

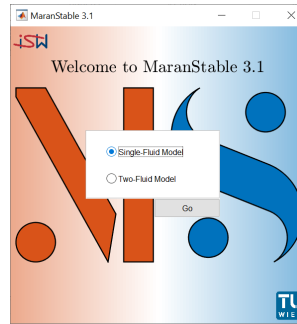
Tutorials

The tutorials presented hereinafter are intended as a guide to the user with the main features implemented in MaranStable. The GUI MaranStable is started by running the file `main.m` with Matlab 2022 or a more recent version.

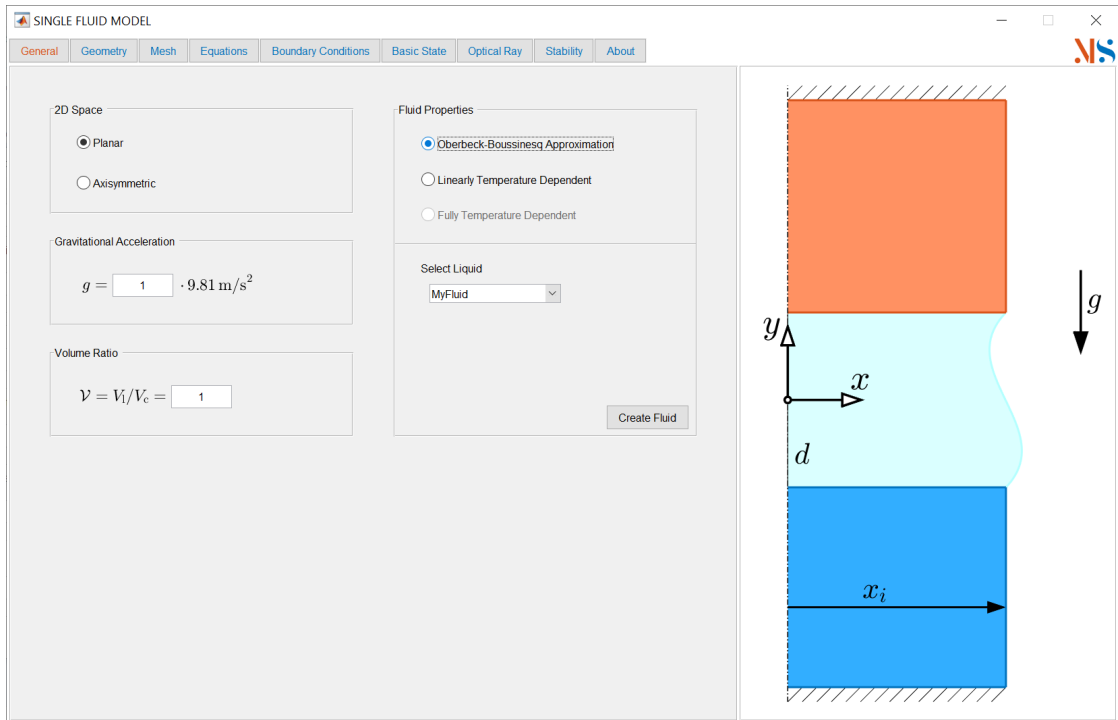
1 Rayleigh–Bénard instability

The first tutorial deals with the Rayleigh–Bénard problem, i.e. the instability of a quiescent fluid layer heated from. Here we consider a planar geometry laterally confined by slip walls as a substitute for an infinite layer. This tutorial corresponds to the file `example_1.mat` in the folder `tutorials`.

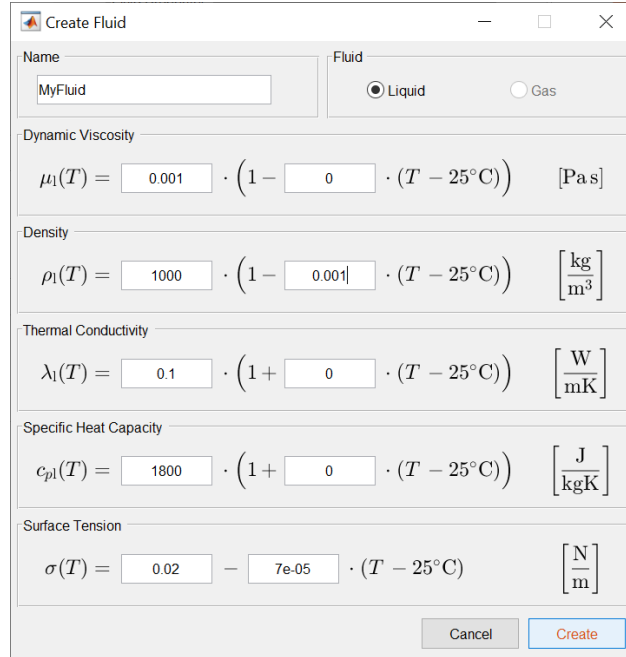
- Select the single-phase solver



- Set up the planar geometry and the gravitational acceleration. Since we consider a rectangular domain, the volume ratio is set to $\mathcal{V} = 1$. Select the Oberbeck–Boussinesq approximation as physical model.



- Set up a new fluid by clicking on **Create Fluid**. The parameters are set as follows. Then click **Create**.



Create Fluid

Name:

Fluid: ☒ Liquid ☐ Gas

Dynamic Viscosity

$$\mu_l(T) = 0.001 \cdot \left(1 - 0 \cdot (T - 25^\circ\text{C})\right) \quad [\text{Pa}\cdot\text{s}]$$

Density

$$\rho_l(T) = 1000 \cdot \left(1 - 0.001 \cdot (T - 25^\circ\text{C})\right) \quad \left[\frac{\text{kg}}{\text{m}^3}\right]$$

Thermal Conductivity

$$\lambda_l(T) = 0.1 \cdot \left(1 + 0 \cdot (T - 25^\circ\text{C})\right) \quad \left[\frac{\text{W}}{\text{mK}}\right]$$

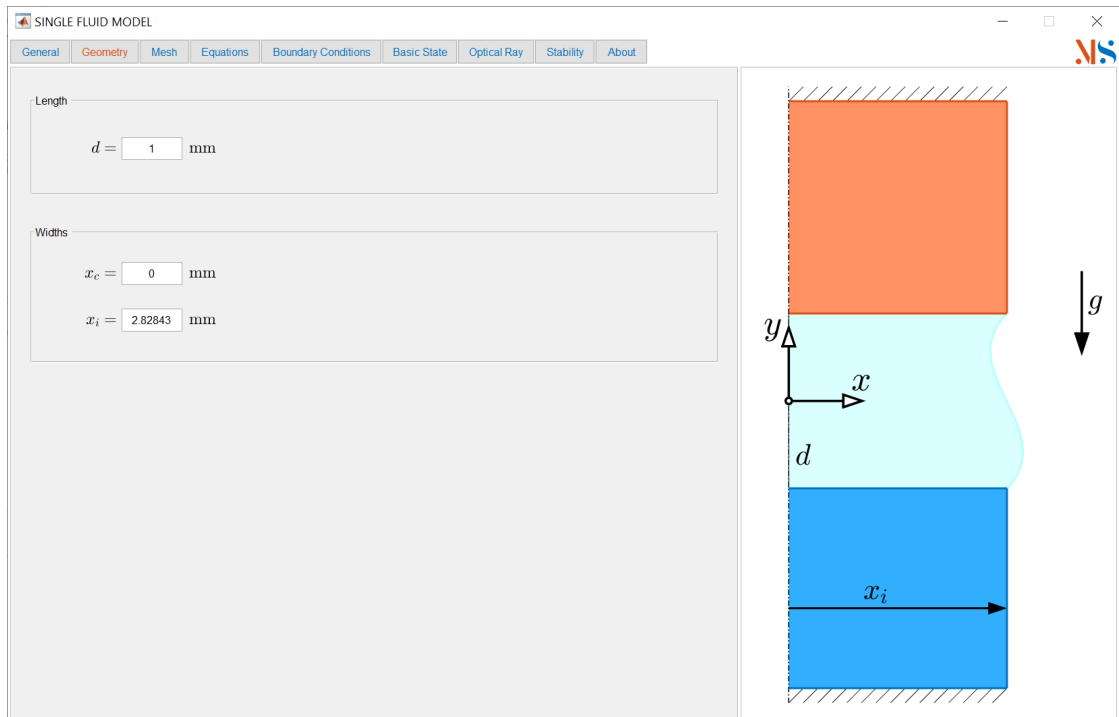
Specific Heat Capacity

$$c_{pl}(T) = 1800 \cdot \left(1 + 0 \cdot (T - 25^\circ\text{C})\right) \quad \left[\frac{\text{J}}{\text{kgK}}\right]$$

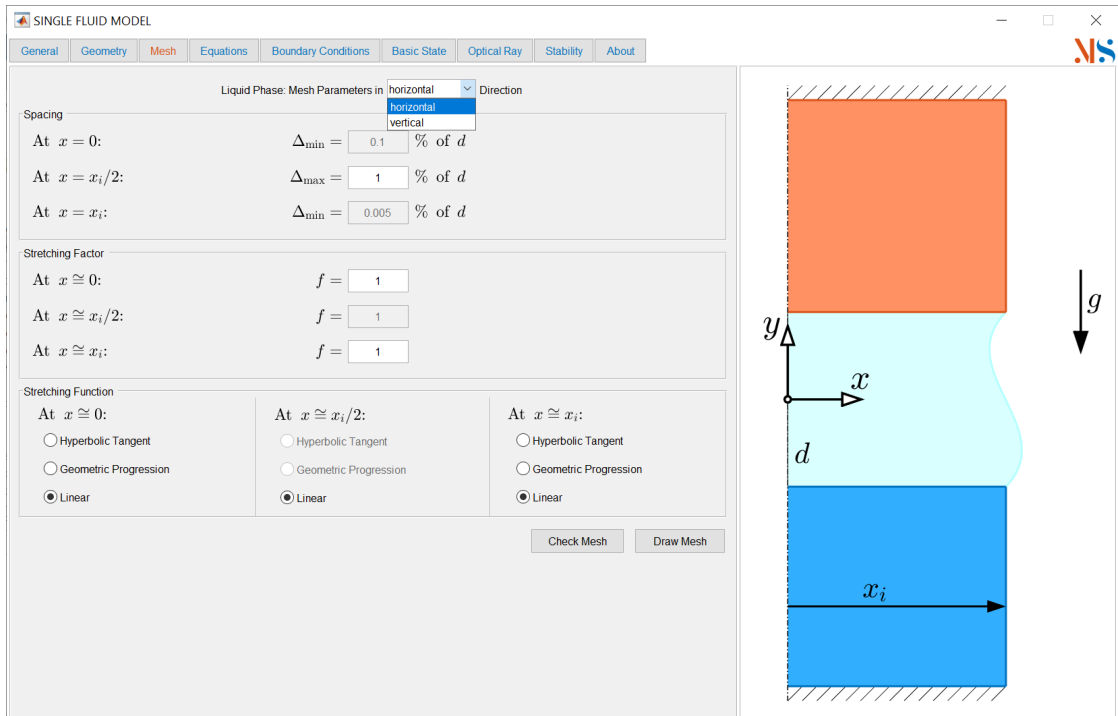
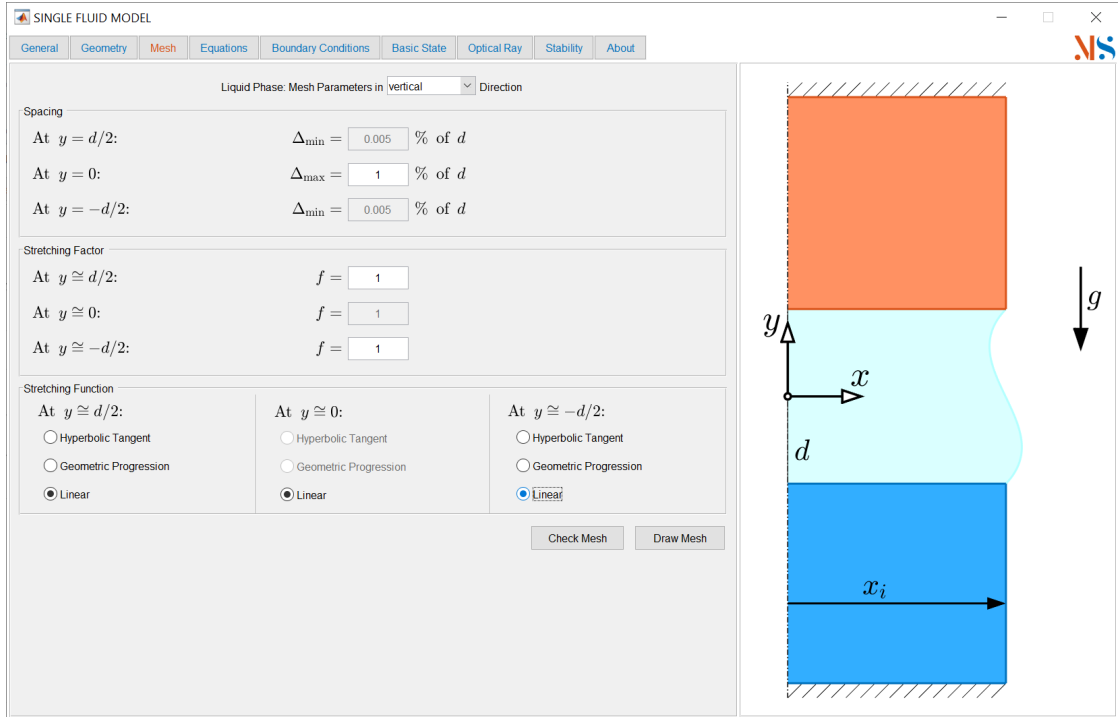
Surface Tension

$$\sigma(T) = 0.02 - 7\text{e-}05 \cdot (T - 25^\circ\text{C}) \quad \left[\frac{\text{N}}{\text{m}}\right]$$

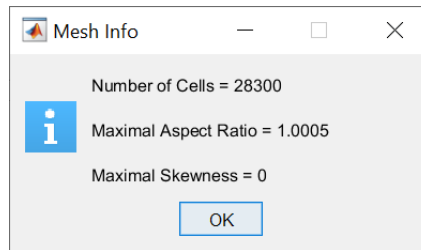
- Set up the planar geometry as follows. The values are selected to coincide with the critical wavelength ($\lambda_c = 2\sqrt{2} = 2.82843$) of the Rayleigh–Bénard instability for free slip on the horizontal boundaries.



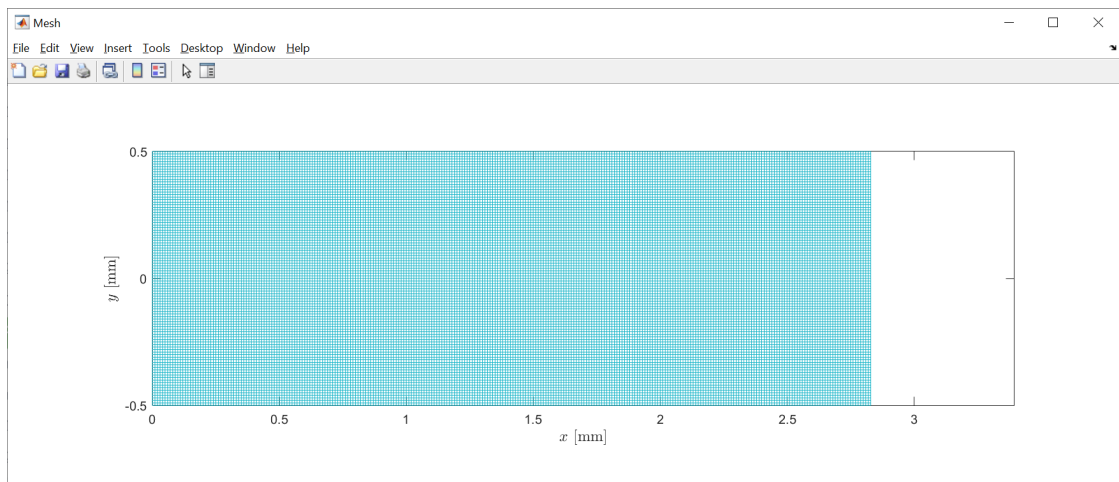
- Set up the mesh as shown below (both horizontal and vertical coordinates must be discretized). You can change the discretization parameters if a finer resolution is needed.



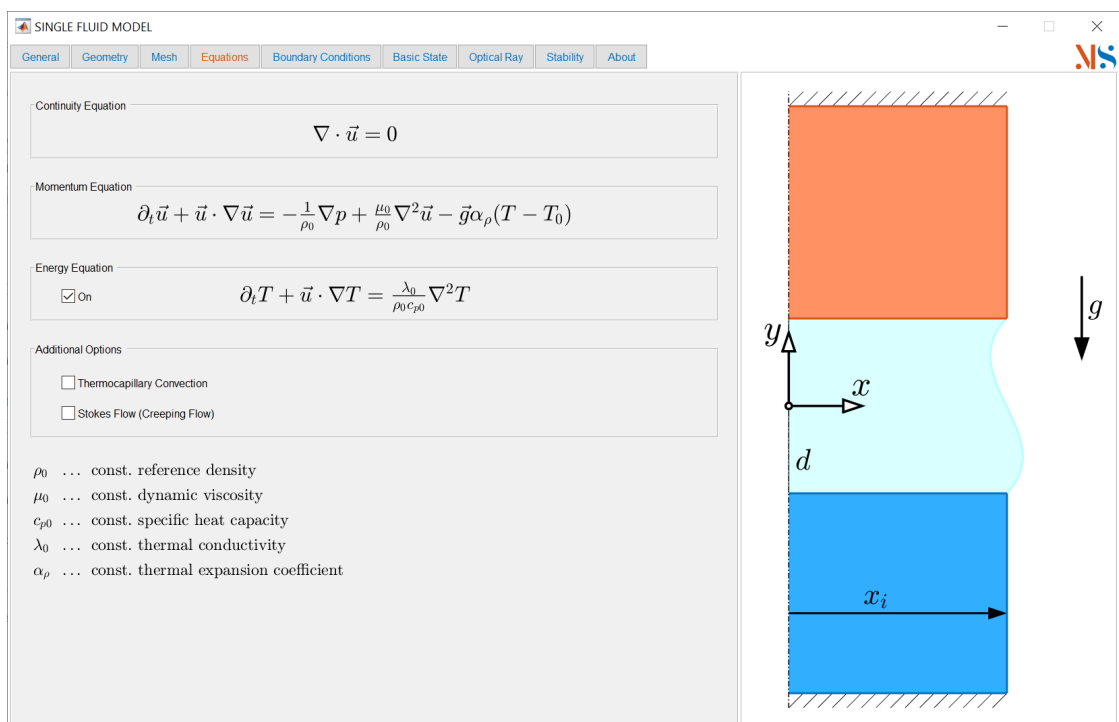
- Click on Check Mesh



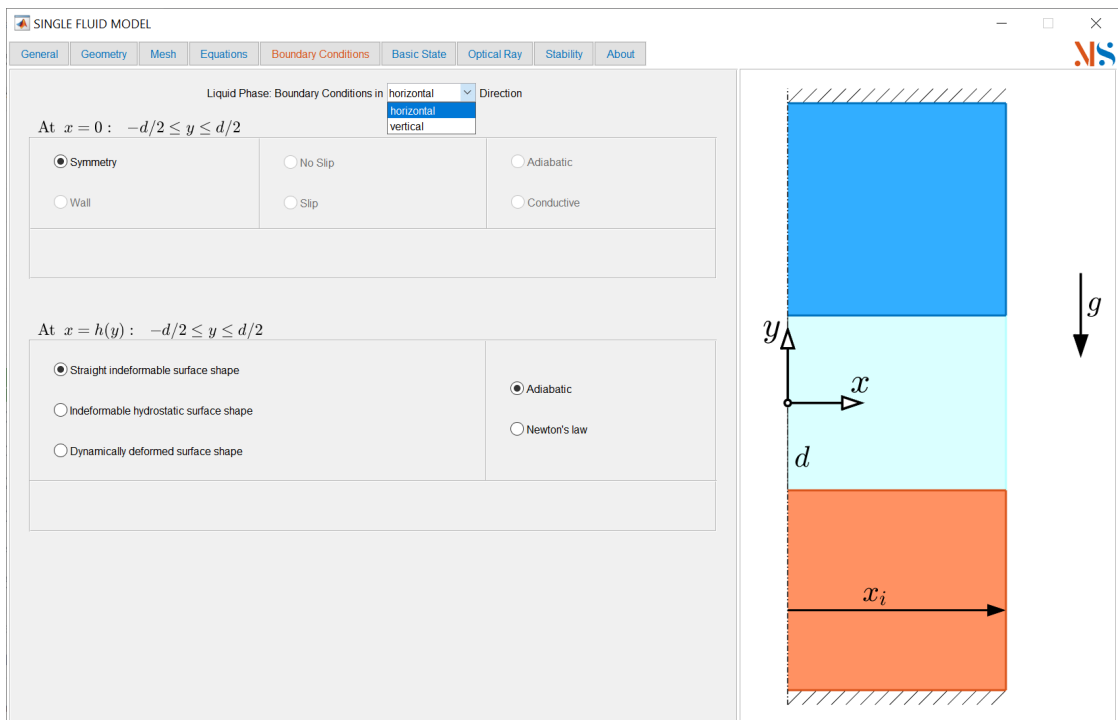
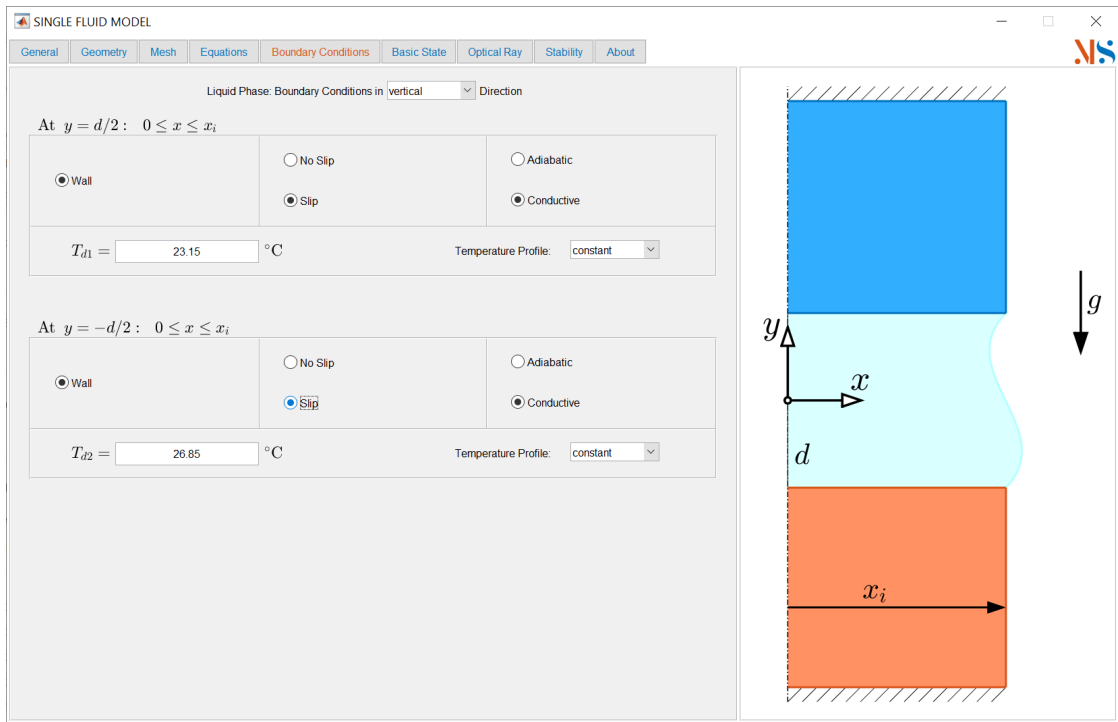
- Visualize the mesh by clicking Plot Mesh



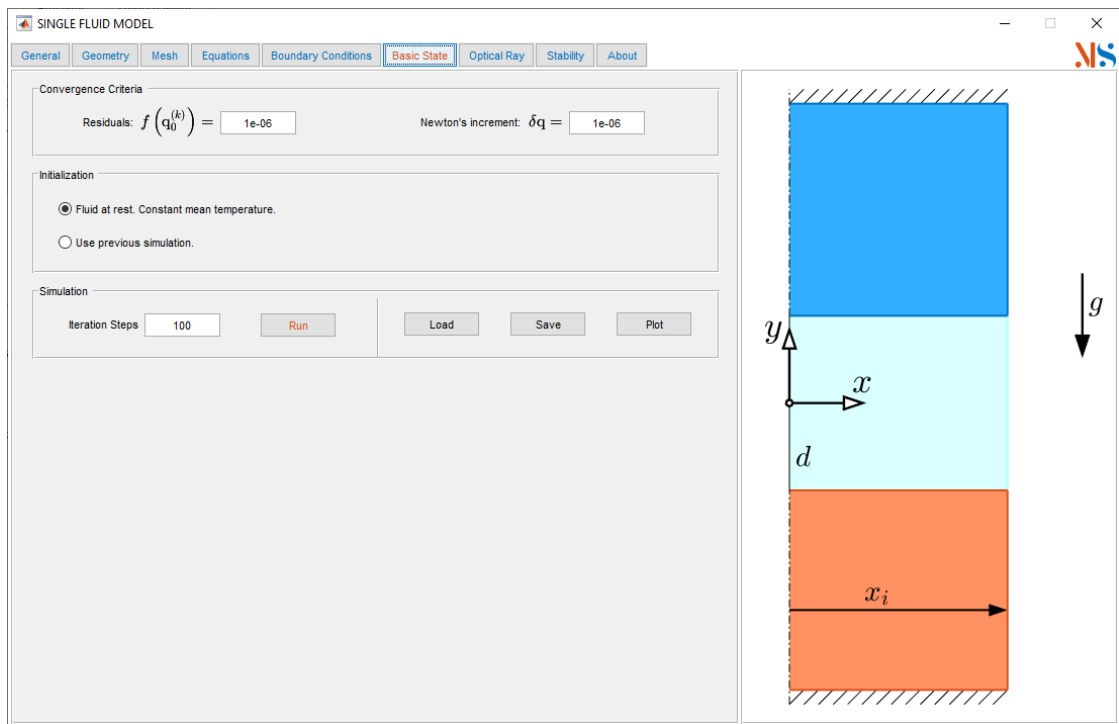
- Leave the energy equation enabled and pay attention to unticking the thermocapillary convection.



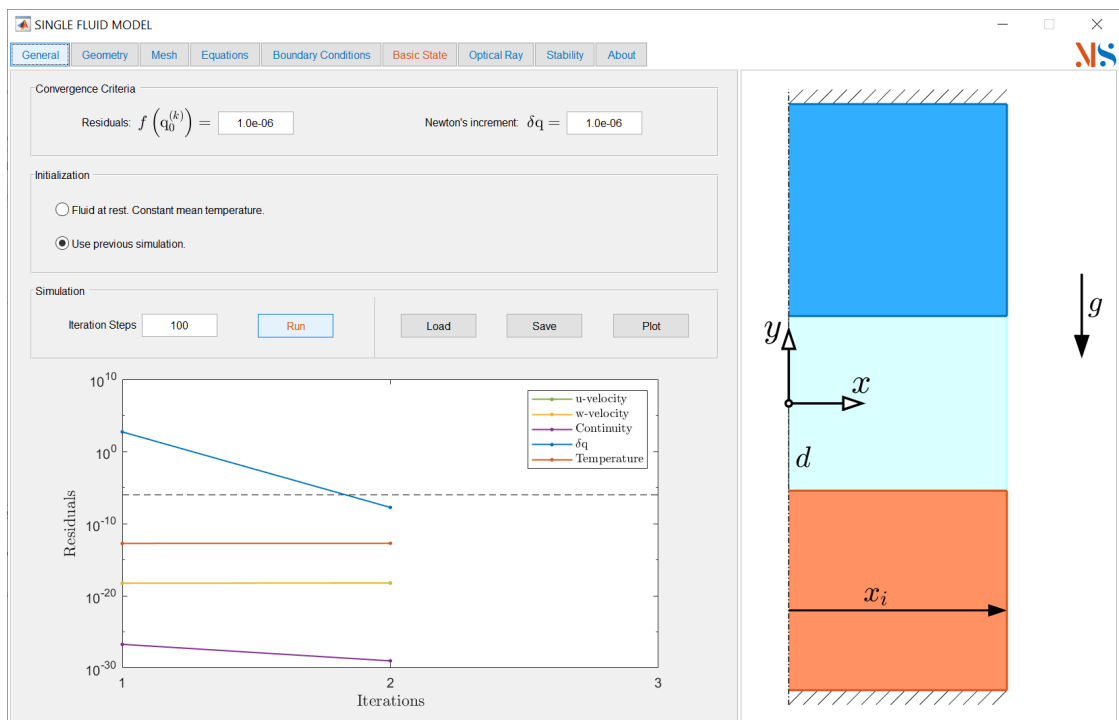
- Set the boundary conditions in the horizontal and vertical directions. Prohibit surface deformations by ticking the box **Straight indeformable surface shape**.



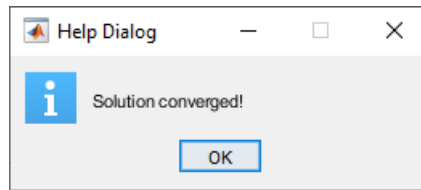
- Set the tolerances of the residuals for the Newton solver and the solution increments.



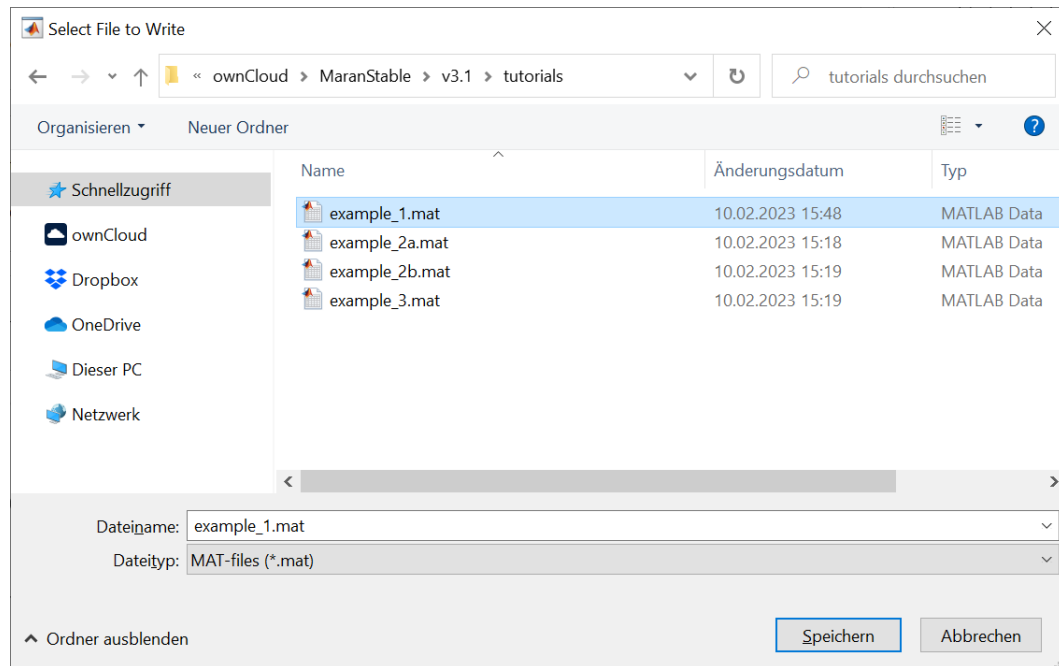
- Solve the basic state by clicking on Run.



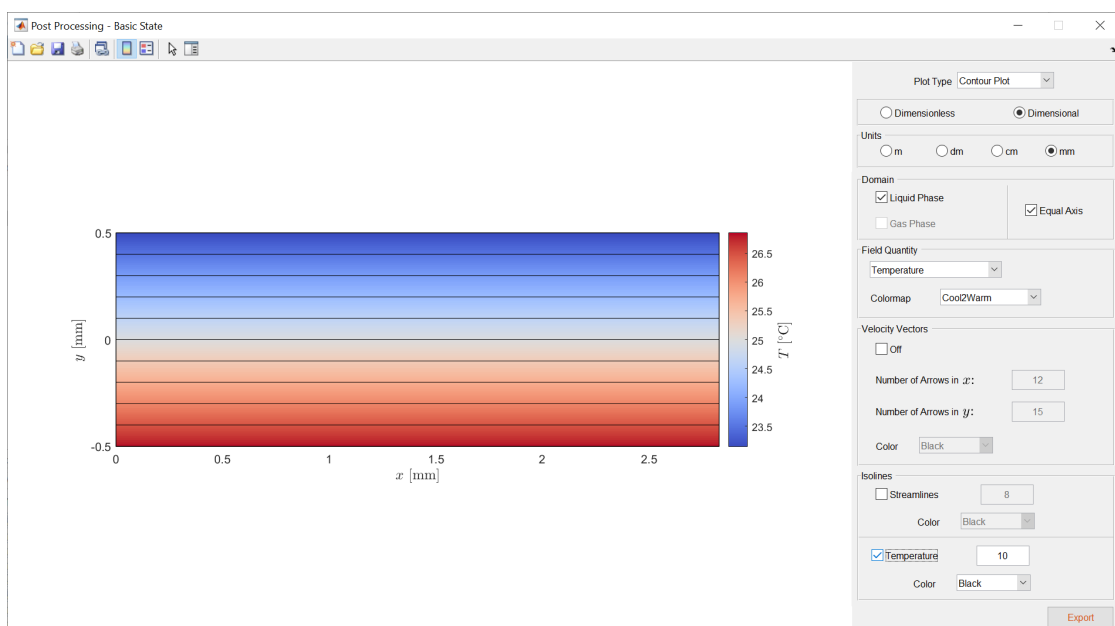
- Upon convergence, MaranStable will provide the message:



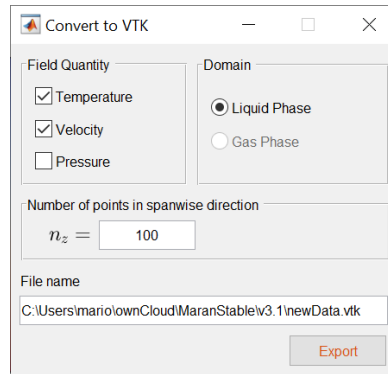
- Click on **Save** to store the converged basic state just computed.



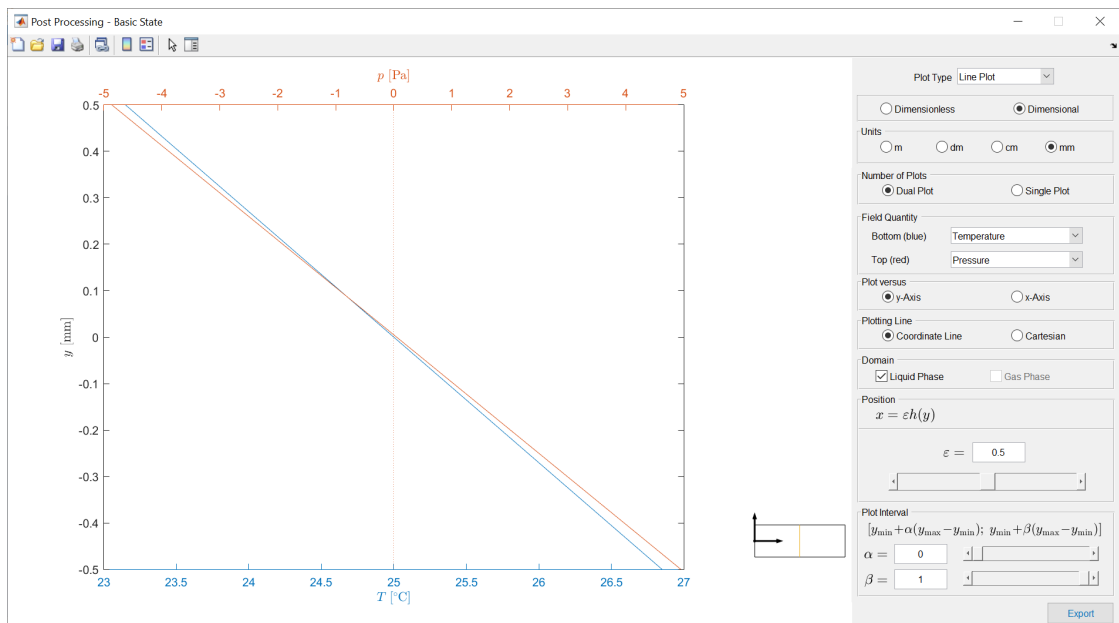
- Click on **Plot** to visualize the basic state. Choose the desired field quantity and enable or disable velocity vectors and/or isolines.



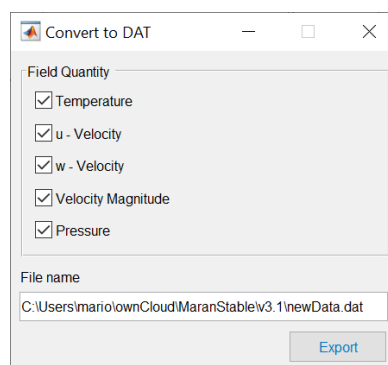
- Click on **Export** to export the solution in vtk format (compatible with ParaView).



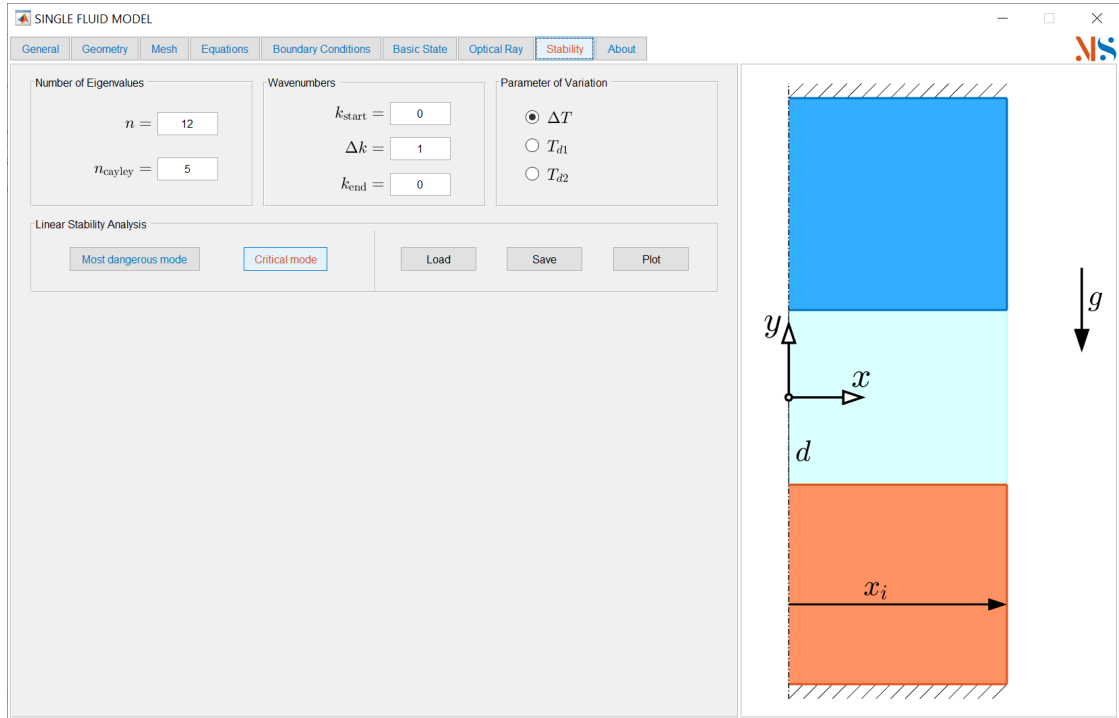
- Change the plot type to **Line Plot** and change the position (location at which the data are evaluated, yellow line) to $\varepsilon = 0.5$ to visualize the temperature and pressure at the vertical midplane.



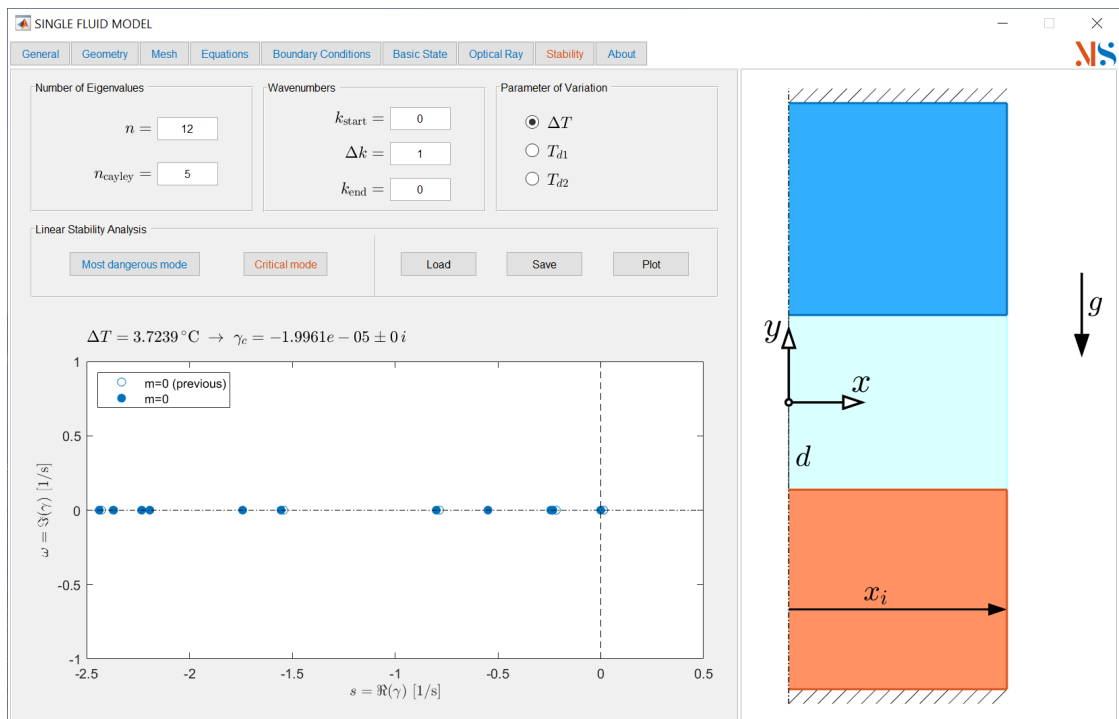
- Click on **Export** to export the solution in dat format (compatible with Xmgrace, Matlab, Excel, etc.).



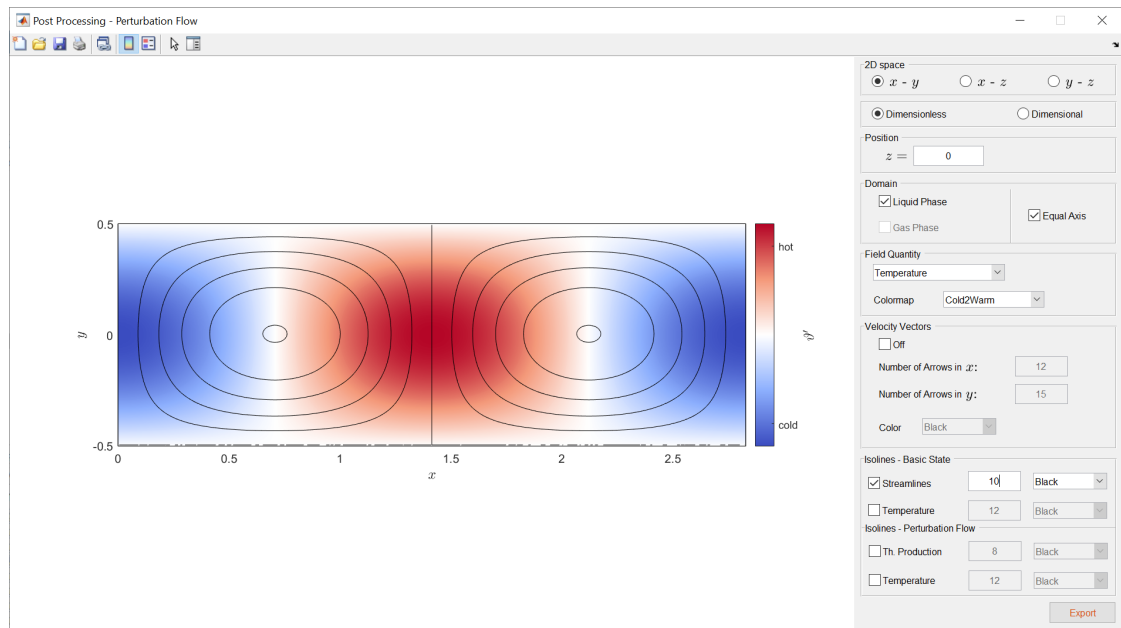
- Set up the parameters for carrying out the stability analysis. The wave number k corresponds to the homogeneous z -direction. Note: Here this is a different direction for the wavelength λ_c above, which was in the y -direction.



- Solve the linear stability analysis by clicking on **Critical Mode**. Here it arises for $k = 0$ which corresponds to a single pair (one wavelength in y direction selected above) of straight convection rolls which are infinitely extended in the z direction.



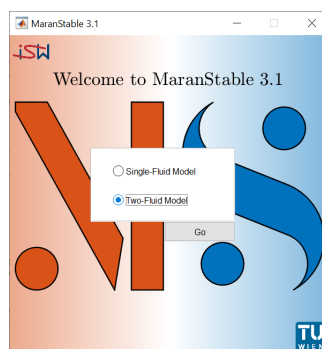
- Click on Plot to visualize the most critical mode



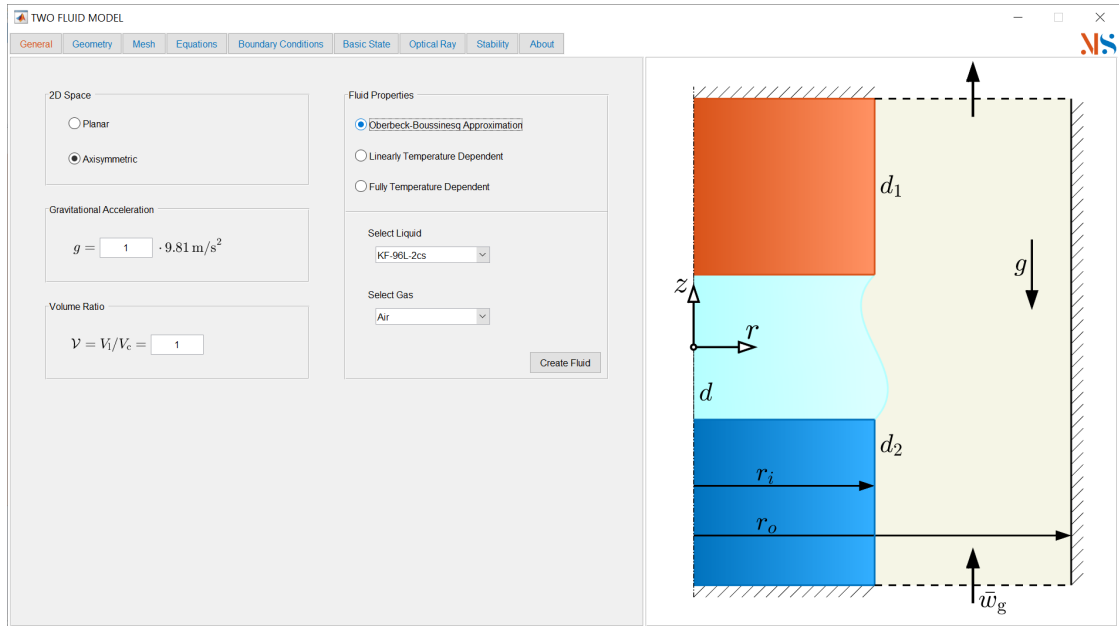
2 Instability of thermocapillary flow

The second tutorial deals with thermocapillary instability in a cylindrical droplet of silicone oil surrounded by air. Both, the liquid and the gas are assumed to be Boussinesq fluids. This tutorial corresponds to the file `example_2a.mat` in the folder `tutorials`. Its counterpart with fully temperature-dependent properties is stored in the file `example_2b.mat`.

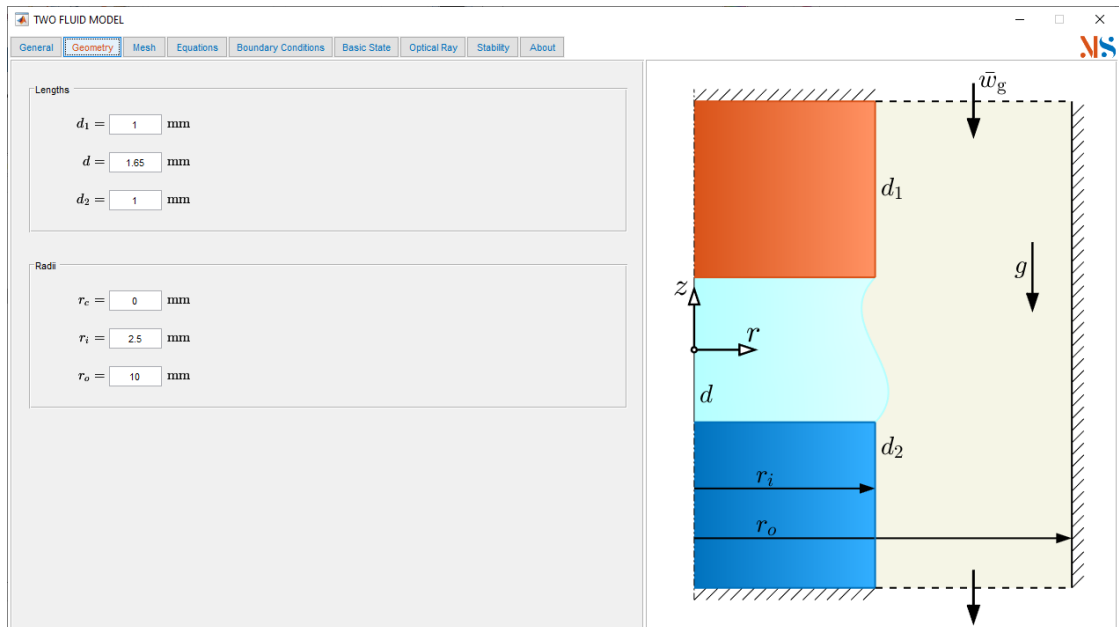
- Select the two-phase solver



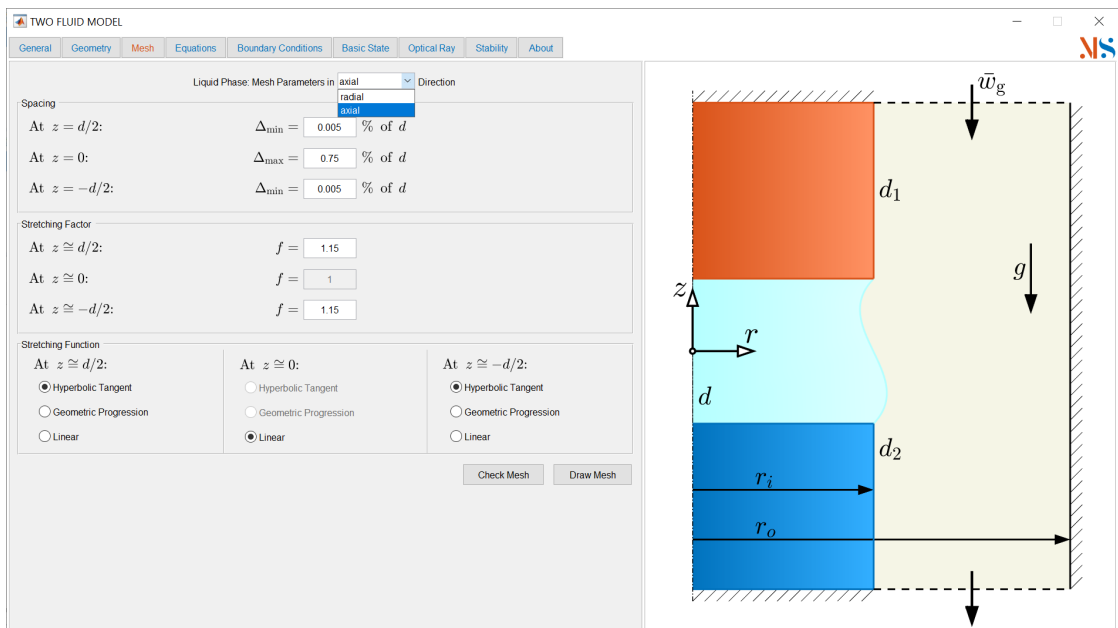
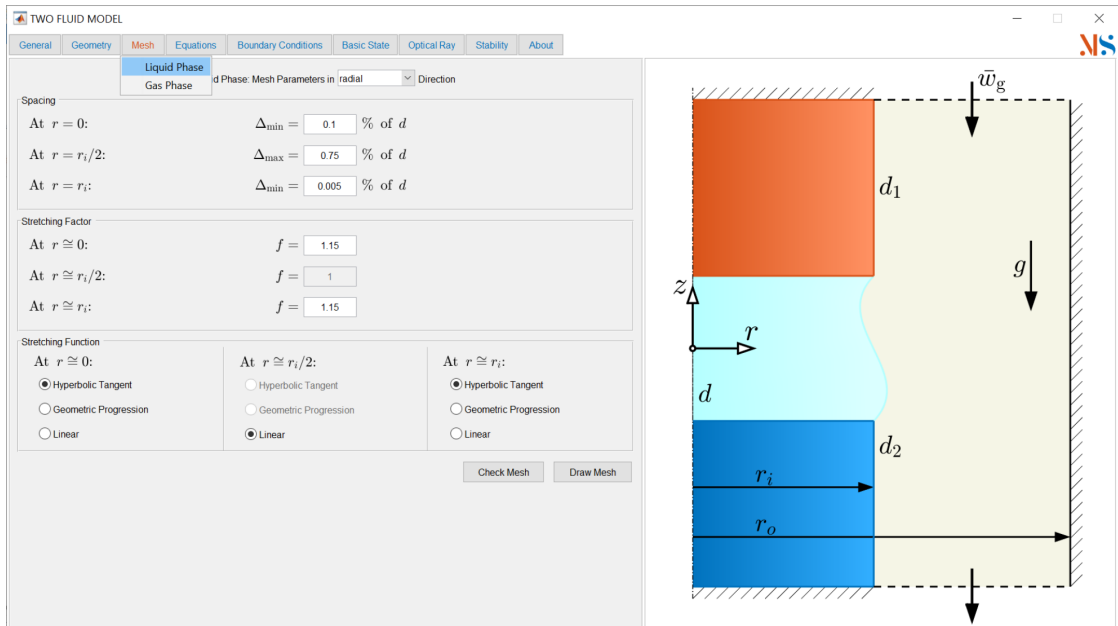
- Set up the axisymmetric geometry and the gravity acceleration. The volume ratio is set to 1 and a 2cSt-silicon oil is considered. Select the Oberbeck–Boussinesq approximation



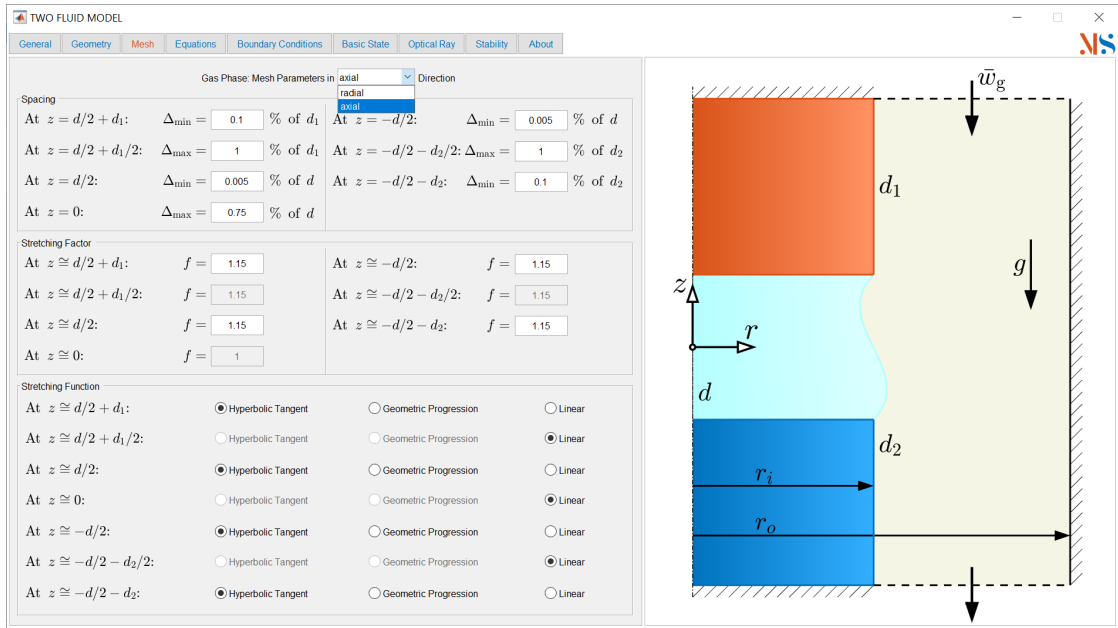
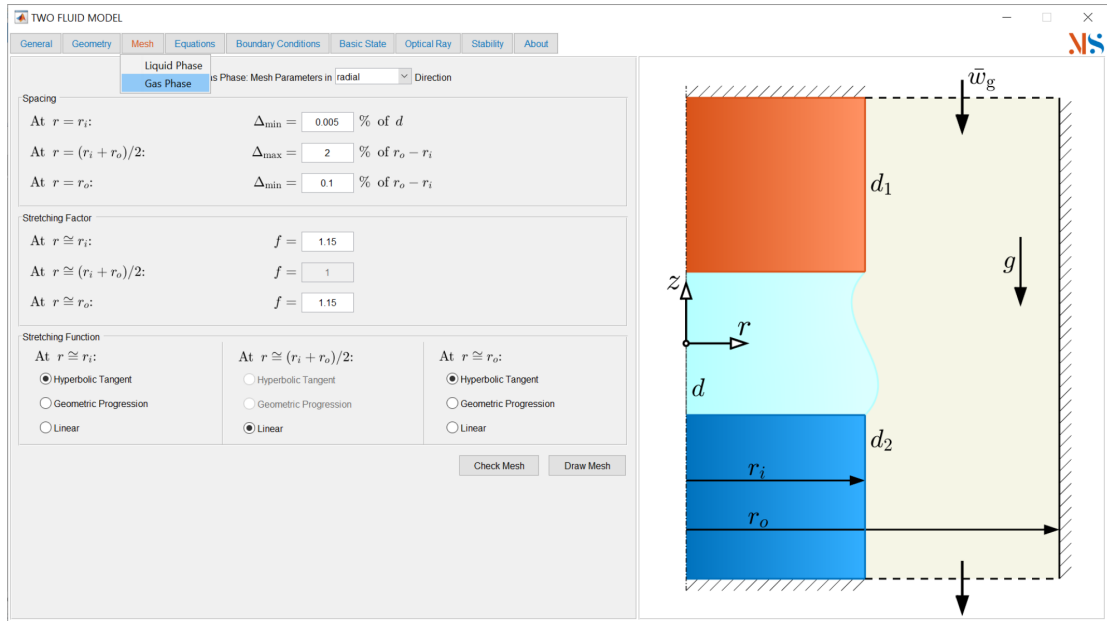
- Set up the cylindrical geometry as follows. The values are selected to coincide with the ones reported in [Stojanović et al. \(n.d.\)](#).



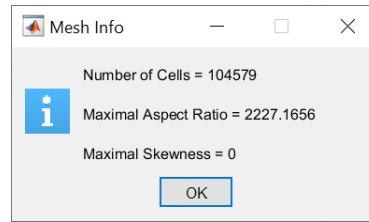
- Set up the mesh for the liquid phase by clicking on **Mesh** and **Liquid Phase**. Define the parameters for both radial and axial coordinates.



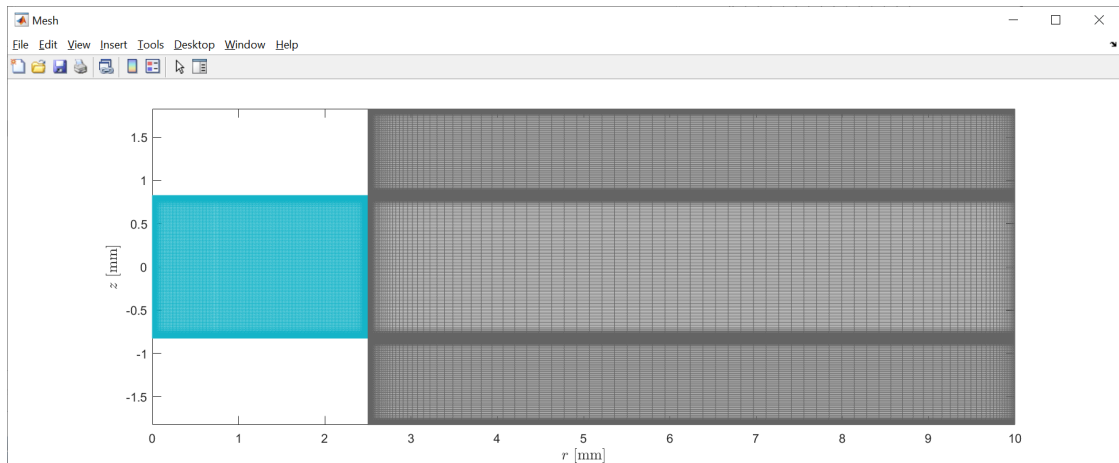
- Set up the parameters for the gas phase in an analogous manner for both radial and axial coordinates.



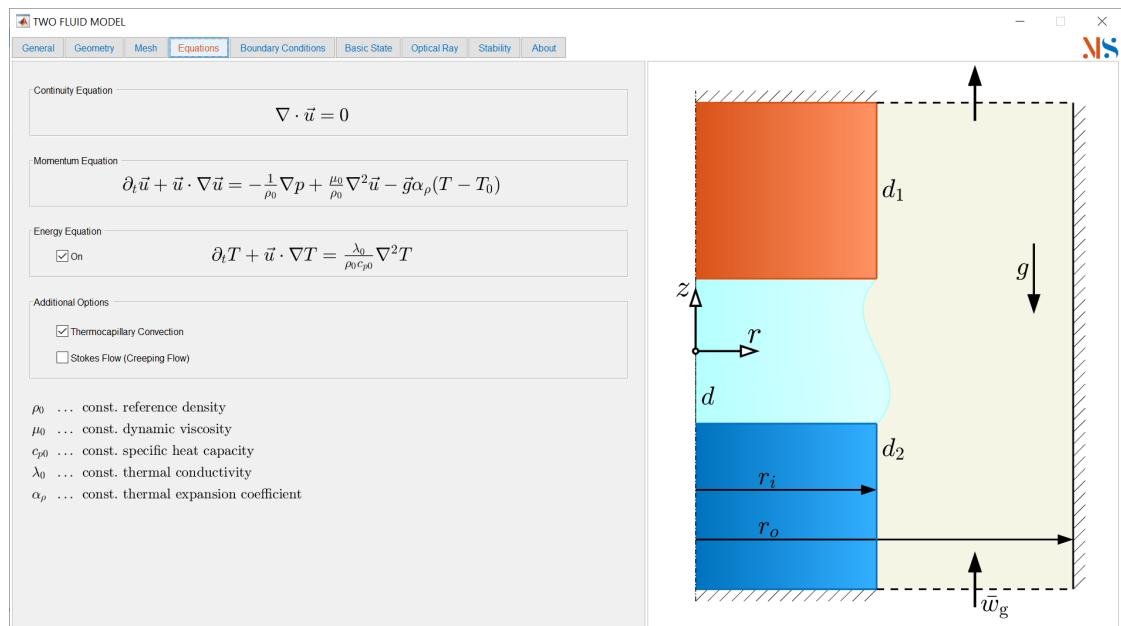
- Click on Check Mesh



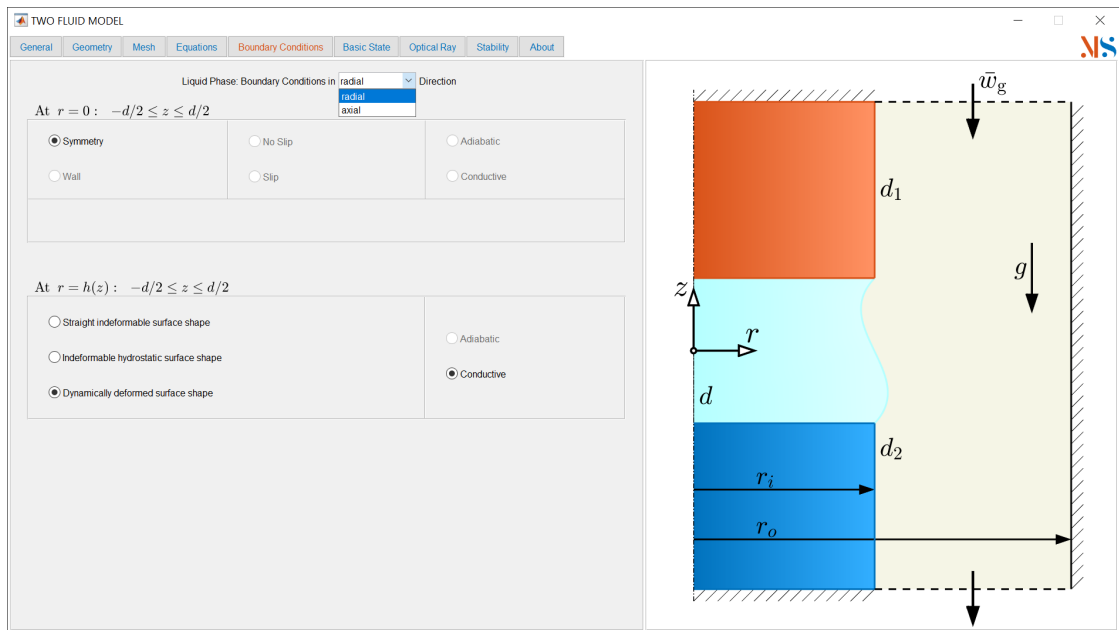
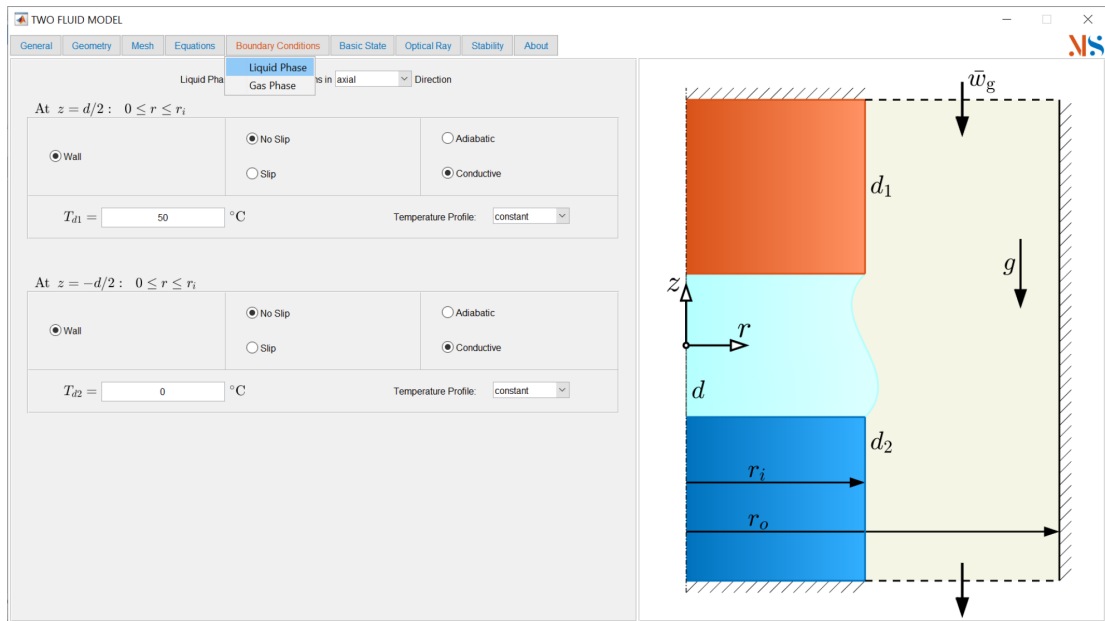
- Visualize the mesh by clicking Plot Mesh



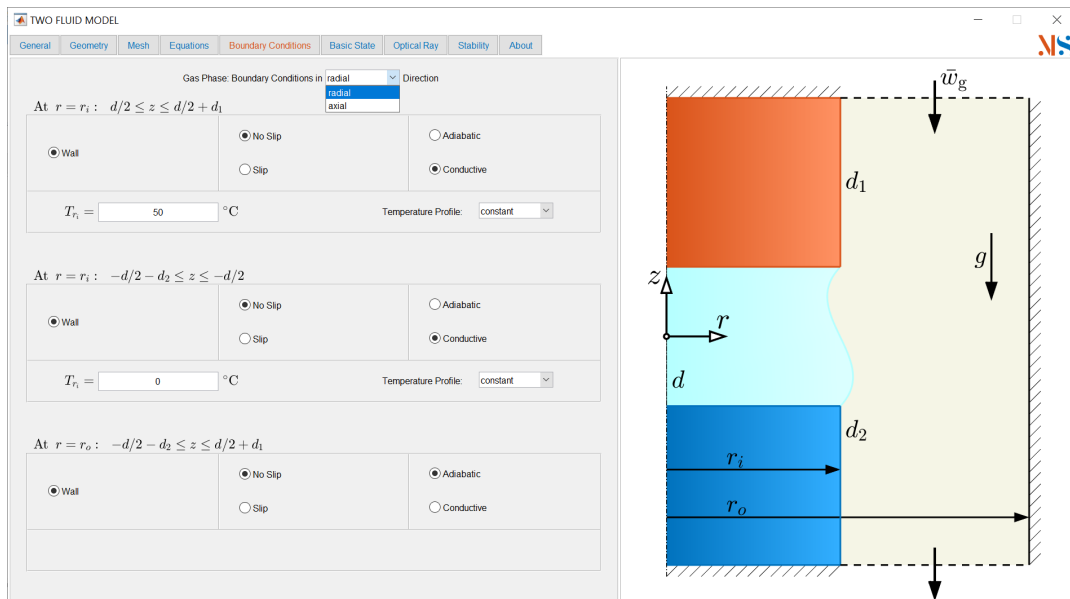
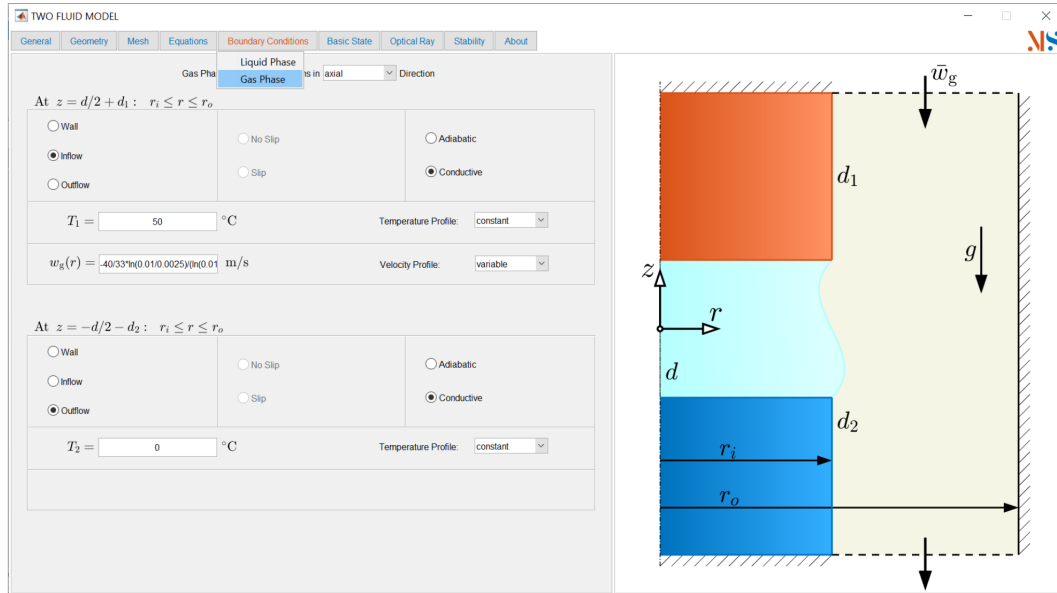
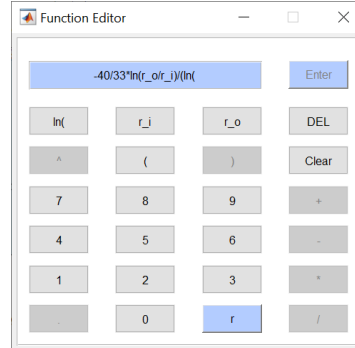
- Select the equations to solve by keeping active the energy equation and the thermocapillary convection.



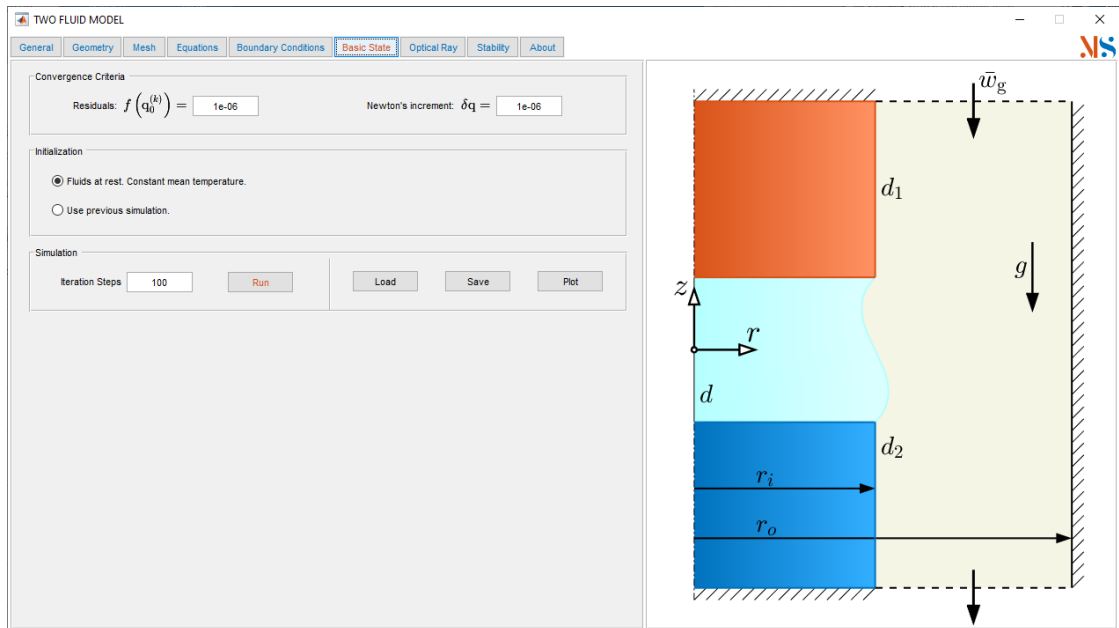
- Set the boundary conditions in the radial and axial directions for the liquid phase. Pay attention to including dynamic surface deformation.



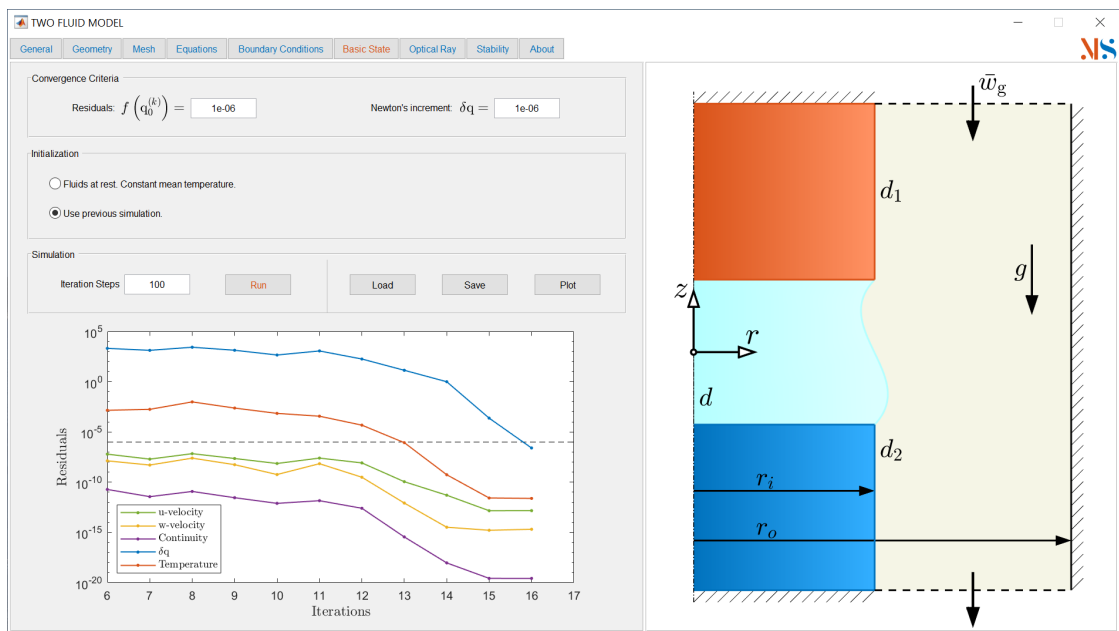
- Set the boundary conditions in the radial and axial directions for the gas phase. Select **variable** in the popup menu for the velocity profile. Use the function editor to prescribe a fully developed profile for $w_g(r)$. The implemented profile is fully developed with a mean inlet velocity of $\bar{w}_g = -(20/33) \text{ m/s}$ (Joseph, 1976).



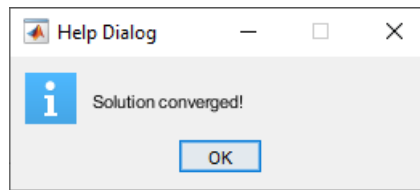
- Set the tolerances of the residuals for the Newton solver and the solution increments.



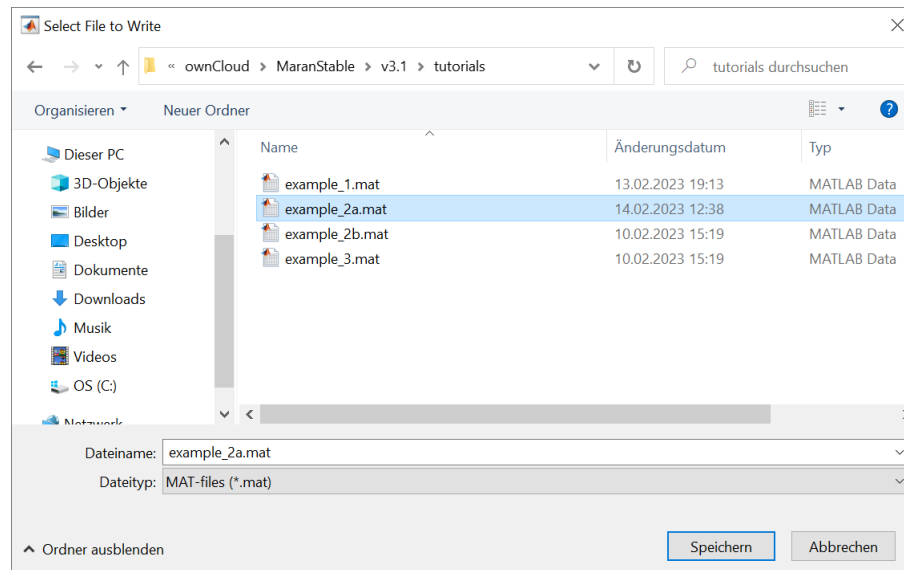
- Solve the basic state by clicking on Run.



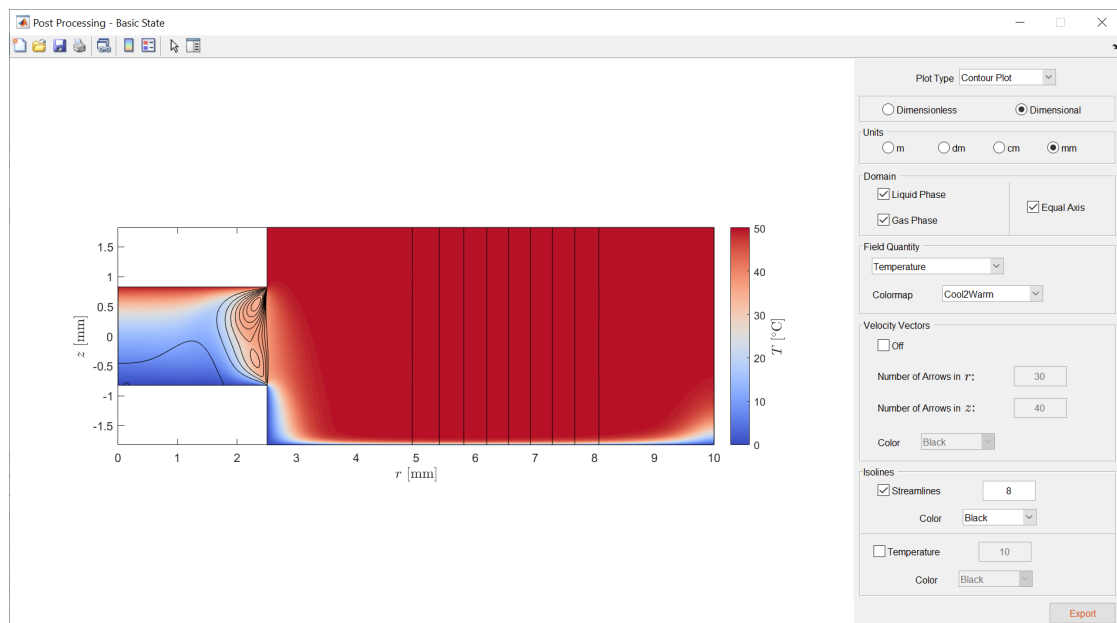
- Upon convergence, MaranStable will provide the message:



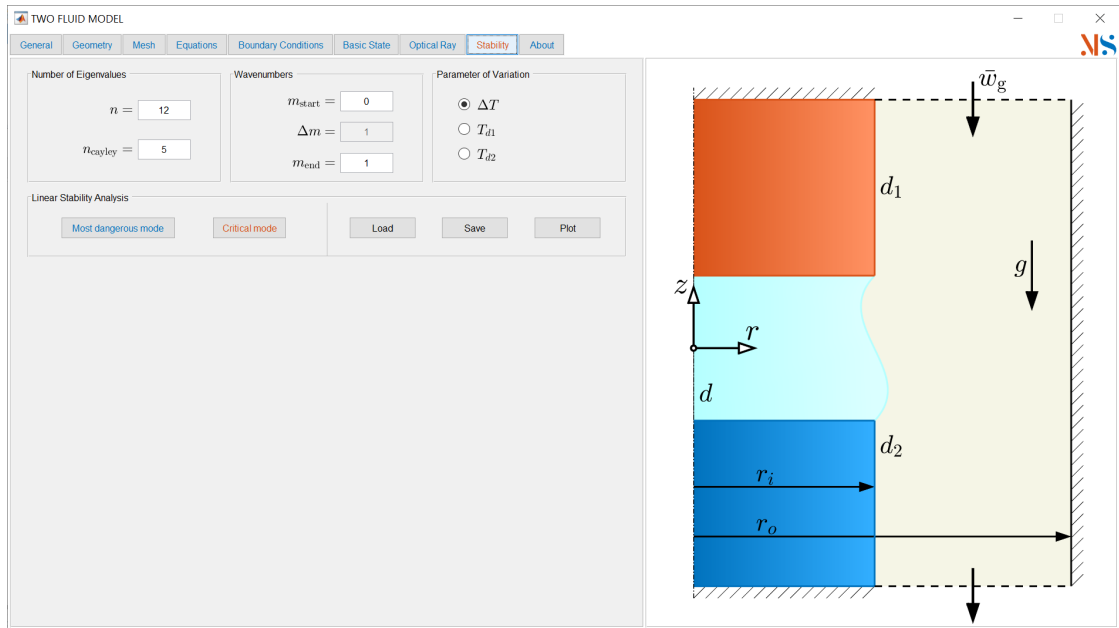
- Click on Save to store the converged basic state just computed.



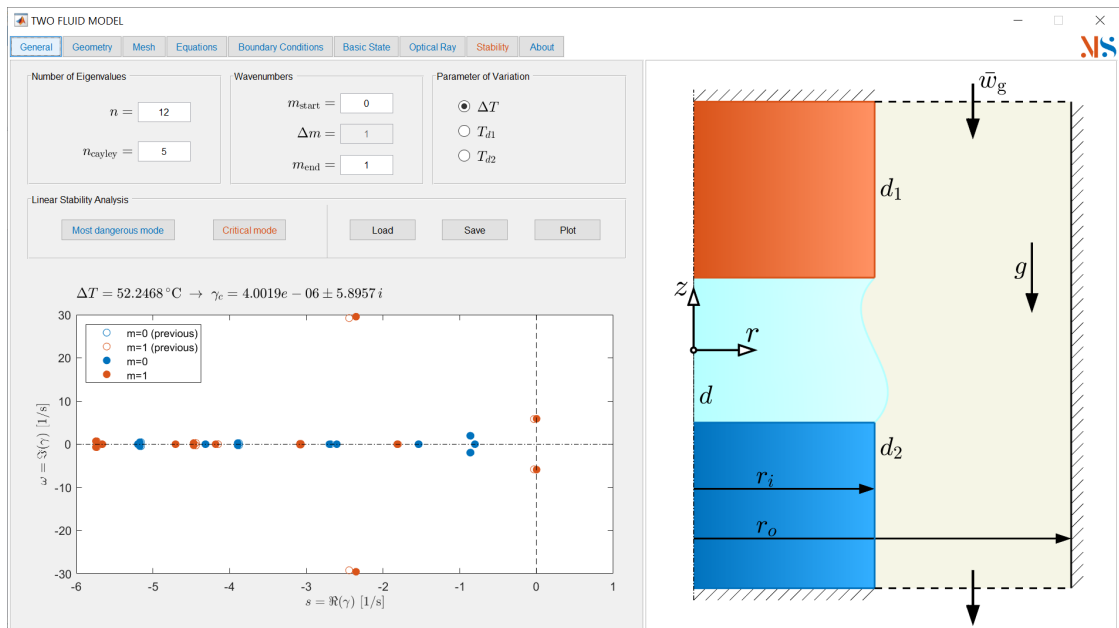
- Click on Plot to visualize the basic state.



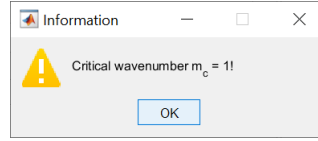
- Set up the parameters for carrying out the stability analysis.



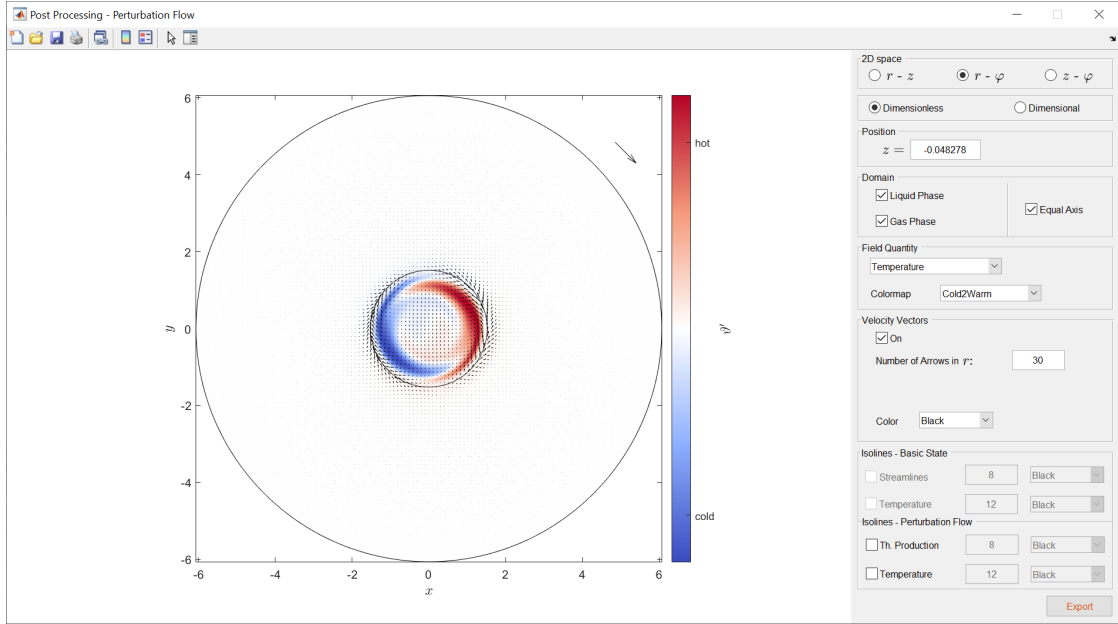
- Solve the linear stability analysis by clicking on Critical Mode.



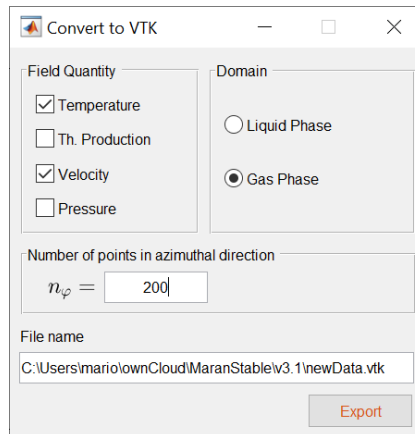
- Once the linear stability analysis is finished, **MaranStable** will provide the message:



- Click on **Plot** to visualize the most critical mode and select $r - \varphi$ in the 2D-space box.



- Export the critical mode in vtk format by clicking on **Export**. Select the field quantities to be exported and the domain (liquid or gas). Increase the number of nodes in the azimuthal direction, if necessary.

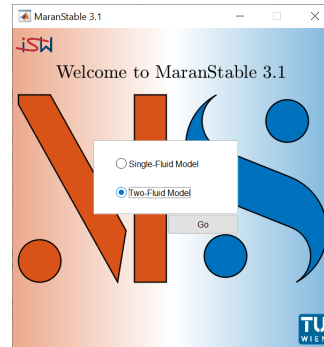


Please note that for the counterpart **example_2b.mat**, computing the basic state for $\Delta T = 50$ K with the initialization 'Fluids at rest. Constant mean temperature.' will run into an error because of the higher-order nonlinearity of the NS3 equations. To circumvent this problem, first compute the basic state with e.g. $\Delta T = 30$ K ($T_{\text{hot}} = 40^\circ\text{C}$, $T_{\text{cold}} = 10^\circ\text{C}$). After the basic state has been computed, change the boundary conditions to $\Delta T = 50$ K and use the just computed flow field as initialization.

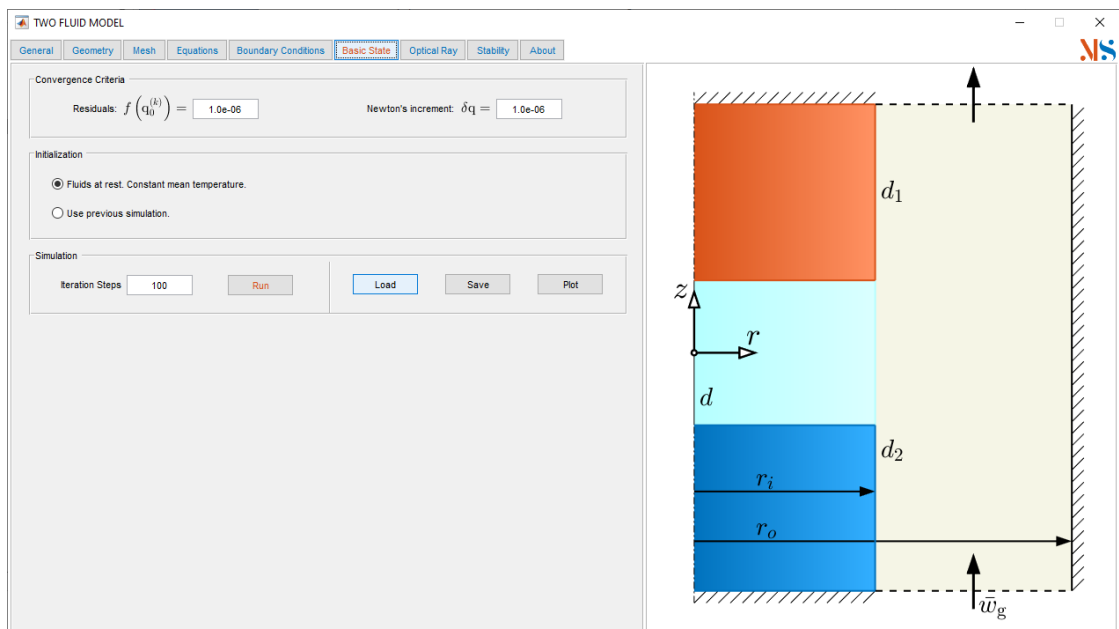
3 Optical ray tracing

The third tutorial deals with tracing an optical ray in a temperature-dependent index of refraction $\mathcal{N}(T)$. This tutorial corresponds to the file `example_3.mat` in the folder `tutorials`.

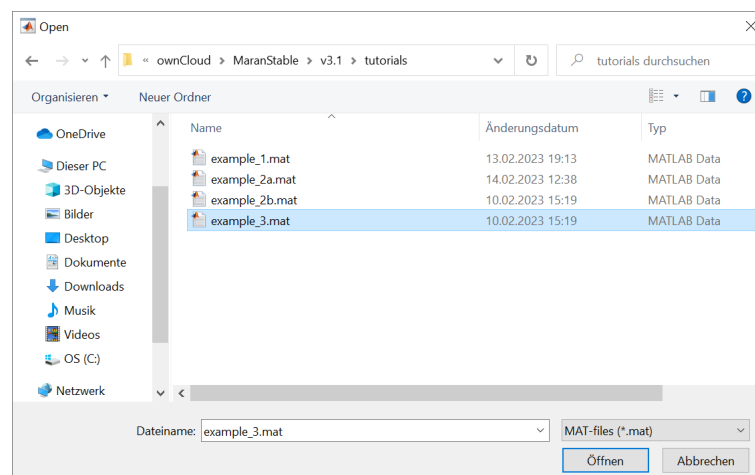
- Select the two-phase solver



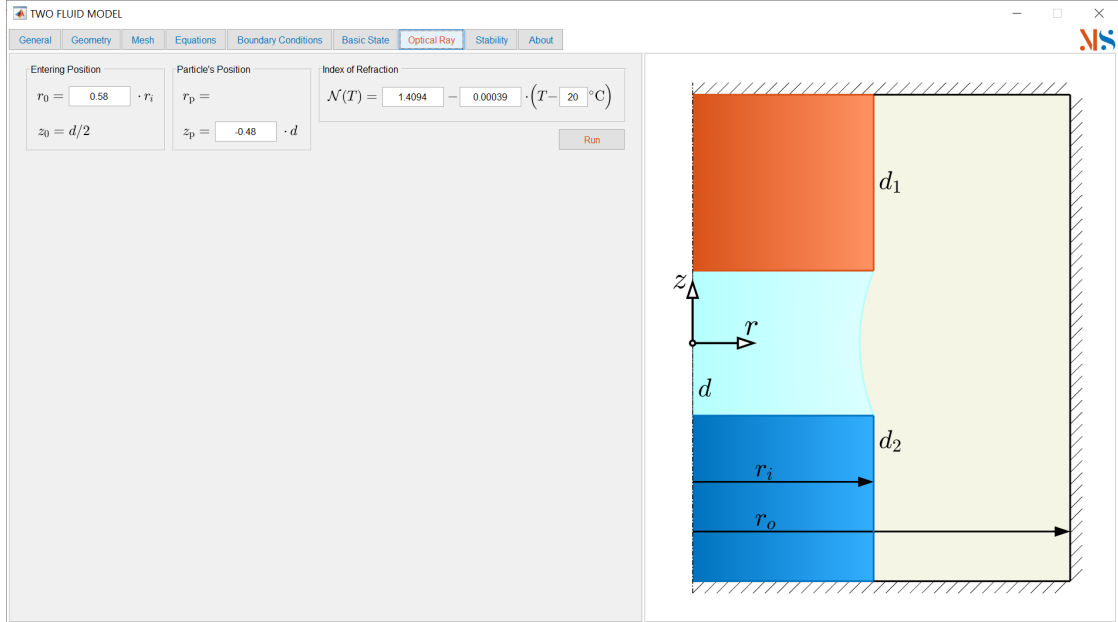
- Select the tab Basic State



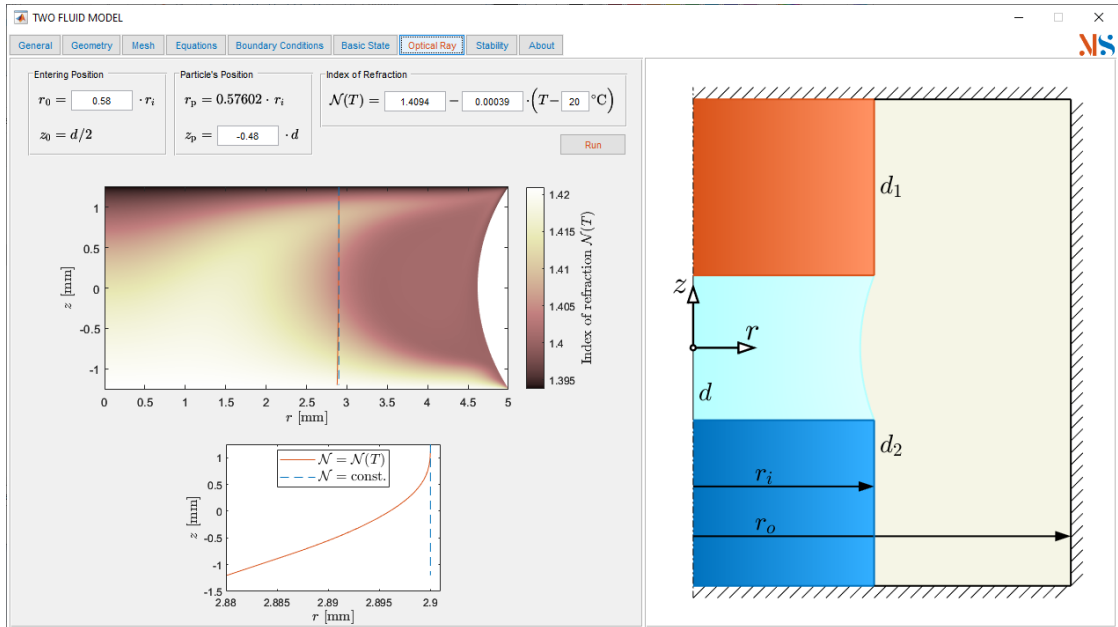
- Load the pre-computed flow field.



- Set up the ray tracing parameters including the location of the ray entering the domain and the temperature dependence of the refractive index $\mathcal{N}(T)$. Leave the default refractive index $\mathcal{N}(T)$ unchanged if dealing with silicone oils ([He et al., 2016](#)).



- Click on Run to compute the optical ray tracing.



References

- He, J., Liu, W. and Huang, Y.-X. (2016), ‘Simultaneous determination of glass transition temperatures of several polymers’, *PLoS ONE* **11**, 0151454 (12pp).
- Joseph, D. D. (1976), *Stability of Fluid motions I*, Vol. 27 of *Springer Tracts in Natural Philosophy*, Springer, Berlin, Heidelberg.
- Stojanović, M., Romanò, F. and Kuhlmann, H. C. (n.d.), ‘High-Prandtl-number thermocapillary liquid bridges with dynamically deformed interface: Effect of an axial gas flow on the linear stability’. In preparation.