

THE IMPORTANCE OF HYDRODYNAMIC OPTIMIZATION IN THE DEVELOPMENT OF SMALL ELECTRIC MARINE VESSELS



CAESES NORTH AMERICAN USER CONFERENCE

March 31, 2026



DESIGN



BUILD + INTEGRATION



FRIENDSHIP SYSTEMS

TECHNICAL PARTNER



PROPULSION + BATTERIES



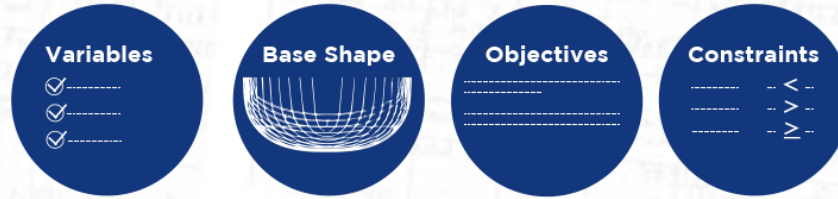
Over last ~ 20 years FYD has made CAESSES an integral part of our design processes.

- Our IDEOS optimization platform uses CAESSES at its core.
- We've used it in the design of everything from Grand Prix Race Boats, to Powerboats and from Stand-Up Paddle Boards to Production Cruisers.
- Most recently was used extensively in the design of American Magic's Patriot Hull and Rudders for America's Cup 37.
- **We strongly believe that these optimization technologies can and should be applied to all our design projects, not just the big budget programs.**



IDEOS / HOW IT WORKS

1. Setup



2. Run



FFD Morph — a hull geometry morphing tool.

Selection of design variables

Hydrodynamic optimization (CFD), weight calculation, rating prediction, VPP, cost calculation produced — this uses several programs, exchanging information between them. It includes proprietary programs developed by us and custom versions of commercially available products.



A probabilistic race modeling program which uses info from the VPPs and weather data to predict the likelihood of a candidate design winning. It is also used to compare the candidate design against the objectives.

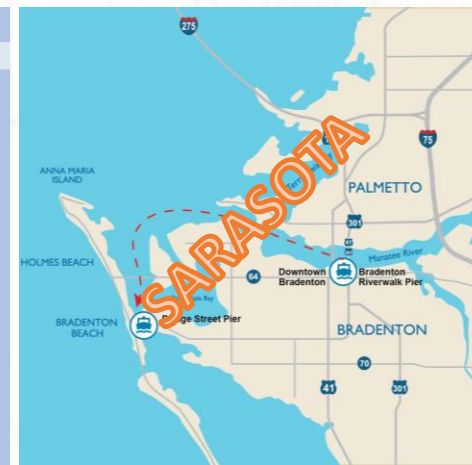
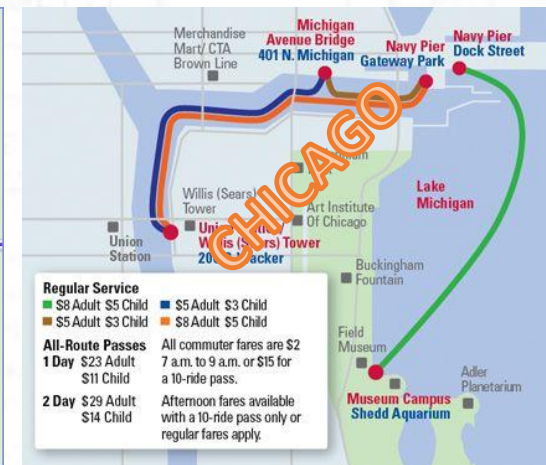
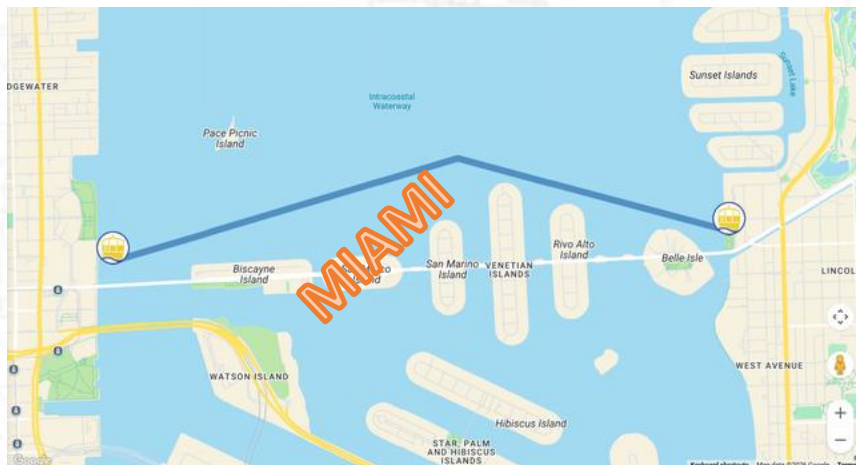
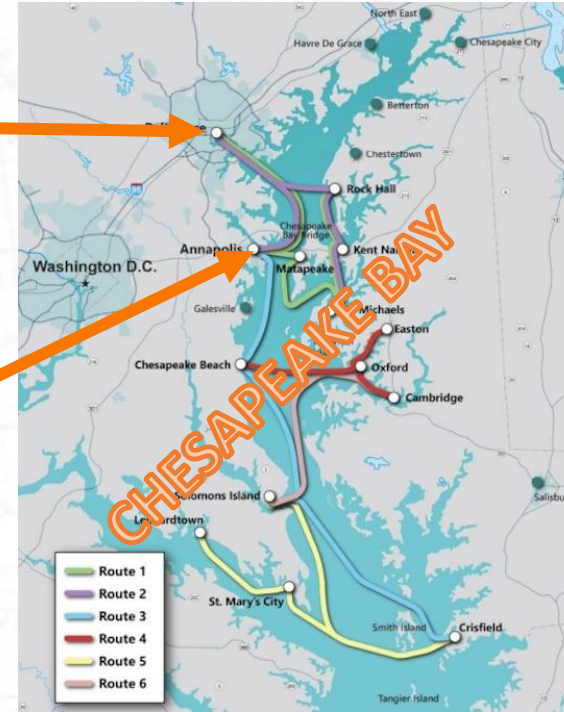
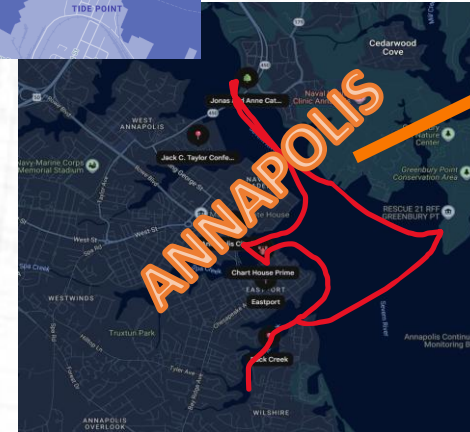
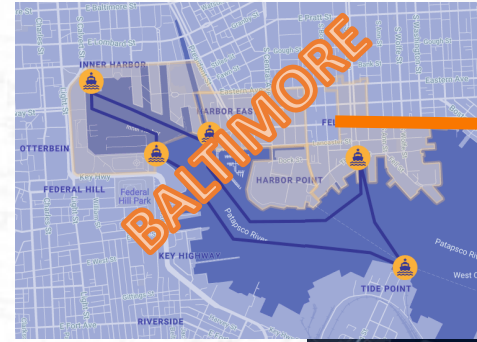
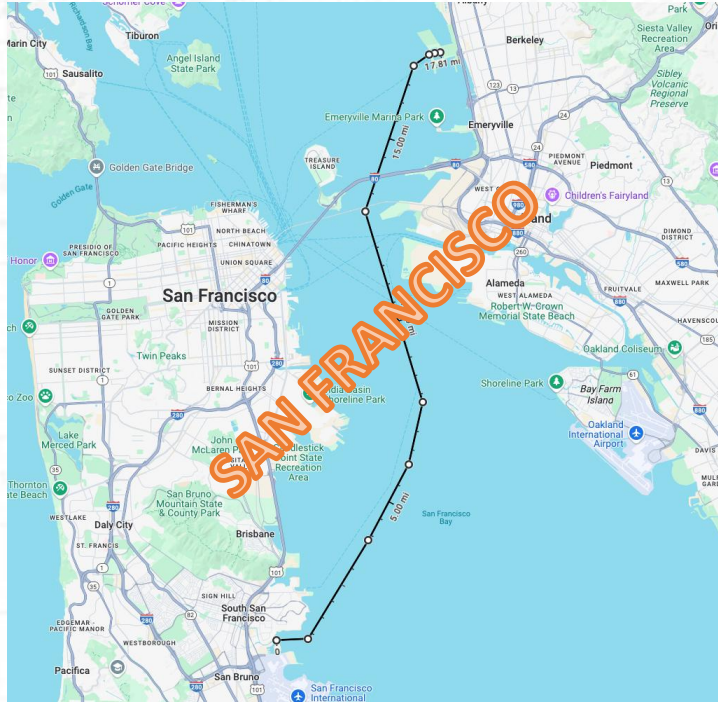


3. Analysis

Figure of merit — Does the candidate design fall within the defined variables? If not, this process goes back until it does.



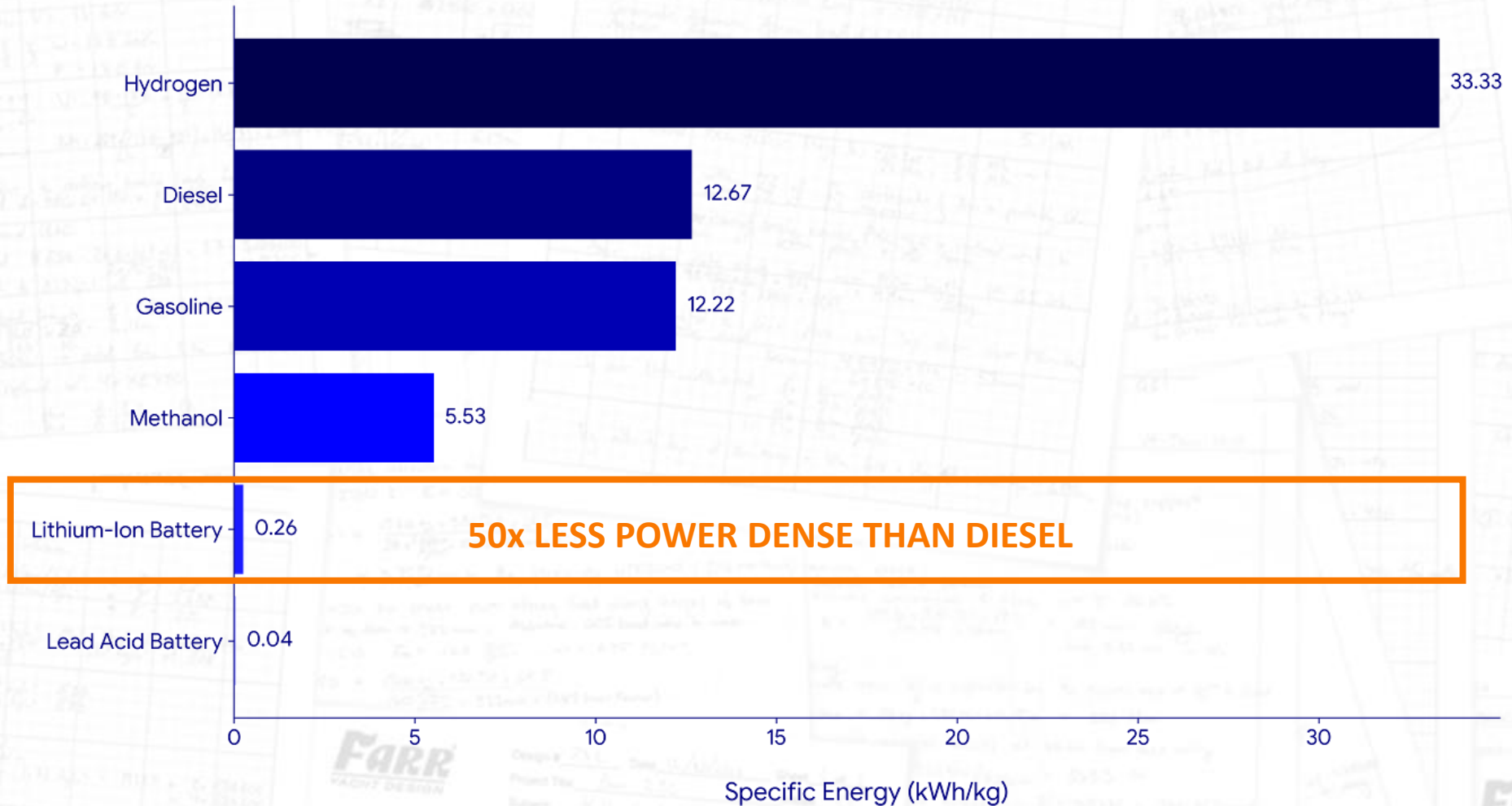
GROWING DEMAND – ELECTRIC WATER TAXI SOLUTIONS



- 20 – 25 passengers
- 30 nm range @ 20 knots
- Photon 150hp Electric Outboards with up to 4 x 63 kWh Batteries
- US Built – Jones Act Compliance
- Year-round operation
- Composite Construction
- USCG CFR 43 Sub Chapter T Compliant
 - Stability
 - Materials
 - Battery Certification/Fire Suppression
- Minimal Lifecycle Maintenance
- High Reliability
- Simple Operation
- Cost Effective to Purchase
- Aggressive Design and Build Timeline



Comparison of Specific Energy (Power Density)



References: US DOE Alternative Fuels Data Center (AFDC), EIA (2024), Battery University (BU-201), Wikipedia.

MAXIMIZING RANGE & PERFORMANCE WITH LITHIUM-ION BATTERIES: THE CRUCIAL ROLE OF DESIGN OPTIMIZATION

PROPULSION OPTIMIZATION

Use **High-Efficiency Motors** (e.g., Permanent Magnet)

Optimize Propeller for electric drive characteristics (low power, specific speeds)

Efficient Gearing or Direct Drive

Li-Ion

HIGH ENERGY (Range) **LOW POWER DENSITY (Peak Performance)**

The Li-Ion Challenge:
Limited Maximum Output and Significant Weight. Design must compensate to achieve high range and performance.

CONSTRUCTION MATERIALS

Lightweight, High-Strength Materials (Composites, Aluminum)

Reduce Structural Weight to free up energy

HULL FORM GEOMETRY

Design for **Minimal Resistance** (Wave, Friction)

Choose appropriate **Hull Type** (e.g., displacement for range, planning with caveats)

Optimize **Stability & Lift**

CONSTRUCTION PROCESSES

Employ **Advanced & Precise Manufacturing**

Minimize Material Waste & Excess Structure

Optimize **Weight** with precise assembly

HULL HYDRODYNAMIC EFFICIENCY

Advanced Coatings (Antifouling, Drag Reduction)

Control Flow for reduced skin friction

Smooth Hull Details

BATTERY SELECTION

Balance Mission Requirements (Range vs. Power)

TRADE-OFF LITHIATION

ENERGY-DENSE vs. POWER-DENSE LITHIUM-ION

Select Batteries with high usable Energy (Wh/kg) & Power (W/kg) within weight limits

Implement **robust Thermal Management**

REDUCING WEIGHT (Weight Management)

KG → **KG** → **KG**

Achieve **Low Structural Mass**

Less Weight = Lower Energy per distance
→ **Increased Range**

Improve **Acceleration & Overall Performance**

LESS MASS = MORE AVAILABLE ENERGY

TOTAL SYSTEM OPTIMIZATION overcomes battery limits to achieve Maximum Range, Enhanced Performance, and Sustainable Efficiency.

- Deadrise Angle
- Bow Asymmetry
- Global Depth Scale
- Inboard Hull Y Scale
- Run Inflection Focus
- Run Inflection Mag
- Knuckle radius
- Stem Fullness
- Sectional Fullness
- Sect Fullness Global
- Rocker Fullness
- Waterline Fullness
- Stern Asymmetry
- Max Rocker X
- Transom Beam
- Knuckle Depth f(Zmax)
- Max Rocker Z
- Trans. Depth f(Zmax)

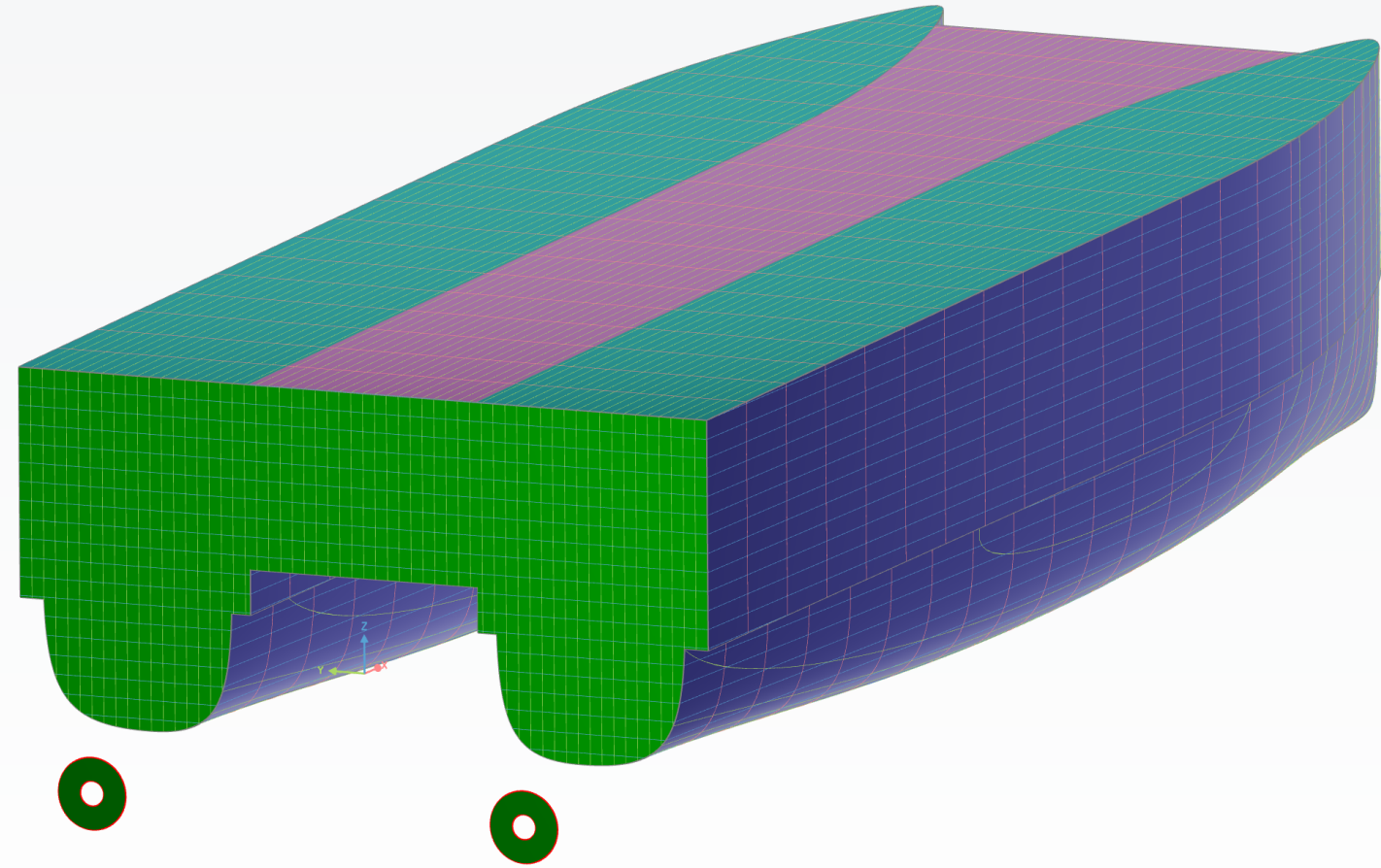
Dependencies x 3DView x 3DView3 x 3DView2 x 3DView1 x

RSOOnIter2_14_des0018

BetaFwd	0.25	?
BetaTrans	0	?
BOA Target	3.9	?
BowAsymDelta	0.02	?
GlobalZ	0.98868	?
IBYscale	0.8	?
InflectionFocus	1	?
InflectionMagFactor	0.85	?
KnuckleRho	0.8	?
KnuckleWidth	0.1	?
LCBTarget	4.6	?
RhoFactEnd	0.75	?
RhoFactFwd	0.7	?
RhoFactMid	0.75	?
RhoGlobal	0.790519	?
RockerFullaft	0.3	?
RockerFullFwd	0.3	?
RockerTanStem	5	?
ShldrFullAft	0.65	?
ShouldTanStem	18	?
SternAsymDelta	0	?
VolTarget	7.6	?
WetDeckHtAtTransom	0.5	?
Xmaxrocker	0.55	?
yTransFactor	0.83	?
ZknuckleFact	0.592426	?
Zmaxrocker	-0.53	?
ZTransFact	0.745793	?

BOA	3.900
BeamCLs	2.449
Displacement	7793.237
volume	7.603
VolTarget	7.600
VolError	-0.003
DRAFT	-0.524
CP	0.737
XCB	4.436
LCBTarget	4.600
LCBError	0.164
LCF	4.395
WS	31.391
ZKnuckleFactFinal	0.592
ZTransFactFinal	0.746
MinClearance	0.077

26 TOTAL AVAILABLE DESIGN VARIABLES



Deadrise Angle

Bow Asymmetry

Global Depth Scale

Inboard Hull Y Scale

Run Inflection Focus

Run Inflection Mag

Knuckle radius

Stem Fullness

Sectional Fullness

Sect Fullness Global

Rocker Fullness

Waterline Fullness

Stern Asymmetry

Max Rocker X

Transom Beam

Knuckle Depth f(Zmax)

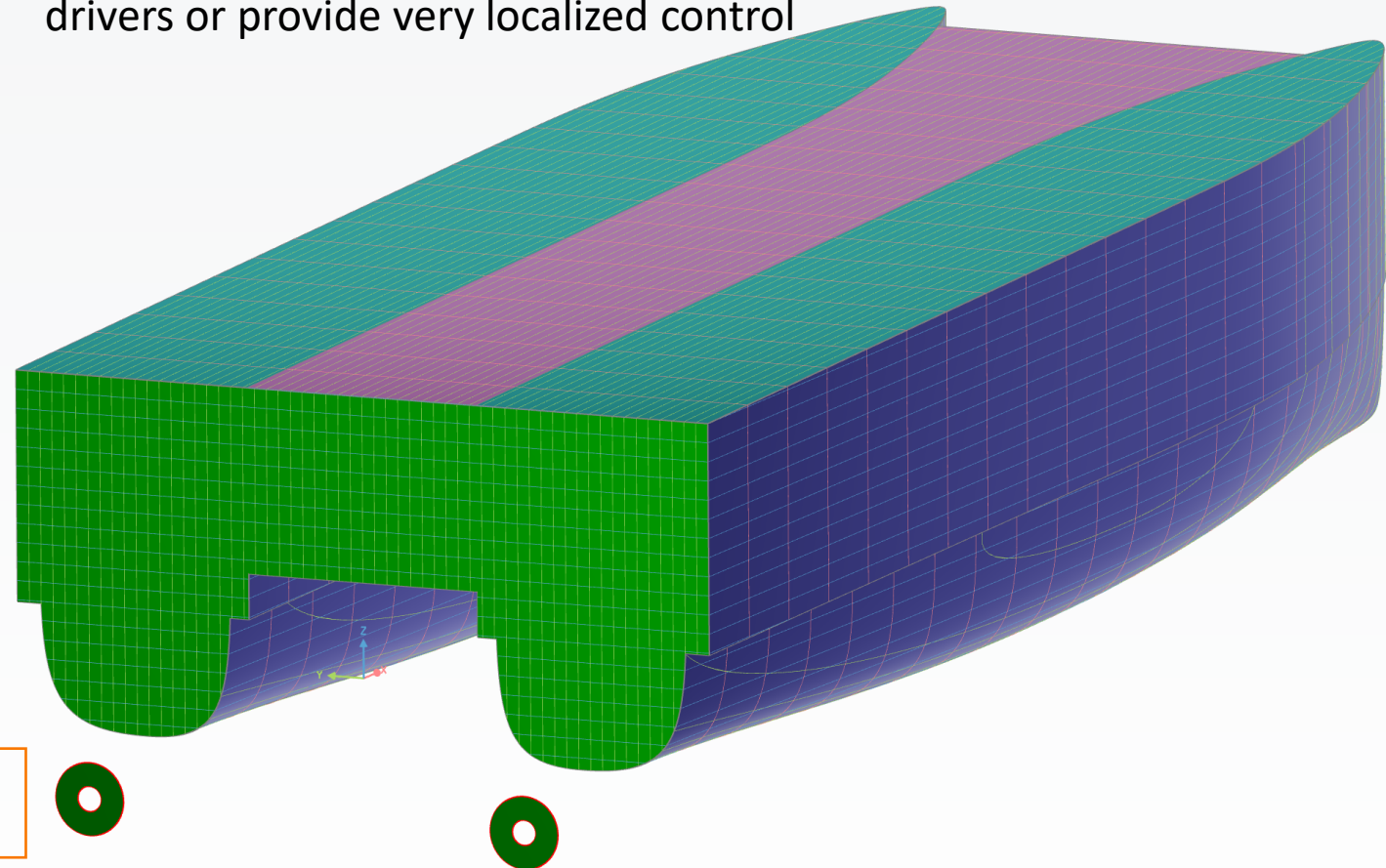
Max Rocker Z

Trans. Depth f(Zmax)

Parameter Name	Value
BetaFwd	0.25
BetaTrans	0
BOA Target	3.9
BowAsymDelta	0.02
GlobalZ	0.98868
IBYscale	0.8
InflectionFocus	1
InflectionMagFactor	0.85
KnuckleRho	0.8
KnuckleWidth	0.1
LCBTarget	4.6
RhoFactEnd	0.75
RhoFactFwd	0.7
RhoFactMid	0.75
RhoGlobal	0.790519
RockerFullaft	0.3
RockerFullFwd	0.3
RockerTanStem	5
ShldrFullAft	0.65
ShouldTanStem	18
SternAsymDelta	0
VolTarget	7.6
WetDeckHTActTransom	0.5
Xmaxrocker	0.55
yTransFactor	0.83
ZknuckleFact	0.592426
Zmaxrocker	-0.53
ZTransFact	0.745793

REDUCE DESIGN VARIABLES BY:

- Combining multiples into single global factors [e.g. Section Fullness]
- Locking variables we know are minor drivers or provide very localized control



Result of Target Vol Iteration

RSOOnIer2_14_des0018	
BOA	3.900
BeamCLs	2.449
Displacement	7793.237
volume	7.603
VolTarget	7.600
VolError	-0.003
DRAFT	-0.524
CP	0.737
XCB	4.436
LCBTarget	4.600
LCBError	0.164
LCF	4.395
WS	31.391
ZKnuckleFactFinal	0.592
ZTransFactFinal	0.746
MinClearance	0.077

CONSTRAINTS:

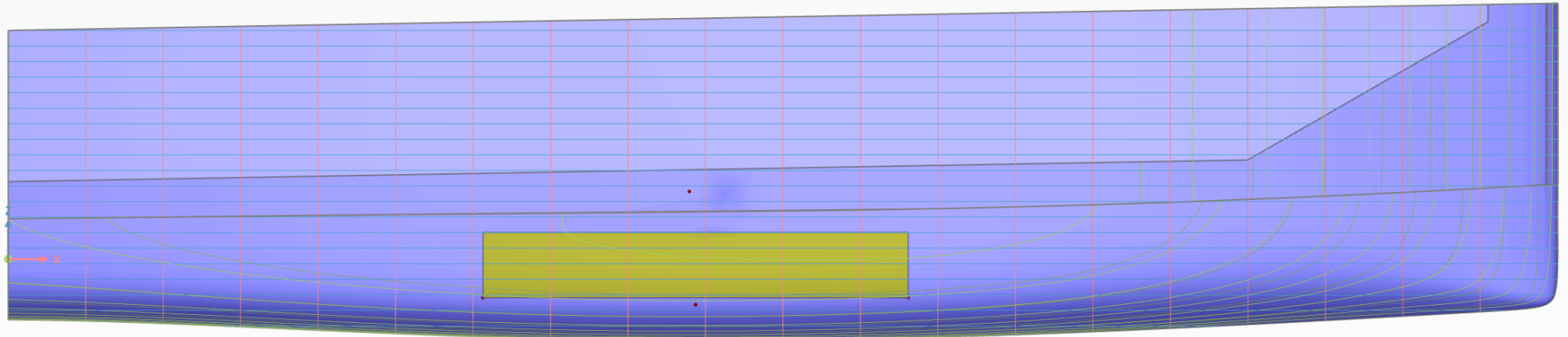
LOA Fixed

BOA Fixed - Automatically shift demi hulls to achieve target

Volume = Target [Achieved by automated Global Z Scale, Lackenby Fine-tune abandoned]

LCB = LCB Target [Initially used Lackenby but caused a lot of robustness issues]

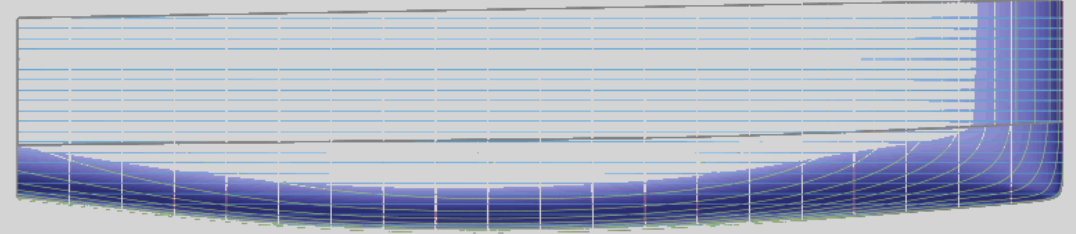
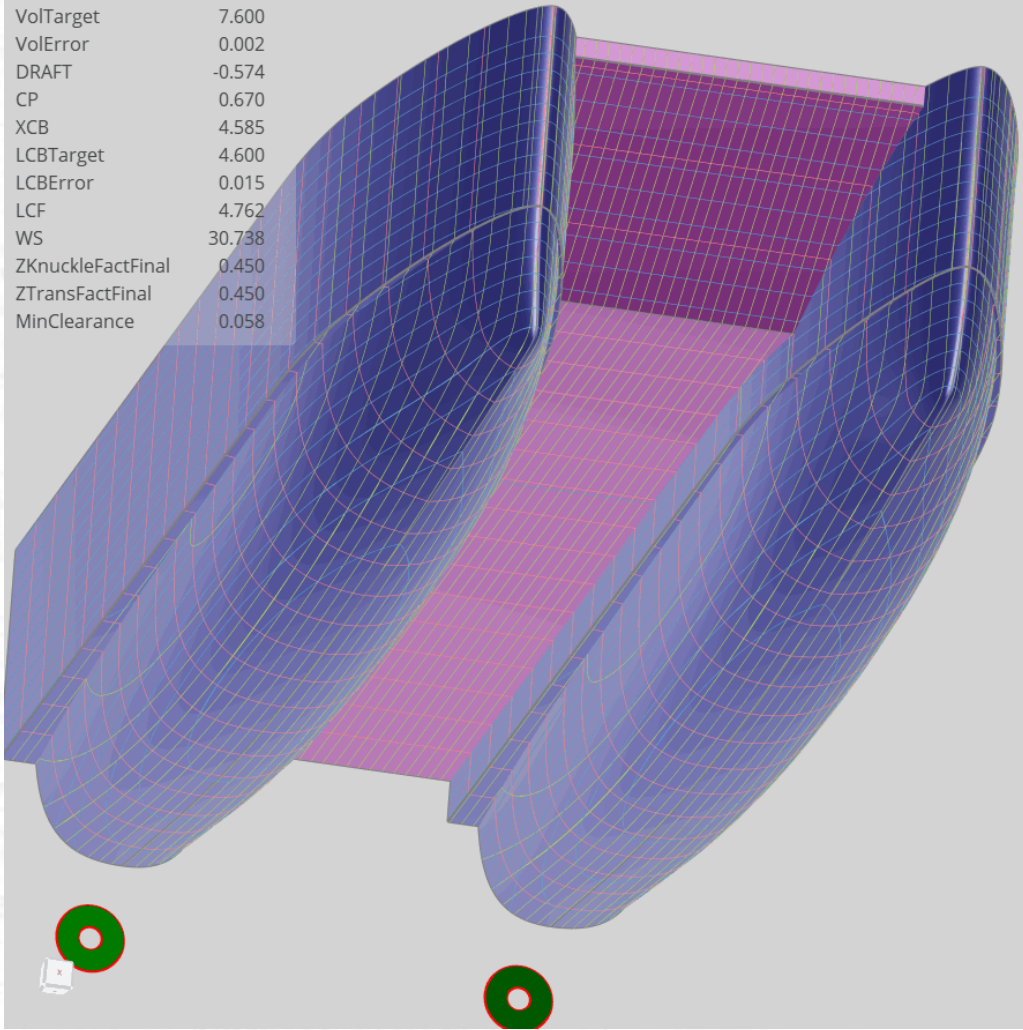
Hardpoints > 0.050m clearance from all corners of battery box



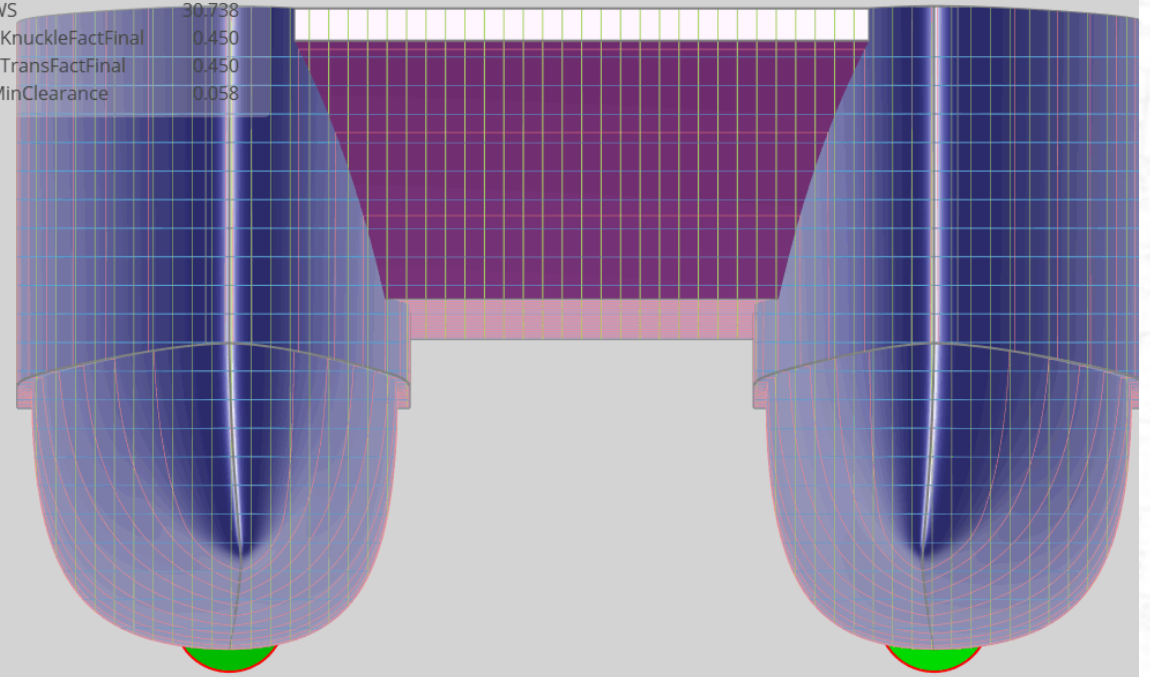
ROBUSTNESS CHECKS

Sobol_04_des0000

BOA	3.900
BeamCLs	2.435
Displacement	7788.358
volume	7.598
VolTarget	7.600
VolError	0.002
DRAFT	-0.574
CP	0.670
XCB	4.585
LCBTarget	4.600
LCBError	0.015
LCF	4.762
WS	30.738
ZKnuckleFactFinal	0.450
ZTransFactFinal	0.450
MinClearance	0.058



LCB	4.565
LCBTarget	4.600
LCBError	0.015
LCF	4.762
WS	30.738
ZKnuckleFactFinal	0.450
ZTransFactFinal	0.450
MinClearance	0.058



OPTIMIZATION WORKFLOW: PROCESS TIERS

TIER 1: PREPARATION & SETUP

Model Creation
Spray Rails/Wet Deck
Stem Closure
Lackeny & Volume Targeting

Parametric Testing
Design Variable bounds
Model Robustness

CFD Connector
OpenFOAM integration.

Optimization Matrix
Testing Matrix [Speed, Displacements]
Hardpoint constraints
Objective Function

TIER 2: OPTIMIZATION PROGRAM

Sobol 1 (4 DVs)
Broad search: 50 designs.

Sobol 2 (3 DVs)
Selection of 3 Design Variables: longitudinal rocker
Tighter variable bounds
20 Additional Designs

Response Surface Optimization & Expansion (3 DVs)
10% improvement
Expand design space to confirm Optima

TIER 3: DESIGN SELECTION

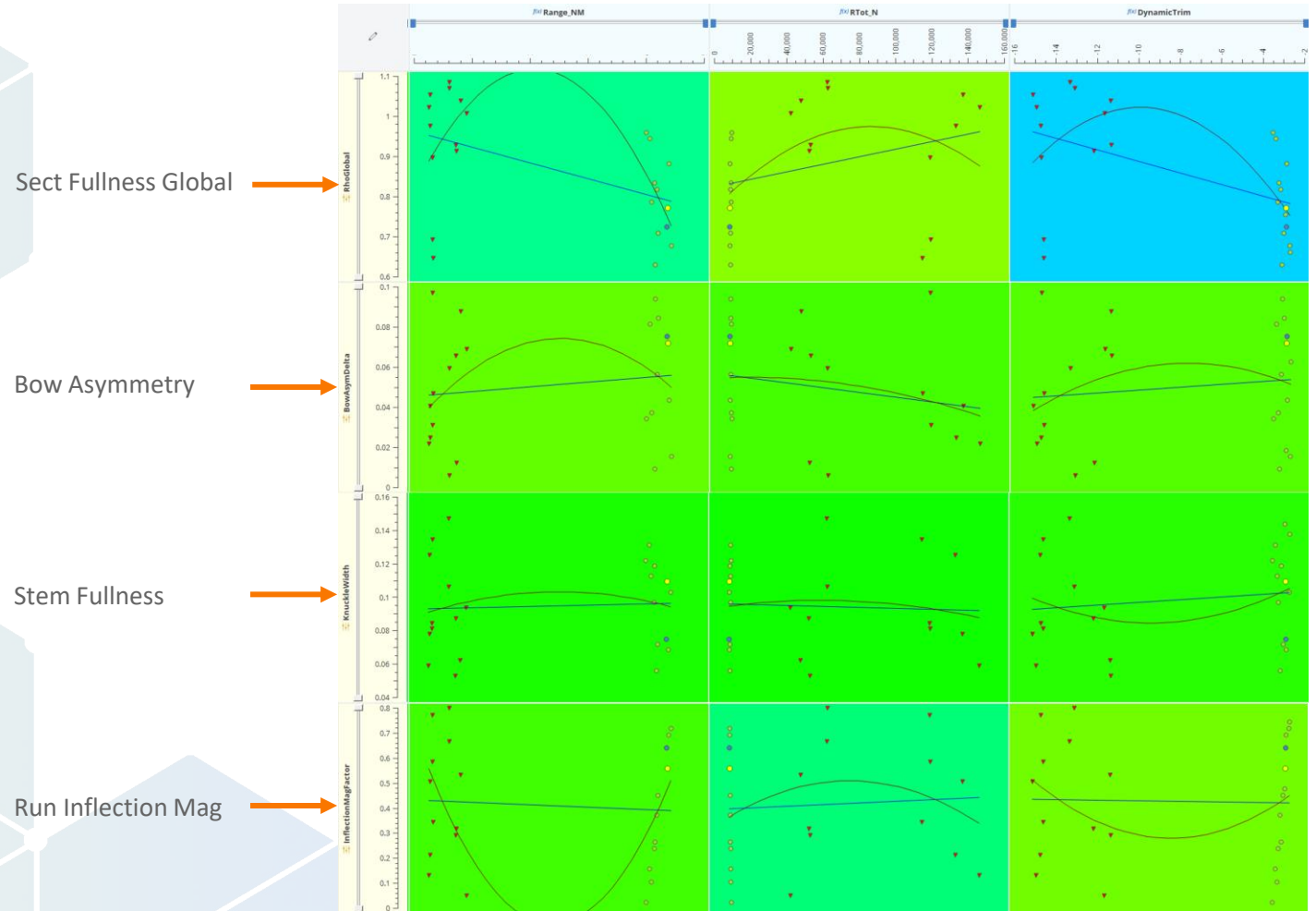
Final Selection
Balance of Range and Dynamic Trim.

TIER 4: DESIGN CHECKING

Final Iterations
Complete Vs Lines at 2 Loadings
Explore impact of Interceptor

Tier 2 - DoE, 1st Sobol

- Four DVs
- 50 designs evaluated
- Large number (60%) of invalid designs due to excessive trim crashing CFD simulations.
- Results gave some indication of preferable location in design space.
- Results indicated the necessity to control trim angle.



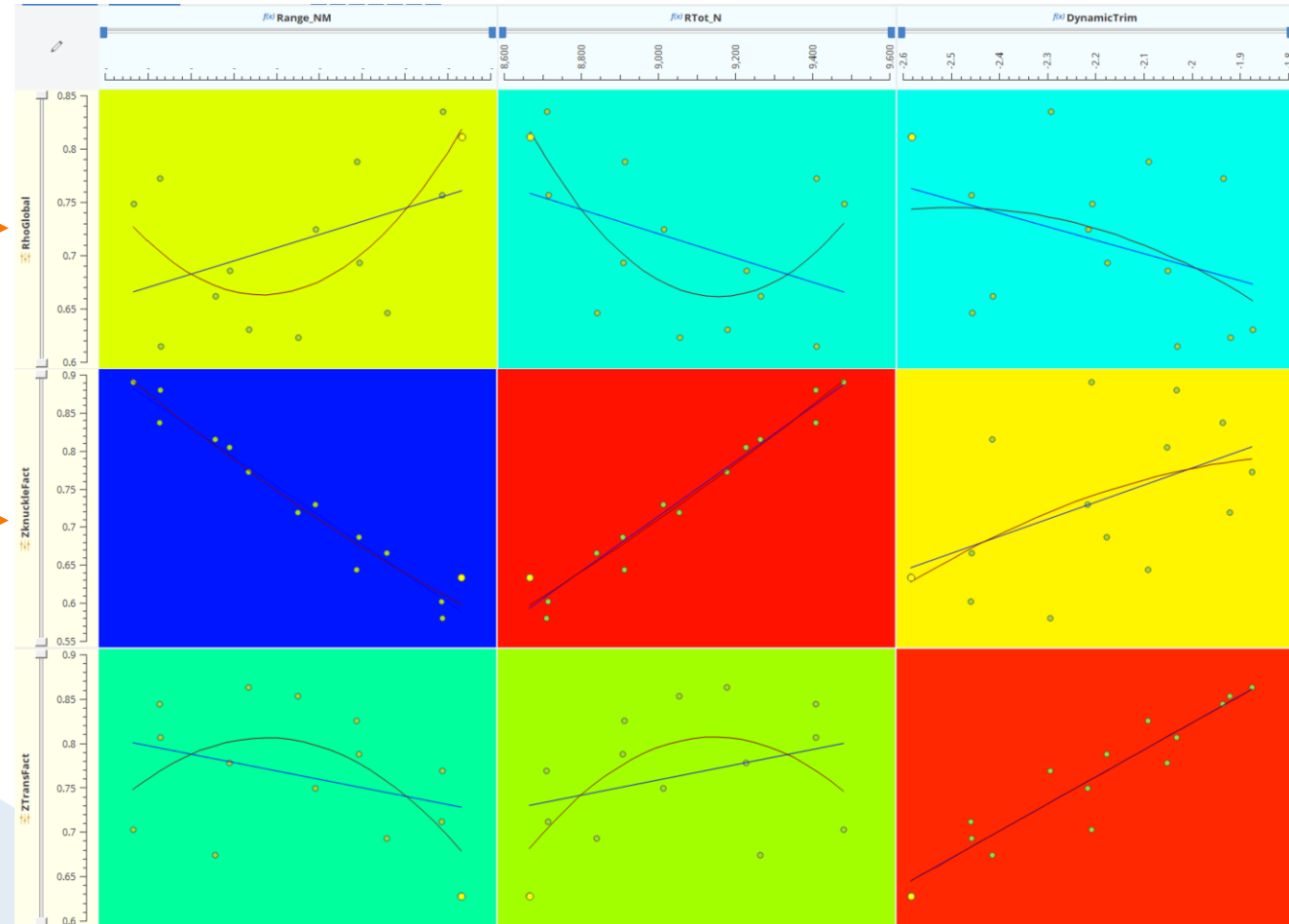
Tier 2 - DoE, 2nd Sobol

- 20 further designs evaluated
- Selection of DVs was modified (three DVs), DVs further constrained.
- Number of invalid designs reduced significantly.
- Strong correlations found

Sect Fullness Global

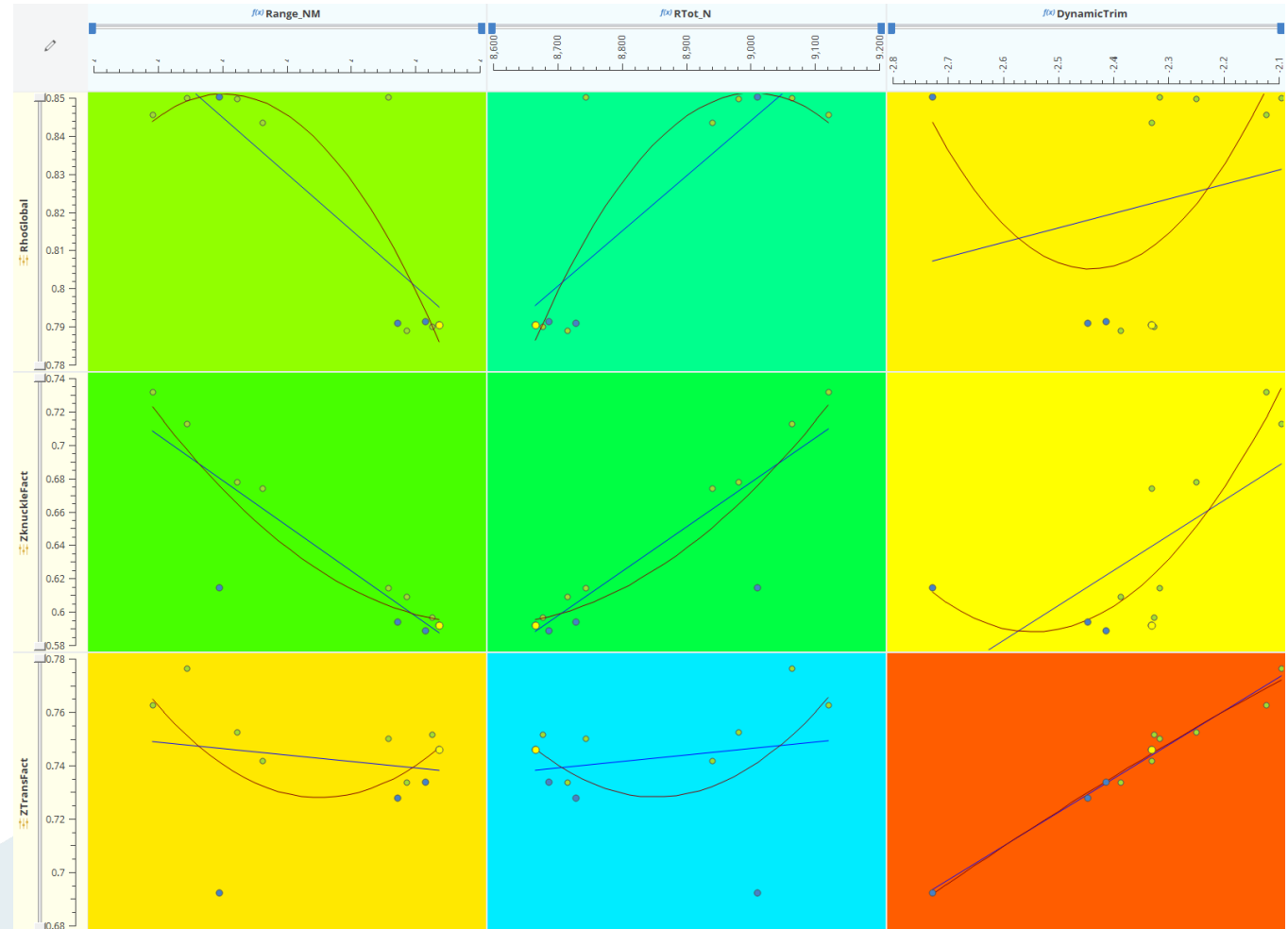
Knuckle Depth $f(Z_{max})$

Trans. Depth $f(Z_{max})$

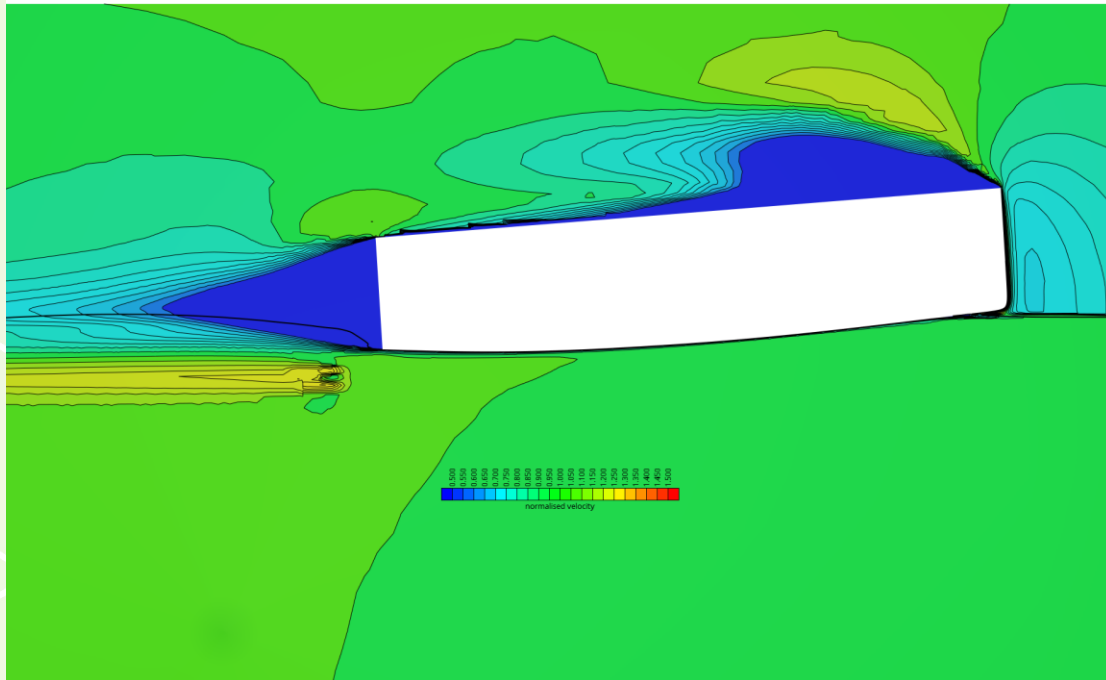


Tier 2 - DoE, Optimization on Response Surface

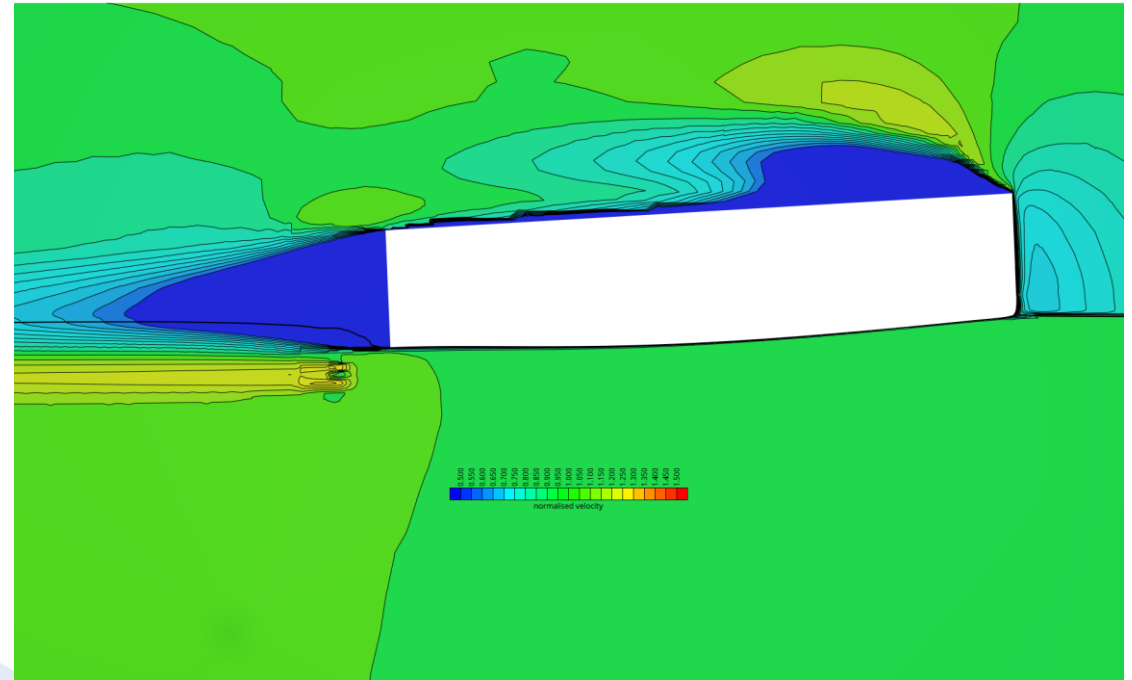
- 20 Designs evaluated
- Same DVs / limits as in 2nd Sobol
- Approx 10% improvement from worst to best design (based on range as objective function)
- Further tests indicated that the optima of the DVs have been found (or very close), extension of design space beyond optima gave worse designs



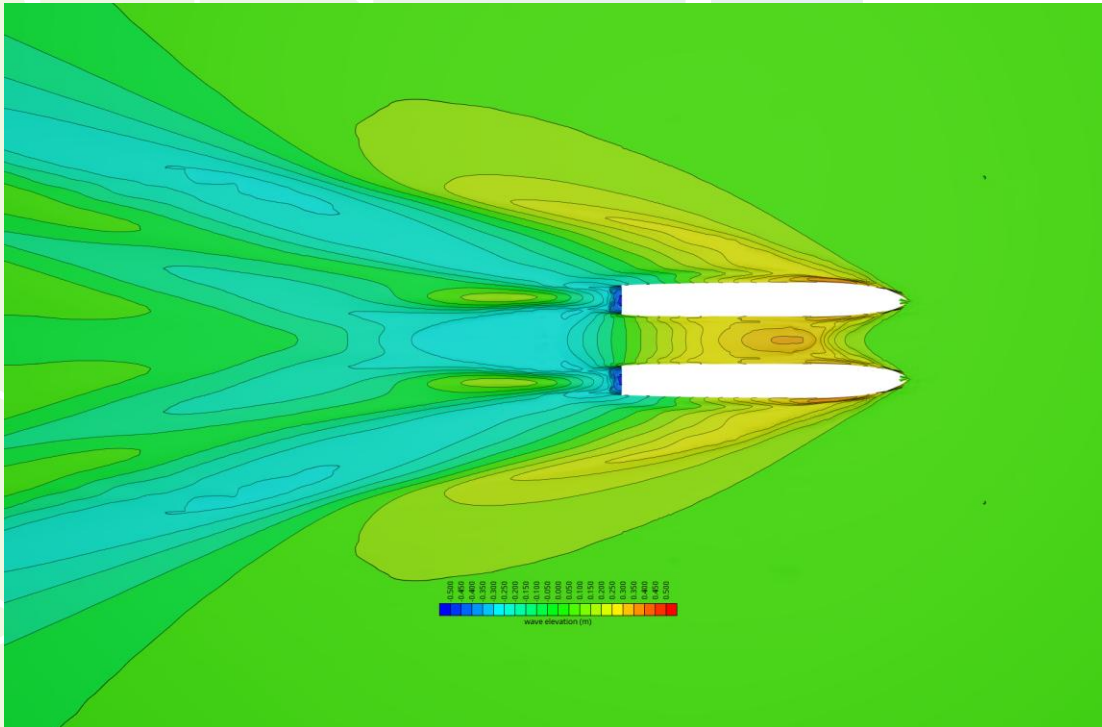
Worst valid design from Sobol



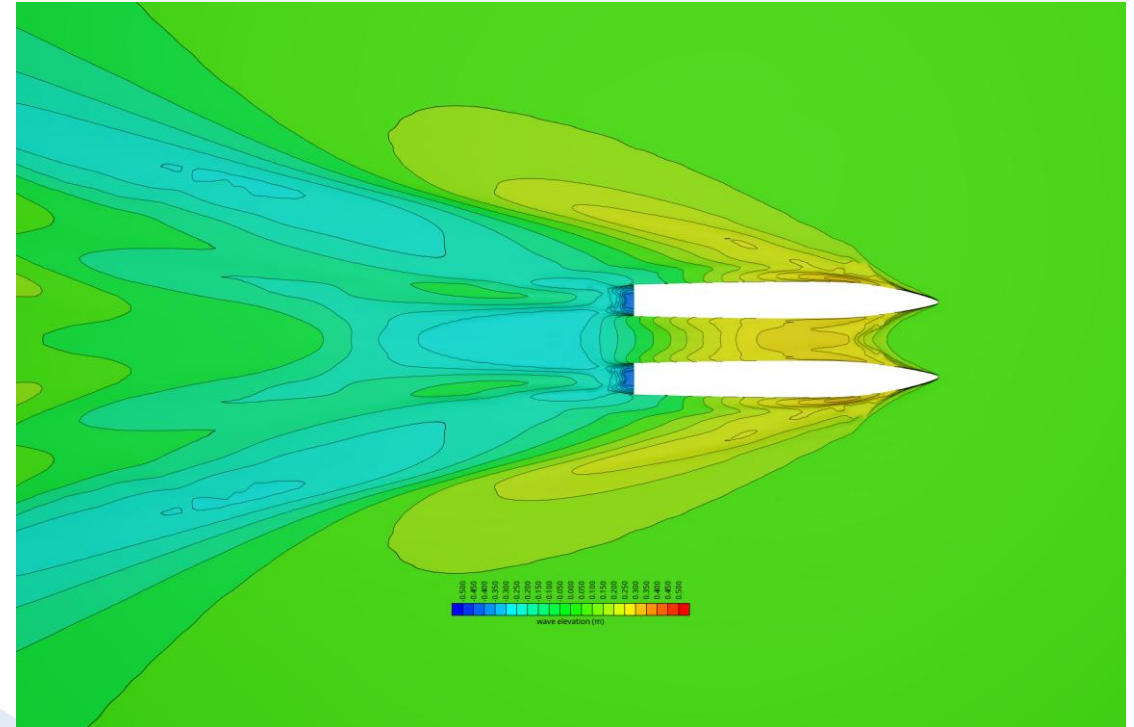
Best Design following RSO



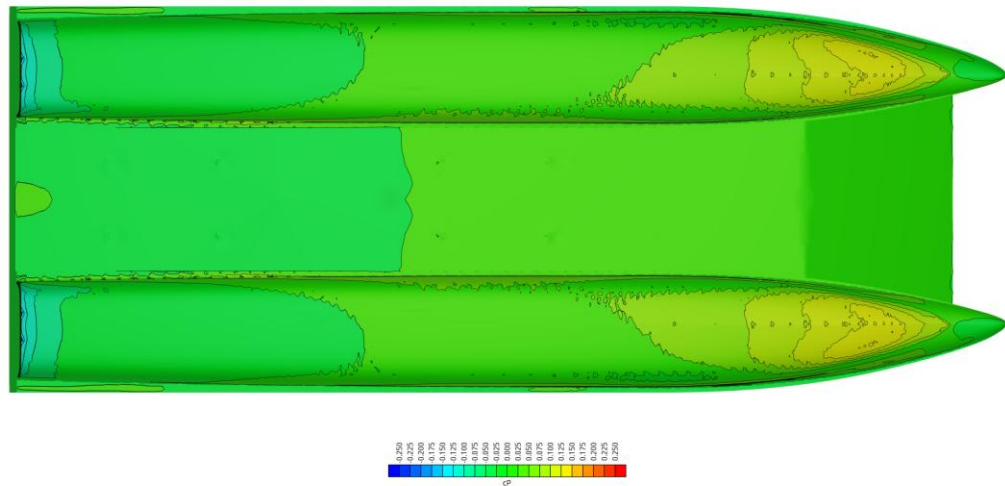
Worst valid design from Sobol



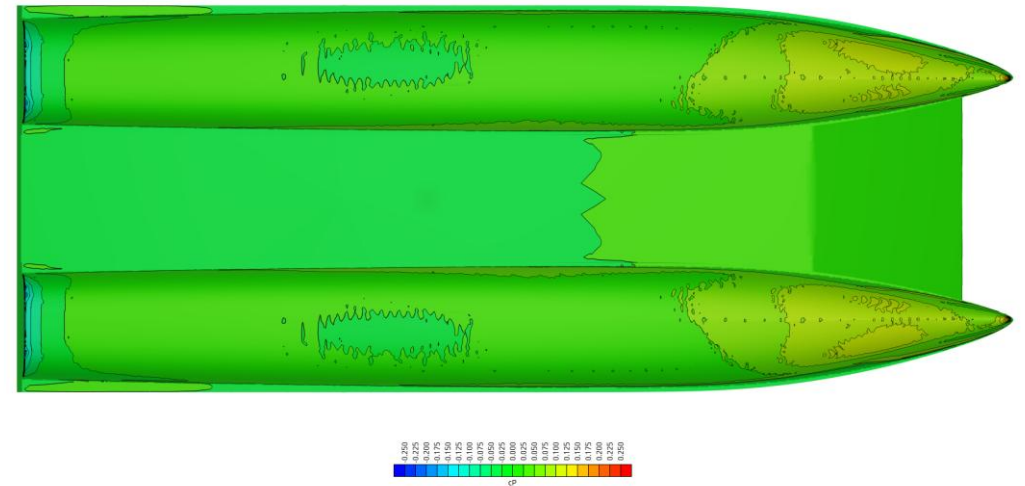
Best Design following RSO



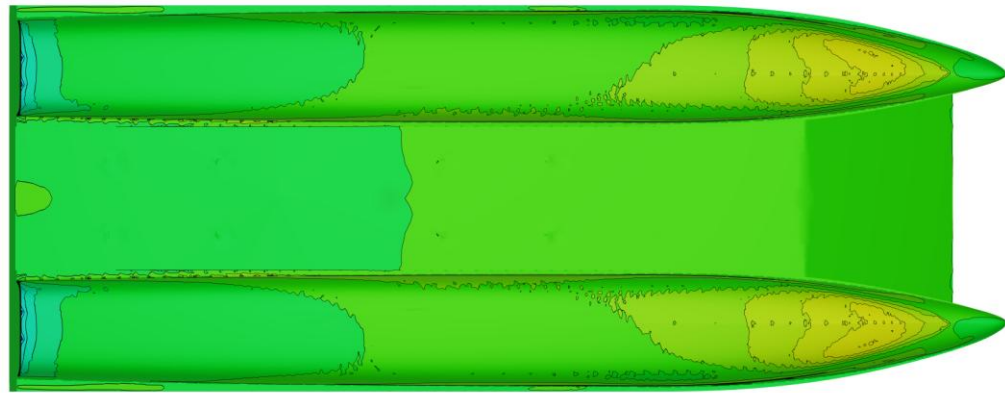
Worst valid design from Sobol



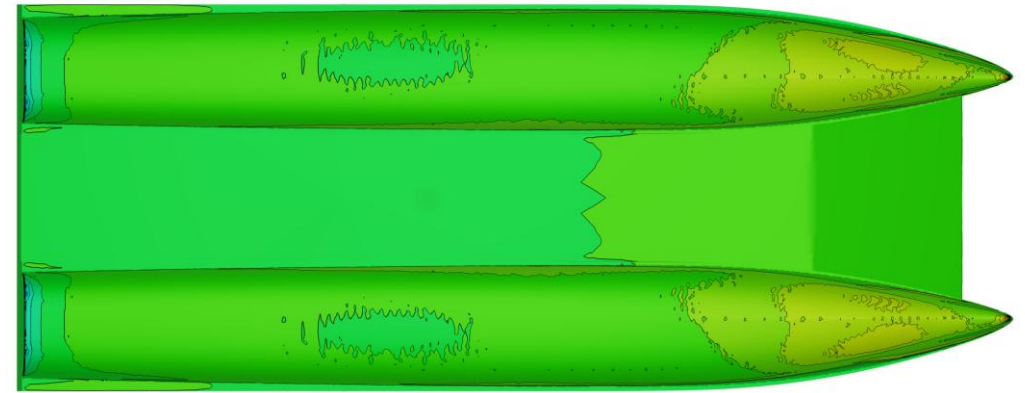
Best Design following RSO



Worst valid design from Sobol

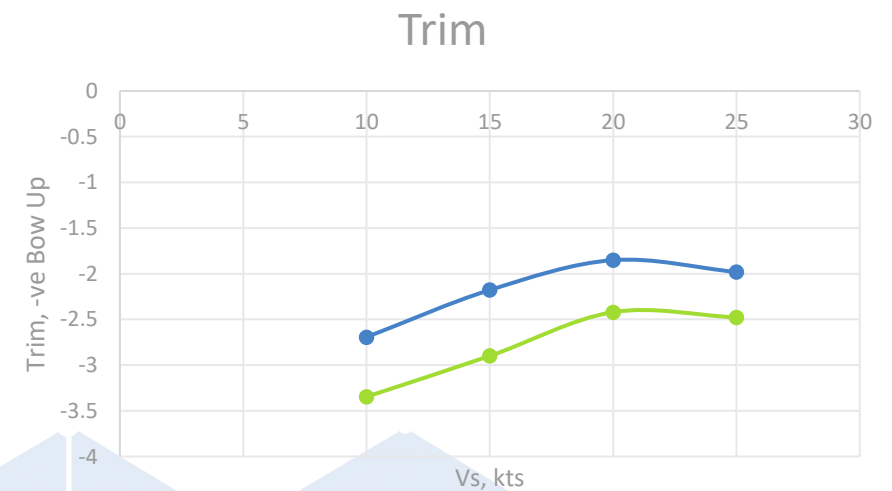
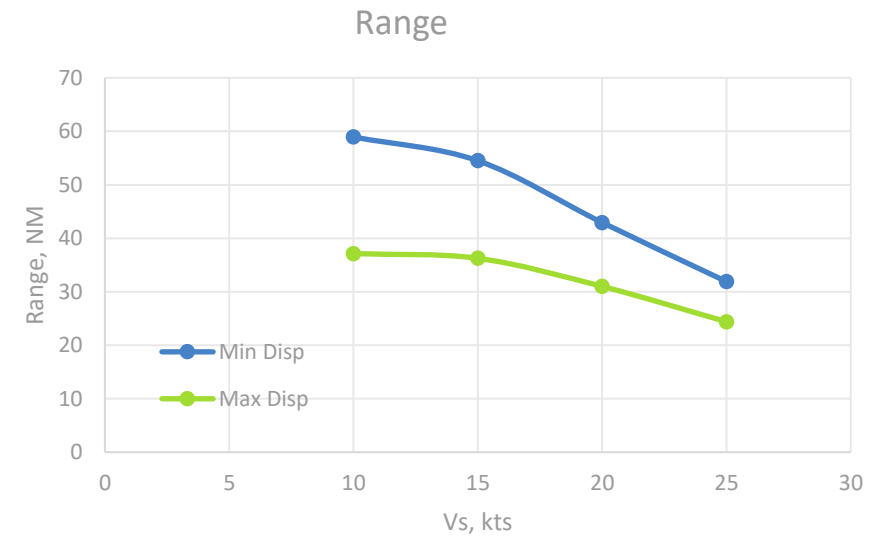
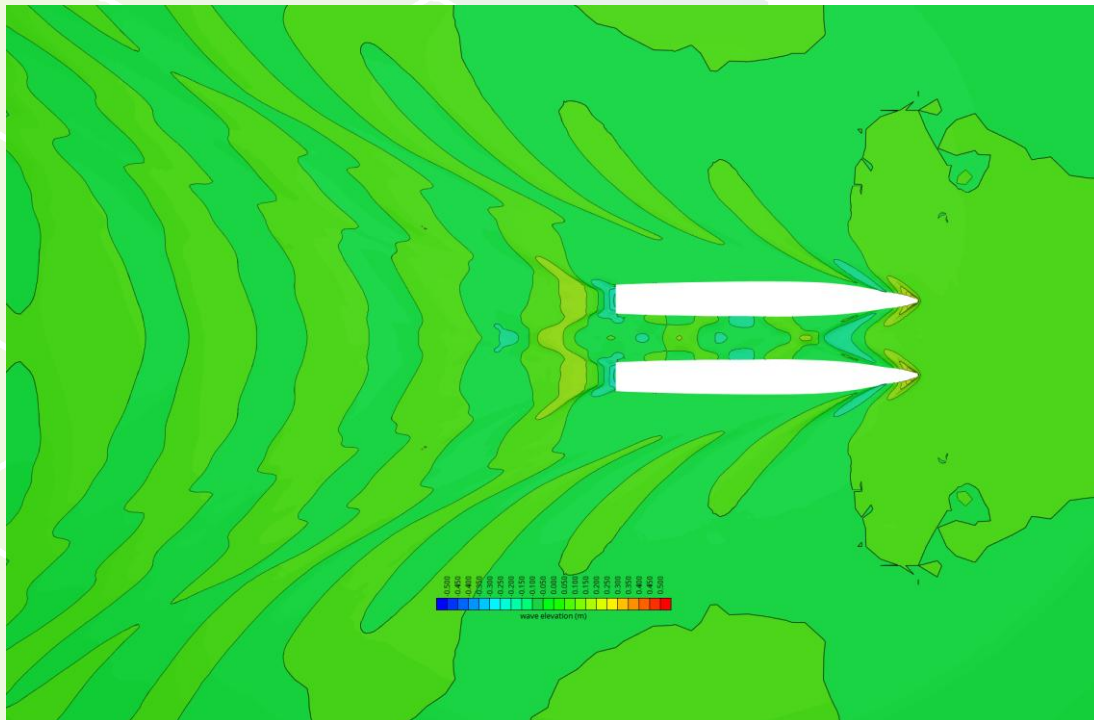


Best Design following RSO



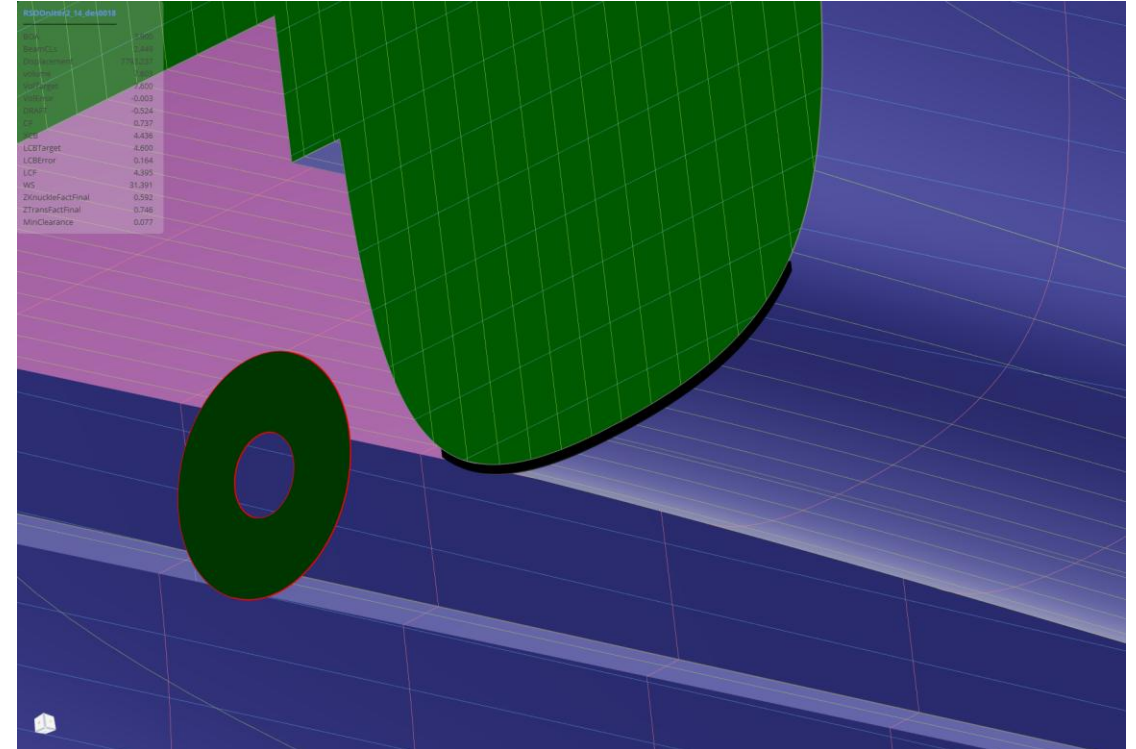
Tier 4 – Design Review

- Selected Design from RSO
- Run at Max and Light Displacements
- Vs – 5, 10, 15, 20, 25 to verify performance behavior in off-optimal conditions



Tier 4 – Design Review

- Dynamic Trim still a limiting factor at lower speeds.
- Investigate impact on dynamic trim of adding interceptor to hull.
- Significant reduction in trim but an increase in drag.
- Promotes modification to knuckle height and rocker transom inflection to rebalance drag for dynamic trim.
- Further evaluation underway.



Conclusion

- Improvements:
 - Range (objective) +12%
 - Significantly reduced dynamic trim angle
 - Less pronounced wave pattern
 - Less intense pressure distribution



- We need to acceleration the shift to electric and zero emissions marine transport.
- The power density challenge is a big impediment
- Requires significant additional focus on all areas of design to maximize efficiency
 - Naval Architecture/Hull form selection/Hydrodynamics
 - Minimize Vessel Mass -> advanced materials
 - Drive system Efficiency
 - Battery Storage
- Even on small projects the use of hydrodynamic optimization methods is affordable and can result in significant design improvements
- Limited time and budget requires intelligent selection of design variables and test matrix specification.

