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THE TRANSIENT MODELING OF BUBBLE PINCH-OFF USING AN ALE MOVING MESH

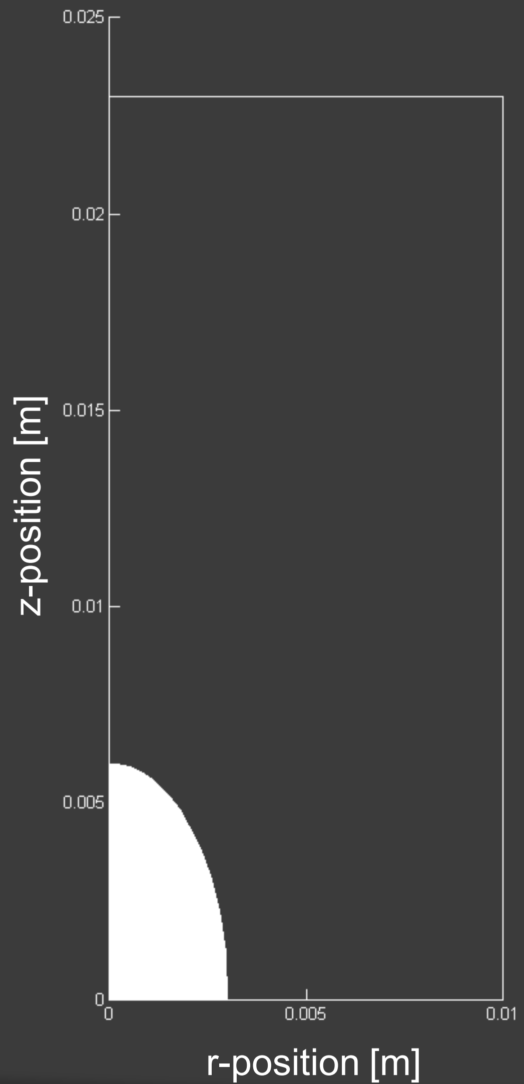
Outline

- Motivation
- Initial Configuration
- Governing Equations
- Pinch-off Procedure
- ALE Simulation Results
- Level-Set and Phase-Field Comparisons
- Conclusions
- Future Work

Motivation

- This model is being developed for modeling boiling heat transfer in the presence of an acoustic field.
  - Increase critical heat flux by delaying transition to film boiling.
- Begin with modeling a single isothermal bubble going through pinch-off.

Initial Configuration



- Model is 2D axisymmetric.
- Initial geometry is used in ALE, level-set, and phase-field models.
- Initial bubble volume is 1.131e-7 m^3.

Boundary Number	Type	Condition Satisfied
1	Wall	No Penetration, Slip
2	Wall	No Penetration, Slip
3	Wall	No Penetration, Slip
4	Open Boundary	Zero Gage Pressure
5	Symmetry	Axial Symmetry
6	Symmetry	Axial Symmetry
7 (inside)	General Stress	Pressure, Continuity of Shear Stress
7 (outside)	Moving Wall	No Slip at Fluid Interface

Governing Equations

Normal-stress boundary condition: $\left(\underline{\underline{\sigma}}_l - \underline{\underline{\sigma}}_g\right)\hat{n} = \sigma\kappa\hat{n}$

Stress tensor and curvature defined as:

$$\underline{\underline{\sigma}}_{g,l} = \left[-P\underline{\underline{I}} + \eta\left(\nabla\underline{u} + \left(\nabla\underline{u}\right)^T\right)\right]_{g,l}$$ and $$\kappa = \nabla_s \cdot \hat{n}$$

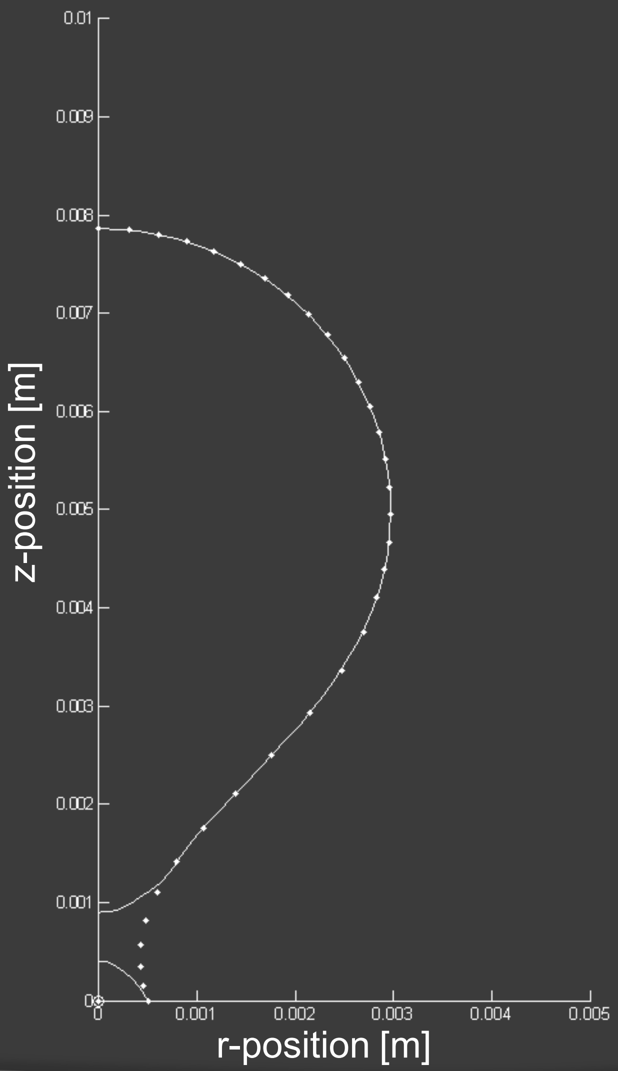
Multiplying both sides by a test function and integrating results in:

$$\int_{\partial\Omega}\left(\tilde{\varphi}\underline{\underline{\sigma}}_l\hat{n}\right)dA = \int_{\partial\Omega}\left(\tilde{\varphi}\underline{\underline{\sigma}}_g\hat{n}\right)dA + \int_{\partial\Omega}\left(\tilde{\varphi}\sigma\kappa\hat{n}\right)dA$$

Applying the surface divergence theorem and substituting back in yields:

$$\int_{\partial\Omega}\left(\tilde{\varphi}\underline{\underline{\sigma}}_l\hat{n}\right)dA = \int_{\partial\Omega}\left(\tilde{\varphi}\underline{\underline{\sigma}}_g\hat{n}\right)dA - \int_{\partial\Omega}\left(\sigma\nabla_s\tilde{\varphi}\right)dA + \int_{\partial^2\Omega}\left(\sigma\tilde{\varphi}\hat{m}\right)ds$$

Pinch-Off Procedure

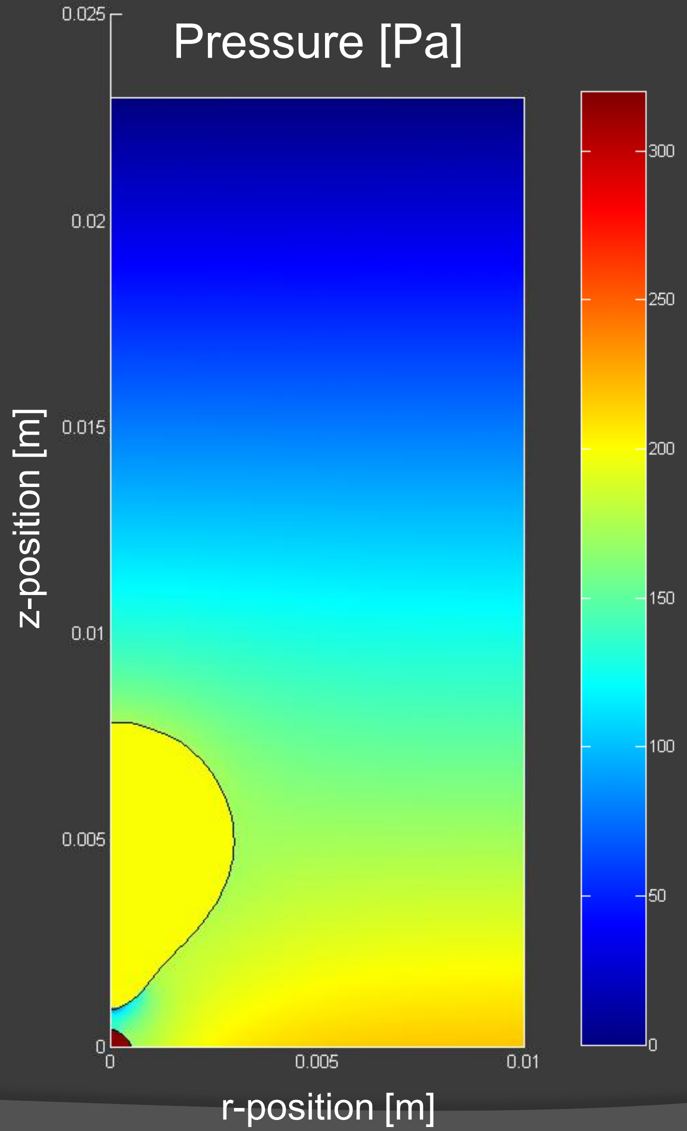


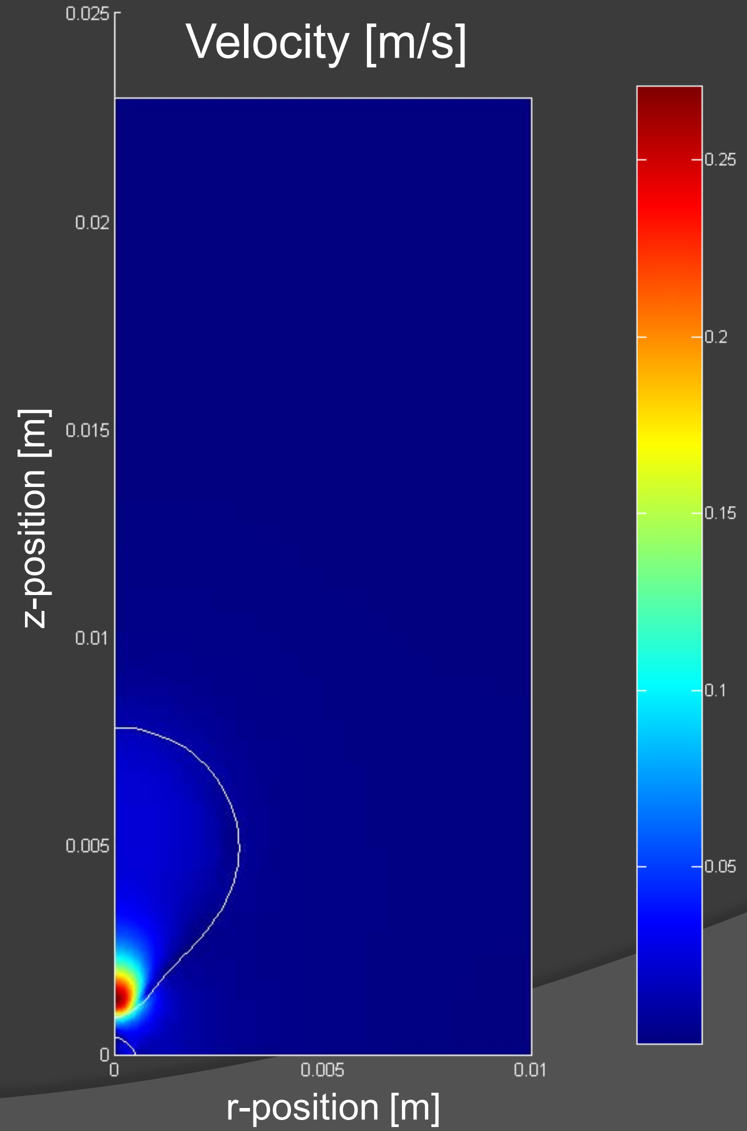
- A pinch-off point is determined visually, near the minimum neck radius. A gap height is chosen and a point is inserted at the top and bottom. Additional points are removed near the edge of the gap to get a smooth profile. Finally, the new set of points are fit with splines.

- A minimum number of points were removed to preserve as much of the original shape as possible.

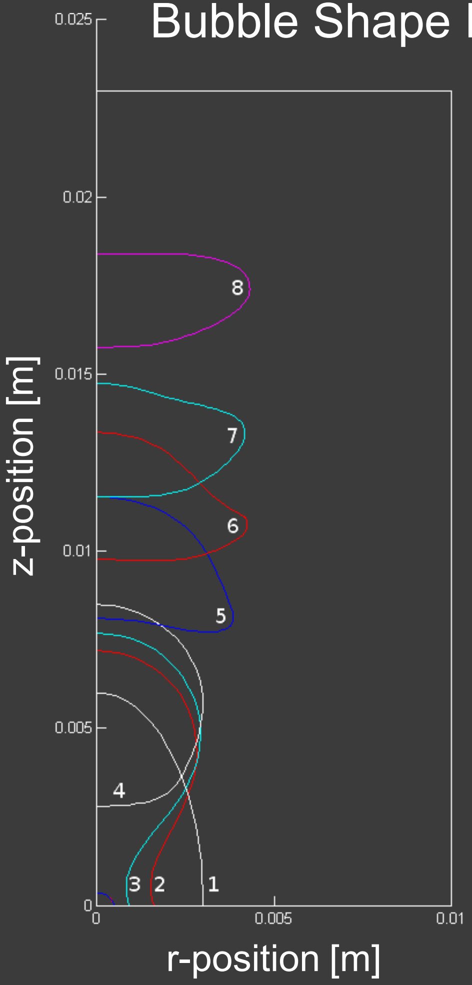
- The pinch-off method in the model presented does not conserve mass during the transition.

Pinch-Off Procedure (cont.)

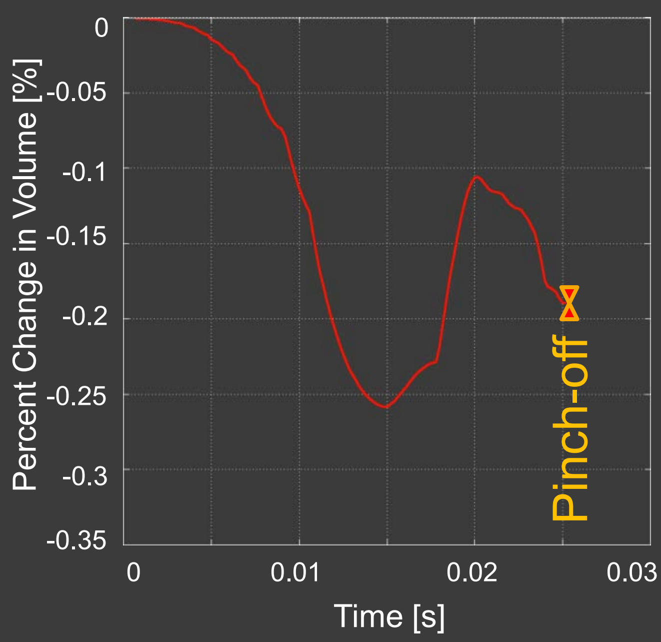


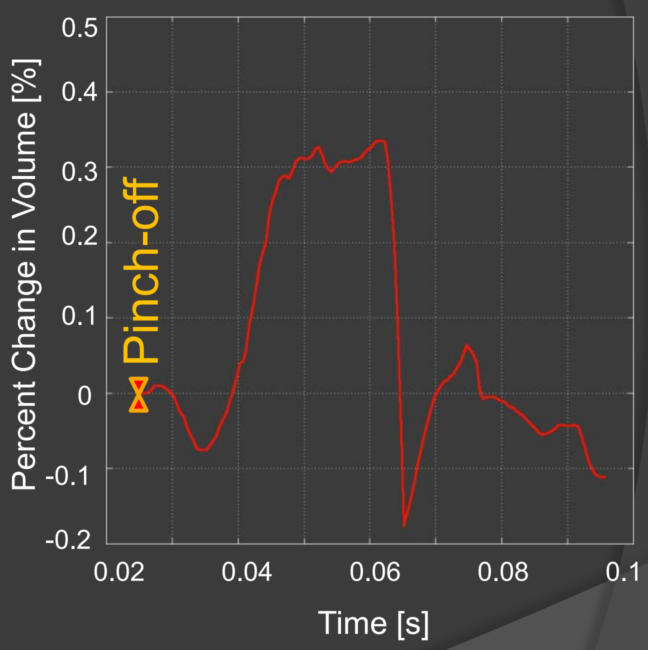


ALE Simulation Results



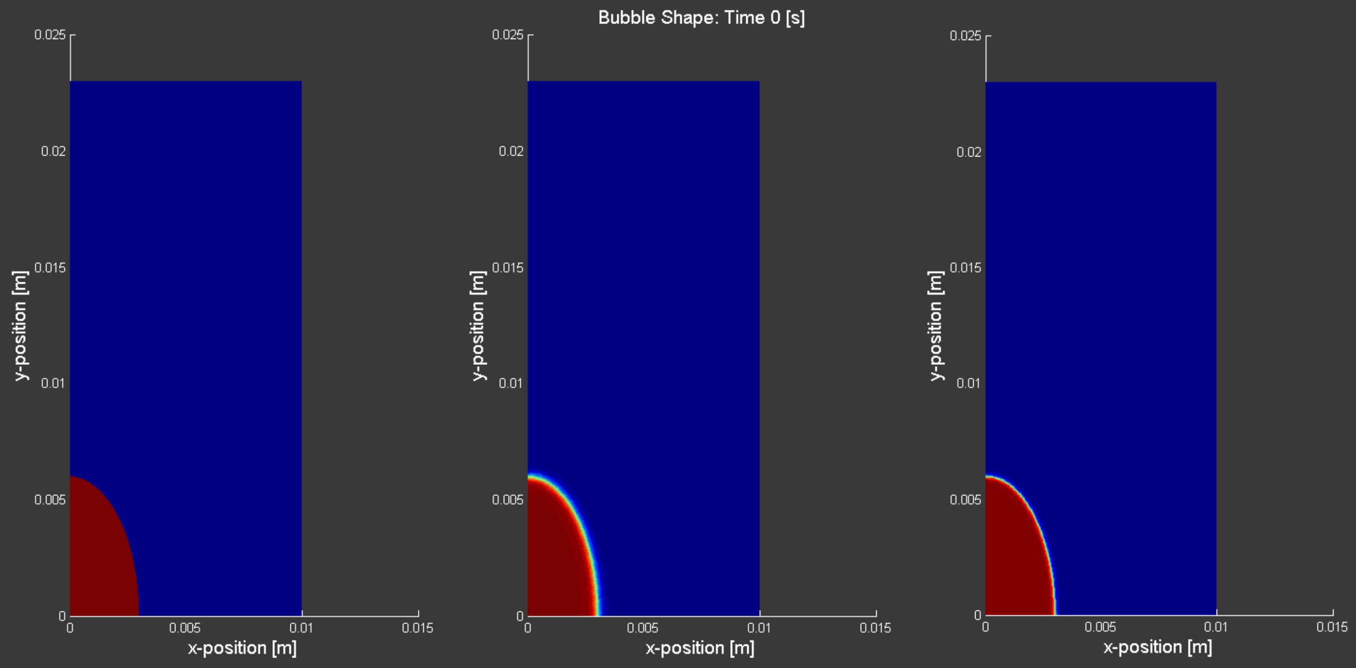
Mass Conservation





Rel. Tolerance – 0.01
Abs. Tolerance – 0.001

Level-Set and Phase-Field Comparisons



ALE
(Slip BC)

Level-Set
(Slip Length BC)

Non-Conservative
Phase-Field
(No-Slip BC)

Level-Set and Phase-Field Comparisons (2)

Model Type	Solution Time [min]	Simulation End Time [s]	*t** [min/ms]
ALE	30	0.096	0.31
LS	700	0.069	10.1
PF Conserv.	280	0.050	5.6
PF, Non-Conserv.	105	0.100	1.05

Model Type	Peak Memory Usage [GB]
ALE	4
LS	4.5
PF, Non-Conserv.	7

$$t^* = \frac{\text{(Computation Time)}}{\text{(Simulation Duration)}}$$

Conclusions

ALE method:

- Provides a sharp interface to apply boundary conditions.
- Tracks fluid interface and conserves mass well.
- Reduces computing requirements in both CPU capabilities and memory capacity.
- ALE application mode allows for the use of a contact line with a fixed angle and no-slip, slip-length parameter, or slip conditions.
- Alternatively, a fixed contact line can be enforced while allowing change in contact angle.

Future Work

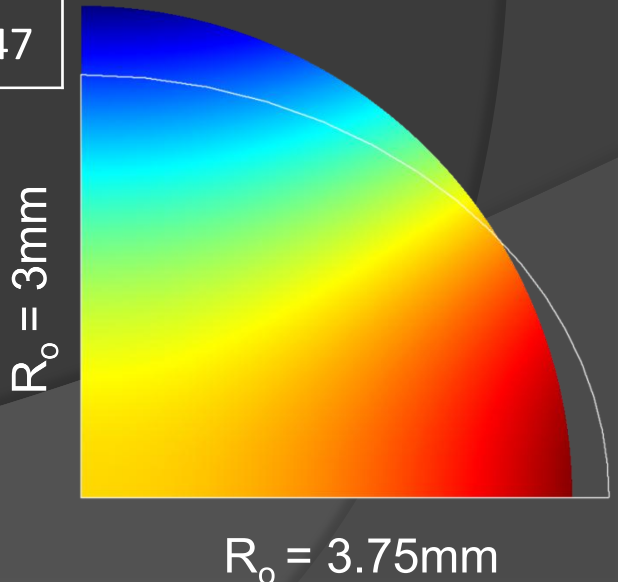
- The pinch-off process will be modeled using asymptotic approximations to compute the new geometry immediately after pinch-off and the corresponding velocity and pressure fields.
  - The spatial and time scales become too small to numerically resolve in a reasonable time frame.
- Incorporate heat transfer and pressure acoustic application modes.

Questions?

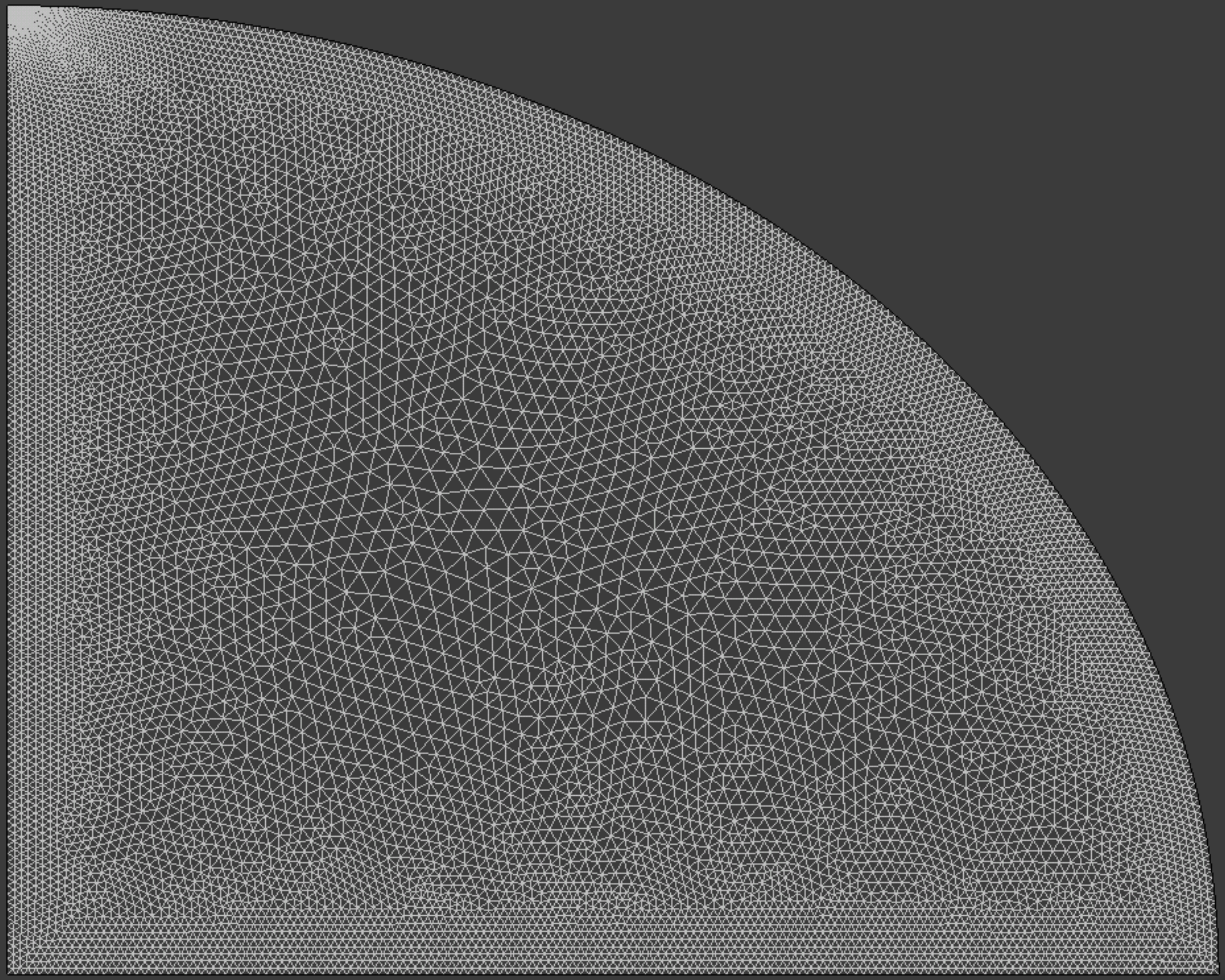
Tolerances – Study

Percent Change in Mass

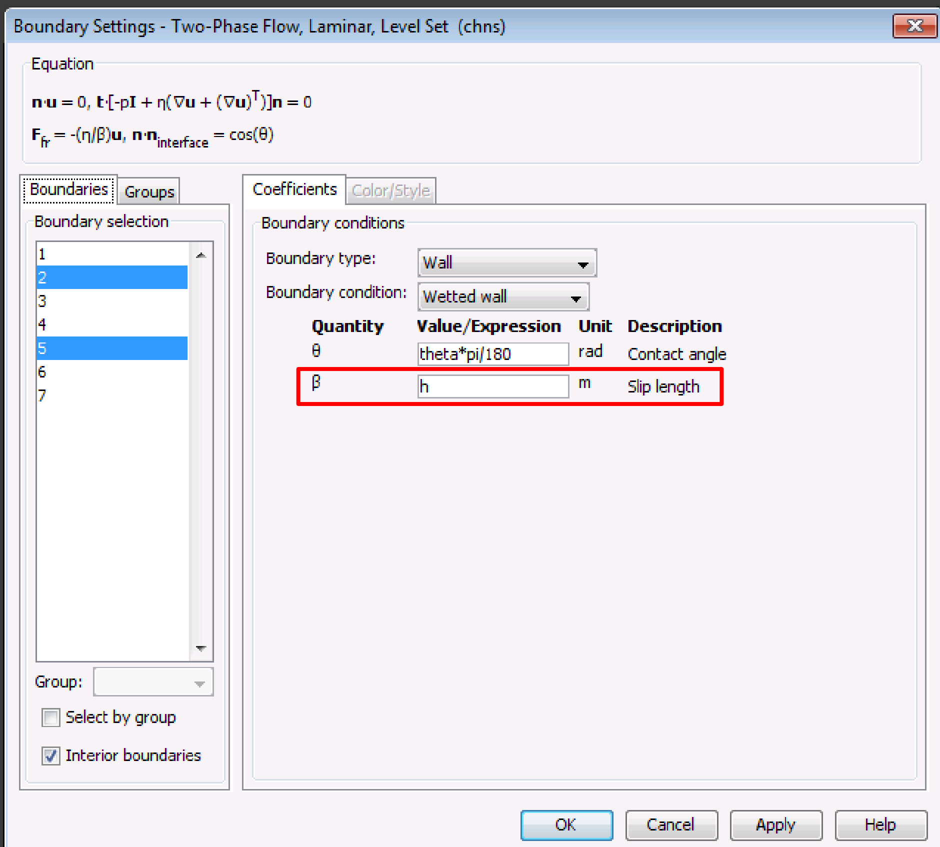
Abs. Tol. \ Rel. Tol.	0.01	0.005	0.001	0.0005	0.0001
0.001	0.7778	0.6748			
0.0005		0.4670	0.1724		
0.0001			0.0396	0.0202	
0.00005				-0.01	
0.00001					-0.0147

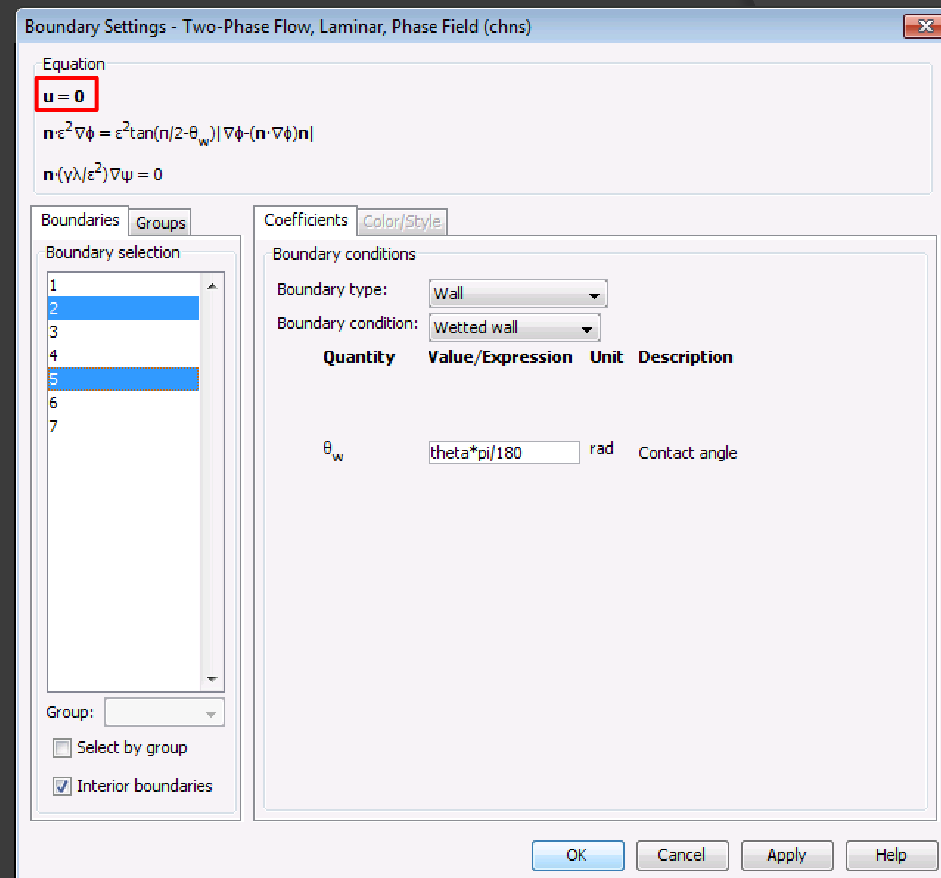


Tolerances – Study (2)



Level-Set and Phase-Field Boundary Conditions





Pre-Pinch-Off Pressure and Velocity Fields