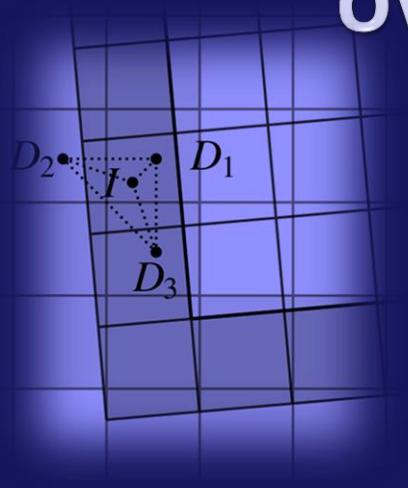
Observations on non-conservative overset grid coupling strategies



S. Voelkner, T. Rung

Overset Grid Symposium 2016, 20.10.2016, Mukilteo, WA, USA

Fluiddynamik und Schiffstheorie

TUHH

Motivation

Coupling of overset grids

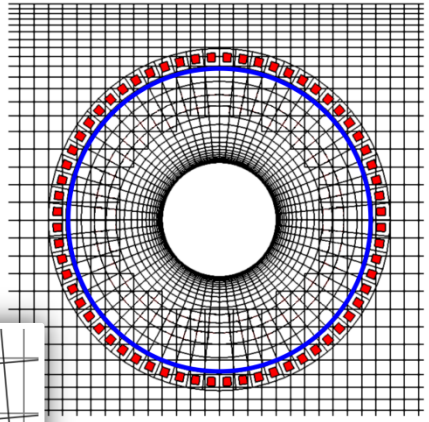
Non-conservative interpolation of field values

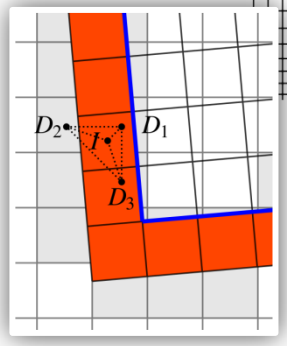
⇨ Mass defect

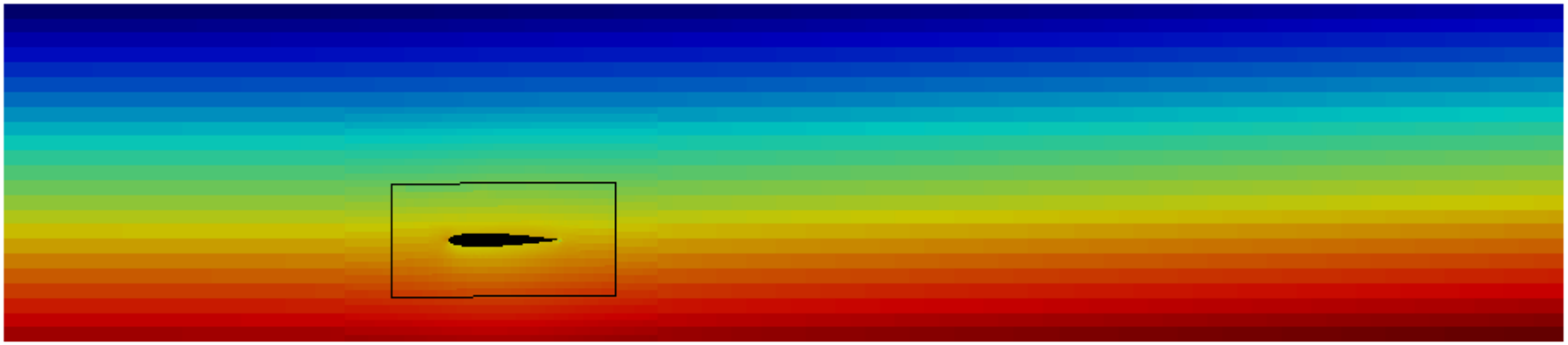
Incompressible finite-volume methods

Violation of inherent mass conservation

⇨ Pressure fluctuations

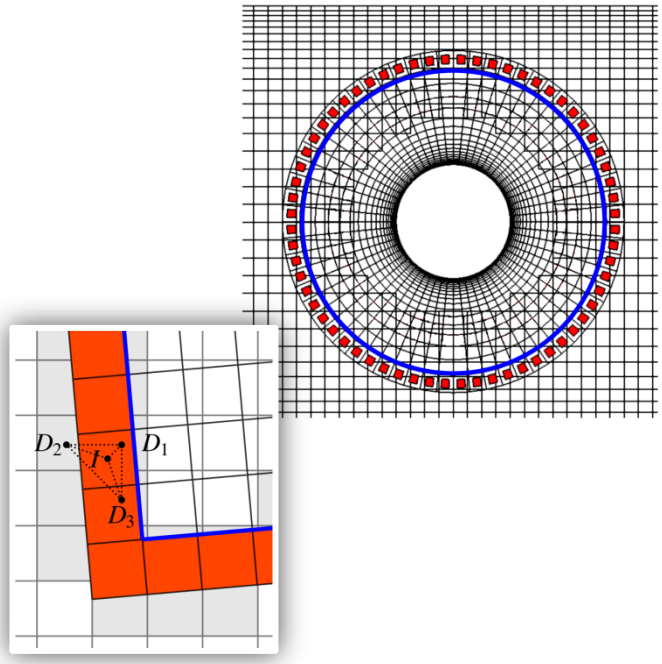






Content

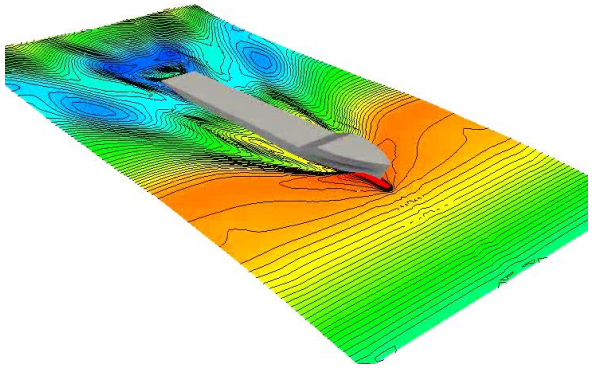
1. **Computational framework**
2. **Effects of the non-conservative interpolation**
3. **Influences on non-conservative effects**
   - Interpolation algorithms
   - Mass correction practices
   - Grid refinement
   - Cell ratio in the overlapping region
   - Free surface
4. **Body-force disturbed channel flow**
5. **Three-dimensional lid-driven cavity flow**
6. **Conclusions**

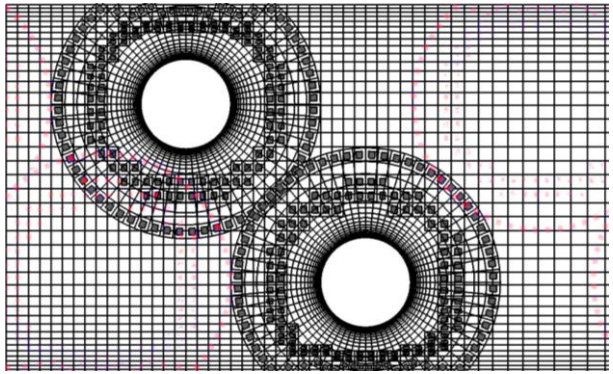


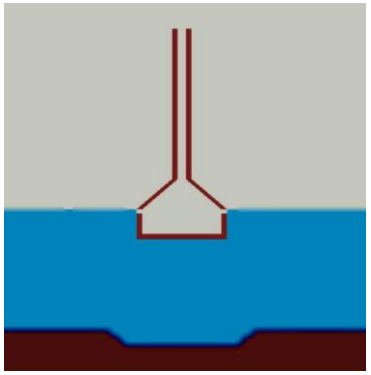
Computational framework

Euler-Lagrange multiphase flow solver

- Cell-centered, 2nd order finite volume
- Grids: unstructured, overset, adaptive refinement
- Free surface capturing: VoF/Level set
- Fluid-structure-interaction
- Turbulence models: RANS/DES/LES, vortex stabilization
- Cont. adjoint for shape/topology optimization
- MPI/OpenMP parallel (15k cells/proc.) with dyn. load balancing



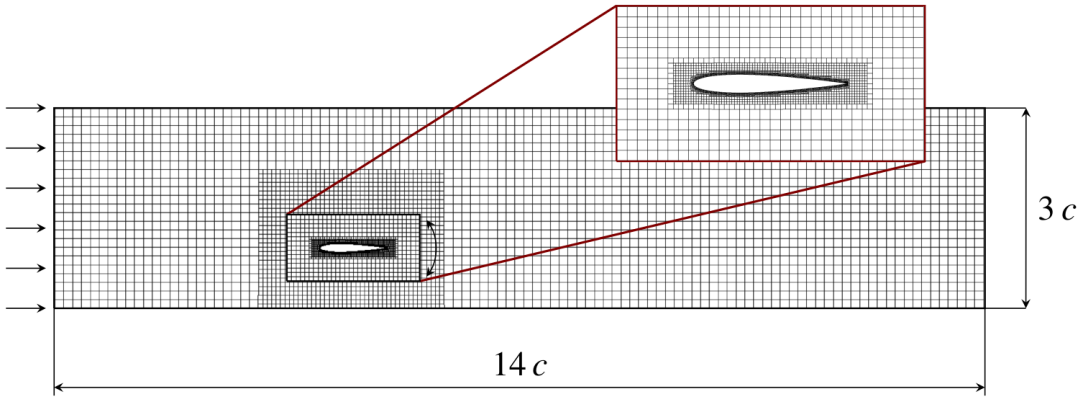


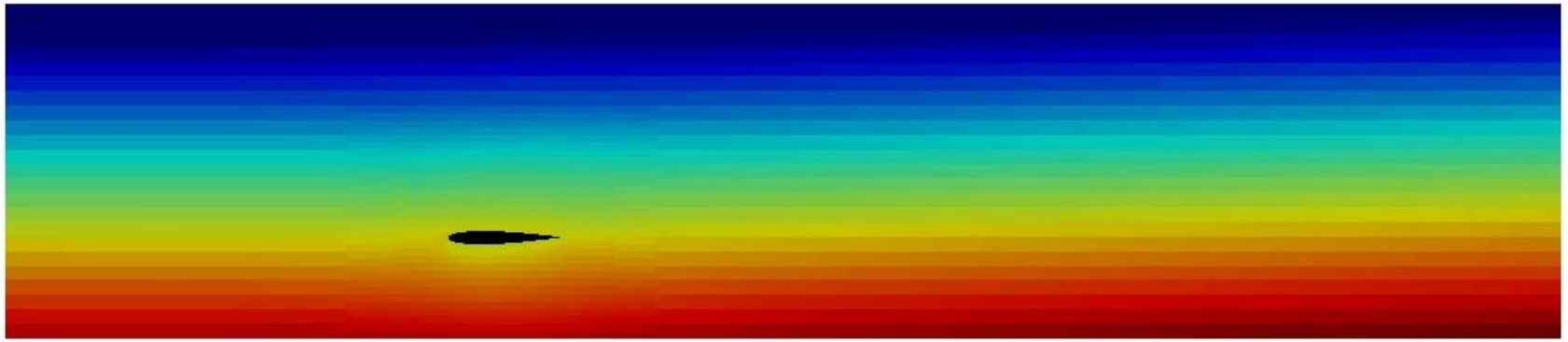


Effects of the non-conservative interpolation

Pitching hydrofoil simulation

- Chord length: 0.203 m
- Pitch frequency: 1 Hz
- Inlet velocity: 0.8 m/s
- Outlet: Hydrostatic pressure
- Foil & Channel: Slip walls





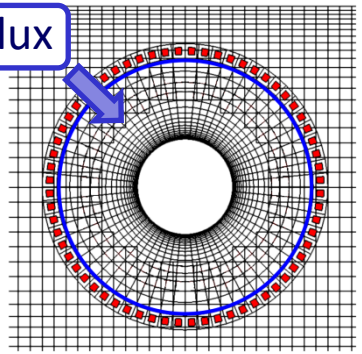
Effects of the non-conservative interpolation

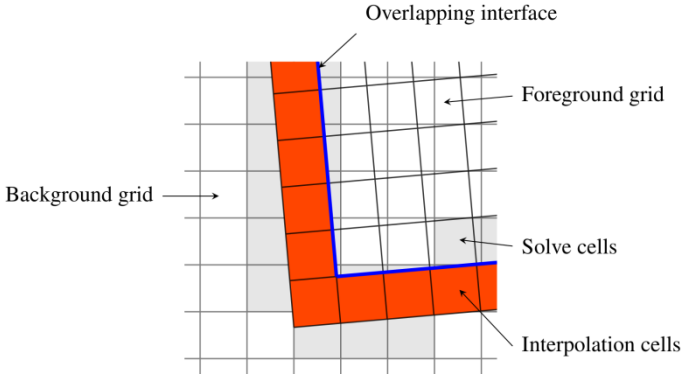
Evaluation of the non-conservative effects

Determination of a mass and pressure defect parameter

- Non-dimensional sum of the mass fluxes over the overlapping interfaces

$$\mathcal{M} = \frac{\Delta \dot{M}_O}{\dot{m}_{inflow}}$$



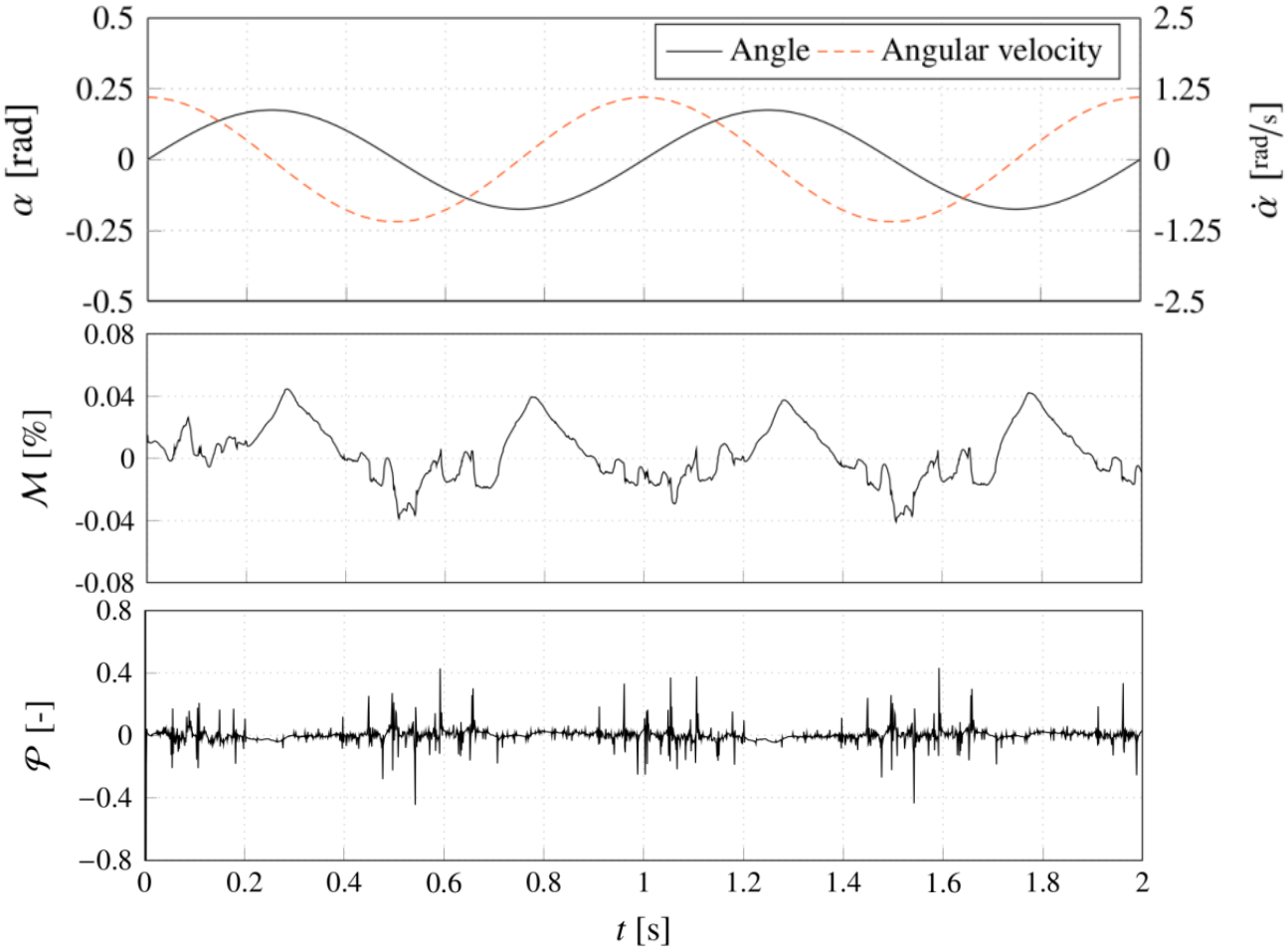


- Non-dimensional average pressure of the simulation domain in each time step

$$\mathcal{P} = \frac{1}{0.5\,\rho\,u_{inflow}^2}\left(\frac{\sum_{\beta=1}^{nC}(p\,\Delta V)_\beta}{\sum_{\beta=1}^{nC}\Delta V_\beta} - p_{average}\right)$$

Effects of the non-conservative interpolation

Evolution of the mass and pressure defect parameter



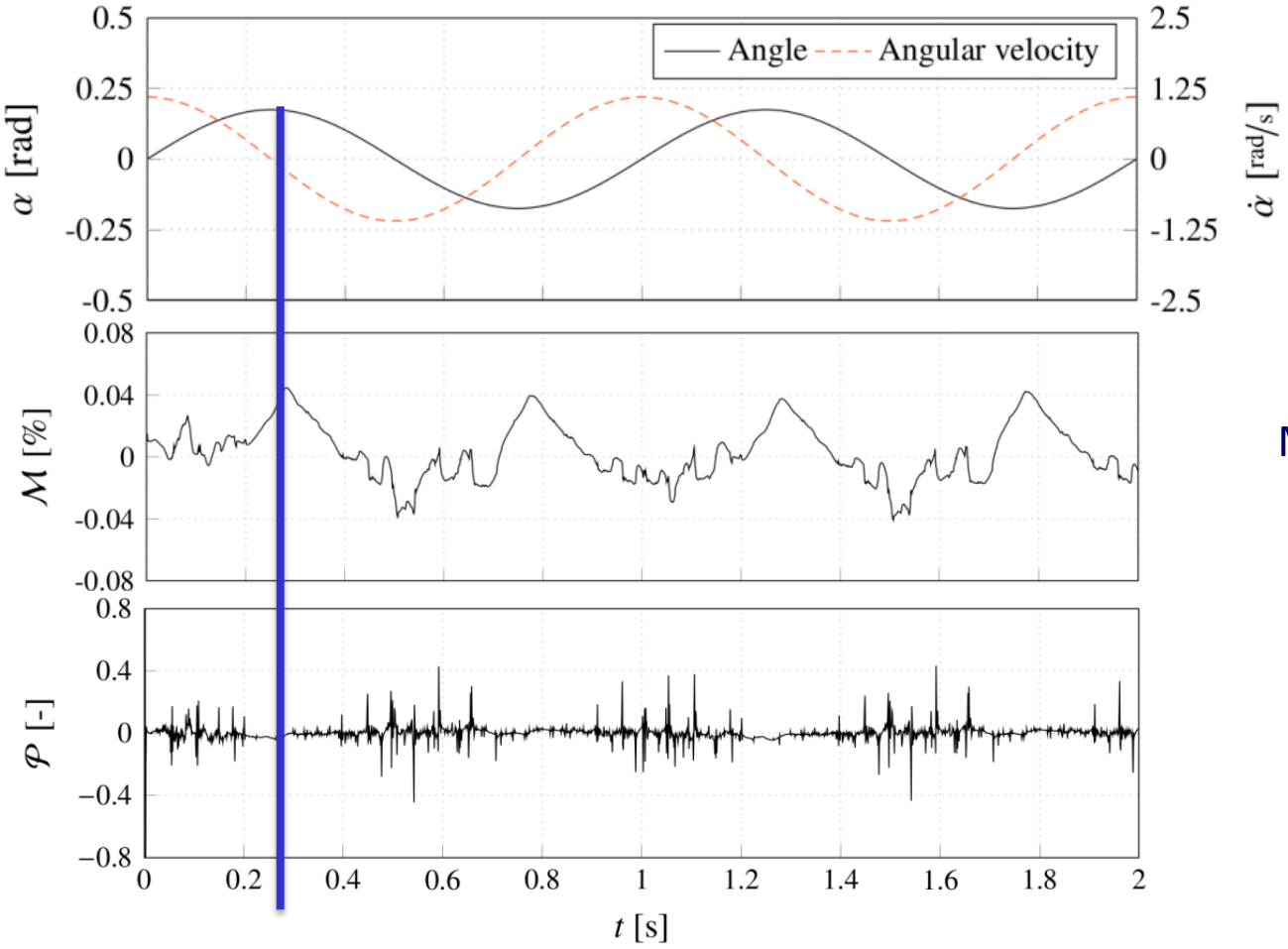
Angle & velocity

Mass defect

Pressure defect

Effects of the non-conservative interpolation

Evolution of the mass and pressure defect parameter



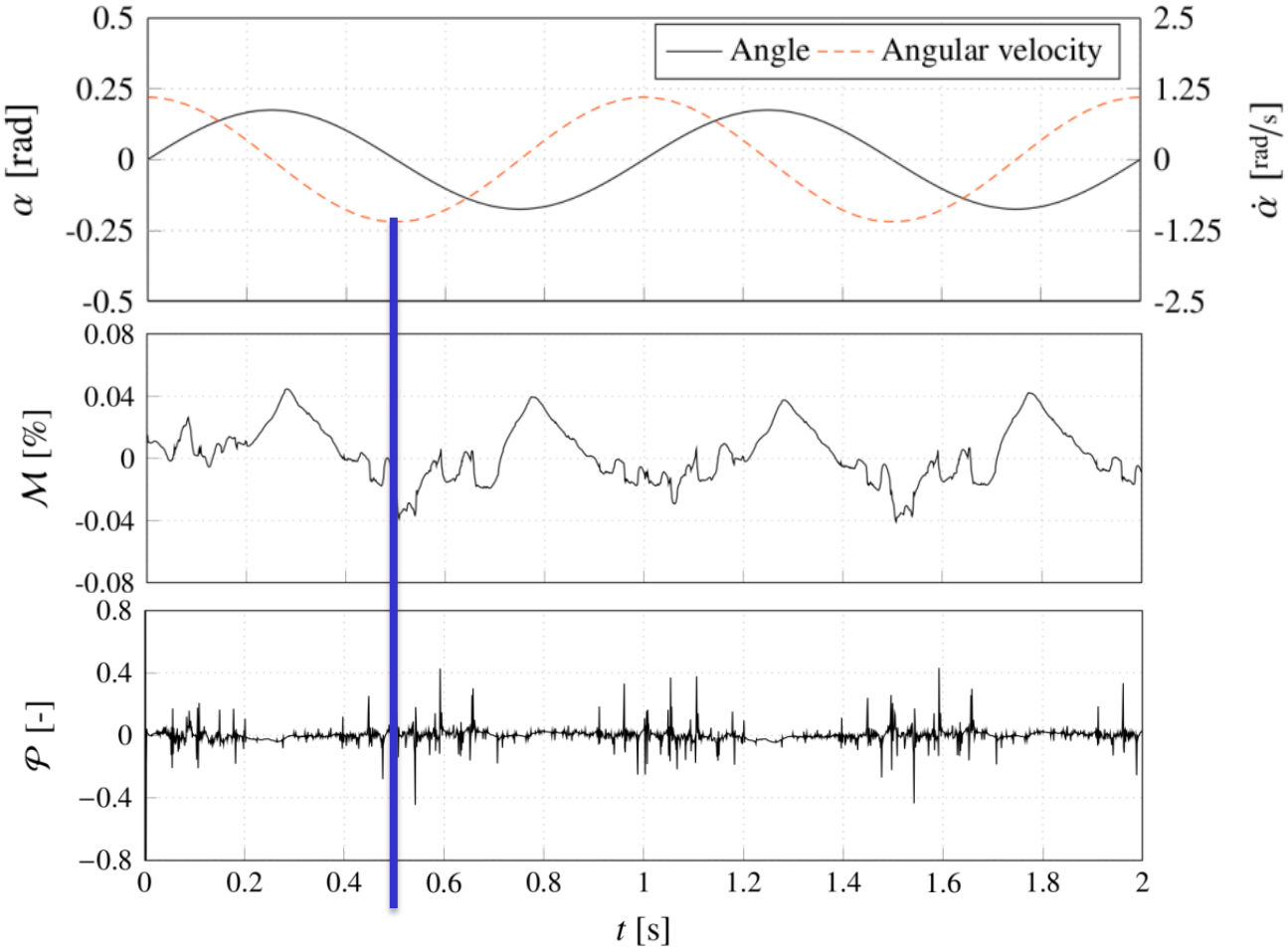
Maximum angle, no angular velocity

Maximum positive mass defect

Smallest pressure fluctuations

Effects of the non-conservative interpolation

Evolution of the mass and pressure defect parameter



No angle,
max. angular velocity

Maximum negative
mass defect

Maximum pressure
fluctuations

Effects of the non-conservative interpolation

Frequencies of the mass and pressure defect parameter

- Mass defect:

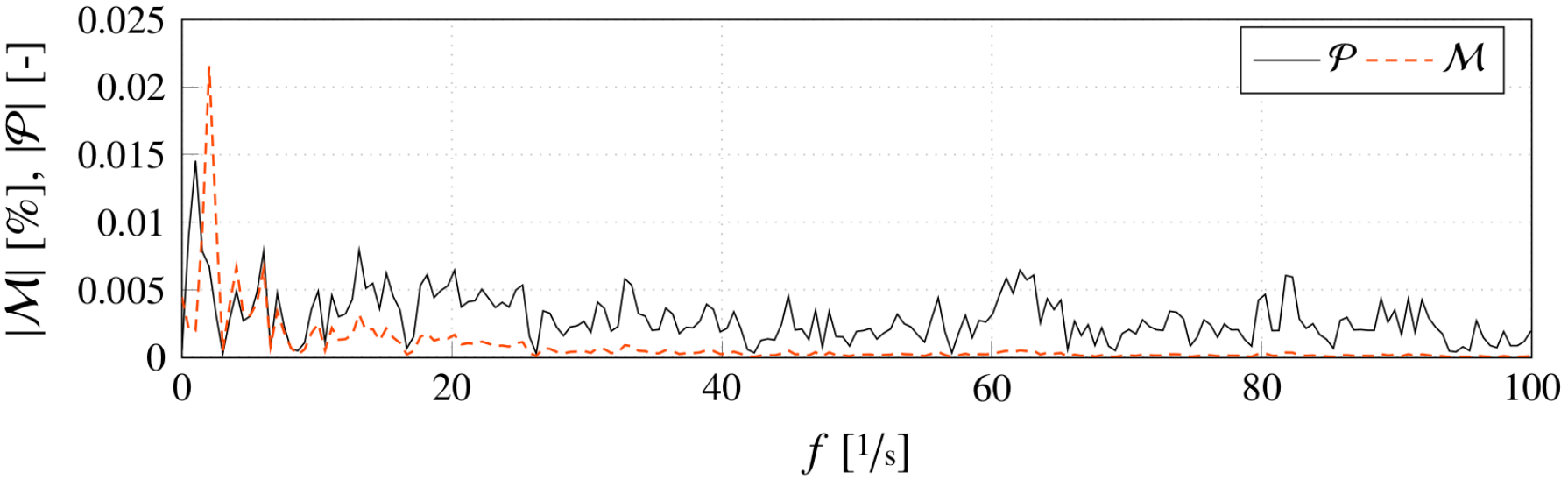
  Main frequency: 2 Hz ⇨ Max. positive or negative angle of the foil

  Significant peaks: 4 Hz, 6 Hz, 7 Hz

- Pressure defect:

  Main frequency: 1 Hz ⇨ Pitching motion

  Distinctive fluctuations up to 100 Hz (coincidence with mass peaks)



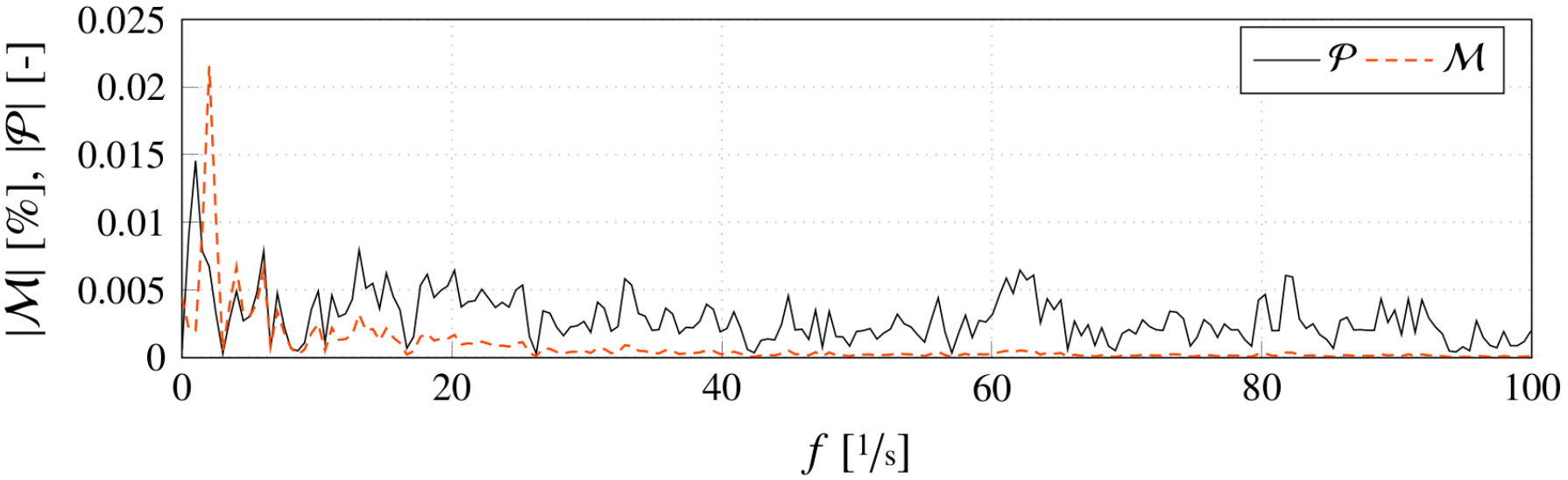
Effects of the non-conservative interpolation

Frequencies of the mass and pressure defect parameter

- Fixed hydrofoil:

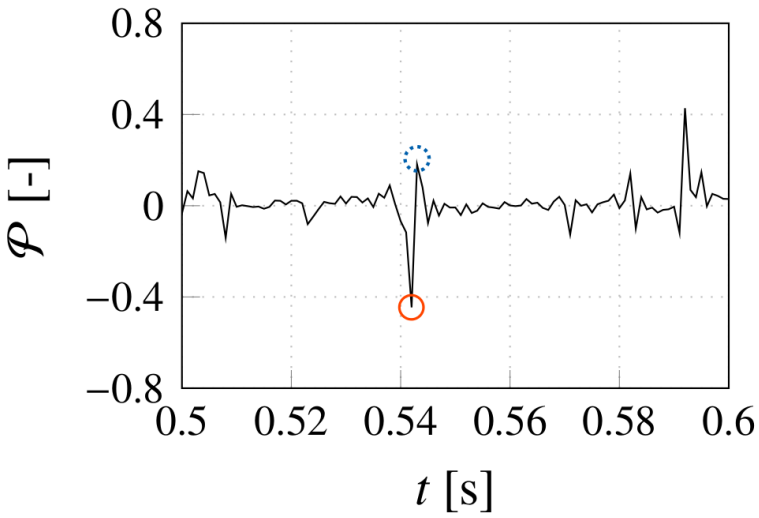
  Negligible mass and pressure defect

- Possible causes for the defects:
  1. Pitch of the foil
  2. Reassignment of the interpolation cells to new donor cells
  3. Allocation as solve or interpolation cell

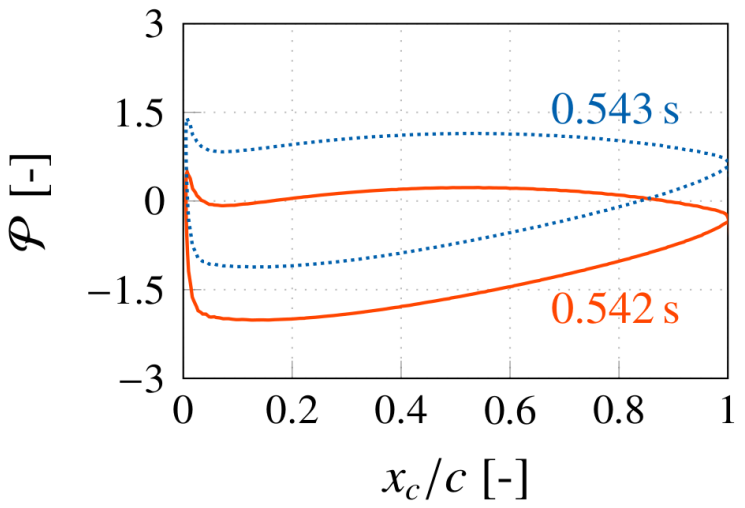


Effects of the non-conservative interpolation

Detailed evolution of the pressure defect parameter



Pressure distribution over the relative chord length of the hydrofoil



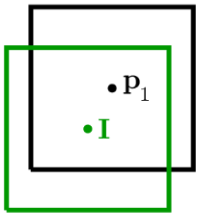
Evaluation:

- **Identical characteristics of the pressure distribution at the hydrofoil**
- **Shift of the pressure level**

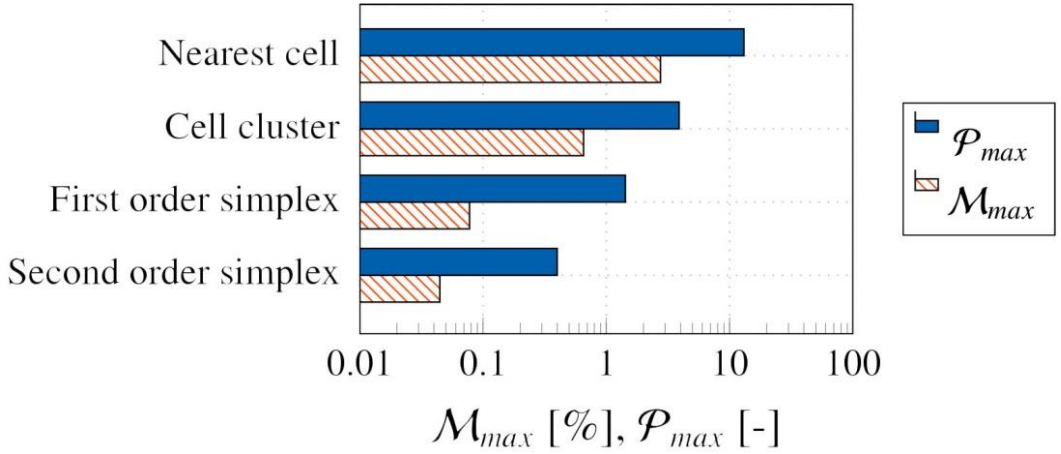
Interpolation algorithms

Interpolation algorithms

- Nearest cell
- Cell cluster
- Simplex



Influence on the mass and pressure defect parameter

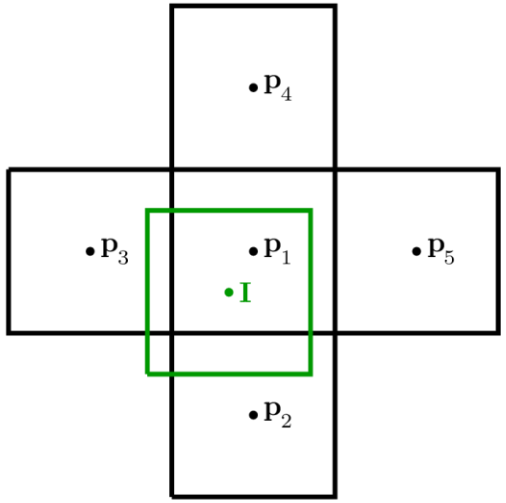


Pressure defect parameter: 13.06

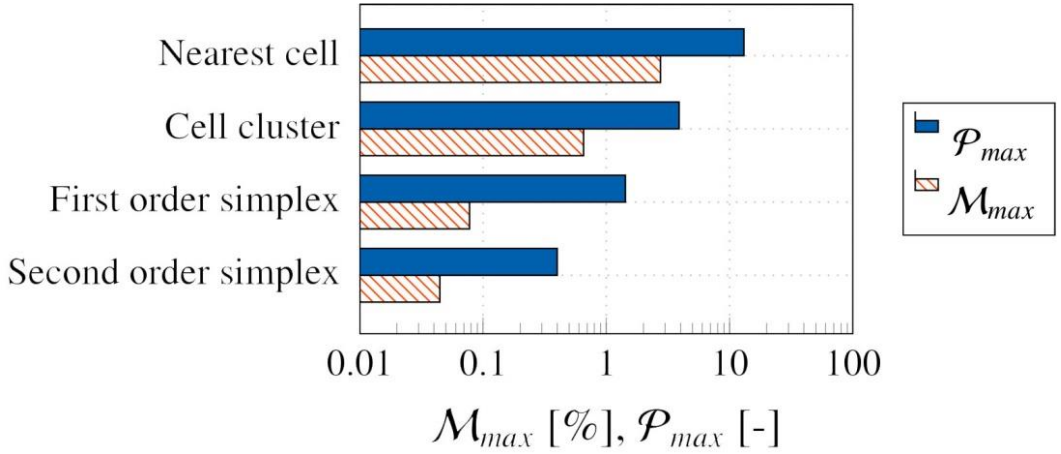
Interpolation algorithms

Interpolation algorithms

- Nearest cell
- Cell cluster
- Simplex



Influence on the mass and pressure defect parameter



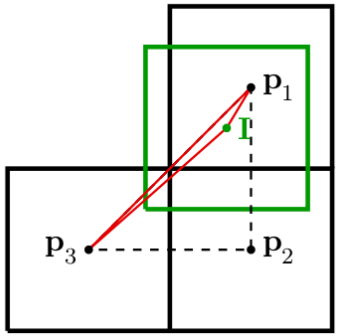
Pressure defect parameter: 3.89

⇨ Reduction to: 30 %

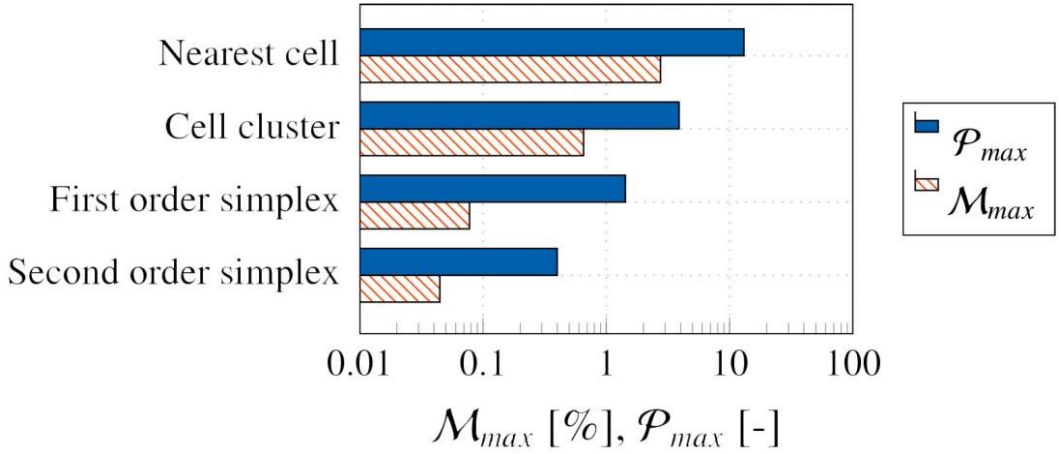
Interpolation algorithms

Interpolation algorithms

- Nearest cell
- Cell cluster
- Simplex



Influence on the mass and pressure defect parameter



Pressure defect parameter: 0.45

⇨ Reduction to: 1 %

Mass Correction Practices

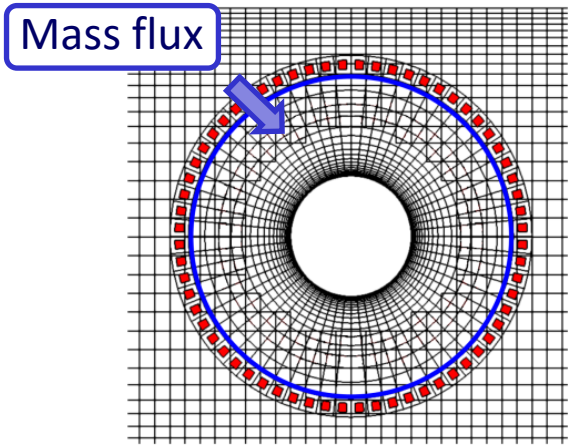
Idea: Compensation of the mass defect ⇨ Reduction of the pressure fluctuations

Procedure

- Add up all erroneous mass fluxes
- Distribute the defect

Distribution of the defect

- Global adaption of cell volume
- Correction of the mass fluxes:
  1. Bulk correction by Hadžić (2006)
  2. Divergence based flux correction



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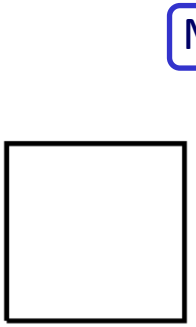

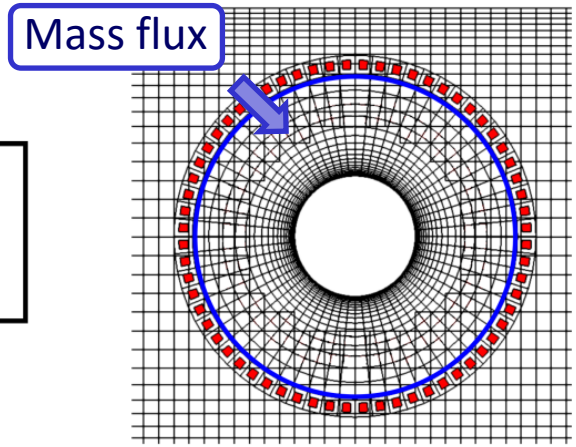

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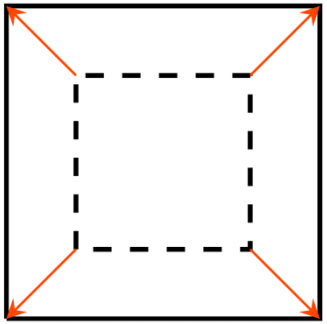

Fictive change of the cell volume

Mass Correction Practices

Idea: Compensation of the mass defect ⇨ Reduction of the pressure fluctuations

Procedure

- Add up all erroneous mass fluxes
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Distribution of the defect

- Global adaption of cell volume
- Correction of the mass fluxes:
  1. Bulk correction by Hadžić (2006)
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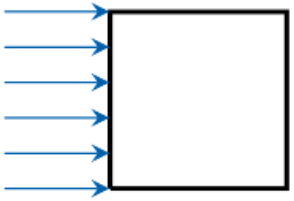

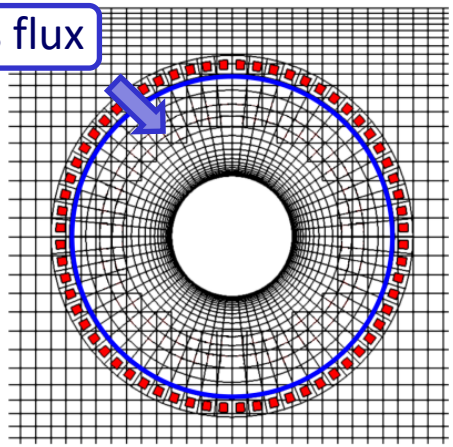

Mass Correction Practices

Idea: Compensation of the mass defect ⇨ Reduction of the pressure fluctuations

Procedure

- Add up all erroneous mass fluxes
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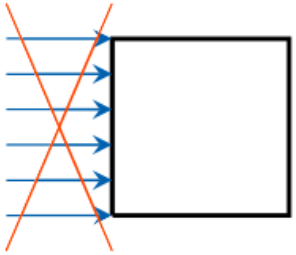

Flux correction proportional to its amount

Mass Correction Practices

Idea: Compensation of the mass defect ⇨ Reduction of the pressure fluctuations

Procedure

- Add up all erroneous mass fluxes
- Distribute the defect

Distribution of the defect

- Global adaption of cell volume
- Correction of the mass fluxes:
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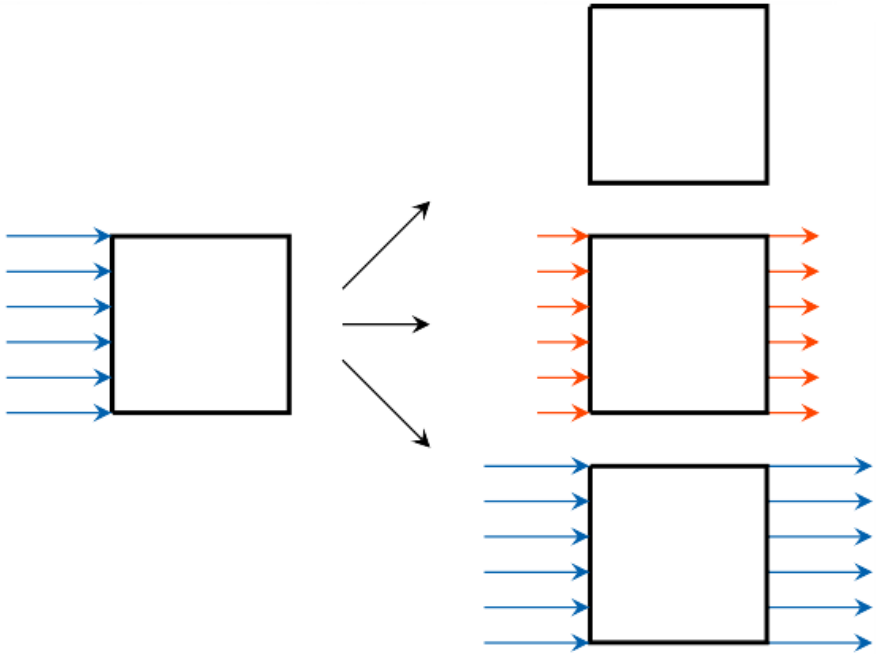
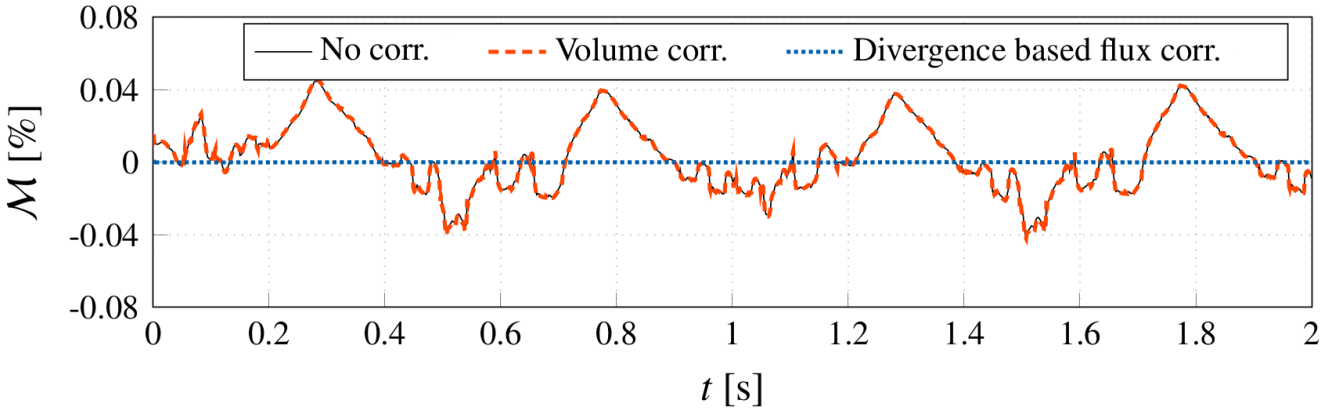


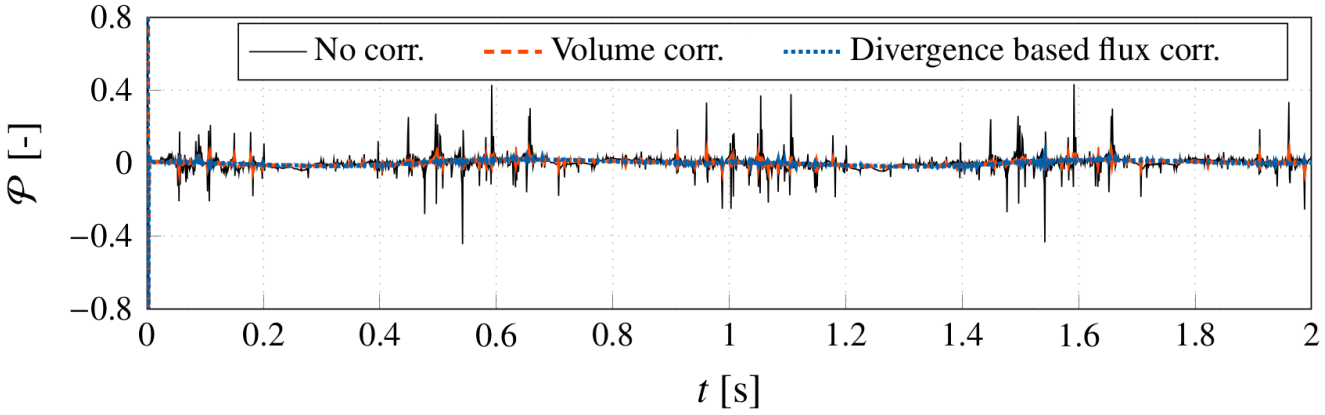
Weighting based on
local flow information

Mass Correction Practices

Results of the mass correction practices



Volume correction does not change the mass defect!



All methods reduce the pressure defects significantly!

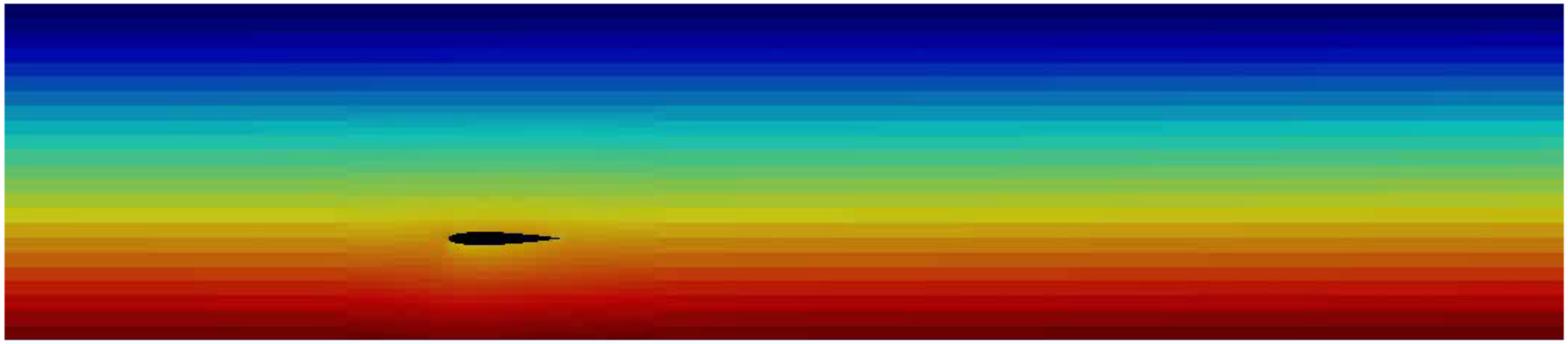
Mass Correction Practices

Results of the mass correction practices

Pressure defect parameter

Compared to the second order simplex interpolation with an initial value of 0.45

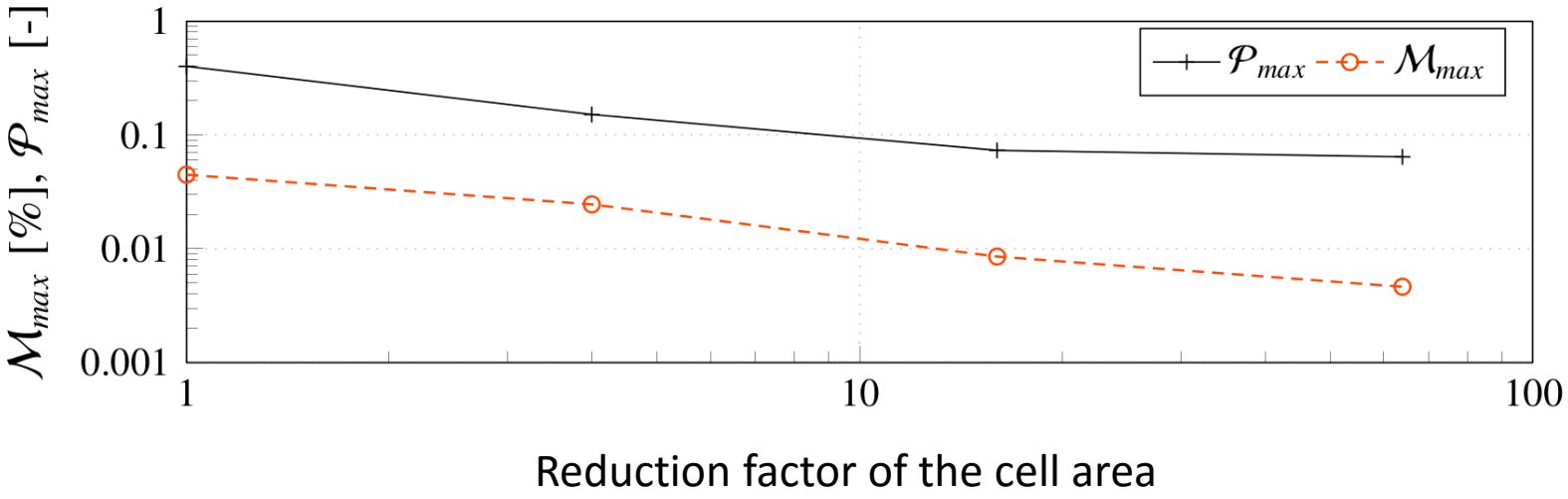
- Volume correction: 0.037 ⇨ Reduction to 8.2 %
- Bulk correction: 0.034 ⇨ Reduction to 7.6 %
- Divergence based flux correction: 0.03 ⇨ Reduction to 6.7 %



Grid refinement

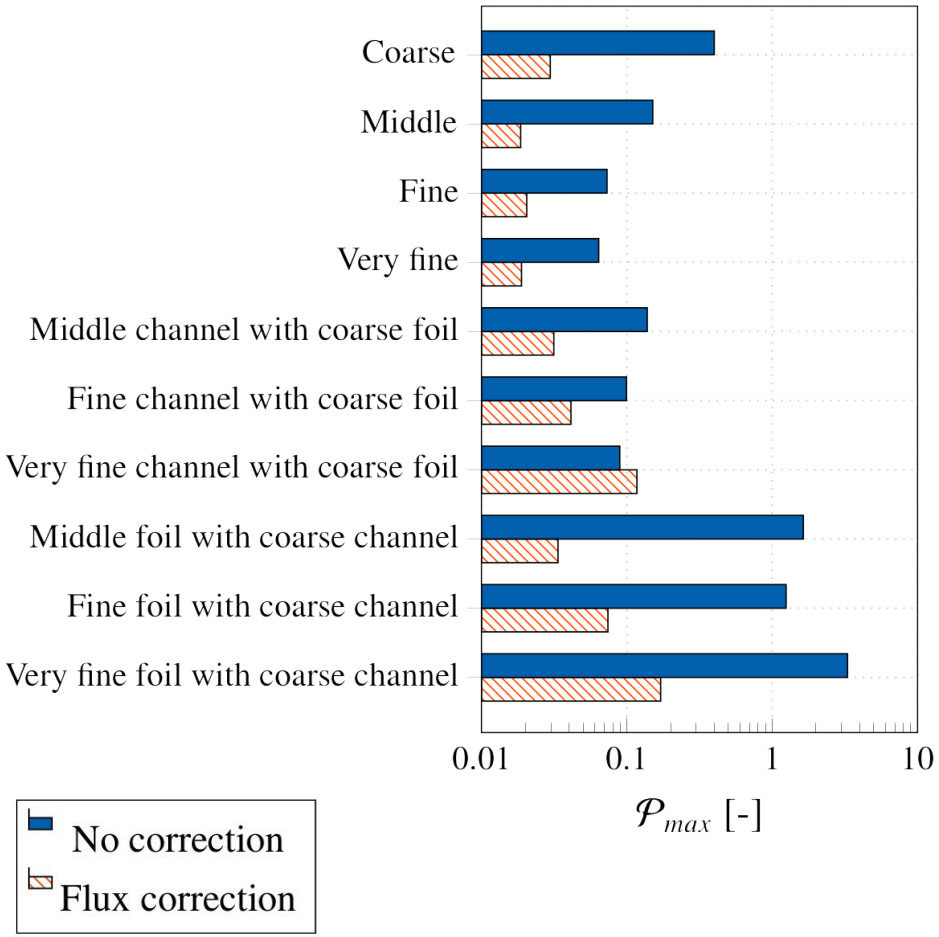
Consistent refinement of the overlapping region

- Reduction factors of the cell area: 4, 16 & 64
- Improvement of the pressure defect parameter to 0.064
  - ⇨ Reduction to 14.2 %
  - ⇨ Twice as much as with the mass correction practices
  - ⇨ Declining trend of the pressure defect parameter
  - ⇨ 64-times more cells in the overlapping region!



Cell ratio in the overlapping region

Different resolution of the foreground and background grid



Reduction factors of the cell area:

4, 16 & 64

Refinement of the background grid:

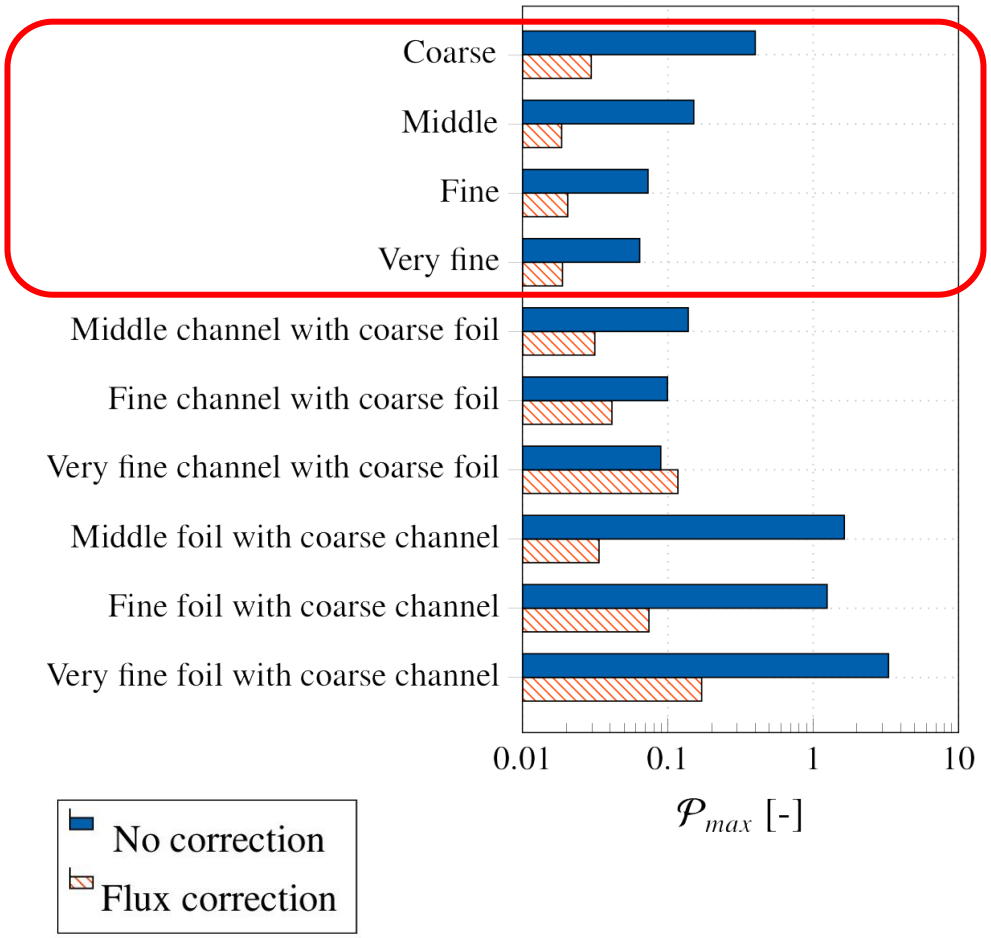
- Without mass correction:
  Similar to a consistent refinement
- With divergence based correction:
  Worse than coarse configuration

Refinement of the foreground grid:

- Worse than coarse configuration

Cell ratio in the overlapping region

Different resolution of the foreground and background grid



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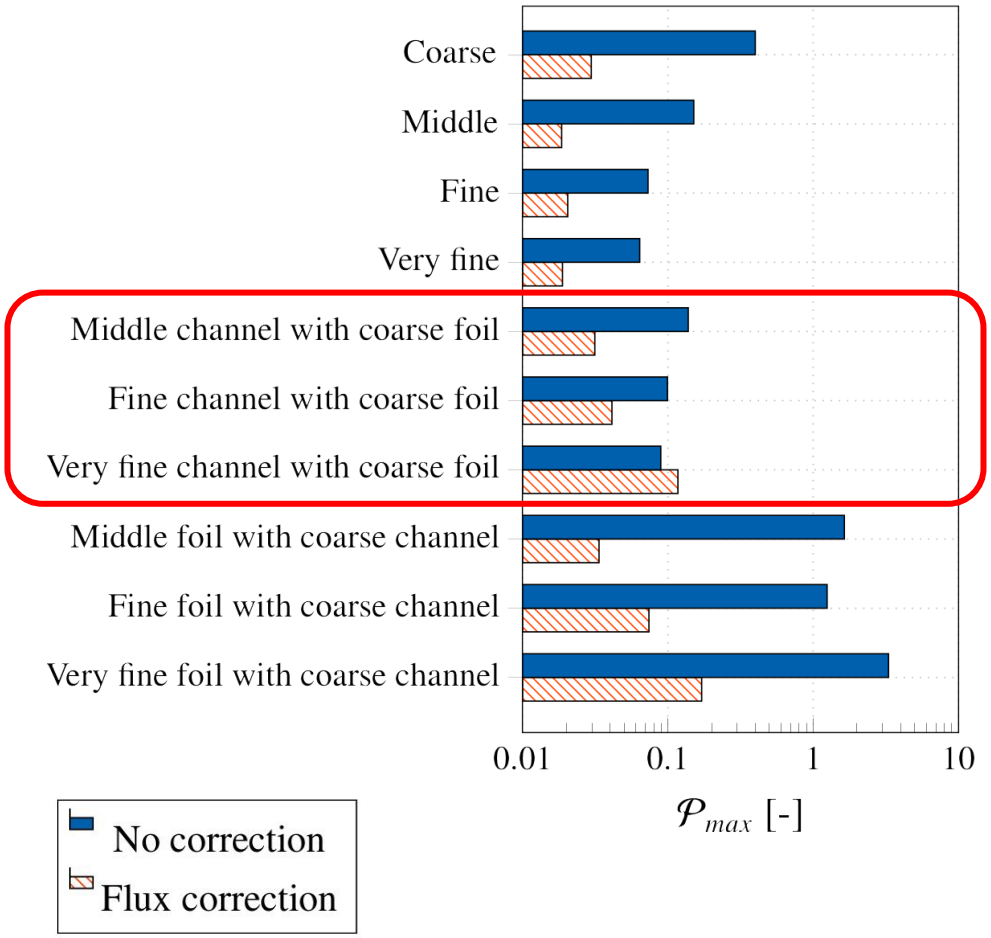
Cell ratio in the overlapping region

Different resolution of the foreground and background grid



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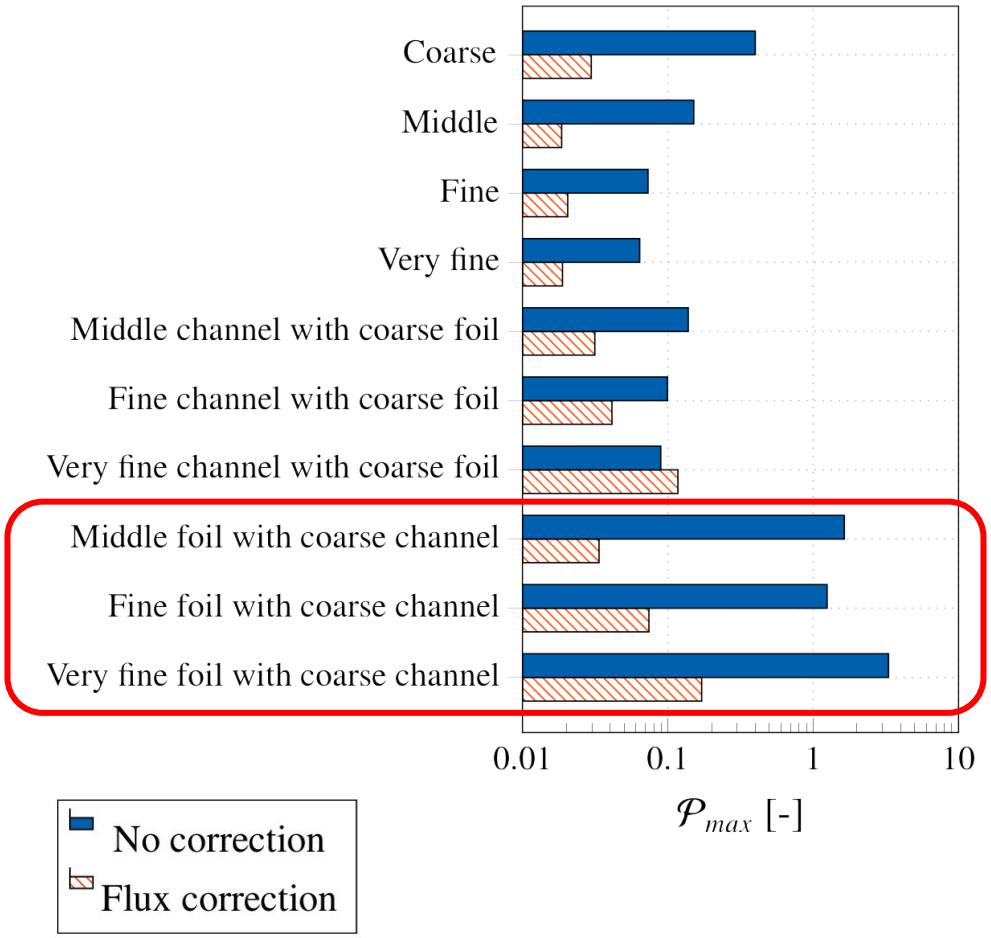


Reduction factors of the cell area:

4, 16 & 64

Refinement of the background grid:

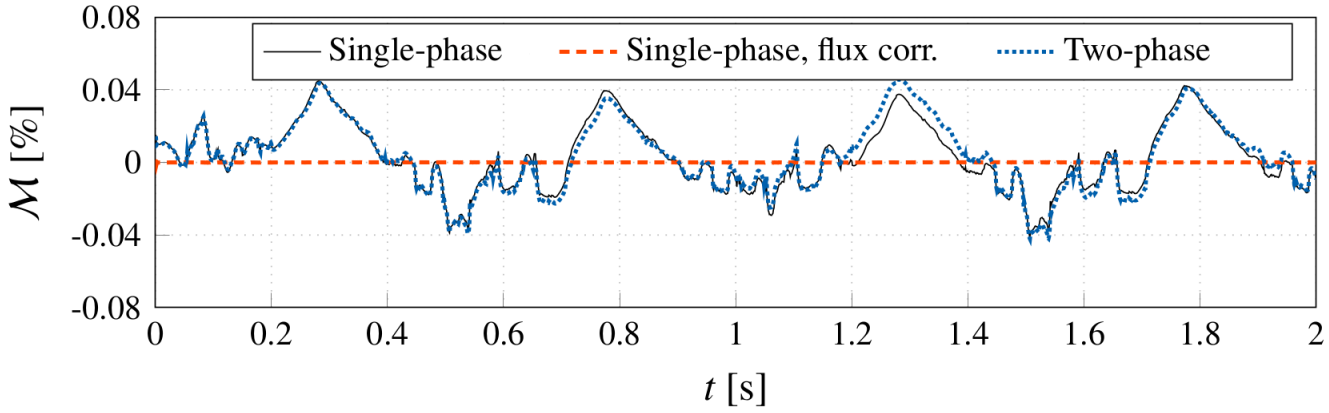
- Without mass correction:
  Similar to a consistent refinement
- With divergence based correction:
  Worse than coarse configuration

Refinement of the foreground grid:

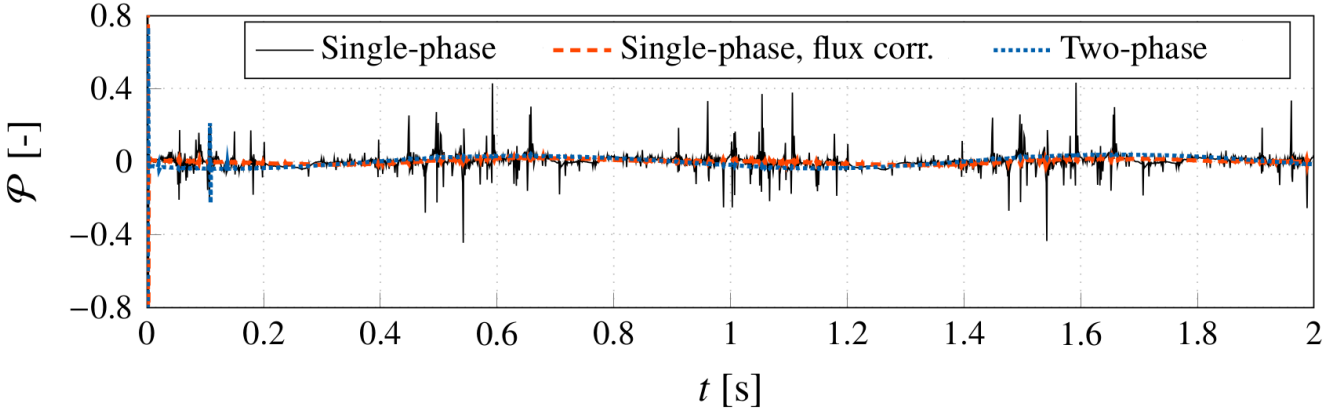
- Worse than coarse configuration

Free surface

Free surface between water and air



No influence on the mass defect!



Vanishing pressure defect!

Free surface

Free surface between two fluids with the same density ratio

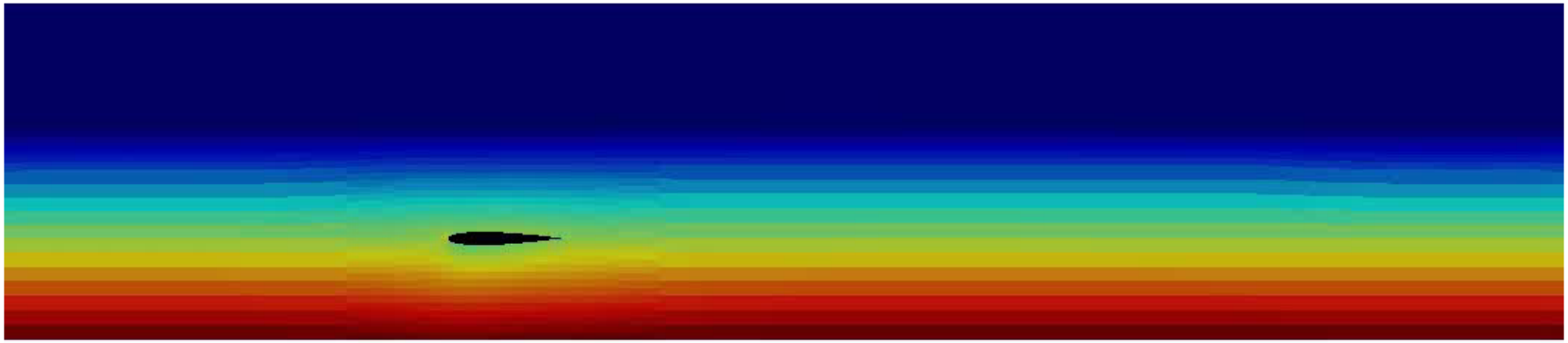
⇨ No improvement!

Reason

The mass defect is compensated by a free surface adaption

⇨ Average elevation of the free surface of $2.65 \cdot 10^{-7}$ m is required.

⇨ Only for high density ratios!



Body-force disturbed channel flow

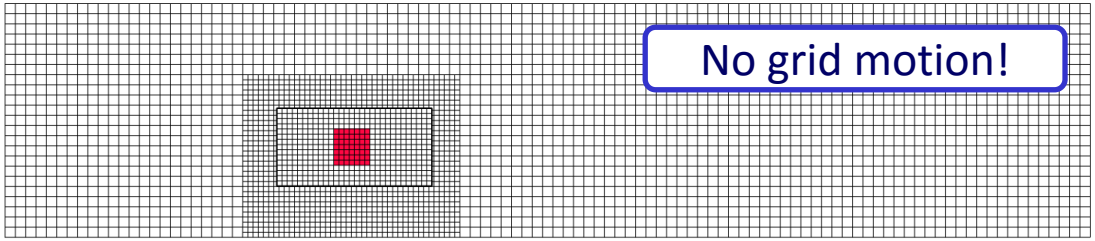
Simulation setup

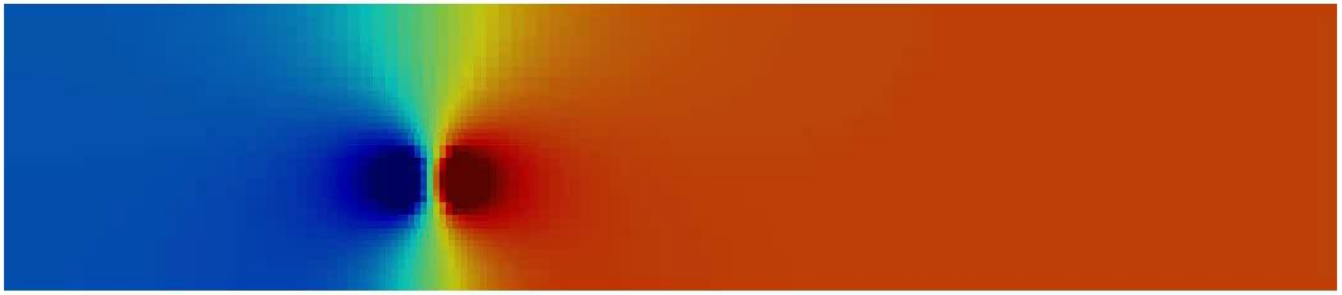
Body-force: 100 N

Inlet velocity: 0.8 m/s

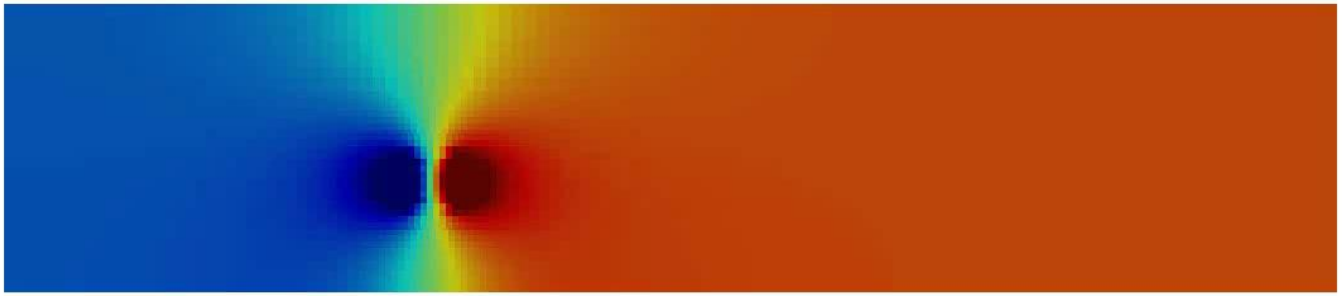
Outlet: Hydrostatic pressure

Channel: Slip walls



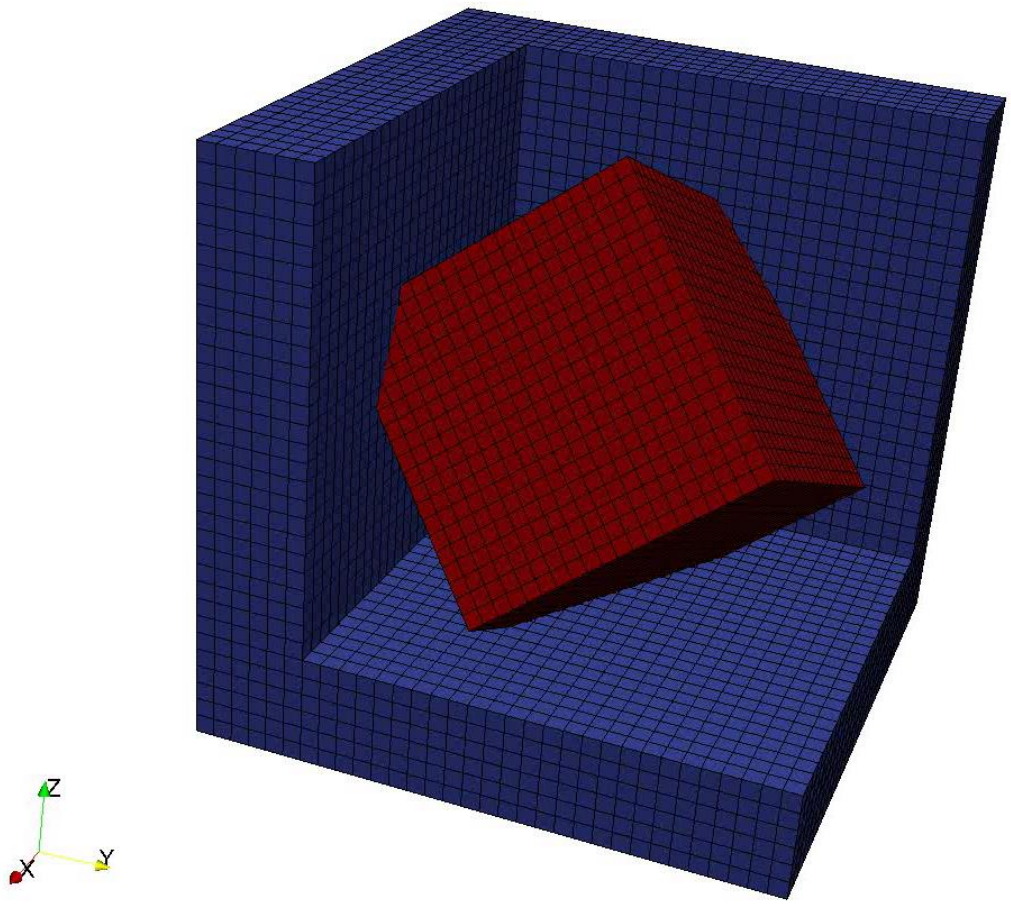


No correction



Divergence based flux correction

Three-dimensional lid-driven cavity



Cubic cavity

- Side length: 1 m
- Cells per side: 32
- Lid velocity: 0.4 m/s
- Reynolds number: 400

Embedded cavity

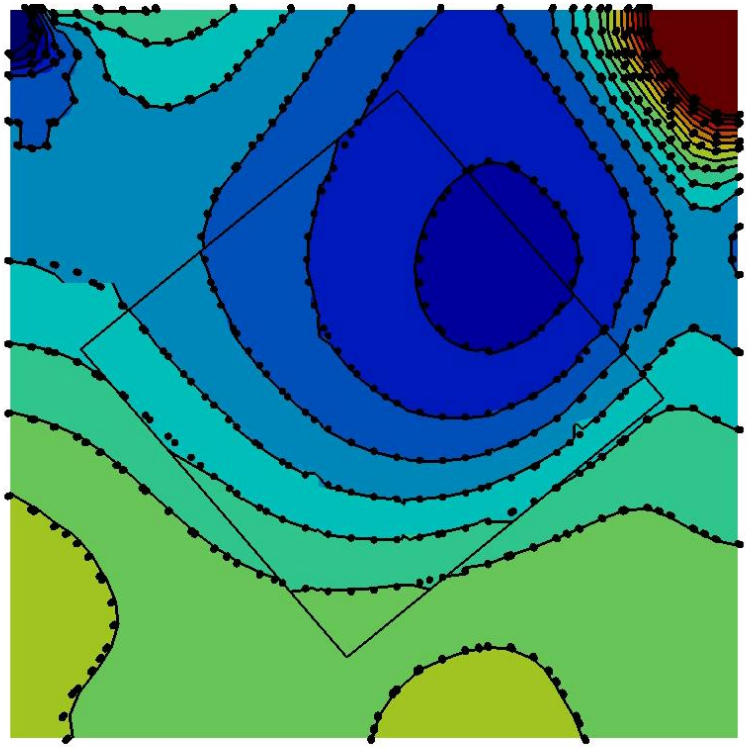
- Side length: 0.55 m
- Cells per side: 20
- Rotation: 0.25 π rad

Evaluation

- Surface at y = 0 m
- With and without correction

Three-dimensional lid-driven cavity

Divergence based flux correction



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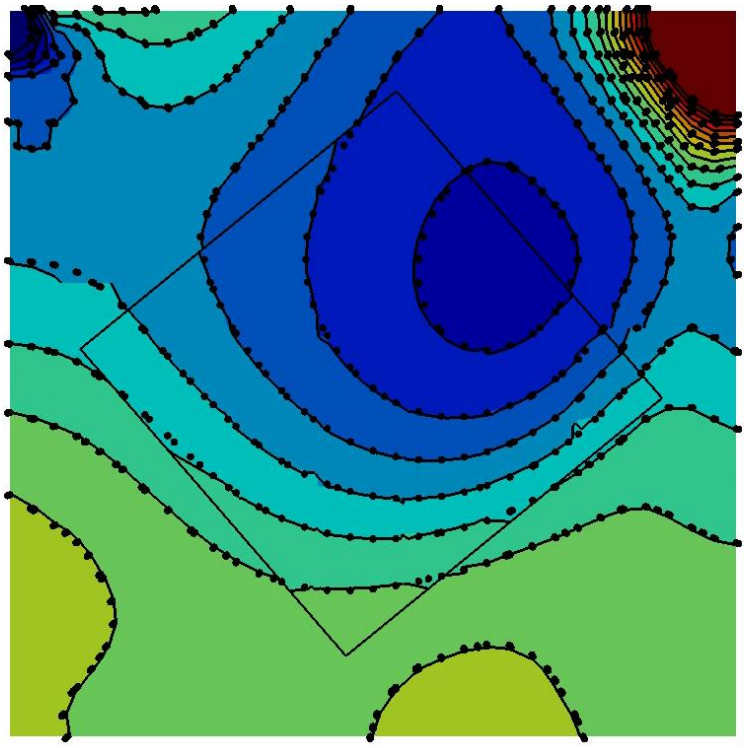
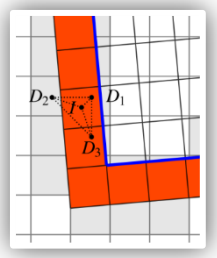


Dots: Single grid results

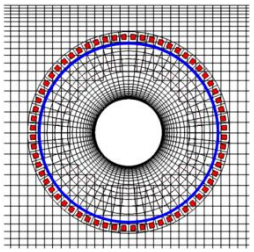
Lines & colors: Relatively moving overlapping grids

Conclusions

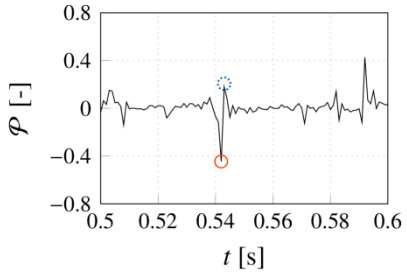
Non-conservative coupling of overset grids



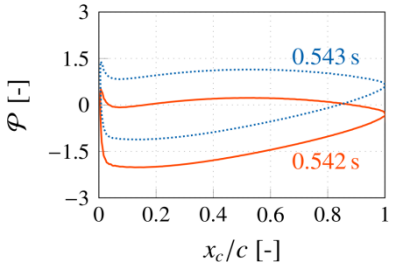
Erroneous fluxes across the overlapping boundaries

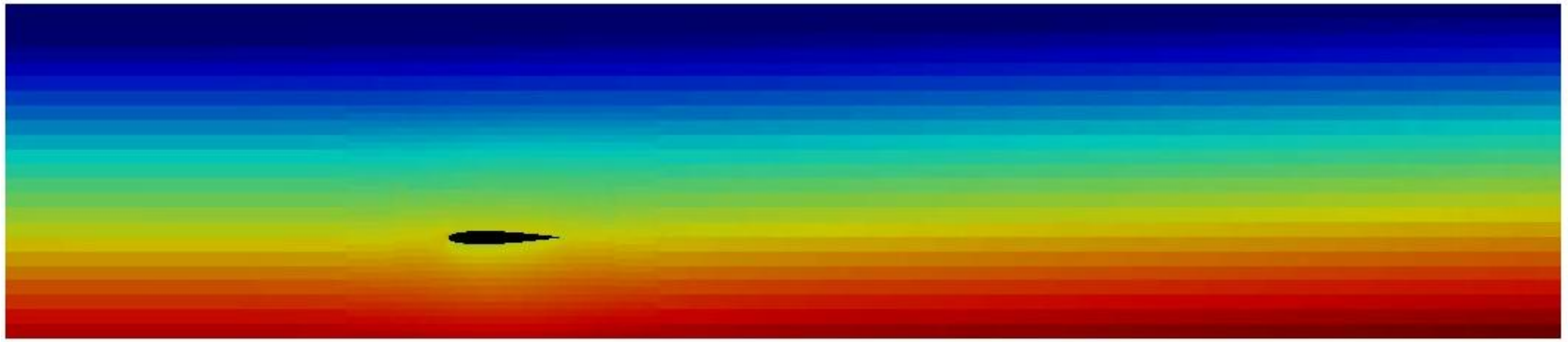


Mass imbalance



Pressure defects

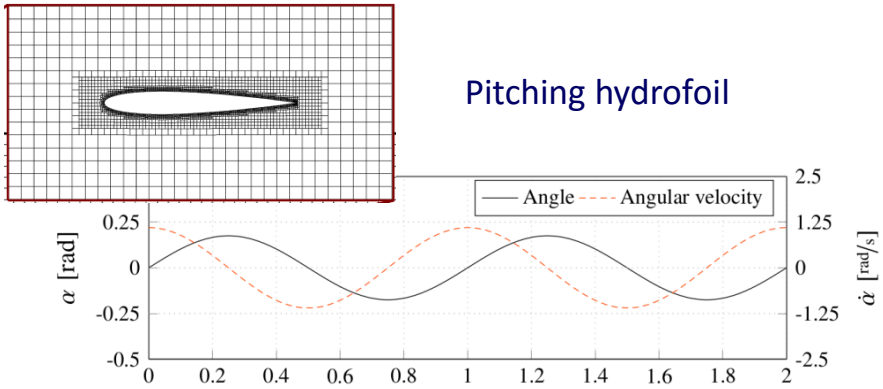




Conclusions

Pressure defects occur only for

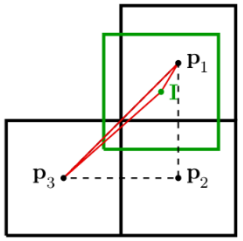
- Single phase flows
- Moving grids
- Transient flow properties



Pitching hydrofoil

Unproblematic

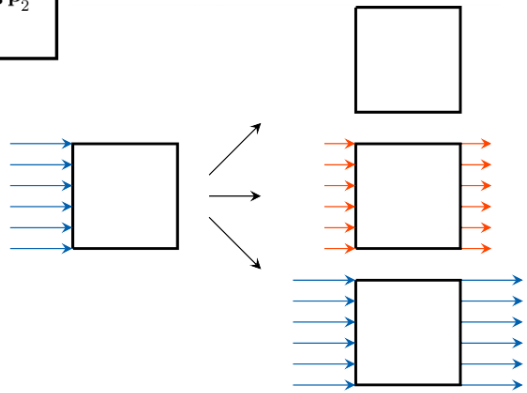
- Steady-state simulations
- Two-phase flows with a high density ratio



High order interpolation

Recommendation

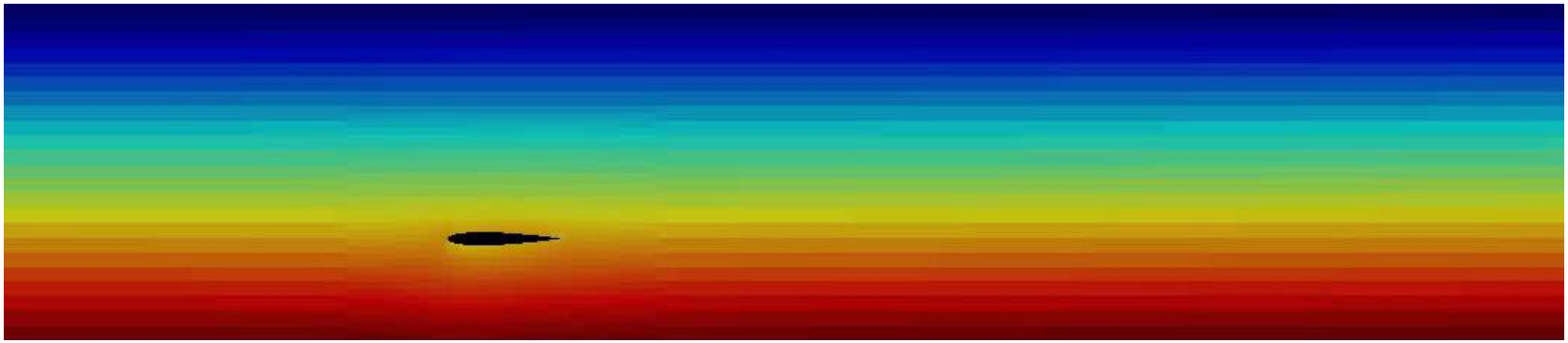
- High order interpolation
- High grid resolution
- Consistent resolution quality on both grids
- Mass correction practice



Mass correction practice

Acknowledgements

This project was funded by the German Federal Ministry for Economic Affairs and Energy under the aegis of the HyMOTT-MOTiON project [grant number BMWi 03SX390].



Thank you for your attention!