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Comparing Thermo-Mechanical Solves in MOOSE and MFEM

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A Fusion Environment

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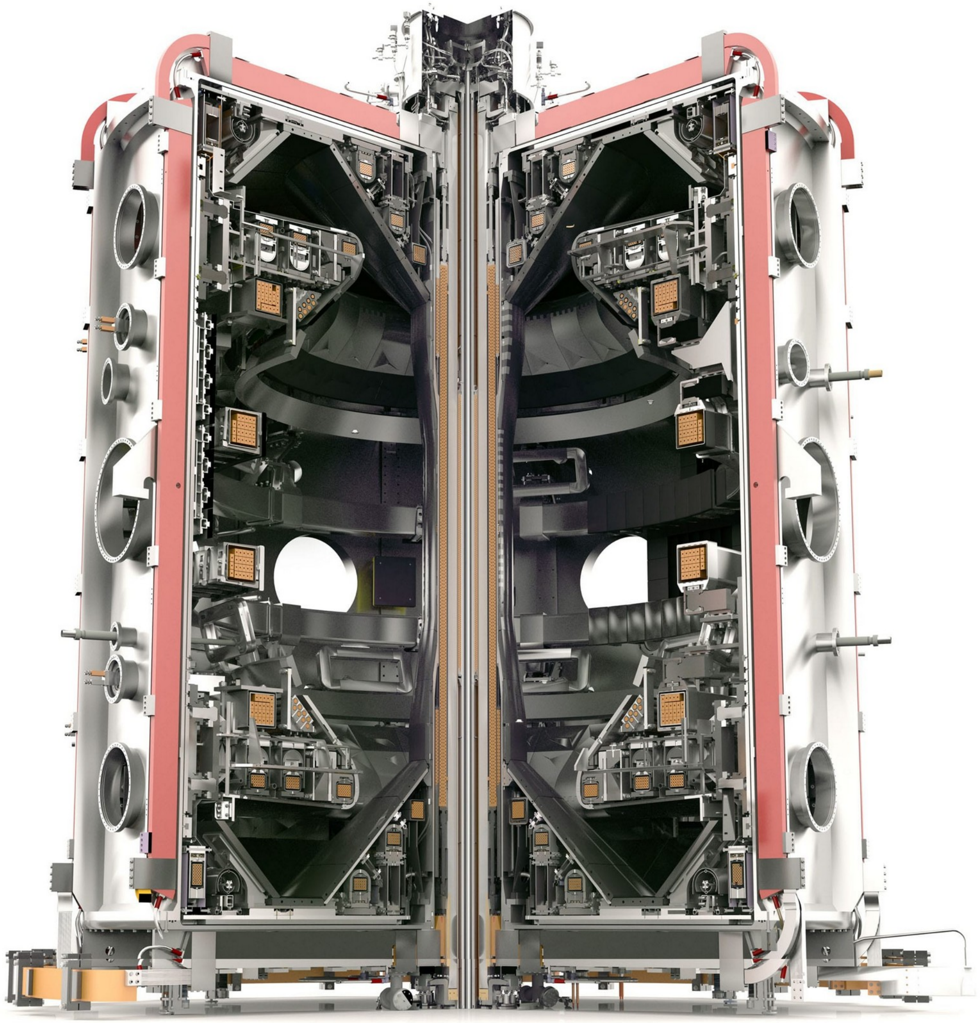
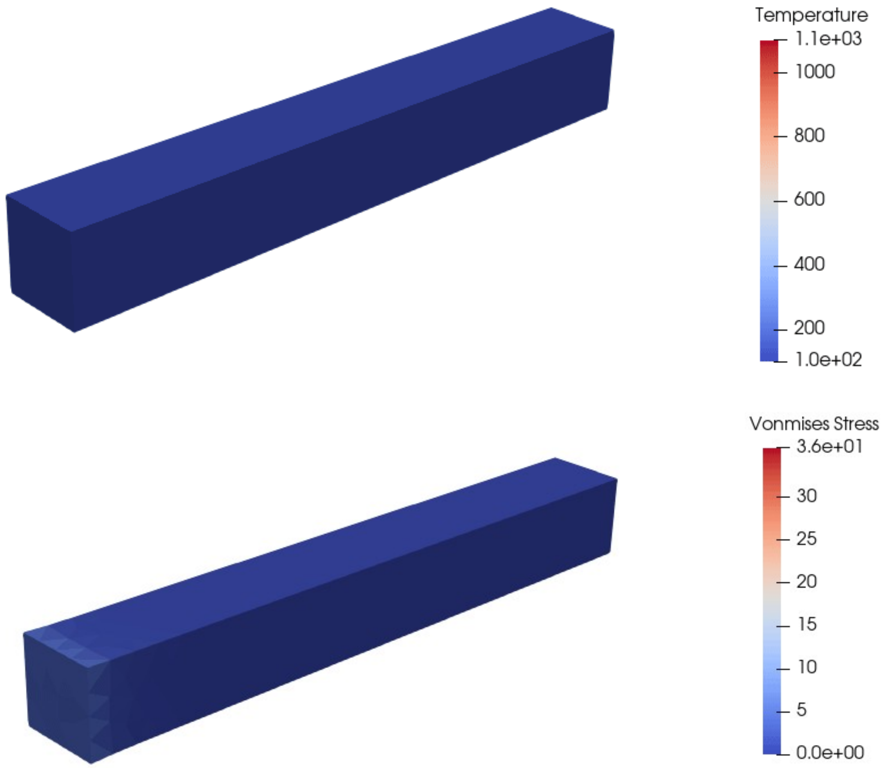


Figure 1: *A tokamak's innards*

- The environment inside a fusion reactor is a materials nightmare
  - High heat fluxes,
  - High temperatures
  - Static and pulsed magnetic fields
- We need to model how components react in this environment
  - Thermal expansion will be the focus of this talk

Thermal Expansion



$$\boldsymbol{\sigma} = \underbrace{\lambda tr(\boldsymbol{\epsilon}) + 2\mu\boldsymbol{\epsilon}}_{Linear Elasticity} - \underbrace{\alpha(3\lambda - 2\mu)(T(x) - T_0)\boldsymbol{I}}_{Thermal Expansion}$$

Figure 2: *Thermal expansion of a simple beam model, showcasing the stresses introduced when thermal expansion is constrained.*

Thermal Expansion Modelling: Current Solutions

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Ansys

- Doesn’t scale as well as alternatives
- Discrete physics modules
  - Lower degree of coupling
- And of course the cost ...

MOOSE

- Much more scalable than ANSYS
- But has limited FE types
- Limits use with electromagnetic problems
- Limited GPU support

Integrators and Initial Testing

$$(\lambda u, \nabla \cdot v) \quad \begin{matrix} u_{temp} \in H1 \\ v_{disp} \in H1^3 \end{matrix}$$

$$(\nabla \cdot v) \quad v \in H1^3$$

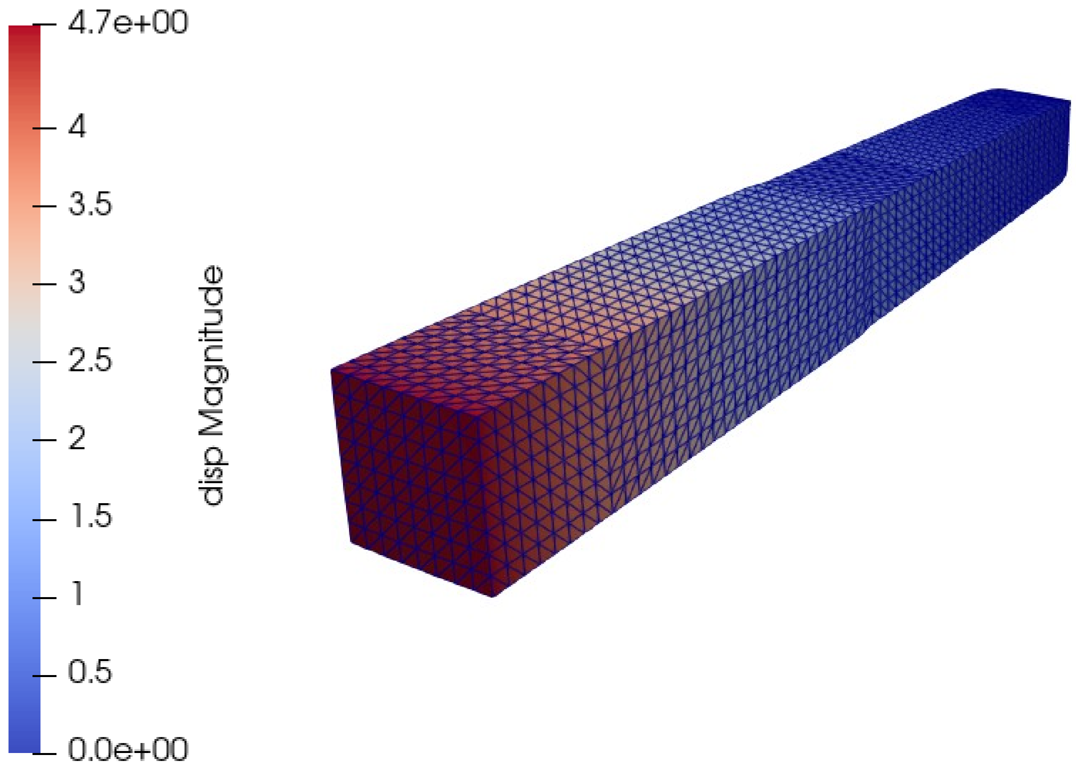


Figure 4: *MFEM results for beam example.*

The Hypervapotron Model

- What is it?
  - An efficient heat exchanger
  - More importantly, our fusion relevant test geometry
- Problem definition
  - Gaussian heat distribution across the top surface (Figure 5)
  - Convective heat transfer boundary applied in channels (Figure 6)
  - Fixed displacement boundaries on bottom

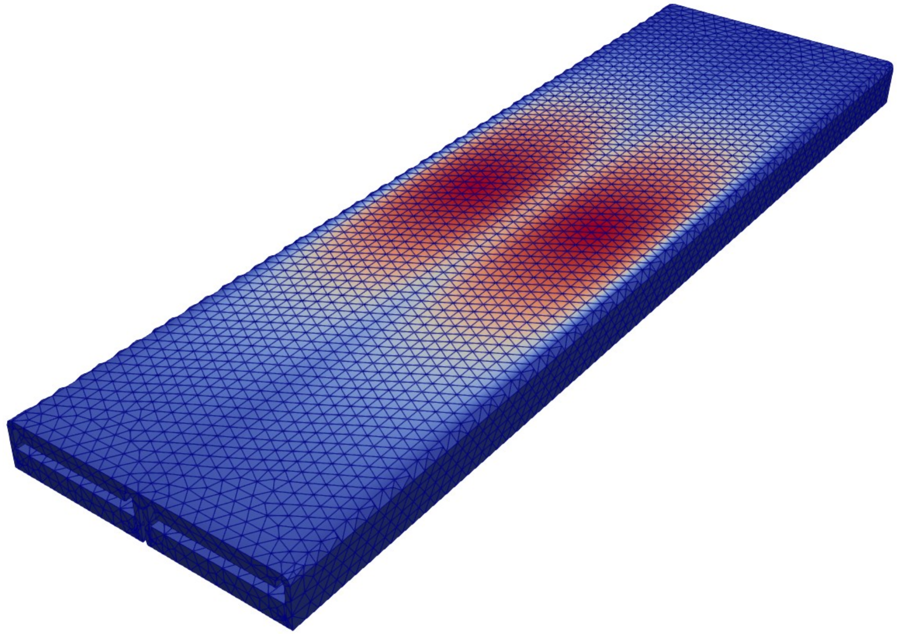


Figure 5: *Hypervapotron model with temperature distribution shown across the top surface*

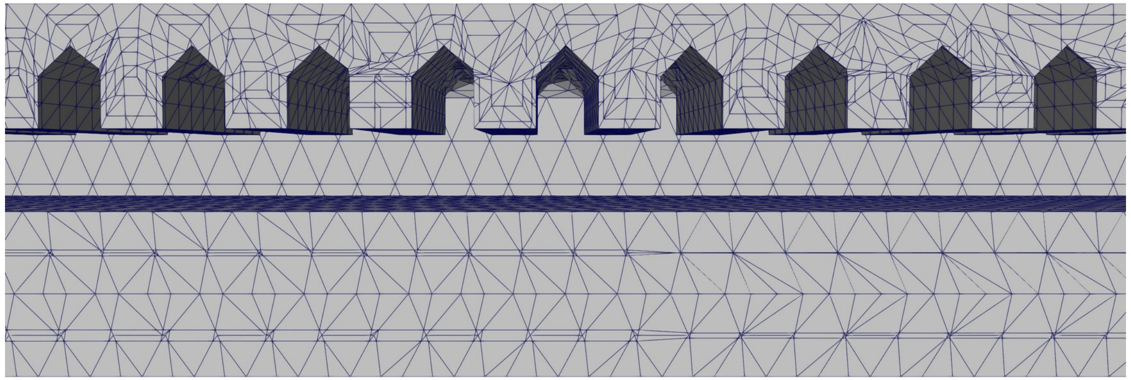
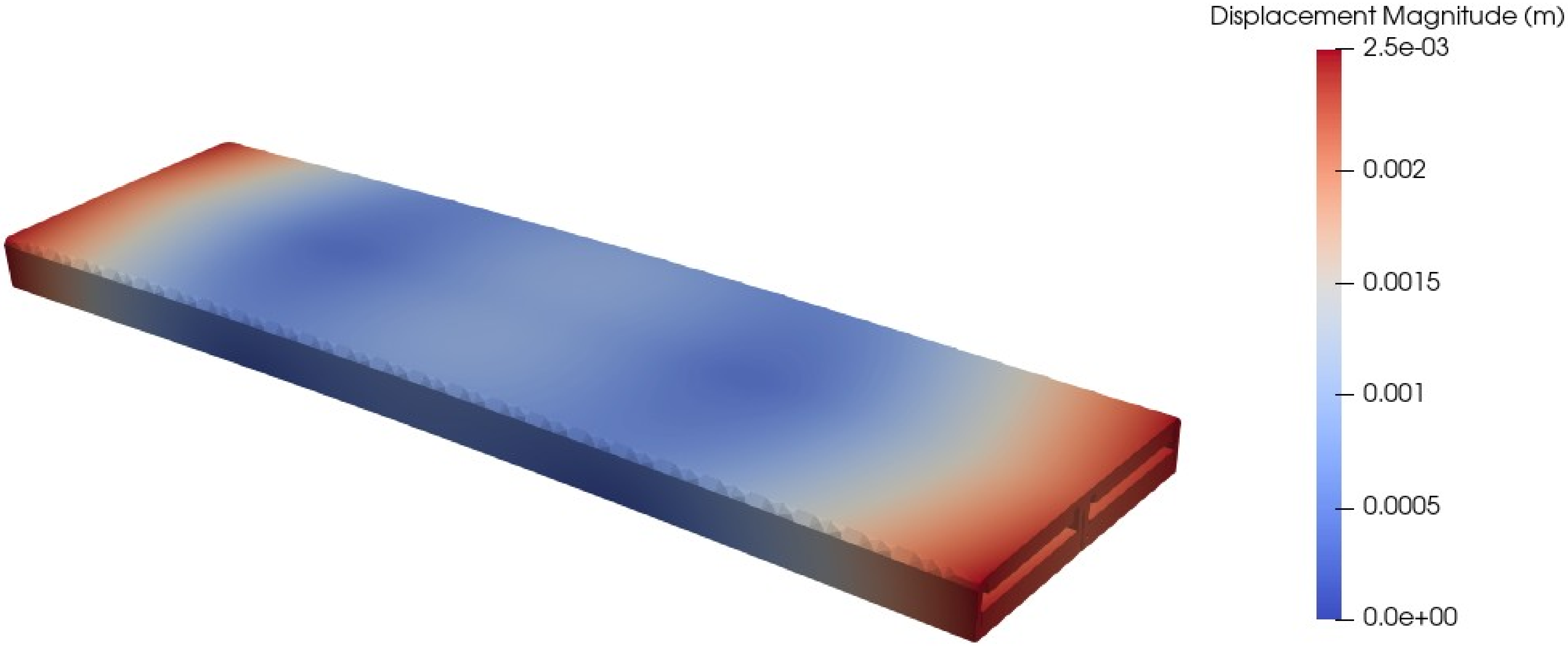


Figure 6: *Cross section of the hypervapotron, showing the internal fins along the channel length*


Displacement Magnitude (m)
2.5e-03
0.002
0.0015
0.001
0.0005
0.0e+00

Solve Methods

- MOOSE solves thermal expansion slightly differently
  - Thermal Expansion is a MOOSE ‘material’ object
  - Temperature is solved for first
  - Temperature becomes a coefficient for thermal expansion linear form
- MFEM can solve for both displacement and temperature in one monolithic matrix
  - Can also do the MOOSE method
- Results are included for both methods

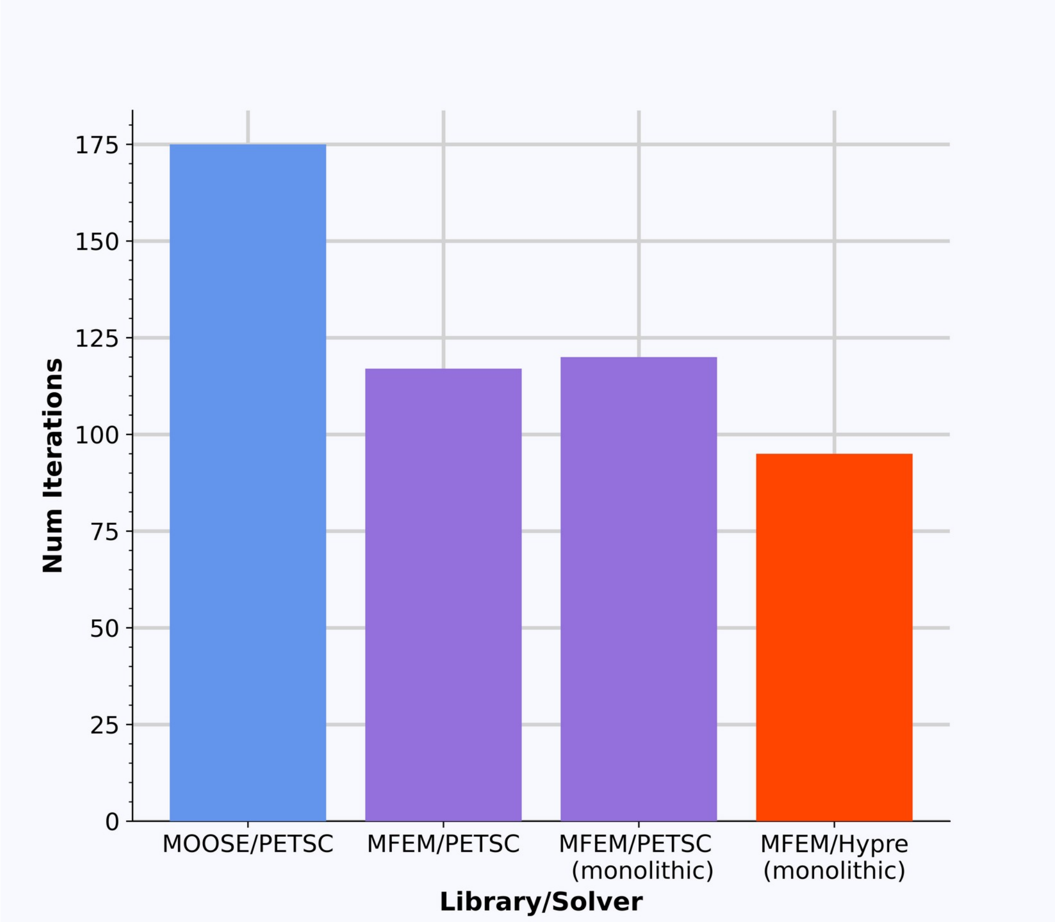


Figure 7: *Example graph showcasing all the solve methods*

Hypervapotron Results

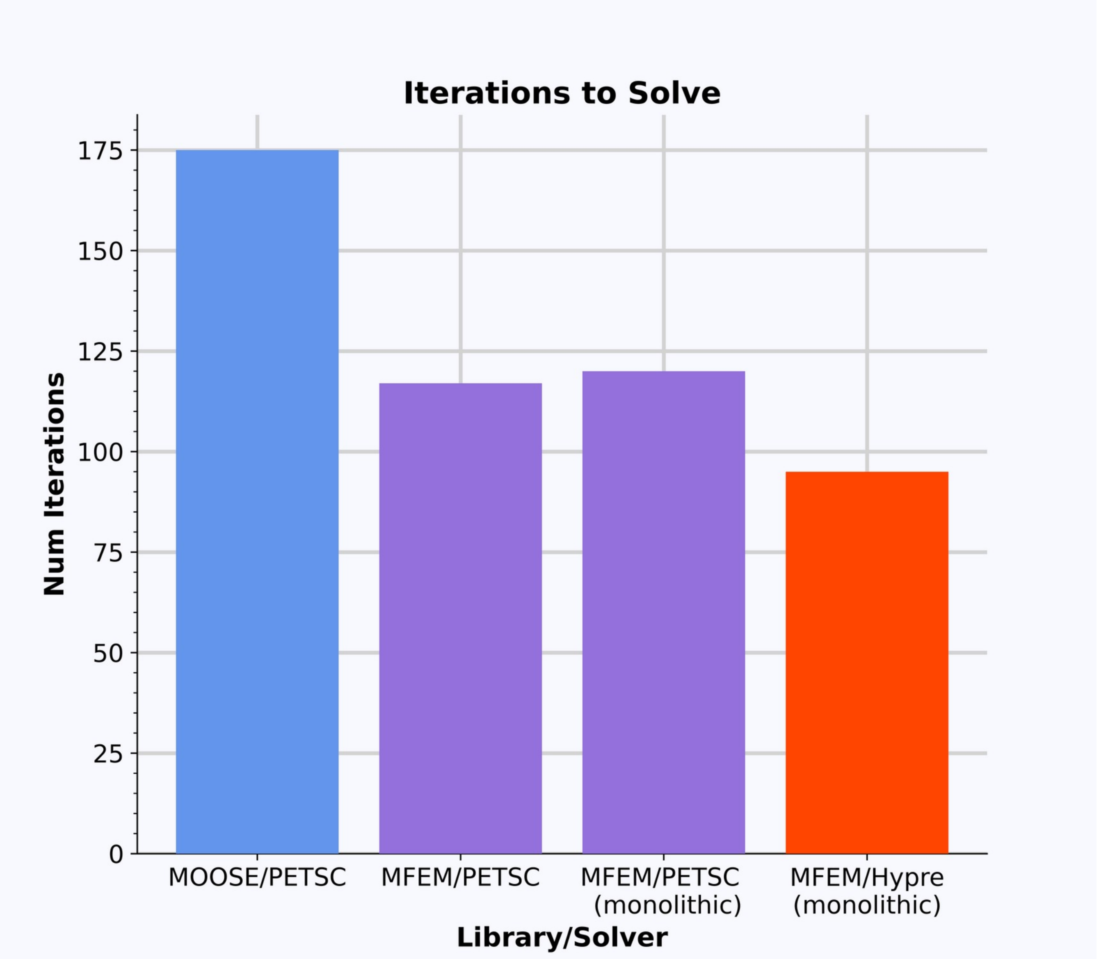


Figure 10: *Number of linear iterations needed to solve*

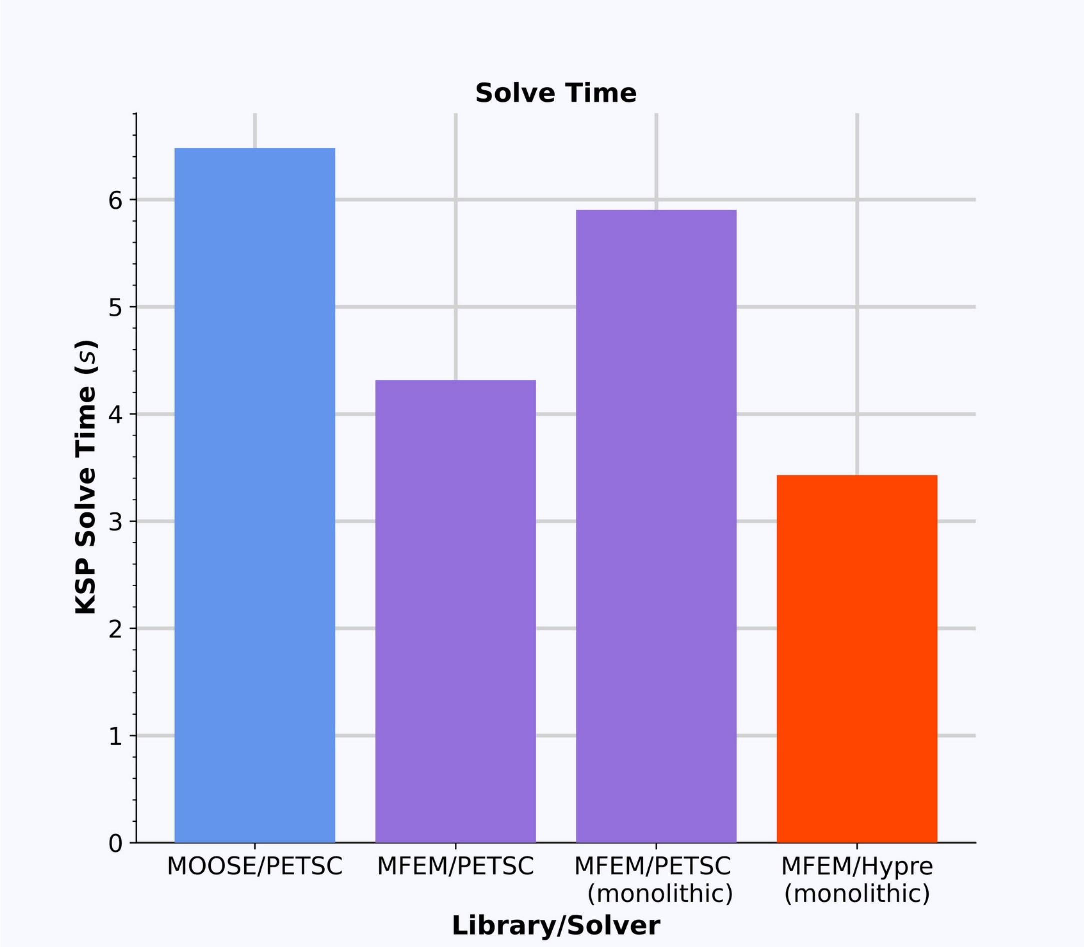


Figure 11: *Time taken for the linear solve to complete*

What next?

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- Results are looking good for MFEM and HYPRE so far!
- Further scaling testing
  - Initial results looks good for MFEM/ Hypre
- GPU testing
- Implement non-linear mechanics formulations