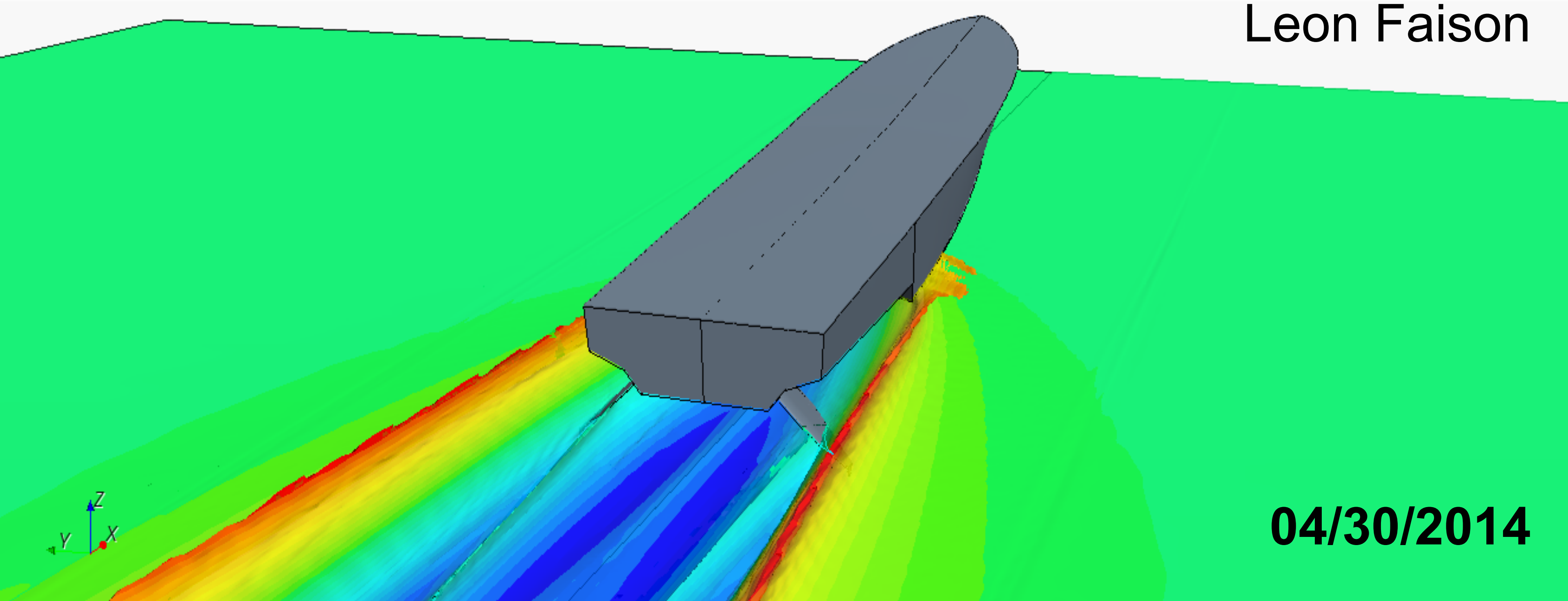
MIT i-Ship

Naval Construction and Engineering Program
Center for Ocean Engineering
Department of Mechanical Engineering

Design of a High Speed Planing Hull with a Cambered Step and Surface Piercing Hydrofoils

Presented by
Leon Faison



04/30/2014

Special Thanks

- Dr. Stefano Brizzolara
  - Asst. Director of Research, MIT Sea Grant
- Prof. Chryssostomos Chryssostomidis
  - Director, MIT Sea Grant

and many others…

Agenda

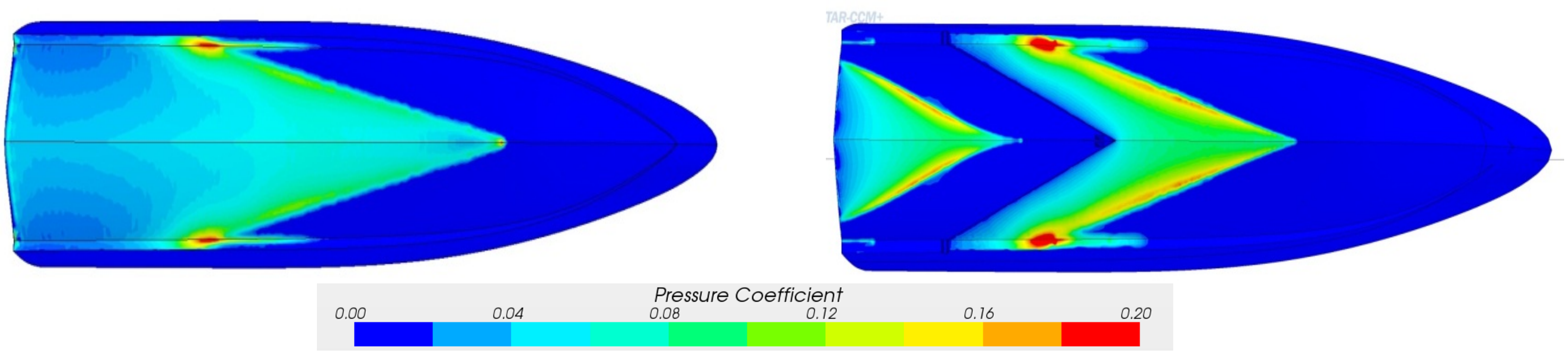
- Thesis Motivation
- Background
- Design Plan
- Computational Model
- Dynaplane Design
- Hydrodynamic Analysis
- Final Thoughts

Thesis Motivation

- Potential improvements for very high speed planing hulls
  - V-Step
  - Cambered Step
  - Fully Ventilated Afterbody
  - Stern Surface Piercing Hydrofoils

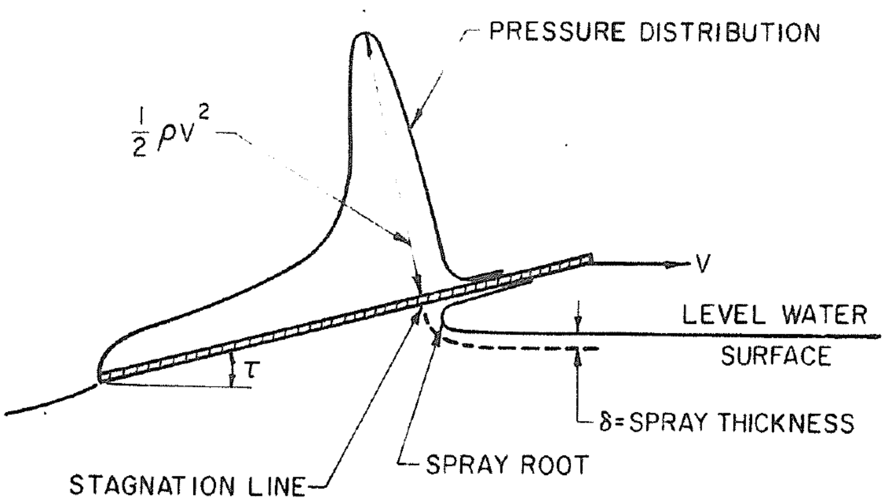
- Demonstrate the capability and accuracy of computational fluids dynamics (CFD) for model testing

- Characterize the hydrodynamic behavior for a new Dynaplane configuration



Background

- Planing hulls' ability to exceed hull speed
- Hydrodynamic forces dominate
- Similitude and the Froude number transition from length to volume dependency
- Past research largely based on empirical methods
  - Savitsky, Clement, and Blount

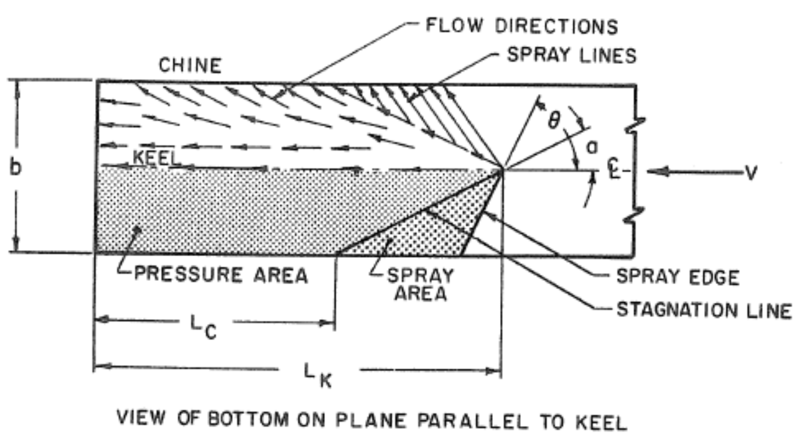


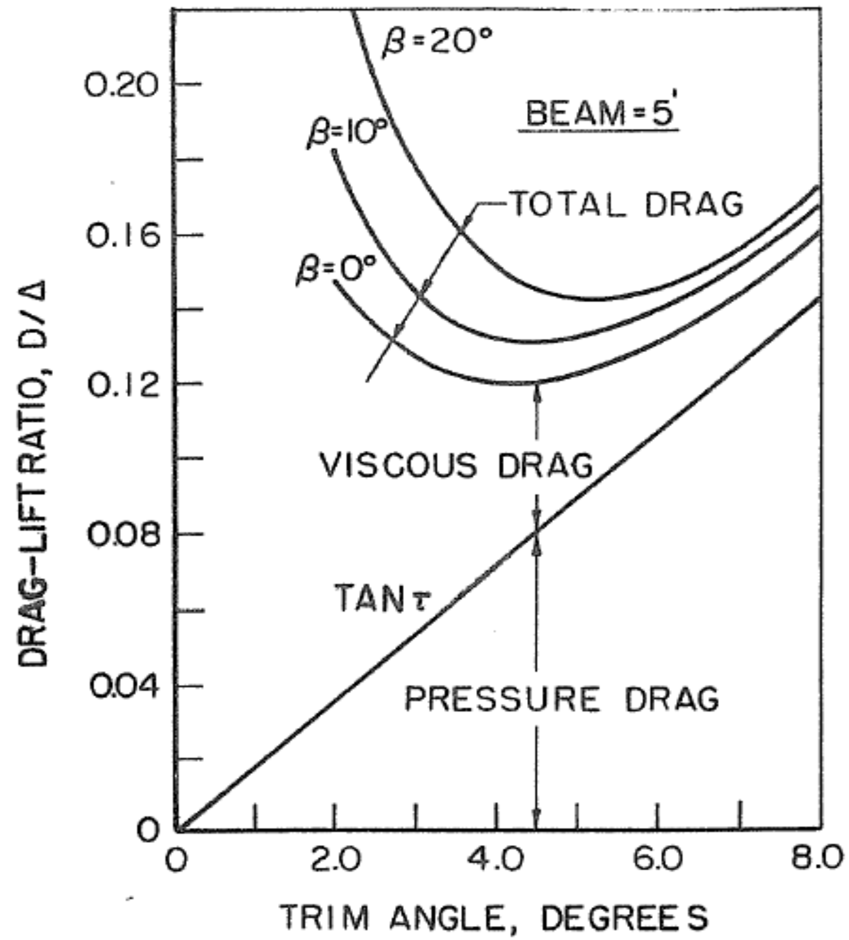
Froude Number

$$\mathrm{FnL} = \frac{v}{\sqrt{gL}} \qquad \mathrm{FnV} = \frac{v}{\sqrt{g\nabla^{\frac{1}{3}}}}$$

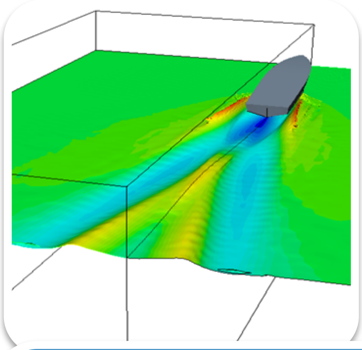
Background

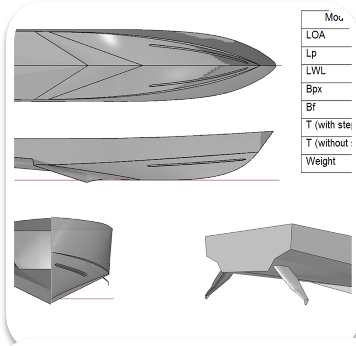
- Conventional methods for designing planing hulls
  1) Running Trim
- Novel approach
  1) Lift
  2) Wetted Area
  3) Step Improvement

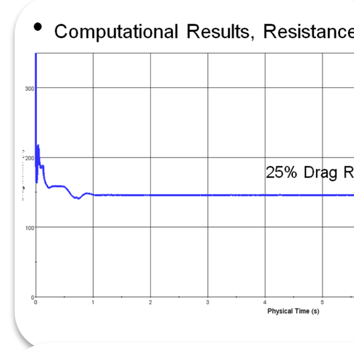




Design Procedure







1. Reference Hull Selection
- Availability of Data
- Similar Parameters
- USCG 47' MLB

2. Computational Model
- Geometry and Mesh Generation
- Setting Initial and Boundary Conditions
- CFD Validation

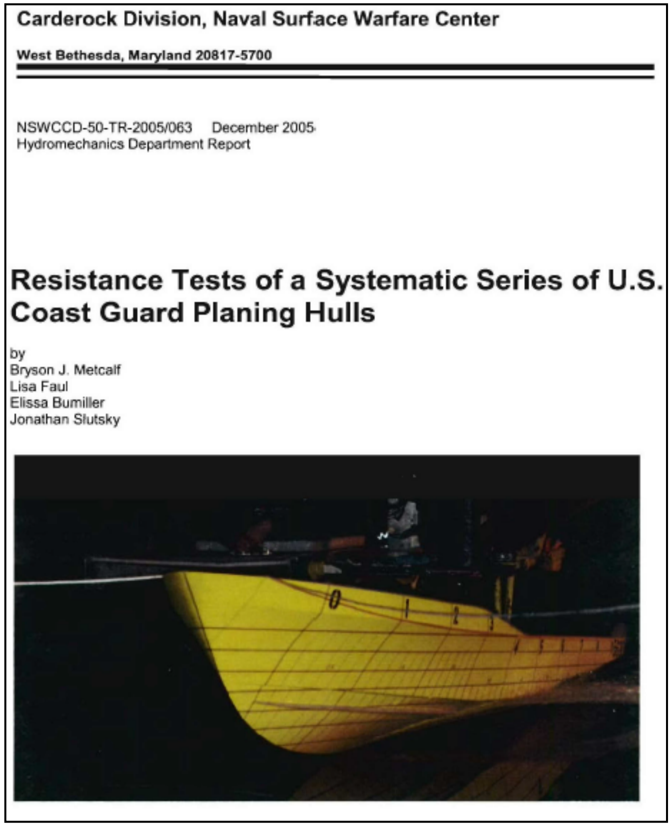
3. High Speed Hull Design
- Incorporate Innovative Design Features
- Eugene Clement's Dynaplane

4. Hydrodynamic Analysis
- Static Equilibrium
- Quasi-Static Stability
- Dynamic Stability Predictions

"[We] encourage the development of CFD since such a tool may be useful in extending the range of parametric variables at modest cost" (Savitsky & Morabito, 2009)

Reference Model Selection

- Based on USCG 47' Motor Lifeboat
- DTMB: Model 5631
  - Extensive resistance test runs consisting of variations in Heave, Trim, & Speed
  - Hard Chine Deep-V Planing Hull



Carderock Division, Naval Surface Warfare Center

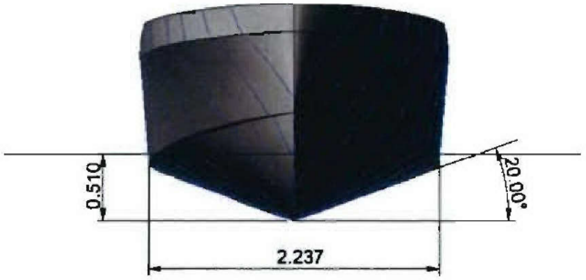
West Bethesda, Maryland 20817-5700

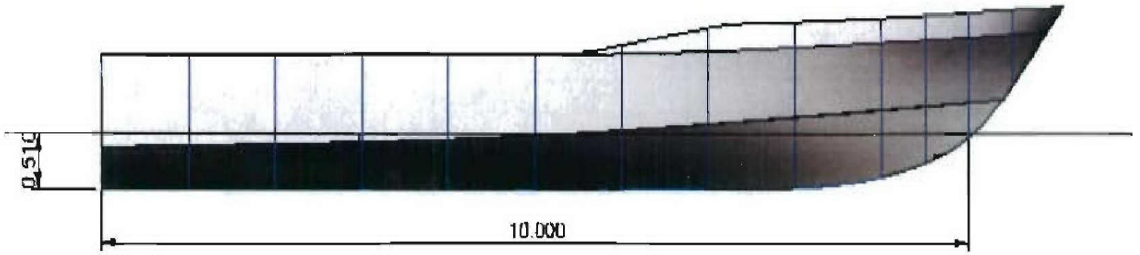
NSWCCD-50-TR-2005/063 December 2005
Hydromechanics Department Report

Resistance Tests of a Systematic Series of U.S. Coast Guard Planing Hulls

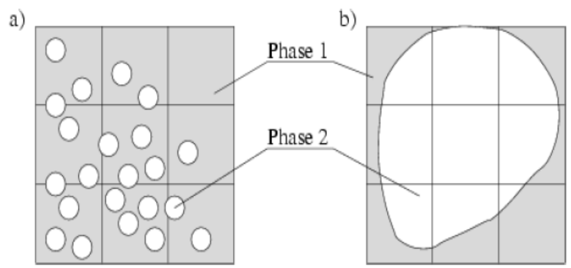
by
Bryson J. Metcalf
Lisa Faul
Elissa Bumiller
Jonathan Slutsky

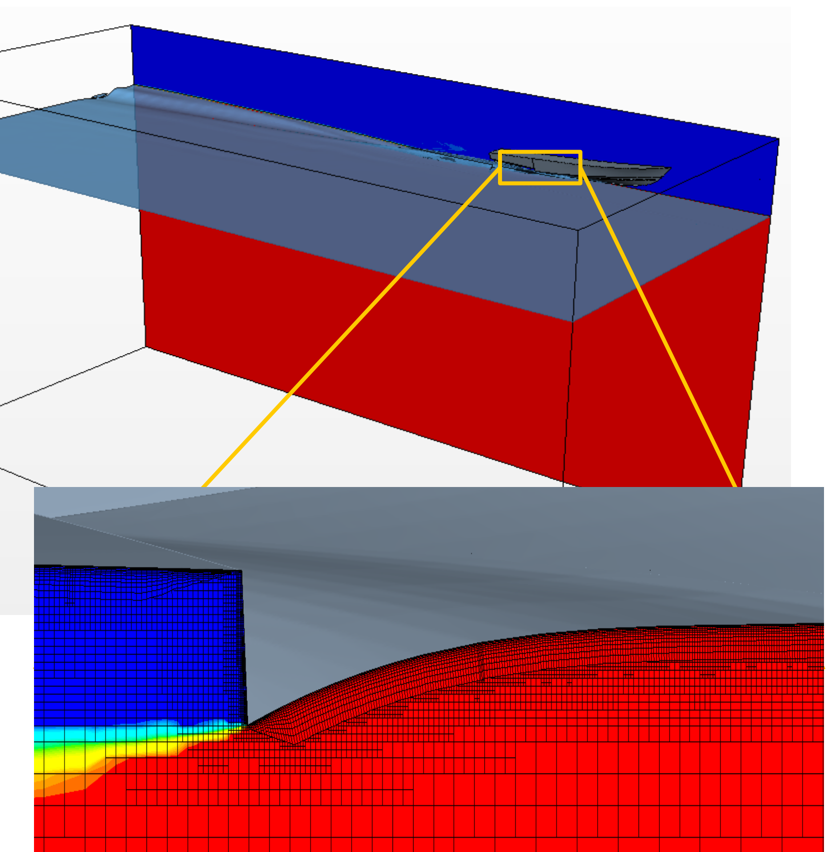
5631, Variant #3 (L/B=4.47, B/T=4.39)





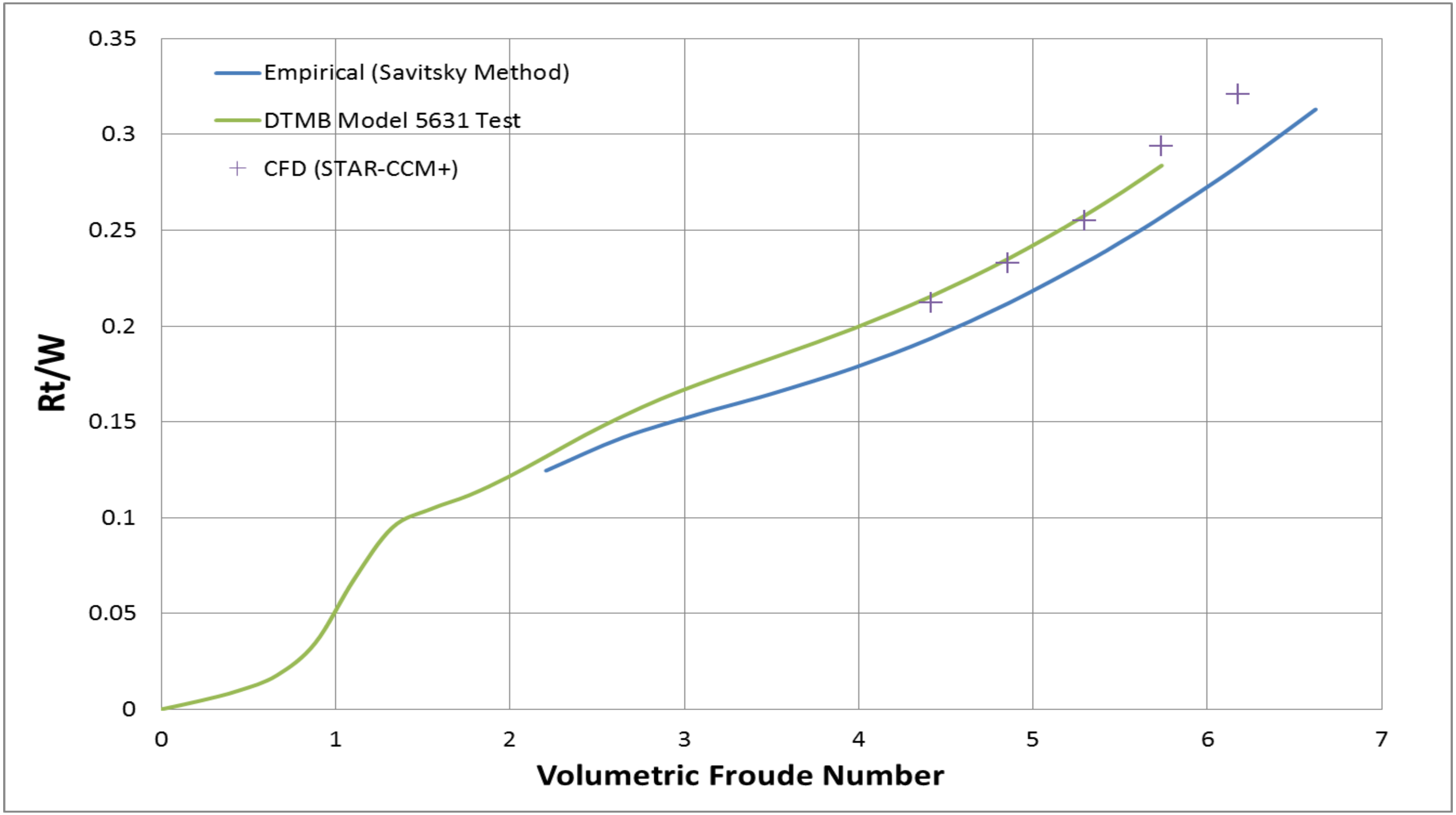
Computational Model





- Robust RANSE solver
  - Semi-implicit unsteady
  - Volume of Fluid
  - Dynamic Fluid Body Interaction
- Defining the domain
  - Velocity Inlet
  - Pressure Outlet
  - Symmetry Planes
- Defining the mesh
  - Density
  - Prism Layer Mesher
  - Volumetric Controls

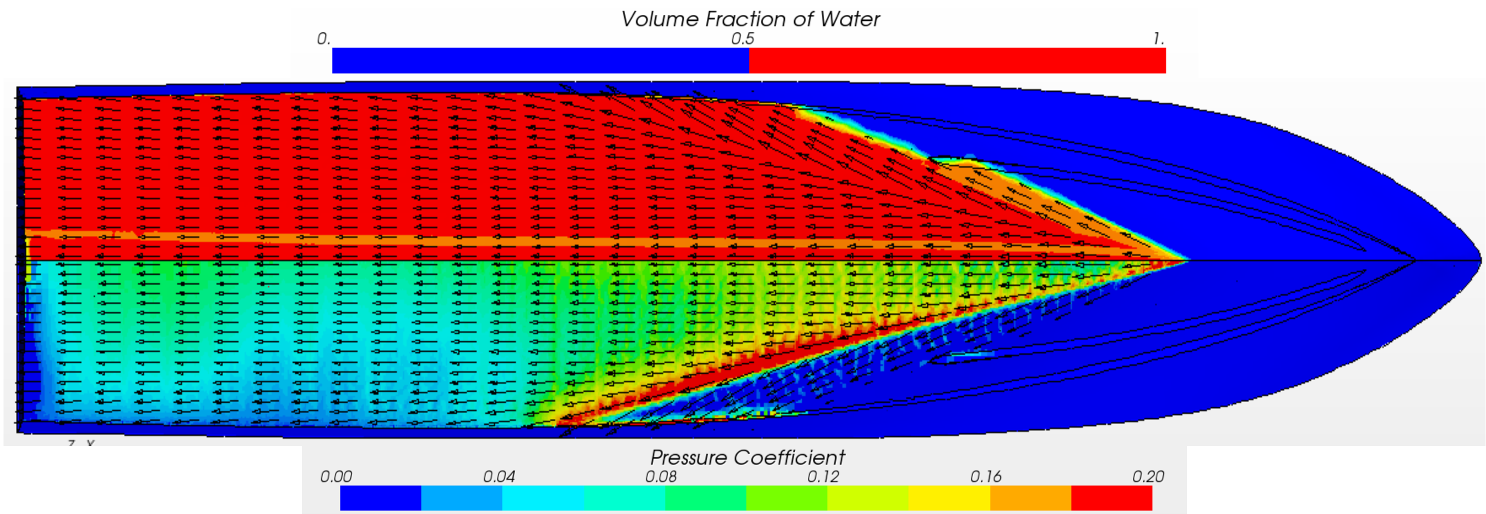
CFD Model Validation

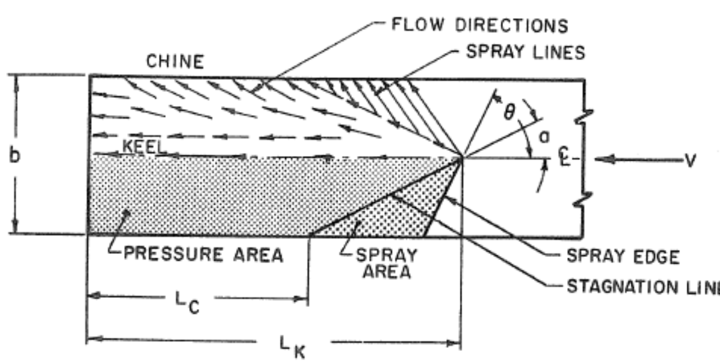


<u>Test Condition:</u> 375 lb Model 5631 in Calm Seas @ 48, 54, 58, 64, and 68 knots

CFD Model Validation

Calm Seas
@ 58 kts

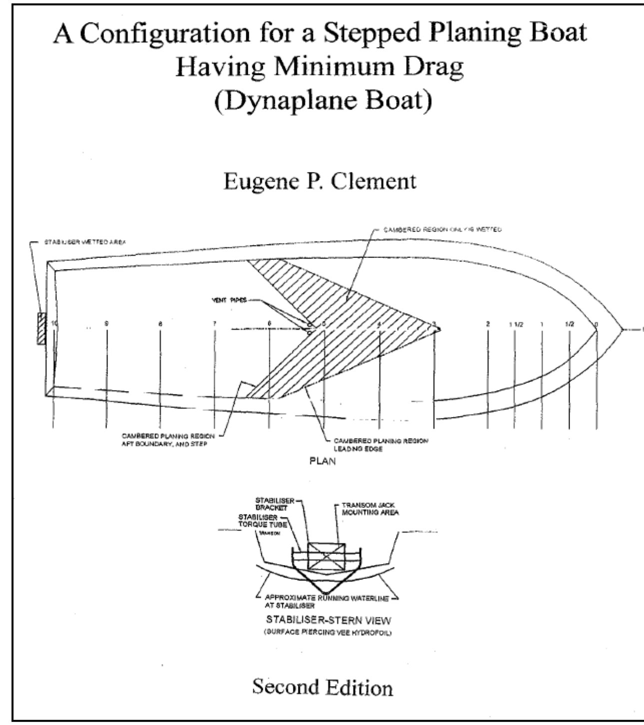


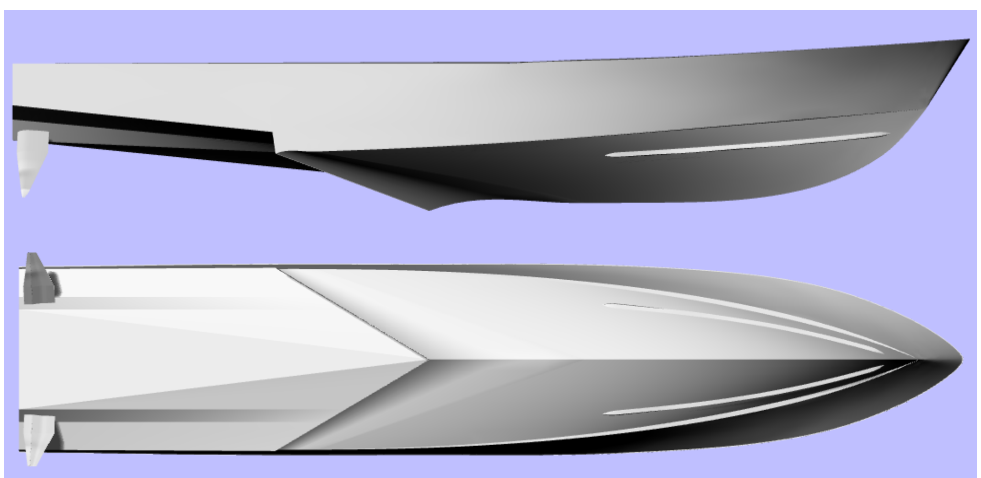


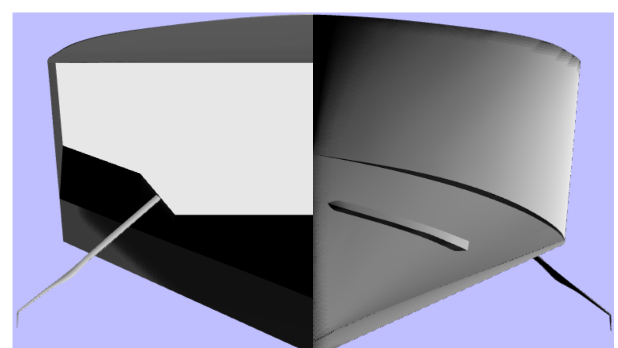
	DTMB Results	CFD Results	% Difference
Wetted Area [m^2]	1.56	1.608	**2.9 %**

High Speed Hull Design

- New Dynaplane Configuration
  - Two lifting surfaces
    - Cambered Step, “Wing”
    - Stern Stabilizer, SPSC hydrofoils
- Powering Improvement
  - Drag Reduction at FnV > 3.5
  - Lift to Drag Increase

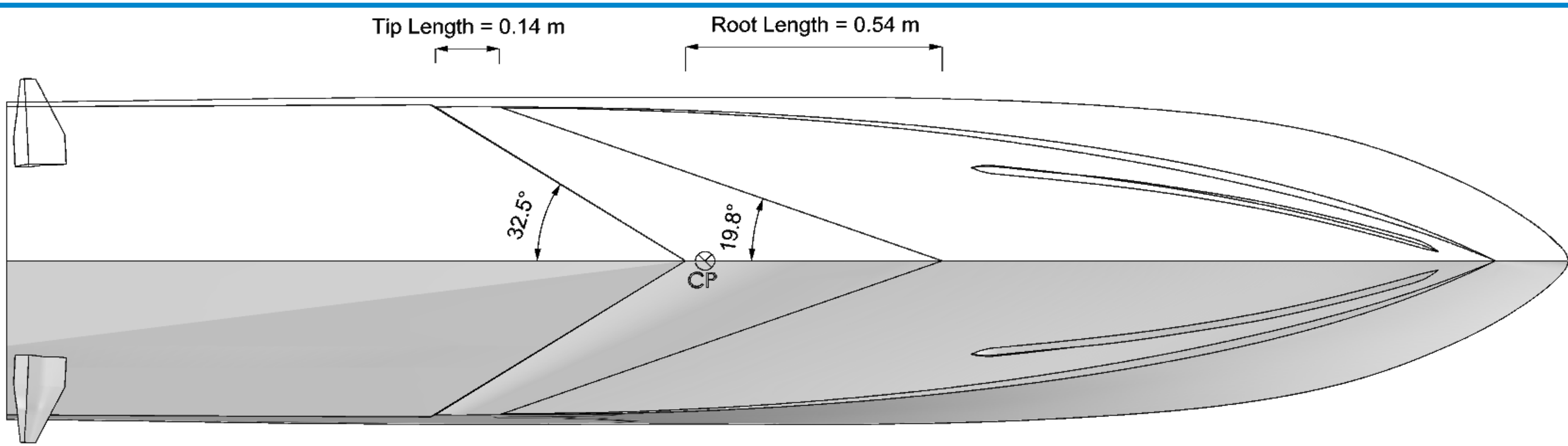


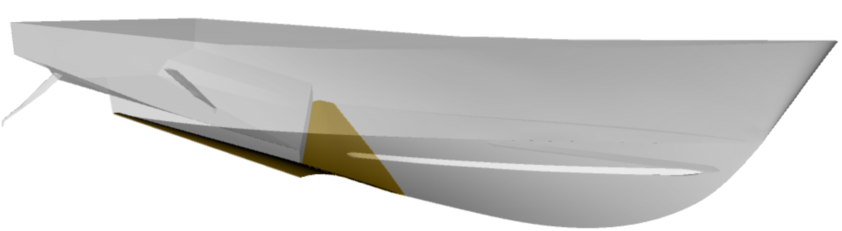




Cambered Step Design

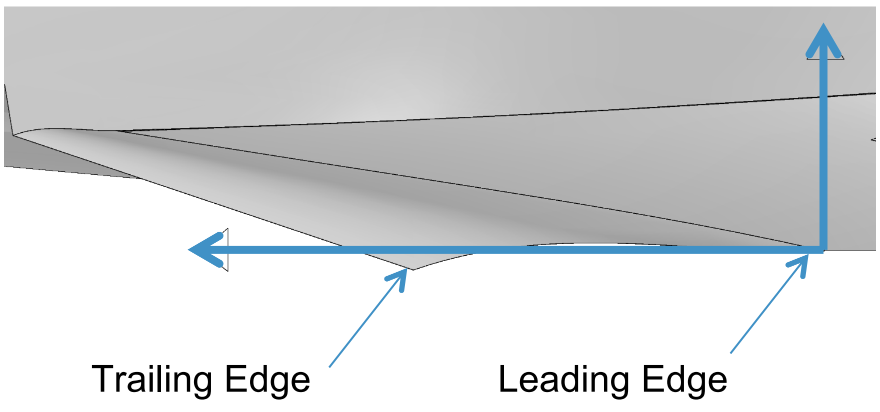
- Designed @ 3.5 deg trim and FnV = 5





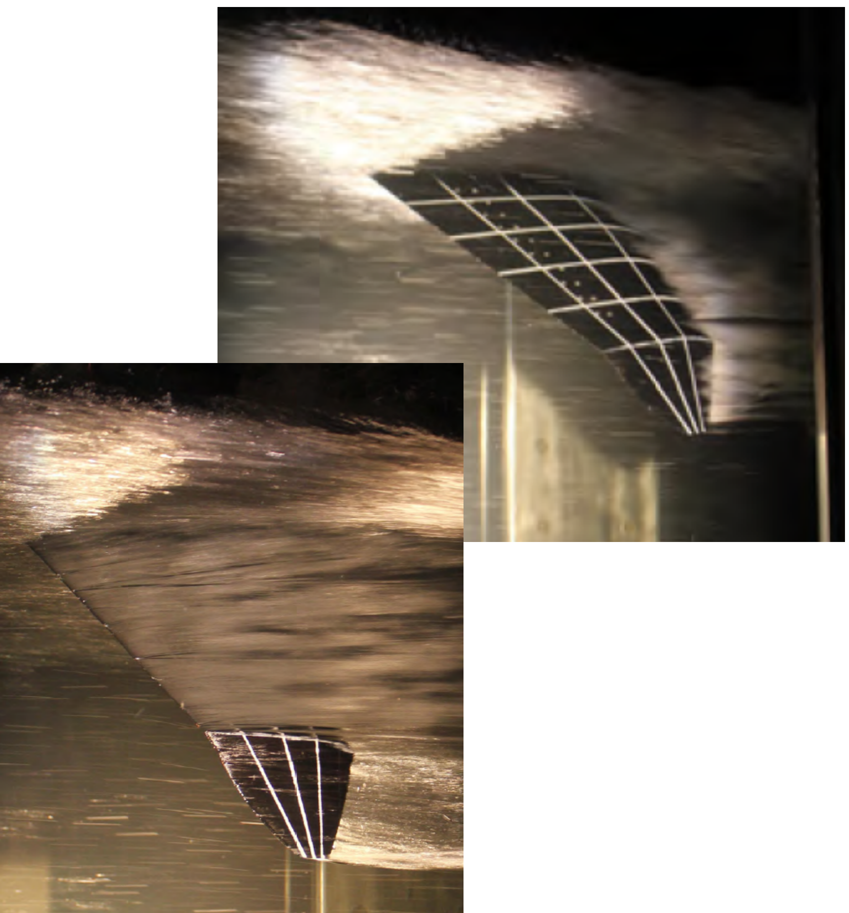
C_L = 0.236, Lift/Drag = 7.2

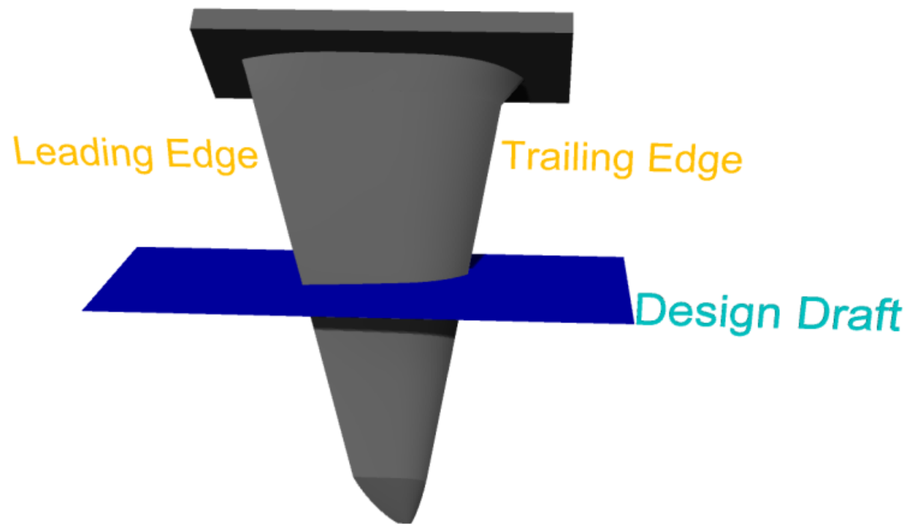
Profile View of Johnson 3-term Camber

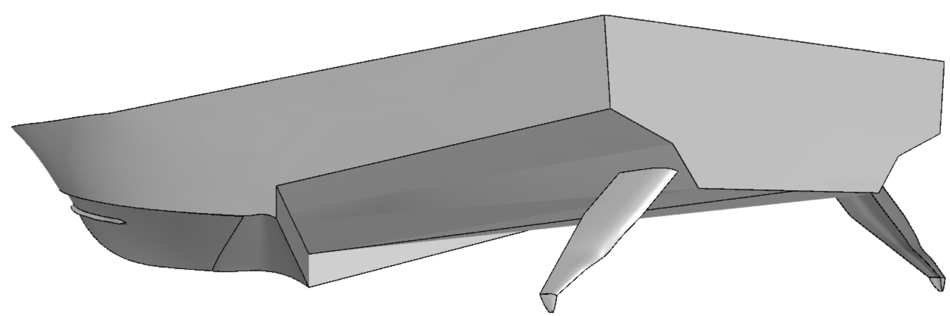


Stern Stabilizer Configuration

- Incorporated Dr. Stefano Brizzolara’s surface piercing, super-cavitating hydrofoil







Hydrofoil Afterbody Placement

- Savitsky & Morabito: Wake Geometry Predictions
  - Series of model tests to determine surface contours
  - Tested β = 10, 20, and 30 deg
  - Developed sets of empirical equations {trim, L_k, B_{PX}, and C_v}

Equations for Longitudinal Surface Wake Profiles

Centerline Profile:

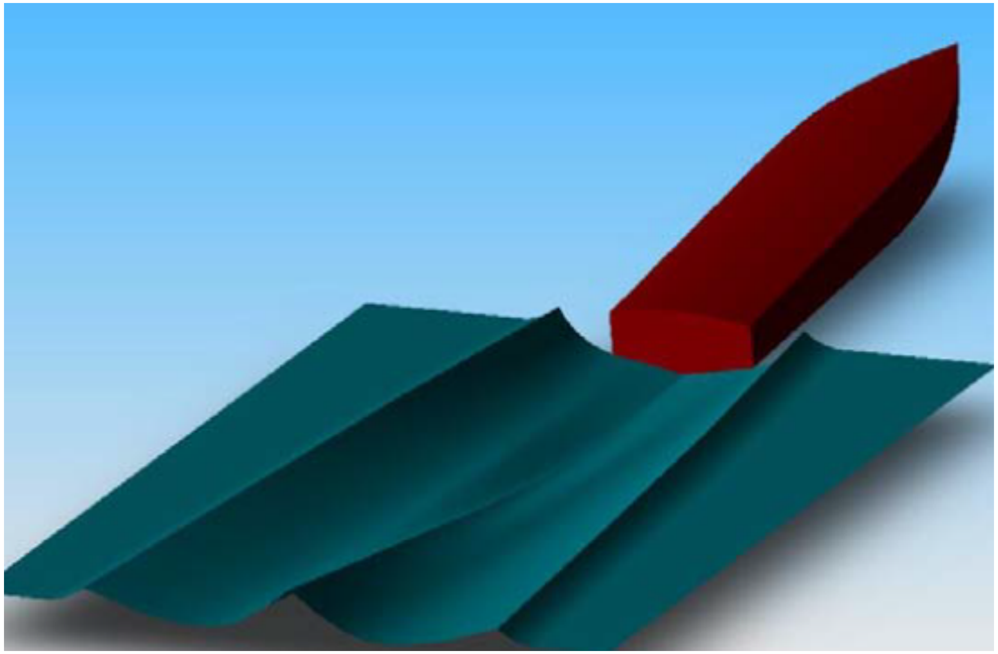
$\beta = 20^o$

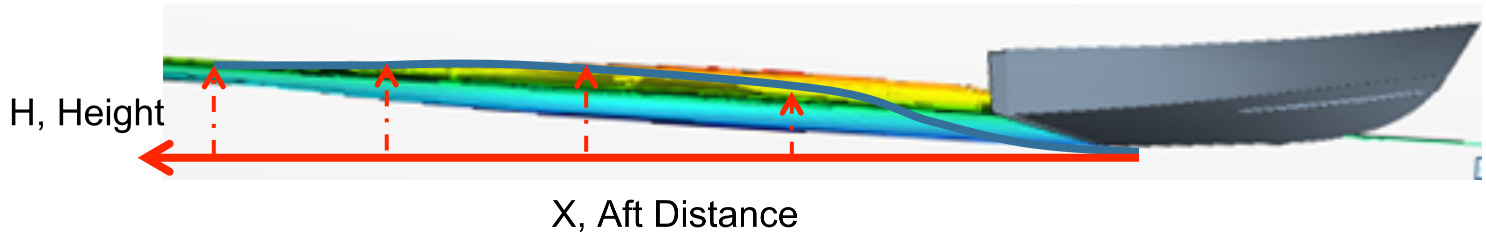
$$H = 0.17\,[2.0 + 0.03\,L_k\,\tau^{1.5}]\,Sin\left[\frac{\pi}{C_v}\left(\frac{X}{3}\right)^{1.5}\right]$$

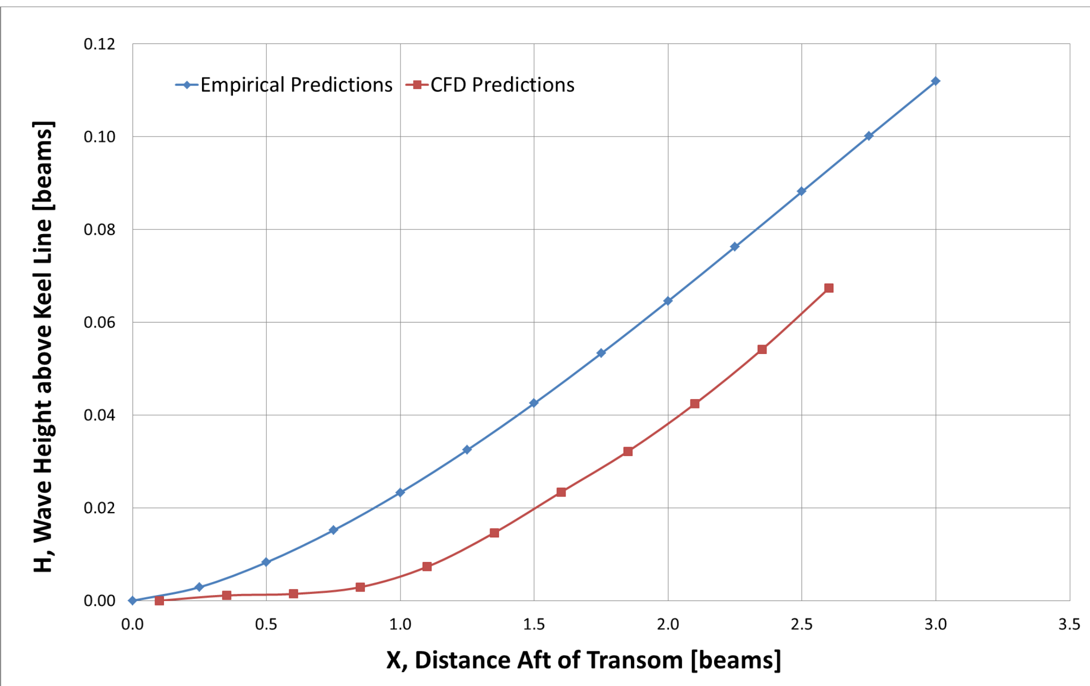
1/4 Beam Buttock

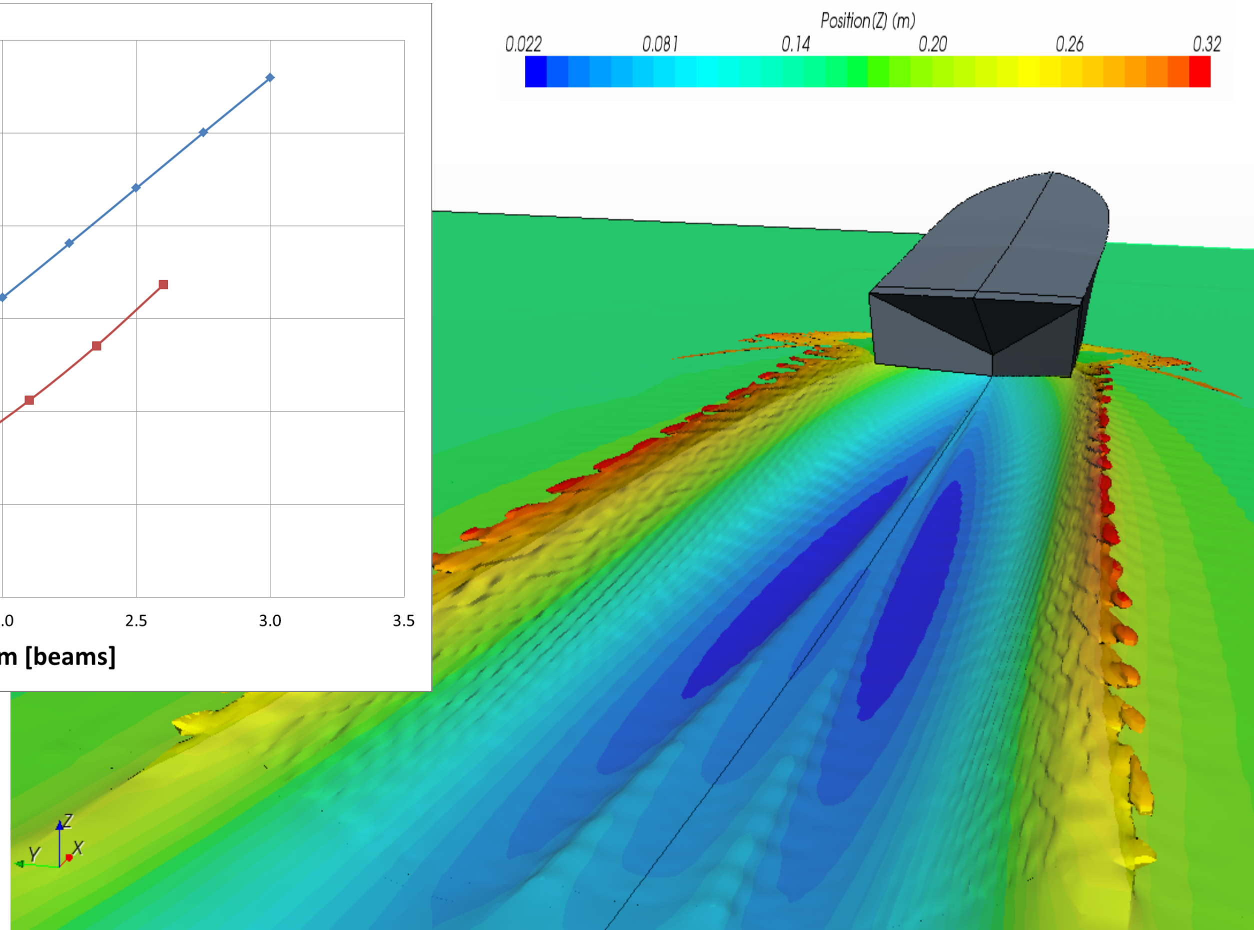
$\beta = 20^o$

$$H = 0.17\,[0.75 + 0.03\,L_k\,\tau^{1.5}]\,Sin\left[\frac{\pi}{C_v}\left(\frac{X}{3}\right)^{1.5}\right]$$



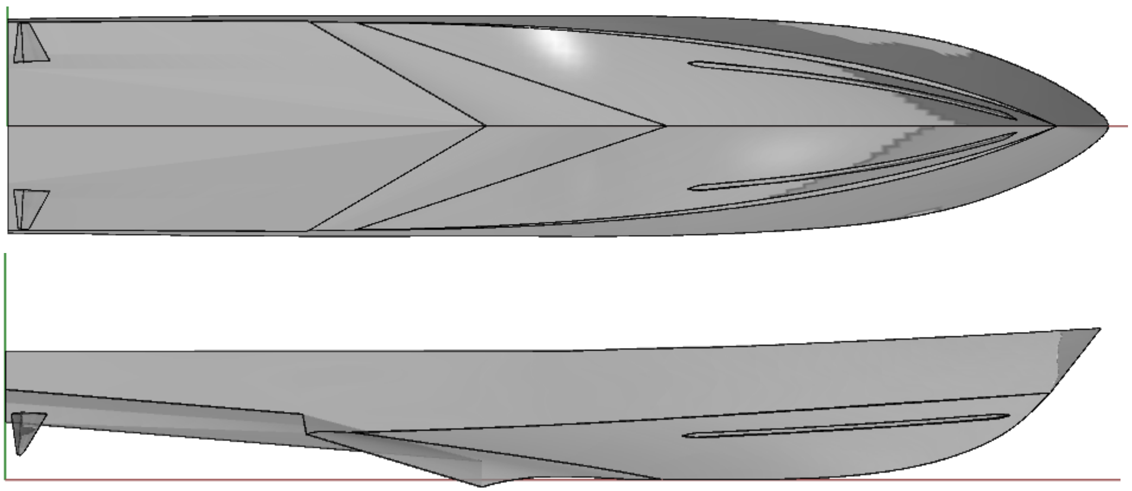

H, Height
X, Aft Distance


Empirical Predictions
CFD Predictions
H, Wave Height above Keel Line [beams]
X, Distance Aft of Transom [beams]
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

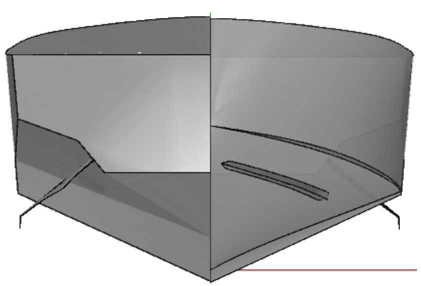

Position(Z) (m)
0.022
0.081
0.14
0.20
0.26
0.32
Z
Y
X

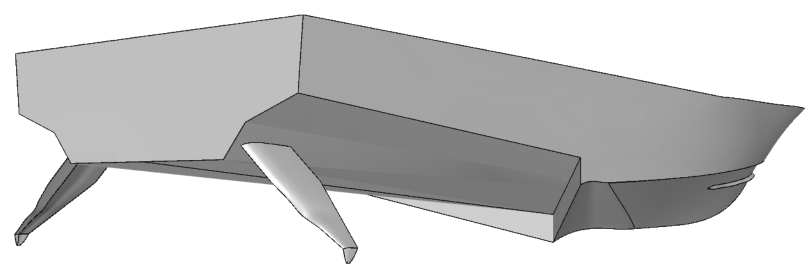
Final Design

- Model 5631 Dynaplane

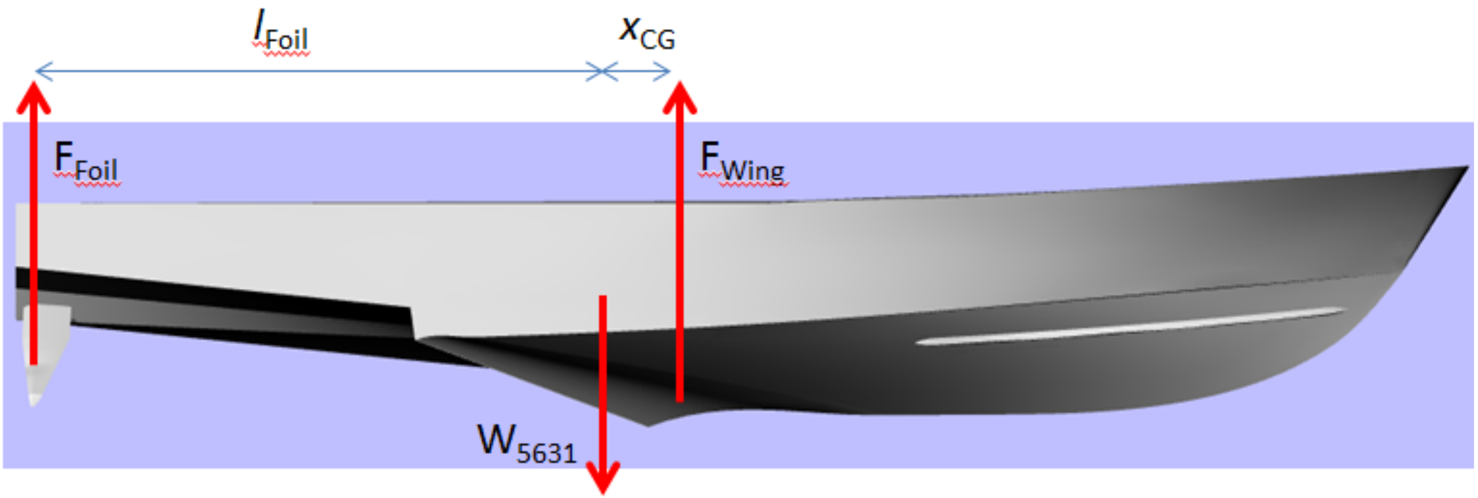


Model 5631 Dynaplane Design	
LOA	3.3 m
Lp	3.2 m
LWL	3 m
Bpx	0.68 m
Bf	0.42 m
T (with step)	0.18 m
T (without step)	0.16 m
Weight	170 kg





Hydrodynamic Analysis

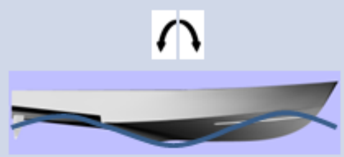
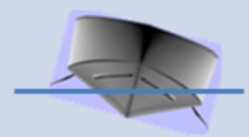
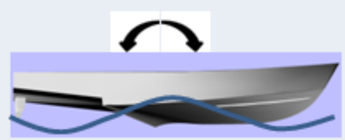
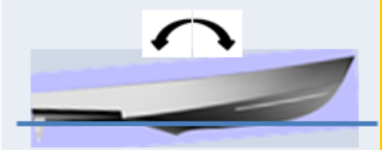
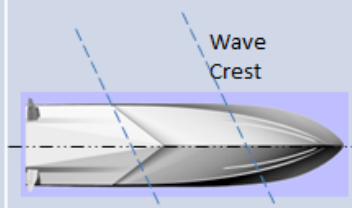


- Moment Balance Approach
- Static Equilibrium Calculation

$$\Sigma M = F_{Wing}\, x_{CG} - F_{Foil}\, l_{Foil}$$

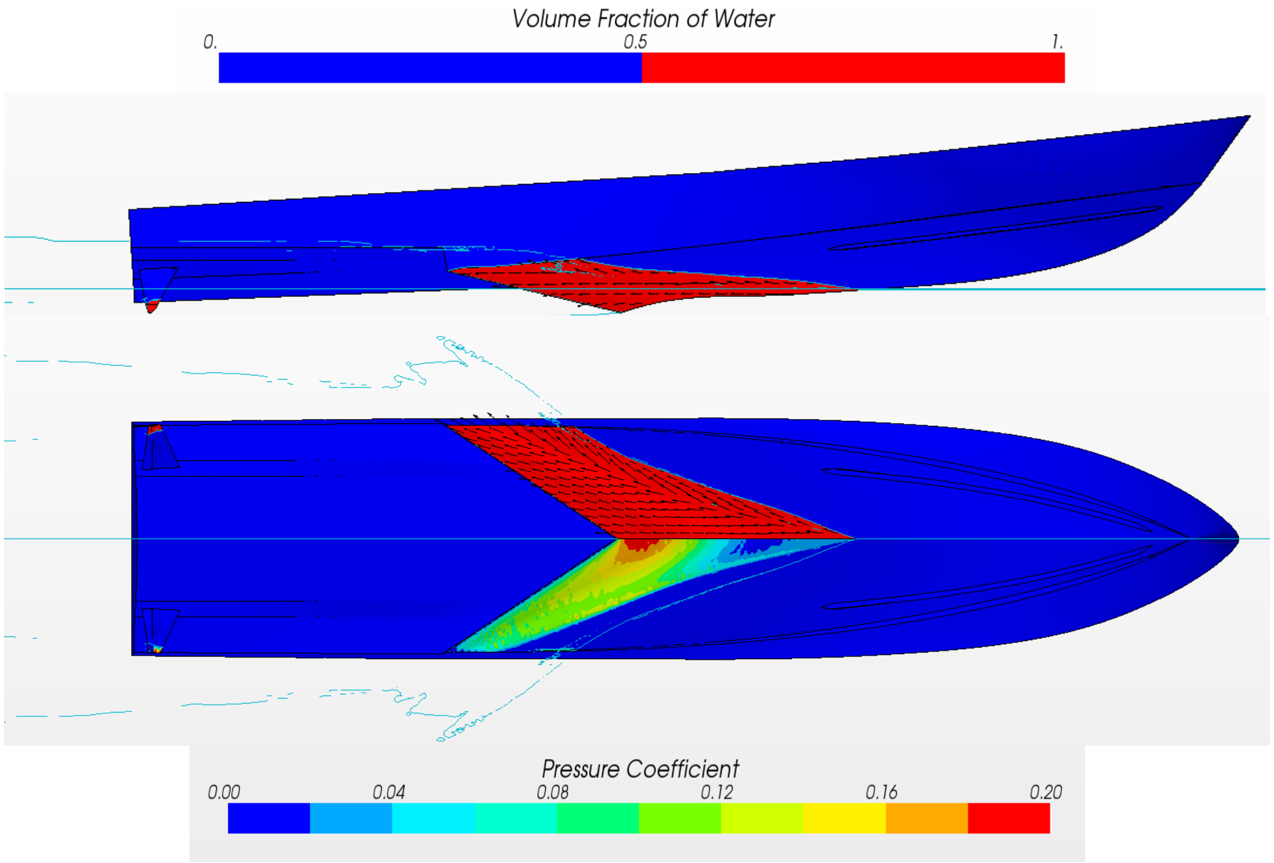
$$\Sigma M > 0$$

Hydrodynamic Analysis

	Hydrostatic →			Hydrodynamic
	Displacement		Semi-Displacement	Planing
	Increasing Froude Number →			
Transverse	Transverse Hydrostatics $GM_T \le 0$	Loss of GM_T Due to Wave Effect 	Roll Instability Non-Zero Heel Non-Oscillatory 	"Chine Walking" Dynamic Roll Oscillation 
Longitudinal	Longitudinal Hydrostatics $GM_L \le 0$	Loss of GM_L Due to Wave Effect 	Trim Instability Bow Drop Non-Oscillatory 	"Porpoising" Dynamic Pitch-Heave Oscillation 
Combined	Combined $GM_T \le 0$ $GM_L \le 0$	Combined Wave Effect  	Broach Non-Oscillatory 	"Corkscrew" Pitch-Yaw-Roll Oscillation 

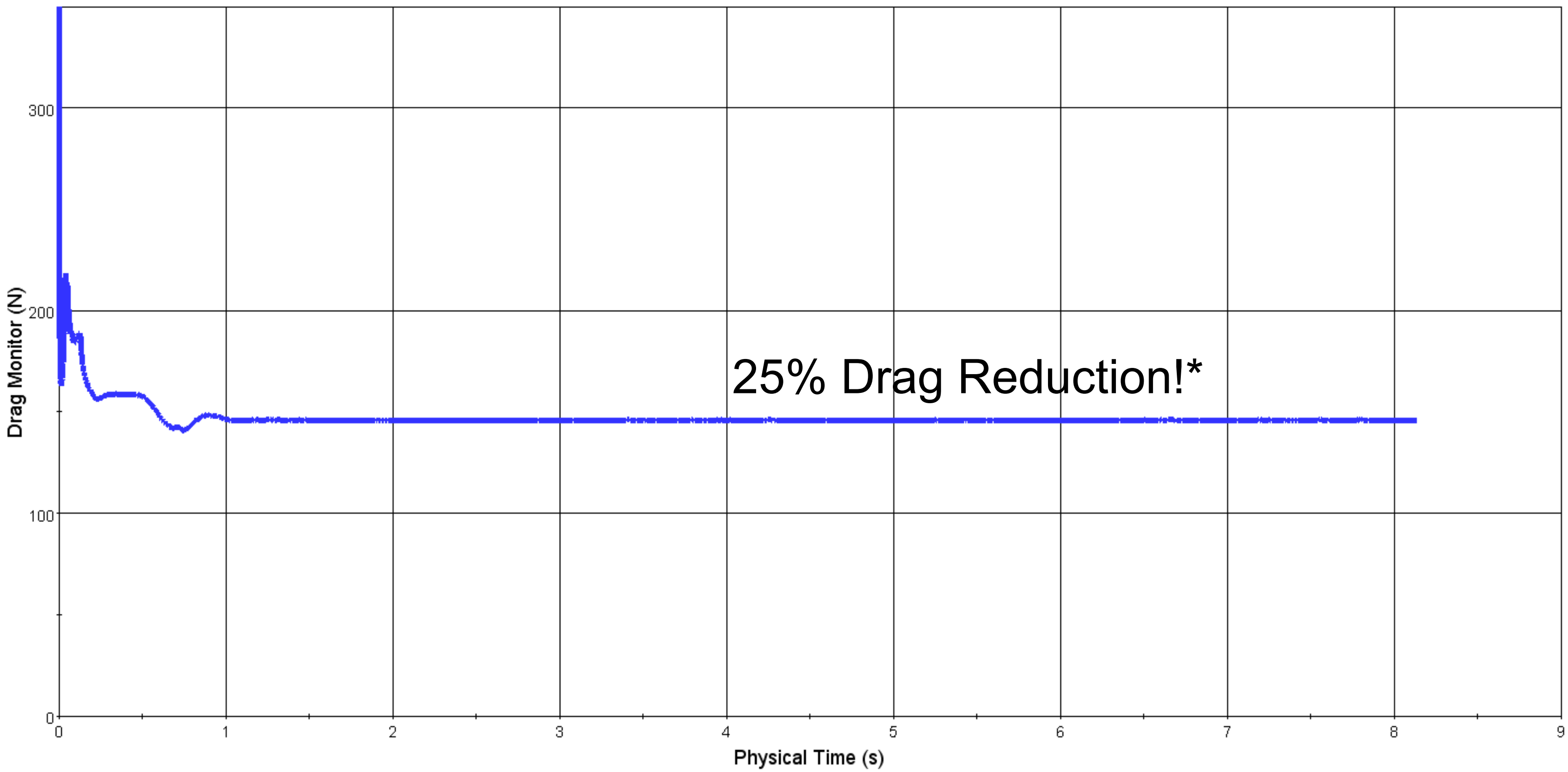
Hydrodynamic Analysis

- 3 Test Runs: 3.5, 4.0, and 4.5 deg; free to heave
- Tests run at FnV=5



Hydrodynamic Analysis

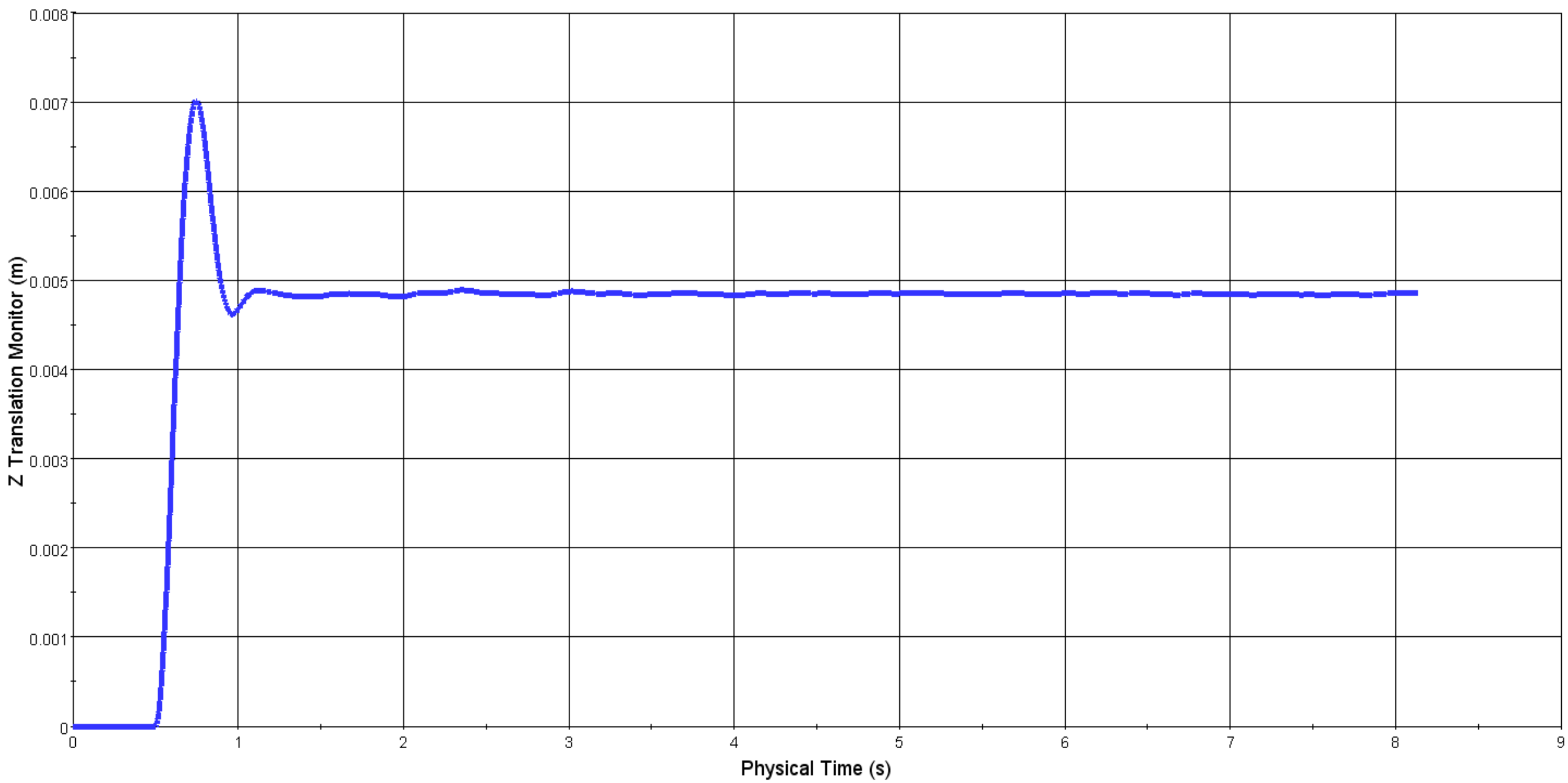
- Drag Results of Run 1: 3.5 deg at FnV=5



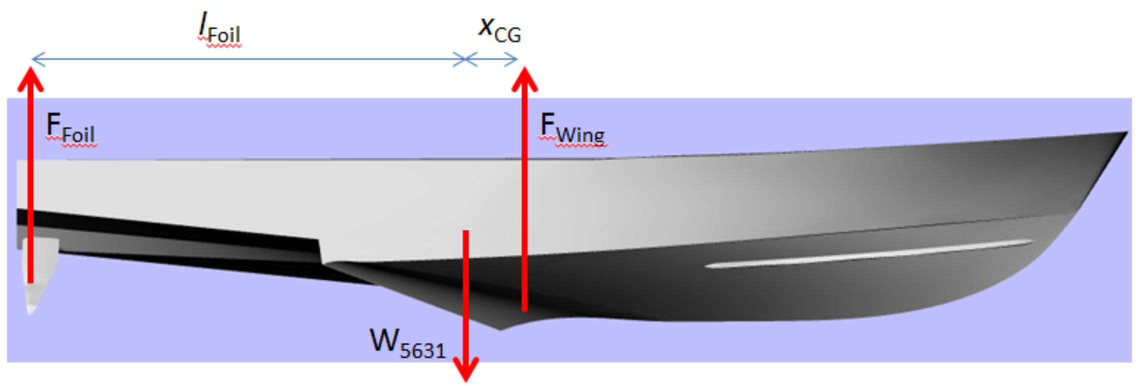
* Compared to CFD Hull 5631 Resistance

Hydrodynamic Analysis

- Heave Results of Run 1: 3.5 deg at FnV=5



Hydrodynamic Analysis

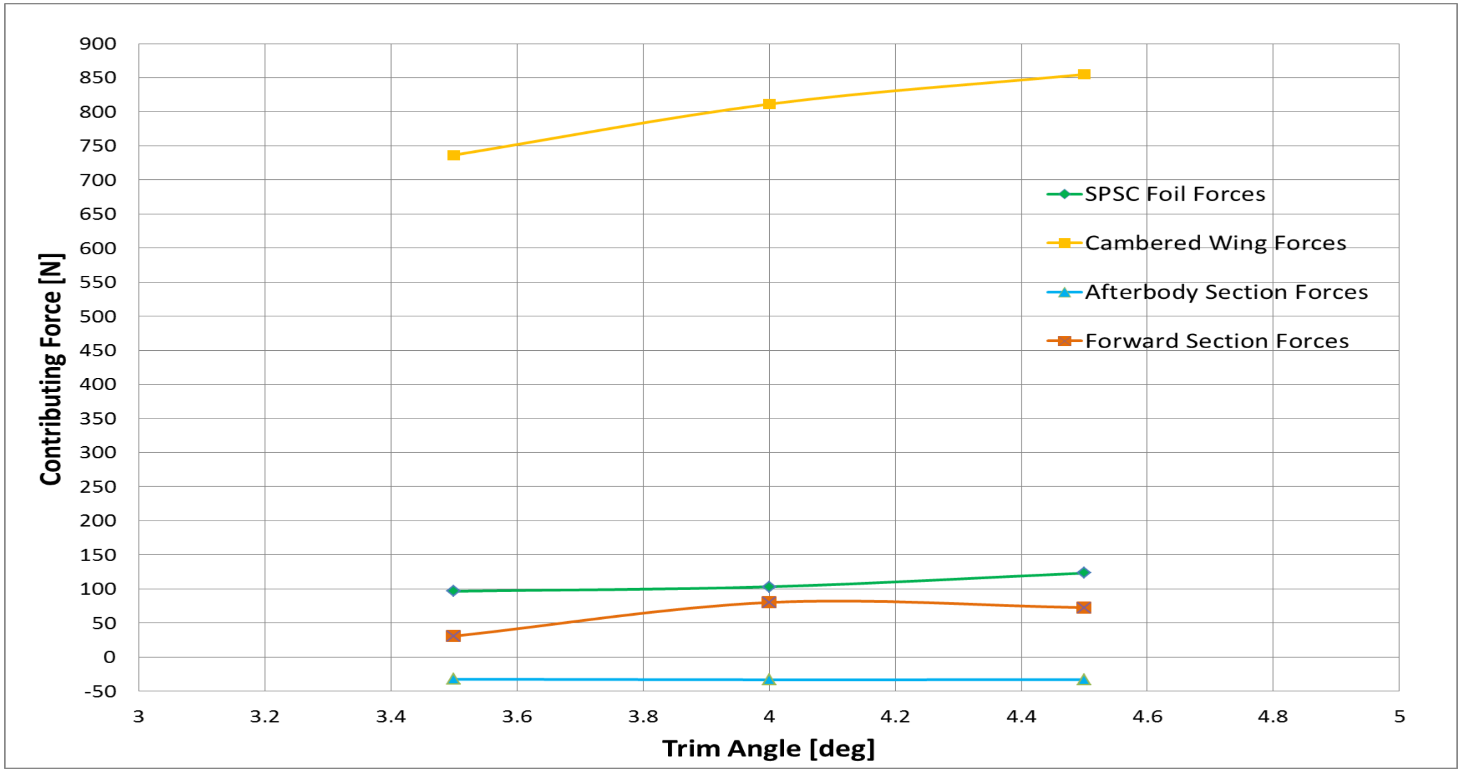


- Additional Moment Contributors
- Quasi-Static Equilibrium Calculation

$$\Sigma M = F_{Wing}\, x_{CG} + F_{Fwd}\, l_{Fwd} + F_{Foil}\, l_{Foil} + F_{Aft}\, l_{Aft}$$

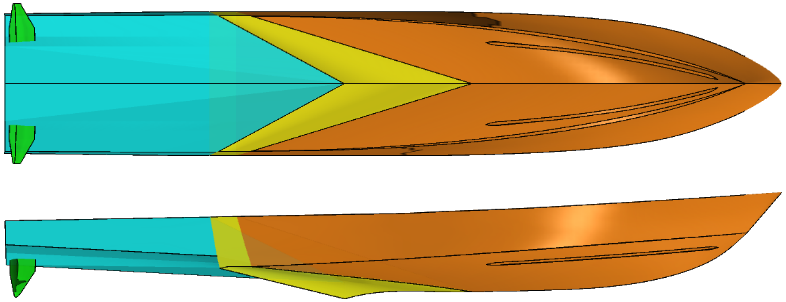
$$\delta M / \delta\tau = \delta F_{Wing} / \delta\tau\, x_{CG} + \delta F_{Fwd} / \delta\tau\, l_{Fwd} + \delta F_{Foil} / \delta\tau\, l_{Foil} + \delta F_{Aft} / \delta\tau\, l_{Aft}$$

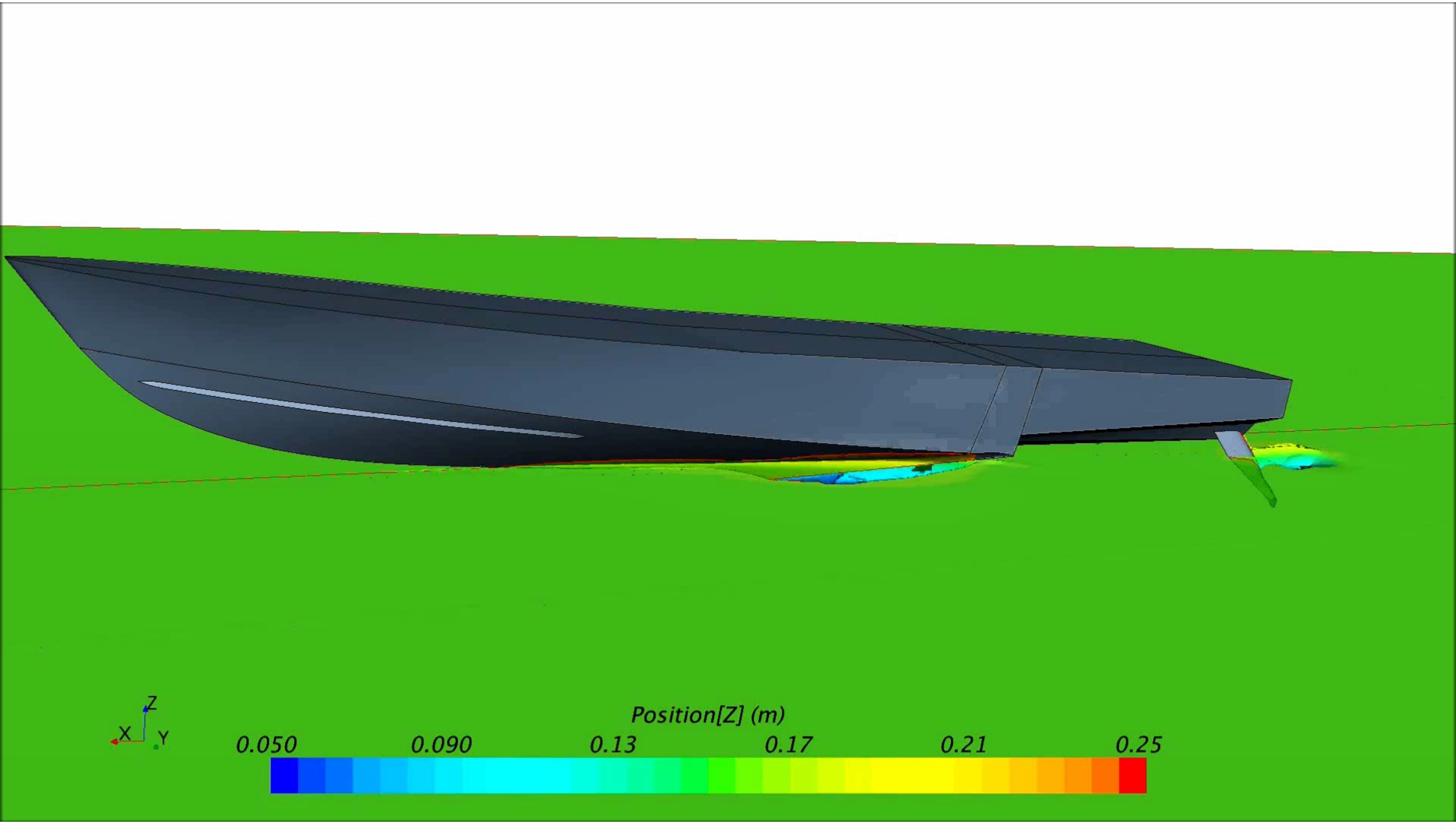
Hydrodynamic Analysis



Trim Instability
Bow Drop
Non-Oscillatory

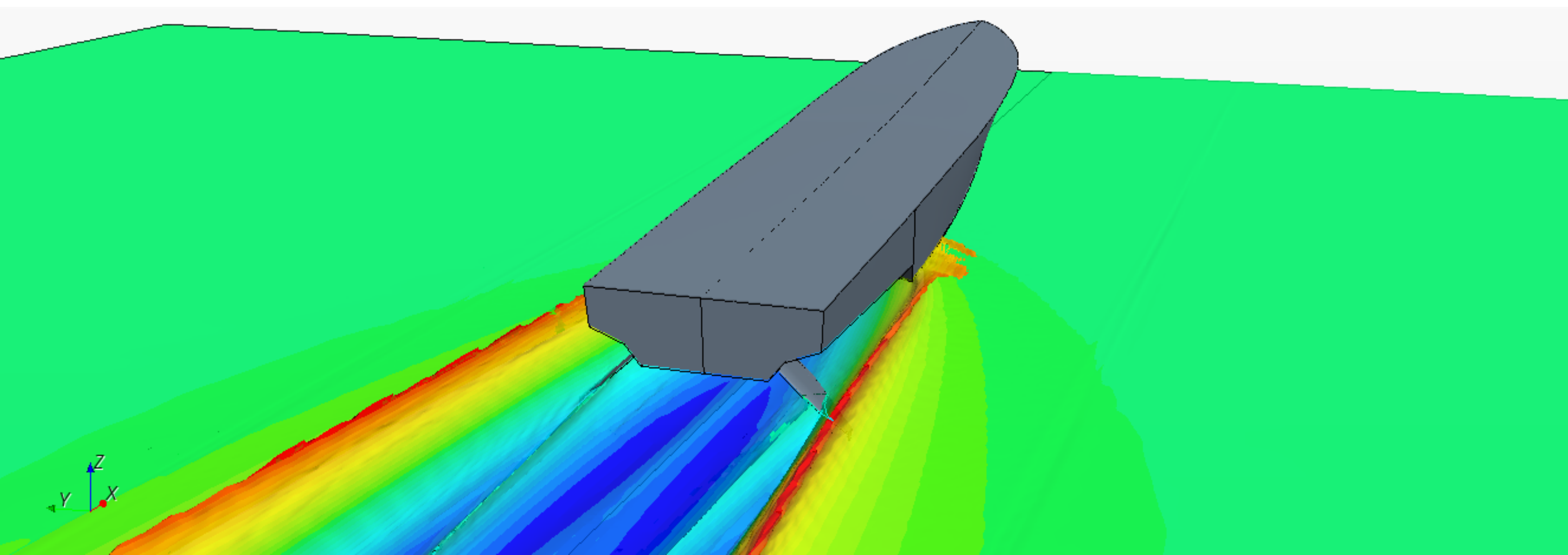
“Porpoising”
Dynamic Pitch-Heave
Oscillation



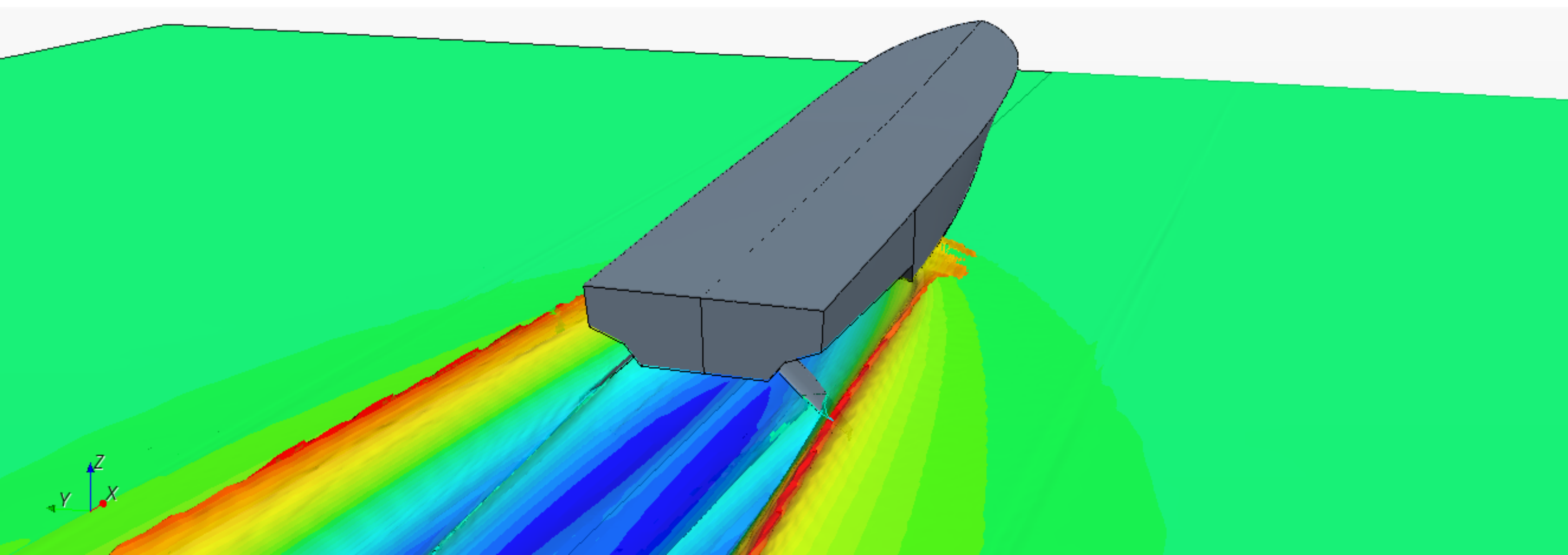

Z
X
Y
Position[Z] (m)
0.050
0.090
0.13
0.17
0.21
0.25

Final Thoughts

	Reference Hull	Dynaplane	% Diff.
Total Drag [N]	388	292	**-25%**
Wetted Area, [m^2]	1.621	0.396	**-75%**
Lift to Drag Ratio	4.28	5.72	**+34%**



Questions?



Future Work

- Run models in a simulated sea state
  - Monochromatic wave
  - JONSWAP
  - Pierson-Moskowitz
- Further improve powering requirements with innovative design features
  - Stepped Hull
  - Hydrofoils
  - Ventilated Hull
  - Double-Chine, Spray Rails