Automated Multidisciplinary Design Optimization Method for Multi-Hull Vessels

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Project Description

This work will develop a multidisciplinary design and optimization (MDO) method, based on a Systems Engineering approach, for use in the preliminary design stage of multihull ships. Using advanced multicriteria optimization, the method will integrate hydrodynamic performance, evaluated by Neural Networks, with structures, seakeeping, powering and payload into a single design tool and will be applied to a baseline trimaran design for demonstration. Processes and algorithms for subsystems and their integration will also be developed.

Outcome

The expected outcome of this project is an MDO design tool based on a multicriteria design optimization methodology, suitable for preliminary (synthesis) design stage and processes and algorithms for various subsystems optimizations and their integration for future extension of the method.

When completed, the outcome will be a comprehensive MDO tool for multihull ships, encompassing, hull form optimization, powering, stability, seakeeping, structures and payload capacity.

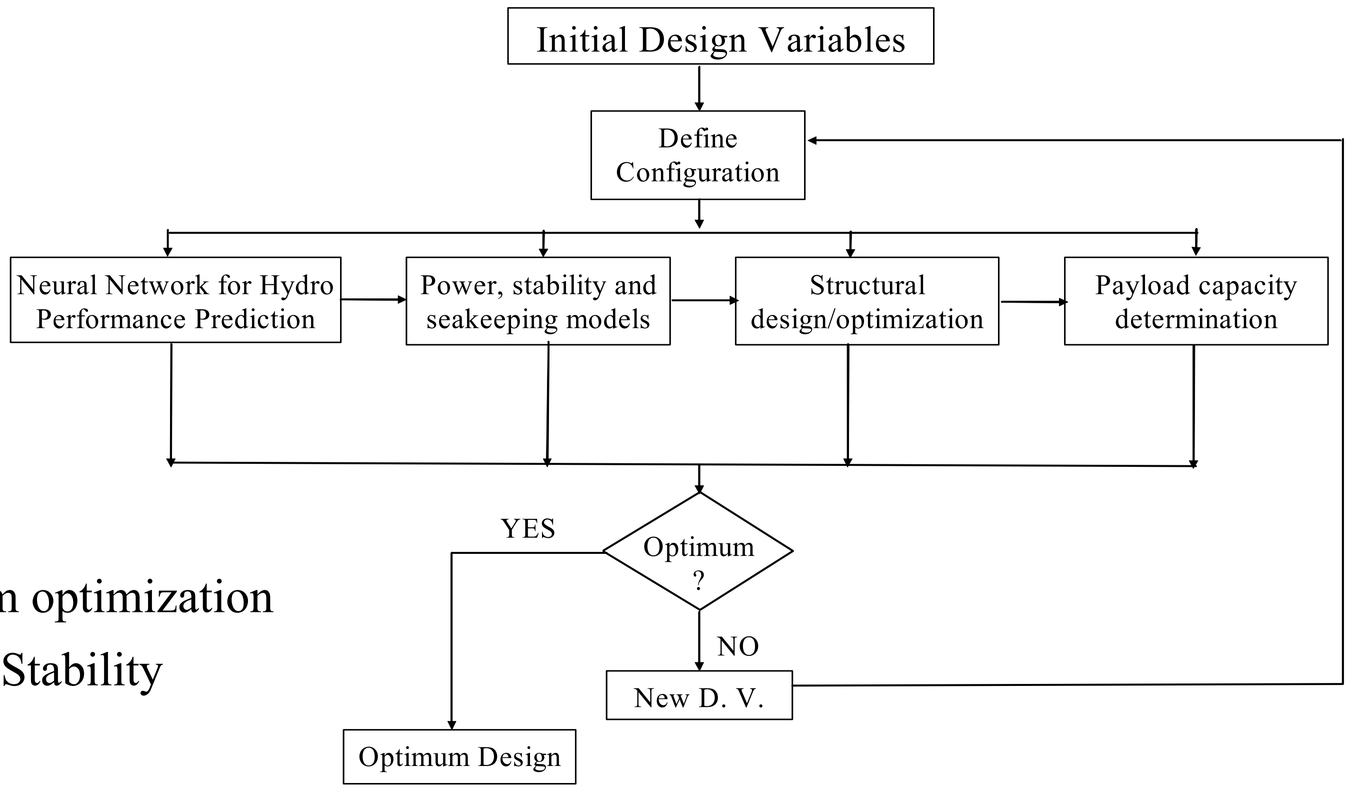
Need / Significance

ONR BAA Announcement #03-013A

A method to optimize the design of high-speed, multi-hull ships is needed. This method will encompass powering, stability, seakeeping, structures, and payload capacity. Currently, the vast majority of U.S. naval ships……., with the Navy's current interest in higher speeds and, in many cases, smaller ships, optimization of multi-hulls requires concurrent consideration of powering performance, payload capacity, stability, and seakeeping. An optimization process and algorithms need to be developed that can be utilized by early stage ship design synthesis models. This capability should include:

- Early stage structural design methods that utilize ……
- Algorithms to address the impacts of wave-making interference relative to longitudinal and transverse spacing between hulls.
- Optimization of 3-D hull form shape and size characteristics and relative location for multi-hull configurations based on powering performance, payload capacity, stability and seakeeping.
- Refined and validated multi-hull seakeeping assessment tools.

Approach



- Hull form optimization
- Damage Stability

Approach

- Successfully used in Aerospace Industry

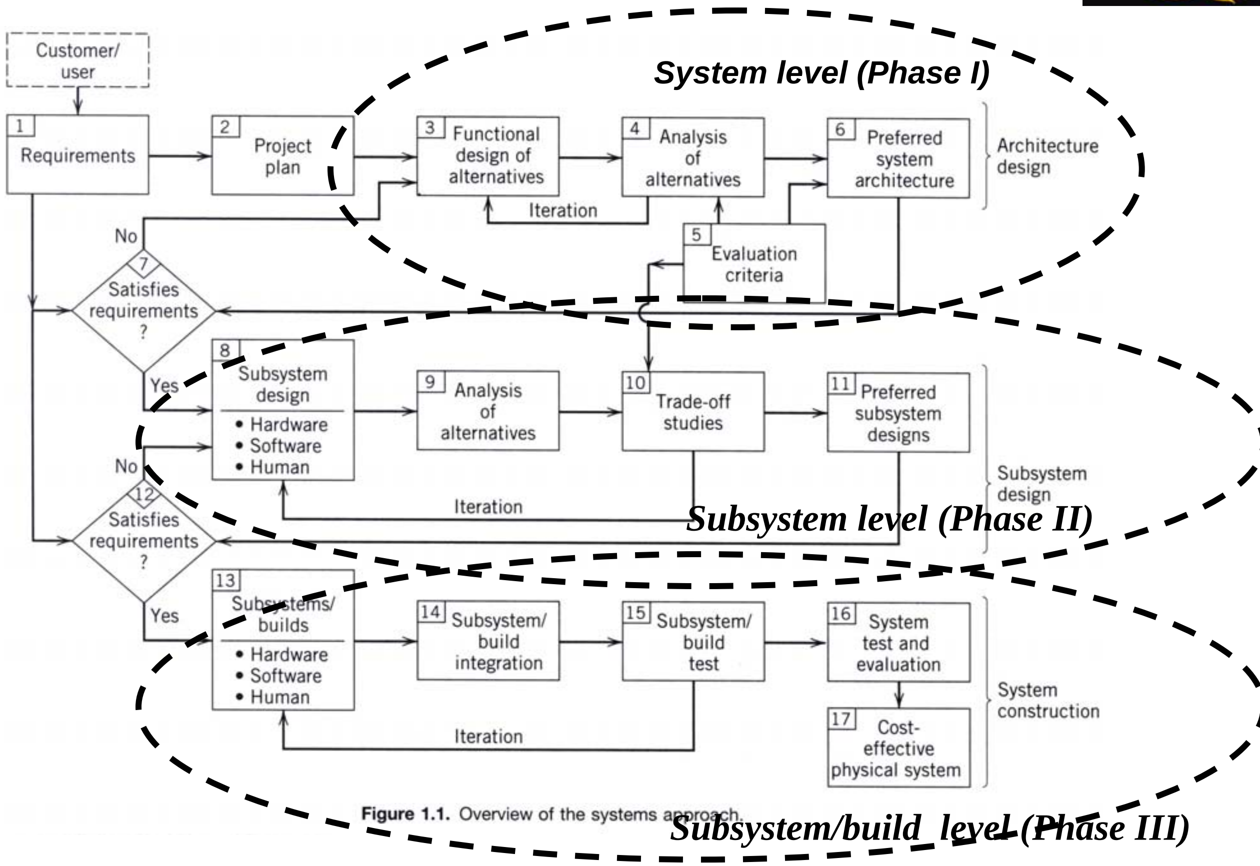
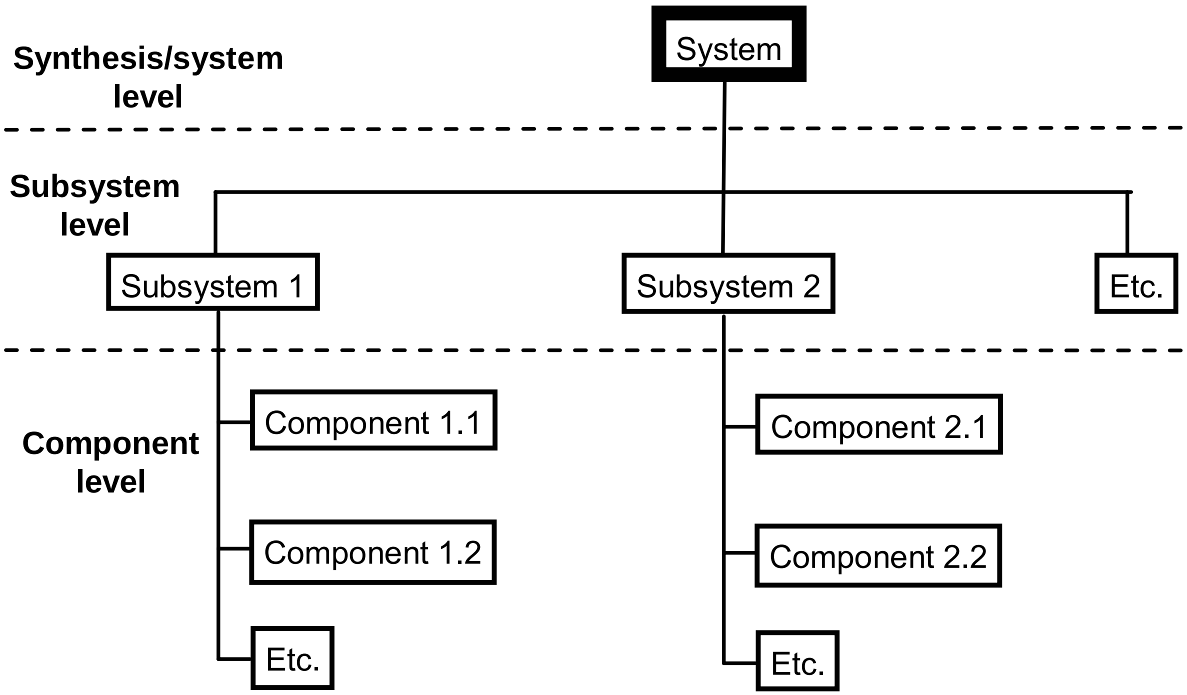


Figure 1.1. Overview of the systems approach.

Overview of the Systems Engineering Approach
(from H. Eisner, *Essentials of Project and Systems Engineering Management*, 2nd Ed., Wiley & Sons, 2002)

Approach



Elements of a System in the Systems Engineering process

Approach

- Main Challenges
    - Conflicting subsystem objectives
    - Complexity of subsystem performance analysis tools

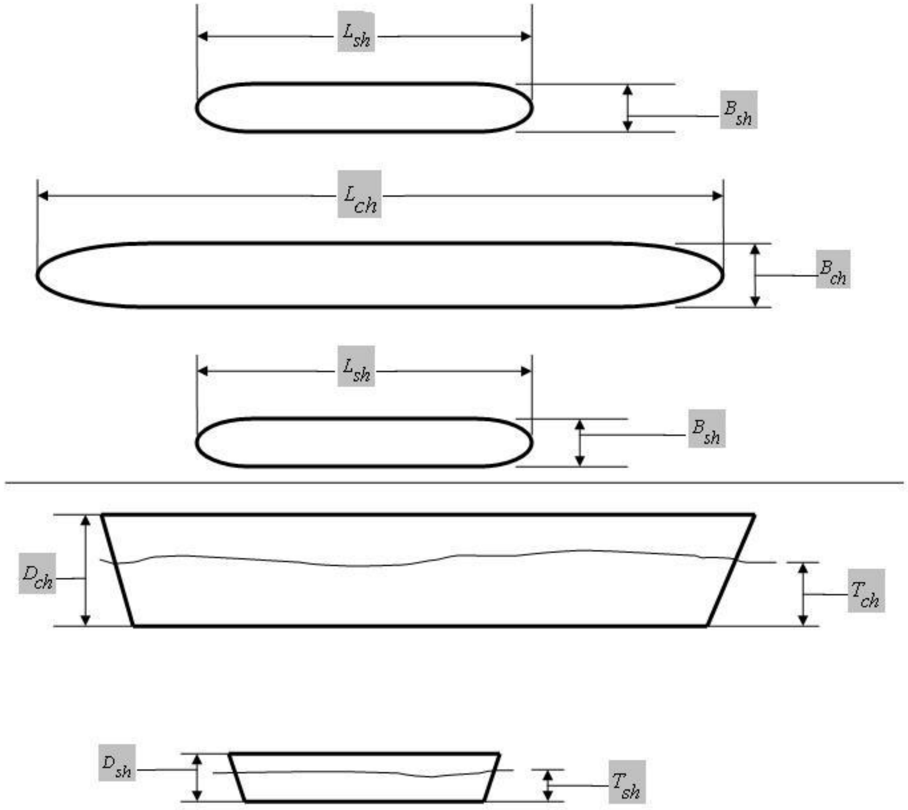
- Our Approach
    - Advanced Multicriteria / Multi-objective optimization
    - Neural Networks for subsystem performance analysis

Progress to date

Task 4.2 Design Variable Selection

<u>Design Variables (Synthesis level):</u>

- Center Hull (ch): Length L_{ch}, Beam B_{ch}, Block Coefficient C_b^{ch}, Depth D_{ch}, Draft T_{ch}
- Side Hull (sh): Ratio of Length sh/Length ch λ_{sh}, Beam B_{sh}, Block Coefficient C_b^{sh}, Depth D_{sh}
- $Displ_{sh}$/ $Displ_{ch}$ Λ, Separation α, Stagger β
- Design Speed V_k



Reference: "Preliminary description of Synthesis Trimaran Mathematical Model", CCDoTT interim report February 05

Task 4.3 Wave making interference Modified QLT (MQLT) Method

- QLT method takes into account non-linearity of boundary conditions on the free surface. QLT method allows to solve the problems:
  - Wave interference for multihulls;
  - Reliable Wave Resistance prediction of the slender hulls for Froude numbers (Fn) not exceeding 0.4-0.75

- Model test results analysis for Fn=0.4-0.75 showed predominant influence of Froude-dependent running trim and transom drag and has led to modification of the QLT method to get out of the conventional assumption about “Form-factor” - Froude-independent proportionality coefficient used in viscous drag estimate

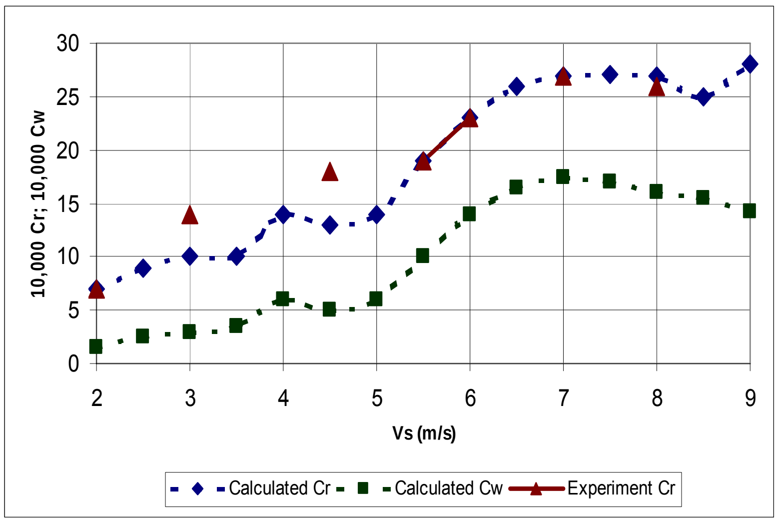
Modified QLT (MQLT) Method

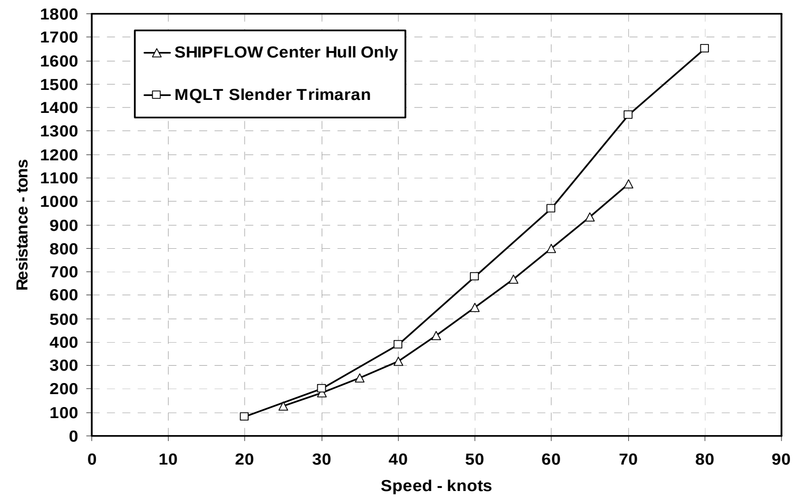
- Modified QLT method includes running trim and dynamic waterline calculations. Transom drag is calculated as viscous-inviscid interaction problem of wake separation behind the transom of the equivalent body of revolution

- Modified QLT method significantly reduced the discrepancies in measured and calculated resistance at Fn>0.4; viscous flow calculations and scale effect analysis on trimaran residuary drag proved considerable negative correlation allowance coefficient (~ -0.5*10^-3) and allowed to provide reliable estimate of the lift to drag ratios for trimaran ship versions for speed up to 70 knots.

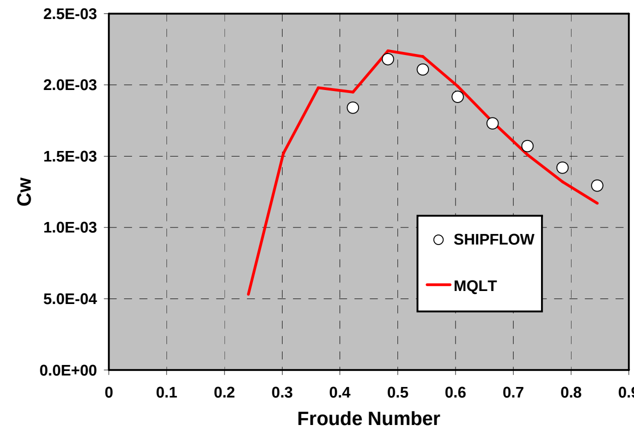
Validation

MQLT Validated by Model Tests





Resistance - SHIPFLOW and MQLT



Quasi Linear Theory method was modified to consider viscous-inviscid calculation of form resistance and transom drag – MQLT.
MQLT was validated with DTMB testing results and compared with SHIPFLOW CFD calculations.
MQLT is a basic tool for VHST hydrodynamic design and optimization.

Progress to date

Task 4.4 Powering Stability, seakeeping model definition

Powering: SHP Shaft Horsepower depends on

CR Total resistance coefficient

CF Friction Coefficient

CK Correlation Coefficient

CO Coefficient of residual resistance

CO is calculated using Neural Networks

- wave interference
- hull form optimization is limited to configuration arrangement (synthesis level)

$$CR = CO + CF + CK$$

$$CO = f(Sl, \alpha, \beta, Fn)$$

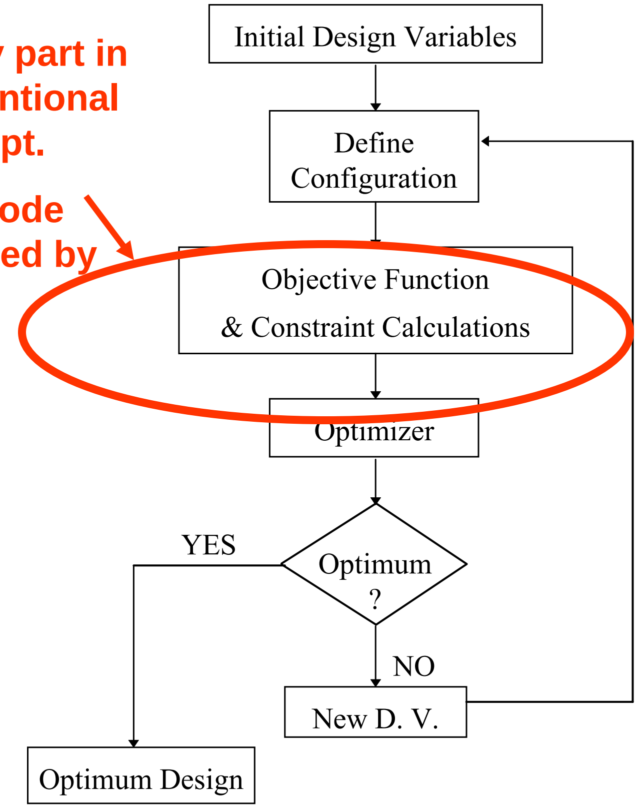
3 step Process:

- Generation of Training Set (TS) & Validation Set (VS): SAIC MQLT Method to approximate CO=f (Sl, β, α,Fn)
- Neural Network Training to obtain "evaluator"
  - Start with a minimal Network without hidden units Add one hidden unit at a time and train the NN to minimize Error between TS and the outputs to the NN. Keep adding HU's one at a time until stopping criterion met. Stopping criterion uses Error on Training and Validation Set to determine when training should be stopped
  - Output to training is a C++ evaluator code containing weights and structure of the NN
- NN evaluator is used in the optimization process

Neural Network

- Objective: Reduce computational cost by replacing the CFD analyses by a Neural Network (NN)
- Characteristics:
  - Cost moved to generating the training set for the NN
  - Less function evaluations needed for NN training set than for optimization
  - Significant CPU time reduction

- **Costly part in conventional CFD opt.**
- **CFD code replaced by NN**



Reference: E. Besnard. & A. Schmitz, and H. Hefazi "Automated Hydrodynamic Shape Optimization Using Neural Networks" 2004 SNAME Maritime Technology Conference & Expo and Ship Production Symposium, Oct 29-Nov 03, 2004, Washington DC.

Neural Network

- Task Status
  - Wave-resistance NN has been generated and verified
  - Continue enhancement of the data used for generating wave-resistance neural networks, including possibly using data from References 1 and 2.
  - Flexibility of the approach

References:

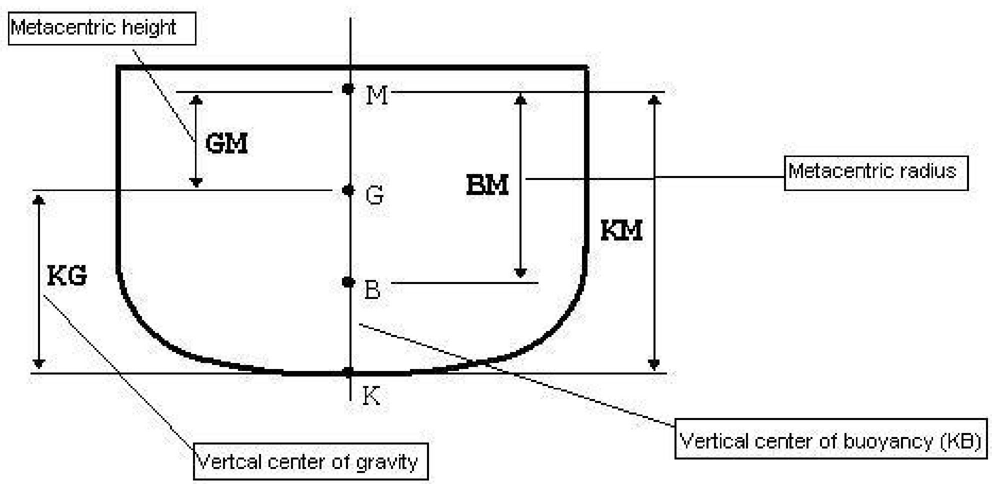
[1] Zafer Elcin, "Wave-making resistance characteristics of Trimaran Hulls", M.S. Thesis, NPS, Dec 2004.

[2] D. Floden, K. Kim and P. Ottosson "A Computational/Experimental Investigation on Resistance and Seakeeping Characteristics of Trimaran Configuration in Comparison with Monohull", 9th Symposium on Practical Design of Ships and Other Floating Structures, Luebeck- Travemunende, Germany, September 12-17, 2004

Progress to date

Task 4.4 Powering Stability, seakeeping model definition

Constraint
BM> 1% of Beam
Overall of the trimaran



Progress to date

Task 4.4 Powering Stability, seakeeping model definition

- Trimaran BM= $(b^2 Sch + Ich)/Vch + (b^2 \cdot Sch + Ish)/Vsh$

b - transverse clearance between the hulls
S – water plane area
V – volume of displacement
I – transverse moment of inertia of waterline

Var (BM)= $[(b1^2 - b2^2) \cdot (Sch+Ssh)/(Vch+Vsh)]$

- Longitudinal

Progress to date

Task 4.4 Powering Stability, seakeeping model definition

Other Constraints:

- Worked on simplified hydrostatic parameters definition for Displacement, Waterplane area, Moment of inertia, etc. as functions of draft. These formulas depend on analytical hull forms and trimaran configuration variables. As the work further progresses the simplified Wigley analytical hull forms would be substituted by direct integration of the practical hull forms

- Metacentric radii (transverse and longitudinal) depend on individual hulls hydrostatic parameters and trimaran configuration variables (transverse and longitudinal clearances). Stability curves are based on simplified hulls forms and further can be substituted by direct integration of the practical hull forms

- For trimaran Seakeeping estimate initiate work with NSWCCD for application of VERIS code for trimaran extreme motion prediction

Progress to date

Task 4.5 Structural design

Structural Weight model

- The structural weight of the trimaran is the sum of steel weight, outfit weight and machinery and propulsion weight,

Structural weight = $W_s + W_o + W_m = \left(W_s^{ch} + 2 \times W_s^{sh}\right) + \left(W_o^{ch} + 2 \times W_o^{sh}\right) + W_m$

References:

1. "Preliminary description of Synthesis Trimaran Mathematical Model", CCDoTT interim report February 05
2. "Formulation of Multicriterion Design Optimization Problems for Solution With Scalar Numerical Methods," *Journal of Ship Research,* Vol48, No.1, pp61-76, March 2004.

Progress to date

Task 4.5 Structural design

• Collected statistics for weight distribution of the various type of multihull ships. Analyzed the available design information and developed the analytical formulas for trimaran basic lightweight groups as functions of sizing, configuration variables number of decks and bulkheads. These formulas are to be used in synthesis design model.

• Started the detailed description of the structural optimization subsystem. Identified set of variables and approximate determination of structural parameter. For external loads estimate.

• Initiated work with NSWCCD for application of SPECTRA code for structural loads and moment of the trimaran ship configuration. SPECTRA code is verified by comparison with segmented trimaran model test results and would be used to generate the set of training points for further optimization process.

Progress to date

Task 4.6 Payload Capacity Algorithm

- Payload capacity model

Round trips per year	RTPA
Sea Days	SD
Port Days	PD

$$RTPA = 365/(SD + PD)$$

- Cost model

$$TransportationCost = AnnualCost / AnnualC\arg o$$

References:

1. "Preliminary description of Synthesis Trimaran Mathematical Model", CCDoTT interim report February 05
2. "Formulation of Multicriterion Design Optimization Problems for Solution With Scalar Numerical Methods," *Journal of Ship Research,* Vol48, No.1, pp61-76, March 2004.

Progress to date

Task 4.6 Payload Capacity Algorithm

• Collected statistics on stowage factors for various types of multihull ships.

• Developed approximate formulas for cargo volumes and areas in relation of sizing and hydrostatic parameters (as determined in Task 4.4). These formulas for basic groups of internal spaces are to be used in synthesis model for simplified Wigley hull forms. As the work further progresses these formulas would be substituted by direct ship compartment summary based on general and cargo arrangement drawings.

•For synthesis design model formulas showing the dependence between payload and range are developed. The range of unrefueled voyage is determined as function of required power, fuel consumption and capacity of fuel tanks. These formulas allow to provide tradeoff and parametric studies between speed-payload-range design requirements.

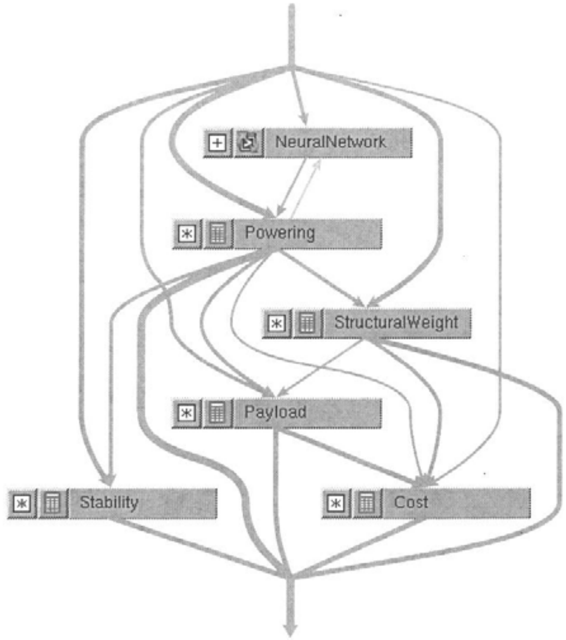
Task 4.7 Integration and application iSIGHT implementation

Optimization: Multi-Objective Genetic Algorithm (MOGA)

- Neighborhood Cultivation Genetic Algorithm (NCGA)

OR

- Non-Dominated Sorting Genetic Algorithm (NSGA II)



Task 4.7 Integration and application iSIGHT implementation

Objectives:

- Min Transportation Cost
- Min Structural Weight
- Max. Annual Cargo Capacity

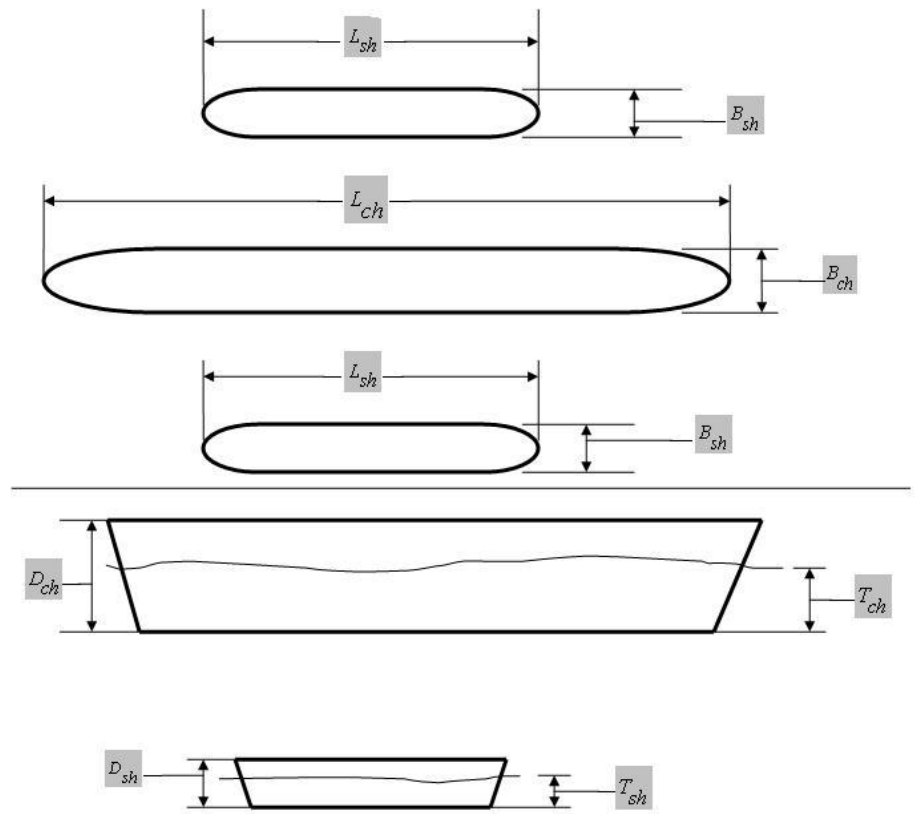
Constraints:

- Geometric: Separation, Stagger, Relative length of Side hull/Center hull, Displacement ratio, Length to beam, Length to Depth and Length to Draft ratios, draft center hull to draft side hull ratio, Block Coefficients
- Dead Weight: 3000 t $<DWT<$500,000 t
- Design Speed: 14 knts $<V_k<$18 knts
- Froude Number: $0.2<Fn<1$
- Initial Stability: Metacentric Height/Beam Overall Length>0.01
- Cargo Mark: TBD
- Financial Conditions: TBD

Task 4.7 Integration and application iSIGHT implementation

<u>Design Variables:</u>

- Center Hull (ch): Length L_{ch}, Beam B_{ch}, Block Coefficient C_b^{ch}, Depth D_{ch}, Draft T_{ch}
- Side Hull (sh): Ratio of Length sh/Length ch λ_{sh}, Beam B_{sh}, Block Coefficient C_b^{sh}, Depth D_{sh}
- $Displ_{sh}$/ $Displ_{ch}$ Λ, Separation α, Stagger β
- Design Speed V_k



TRIMARAN MODEL

Powering

Inputs:

$L_{ch}, B_{ch}, \Lambda, T_{ch}, C_b^{ch}, \lambda_{sh}, V_k, \alpha, \beta$

Outputs:

$L_{sh}, Displ, Displ_{ch}, Displ_{sh}, WS, WS_{ch}, WS_{sh}, Sl, Sl_{ch}, Sl_{sh}, V, RE, RE_{ch}, RE_{sh}, F_n, CF, CK, CO, CR, RES, EHP, SHP$

Structural Weight

Inputs:

$L_{ch}, B_{ch}, D_{ch}, C_b^{ch}, B_{sh}, D_{sh}, C_b^{sh}, L_{sh}, SHP$

Outputs:

$W_s, W_s^{ch}, W_s^{sh}, W_o, W_o^{ch}, W_o^{sh}, StructuralWeight$

Payload

Inputs:

$V_k, SHP, Displ, StructuralWeight$

Outputs:

$DCon, SD, Fc, DWT, miscDWT, PD, Payload, RTPA, AnnualCargo$

Cost

Inputs:

$W_s, W_o, DWT, DCon, SD, RTPA, SHP, AnnualCargo$

Outputs:

$SC, CC, RC, PC, FC, VC, AnnualCost, TransportationCost$

Stability

Inputs:

$L_{ch}, L_{sh}, B_{ch}, D_{ch}, C_b^{ch}, B_{sh}, D_{sh}, C_b^{sh}, T_{ch}, Displ_{sh}$

Outputs:

$BM_T^{ch}, BM_T^{sh}, T_{sh}, KG_{ch}, KG_{sh}, KB_{ch}, KB_{sh}, GM_T^{ch}, GM_T^{sh}$

Conclusions

- Progress has been made in all tasks of the project

✓ Synthesis level model is almost complete

- Progress is being made on refinement of synthesis level model
- Progress is made on subsystem model definition and processes