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Modeling 6-DOF Rigid-Body Motion Of A Thermocapillary Microswimmer

A Fatih Tabak, Guillermo J Amador, Metin Sitti

Max Planck Institute for Intelligent Systems

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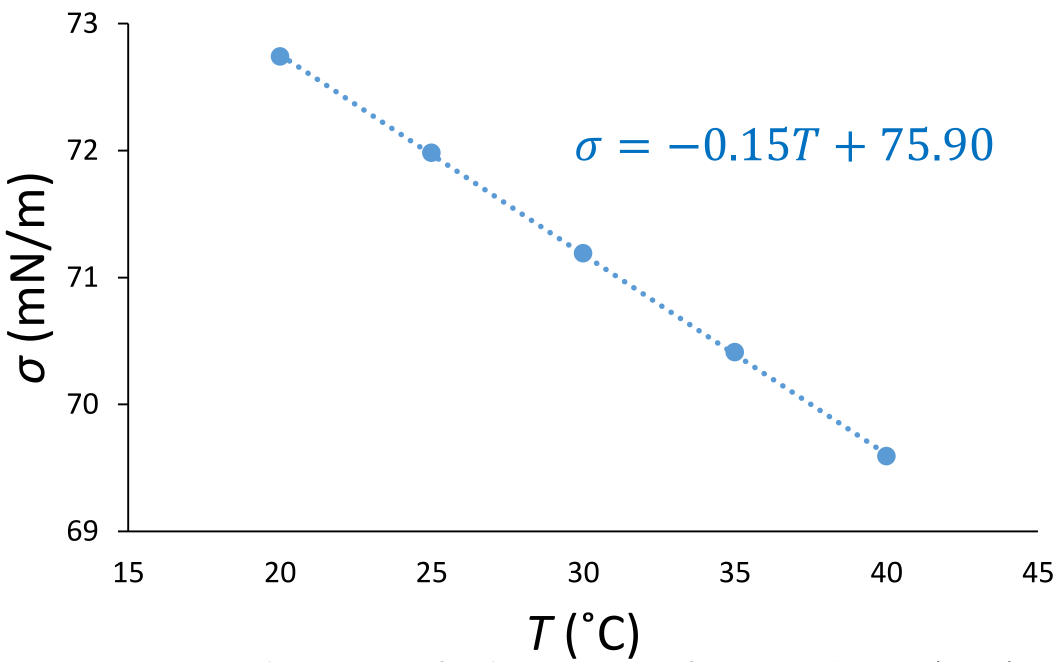
MAX-PLANCK-GESELLSCHAFT

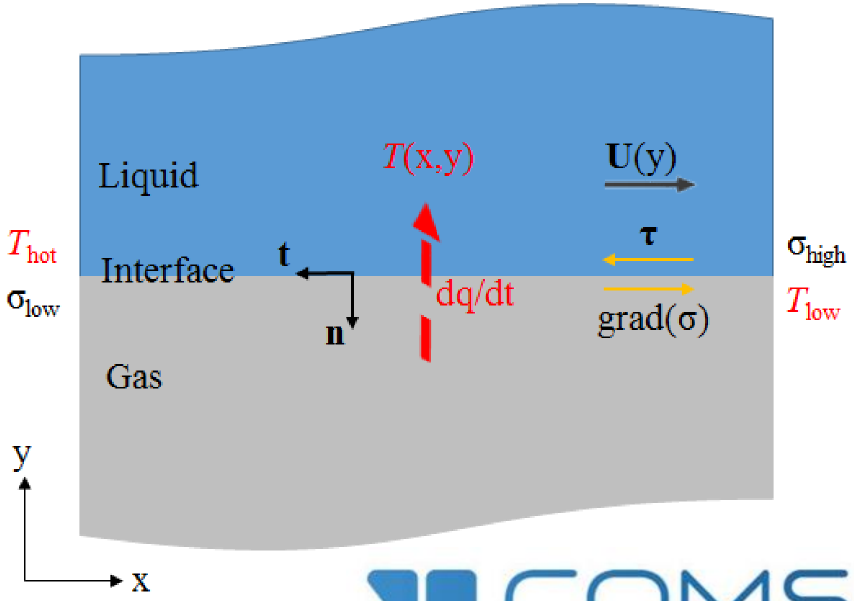
Physical Intelligence Department

Thermocapillary Flow

- The surface tension of an air-water interface decreases with increasing temperature
- A gradient in surface tension leads to fluid flow at a fluid-gas or fluid-fluid interface
- At small scales, this phenomenon is very efficient, $F \propto L$



International Association for the Properties of Water and Steam (2014)



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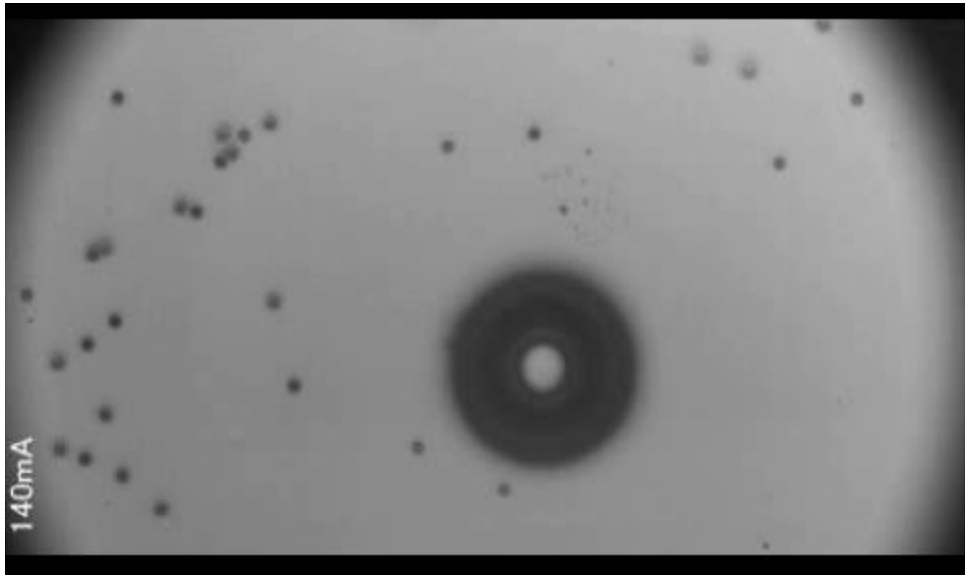
Thermocapillary Flow: Implementation

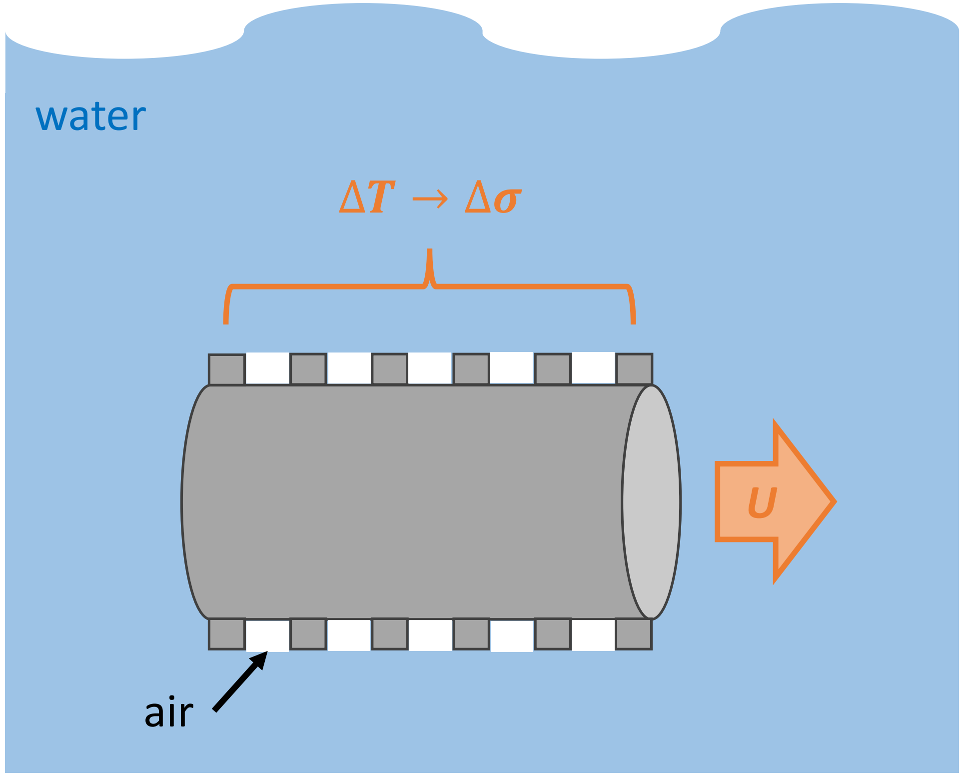
- Most work with thermocapillary flow is done on top of a water surface
- Recently researchers have shown thermocapillary flow with submerged air bubbles
- Flows on the order of cm s^{-1} have been observed for temperature gradients on the order of ˚C cm^{-1}



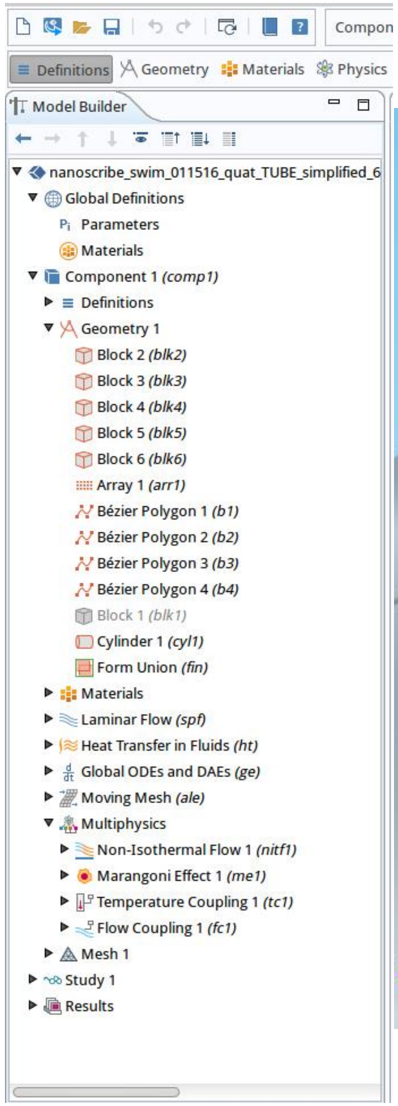
Namura *et al* (2015) *Appl Phys Lett*

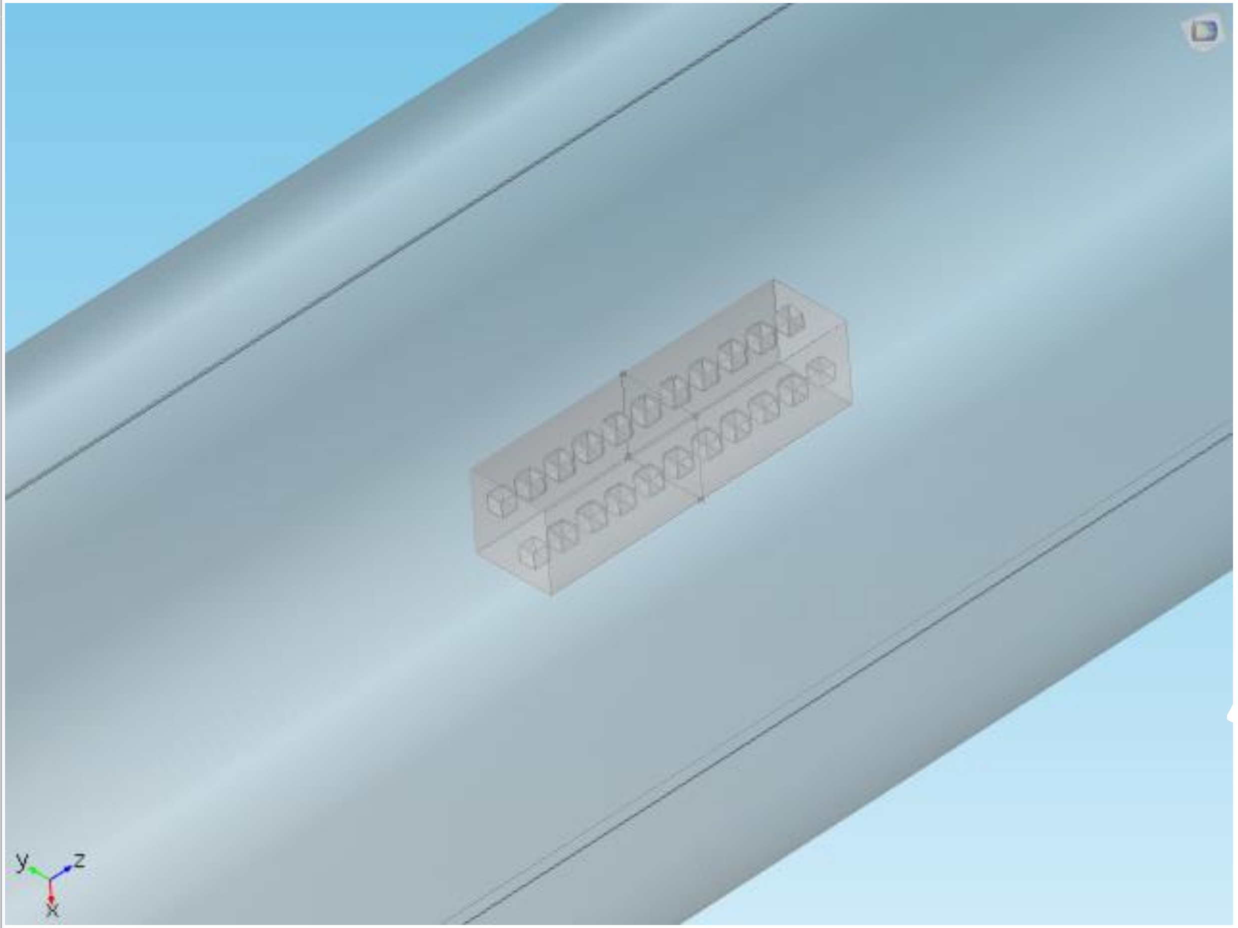
Proposed Thermocapillary Microswimmer

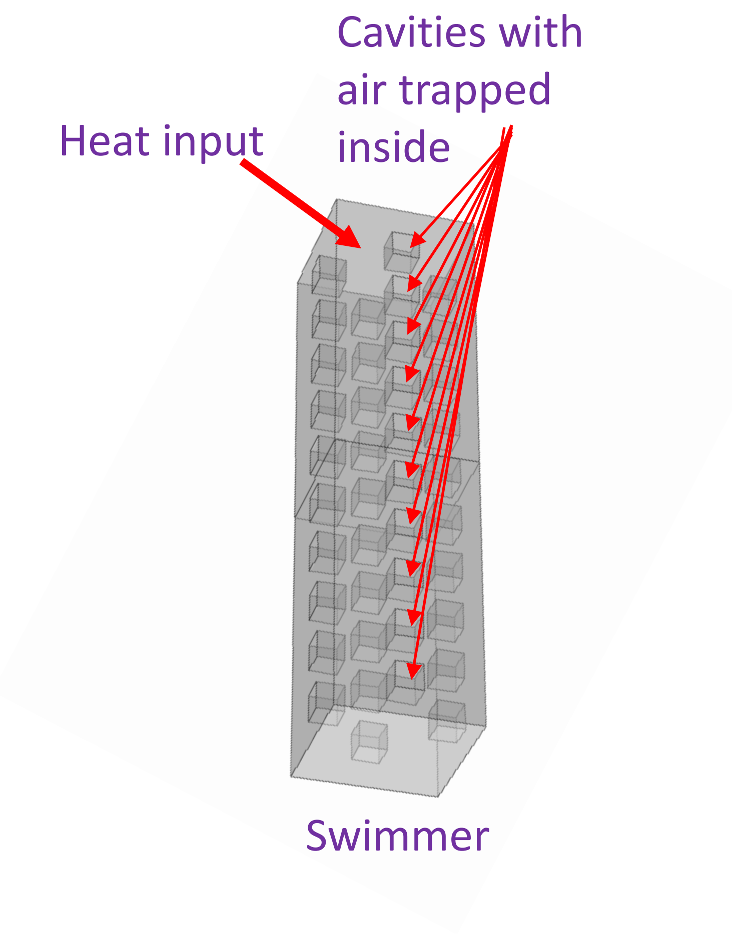
- By trapping air on the surface of a submerged microswimmer, we may exploit interfacial phenomena
- Imposing a temperature gradient across the swimmer may generate a surface tension gradient
  - Remote heating by AC-magnetic field
- The net force from the surface tension gradient may drive flow around the swimmer, generating propulsion



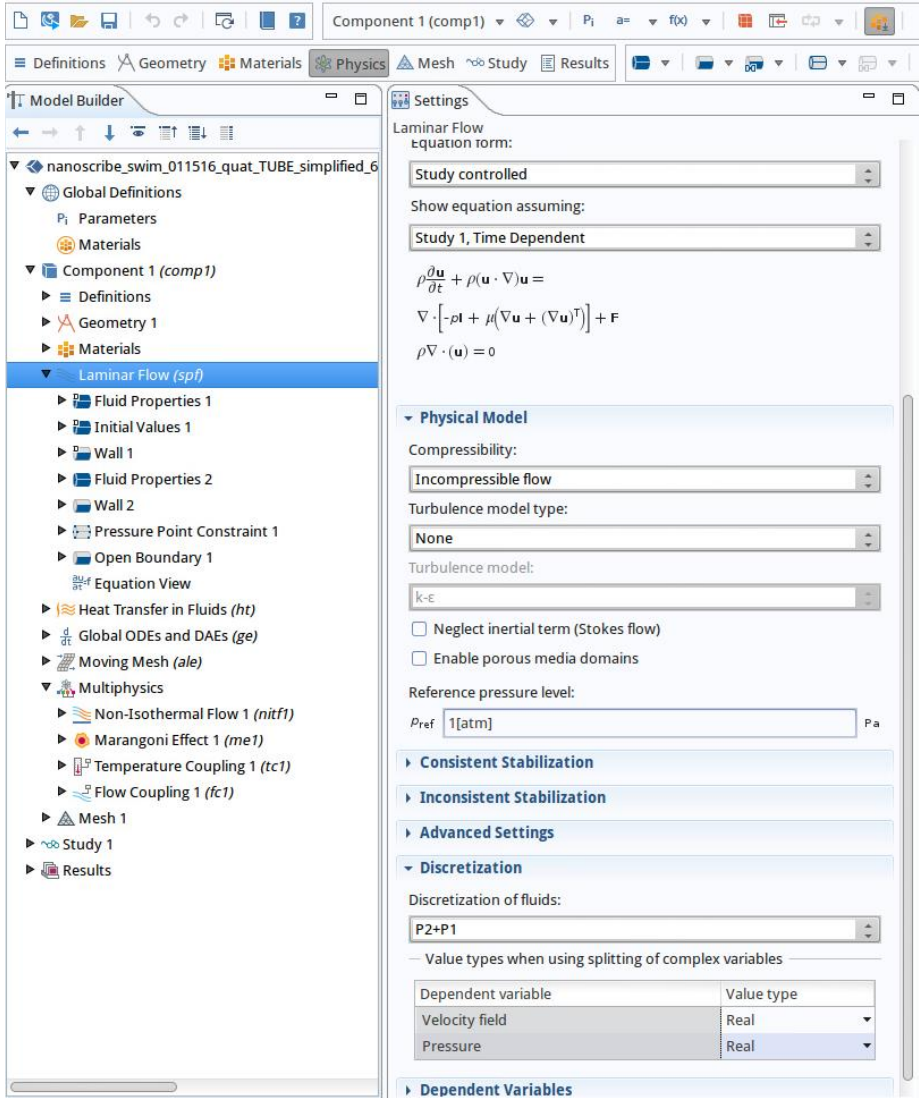
Geometry: Channel and Swimmer

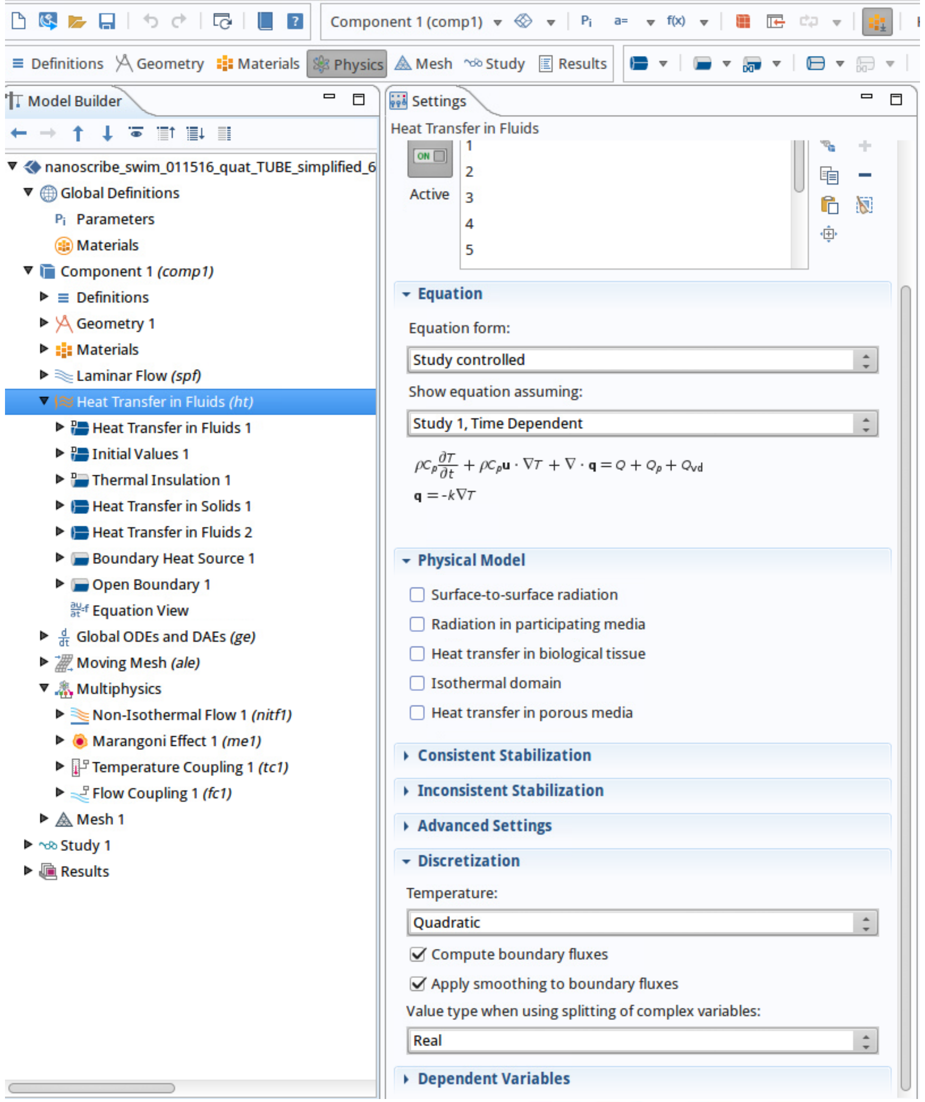






Main Modules





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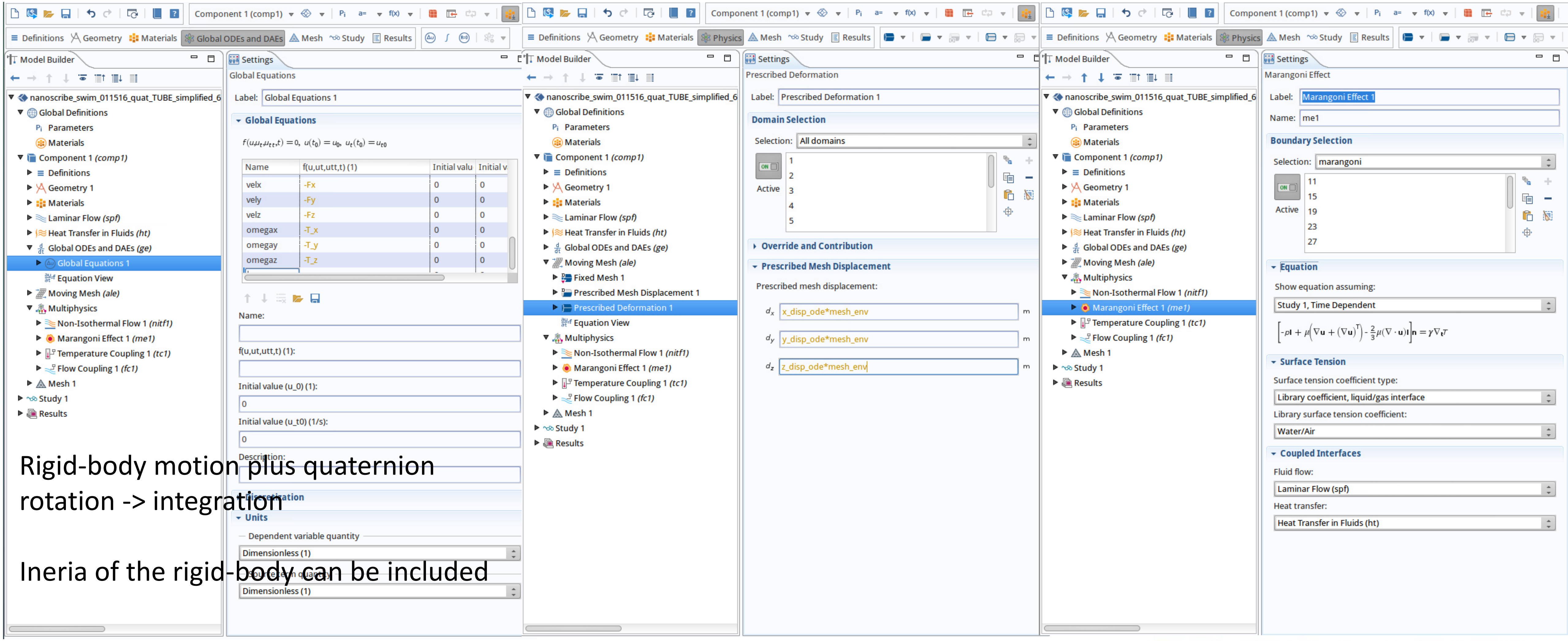
Auxiliary Modules



Rigid-body motion plus quaternion rotation -> integration

Ineria of the rigid-body can be included

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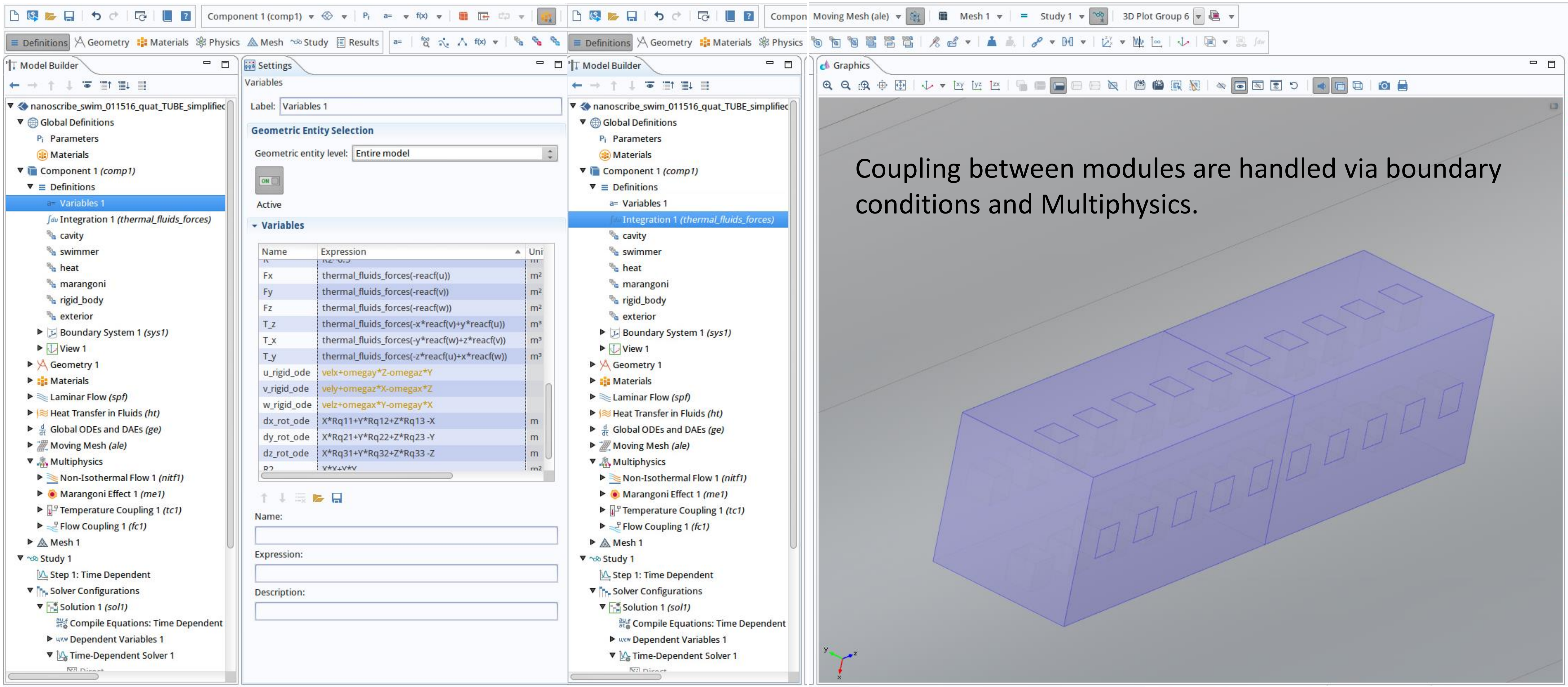
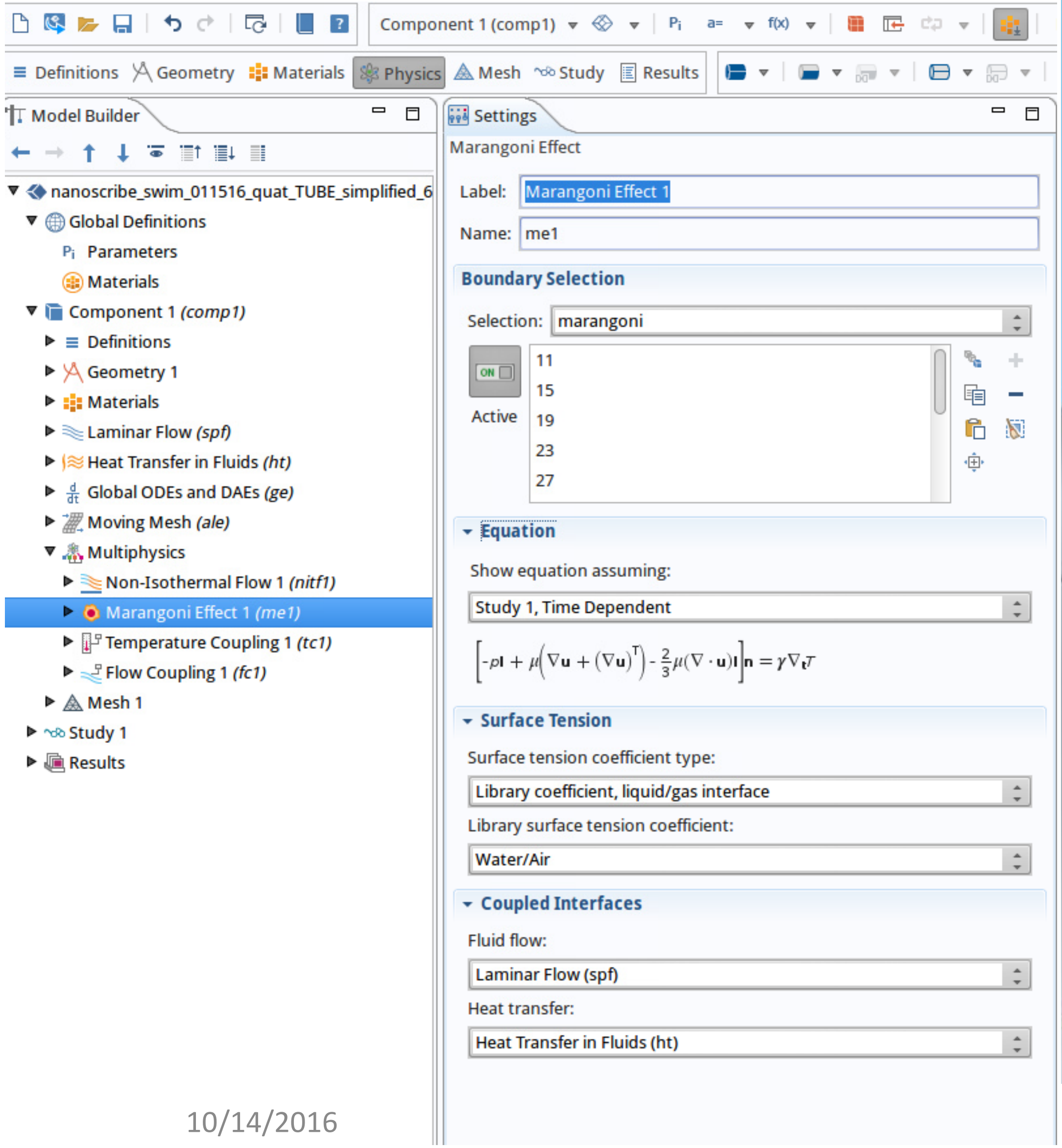
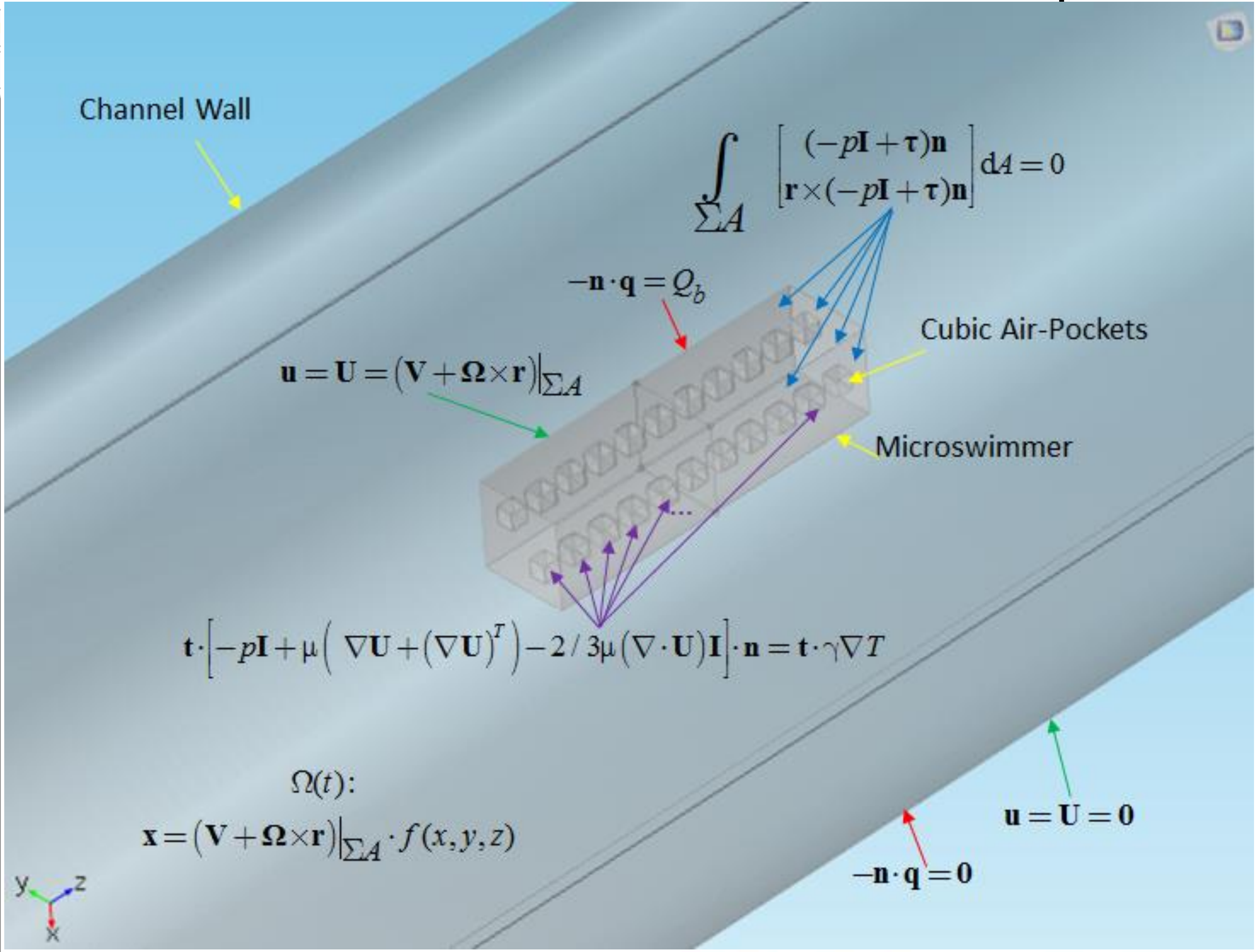
Variables and Force-Integrations



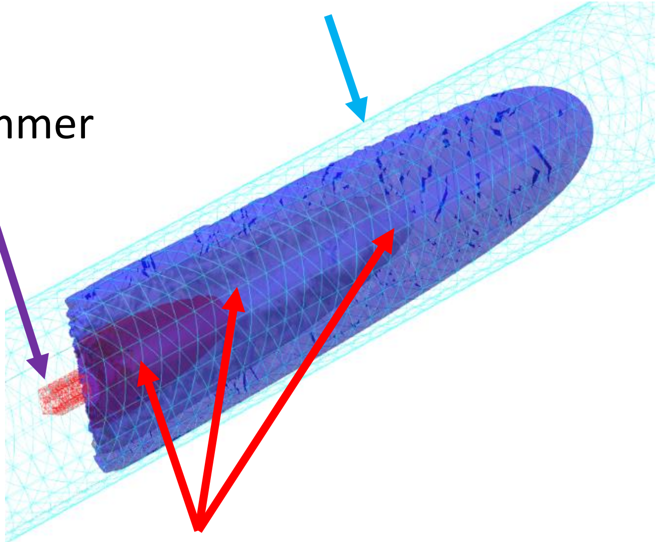
Marangoni Swimmer: Overview of the Numerical Setup

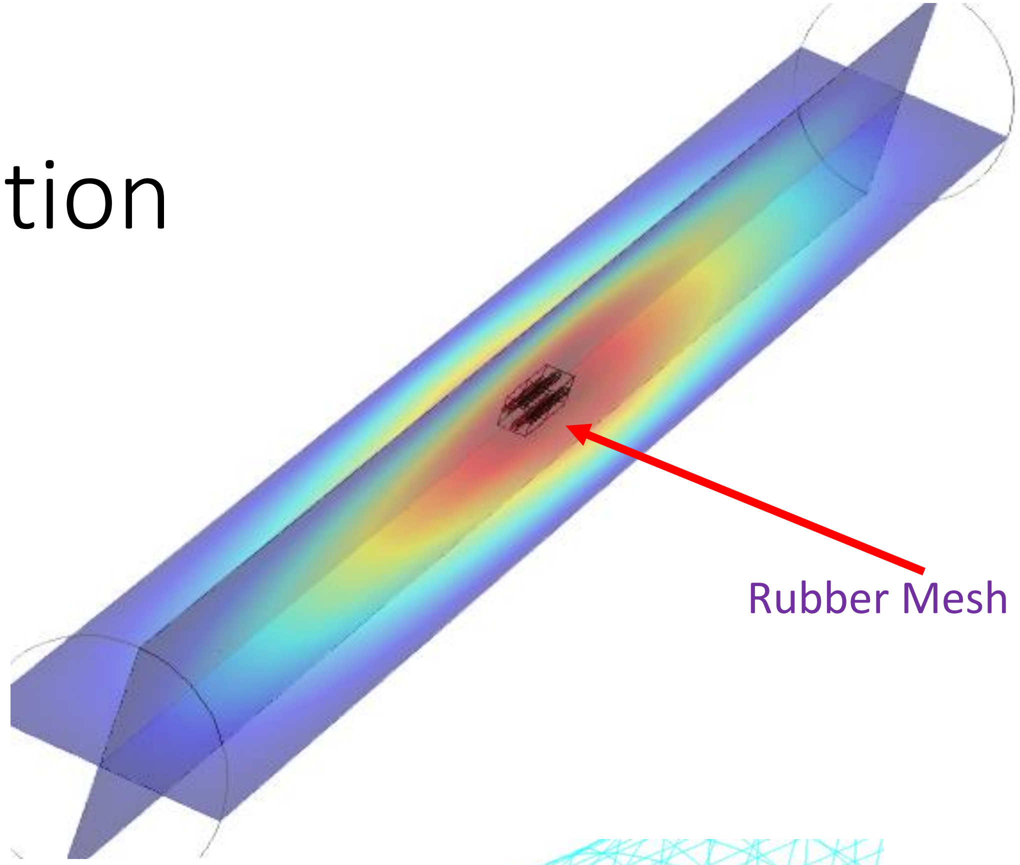


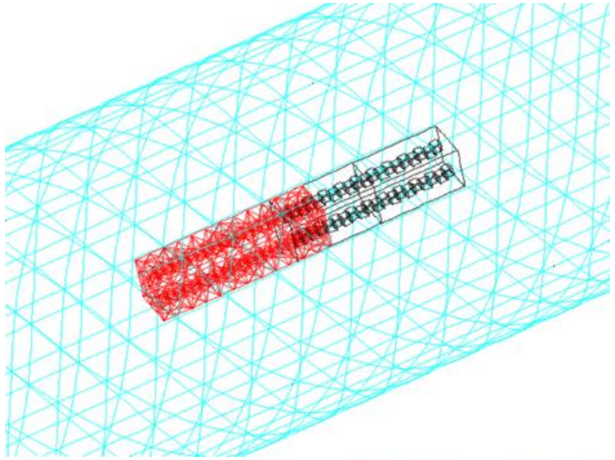


Handling Mesh Deformation

Mesh Deformation (time-dependent ALE)



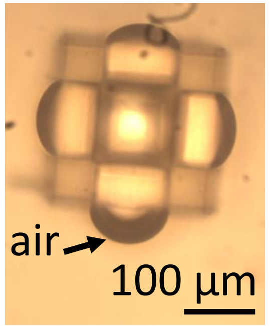


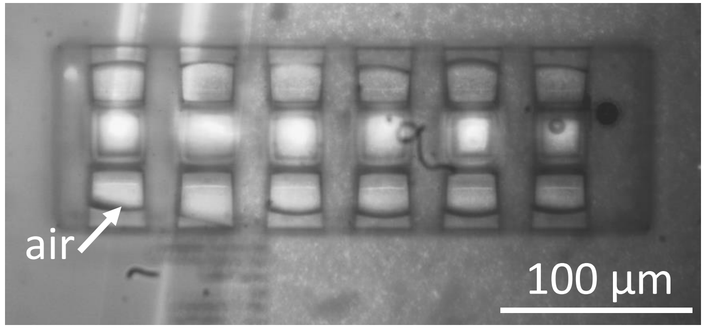


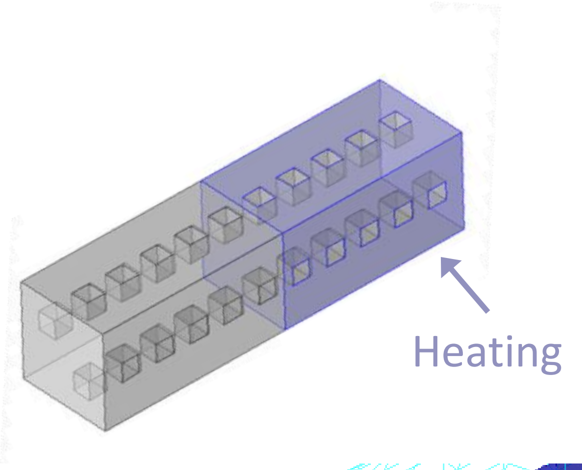
Rubber Mesh Ref: **Tabak, A.F.**, Simulation based experiments of travelling-plane-wave-actuator micropumps and microswimmers, MSc Thesis submitted to Faculty of Engineering and Natural Sciences, Sabanci University, Istanbul, 2007.

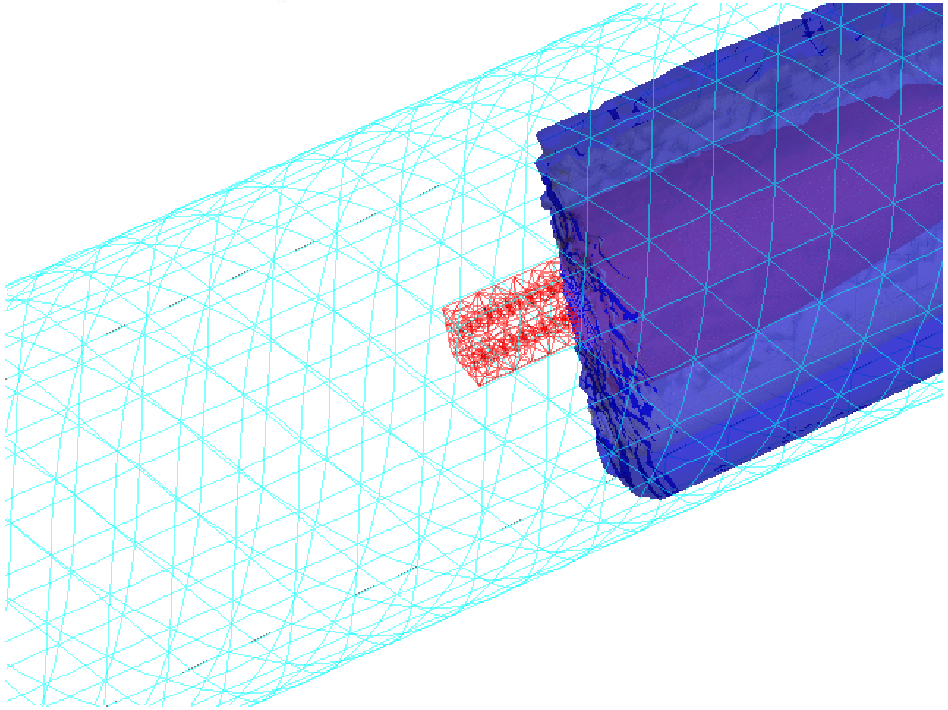
Microswimmer: Simulations

- Mimicked geometry that can be produced by two photon polymerization
  - 100 µm long, 25 µm wide, 10 µm cavities
- Use 30 µW of heating
  - Similar to measured hysteresis loss of 100nm-thick Ni film
- Swimmer propels at 1 body length s^{-1}









stationary: channel; moving: swimmer Δt = 1 s

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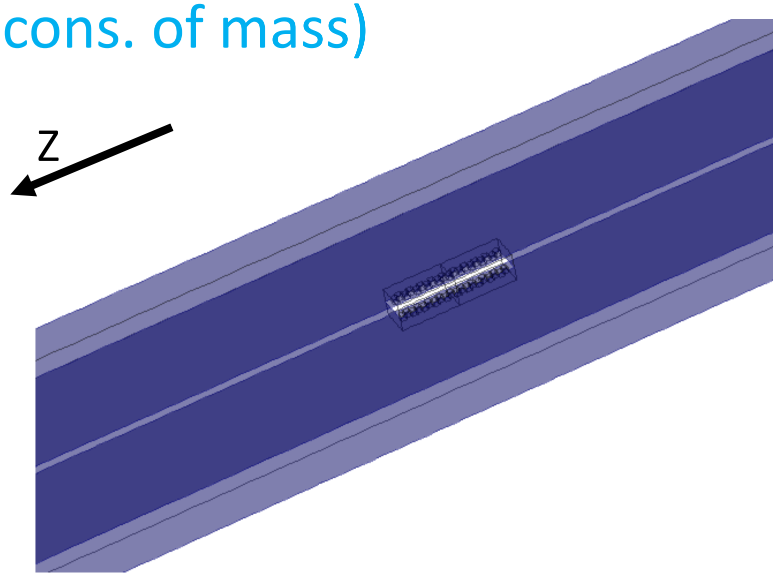
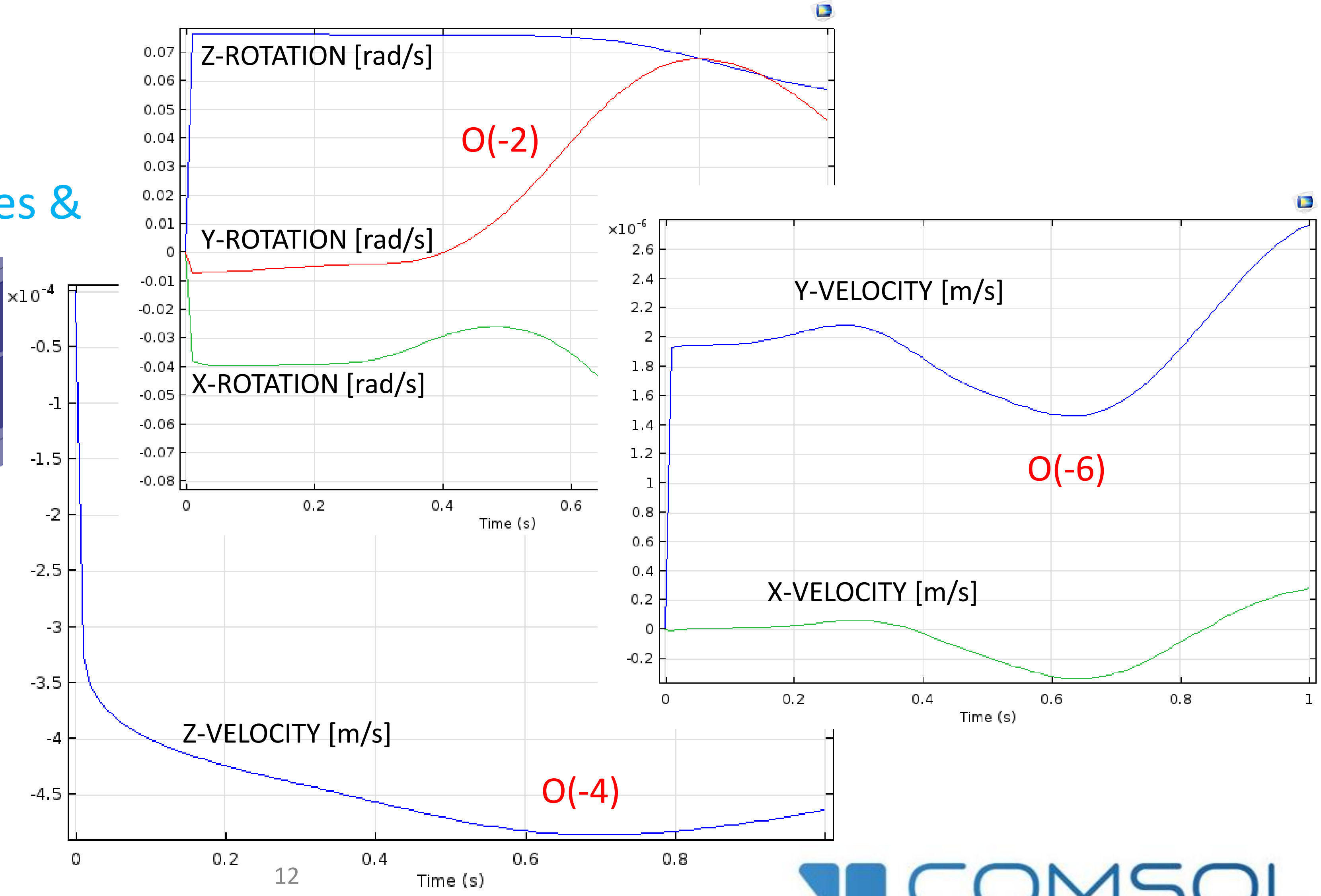
Marangoni Effect Swimming: Case Study

Flow Field
(time-dependent Navier-Stokes & cons. of mass)



Re_{max} ~ 0.5 !!!



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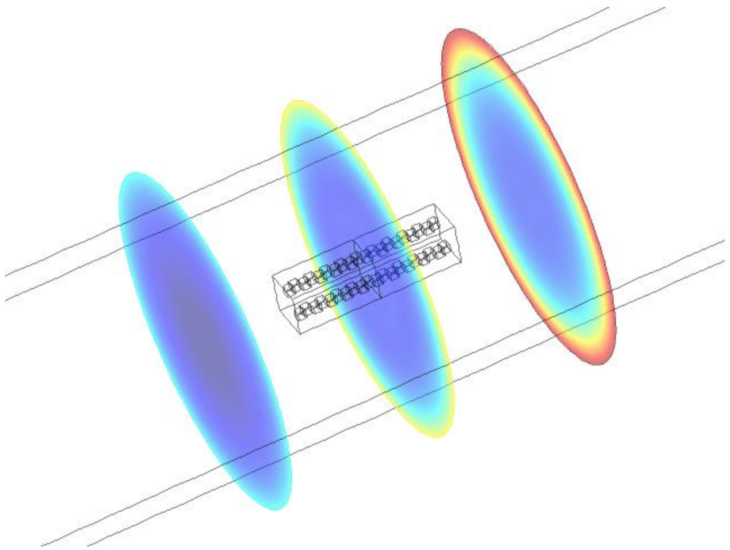
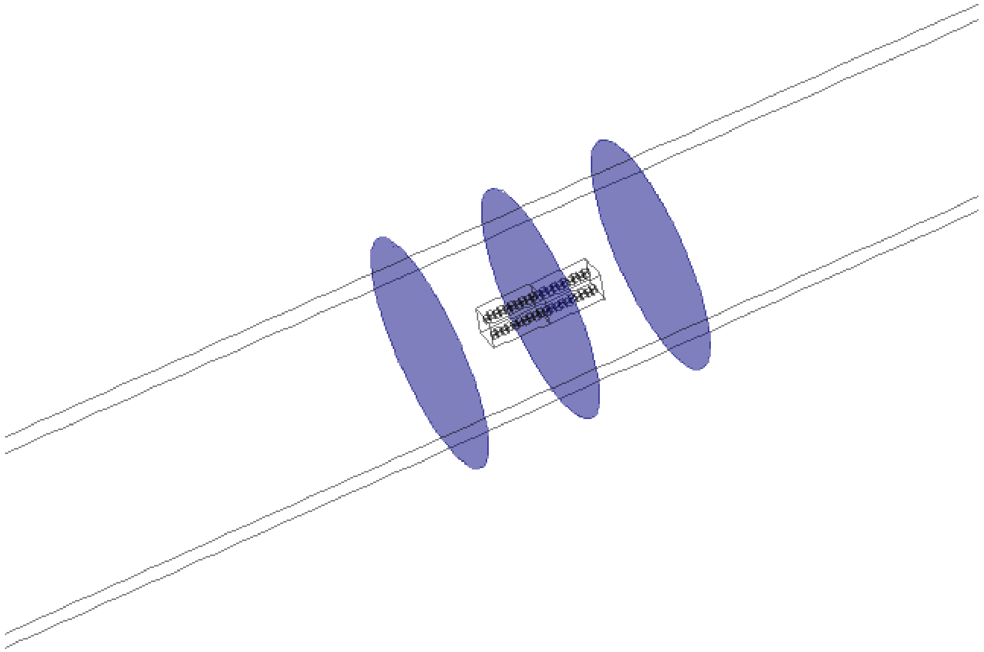
Temperature Profile (at the trailing edge)

Temperature Profile
(time-dependent Cons. of Energy)





3 layers with moving mesh
0 [s] <= t <= 1 [s]

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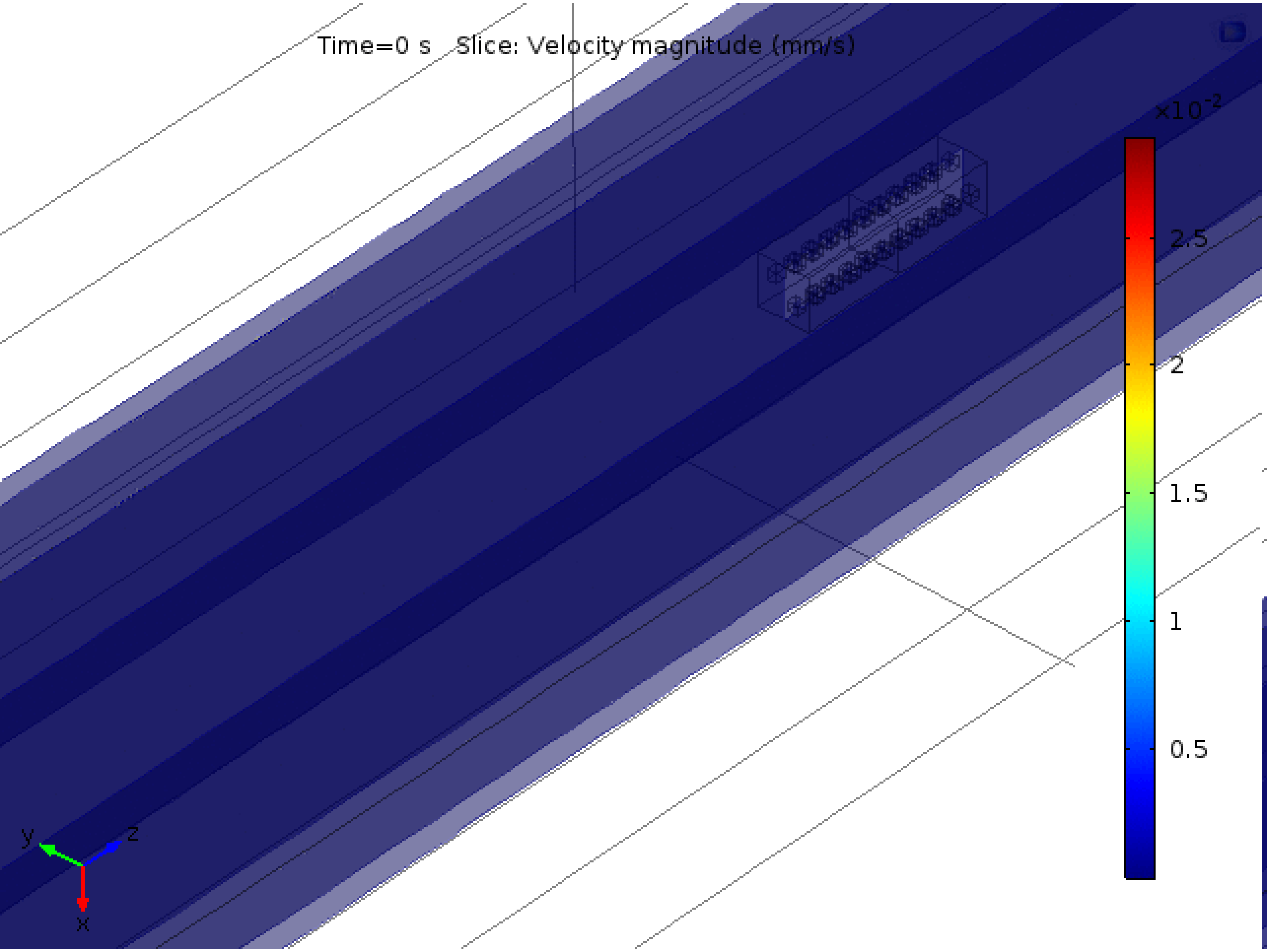
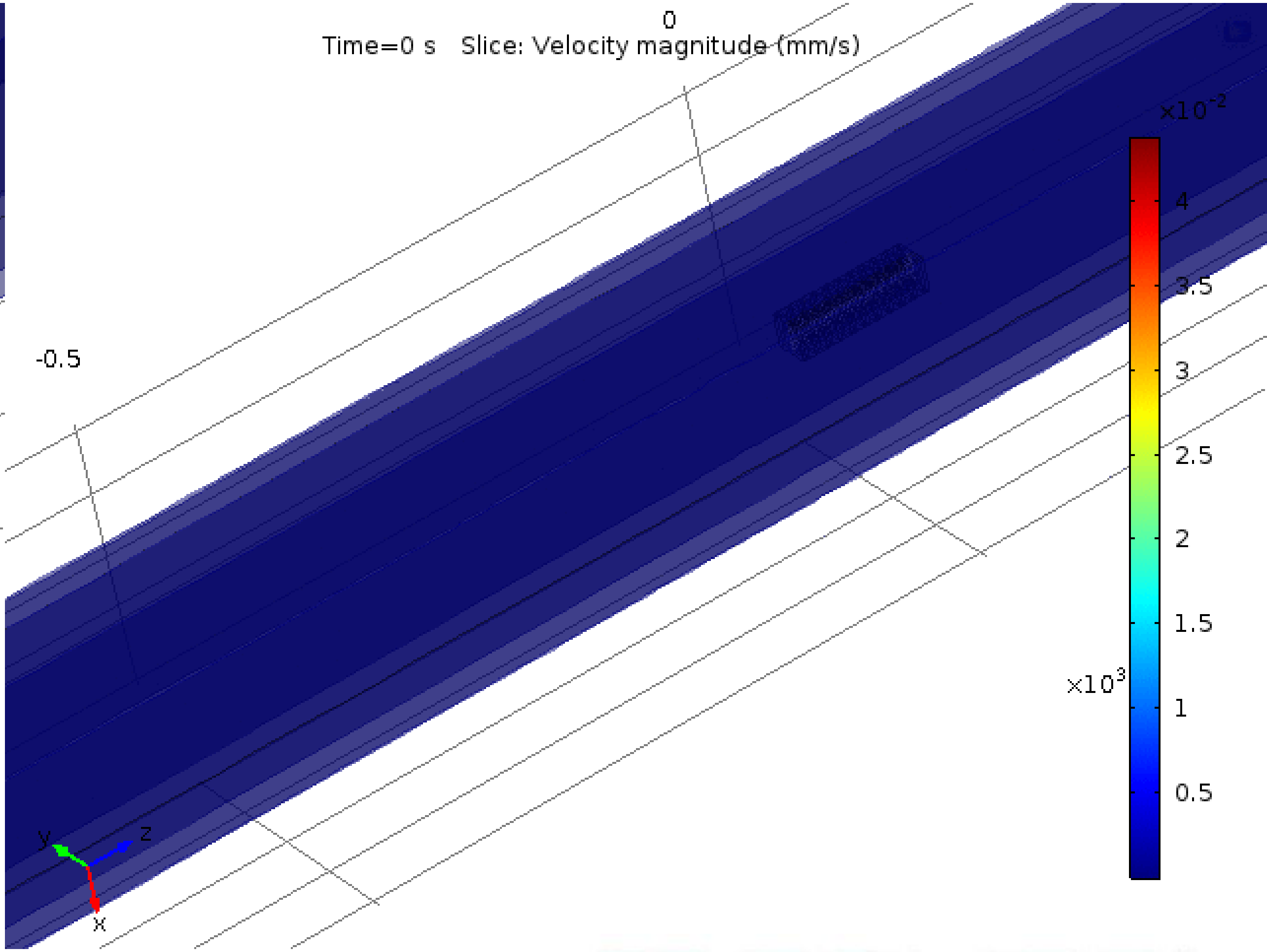
Simulation Results: Rectangle Swimmer

Rectangle, Janus ~ 4 body lengths per second



Rectangle, Striped ~ 4.5 body lengths per second



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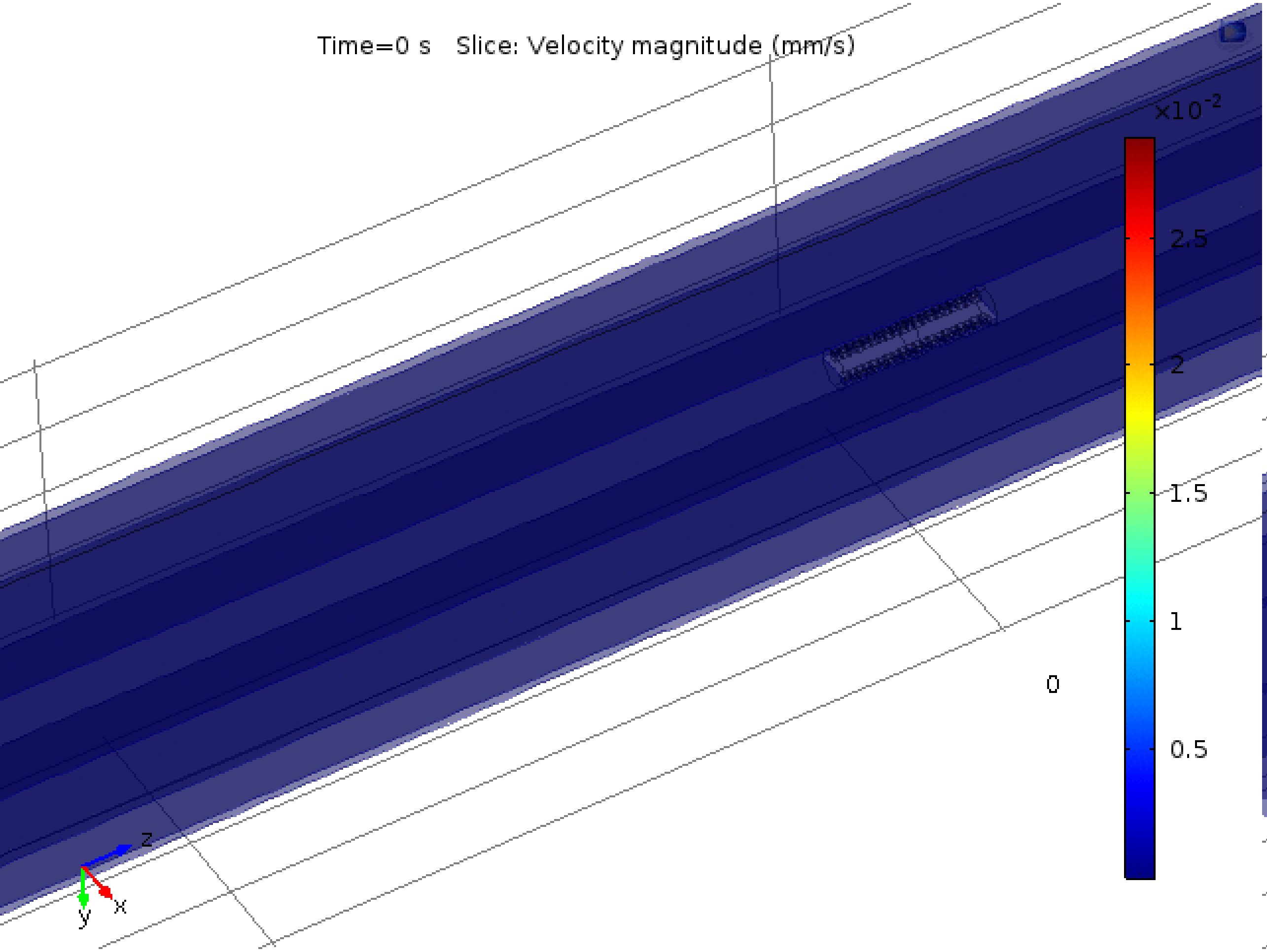
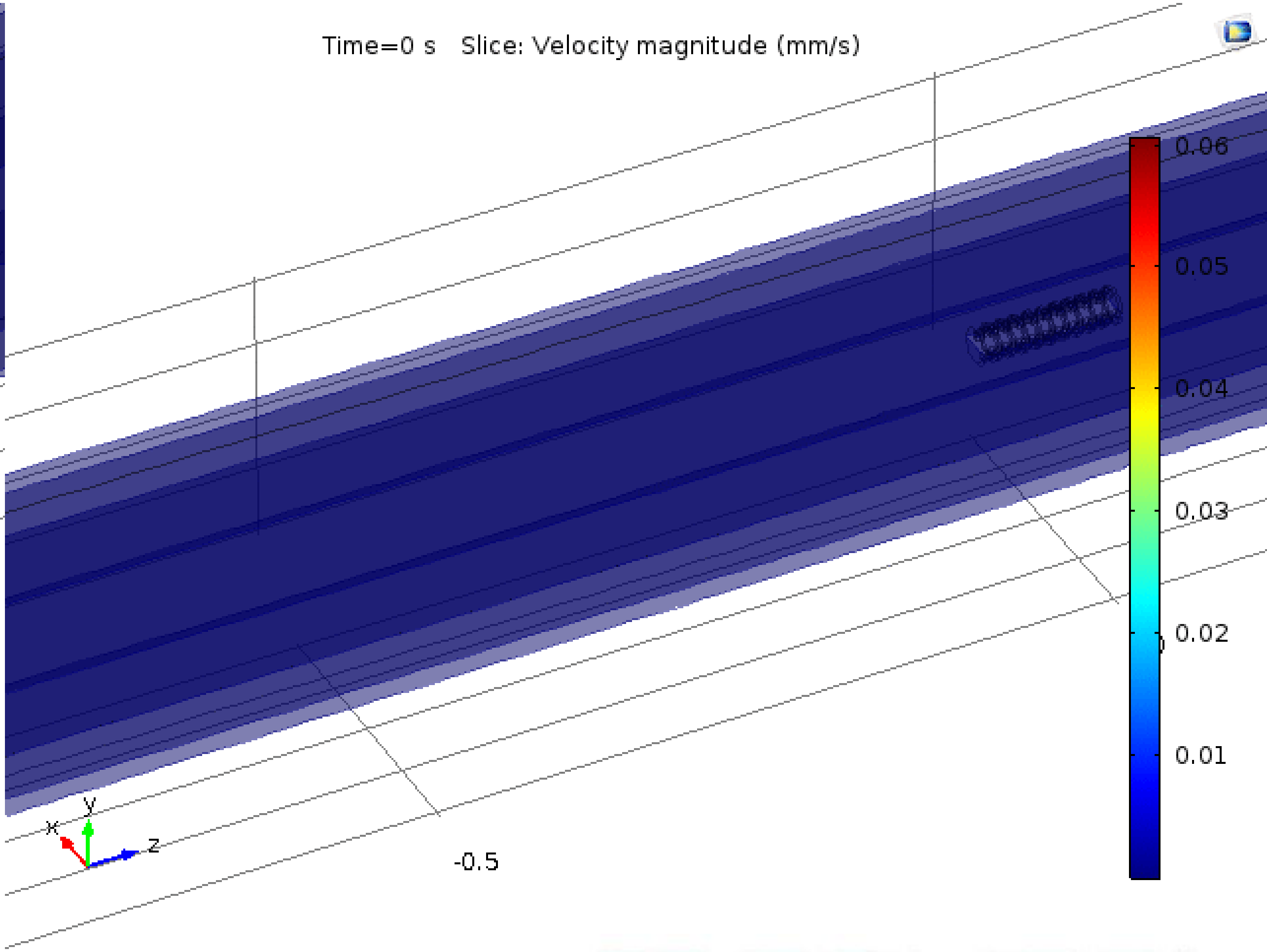
Simulation Results: Cylinder Swimmer

Cylinder, Janus ~ 4.5 body lengths per second



Cylinder, Striped ~ 6 body lengths per second



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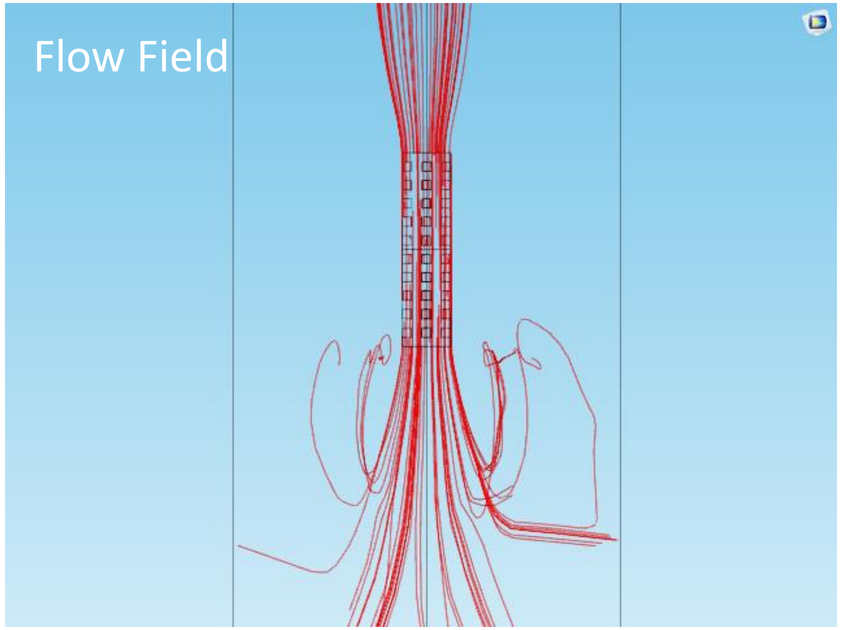
Conclusions and outlook

- Achieved the simulation of rigid-body motion with respect to given heat input,
- Local Marangoni-effect-based flow fields add up to a global flow field,
- Net-thrust is obtained by Marangoni-effect,
- N-S is more suitable to govern the flow field.



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