Automated Multidisciplinary Design Optimization Method For Multi-Hull Vessels

IMPACT 2005, November 9-10, Long Beach, CA

Dr. Hamid Hefazi, Professor & Chair
562-985-1502 – hefazi@csulb.edu
California State University, Long Beach

In Collaboration with SAIC

Dr. Igor Mizine

Key contributions by:

- Ms. Adeline Schmitz, Research Associate, Ph.D. Candidate
- Dr. Eric Besnard, Associate Professor, CSULB
- Mr. Rahul Shinde, Graduate Student, CSULB

Outline

Update

- Task 4.2 Design Variable Selection
- Task 4.3 Wave Making Interference
- Task 4.4 Powering Stability, Seakeeping Model Definition
- Task 4.5 Structural Design
- Task 4.6 Payload Capacity Algorithm
- Task 4.7 Integration and Application iSIGHT Implementation
- Extension of the Program

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.

Approach

- Successfully used in Aerospace Industry

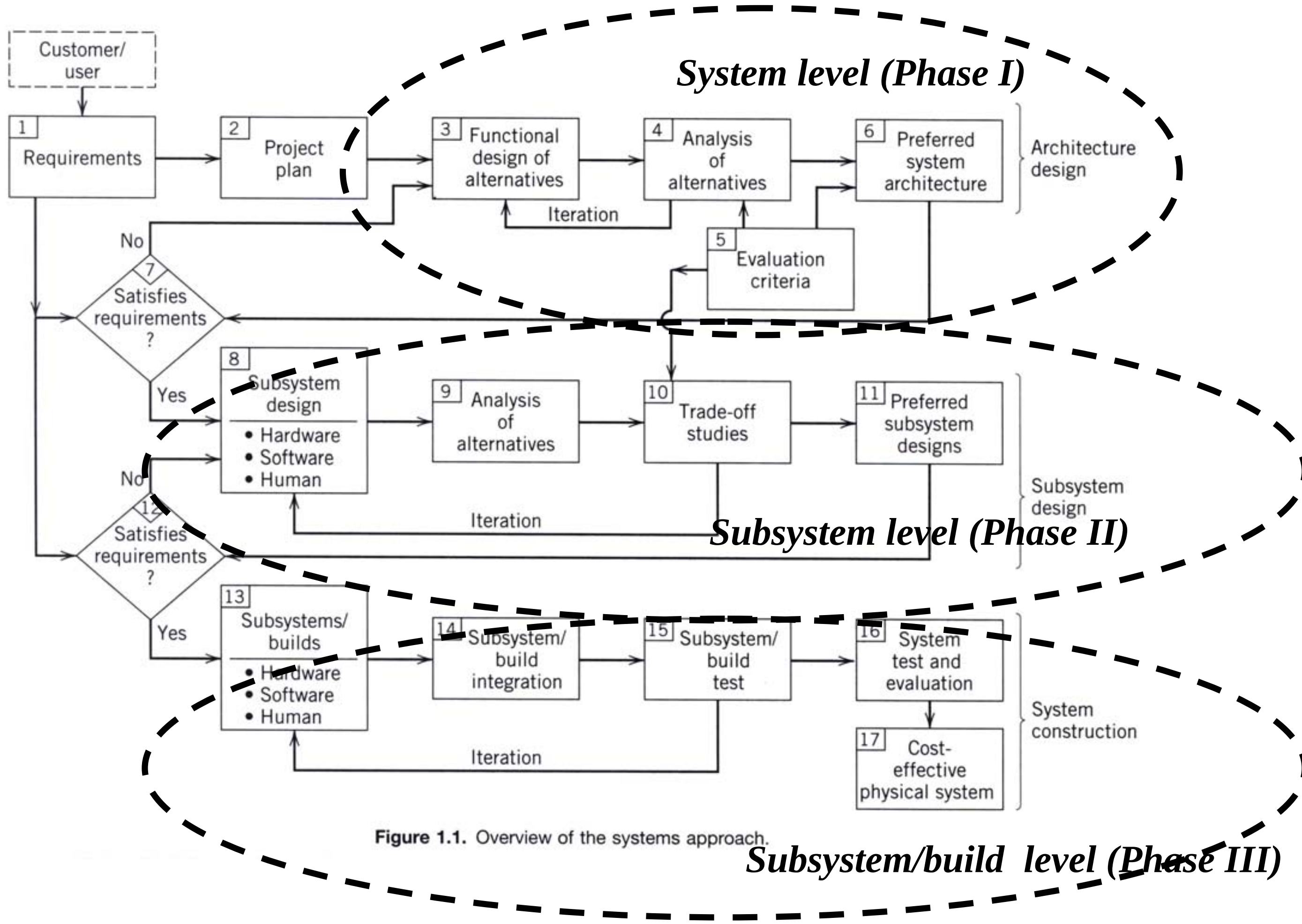
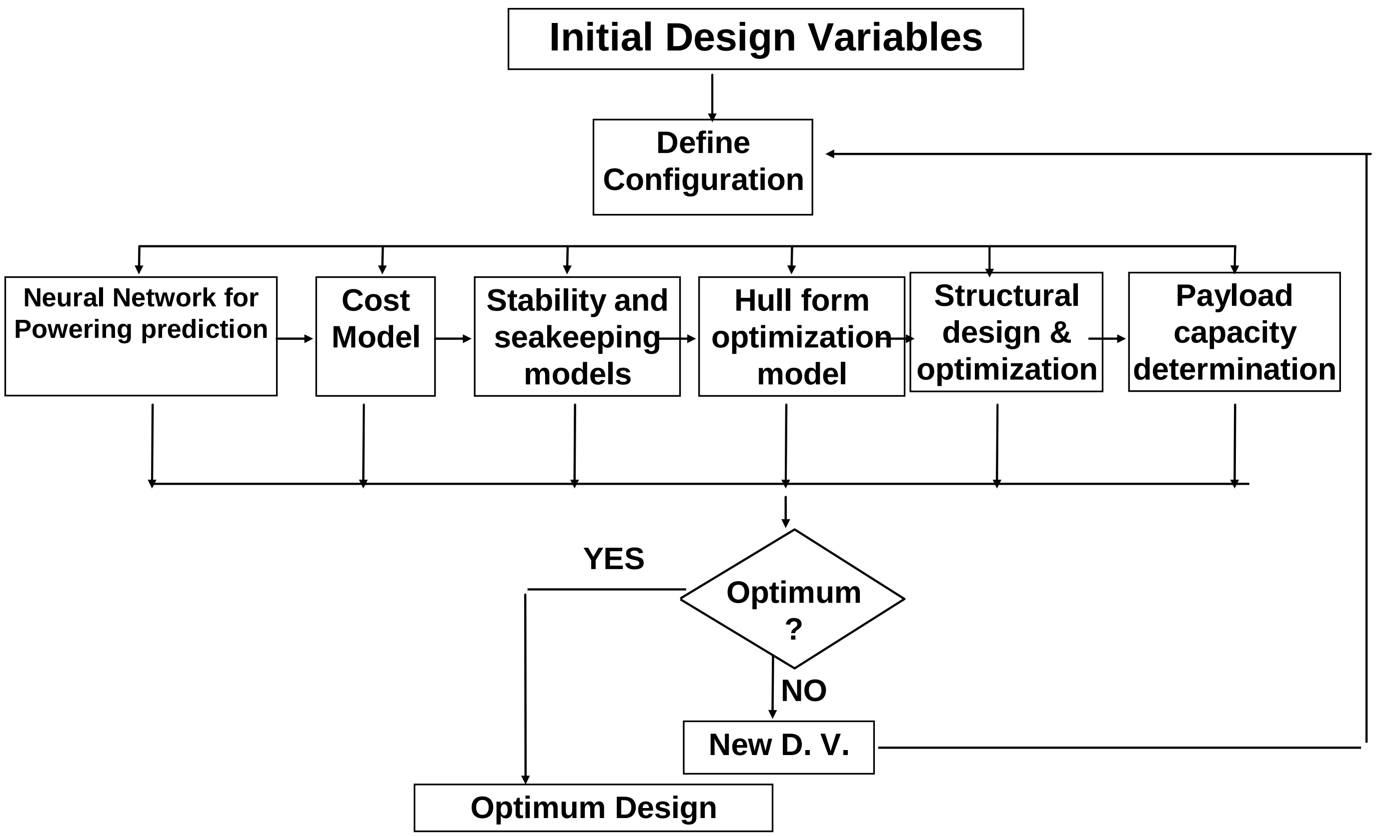


Figure 1.1. Overview of the systems approach.

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

Approach


Initial Design Variables
Define Configuration
Neural Network for Powering prediction
Cost Model
Stability and seakeeping models
Hull form optimization model
Structural design & optimization
Payload capacity determination
Optimum ?
YES
NO
New D. V.
Optimum Design

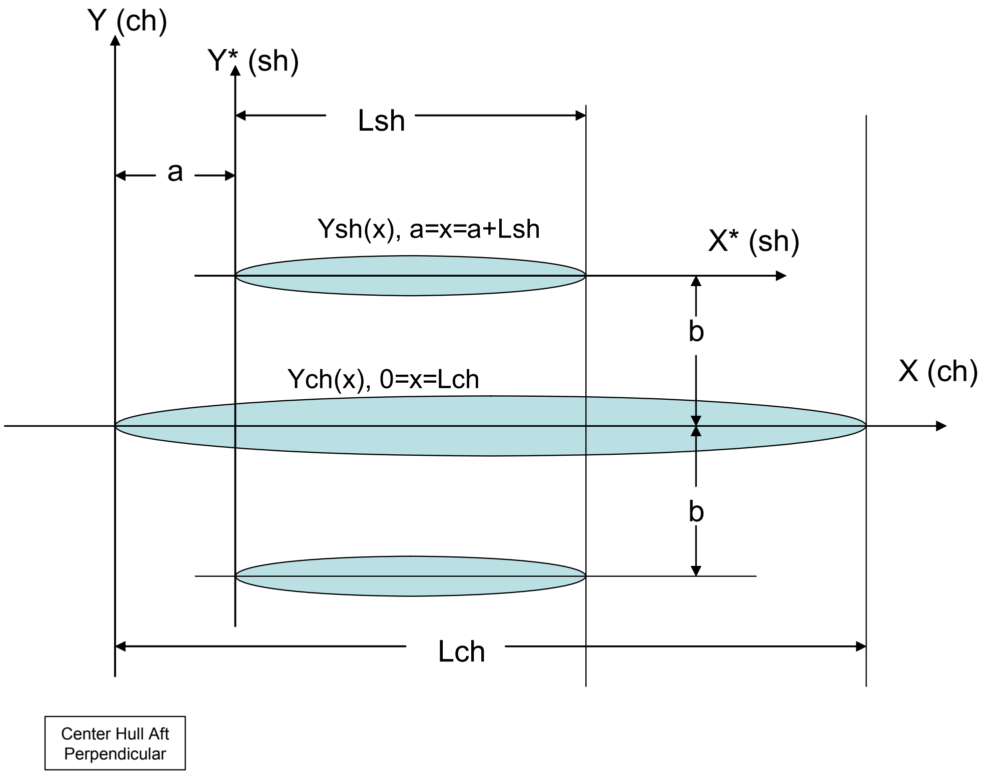
Approach

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

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

Design Variable Selection

- Synthesis level DV



Reference: Hefazi, H. et al "Automated Multidisciplinary Design Optimization Method for Multi-Hull Vessels" CCDoTT PE# 1.2 Final Report, www.ccdott.org July 2005.

Synthesis Level DV

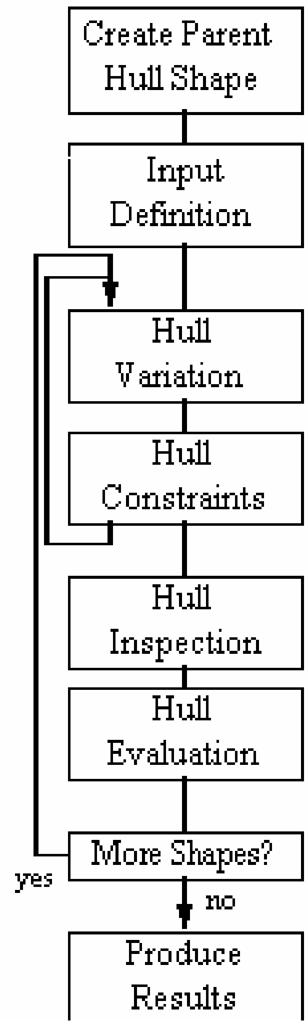
SR. NO	DESIGN VARIABLE	LOWER BOUND	UPPER BOUND	DESCRIPTION
1	L_{ch}	100	250	Length of Center Hull
2	B_{ch}	12	24	Beam of Center Hull
3	B_{sh}	3	8	Beam of Side Hull
4	T_{ch}	4	12	Draft of Center Hull
5	C_b^{ch}	0.45	0.60	Block Coefficient of Center Hull
6	C_b^{sh}	0.45	0.60	Block Coefficient of Side Hull
7	V_k	25	45	Speed (knots)
8	N_d	2	4	Number of Decks
9	α	0.5	1.5	Separation
10	β	0	1.0	Stagger
11	Λ	0.03	0.15	Lambda
12	λ_{sh}	0.1	0.75	Lambda-sh

Automated Multi-hull Forms Generation Method

Subsystem Level DV

- Hull form definition
  - NURBS surface definition
  - Polyhedron mesh definition
  - Station definition
- Hull variation & constraints
  - Constant displacement
  - Constant draft
- Hull inspection outputs
  - Volume, wetted surface, water plane area
  - Righting moments, or Polyhedron mesh

Hull Variation/Evaluation Process



Automated Multi-hull Forms Generation Method

- HULL EVALUATION ROUTINE

1. **Geosim Coefficient Resistance Evaluation**
   - Neural Networks
2. **Ship Motion and Structural Loads Prediction Methods**
   - Polyhedron mesh as input data
   - SPECTRA, VERES, LAMPS, SWAN/WASIM.
3. **Computational Fluid Dynamics Methods (CFD)**
   - Polyhedron mesh as input
   - Navier Stokes (RANS) methods
4. **Finite Analysis Methods (FEM)**
   - Polyhedron mesh as input
   - Perform structural finite element analysis of the hull shell

Powering: SHP Shaft Horsepower depends on:

CR Total resistance coefficient $CR = CO + CF + CK$
CF Friction Coefficient
CK Correlation Coefficient
CO Coefficient of residual resistance $CO = f(Sl, \alpha, \beta, Fn)$
CO is calculated utilizing Neural Networks

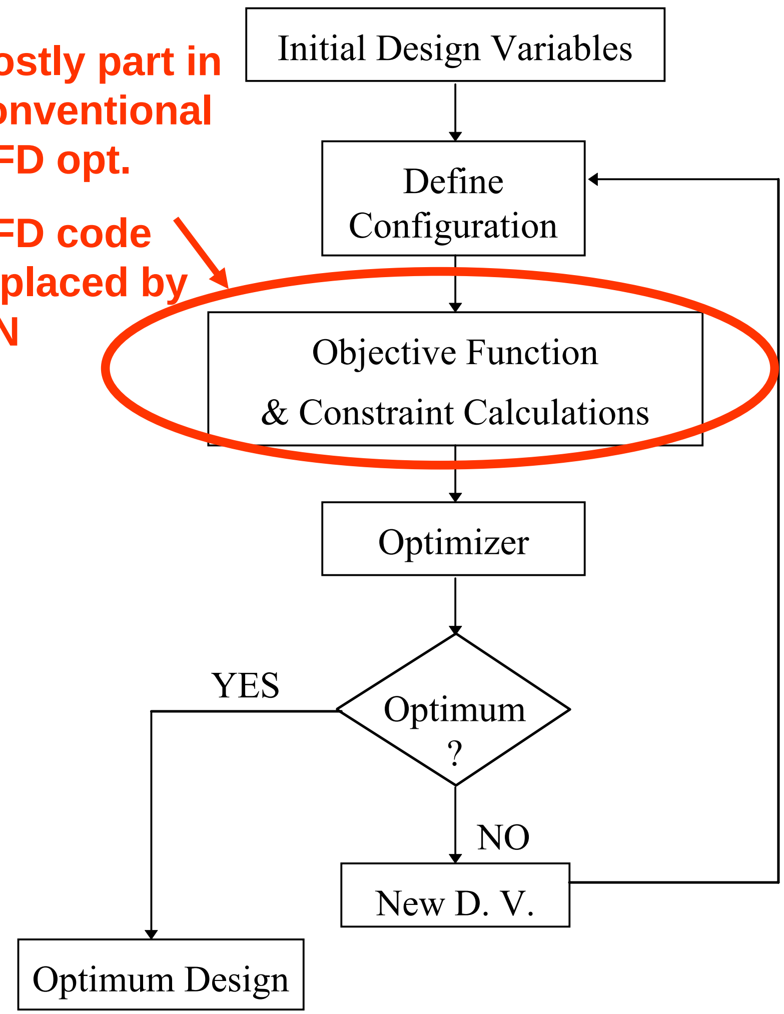
- Wave interference
- Hull form optimization is limited to configuration arrangement (synthesis level)

Why Neural Networks ?

- 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

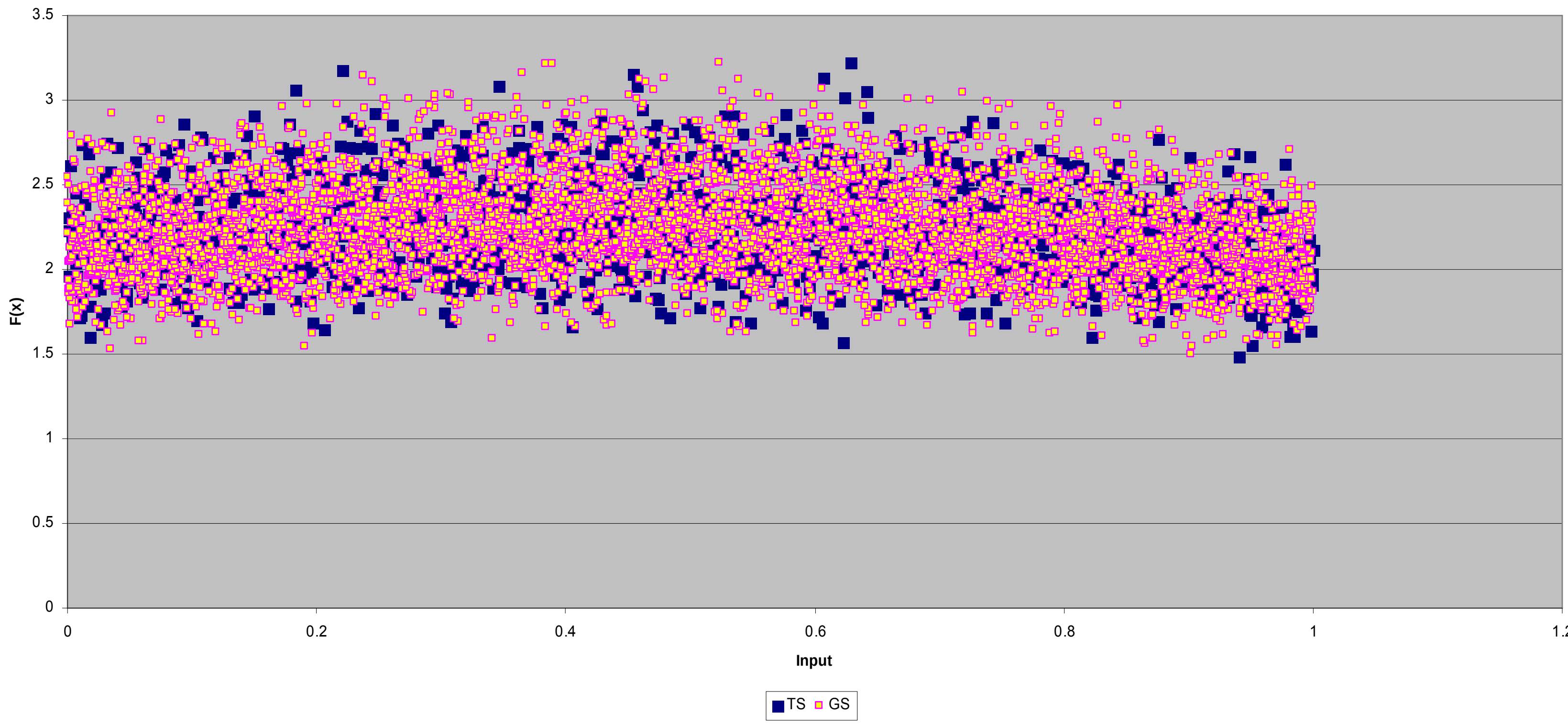
Reference: E. Besnard. & A. Schmitz, and H. Hefazi "Automated Hydrodynamic Shape Optimization Using Neural Networks" 2004 SNAME Maritime Technology Conference & Expo and Ship Production Symposium, Oct 29 - Nov 03, 2004, Washington DC.

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



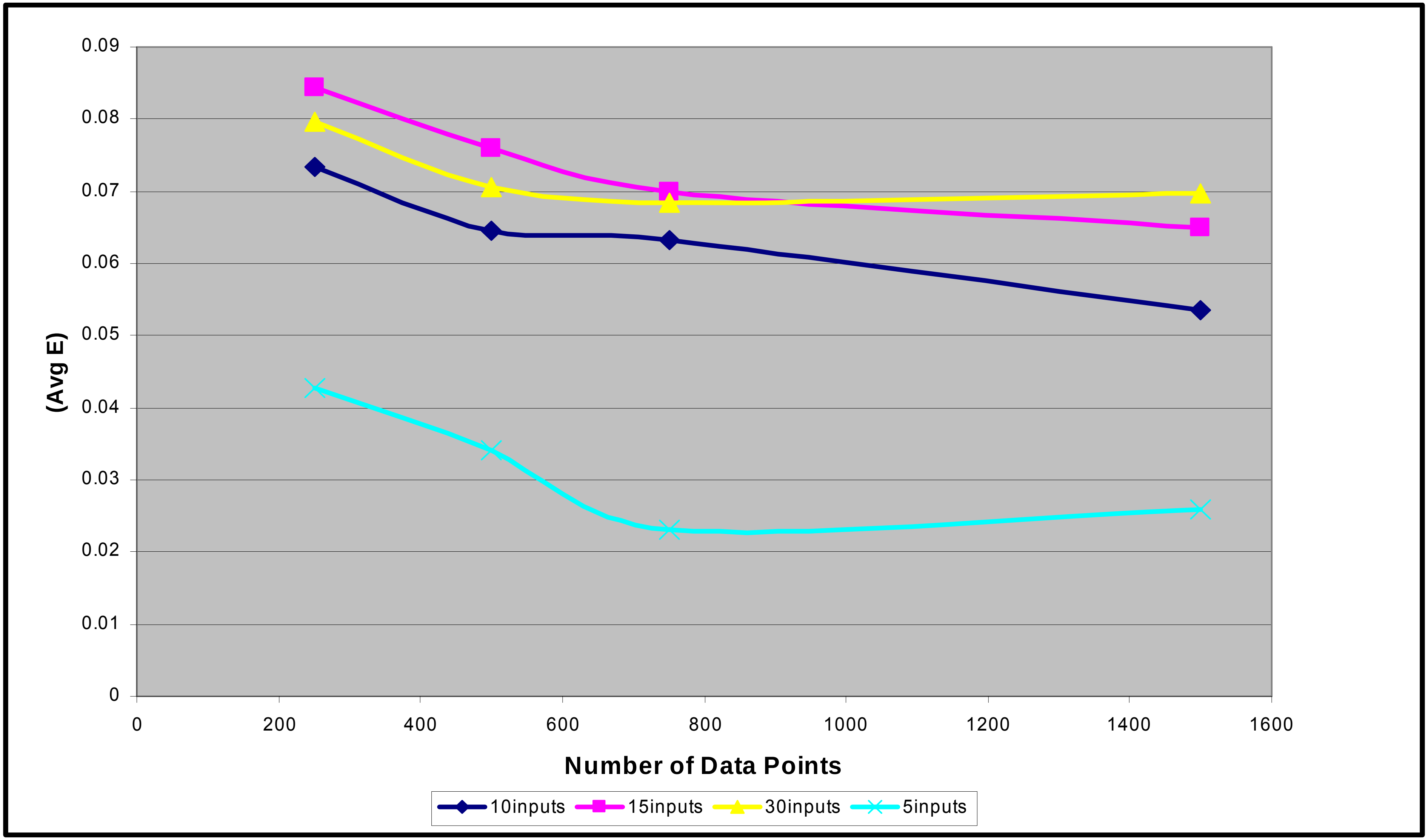
Why Neural Networks ?

$$F(x) = \sum \frac{1}{1 + |x - x_a|^2}$$



Why Neural Networks ?

Average Error (validation set)



Neural Networks for powering prediction

3 Step Process:

- Generation of Training Set (TS) & Validation Set (VS) to approximate CO=f (Sl, β, α,Fn)

- Neural Network Training to obtain “evaluator”:

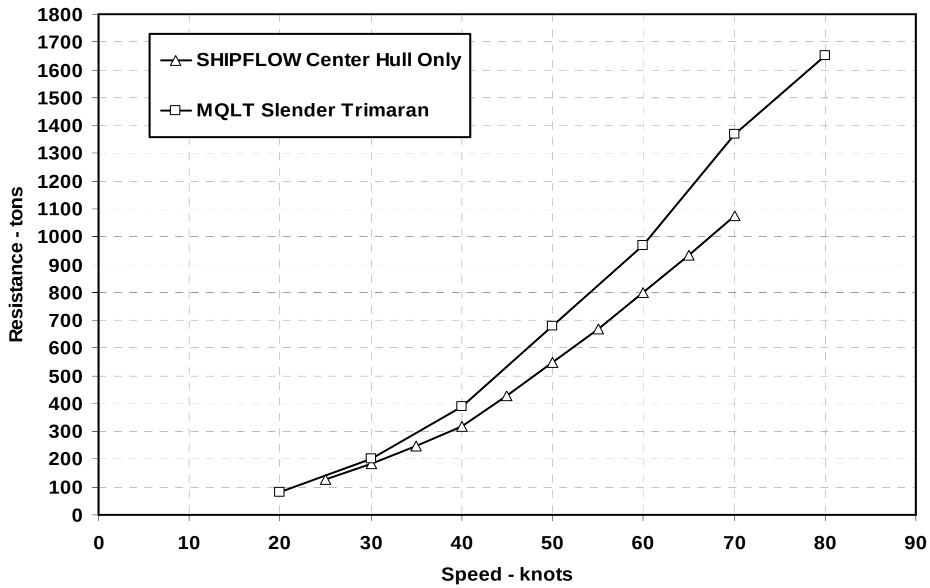
  Start with a minimal Network without hidden units. Add one hidden unit at a time and train the NN to minimize Error between TS and the outputs to the NN. Keep adding HU’s one at a time until the stopping criterion is met. The Stopping criterion uses the Error on Training and Validation Set to determine when training should be stopped. The output to training is a C++ evaluator code containing the weights and structure of the NN.

- NN evaluator is used in the optimization process

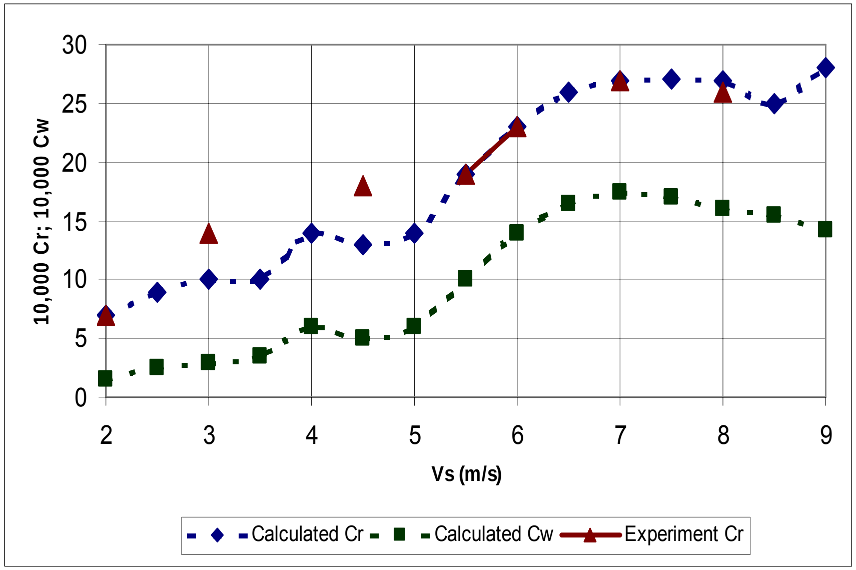
Validation

CSULB

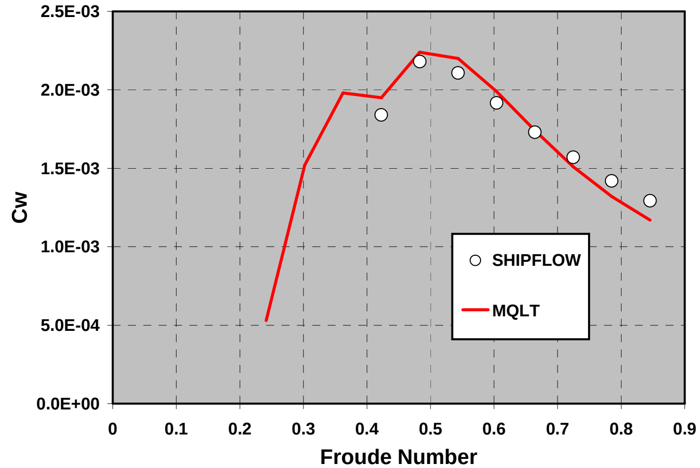
Mechanical and Aerospace Engineering



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.

Powering Stability, Seakeeping Model Definition

CSULB
Mechanical and Aerospace Engineering

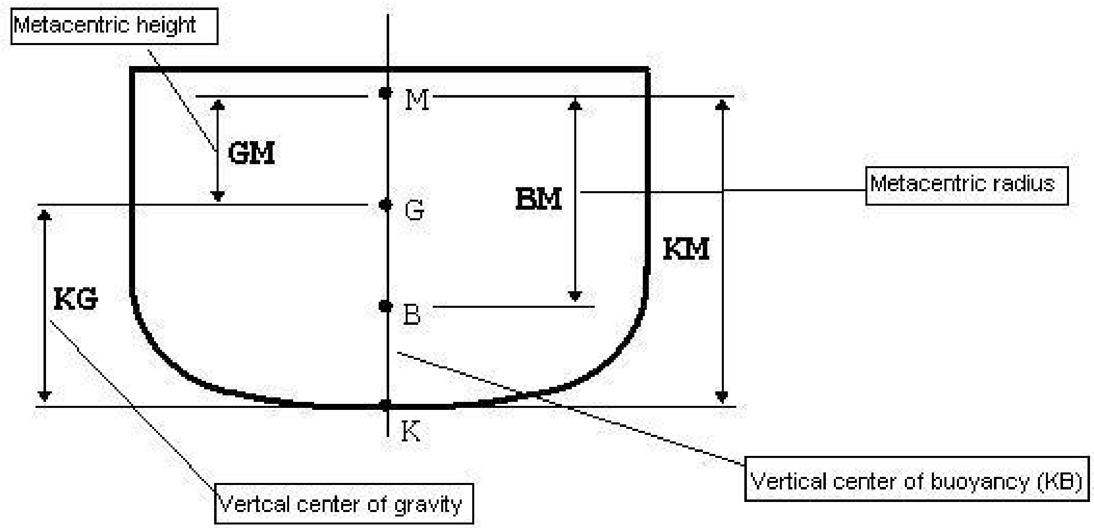
Total Required Power($P_{full-speed}$) - not to exceed the following amount [MW]	Number of Diesel Engines (N_{diesel})	Total Power Output for the Diesel Engines (P_{diesel})	Number of Gas Turbine Engines(N_{GT})
<20	2	18MW	0
<40	2	18MW	1
<60	2	18MW	2
<80	2	18MW	2
<100	4	36MW	2
<120	4	36MW	2
<140	2	40MW	3
<160	2	40MW	4
<180	2	40MW	4
<200	-	0MW	5

$$P_{GT} = P_{full-speed} - P_{diesel}$$

Powering Stability, Seakeeping Model Definition

CSULB
Mechanical and Aerospace Engineering

Constraint
GM> 1% of BOL



$$BM = (B_{ch}^2 \times (0.0106 + 0.0727 \times C_{wl}^{ch}) \times C_{wl}^{ch} \times B_{ch} \times L_{ch}) + 2 \times [((B_{sh}^2 \times (0.0106 + 0.0727 \times C_{wl}^{sh}) + b^2) \times C_{wl}^{sh} \times B_{sh} \times L_{sh}] / (V_{ch} + 2 \times V_{sh})$$

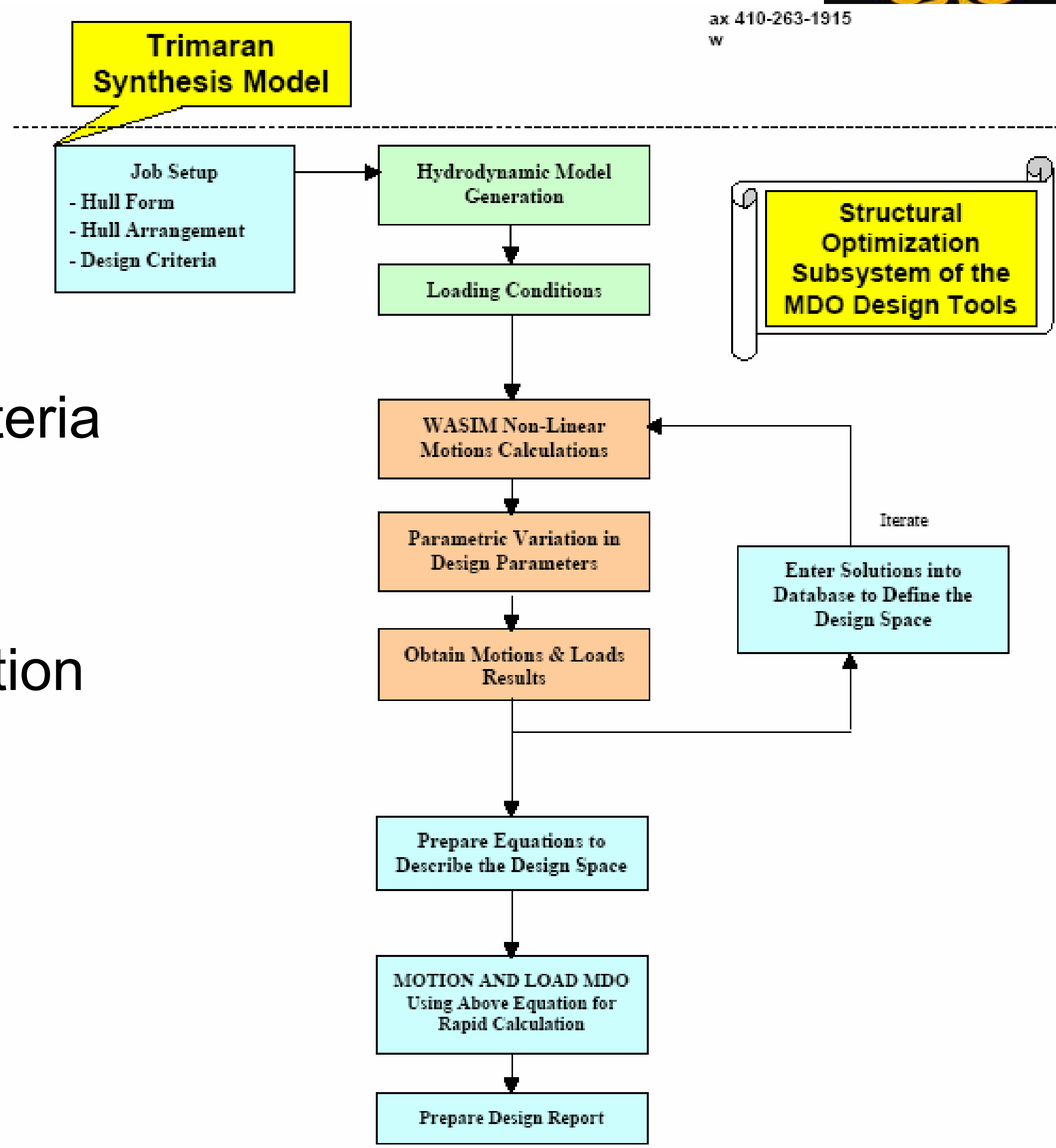
where $$b = \frac{(1+\alpha) \times B_{ch}}{2} + \frac{B_{sh}}{2}$$ $$GM_T = KB + BM - KG$$

Powering Stability, Seakeeping Model Definition

CSULB
Mechanical and Aerospace Engineering

Viking Systems

- Define Trimaran performance assessment & seakeeping criteria
- Use WASIM/SWAN
  - Generate TS & VS
- Train Neural Networks for motion prediction



Lightship Weight (Synthesis Level)

$$LWT = W_{hull\_no\_deck} + W_{m\_GT} + W_{m\_diesel} + W_{o} + W_{LWT-misc}$$

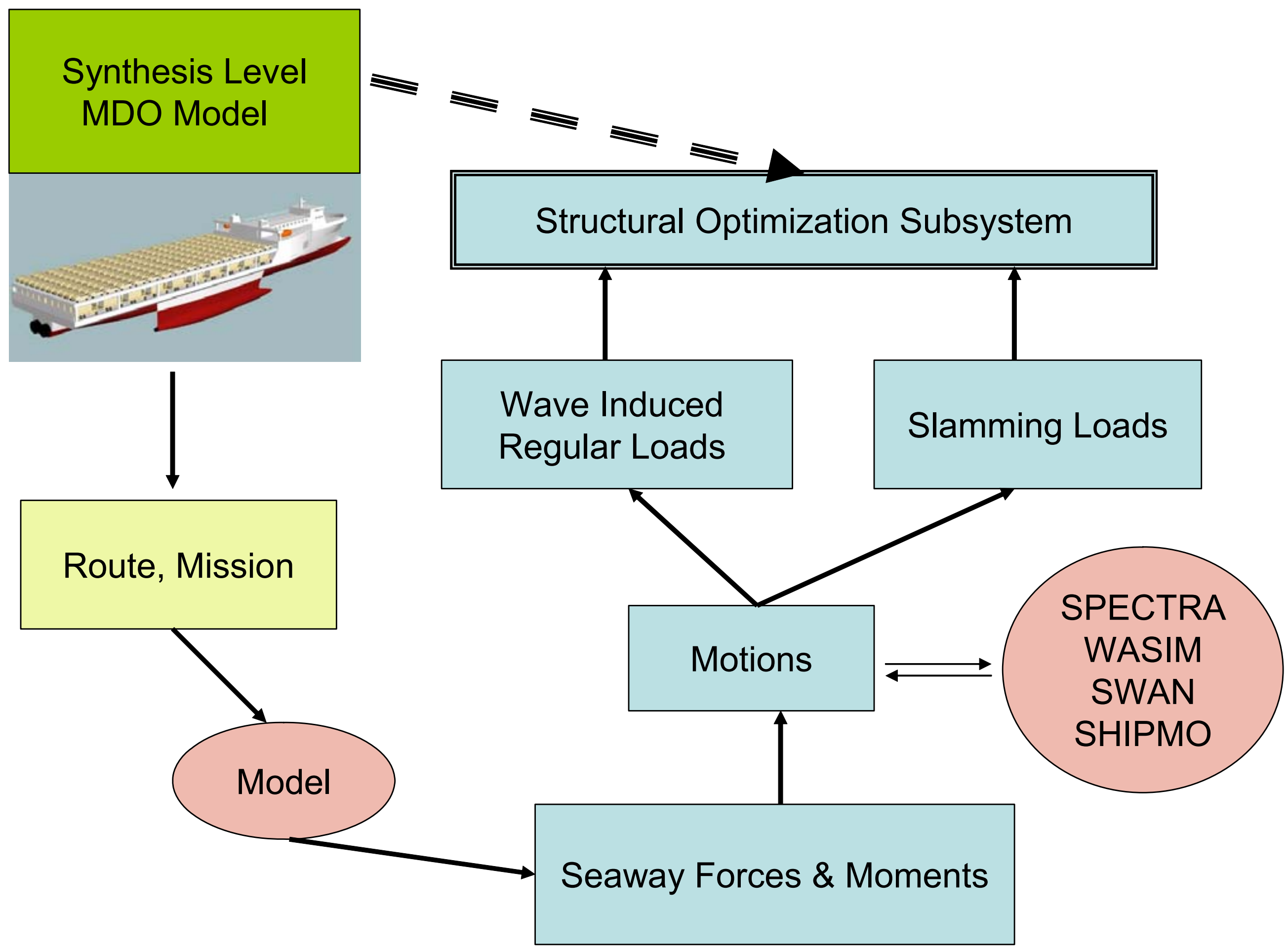
Number of decks (payload) $Nd\_MAX. = 4$

$$N_d = \min(ceil(\frac{Total\_Deck\_Area}{Area\_C_{deck\_MAX}}), N_{d\_MAX})$$

References:

1. Hefazi, H. et al "Automated Multidisciplinary Design Optimization Method for Multi-Hull Vessels" CCDoTT PE# 1.2 Final Report, www.ccdott.org July 2005.
2. "Formulation of Multicriterion Design Optimization Problems for Solution With Scalar Numerical Methods," *Journal of Ship Research,* Vol48, No.1, pp61-76, March 2004.

Subsystem Level



Schematic representation of the Structural Optimization Subsystem

Payload

$$Payload = \left(\frac{Displ - LWT_{no\_deck} - W_{deck}}{1.1} \right) - WFUEL$$

- W_{deck} being the unknown
- Trailers $NTEUTRAI_{rows} = 2$
- TEU $NTEUTRAI_{rows}$

$$N_{TEUTRAI} = \text{int}\left(\frac{CARGO_{area}}{STOW_{TEUTRAI} \times W_{TEUTRAI}} \right)$$

$$Payload = N_{TEUTRAI} \times W_{TEUTRAI}$$

$$AnnualCARGO = Payload \times NTRIP$$

Cost Model

- Building Cost $SCOST = C\_HULL + C\_MACHINERY + C\_OUTFIT + C\_MISC$
- Type of Ship Yard
- Annual Operating Cost
- Capital Cost

Annual Cost of Fleet
$ACFLEET$

$$RFR = ACFLEET / AF_{volume} / R$$

$/TEU/nm or $/Trailer/nm

Extension (to Catamaran) and refinement of these models are underway.

iSIGHT Implementation MDO-v1

Single Objectives Cases Using NLPQL Method

- Minimize RFR
- Maximize Annual Cargo
- Minimize Building Cost
- Eleven (11) Design Variables
- 60-240 CPU time/ case on a PC

User Application

- Must have iSIGHT license
- Import .desc file to user's computer

References:

Hefazi, H. et al "Automated Multidisciplinary Design Optimization Method for Multi-Hull Vessels" CCDoTT PE# 1.2 User Manual, www.ccdott.org July 2005.

Integration and Application
Synthesis Level Model

iSIGHT Implementation MDO-v1

- Define Input Model Parameters (IMP)
  - 66 constants related to LWT, payload & cost models
- Input Optimization Problem Parameters (IOPP case dependent)
  - Type of Cargo (TEU or Trailer)
  - Payload
  - Shipping line information: range, speed of pilotage, costs of cargo handling, and port pilot services
  - Cost of fuel
  - Type of Trimaran conventional or SWA
  - Type of building facility: international commercial, US commercial, US Navy

iSIGHT Implementation MDO-v1

Test Runs

$Payload_{MIN}$ = 1000 tons
BOL_{MAX} = 57m
N_{d_MAX} = 4
R = 800nm

$STOW_{TEUTRAI}$ = 1.4865 m^2/ton
$W_{TEUTRAI}$ = 10 tons
$NTEUTRAI_{rows}$ = 2 or more
$COST_{TEUTRAI}$ = $ 125/TEU

$STOW_{TEUTRAI}$ = 1.6723 m^2/ton
$W_{TEUTRAI}$ = 10
$NTEUTRAI_{rows}$ = 2
$COST_{TEUTRAI}$ = $ 30/TEU

iSIGHT Implementation

Define Constraints:

- The ratio between draft for center hull and side hull: $0 \le T_{sh} / T_{ch} \le 1.5$
- The ratio between beam of center hull and draft of center hull: $1.5 \le B_{ch} / T_{ch} \le 4$
- The ratio between beam of side hull and draft of side hull: $1 \le B_{sh} / T_{sh} \le 3$
- Froude number: $0.2 \le F_n \le 1$
- Volumetric Froude number: $F_{n\_vol} = V_s / \sqrt{g \times \sqrt[3]{V}}$ $\quad F_{n\_vol} \le 1.5$
- Total power generated: $P_{full-speed} < 200MW$
- Beam overall length: $(BOL / BOL_{\max}) < 1$

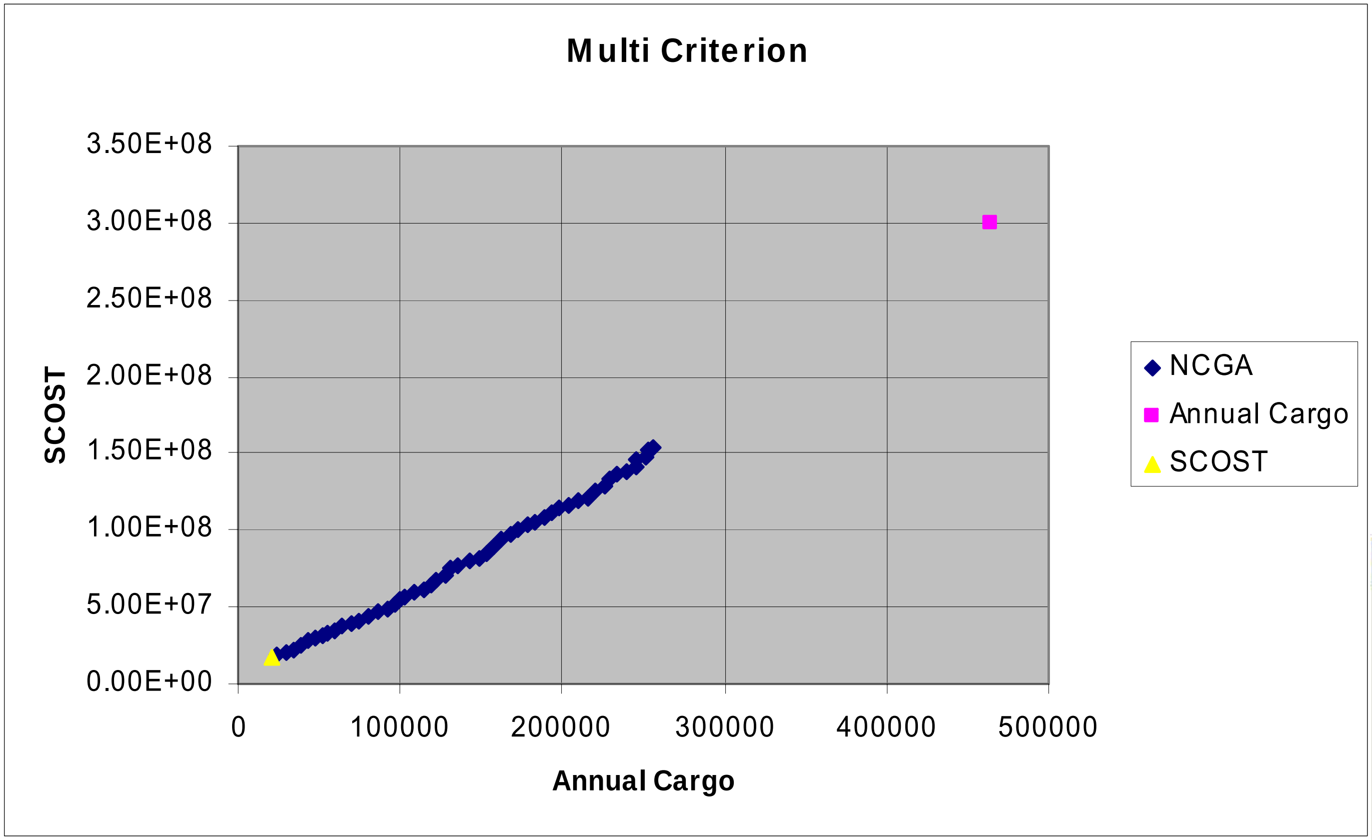
TABLE 4: SINGLE OBJECTIVE OPTIMIZATIONS RESULTS

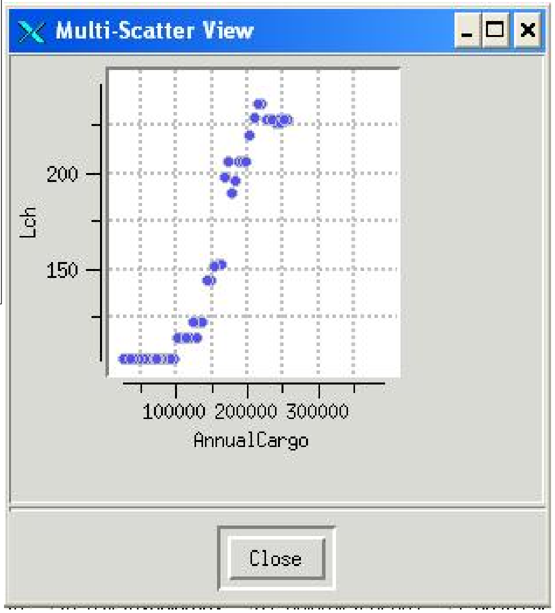
Objective	Max Annual Cargo	Min. SCOST	Min. RFR
DV's			
Cbsh	0.6	0.45	0.6
Cbch	0.6	0.45	0.6
Vk	30	25	25
Bch	24	12	17.99
Bsh	8	3.91	7.88
Tch	12	4	11.99
lambda	0.1134	0.03	0.03
lamdash	0.6604	0.1	0.1107
Lch	222.20	122.64	206.60
Beta	0.0122	1	0.4414
alpha	0.5	2	1.29
OBJECTIVE			
AnnualCargo	**464,488**	21,000	15,112
SCOST	299,890,428	**16,658,916**	135,757,373
RFR	0.7951	1.18	**0.6313**
Some Dependent Variables			
Tsh	7.99	3.94	7.89
Sl	7.26	8.49	6.61
Displ	50,910	2,890	29195
Pfullspeed	177.50	13.31	46.62
Ndiesel	2	2	2
Ngt	4	0	2
GMt	15.52	12.40	2.74
Nd	4	1	4
Ld	184.37	44.99	108.73
BOL	52.0	43.83	56.99
Hship	33.0	10.25	32.99
Nteutrai	1,935	100	1251
LWT	28,148	1,716	15,112
ACFLEET	295,460,939	19,841,783	132,683,251

Integration and Application
Synthesis Level Model

- *Multi-Objective*
  - Multi-objective Genetic Algorithm (Neighborhood Cultivation Genetic Algorithm – (NCGA))
  - Objectives: Minimize Building Cost and Maximize Annual Cargo
  - The results presented here are obtained with a population of 100 in 50 generations, which was found to be the optimum based on previous experience

Integration and Application
Synthesis Level Model





Pareto Plot for NCGA Optimization

Integration and Application
Synthesis Level Model

In Progress

- Revision and Refinement of Synthesis Level Design Relationships
- Application to Navy Strategic Sealift and Theater Support Vessel
- Application to Short Sea Shipping Ships
- Expansion of the Method to Catamaran Types of Ships

- Hull Forms Development Subsystems
- Inclusion of Seakeeping Using Neural Networks
- Structural Optimization Subsystem
  - Develop Nomenclature of Structural Constraints
  - Assess Methods for Calculations of Global and Local Structural Loads

Other Multihull MDO Projects

TOOLS FOR MULTI-HULL DESIGN OPTIMIZATION

Prof. Robert F. Beck University of Michigan

Objective: To develop a software system that will allow the optimization of the hydrodynamic design of high-speed multi-hull craft.

Other Multihull MDO Projects

Approach:

- Develop computationally fast modules to predict the calm water and seakeeping performance of high-speed multi-hulls.
- Develop a design interface incorporating the modules and multicriterion optimization that will allow the designer to optimize the hydrodynamic performance of a multi-hull vessel and arrive at the desired compromises between calm water and seakeeping performance.

Other Multihull MDO Projects

Comparison of CSULB & UM Approaches

- Commonality
  - Multicriterion optimization
- Differences
  - Strictly limited to hydrodynamic optimization
    - Powering
    - Seakeeping
    - Shape optimization
  - No account is taken of structural, payload, cost issues
  - Use of ASSET

Other MDO Programs

ENDEAVOR (Environment for Design of Advanced Marine Vehicles and Operation Research)

www.projectendeavor.org

- Maui High Performance Computing Center, SAIC & U of Hawaii
- Focus on mission planning, design and performance analysis
  - NOAA Wave Watch III deep water condition data base
  - LAMP
  - HPC
- Not focused on optimization at present

CCDoTT Proposes International CFD Code Development and Utilization Conference in FY 06