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HOLISTIC SHIP DESIGN OPTIMISATION: Theory and Applications

by

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Important Design Optimization Notions (1)

- *Holism (from Greek όλος, meaning entire, total)-holistic*

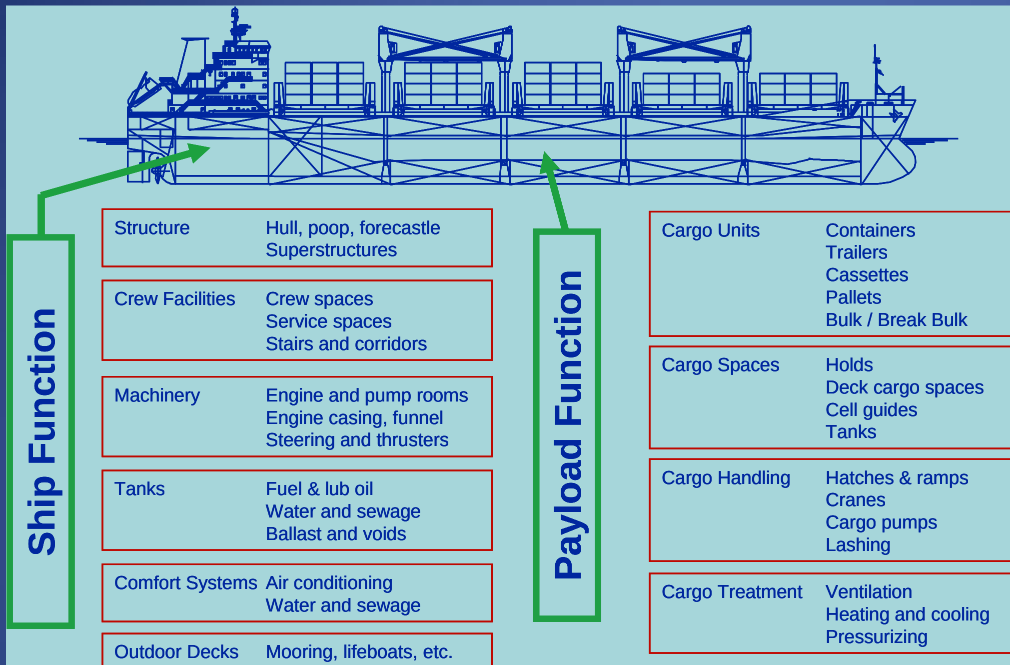
  The properties of a system cannot be determined or explained by looking at its component parts alone; instead of, the system as a whole determines decisively how the part components behave or perform.

  "The whole is more than the sum of the parts" (*Aristotle Metaphysics*)
- *Reductionism-reduction*: is sometimes interpreted as the opposite of *holism.* "A complex system can be approached by reduction to its fundamental parts"
- *Holism* and *reductionism* need, for proper account of complex systems, to be regarded as complementary approaches to system analysis.
- *Systemic and analytical* approaches are also complementary and strongly related to *holism* and *reductionism*
- *Risk (financial)*: "A quantifiable likelihood of loss *or* of less-than-expected returns"
- *Risk (general)*: "A quantifiable likelihood of loss of an acceptable state *or* of a worse-than-expected state condition"
- *Safety*: may be defined as "An acceptable state of risk"

Important Design Optimization Notions (2)

- *Optimization*: "The identification of the best out of a series of many feasible options"
- *Holistic Ship Design Optimisation*: "The multi-objective optimisation of ship design considering simultaneously all (*holistically*) design aspects of the system ship and for the entire ship life cycle"
  - Major design objectives
    - Performance
    - Safety
    - Cost
  - Major design constraints
    - Safety regulations
    - State of market (demand, supply, cost of steel, fuel, etc)
    - Other, more case specific
- Considering the risk of an investment in a new shipbuilding, the design of which should be *holistically* optimized, we might interpret the Holistic Ship Design Optimisation also as a *generic Risk-based Ship Design Optimisation*, where the risk of an investment with specific profit expectation is minimised , or the profit maximised for an acceptable risk.

Systemic Approach to Ship Design

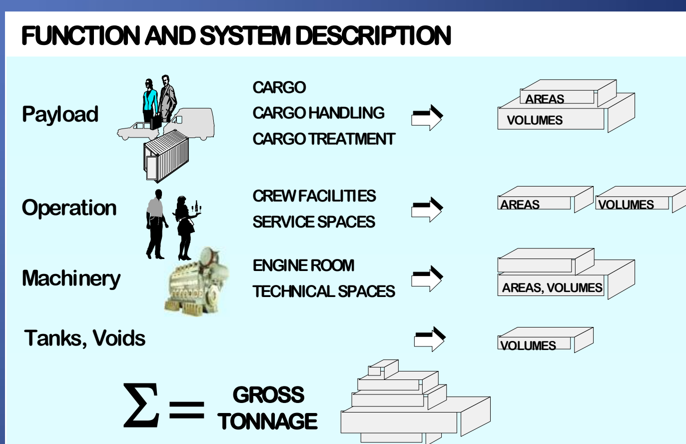


K. Levander, 2003)

A systemic approach to ship design may consider the ship as a complex system integrating a variety of subsystems and their components.

Ship functions may be divided into two main categories, namely payload functions and inherent ship functions

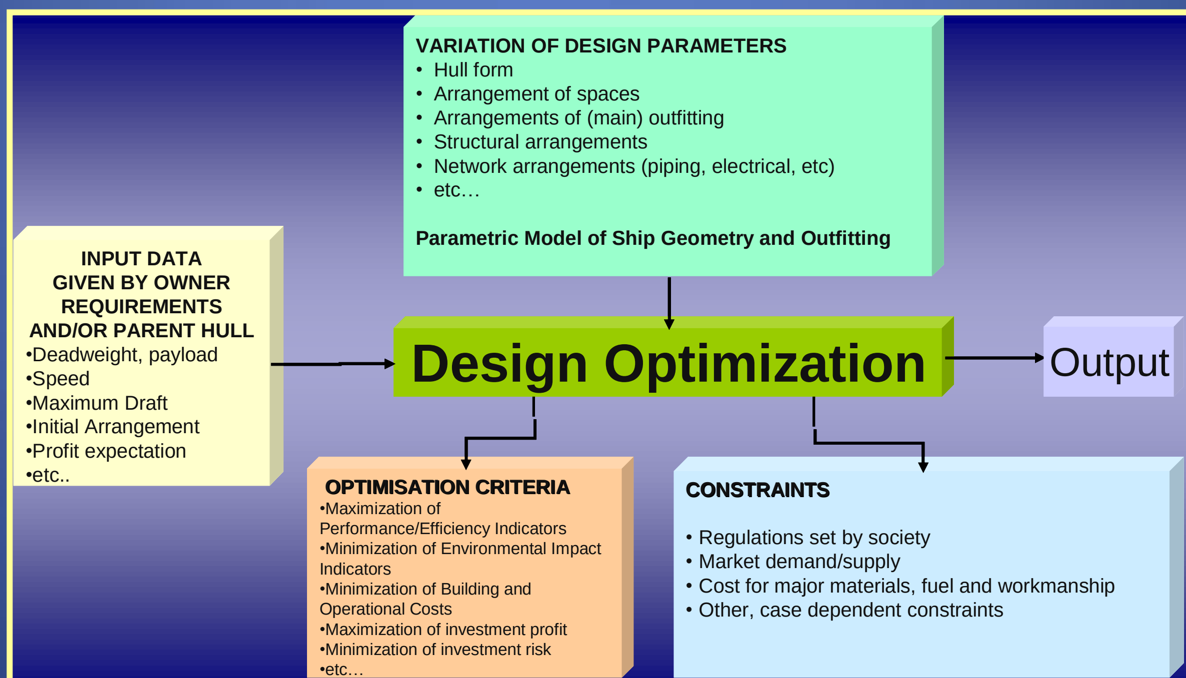
Considering that ship design should actually address the whole ship's life cycle, we may consider ship design composed of various stages, namely besides the traditional concept/preliminary /contractual and detailed design, the stages of ship construction/fabrication process, ship operation for her economic life , incuding scrapping/recycling.



Holistic Ship Design Optimization

Within a holistic ship design optimization we need to mathematically understand exhaustive multi-objective and multi-constrained optimization procedures with least reduction (‘*simplification*’) of the entire real design problem.

The definition of the generic ship design optimization problem and its basic elements is illustrated in the Figure below.



Performance Indicators/Objectives

Key performance indicators for cargo vessels (Levander, 2003)

Impact Area	Technology Drivers	Goal	Indicator
Construction	Design Concept Standard Solutions Modular Construction Supplier Networking	Construction Efficiency	Building cost [$ / Payload unit]
Payload Functions	Payload Capacity Speed & Power Cargo Units Cargo Handling	Transport Capacity	Money making potential [RFR]
Ship Functions	Hull Form Propulsion Solution Fuel Type & Consumption Heat Recovery	Propulsion Efficiency	Bunker cost [$ / Year]
	Navigation Machinery Operation Docking & Mooring	Automation	Crew cost [$ / Year]
	Planned Maintenance Preventive Maintenance Condition Monitoring	Reliability	Keep schedule Time saving
	Fire prevention Grounding prevention Collision Prevention	Safety	Casualties Insurance cost Repair & replacement cost
Social Values	Smoke & Emissions Waste, Sewage, Ballast Wake & Noise Recycling & Scrapping	Environmental Friendliness	Health Risk Environment fees & fines Disposal cost

Holistic Design Optimisation

VARIATION OF DESIGN PARAMETERS

- Hull form
- Arrangement of spaces
- Arrangements of (main) outfitting
- Structural arrangements
- Network arrangements (piping, electrical, etc)
- etc…

Parametric Model of Ship Geometry and Outfitting

INPUT DATA GIVEN BY OWNER REQUIREMENTS AND/OR PARENT HULL

•Deadweight, payload
•Speed
•Maximum Draft
•Initial Arrangement
•etc..

Design Optimization

Output

OPTIMISATION CRITERIA

•Maximization of Performance/Efficiency Indicators
•Minimization of Environmental Impact Indicators
•Minimization of Building and Operational Costs
•Maximization of investment profit
•Minimization of investment risk
•etc…

CONSTRAINTS

- Regulations set by society
- Market demand/supply
- Cost for major materials, fuel and workmanship
- Other, case dependent constraints

Multi-objective Optimization of RoPax Ships

EU PF5 Project ROROPROB (2000-2003) and ΕΠΑΝ-ΜΕΤ4 (2004-2007)

Objectives of the Optimization (ROROPROB)

- The objectives of the developed ROPAX optimisation procedure were the maximization of ship's resistance against capsize (survivability), expressed by the Attained Subdivision Index and of her transport capacity, in terms of both increased deadweight and garage deck space.
- Alternatively, the Attained Subdivision Index may be treated as a constraint ($A \geq R$) and the optimisation may be performed with respect to the maximisation of the transport capacity and minimisation of the building cost, an approach closer to a ship-owner's perspective.
- Building cost reduction is herein considered mainly as the result of steel weight minimization. The reduction of the number of watertight compartments below the subdivision deck is also considered to have a significant impact besides structural weight, also on equipment costs.

Outline of the Optimisation Procedure (1)

- The adopted procedure is based on the integration of a well-known commercial ship design software package (*NAPA*) and a general-purpose optimisation software package (*modeFRONTIER*).
- Appropriate *NAPA* macros were created for the generation of the ship's internal watertight arrangement for a given hullform, based on a set of design variables, forming the so-called 'design space', and in addition on a set of design parameters supplied by the user.
- The design variables are systematically updated during the optimisation, using appropriate utilities within *modeFrontier* to perform the design space exploration.
- The user-supplied design parameters are used to define the vessel's intact loading conditions in partial and full draught, and to provide necessary data for a variety of calculations.

Outline of the Optimisation Procedure (2)

- Selected quantities may be treated either as design variables or parameters, depending on the user's intentions or the specific requirements of each design case.
- Following the generation of the internal layout, the procedure continues with the assessment of each design variant, making full use of the calculation capabilities available within *NAPA*.
- Appropriate *NAPA* macros have been developed to control the damage stability analysis, to calculate the structural weight and transport capacity (both in terms of DWT and lanes length) and to verify the consistency of each design.

Employed Assumptions (1)

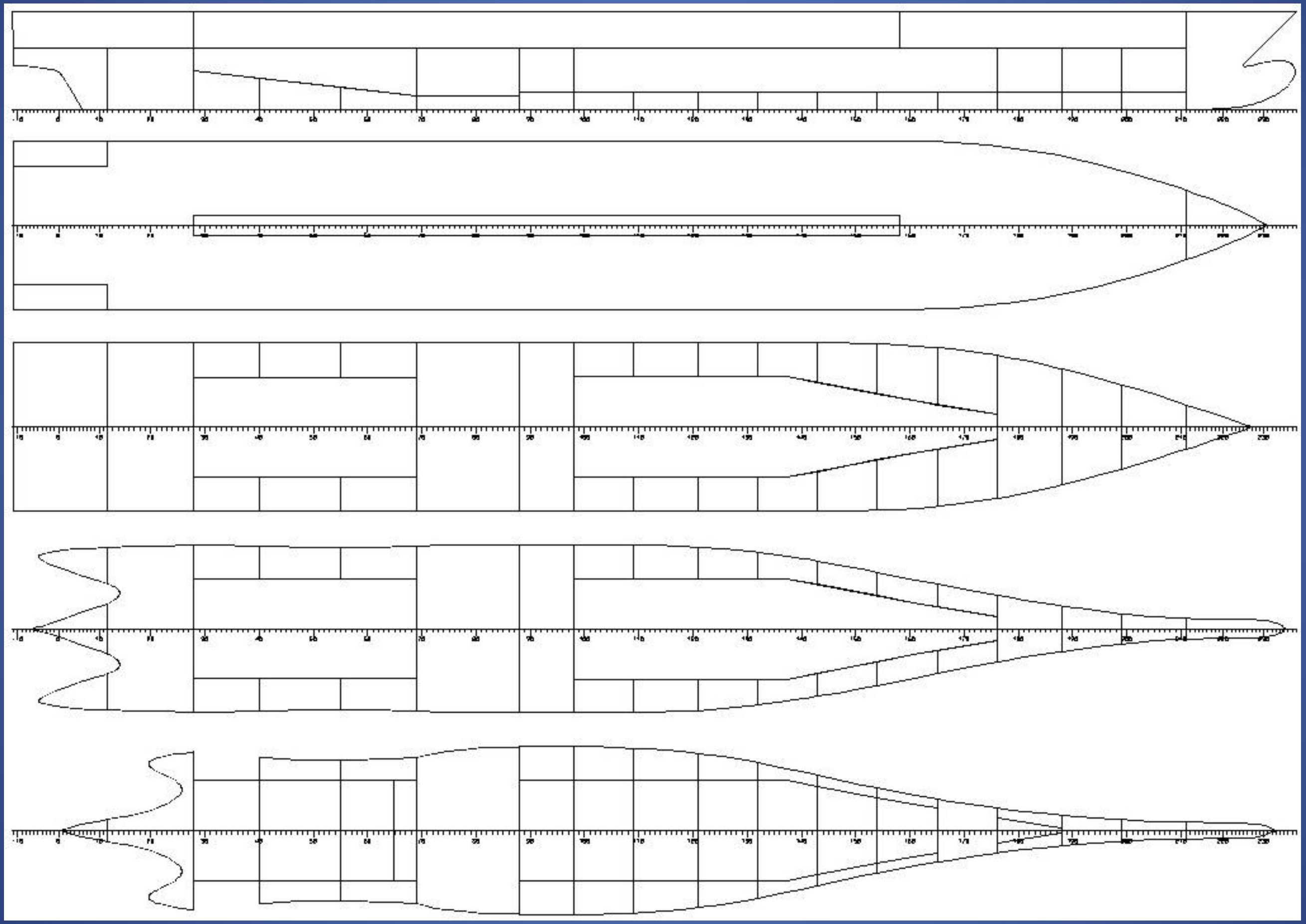
The optimisation procedure has been developed under the following assumptions:

- The vessel's length, beam and draught and the hull form are kept constant during the optimisation. Since the vessel's displacement is fixed, Light Ship variations are compensated by corresponding variations of DWT.
- The depth up to the bulkhead deck is treated as a free variable. The vessel's vertical centre of gravity is varied in accordance with the vessel's depth variation..
- The structural weight and the corresponding centre of gravity position estimation are based on user-supplied specific weight coefficients pertaining to the various ship zones.
- A lower hold intended for vehicles transportation may be generated forward of the Main Engine Room (MER). A second lower hold (not intended for vehicles transportation) may be also created aft of MER.
- A main deck configuration with either central or side casings may be selected. In either case, a small aft casing on each side is always generated, to accommodate the passengers staircases, storerooms, auxiliary rooms, etc. usually located in this area.

Employed Assumptions (2)

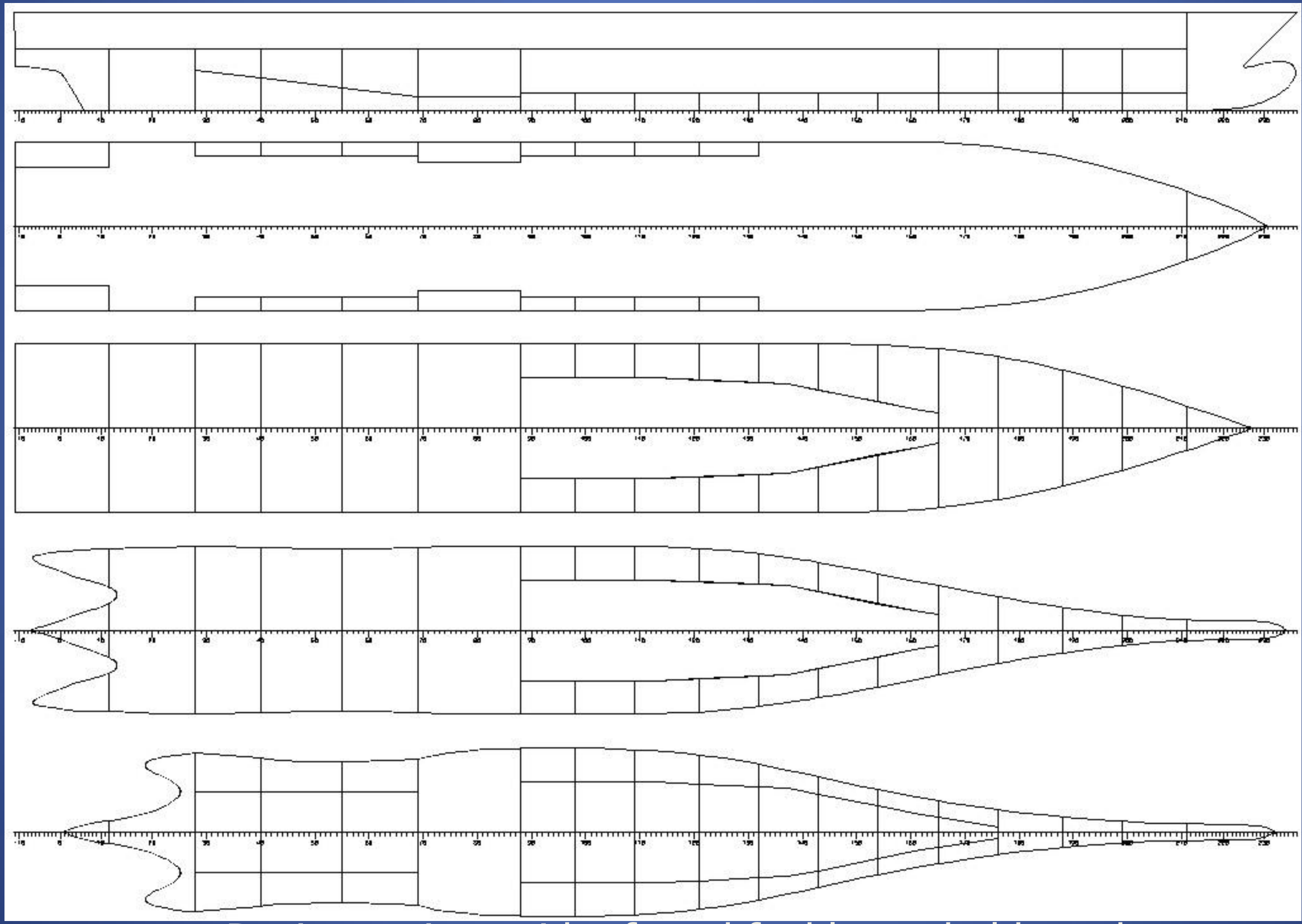
- The vessel's transport capacity is expressed by the vehicles lanes length, calculated separately for the main deck and the lower hold. The user defines the typical size of the vehicles carried on these spaces. The final transport capacity is calculated adding the main deck and lower hold lanes length. To account for the possibility that different kinds of vehicles are carried on the main deck and in the lower hold, the lower hold lanes length is multiplied by a user-supplied equivalence coefficient.
- Downflooding openings may be defined to limit the range of positive stability after damage. To simplify the use of the procedure and to keep the necessary input at this early design stage as simple as possible, only the height of the downflooding openings above the subdivision deck is needed. The user does not have to supply their longitudinal position, or to specify the actual compartments connected by these openings. A number of openings are automatically distributed along the vessel at pre-selected positions so that they are effective in all damage cases.

Parametrically Defined Watertight Subdivision



Design variant with aft and fwd lower holds and
a central casing on the Main Deck

Parametrically Defined Watertight Subdivision

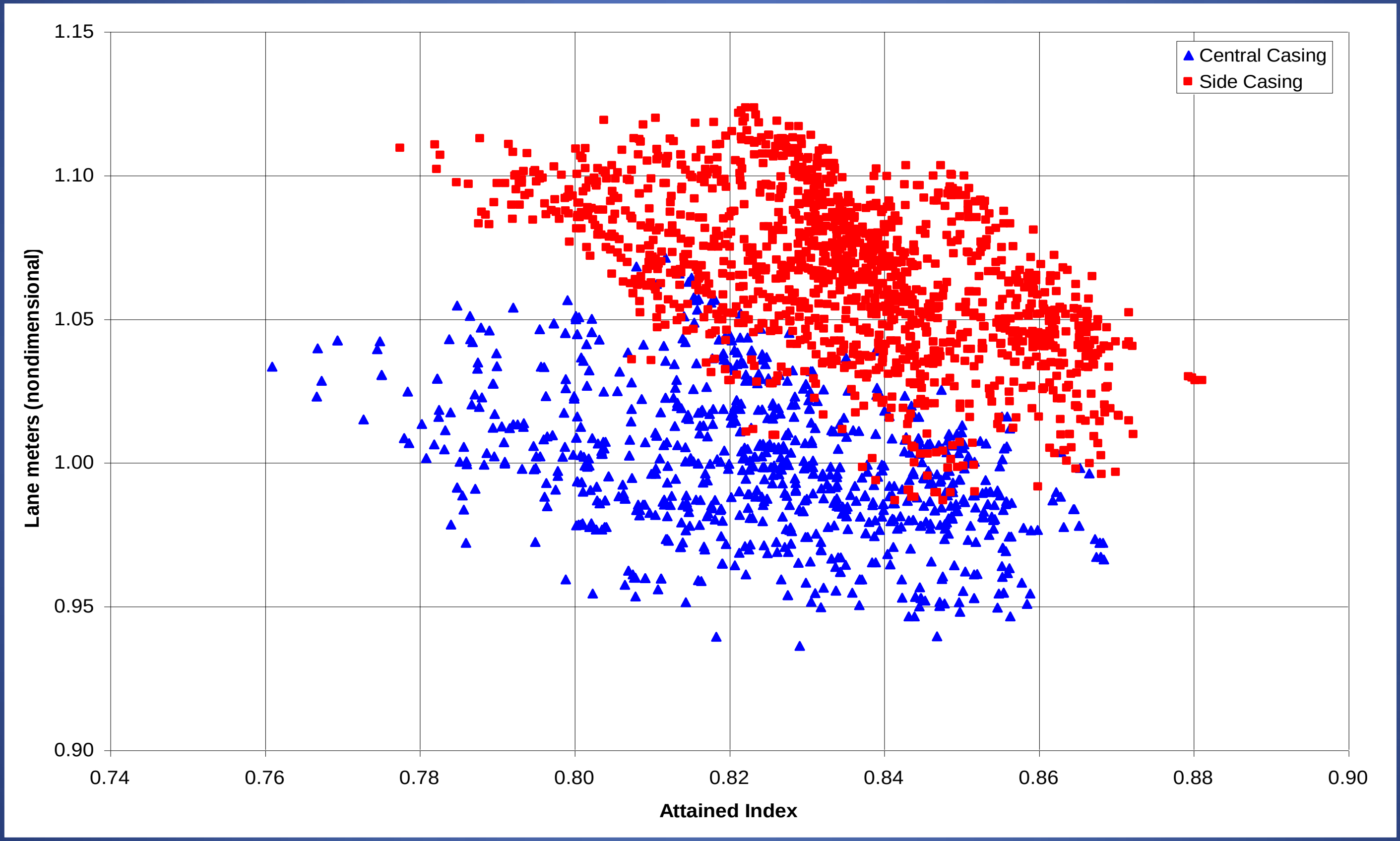


Design variant with aft and fwd lower holds and side casings on the Main Deck

Sample Ro-Ro Passenger ship

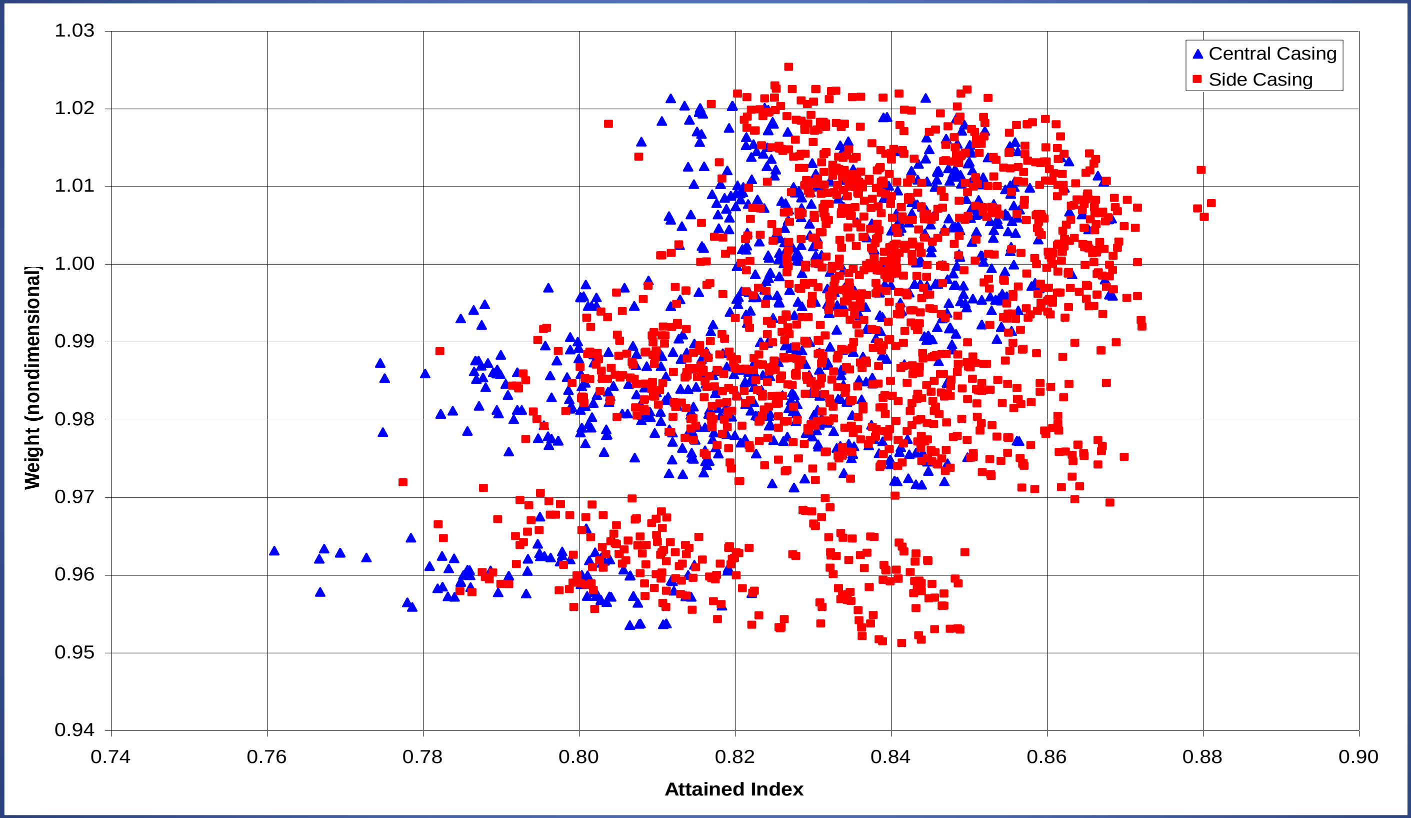
Length o.a.	193.6m
Length b.p.	176.0m
Breadth	25.0m
Depth (reference)	9.100m
Design draught	6.550m
Full load draught	6.520m
Full load displacement	17520t
Full load reference GM	2.440m
Partial load draught	5.884m
Partial load displacement	14880t
Partial load reference GM	1.830m

Comparison of Central vs, Side Casings Configurations



Attained Index vs. Lanes Length for Central and Side Casings Configurations

Comparison of Central vs, Side Casings Configurations



Attained Index vs. Structural Weight for Central and Side Casings Configurations

Multi-objective Optimization of RoPax Ships

ΕΠΑΝ-ΜΕΤ4 (2004-2007)

Multi-objective Optimization of High-Speed Ferries

EU FP5 Project FLOWMART (2000-2003)

Problem: Excessive wash waves from HSC operation

•Excessive ship-generated waves are frequently reported, as a result of the increase in size, service speed and propulsion power of High Speed Ferries.

•Excessive wash waves represent a potential danger to small boats, fishermen and swimmers, while their environmental impact on the marine life, the seabed and the shoreline deserves careful and systematic investigation.

•Restrictions in wash-sensitive areas have been already imposed, either in the form of explicit wash criteria, or by requesting a full assessment of risks of wash impact along the route, or finally by simply setting speed restrictions for vessels approaching harbor areas.

Numerical prediction method

The employed procedure for the numerical prediction of ship generated waves is based on a number of significant simplifications:

- Ideal fluid – irrotational flow
- Constant water depth, at least in the direction of motion
- Constant speed of advance
- Constant heading

The calculations presented herein are performed using the ®SHIPFLOW code of Flowtech, which based on the distribution of Rankine sources over the free surface and the wetted surface. An iterative solution scheme is applied to account for the nonlinear free-surface boundary condition.

Validation of the Numerical Procedure

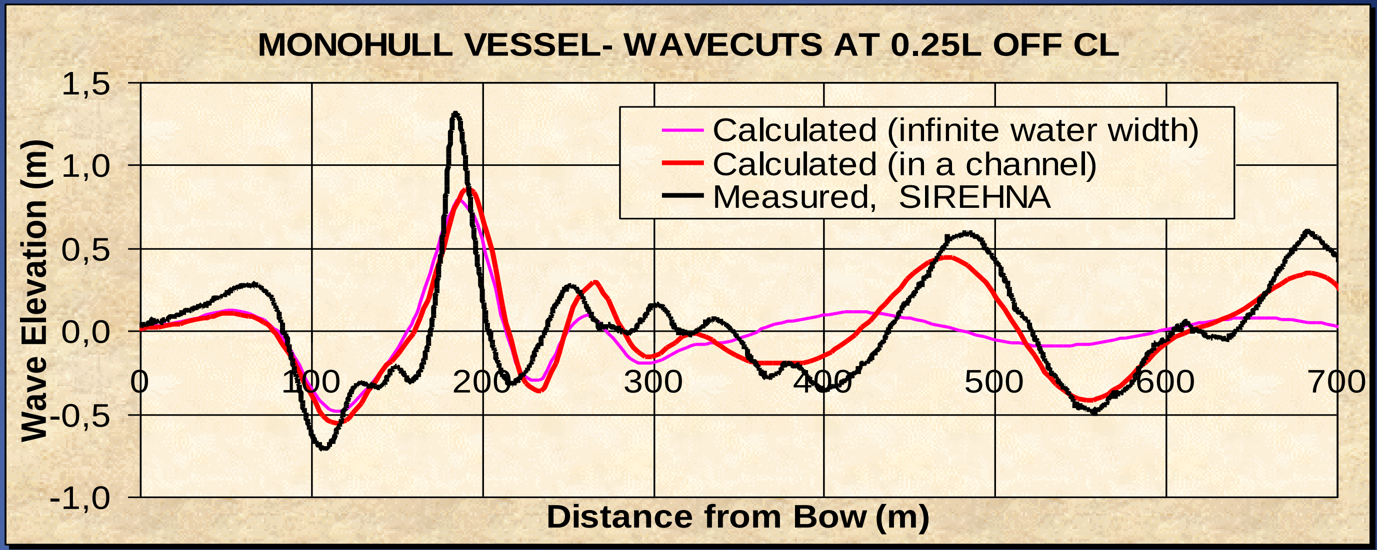
The validity of the developed hullform optimization procedure depends on the accuracy of the numerical predictions.

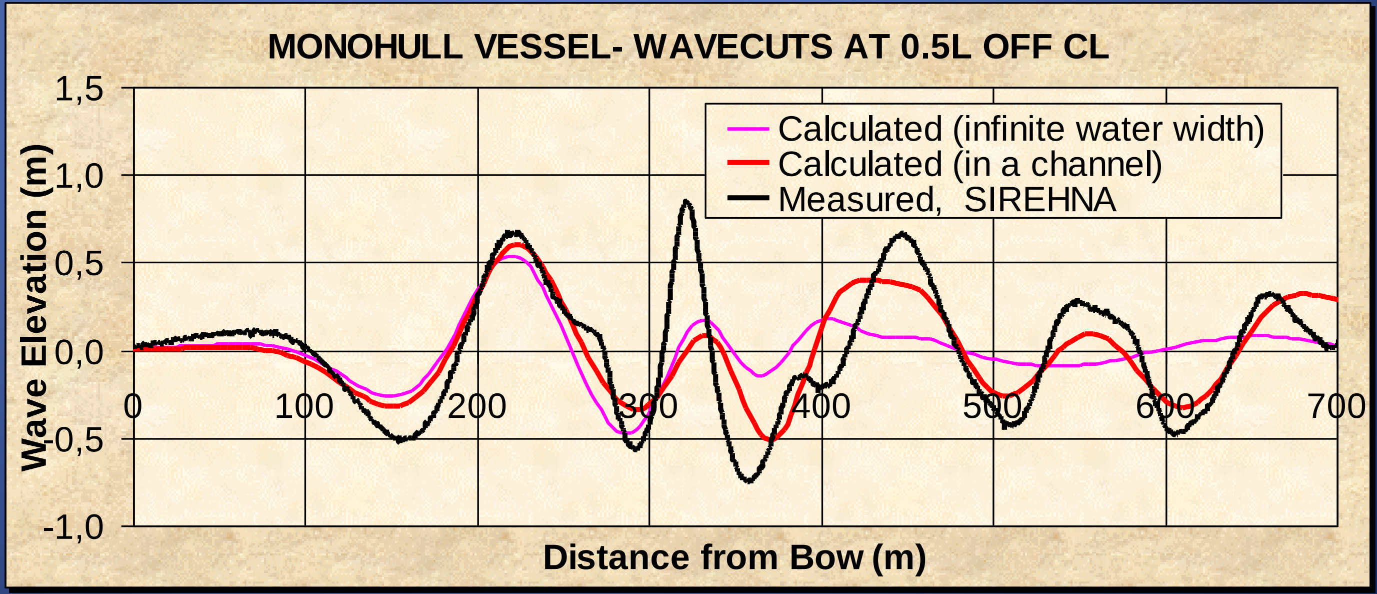
A comparison of numerical predictions with experimental measurements is presented for three vessels:

- A semi-displacement Monohull vessel
- A high-speed Catamaran vessel
- A medium-speed Catamaran vessel

Semi-displacement Monohull vessel

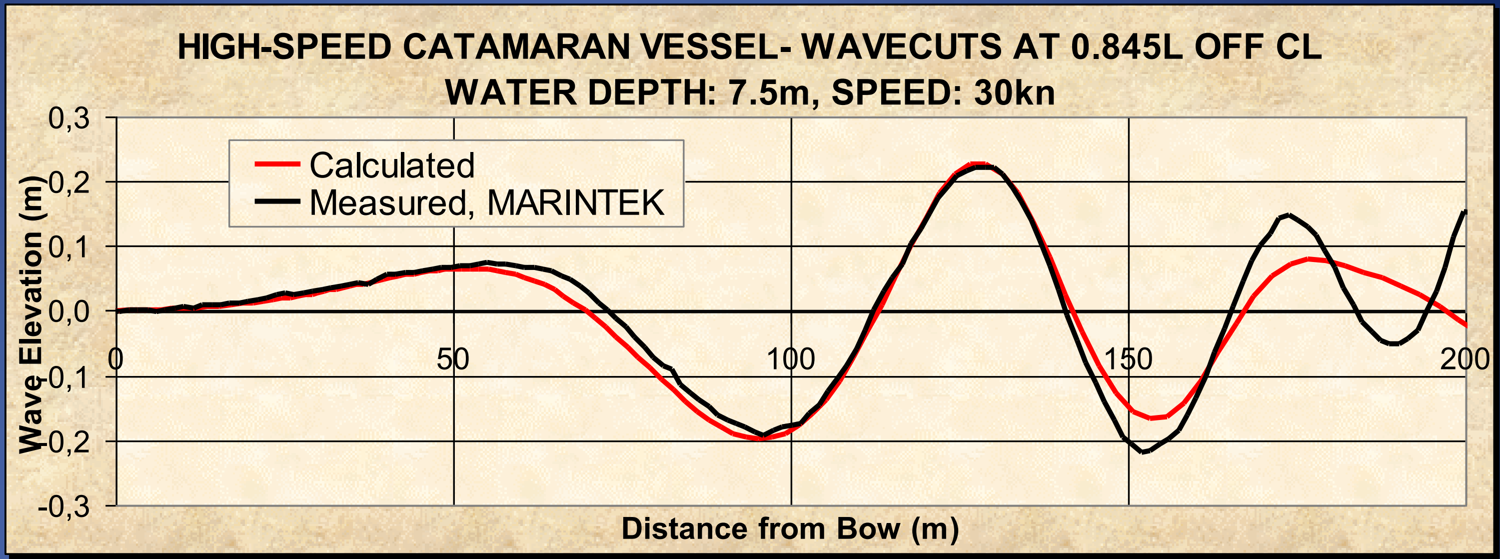
L_{WL}	87.5m
B	15.4m
T	2.5m
H	90.0m
Vs	37kn
Fn	0.650
Fn_H	0.641
Theor. channel width	150m

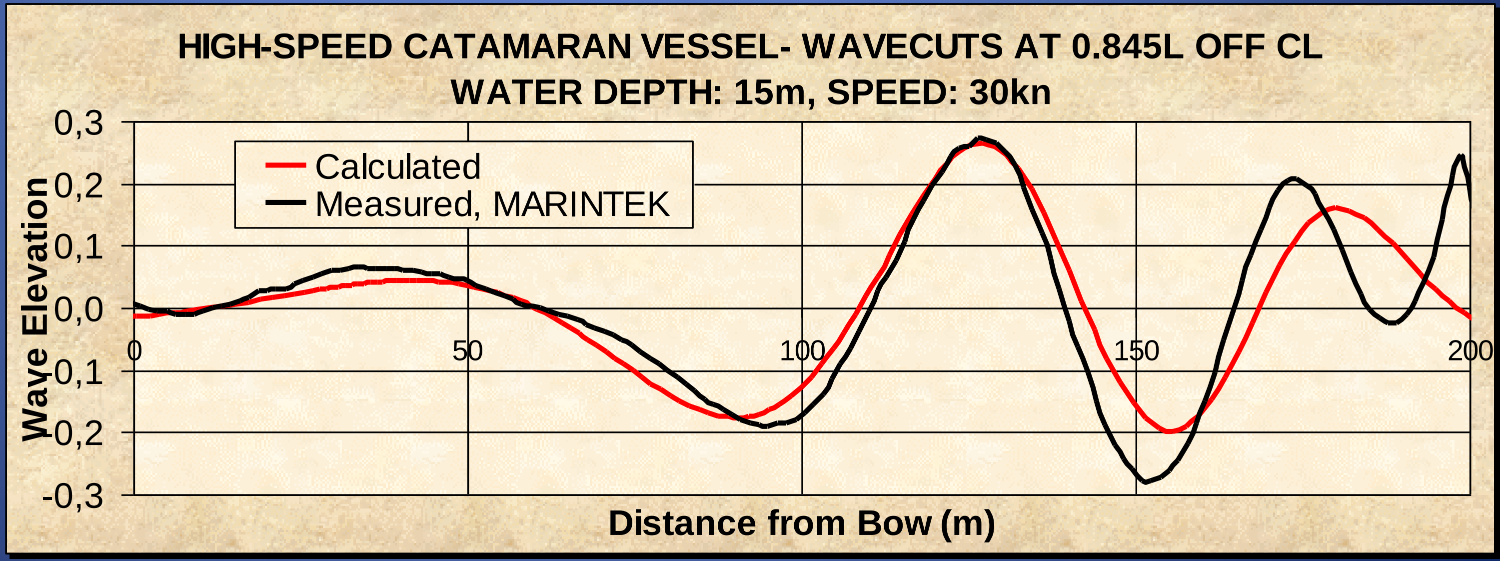




High-speed Catamaran vessel

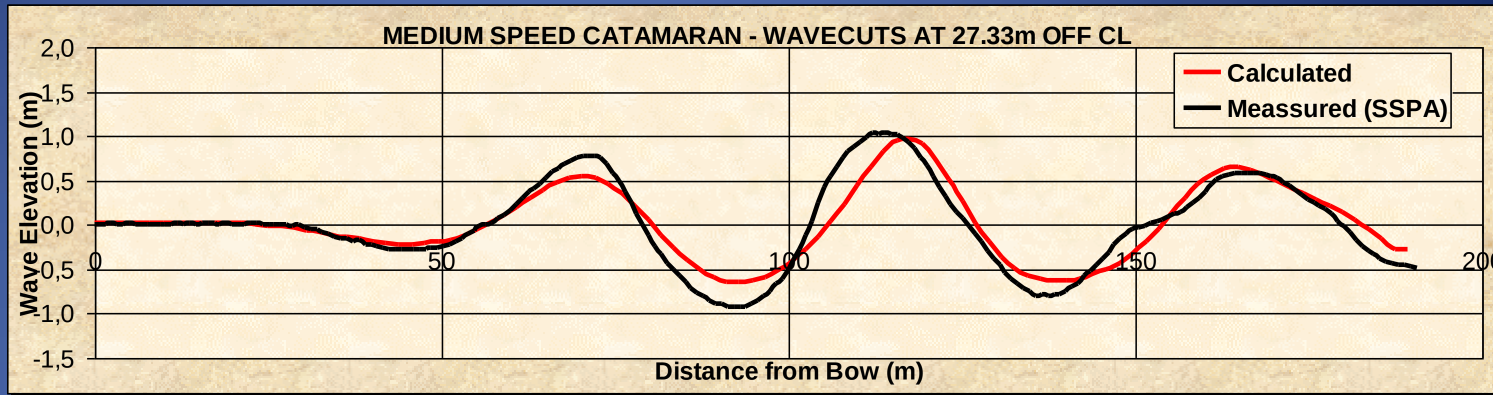
L_{WL}	29.580m
B_{OA}	8.320m
B_{DH}	2.270m
T	1.133m
H	7.5/15.0m
Vs	30kn
Fn	0.906
Fn_H	1.80/1.27

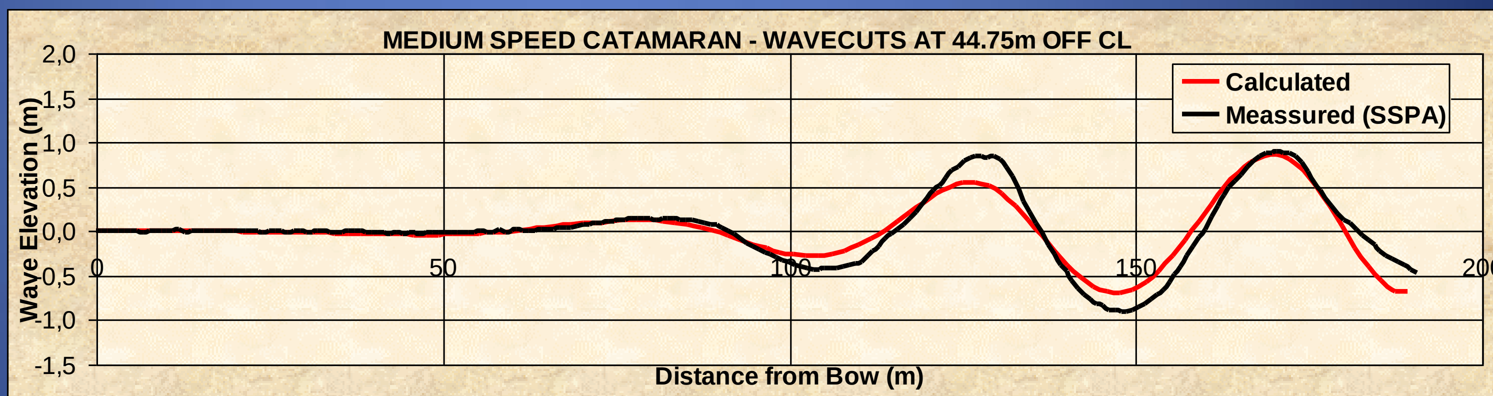




Medium-speed Catamaran vessel

L_{WL}	38.130m
S_{DH}	11.000m
B_{DH}	3.543m
T	3.600m
H	36.108m
Vs	18kn
Fn	0.479
Fn_H	0.492





Optimization Procedure

A procedure for the multi objective hullform optimization of Monohull and Catamaran vessels for minimum wash and total resistance at constant displacement and length at waterline will be presented.

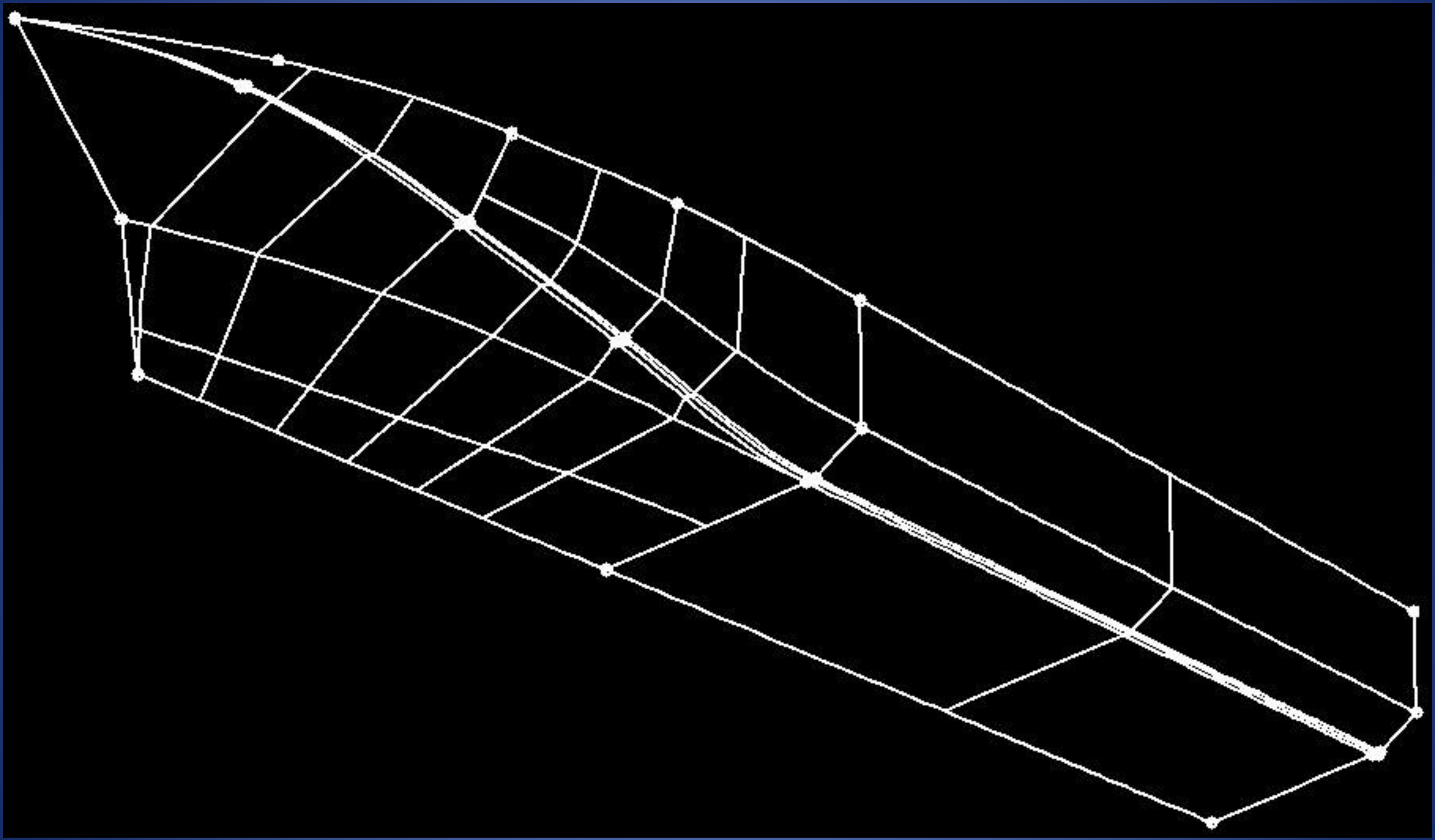
The adopted procedure is based on the integration of three software packages:

- *®Napa*: Hull form generation based on a number of design variables
- *®Shipflow*: Evaluation of candidate hull forms with respect to wave resistance and wash characteristics
- *®modeFrontier*: Optimization methods and control of the overall procedure

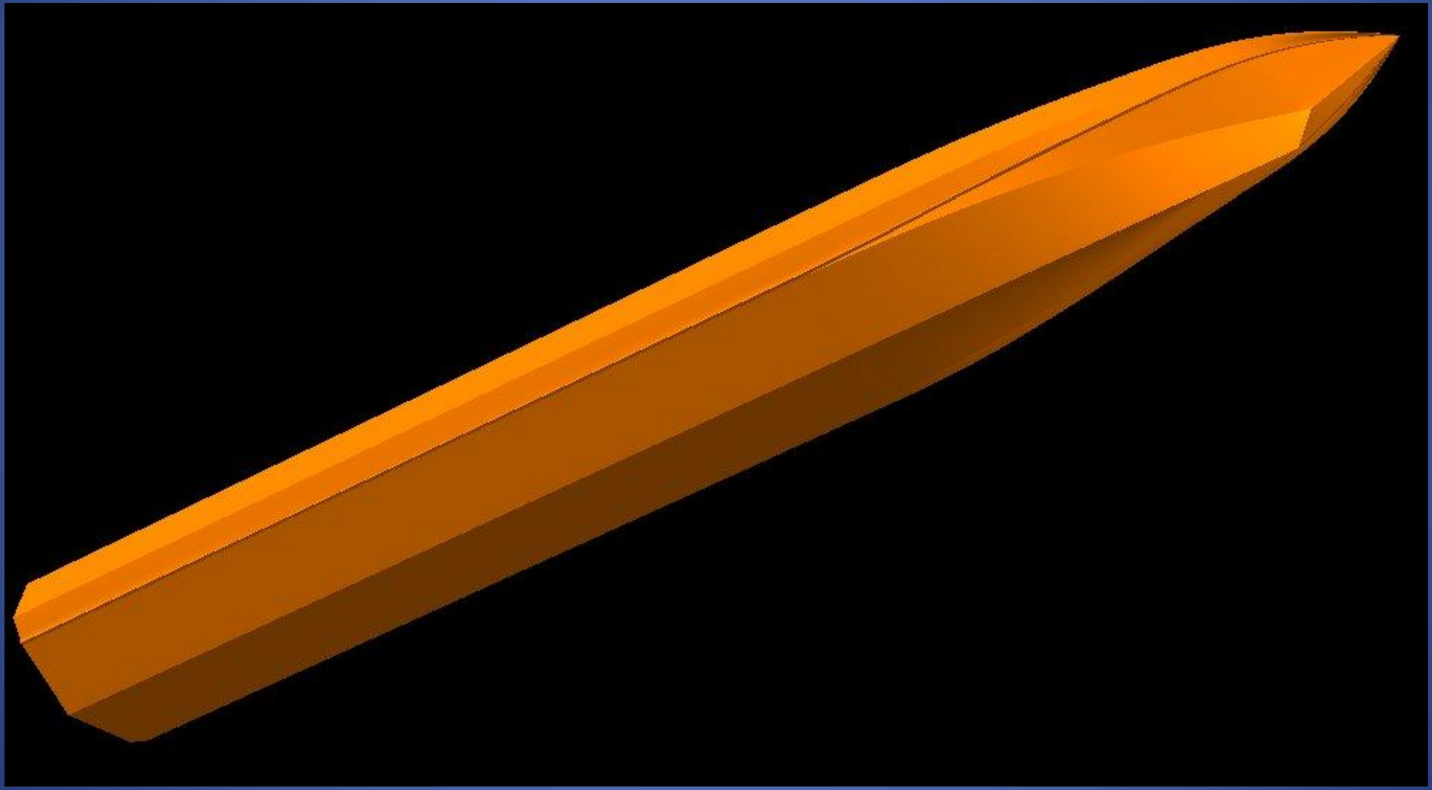
The employed wash measure W is defined equal to:

$$W = \sqrt{\frac{1}{x_2 - x_1} \int_{x_1}^{x_2} \zeta(x)^2 \, dx}$$

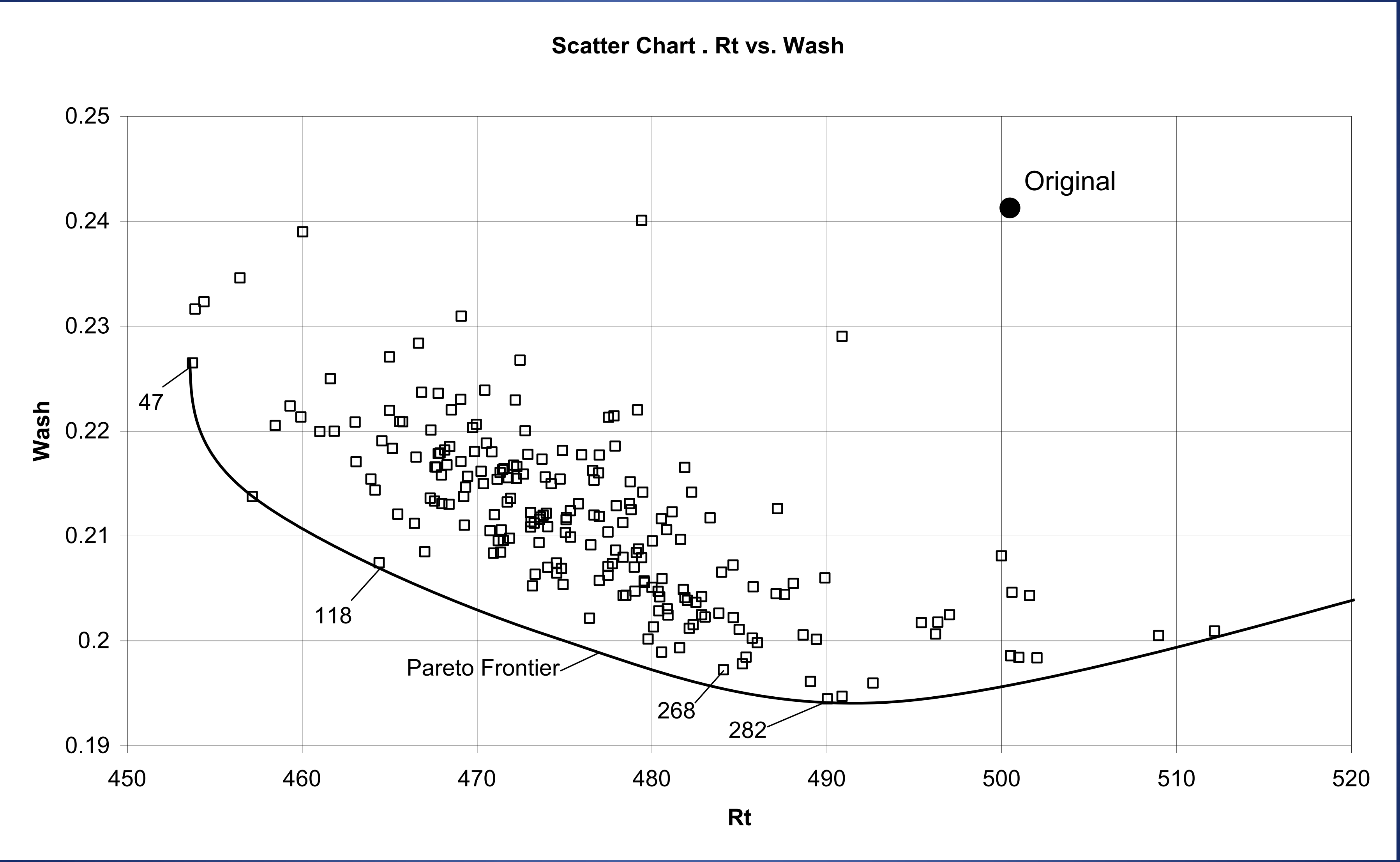
Parametric geometric design



Development of a low–wash semi–displacement monohull vessel



Optimization Results - Monohull

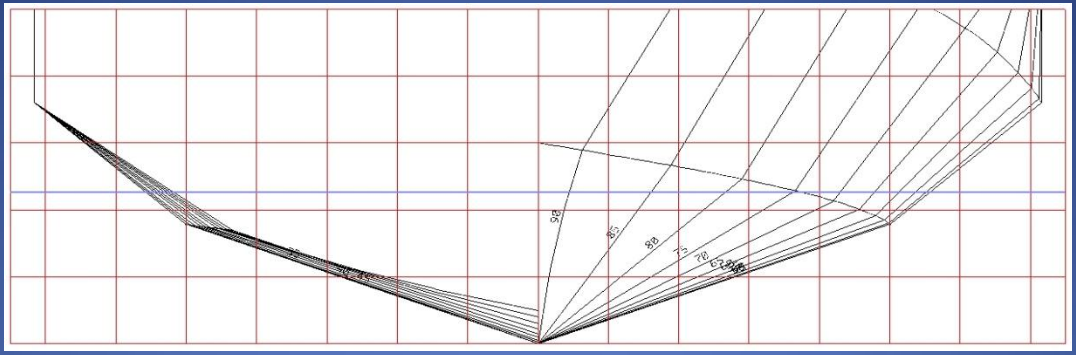


Comparison of Hullforms - Monohull

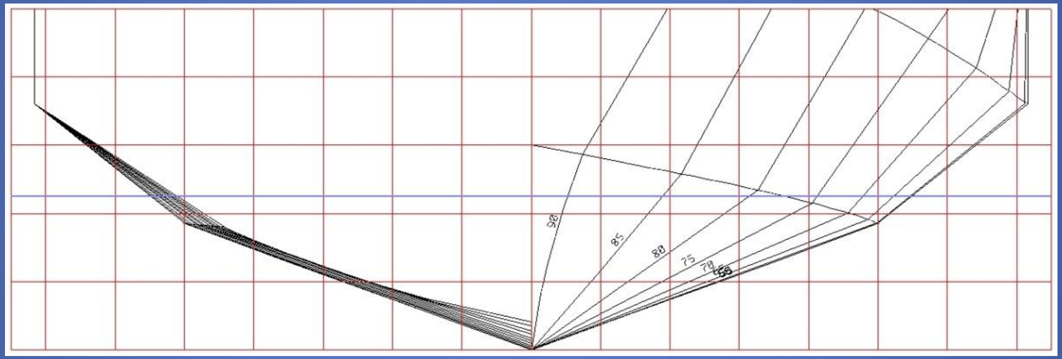
	ORIGINAL	HULL 47	HULL 118	HULL 268	HULL 282
LWL [m]	87,480	91,904	91,899	91,848	91,856
Maximum breadth [m]	15,000	14,320	14,320	14,320	14,320
Draft at FP [m]	2,280	2,261	2,248	2,119	2,141
Draft at AP [m]	2,059	1,761	1,831	2,119	1,891
Displacement [t]	1041,170	1035,300	1035,300	1035,300	1035,300
LCB from AP [m]	36,667	40,266	41,536	41,955	42,620
Block coefficient Cb	0,410	0,395	0,397	0,421	0,417
WSA [m²]	990,000	952,000	961,000	981,000	983,000
WLA [m²]	897,200	845,900	861,500	888,600	893,000
Transom stern area (TSA) [m²]	13,736	11,114	11,289	11,176	10,701
Half entrance angle [deg]	12,800	13,680	16,341	19,096	16,879
KMT [m]	13,451	8,798	8,922	9,413	9,589
Cw	1,259E-03	1,112E-03	1,173E-03	1,236E-03	1,279E-03
Cf (ITTC)	1,438E-03	1,430E-03	1,430E-03	1,430E-03	1,430E-03
Rw (N)	2,314E+05	1,966E+05	2,092E+05	2,251E+05	2,334E+05
Rf (N)	2,643E+05	2,527E+05	2,551E+05	2,604E+05	2,610E+05
Rt [N]	500482,1	449327,5	464357,6	485518,6	494374,1
Rt/Displacement [kg/t]	49,000	44,255	45,735	47,819	48,692
Wave wash W [m]	0,241	0,223	0,207	0,200	0,196
Dynamic trim [deg]	0,619	0,536	0,387	0,331	0,286
Draft variation at FP [m]	0,437	0,346	0,191	0,130	0,077
Draft variation at AP [m]	-0,50915035	-0,514	-0,429	-0,400	-0,382

Comparison of Body Plans

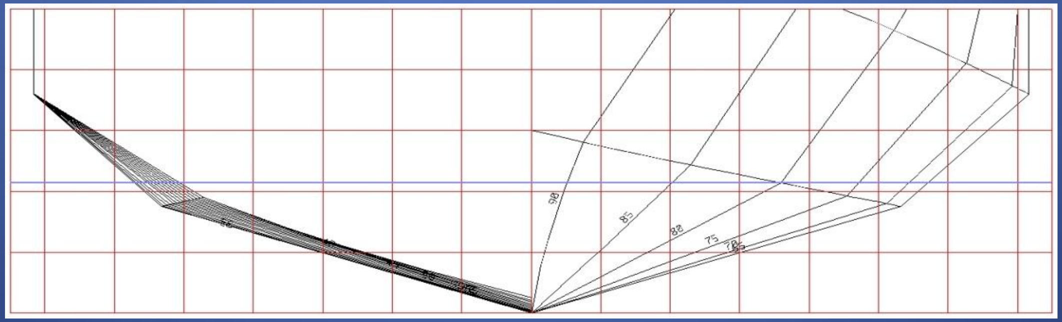
Hull 47



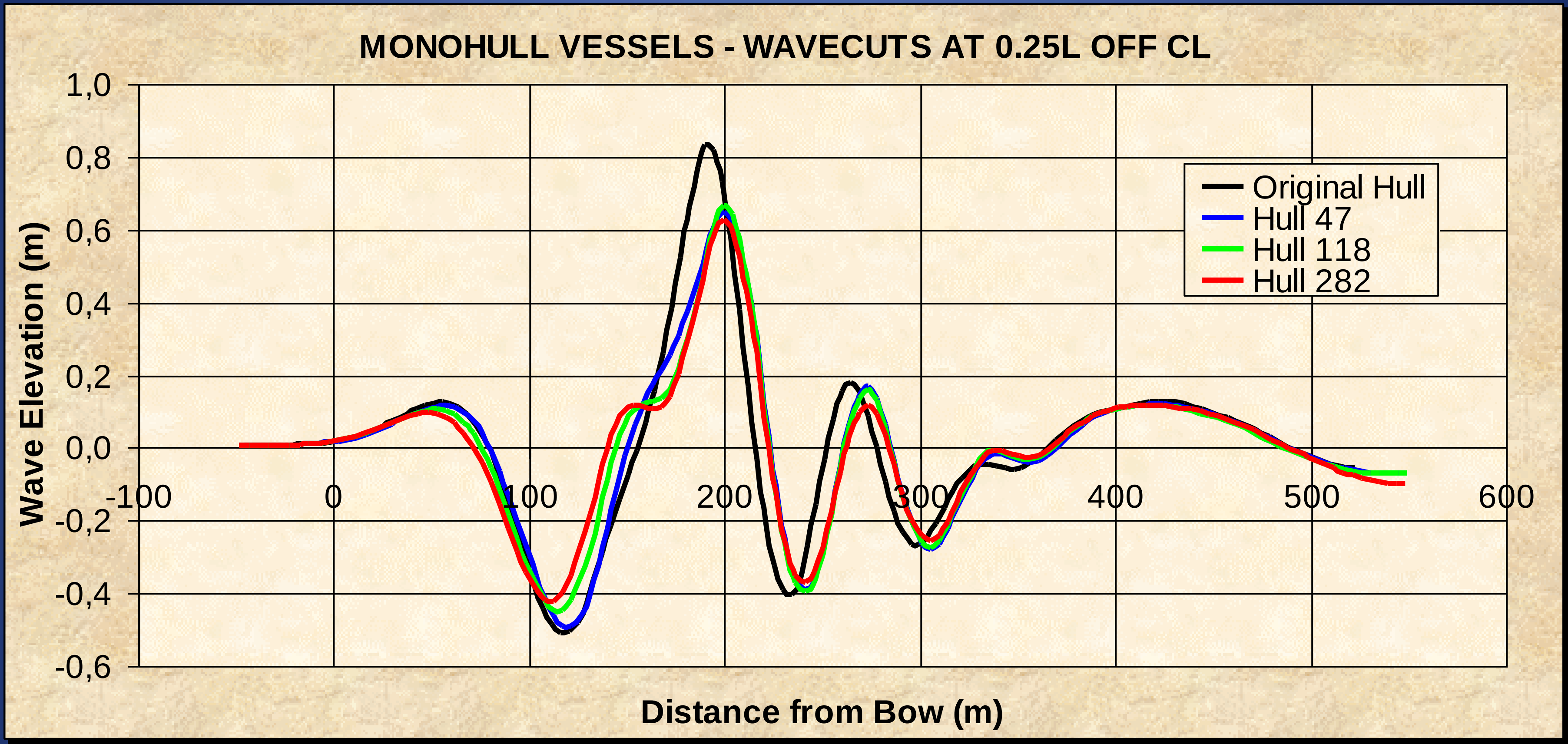
Hull 118



Hull 282

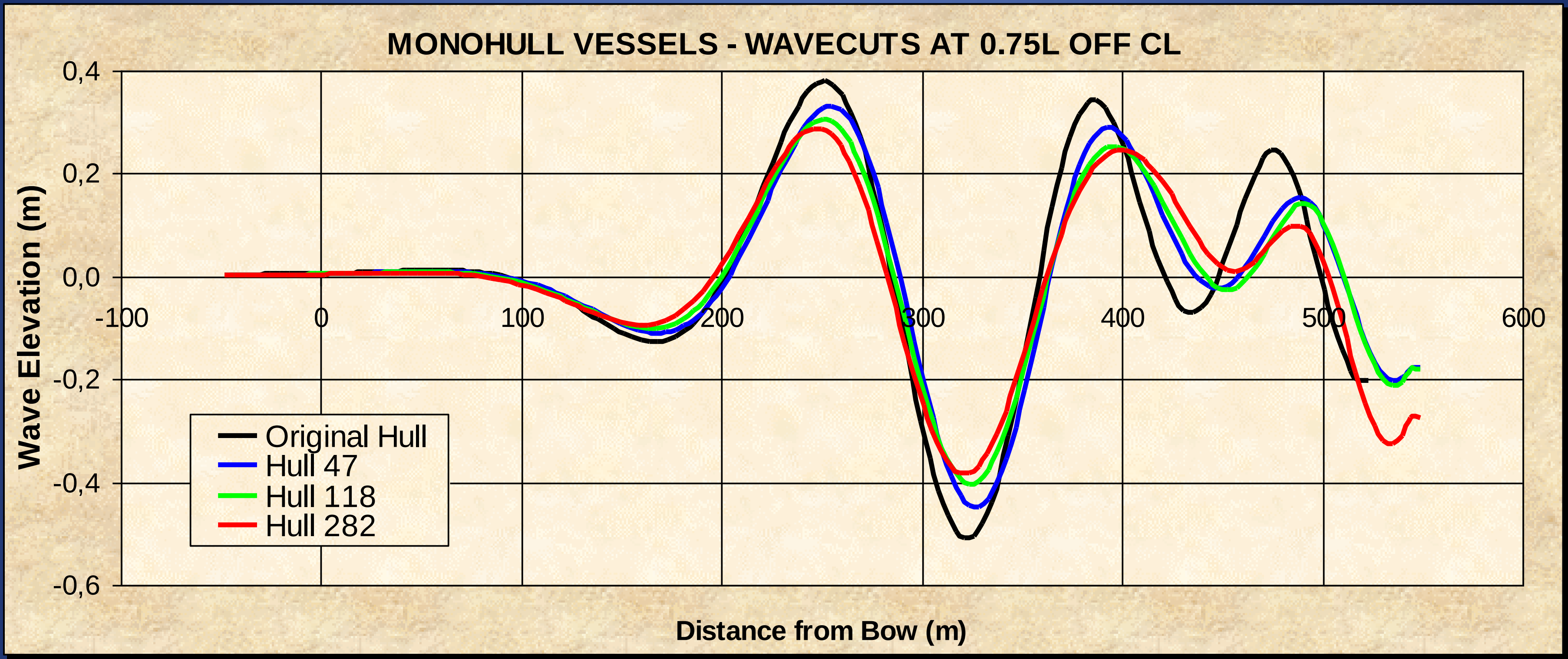


Comparison of Wave Cuts at 0.25L off CL



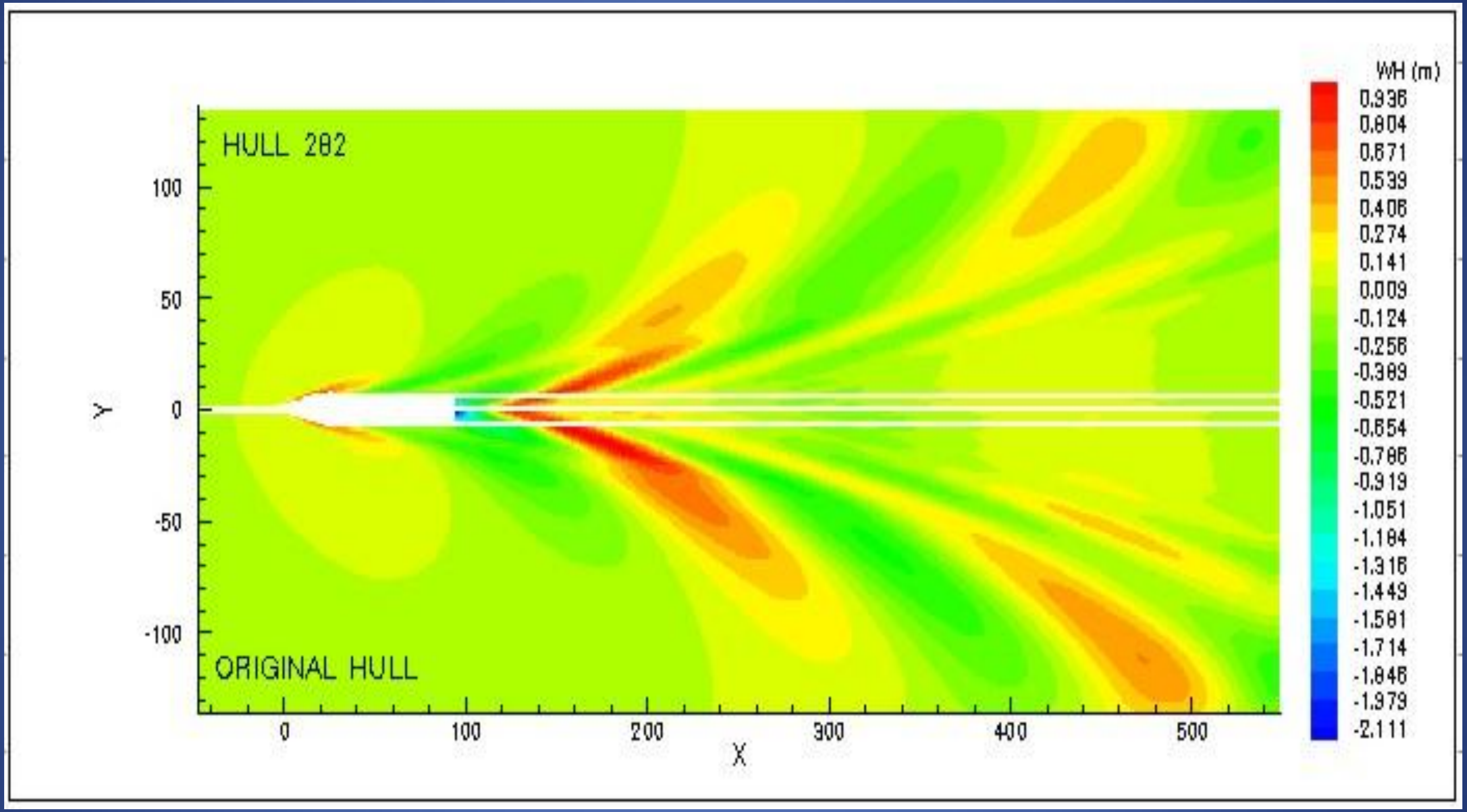
HULL	R_T (kN)	Diff (%)	W (m)	Diff (%)	H_{MAX} (m)	Diff (%)
Original	500,5	0,0	0,231	0,0	1,338	0,0
Hull 047	449,3	-10,2	0,220	-4,8	1,1368	-15,0
Hull 118	464,3	-7,2	0,191	-17,3	1,1095	-17,1
Hull 282	494,4	-1,2	0,180	-22,1	1,0503	-21,5

Comparison of Wave Cuts at 0.75L off CL

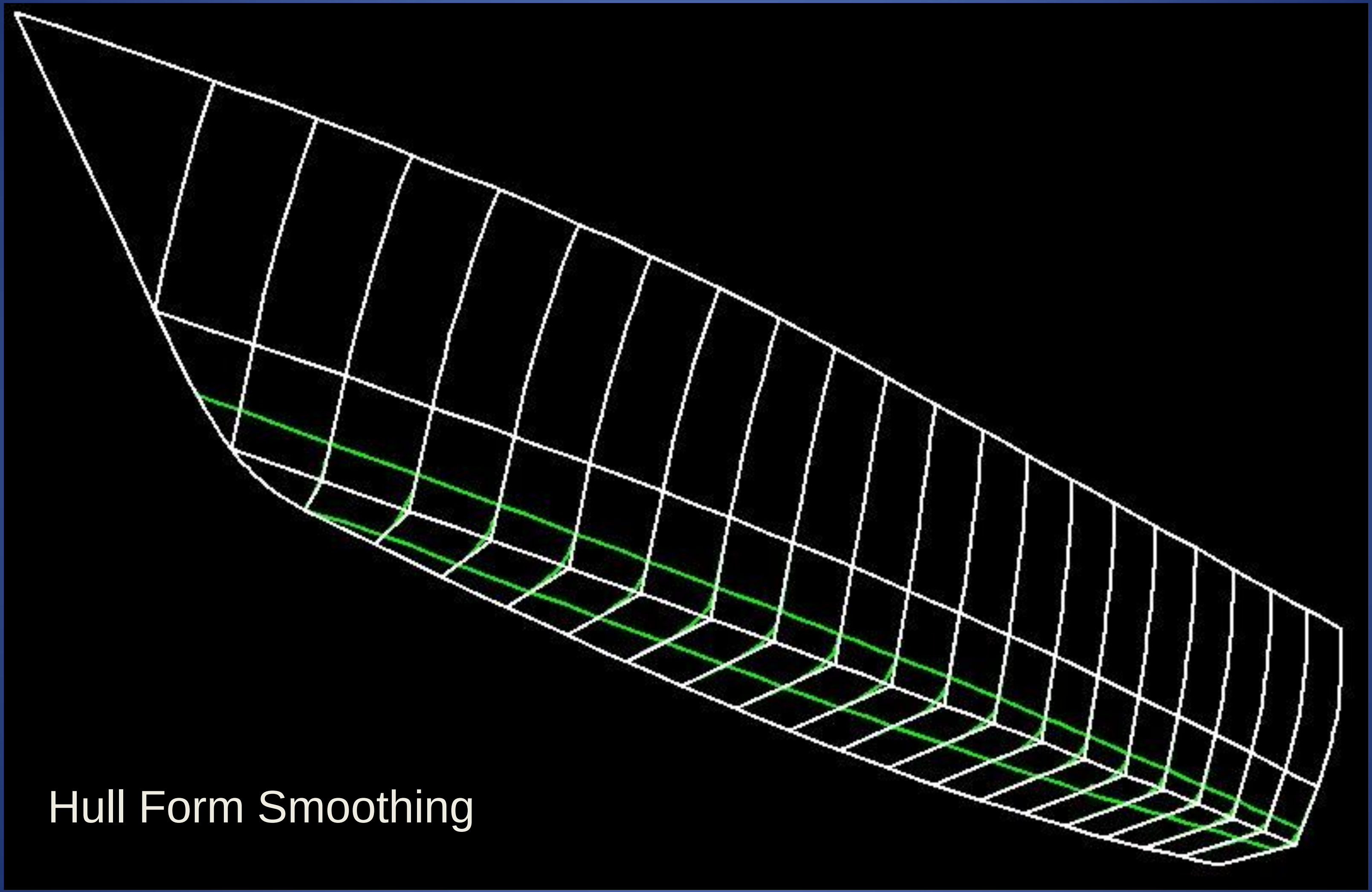


HULL	R_T (kN)	Diff (%)	W (m)	Diff (%)	H_{MAX} (m)	Diff (%)
Original	500.5	0.0	0.184	0.0	0.8889	0.0
Hull 047	449.3	-10.2	0.157	-14.7	0.781	-12.1
Hull 118	464.3	-7.2	0.143	-22.3	0.7088	-20.3
Hull 282	494.4	-1.2	0.139	-24.5	0.6712	-24.5

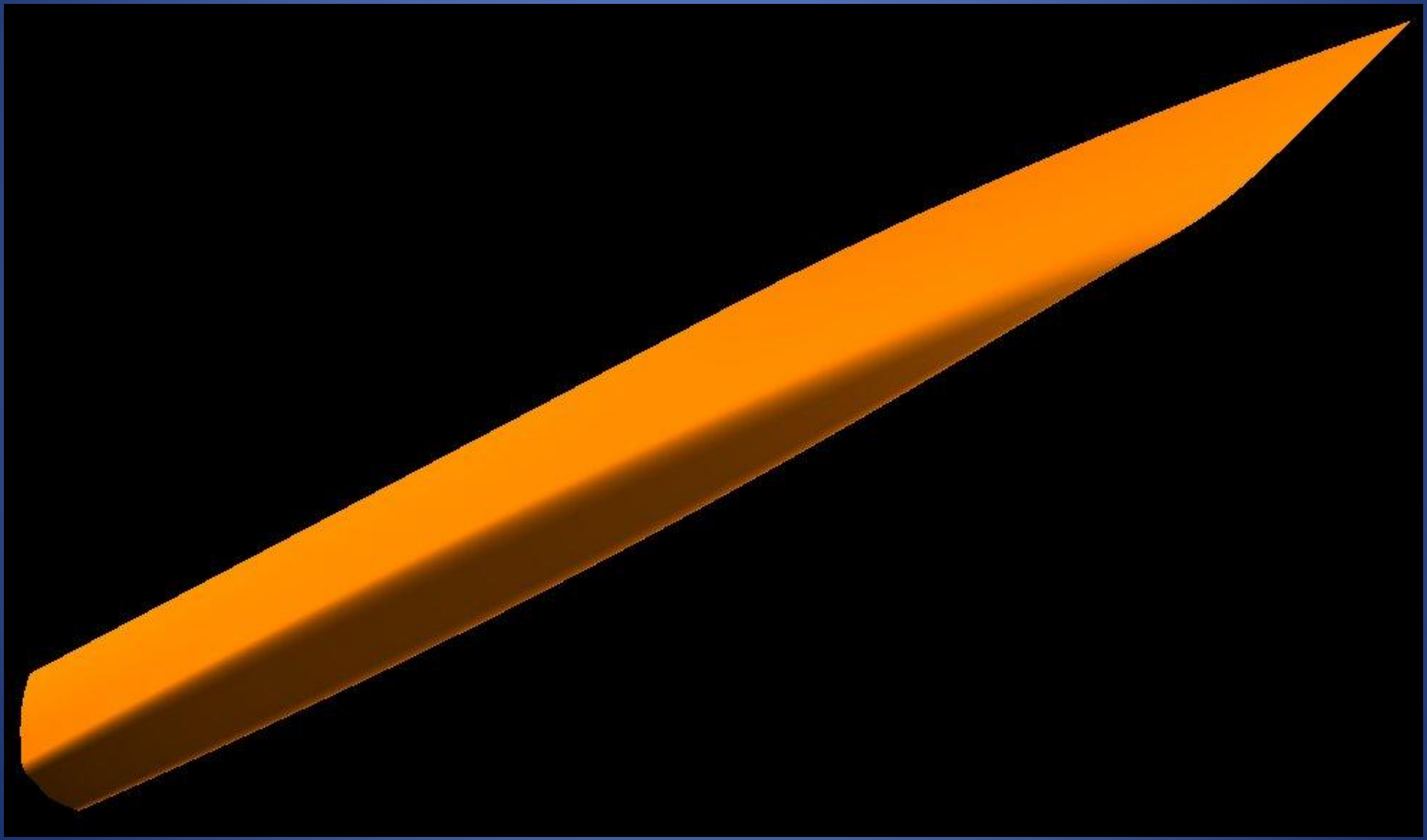
Comparison of Wave Patterns - Monohull



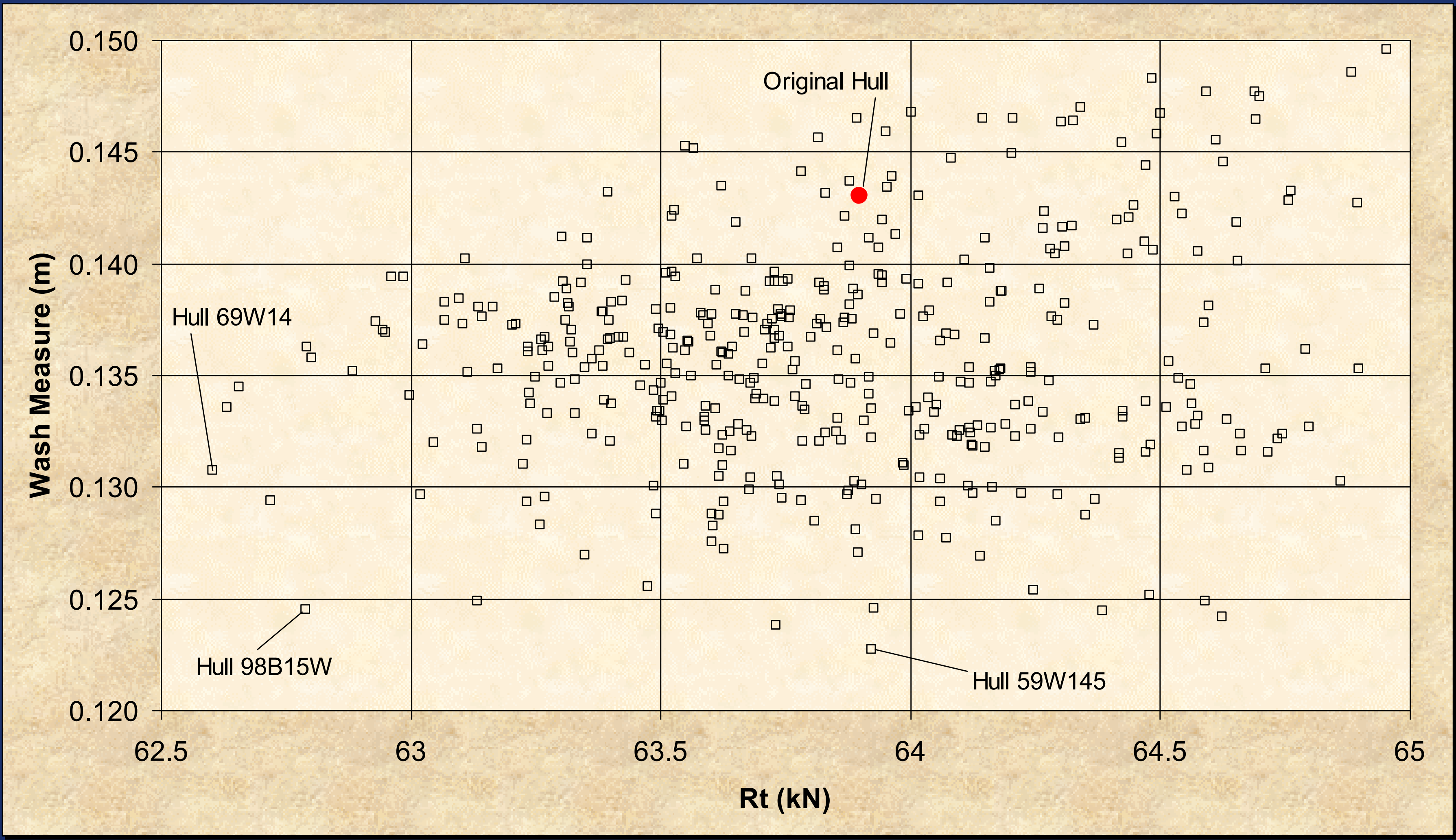
Hull Form Definition: Stage 2



Development of a low–wash high–speed catamaran vessel



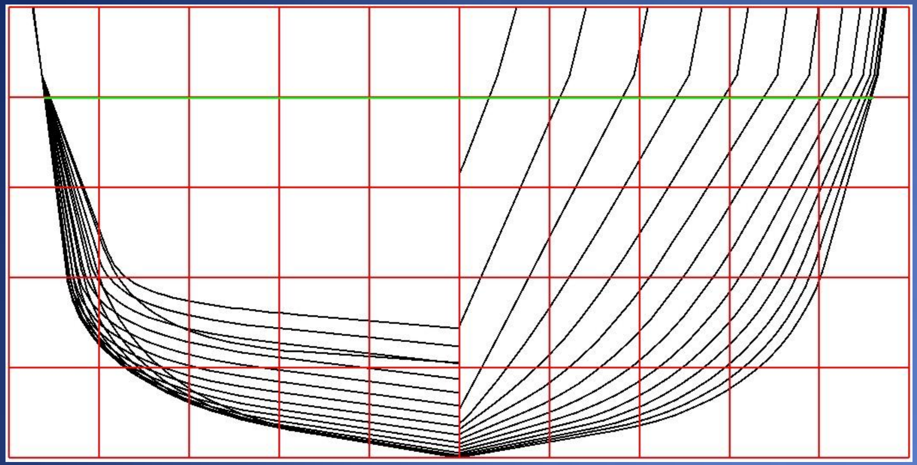
Optimization Results – high-speed catamaran



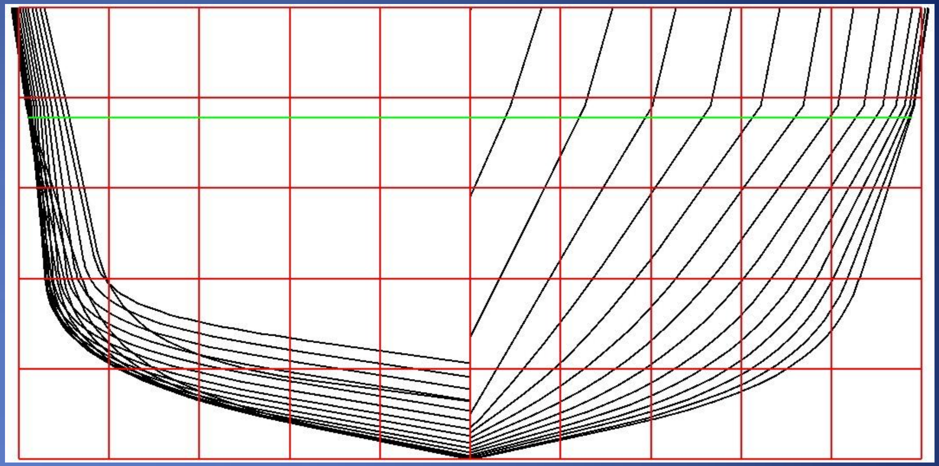
Comparison of Hullforms – high-speed catamaran

	Original	98W15	69(W14)	59 (W14.5)
LWL [m]	29,490	29,386	29,306	29,435
BWLN [m]	2,285	2,279	2,102	2,442
Draft [m]	1,142	1,002	1,050	0,946
Displacement [t]	85,500	84,284	84,284	84,285
LCB/aft PP [m]	12,289	12,692	12,559	12,608
Block coefficient Cb	0,312	0,306	0,318	0,303
WSA [m²]	176,072	175,598	174,177	177,037
WLA [m²]	102,483	117,000	110,200	123,200
Cw	7,485E-03	7,112E-04	7,231E-04	7,352E-04
Cf (ITTC)	1,709E-03	1,710E-03	1,711E-03	1,710E-03
Rw (N)	19463	18443	18600	19223
Rf (N)	44447	44348	44005	44702
Rt [N]	63910	62791	62605	63924
Rt/Displacement [kg/t]	76,220	75,965	75,740	77,335
Wash meassure W [m]	0,143	0,125	0,131	0,123
Sinkage [m]	0,049	0,039	0,046	0,043
Dynamic trim [deg]	0,371	-0,236	-0,148	-0,238
Draft variation at FP [m]	0,144	-0,020	0,008	-0,018
Draft variation at AP [m]	-0,047	0,101	0,084	0,104

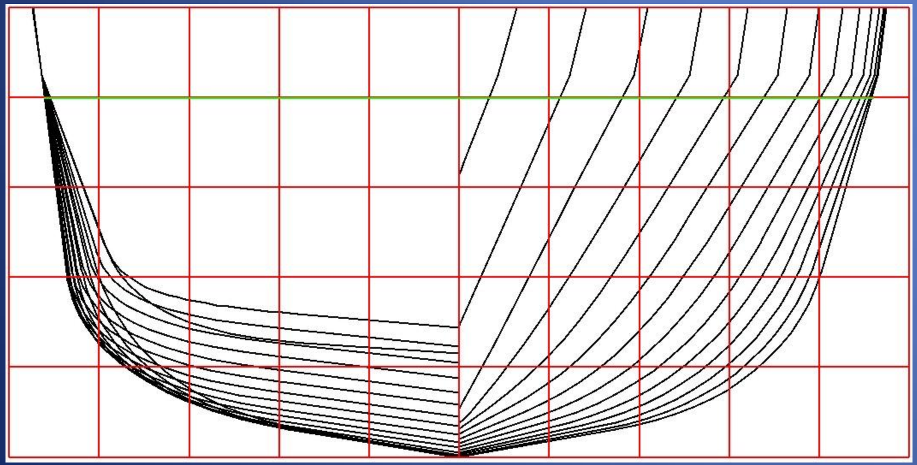
Comparison of Body Plans



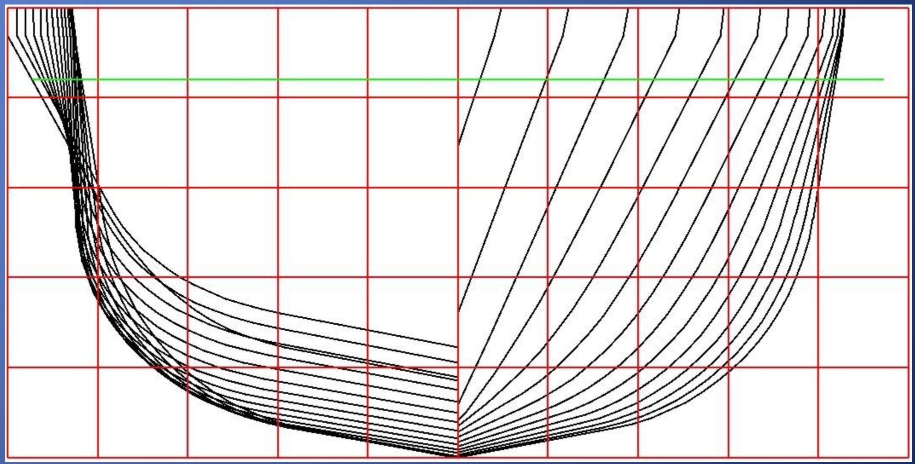
Hull 98B15W



Hull 59W145

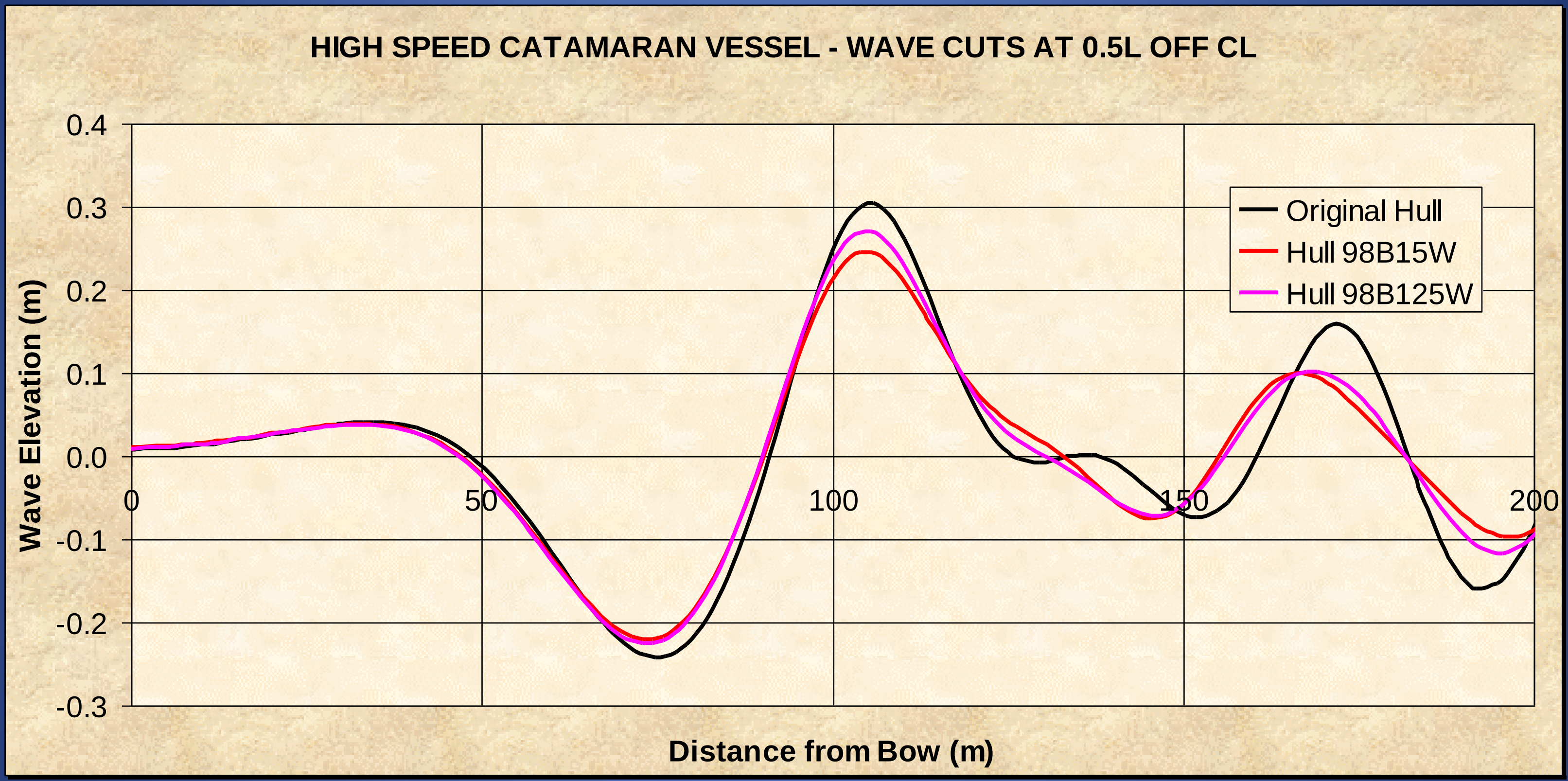


Hull 98B125W



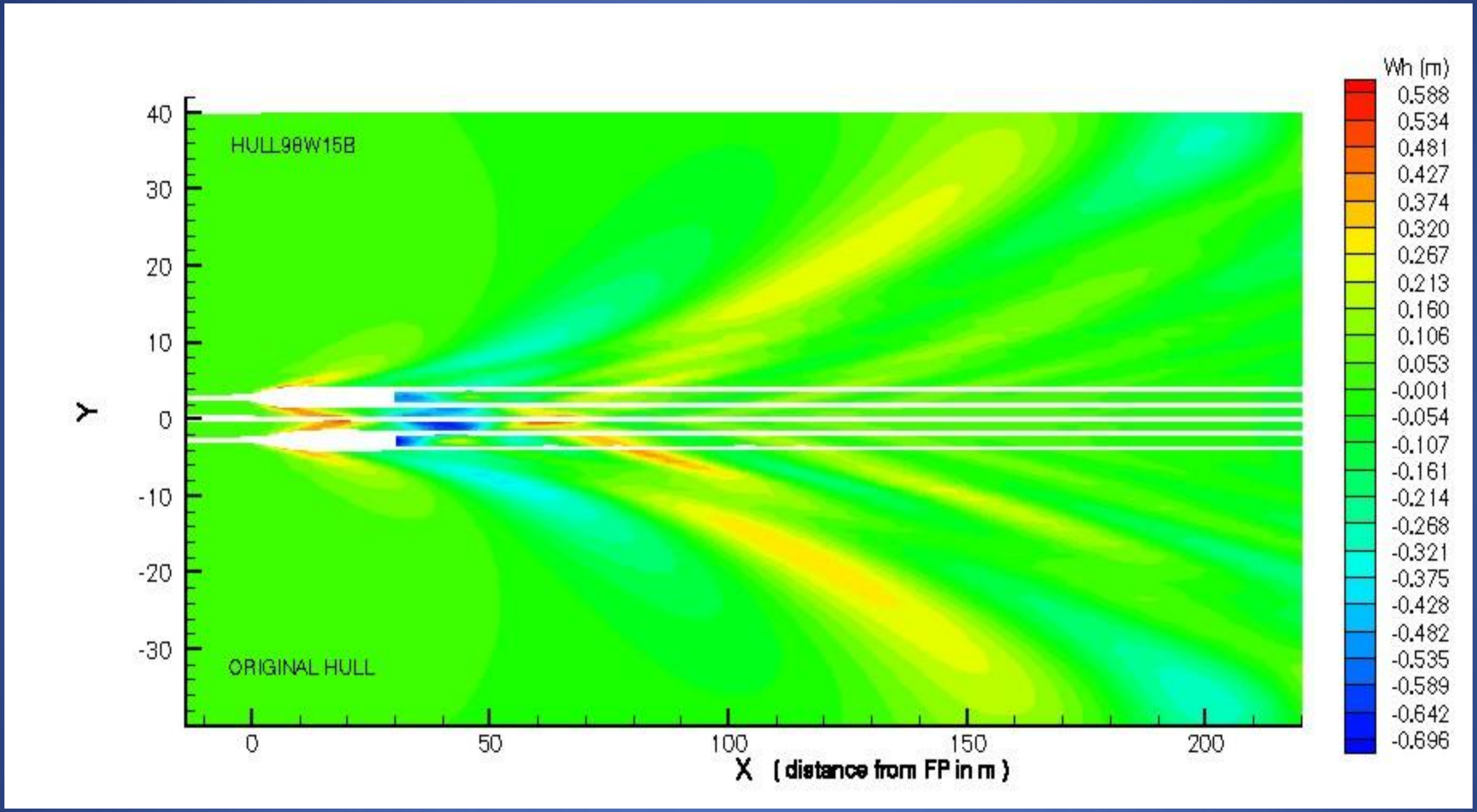
Hull 69W140

Comparison of Wave Cuts at 0.50L off CL



HULL	R_T (kN)	Diff (%)	W (m)	Diff (%)	H_{MAX} (m)	Diff (%)
Original vessel	64.09	0	0.116	0	0.546	0
Hull no 98B15W	63.65	-0.70%	0.1	-13.80%	0.462	-15.40%
Hull no 98B125W	63.76	-0.50%	0.105	-9.50%	0.496	-9.20%

Comparison of Wave Patterns

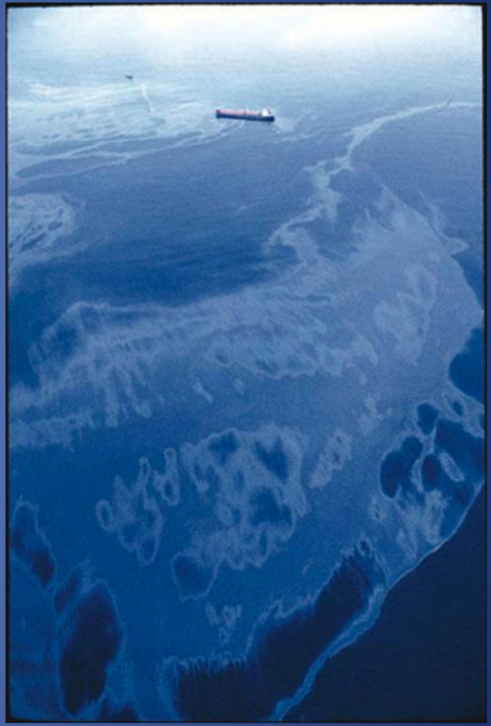


Holistic Optimization of Tanker Ships

EU FP6 project SAFEDOR (2005-2009) and GL-NTUA BEST+ (2009-2011)

State of the Market

- Following a series of catastrophic single hull tanker accidents (in European waters: ERIKA & PRESTIGE), currently in force IMO regulations (and long before US OPA90) recognised double hull tanker designs as the only acceptable solution for the safe carriage of oil in tanker ships.
- Recently introduced, accelerated phase-out of single hull tankers by EU (ERIKA I, II & III packages) and IMO-MEPC50 has increased the pace of transformation/renewal of the world oil tanker fleet.
- The resistance towards the acceptance of alternative double hull tanker designs by the authorities (and the industry) has been limiting creativity within the industry, though currently in force MARPOL regulations appear challengeable without increasing the risk of negative environmental impact.
- AFRAMAX class tankers, considered in this study, are today mainly built by Far East yards and are among the most successful tanker categories.

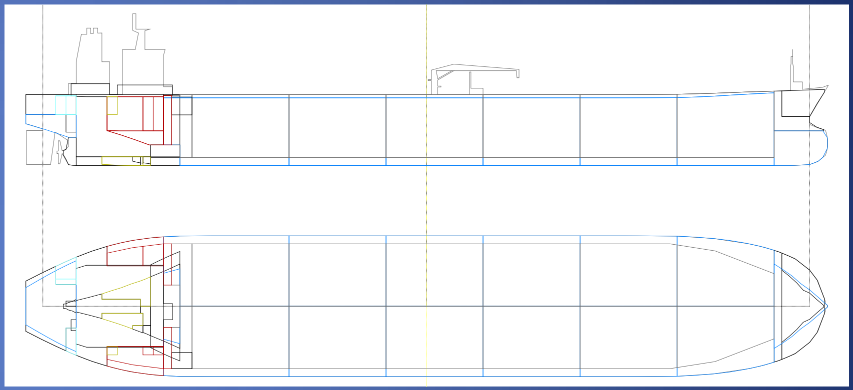


Outline of Early Research

- Optimization of an AFRAMAX tanker with respect to:
  - maximization of cargo capacity
  - minimization of steel weight
  - while minimizing the risk of accidental oil outflow according to MARPOL
- This is a multi-objective optimisation problem with multiple constraints
- The steel weight of generated design solutions is calculated using GL-POSEIDON software; this ensures realistic estimates of the weight impact on the different design solutions
- Background research: SAFEDOR 6.9 subproject (Risk-based design of AFRAMAX tanker); extended through a new collaborative project of NTUA-SDL and Germanischer Lloyd
- Background regulatory developments:
  - Tanker FSA – ALARP - CATS
  - Common Structural Rules-Goal Based Standards

Case Study Vessel: AFRAMAX Tanker

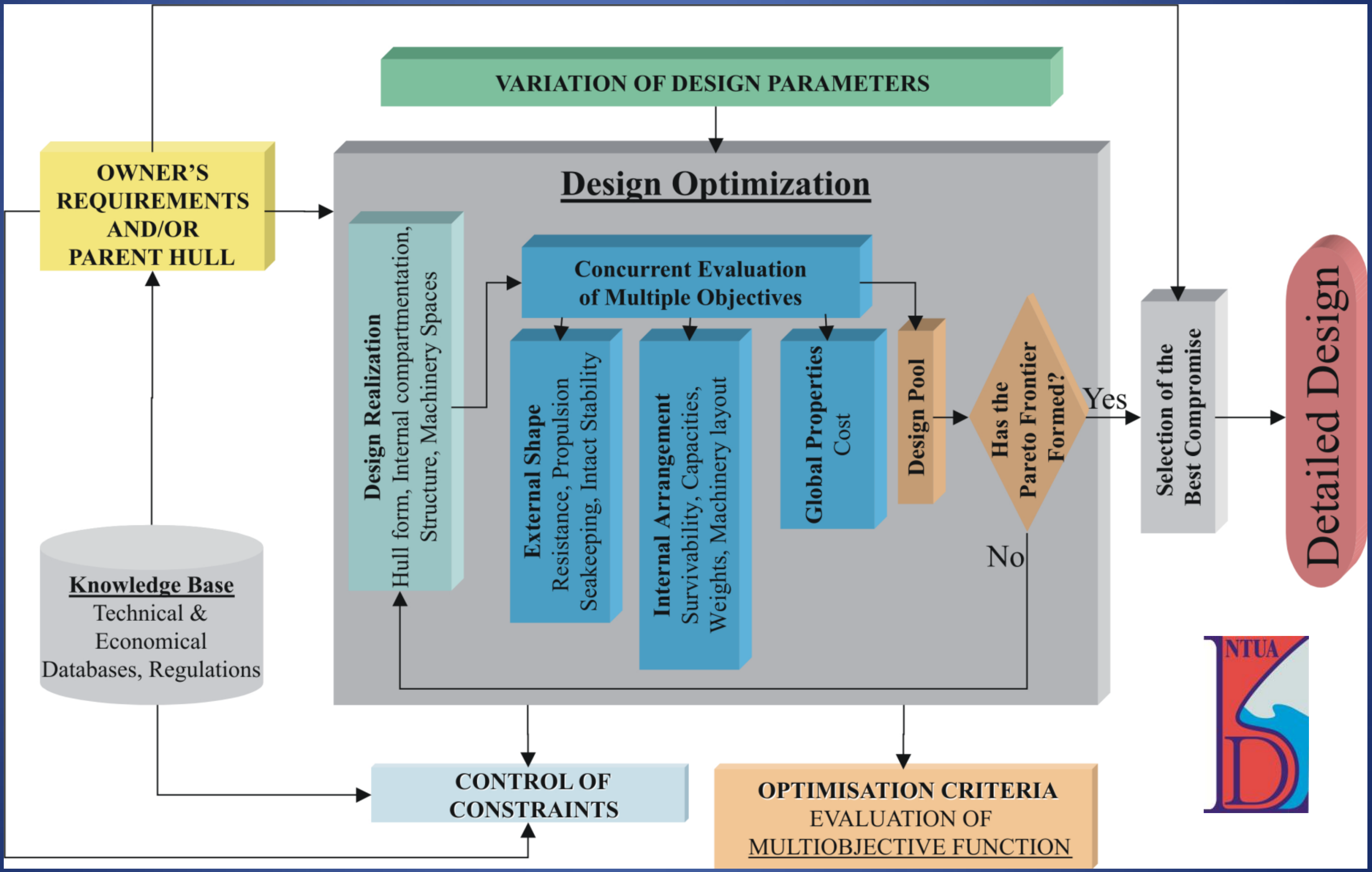
Length, oa	250.10m
Length, bp	239.00m
Breadth, moulded	44.00m
Depth, moulded to main deck	21.00m
Width of double skin	
sides	2.50m
bottom	2.50m
Draught (scantling)	14.60m
Deadweight	
at scantling draught (comparable with design proposed)	109,800dwt (cargo density 0.868 t/m3)
Cargo capacity	
liquid cargo volume	122,375m3+2830m3 (Slop)
heavy oil	3,380m3
diesel oil	260m3
Water ballast	41,065m3 + 3,500 m3 (peaks)
Classification	Lloyds Register
Propeller Diameter	7,200mm
Number Cargo tanks	12 plus 2 slop tanks
Cargo Tanks Block length	181.44 m



Main data of reference vessel disposed by the EU funded FP6 project POP&C

Case study was conducted by a design team consisting of NTUA-Greece, SSRC-UK, NAVANTIA-Spain, Alpha-Marine-Greece and LR-UK within subproject 6.9 of SAFEDOR (http://www.safedor.org)

GENERIC OPTIMIZATION NTUA-SDL

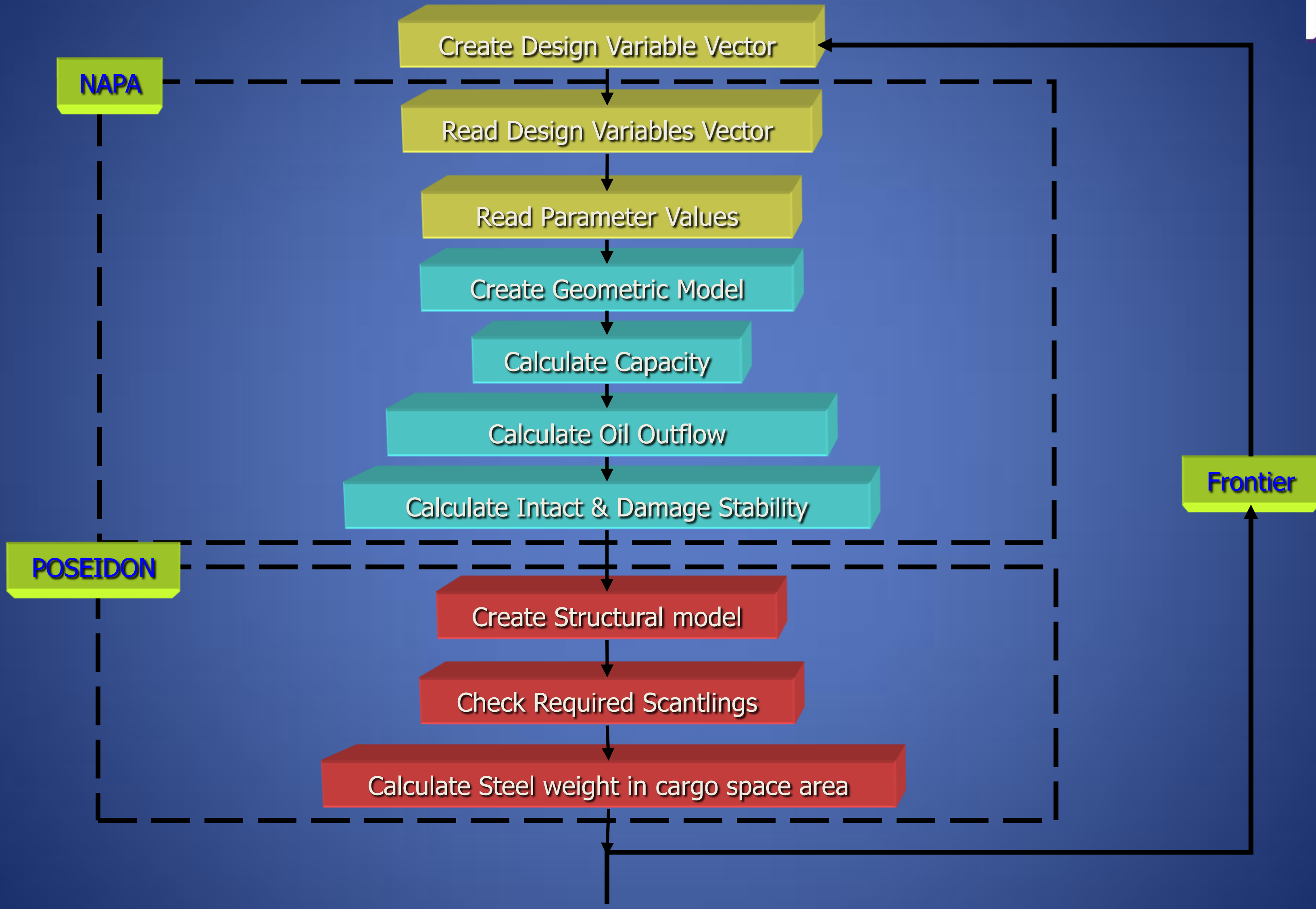


Objectives & Constraints

- **OBJECTIVES**
  - Maximization of the CARGO CAPACITY
  - Minimization of the ACCIDENTAL OIL OUTFLOW
  - Minimization of STEEL WEIGHT
- **CONSTRAINTS**

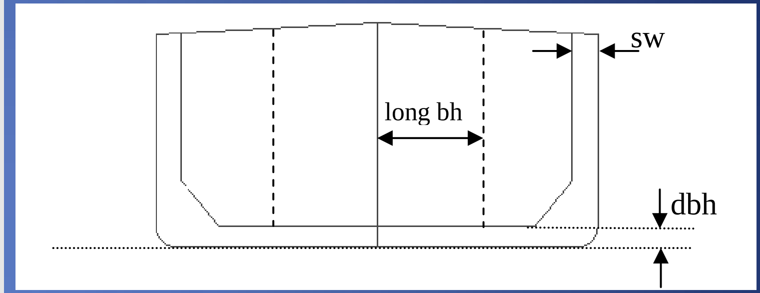
  The constraints used were:
  - MARPOL Reg. 18 requirements (mean draft, trim, propeller immersion etc.)
  - MARPOL Reg. 23 (accidental oil outflow)
  - Intact stability requirements
  - Damage stability requirements

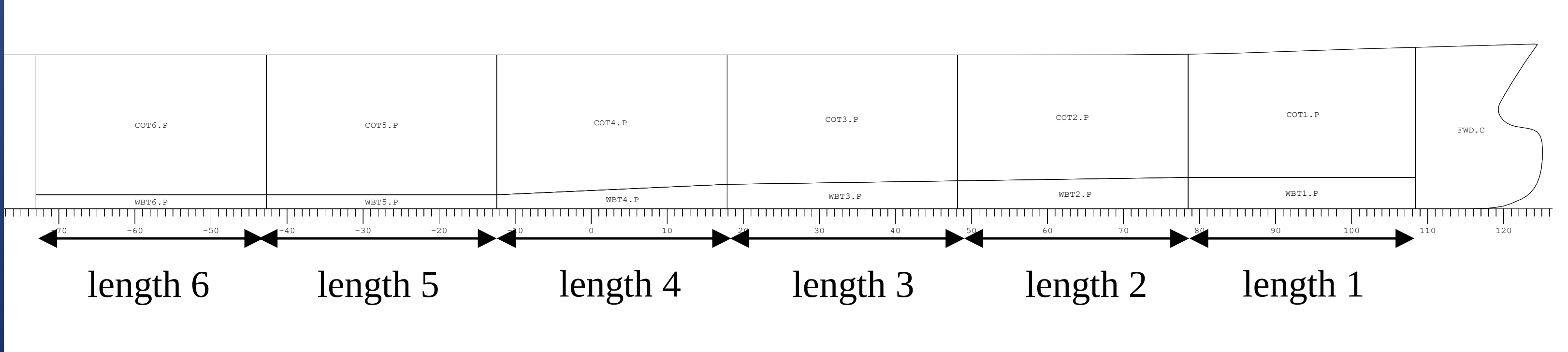
Optimization Flowchart



Design Parameters

Variable	*Explanation*
Layout type	0: Double Hull, 1: SBT-PL, 2: Hybrid Hull
long bh	Position of the longitudinal bulkhead from C.L.
dbh 1,..,6	Double Bottom height for Cargo Tank 1…6
sw 1,..,6	Side wing tank clearance 1…6
length 1,..,6	Length of Cargo Tank 1…6 / Length of the cargo block
centre 1,..,6	0: Ballast Tank, 1: Cargo Tank
side 1,..,6	0: Ballast Tank, 1: Cargo Tank
Aft limit	Aft limit of Cargo Block
Fwd limit	Forward limit of Cargo Block





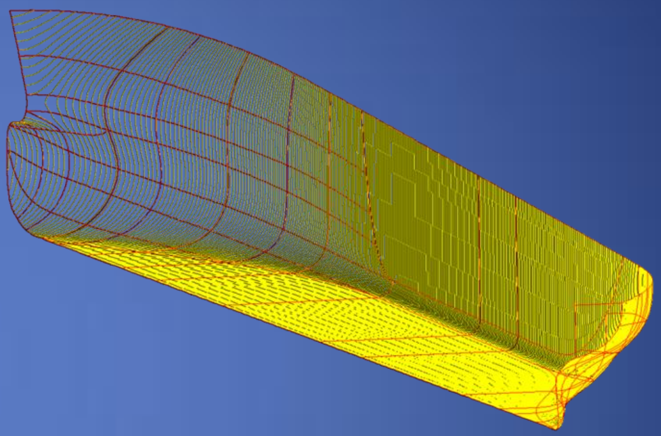
Structural Design Parameters

- **STRUCTURAL DESIGN PARAMETERS (21)**
  - NONDIMENTIONAL CORRUGATION GEOMETRY PARAMETER e (frame spacing/e)
  - NONDIMENTIONAL CORRUGATION GEOMETRY PARAMETER b [b/e]
  - NONDIMENTIONAL CORRUGATION GEOMETRY PARAMETER d [d/e]
  - VERT. DISTANCE BETWEEN TOP SIDE OF BOTTOM STOOL AND DOUBLE BOTTOM [MM]
  - VERT. DISTANCE BETWEEN BOTTOM SIDE OF TOP STOOL AND STRENGTH DECK ON CENTER LINE [MM]
  - BREADTH BOTTOM STOOL FOR LONG BULKHEAD [MM]
  - BREADTH TOP STOOL FOR LONG BULKHEAD [MM]
  - BREADTH BOTTOM STOOL FOR TRANS BULKHEAD [MM]
  - BREADTH TOP STOOL FOR TRANS BULKHEAD [MM]
  - STIFFENER SPACING SHELL [M]
  - STIFFENER SPACING VERTICAL SEGMENT (INCL. HOPPER PLATE) [M]
  - STIFFENER SPACING DOUBLE BOTTOM [M]
  - STIFFENER SPACING STRENGTH DECK [M]
  - STIFFENER SPACING LONGITUDINAL GIRDERS [M]
  - STIFFENER SPACING STRINGER DECKS [M]
  - STIFFENER SPACING TRANSVERSE MEMBERS [M]
  - STIFFENER SPACING LONGITUDINAL BULKHEAD (IGNORED FOR CORRUGATED BULKHEADS) [M]
  - NUMBER OF STRINGER DECKS
  - Z-COORDINATE STRINGER DECK 1 [M]
  - Z-COORDINATE STRINGER DECK 2 (IGNORED IF NUMBER OF STRINGER DECK< 2) [M]
  - Z-COORDINATE STRINGER DECK 3 (IGNORED IF NUMBER OF STRINGER DECK < 3)

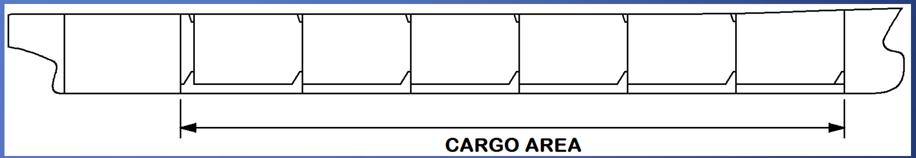
Parametric definition of internal arrangement by use of NAPA

Main assumptions (1):

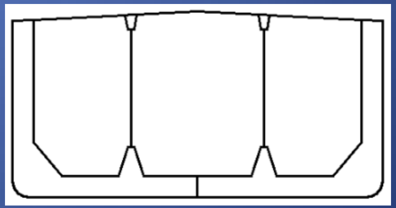
1. Fixed Hullform



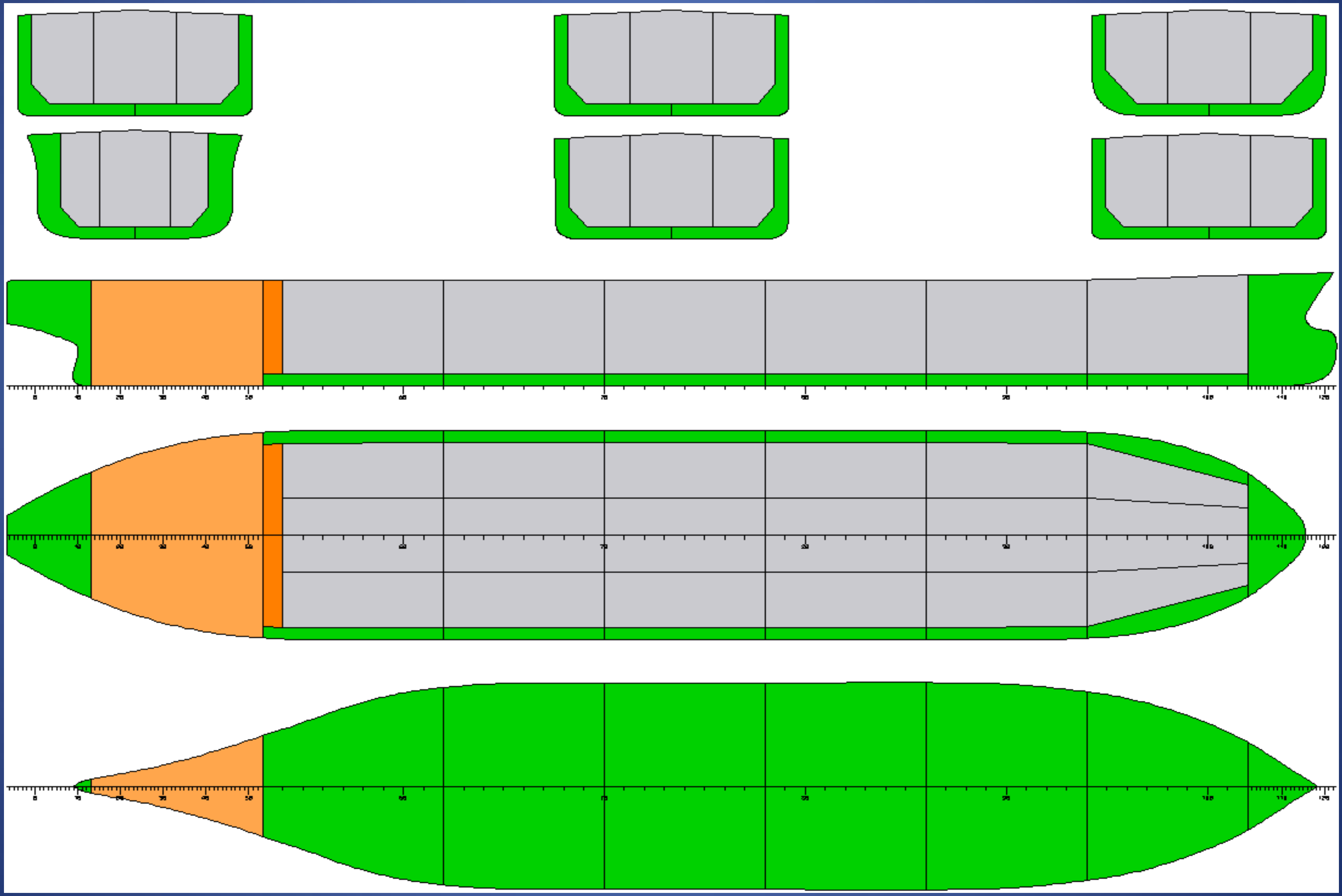
2. Fixed Cargo Length



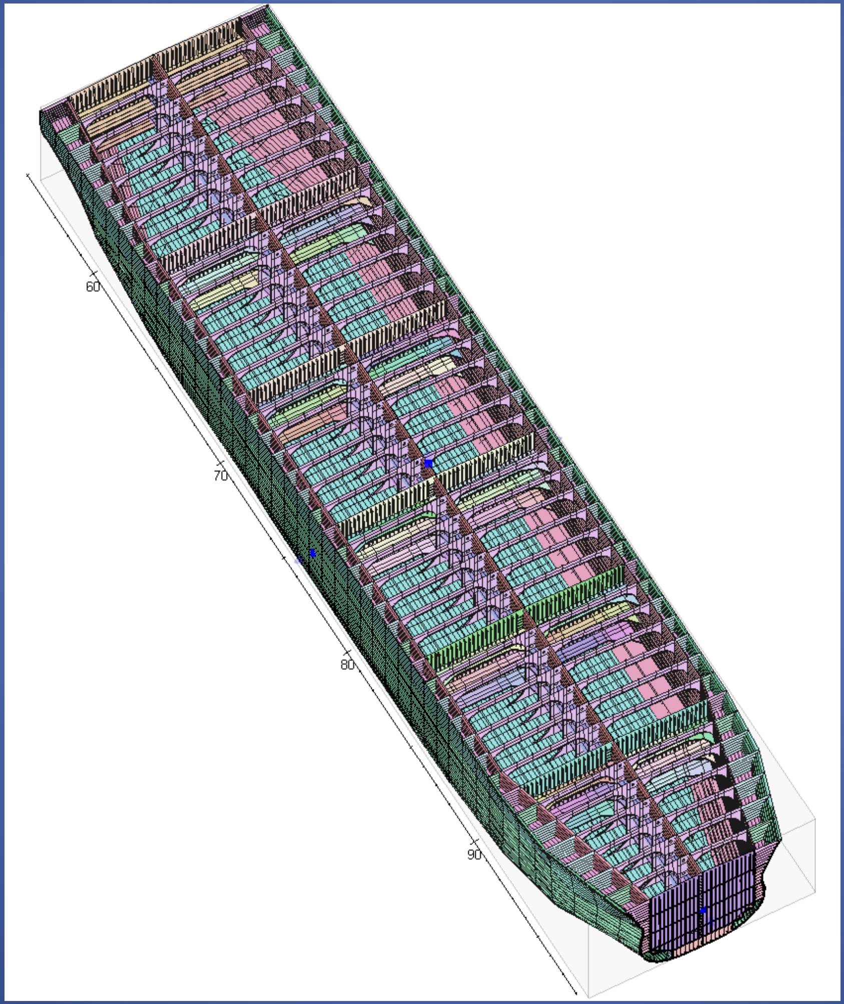
3. Double Hull Concept



Design Alternatives (3): example: 3x6 tanks, flat BHDs



POSEIDON MODEL

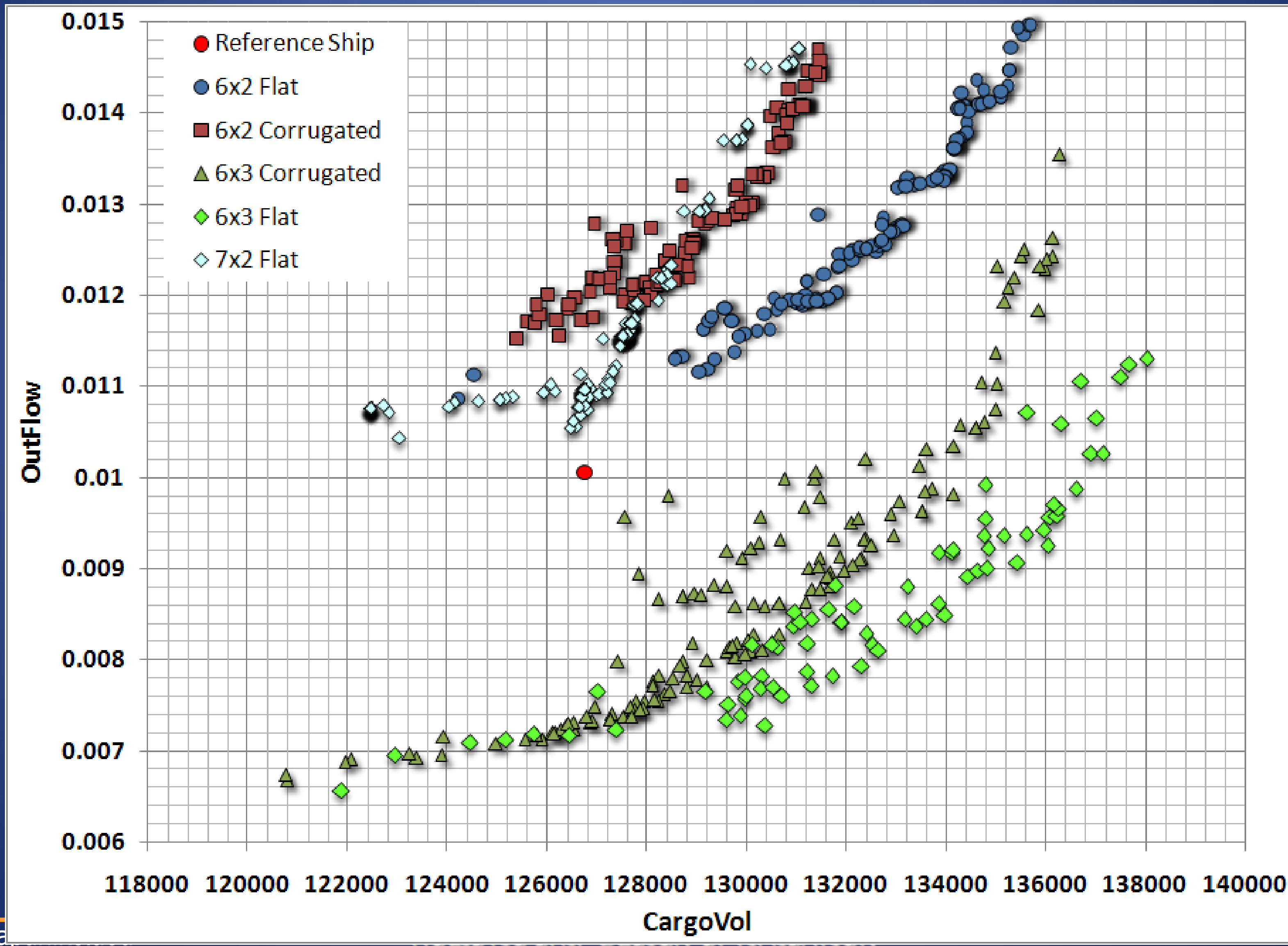


Explored Design Scenarios

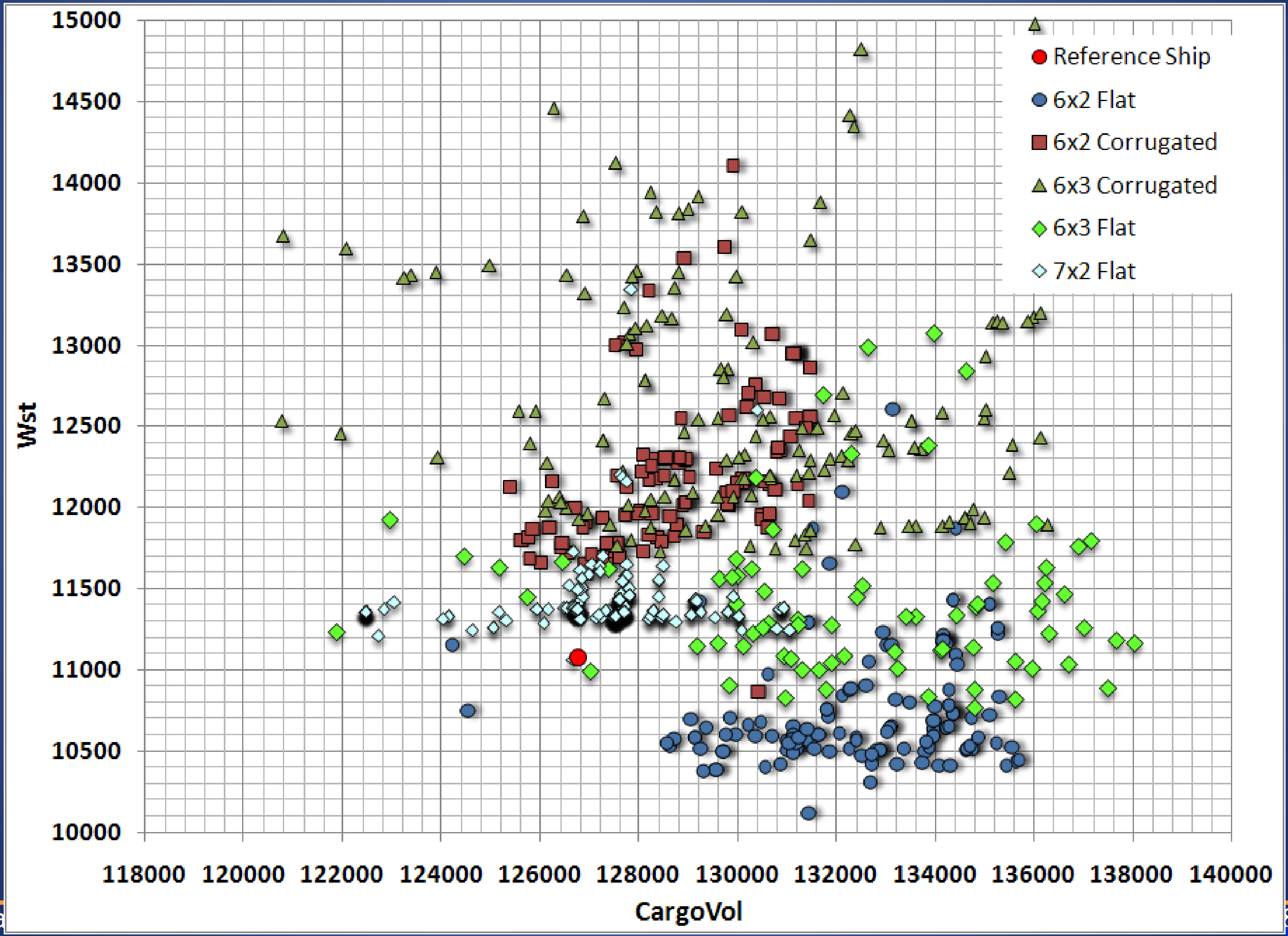
- Total no of design variables: 41
- Total Number of designs examined: >21,500 (25,000)
- Initially, four (4) different scenarios were examined for the arrangement with the 6 cargo tanks along the ship (corrugated and flat BHDs); later studies of 7x2 COT and most recently 5x3 COT (Dipl. Thesis L. Nikolopoulos)

	6x2 COT	6x3 COT	7x2 COT	5x3 COT (last)
Flat	7287	6147	3043	3000
Corrugated	1738	3270		

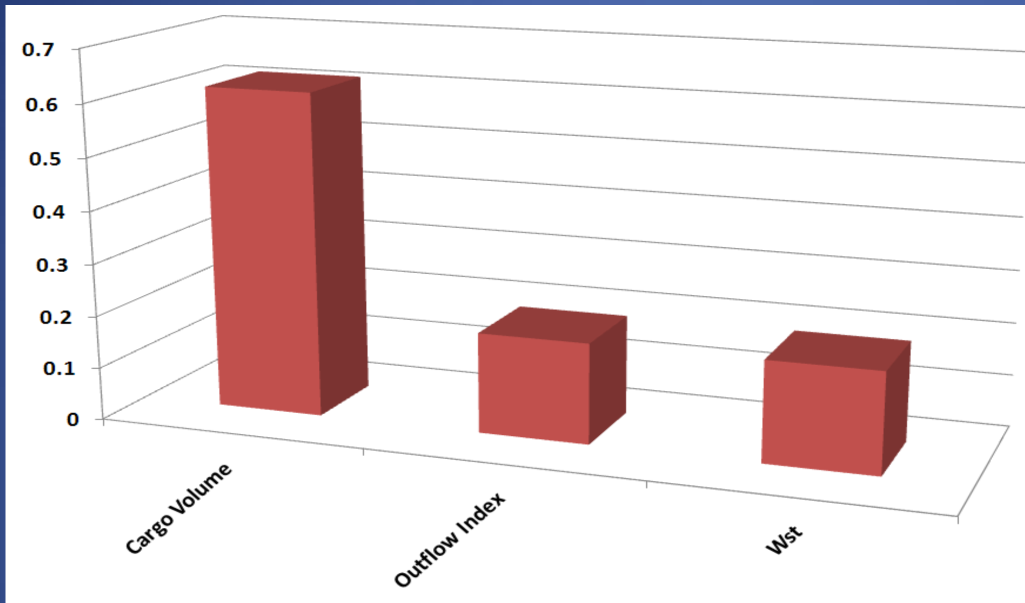
Comparison of Pareto Designs (1)



Comparison of Pareto Designs (2)

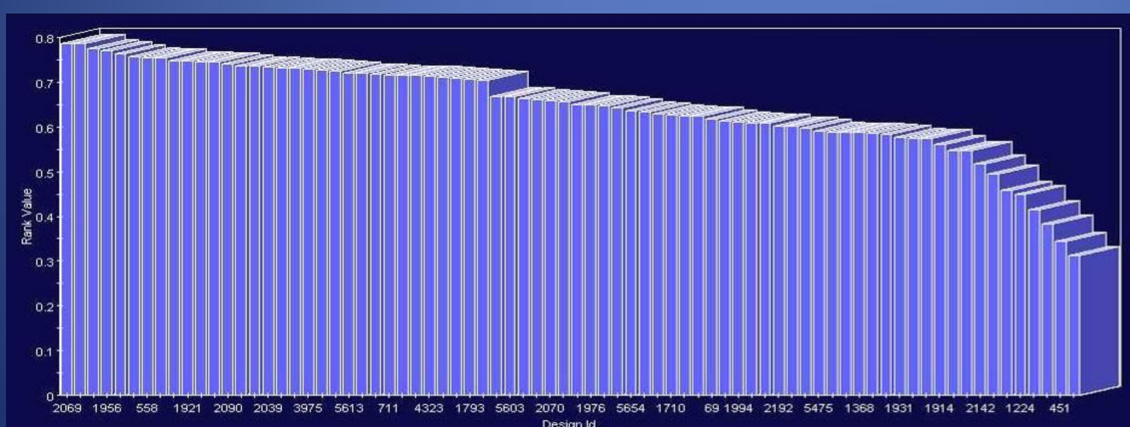


Multi-criteria Decision Making



Case	6x3 Flat
Design ID	2069
Cargo.Vol	137494 (+8%)
Oil.Outflow	0.0111 (+10%)
Wst.cargo.area	10894 (-2%)

Case	6x3 Flat
Design ID	2122 (#2)
Cargo.Vol	135950 (+7%)
Oil.Outflow	0.00942 (-6%)
Wst.cargo.area	11013 (-1%)



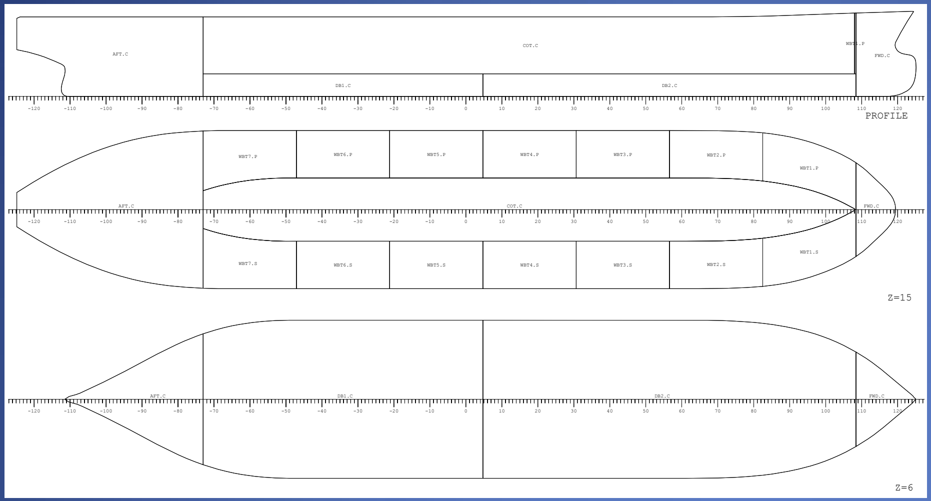
Reference Design	
Cargo.Vol	126765
Oil.Outflow	0.01006
Wst.cargo.area	11077

Early Conclusions

- The application of the implemented optimization procedure to a reference AFRAMAX design, which was already optimized by the yard, showed
  - That the reference design was close to the Pareto Frontier (optimal solutions) of the optimal generated designs
  - A series of generated Pareto Front designs were of improved oil outflow performance and comparable steel weight and capacity, whereas other sets of designs were of improved capacity but slightly worse oil outflow performance
  - Observed (in SAFEDOR 6.9) design features of optimal designs with respect to the increase of double bottom height and decrease of size of tanks towards the bow were confirmed.
  - Fine-tuning of hull-form around the cargo block is expected to further increase the performance of generated designs

60

Zero Oil Outflow Design Alternative

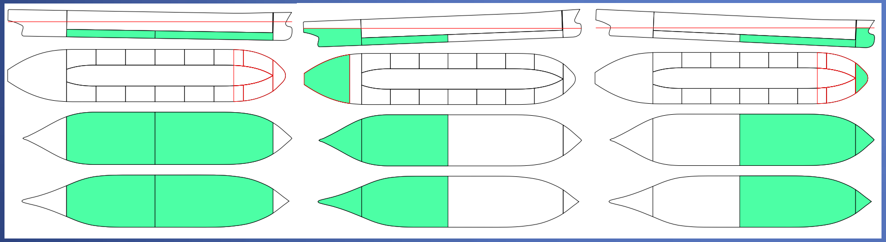


Oil tank capacity of 46000 m^3

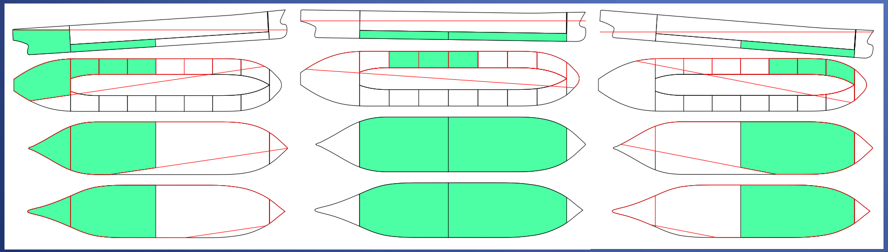
Side tanks capacity of 73700 m^3

13.2 m side shell clearance

6.3 m bottom height clearance



Floating positions after extreme bottom damage extent scenarios



Floating positions after extreme side damage extent scenarios

BEST+ project: Aframax tanker trades in the Caribbean

Special situation

Up to 30% of the transit could be inside Emission Control Areas (ECA)

Project BEST+: Germanischer Lloyd, NTUA and Friendship Systems

Design task for Aframax tanker

Operational requirements

- Relatively high speed is required for competitiveness
- Port facilities in the US gulf area set maximum dimensions
- Emission Control Area in US waters (possible extension to Mexican waters)

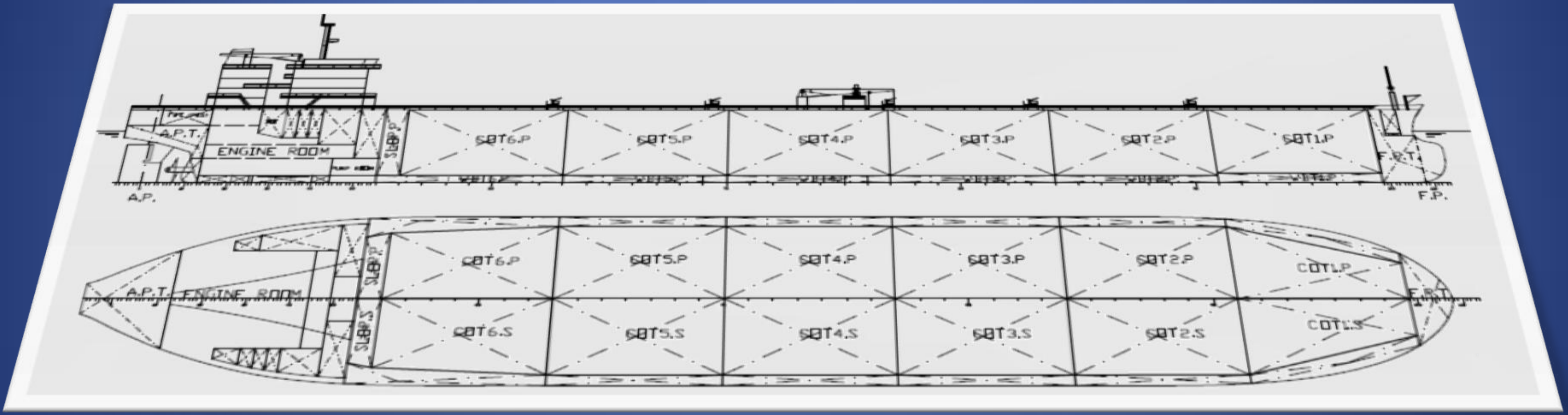
Operators' wish

No major deviations from current practice

Design focus

- Optimize hull form to match speed requirement with future EEDI constraints
- Minimize steel weight while providing and IACS CSR compliant hull structure
- Maximize cargo capacity but minimize oil outflow after accidents

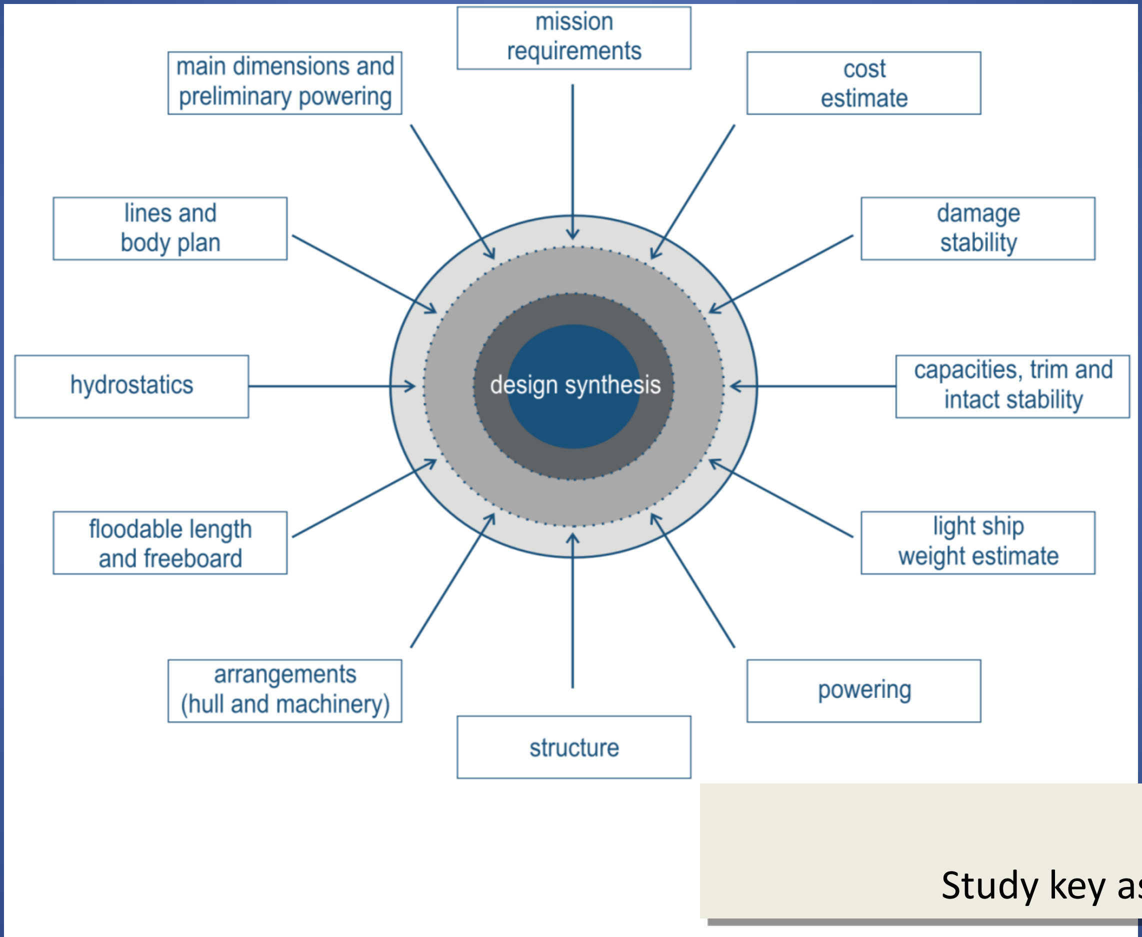
General arrangement



Assumption

6 x 2 tank layout

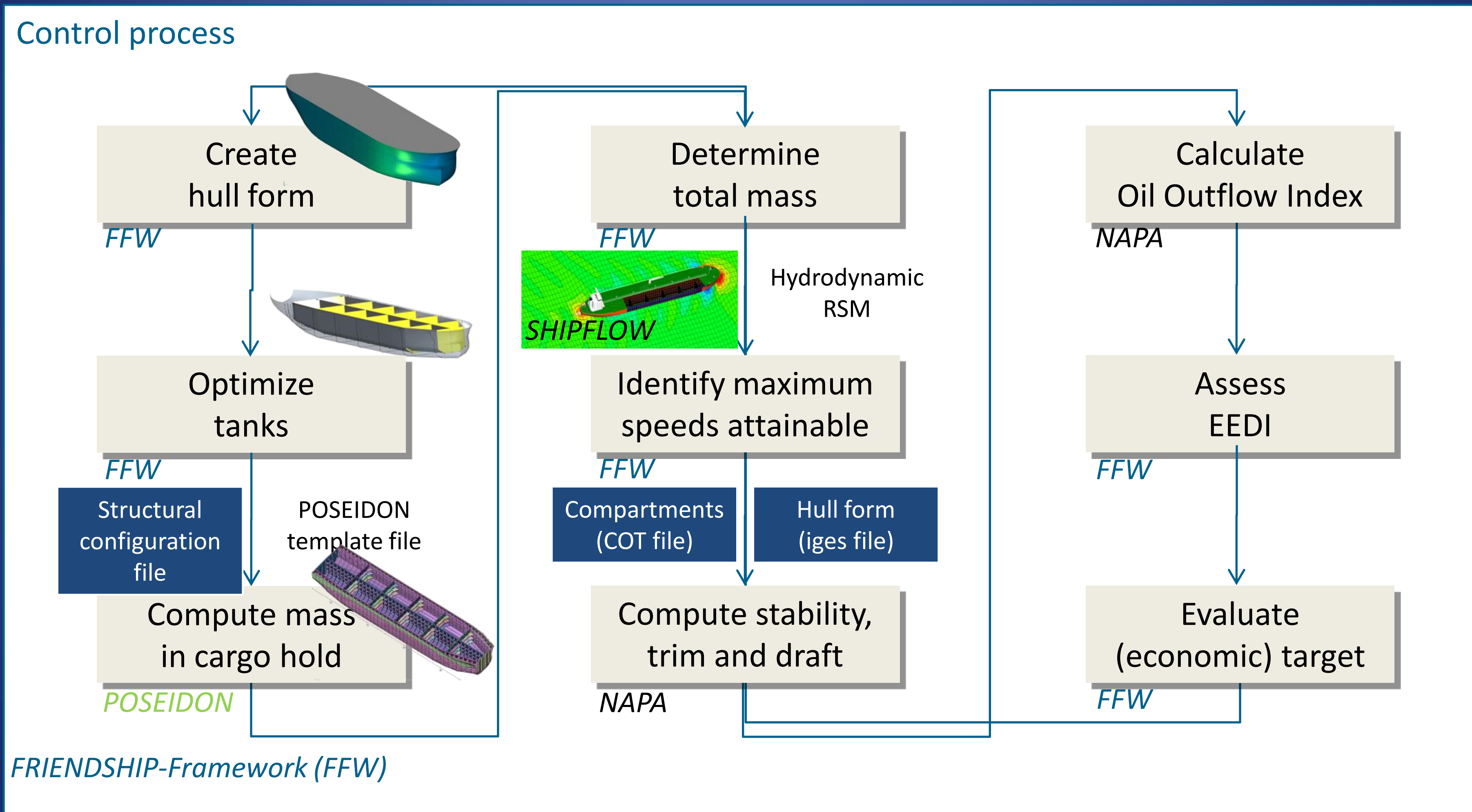
Integrated approach



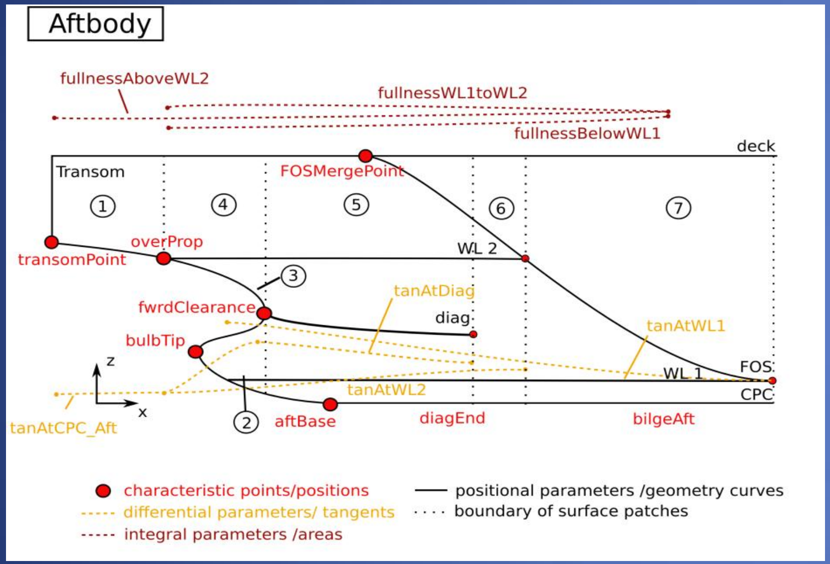
Design synthesis

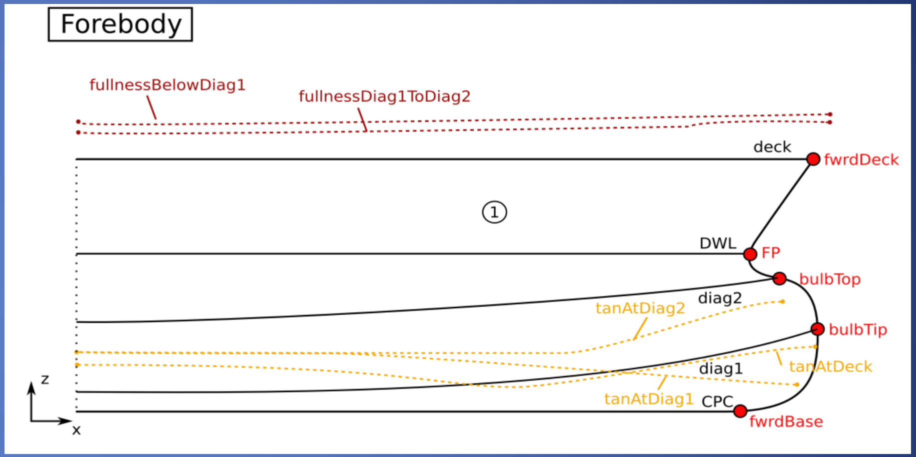
Study key aspects simultaneously

FFW Integrated Design approach



Parametric model for hull form



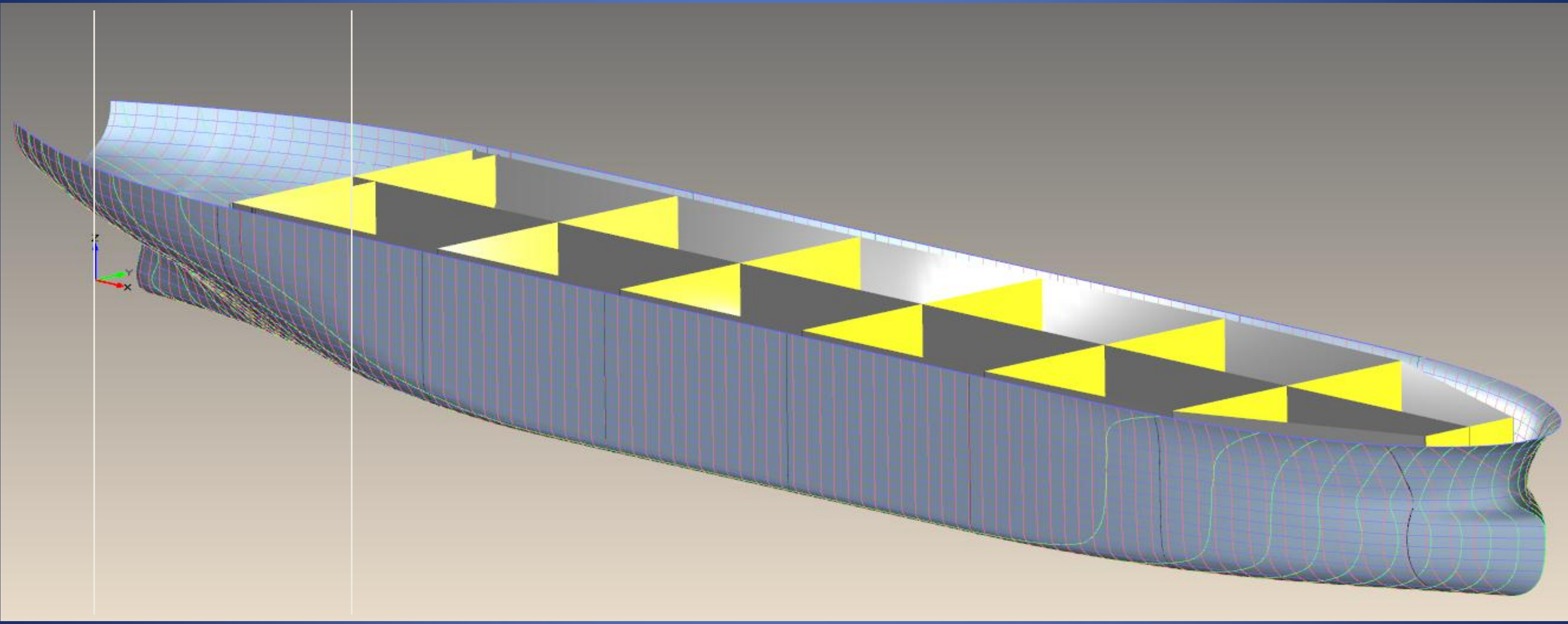


Hybrid model

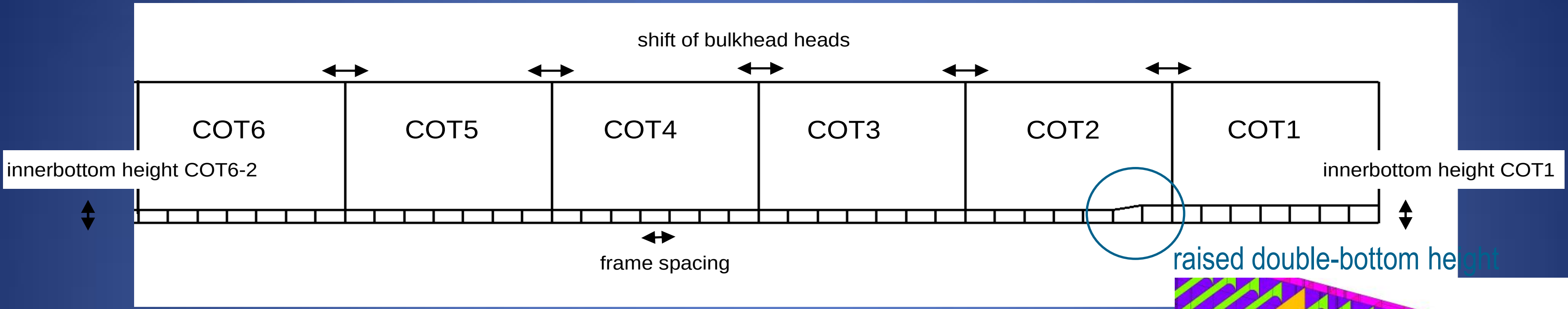
Fully parametric model for generation and variation

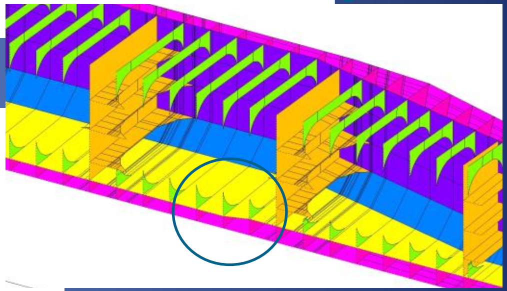
plus partially parametric model for variation and adjustment

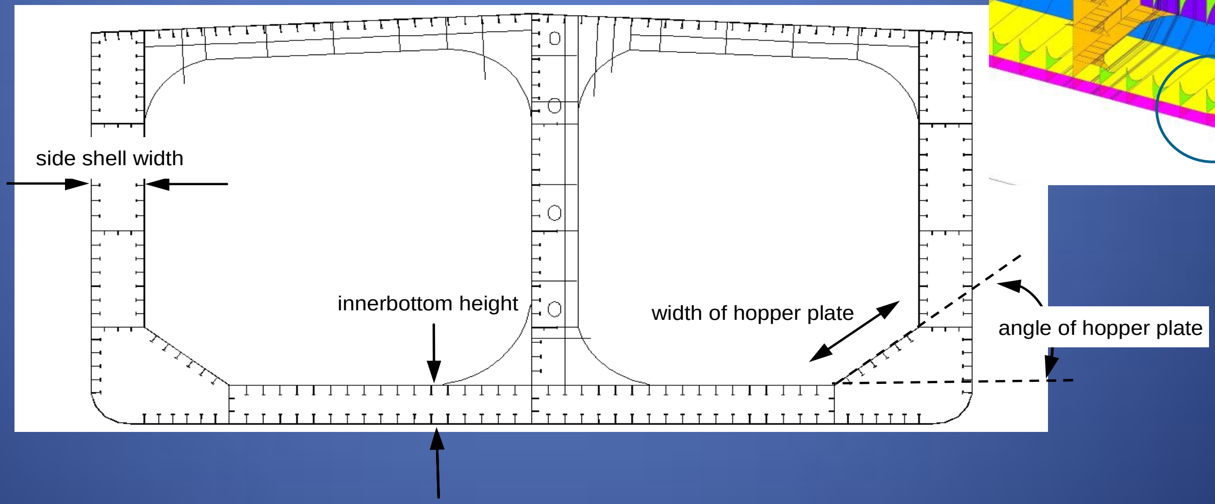
Selected variants



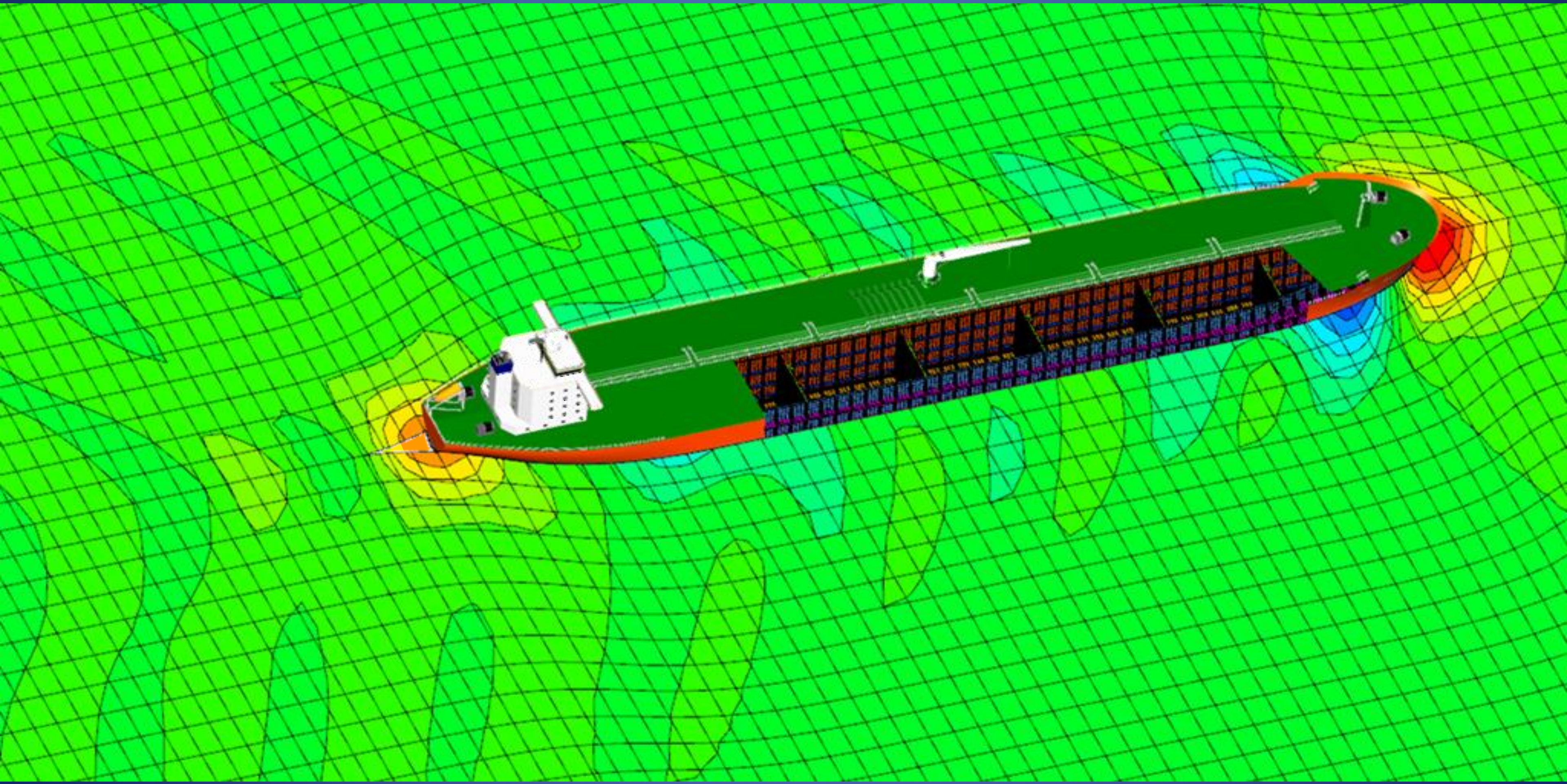
Free variables of inner structure



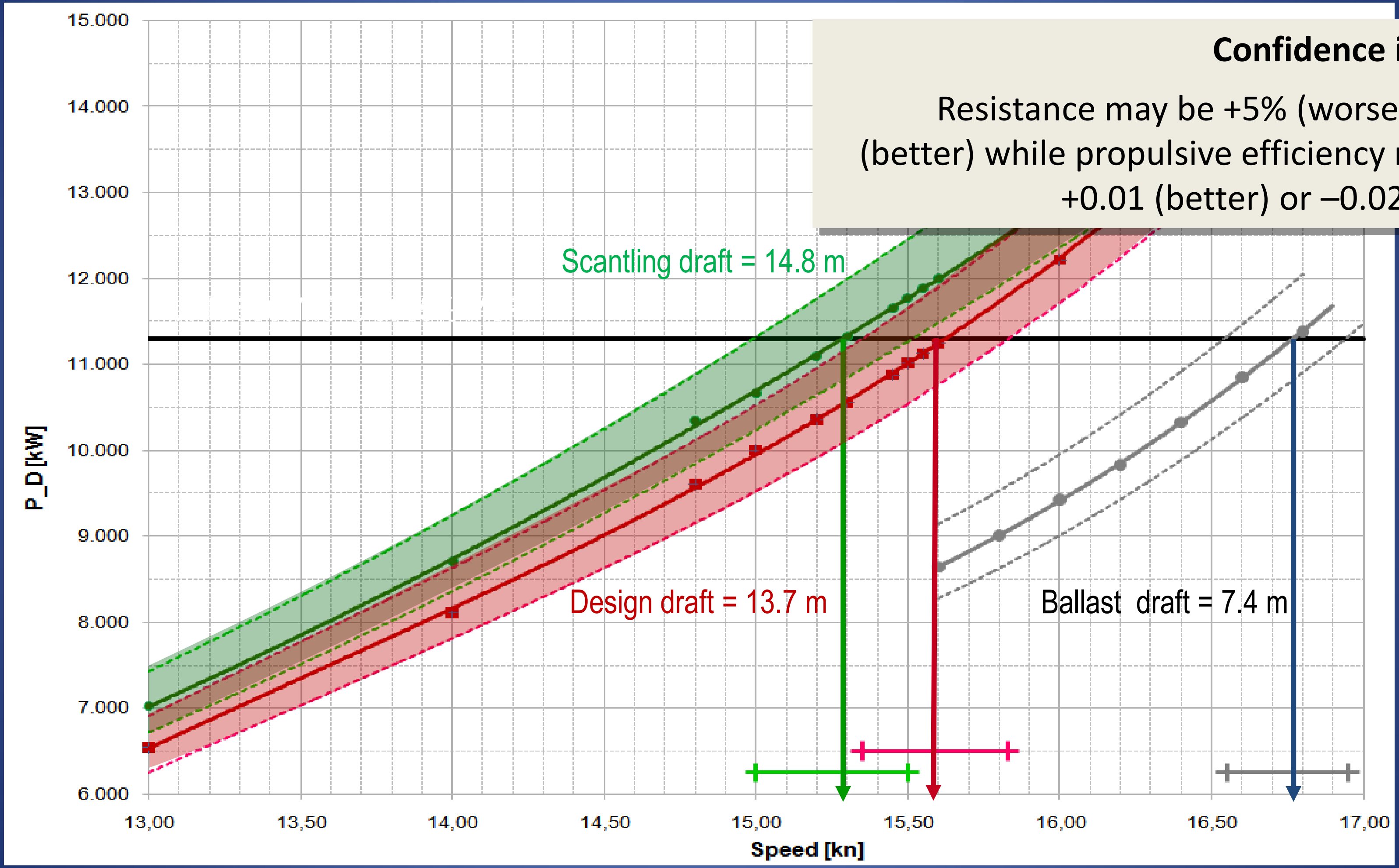




Structural analysis and hydrodynamic simulation



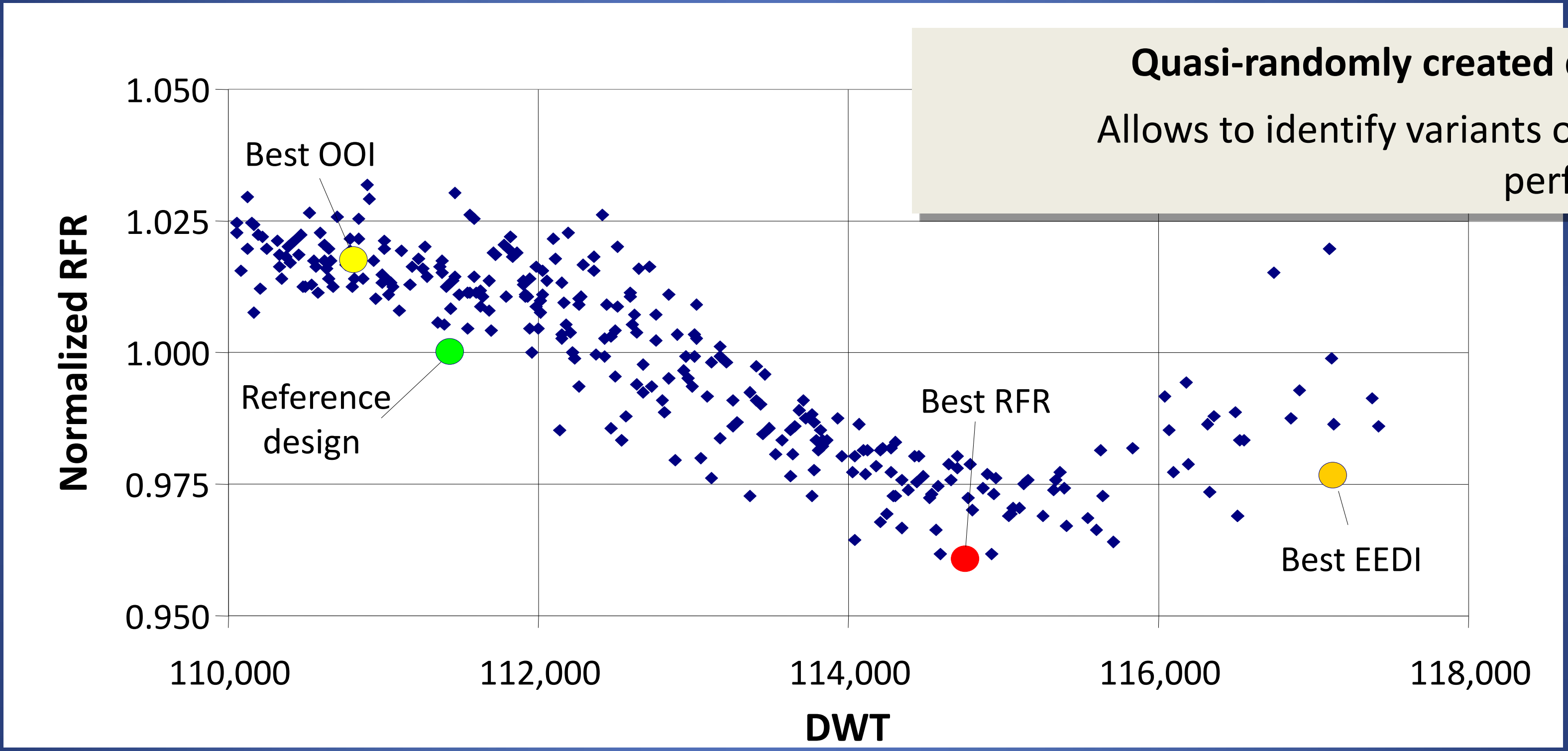
Speed-power curves of favored design



Confidence intervals

Resistance may be +5% (worse) or –5% (better) while propulsive efficiency might be +0.01 (better) or –0.02 (worse)

Design Exploration



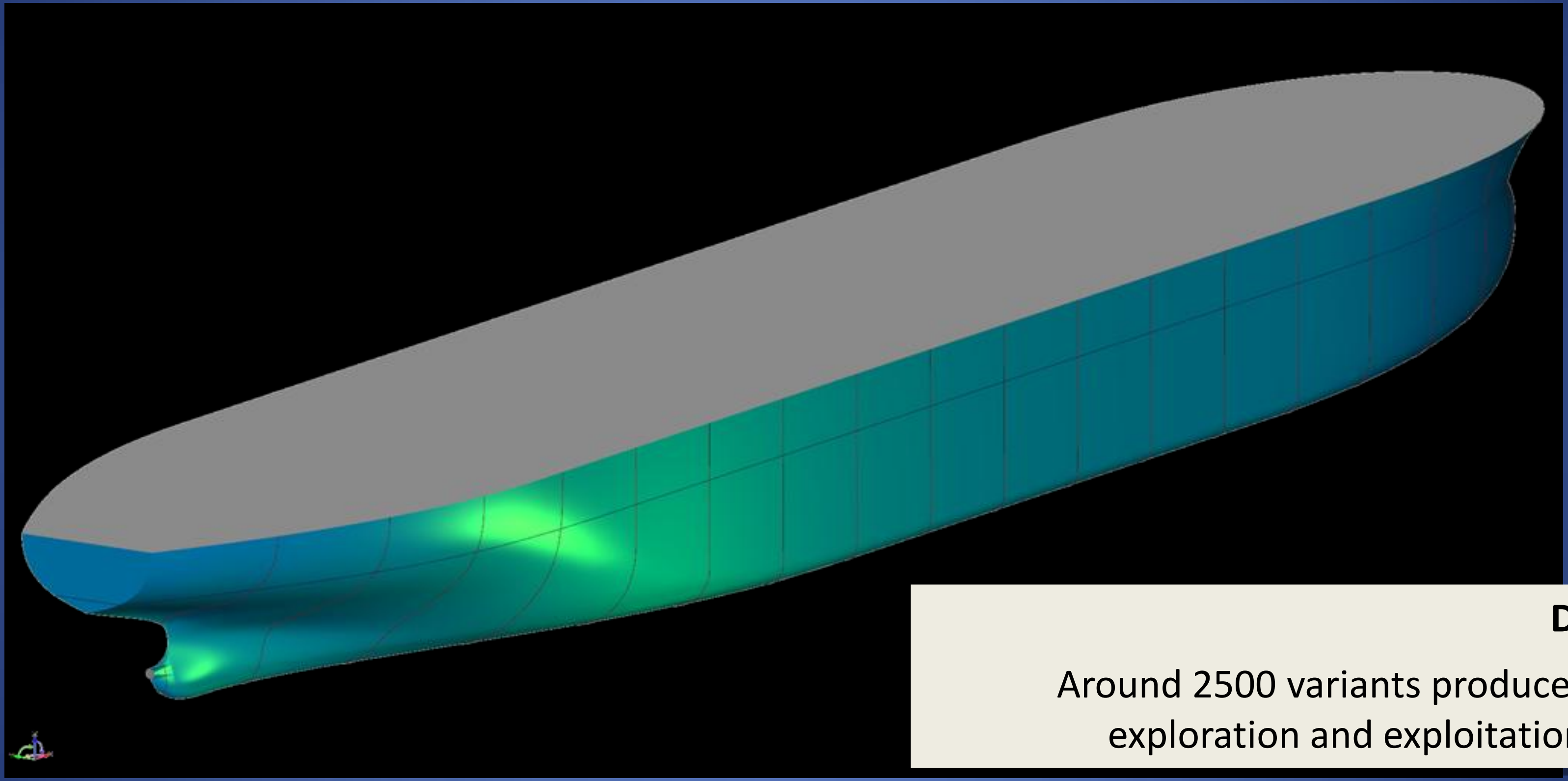
Quasi-randomly created database

Allows to identify variants of specific performance

Further fine-tuning for EEDI

Parameter	Reference design	Favored design
Length over all	250 m	250 m
Beam	44 m	44 m
Depth	21.0 m	21.5 m
Design draft	13.7 m	13.7 m
Block coefficient	0.83	0.85
Inner bottom height COT 2-6 (S+P)	2.50 m	2.10 m
Inner bottom height COT 1 (S+P)	2.50 m	2.75 m
Side shell width	2.50 m	2.65 m
Angle of hopper plate	50°	37°
Width of hopper plate	5.25 m	5.20 m
Frame spacing	3.780 m	4.400 m
Shift of bulkheads	0 m	0 m
DWT	111 436 t	114 923 t
Maximum cargo volume	124 230 m^3	129 644 m^3
OOI	0.0138	0.0142
Speed at design draft	15.1 kn	15.6 kn
Speed at ballast draft	15.9 kn	16.8 kn
EEDI	3.541 g CO_2 / (t nm)	3.281 g CO_2 / (t nm)

Hull form of favored design

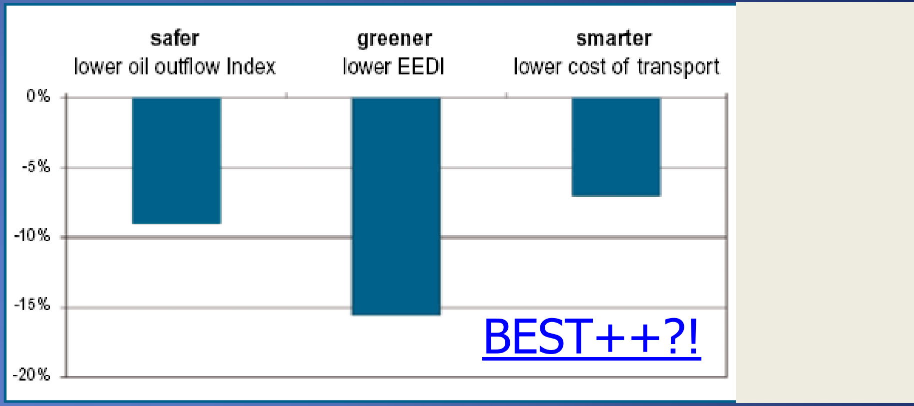


Database

Around 2500 variants produced during exploration and exploitation phases

Formal exploration and exploitation

- Safer
  - Reduce risk for the environment by minimizing OOI in accidents
- Greener
  - Reduce emissions by minimizing EEDI
- Smarter
  - Reduce operating costs by minimizing RFR



Conclusions-Way Ahead

Four (4) decades after the introduction of the Computer-Aided Ship Design and Optimisation in the late 60ties, with the land marking contribution of em. Prof. Horst Nowacki (Tech. Univ. Berlin, former Univ. of Michigan), we can certainly say that today's state of the art of knowledge and technology allows comprehensive holistic multi-objective optimisation approaches to the design of a ship as a system (and its individual components or for individual objectives/functions) for her entire life cycle, leading to ships of enhanced efficiency, safety, comfort and environmental protection to the benefit of society, world and national economies and of the shipping industry.

It should be noted, however, that the *implementation* of the required relevant optimisation procedures needs still to be developed for a long list of practical cases by experienced software programmers supported by ship designers (ideally by naval architects), which will be a demanding R&D task for the decade(s) to come.

Acknowledgements

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The author likes to thank his NTUA-SDL laboratory associates,
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Finally, the author would like to express his gratitude to his mentor em. Professor Horst Nowacki for introducing him, during his studies and work at the Technical University of Berlin, into the philosophy, methods and practice of ship design optimization at a time when only very few scientists around the world were dealing systematically with this in many respects very demanding discipline.

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Greek Section – Technical Meeting
15. March 2012, Athens

HOLISTIC SHIP DESIGN OPTIMISATION: Theory and Applications

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