Novel Hybrid Heat Pipe
for Space and Ground Applications

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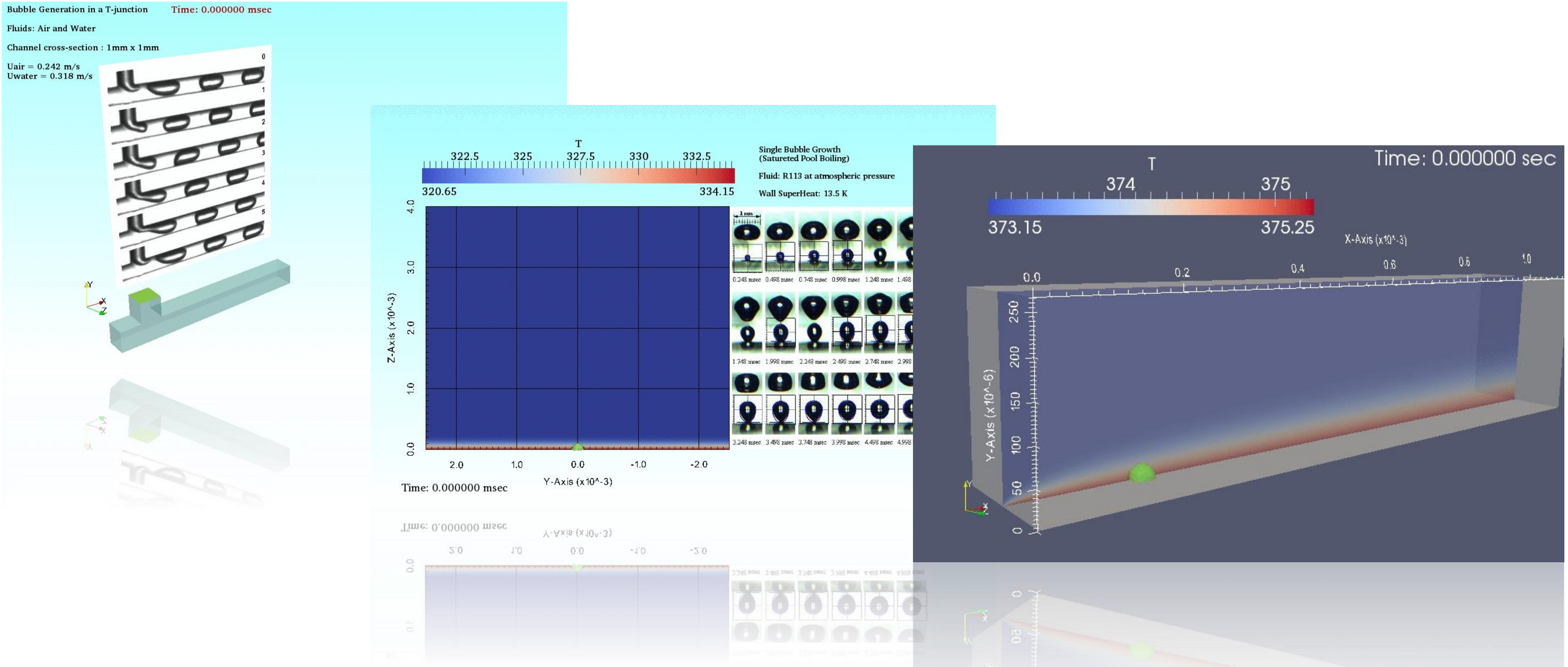
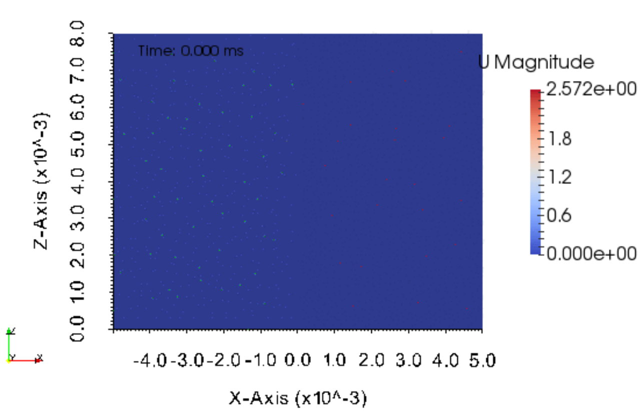
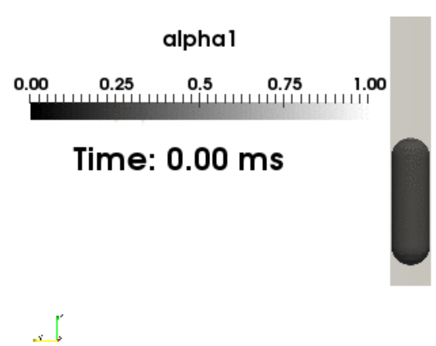
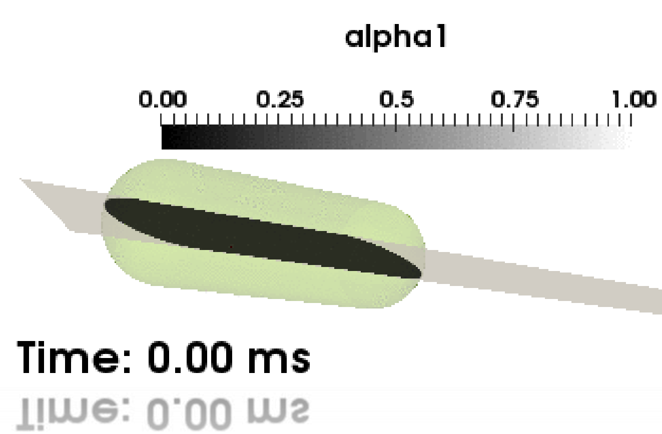


Enhanced VOF Simulations of Phase-changing Interfaces







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LIBERTINE
LINEAR POWER SYSTEMS

SUSTAINABLE ENGINE SYSTEMS

Dr. Anastasios Georgoulas

University of Brighton
Advanced Engineering Centre

ADVANCED PROPULSION CENTRE UK
UNIVERSITY OF BRIGHTON
ICE Thermal Efficiency Spoke

HyHP Novel Hybrid Heat Pipe for Space and Ground Applications

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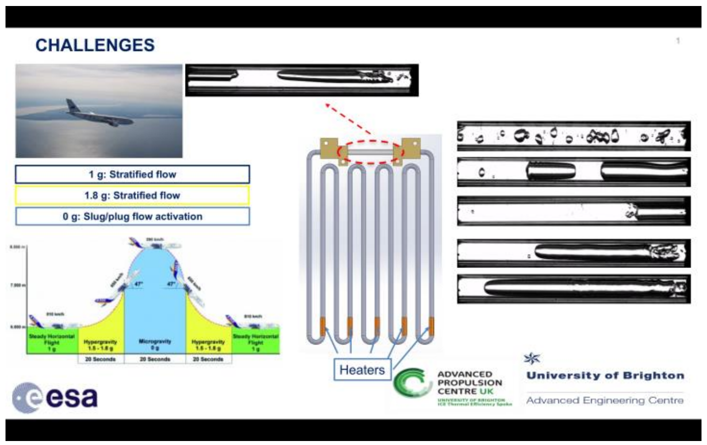
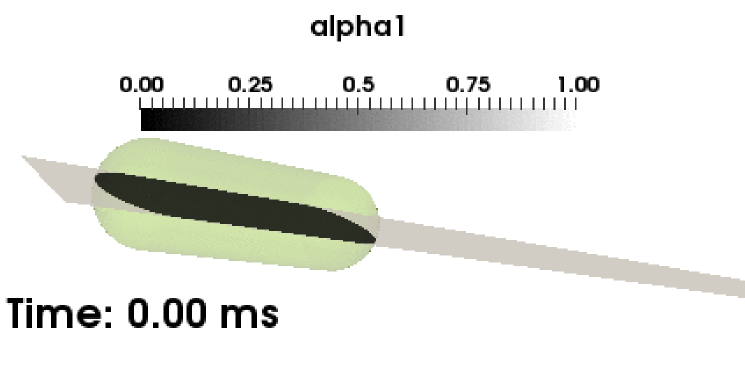
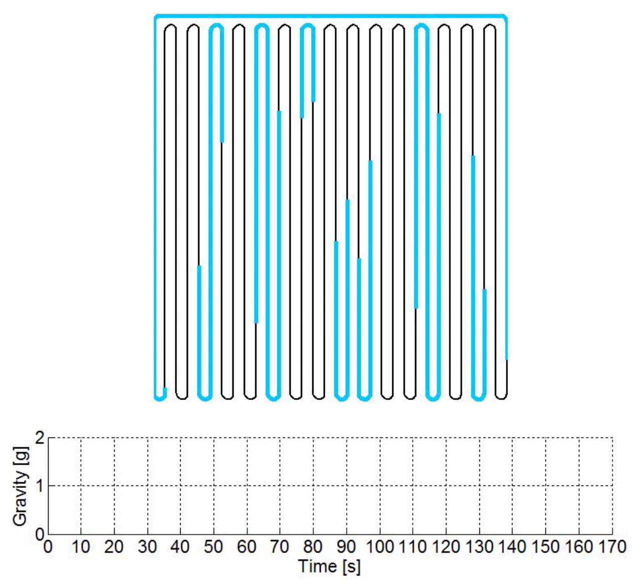
Experiments



VOF "DNS" Simulations



Lumped Parameter 1-D Modelling



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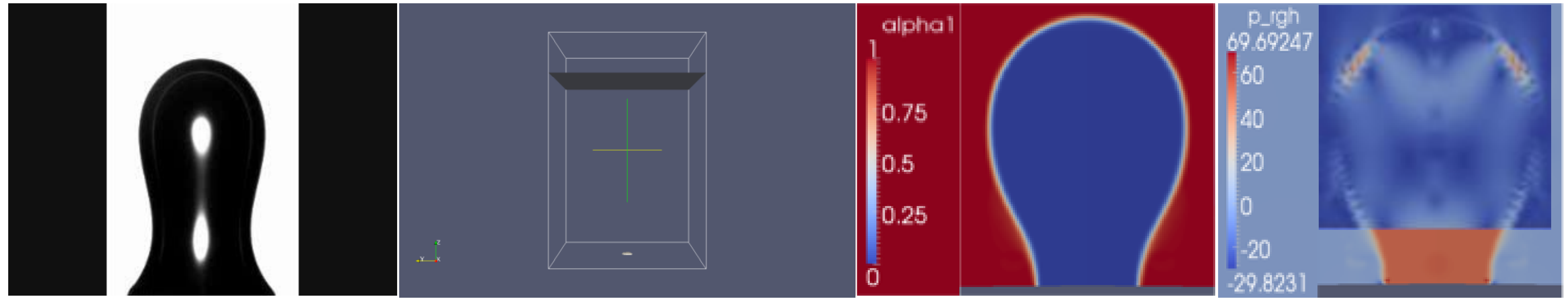
Modelling Approach Overview

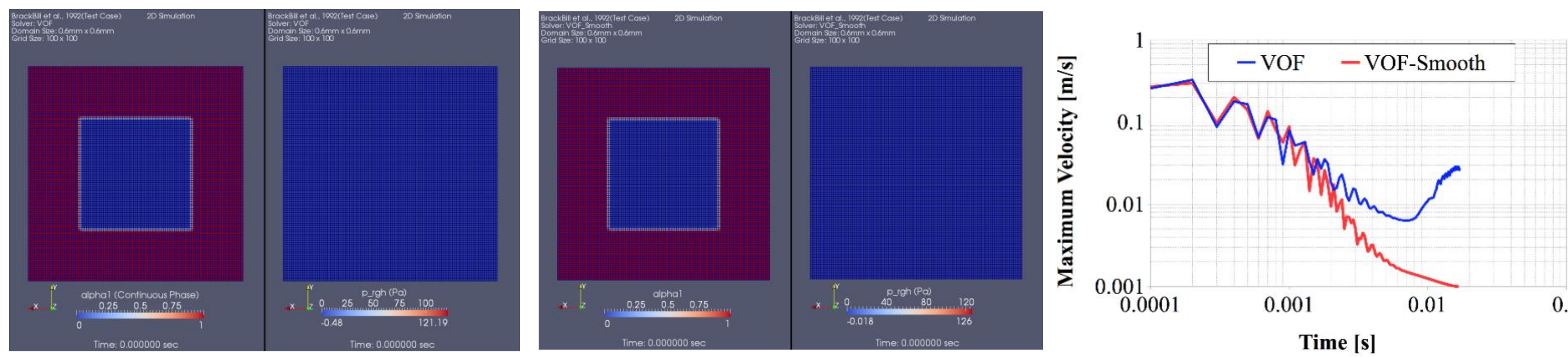
Original VOF-based solver (OpenFOAM)

OpenFOAM
VOF



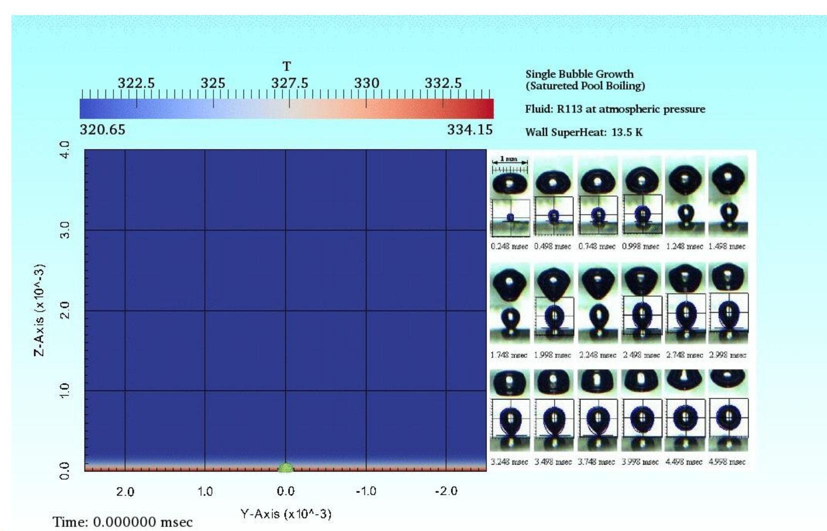
Treatment for spurious velocities dampening

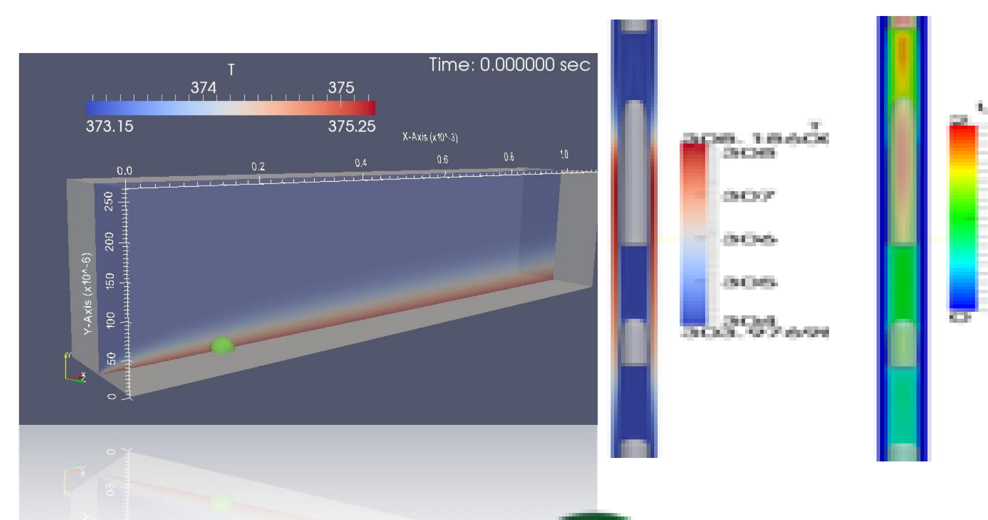
Improved OpenFOAM
VOF



Addition of Energy Equation and Phase-change model of Hardt & Wondra (2008)

Improved OpenFOAM
VOF coupled
Phase-change
(boiling and condensation)





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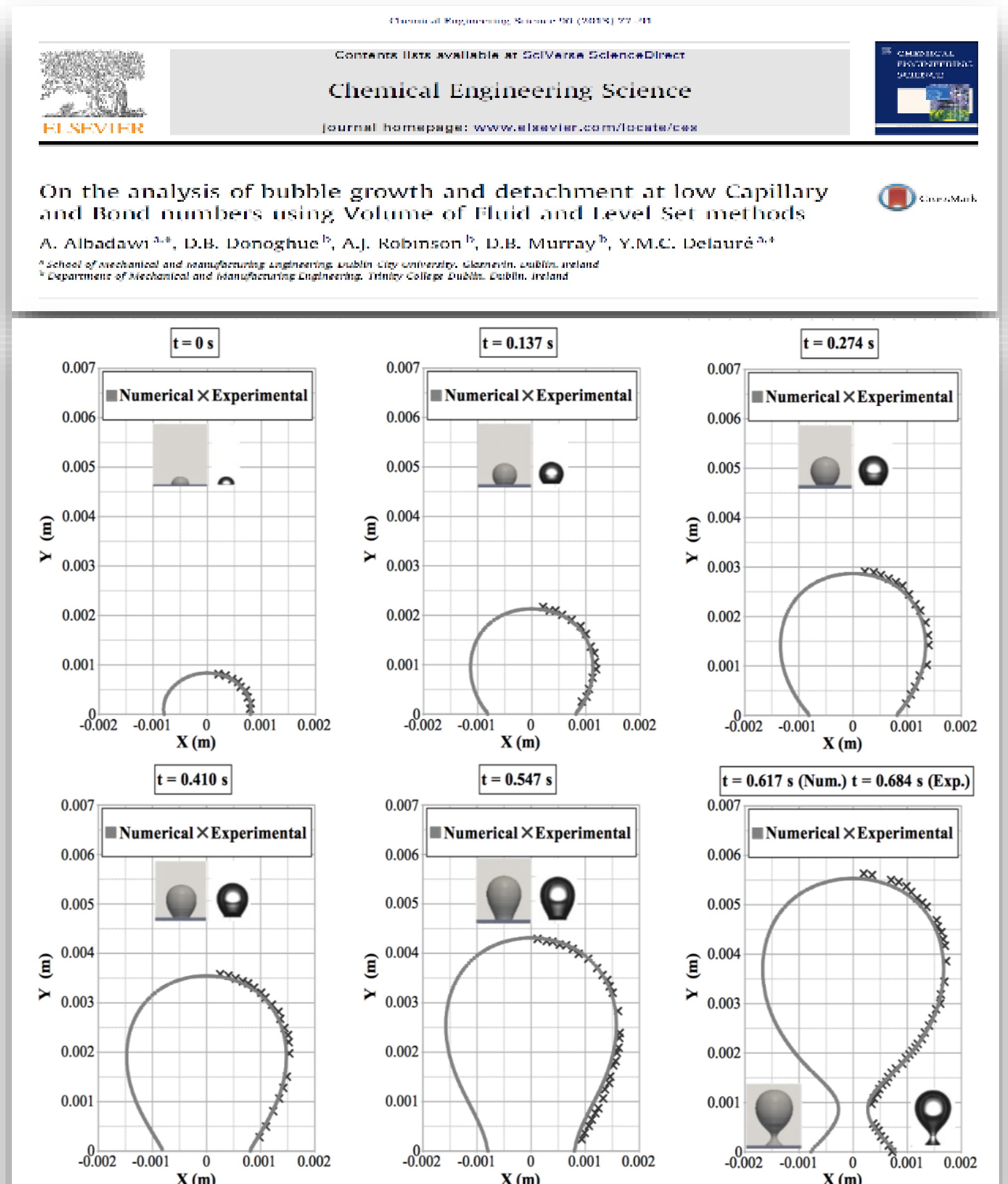
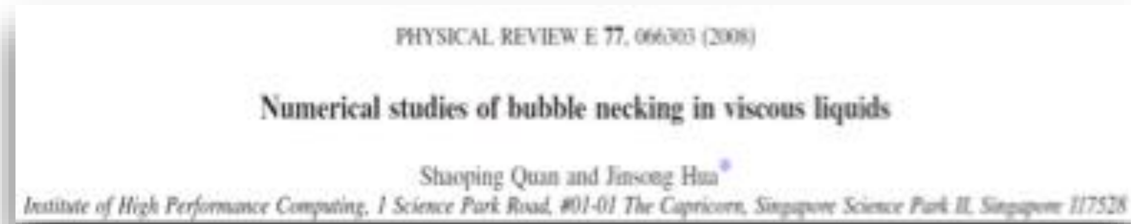
Improved VOF Model (Isothermal)

Validation with Experimental Data on Bubble Growth & Pinch-off from Submerged Orifices in Stagnant Liquid Pools


Chemical Engineering Science

On the analysis of bubble growth and detachment at low Capillary and Bond numbers using Volume of Fluid and Level Set methods

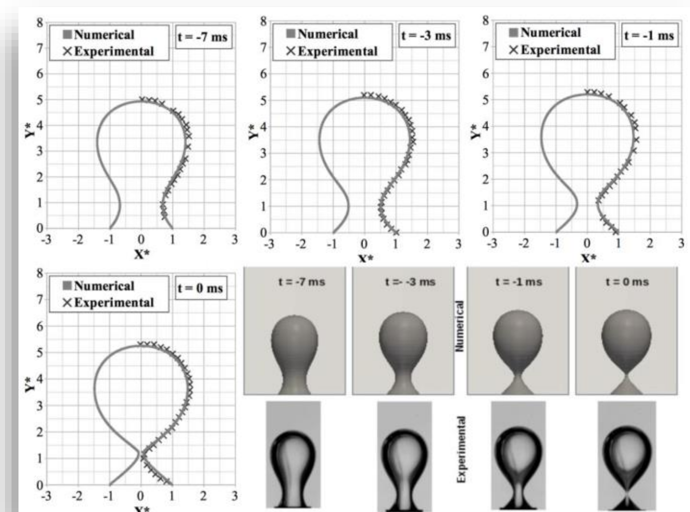
A. Albadawi[a,*], D.B. Donoghue[b], A.J. Robinson[b], D.B. Murray[b], Y.M.C. Delauré[a,*]


PHYSICAL REVIEW E 77, 066303 (2008)

Numerical studies of bubble necking in viscous liquids

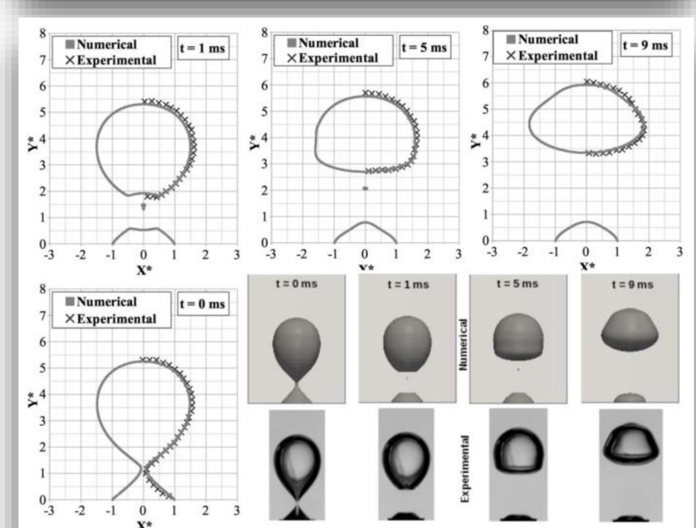
Shaoping Quan and Jinsong Hua

Institute of High Performance Computing, 1 Science Park Road, #01-01 The Capricorn, Singapore Science Park II, Singapore 117528



Before Detachment

After Detachment



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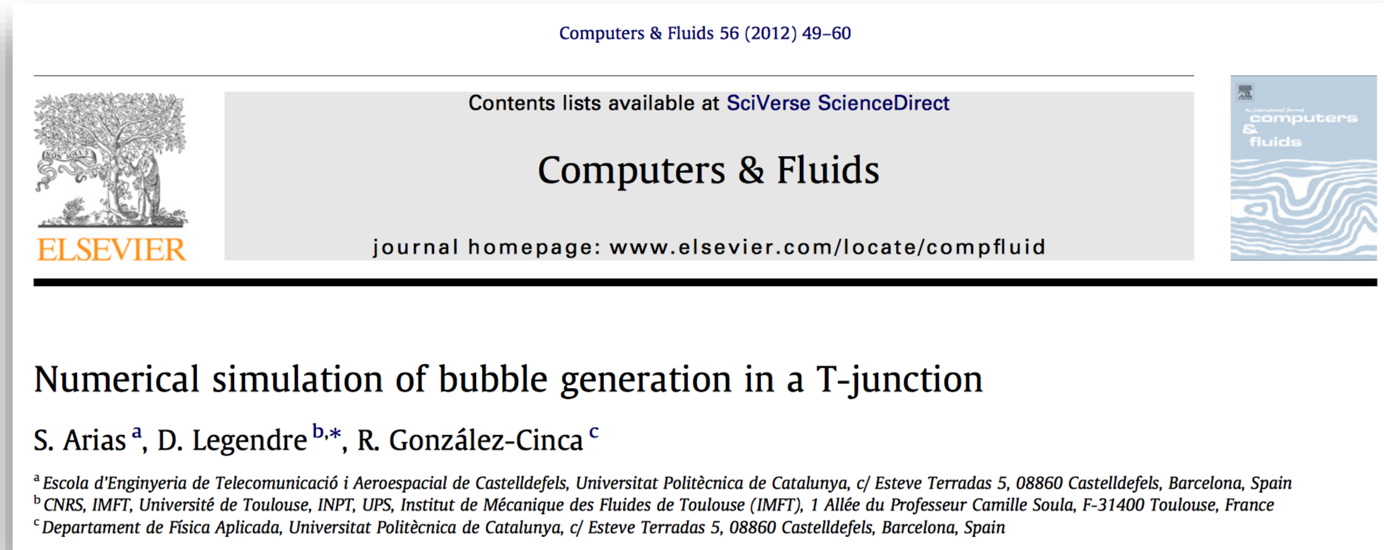
Improved VOF Model (Isothermal)


Computers & Fluids 56 (2012) 49–60

Contents lists available at SciVerse ScienceDirect

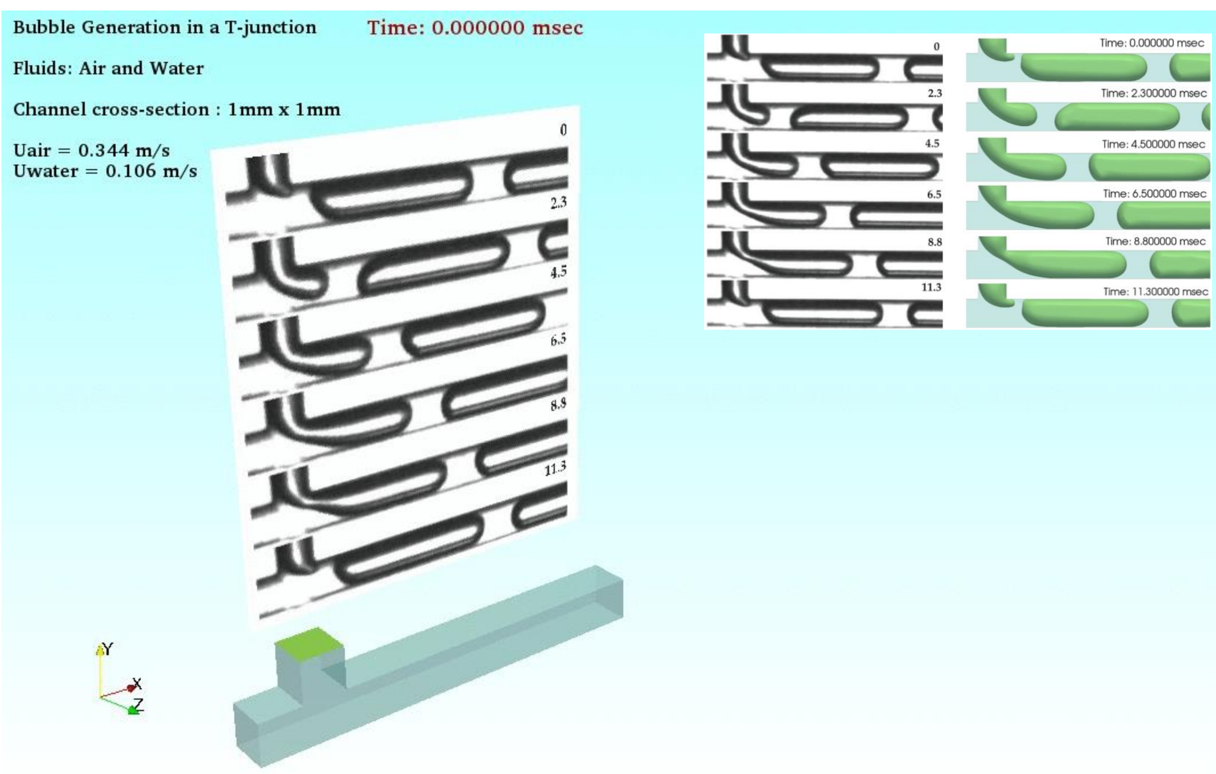
Computers & Fluids

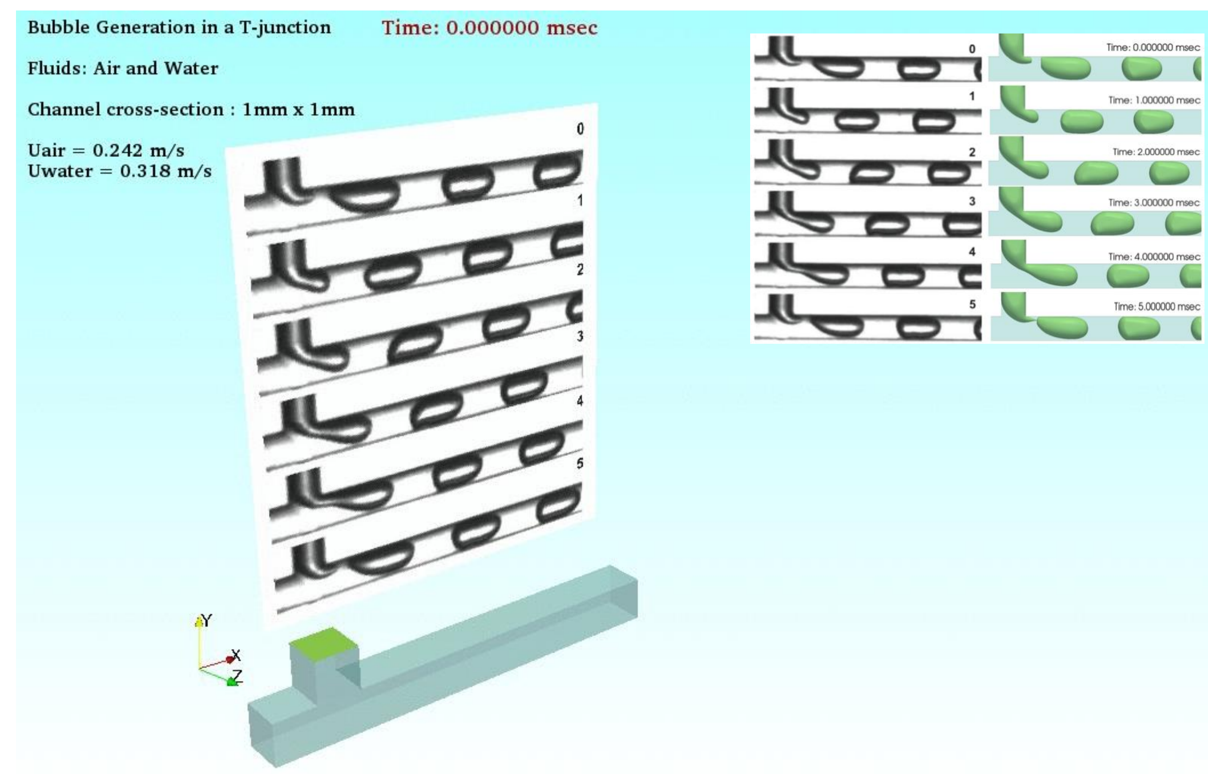
journal homepage: www.elsevier.com/locate/compfluid

Numerical simulation of bubble generation in a T-junction

S. Arias [a], D. Legendre [b,*], R. González-Cinca [c]

[a] Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels, Universitat Politècnica de Catalunya, c/ Esteve Terradas 5, 08860 Castelldefels, Barcelona, Spain
[b] CNRS, IMFT, Université de Toulouse, INPT, UPS, Institut de Mécanique des Fluides de Toulouse (IMFT), 1 Allée du Professeur Camille Soula, F-31400 Toulouse, France
[c] Departament de Física Aplicada, Universitat Politècnica de Catalunya, c/ Esteve Terradas 5, 08860 Castelldefels, Barcelona, Spain





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HyHP Novel Hybrid Heat Pipe for Space and Ground Applications

Improved VOF Model coupled with Heat Transfer and Phase-change

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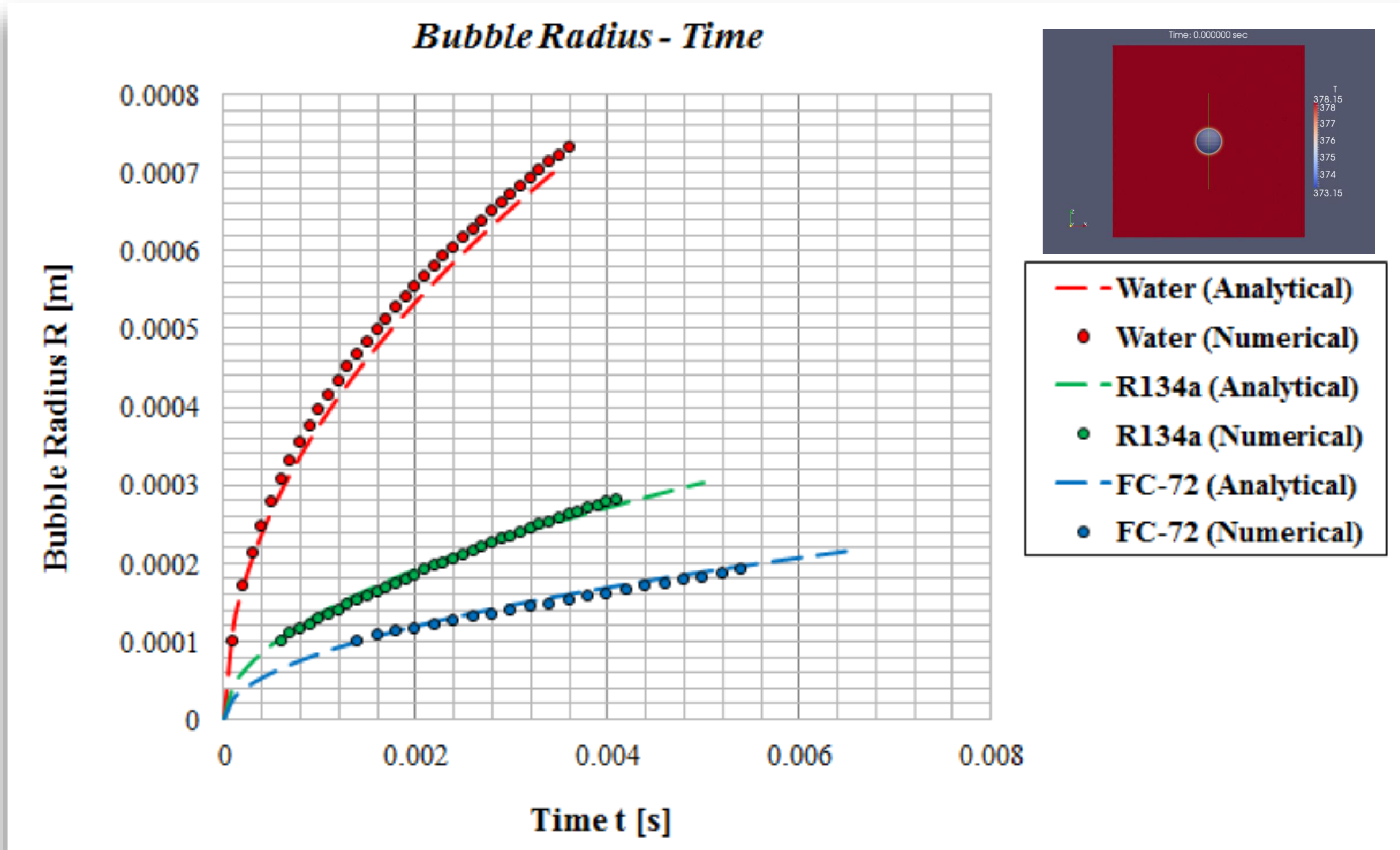

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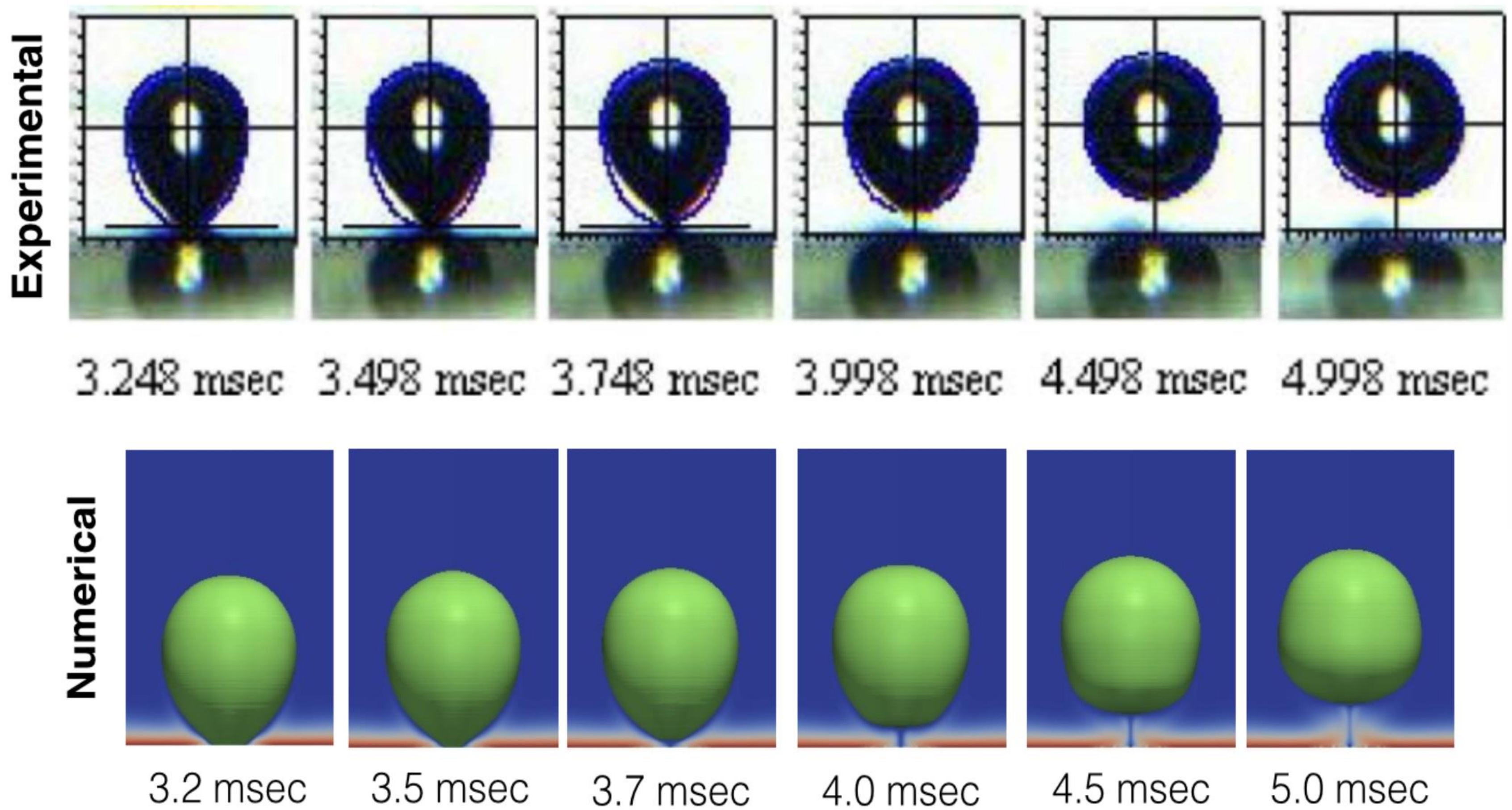
Improved VOF Model coupled with Heat Transfer and Phase-change

Validation with Experimental Data on Single Bubble Growth in Saturated Pool Boiling with a Constant Temperature Plate

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International Journal of Multiphase Flow 29 (2003) 1857–1874
International Journal of Multiphase Flow
www.elsevier.com/locate/ijmulflow

Single bubble growth in saturated pool boiling on a constant wall temperature surface

Han Choon Lee [a], Byung Do Oh [a], Sung Won Bae [b], Moo Hwan Kim [a,*]

	Bubble detachment time (msec)	Equivalent bubble detachment diameter (mm)
Experimental (Lee et al., 2003)	3.748	0.704
Numerical (present investigation)	3.700	0.740
% Error	1.28	5.11

Comparison of Experimental and Numerical Results

Further details on VOF code current status

International Journal of Multiphase Flow 74 (2015) 59–78

Contents lists available at ScienceDirect

International Journal of Multiphase Flow

journal homepage: www.elsevier.com/locate/ijmulflow

ELSEVIER

Numerical investigation of quasi-static bubble growth and detachment from submerged orifices in isothermal liquid pools: The effect of varying fluid properties and gravity levels

CrossMark

A. Georgoulas [a,b,*], P. Koukouvinis [c,d], M. Gavaises [c], M. Marengo [a,e]

[a] *Department of Engineering, University of Bergamo, Viale Marconi 5, 24044 Dalmine (BG), Italy*
[b] *Engine Research and Development Centre, Caterpillar Inc., Frank Perkins Parkway, PE1 5FQ Peterborough, UK*
[c] *School of Engineering and Mathematical Sciences, City University London, Northampton Square, London EC1V 0HB, UK*
[d] *Caterpillar Fuel Systems (CFS), Mossville, IL, USA*
[e] *School of Computing, Engineering and Mathematics, Cockcroft Building, Lewes Road, University of Brighton, Brighton, UK*

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VOF method
Adiabatic bubble dynamics
Bubble detachment characteristics

ABSTRACT

The present investigation, identifies the exact quantitative effects of fundamental parameters, on the detachment characteristics of isolated bubbles, emanating quasi-statically from submerged orifices into isothermal liquid pools. For this purpose, a Volume of Fluid (VOF) based interface capturing approach is further improved, for the conduction of axisymmetric and 3D numerical experiments on adiabatic bubble growth dynamics. The predictions of the model, are quantitatively validated against literature available experimental data, showing excellent agreement. Two series of numerical experiments are performed, quantitatively exploring the parametric effects of the liquid phase properties in five different gravity levels, and the effect of the gravity vector direction inclination angle, respectively. It is found that the bubble detachment characteristics, are more sensitive in the variation of the surface tension, liquid phase density and gravity, while the effect of liquid phase dynamic viscosity is generally minimal. From dimensionless analysis, two correlations are derived, which for the examined range of Eötvos numbers, are able to predict the equivalent bubble detachment diameter and the bubble detachment time, respectively. It is also found that the bubble detachment characteristics, reduce significantly as the gravity vector direction gradually deviates from being parallel to the bubble injection orifice, following a non-linear decrease.

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Article

An Enhanced VOF Method Coupled with Heat Transfer and Phase Change to Characterise Bubble Detachment in Saturated Pool Boiling

Anastasios Georgoulas *, Manolia Andredaki and Marco Marengo

Advanced Engineering Centre, School of Computing, Engineering and Mathematics, Cockcroft Building, Lewes Road, University of Brighton, Brighton BN2 4GJ, UK; M.Andredaki@brighton.ac.uk (M.A.); M.Marengo@brighton.ac.uk (M.M.)
* Correspondence: A.Georgoulas@brighton.ac.uk; Tel.: +44-01273-642-900

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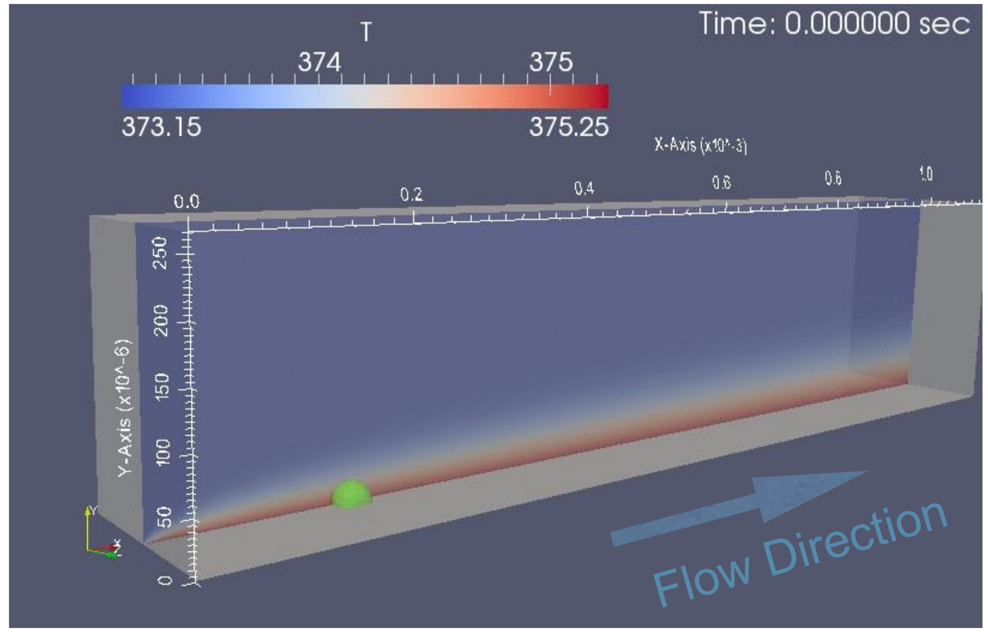
Abstract: The present numerical investigation identifies quantitative effects of fundamental controlling parameters on the detachment characteristics of isolated bubbles in cases of pool boiling in the nucleate boiling regime. For this purpose, an improved Volume of Fluid (VOF) approach, developed previously in the general framework of OpenFOAM Computational Fluid Dynamics (CFD) Toolbox, is further coupled with heat transfer and phase change. The predictions of the model are quantitatively verified against an existing analytical solution and experimental data in the literature. Following the model validation, four different series of parametric numerical experiments are performed, exploring the effect of the initial thermal boundary layer (ITBL) thickness for the case of saturated pool boiling of R113 as well as the effects of the surface wettability, wall superheat and gravity level for the cases of R113, R22 and R134a refrigerants. It is confirmed that the ITBL is a very important parameter in the bubble growth and detachment process. Furthermore, for all of the examined working fluids the bubble detachment characteristics seem to be significantly affected by the triple-line contact angle (i.e., the wettability of the heated plate) for equilibrium contact angles higher than 45°. As expected, the simulations revealed that the heated wall superheat is very influential on the bubble growth and detachment process. Finally, besides the novelty of the numerical approach, a last finding is the fact that the effect of the gravity level variation in the bubble detachment time and the volume diminishes with the increase of the ambient pressure.

Keywords: two-phase flow; VOF method; OpenFOAM; pool boiling; phase change

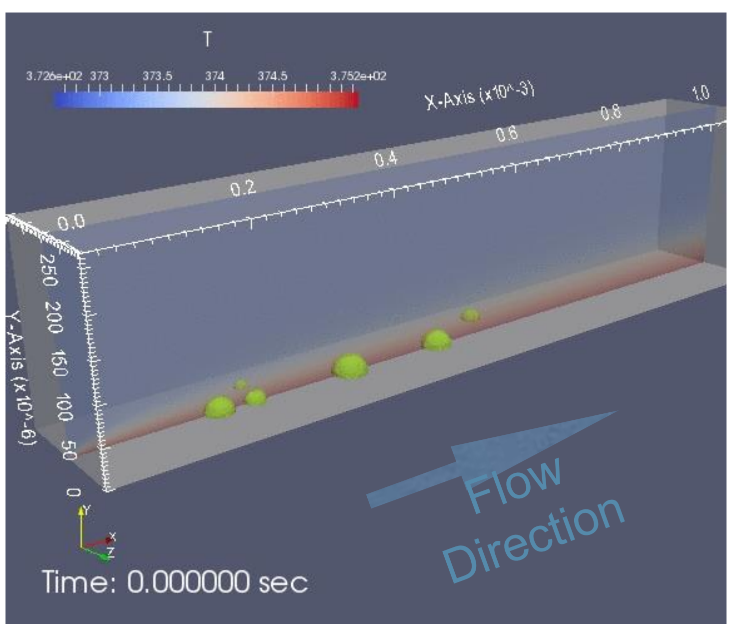
Successful applications of the enhanced VOF-model so far

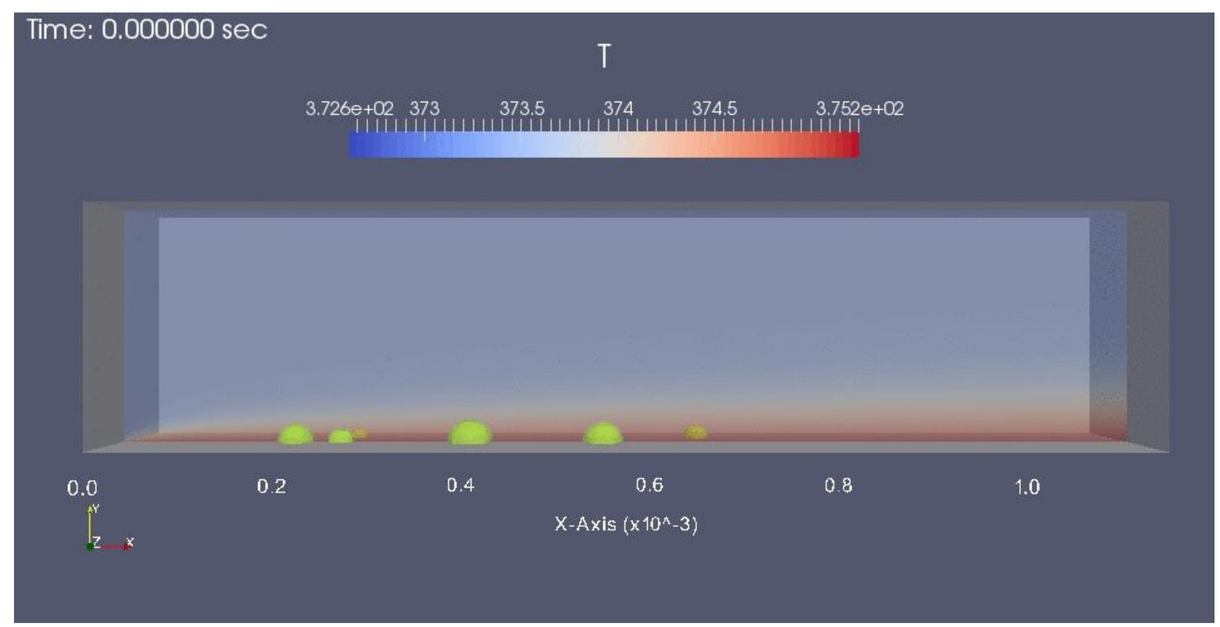
Flow Boiling in Mini- and Micro-channels



3D View

Flow Direction



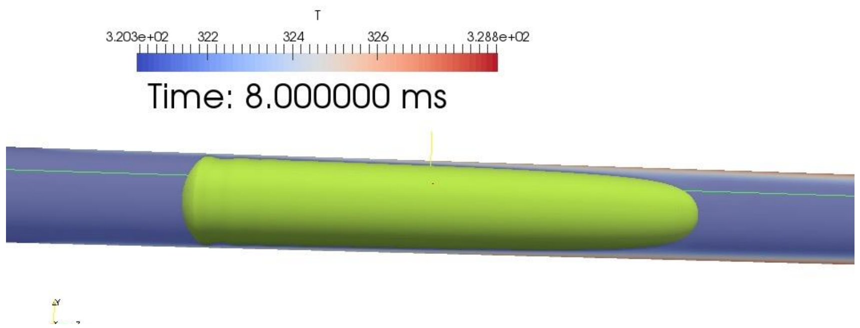


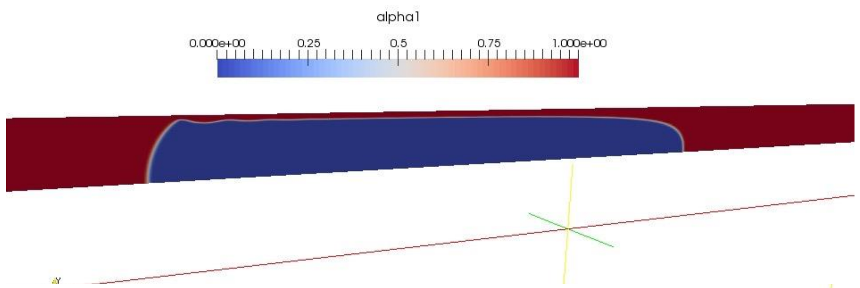
Side View

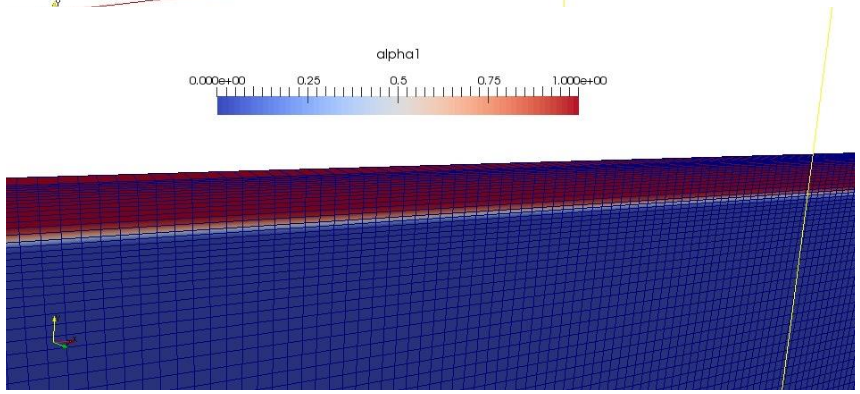
3D View

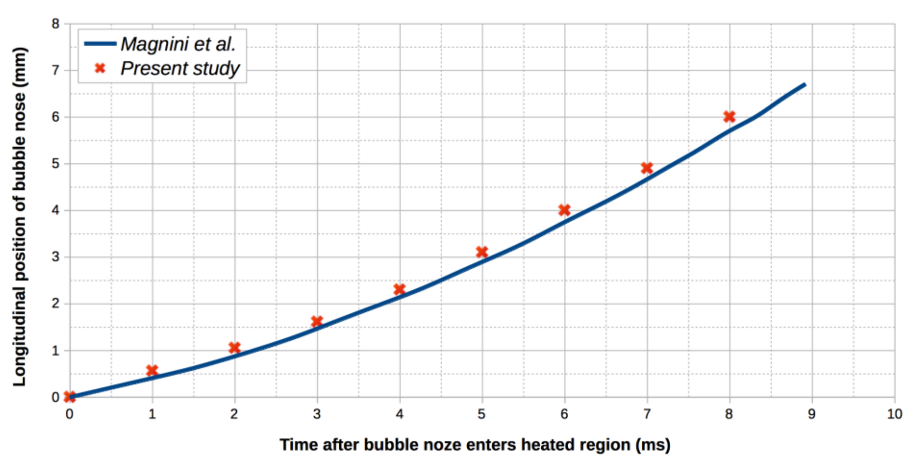
Successful applications of the enhanced VOF-model so far

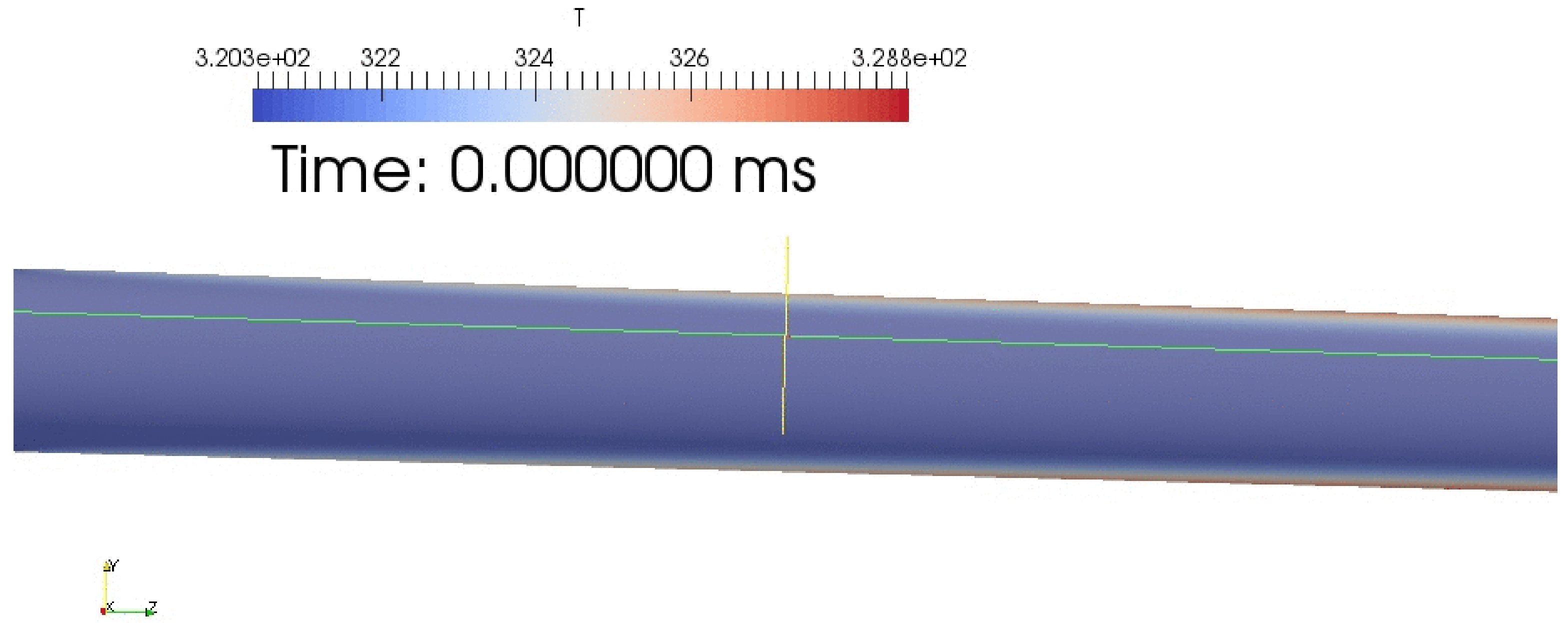
Flow Boiling in Mini- and Micro-channels

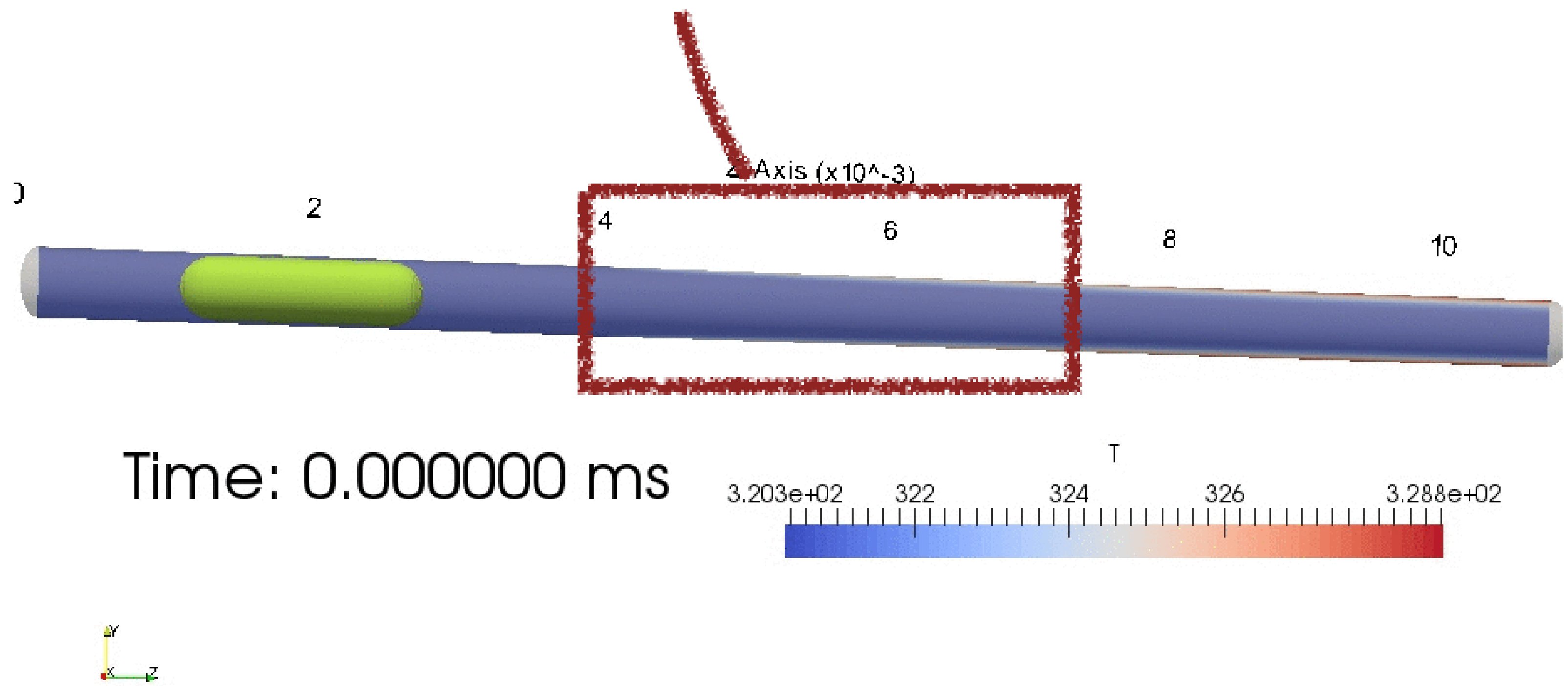












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HyHP Novel Hybrid Heat Pipe for Space and Ground Applications

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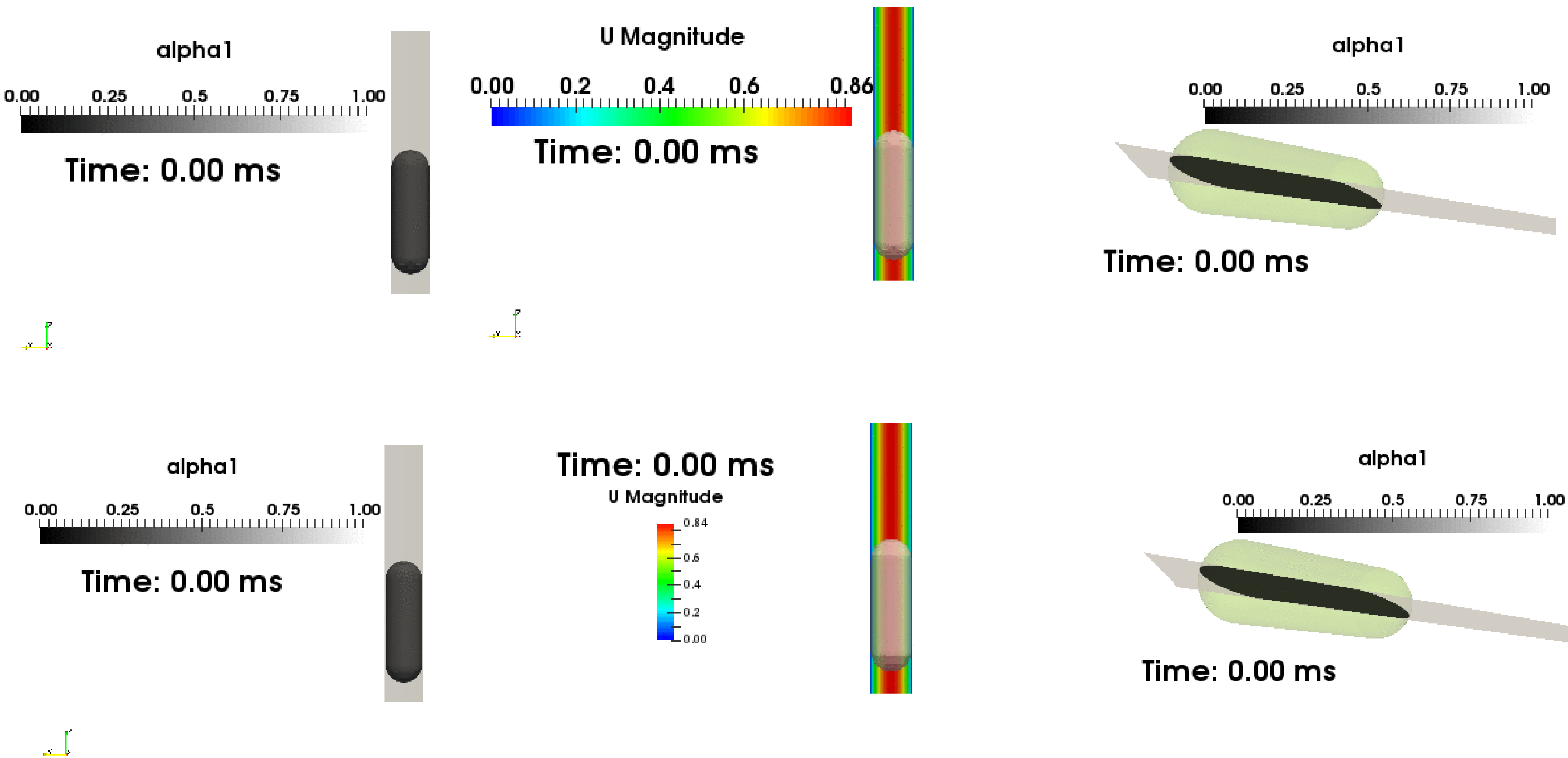
Hydrodynamic Vapour Bubble Break-up Regimes in Mini-channels



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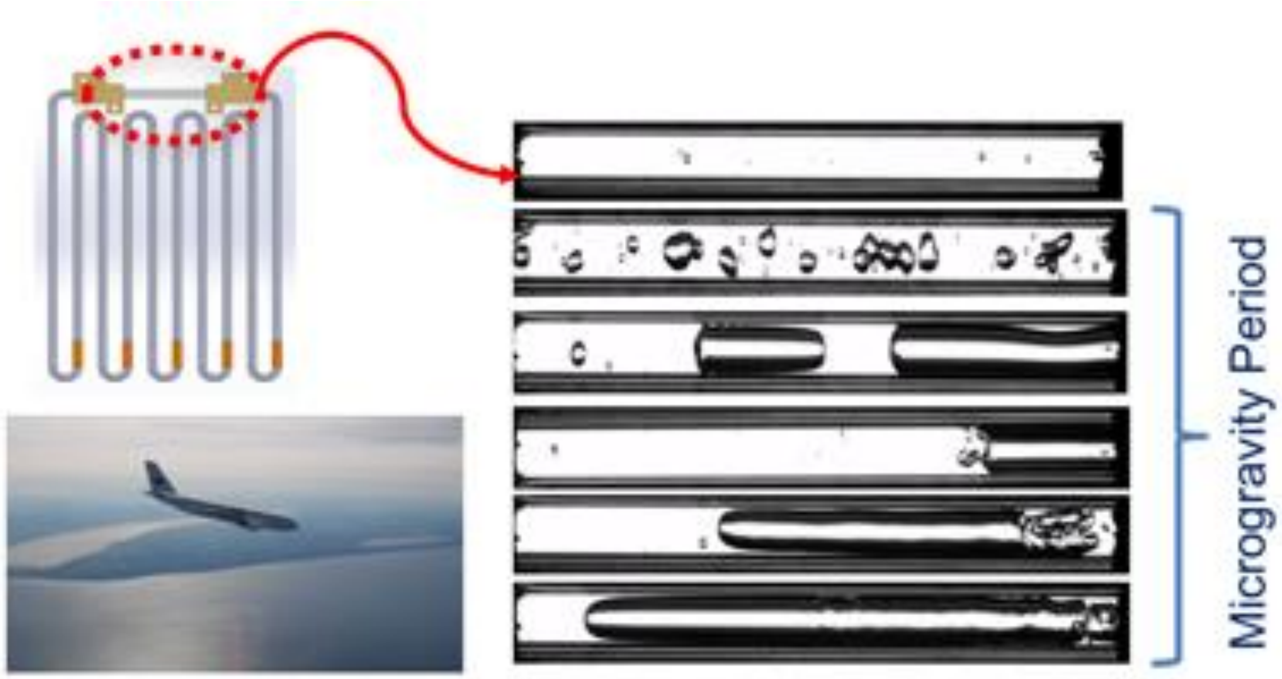
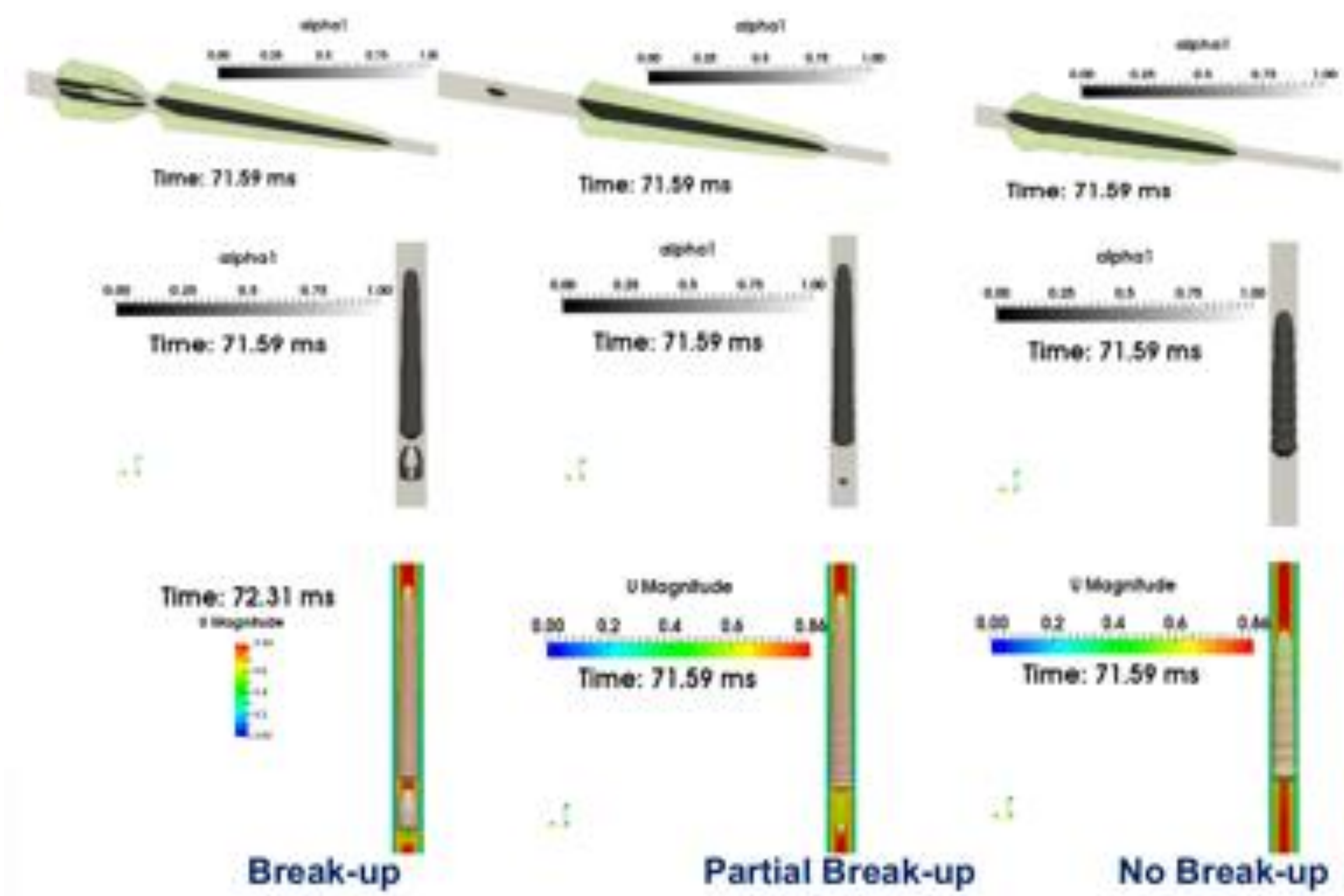
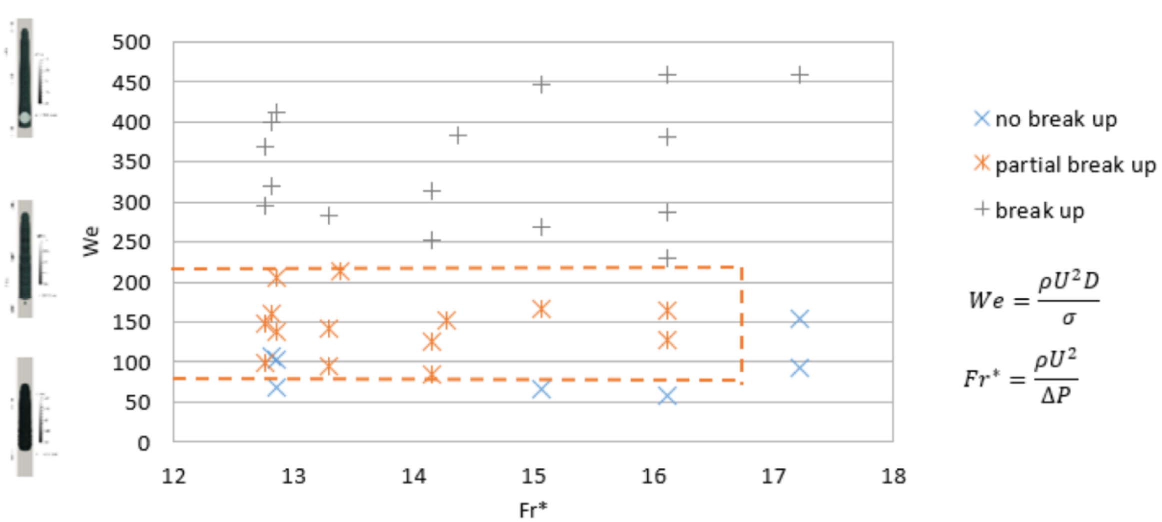


Observed Break-up phenomena in vapour slugs during PHP microgravity experiments in parabolic flights





$$We = \frac{\rho U^2 D}{\sigma}$$

$$Fr^* = \frac{\rho U^2}{\Delta P}$$

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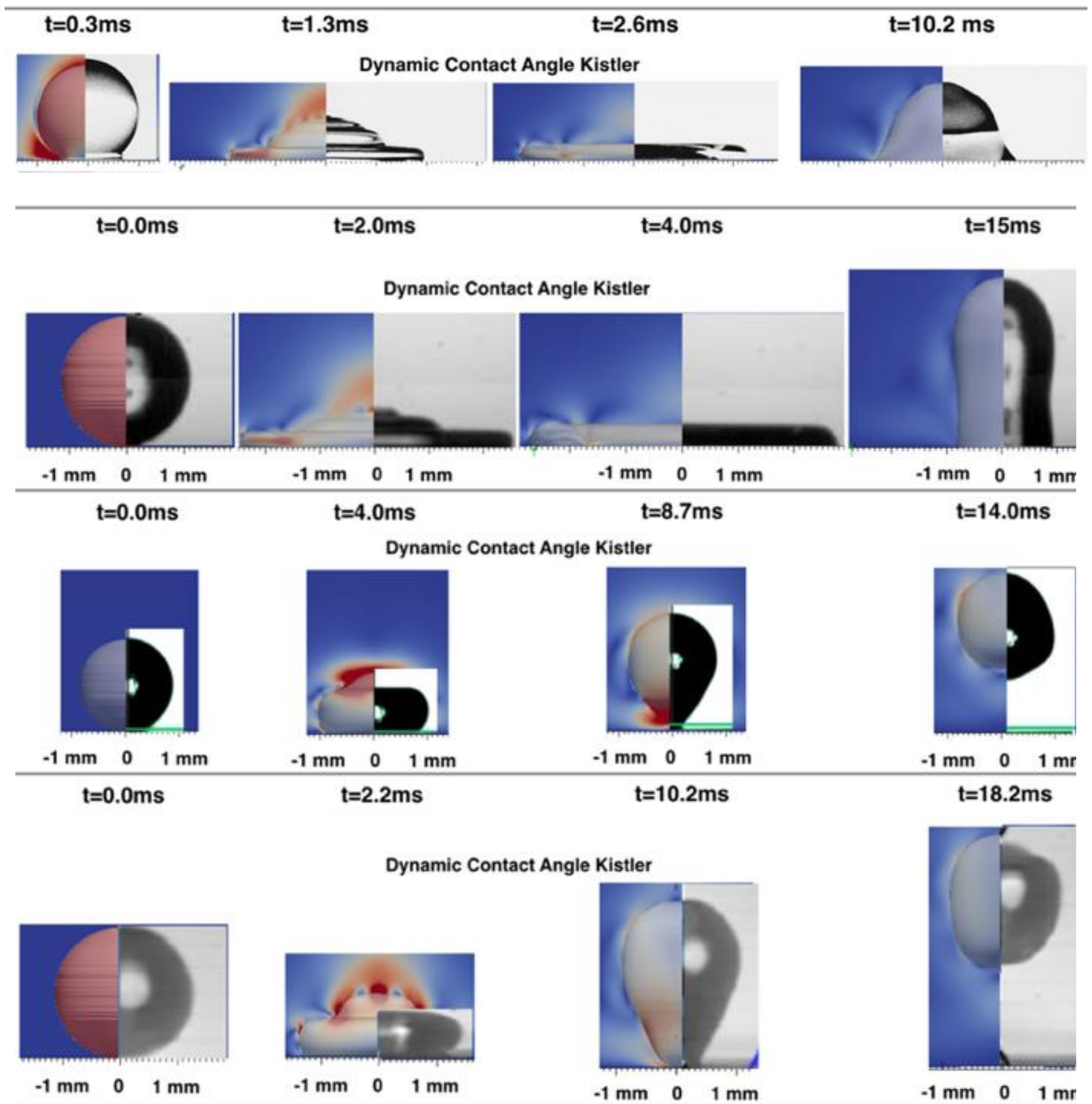
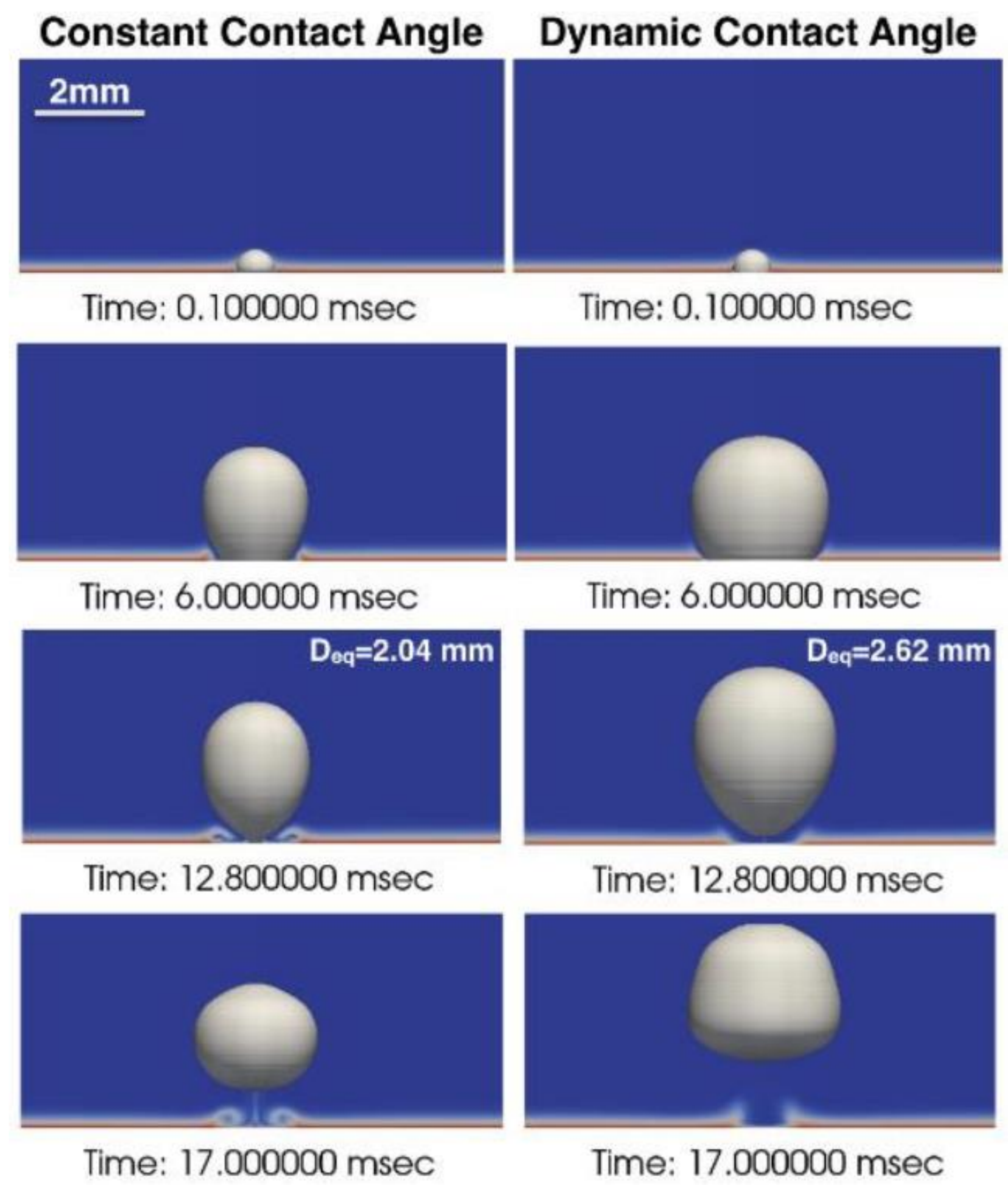
Further Recent Implementations

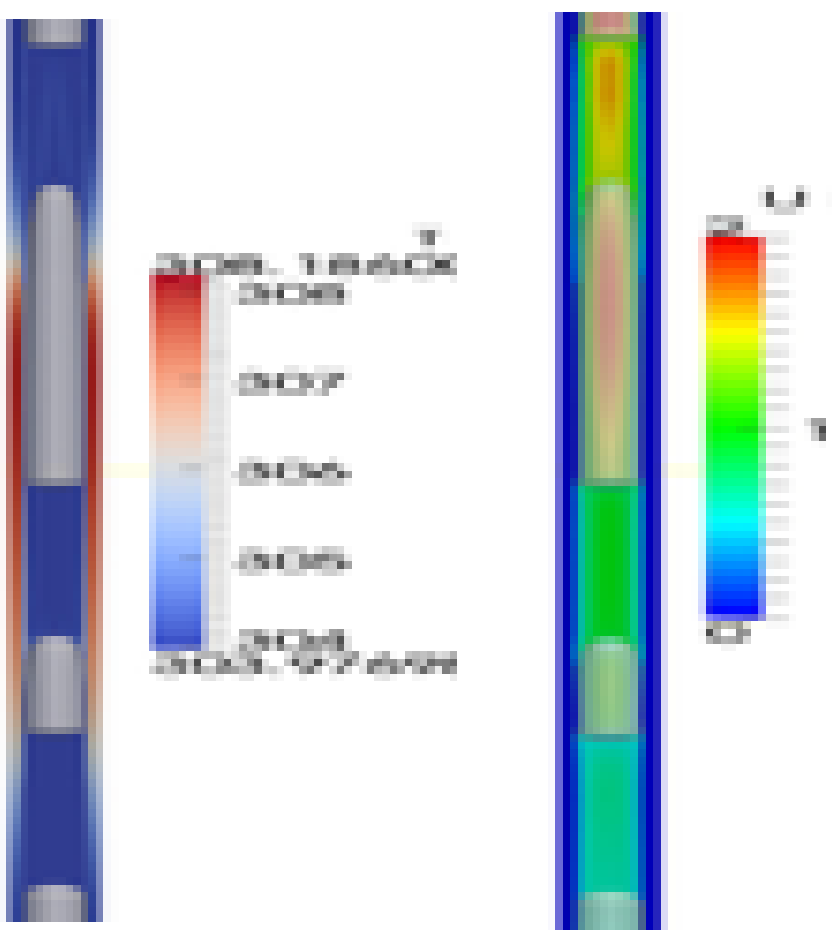
Dynamic Contact Angle Modelling

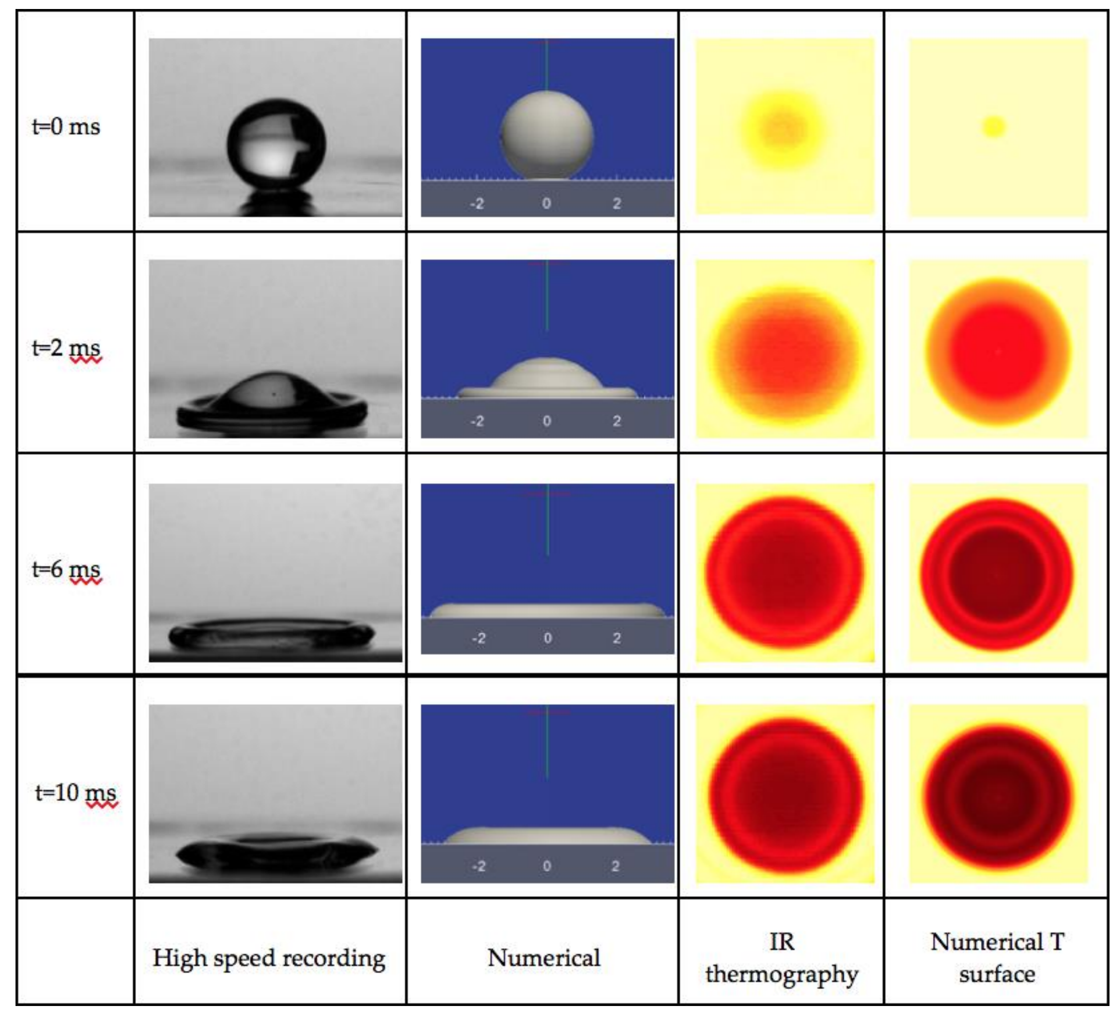




Necessary Additions for HyHP

- **Coupling of the two-phase fluid solver with solid heat transfer in order to perform conjugate heat transfer simulations**
- **Adaptive computational mesh refinement in the vicinity of the interface**





Necessary Additions for HyHP

- **The addition of compressibility effects in order to account for the variation of the working fluid properties with temperature**
- **The addition of appropriate sub-grid scale evaporation and condensation models**

Thank you very much!!