Immersed Boundary Method

- Represent solid as collection of material points on background FVM mesh
- Label fluid cells as “Solid”, “Immersed Boundary (IB)” or “Fluid” cells
- Faces between “IB” and “Fluid” cells are labeled “IB” faces
- Linear least-squares interpolation from a neighborhood of fluid and material point velocities to specify IB face velocity vector \( \mathbf{V}_f \)
- Finite volume solution used for fluid cells
- Linear least-squares interpolation are labeled “IB” faces
- Faces between “IB” and “Fluid” cells
- Fluid stress tensor computed on stencil of fluid cells and sent back to MPM

Verification: Flow Over a Cylinder

- Velocity profile for flow past a rotating cylinder
- Velocity profile for flow past a stationary cylinder
- Stream line of flow past a stationary (top) and rotating (bottom) cylinder
- Velocity profile for flow past a rotating cylinder

Verification: Stokes Flow Over a Sphere

- Analytical solution:
  - \( \omega_r = U \sin \theta \)
  - \( \omega_\theta = U \cos \theta \)
- Drag force:
  - \( F_D = 3 \pi \mu DU \)

Table: Mesh dependence of drag force

<table>
<thead>
<tr>
<th>Mesh size</th>
<th>F_D (0.5 \rho U^2 D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27,000</td>
<td>RMS = 835</td>
</tr>
<tr>
<td>125,000</td>
<td>RMS = 870</td>
</tr>
<tr>
<td>1,000,000</td>
<td>RMS = 905</td>
</tr>
</tbody>
</table>

Conclusions

- Verification and validation tests show satisfactory results.
- Current IBM only has first order convergence.

Future Work

- Improvements to interpolation procedures and FVM-MPM coupling
- Extend to variety of physics – electrostatics, rarefied gas dynamics, thermals

Verification: Driven Cavity

- Velocity vector contour (Re=1.0)
- Root Mean Square (RMS) error
  - \( \text{RMS} = \sqrt{\frac{\sum (V_{\text{IBM}} - V_{\text{Fluid}})^2}{N}} \)
- Velocity on horizontal mid-plane
- Velocity on vertical mid-plane

Verification: Stokes Flow Over a Sphere

- Velocity profile on centerlines
- Velocity profile on vertical mid-plane
- Projection of IB cells on x-y plane

Mesh Convergence Study

- Exact solution
- Apply exact solution on IB faces
- Solve temperature field
- Define error
- Order of convergence \( p \) is defined by the slope of log(\( E \)) and log(\( N \))
  - \( \log(|\text{Error}|) = \log(C) + p \log(N) \)

Future Work

- Improvements to interpolation procedures and FVM-MPM coupling
- Extend to variety of physics – electrostatics, rarefied gas dynamics, thermals