Direct Numerical Simulations of Annular Internal Condensing Flows

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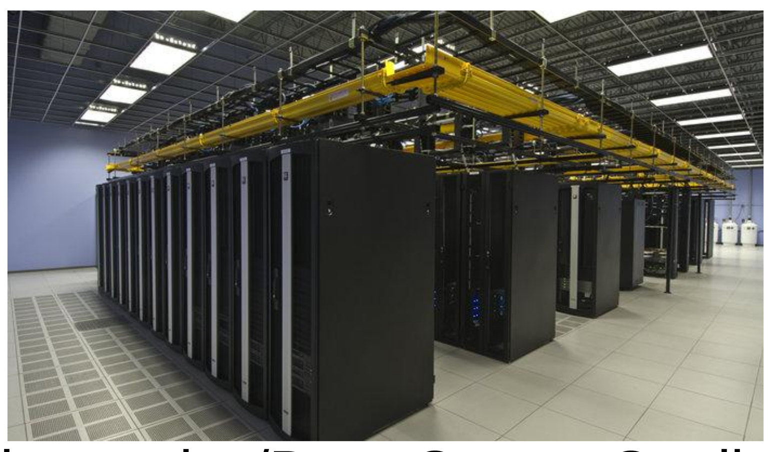
Acknowledgements: NSF - CBET-1033591

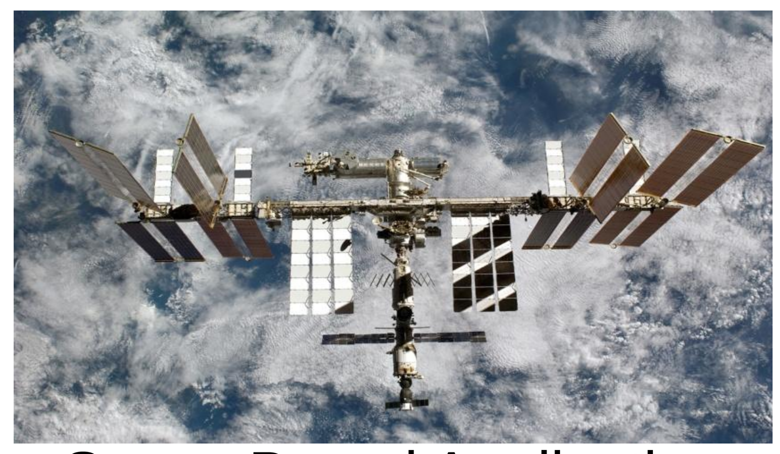
COMSOL CONFERENCE BOSTON 2013

Emerging Trends in Phase-Change Flow Applications



Electronics/Data Center Cooling

http://www.pgal.com/portfolio/rice-university-data-center



Space Based Application

http://spaceflightsystems.grc.nasa.gov

Figure 1. Condensing and Boling Flow Applications

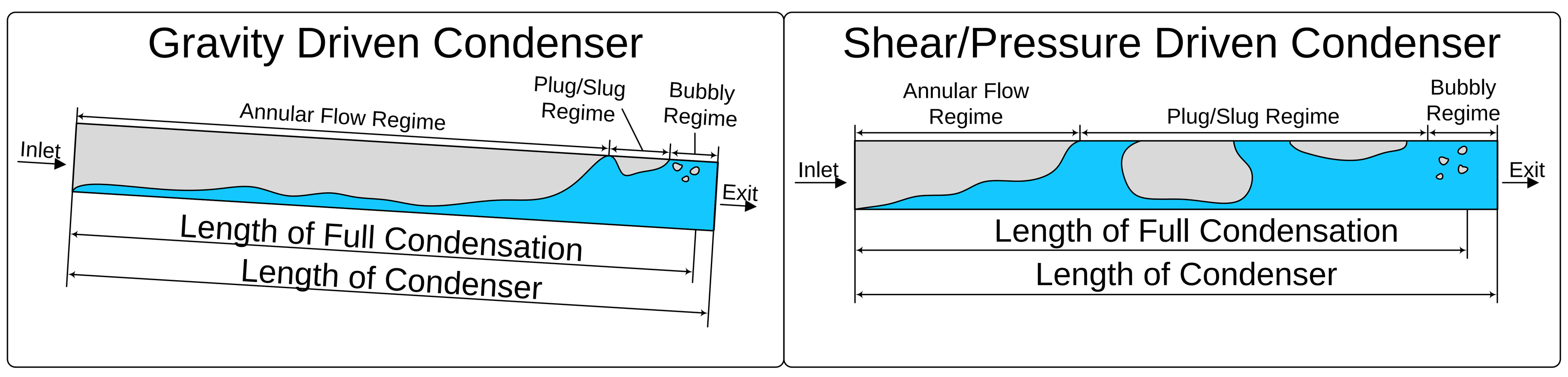


Figure 2. Schematic of gravity driven/assisted versus shear/pressure driven condenser

Gravity Driven/Assisted Features

- Ground Based - Vertical/ Inclined Configuration
- Large Annular Regime Lengths
- Thermally/Hydrodynamically efficient
- Still not sufficiently efficient for electronic cooling applications

Shear/Pressure Driven Features

- Horizontal Configuration/Reduced Gravity
- Smaller Annular Regime Lengths
- Thermally/Hydrodynamically inefficient
- Extreme sensitivity to ever present noise and lack of repeatability

Prediction capability needed for scientific understanding and successfully designing high heat-transfer condensers and boilers.

Computational Approach

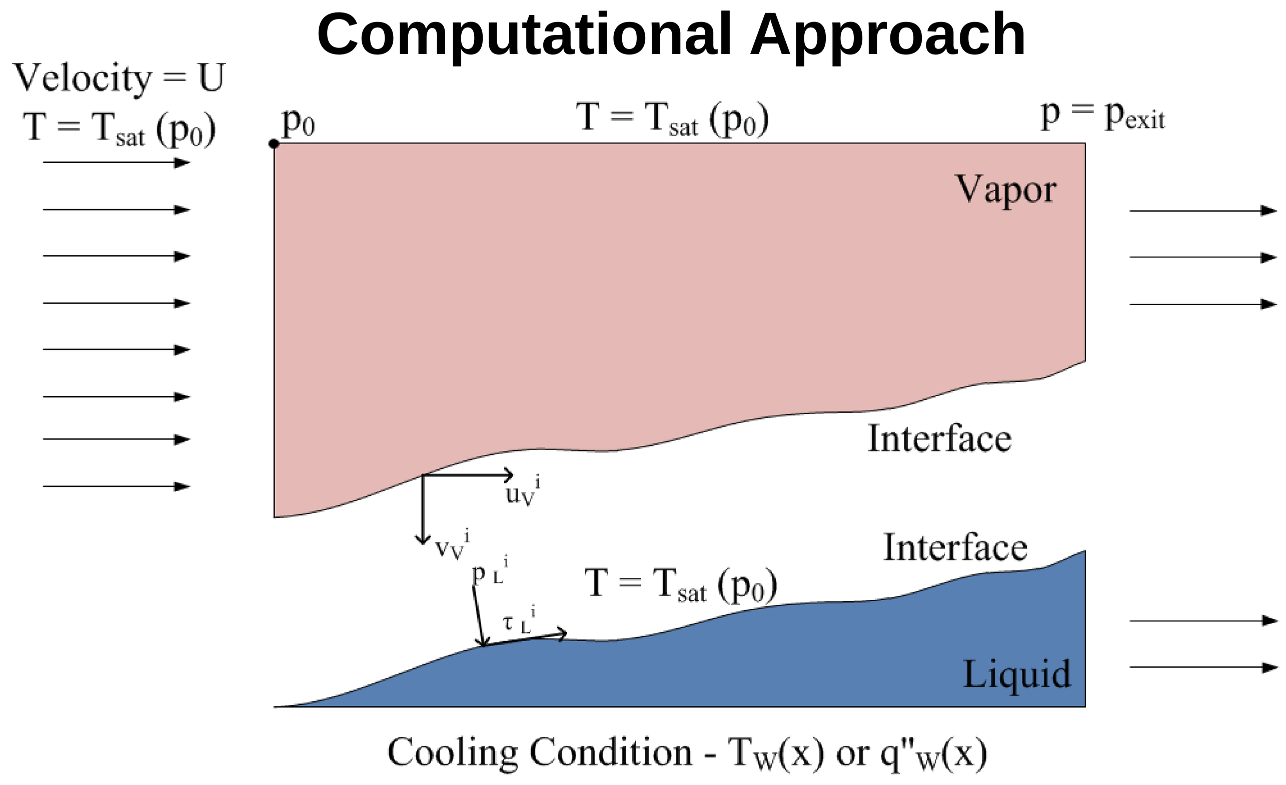


Figure 3. Schematic of a condensing flow problem showing boundary conditions. A sharp interface model along with single-phase solution approach for separately solving (using COMSOL solvers) for liquid and vapor domain flows are used.

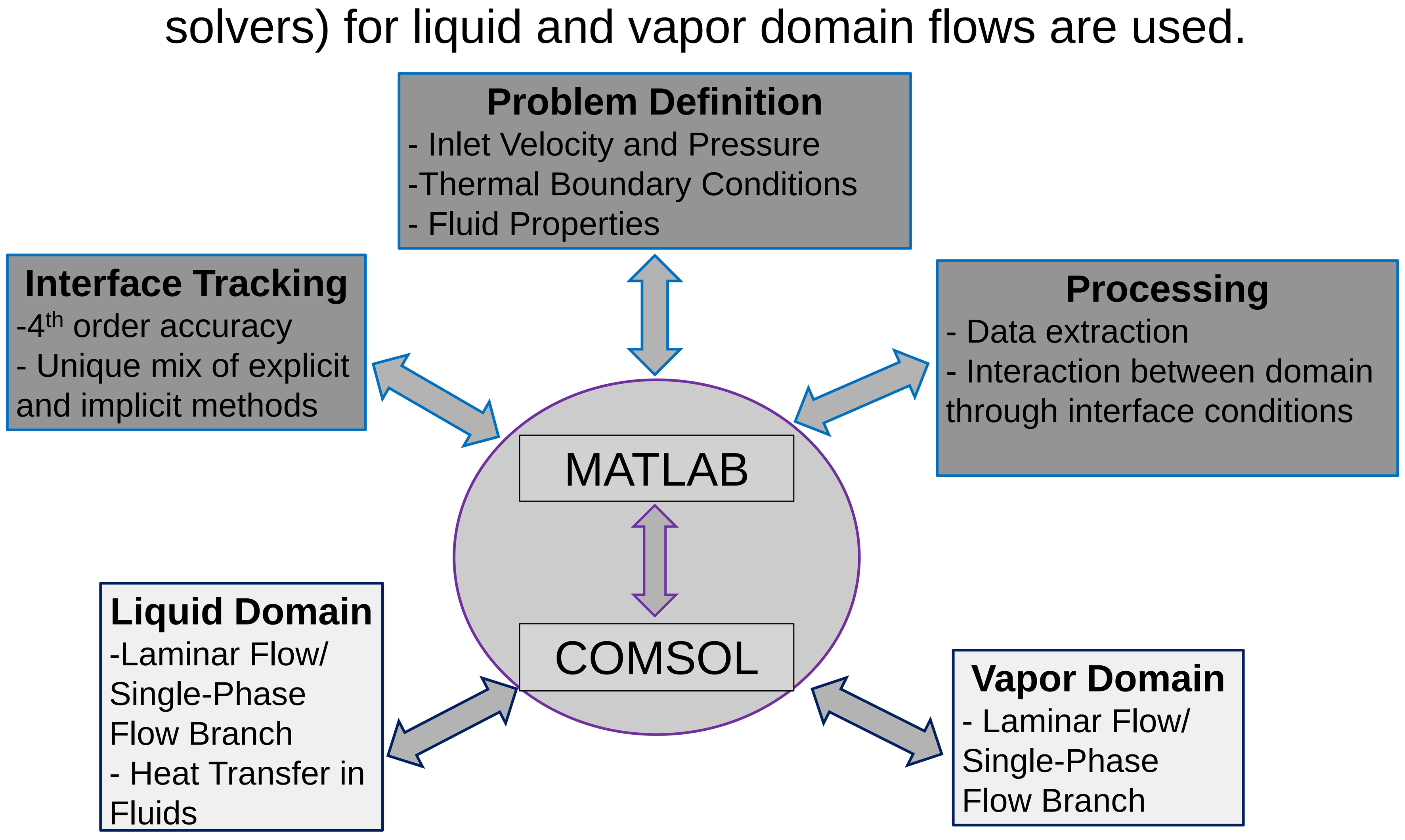


Figure 4. Computational algorithm showing the interaction of COMSOL and MATLAB for solving the condensing flow problem. Interface location and the solutions for the two domains are iteratively improved by the use of interface conditions.

Results

Shear Driven Condensing Flow

Gravity Driven Condensing Flow

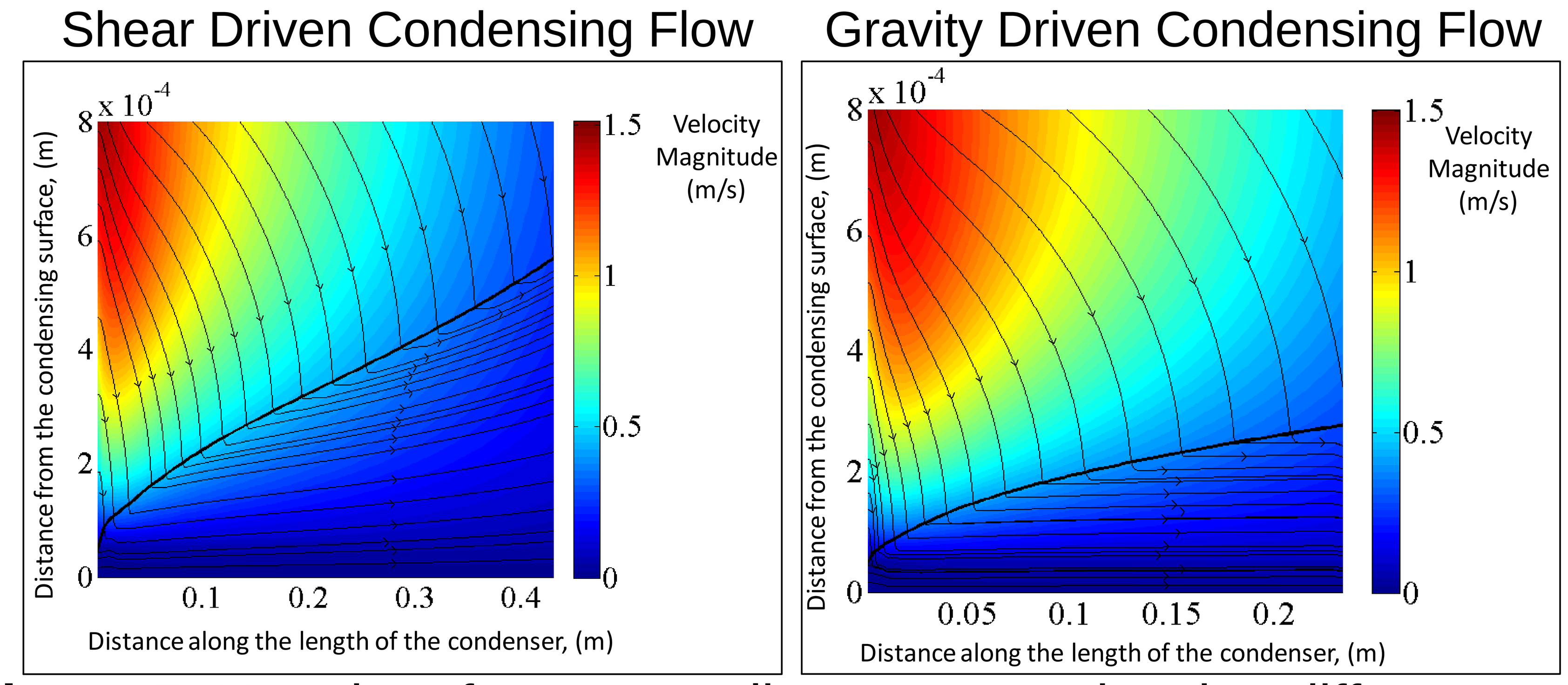
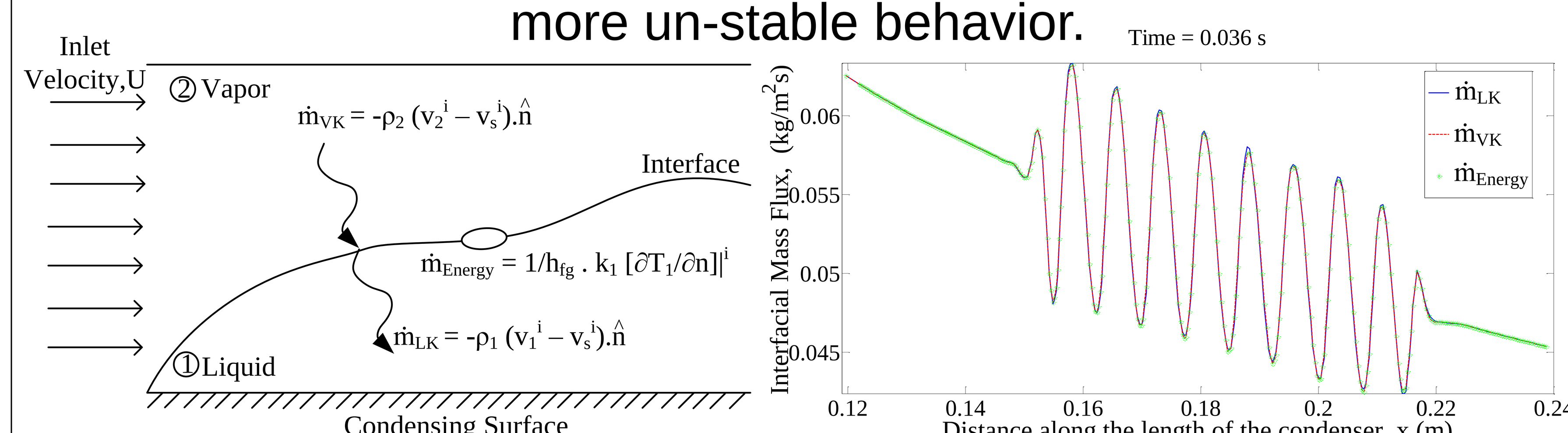


Figure 5. Near interface streamline patterns showing differences in flow physics for a condensing channel flow between a shear-driven and a 2 degree inclined gravity-assisted [1] condition. FC- 72 vapor ($\dot{m}_{in}$ = 0.4 g/s, ΔT = 17.45 deg C, and h = 2 mm) is used. Shear driven case streamlines show a tendency to lift-off - indicating a more un-stable behavior.



(a). (b)

Figure 6. **(a)** Condensing flow schematic showing the three independent methods of computing the interfacial mass fluxes (kg/m²-s) which need to be made accurately equal.**(b)** Interfacial mass fluxes at any specific time instant during an unsteady simulation show our ability to achieve **very good equality.** *The other fixed grid techniques are typically unable to accurately satisfy this condition due to their use of a "band" approach to track the interface.*

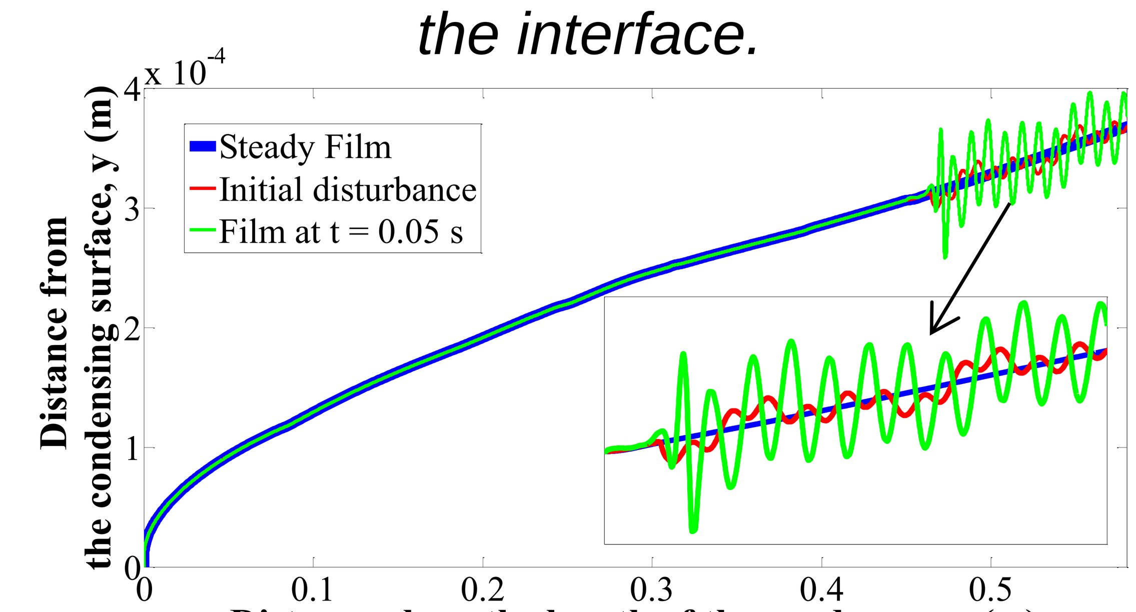


Figure 7. The 0 m ≤ x ≤ 0.57 m steady and unsteady simulations for an experimental case. The initial disturbance at t = 0 s (with three different wavelengths) and its unsteady evolution at t = 0.05 s are shown. The steepening and growing wave front around $x \sim x_A$ has been assessed to indicate transition from annular to non-annular regimes (on-going work).

Conclusions

- **Fundamental 2-D steady/unsteady predictive tools** for flow condensation have been developed.
- Excellent accuracy in satisfaction of interface conditions in the presence of waves – ***an accomplishment for phase-change free surface problems.***
- The scientific tool has an ability **to handle different non-uniform and realistic boundary conditions** of real world condenser situations.
- A path forward towards identifying the **transition from annular to non-annular regimes is proposed (on-going)**. This can be used to **design next generation high heat-transfer condensers and boilers** ([2]) .

References

1. S. Mitra, Development Of One-Dimensional And Two-Dimensional Computational Tools To Simulate Steady Internal Condensing Flows In Terrestrial And Zero-Gravity Environments, PhD Thesis, Michigan Technological University, Houghton, MI, 2012.
2. A. Narain,et.al., Results for Hight Heat-flux Realizations in Innovative Operations of Milli-meter Scale Condensers and Boilers, Proceedings of the 11th International ISHMT-ASME Heat and Mass Transfer Conference, 2013.