Tip Vortex Flows in Marine Applications

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RoughProp Project
Suppress tip vortex cavitation by using roughness

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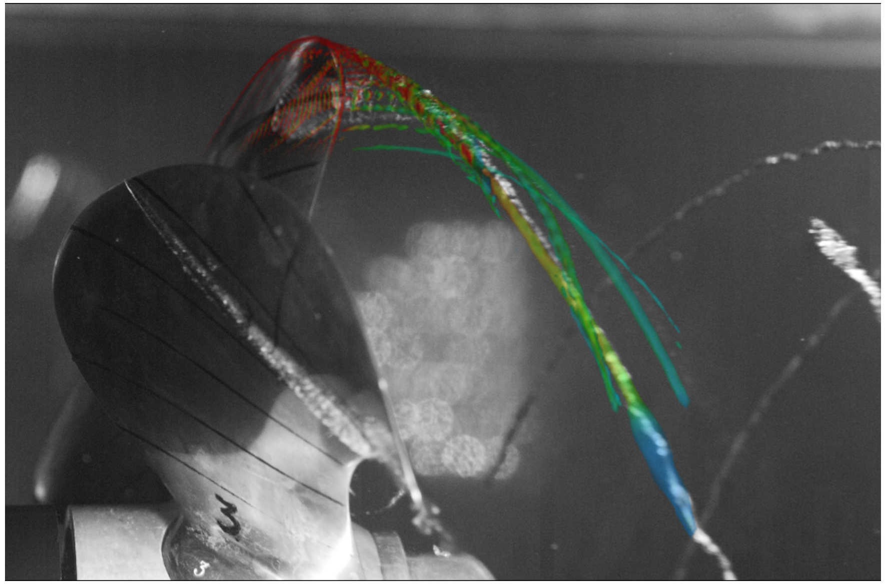
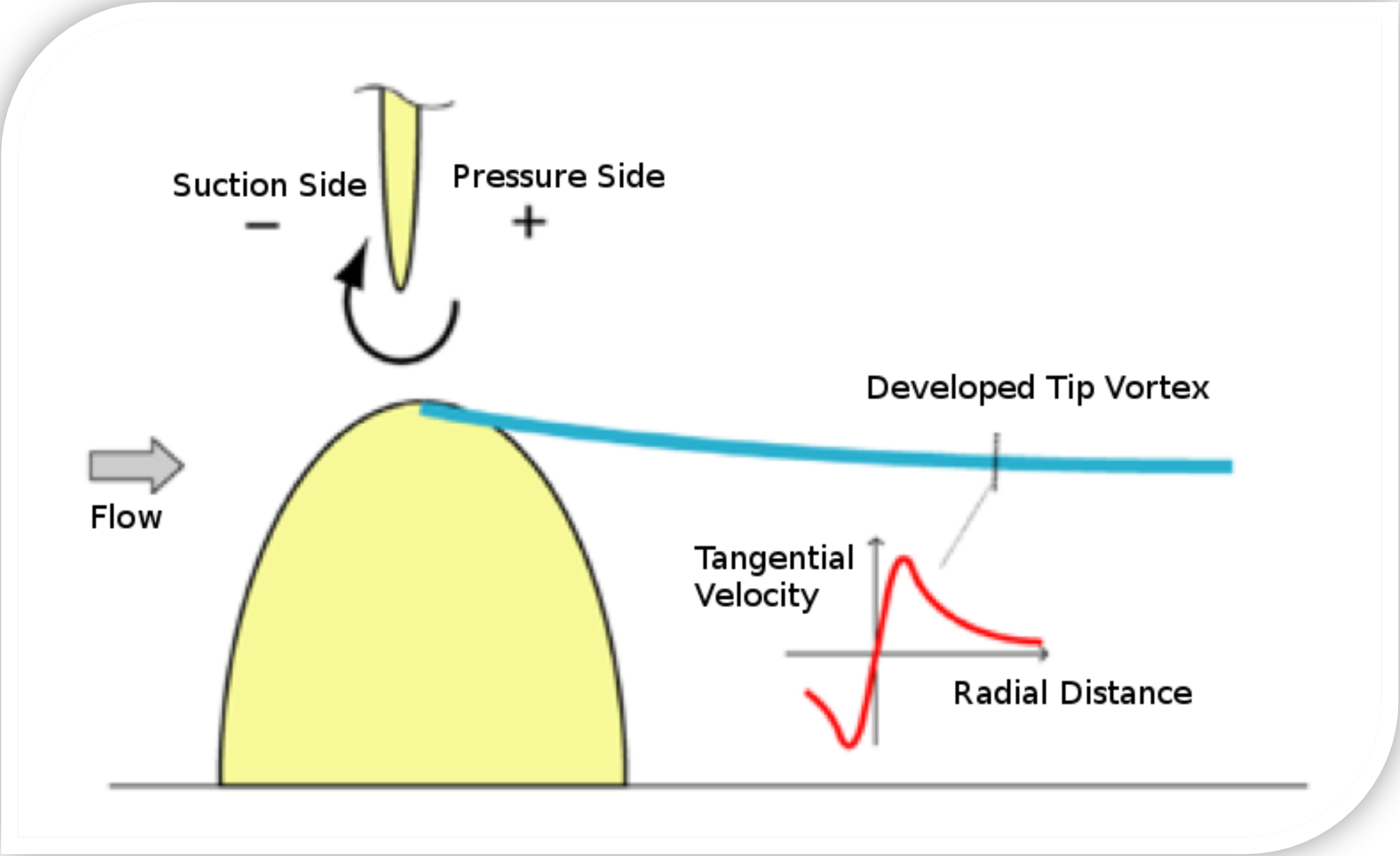


VINNOVA
Sweden's Innovation Agency

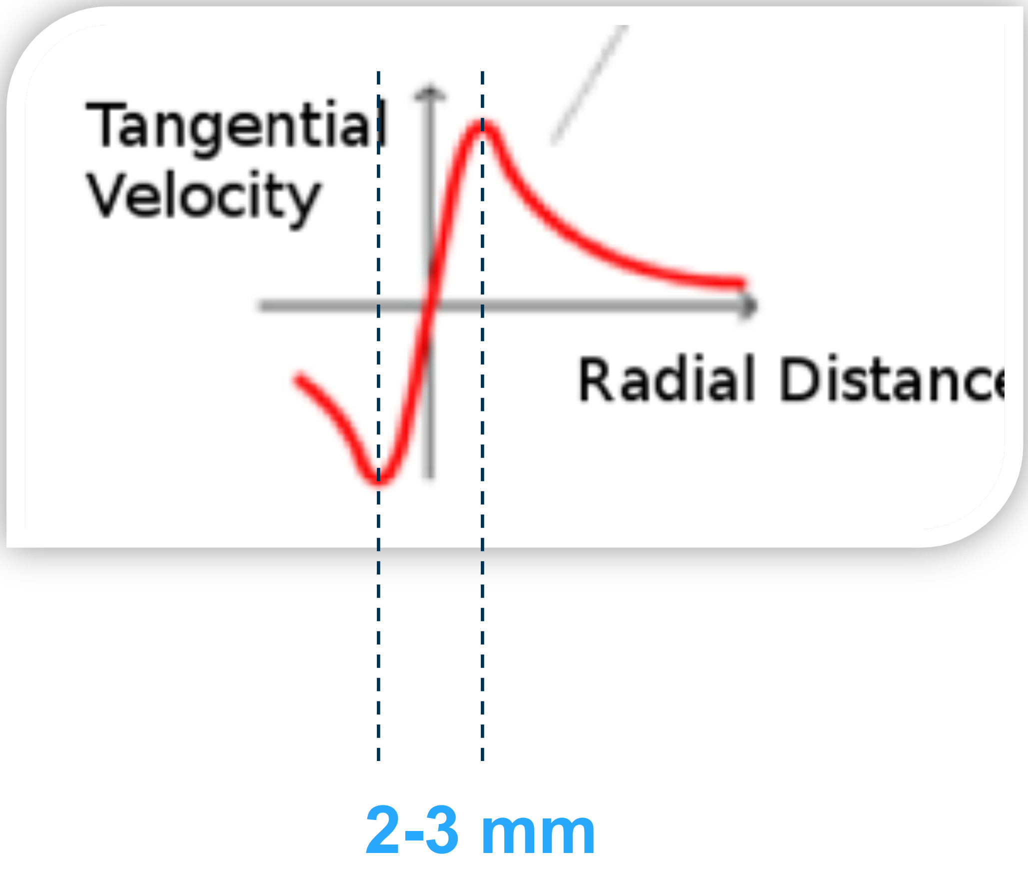
Gothenburg Region OpenFOAM User Group Meeting, November 20th, 2019

KONGSBERG

Tip Vortex Formation



Tip Vortex Formation

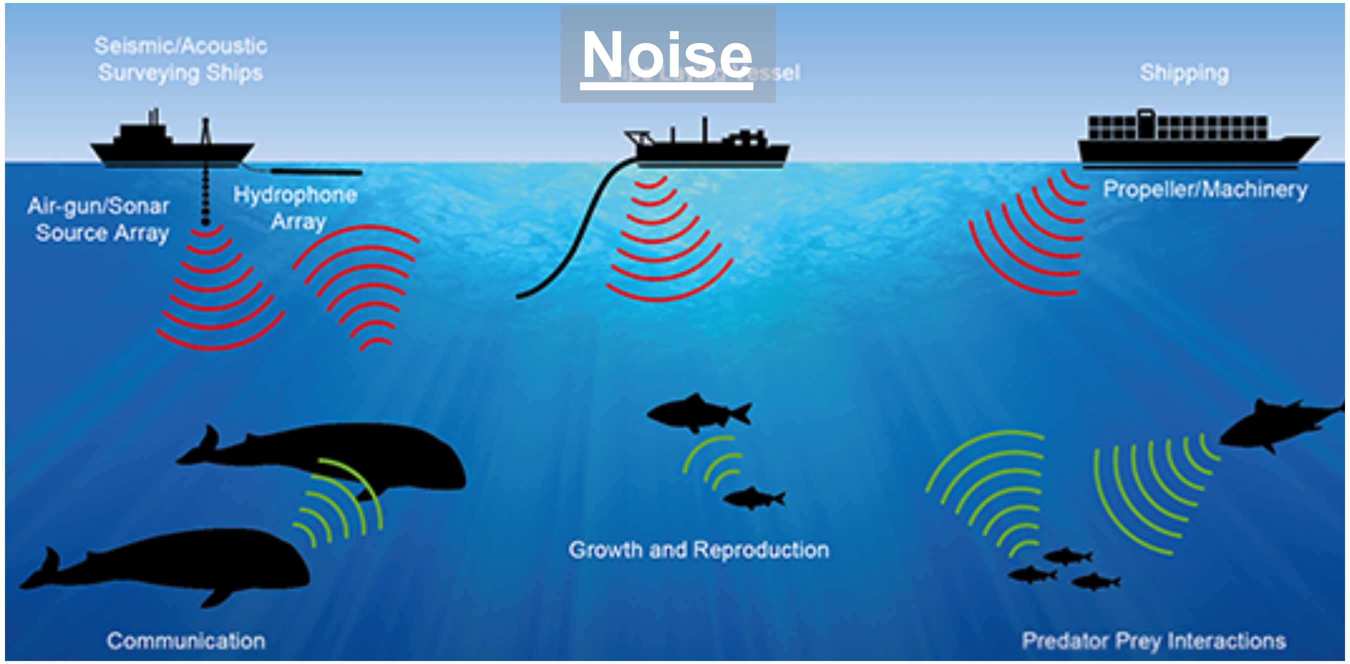


Challenges:

- Providing very fine spatial resolution
    - A few bad quality cells on the vortex trajectory impair the results
- Very low dissipative numerical schemes
- Stable schemes to prevent early vortex breakdown
- Turbulence modelling impact

Erosion

Noise



Tip Vortex Cavitation (TVC)

Numerical Specifications

Task	Tool
Mesh generation	Pointwise or StarCCM+
Simulation	OpenFOAM (2.3x and v1806)
Solvers	simpleFoam, pimpleFoam, interPhaseChangeFoam
Propeller rotation	MRF in steady simulations or SolidBodyMotion in unsteady simulations
Cavitation modelling	modified version of Schnerr-Sauer
Turbulence modelling	Implicit LES, One Equation Eddy Viscosity Model (kEqn)
	SST kOmega + CC

Modelling Roughness

Roughness Modelling In OpenFOAM

1. Modeling the roughness via the wall function
2. Including the roughness geometries in the computational domain
3. Adding a source term into Navier-Stokes equations
4. Changing the turbulence model production/destruction terms
5. …

Roughness Modelling: Pros & Cons

Wall function

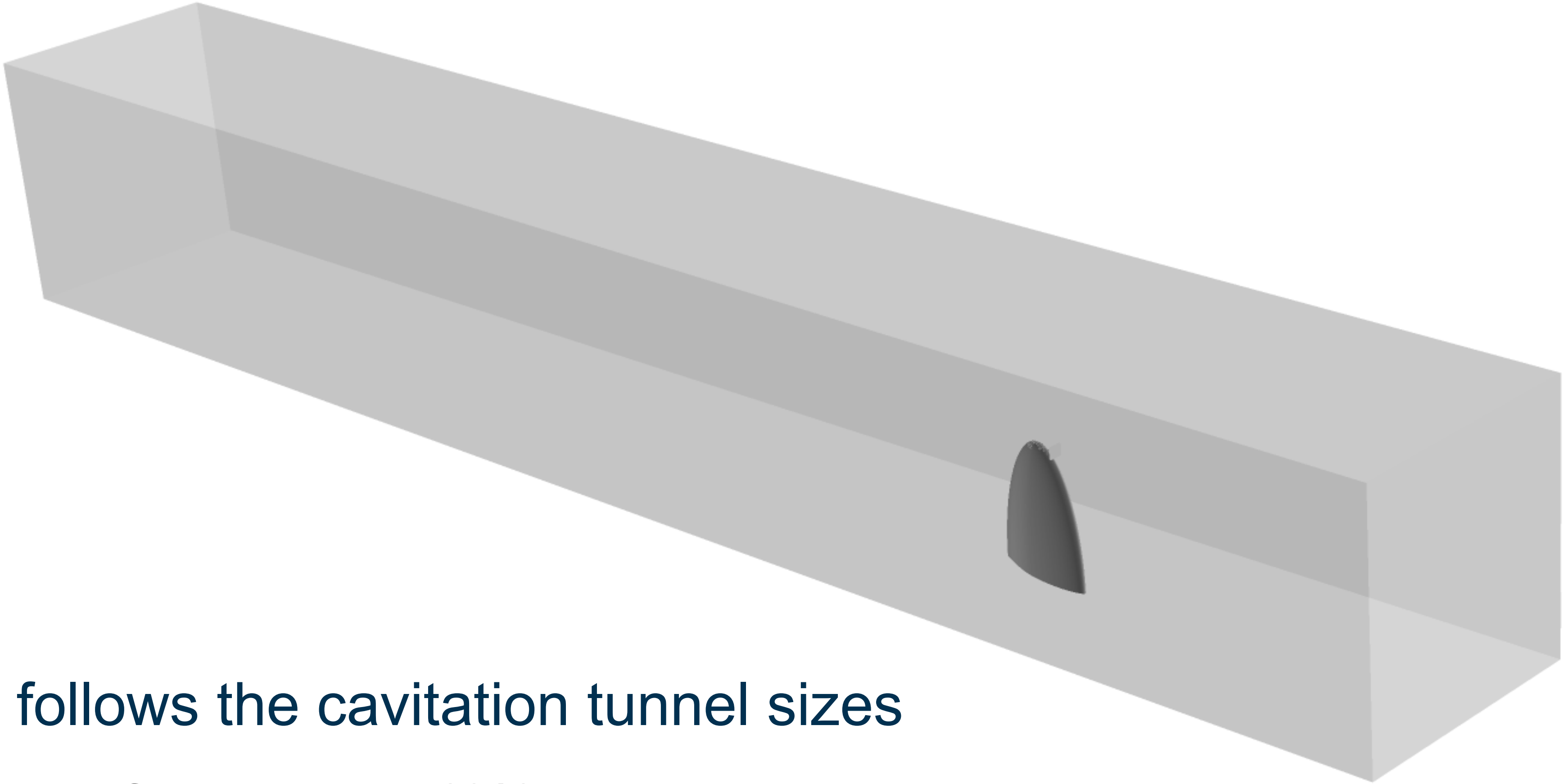
- Simplicity of application
- It is not very easy to test different roughness patterns
- The first cell size (y+) should be higher than the roughness height
  - Loosing some flow dynamics

Including the roughness geometries in the computational domain

- Provides more accurate predictions
- Increase the computational cost considerably

Results & Findings

Benchmark case: an elliptical foil

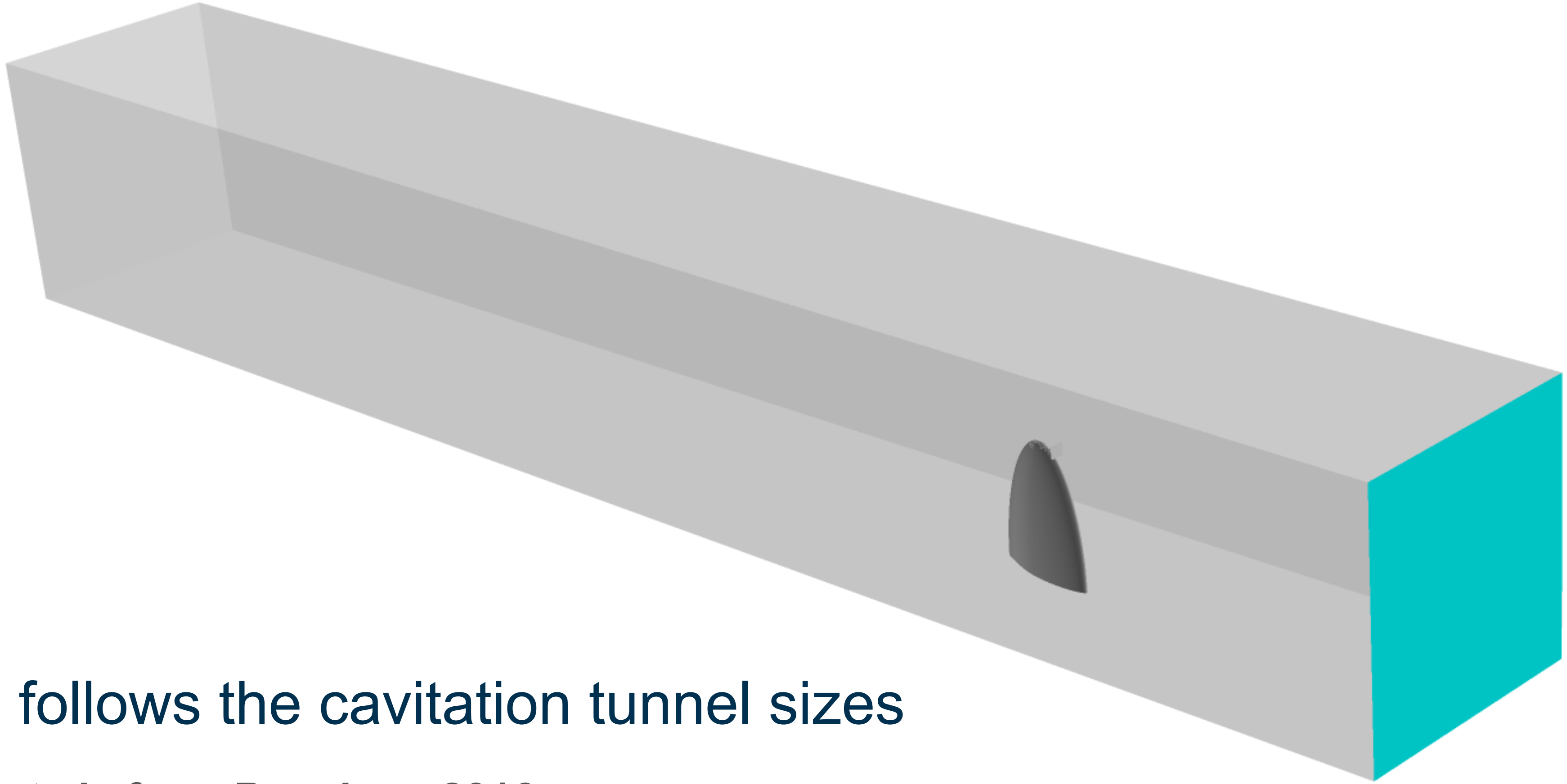


The domain follows the cavitation tunnel sizes

Experimental Data is from Pennings 2016

Tip vortex radius ~ 1.1 mm for $Re=8.5\times10^5$

Benchmark case: an elliptical foil



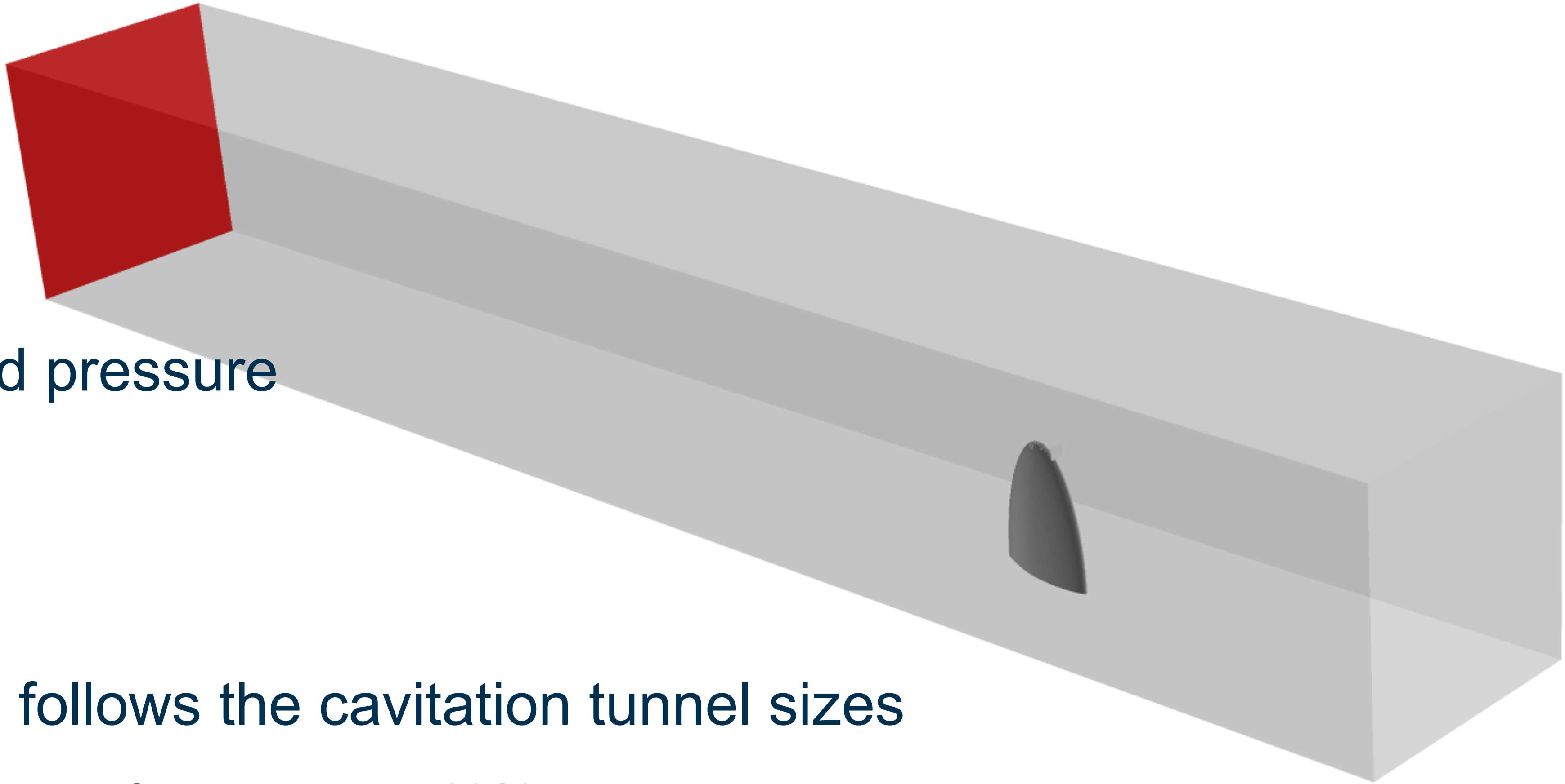
The domain follows the cavitation tunnel sizes

Experimental Data is from Pennings 2016

Tip vortex radius ~ 1.1 mm for Re=8.5×10^5

Benchmark case: an elliptical foil

Outlet: fixed pressure



The domain follows the cavitation tunnel sizes

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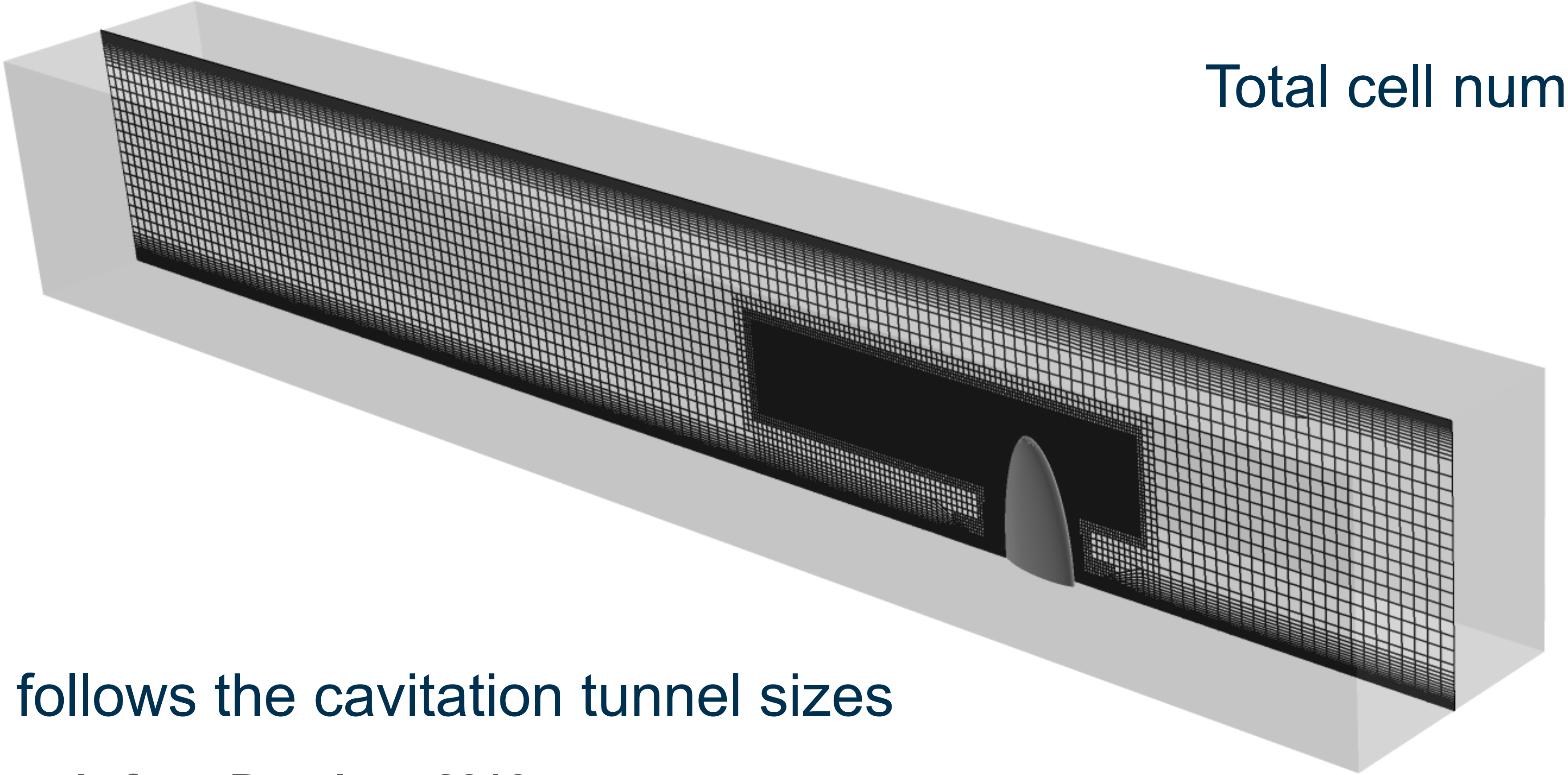
Benchmark case: an elliptical foil



Total cell number: 48 M

The domain follows the cavitation tunnel sizes

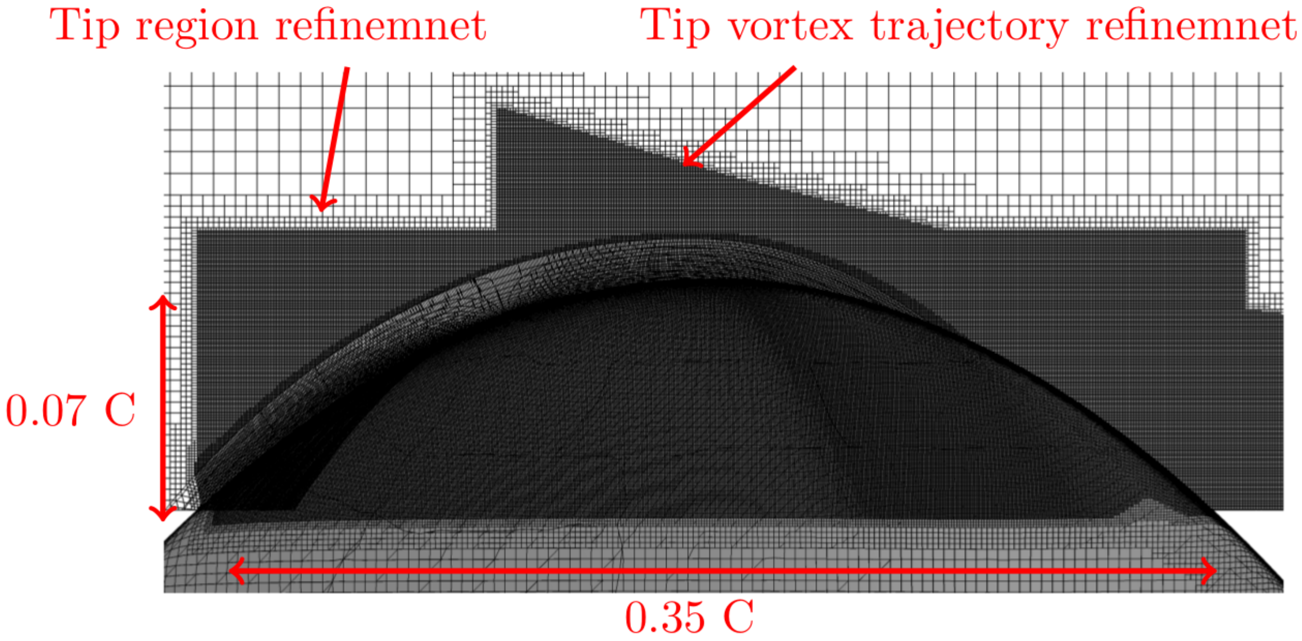
Experimental Data is from Pennings 2016

Tip vortex radius ~ 1.1 mm for Re=8.5×10^5

Mesh Resolution Recommendation

Cell size: 0.06 mm

Cell size:
0.06 mm inplane
0.12 mm streamwise



At least 32 grid points across the vortex core diameter in the inplane section are required.

The streamwise grid point demand is found to be lower (equal to 16 grid points).

Elliptical Foil

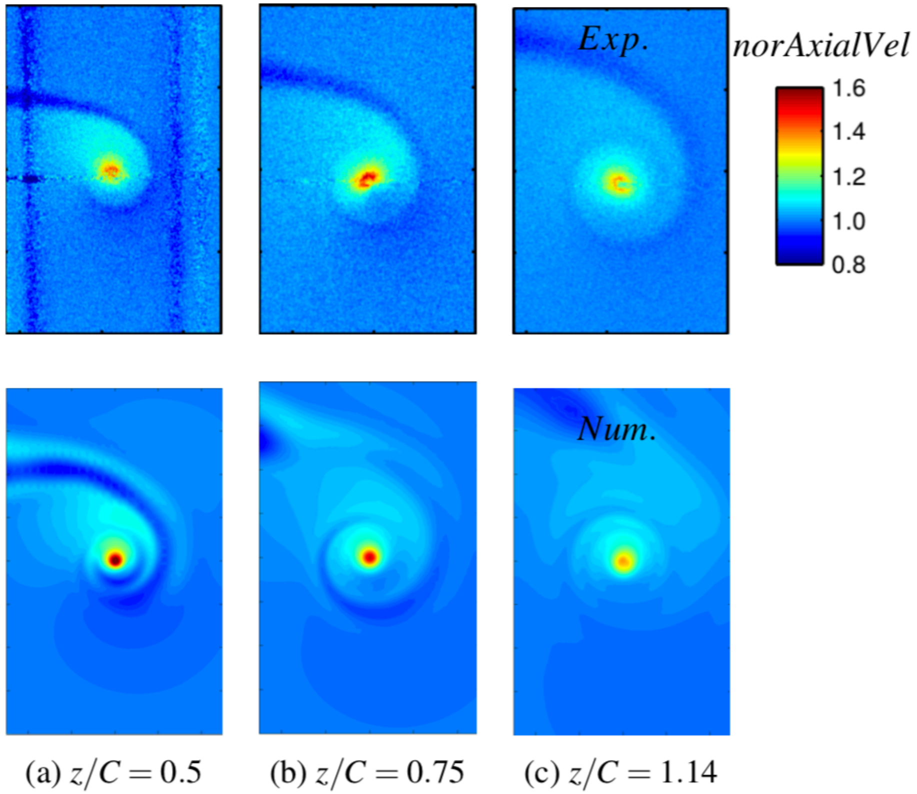


Figure 4.4: Comparison of normalized axial velocity between experimental PIV data and numerical results of P2S2 ILES

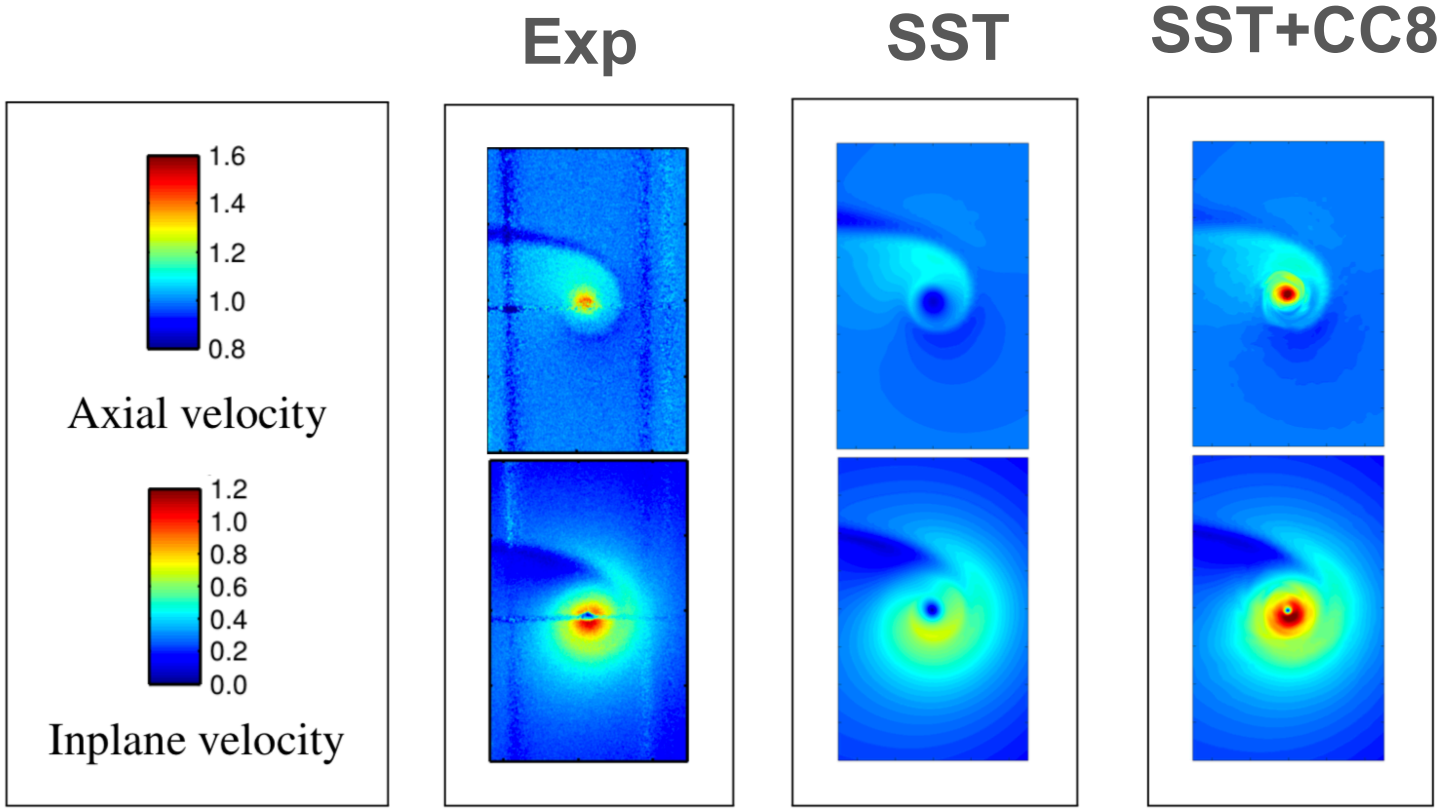
SST + Curvature Correction Models

Table 2.1: Summary of curvature correction models

Name	Reference	Modification
CC1	Pettersson [53]	Modify the turbulent viscosity coefficient
CC2	Arolla [52]	
CC3a	StarCCM+ [54]	
CC3b	StarCCM+ [54]	Modify the production term in k equation
CC4	η_3 based [55]	Modify the production term of ω-equation
CC5	Br based [47]	Modify the destruction term of ω-equation
CC6	Menter [56]	Modify the production terms in k and ω-equations
CC7	Stabnikov [57]	Modify the production term in k equation
CC8	Kato and Launder [58]	Modify the turbulent viscosity coefficient

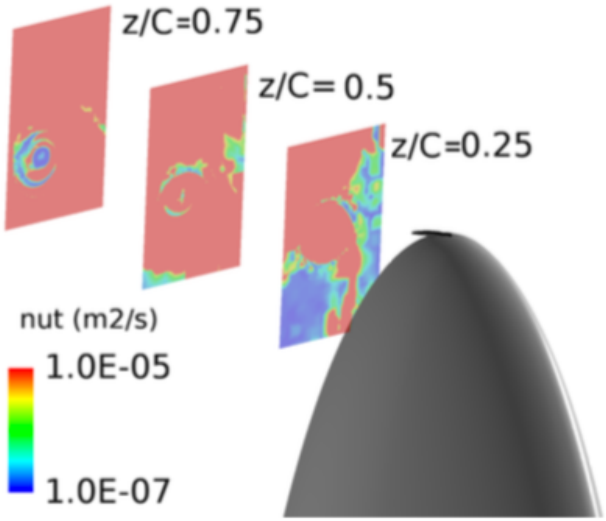
Elliptical Foil

Curvature correction

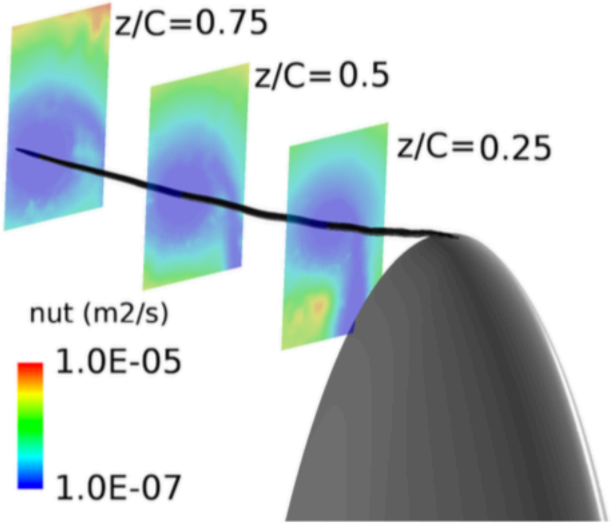


Elliptical Foil

Curvature correction



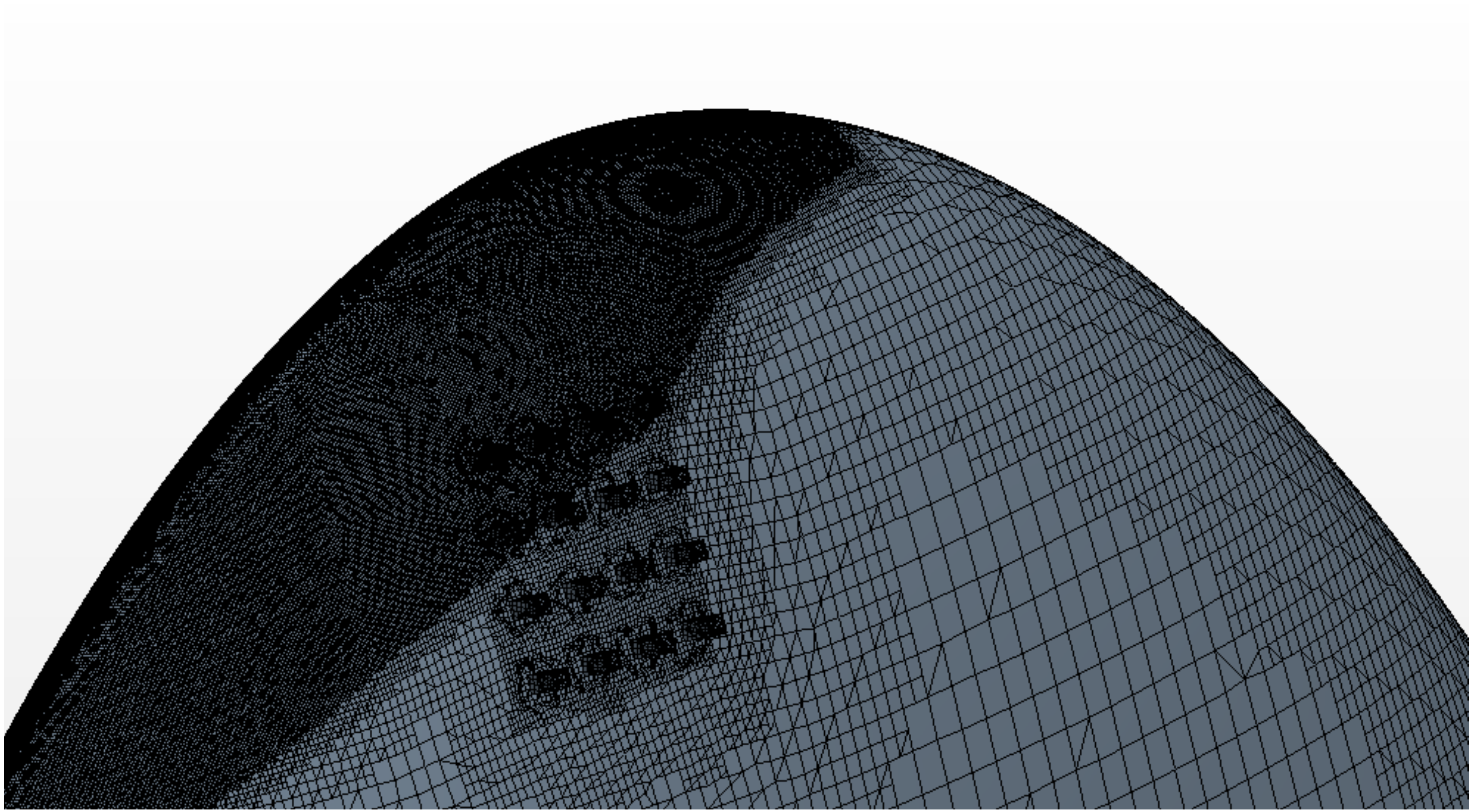
SST



CC8

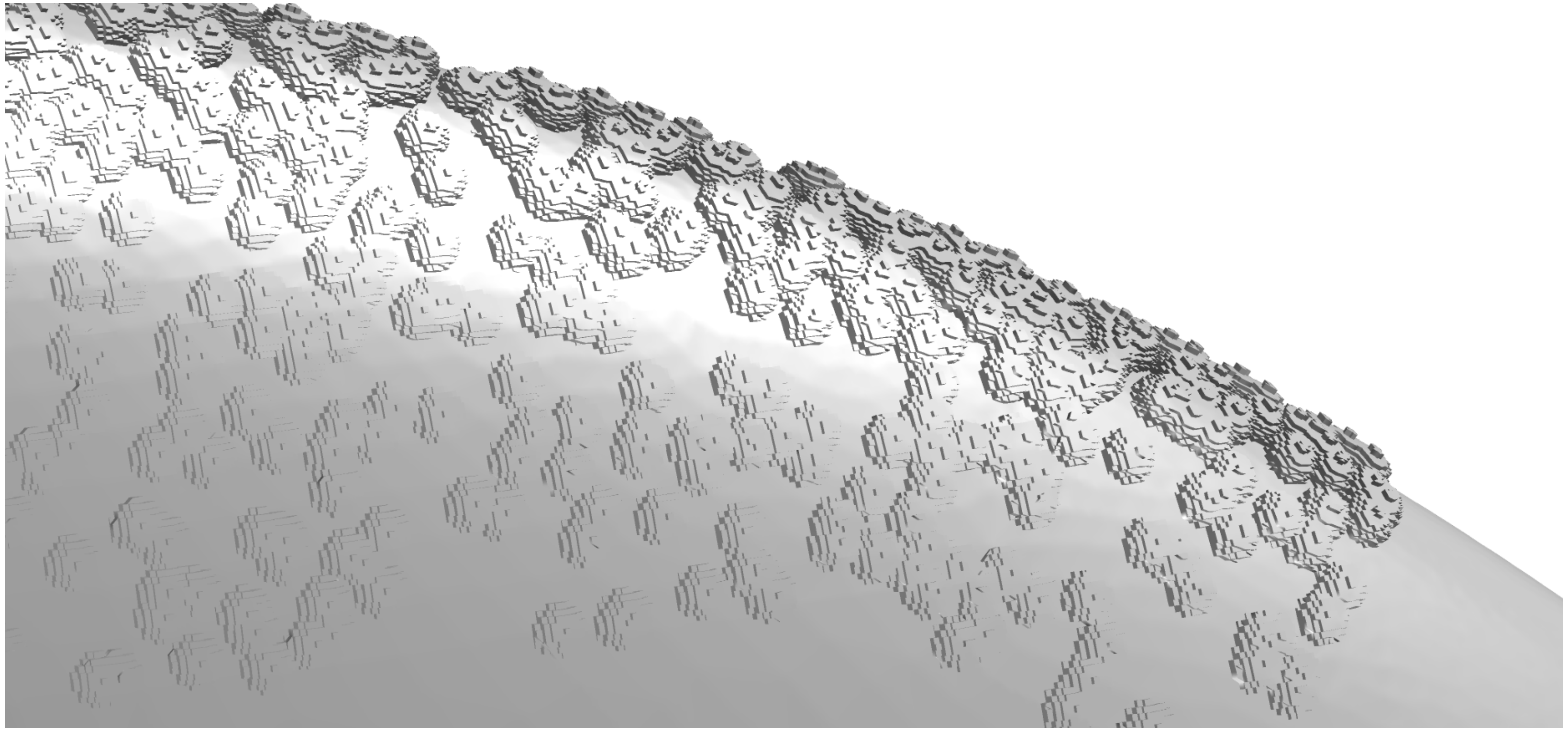
Including Roughness Elements

Adding to CAD file



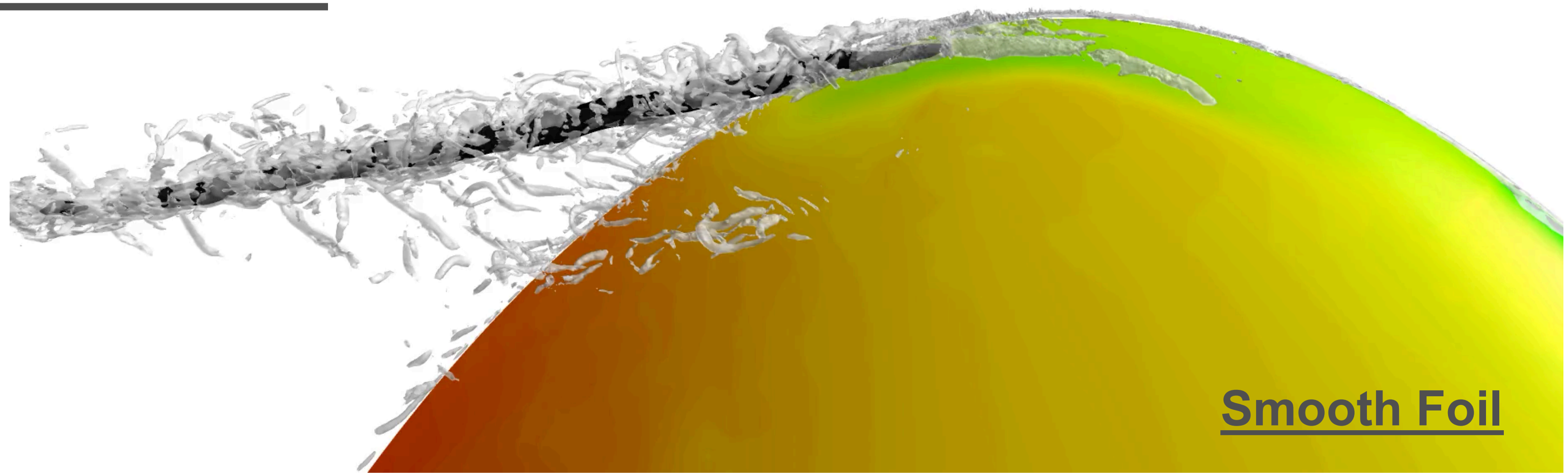
Including roughness geometry during mesh generation

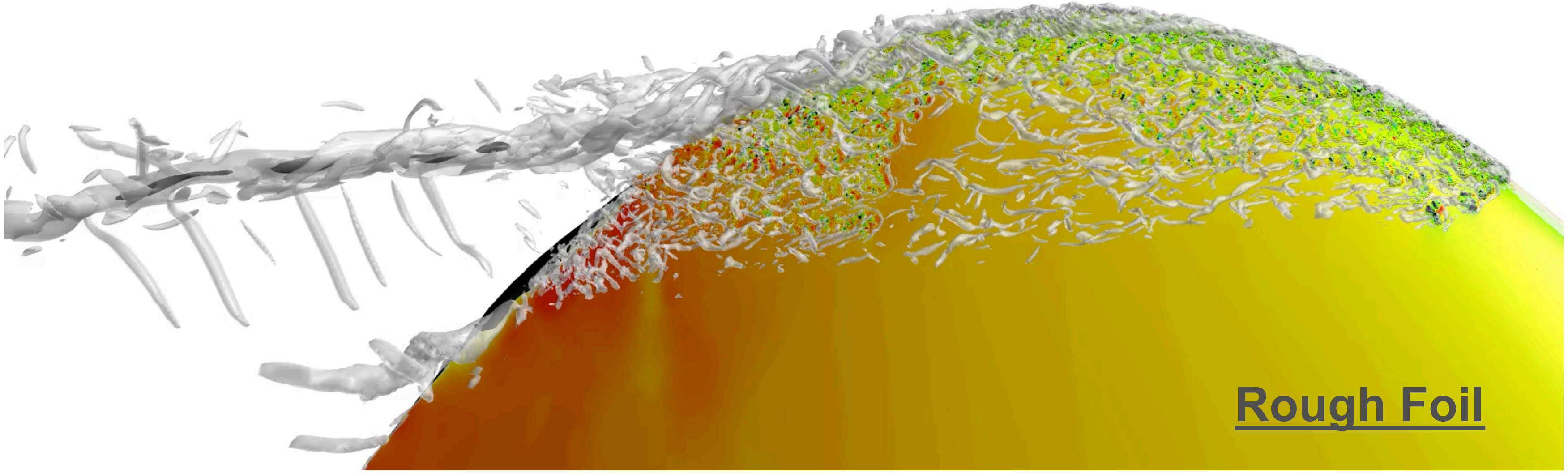
Editing the existing mesh…



Including roughness geometry as a post processing tool (removing cells)

RoughProp Project + ILES results

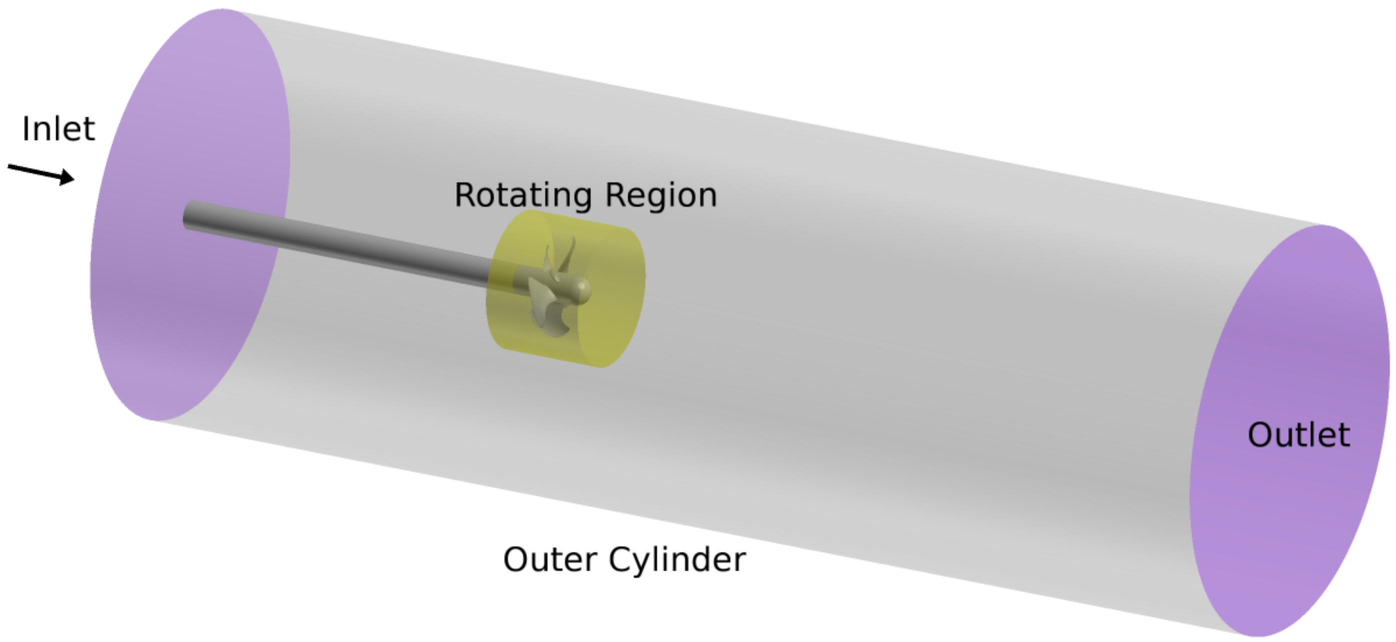




Model Scale Propeller

Can the current CFD tool provide further insights of these complex flow structures?

Computational domain



Model Scale Propeller

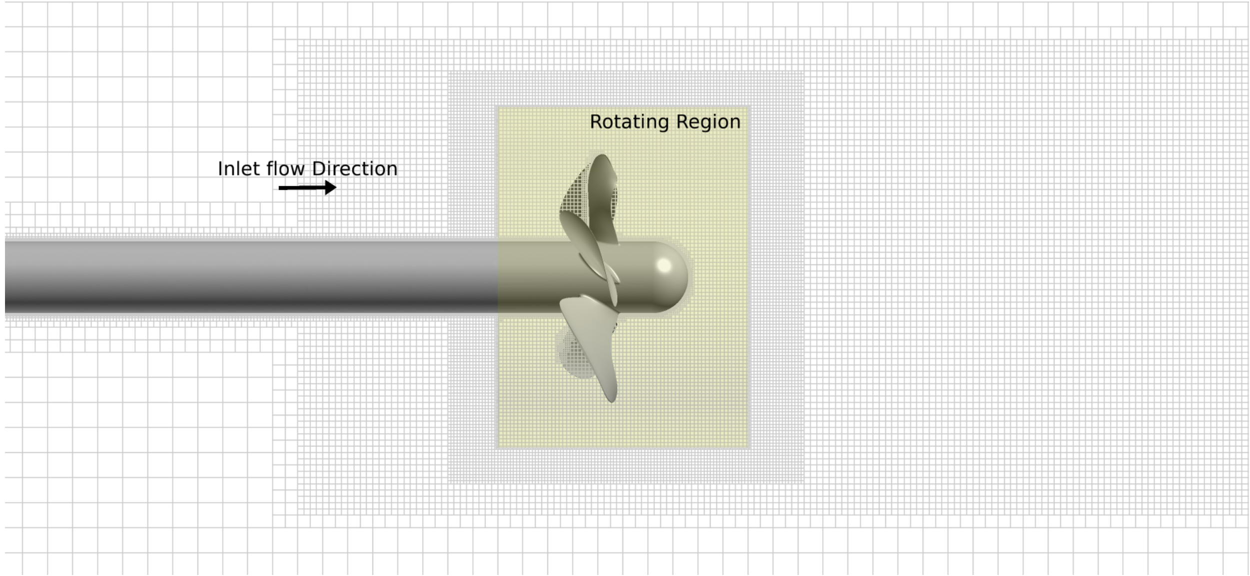
Diameter = 25 cm

Va = 4.2 m/s

Re = 10^6

Tested at different conditions

Mesh specifications

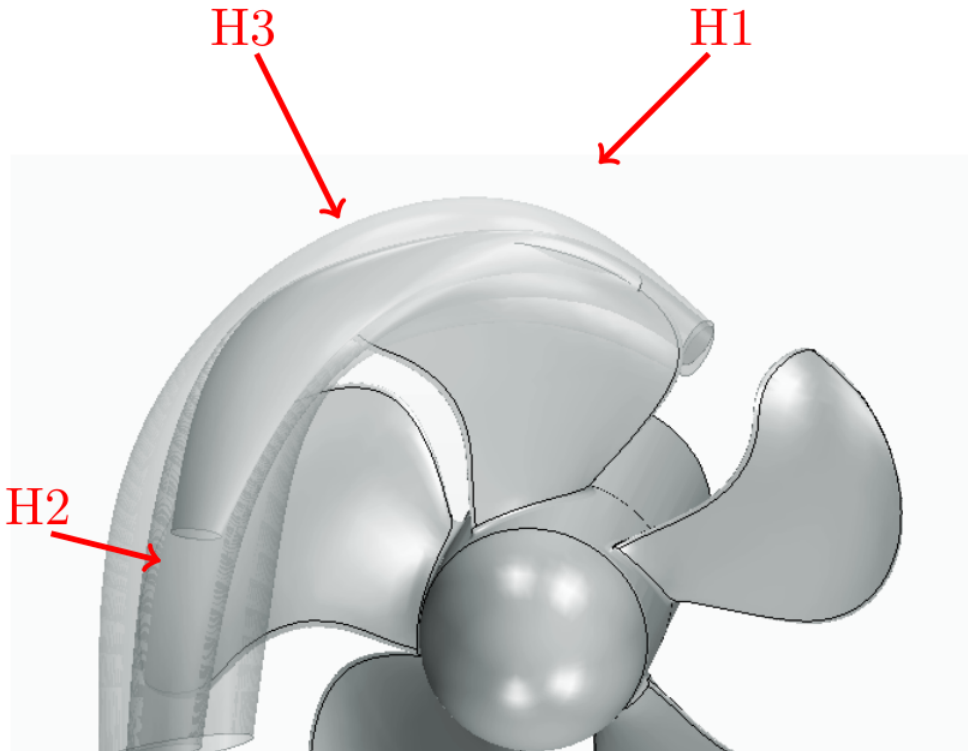


<u>1301B Model Scale</u>

Mesh size = 110 M cells

Tip refinement = 0.062 mm

Mesh specifications

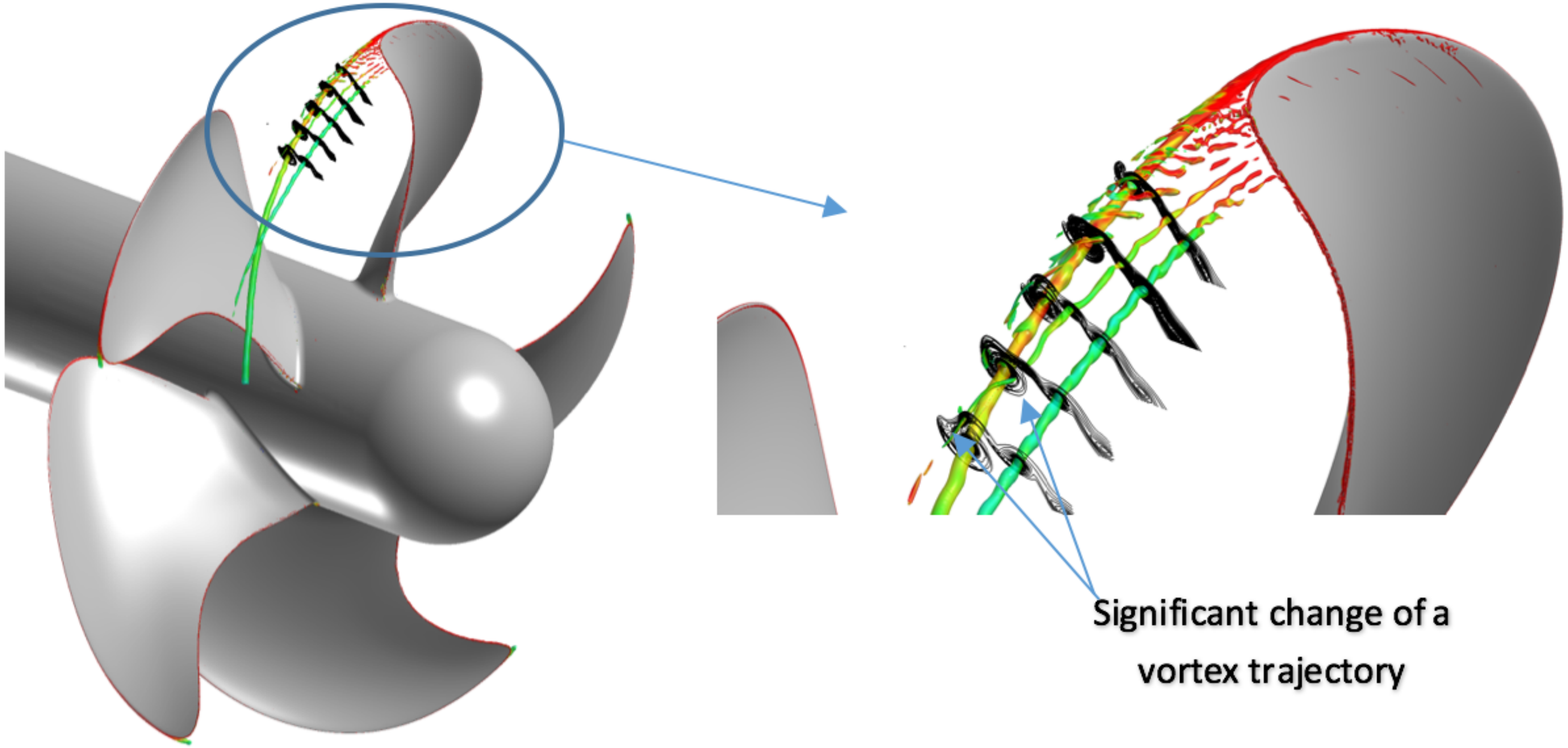


1301B Model Scale

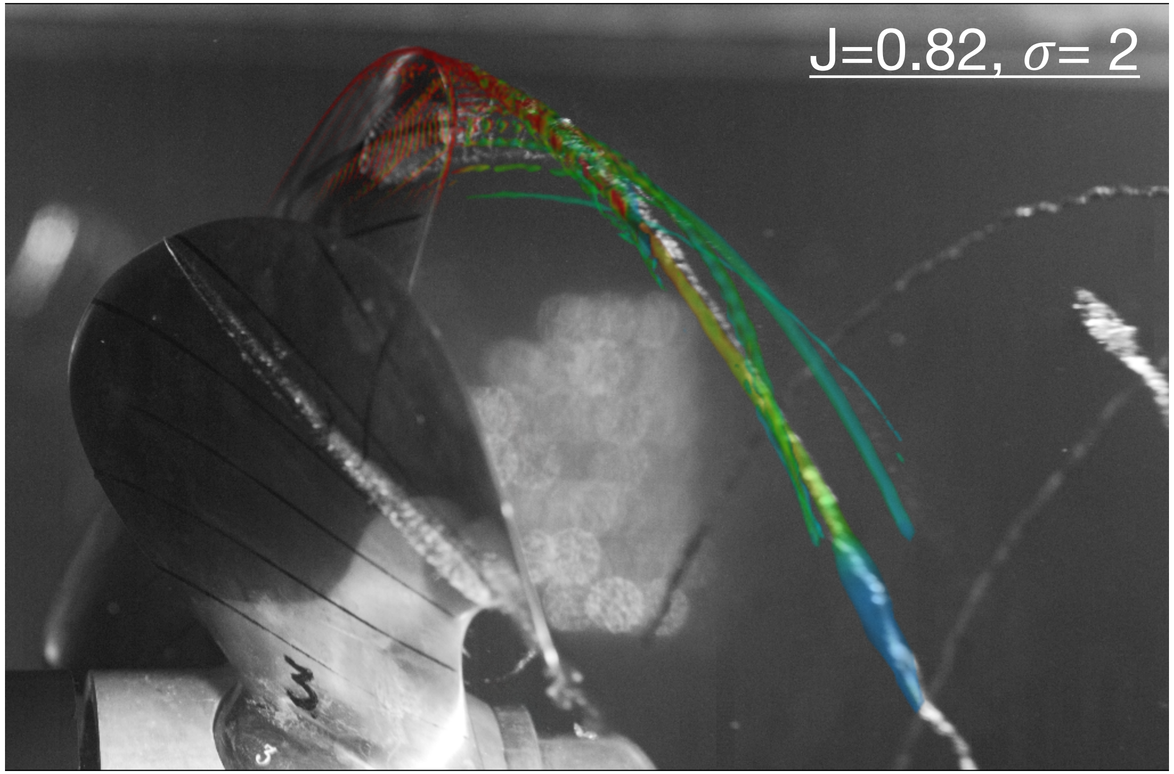
Mesh size = 110 M cells

Tip refinement = 0.062 mm

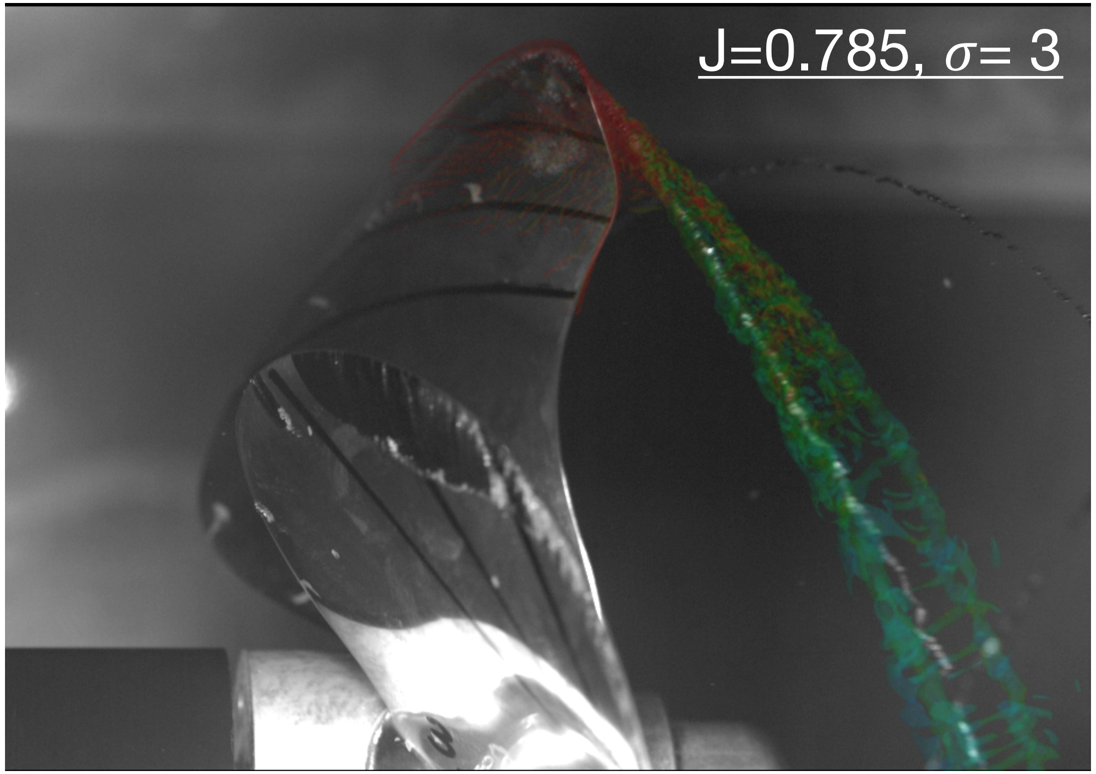
Propeller Hydrodynamics



Propeller Hydrodynamics



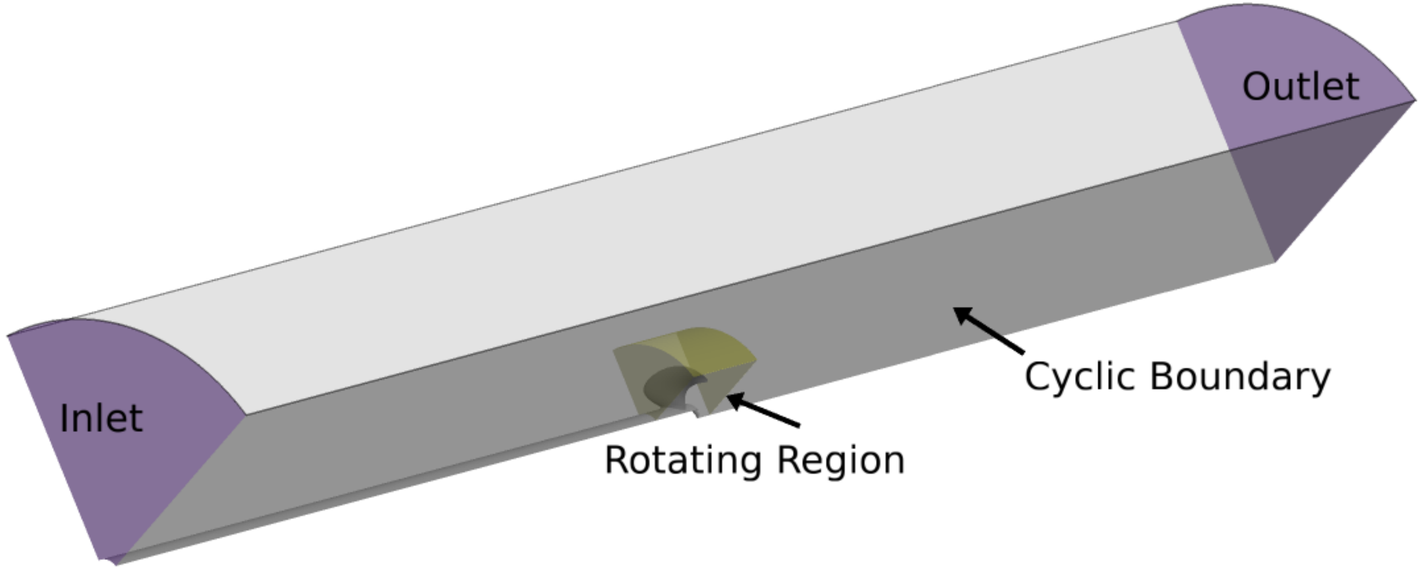
Design A



Design B

Full scale propeller & roughness

Computational domain



<u>1301B Full Scale</u>

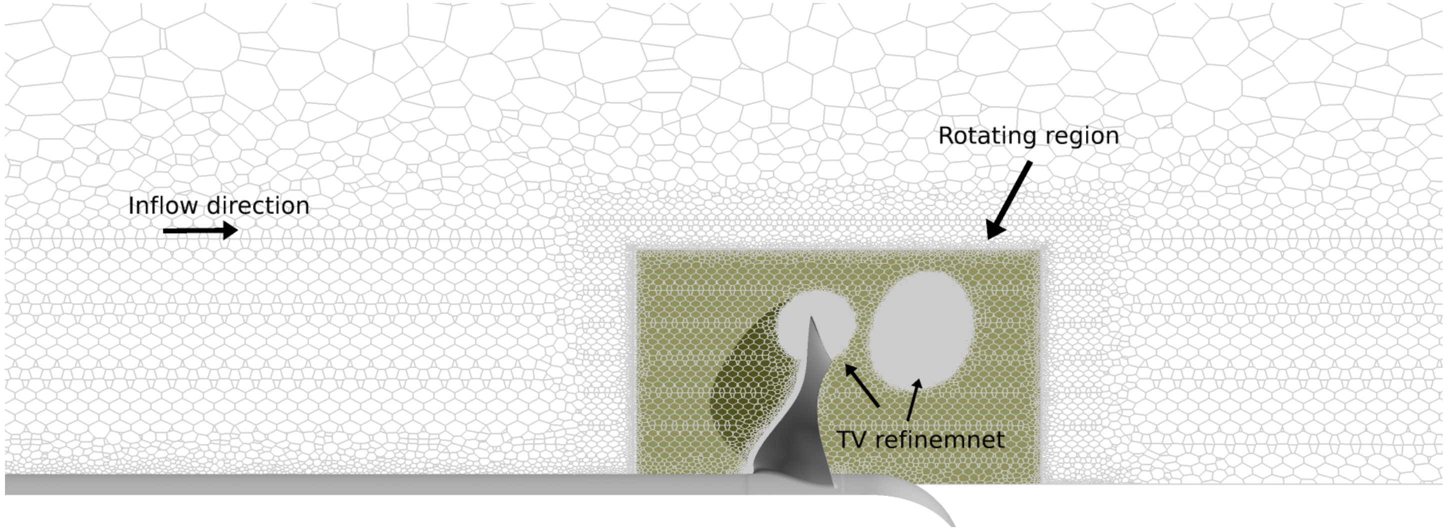
Mesh size = 50 M cells (280 M faces)

Tip refinement= 0.9 mm

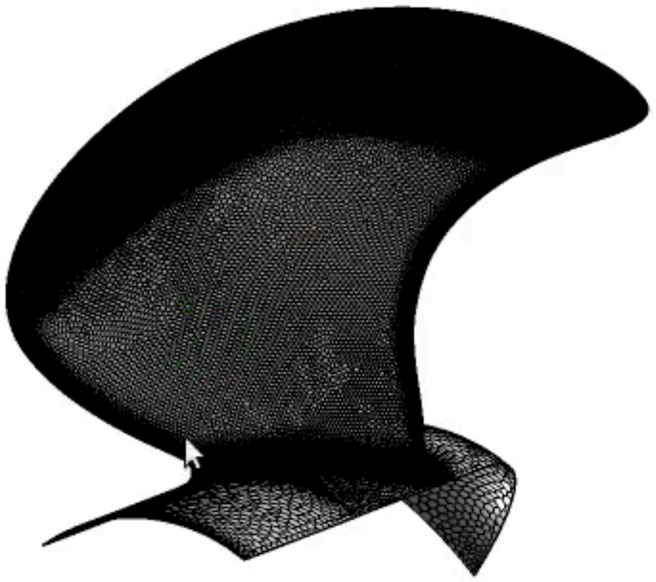
Propeller Diameter = 3.8145 m

Va = 8 m/s

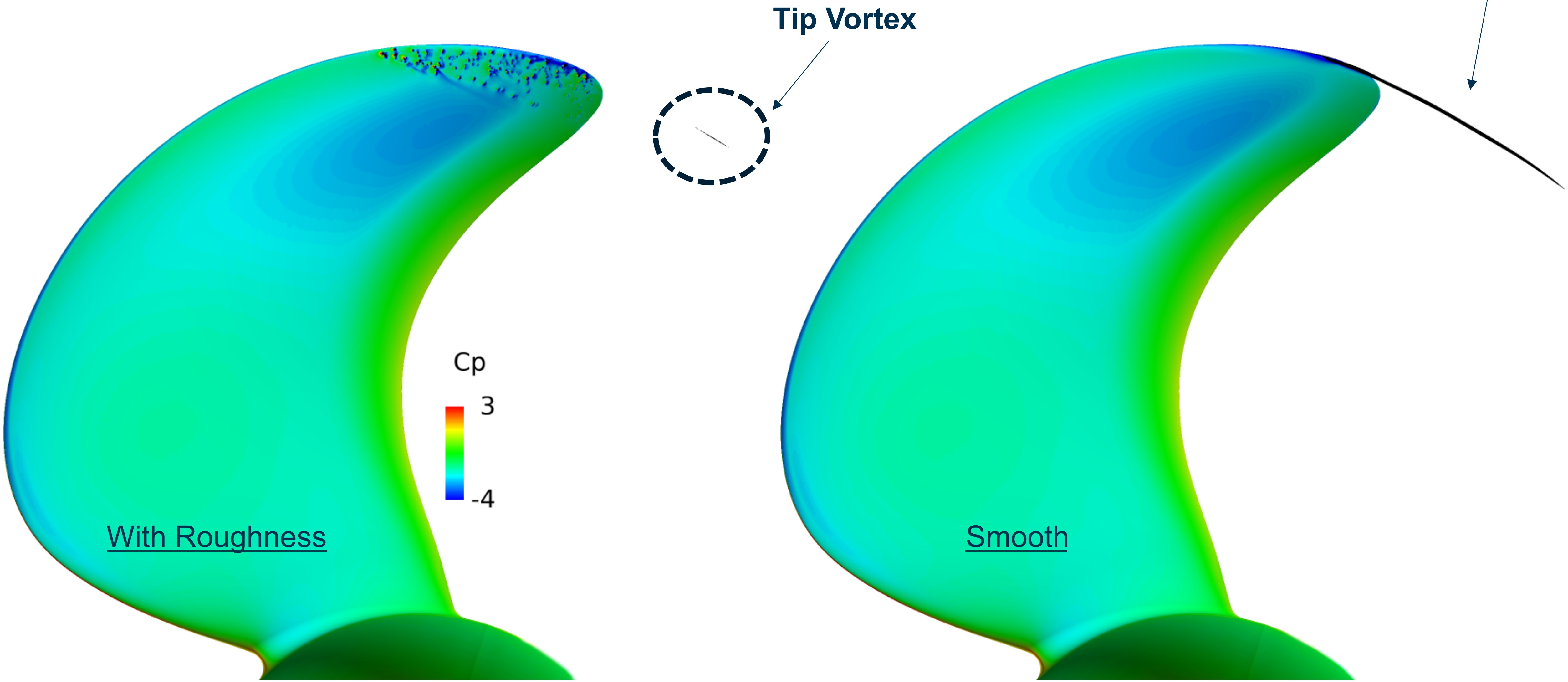
Re = 30 * 10^6



Application of Roughness, D=3.8 m, Ks = 4 mm



Full Scale Propeller, J=0.82, OW



Question/Comment