OpenFOAM® Beginner training session

Presented at the 15th OpenFOAM workshop.
June 22-26, 2020. Arlington, VA, USA.
http://www.cpe.vt.edu/ofw15/

A Crash Introduction to the Finite Volume Method and Discretization Schemes in OpenFOAM®

wolf dynamics

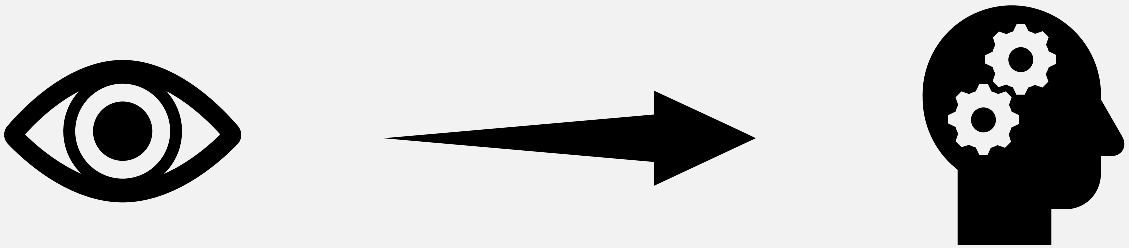
Roadmap

- **Theoretical background and computational pointers:**
  1. Important concepts to remember
  2. The Finite Volume Method: An overview
  3. The FVM in OpenFOAM®: some implementation details and computational pointers
  4. Some kind of conclusion
  5. What else we did not cover?
  6. Goodbye

- **After addressing the theory, we will work on seven tutorials to put all the knowledge acquired into action.**

Roadmap

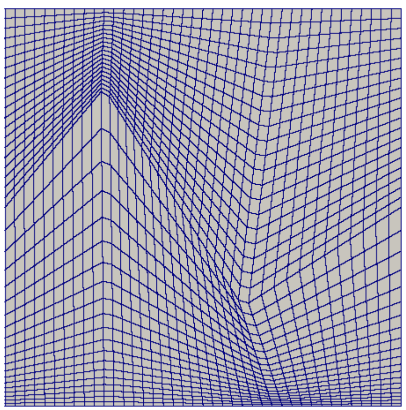
- In this training, we will focus our eyes to train our brain.

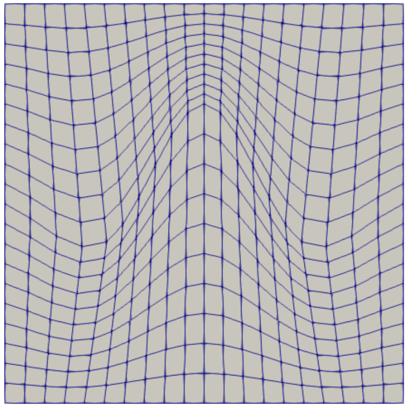


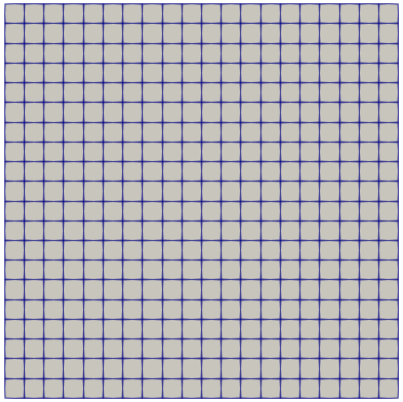
Roadmap

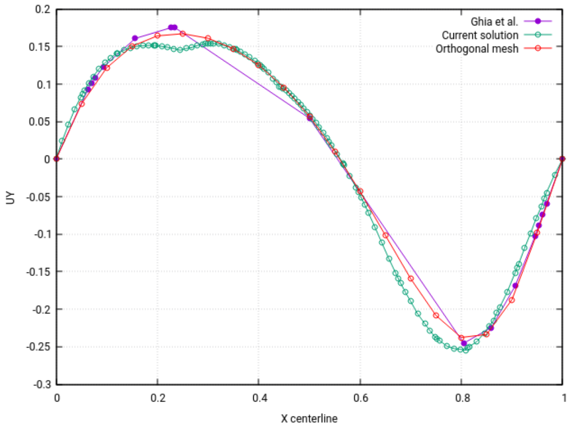
Orthogonal corrections and mesh quality issues

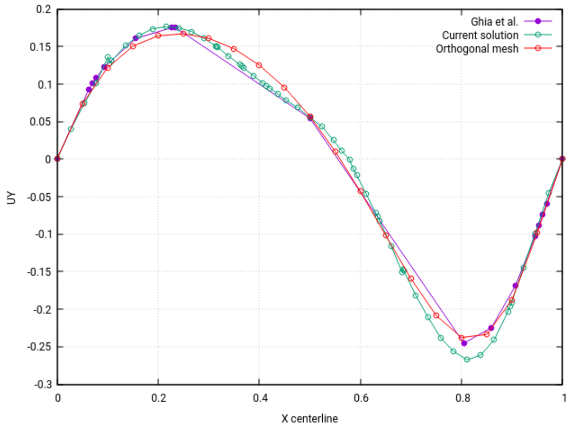
- The quality of all three meshes is acceptable; however, to get an accurate and stable solution we need to add corrections du to non-orthogonality.

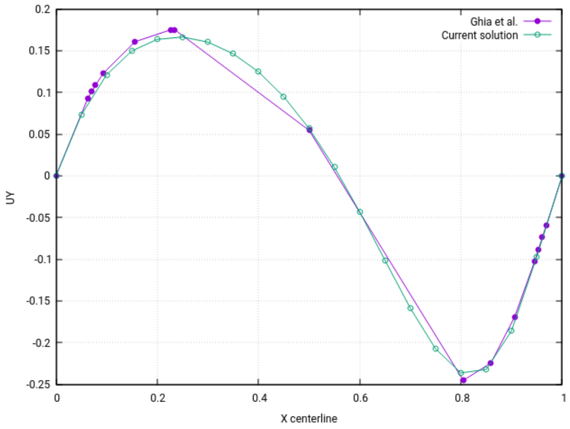






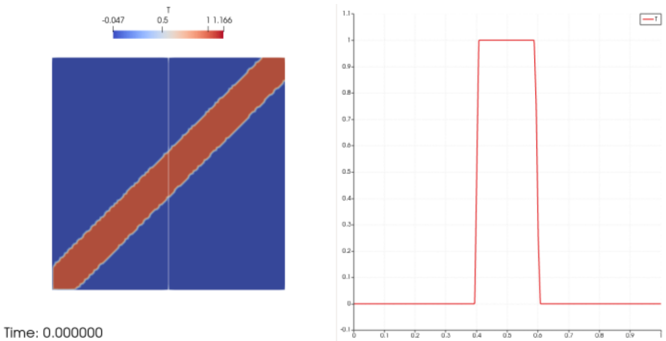




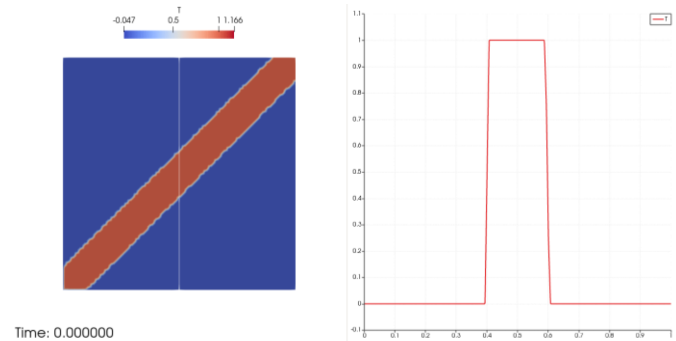


Roadmap

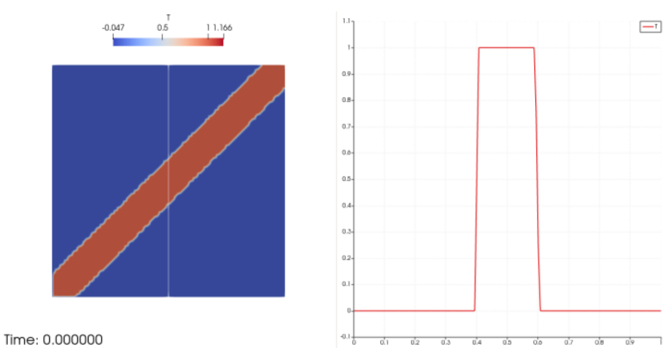
Strong discontinuities – Influence of discretization schemes



Linear
www.wolfdynamics.com/training/OF_WS2020/figs/f1.gif



Second order upwind
www.wolfdynamics.com/training/OF_WS2020/figs/f2.gif



SuperBEE
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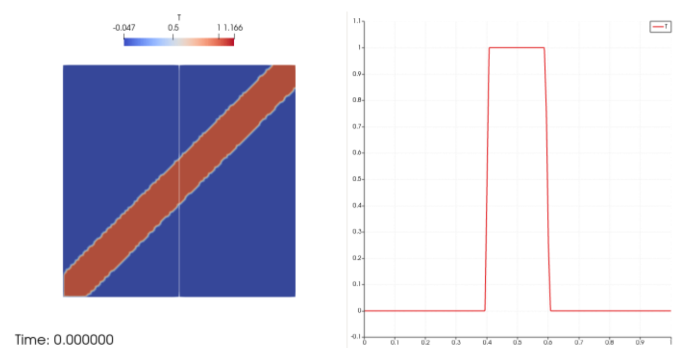
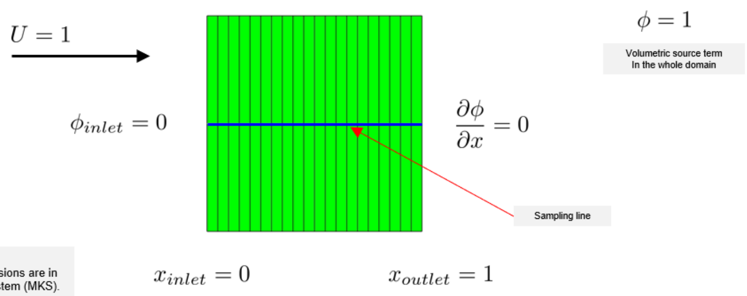


Upwind
www.wolfdynamics.com/training/OF_WS2020/figs/f4.gif

Roadmap

Influence of URF and tolerances on the accuracy and stability

$$\underbrace{\int_{V_P} \frac{\partial \rho \phi}{\partial t} dV}_{\text{Temporal derivative}} + \underbrace{\int_{V_P} \nabla \cdot (\rho \mathbf{u} \phi)\, dV}_{\text{Convective term}} - \underbrace{\int_{V_P} \nabla \cdot (\rho \Gamma_\phi \nabla \phi)\, dV}_{\text{Diffusion term}} = \underbrace{\int_{V_P} S_\phi(\phi)\, dV}_{\text{Source term}}$$



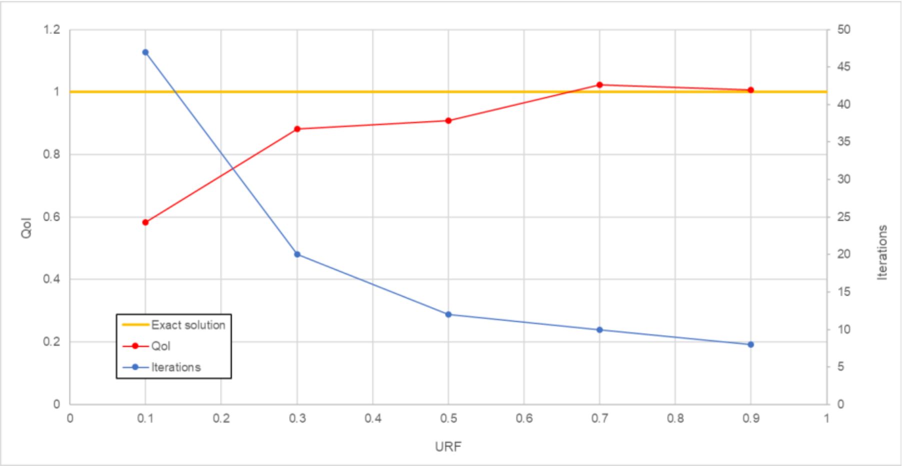
Note:
All dimensions are in the SI system (MKS).

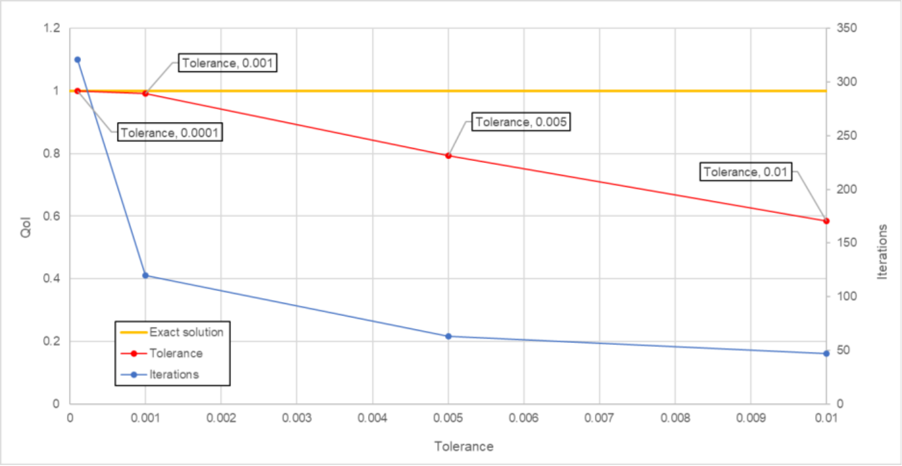
$$\frac{\partial \phi}{\partial x} = 1$$

Governing equation

$$\phi_x = x$$

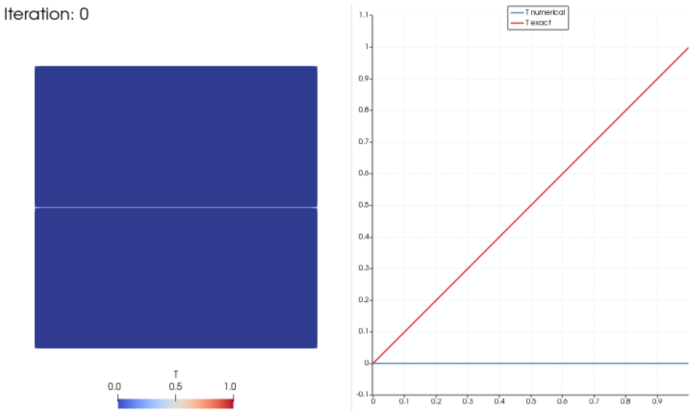
Analytical solution



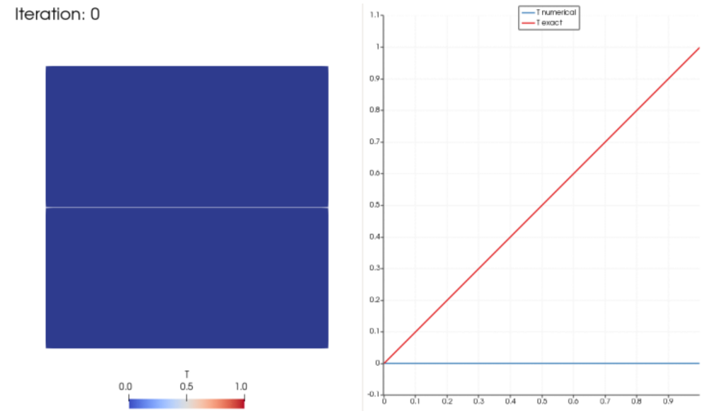


Roadmap

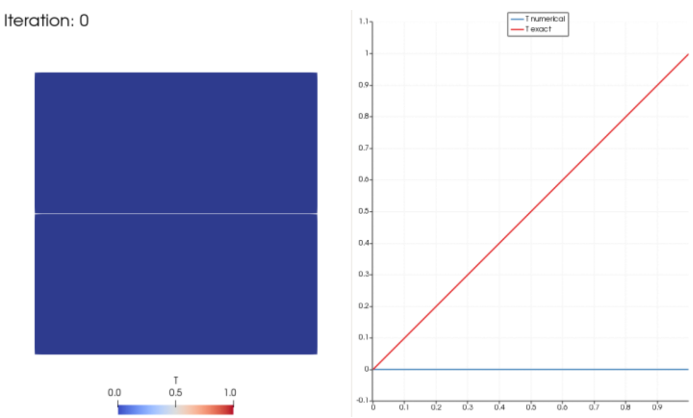
Influence of URF and tolerances on the accuracy and stability



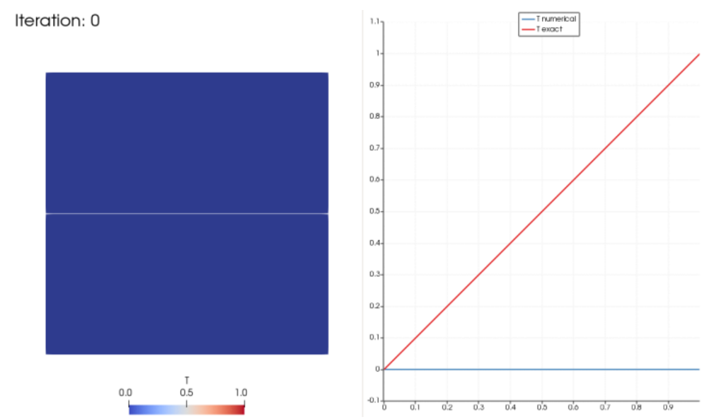
URF 0.1
Tolerance 0.01
www.wolfdynamics.com/training/OF_WS2020/figs/f5.gif



URF 0.5
Tolerance 0.01
www.wolfdynamics.com/training/OF_WS2020/figs/f6.gif



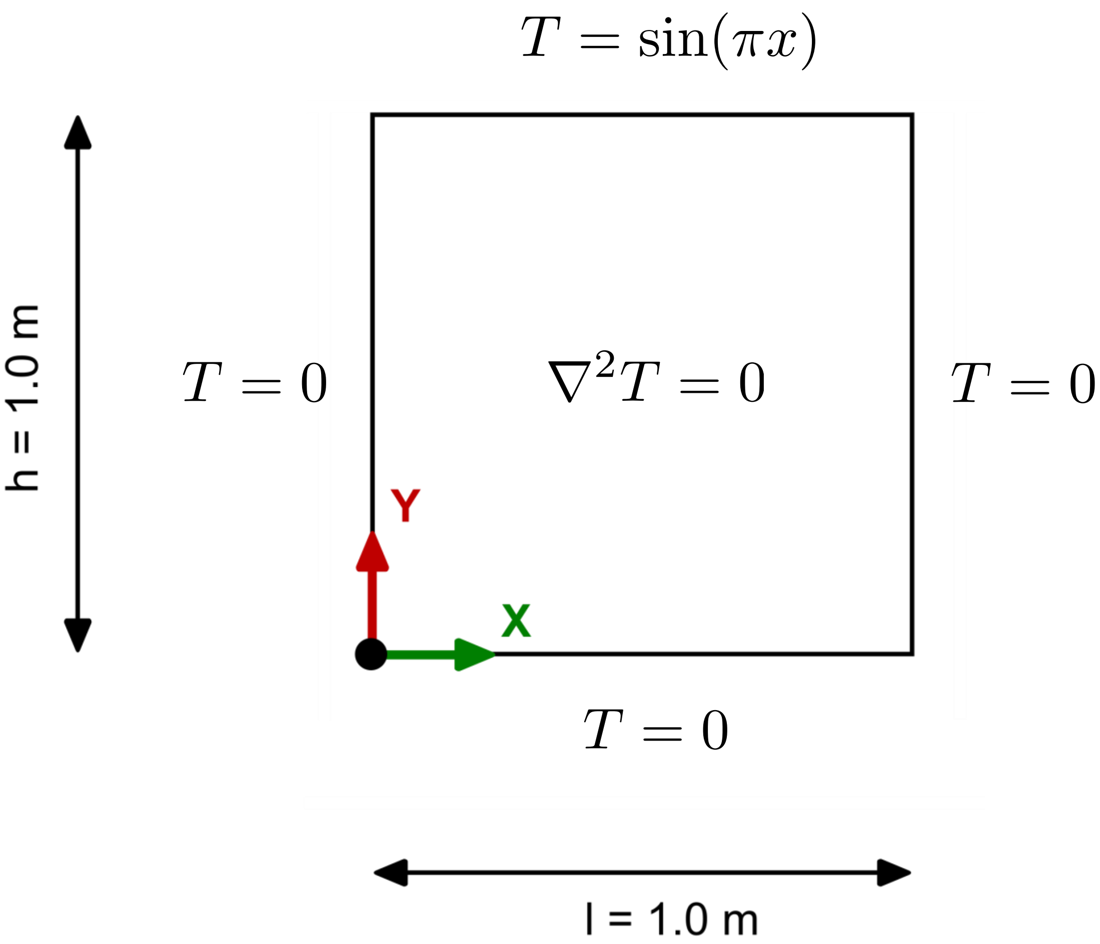
URF 0.5
Tolerance 0.001
www.wolfdynamics.com/training/OF_WS2020/figs/f7.gif



URF 0.7
Tolerance 0.0001
www.wolfdynamics.com/training/OF_WS2020/figs/f8.gif

Roadmap

Mesh influence on gradients computation – How to smooth gradients



This problem has the following analytical solution:

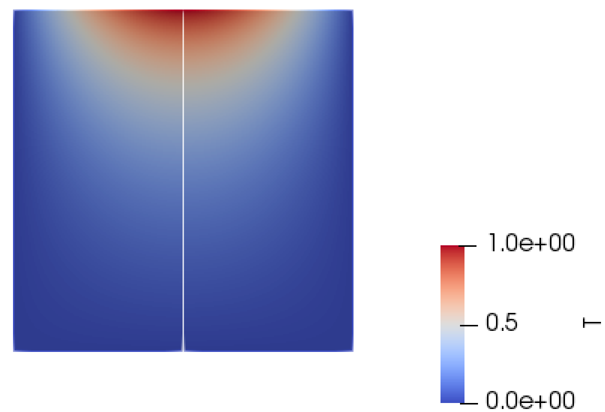
$$T(x,y) = \frac{\sin(\pi x) \times \sinh(\pi y)}{\sinh(\pi)}$$

Roadmap

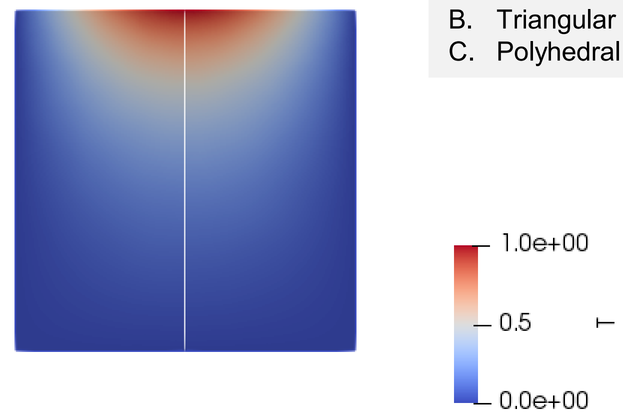
Mesh influence on gradients computation – How to smooth gradients

A. Hexahedral mesh
B. Triangular mesh
C. Polyhedral mesh

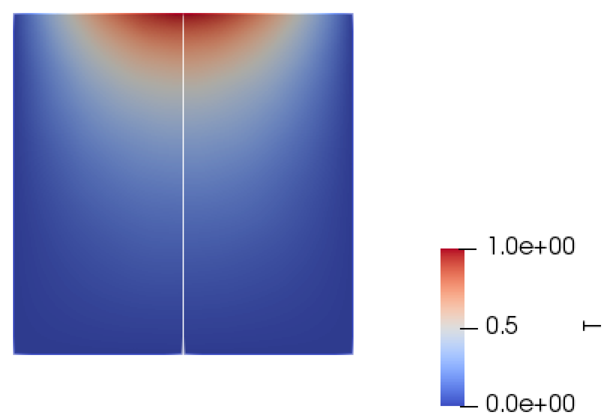
A

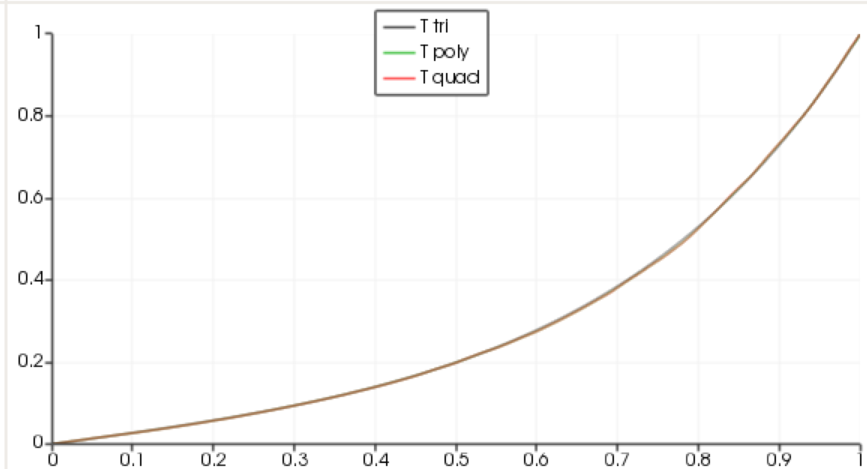


B



C

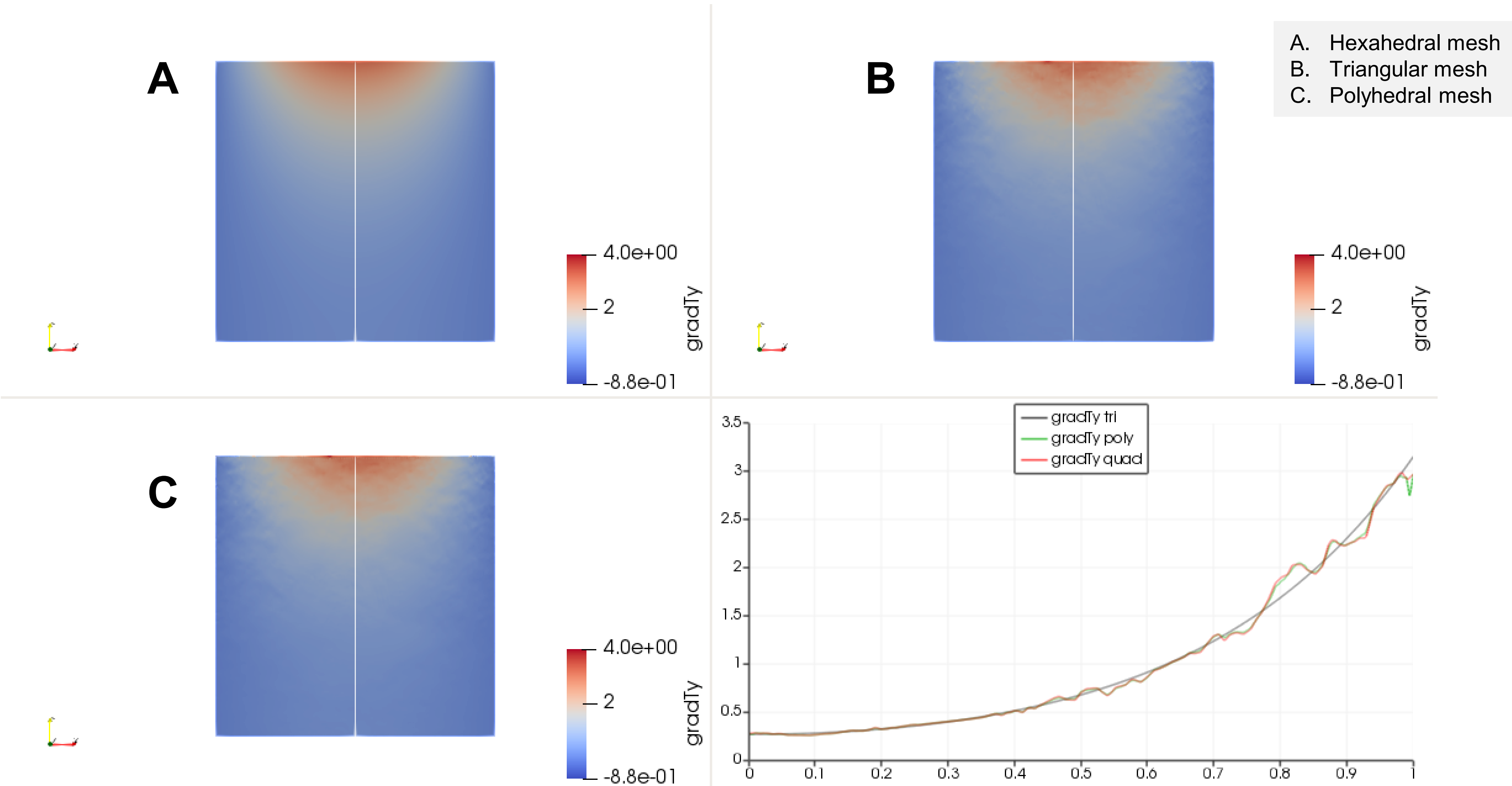




T field – Solution to the governing equation $\nabla^2 T = 0$

Roadmap

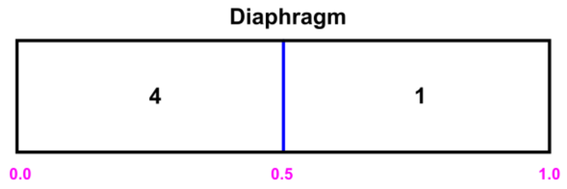
Mesh influence on gradients computation – How to smooth gradients



$\mathrm{grad}_y(T)$ **field – Used to compute the T field in the governing equation** $\nabla^2 T = 0$

Roadmap

Sod's shock tube – An extreme case to test solvers



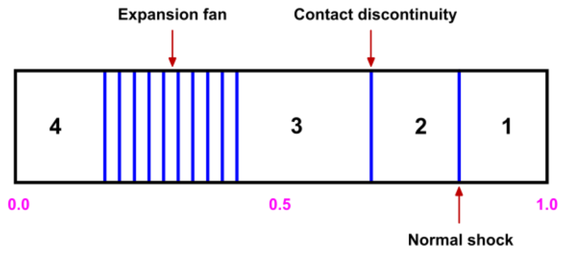
All walls are slip

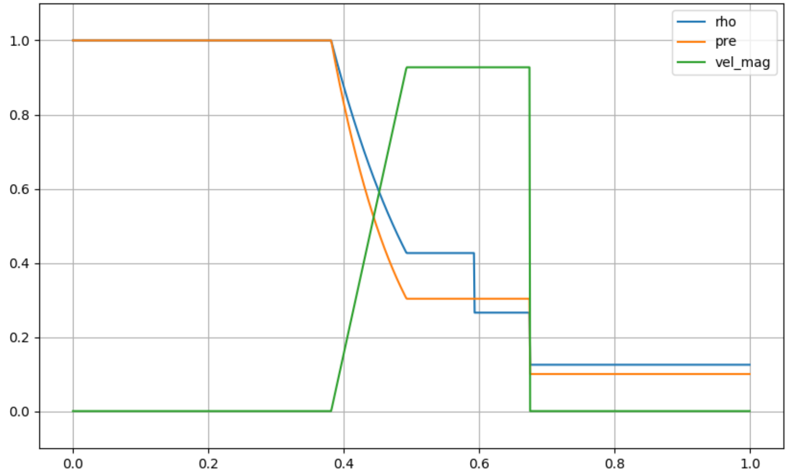
$$\mathbf{U_4} = \mathbf{U_1} = 0$$

$$p_4 = 1, \;\; p_1 = 0.1$$

$$T_4 = 0.00348, \;\; T_1 = 0.00278$$

Boundary conditions and initial conditions

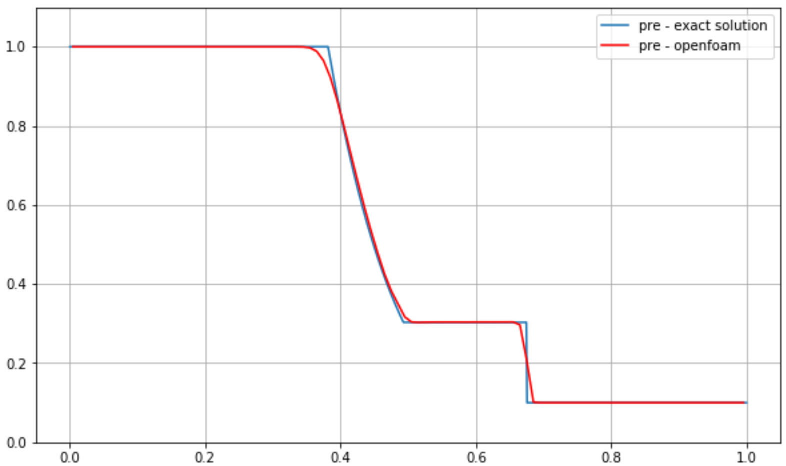




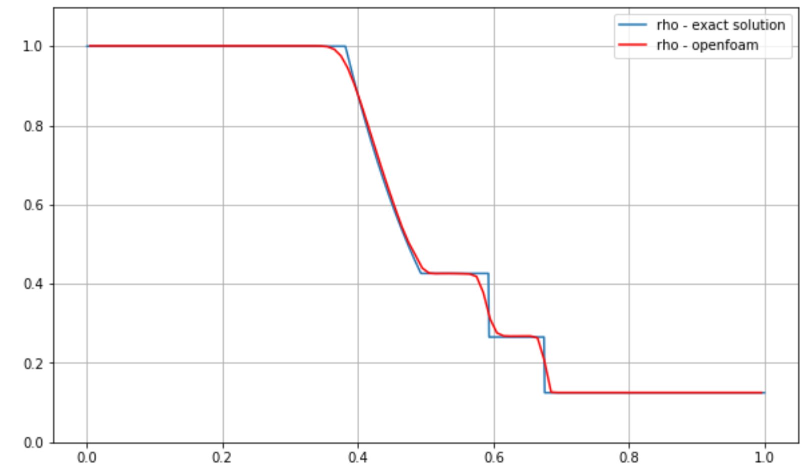
Analytical solution

Roadmap

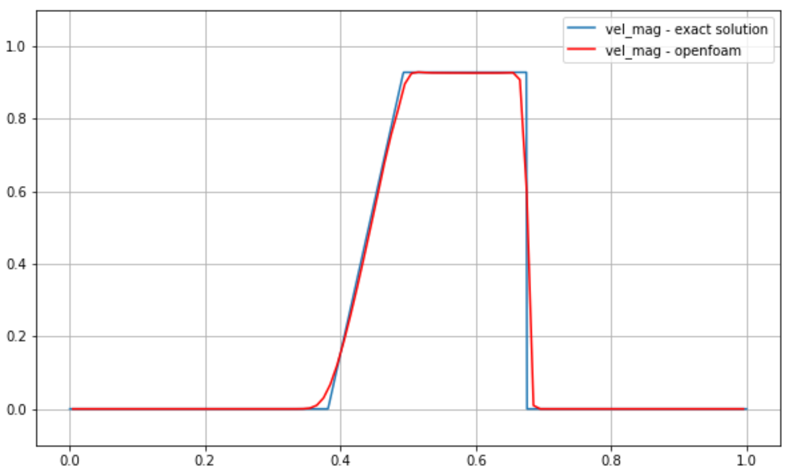
Sod's shock tube – An extreme case to test solvers



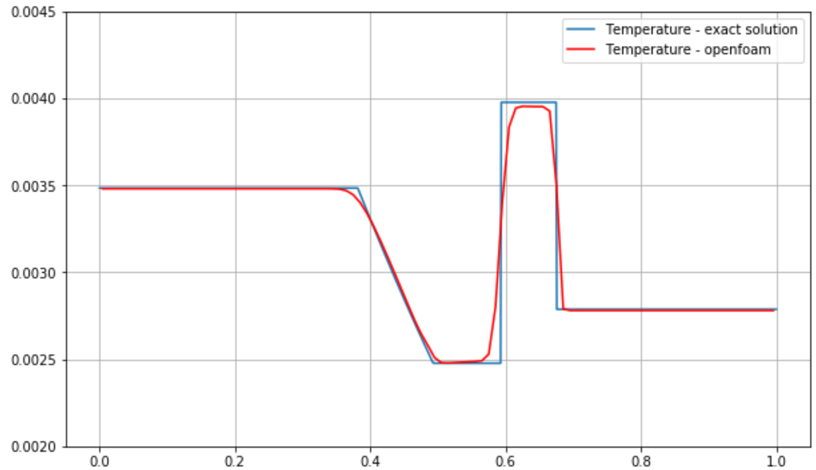
Pressure field



Density field



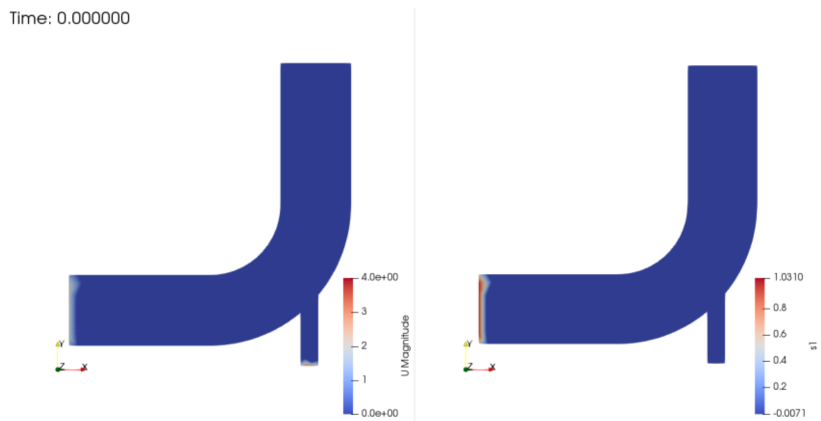
Velocity magnitude field



Temperature field

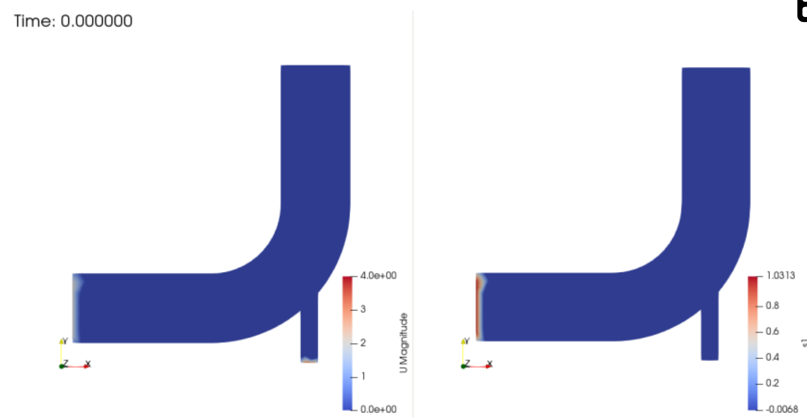
Roadmap

Under-relaxing unsteady solvers?



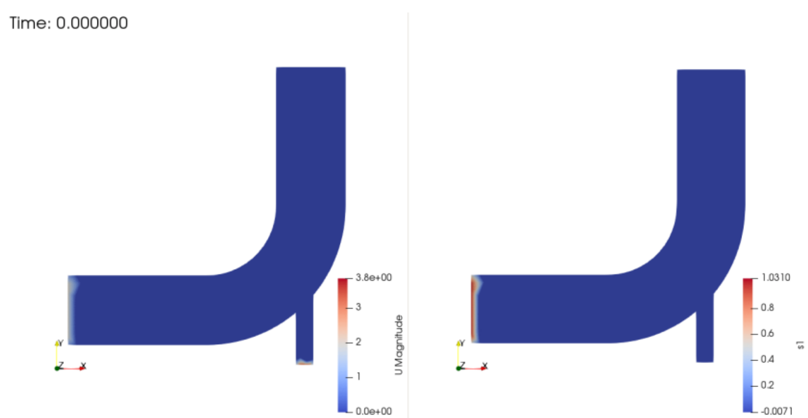
No under-relaxation

www.wolfdynamics.com/training/OF_WS2020/figs/f12.gif



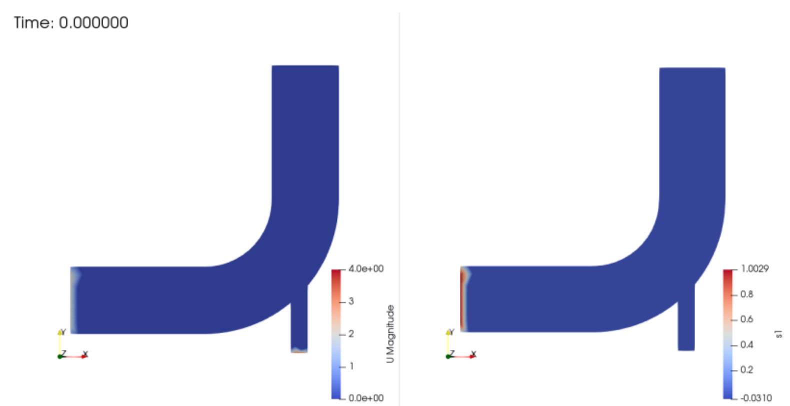
Under-relaxation factors – 0.7

www.wolfdynamics.com/training/OF_WS2020/figs/f11.gif



Under-relaxation factors – 0.5

www.wolfdynamics.com/training/OF_WS2020/figs/f10.gif

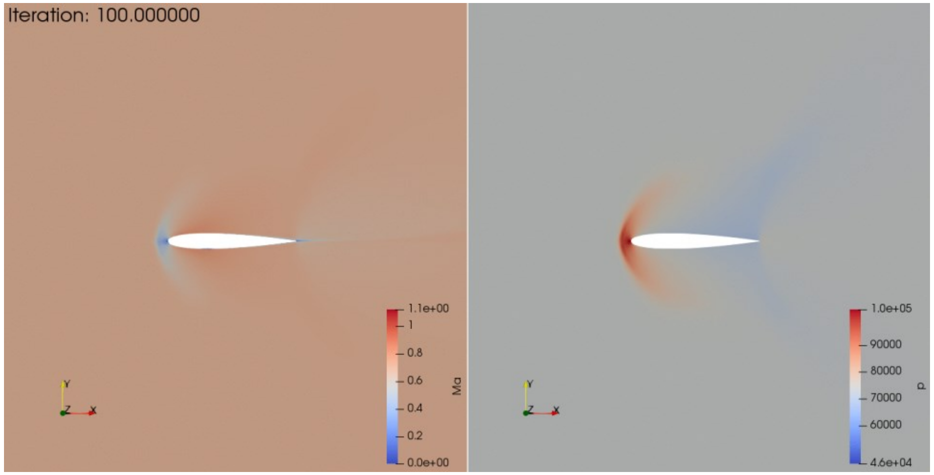


Under-relaxation factors – 0.1

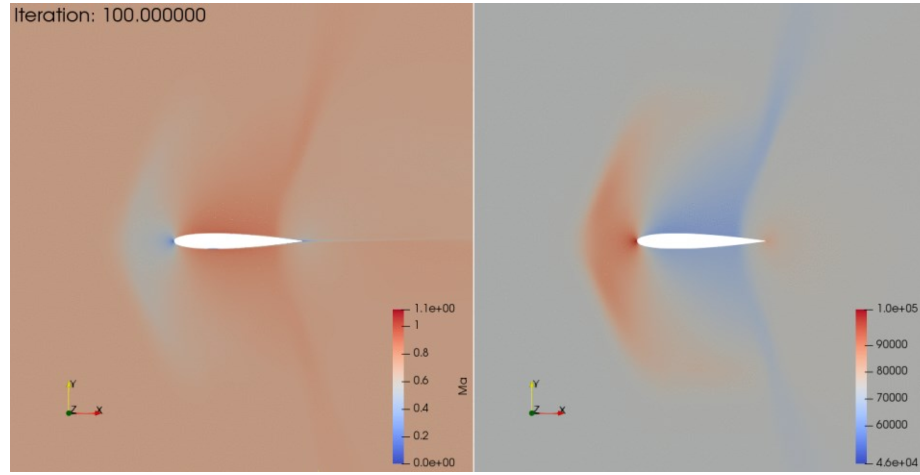
www.wolfdynamics.com/training/OF_WS2020/figs/f9.gif

Roadmap

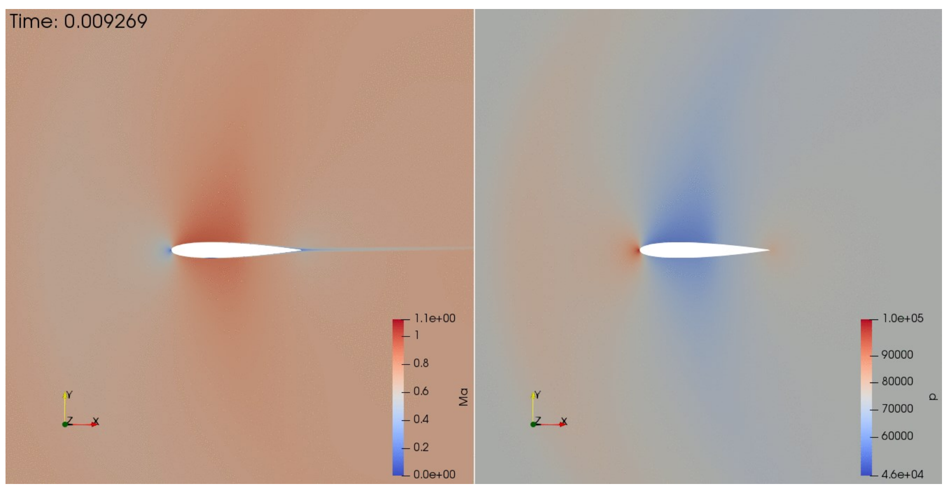
High speed aerodynamics – Unsteady, steady, and local time-stepping



Steady solution
www.wolfdynamics.com/training/OF_WS2020/figs/f14.gif



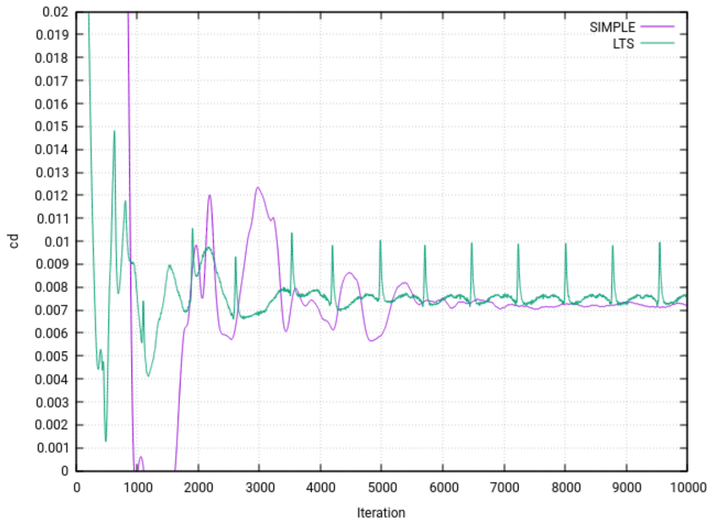
Pseudo-transient solution – Local time-stepping
www.wolfdynamics.com/training/OF_WS2020/figs/f13.gif

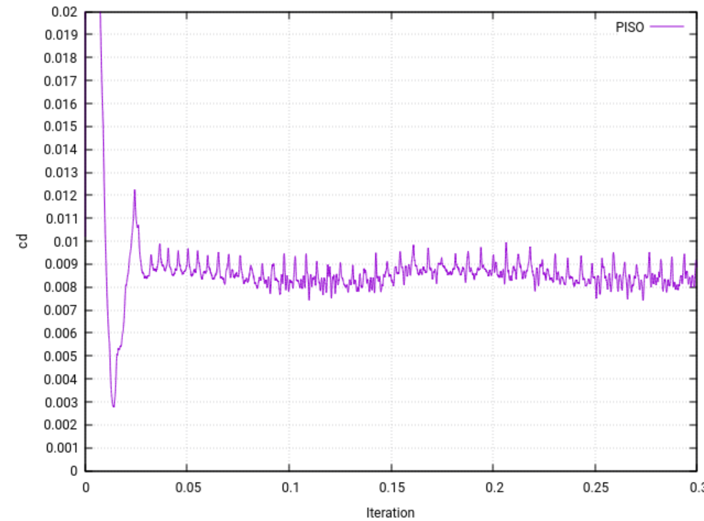


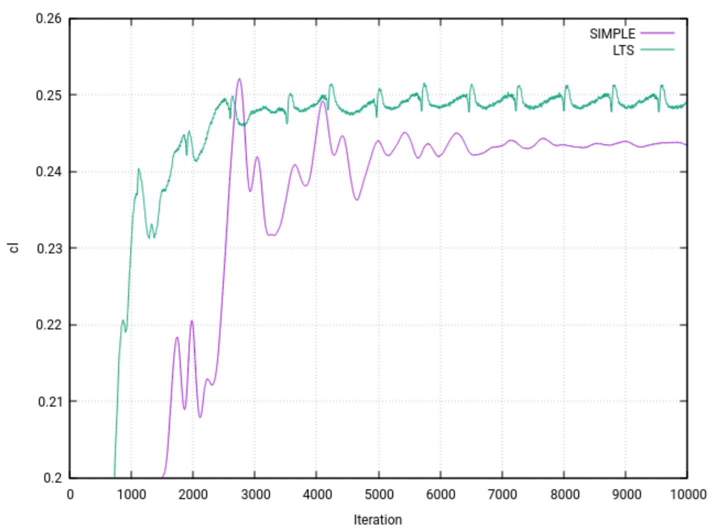
Unsteady solution
www.wolfdynamics.com/training/OF_WS2020/figs/f15.gif

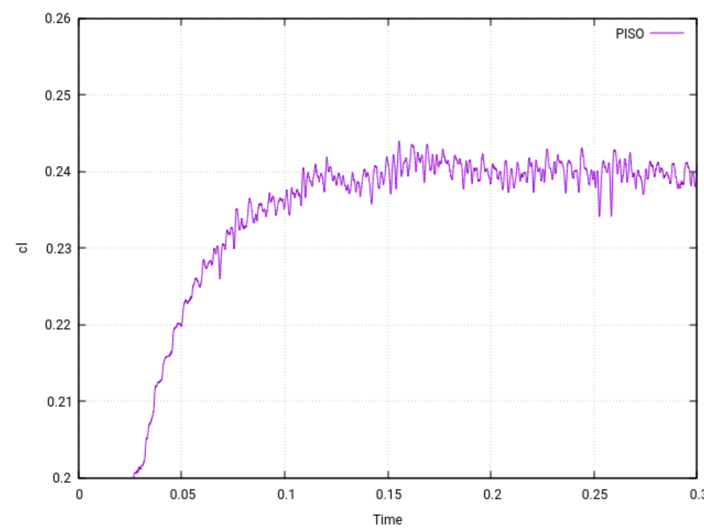
Roadmap

High speed aerodynamics – Unsteady, steady, and local time-stepping



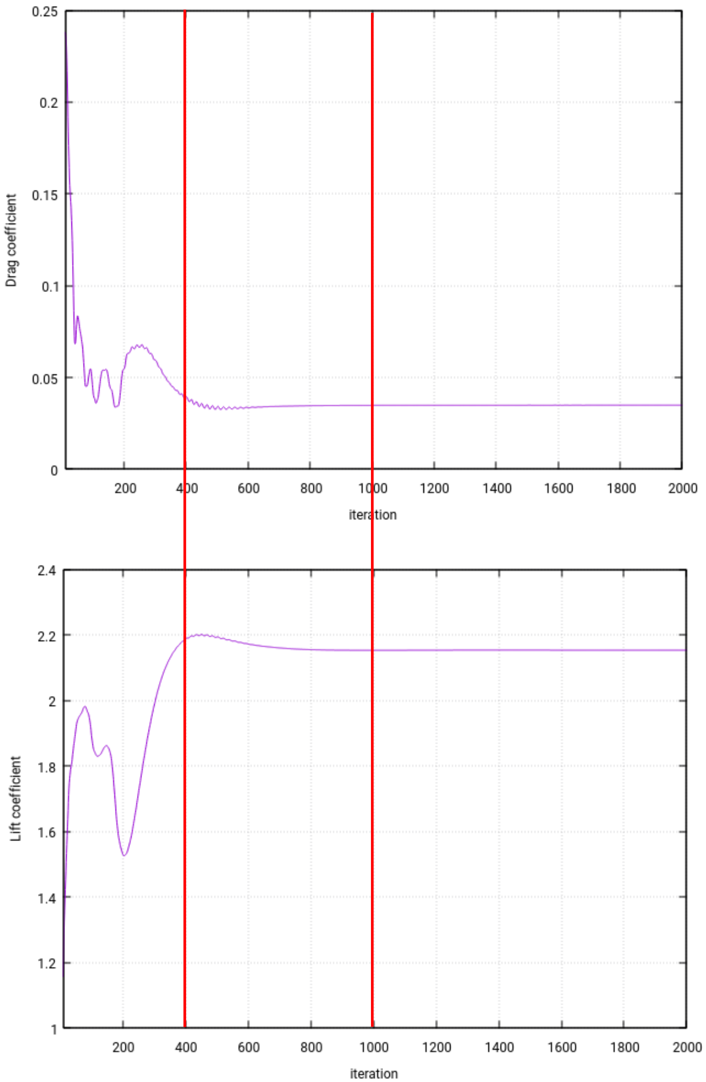


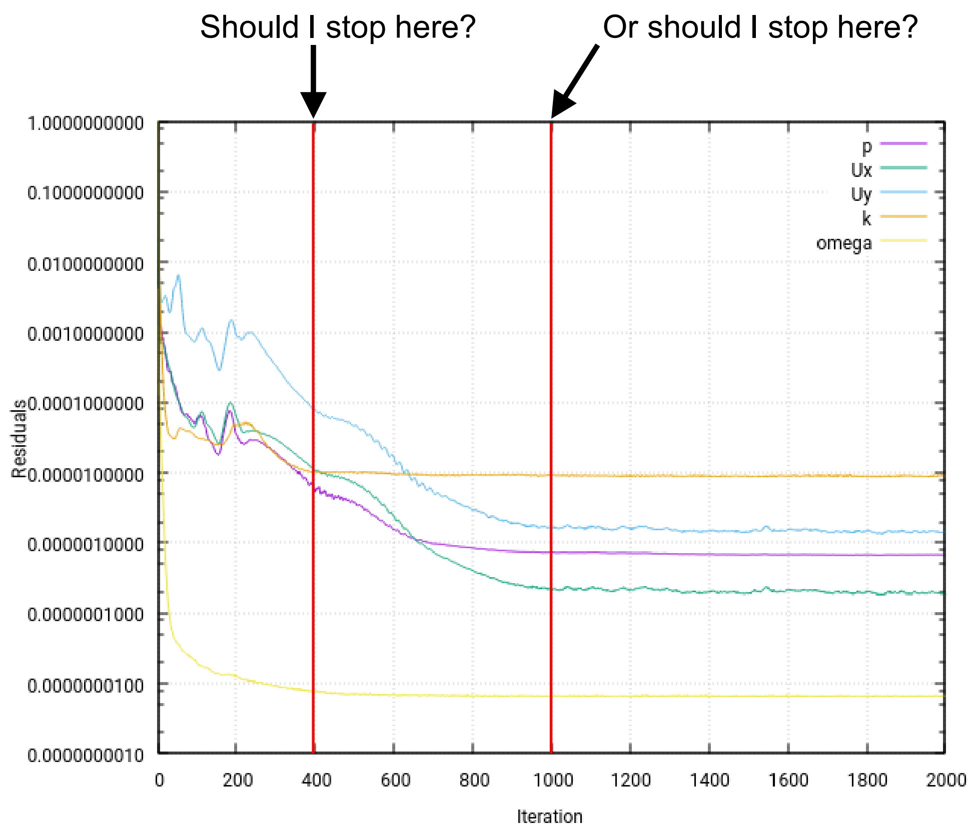




Roadmap

Monitoring steady simulations – When should I stop?





Quantitative post-processing – Assessing residuals