

Holistic Optimization of a Twin Screw AFRAMAX Tanker with Dual Fuel Electric Hybrid Propulsion



Better Economics with a Safer Tanker (BEST++)
VISIONS 2012 Competition

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Presentation at MarineLive International Conference, 5th June 2012



Contents



- ▣ **Background**
- ▣ **Design Concept, Methodology and Theory**
- ▣ **Optimization Studies and Analysis**
- ▣ **Multi Venture: The case of the All Electric Tanker**
- ▣ **Conclusions, Future Work and Discussion**

BACKGROUND



SCIENCEPHOTOLIBRARY





Study Objectives

- Above study is part of the Diploma Thesis of L. Nikolopoulos at NTUA:

"A Holistic Methodology for the Optimization in Tanker Design and Operation and its Applications", supervised by Prof. A. Papanikolaou

- Investigation of
 - *Innovative, shallow draft, twin skeg/screw* AFRAMAX Tanker of *5X3 Tank Arrangement* (current presentation)
- Emphasis on the following design aspects:
 - **Safety**, especially minimization of probabilistic oil outflow
 - **Efficiency**
 - **Competitiveness**
- Global and Risk-Based Approach, with the aim to generate a safer tanker which is also more competitive.
- **Holistic:**
 - Aristotle definition of «*όλον*» being greater than the sum of all parts
- Employed software platform for this project is the **Friendship Framework**

References and Other Studies on the Case

- Continuous collaboration with GL in tanker Optimization
- Previous Research Project (TANKOPT-BEST) suggested optimal arrangement :

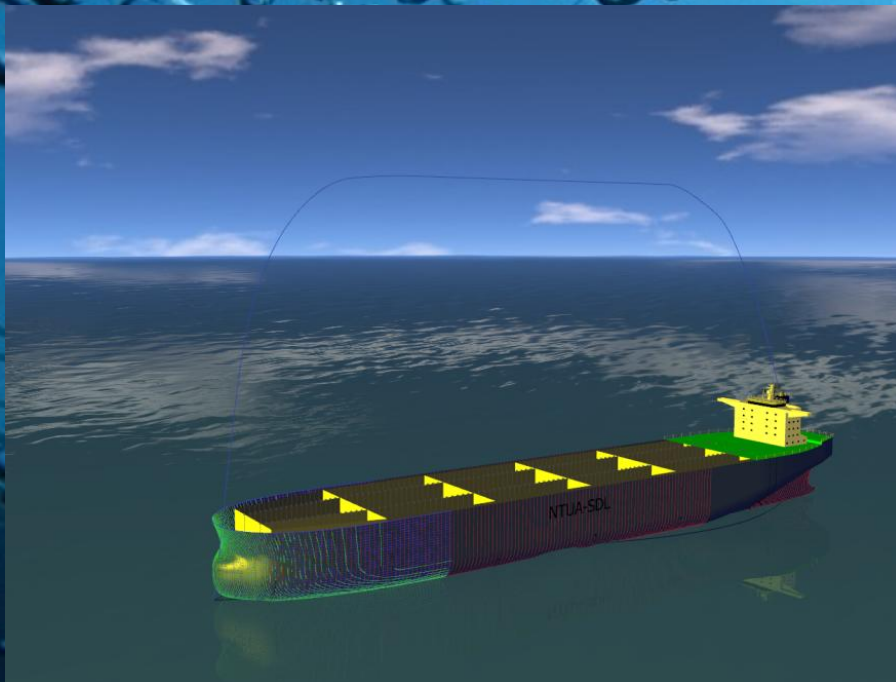
Table 4. Comparison of optimum and reference design according to scenario #2

	Ref. Design	6x3 Flat		6x3 Flat	
ID		2069		2122	
Rank		1		2	
Cargo.Vol	126765	137494	+8%	135950	+7%
Oil.Outflow	0.01006	0.0111	+10%	0.00942	-6%
Wst.cargo.area	11077	10894	-2%	11013	-1%

“Optimization of an AFRAMAX Oil tanker”, A. Papanikolaou, G. Zaraphonitis, E. Boulougouris, U. Langbecker, S. Matho, P. Sames, Journal JMST, 2009

- Comparison with BEST+ project.
- Part of the BEST++ project (official release in SMM Hamburg 2012).

Design Concept





Main Idea of Present Design Concept

Shallow draft , twin screw arrangement



▣ Advantages of shallow draft, twin screw tanker:

- Increased **safety** through
- Shallow Draft Design increases the **accessibility** in ports with draft restrictions
- Increased **hull fullness** (block coefficient),
- Expected to reduce building cost per ton steel.
- **Reduced ballast water amount**
 - ▣ Reduced costs for BWT
 - ▣ Reduced Structural Maintenance
 - ▣ Reduced fuel costs for ballast leg (65% MCR)
 - ▣ Reduced coating costs

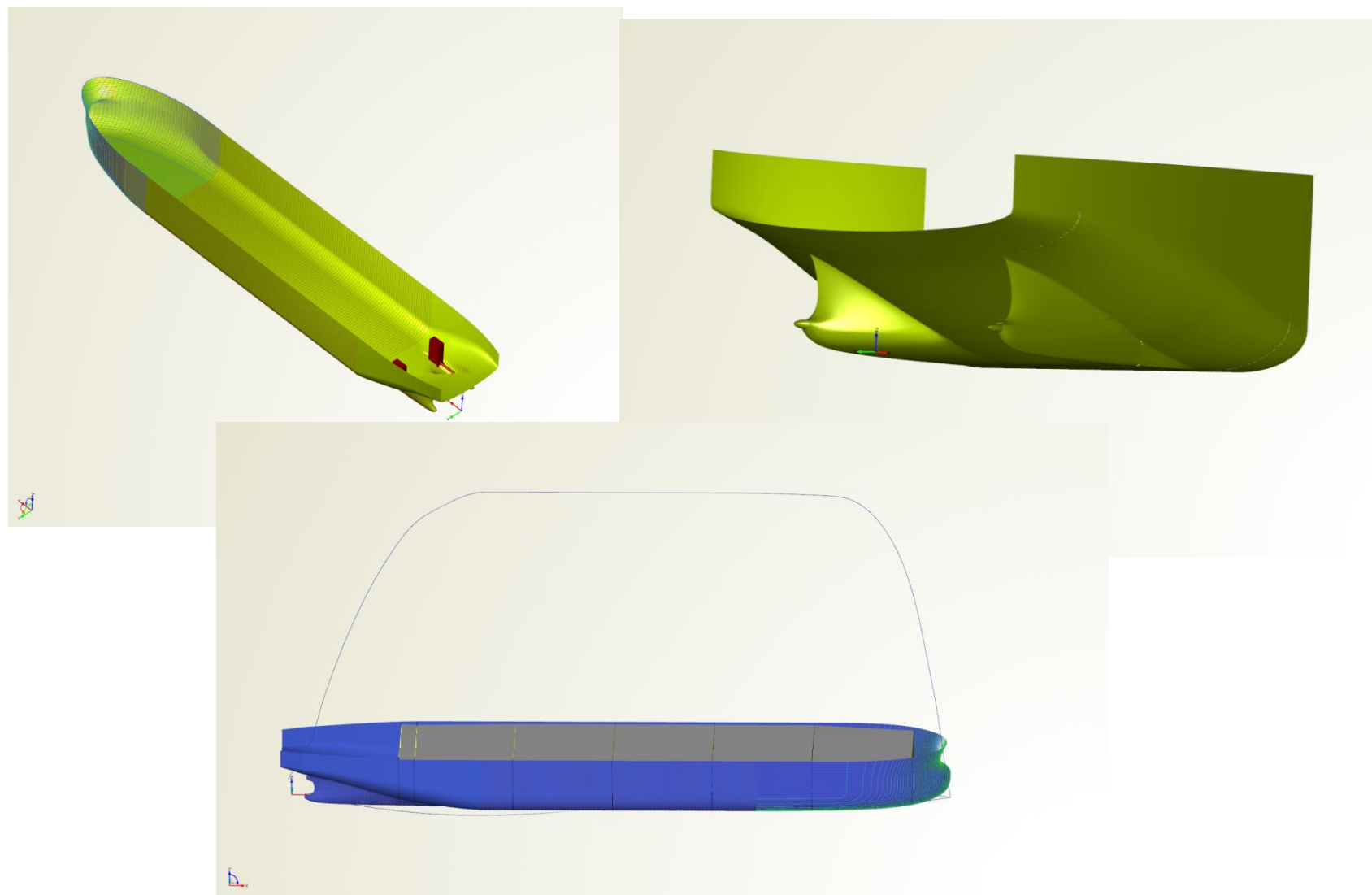
▣ Disadvantages:

- Increased Steel Weight, if not optimised
- Lack of reference designs for AFRAMAX class ships
- Increased Initial Cost



Design Concept

Twin Skeg Arrangement



Holistic Optimization of an Innovative AFRAMAX Tanker with Electric Propulsion, Ship Design Laboratory
NTUA, Marine Live International Conference, June 2012, Athens



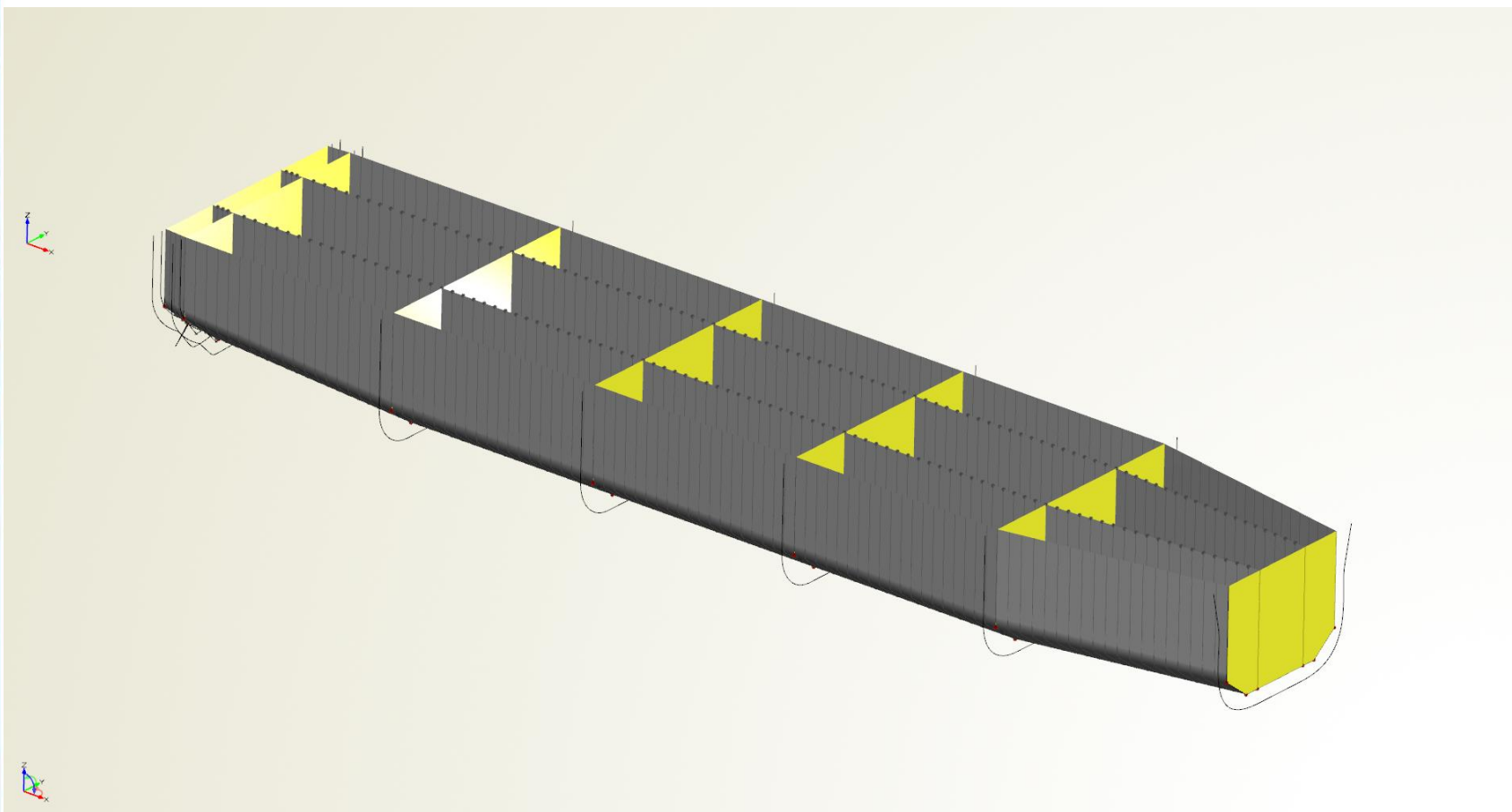
Design Concept Tank Arrangement



- NX3 tank arrangement was herein chosen by default:
 - due to the superior performance in terms of accidental oil outflow (as indicated by the TANKOPT results).
- Number of longitudinal tanks reduced to 5 (instead of 6):
 - compensate the increase in structural weight due to the introduction of a second longitudinal bulkhead (approx. 200 tones weight).
- Other ways to compensate the increase of structural weight:
 - increase the tank size and capacity together
 - increase in displacement (due to a bigger C_b thanks to twin skeg).
- Use of deep well pumps (instead of conventional pump room):
 - Engine room bulkhead moved towards the aft of the ship.
 - Initial estimation of 2-3% increase
 - Increase was up to 6%.
- Tank Variables:
 - Double Bottom height
 - Double Hull Width
 - Mid Tank Width



Design Concept Tank Arrangement-Modeling



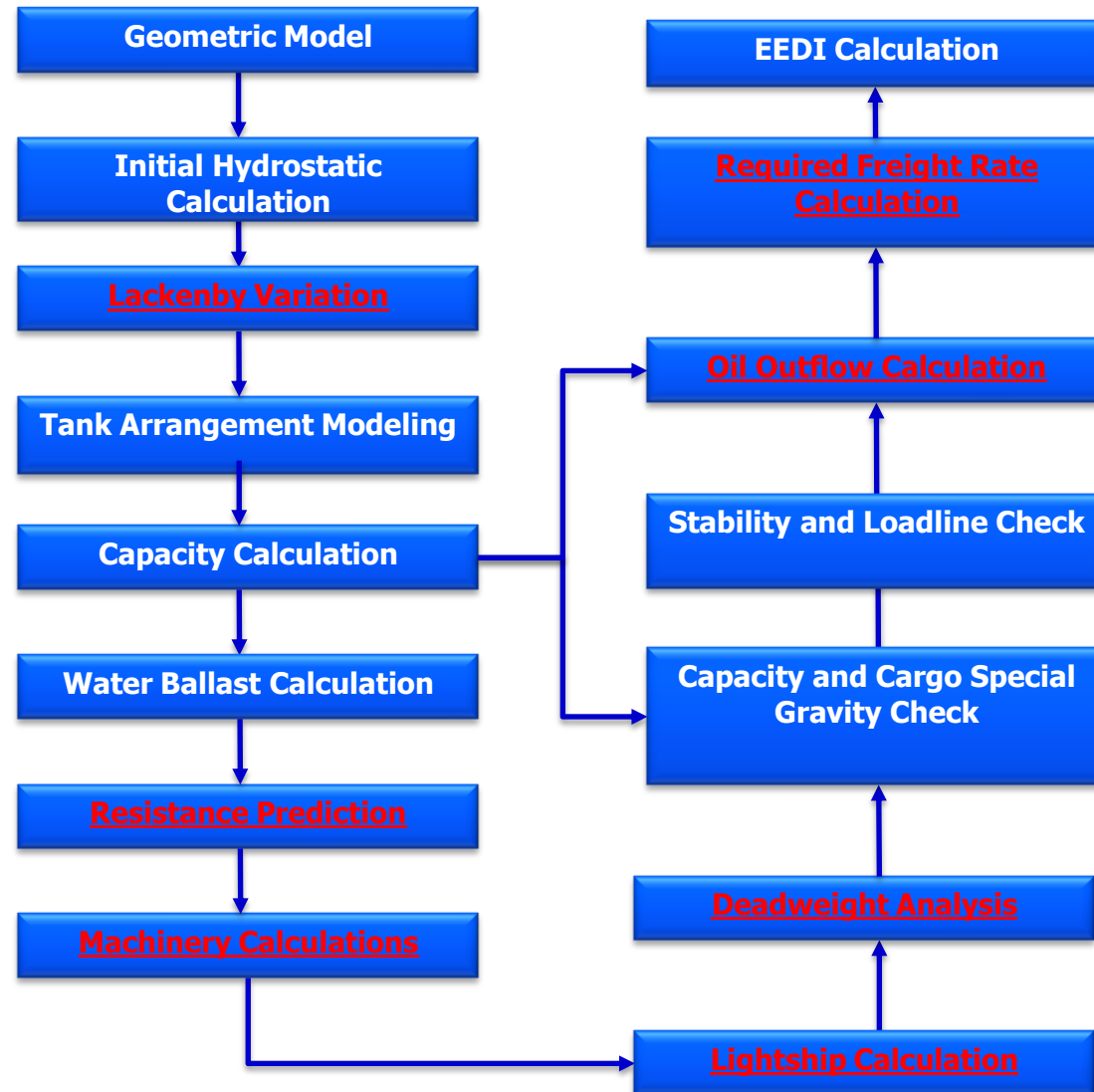
Design Methodology and Theory



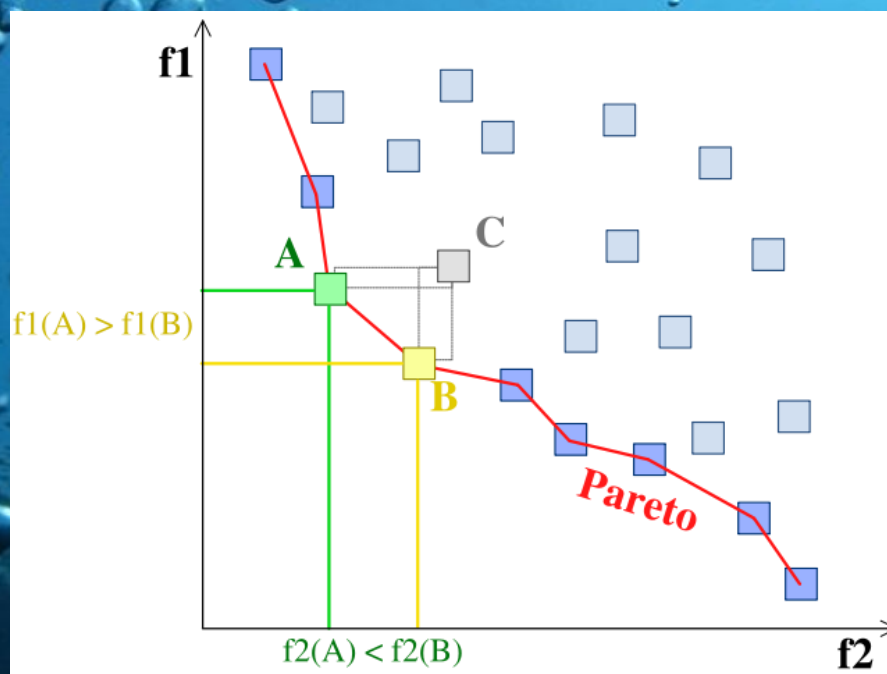
The computations, assumptions and workflow of the analytical model



Calculations Workflow



Optimization Studies





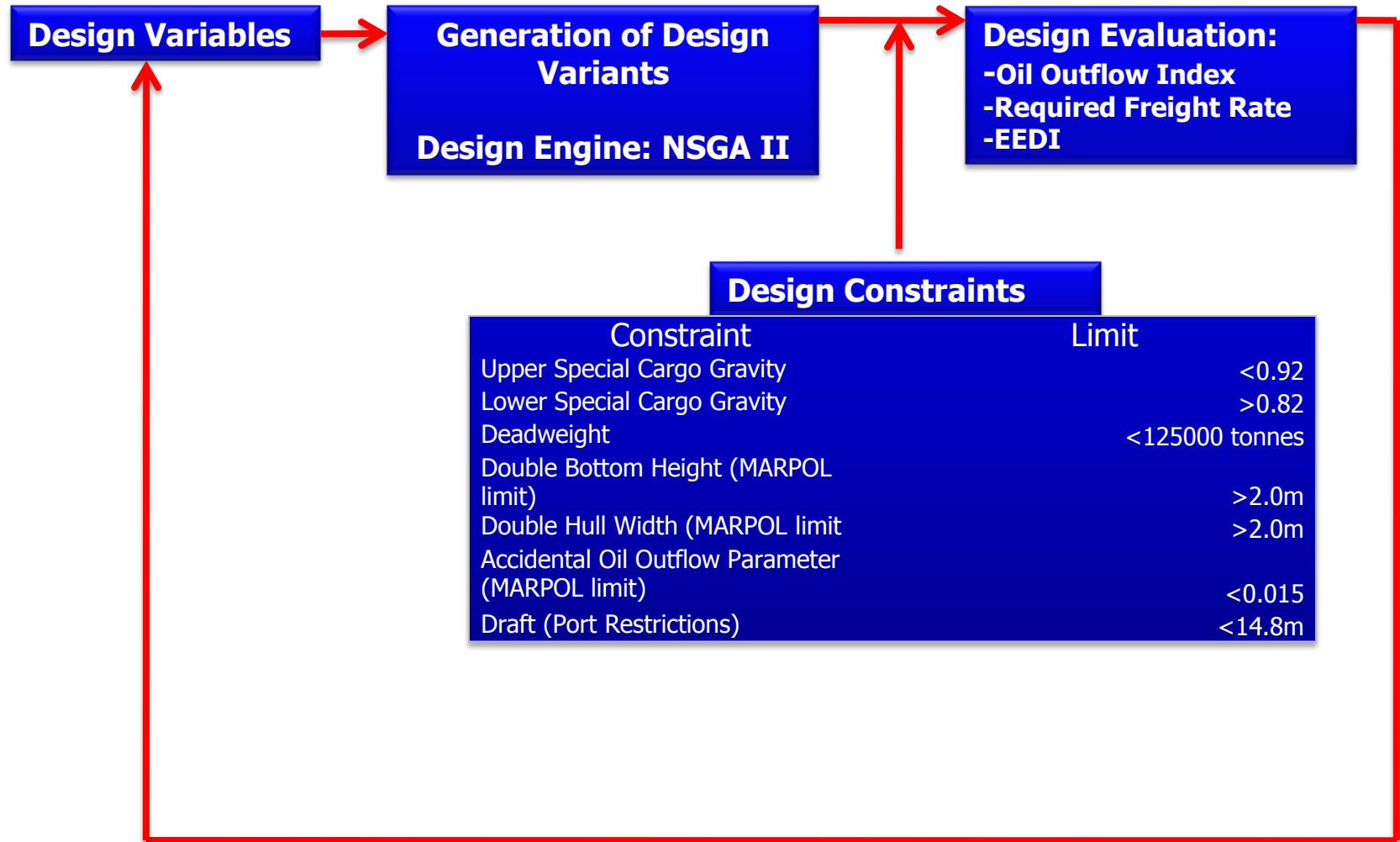
Objectives for Optimization

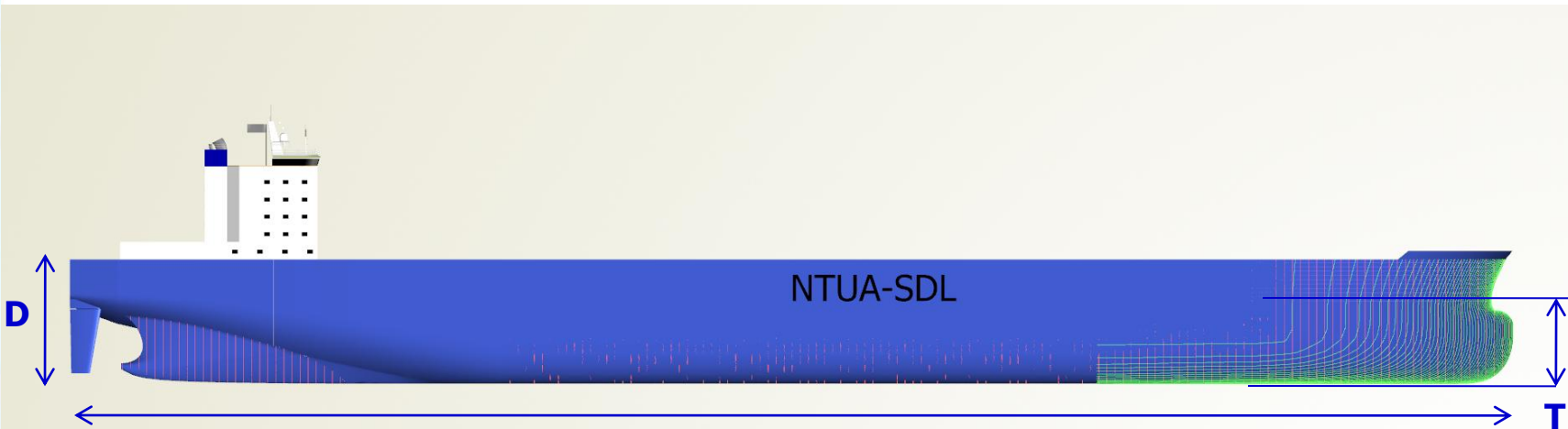
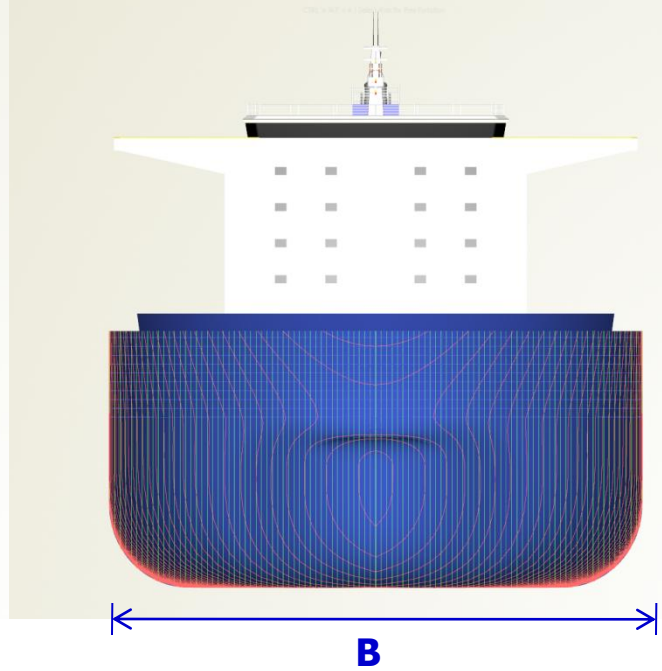
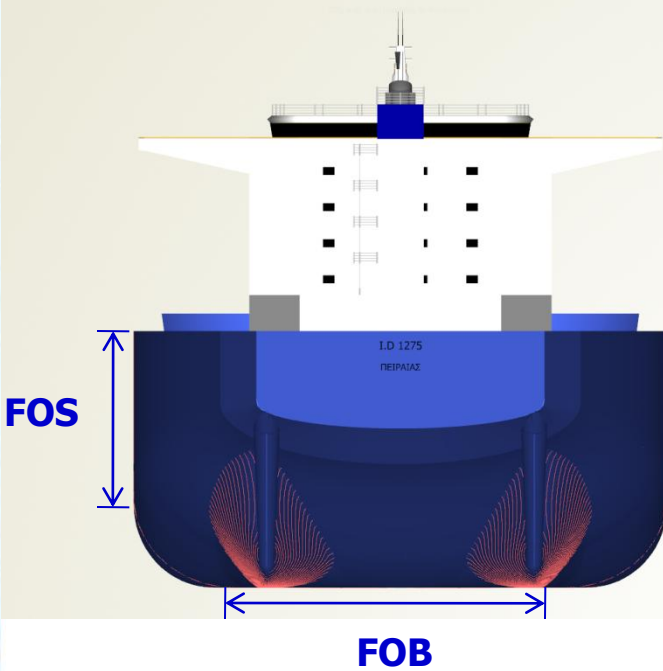


- Main Aim:
 - Make a safer tanker more competitive and more efficient.
- Objectives:
 - Increase of Cargo Volume
 - Decrease of Accidental Oil Outflow
 - Decrease of Installed Power
 - Decrease of EEDI
 - Decrease of Required Freight Rate.
- Simplified objectives (functions/criteria) due to correlations:
 - RFR maximization (via Cargo Volume, Installed Power and Lightship Weight)
 - EEDI minimization (via Deadweight, Installed Power)
 - Accidental Oil Outflow Minimization.



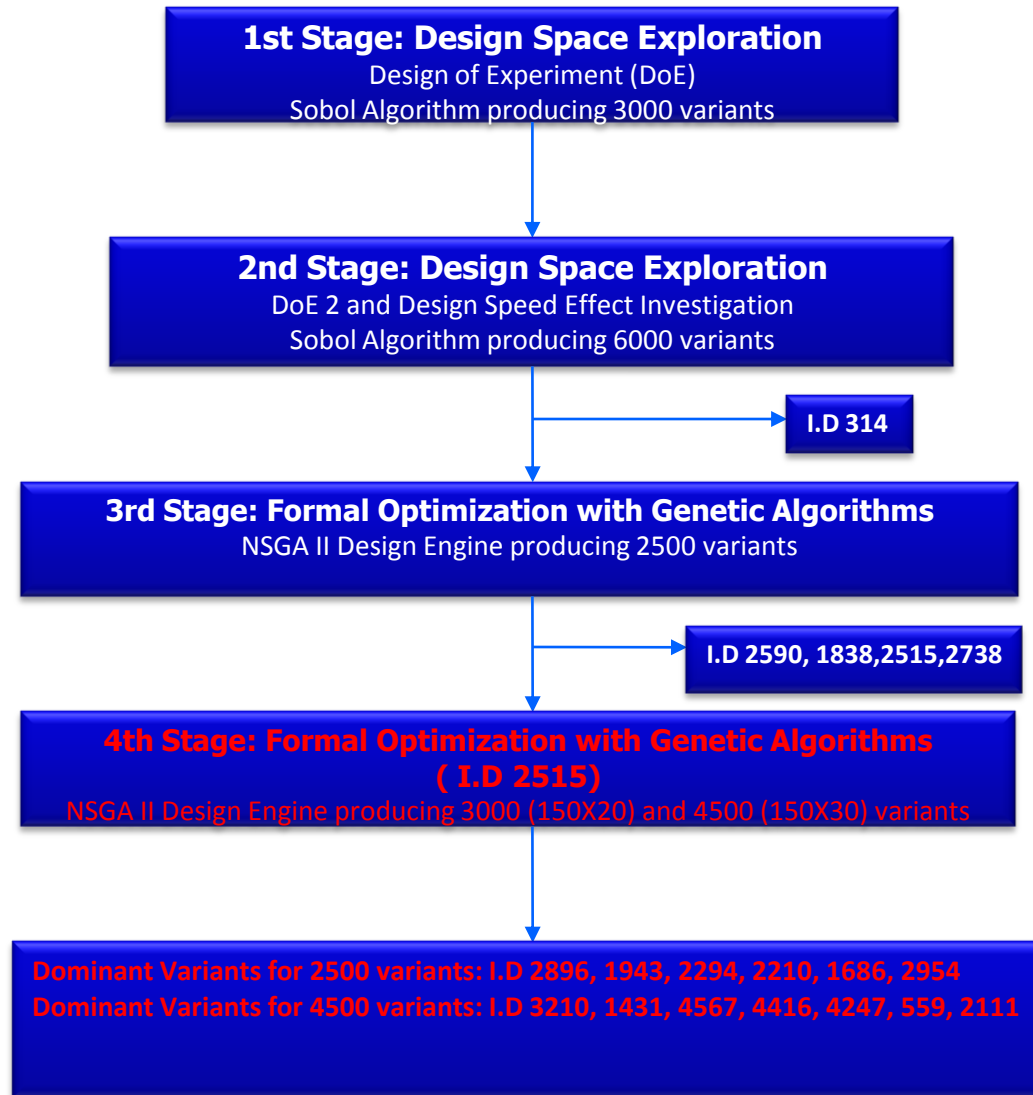
Optimization Principles





Optimization Stages

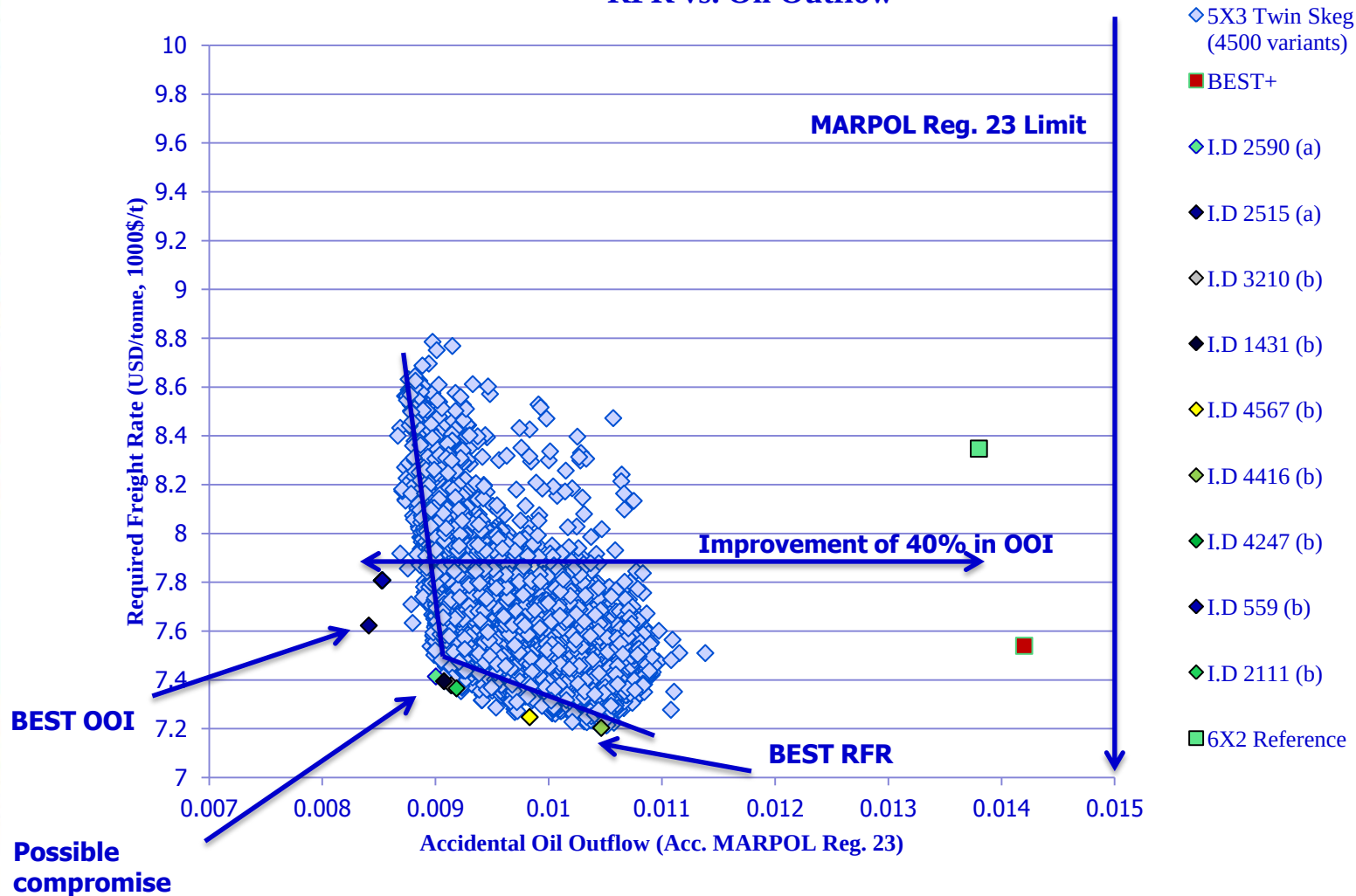
A multi-staged Approach



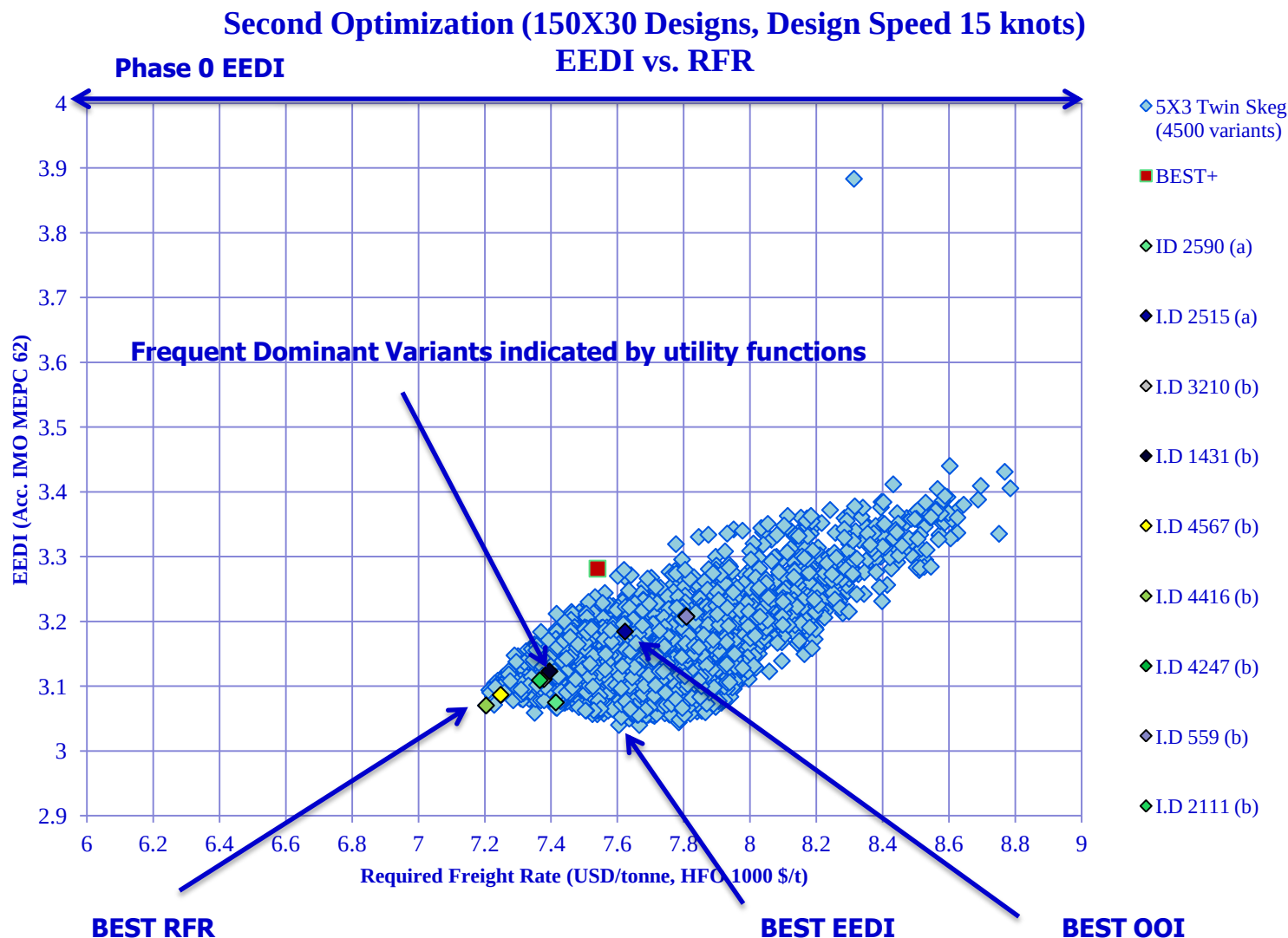
4th Stage: 2nd Genetic Algorithm Run

150 Generations with 30 Population: RFR vs. Oil Outflow

Second Optimization (150X30 Designs, Design Speed 15knots)
RFR vs. Oil Outflow



4th Stage: 2nd Genetic Algorithm Run 150 Generations with 30 Population: EEDI vs. RFR

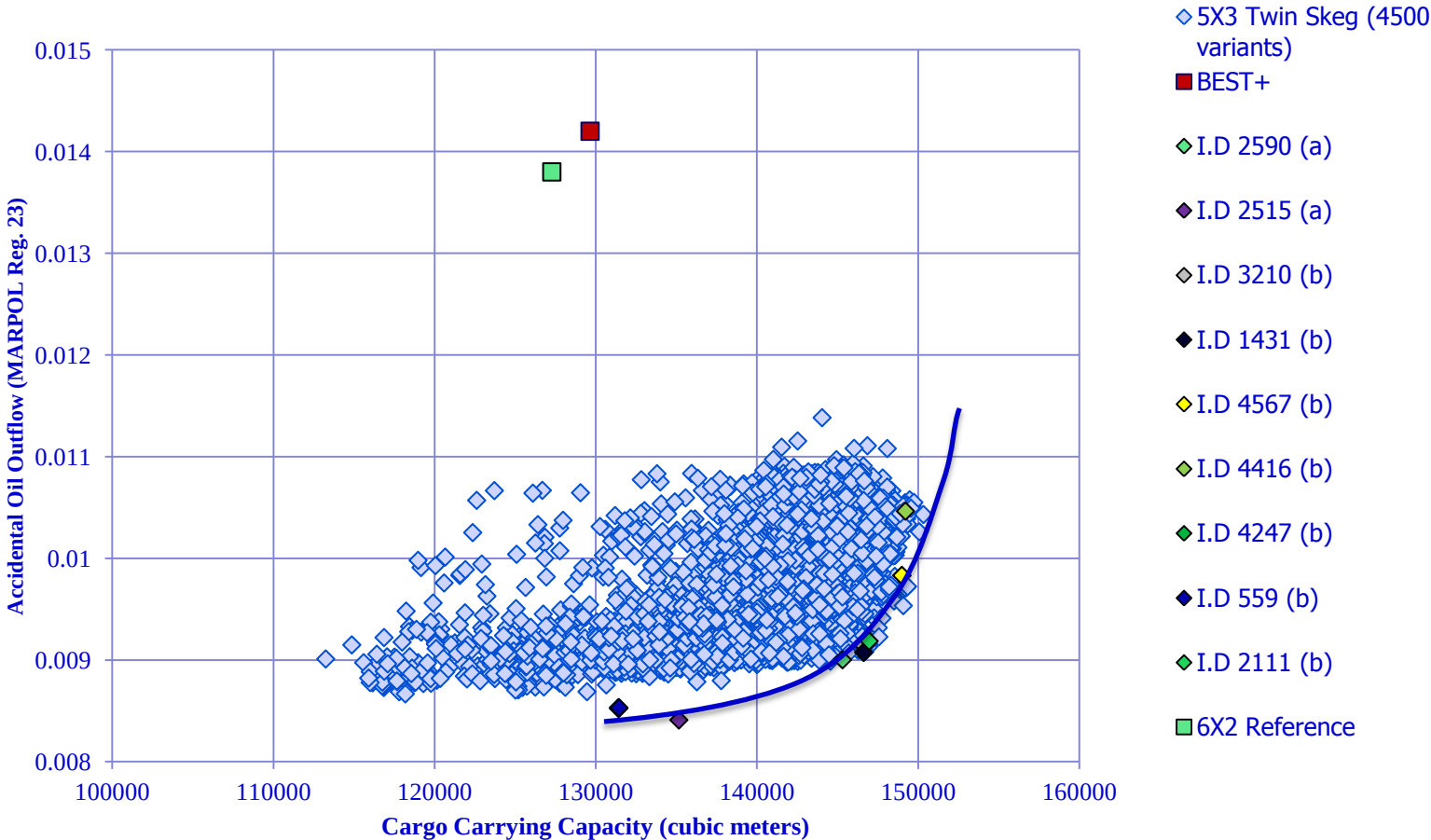




4th Stage: 2nd Genetic Algorithm Run

150 Generations with 30 Population: Vcargo vs. Oil Outflow

Second Optimization (150X30 Designs, Design Speed 15 knots)
Cargo Capacity vs. Oil Outflow





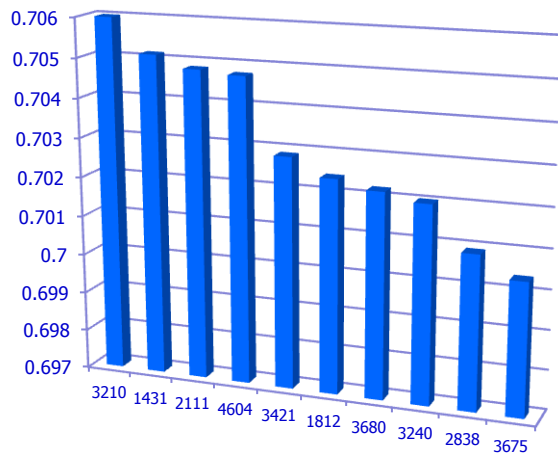
4th Stage: 2nd Genetic Algorithm Run 150 Generations with 30 Population-Comments

- The scatter diagrams now are more dense.
- V-shaped pareto front instead of peaks
- The EEDI-RFR pattern remains the same.
- The Lowest OOI has a satisfactory RFR performance
- The Lowest RFR is at the upper boundaries of the variants size.
- BEST-Trade-off:
 - Frequently appeared in the ranking of the utility functions
 - **Better RFR, OOI and EEDI performance than 6X2 AFRAMAX designs.**

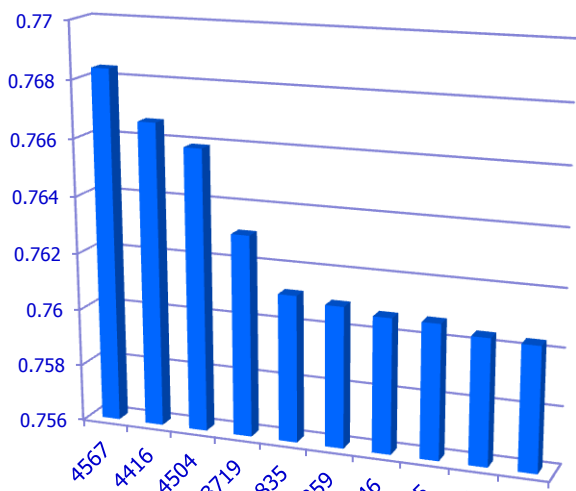


4th Stage: 2nd Genetic Algorithm Run 150 Generations with 30 Population-Design Ranking

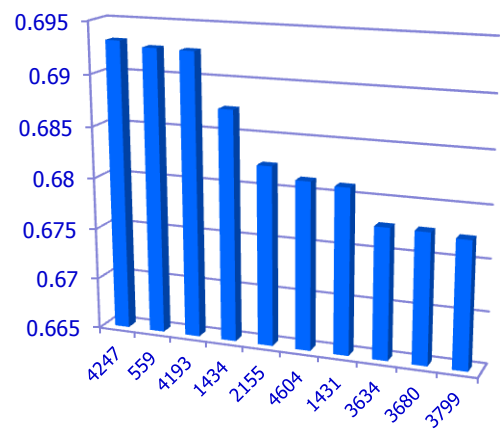
U1: 1/3 EEDI, 1/3RFR, 1/3 OOI



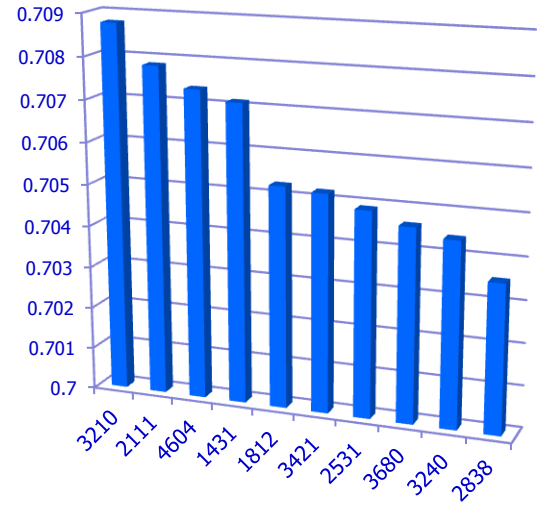
U2: 0.1 EEDI, 0.8 RFR, 0.1 OOI



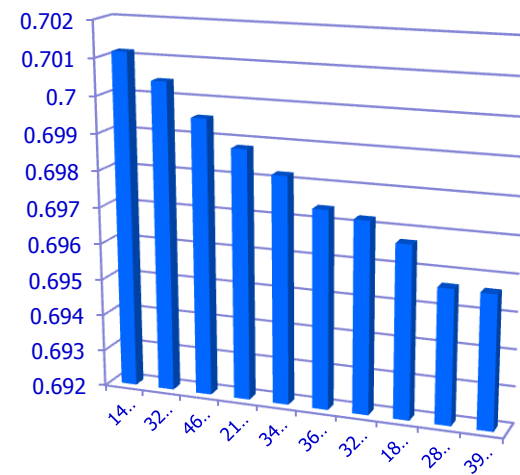
U3: 0.2 EEDI, 0.2 RFR, 0.6 OOI



U4: 0.4 EEDI, 0.3 RFR, 0.3 OOI



U5: 0.2 EEDI, 0.4 RFR, 0.4 OOI





Optimization Results

Dominant Variants Comparison

Results indicate an increase of the cargo structural weight which however is not influencing the RFR value which is decreased:

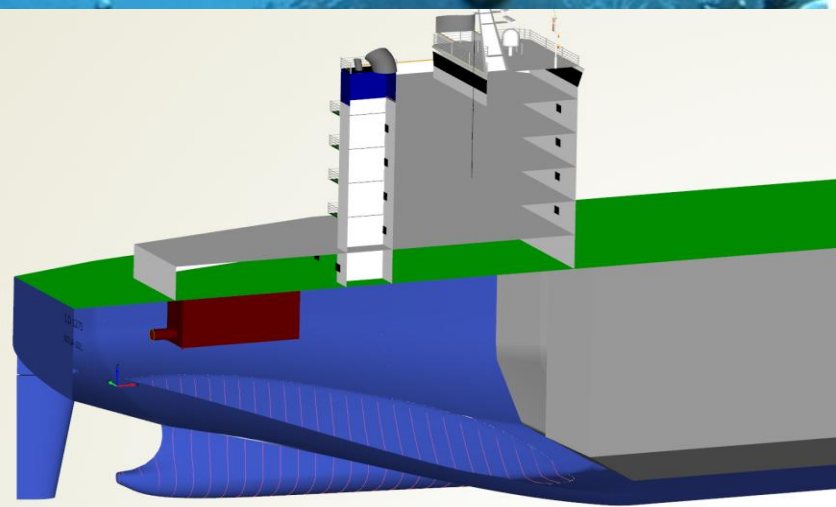
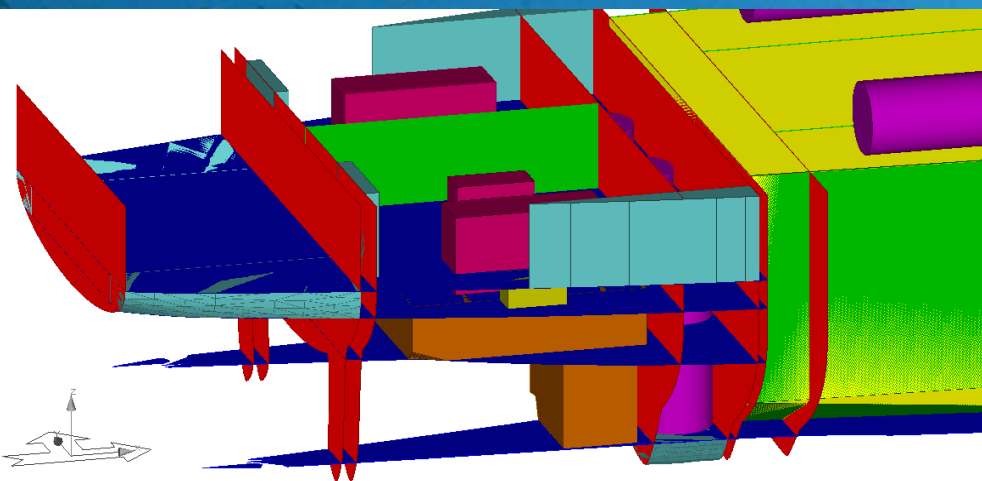
	6X2 Reference	I.D 2515		I.D 3210	
OOI	0.0138	0.00841	-39.057%	0.009139	-33.78%
Wst cargo	11077 t	13590	+18.49%	14261 t	+22.32%
Cargo Capacity	126764.7 m ³	135154 m ³	+6.21%	146642.7 m ³	+15.68%
RFR	8.347 \$/t	6.7209 \$/t	-8.67%	7.378 \$/t	-11.61%
Ballast Water	35378 m ³	18699 m ³	-47%	29287 m ³	-17.2%

	BEST+	I.D 2515	
OOI	0.0142	0.00841	-40.77%
Wst cargo	12132 t	13590	+10.72%
Cargo Capacity	129644m ³	135154 m ³	+4.07%
RFR	6.7299 \$/t	6.7209 \$/t	-0.1%
Ballast Water	35378 m ³	18699 m ³	-47%
EEDI	3.2814 gCO2/t	3.1843 gCO2/t	-2.95%

Multi Venture



All Electric, Dual Fuel Hybrid
Propulsion System for a Tanker





Part Two: Multi Venture The All Electric Tanker



Participation in VISIONS 2012 Ship Design Olympics

Team:

- Lampros Nikolopoulos, Nikos Mantakos, Michalis Pytharoulis

Objectives for the Competition:

- Energy Efficient Tanker
- Use of Alternative Fuels

Multi Venture:

- Hull Efficiency:
 - Results of Global Optimization
 - Optimized Bow
- Propulsion Efficiency:
 - Wake Adapted Propeller
 - Use of LNG as a fuel
 - Use of Hybrid Technologies (e.g Fuel Cells)

Lifecycle Assessment of Environmental Performance



Bulb Optimization



Objectives:

- Reduction of Wetted Surface,
- Reduction of Wave Making Resistance



Computation:

- Geometry built in FFW,
- Minimization of Wetted Surface with NSGA II
- Assessed by CFD code SHIPFLOW, using Potential Flow Theory (XPAN code)



Constraints:

- Displacement and Deadweight Constraint (up to 1% deviation)
- Tank Capacity Constraint (up to +1% deviation).



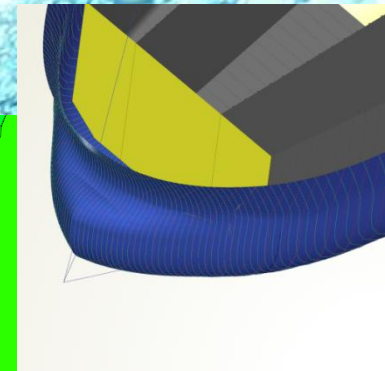
Result:

- 42% reduction of the Wave Making Resistance (compared to original)
- 1.5% reductional of total resistance and installed power

[Global System]
z-axis

Multi Venture

I.D 2515



All Electric Propulsion for a Tanker

Merits:

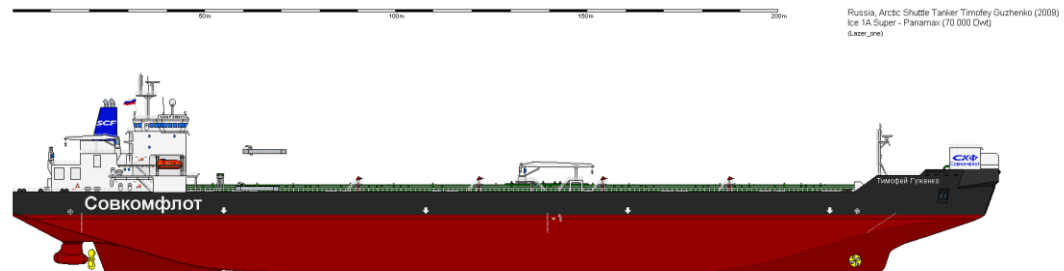
- Decreased Weight and Space
- More Flexible Operational Profile (e.g Slow Steaming)
- LNG as a fuel can increase efficiency and decrease emissions
- Platform for introduction of alternative energy

Drawbacks

- Increased Capital Cost
- Human Factors on Operation and Maintenance

Application so far:

- Shuttle Tankers





All Electric Tanker Load Analysis



Propulsion Loads:

- as before (2stroke)
- Predicted by Holtrop and Mennen



Auxilliary Loads:

- calculated based on equivalent size Bulk carrier data
- Normal Sea going, Maneuvering, Cargo Unloading and Harbour Conditions
- FRAMO power pack for cargo pumps



Propulsion Motors:

- Asynchronous motors
- Chosen from ABB according to Azipod range (same internal motor)
- Type 25 : ~ 12 MW at 100 RPM



Generators:

- Medium Voltage (6600 V, 60 Hz)



All Electric Tanker Hybrid Dual Fuel Electric Propulsion

□ Schematic



All Electric Tanker Dual Fuel Generating Sets

Wartsila Marine Program Used:

Dual Fuel Generating Sets:

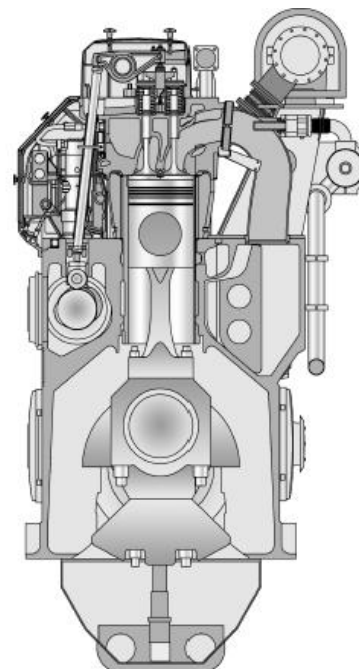
- Twin 8L50 DF gensets
- Twin 6L34 DF ,
- One 6L20 DF (for auxilliary loads in port)

Lean Burn Principle:

- High compression ratio
- Reduction of NOx (reduced peak tempratures)

Reduced Size and Weight

- 700 tons decreased lightship
- Located at the upper decks for better accessibility





All Electric Tanker Engine Room and LNG tank Arrangement

Engine Room Arrangement:

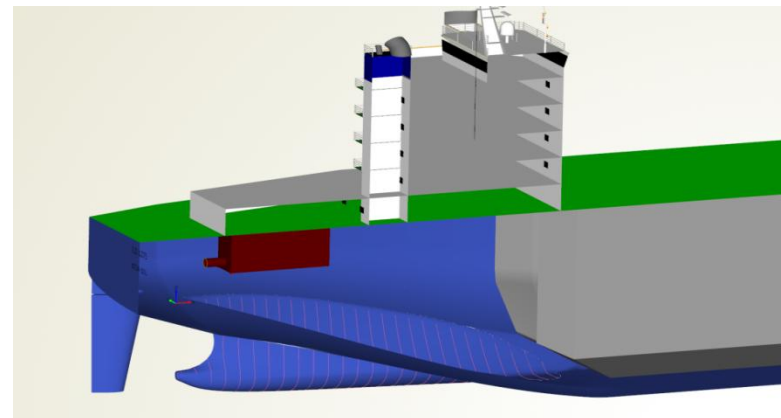
- Upper Deck
- Fire proof Type A60 longitudinal bulkhead → Design for Safety
- Daily and Settling tanks modeled
- Control Room aft of the Generator Room } Design for Security
- Steering Gear in the same position }

LNG Tank Arrangement:

- IMO C-Type tanks
- 4X400 m³ Tanks on deck
- 3X200 m³ Vertical tanks in E.R
- LNG Range: 4000nm
- Combined Range: 15000nm

Modularized Engine Room Concept:

- Retractable Roof on main deck and hatches,
- Easily accessible engine room
- Engine Leasing Program

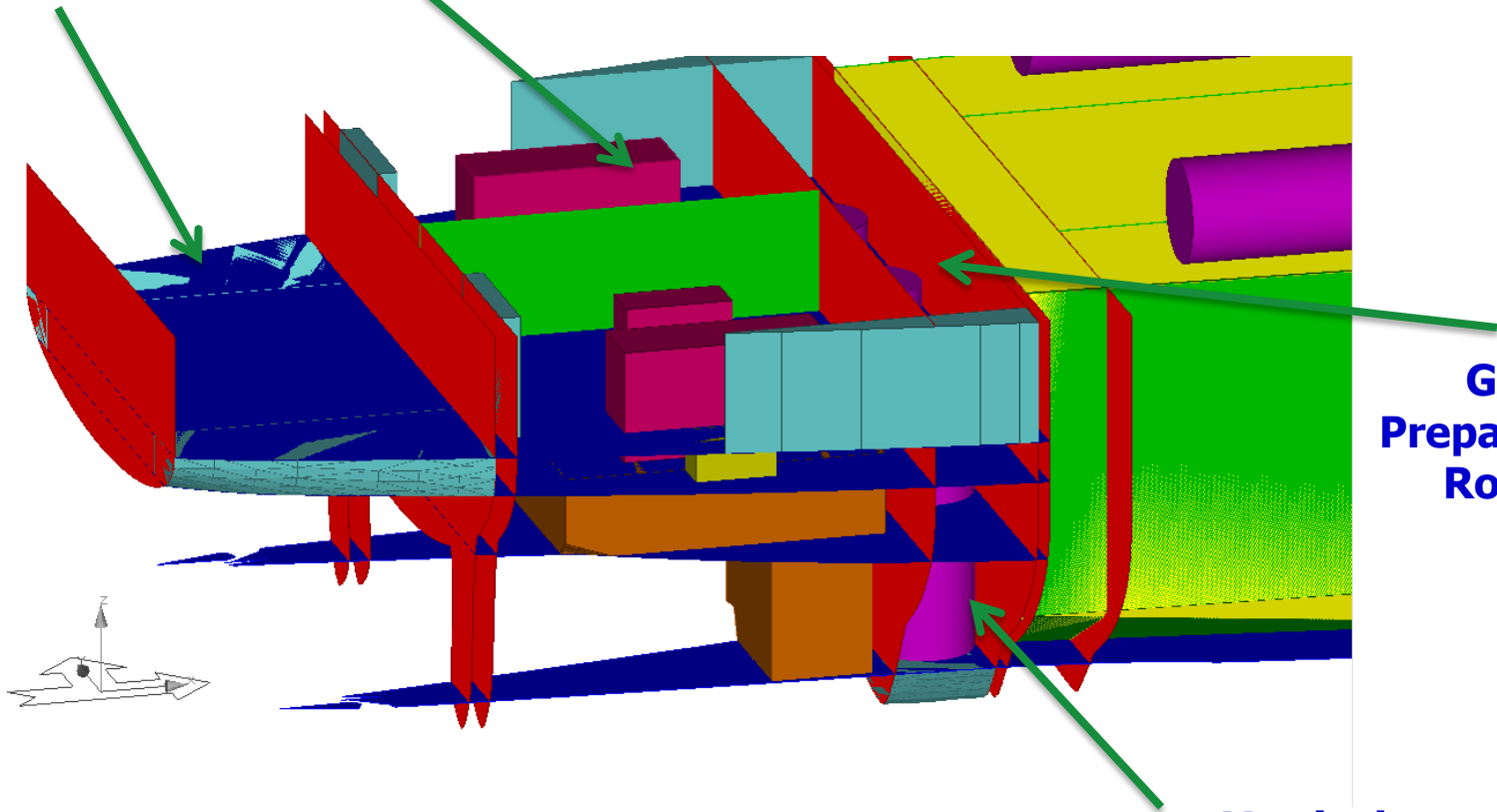




All Electric Tanker Engine Room and LNG tank Arrangement

**S.G/Control
Room**

**Generator
Room**



**Gas
Preparation
Room**

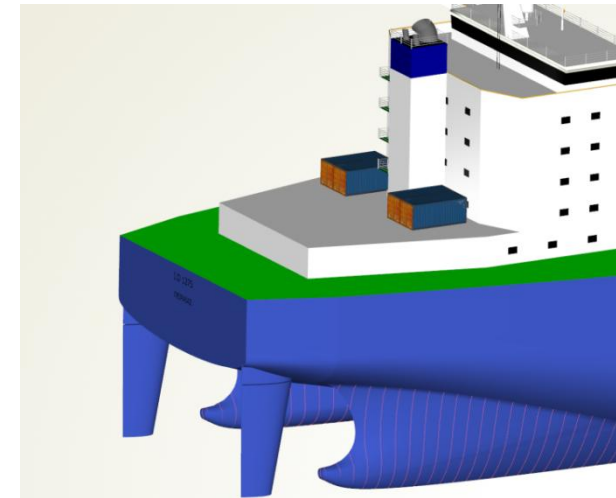
**Vertical
LNG tanks**

All Electric Tanker Fuel Cells



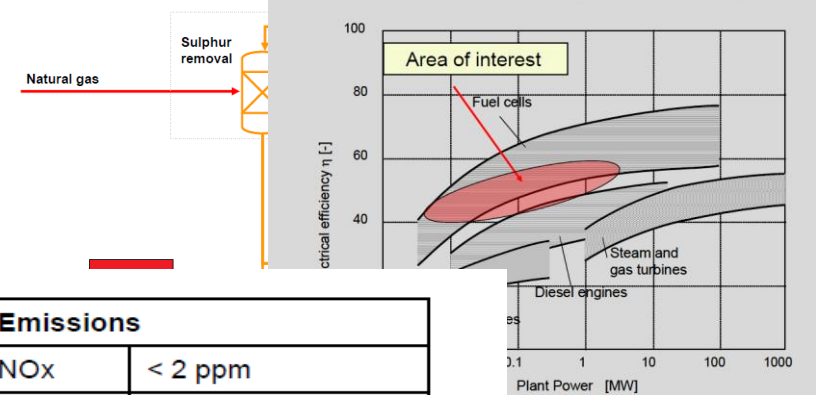
Wartsila 50 kW packs:

- Containerized modules of 4X50kW
- Compact unit: installed in one T.E.U
- Location close to funnel:
 - Utilization of fuel cell waste heat (exhaust at $\sim 800^{\circ}\text{C}$)
- Completes the modularized propulsion concept



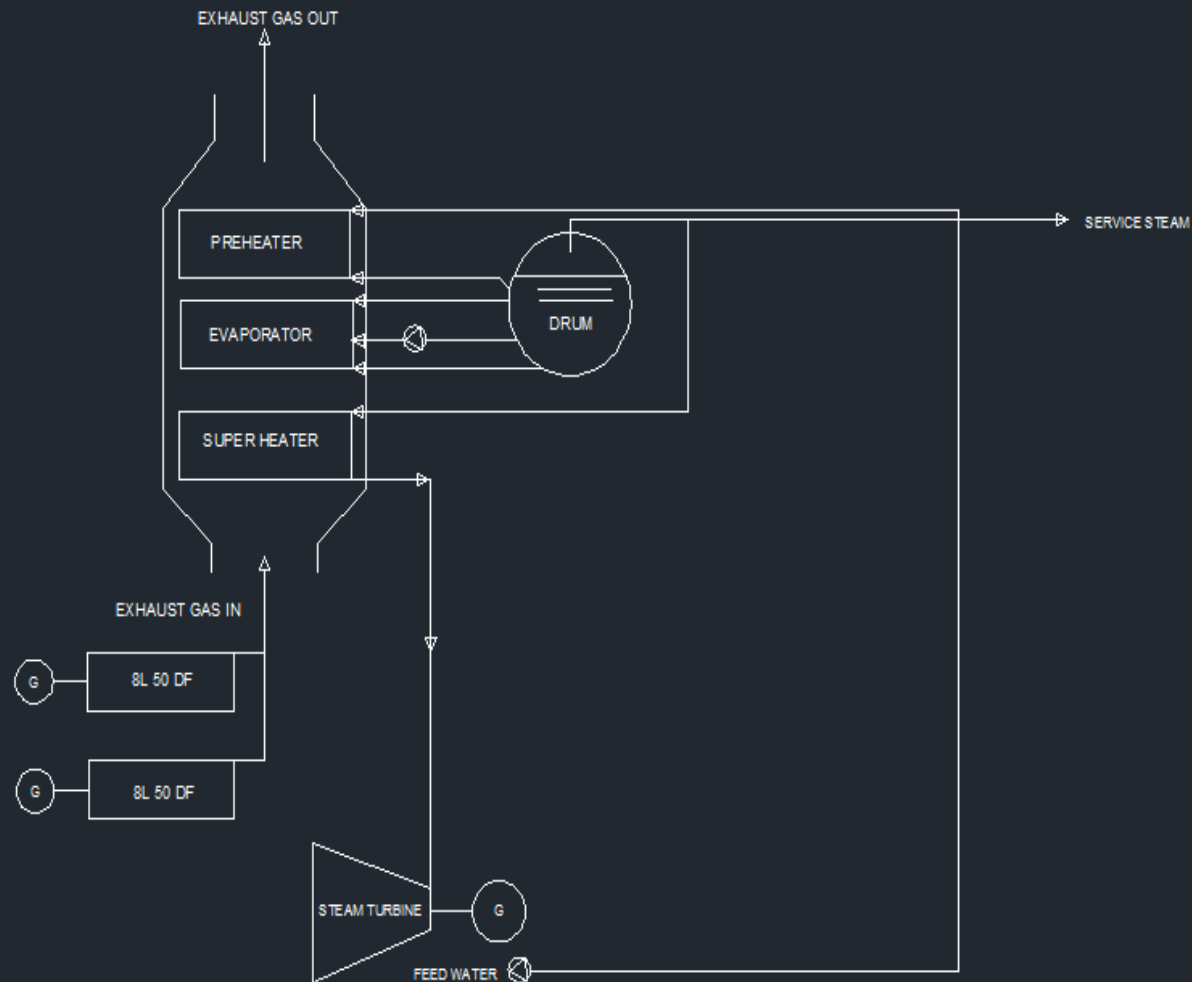
Fuel Cell Technology:

- SOFC technology
- Use of Natural Gas or Bio Gas as a fuel
- Installed in Pure Car Carriers (PCC) and ferries
- Electrical Efficiency of approx. **53 %**
- Easy to maintain and without vibrations
- Assistive in harbor operations
- Very Low emissions





All Electric Tanker Steam Turbine





All Electric Tanker Steam Turbine



Waste Heat from Generators

- Exhaust Gas Boiler, used in LNG and Diesel modes,
- LNG mode can have better heat recovery (bigger LHV)
- Approx. 6.5 MW of exhaust gas energy
- Preheater, Evaporator and Superheater
- Single, High Pressure System



Steam Turbine:

- High pressure turbine
- Steam pressure (inlet): 15bar
- Outlet pressure: 0.05 bar
- Electrical Output of approx. **1.7 MW**
- Combined with fuel cells 2MW of hybrid propulsion (15% of installed power)



All Electric Tanker Economic Assessment



Increased CAPEX:

- 6.6 mil cost for LNG bunker installation
- Initial 15% twin screw extra taken to 20% for Diesel Electric Drive
- Reduced Lightship



Reduced OPEX, VOYEX:

- Cheaper Fuel (LNG)
- Better engine loading in laden and ballast legs



RFR difference:

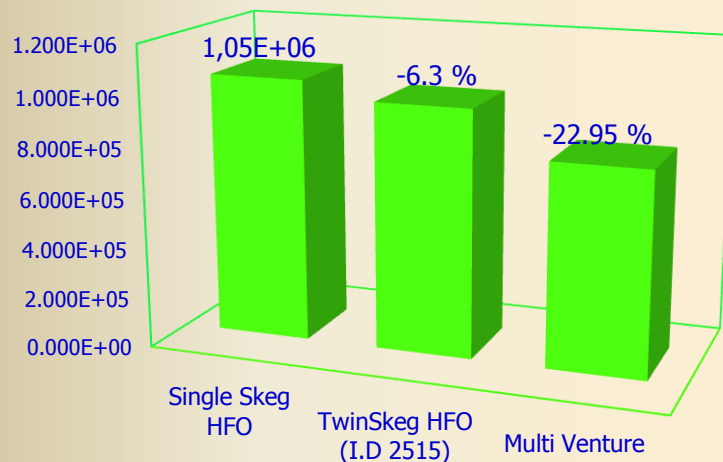
- HFO as fuel (750\$/t): **+1.41%**
- LNG as fuel (500\$/t): **-11.7%**
- HFO and LNG (eq. 650\$/t): **-4.16%**



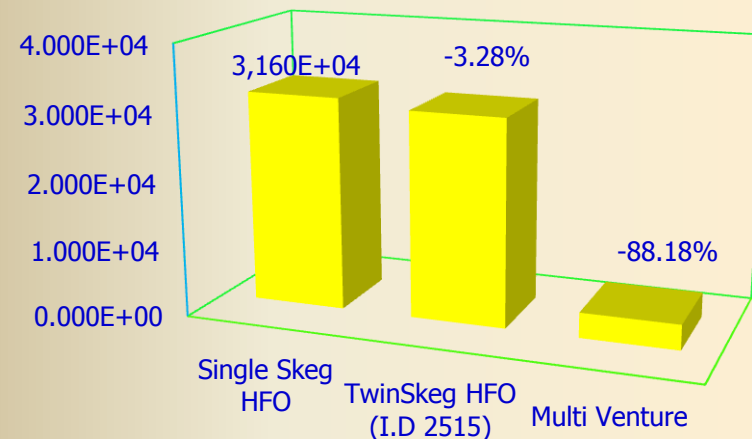
All Electric Tanker Environmental Assessment

- ▣ Environmental Assessment:
 - EEDI is not applicable for DE applications!
 - Need for Lifecycle Assessment Tool of Machinery Emissions
 - Thesis of Mr. Nikos Mantakos (super. By Prof. Ventikos)
 - Emissions Breakdown:
 - ▣ CO₂, SO_x, NO_x, PM
 - ▣ Increase of CH₄ by 39%
- ▣ Major improvement in comparison with existing AFRAMAX ships
- ▣ Methane increase can be tackled by:
 - Improvement in combustion technology
 - Use of afterburner

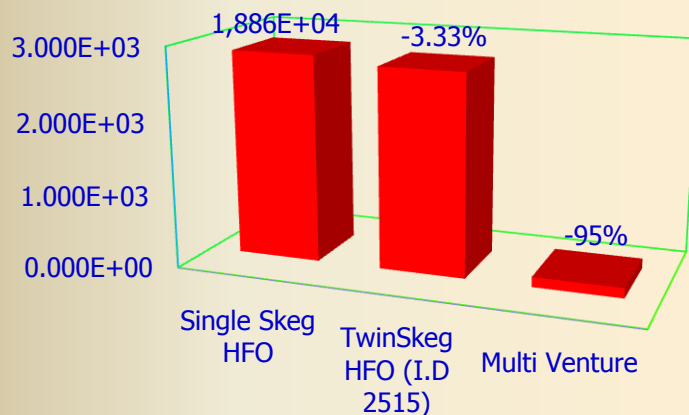
Life Cycle CO2 Emissions (Operation)



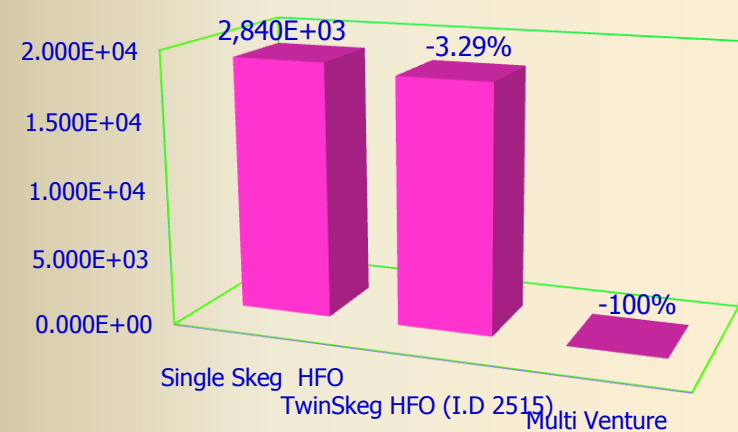
Life Cycle NOX Emissions (Operation)



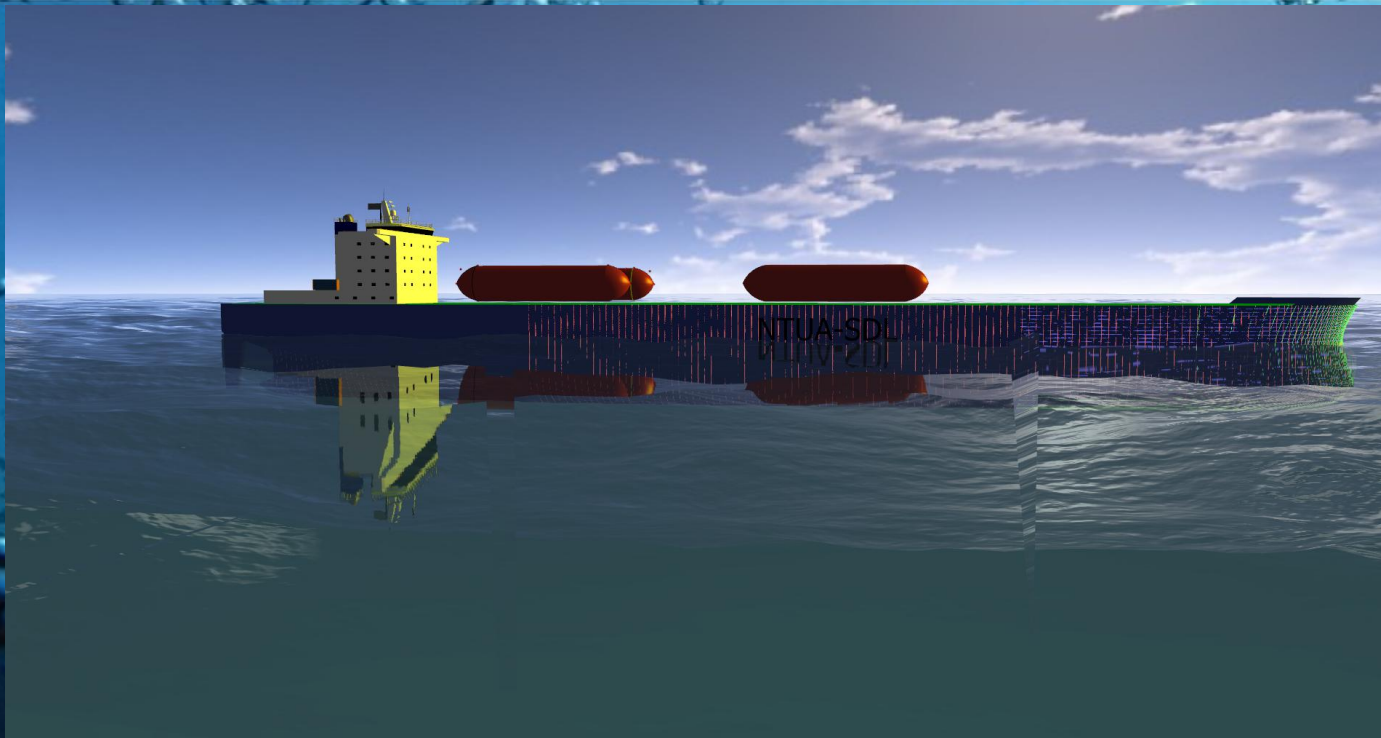
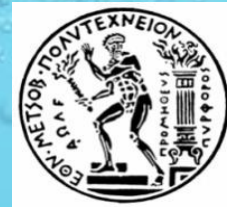
Life Cycle PM Emissions (Operation)



Life Cycle SO2 Emissions (Operation)



Discussion-Conclusions





Conclusions

- A novel model of a *Twin Screw, Shallow Draft, Beamy* AFRAMAX tanker with *5X3 tank arrangement* has been created and systematically varied, **entirely within the Friendship Framework**

- Initial Optimization results (differences from existing conventional design):

- Required Freight Rate reduced up to **10%**
- Accidental Oil Outflow reduced by **43%**.
- Ballast Water Reduced by **47%**.

- Multi Venture:

- Emissions are greatly reduced
- Even with increased CAPEX, RFR is reduced by 12%
- New innovative maintenance systems

- It is possible to create an AFRAMAX that is safer and more competitive and efficient than existing designs...

-and is also Dual Fuel Diesel Electric without having to sacrifice the Economic sustainability of the design.



Pending Work-Future Prospects

- Wake Adapted Propeller:
 - Expected Results by mid-June
 - Increase of Propulsion Efficiency from 62% to 70%.
- Second application of the methodology is to be done for a VLCC with a global approach (one stage only, results in July 2012).
- Include the use of batteries onboard (work of Dedes et al.)
- Use of biomimetic foil for thrust (run by V. Tsarsitalidis):
 - Shallow draft principle increases the lateral movement
 - Increased propulsion efficiency up to 85% (from initial 62%)
 - Needs time to mature and research for the servomechanisms



Acknowledgements



- The author needs to acknowledge the help and support of the following people, whose contributions have been critical for the completion of this work at various stages:

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- Associate Professor John Prousalidis (NTUA),
- Mr. Elias Sofras (NTUA),
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- Dr. Stefan Harries (FS),
- Mr. Utvaer Alf-Morten (FRAMO)

Thank you for your kind attention !



Questions ?

