Evaluating OpenFOAM's Functionality for Ship Powering Prediction in Calm Water and in Waves

MITMECHE

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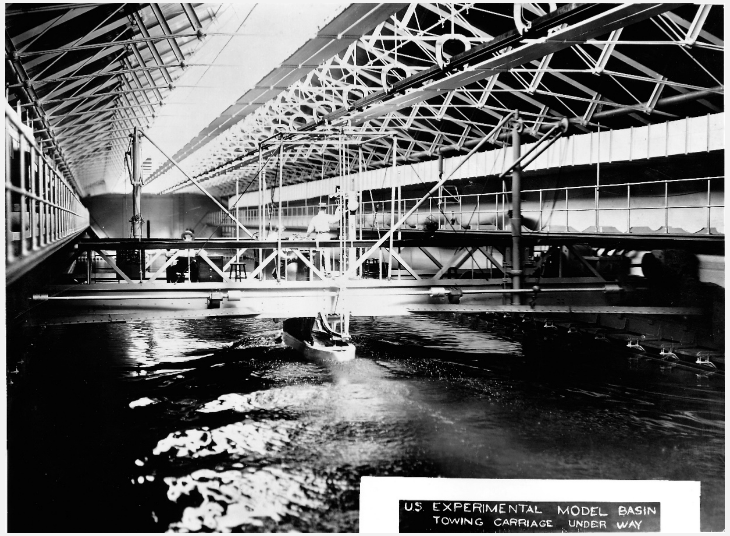
Motivation

- Ship resistance and seakeeping are primary factors in hull-design
- Predominated by empirical design and application of series
- Prohibitively high cost of tank testing for preliminary design
- Faster iteration
- Lower per trial cost



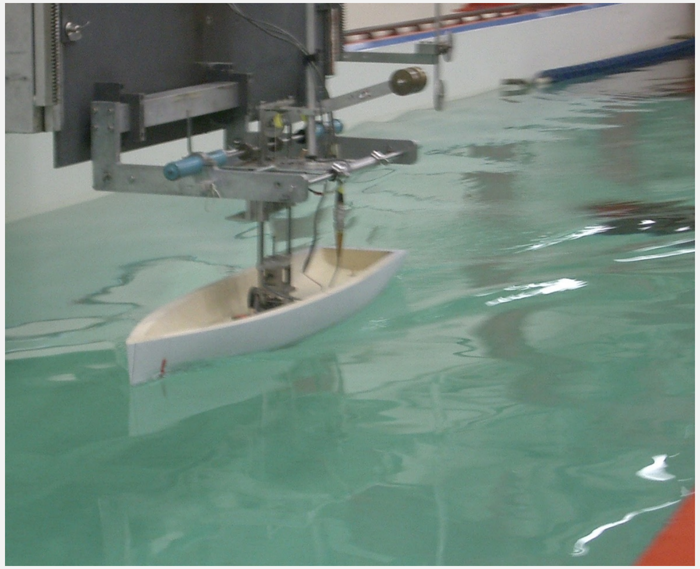



Image credits: David Taylor Model Basin, G.Nannig, NRC-Canada

Problem Setup

- **Primary concern is accuracy of flows around the hull**
  - Pressure fields and Wave-making
  - Friction and Turbulence Modeling
- **Stationary hull and moving flow field**
  - Similar to circulating water channel
- **Boundaries are kept far enough from model to not impact flow around model**
  - Typically 1 hull-length considered sufficient
- **Used symmetry for midplane to reduce computational domain**

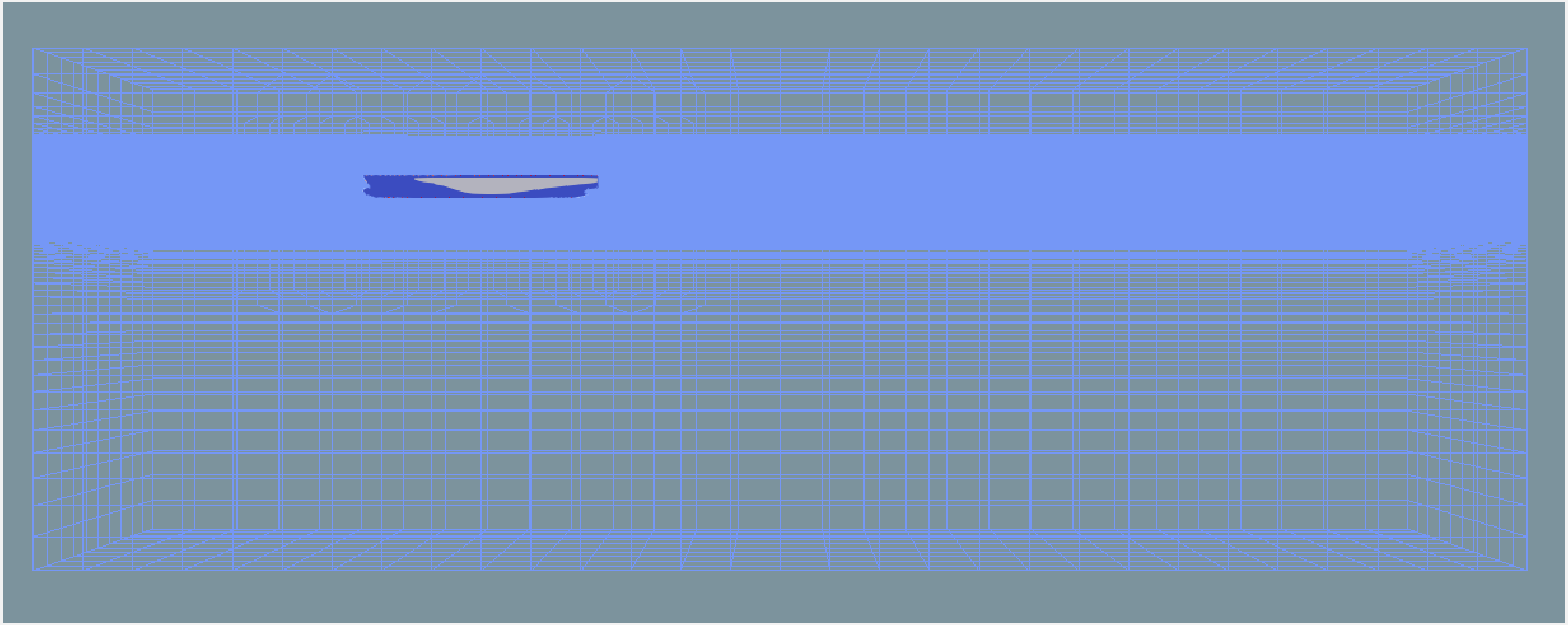
- **Ref: ITTC Recommendations for Numerical Simulation and Resistance Testing**

Meshing

1. **Created a background base-mesh**
2. **Refined mesh in area around vessel**
3. **Refined mesh in region in vicinity of the free-surface**
4. **Used snappyHexMesh to add vessel geometry into existing mesh**
    1. Split cells around model edge and remove the wholly interior cells from the mesh
    2. Further refine around geometry by splitting cells to specified boundary resolution
    3. Define boundary faces as walls

- **Resulting mesh 4×10^5**

Sample Mesh



Methods Used

- **PISO-SIMPLE-mixed (OpenFOAM's PIMPLE implementation)**
  - Variable timestep based on Courant number

- **Volume of Fluid Method**
  - Fixed grid method
  - Fraction of partially filled cells are calculated (c=0 air only, c=1 water only)
    - $\frac{\partial c}{\partial t} + \nabla \cdot (c \cdot \vec{v}) = 0$
  - Advantages: lower computational effort than interface tracking
  - Disadvantages: surface subject to smearing at low order – very fine grid required
- **RANS (k-ω Shear Stress Transport)**
  - Menter's Shear Stress Transport combines k-ω and k-ε models
  - Improved performance with adverse pressure gradients

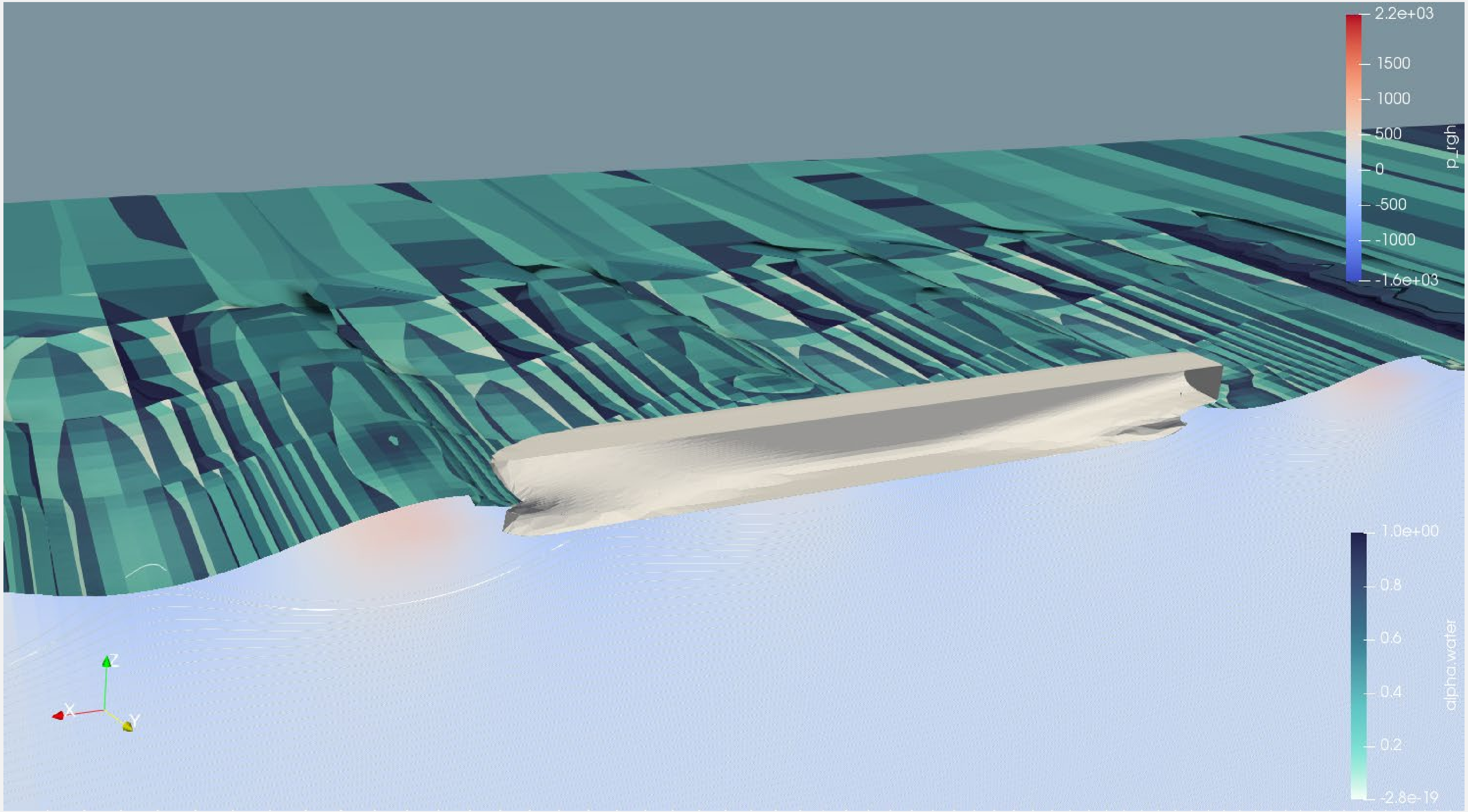
Boundary Conditions

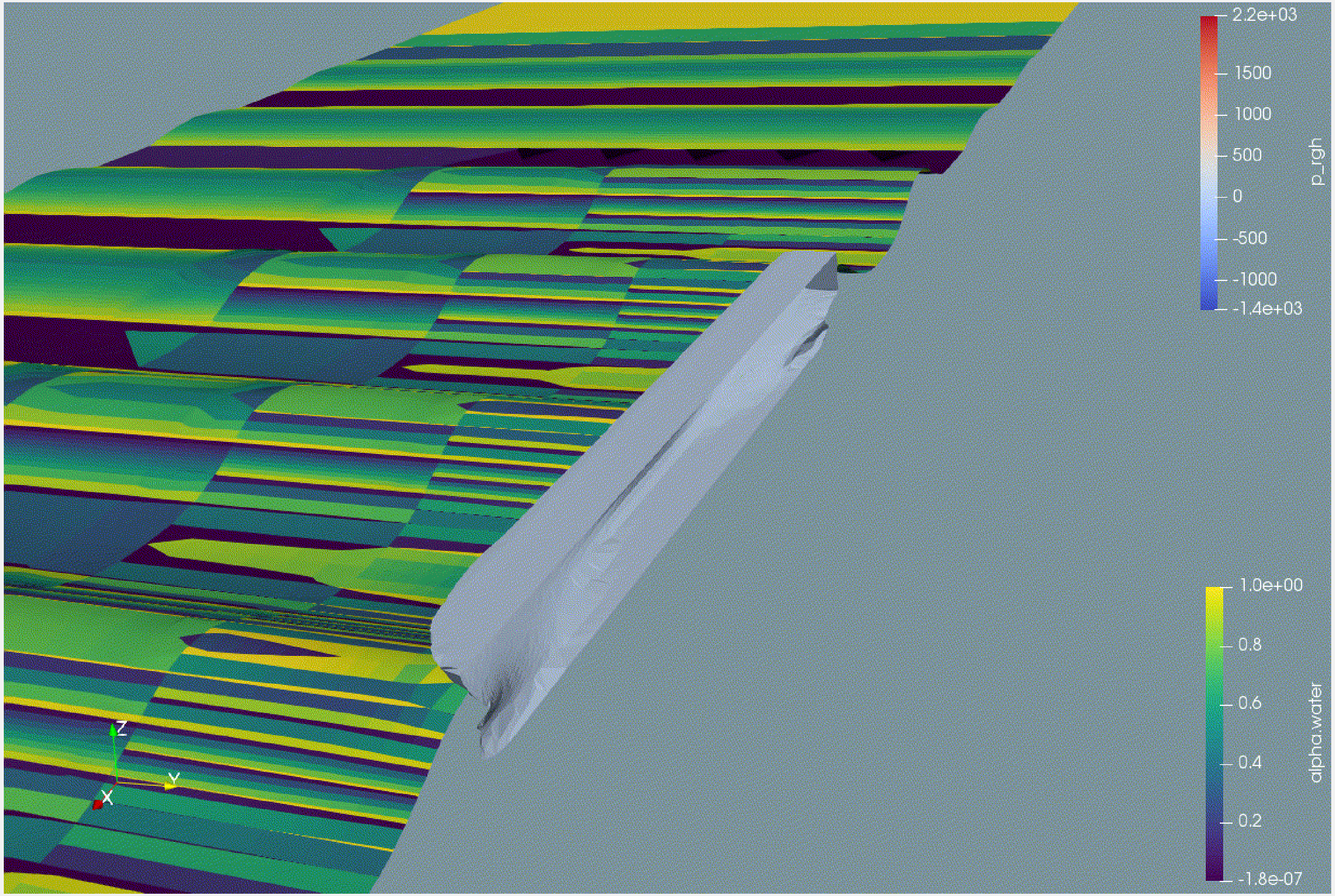
- **Inlet: Direchlet boundary condition**
  - Determined by wave input file
- **Outlet: Neumann boundary condition**
- **Edges: symmetry condition sufficient**
- **Midplane: symmetry condition**
- **Atmosphere: zero-gradient**
- **Vessel Hull: Walls**
  - Modeled no-slip condition

Issues and Difficulties

- **Meshing difficulties with imprecise input files**
  - Fixing geometry is a real time sink
- **Tracking units through simulation**
- **Bug finding in code**
  - Typos, or improper declaration

Preliminary Results

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0.4
0.2
-1.8e-07
alpha.water
Z
Y
X

Next Steps

- **Fix bugs in code**
  - Verify units and coefficients
  - Check vessel inertia values
- **Generate results for known speeds**
  - Compare against "canonical" tank tested results
  - Wave results for comparable input spectra or waveheights
- **Computational geometry lessons**
- **Integrate external meshing into workflow**

References

- Chapter 12 on "Special Topics" of J. H. Ferziger and M. Perić, "Computational Methods for Fluid Dynamics." Springer, NY, 3rd edition, 2002
- Chapter 11 on "SIMPLE, PISO, and PIMPLE" of T Holzmann, "Mathematics, Numerics, Derivations and OpenFOAM®." Holzmann CFD, Online 1st edition, 2018
- Chapters 15, 17 "Fluid Flow Computation: Incompressible Flows" of F. Moukalled, L. Mangani, and M. Darwish, "The Finite Volume Method in Computational Fluid Dynamics." Springer, NY, 1st edition, 2016
- RP 7.5-02 on Resistance Tests and Seakeeping Tests, and RP 7.5-03 on CFD Procedures. "ITTC –Recommended Procedures and Guidelines." ITTC, Denmark, 2017, Rev 07