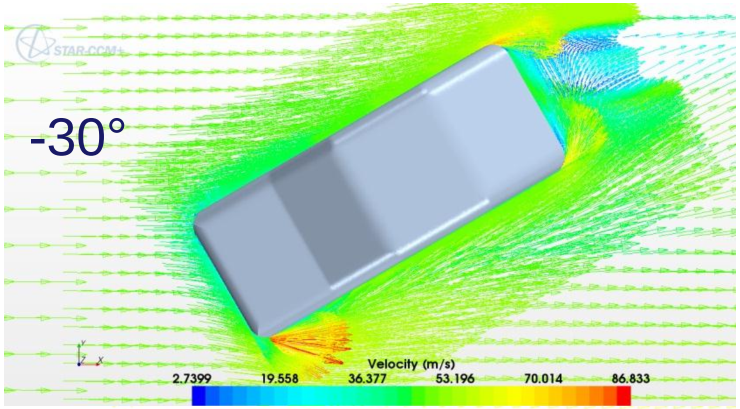
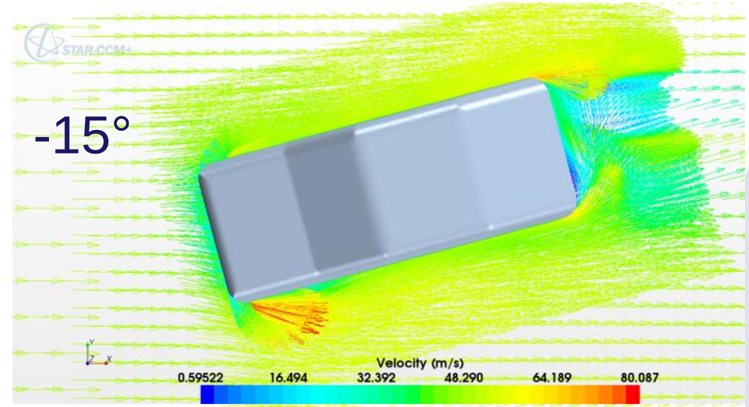
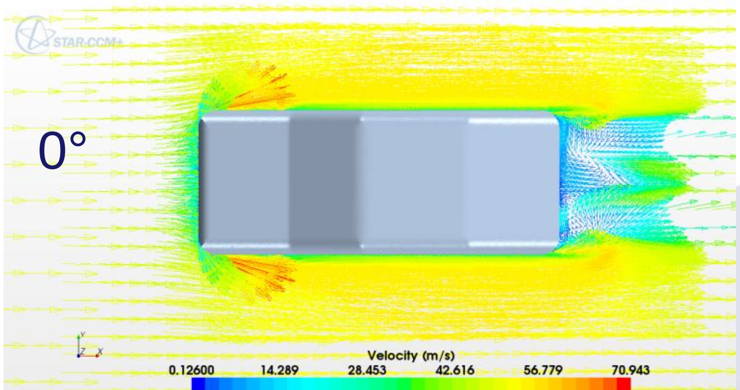
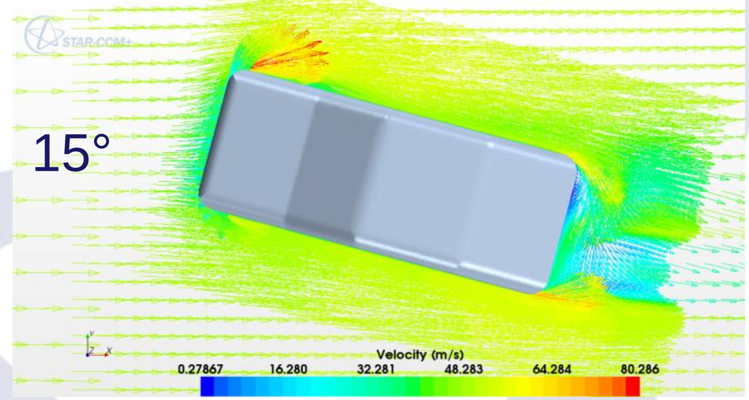
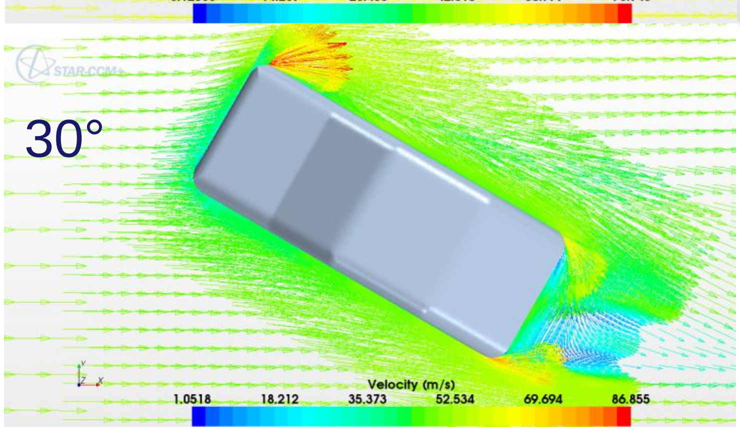
Application to Parametric Studies, II











Velocity distribution in a section parallel to bottom wall for different angles of attack

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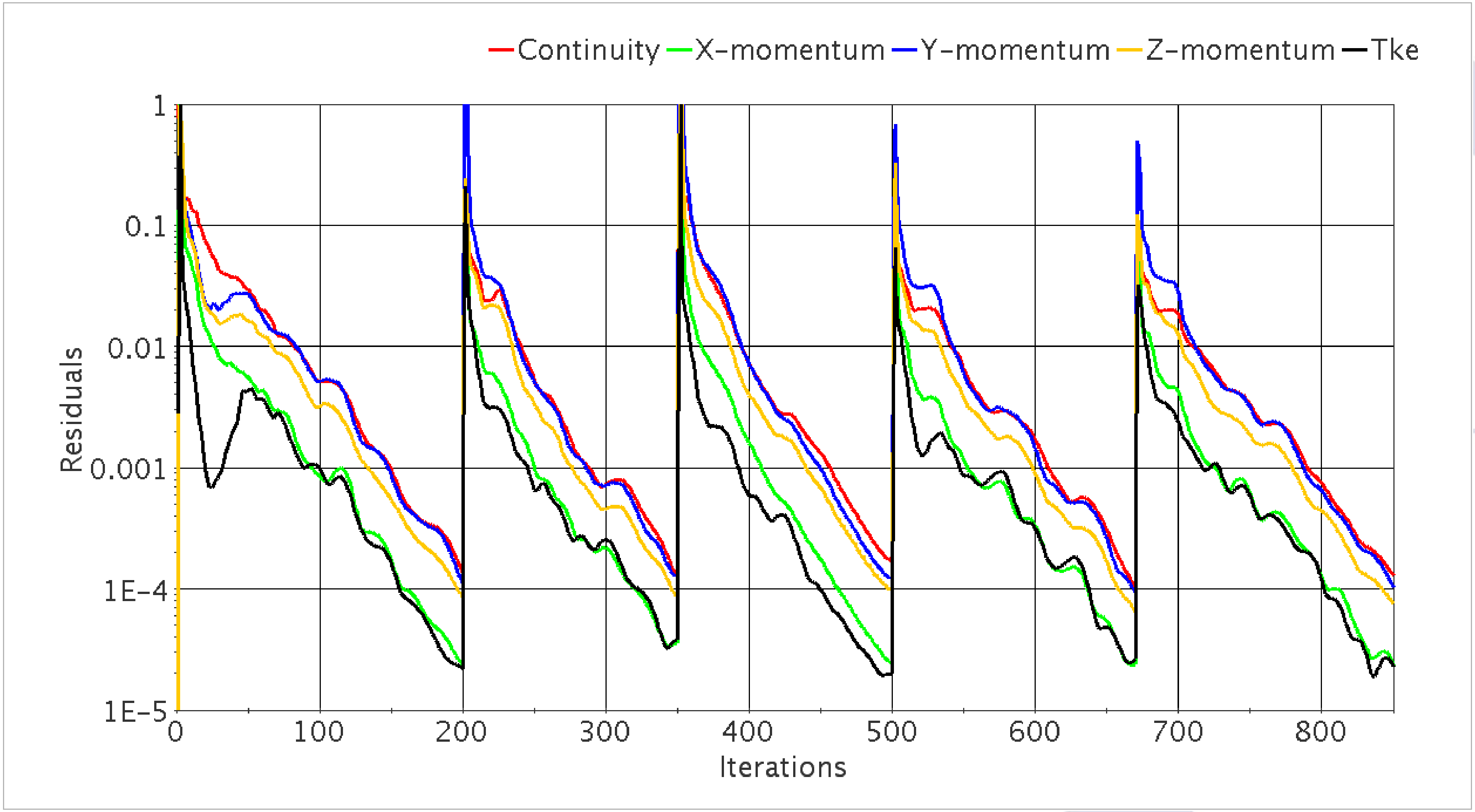
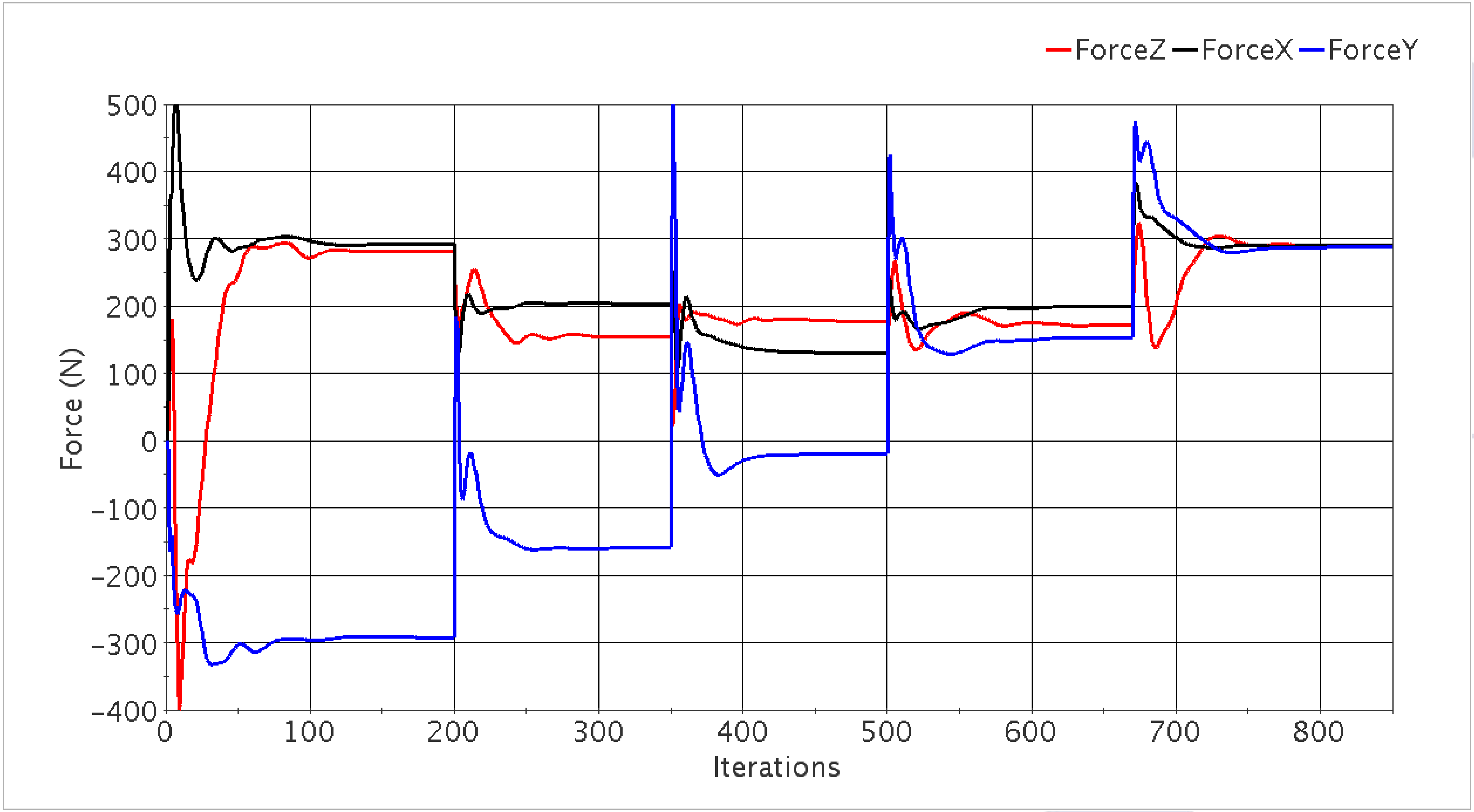
Application to Parametric Studies, III



Residual history from the computation of flow around a vehicle in a wind tunnel at different angles of attack: time step 1000 s, rotation 15° per time step, standard *k*-*ε* turbulence model, under-relaxation 0.9/0.1/0.9 for velocities/pressure/turbulence, wind speed 40 m/s

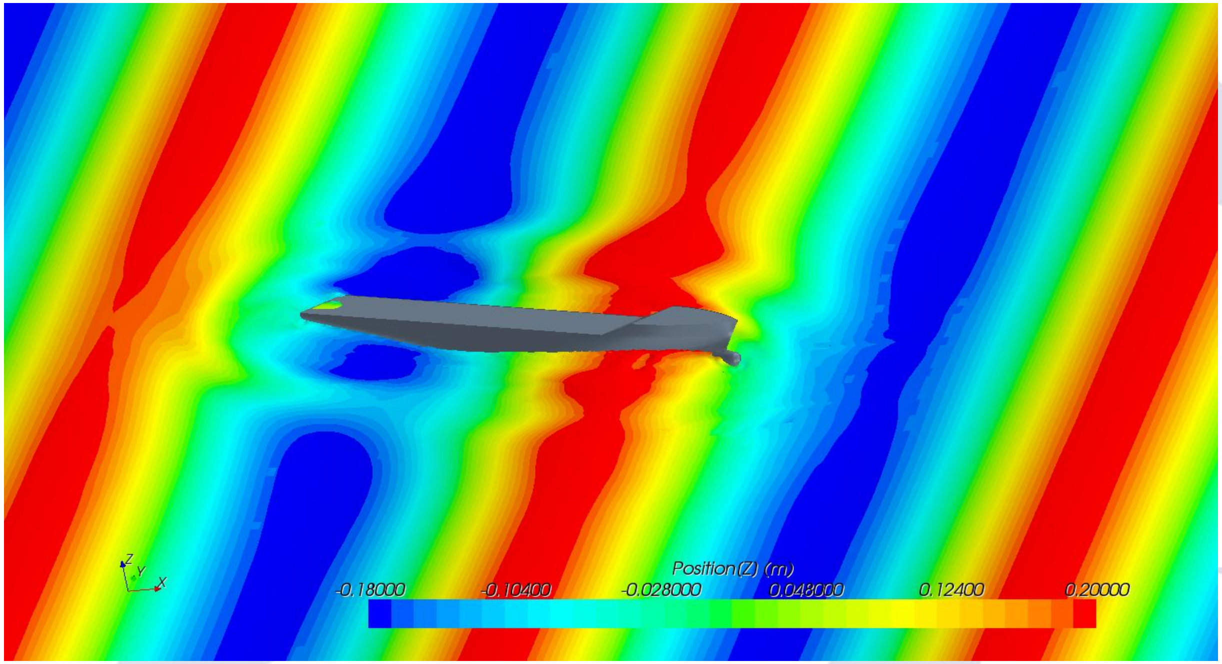
Application to Parametric Studies, IV

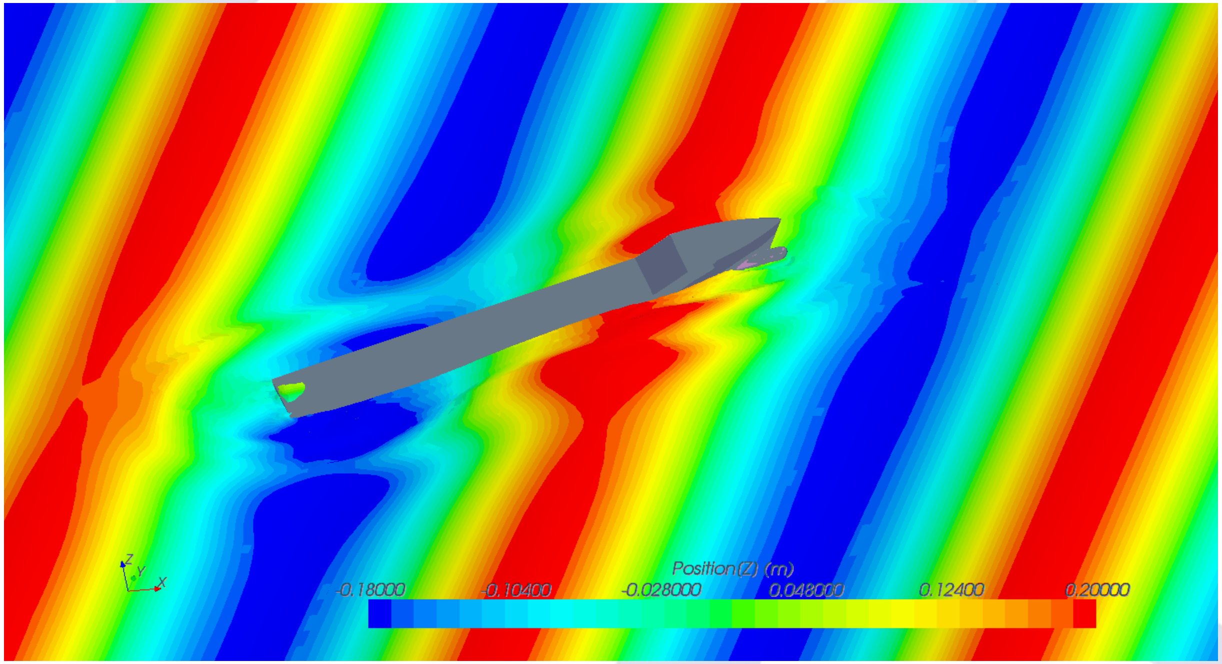


History of computed forces from the computation of flow around a vehicle in a wind tunnel at different angles of attack (since the time step is very large, steady-state solutions are obtained).

Application to Parametric Studies, V

Simulation of motion of a container ship in Stokes waves propagating from right to left: initial vessel orientation 30° (upper) and -30° (lower) relative to the direction of wave propagation





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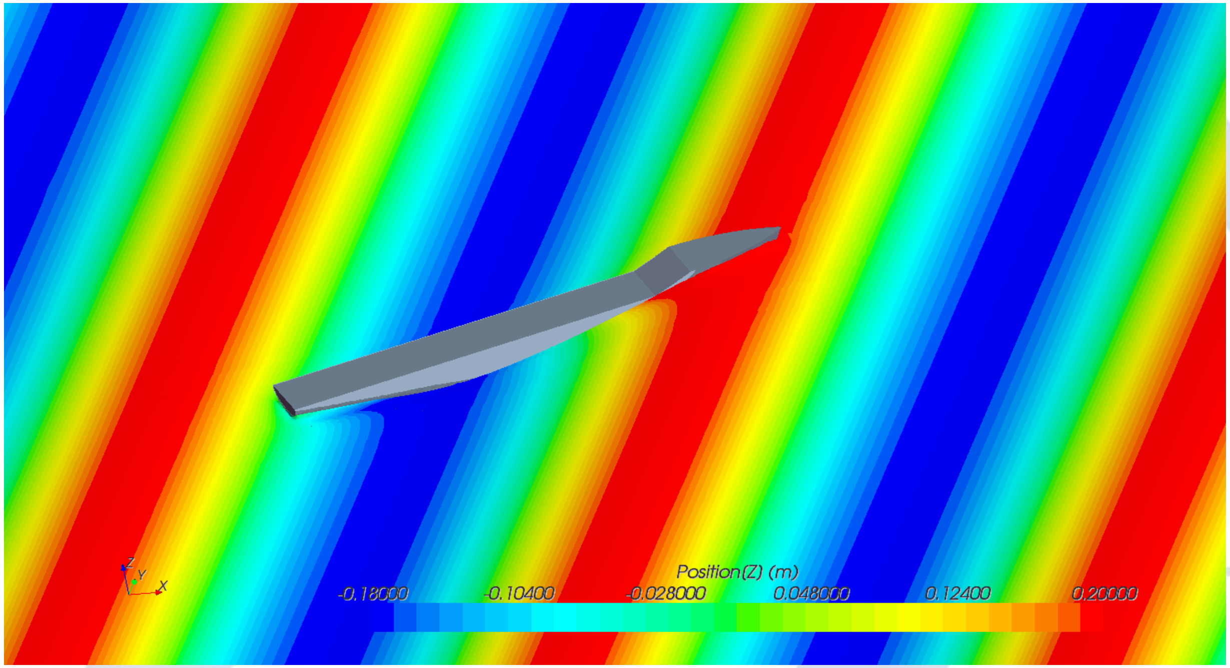
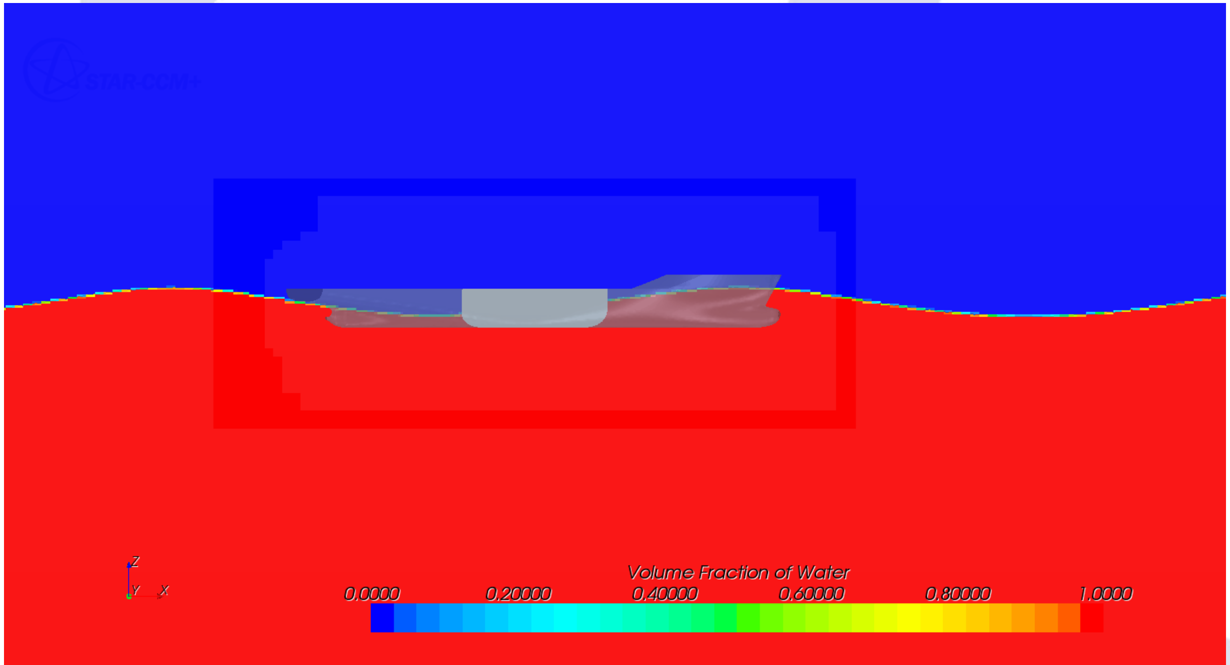
Application to Parametric Studies, VI

Simulation of motion of a container ship in Stokes waves propagating from right to left: initial vessel orientation 30° (upper) and -30° (lower) relative to the direction of wave propagation





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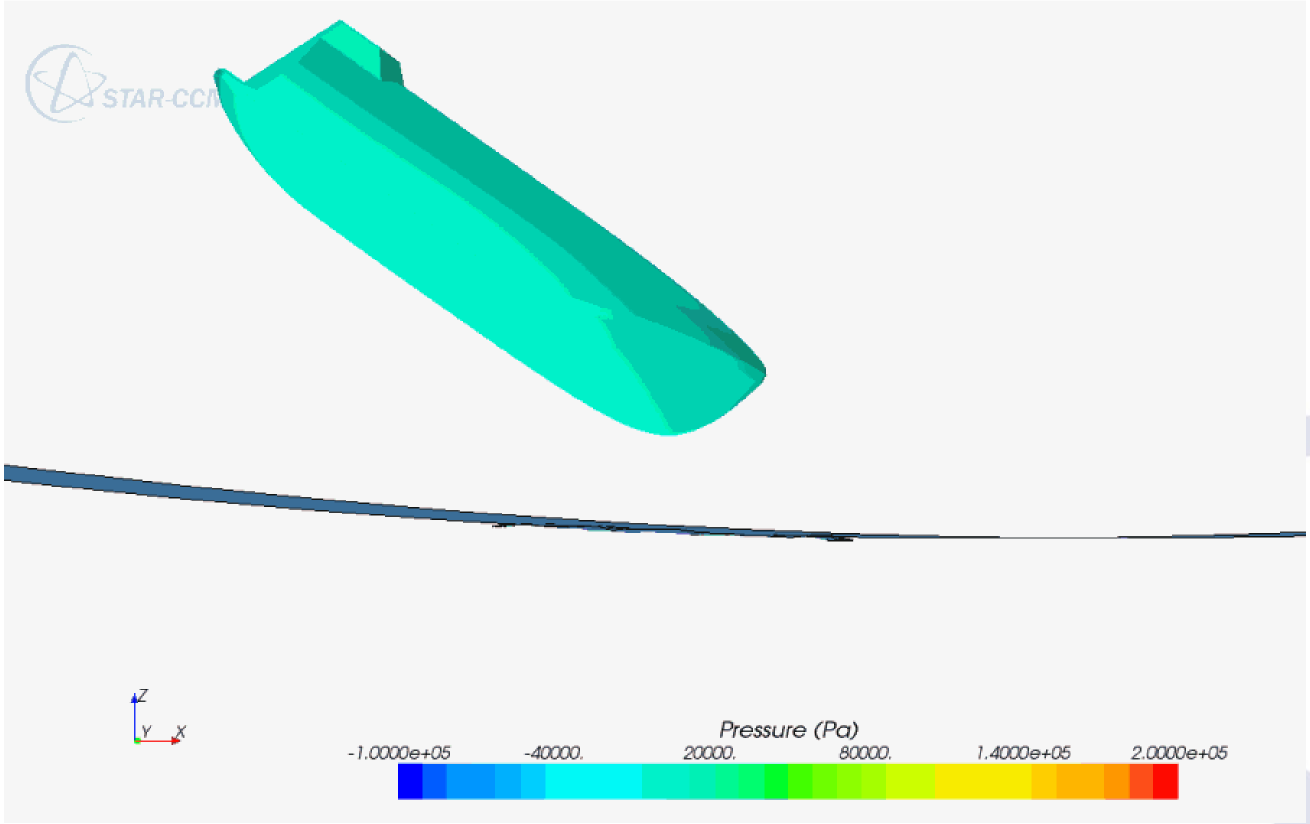
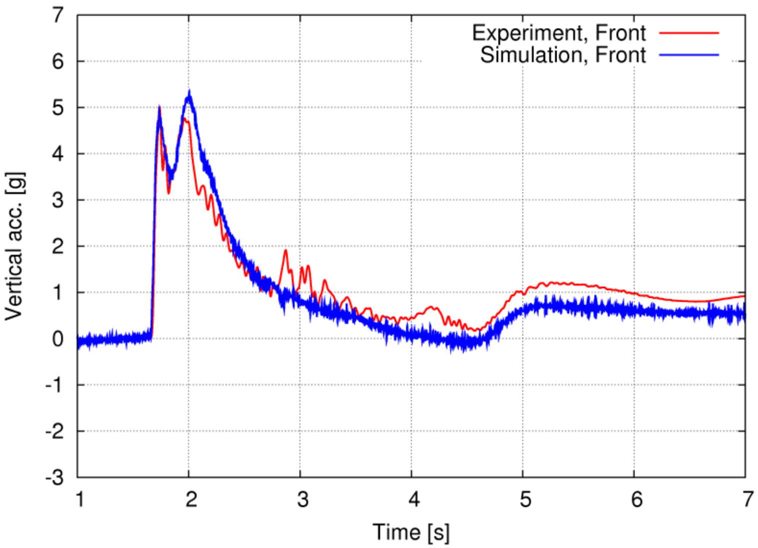
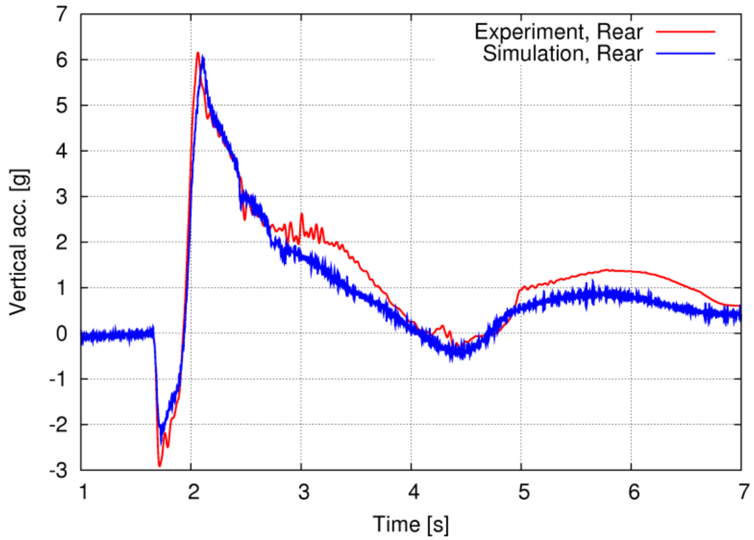
Simulation of Lifeboat Launching, I

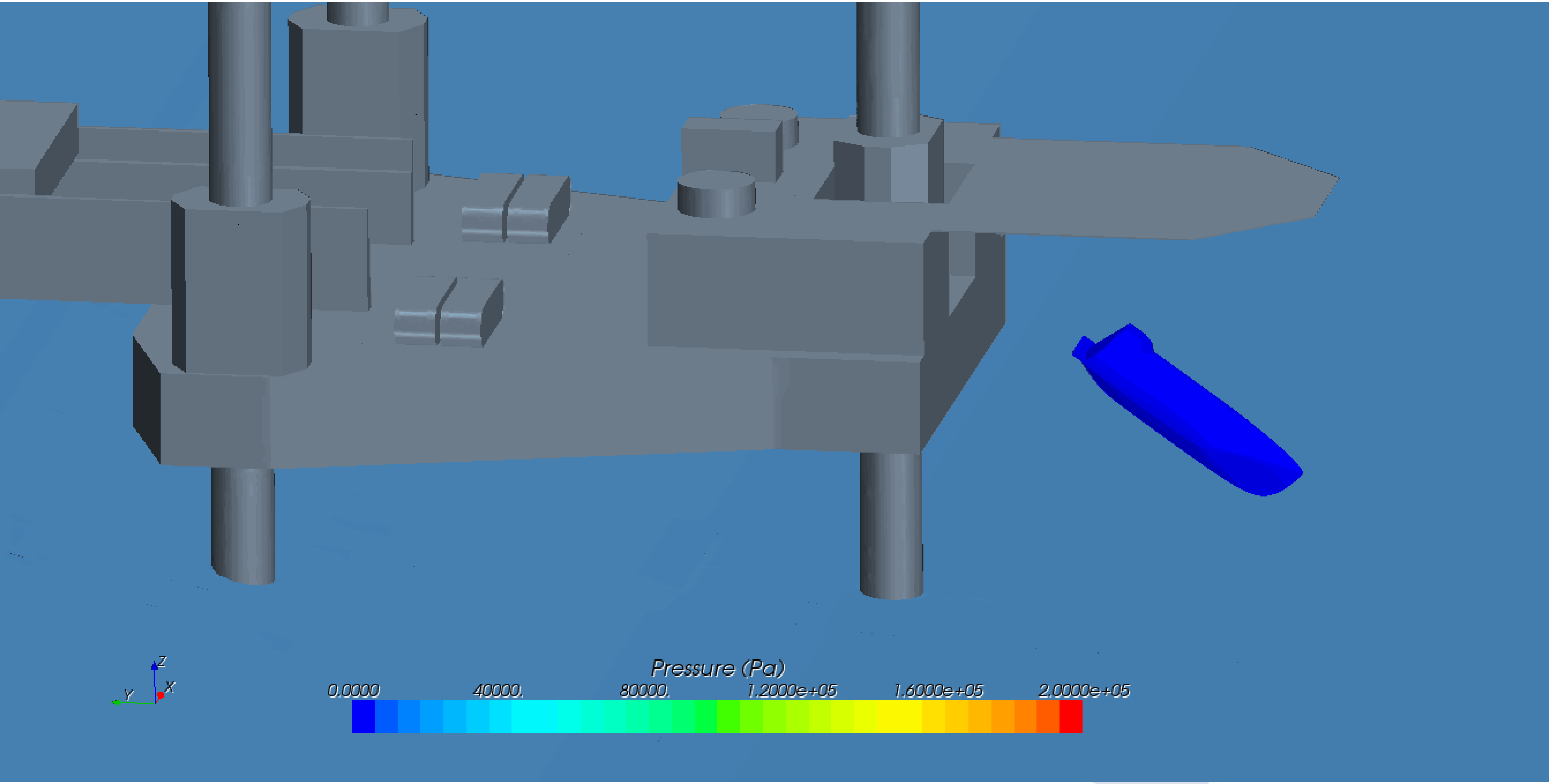






Simulation by H.J. Morch, CFD Marine;
Experiment by Norsafe AS

Simulation of Lifeboat Launching, III



Simulation of lifeboat launching from a platform

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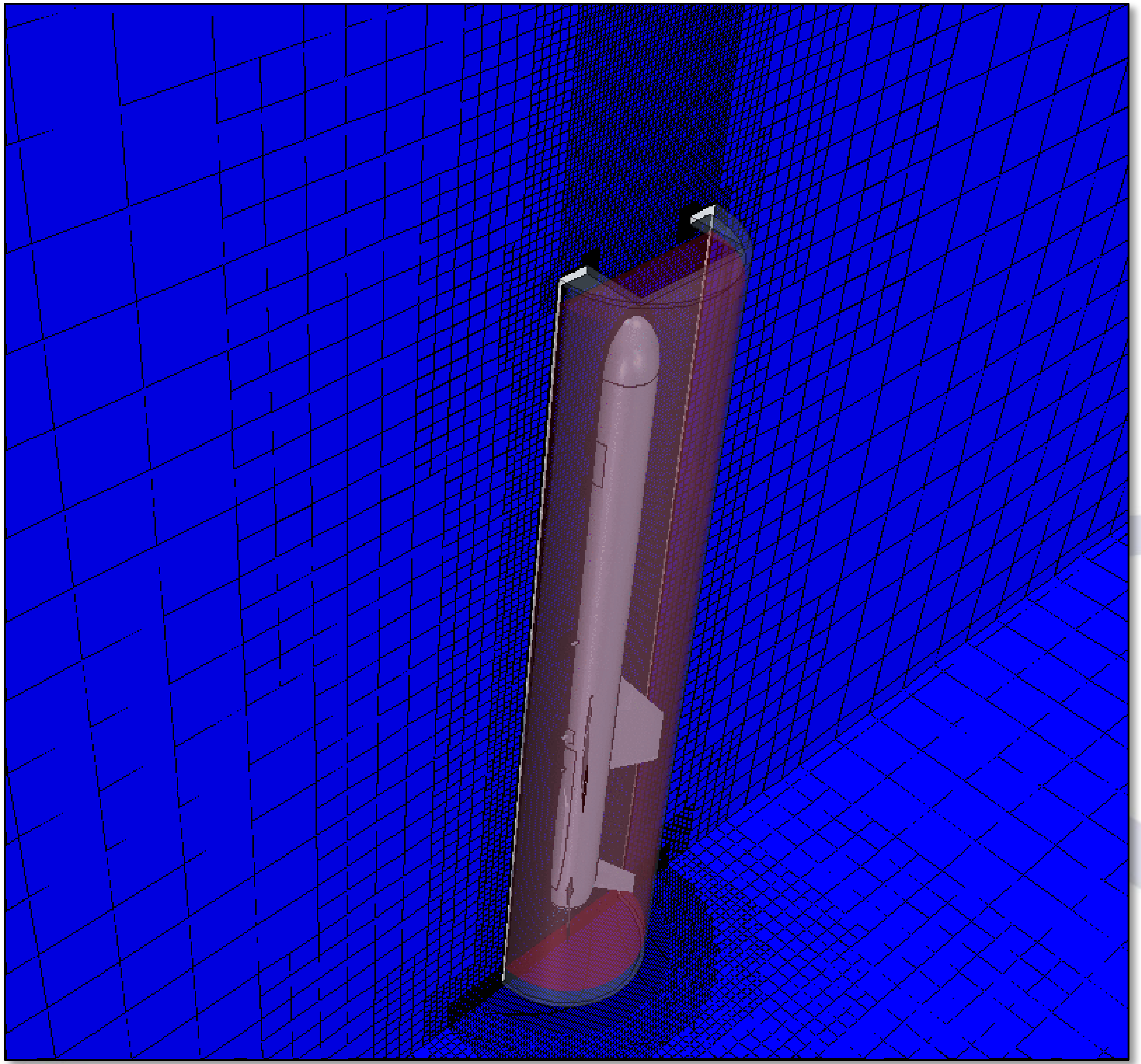
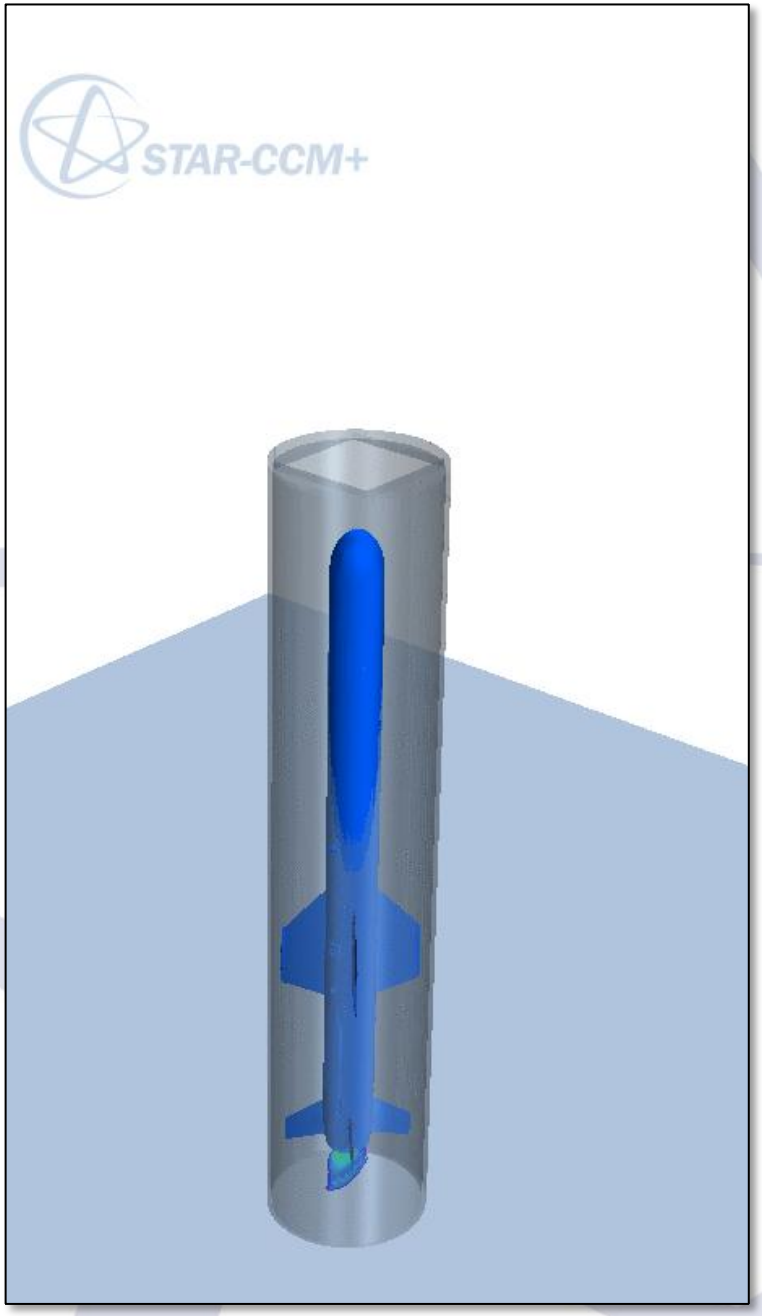
Simulation of Missile Launching

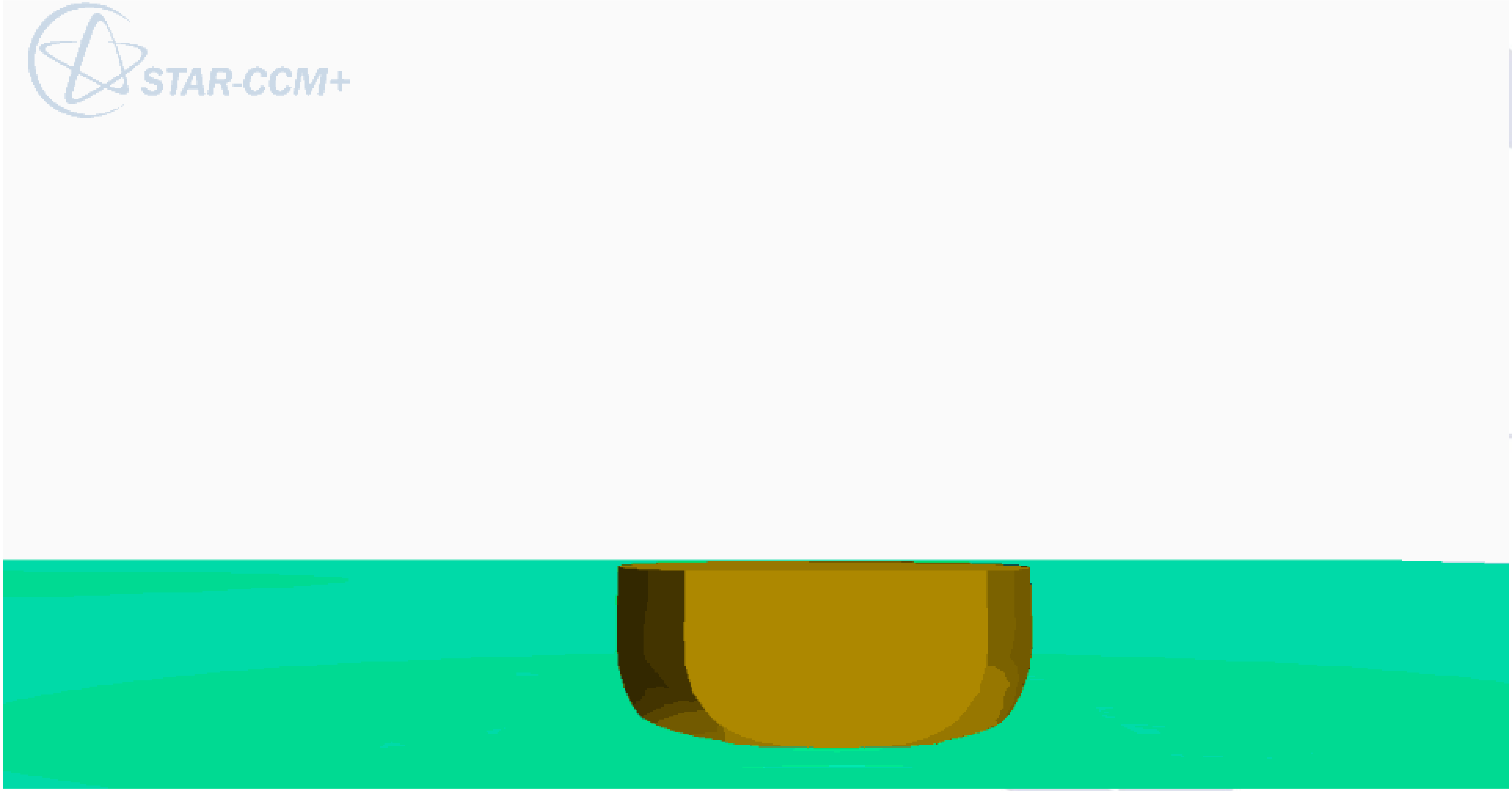


Temperature



Mach Number / Surface Temperature

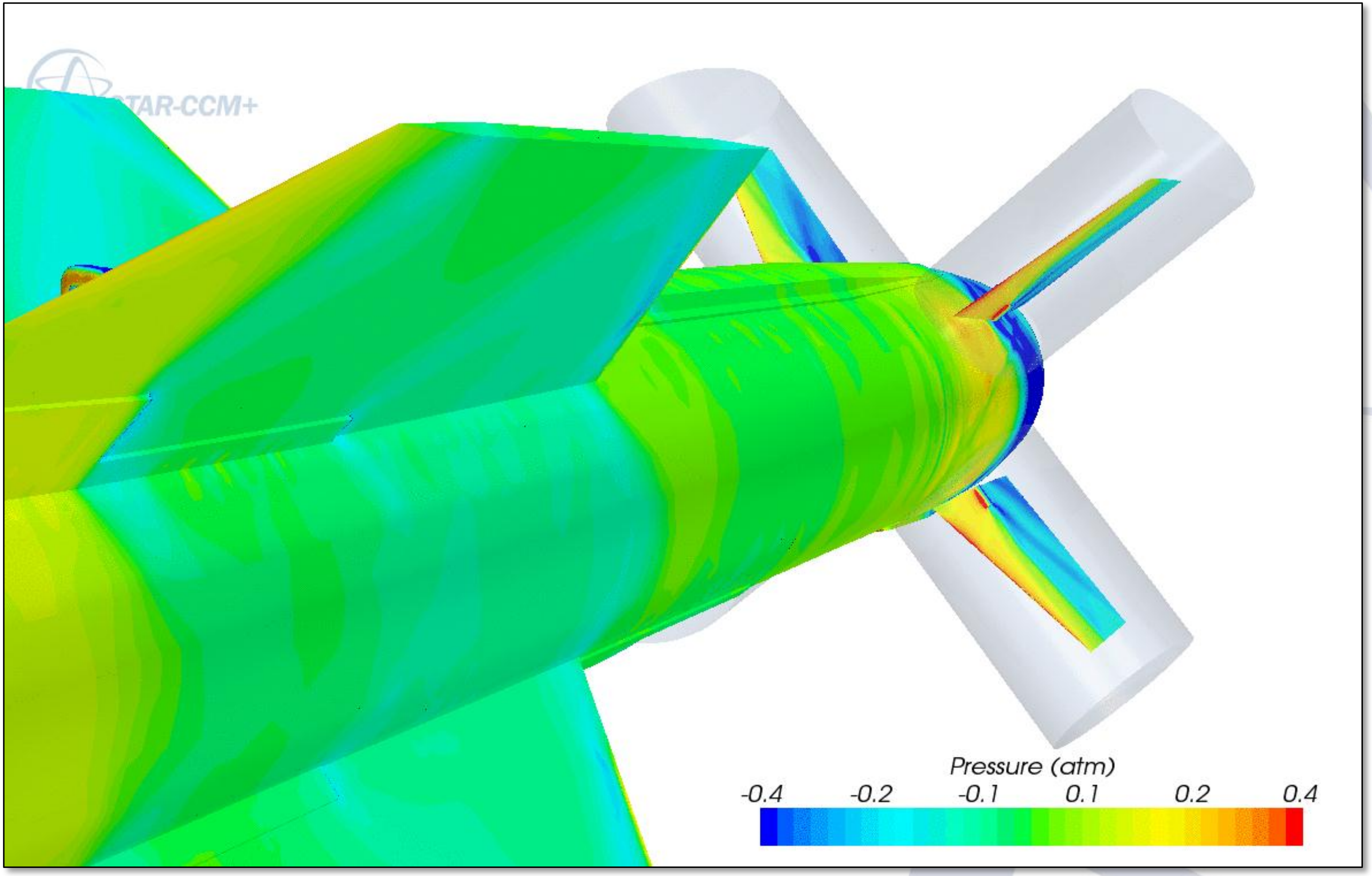
Vessels With Crossing Paths



Two vessels with crossing paths:

This kind of simulation would be difficult to perform without overset grids (sliding grids cannot be used; morphing would require frequent re-meshing)

Moving Control Surfaces



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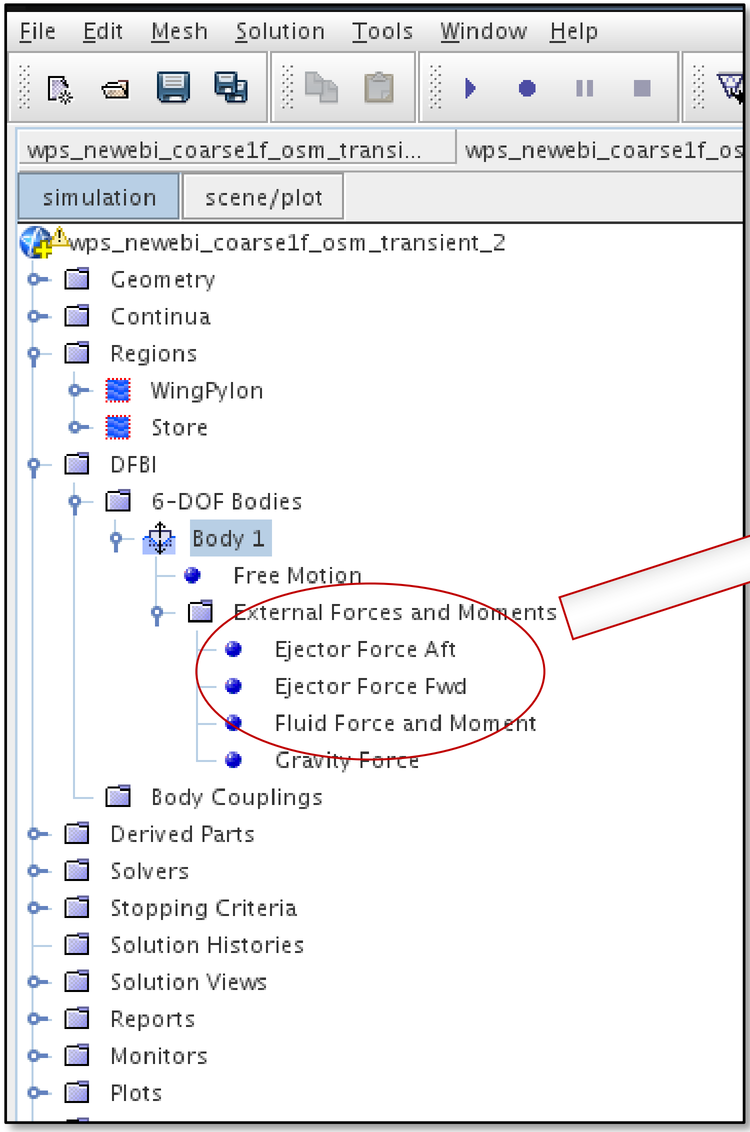
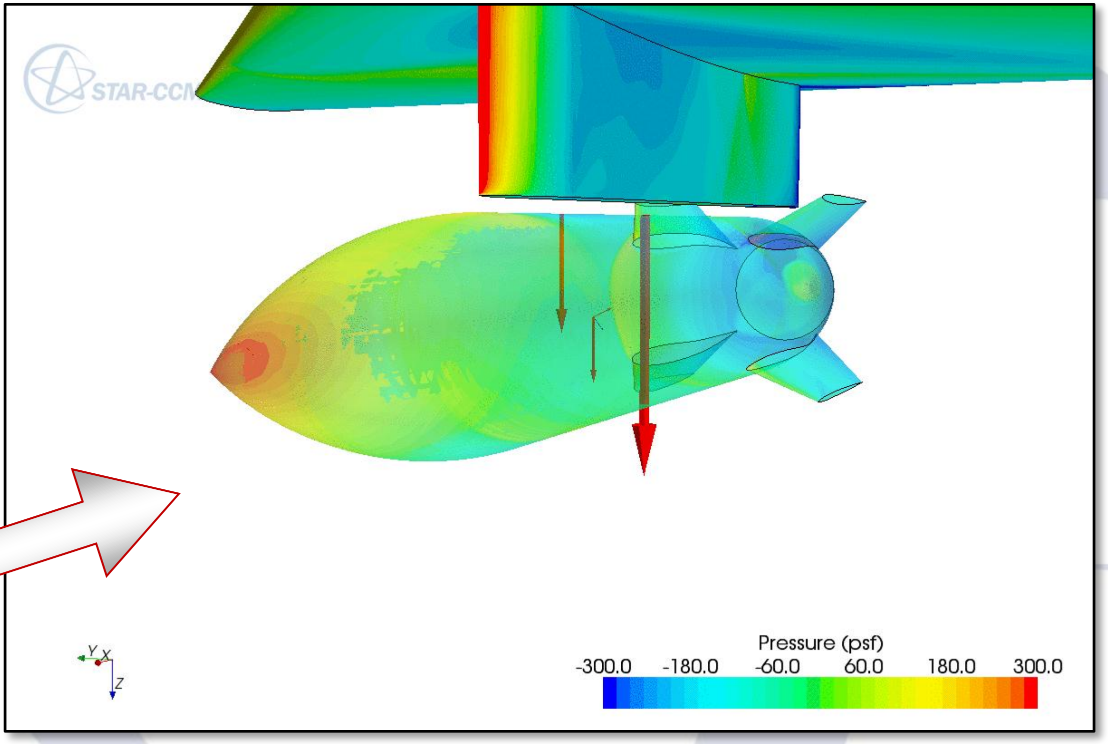
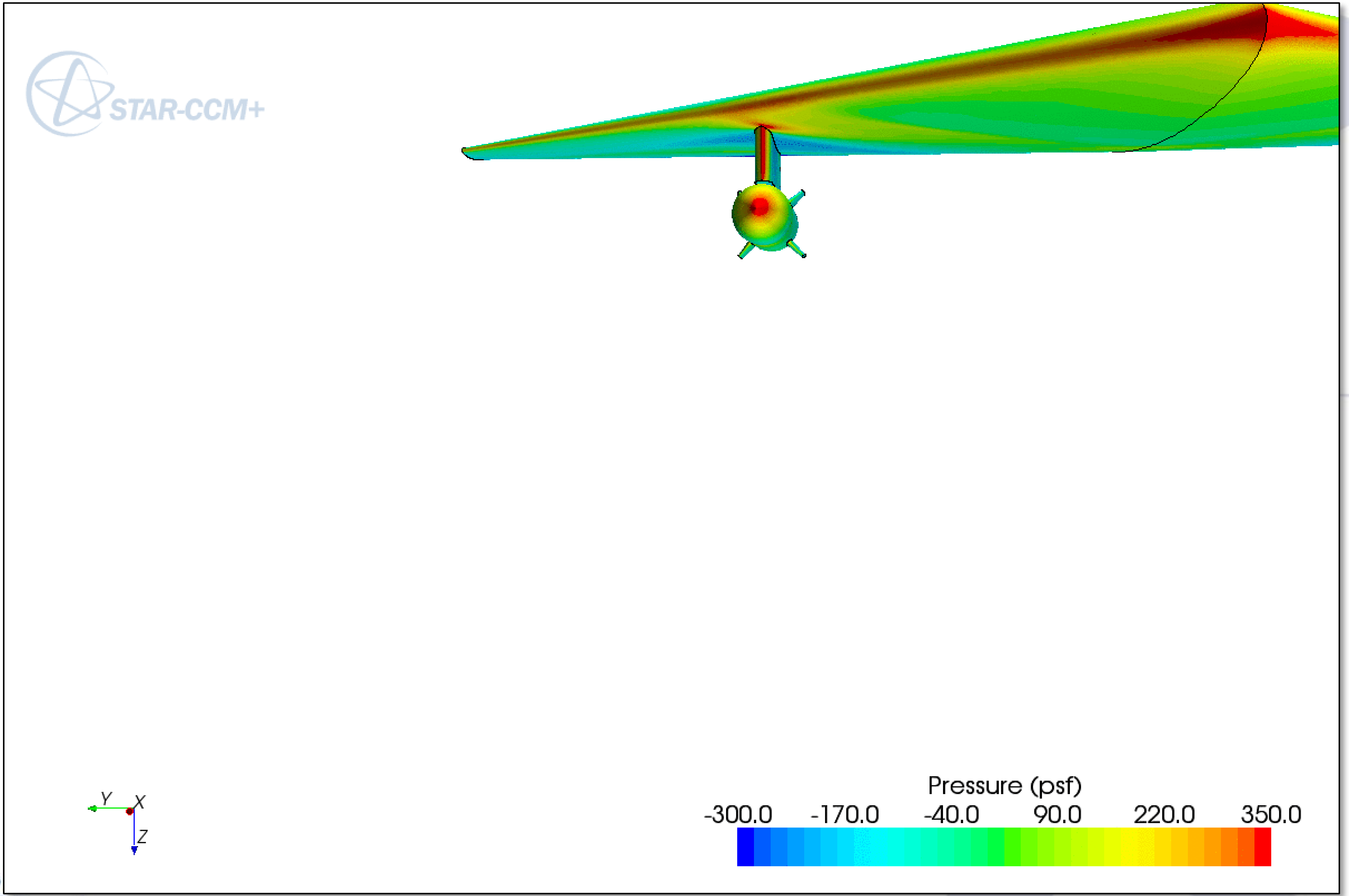
Store Separation, I



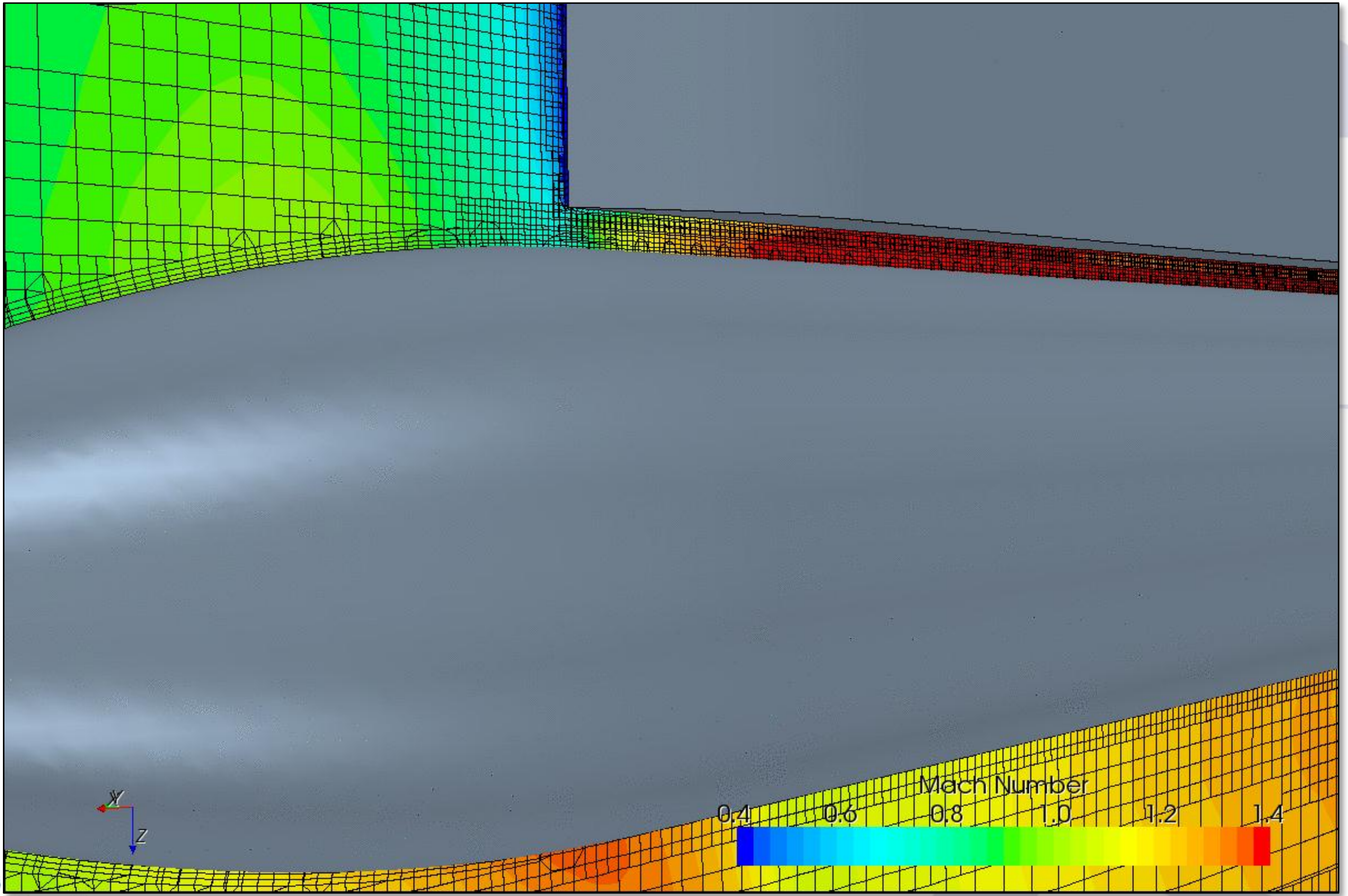


- Modeled as arbitrary point loads
  - Defined through the GUI
  - Custom functional relationships to match ejector force and stroke length
- Visualize loads real-time
  - Note that initial motion is dominated by ejector forces

Store Separation, II



Store Separation, III



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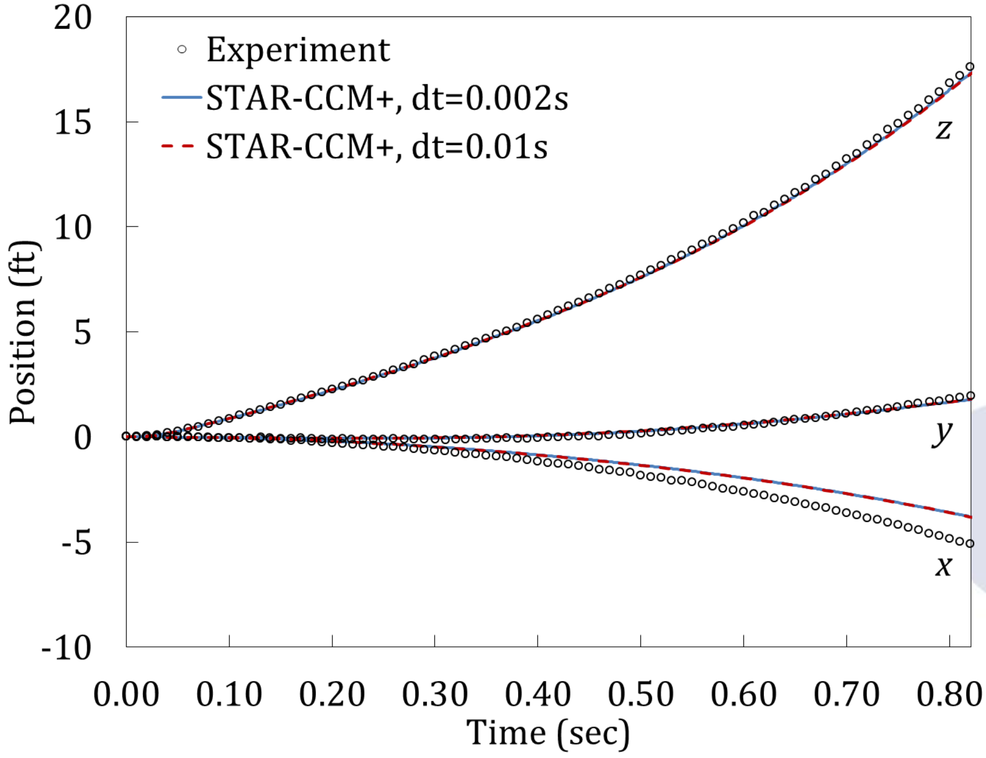
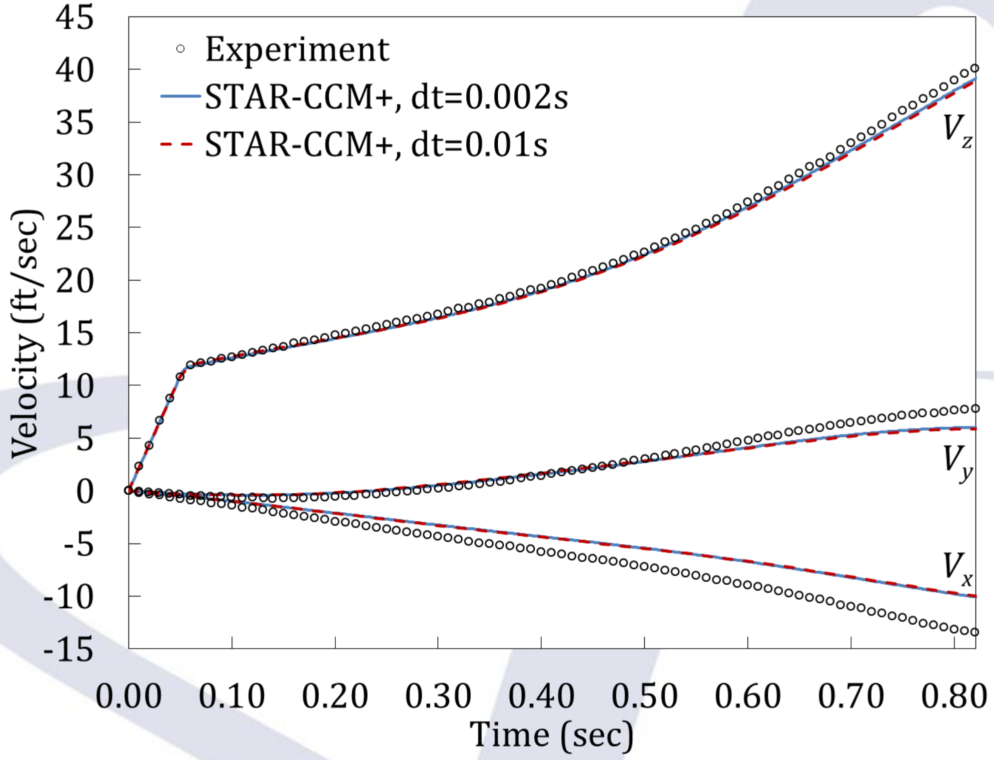
Store Separation, IV





Comparison of motion in simulation and experiment

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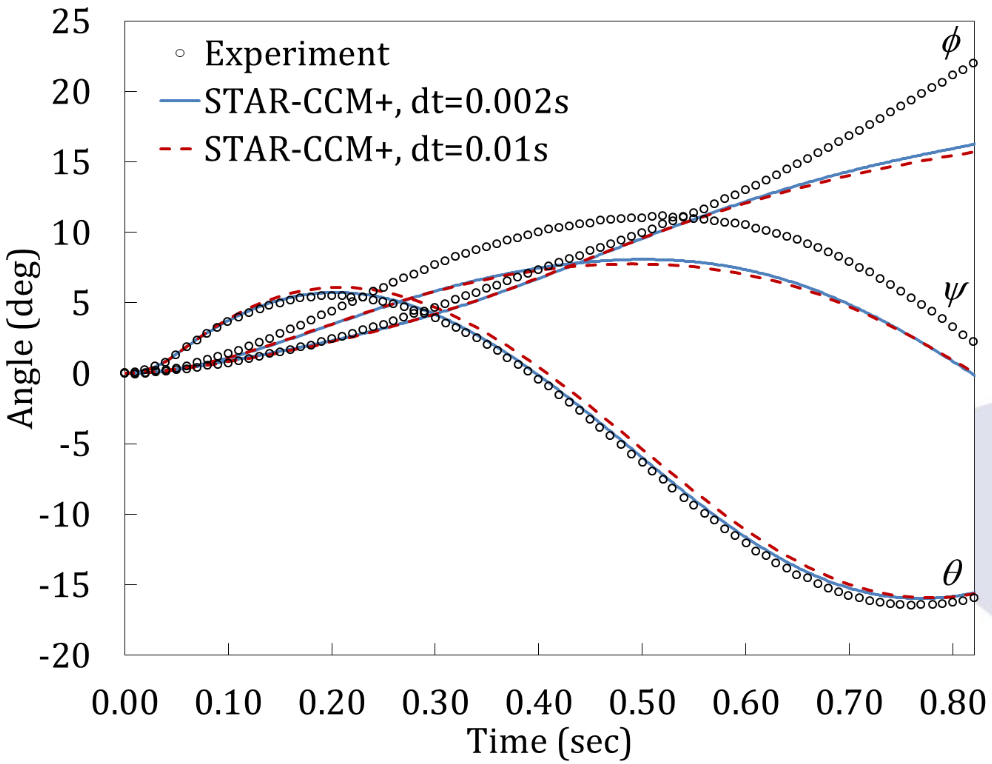
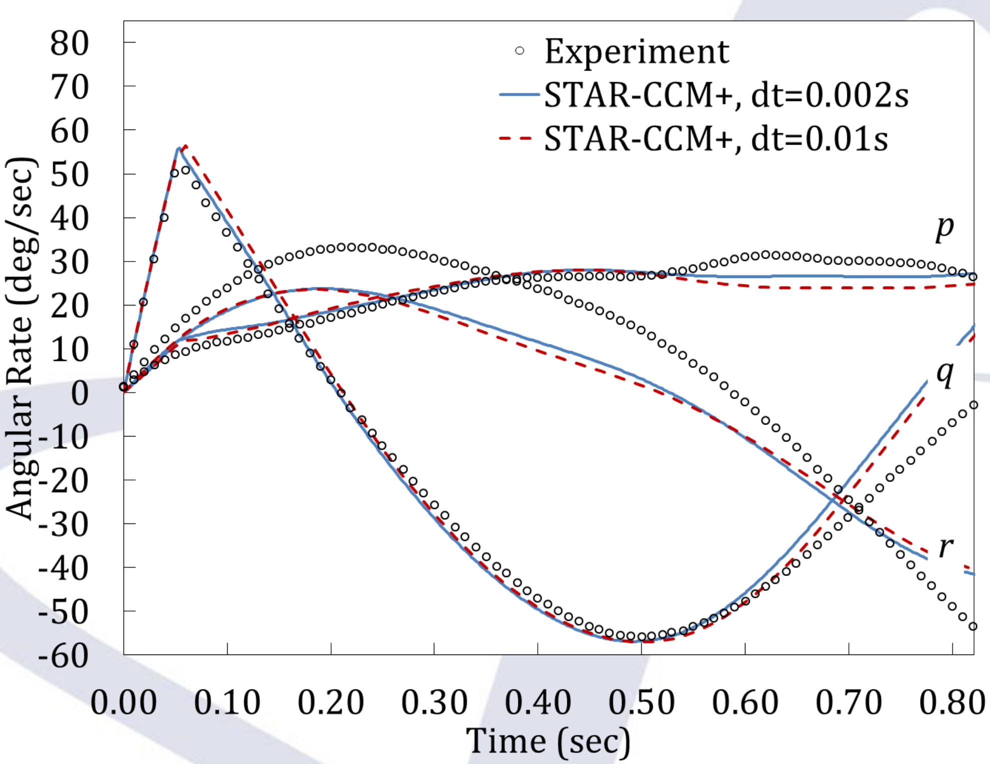
Store Separation, V





Comparison of motion in simulation and experiment

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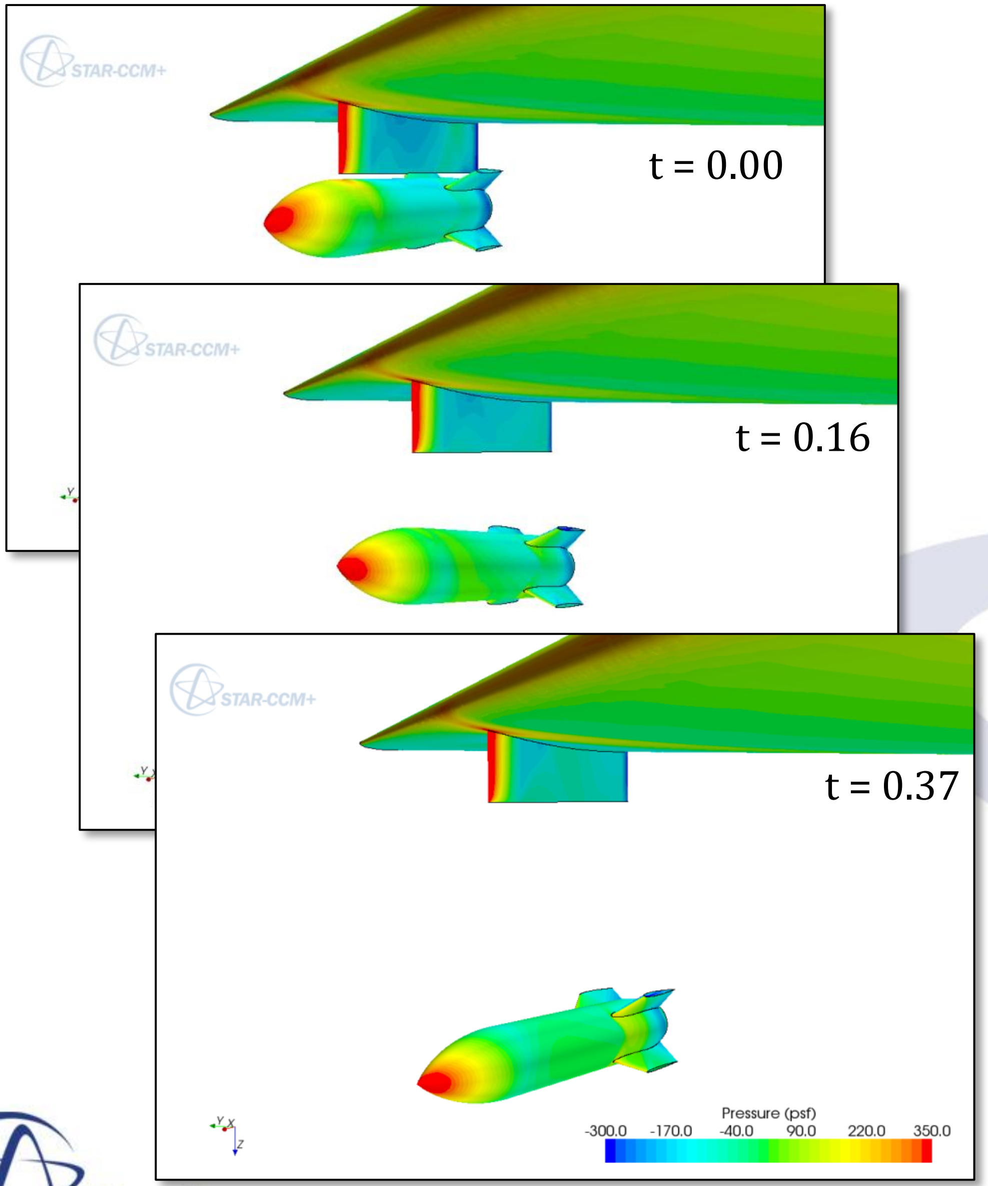
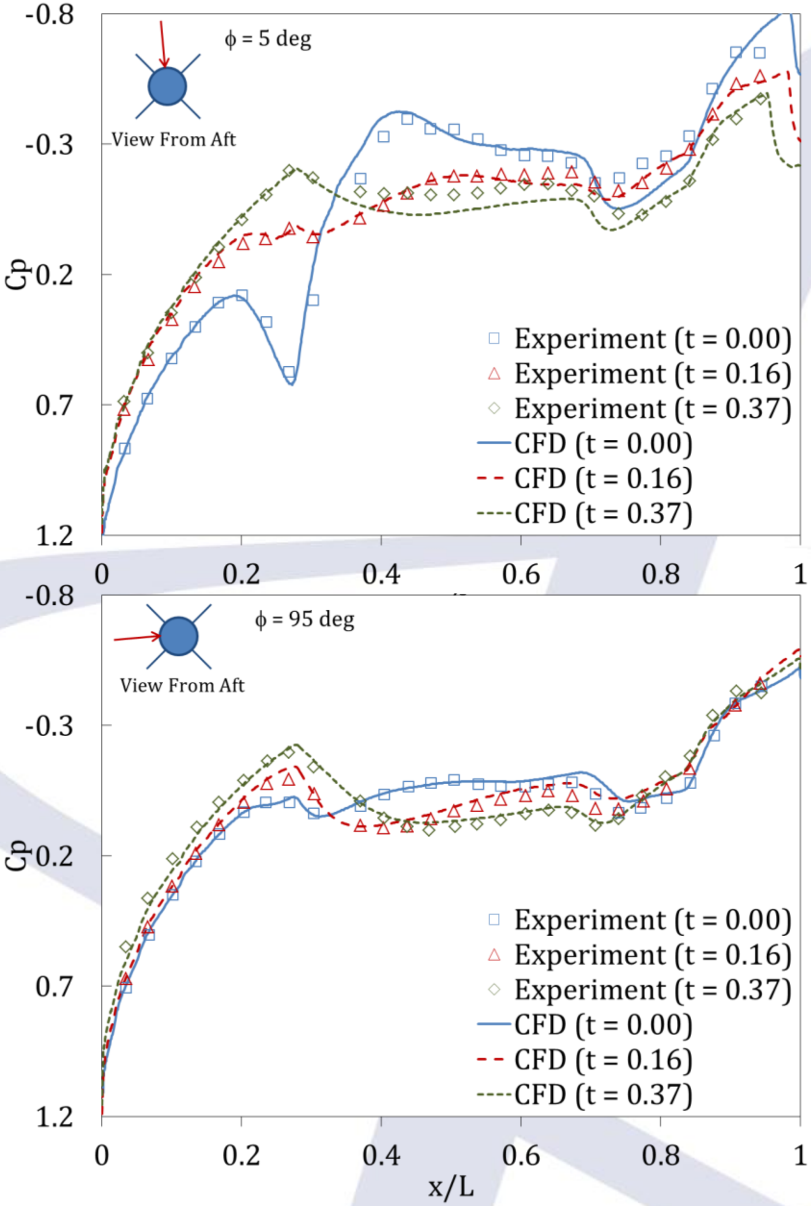
Store Separation, VI





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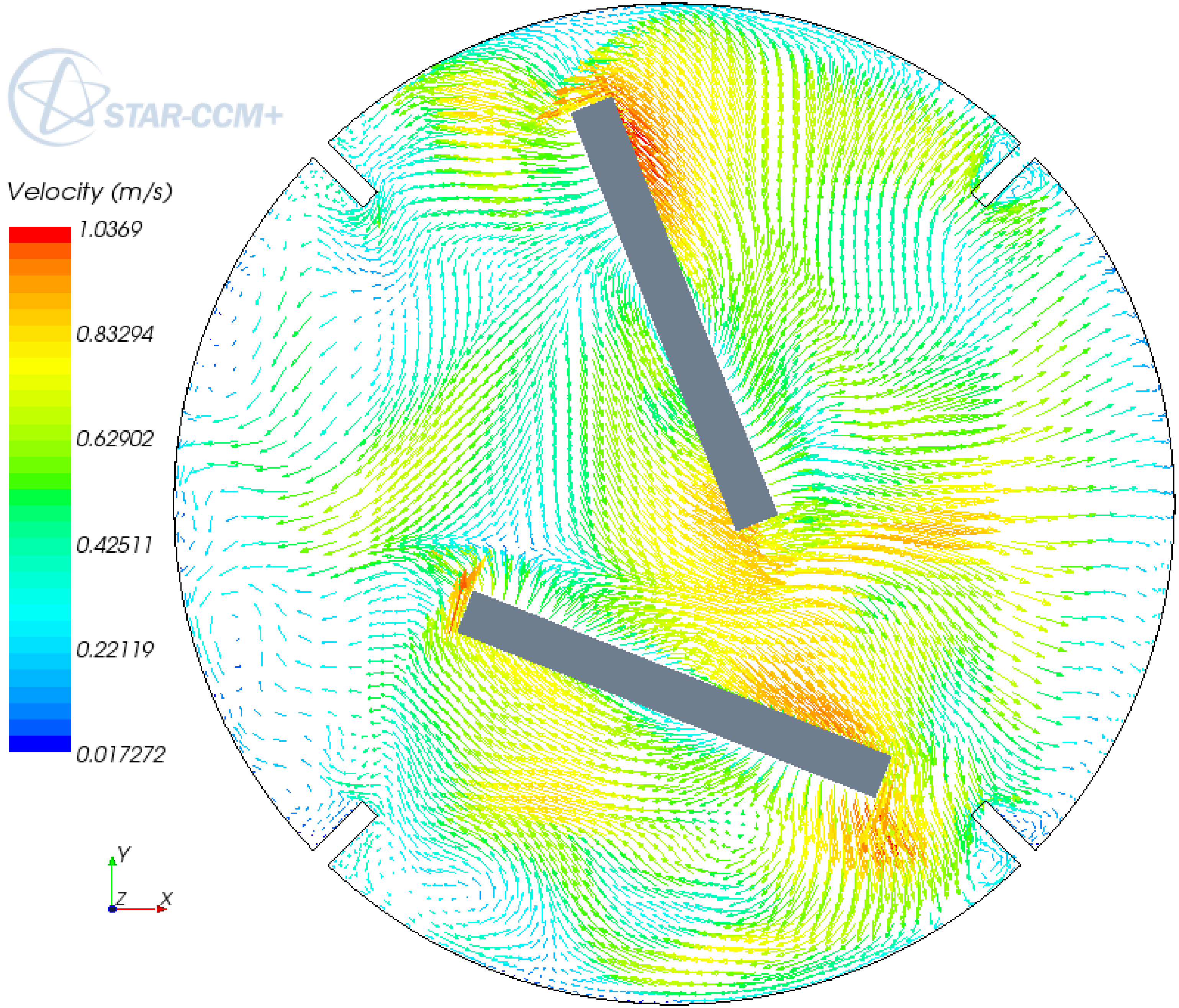
Comparison of pressure in simulation and experiment

Simulation of Flow in a Mixer, I



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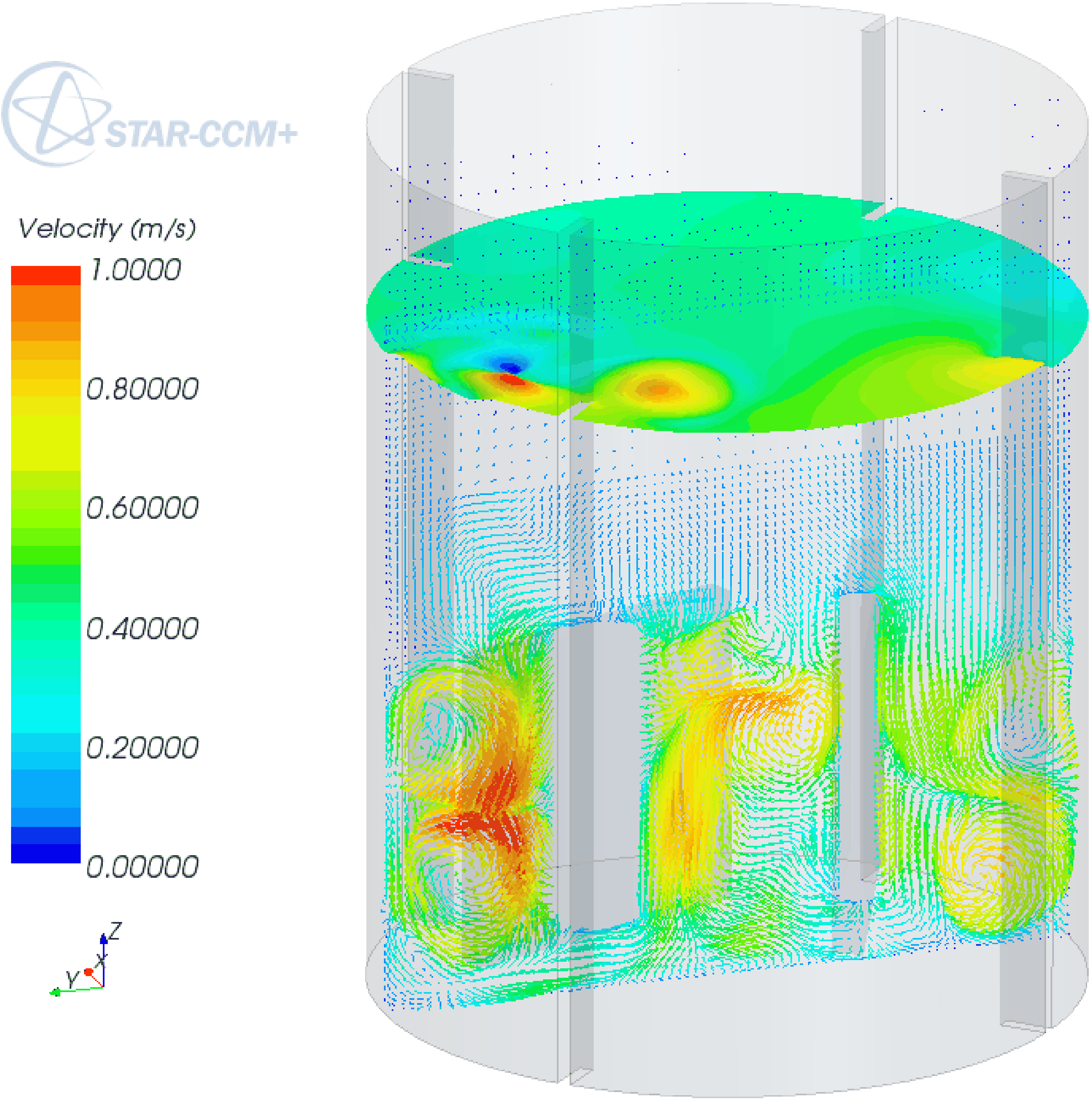
Simulation of Flow in a Mixer, II



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Future Developments

- The most important future developments include:
  - Allowing for multiple overset grids, overlapping each other (currently in progress);
  - Automatic mesh adaptation to fulfil requirements of overset grids (avoid failures due to inadequate grids in the overlapping zone):
    - Minimum number of cell layers in gaps
    - Similar cell size in overlapping zone
    - Refining the background grid ahead and coarsening behind a moving body, to facilitate simulation of motion over large distances.

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Simulation of Pouring

Thank you for your attention!

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