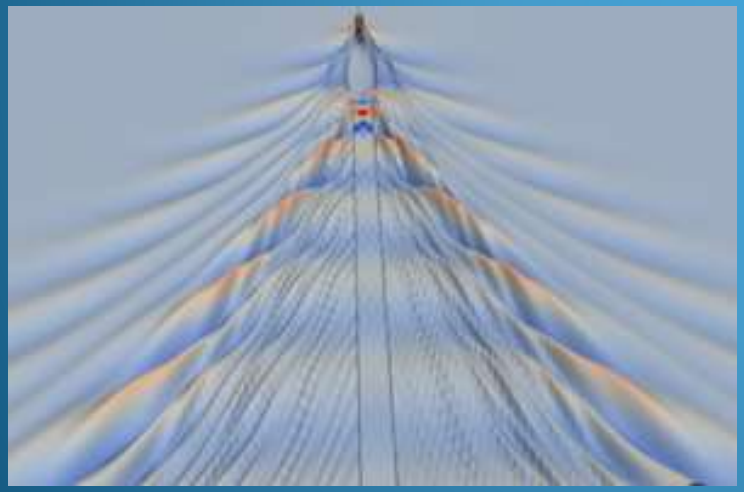
Hydrodynamic Analysis and Design Methods for Energy Efficient Ships

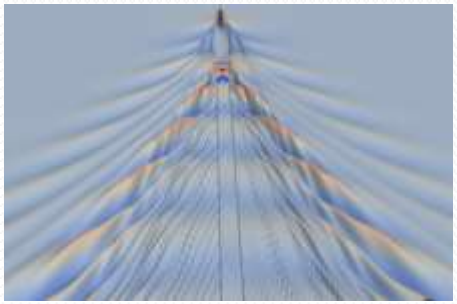
David Kring April 8, 2014



Green Boats: Ship Design Tools

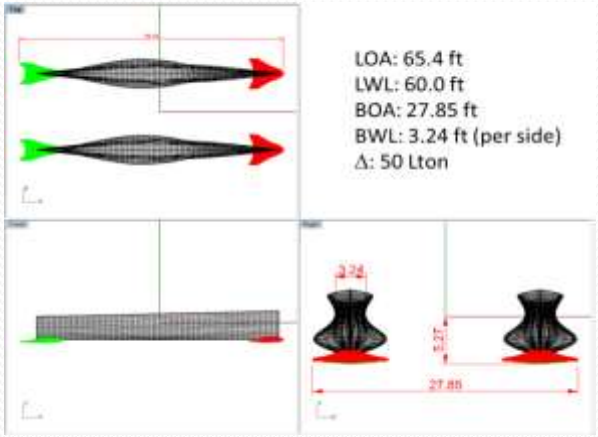
Green Ports: Alternative Energy

Overview



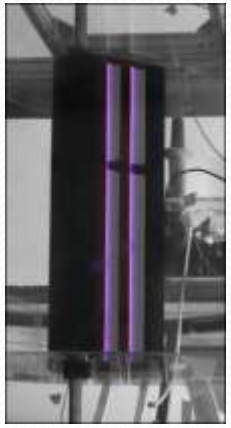
Green Boats:

- Analysis and Design Methods
- Hydrodynamic Research
- Case Study: Wind Farm Vessel



Green Ports:

- Plasma actuation for Wind Turbines



Developer and User Community

Codes must be supported across a wide base to survive and thrive
... some shared source development, no-cost executable licenses

Academic Partners:

Univ. of Rhode Island (Prof. Stephan Grilli, Prof. Jason Dahl ... Ocean Eng)
Univ. of Michigan (Prof. Julie Young, Prof. Kevin Maki, Prof. David Singer)
MIT (Prof. Stefano Brizollara)
George Mason Univ. (Prof. Chi Yang)
Stevens Institute (Prof. Raju Datla, Prof. Len Imas)
Webb Institute (Prof. Rick Royce, Prof. Adrian Onias)
with additional involvement from others, eg. US Naval Academy

Government:

ONR, NAVSEA, NSWC-CD
US Marine Corps
Sandia National Labs, NREL

Industry: various companies

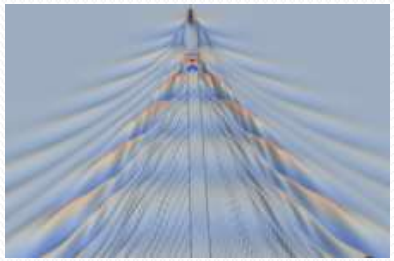
Foreign: French Naval Academy and DCNS, Denmark, Italy (INSEAN), Singapore, UK

NAVATEK

Navatek Analysis and Design Tools

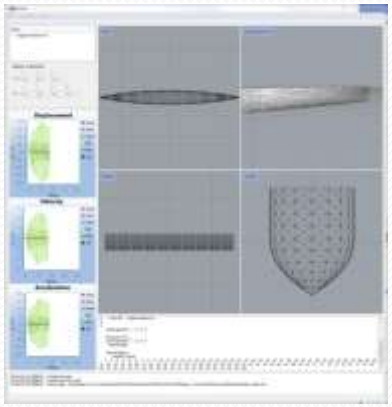
"Open" Source shared development via a Git Server

Aegir & RANS



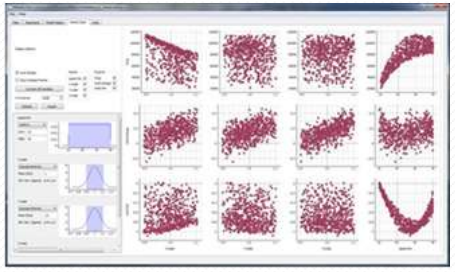
Hydrodynamic Analysis

NavaSim



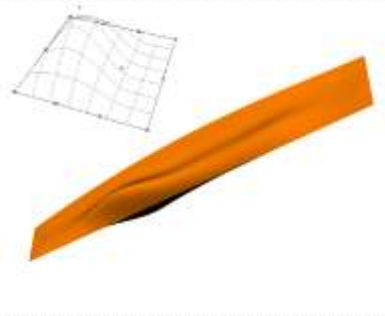
Hydromechanical Simulation

MetaVis / Design Tools



Data Visualization, Design

NavADE



Hull Optimization

Design Methods: Escaping the Design Spiral

Set-based Design

flexibility in the design process

Network Theory

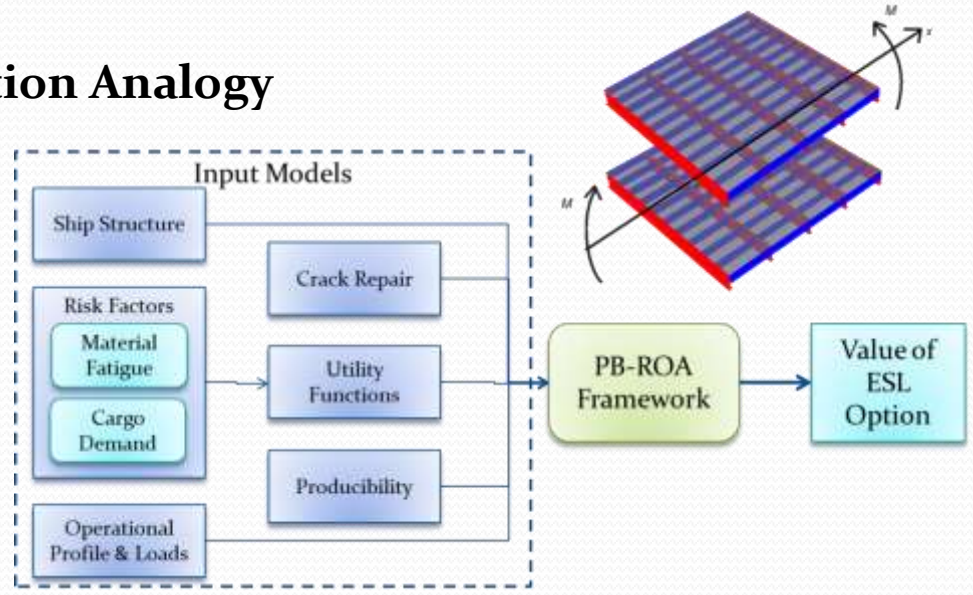
identifying important couplings

Markov Decision Process

ramifications of design decisions

Prospect-Theory Based Real Option Analogy

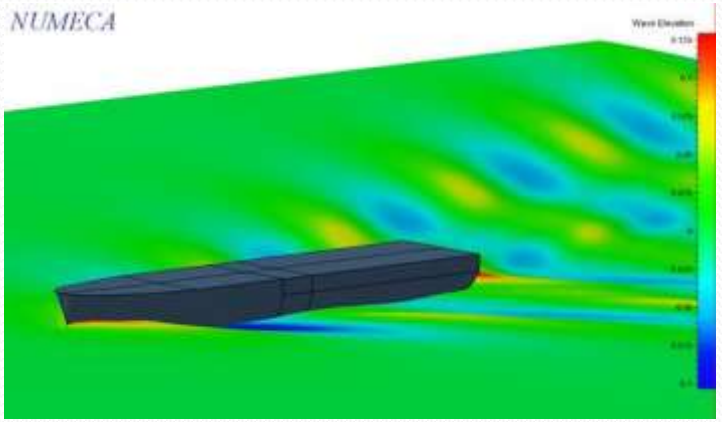
hedging the design



Courtesy of Dr. Josh Knight, Prof. Dave Singer U.Mich

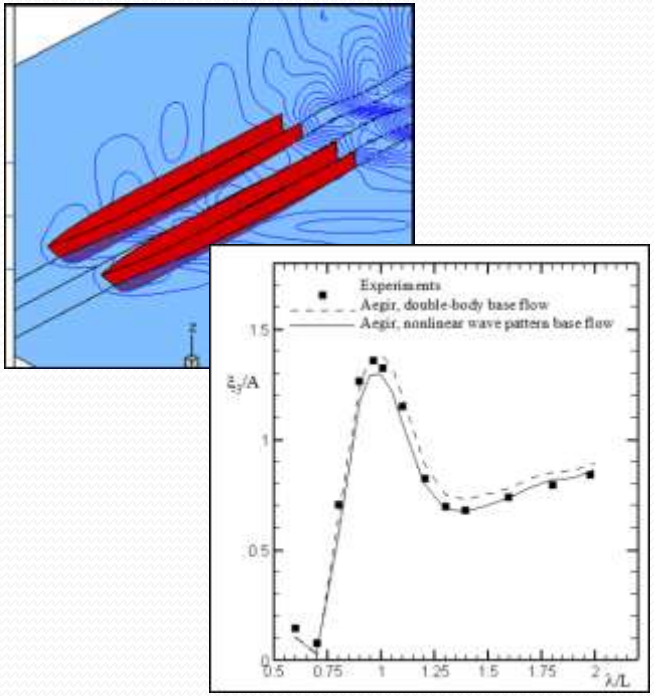
Multi-Fidelity Hydrodynamic Analysis

Free-surface hydrodynamics (Waves) … complex computational challenge due to dispersion and nonlinearity



High-Fidelity (OpenFOAM, FINE/Marine)

- Few physical assumptions
- Very expensive computationally … orders of magnitude slower than medium fidelity



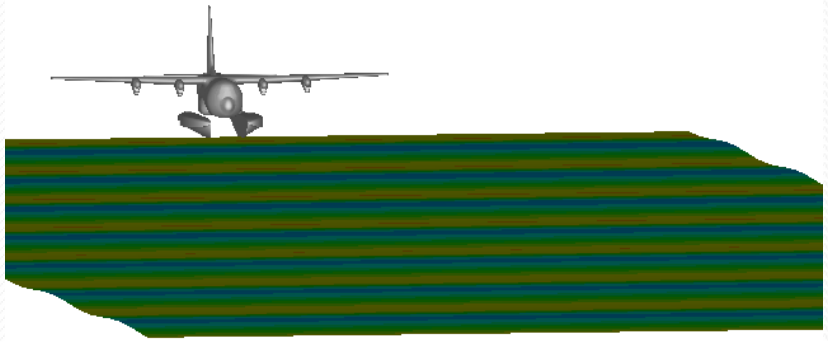
Medium-Fidelity (Aegir)

- Sufficient assumptions to capture design trends
- Seakeeping simulation faster than real time

Low-Fidelity (Slender body theory, semi-empirical forms, …)

Aegir Capabilities

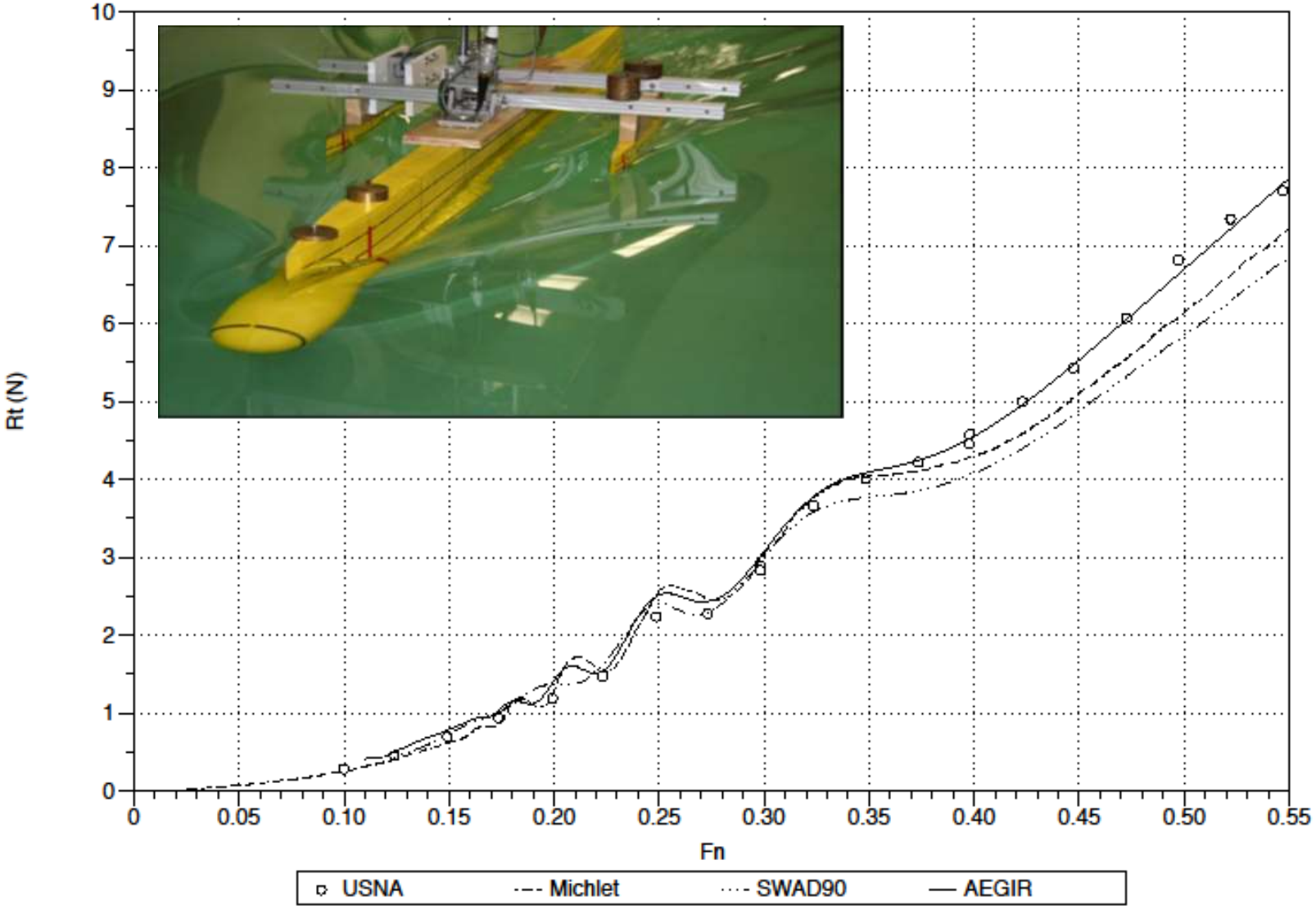
- Steady wave resistance
- Seakeeping and added resistance in waves
- Lift modeling for hydrofoils or propulsors
- Fluid-structure interaction … weight can hurt energy efficiency
- Flexible application
  - Commercial or Naval Ships
  - Offshore Platforms
  - Control algorithms
  - Flight dynamics
  - Air Cushion Vehicles
  - Multi-body connections



C130 Float Plane Study

Articulated Stable Offshore Platform

Multi-hull Wave Resistance Validation

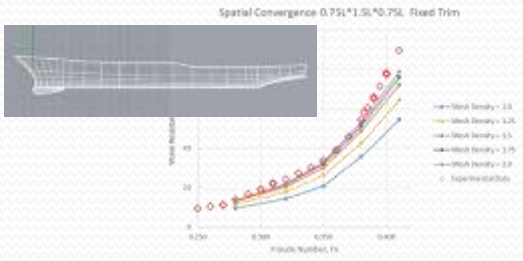


NAVATEK

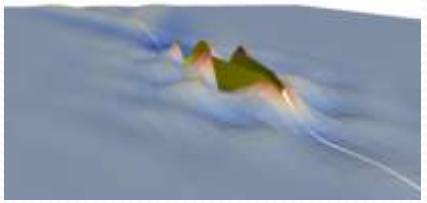
Hydrodynamics Research

Transom Stern Modeling

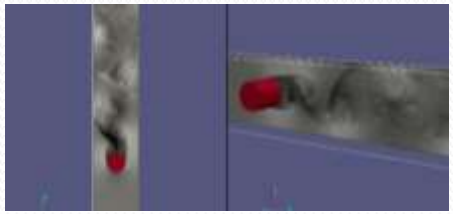
Verification and Validation



Nonlinear Free Surface



Efficient Hybrid Methods



3D High-Speed Simulations

Impulse Response Functions

Input $(v(t))$

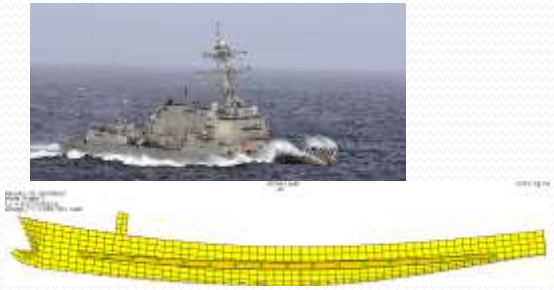
Forcing Function
Forces and Moments

Linear System (Fluid + Ship)

Output $(f(t))$

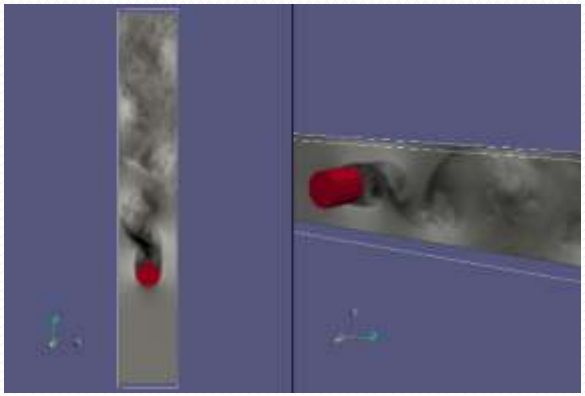
Motion
Force

Wave Loads & Structures

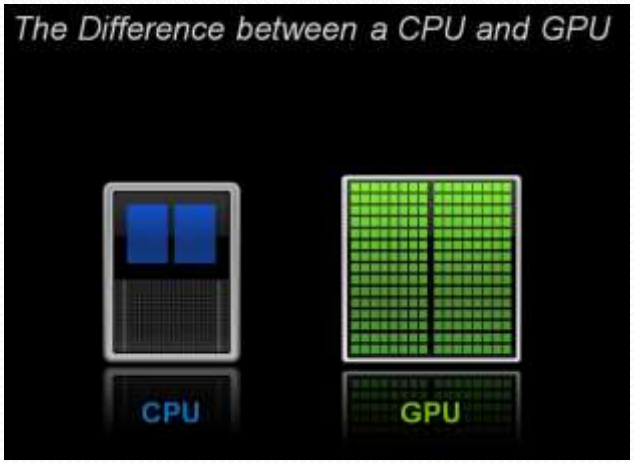


STEM Ship Design Competition

Hybrid Viscous Methods

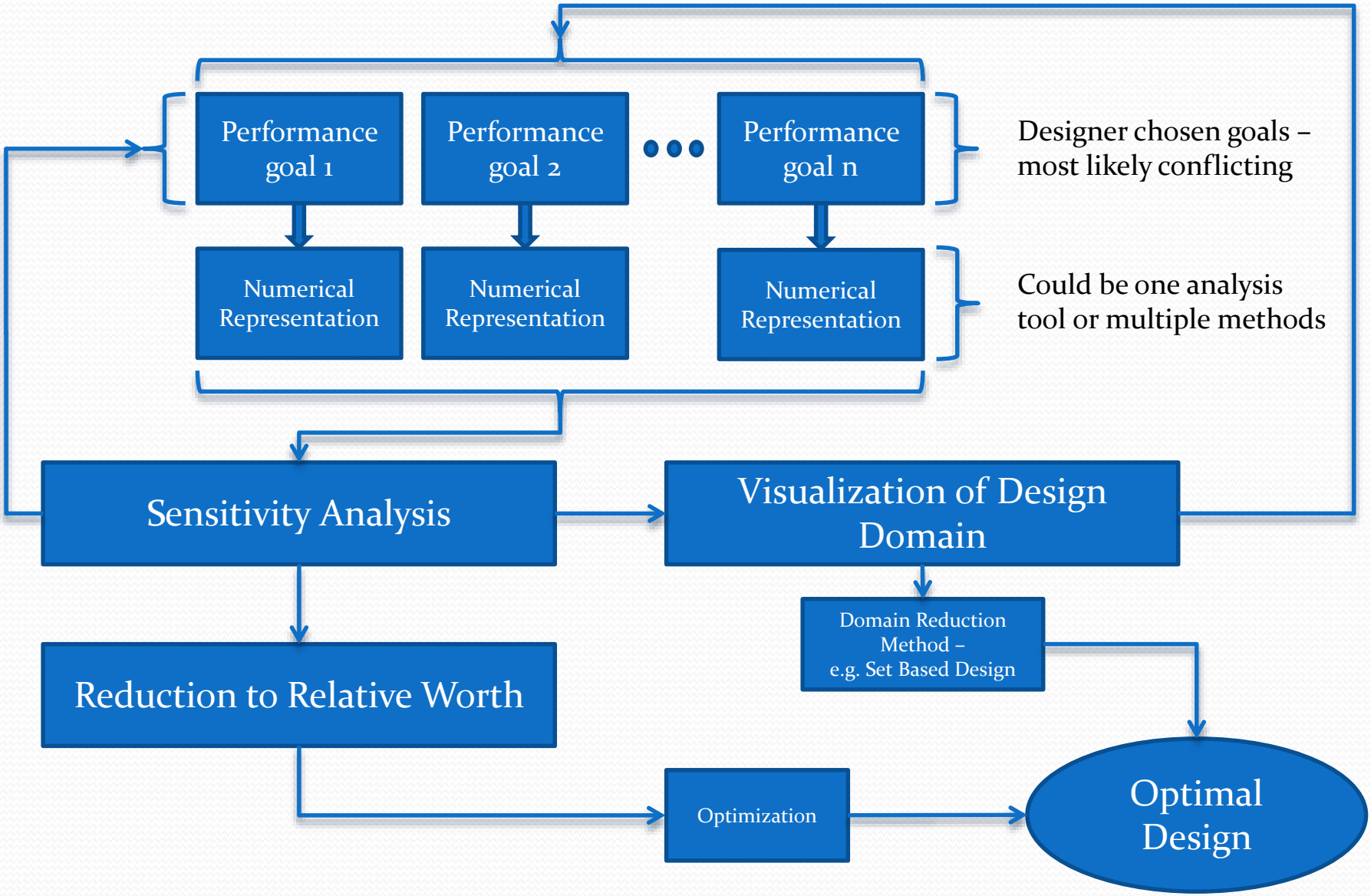


- Flow decomposition through a perturbation approach, combining potential flow solution (Aegir) with viscous terms
- Lattice Boltzmann Method (URI)
  - Particle distribution functions with a position and momentum propagate over a defined lattice
  - Highly suited to efficient implementation on GPGPU's



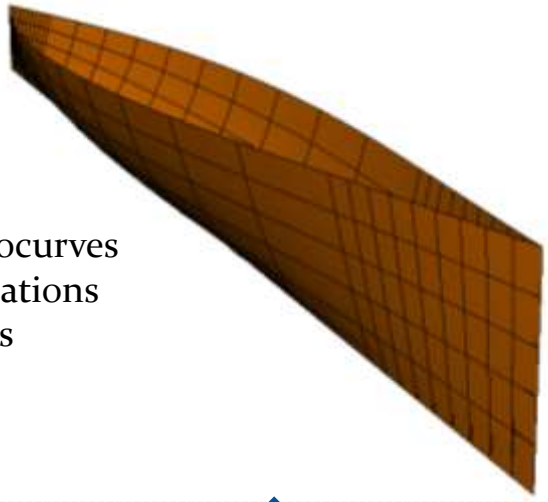
Collaboration with URI (Jason Dahl, Stephan Grilli)

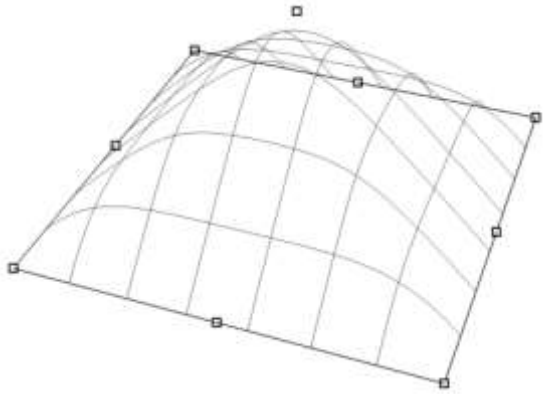
Wind Farm Service Vessel



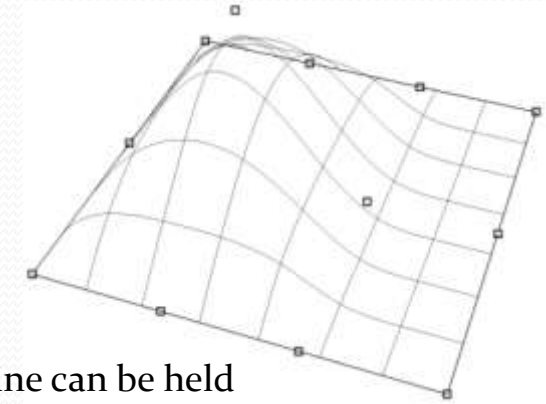
Shape Manipulation – Hull

Radial basis functions applied to a spline allow for large variations in geometry





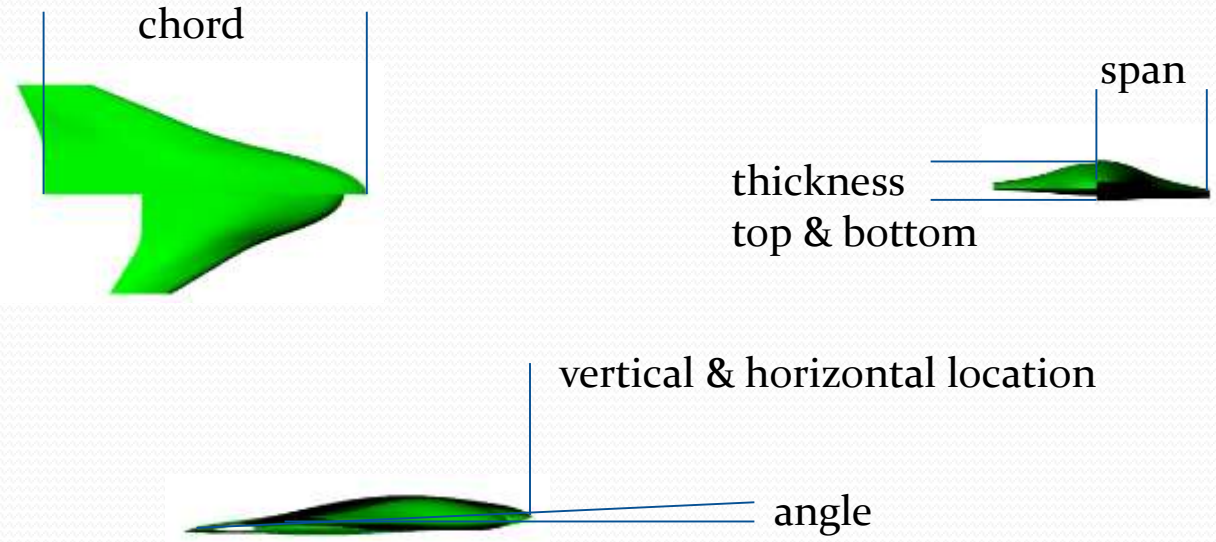
Corners of isocurves represent locations of radial basis functions



Regions of spline can be held constant by holding some basis functions fixed

Result is a continuous spline with guaranteed 2nd order fairness with large amount of control

Shape Manipulation – Lifting Bodies



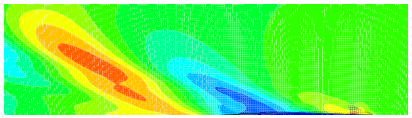
- Radial basis functions not well suited for lifting surfaces in non-viscous solution – amount of freedom too great

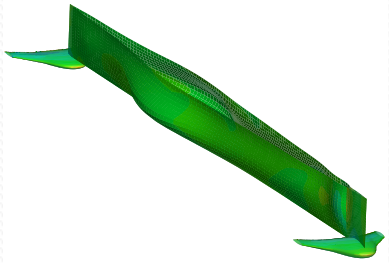
- Direct manipulation of gross dimensions used – span, chord, camber, thickness, angle, & position

Evaluation of Candidate Designs

Aegir Steady Solution

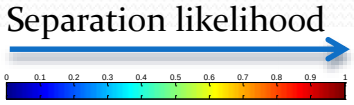
- Wave Making Resistance
- Total Lift
- Dynamic Lift
- Total Moment

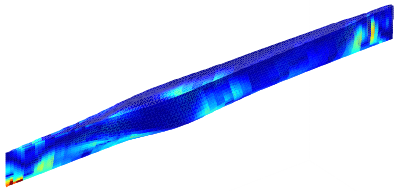




- Wetted Area
- Sinkage
- Trim

Separation likelihood



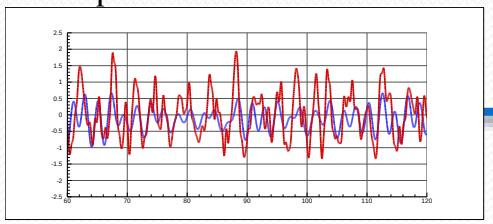


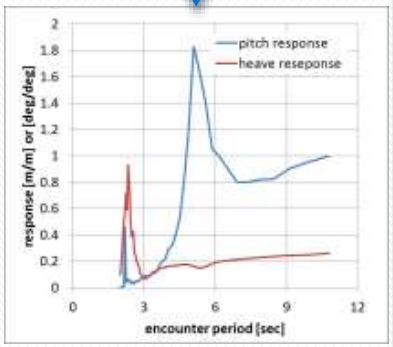
Stratford Criterion

$$C_P\sqrt{x\frac{dC_p}{dx}} = \left(\frac{Re}{10^6}\right)^{0.1} S$$

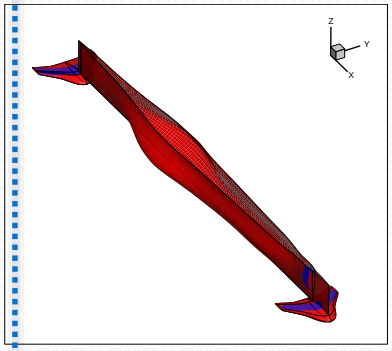
$$S = \begin{cases} 0.35 & \frac{d^2y}{dx^2} > 0 \\ 0.39 & \frac{d^2y}{dx^2} < 0 \end{cases}$$

Flat Spectrum Solution





Motions in flat spectrum can be used to estimate response in various conditions



Cavitation? – pressure < P_{cav}

Frictional resistance – ITTC '78

Aegir Unsteady Solution

Other Checks

Determination of Relative Worth

Objective Function

Heave motions at CG

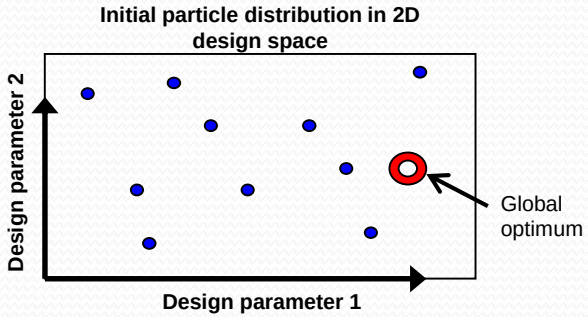
Pitch motions at CG

$$C = \left(\frac{L}{D} - \sum_{U=0,17} \xi_3 + \xi_5\right) * CAV * SEP$$

$$CAV = \begin{cases} 1 & Hull\ is\ not\ cavitating \\ 0 & Hull\ is\ cavitating \end{cases}$$

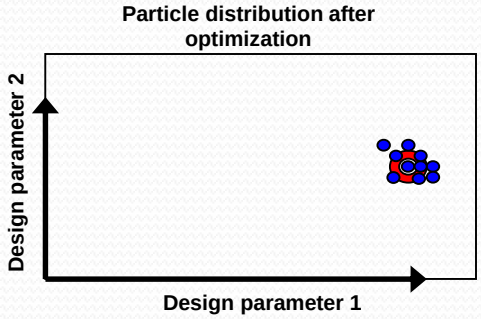
$$SEP = \begin{cases} 1 & Hull\ is\ not\ separating \\ 0 & Hull\ is\ separating \end{cases}$$

Particle Swarm Optimization



$$v_i[t+1] = wv_i[t] + C_l(l_i - x_i[t]) + C_g(g[t] - x_i[t])$$

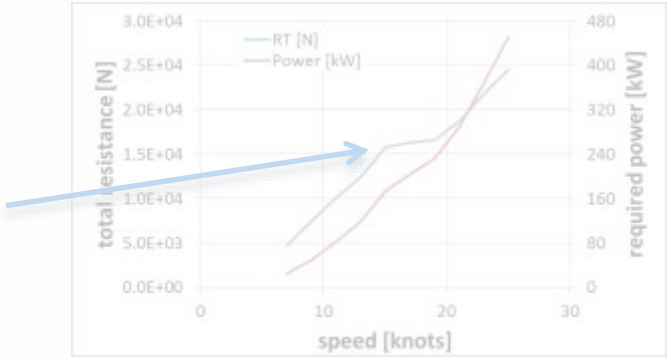
$$x_i[t+1] = x_i[t] + v_i[t+1]$$



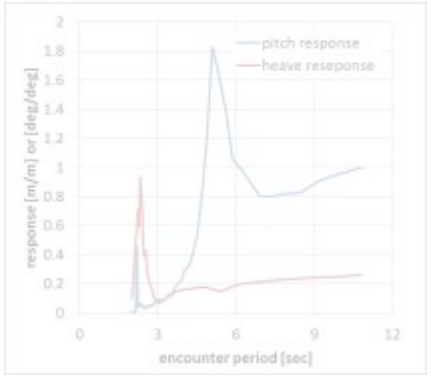
Optimal Design

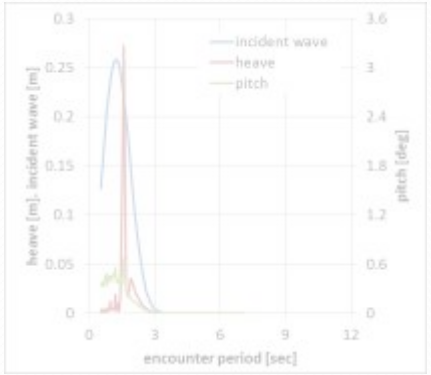
Motions were optimized to avoid incident wave spectrum peak – could perform poorly outside of this spectrum

Total resistance shows that the single-speed steady resistance check was somewhat exploited

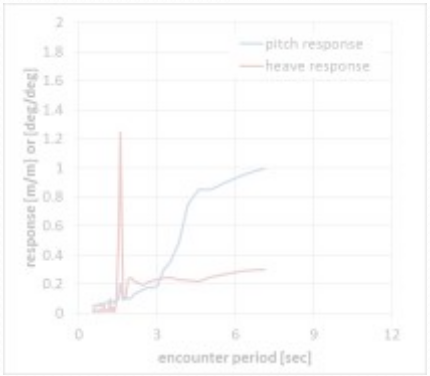


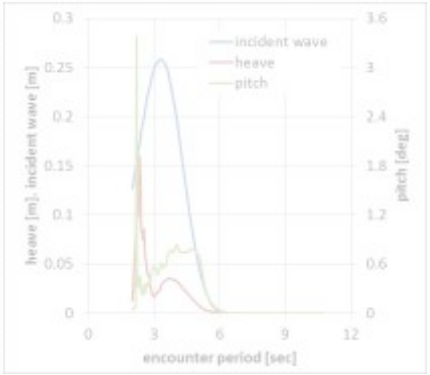
0 Speed

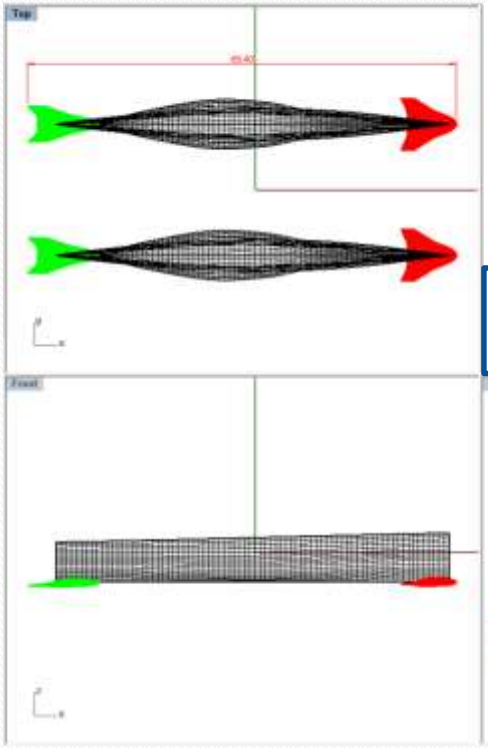




17 knots





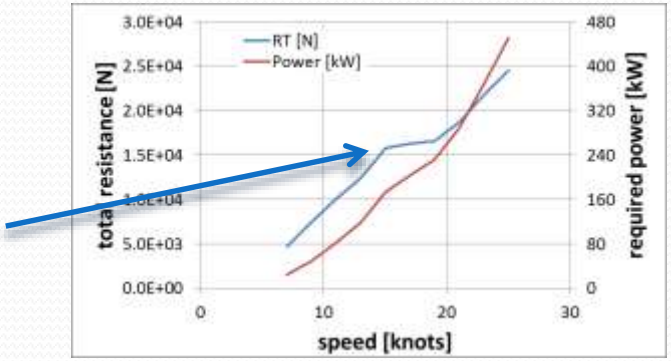


LOA: 19.9 m
LWL: 18.3 m
BOA: 8.5 m
BWL: 1.0 m (per side)
Δ: 45 MT
AWP: 21.0 m²
$2\nabla^{2/3}$=23.8

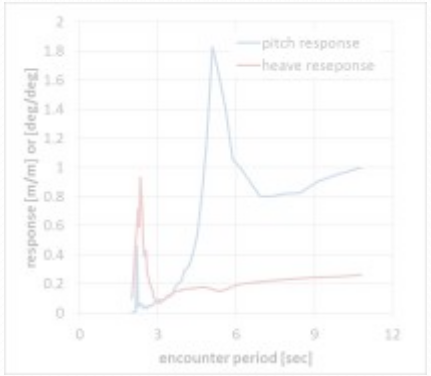
Optimal Design

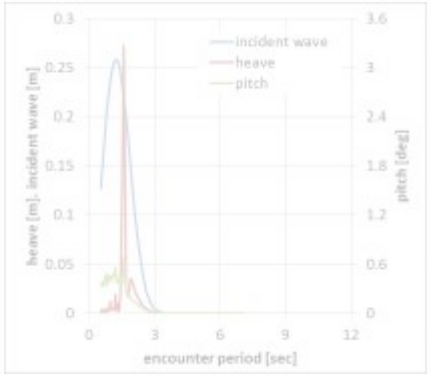
Motions were optimized to avoid incident wave spectrum peak – could perform poorly outside of this spectrum

Total resistance plot indicates that checking resistance at only 17 knots was exploited by optimization routine



0 Speed





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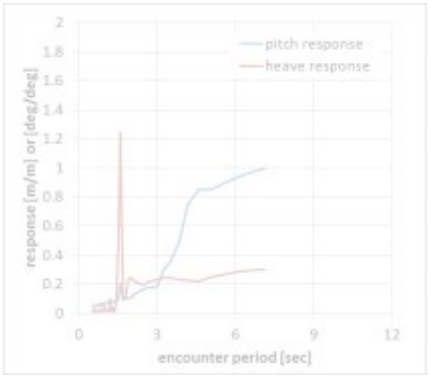

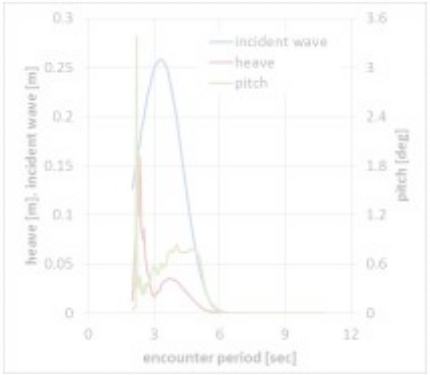

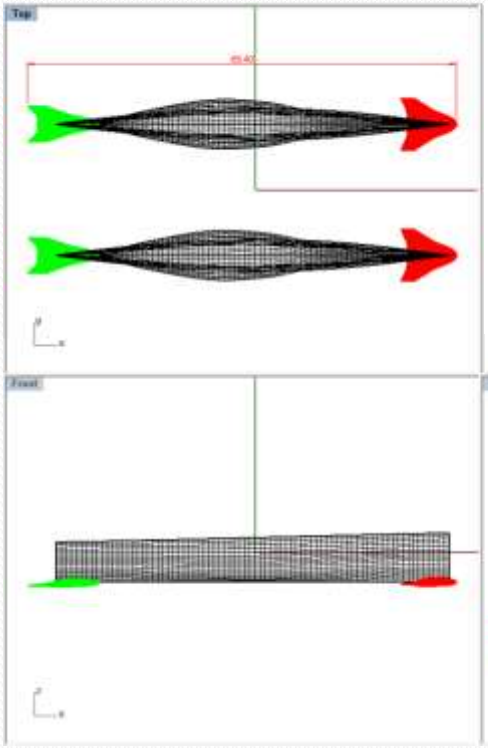

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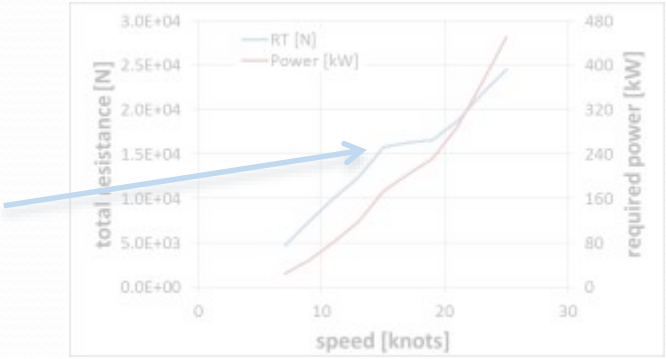
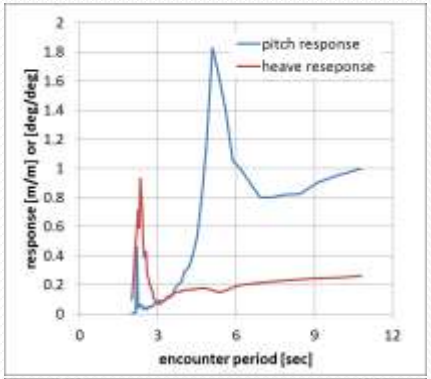
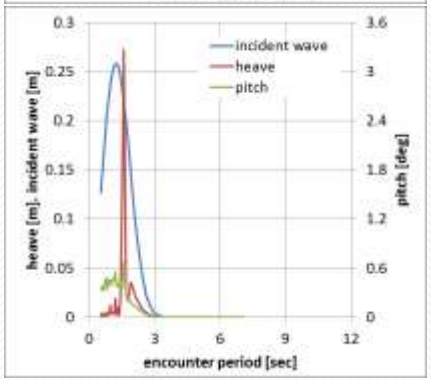
Motions were optimized to avoid incident wave spectrum peak – could perform poorly outside of this spectrum

Total resistance plot indicates that checking resistance at only 17 knots was exploited by optimization routine

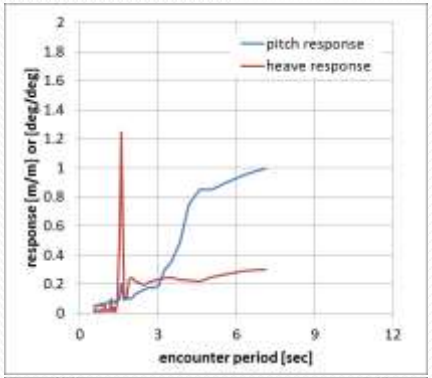


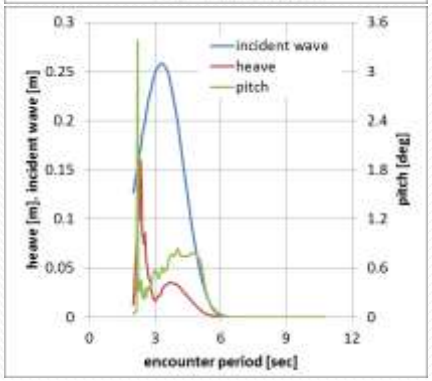
0 Speed

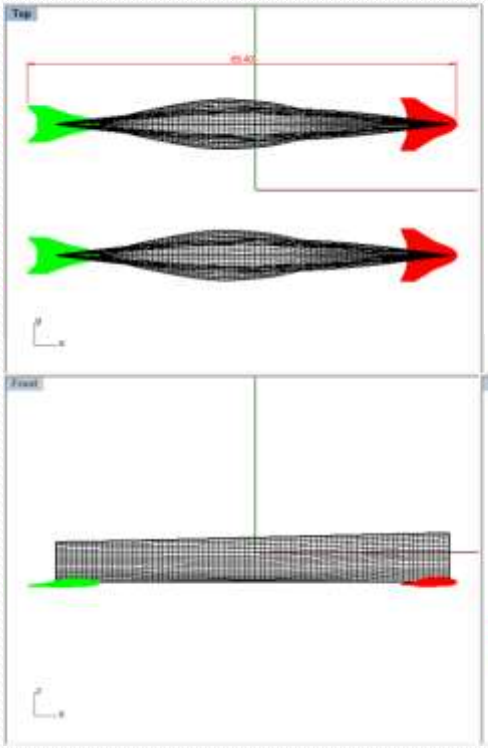




17 knots







LOA: 19.9 m
LWL: 18.3 m
BOA: 8.5 m
BWL: 1.0 m (per side)
Δ: 45 MT
AWP: 21.0 m^2
$27^{2/3}$=23.8