Two-fluid flow simulation using higher order methods

Ido Akkerman[1], Yuri Bazilevs[2]
Chris Kees[1], Matthew Farthing[1]
1) U.S. Army Engineering Research and Development Center (ERDC/CHL)
2) University of California San Diego (UCSD)

Transforming the Marine Transport System:
A Vision for Research and Development
June 29 - July 1, 2010 Irvine(CA)

Acknowledgement

- USACE Navigation Systems Research Program (Jim Clausner, Eddie Wiggins, Jeff Lillycrop)
- USACE Military Engineering 6.1 Research Program (David Horner)
- CHL Deep Draft Navigation Focus Area (Mike Briggs, Zeki Demirbilek, Jeff Melby)
- University of California, San Diego
- Texas Advanced Computing Center

UCSD

Goal

High fidelity predictive simulation of dynamic 3D marine transport phenomena.

Build models that solve full the 3D Navier-Stokes equations with breaking waves and Fluid/vessel interaction

Outline

- Model hierarchy
- Simulation pipeline
- Geometry modeling/preparation
- Software framework
- Validation/capabilities
- Conclusion/outlook

Model hierarchy

Two-phase Navier-Stokes
(3D air/water w/ free boundary)

Single-Phase Navier-Stokes
(3D free boundary)

- Fully non-hydrostatic
(Deforming domain,...)
- Hydrostatic
(3D shallow water)

2D Horizontal
(Depth Averaged Models)

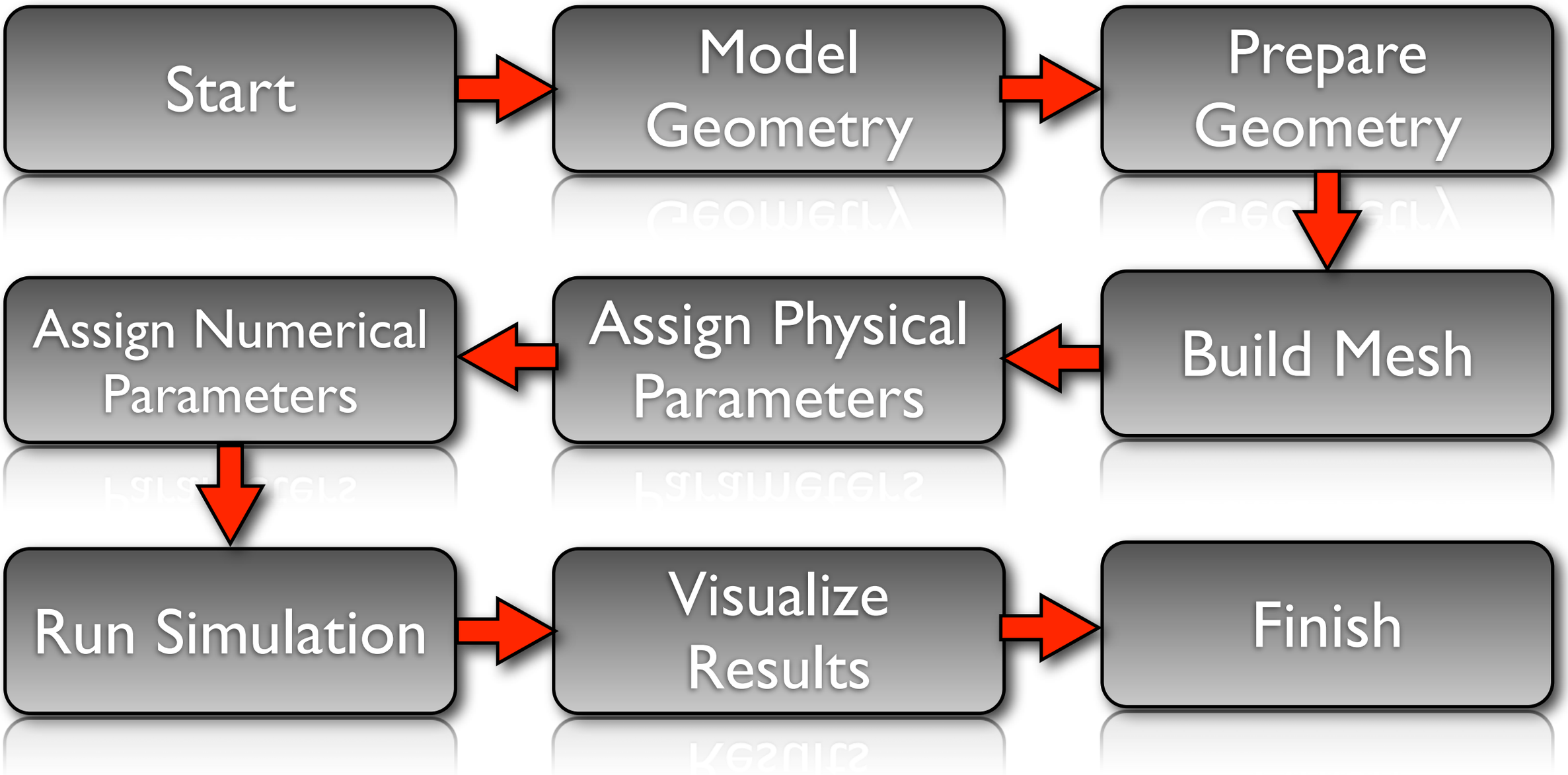
- Boussinesq
- Hydrostatic
(2D shallow water)
- Diffusive wave
(overland flow)

Wave Models

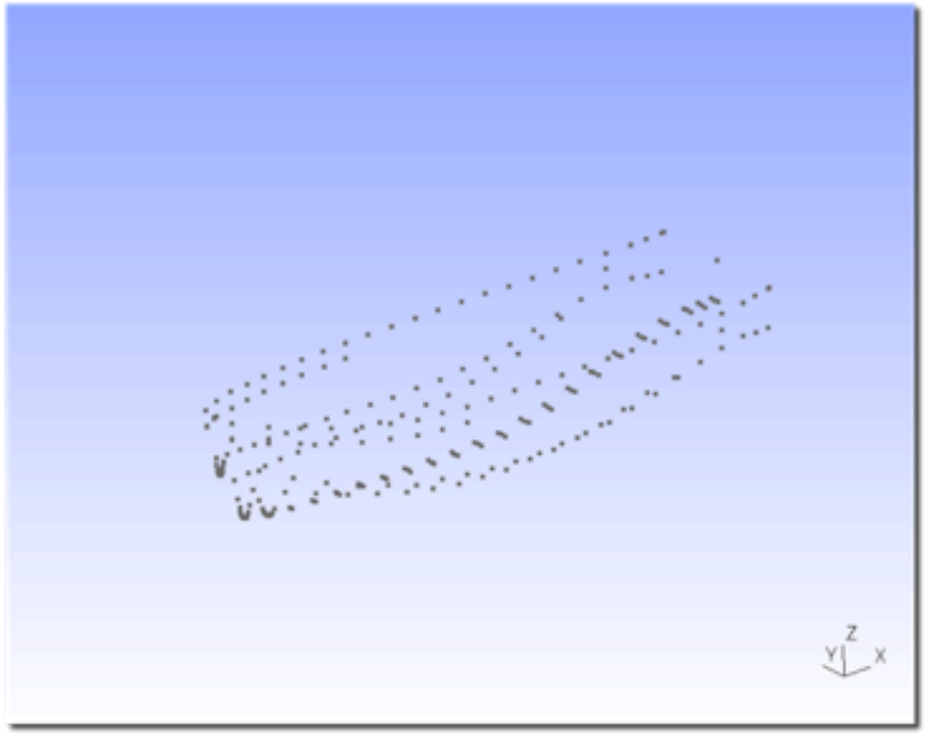
- Spectral Methods
- Galerkin Methods

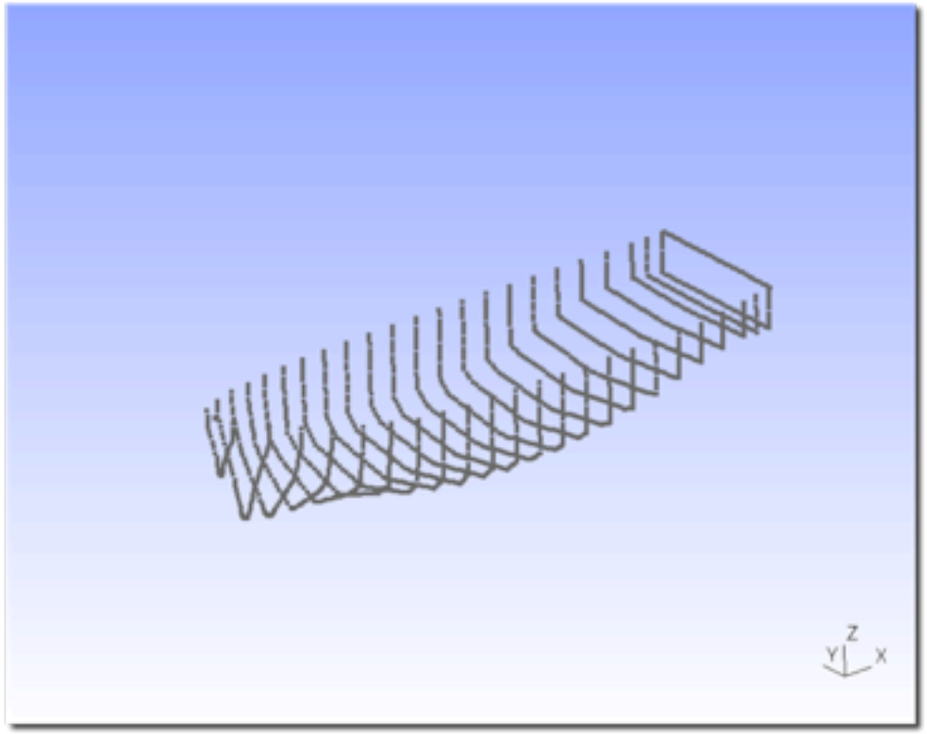
UCSD

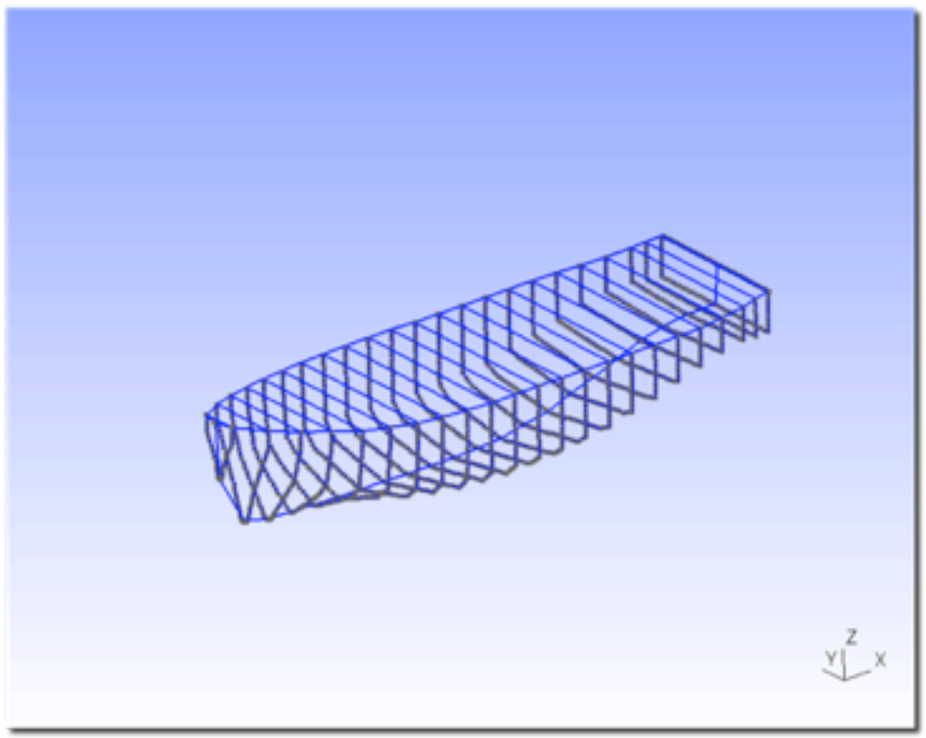
Simulation pipeline

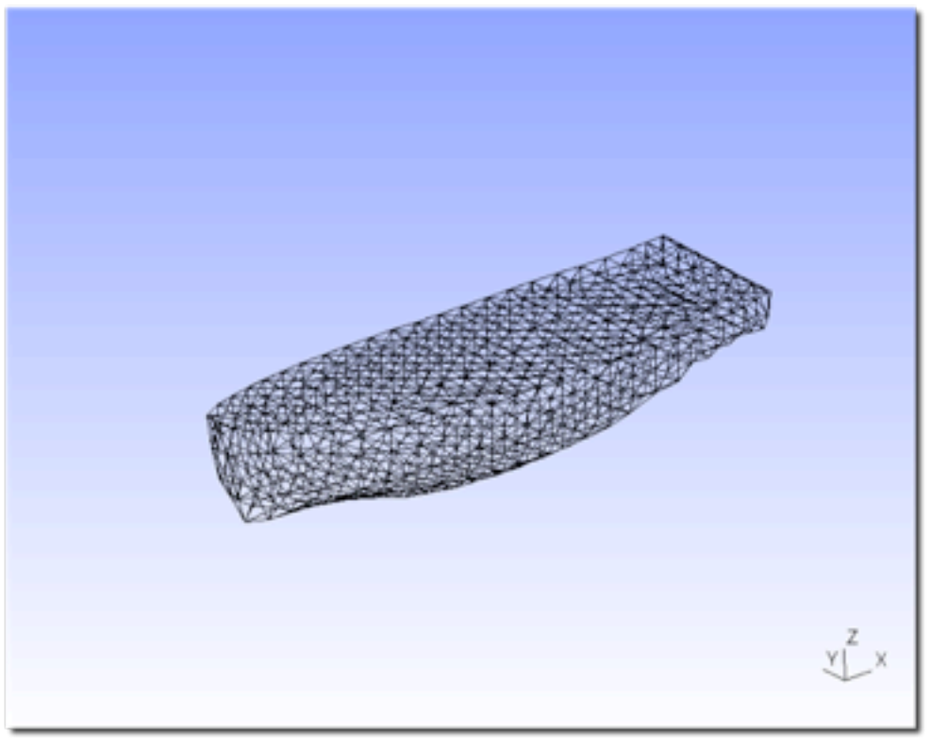


Meshing a vessel using GF-file

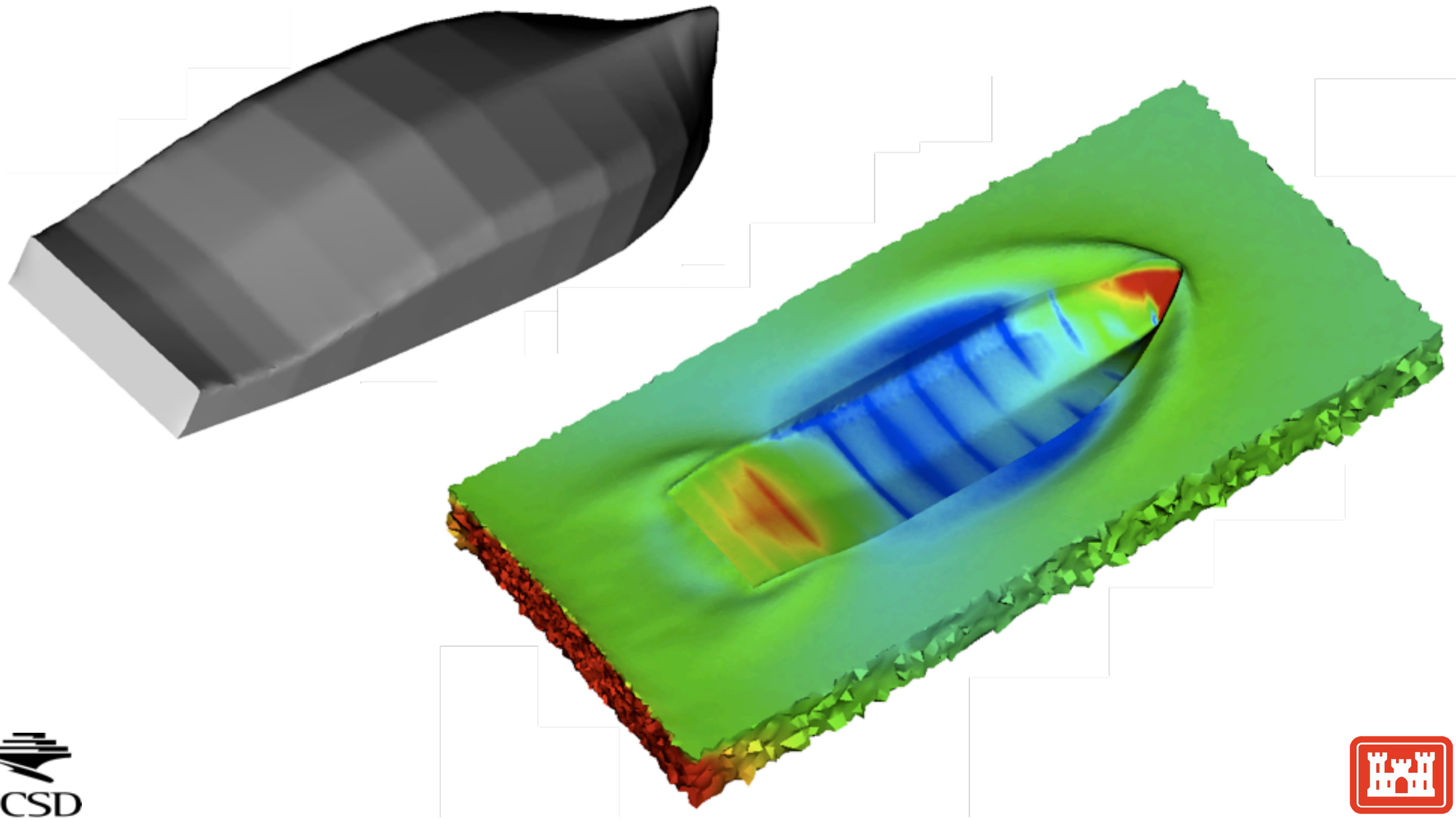




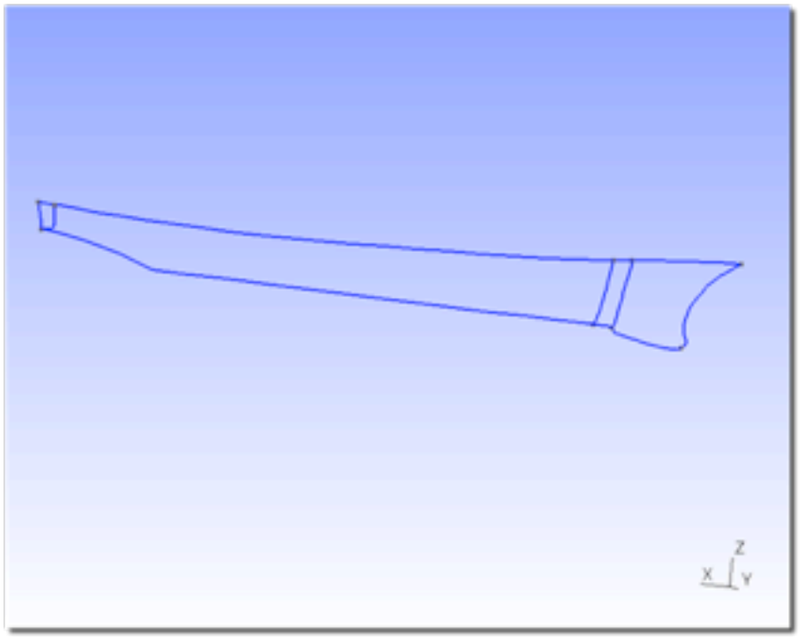


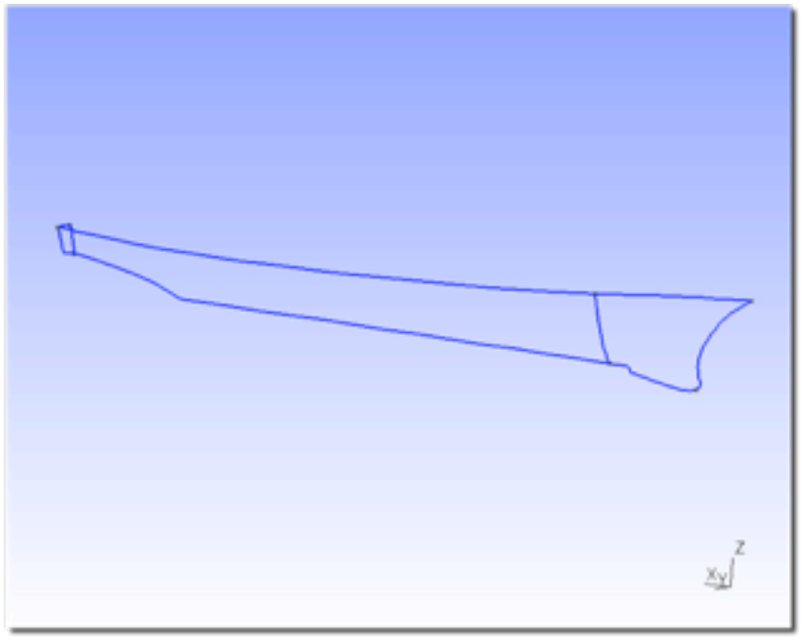


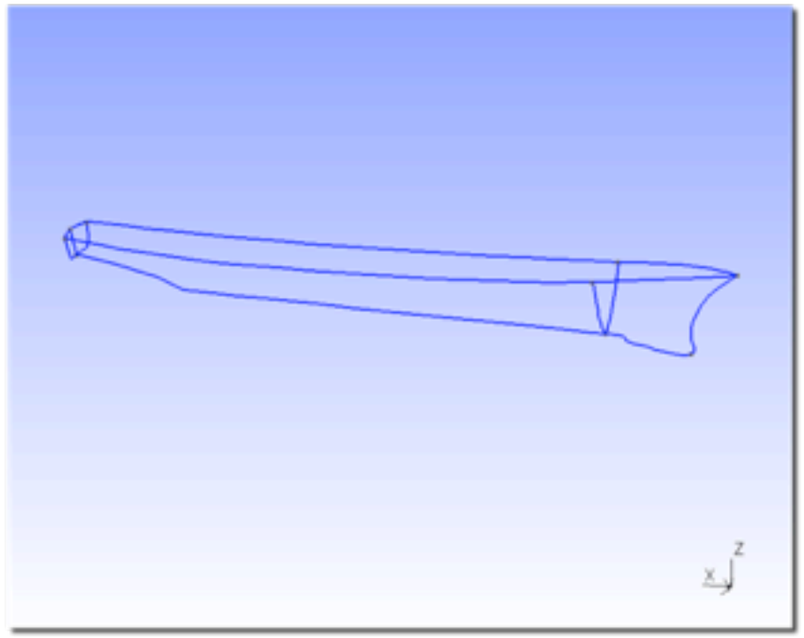
Result: faceted Surface

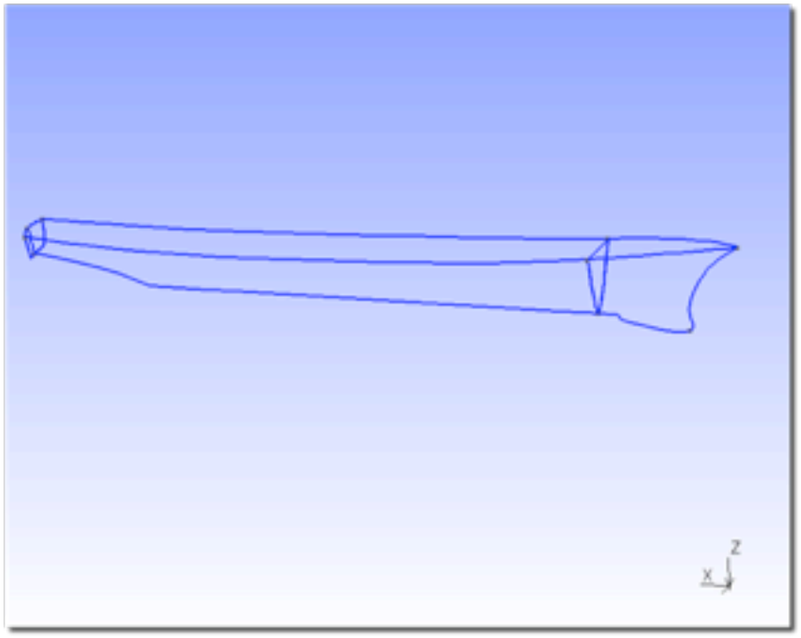


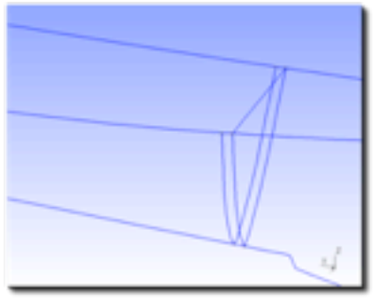
Meshing a vessel using IGS-File

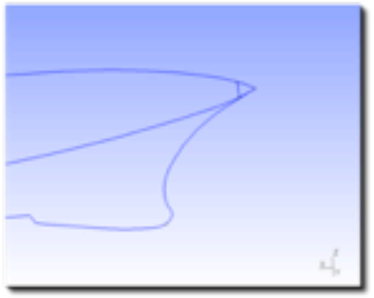


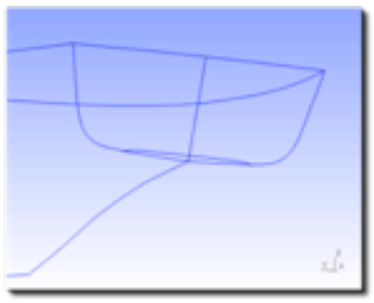


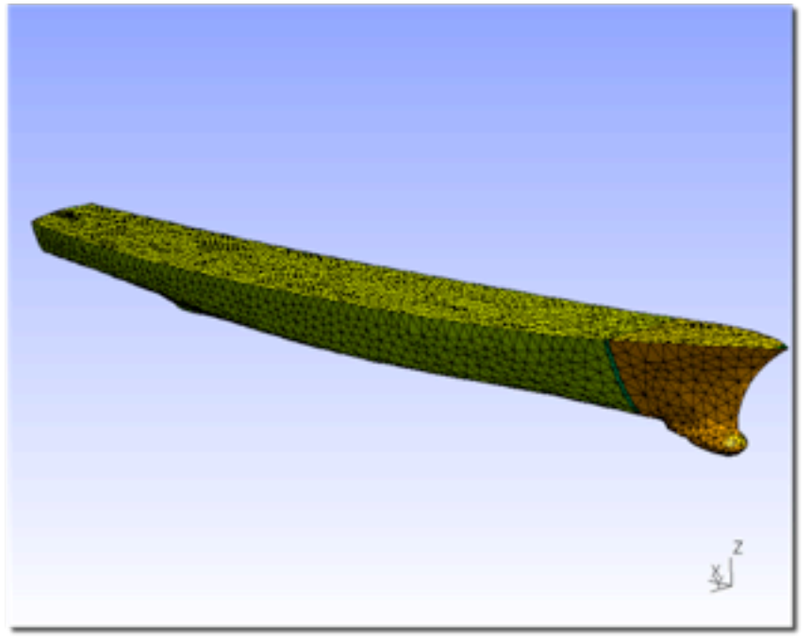






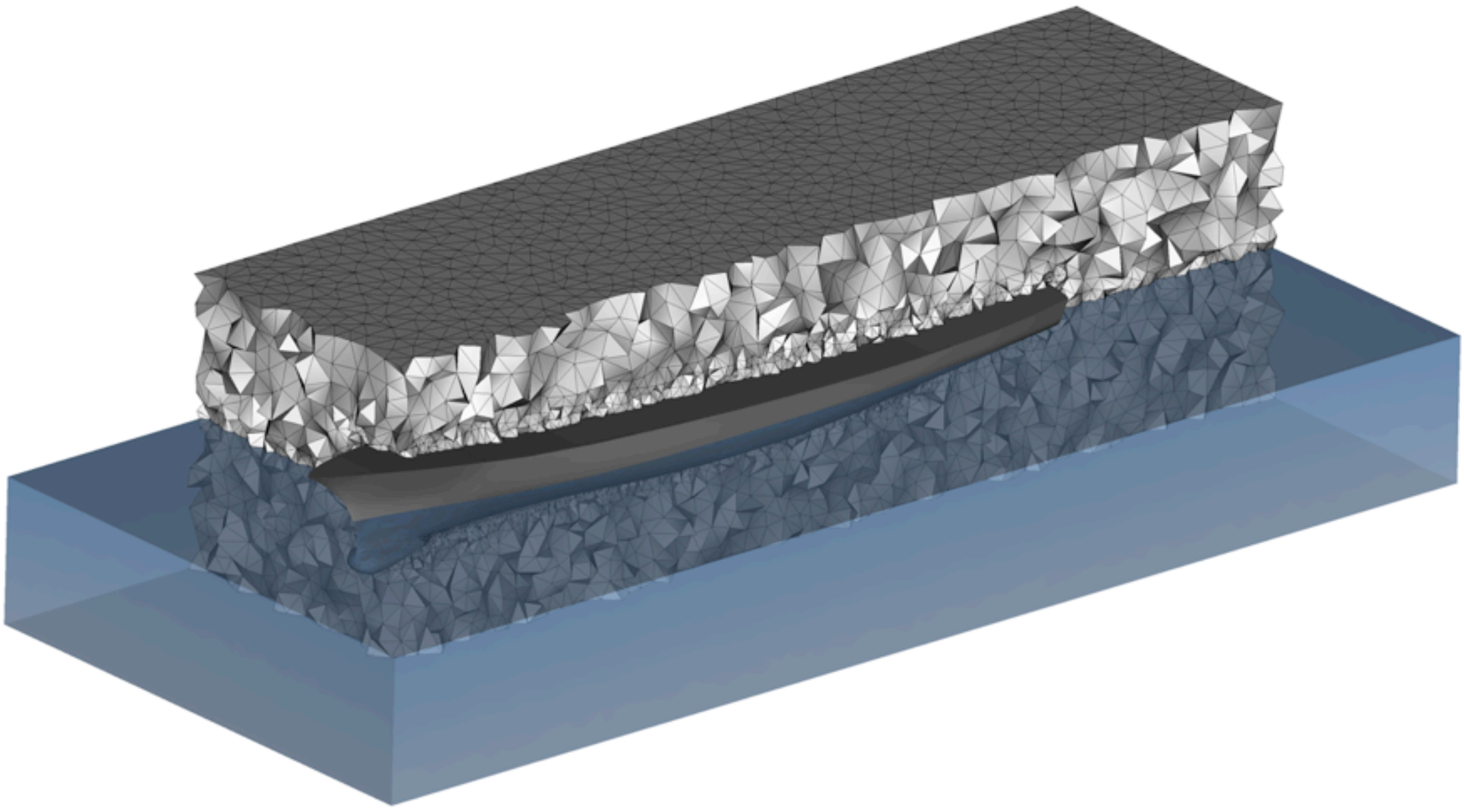






UCSD

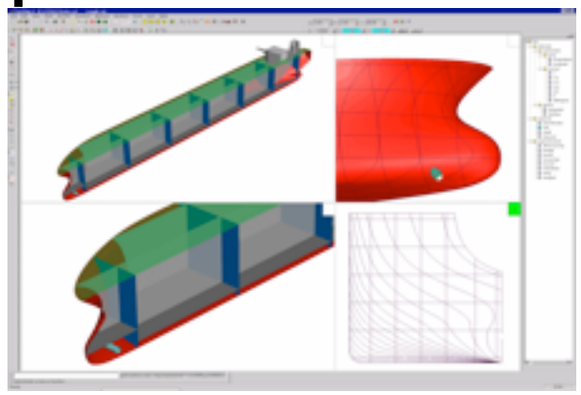
Result



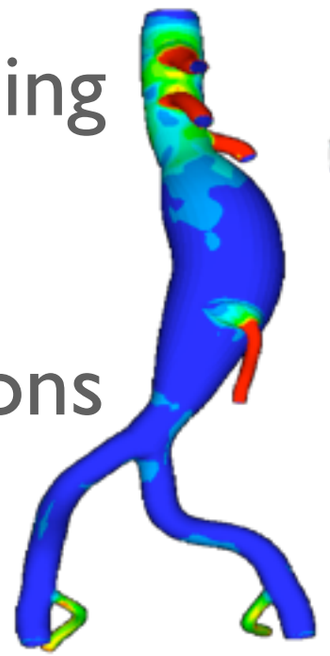
UCSD

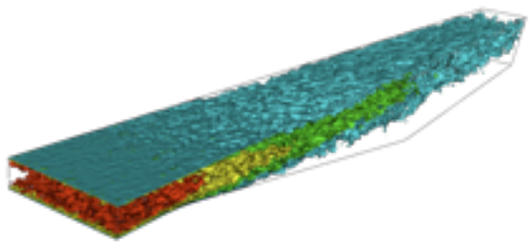
Isogeometric Analysis

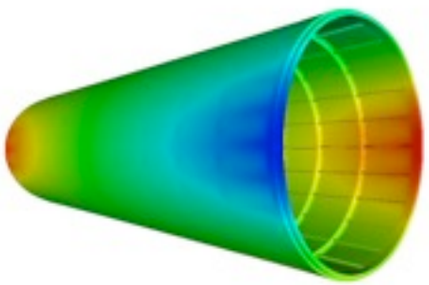
- Hughes, Cottrell, and YB. First paper appeared in Fall 2005
- Based on technologies (e.g., NURBS) from computational geometry used in:
  - Design (CAD)
  - Animation (CG)
  - Visualization (CG)



- Same ("exact") functional description is used for geometry and simulation
- Includes standard FEA as a special case, but offers other possibilities:
  - Precise and efficient geometric modeling
  - Simplified mesh refinement
  - Superior approximation properties
  - Smooth and higher-order basis functions
  - Integration of design and analysis





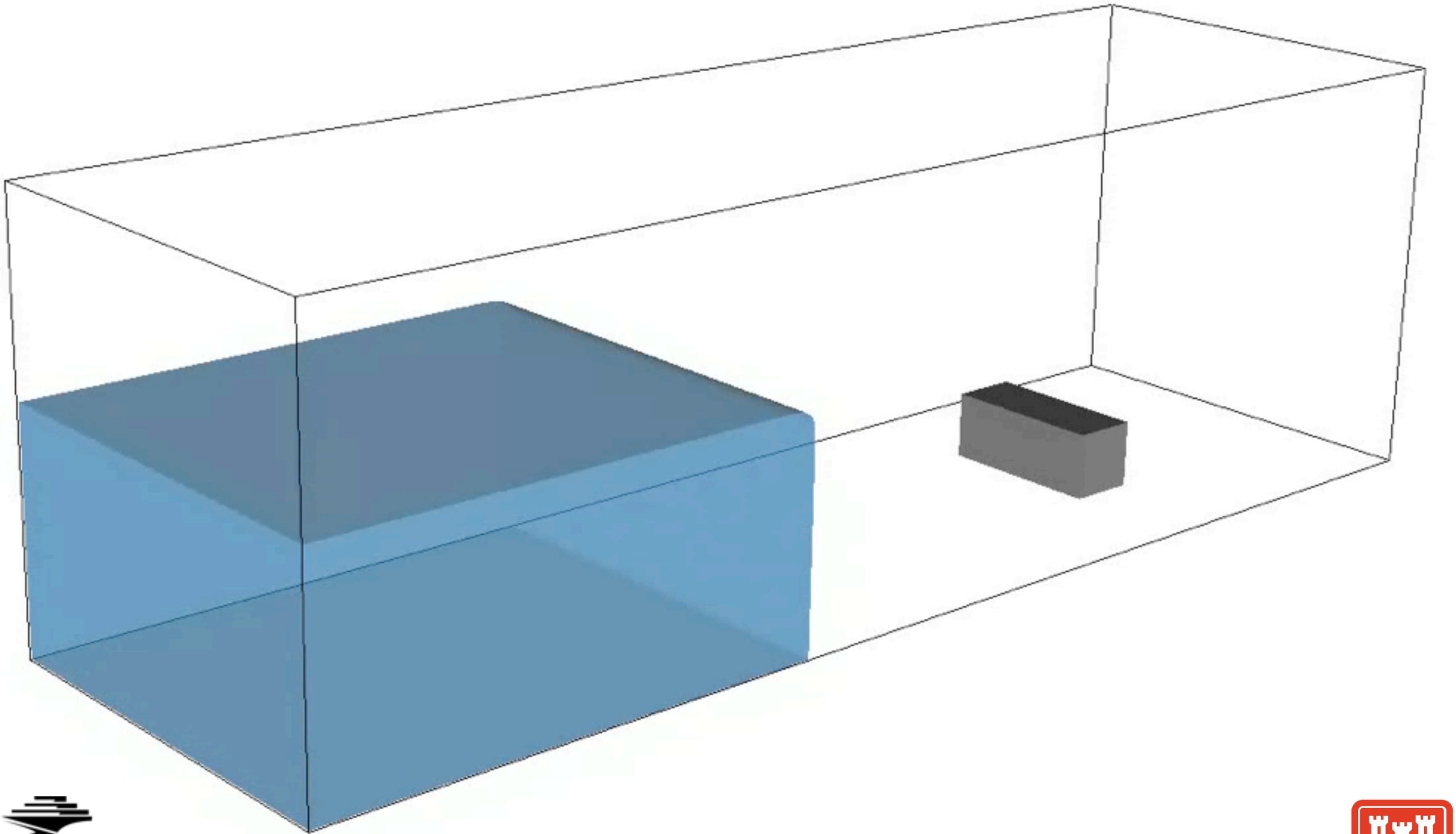


UCSD

Software framework

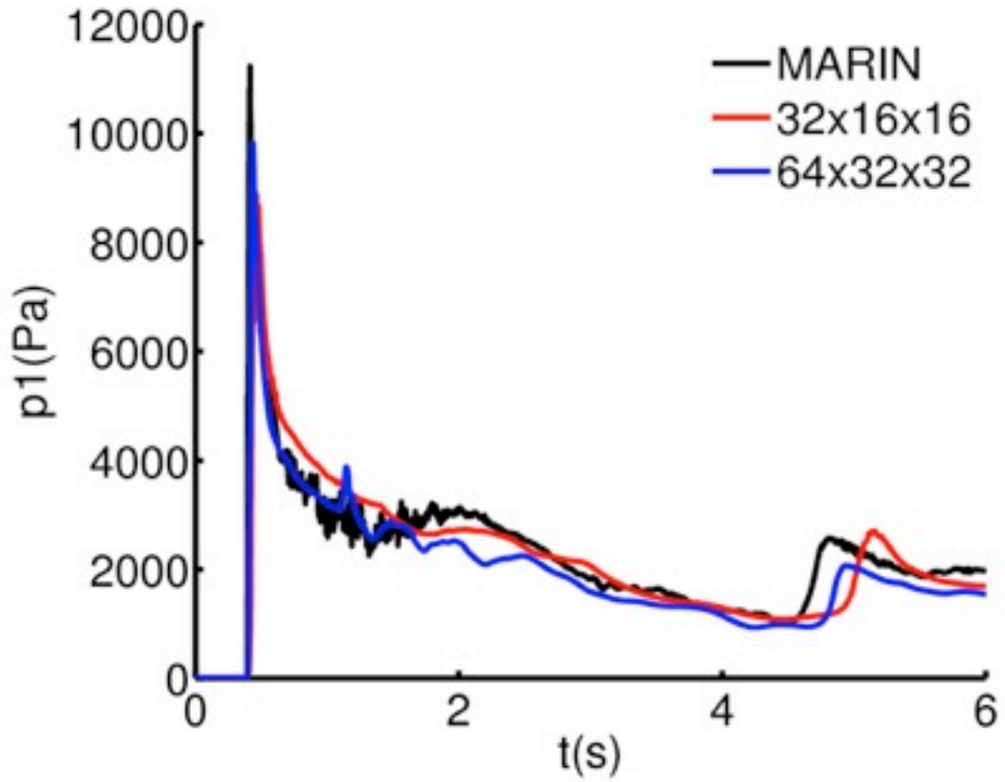
- ERDC in-house finite element simulation framework
- UCSD Isogeometric analyses research code
- Interface capturing
  - Level Set
  - Volume of Fluid (VOF)
- Turbulence modeling
  - Reynolds-Averaged Navier-Stokes
  - Residual-Based Large-Eddy Simulation
- Weak Dirichlet boundary conditions
- Basis function independent (P1,P2,Q1,NURBS,...)

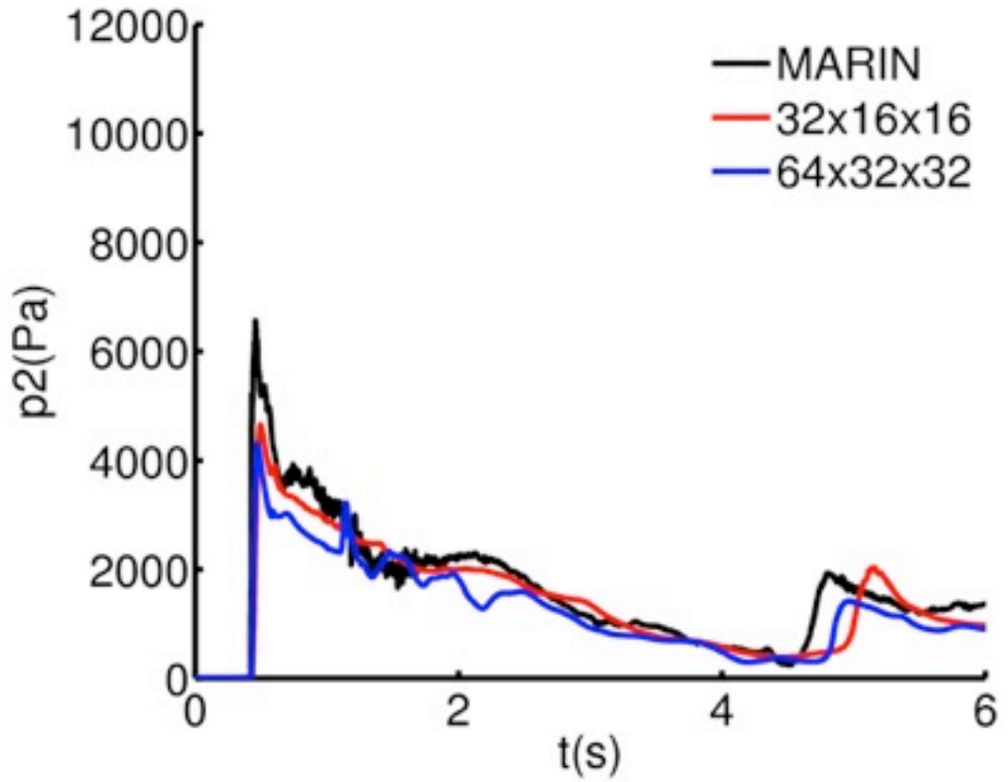
Dam break with obstacle

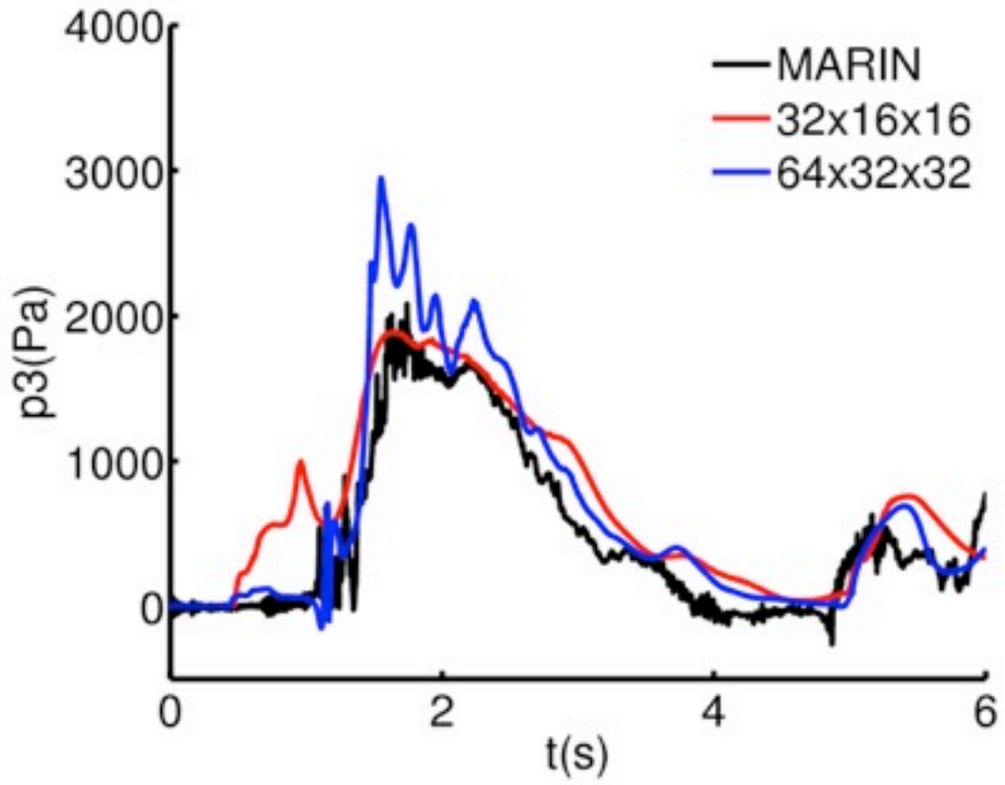


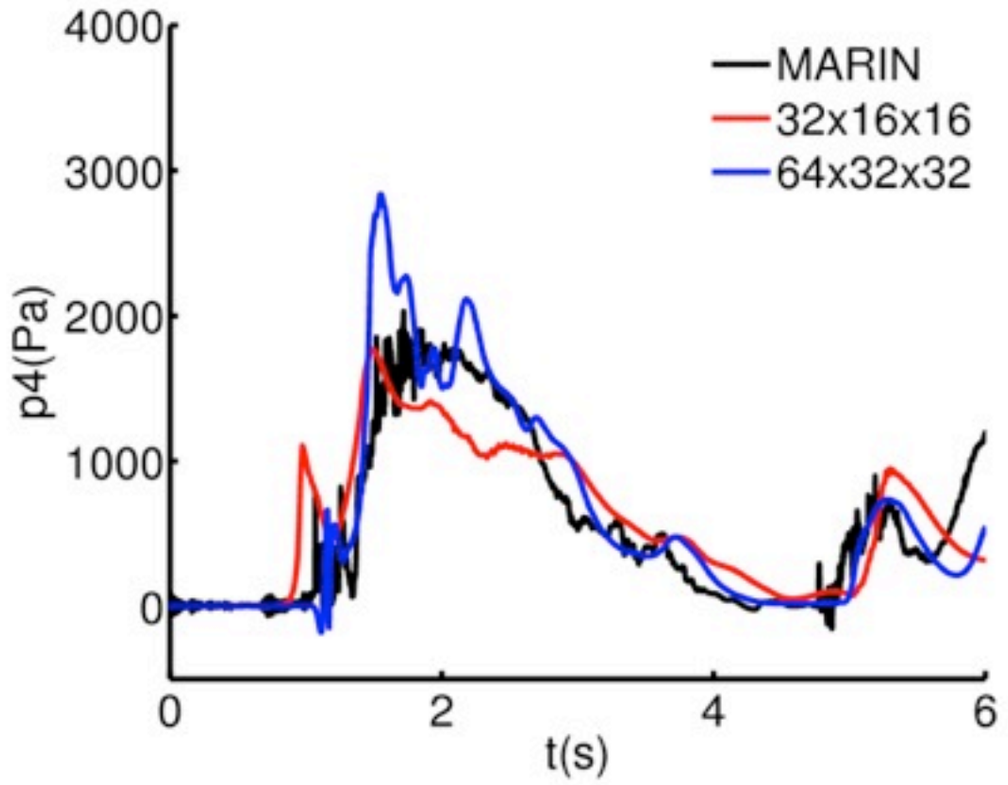
UCSD

Pressure on obstacle



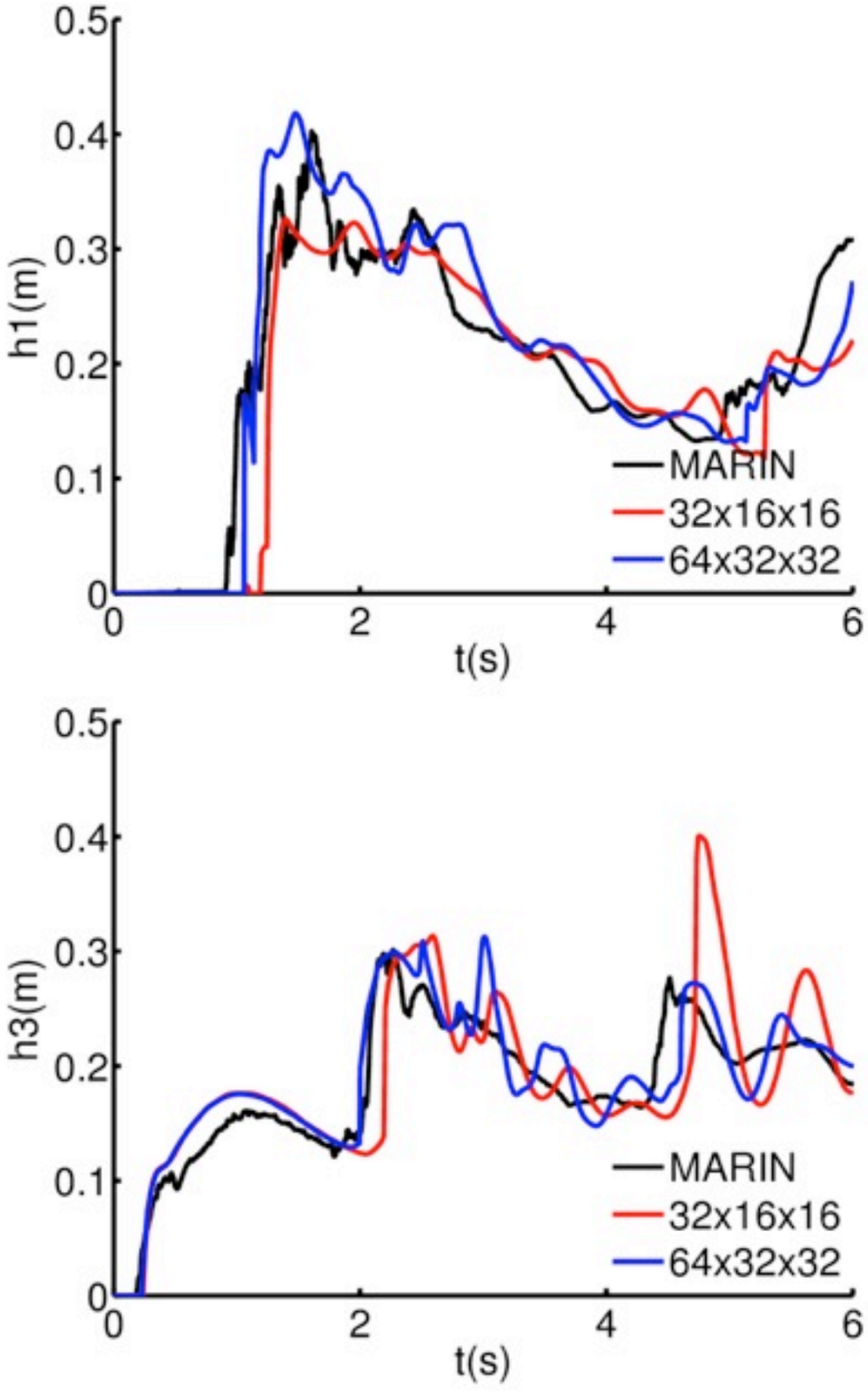


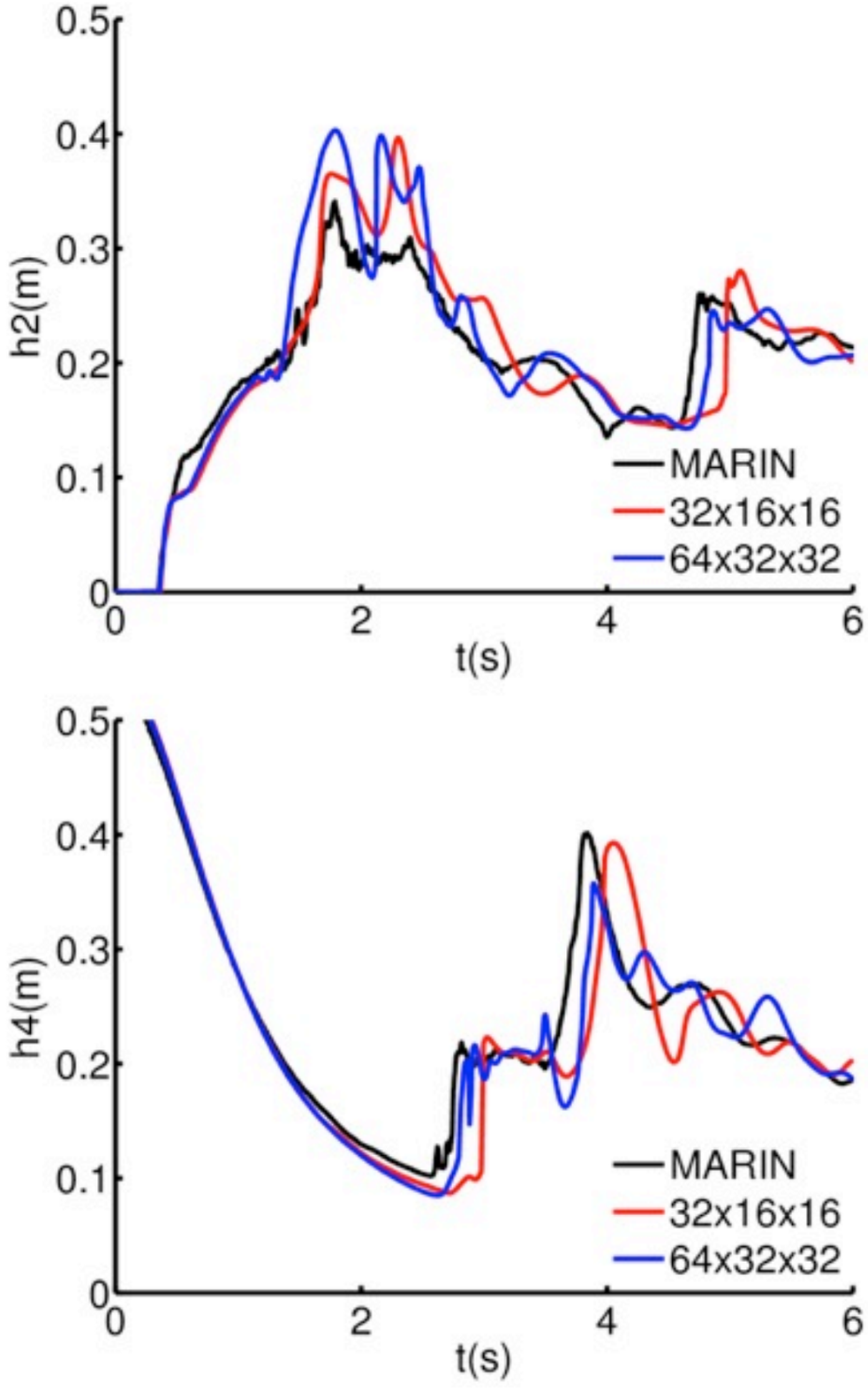




UCSD

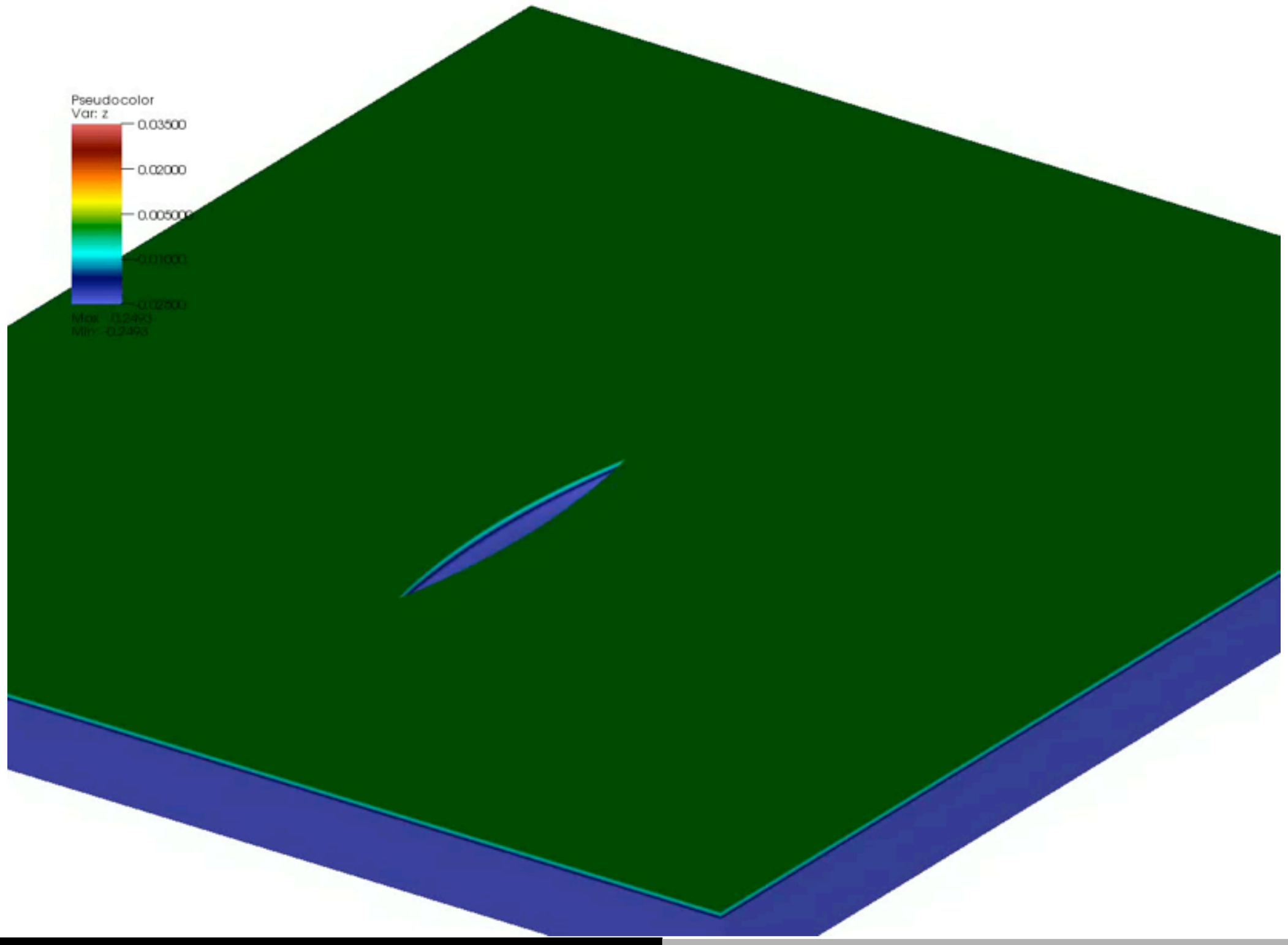
Water height in tank



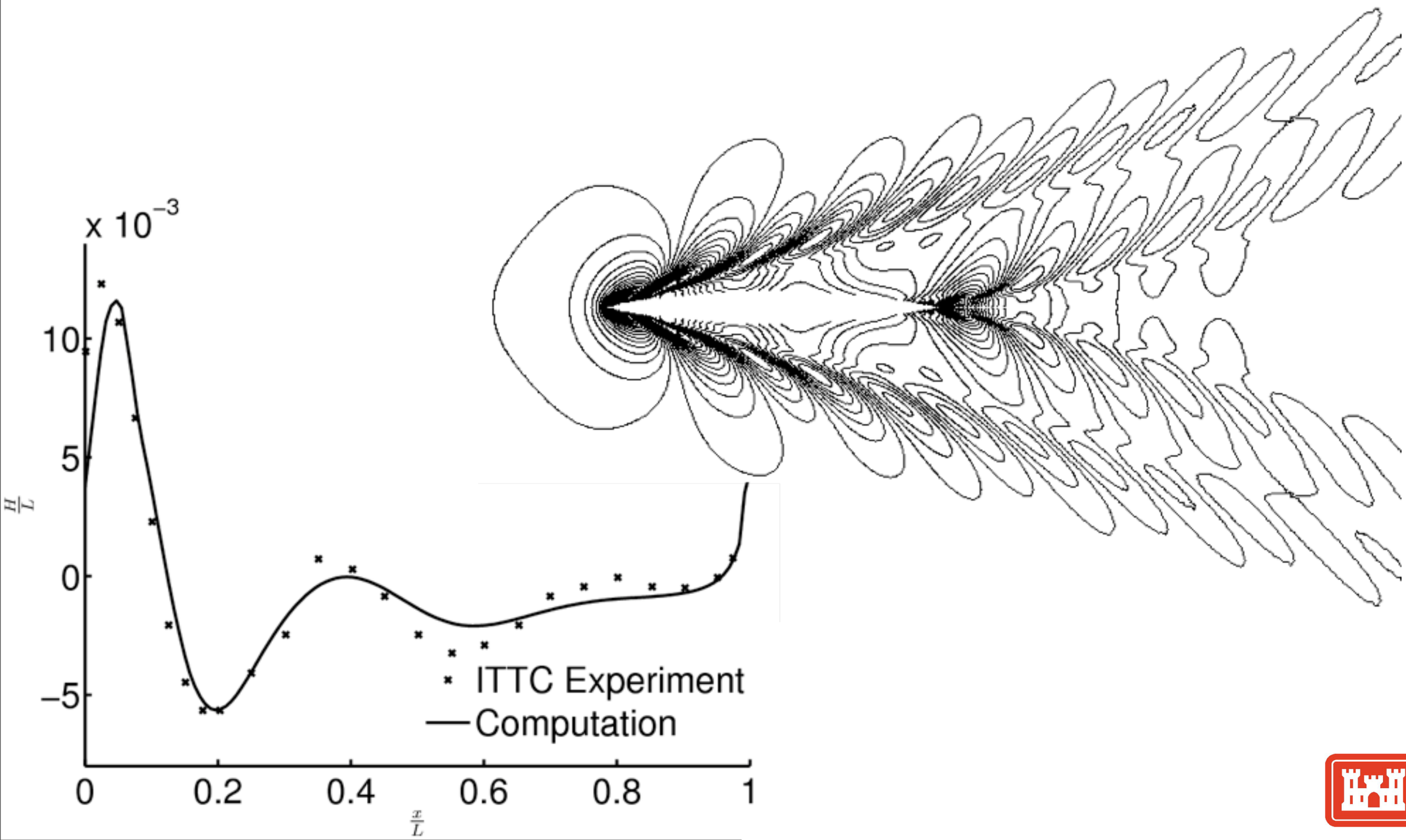


UCSD

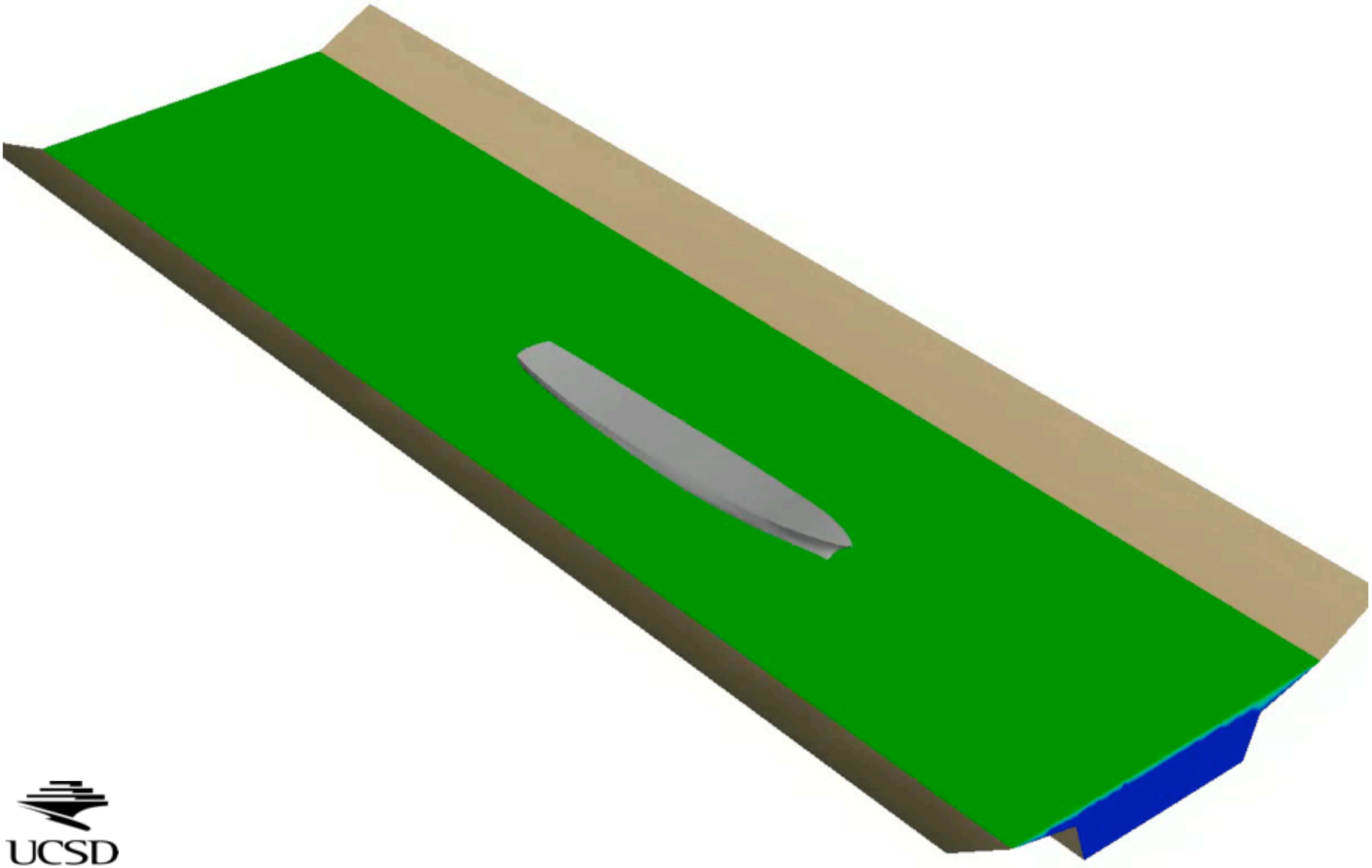
Wigley Hull


Pseudocolor
Var: z
0.03500
0.02000
0.005000
-0.01000
-0.02500
Max: 0.2493
Min: -0.2493

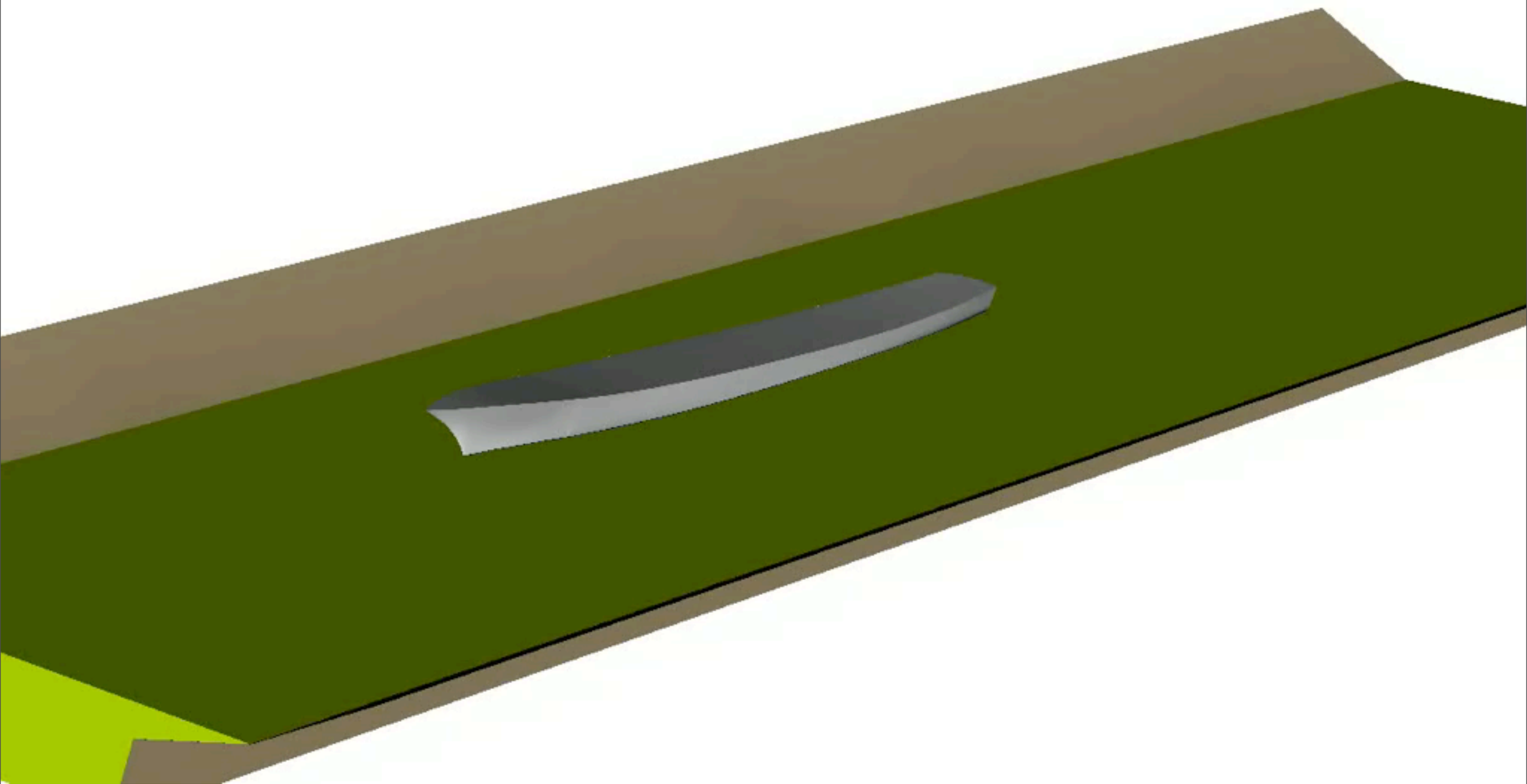
Waterline and Wave pattern



Vessel in shallow channel



Vessel in shallow channel



UCSD

Conslusion

- Finite element based 3D Navier-Stokes
  - Complex geometry(description??)
  - High accuracy (high order)
  - Boundary conditions (Boundary layer/outflow)
- Interface capturing
  - Sharp interfaces (breaking/smooth waves)
  - Mass conservative

Outlook

- Release of tetrahedral 3D air/water/vessel capability in August 2010
- Integration of Isogeometric methods in ERDC in-house code
- Isogeometric tools for complex geometry
  - Vessels
  - Bathymetry
  - Structures
- Adjoint-based space-time adaptivity