CFD simulations of MYRRHA Control Rod system in COMPLOT facility

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CRS4

SEARCH-MAXSIMA 2014
International Workshop

Objectives in MAXSIMA, Task 3.4

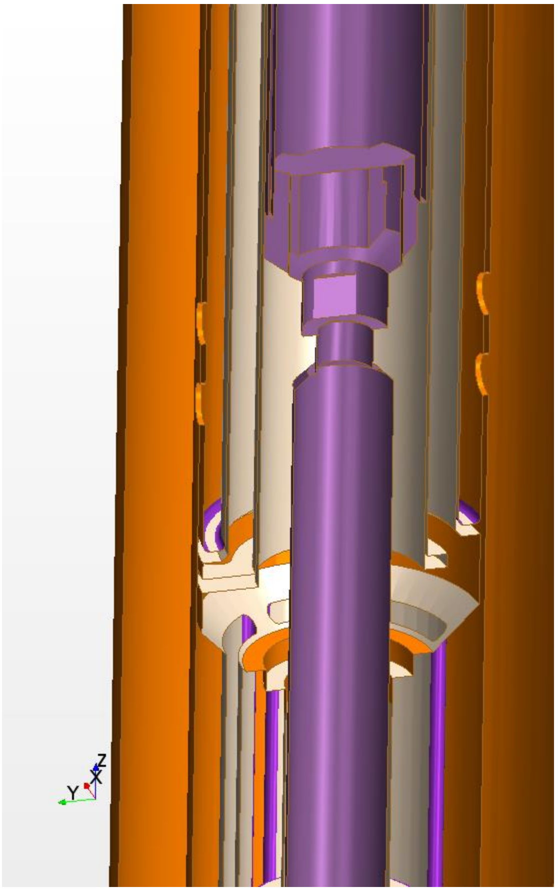
Numerically reproduce the control/safety rod system movement as in COMPLOT (COMPonent LOop Testing) facility, with imposed displacement.

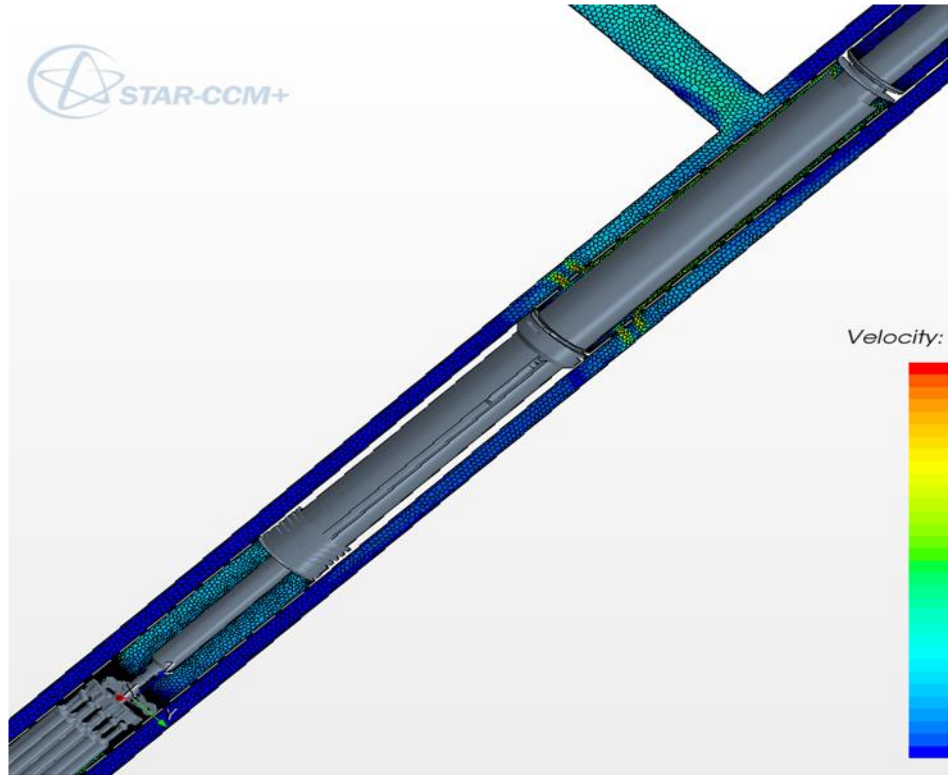
Validate the simulations against experimental tests in COMPLOT.

CFD: a predicting tool for moving bodies?

Simulate the safety/control rod displacement in the MYRRHA primary loop configuration.

Control Rod geometry in COMPLOT





- Courtesy of SCK providing CAD and help in understanding the components functions

LBE–COMPLOT physical properties and dimensions

Parameter	Value	Steady-state (SS) / Transient
LBE Temperature Range (˚C)	200 – 400	SS / Transient
LBE Density (kg/m^3)	10470	SS/ Transient
LBE dynamic viscosity μ	2.432E-03	SS/Transient
Kinematic viscosity υ	2.323E-07	SS/Transient
Nominal flow ΔP (Bar(g))	2.5	SS
Mass flow rate (kg/s)	Tbd, 38	SS
Rod bundle displacement (mm)	0 - 680	Transient
Guide tube diameter / lenght (mm)	100/5000	

Route to motion

Steady state with imposed MFR in Inlet

- Calculate
  ΔP Inlet-Outlet,
  ΔP Inlet-Outlet holes

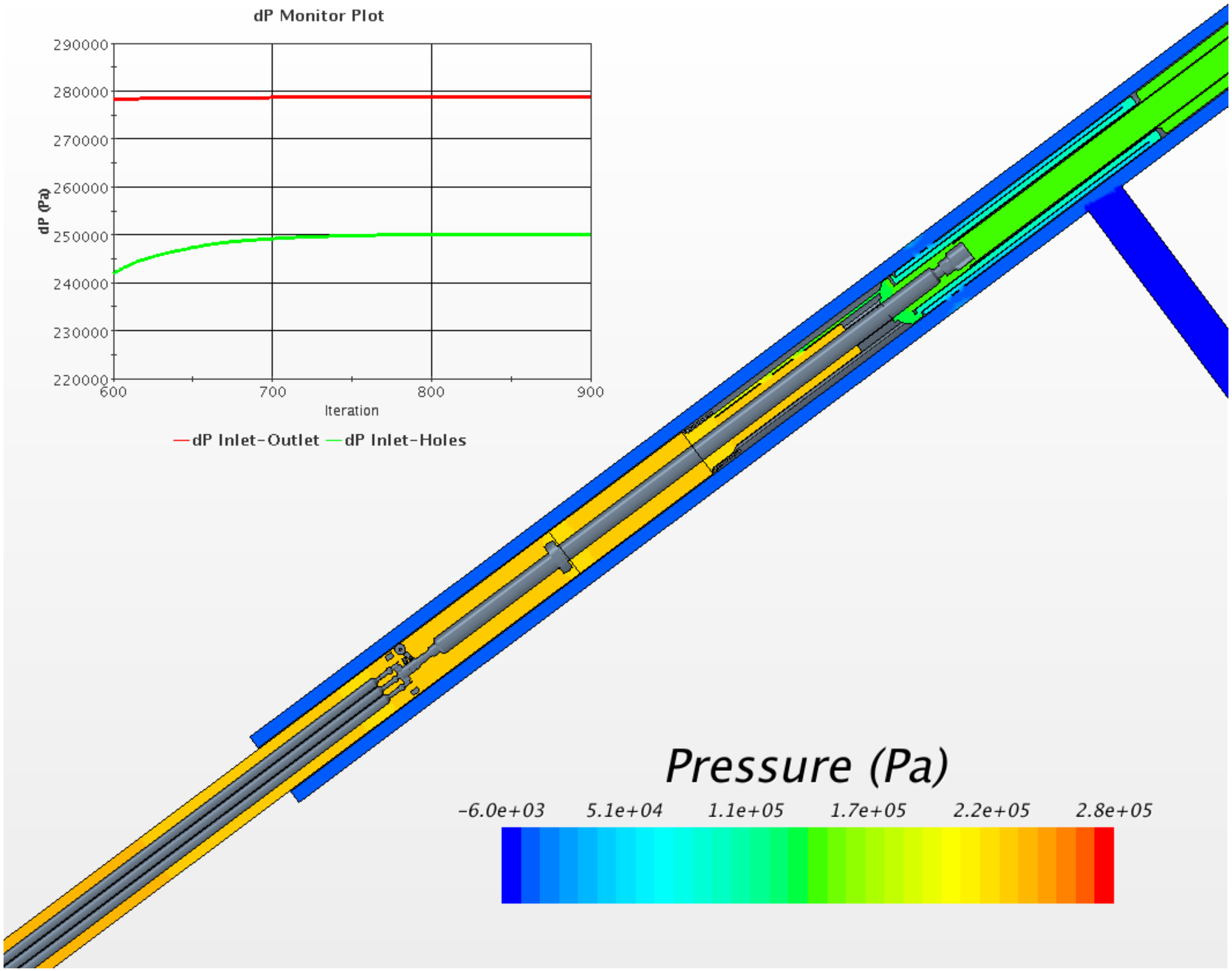
Unsteady state with stationary bundle

- Given MFR, calculate ΔP.
- Impose ΔP in Inlet (Stagnation Inlet boundary condition).

Unsteady simulation, moving bundle

- Imposed ΔP in Inlet as Total Pressure.
- Imposed displacement.
- Outputs:
  ΔP Inlet-Outlet holes
  Velocity, Pressure
  Force fields

Steady state simulation

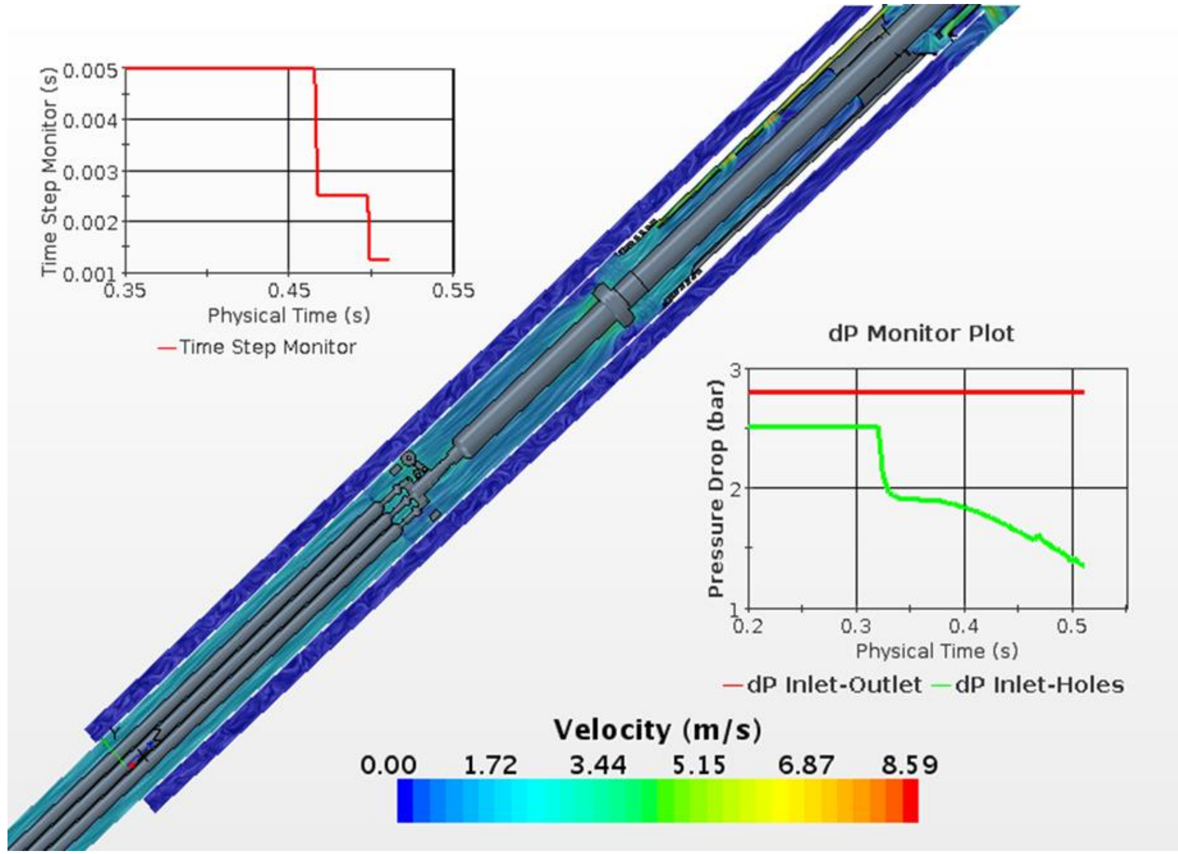


Motion with Morphing and re-meshings

Mesh quality criteria

- finer mesh in the morphed regions
- threshold on the compressed/total lenght ratio of the compressed region
- progressive smaller time step

Coupling Starccm+ with Java.

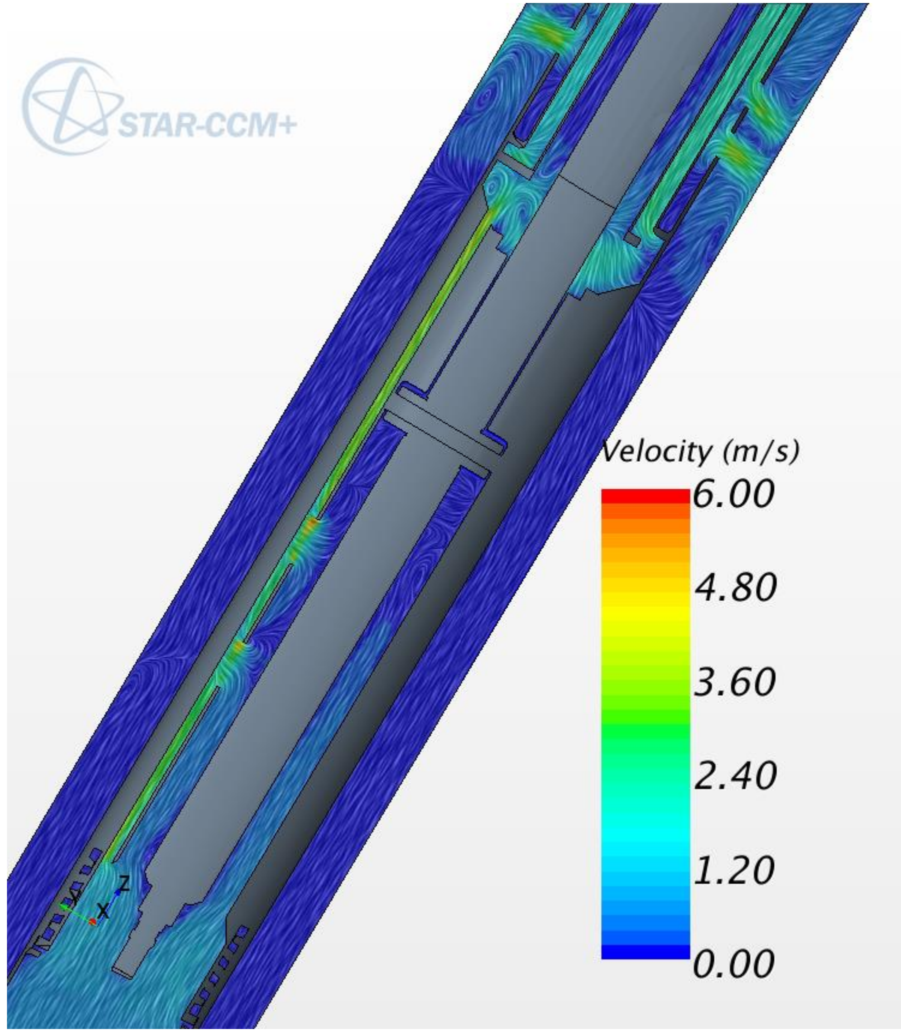


Change strategy of simulating motion

Recent Overset Mesh methodology implemented in STAR-CCM+.

Enough confidence to simulate the entire CR displacement.

Switch to Overset Mesh - Chimera grids.



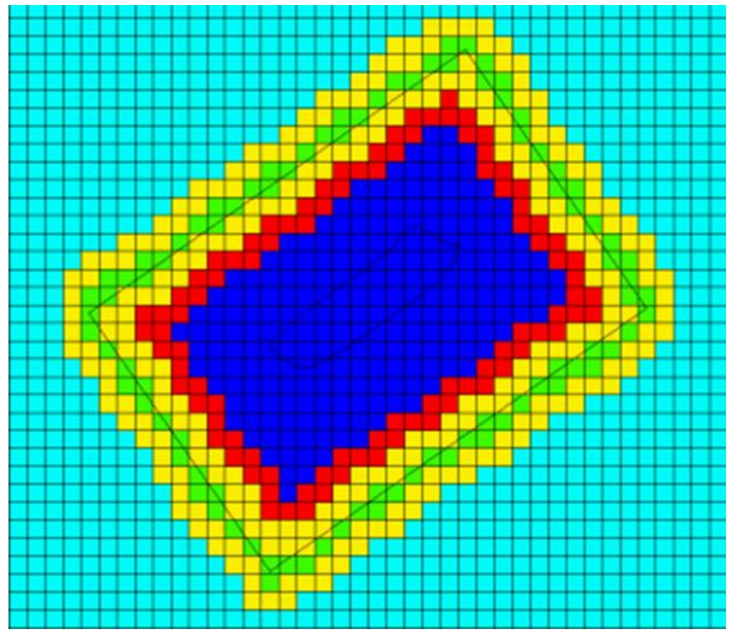
Overset Mesh methodology

Background region
- containing the flow domain

Overset region
- a separate region enclosing the moving body

Overset Mesh "Interface"
- "Volume" interface for information exchange

Conditions for successful coupling
- 2-4 layers of cells attached to the moving body boundary
- same mesh size in both regions in the overlapping zone.

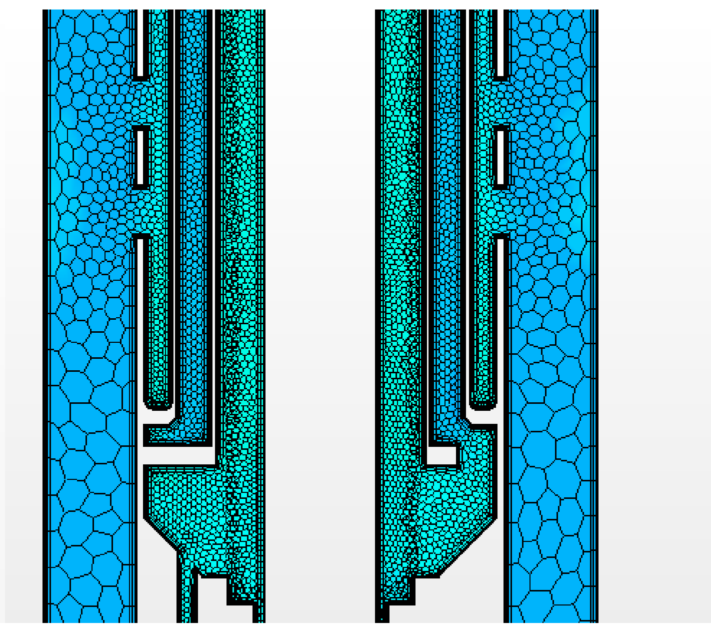


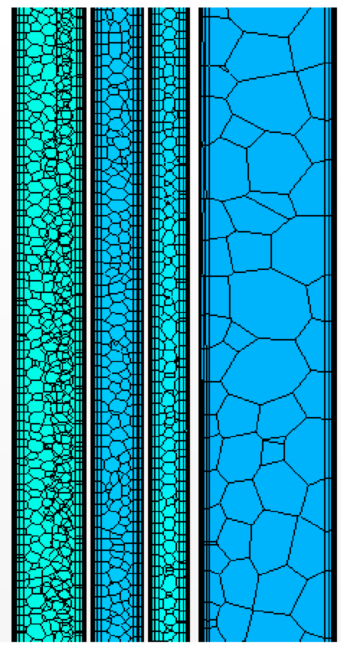
•CD-adapco,Spotlight on Overset Mesh V902

Challenges of Overset Mesh in CR model

- **Reduce interpolation errors**
  - Dispose a suitable mesh, fine enough, take account of all anticipated motion.
- **Approach narrow gaps**
  - Find an acceptable compromise between mesh density and geometrical accuracy.
  - Obtain near zero leakeage seal-damper.

Hard work to get Overset Method functional on CR

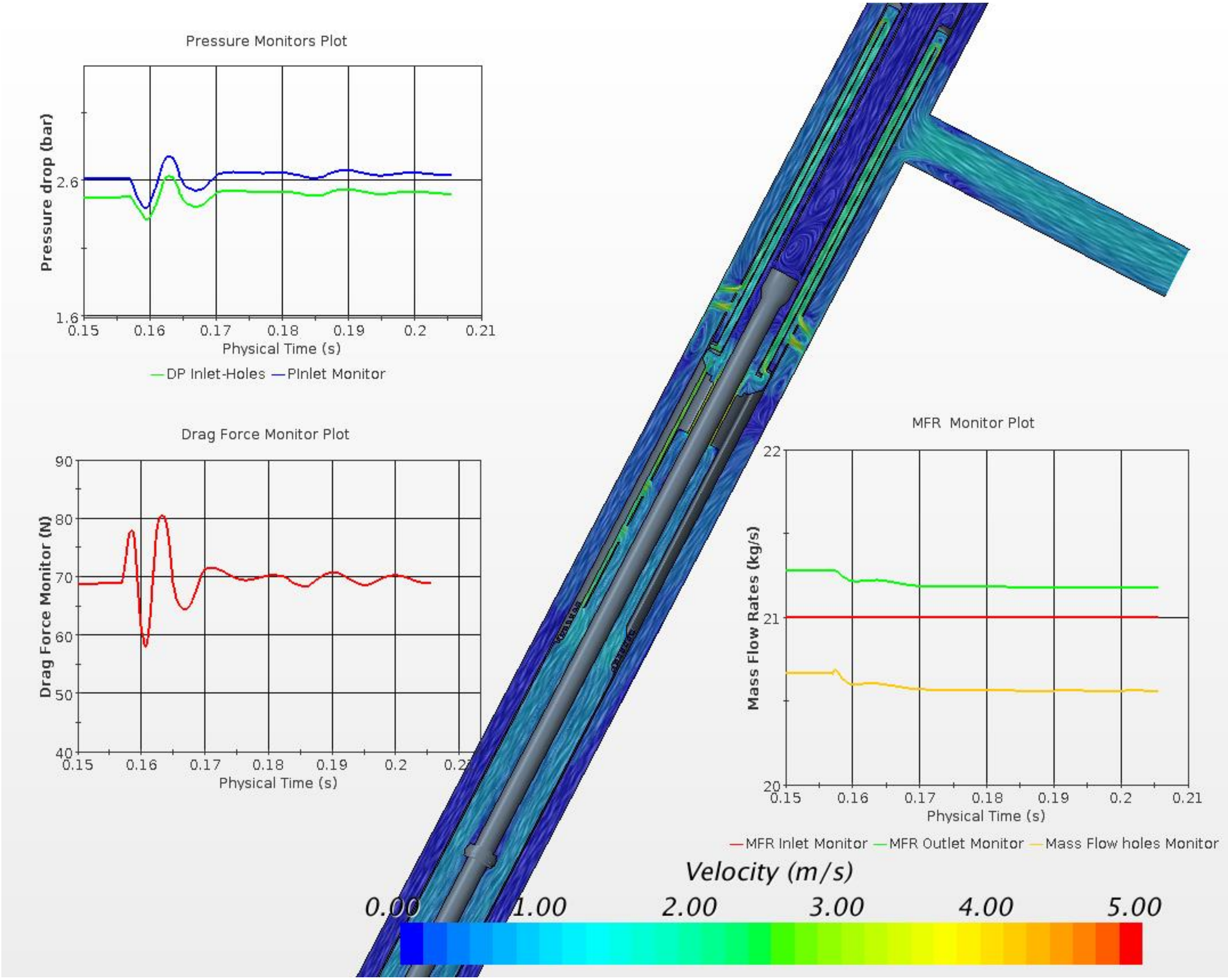




- Volume mesh 5 M cells
- Mesh good enough for motion
- Not good enough for physics

- Important Mass error MFR =1 kg/s (5% wrt 0.1% expected)
- Strong oscillations in pressure and force fields

Stabilized flow in new mesh approach

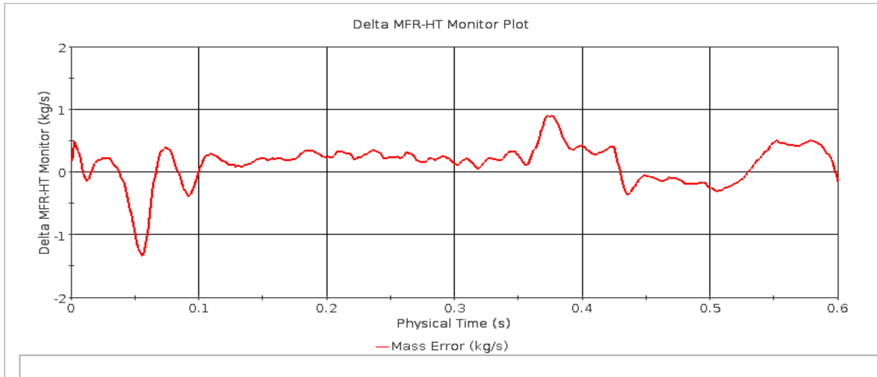


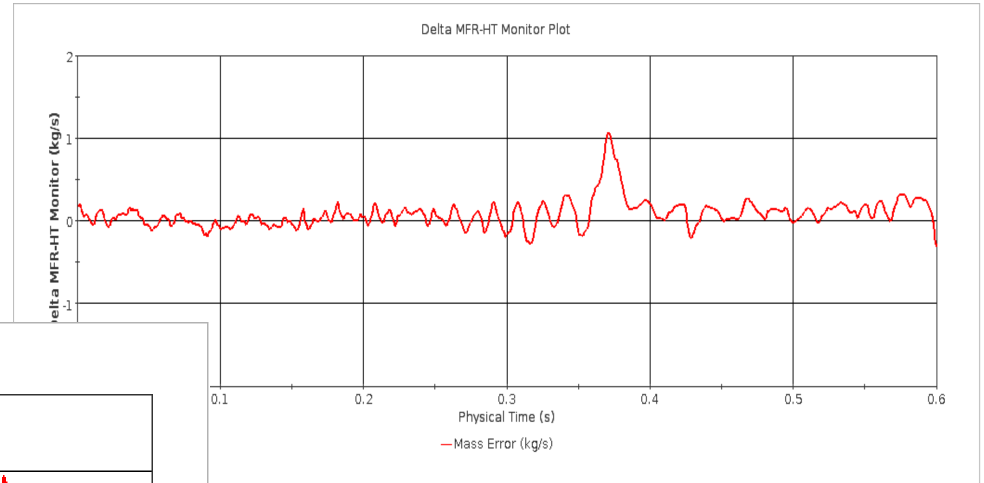
- Acceptable mass error
- MFR = 0.2 kg/s
- Stabilized fluid
- Dependence on time step!
- Smaller time step helped to reduce mass error.

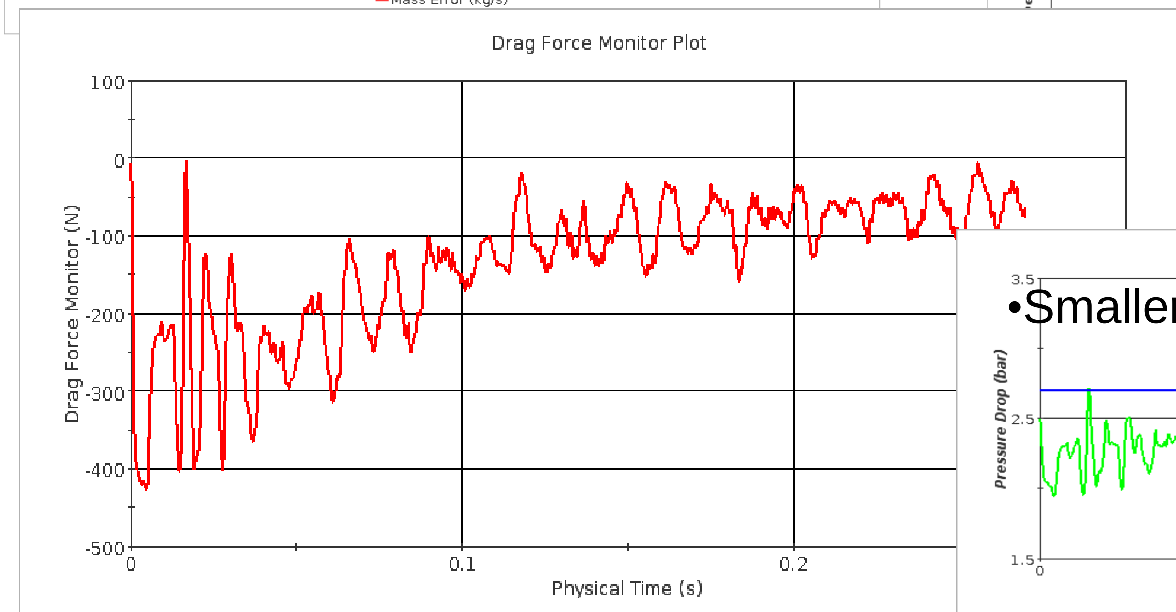
Issues in Motion

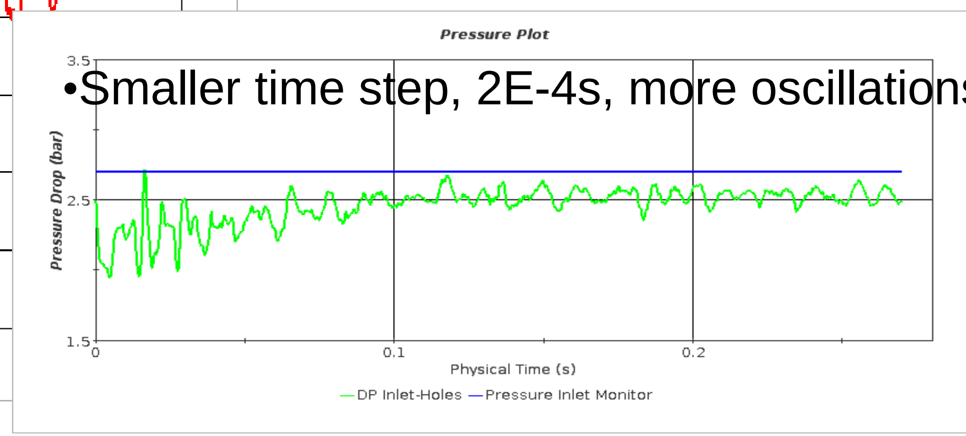
- Time Step 1E-3s with 10 inner iterations: not enough

- 20 inner iterations: slower, but better results



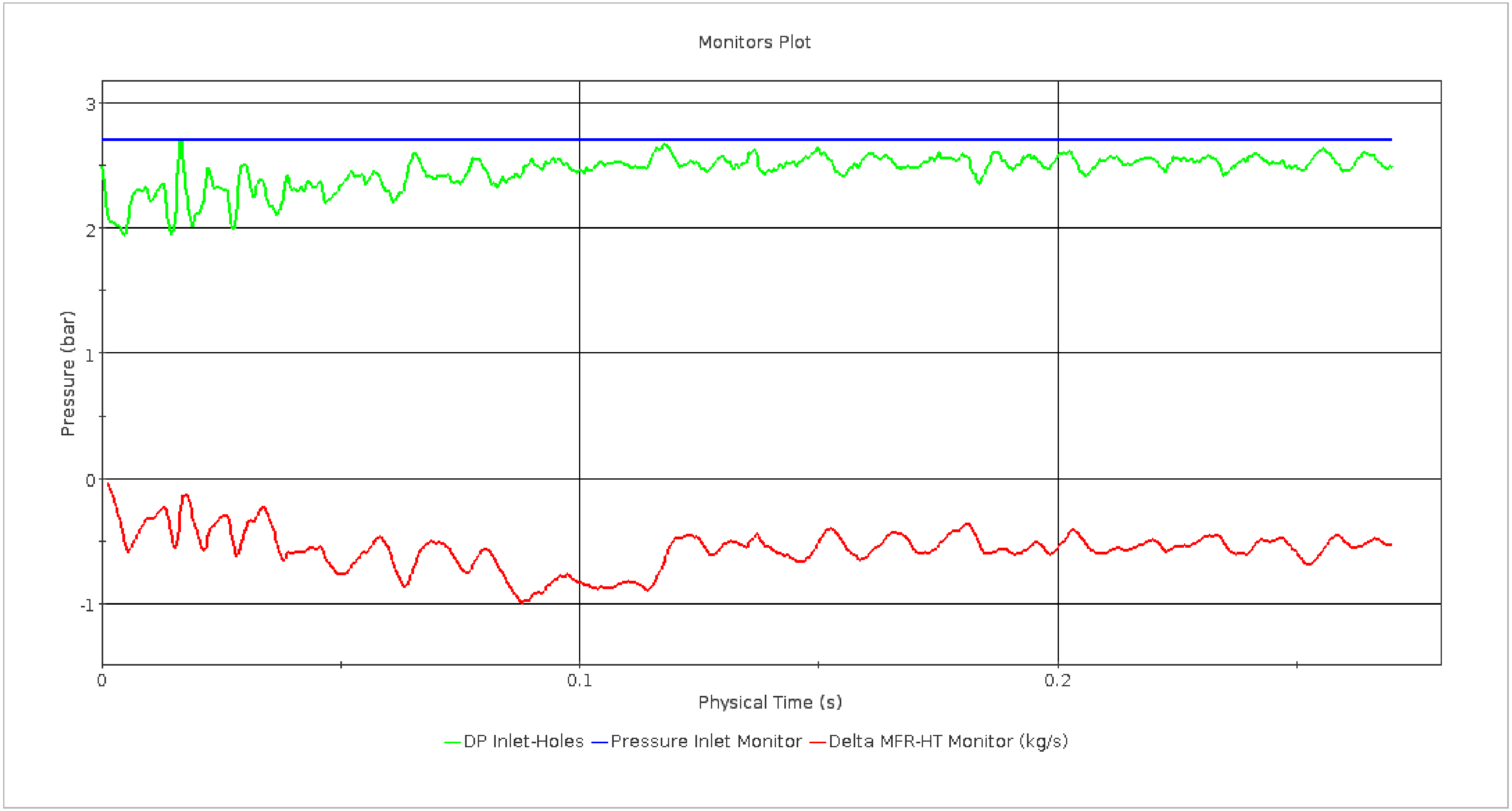




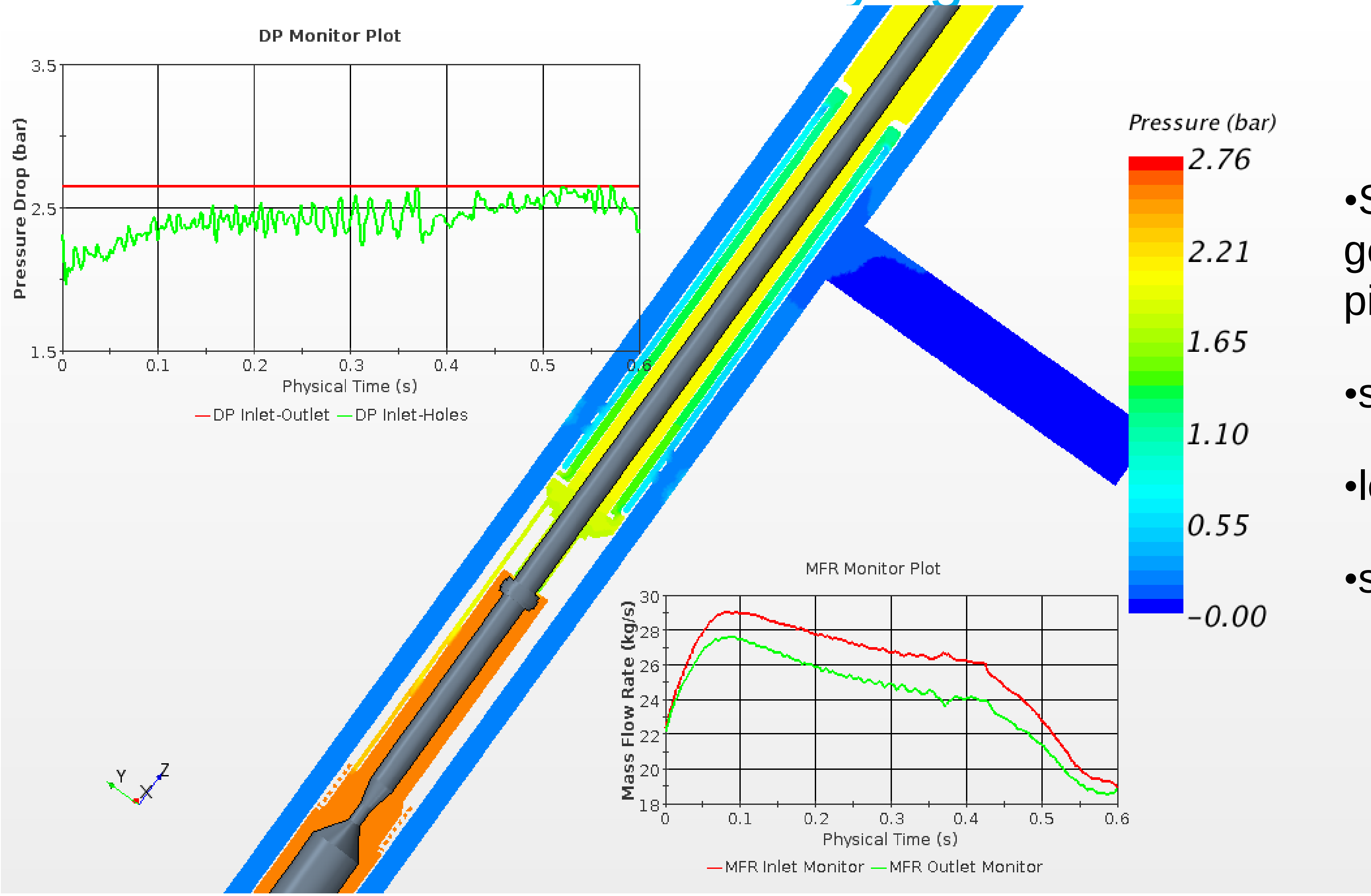


- Smaller time step, 2E-4s, more oscillations

Pressure and mass oscillations in correspondence

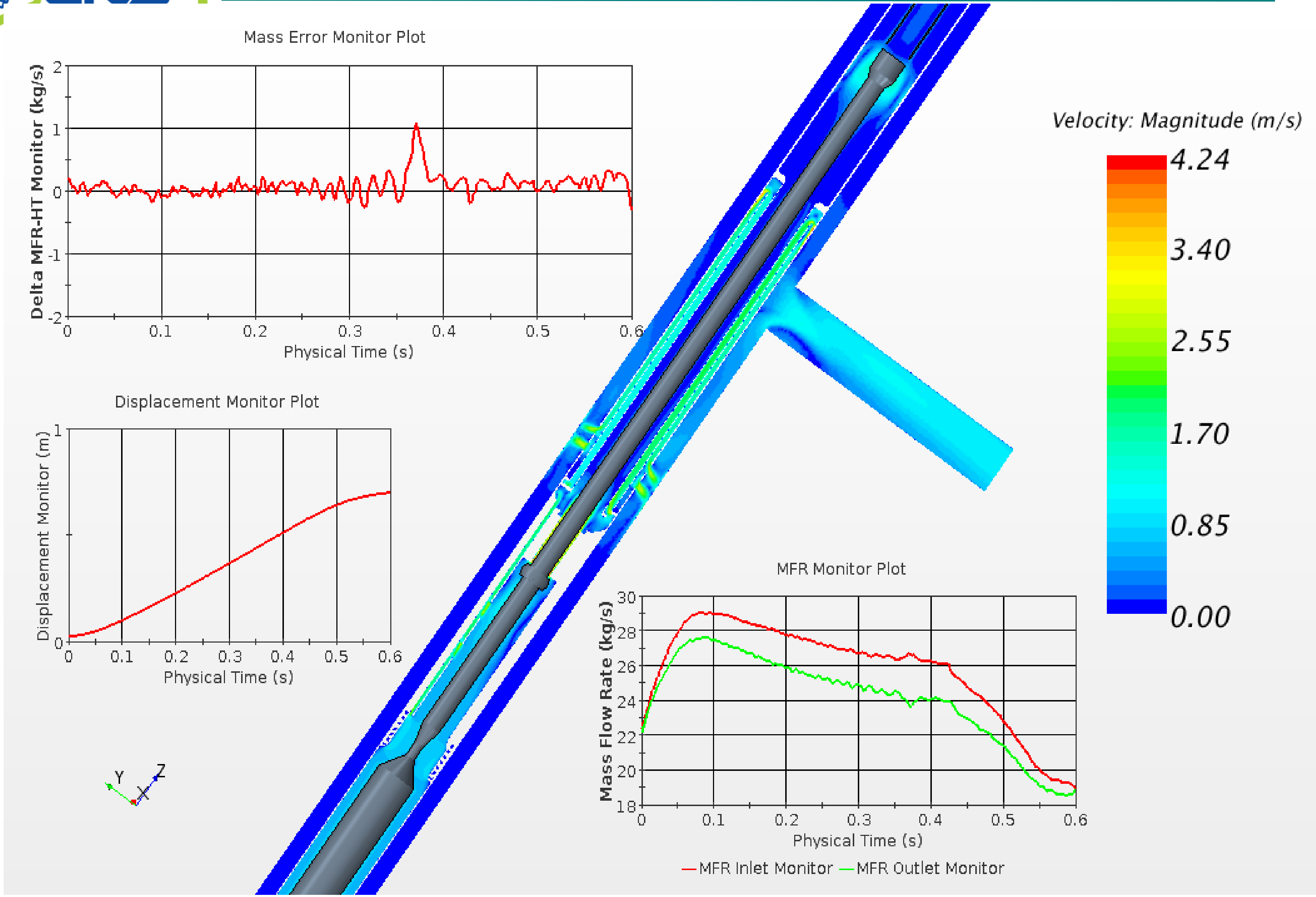


First satisfying results



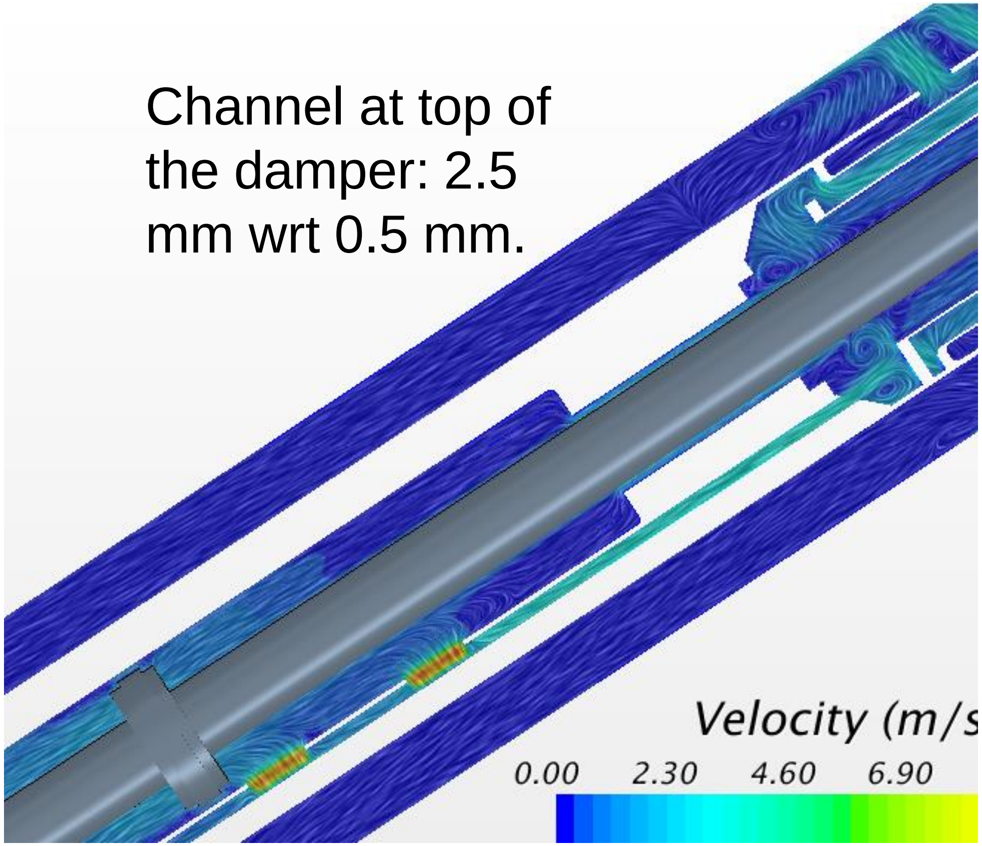
- Simplified geometry of the piston:
- still large gaps
- less oscillations
- smooth motion

- Non negligible cost: Volume mesh **8 M Cells** for half domain, Runtime 12 hours on 128 cores

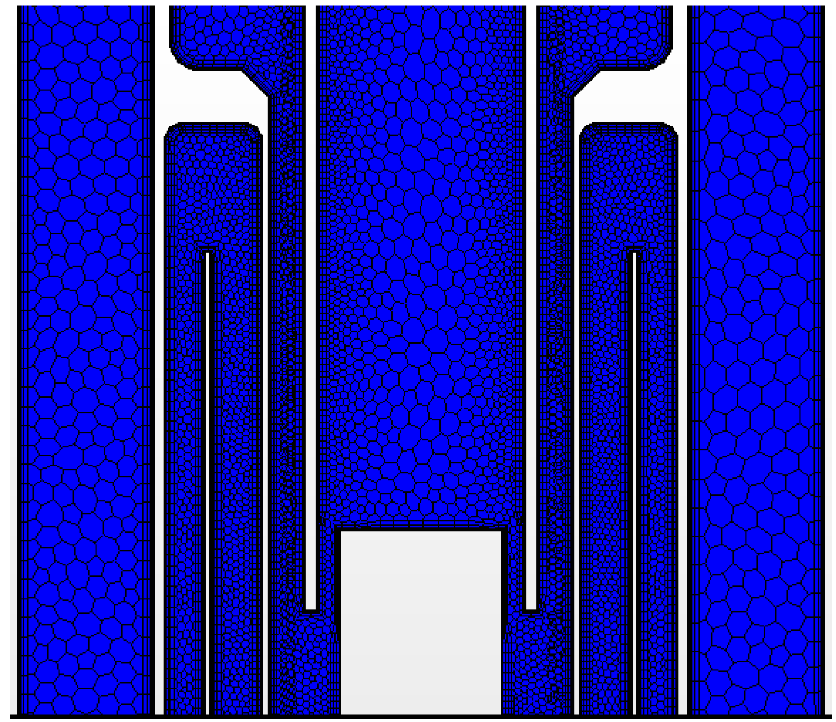

Mass Error Monitor Plot
Delta MFR-HT Monitor (kg/s)
Physical Time (s)
Displacement Monitor Plot
Displacement Monitor (m)
Physical Time (s)
Velocity: Magnitude (m/s)
4.24
3.40
2.55
1.70
0.85
0.00
MFR Monitor Plot
Mass Flow Rate (kg/s)
Physical Time (s)
MFR Inlet Monitor
MFR Outlet Monitor

Narrow gaps less and less narrow

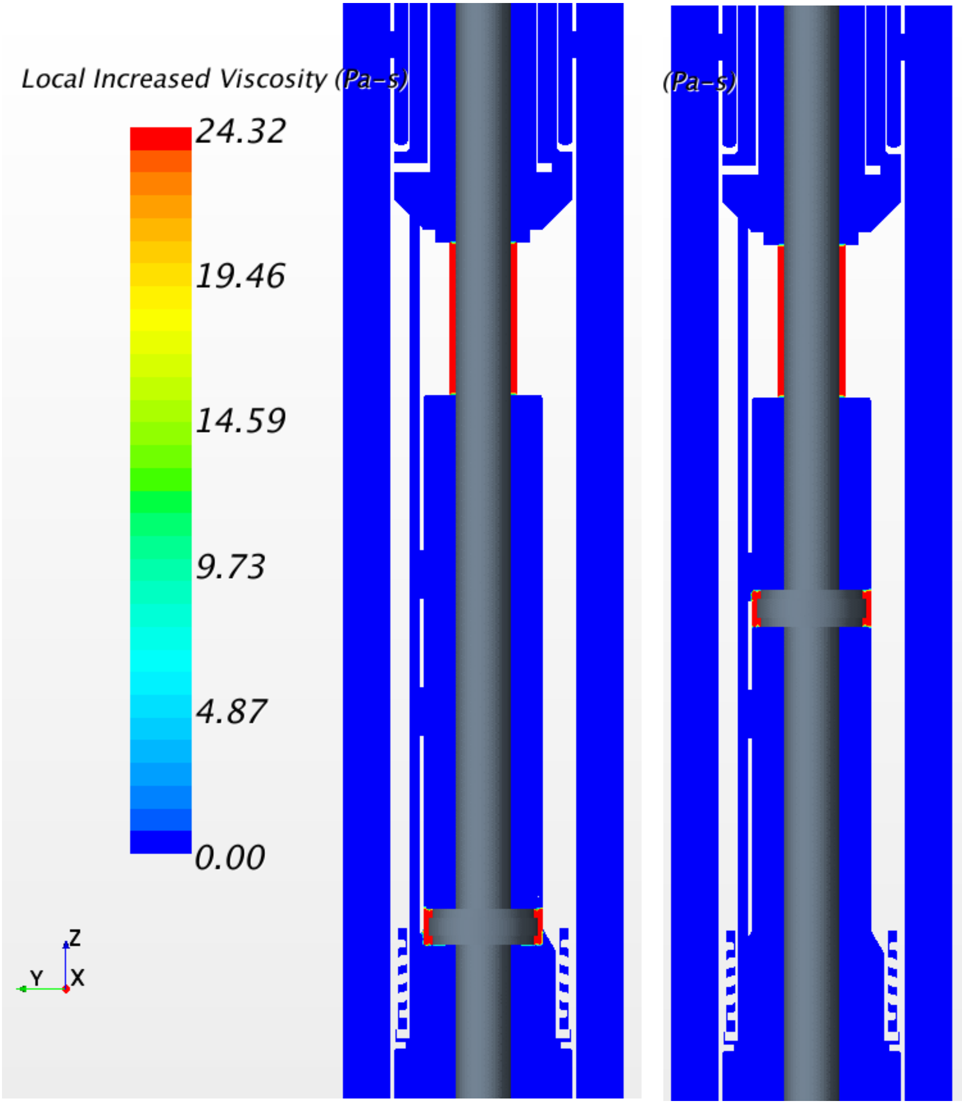
Channel at top of the damper: 2.5 mm wrt 0.5 mm.



Seal – damper gap: 2.5 mm wrt to perfect matching.

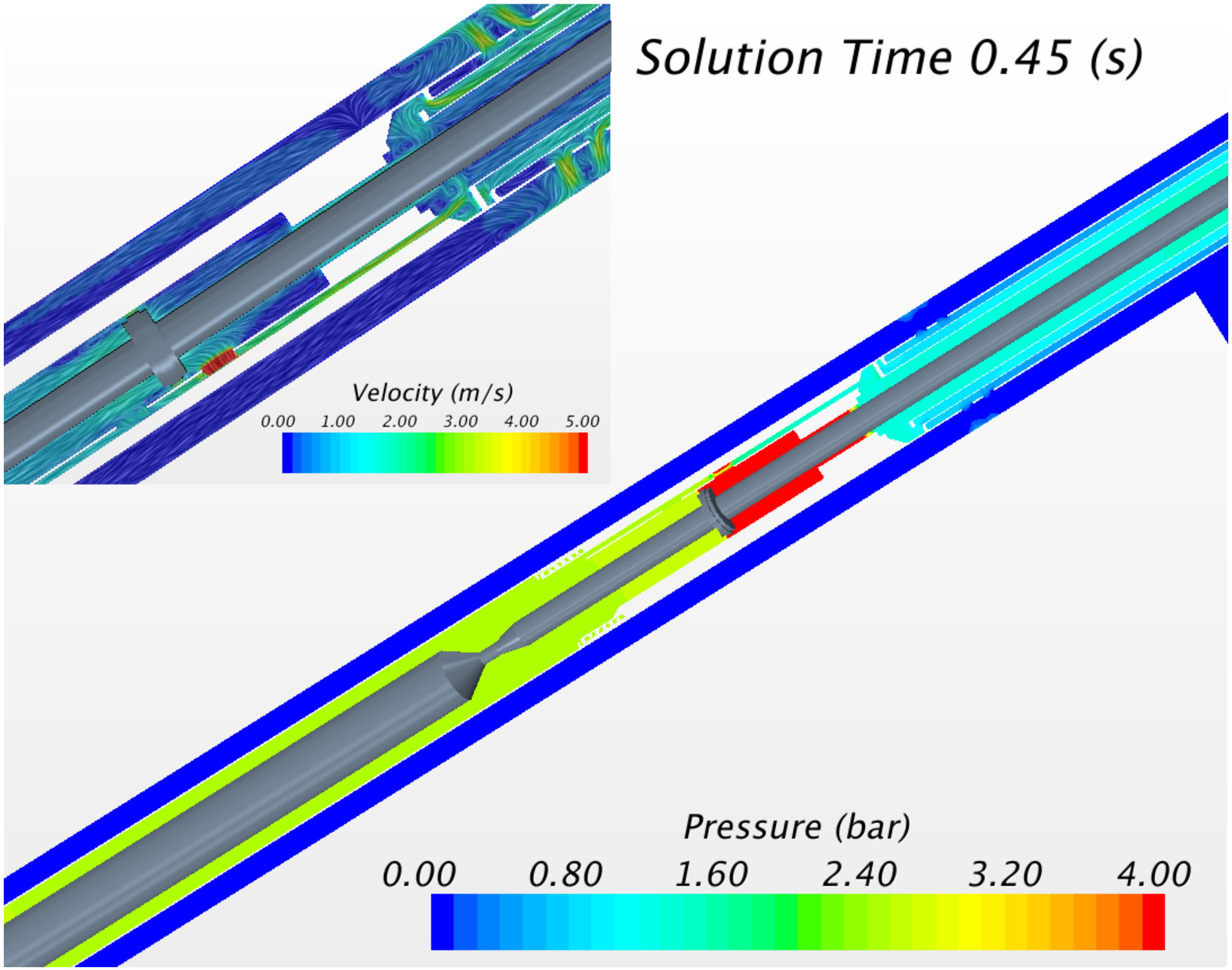


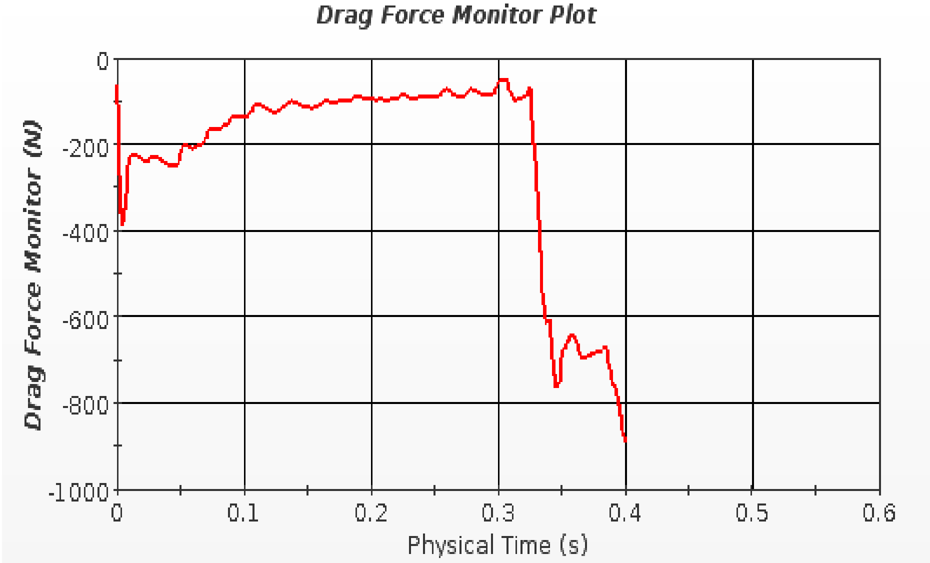
Motion in stiff context adjusted with the Physics

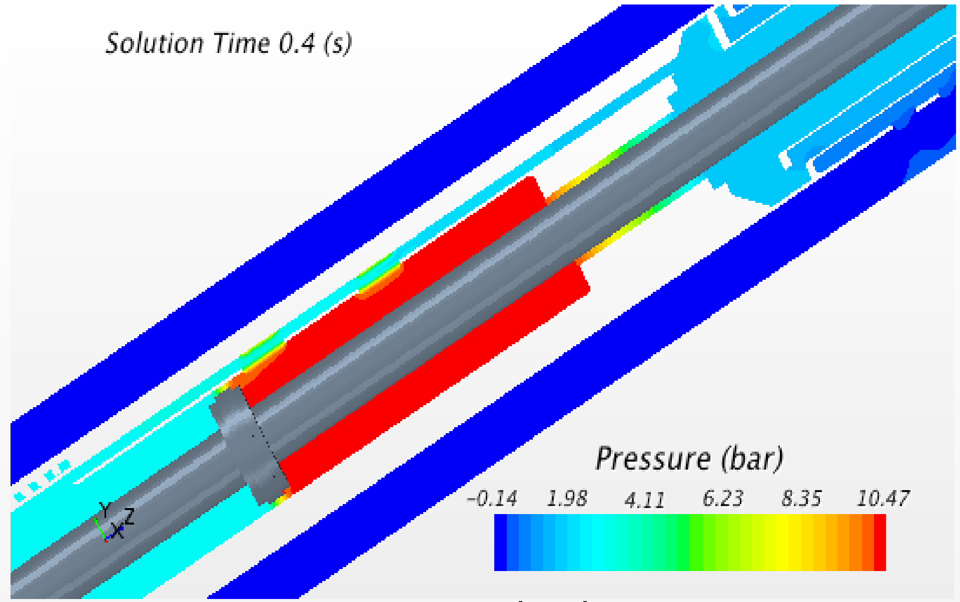


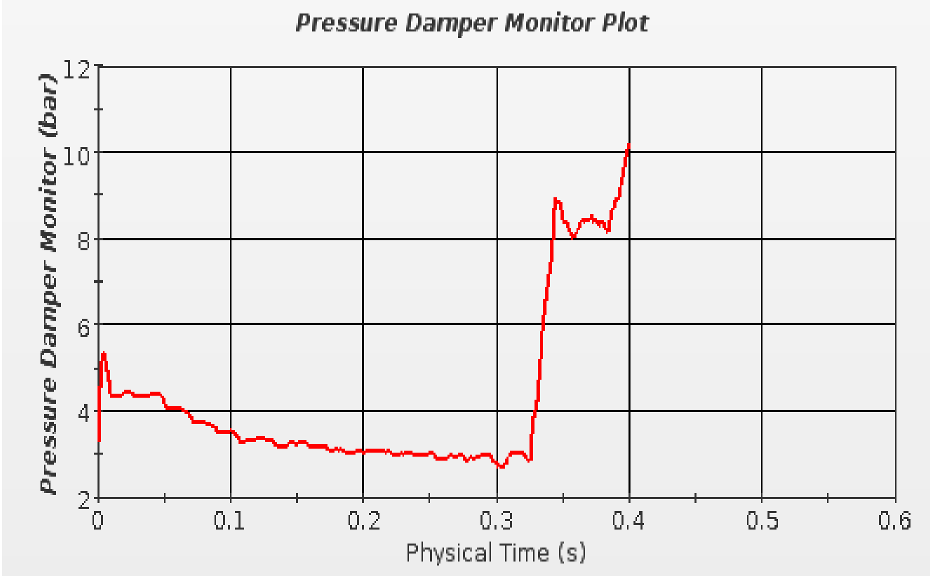
- LBE dynamic viscosity increased by 4 orders of magnitude
  - Fixed, in the 0.5 mm gap at top of damper
  - Mobile, attached to the seal.

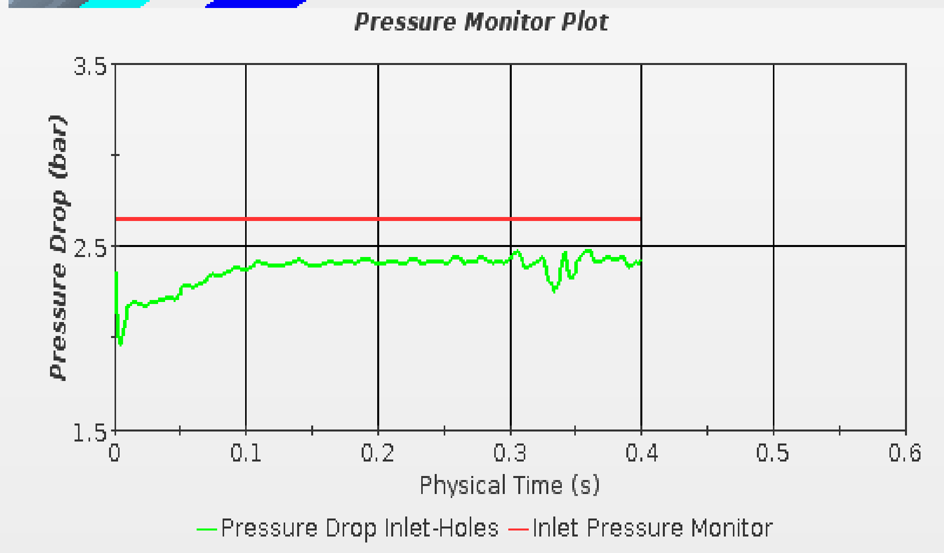
Increased pressure in the damper

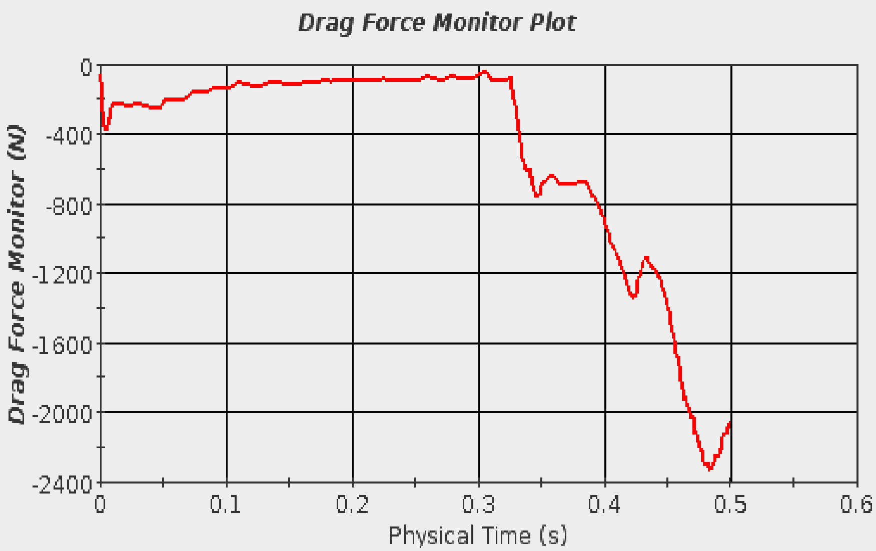


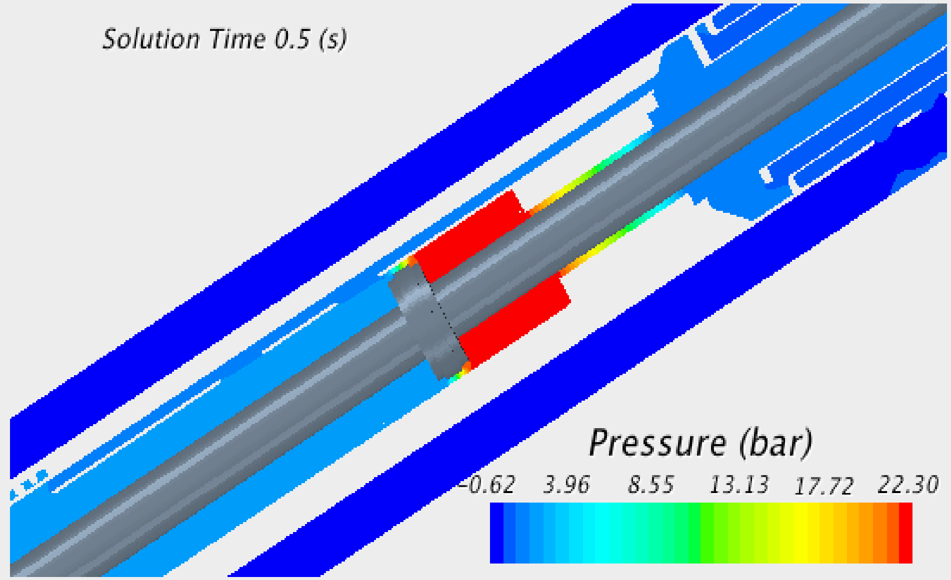

Drag Force Monitor Plot
Drag Force Monitor (N)
0
-200
-400
-600
-800
-1000
0
0.1
0.2
0.3
0.4
0.5
0.6
Physical Time (s)

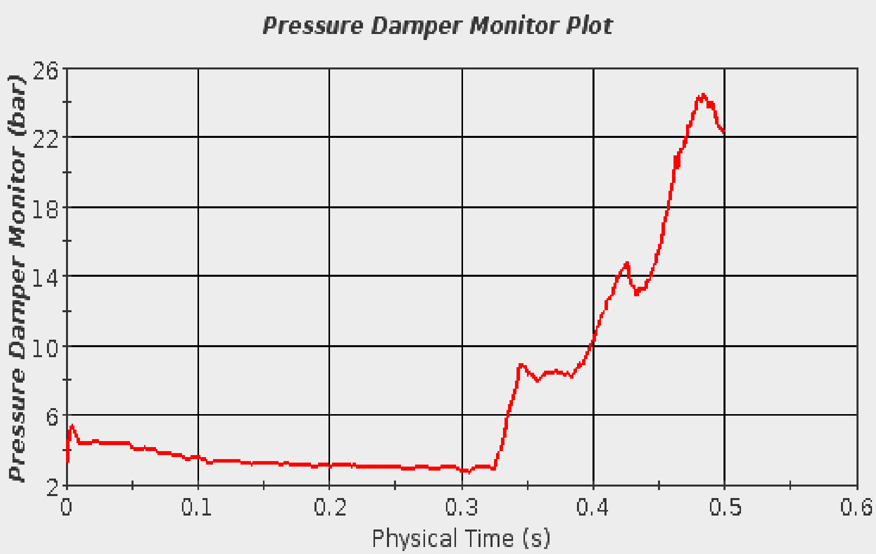

Solution Time 0.4 (s)
Pressure (bar)
-0.14
1.98
4.11
6.23
8.35
10.47

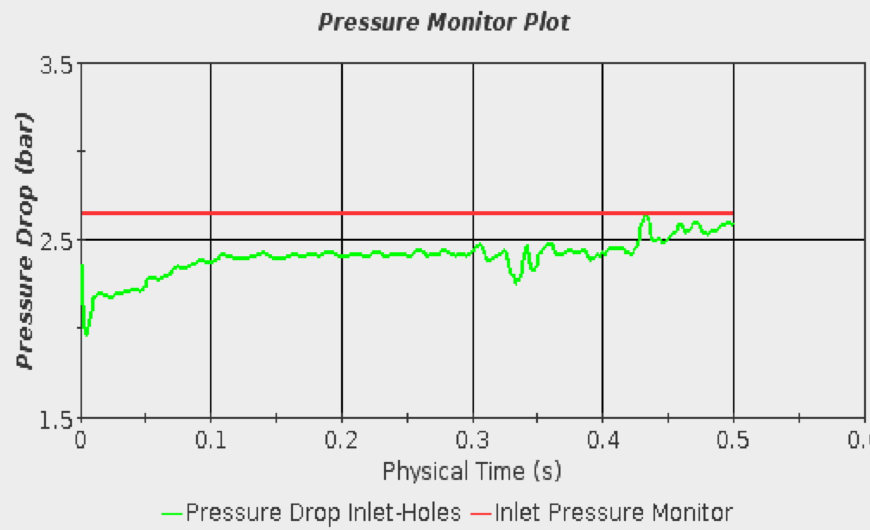

Pressure Damper Monitor Plot
Pressure Damper Monitor (bar)
12
10
8
6
4
2
0
0.1
0.2
0.3
0.4
0.5
0.6
Physical Time (s)

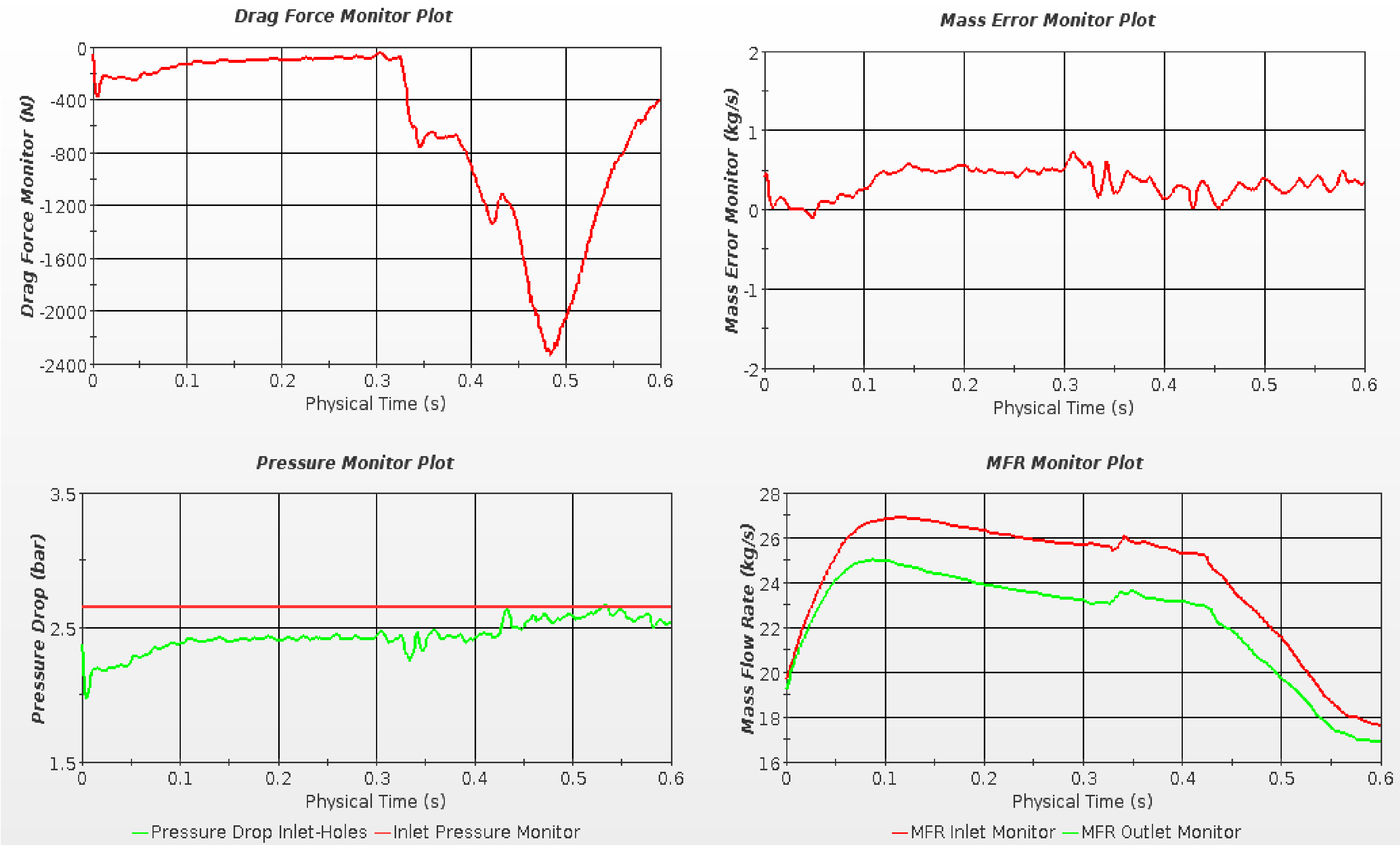

Pressure Monitor Plot
Pressure Drop (bar)
3.5
2.5
1.5
0
0.1
0.2
0.3
0.4
0.5
0.6
Physical Time (s)
Pressure Drop Inlet-Holes
Inlet Pressure Monitor


Drag Force Monitor Plot
Drag Force Monitor (N)
0
-400
-800
-1200
-1600
-2000
-2400
0 0.1 0.2 0.3 0.4 0.5 0.6
Physical Time (s)


Solution Time 0.5 (s)
Pressure (bar)
-0.62 3.96 8.55 13.13 17.72 22.30


Pressure Damper Monitor Plot
Pressure Damper Monitor (bar)
26
22
18
14
10
6
2
0 0.1 0.2 0.3 0.4 0.5 0.6
Physical Time (s)


Pressure Monitor Plot
Pressure Drop (bar)
3.5
2.5
1.5
0 0.1 0.2 0.3 0.4 0.5 0.6
Physical Time (s)
Pressure Drop Inlet-Holes
Inlet Pressure Monitor


Drag Force Monitor Plot
Drag Force Monitor (N)
0
-400
-800
-1200
-1600
-2000
-2400
0
0.1
0.2
0.3
0.4
0.5
0.6
Physical Time (s)
Mass Error Monitor Plot
Mass Error Monitor (kg/s)
2
1
0
-1
-2
0
0.1
0.2
0.3
0.4
0.5
0.6
Physical Time (s)
Pressure Monitor Plot
Pressure Drop (bar)
3.5
2.5
1.5
0
0.1
0.2
0.3
0.4
0.5
0.6
Physical Time (s)
Pressure Drop Inlet-Holes
Inlet Pressure Monitor
MFR Monitor Plot
Mass Flow Rate (kg/s)
28
26
24
22
20
18
16
0
0.1
0.2
0.3
0.4
0.5
0.6
Physical Time (s)
MFR Inlet Monitor
MFR Outlet Monitor

Conclusions

- Moving meshes techniques and automatic optimized re-meshing strategies have been successfully developed and employed in the context of MAXSIMA project, including coupling of the simulation code with Java scripts.

- The full control on the overset mesh methodology in stiff flow path configuration has been acquired.

- Capacity to approach narrow gaps: an acceptable compromise between mesh density and geometrical accuracy was found.

- In order to correctly model the zero leakeage in the damper the dynamic viscosity was locally modified. We intend to switch to the resistance force (quadratic with the velocity).

- A correct drag curve was obtained, rappresentative of the considered model.