Nearfield Anisotropic Mesh Adaptation for the Third AIAA Sonic Boom Workshop

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Scope of the presentation

Near field cases:

biconvex	provided-unstructured (not presented)
c608	provided-unstructured and adaptive grids

Improvements from previous worskhops :

$\Longrightarrow$ Only RANS computations

$\Longrightarrow$ Fully adaptive unstructured boundary layer

General context

- FV Solvers : Wolf (INRIA) & FUN3D-FV(NASA)
- Feflo.a (INRIA) & *refine* (NASA) adaptive remeshers
- Error estimate [Alauzet & Loseille, JCP 2008], [Loseille et al., JCP 2010]

multiscale (Lp)	interpolation error	Mach number
goal-oriented (GO)	approximation error	pressure observation

INRIA Wolf Flow Solver

[Alauzet & Loseille, JCP 2012], [Menier et al., AIAA 2014], [Frazza et al., AIAA 2018]

Compressible Turbulent Navier-Stokes flow solver:

- Turbulence models: Spalart-Allmaras
- Full unstructured tetrahedra/hybrid meshes
- Mixed-Element-Volume Method:
  - Convective and source terms by Finite Volume method
  - Diffusive terms by Finite Elements method or Edge Based viscous formulation
- Vertex centered: low complexity
  - Median cells
  - Containment sphere cells
- Edge-based fluxes computation with a 2^{nd}-order scheme using MUSCL reconstructions.
- Full differentiation with 1^{st}-order matrix.

NASA FUN3D-FV flow solver

[Biedron et al., NASA TM-2019-220416], [Anderson and Bonhaus, C&F 1994]

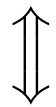
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Metric-based adaptive mesh generation

- **Main idea:** change the mesh generator distance computation
  [George, Hecht and Vallet., Adv. Eng. Software 1991]
- **Fundamental concept:** **Unit mesh**

Adapting a mesh



Work in adequate Riemannian metric space

Generating a uniform mesh w.r. to $\mathcal{M}(\mathbf{x})$

Adaptive mesh generators

- Feflo.a: cavity-based operators and geometry projection based on EGADSLite [Loseille, Handbook 2018]
- *refine*: standard operators with functional based optimization and reconnection. [Park, 2008]

Feflo.a/*refine* are part of the Unstructured Grid Adaptation Working Group. `https://UGAWG.GitHub.io`.

- Verification of grid components : error estimates, parallelism, and geometry
- Code-to-code verification

Metric-based Anisotropic Mesh Adaptation

Feature-based anisotropic mesh adaptation

Deriving the **best mesh** to compute the characteristics of a given solution **w**

[Tam et al., CMAME 2000], [Pain et al., CMAME 2001], [Picasso, SIAMJSC 2003], [Formaggia et al., ANM 2004], [Bottasso, IJNME 2004], [Li et al., CMAME 2005], [Frey and Alauzet, CMAME 2005], [Gruau and Coupez, CMAME 2005], [Huang, JCP 2005], [Compere et al., 2007], ...

Multiscale anisotropic mesh adaptation

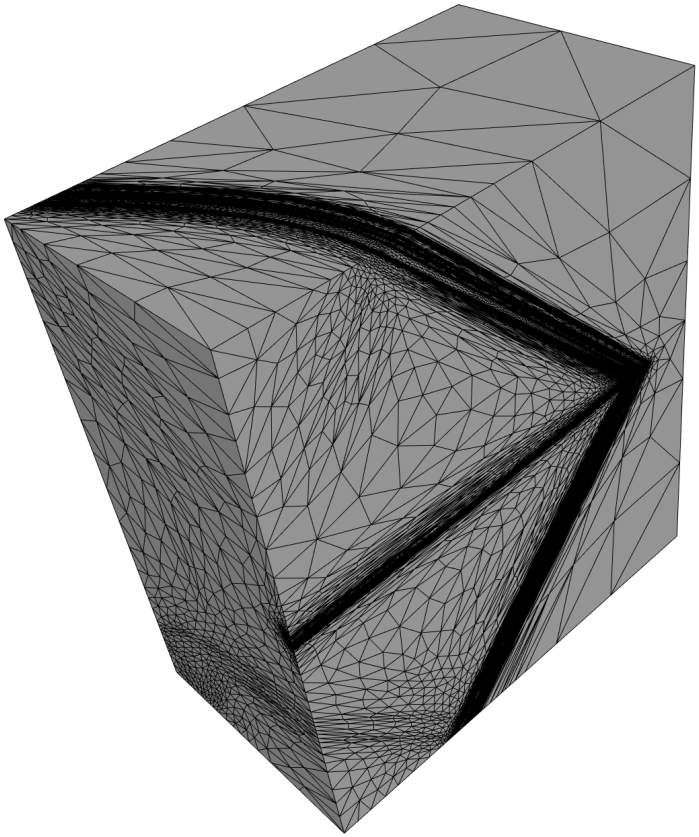
[Loseille et al., AIAA 2007], [Alauzet, IJNMF 2008]

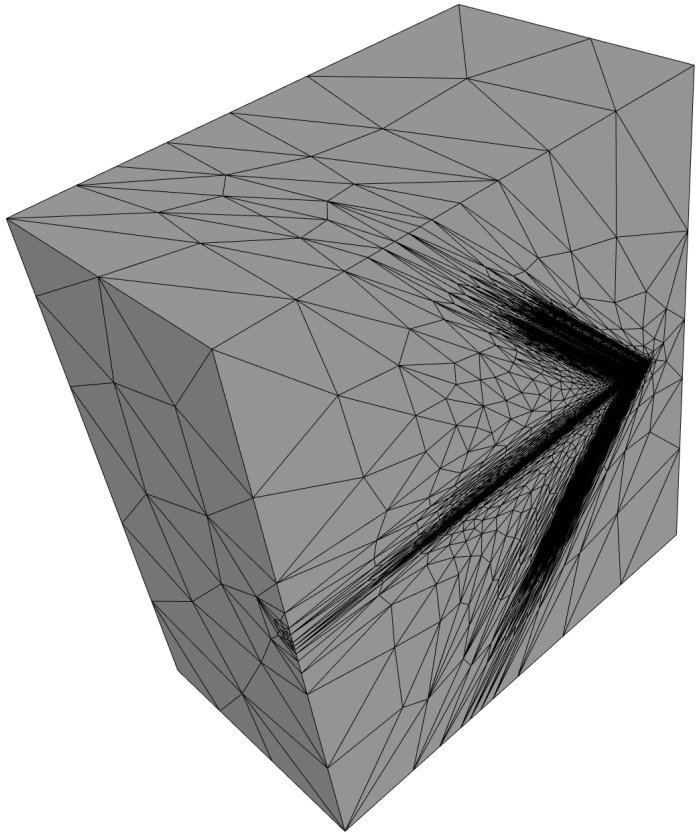
- Optimal control of the interpolation error in L^p norm :

$$\|W - \Pi_h W\|_{L^p(\Omega_h)}$$

- Solve this problem in the continuous framework $\Longrightarrow$ $\mathcal{M}_{L^p}(H_W)$
- Highly anisotropic meshes
- Capture all scales of the flow
- Global 2^{nd} mesh convergence of the mesh adaptation process
- Early capturing property: asymptotic convergence is reached faster

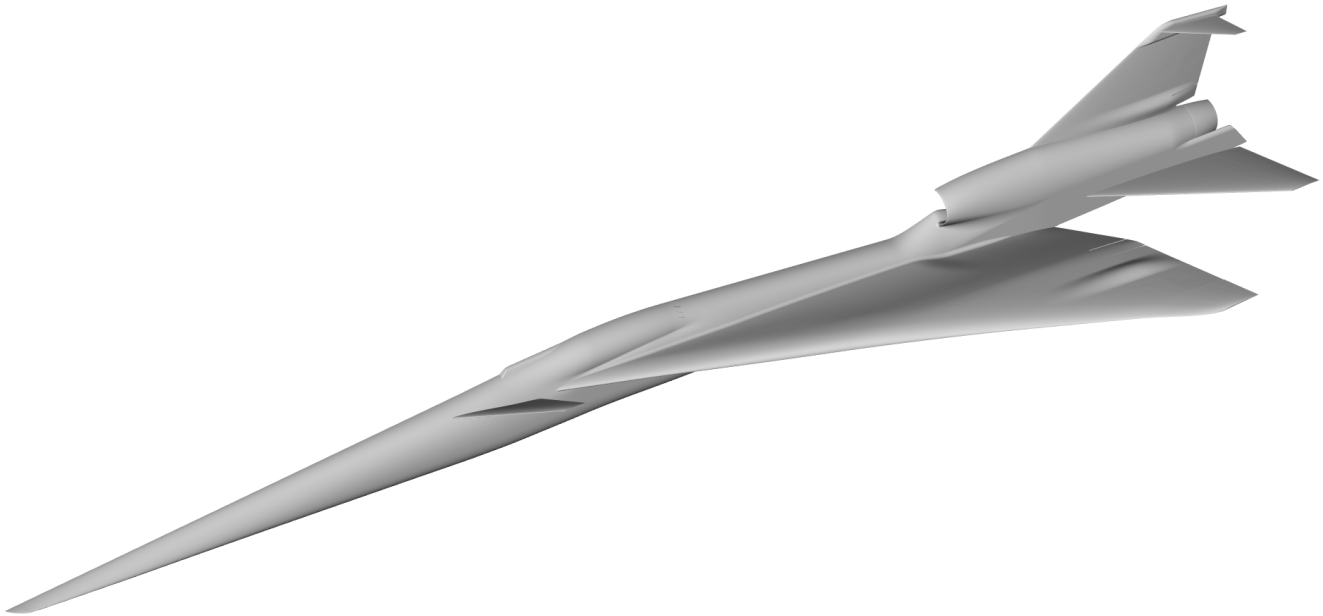
Hessian artificial diffusion





- Hessian anisotropic diffusion for $R > 4000$
- 5 adaptations are performed at fixed complexity from 200000 to 1280000

C608 case

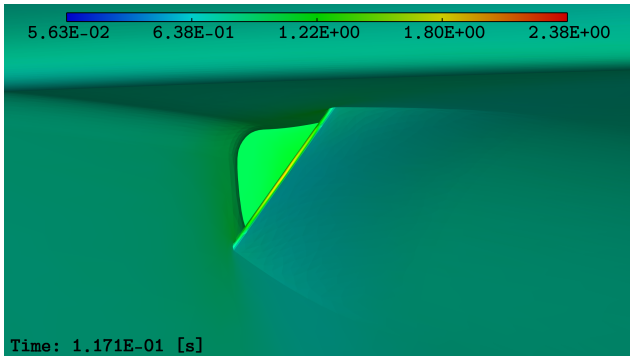


Characteristic	Symbol	Value	Units
Mach	M	1.4	$[-]$
Angle of attack	α	0.0	$[-]$
Body length	L	1080	$[in]$
Altitude	H	53200	$[ft]$
Unit Reynolds number (per inch)	Re	109776	$[-]$

C608 case

Presented results :

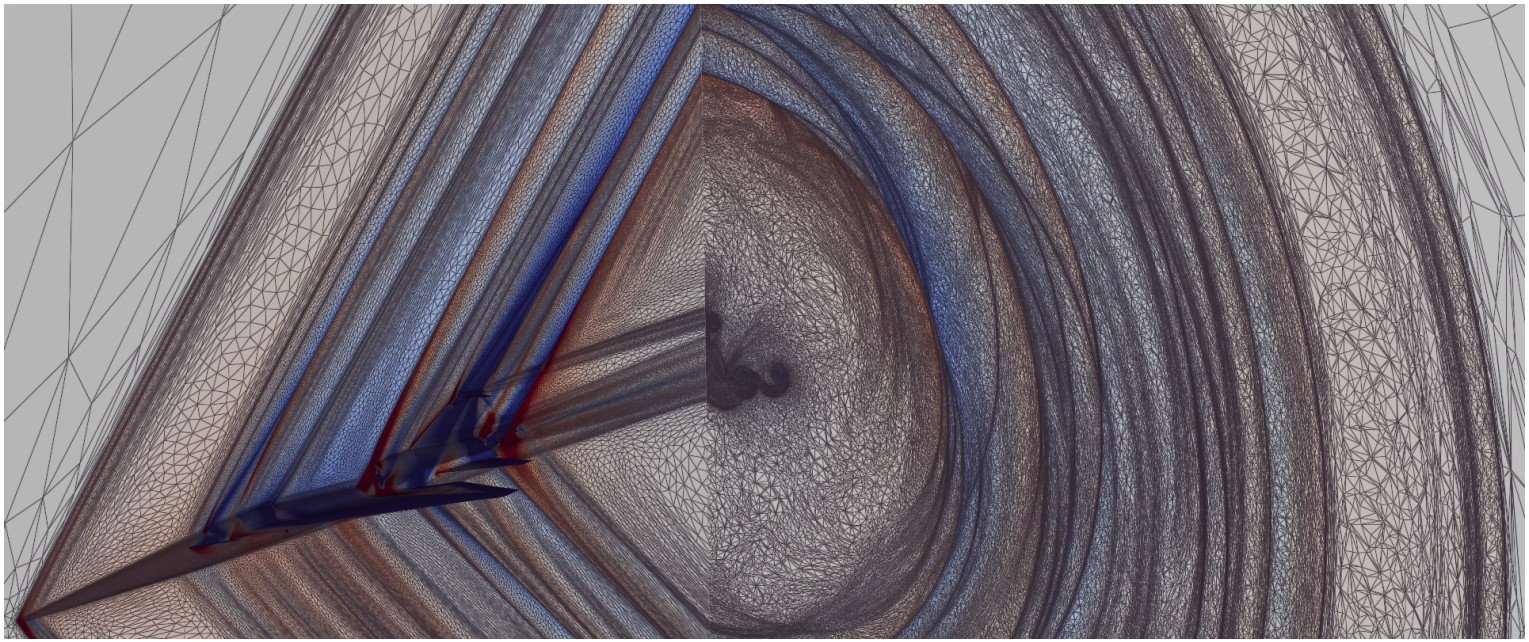
- FUN3D Workshop Grids Pressure condition : FUN3D-WGP
- FUN3D Workshop Grids Mach condition : FUN3D-WPM
- FUN3D L^2 Adapted Mesh : FUN3D-AM
- Wolf L^2 Adapted Mesh with Pressure Boundary Condition : Wolf-AP



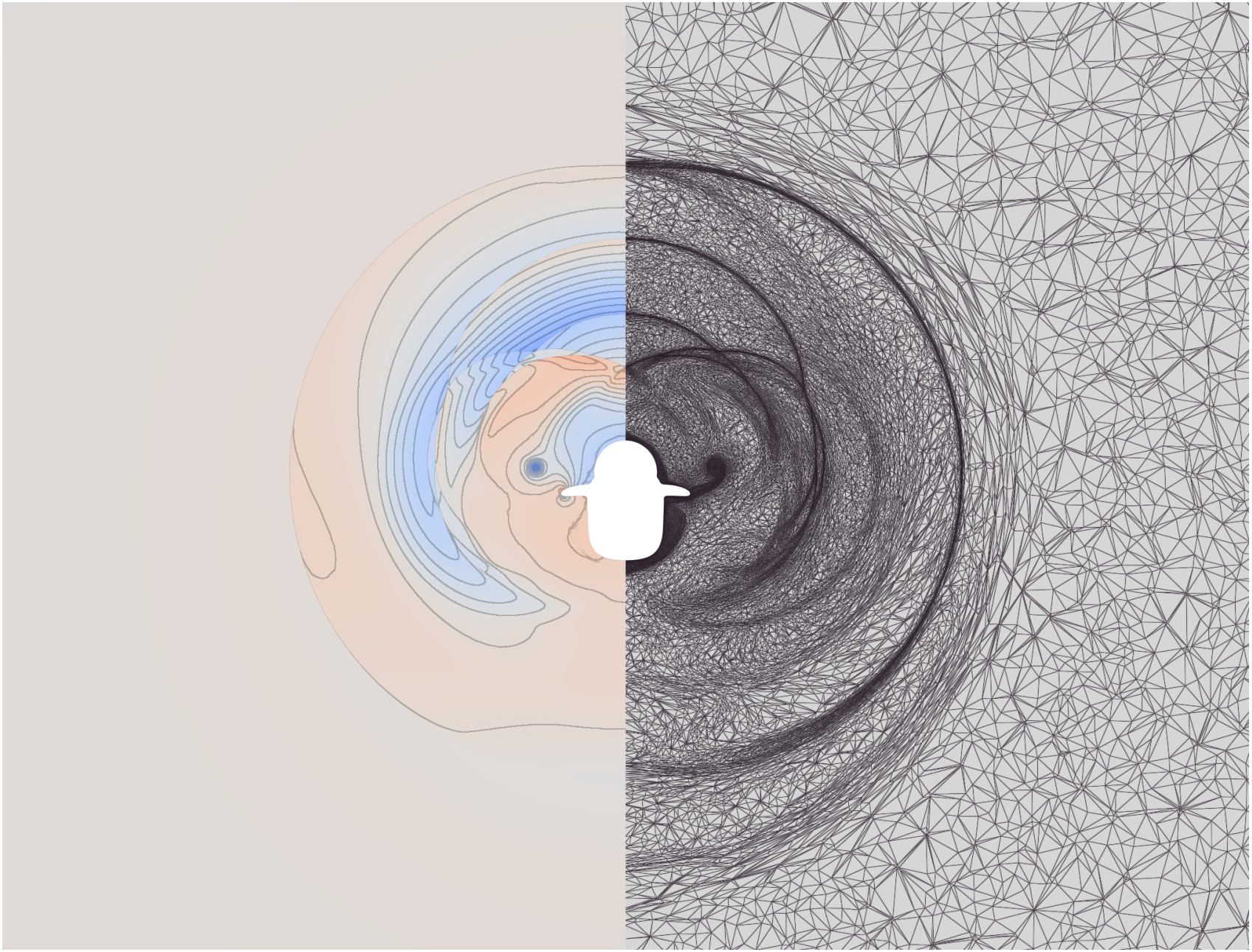
ECS boundary condition

- FUN3D : Mach condition (M) and Pressure condition (P)
- Wolf : Pressure condition (P)

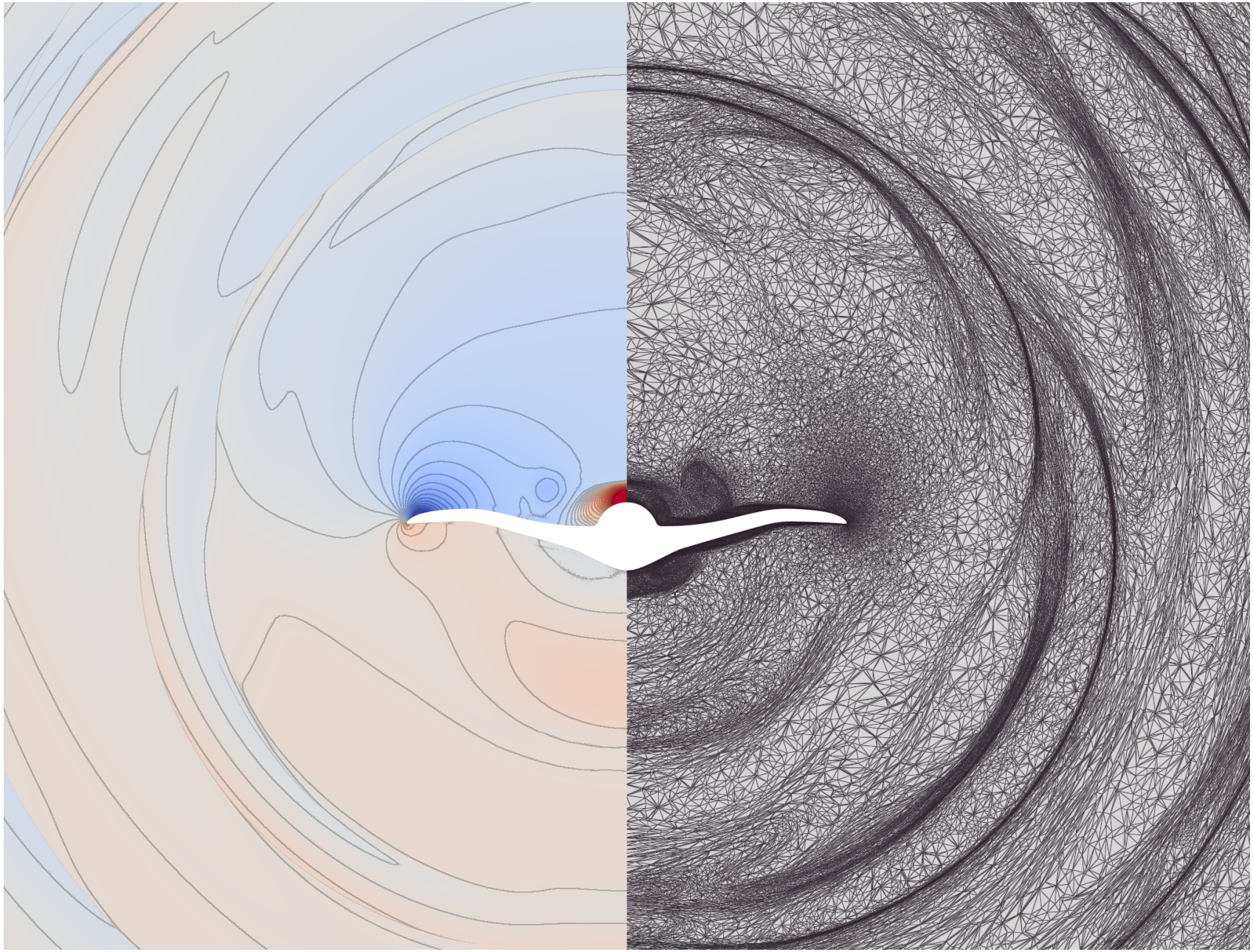
C608 case : Adapted results



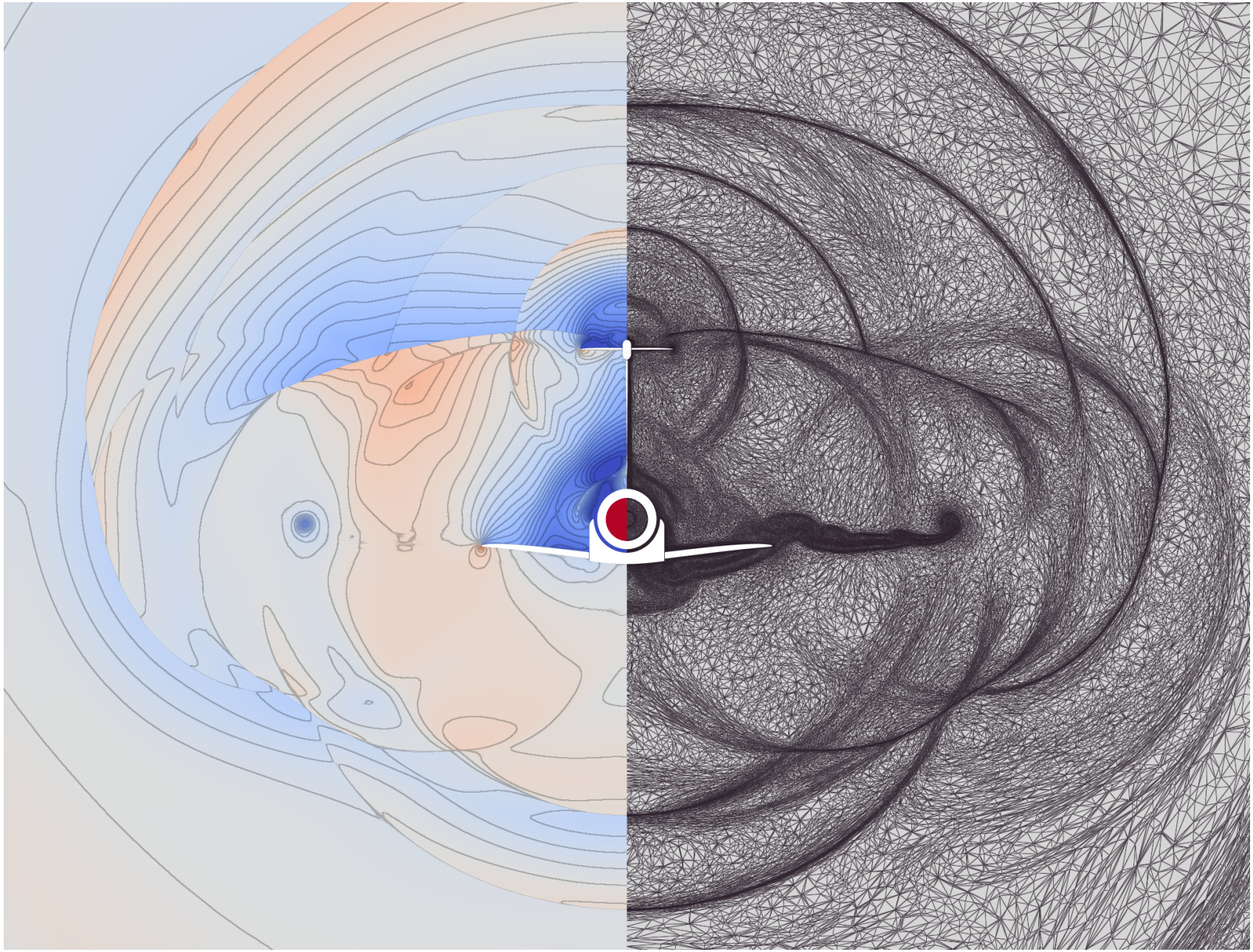
- L^2 control of the Mach number
- 25 meshes in total with complexities :
  $[0.8\text{M}, 1.6\text{M}, 3.2\text{M}, 6.4\text{M}, 12.8\text{M}]$



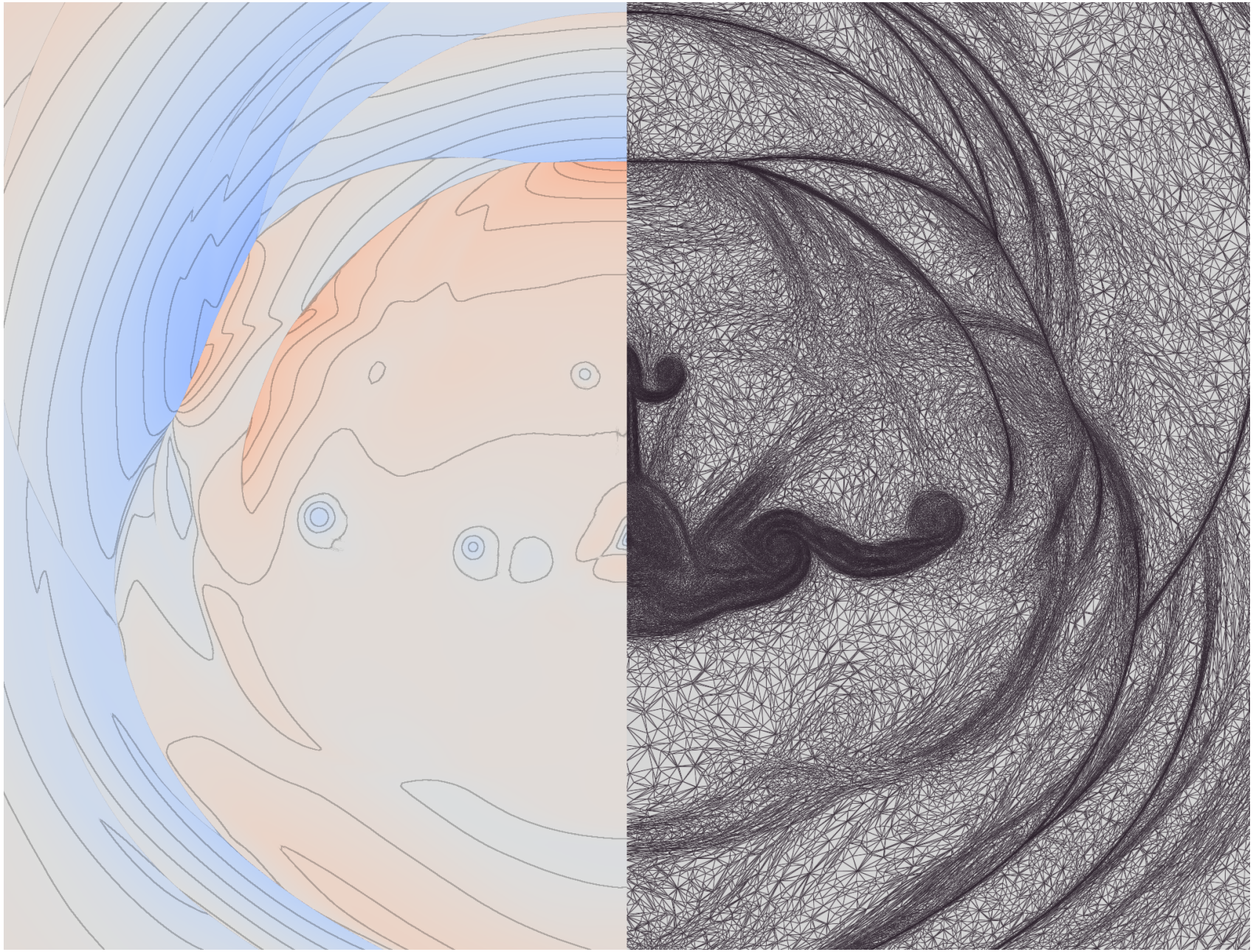
$x/L = 0.50$ $[-]$.



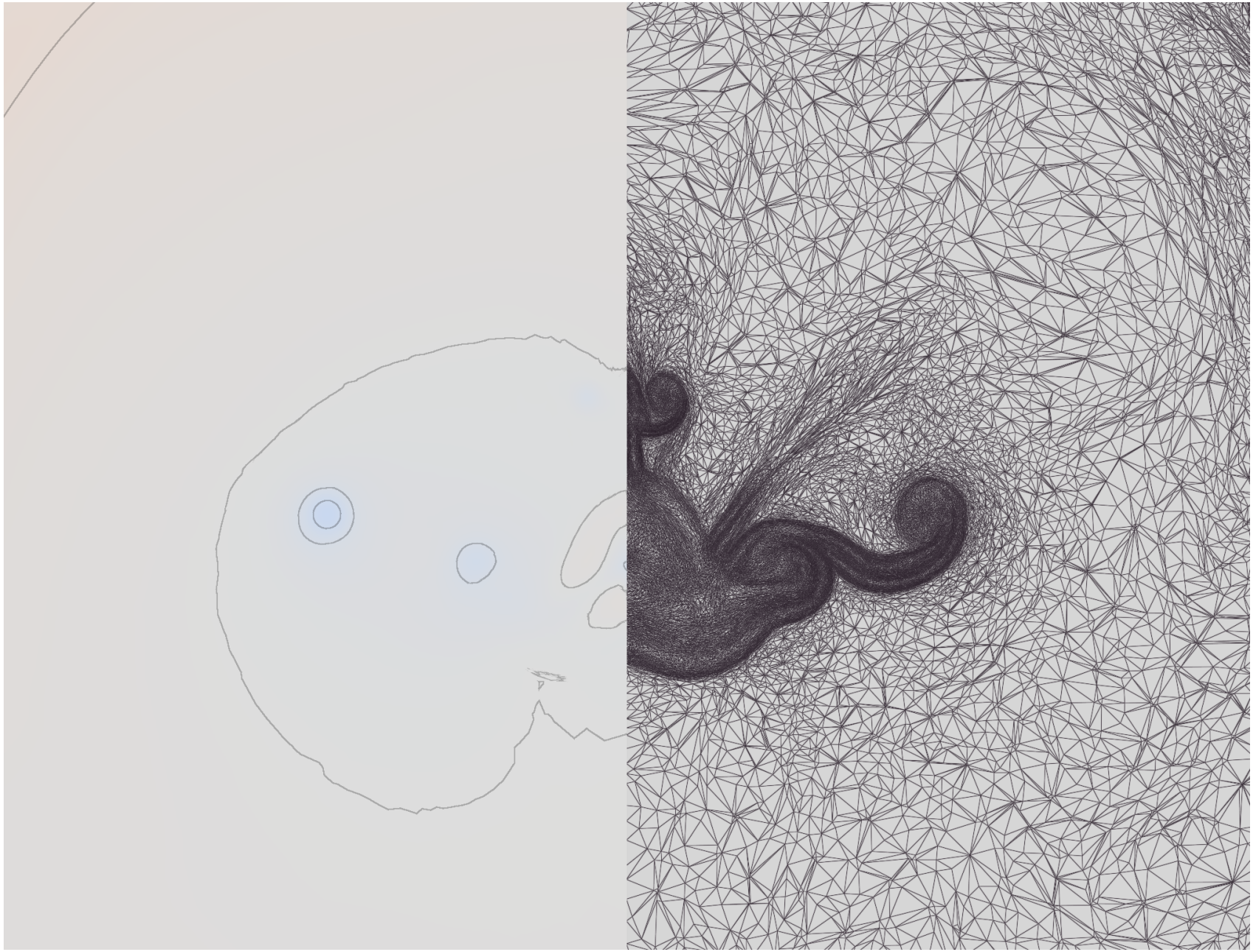
$x/L = 0.75$ [−].



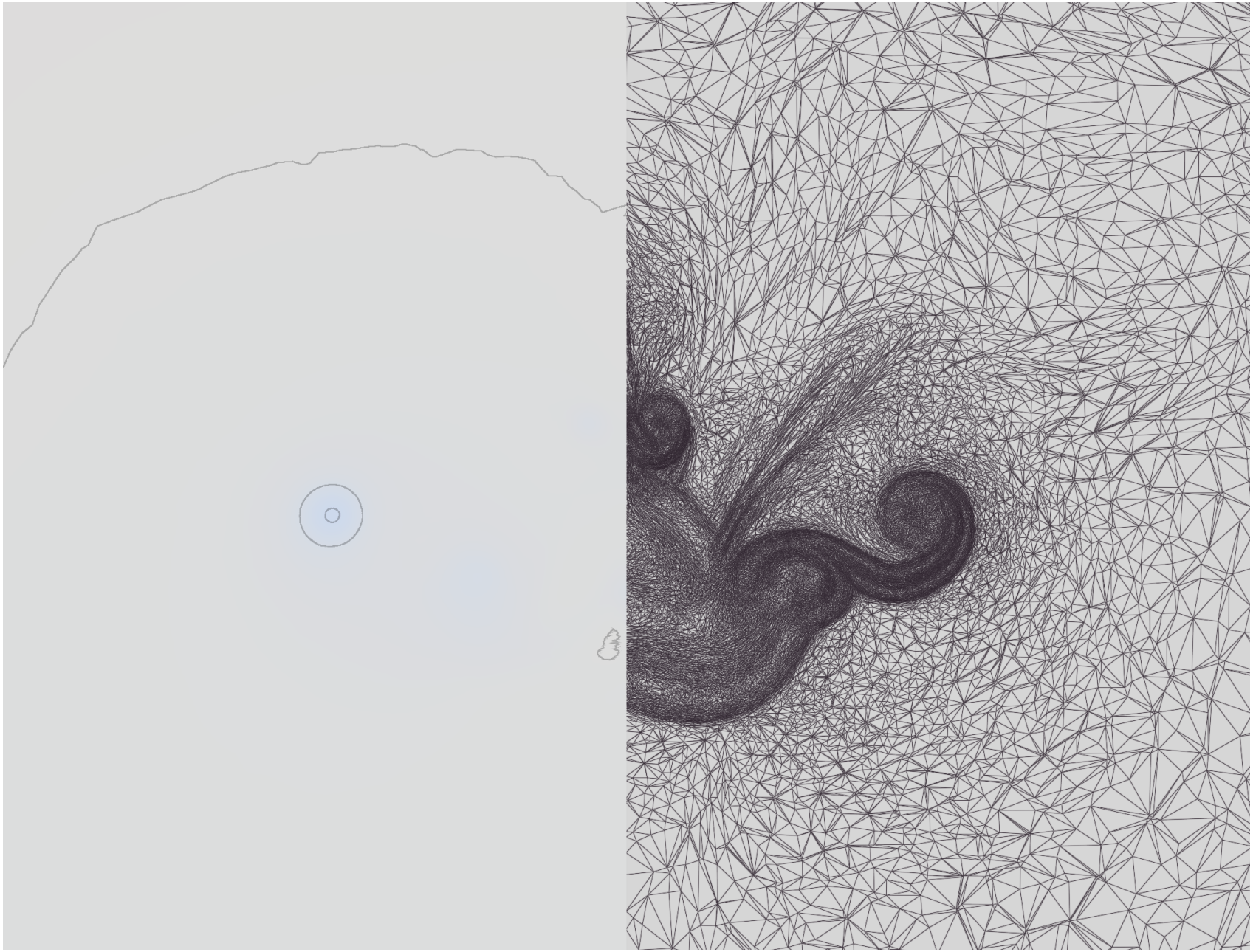
$x/L = 1.00$ [−].



$x/L = 1.25$ [−].

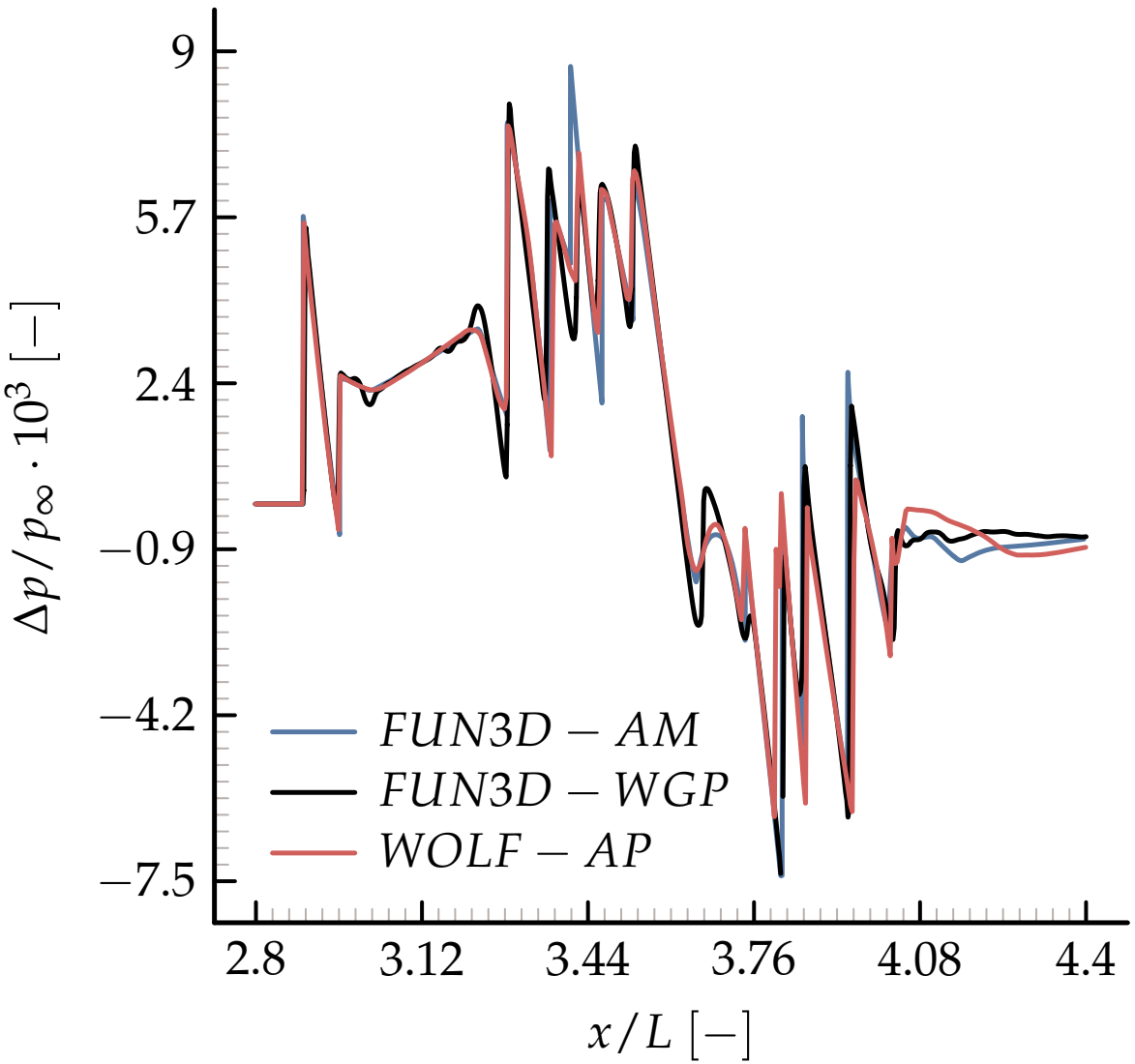


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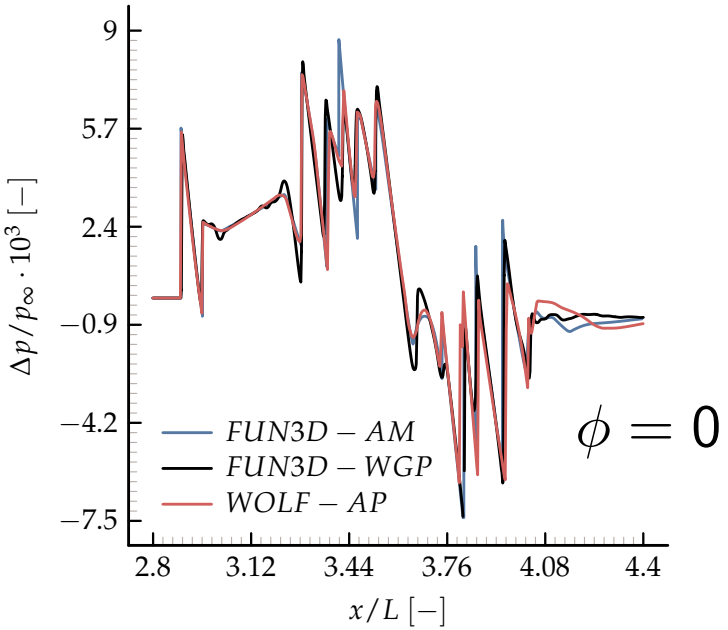
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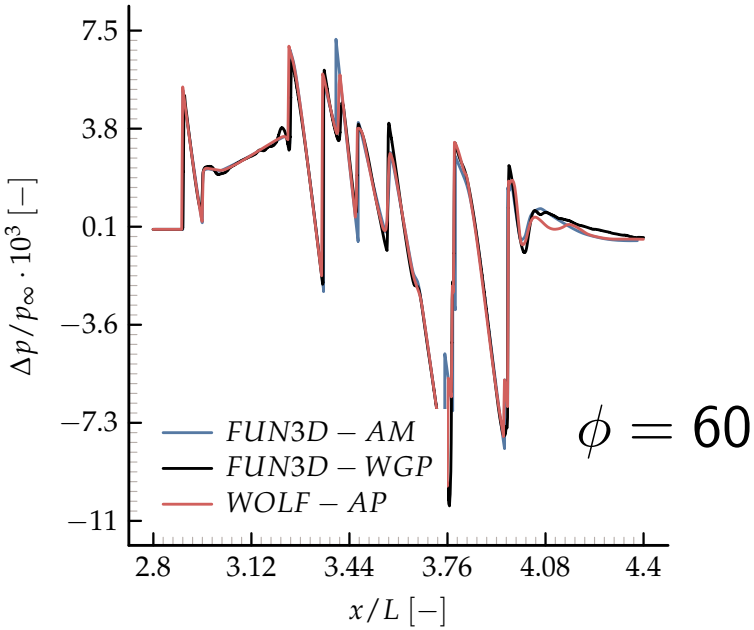
C608 case : BC comparison $\phi = 0$

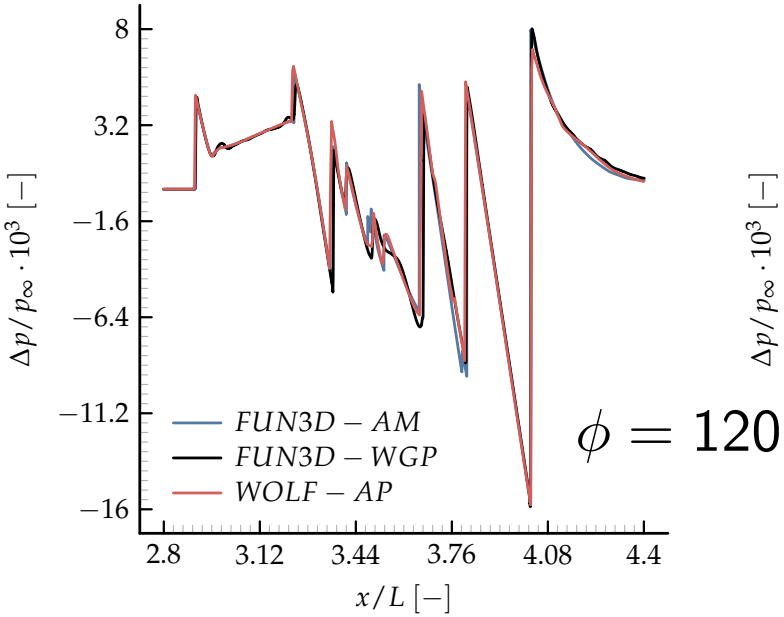


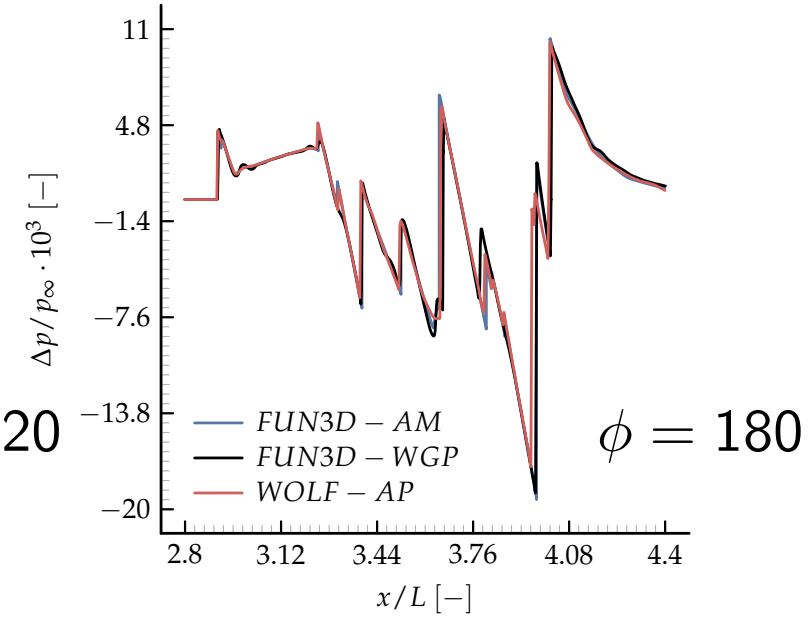
- Differences in Environmental Control System (ECS) boundary conditions are seen at $x/L = 3.4$ [−]

C608 case : Comparison

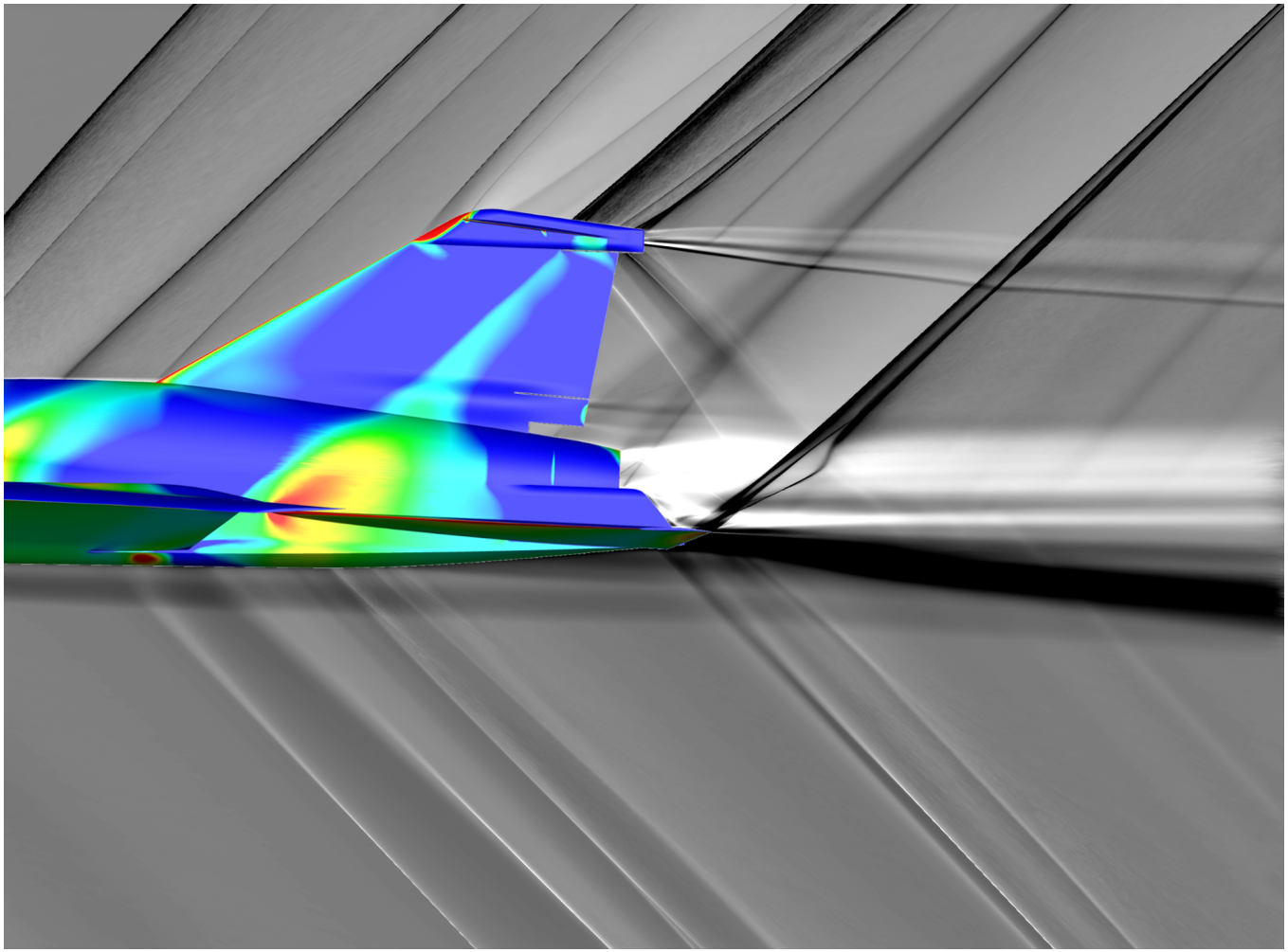








C608 case : Schlieren with surface pressure



- FUN3D-AM
- tail and near-plume regions.

Conclusion

- Adaptative meshes reveal some details on shock generator and plume not seen in provided grids
- Dependency on the boundary condition for the ECS (Mach or Pressure)
- Near field signatures consistent with an adaptive strategy based on L^2 meshes

Future work and limitations

- Convergence on complex geometries needs larger meshes (20-100M) to observe full signal convergence
- More analysis is needed especially for the multiscale balance between the boundary layers and shocks