A Numerical Investigation of Interface Deformation Forced by a Bluff Body

James Percival, Dimitrios Pavldis, Zhihua Xie,
Omar Matar, Chris Pain (ICL)
Kyeong Park, Maxime Chinaud, Panagiota Angeli (UCL)

memphis multiphase

People

Imperial College London


Dr. James Percival


Dr. Dimitrios Pavlidis


Dr. Zhihua Xie


Prof. Chris Pain

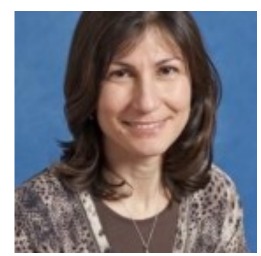
memphis multiphase


Prof. Omar Matar

UCL


Kyeong Park


Dr. Maxime Chinaud

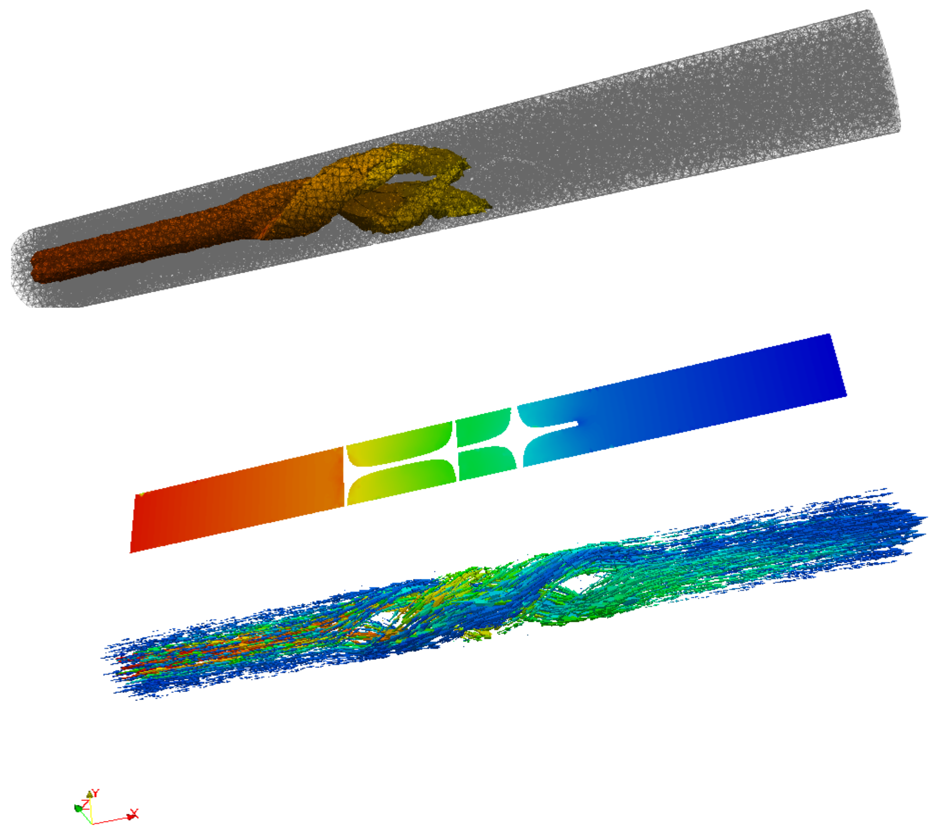

Prof Panagiota Angeli

Overview

- Two phase flow in a pipe with interface deformation forced by a transverse bluff body
- Core problem part of experimental work at UCL Chemical Engineering Dept.
- Numerical investigation conducted at ICL in Applied Modelling & Computation Group using in-house code, Fluidity

FLUIDITY

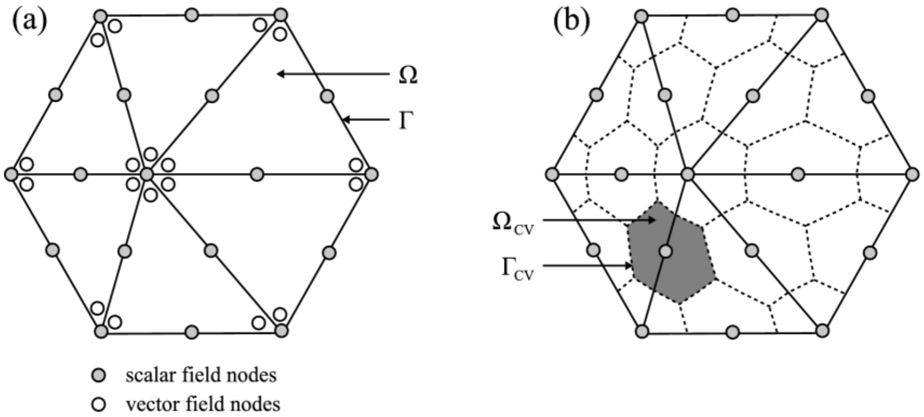
- Control volume-Finite element solver framework
- Mesh adaptivity capability
- Multiphase & multimaterial formulations (and both together)

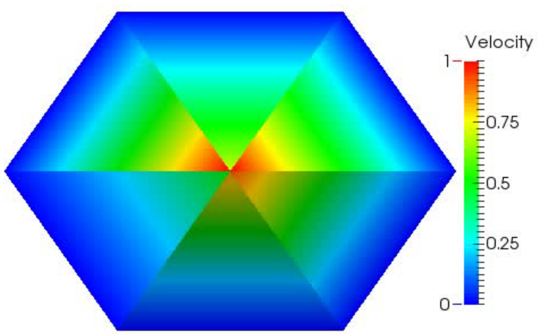


CVDFEM methods

Control Volume Finite Element Method

- Solve weak form PDEs
- piecewise smooth fns for unconserved, unbounded variables
- piecewise flat fns for conserved & bounded tracers



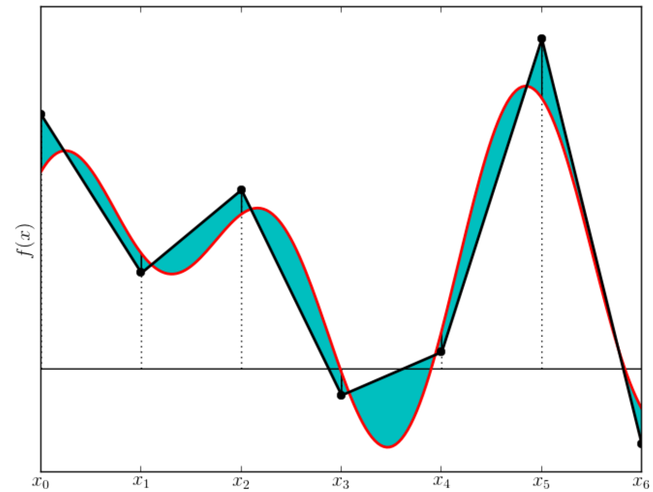


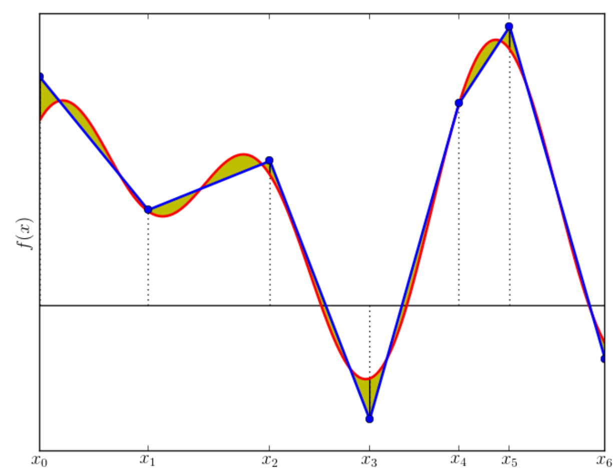
Discontinuous Galerkin Methods
Don't strongly enforce continuity of the finite element variables across finite element boundaries

Mesh Adaptivity

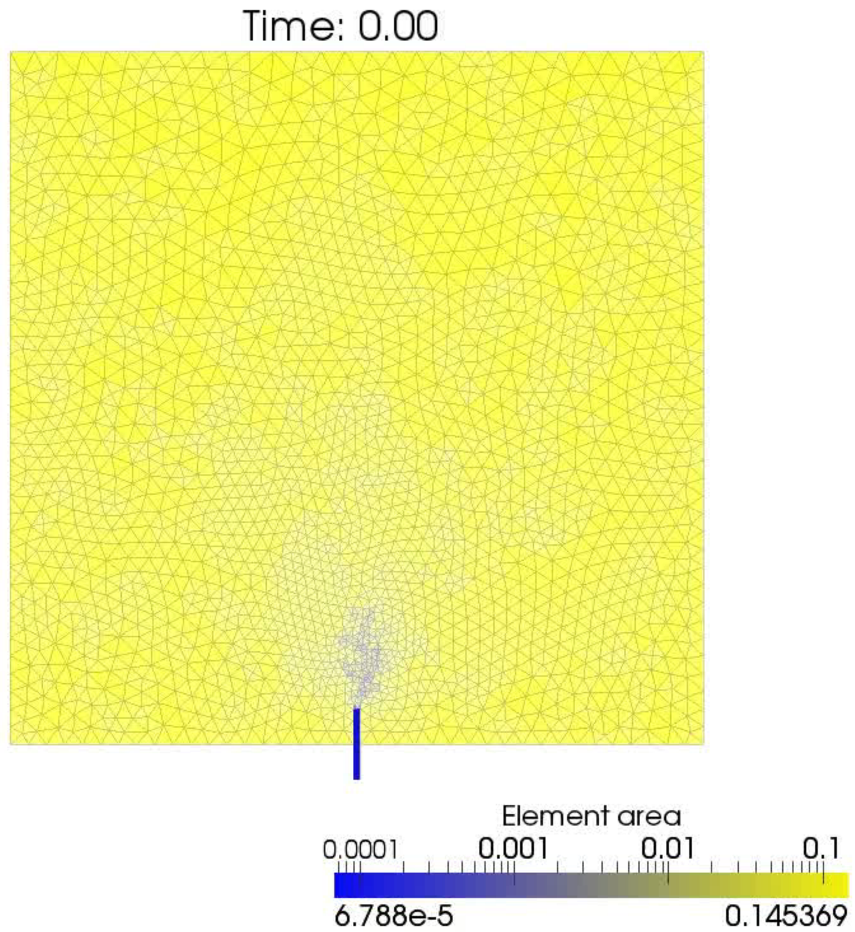
- Minimise weighted sum of estimated linear interpolation error
- Estimate calculated from the data
- Place resolution in regions of solution curvature
  - Boundary layers
  - Filaments
  - Droplets
- Method is anisotropic
  - Aligns with flow

C.C. Pain, A.P. Umpleby,
C.R.E. de Oliveira & A.J.H. Goddard (2001)
Computer Methods in Applied
Mechanics and Engineering





Mesh Adaptivity

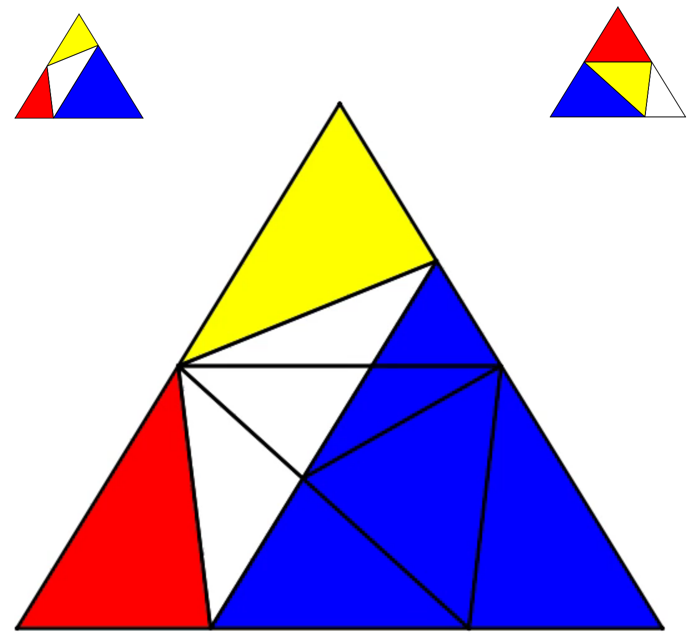


Supermeshing

FE solutions/test functions piecewise smooth over mesh elements

Elements of supermesh: old variables and new test fns both smooth.
No jumps.

Allows efficient conservative mesh to mesh interpolation via projection methods

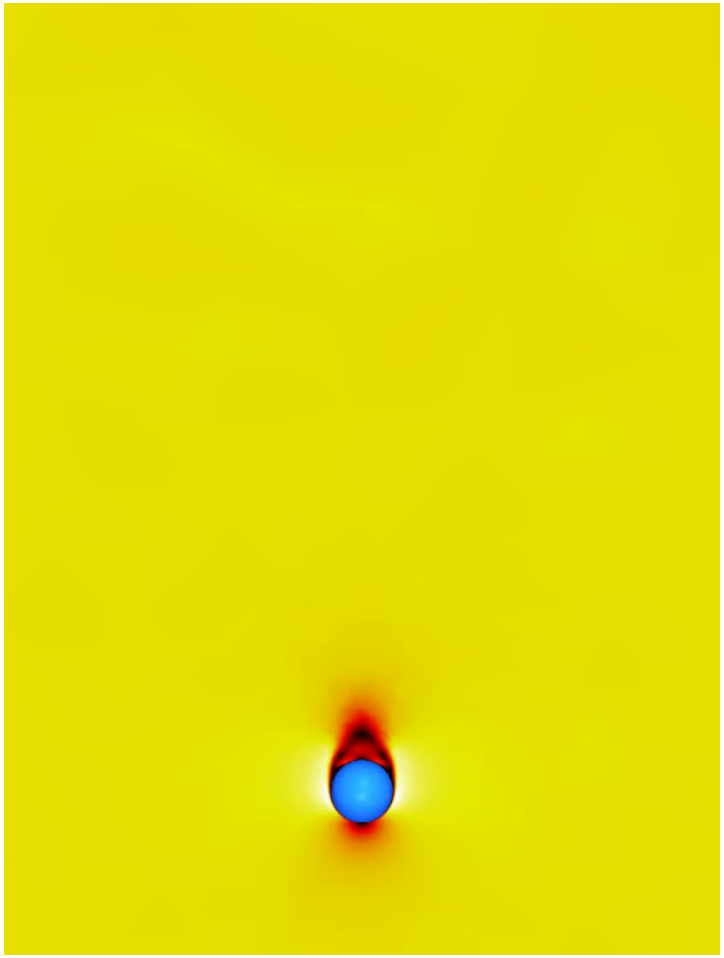


P. E. Farrell & J. R. Maddison (2011) Computer Methods in Applied Mechanics and Engineering

$$\sum_{k\in\{1,\dots,|T_3|\}} \int_{\Omega_k} N_{\sigma_i(k)} N_{\sigma_j(k)} \hat{\alpha}_{\sigma_j(k)} \, dA = \sum_{k\in\{1,\dots,|T_3|\}} \int_{\Omega_k} N_{\sigma_i(k)} N_{\pi_j(k)} \alpha_{\pi_j(k)} \, dA$$

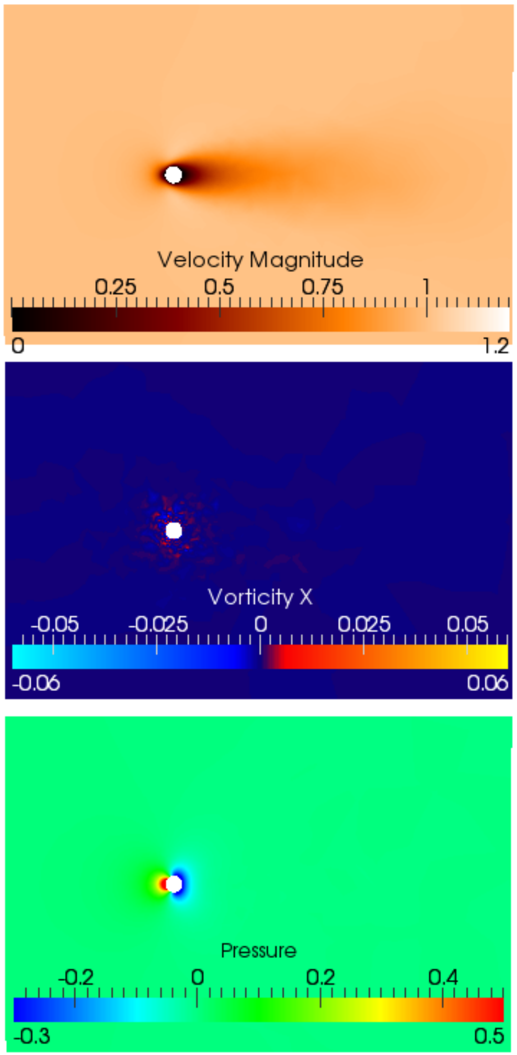
Flow past a body

- Fixed solid body inserted into turbulent background flow
- Classic problem in single phase flow
- As flow becomes more turbulent object begins shedding sheet of alternating von Karman vortices.

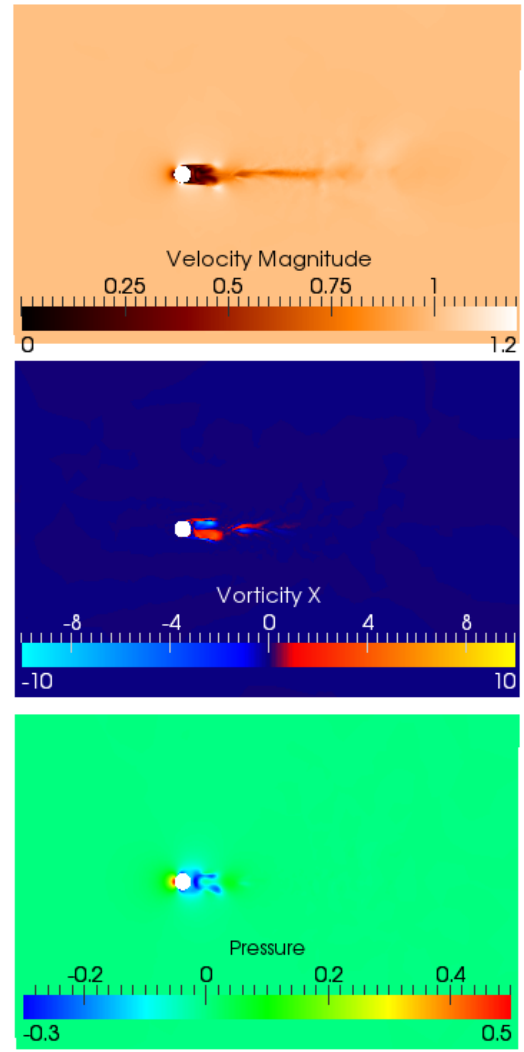


Flow Past a Body

Re 10



Re 1000

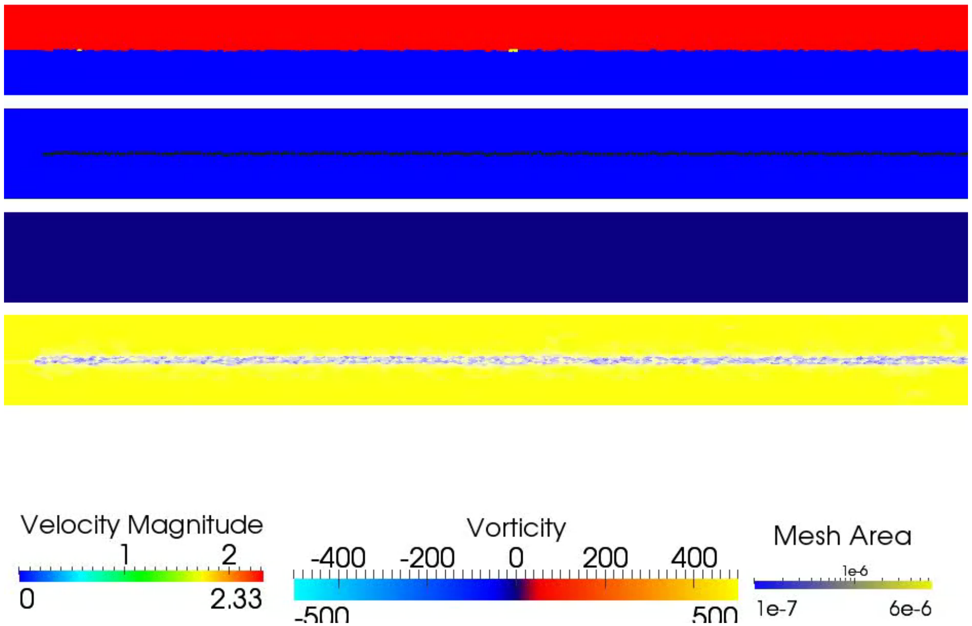


Two phase flow

Number of additional physical processes

Numerically “hard”

- Material Interfaces
- Viscosity differences
- Surface tension
- Droplets

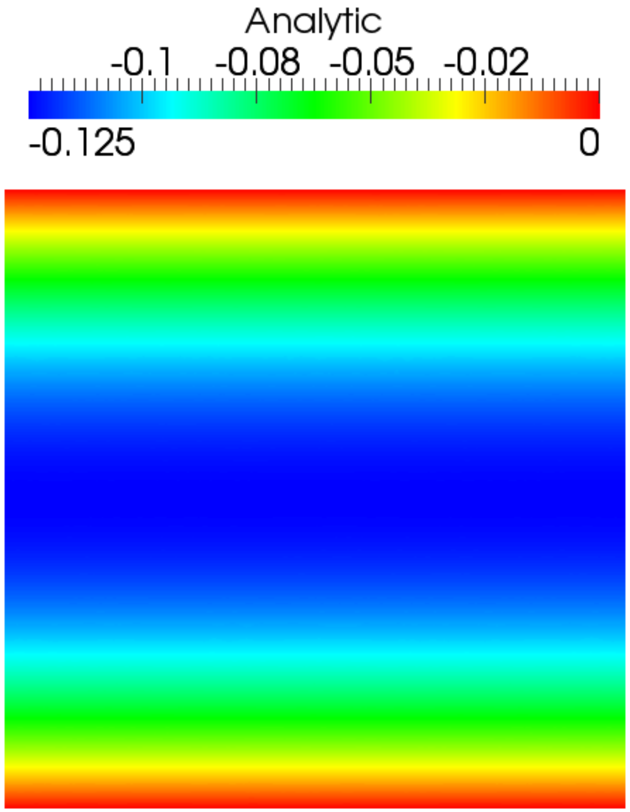


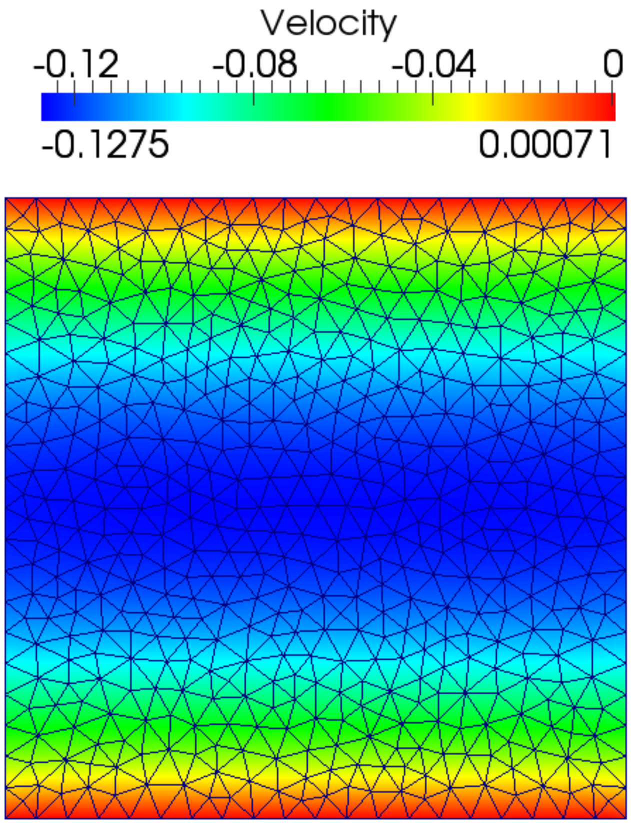
Verification of flow model

Single phase laminar channel flow

Spin up from
Pressure differential

$$u(y) = -\frac{1}{2\mu}\frac{\partial p}{\partial x}(h^2 - y^2)$$





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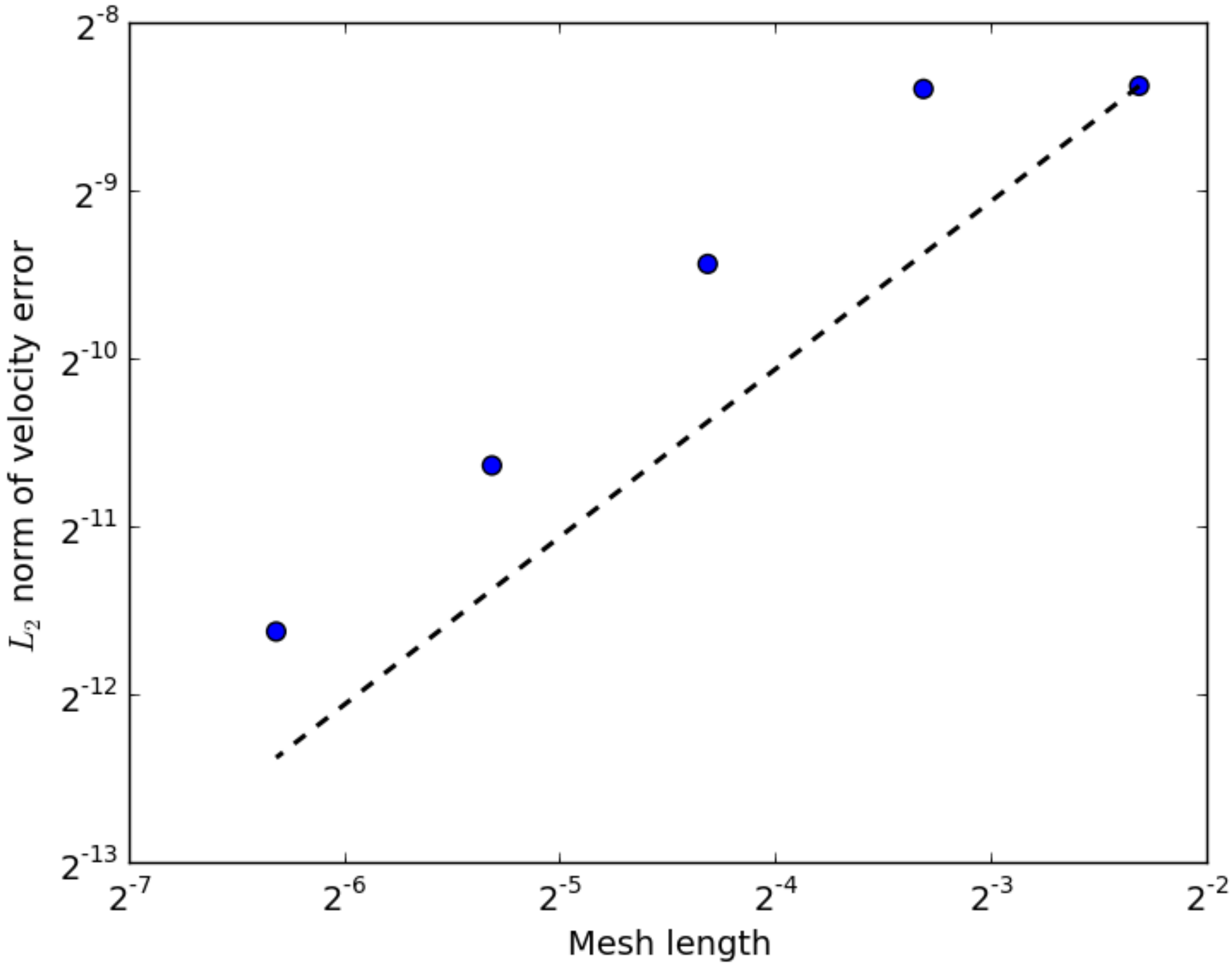

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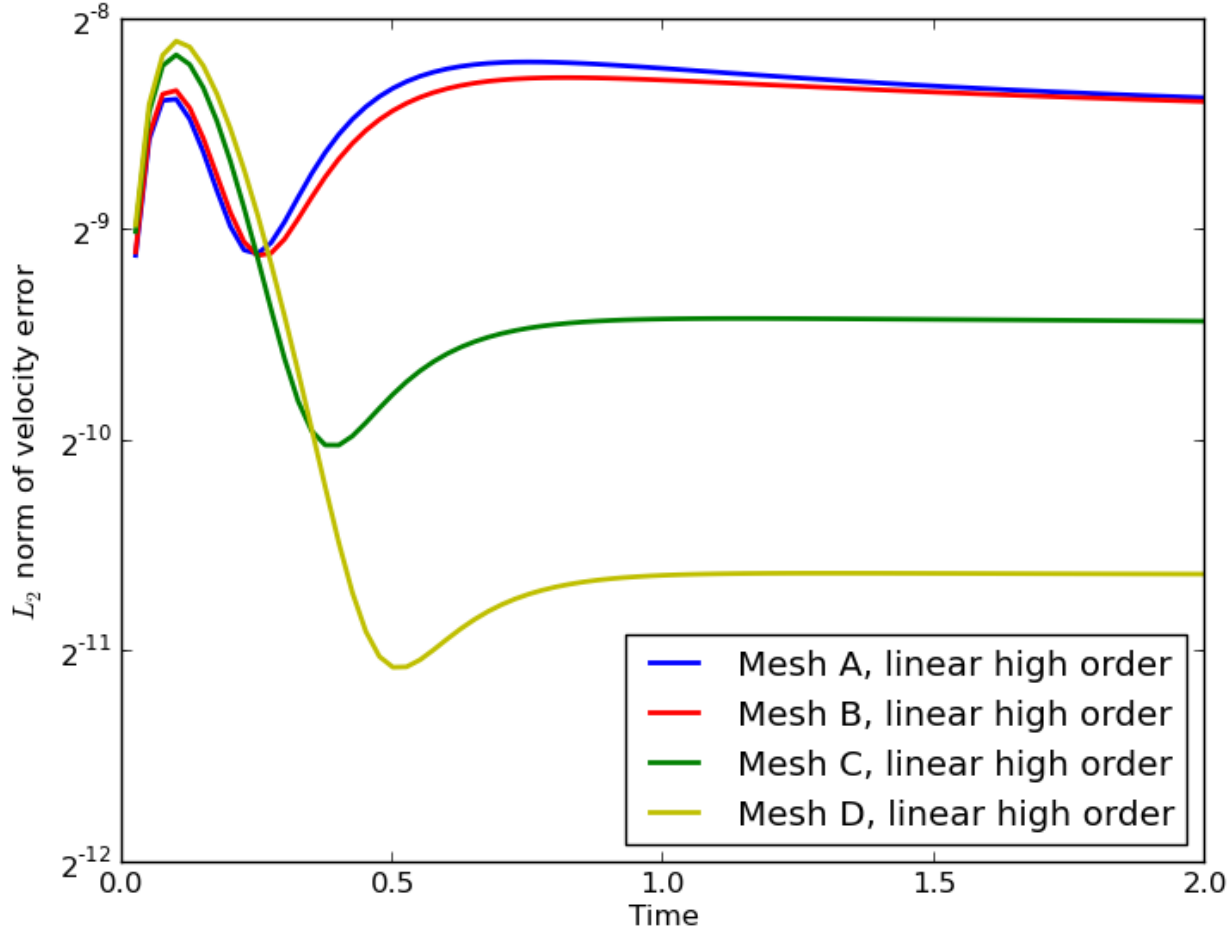


Verification of flow model

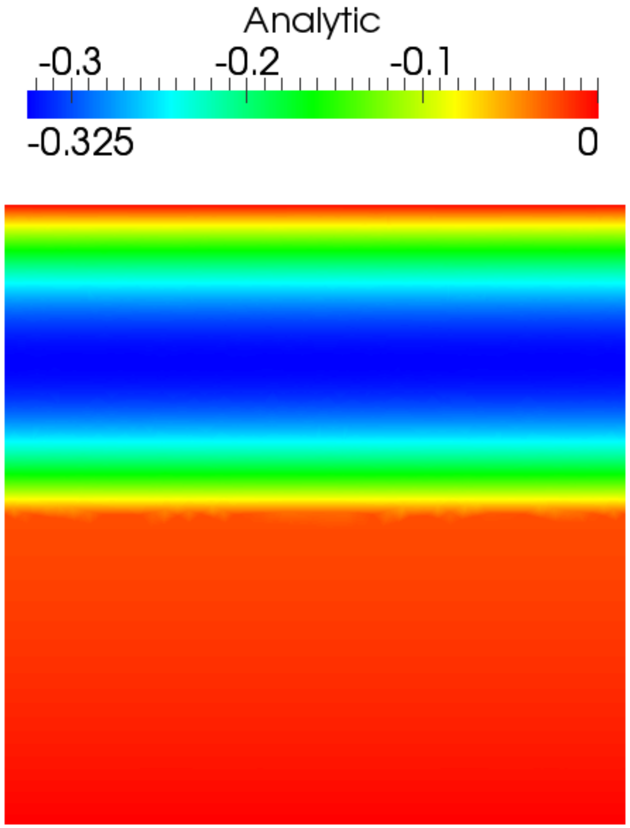
multiphase laminar channel flow

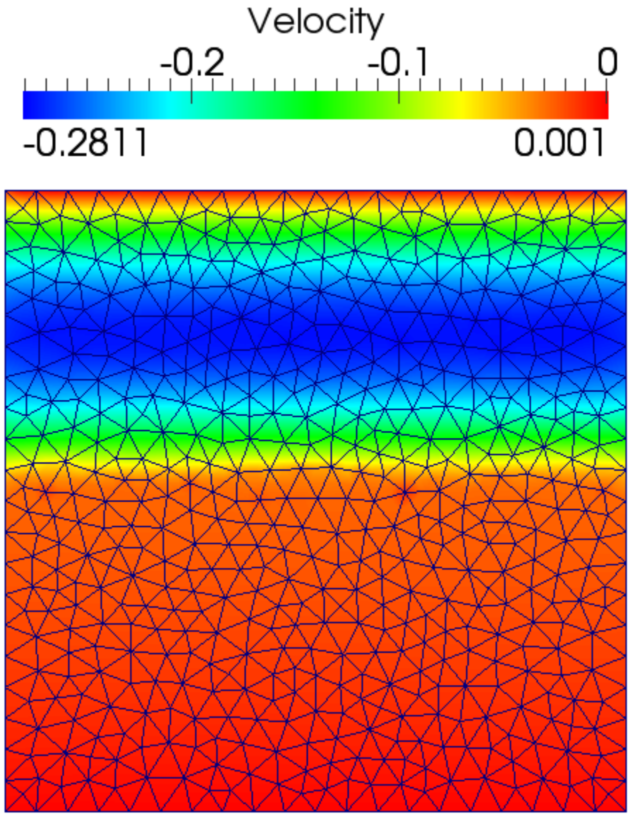
Spin up from
Pressure differential

$$c_0 = \frac{1}{2}\left[\frac{(\mu_1 - \mu_0)\,h_c^2 + \mu_0 h^2}{(\mu_1 - \mu_0)\,h_c + \mu_0 h}\right]$$

$$u(y) = -\frac{1}{2\mu_0}\frac{\partial p}{\partial x}\left[2c_0 y - y^2\right]$$

$$u(y) = -\frac{1}{2\mu_1}\frac{\partial p}{\partial x}\left[2c_0(y - h) + h^2 - y^2\right]$$





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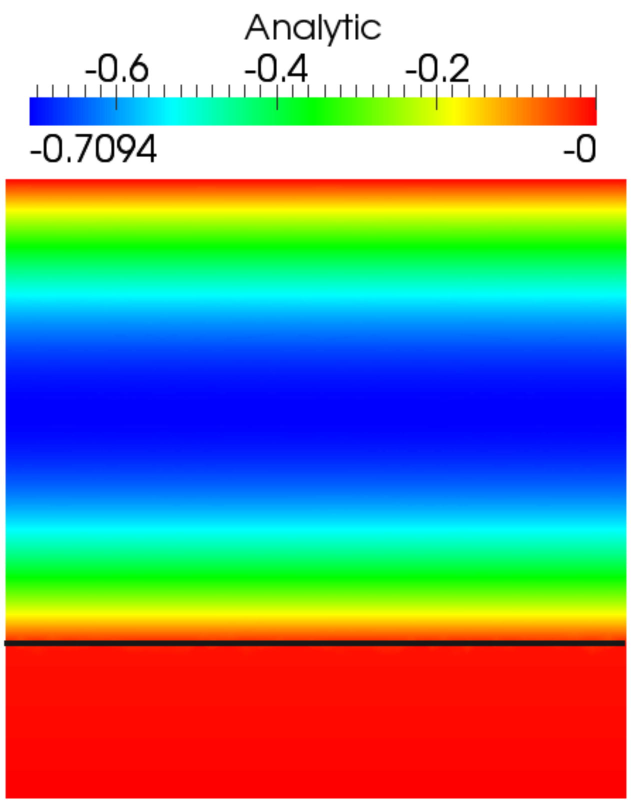

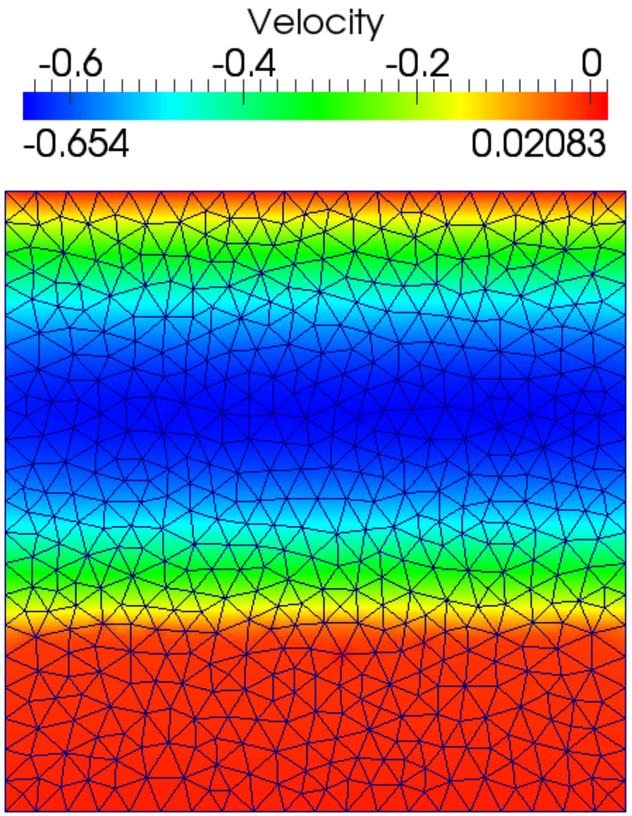

Verification of flow model

multiphase laminar channel flow

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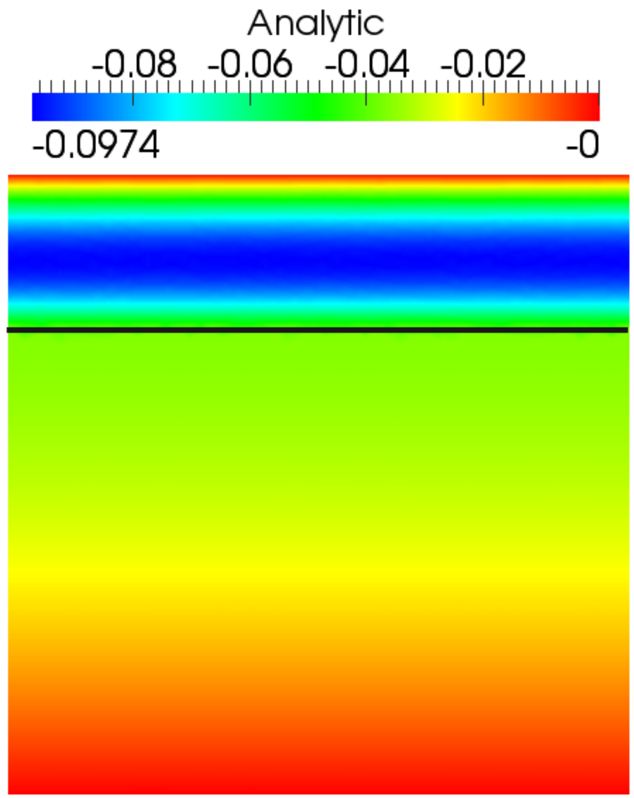

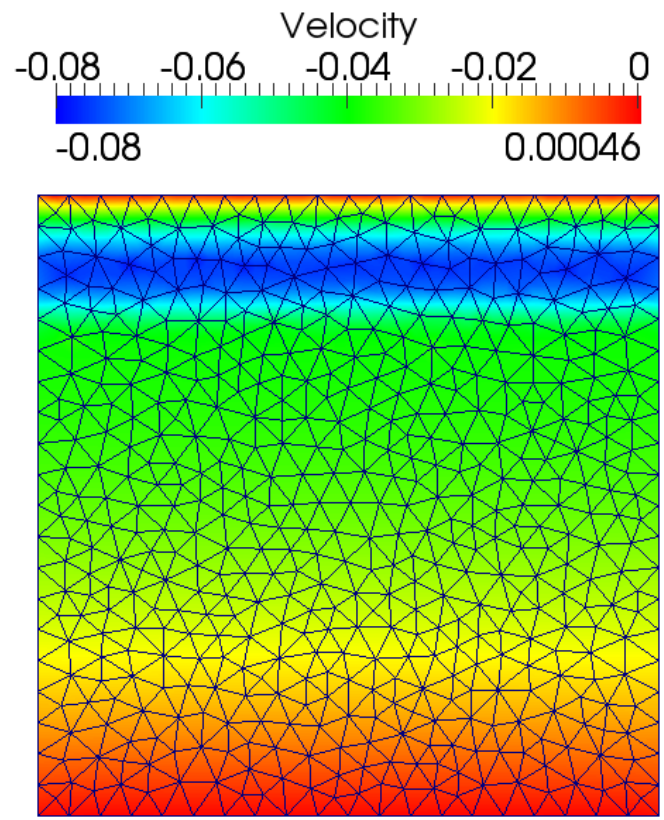

Verification of flow model

multiphase laminar channel flow

Spin up from
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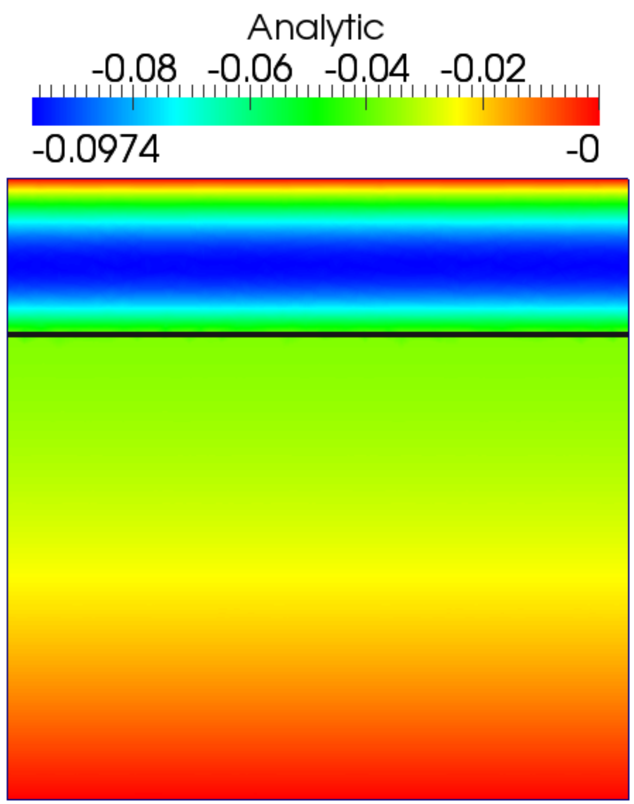
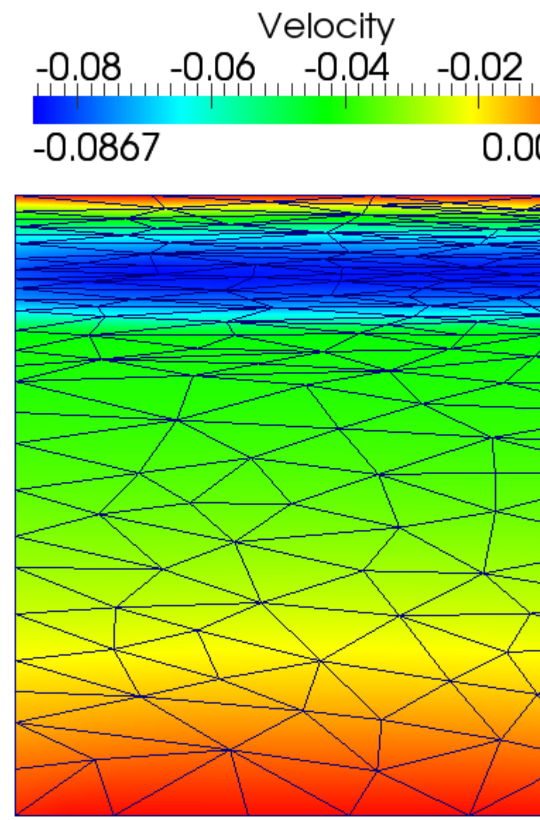
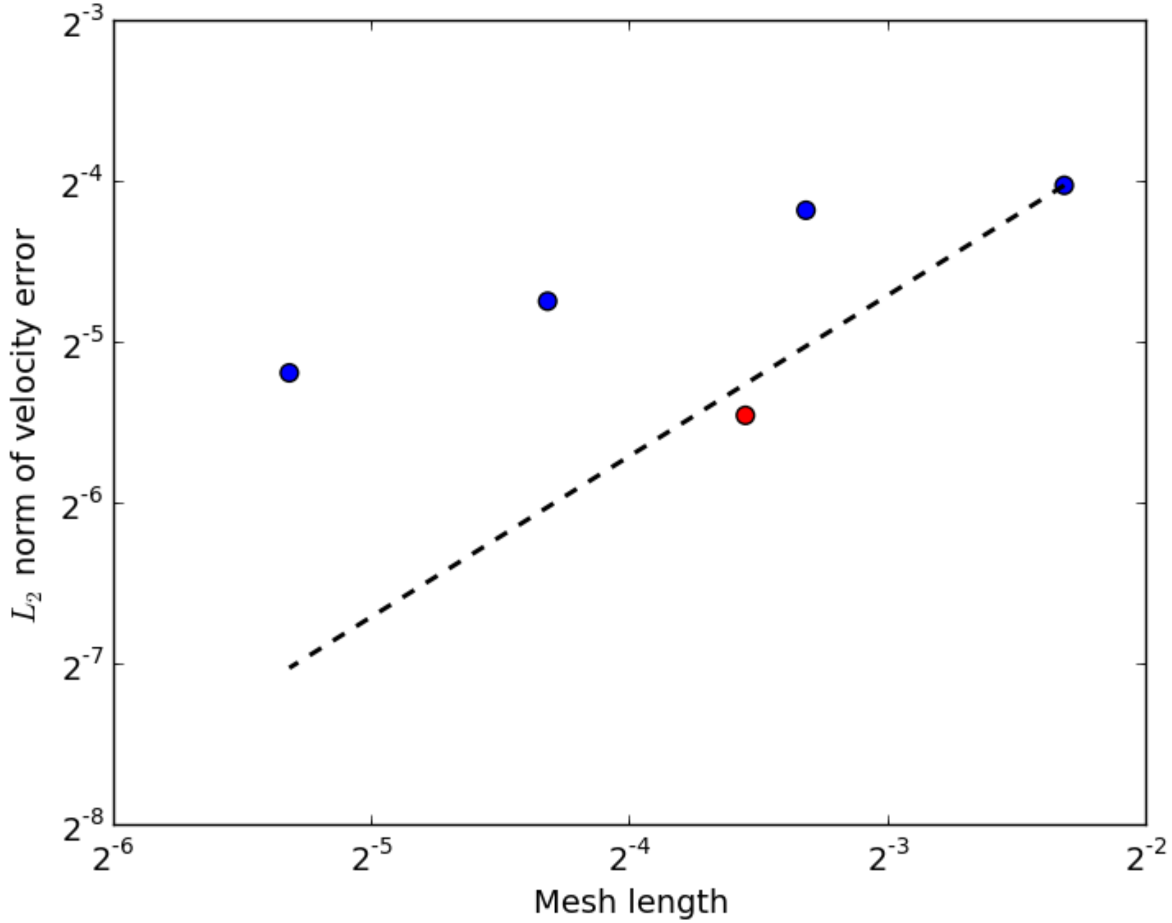




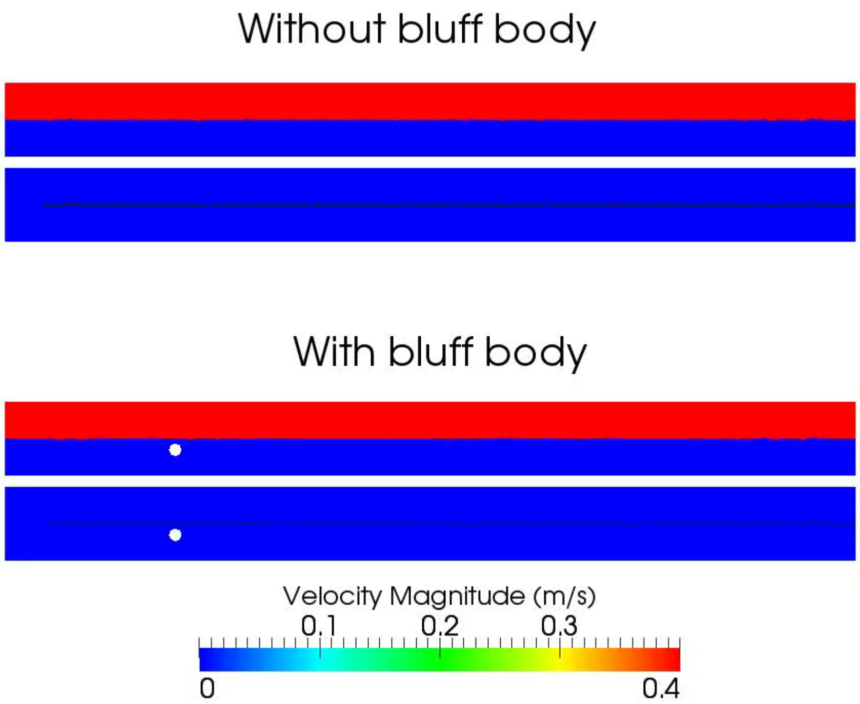
Verification of flow model



Two phase flow past a bluff body

- Combines both contribution of vortex shedding from the cylinder and interface instability

- Acts as an actuator for wave generation, wave breaking & droplet formation



Red = ExxsolD140 oil
ρ = 830 kg.m^{-3}
μ = 0.0055 kg.m^{-1}s^{-1}
σ=0.02 Nm^{-1}

Blue = Water
ρ = 1000 kg.m^{-3}
μ = 0.001 kg.m^{-1}s^{-1}
σ=0.07 Nm^{-1}

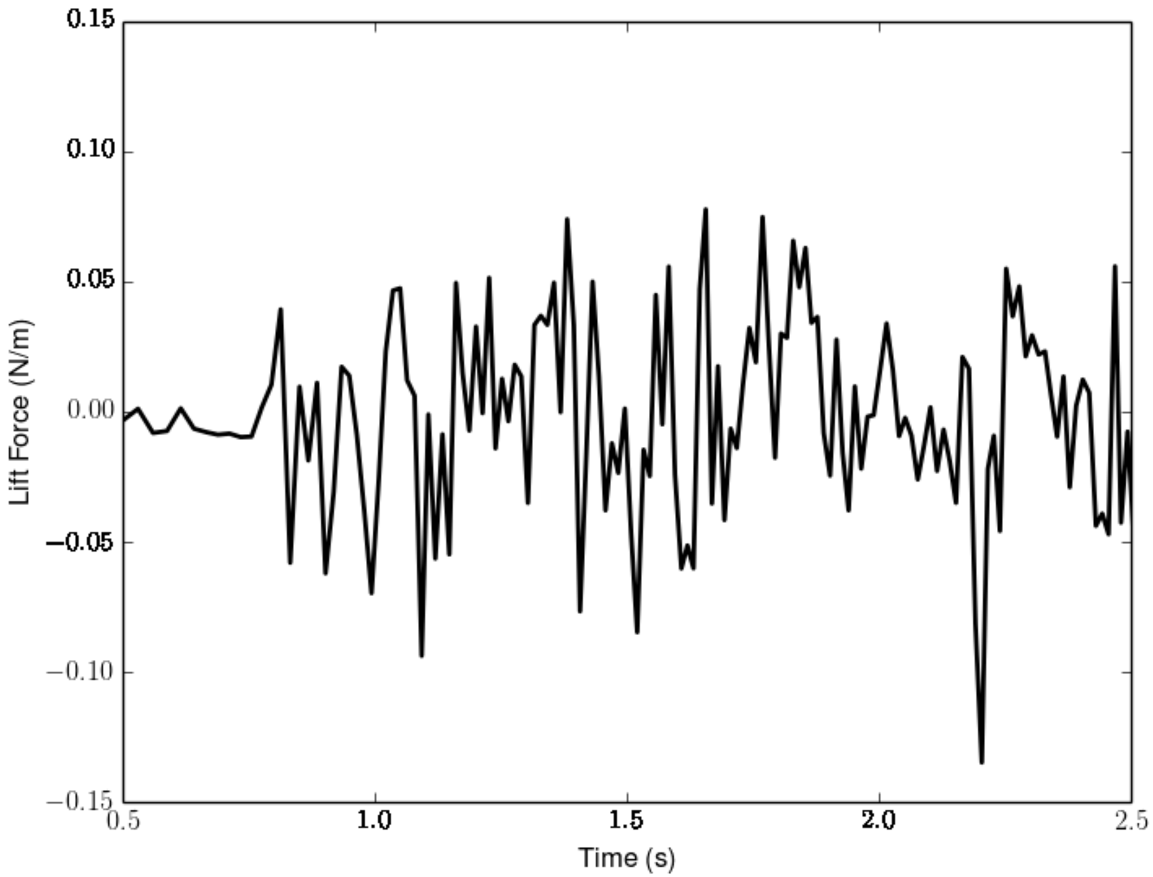
U_{max}=0.375, velocity driven

Without body

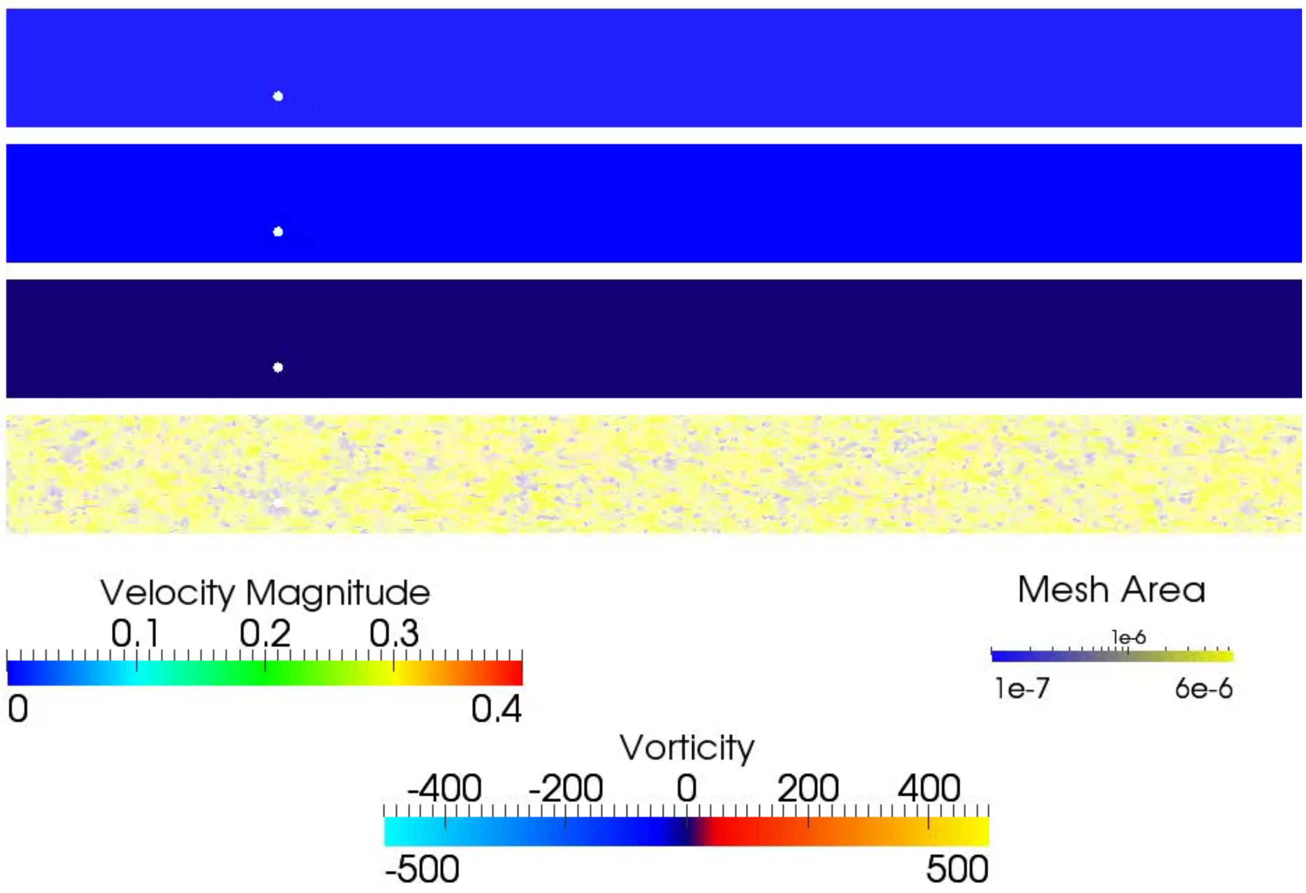
With body

Forces on the body

Diagnostic: lift force on cylinder



Comparison: Single Phase



Forces on the body

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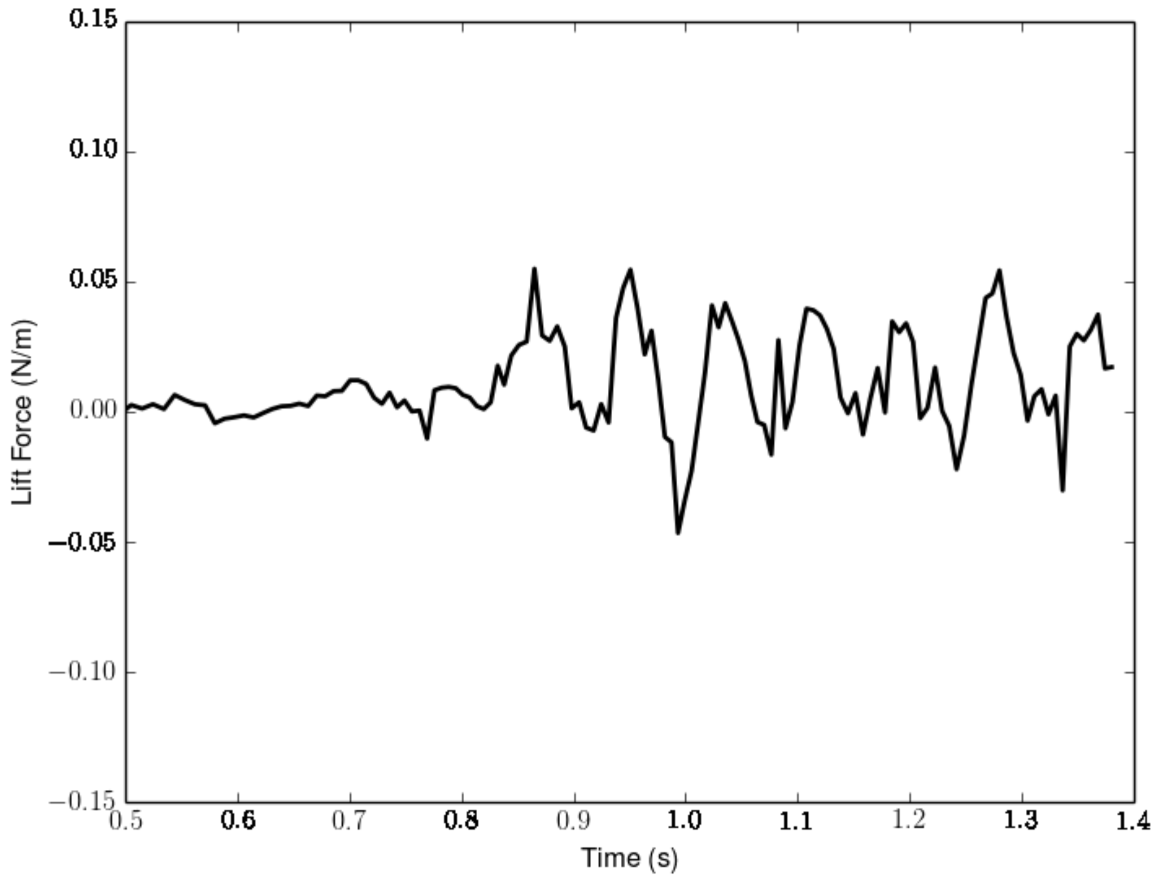
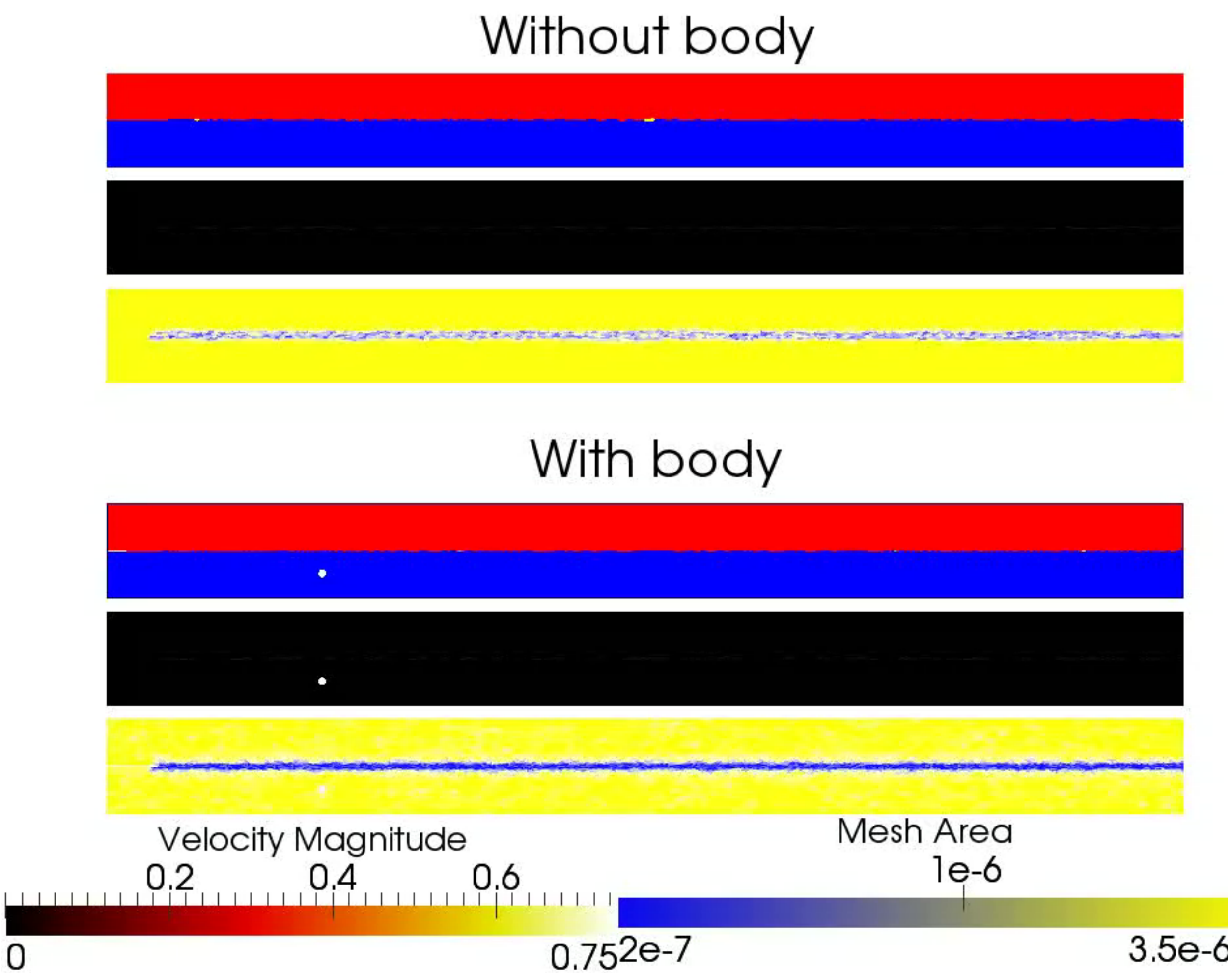
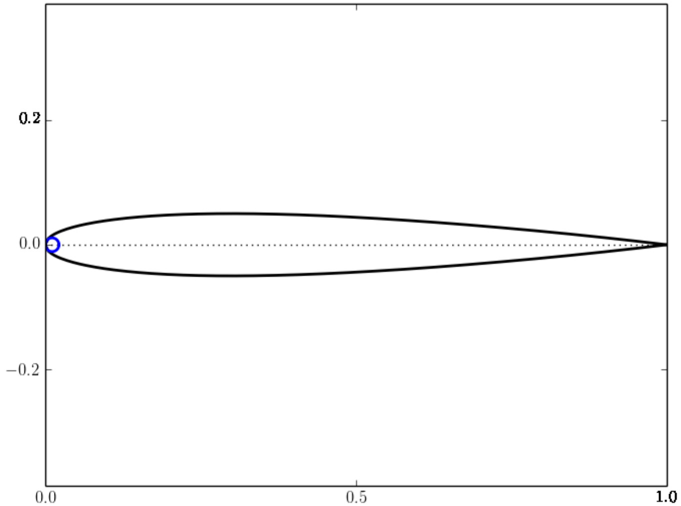


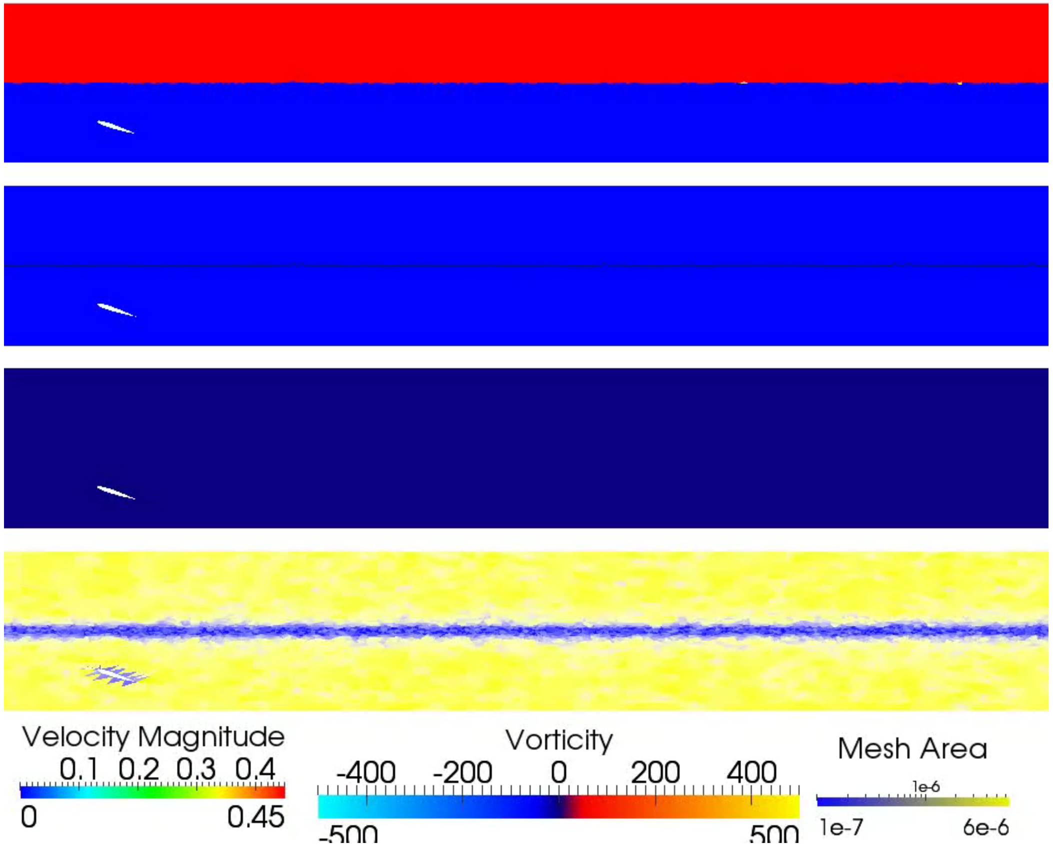
U_{max}=0.75, velocity driven



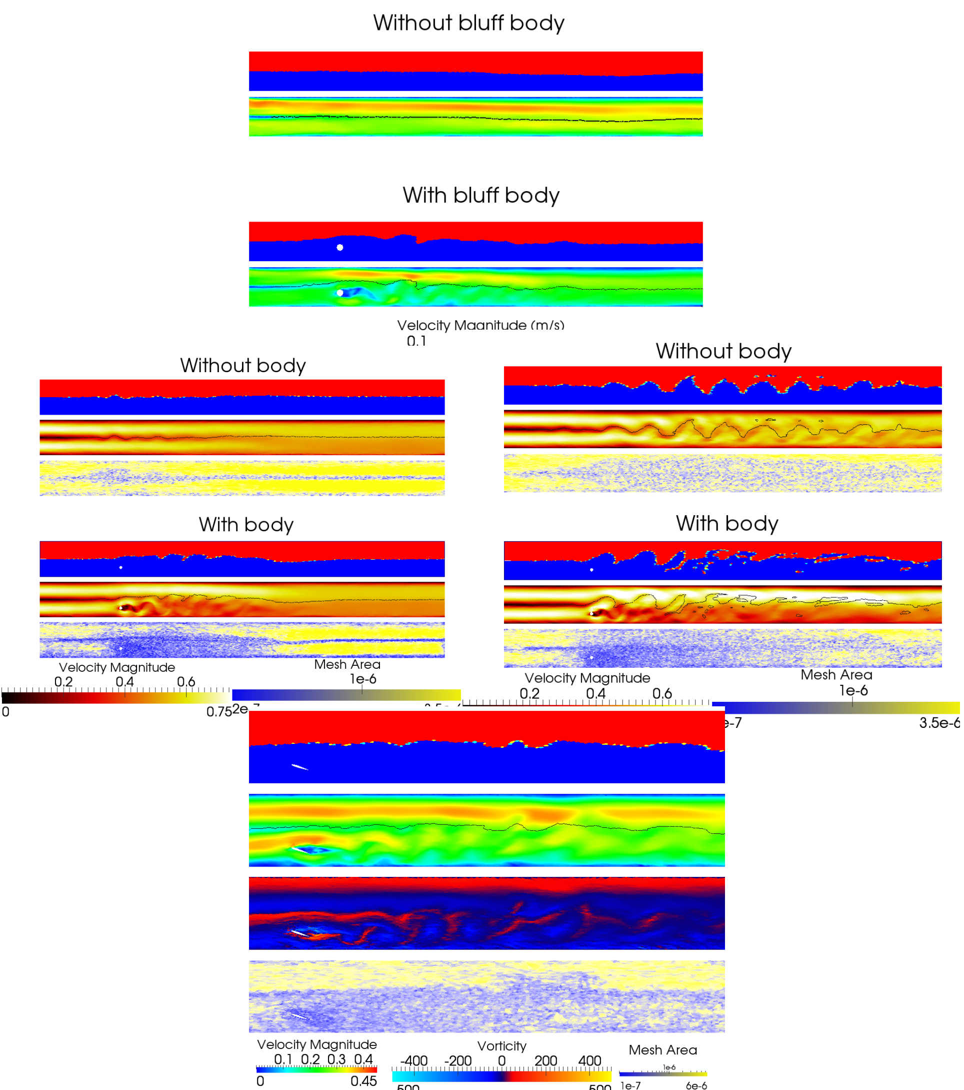
Noncylindrical bodies

- Trivial to investigate objects other than a cylinder numerically within Fluidity
- Eg. NACA modified airfoil





Summary



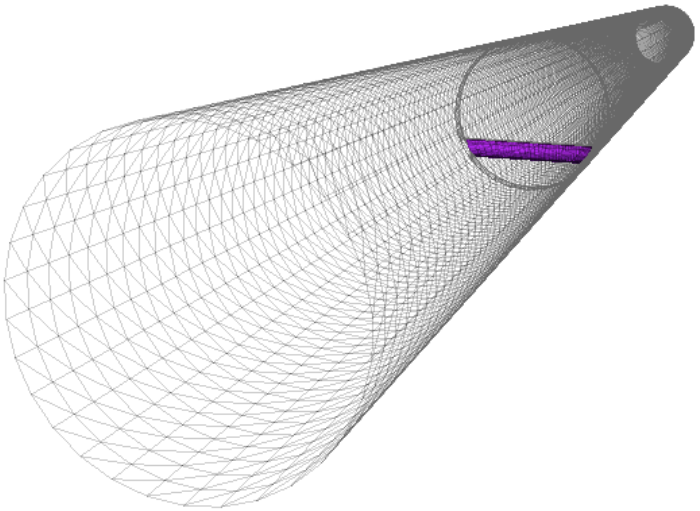
- Preliminary numerical study of two-phase oil-water interface deformation forced by a bluff body.
- In two dimensional experiments addition of a cylindrical body below a material interface is shown to variously
  - generate,
  - enhance,
  - or break interfacial waves

depending on flow regime.

- Interaction between frequencies of KH instabilities at the interface & von Karman vortices shed from obstruction

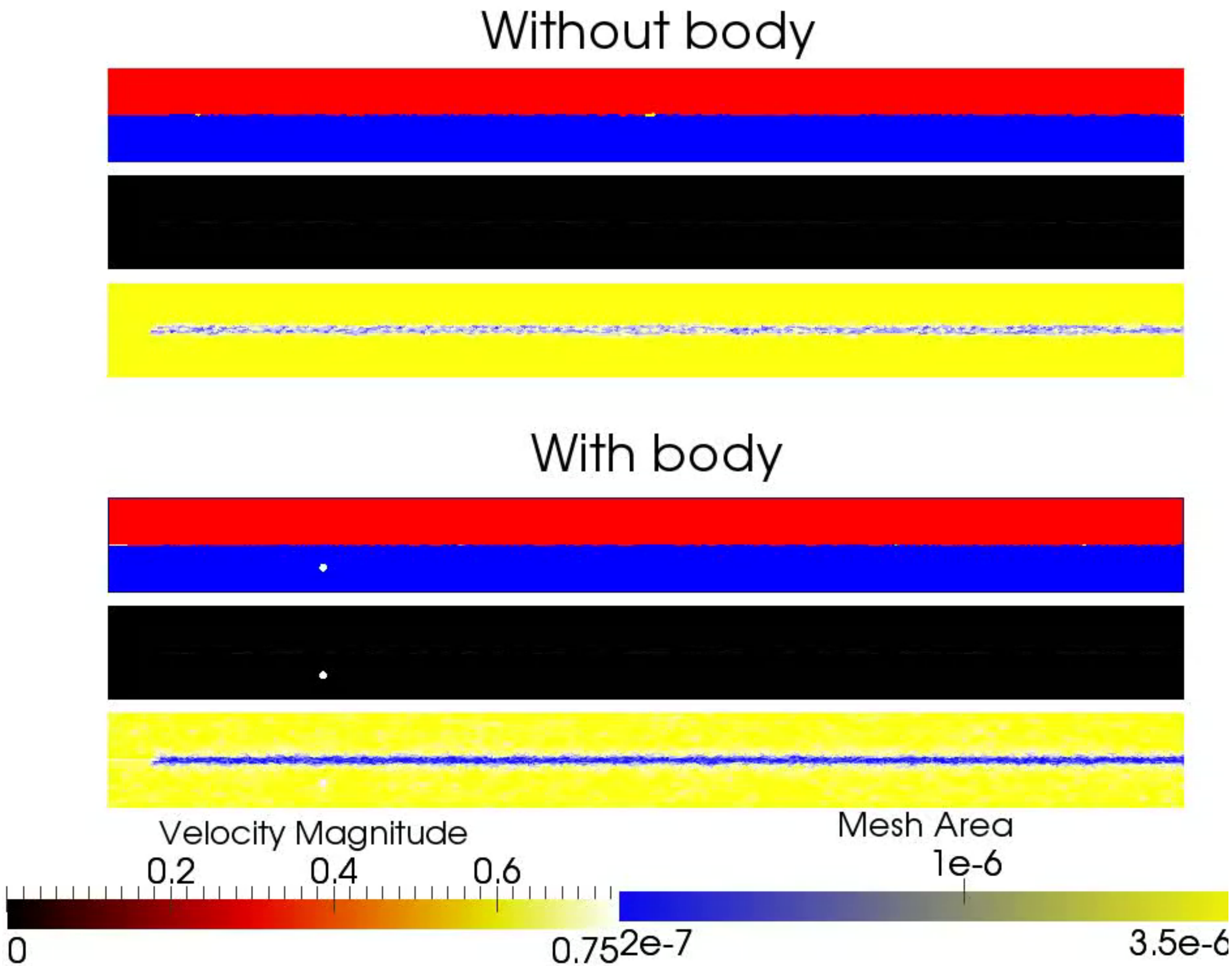
Future work

- Full 3D modelling
  - Effects of the walls
- Investigate role of surface tension:
  - Qv talk by Z. Xie
  - Droplet formation due to forced wave breaking
- Detailed intercomparison with the experimental work of K.Park et. al



Thank you!

Any Questions?


Without body
With body
Velocity Magnitude
0.2
0.4
0.6
0
0.75
Mesh Area
1e-6
2e-7
3.5e-6