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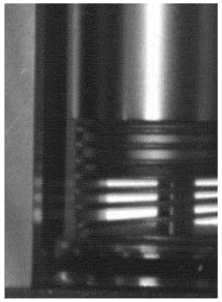

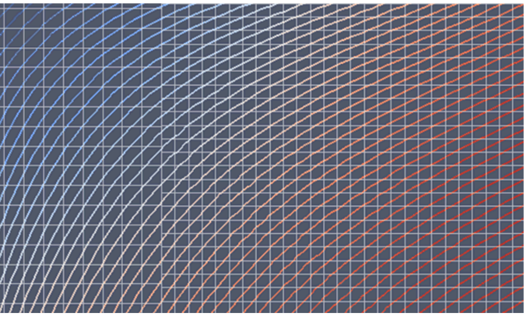

Simulating Rectified Motion in a Piston Assembly Subjected to Vibrational Acceleration

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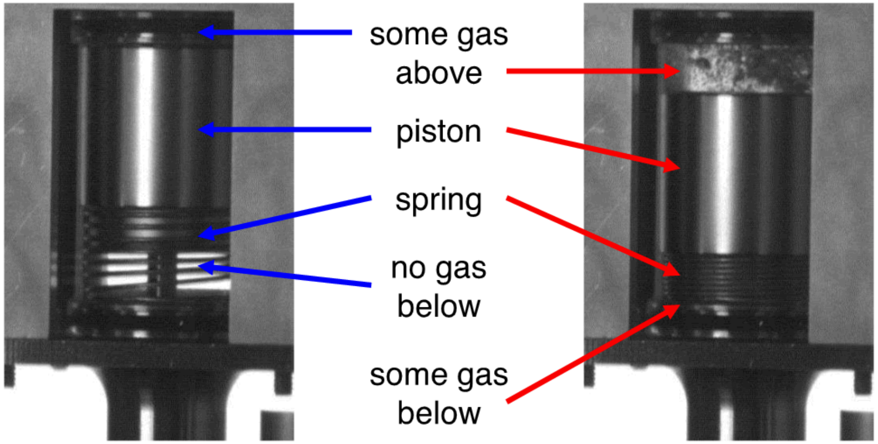
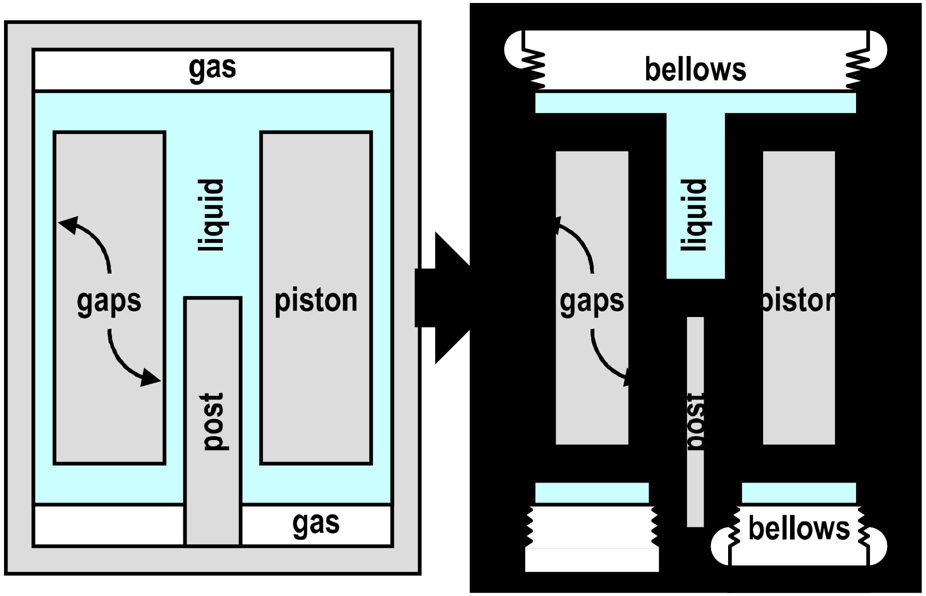
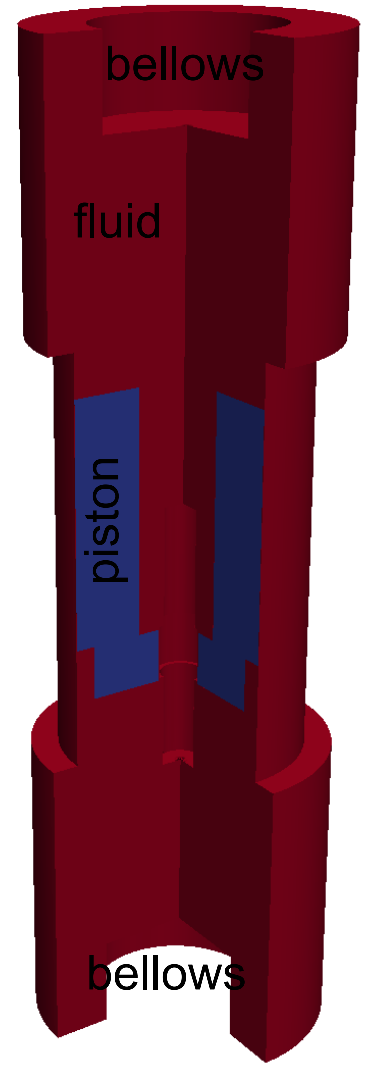
Piston Assembly



Vibration off
Spring supports piston

Vibration on
Piston compresses spring





axisymmetric

Summary of Theory

Piston	$M_P\ddot{Z}_P = -K_P Z_P - M_{PG} g_V + F_P,\ \ M_{PG} = M_P - M_{LP}$
Bellows	$M_B\ddot{Z}_B = -K_B Z_B - M_{BG} g_V + F_B - \rho g (1-\kappa) A_B Z_B$
	$Z_{BU} = Z_B,\ \ Z_{BL} = \kappa Z_B,\ \ \kappa = A_{BU}/A_{BL},\ \ A_B = A_{BU},\ \ g_V = g_1 \cos \omega t$
	$M_B = M_{BU} + \kappa^2 M_{BL},\ \ K_B = K_{BU} + \kappa^2 K_{BL},\ \ M_{BG} = M_{BU} + \kappa M_{BL} + \rho L_B A_B$
Liquid Forces	$F_P = \hat{\mathbf{e}}_z \cdot \int_{S_P} \boldsymbol{\sigma}\cdot\hat{\mathbf{n}}\,dS,\ \ F_B = \hat{\mathbf{e}}_z \cdot \int_{S_{BU}} \boldsymbol{\sigma}\cdot\hat{\mathbf{n}}\,dS + \kappa\hat{\mathbf{e}}_z \cdot \int_{S_{BL}} \boldsymbol{\sigma}\cdot\hat{\mathbf{n}}\,dS$

Liquid	$\frac{\partial}{\partial \mathbf{x}} \cdot \mathbf{u} = 0$
	$\rho\left(\frac{\partial}{\partial t} + \mathbf{u}\cdot\frac{\partial}{\partial \mathbf{x}}\right)\mathbf{u} = \frac{\partial}{\partial \mathbf{x}}\cdot\boldsymbol{\sigma}$
	$\boldsymbol{\sigma} = -p\mathbf{I} + \mu\left(\frac{\partial \mathbf{u}}{\partial \mathbf{x}} + \frac{\partial \mathbf{u}}{\partial \mathbf{x}}^T\right)$
	$\mathbf{u} = \mathbf{u}_{\text{surface}}$ on walls

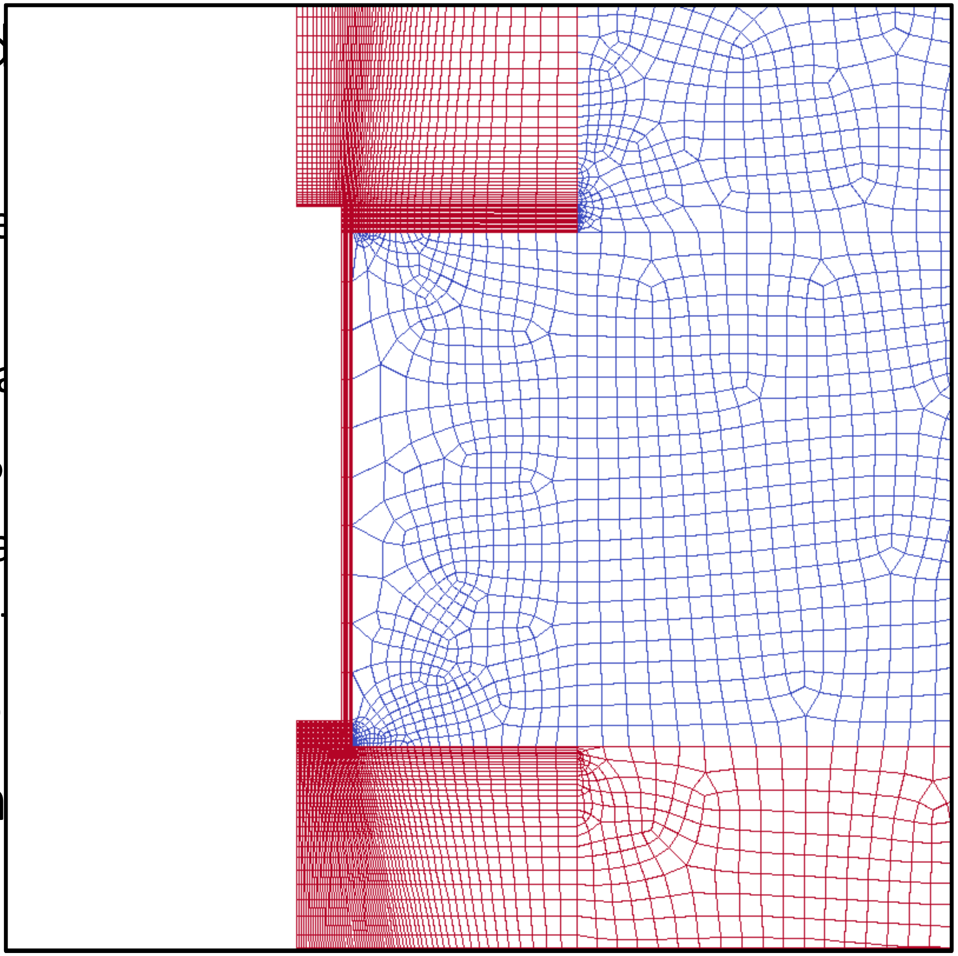
Quasi-steady theory

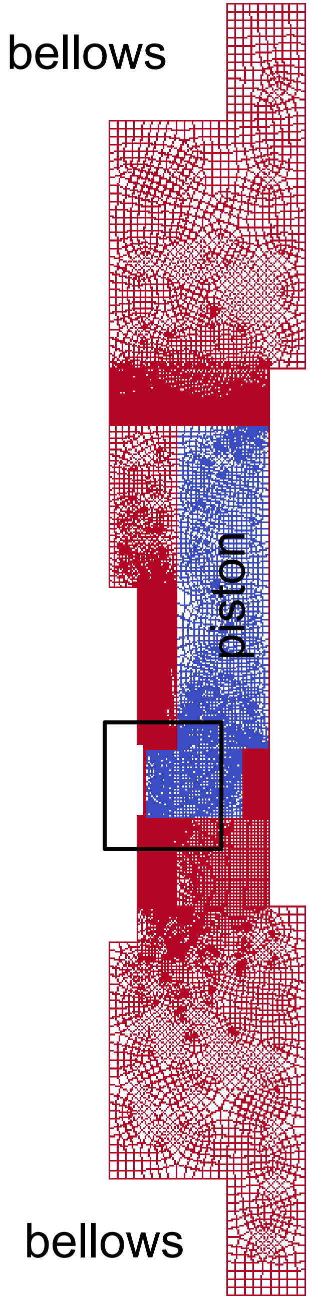
Two modes of motion

- Poiseuille
  - high dissipation; high added mass
  - high pressure difference
- Couette
  - lower dissipation
  - less drag on piston
  - piston and bellows motion dictated by area ratio
  - resonance behavior

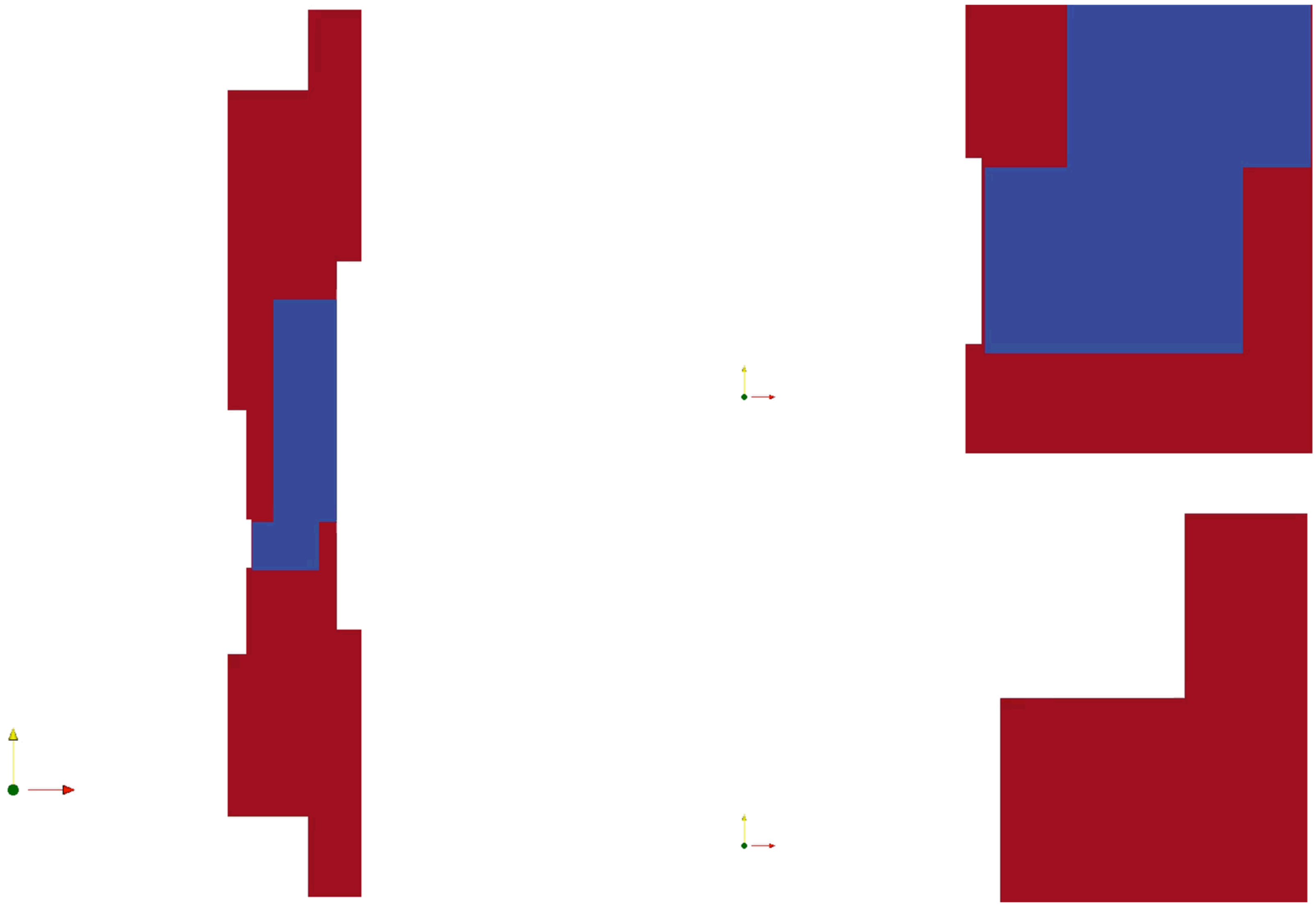
Simulation Details

- Quasi-stead
- Sierra/TF
  - Q1 finite e
  - Full sensit
  - ALE simula
- Equations S
  - Solid Dyna
  - Navier—St
- Bellows mo
- Piston sprin

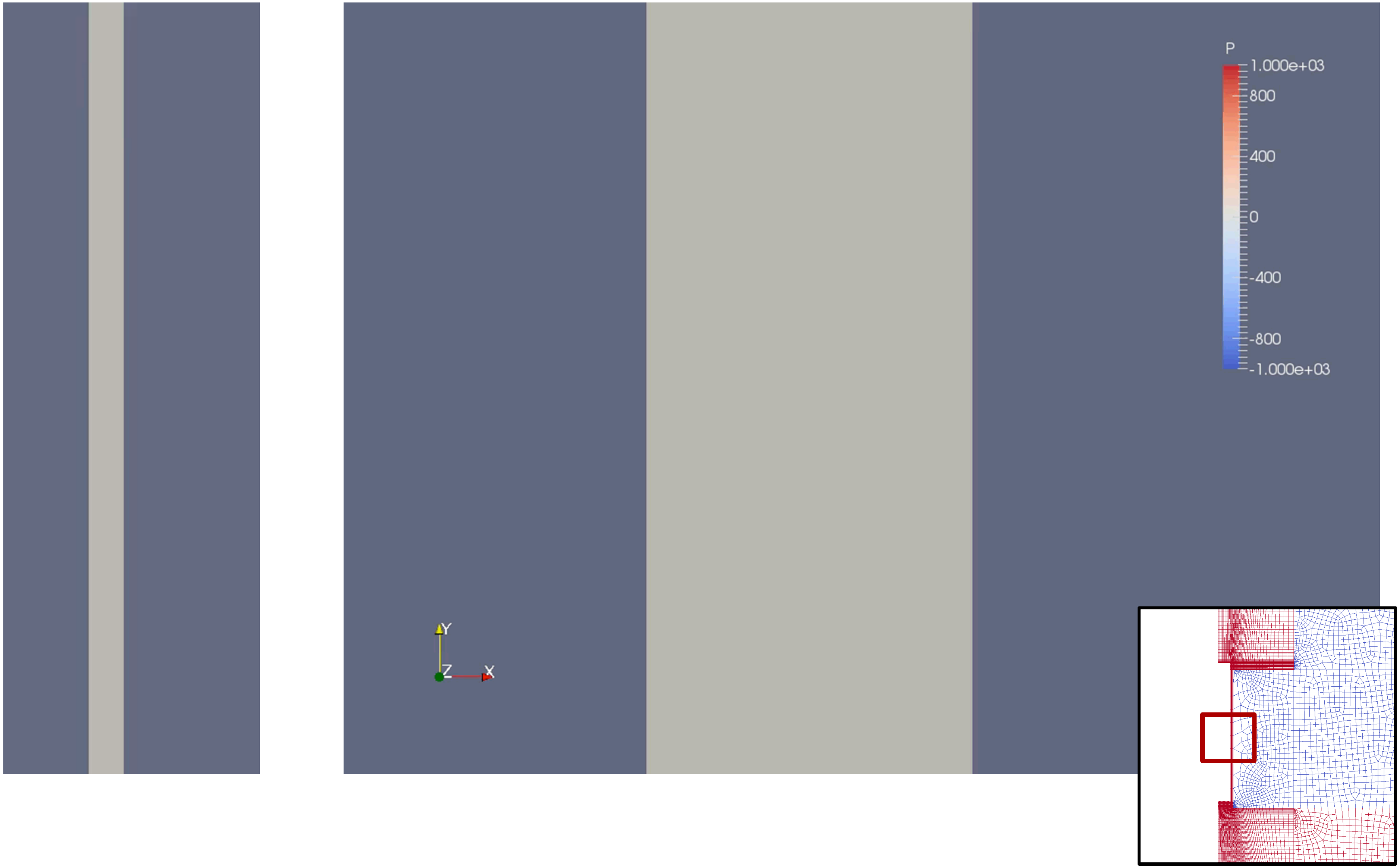




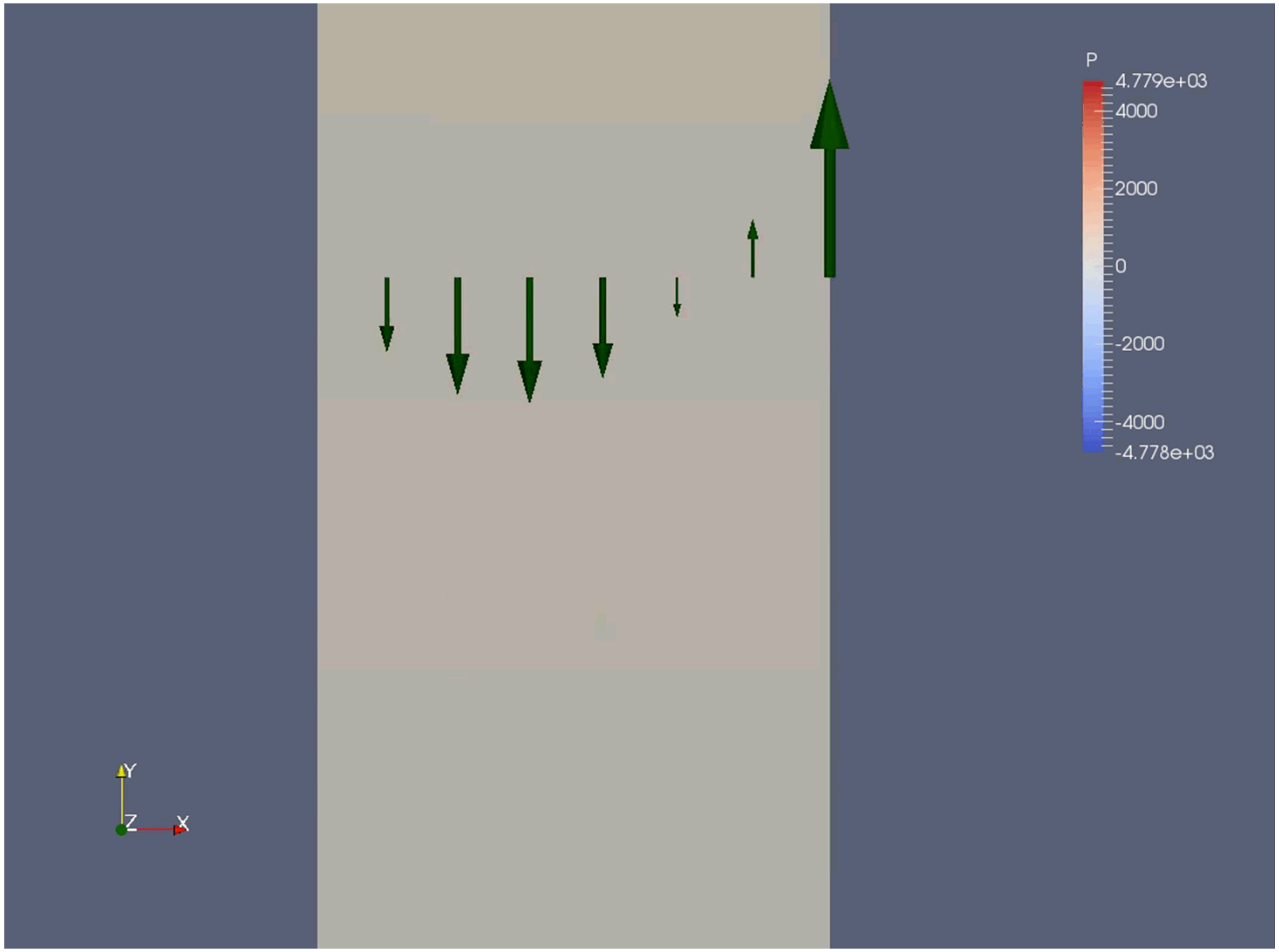
ALE Simulation of Piston



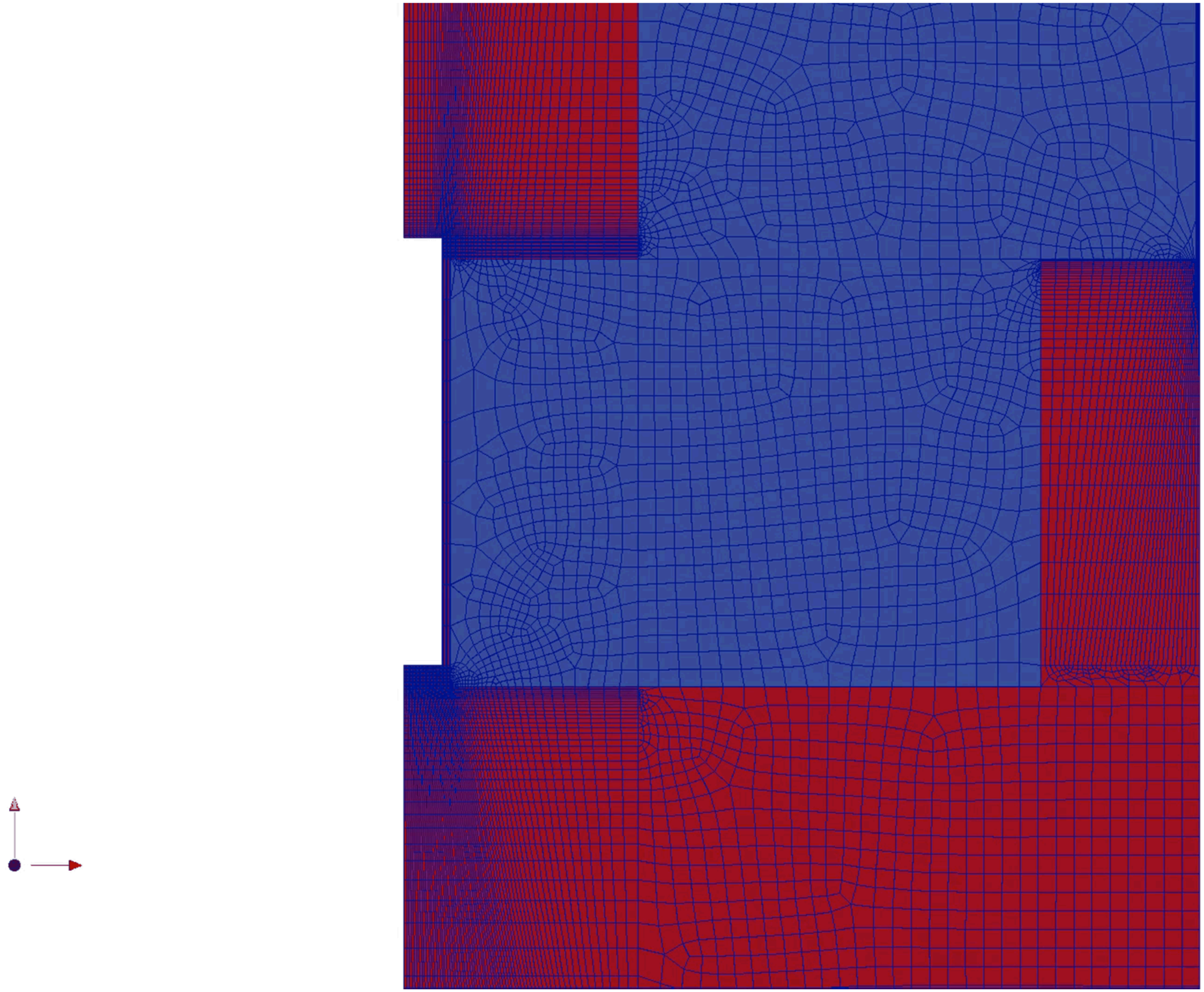
ALE Simulation of Piston

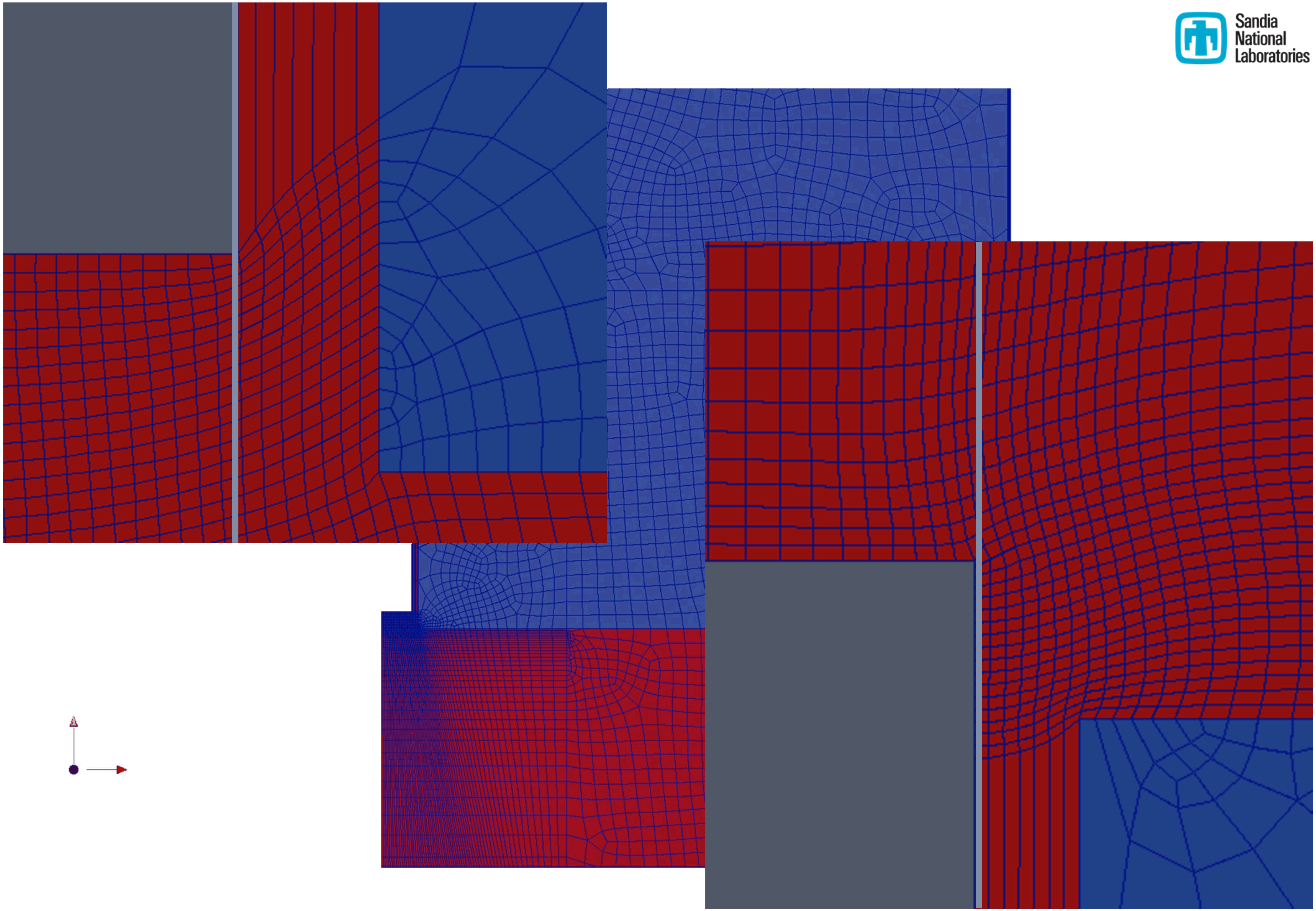


Flow modes

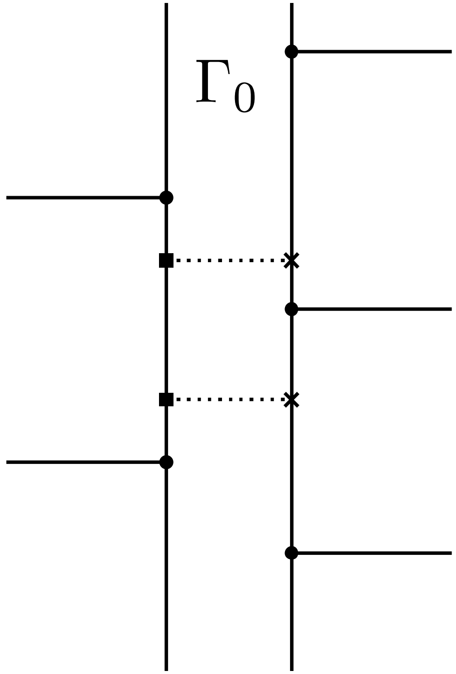


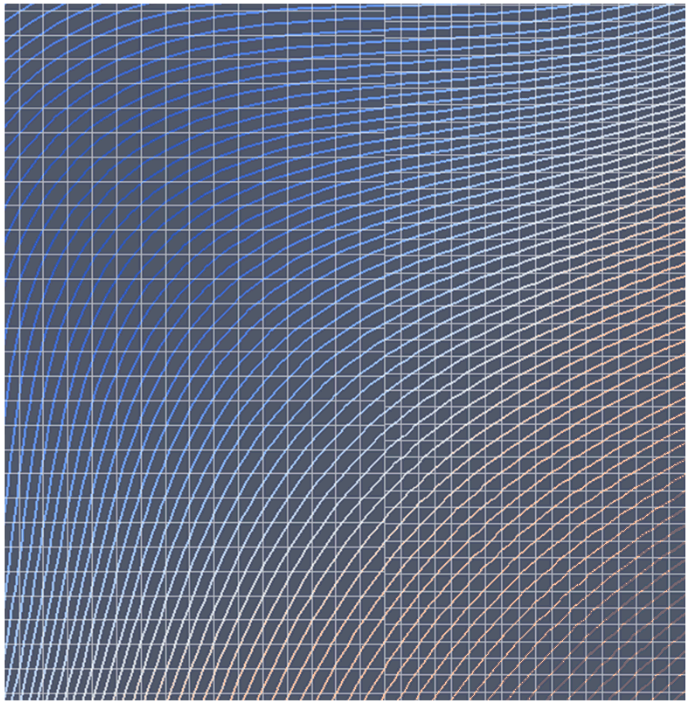
ALE Simulation of Piston





Sliding Mesh Scheme



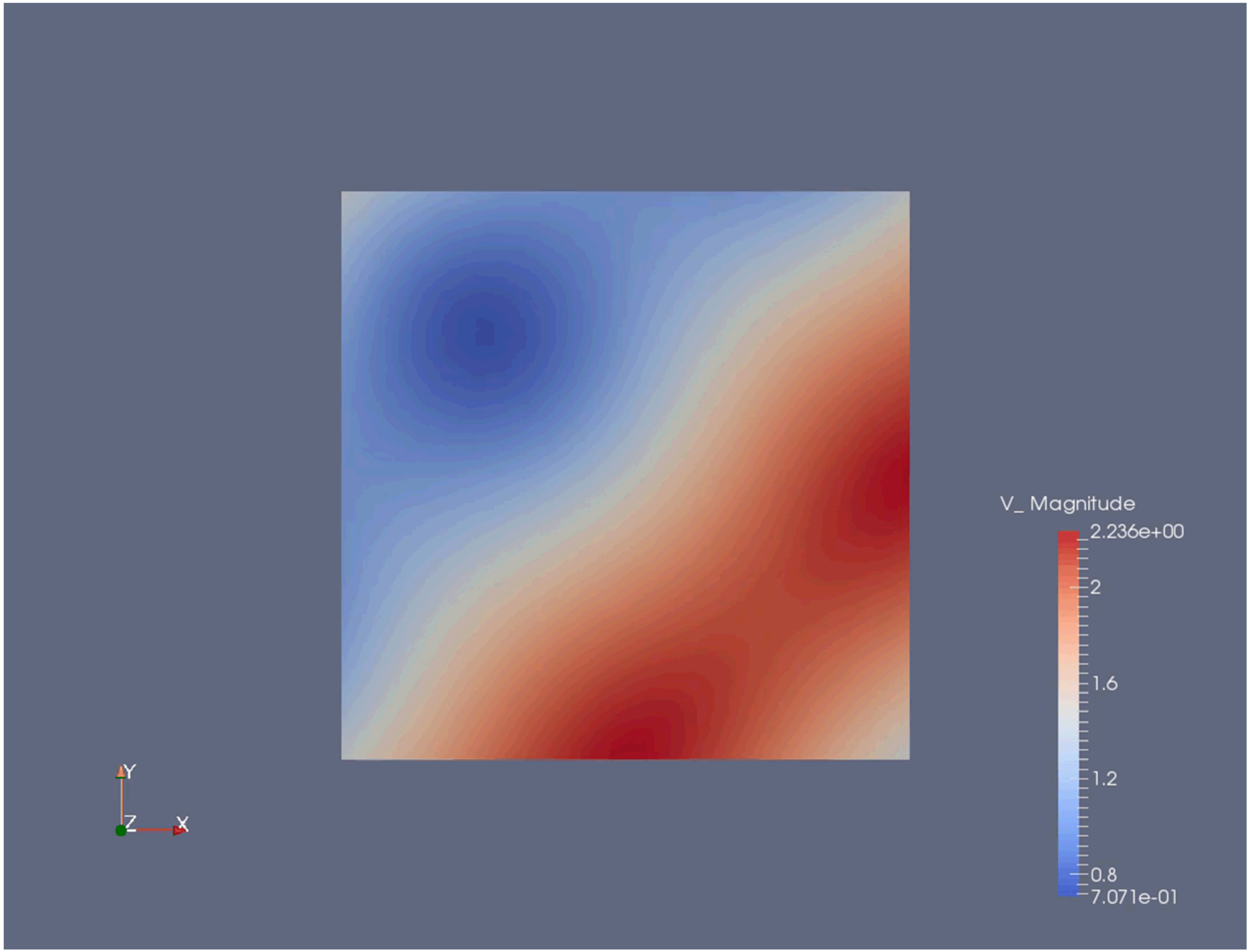


$$\nabla \cdot \boldsymbol{\sigma} \rightarrow -\int_{\Omega} \nabla \boldsymbol{w} : \boldsymbol{\sigma} \, \mathrm{d}x + \sum_{k \in \mathcal{T}_h} \int_{\Gamma_0} \boldsymbol{w} \cdot \hat{\boldsymbol{\sigma}} \cdot \boldsymbol{n} \, \mathrm{d}s$$

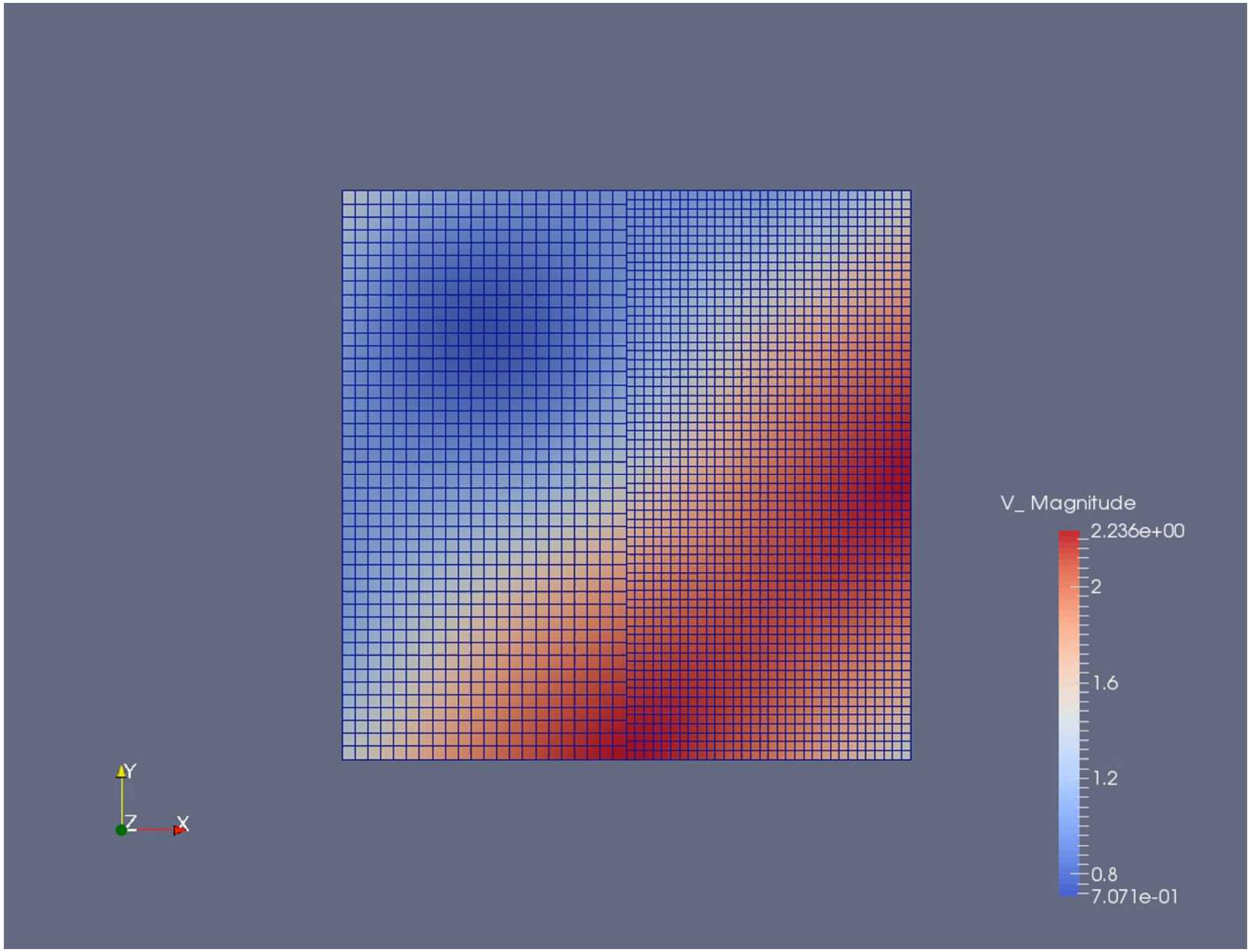
$$\sum_{k \in \mathcal{T}_h} \int_{\Gamma_0} \boldsymbol{w} \cdot \hat{\boldsymbol{\sigma}} \cdot \boldsymbol{n} \, \mathrm{d}s = \int_{\Gamma_0} \{\hat{\boldsymbol{\sigma}}\} \cdot [\![\boldsymbol{w}]\!] \, \mathrm{d}s$$

$$\{\hat{\boldsymbol{\sigma}}\} = \{\boldsymbol{\sigma}\} - \alpha([\![\boldsymbol{u}_h]\!])$$

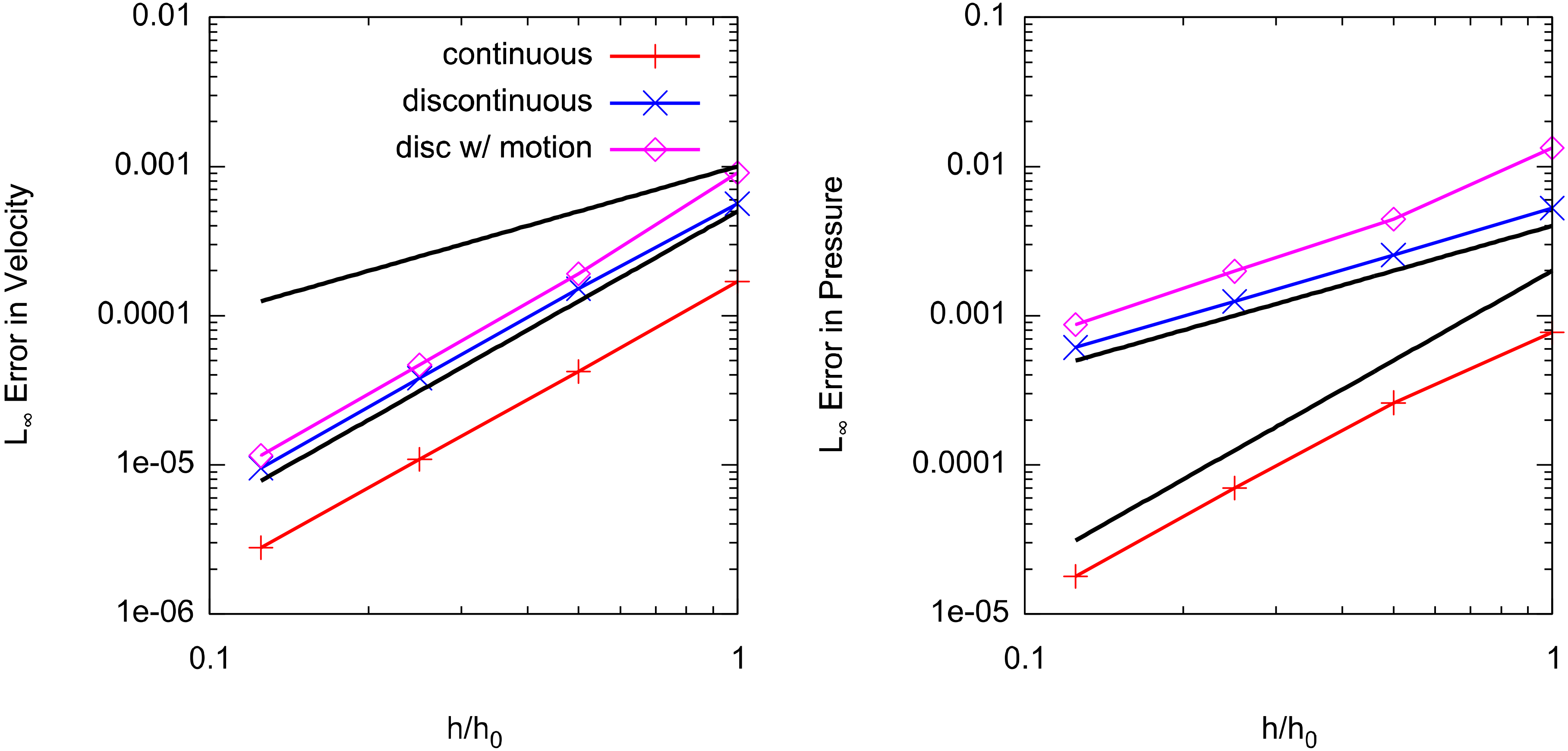
Taylor Vortex Verification



Taylor Vortex Verification



Taylor Vortex Verification



Conclusions

- resonance
  - Poiseuille
  - Couette
- rectified motion
- dynamic model
- ALE simulations
  - modes
  - amplitude limited
- sliding mesh scheme