Sea Connector Family and Seabase Architecture

Systems Engineering & System Architecture

Presentation to

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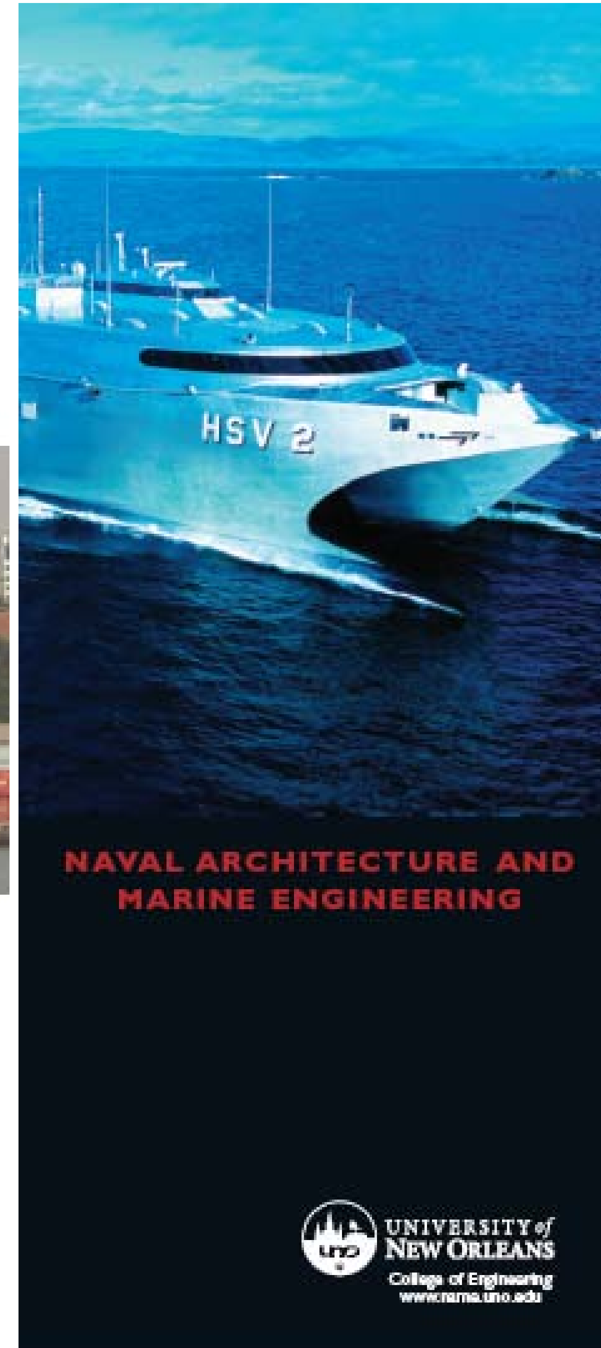
Naval Architecture and Marine Engineering
at the University of New Orleans

{name} naval architecture and marine engineering

Naval Architecture and Marine Engineering (NAME) is an exciting, high-tech and highly specialized field of study that encompasses many aspects of the marine industry. NAME graduates work in the fields of shipbuilding, offshore construction, oil and gas production, deep sea exploration, mineral recovery, and small boat and yacht design, to name a few.

The University of New Orleans NAME program is the largest naval architecture and marine engineering program in the U.S. Its graduates are employed as engineers, project managers and business executives throughout the world. Our program is one of only a handful in the country, and has independently been rated as the best. The Princeton Review 2000 Edition called UNO's "the best naval architecture program in the United States."



Outline

- Systems Engineering
- System Architecture
- Sea Connector Project
  - DOE/RSM process

Systems Engineering

- Systems Engineering - an interdisciplinary approach and means to enable the realization of successful systems. (INCOSE Handbook)

Definitions

- System - An interacting combination of elements to accomplish a defined objective. These include hardware, software, firmware, people, information, techniques, facilities, services, and other support elements. (INCOSE)
- System - A group of interacting, interrelated, or interdependent elements forming a complex whole. (American Heritage® Dictionary of the English Language)
- Engineering - The application of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems. (American Heritage® Dictionary of the English Language)

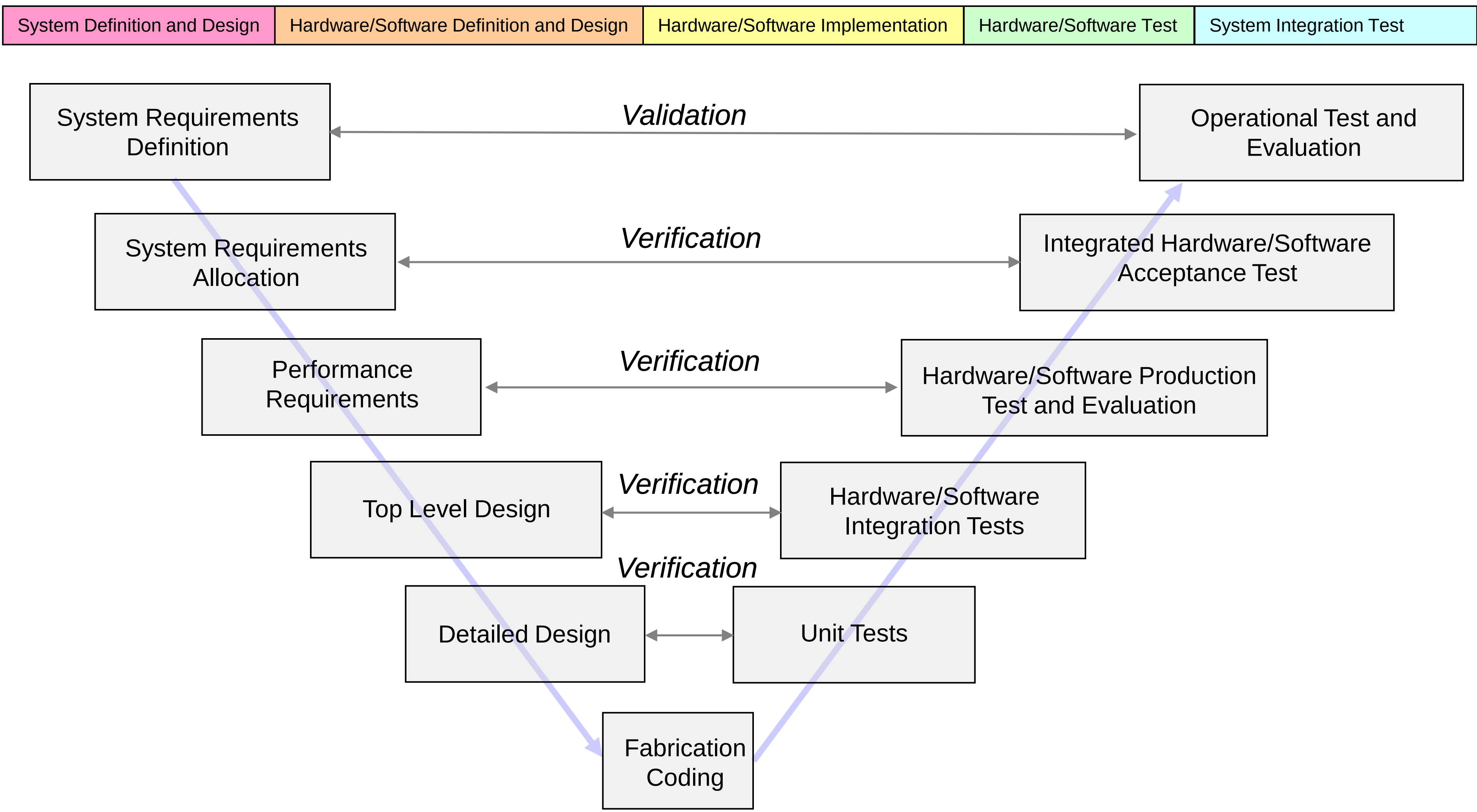
Systems Engineering

- Systems engineering - The application of scientific and mathematical principles to the design, manufacture, and operation of efficient and economical combinations of interacting elements that accomplish a defined objective.

Systems engineering finds its focus in constructs of synthesis and analysis for problems involving multiple aspects of the real world.

Source: The Institute for Systems Research, U of Maryland, College Park, MD

Systems Engineering Approach



What is a Systems Engineer?

- Defines, Develops, and Deploys Solutions
  – Use systems engineering processes
- Roles
  – Involved in design from day one
  – As “system developer”
    - Employ SE techniques for development
  – As “customer support organization”
    - Provide SE oversight and management
- Supports Decision Making
  – Use quantitative and qualitative formulation, analysis, and interpretation to determine impacts of alternatives

Systems Engineer Responsibilities

- Lead Proactively at System Level
  - Maintain system perspective
- Support Decision Making
  - Provide factual recommendations
- Enforce Program Decision Making Discipline
- Serve as Chief Communicator and Honest Broker
- Be Guarantor of Success

Dimensions to SE

Holistic View

- Education (Academia)
- Practice (Organizations)
  - Capabilities
  - Effectiveness
- Knowledge (Critical Thinking and Research)
  - Creation of Knowledge
  - Think Different*ly*
  - Discovery of Principles?
- Profession
  - International Council on Systems Engineering (INCOSE) www.incose.org
  - Certification

Systems Engineering Trends

- Corporations Want ‘it’ (SE) Now
  - Organizational Focus
- Expansion and Diffusion of Fundamentals
  - From disciplinary specialization to generalization
- Life Long Learning
  - Field is ill defined and dynamic
  - Discovery is continuous (discontinuities exist, however)
  - Incorporate projects and case studies (since current learning not always shared)

Education is that which remains when one has forgotten everything he learned in school.
- Albert Einstein

SE Practice

<u>Current State</u>:
Reactive according to each understanding of System Engineering

<u>Future State</u>:
Proactive and in accordance with domain definition of System Engineering (Thinking?)

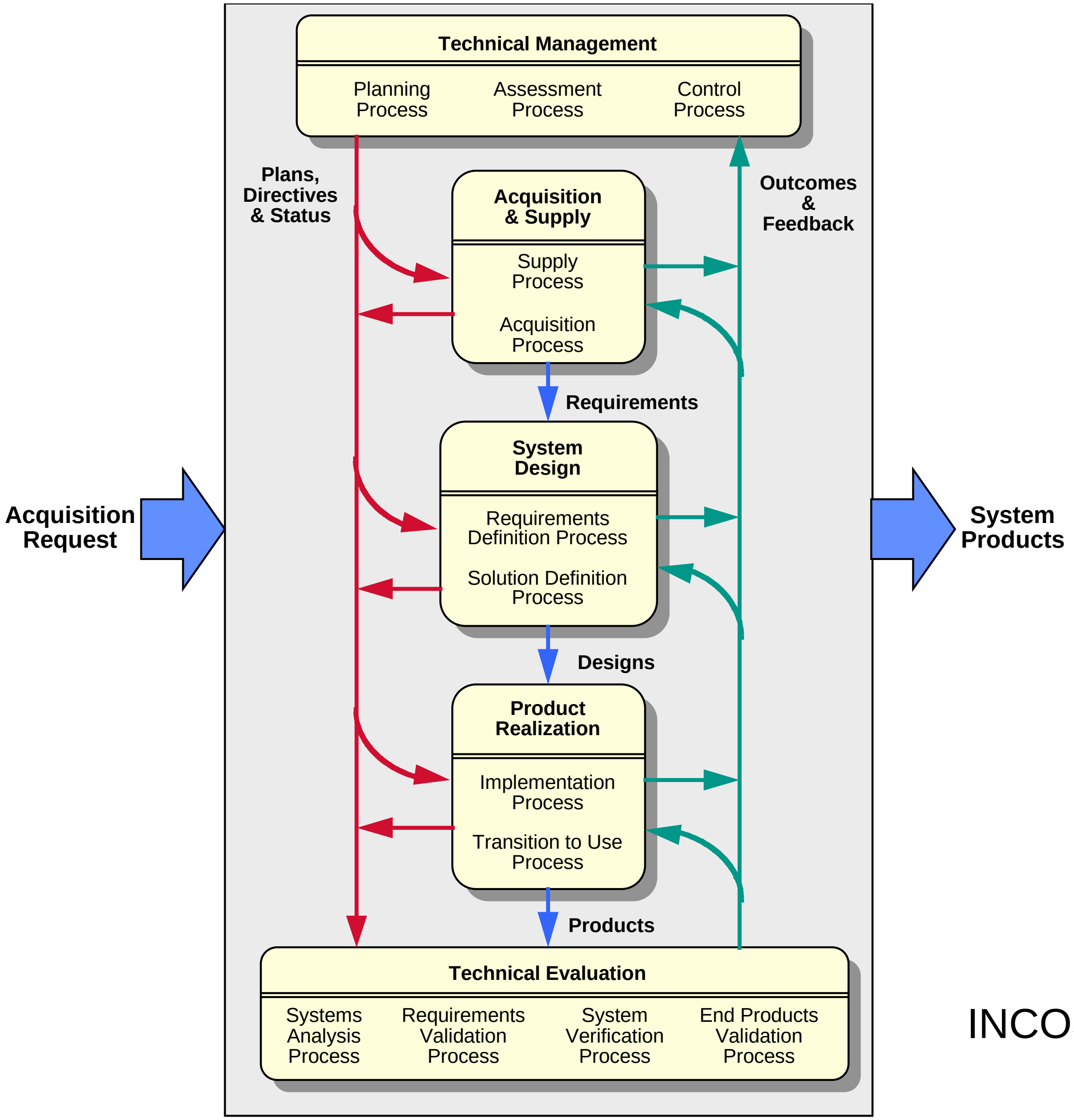
You can observe a lot by watching.
- Yogi Berra

What's the Problem?

- System Engineering used to be the domain of the Chief Engineer
- More complex systems, more outsourcing, increasing computer based control, increase the need for system engineers
- System Engineering is a combination of art & science
- Even in business domains that encourage SE, there is a cyclic nature to the emphasis
- Domain knowledge is essential
  - Hiring System Engineers from other companies is not immediately cost effective

Source: Ginny Lentz, Otis Elevator

EIA 632 Systems Engineering Model



EIA 632
INCOSE Handbook

Why Develop an Architecture?

- Typically, an architecture is developed because key people have concerns that need to be addressed by the systems within an organization
- Such people are commonly referred to as the "stakeholders" in the system
- The role of the architect is to address these concerns
  - Identifying and refining the requirements that the stakeholders have
  - Developing views of the architecture that show how the concerns and the requirements are going to be addressed
  - Showing the trade-offs that are going to be made in reconciling the potentially conflicting concerns of different stakeholders

Without an architecture, it is highly unlikely that all the stakeholder concerns and requirements will be considered and met.

Architecture Definition

- The arrangement of elements and subsystems and the allocation of functions to them to meet system requirements. (INCOSE)
- The arrangement of the functional elements into physical blocks. (Ulrich & Eppinger)
- The embodiment of concept, and the allocation of physical/informational function to elements of form and definition of structural interfaces among the elements. (Prof. Crawley, MIT)
- The arrangement of function and feature that maximizes some objective. (Jack Ring)

Architecture Aspects

- The *arrangement* of *elements* and subsystems and the allocation of *functions* to them to meet system *requirements*. (INCOSE)
- The *arrangement* of *function* and *feature* that maximizes some *objective*. (Jack Ring)
- The embodiment of *concept*, and the allocation of physical/informational *function* to *elements* of *form* and definition of structural *interfaces* among the *elements*. (Ed Crawley, MIT)
- The *arrangement* of the *functional elements* into physical *blocks*. (Ulrich & Eppinger)

The interconnection and arrangement of function and feature that maximizes some objective.

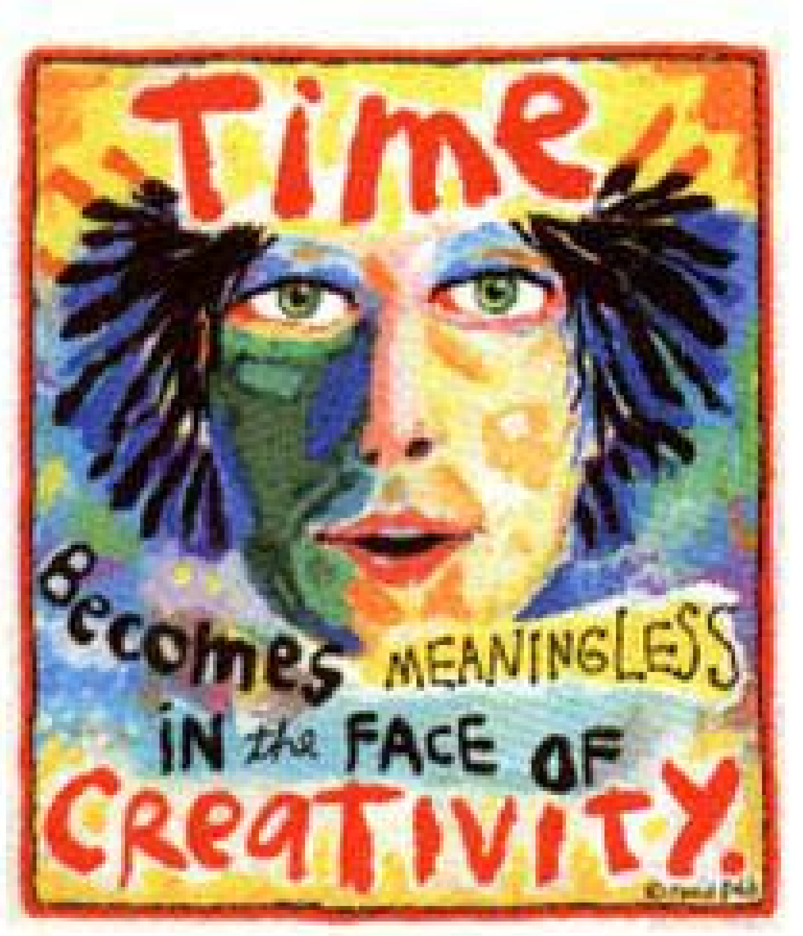
System Architecture Considerations

- Harmonize Definition with that of Established Architects
- Architecture is Concerned with
  - Relationships and patterns of relationships (e.g. Frank Lloyd Wright, M. Pei)
  - System design pattern of “context, content, structure”
  - Practices of Model-Based Systems Engineering
- Architect
  - Function and feature are givens
  - Primarily concerned with arrangement of these

"The better architecture is the one that yields the best fit (or score) with respect to the purpose for which the system is to be created." Jack Ring, Discovering the Architecture of Product X, INCOSE International Symposium 2001

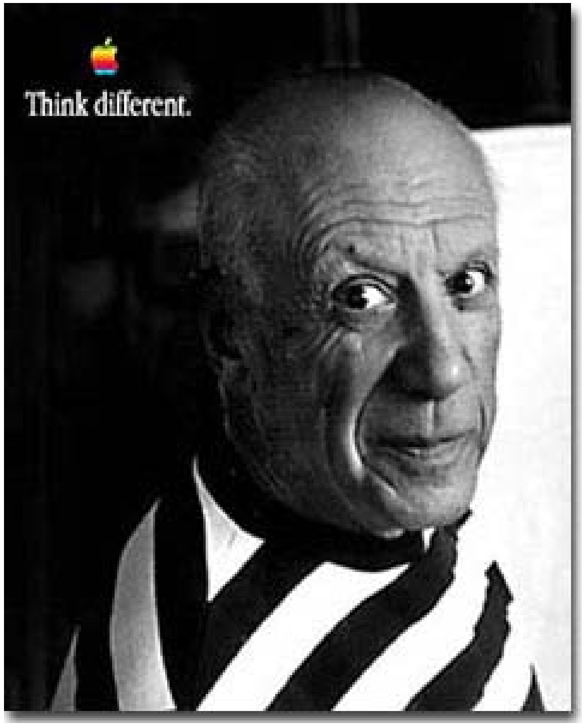
The Architect

- Proposes and develops options
  - Applies creativity in the development of concepts
  - Considers new technology
- Thinks holistically considering product life cycle
- Resolves ambiguity
- Communicates ideas to others



Underlying Architecting Objectives

- Be synthetic first, analytic second
- Think holistically - with a global perspective
- Use creative and critical thinking
- Learn from best practices in System Architecting



Good artists copy.
Great artists steal.
Pablo Picasso

Architecting Scope

- No Universally Applicable Stopping Point

Conceptual development complete when design is sufficiently refined (in enough views) for the client to make a decision to proceed.

- Architecting Continues Beyond Concept

Shepard the conceptual design through detailed design, oversee creation, and advise client on certification.

Design Progression

- Progressive Refinement
  - Basic pattern of engineering
  - Organizes progressive transition in processes
    - From Ill-structured, chaotic, heuristic
    - To rigorous engineering implementation
    - From mental concept
    - To physical manifestation

Design Concepts for System Architecture

- Architecting
  - Predominantly eclectic mix of rational and heuristic processes
  - Normative rules and group processes enter in lesser roles
- Process Revolves Around Models
  - Composed of scoping, aggregation, decomposition (partitioning), integration, certification
  - Few rational guidelines exist for these processes
- Uncertainty
  - Inherent in complex systems design
  - Use tools and heuristics to reduce uncertainty
- Continuous Progression
  - Organizing principle of architecting, models, and supporting activities

Fusion of Art and Science

MIT Stata Center

MIT Building 20

If you want to know how a building will fare in a hurricane, ask a civil engineer. If you want a building to express your desires, and do so beyond rote calculations of floor space and room types, ask an architect.

Sea Connector System Architecture

- Connector concepts vital to Seabasing and Seapower 21.
- SEA 05D1 exploring design alternatives for SEA00 using a systematic approach; result is a framework and set of concepts that characterize the design space.
- SEA 05D1 tasked CSC/JJMA/G&C to conduct concept studies.
- Study being performed in three phases:
  - Initial studies to conduct initial ASSET based concept studies for each of three families
  - Second Phase to refine the ASSET studies, apply additional analysis tools, explore cargo handling and other issues in greater detail
  - Third Phase TBD

Stakeholder Guidance

- NAVSEA 05D1 Initial Guidance
  - "Power Projection Architectures" Brief - Provided guidance on CONOPS
  - "Connector Options" Document - Defined requirements for three families of concepts:
    - HSS – High Speed Sealift
    - HSC – High Speed Connector
    - HSAC – High Speed Assault Connector
- NAVSEA 05D1 Additional Guidance
  - "Sea Connectors Brief to NAVSEA 05D"
  - Focus on "Next Navy" rather than "Navy After Next" (i.e. 2010-2015)
  - Draw from MPF(F) efforts for developments such as ILP

Overall Objective

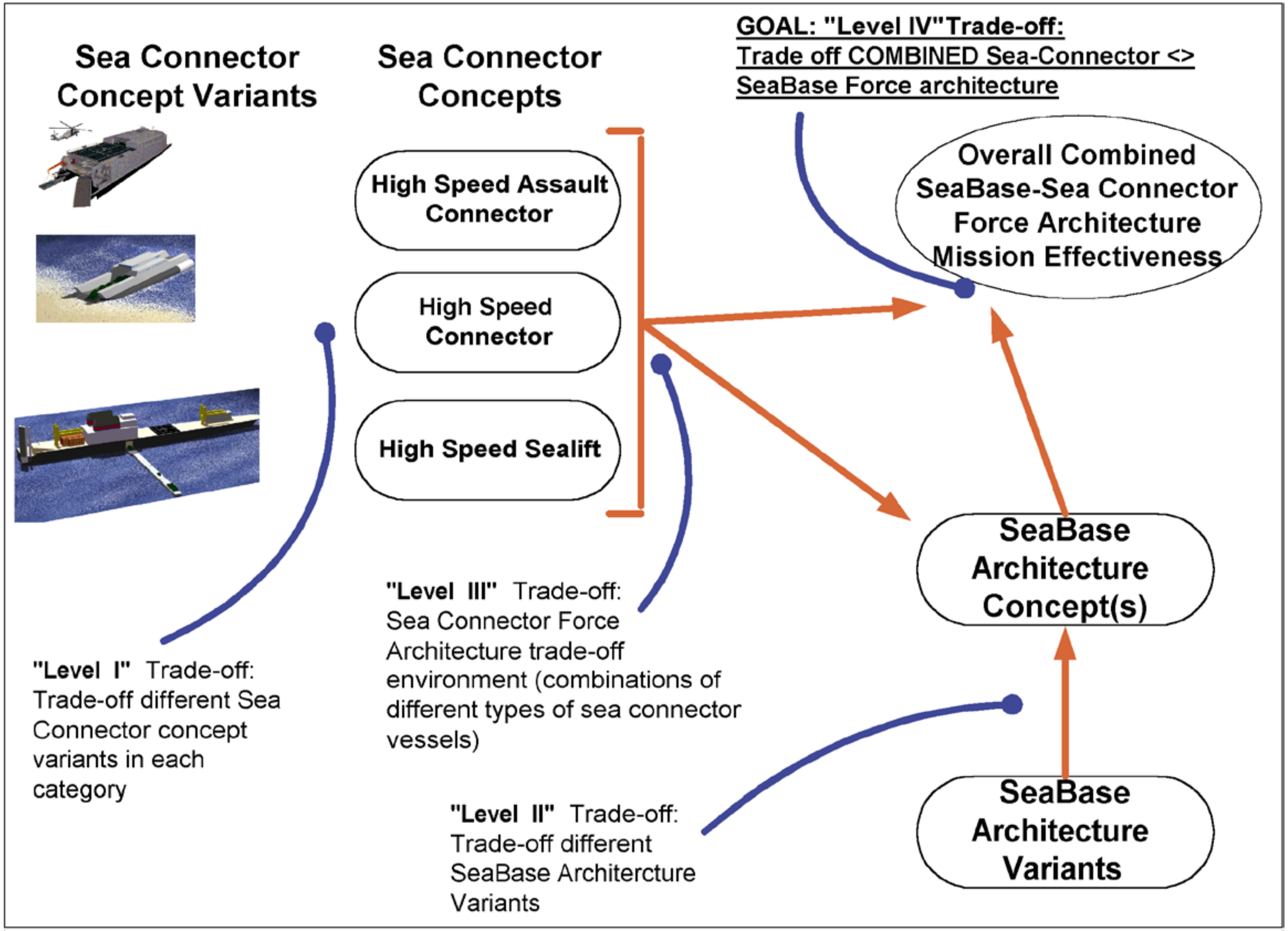
- Transport 1 Marine Expeditionary Brigade (MEB 2015) 6,000 nm – from CONUS to SeaBase – in 10 days
- MEB totals:
  - ~ 14,500 personnel
  - ~ 3,700 vehicles
  - ~ 140 aircraft
  - ~ 1.6 M cu ft. cargo
- Transport 1 Surface Battalion (Surface BLT) from SeaBase to objective (beach), potentially 200 nm, in one period of darkness (8 hours)
- Overall Measure of Effectiveness (OMOE)
  - Time to objective
  - Combat Power Index (CPI) accumulated at objective over time

Baseline Marine Expeditionary Brigade 2015

- Major Items of Equipment (496,780 ft^2 Vehicle Square*)
  - AAAV 106
  - LAV 60
  - M1A1 29
  - LW155 18
  - EFSS 8
  - HIMARS 6
  - UH-1Y 9
  - AH-1Z 18
  - JSF 36
  - EA-6B 5
  - KC-130 12
  - MV-22 48
  - CH-53E 20
  - UAV 6
  - Comm Veh 247
  - HMMWV 743
  - ITV 21
  - MTVR 430
  - LVS 105
- Personnel 14376*
- MCBul 3501 14403*
- * does not include NSE

Enclosure (4) to MPF(F) Action Memo Number 3 (CME D0007584.A1)

4 Levels of Trade-off

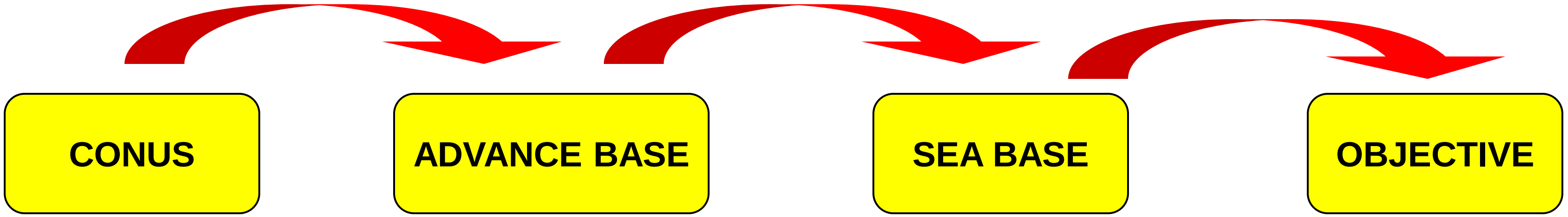


Levels of Trade-off

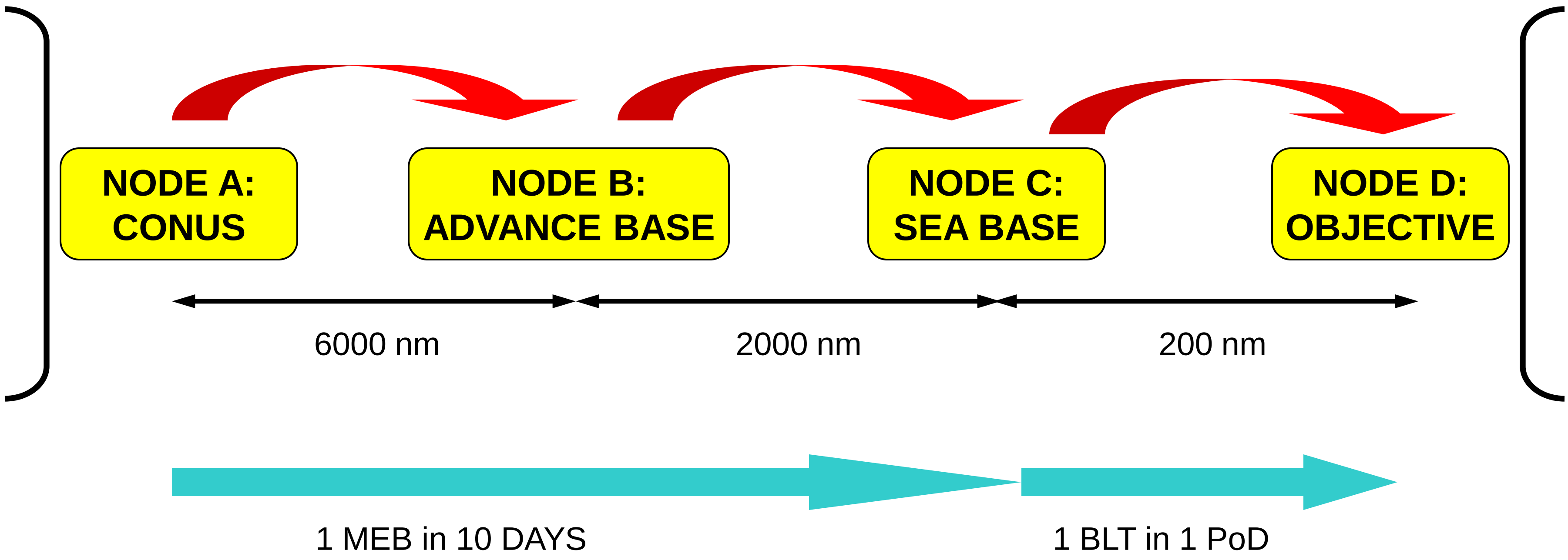
- Trade-off between different concepts within each ship class: HSS, HSC, HSAC
  - Need to define generic MOEs for each class of vessels
    - To include ‘binary’ MOEs (beachable / non-beachable)
  - Develop Response Surface for each class of vessels
  - Include MOEs as additional variables/“columns” in RS matrix
- Trade-off between different combinations of vessels (force architecture)
  - Model using EXTEND
  - EXTEND OMOEs
    - Time (days / hours) to achieve objectives
    - Combat Power Index (over time period)
  - Each ‘class’ of Sea Connector will be represented as a generic “ship” entity in EXTEND (with associated MOPs/MOEs)

Establish 4 ‘Nodes’

- Depending on which scenario, path may ‘skip’ node
- Scenarios:
  - MPF(F)-centered Architecture
  - Reduced Forward Presence
  - CONUS Based
  - Warehouse Pre-Positioning
- Ships/equipment ‘queued’ in EXTEND by “orders”
- Logic paths at each node to account for transfer modes/times

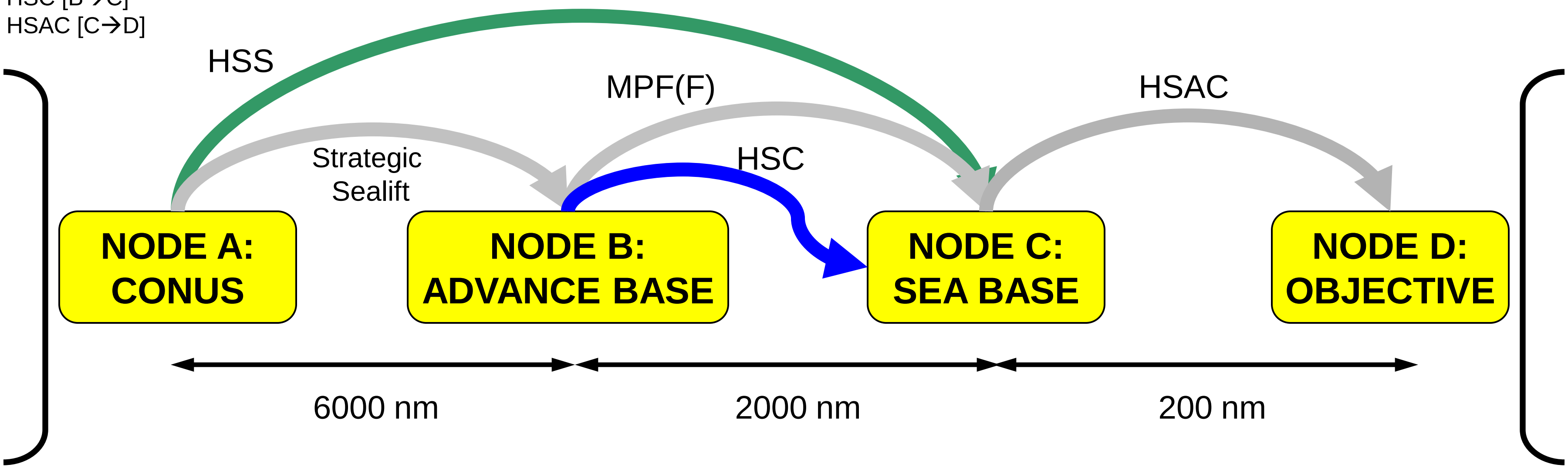


Generic 4-Node Model



Scenario 1: MPF(F)-Centered Model

Simplified sequential Task List:
HSS [A→C]
Strategic Sealift [A→B]
MPF(F) [B→C]
HSC [B→C]
HSAC [C→D]

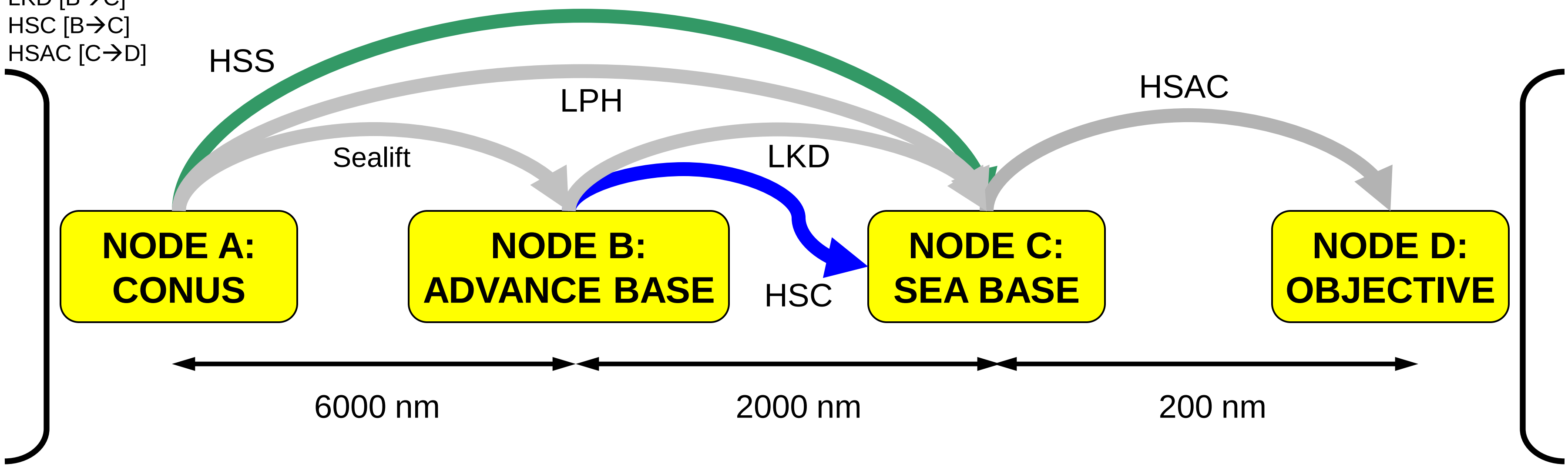


ISSUES ARISING:

-- We will likely need to model MPF(F) and "Strategic Sealift" in EXTEND for this scenario
-- Need to decide how to 'split' MEB load between MPF(F) [B → C] and HSS [A → C]
-- HSC is HCFNB variant
-- HSAC is MCMB variant
-- **NOTE: RANGE FROM A→C == 8,000 NM**

Scenario 2: Reduced Forward Presence Model

Simplified sequential Task List:
HSS [A→C]
Sealift [A→B]
LPH [A→C]
LKD [B→C]
HSC [B→C]
HSAC [C→D]



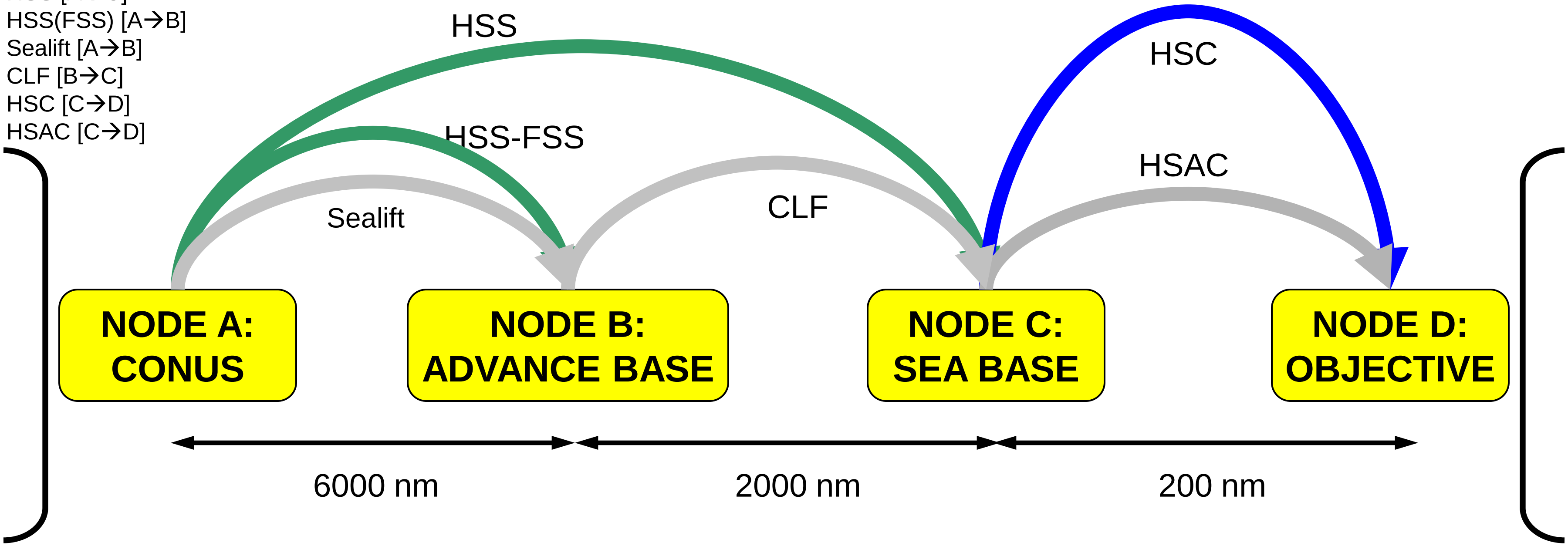
ISSUES ARISING:

-- We will likely need to model "Sealift" ships (?existing vessels) and LPH, LKD classes in EXTEND for this scenario
-- Need to decide how to 'split' MEB load between Sealift [A → B], LPH [A→C], LKD [B→C] and HSS [A → C]
-- HSC is HCFNB variant
-- HSAC is FWDB variant: **RANGE IS ONLY 150 NM**
-- NOTE: RANGE FROM A→C == 8,000 NM

Scenario 3: CONUS Based Model

Simplified sequential Task List:

HSS [A→C]
HSS(FSS) [A→B]
Sealift [A→B]
CLF [B→C]
HSC [C→D]
HSAC [C→D]

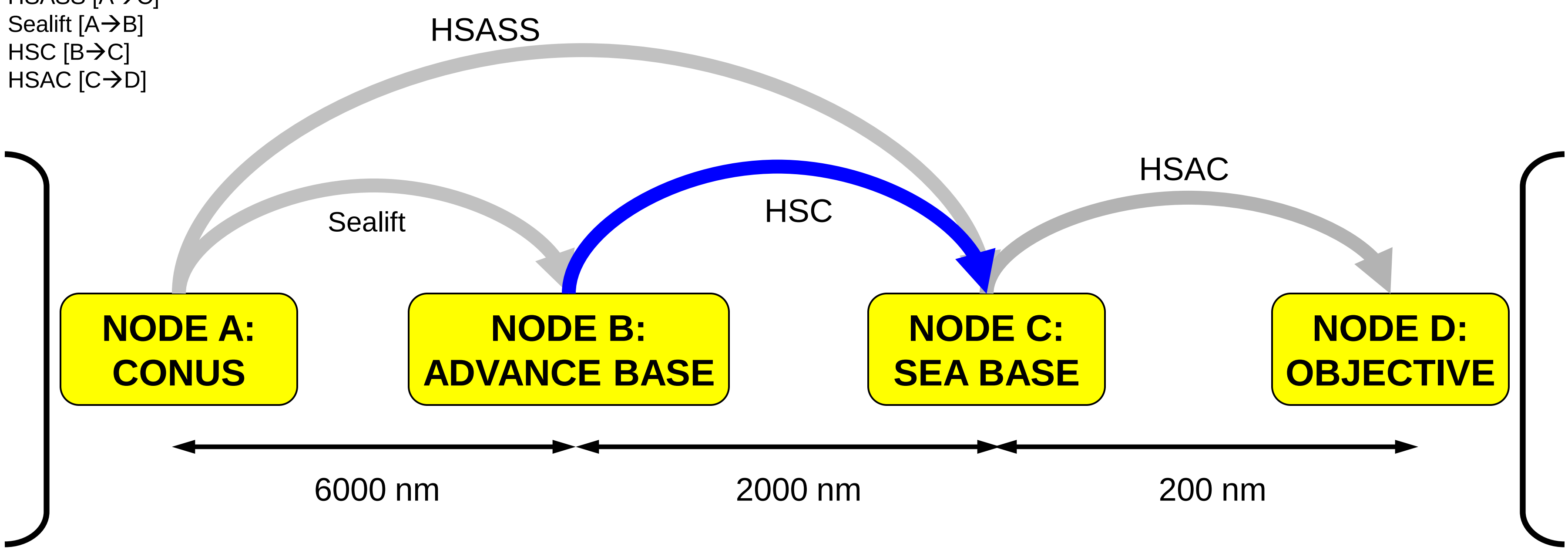


ISSUES ARISING:

-- We will likely need to model “Sealift” ships (?existing vessels) and CLF class in EXTEND for this scenario
-- Need to decide how to ‘split’ MEB load between Sealift [A → B] and HSS [A → C]
-- HSC is HCMB or HCFB variant, I.e. both “beachable” variants (required for this scenario)
-- HSAC is MCMB or MCSB variant
-- **NOTE: RANGE FROM A→C == 8,000 NM (FOR HSS)**

Scenario 4: Warehouse Pre-Positioning Model

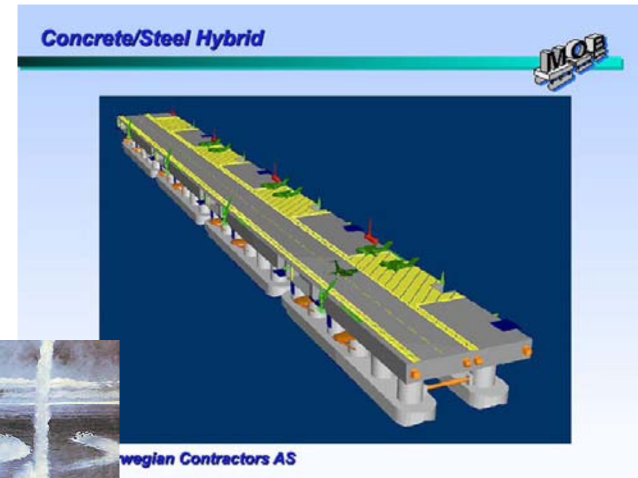
Simplified sequential Task List:
HSASS [A→C]
Sealift [A→B]
HSC [B→C]
HSAC [C→D]

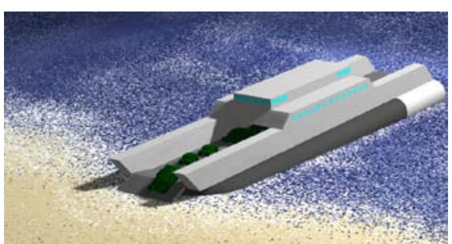


ISSUES ARISING:

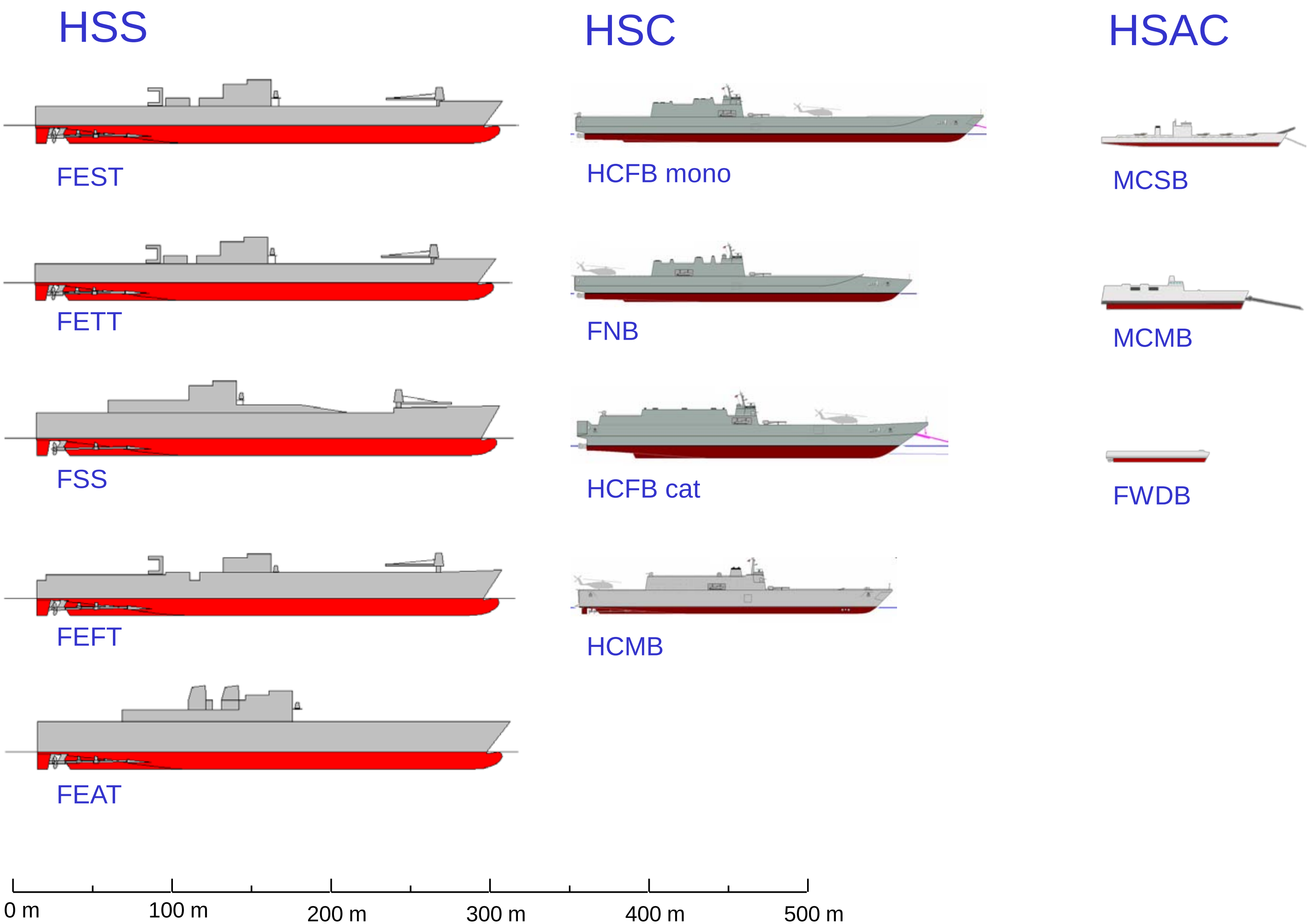
-- We will likely need to model "Sealift" ships (?existing vessels) and HSASS class in EXTEND for this scenario
-- Need to decide how to 'split' MEB load between Sealift [A → B] and HSASS [A → C]
-- HSC is FNB, HCMB or HCFB variant
-- HSAC is MCMB or MCSB variant
-- ****NB** NO HSS VARIANTS IN THIS SCENARIO**

Ship Concept Design Overview





Ship Concept Results



High Speed Sealift (HSS) Family

- Characteristics
  - FEST = Fast Expeditionary Sealift Transport
  - FEAT = Fast Expeditionary Aviation Transport
  - FETT = Fast Expeditionary Troop Transport
  - FEFT = Fast Expeditionary Force Transport
  - FSS = Fast Sealift Ship

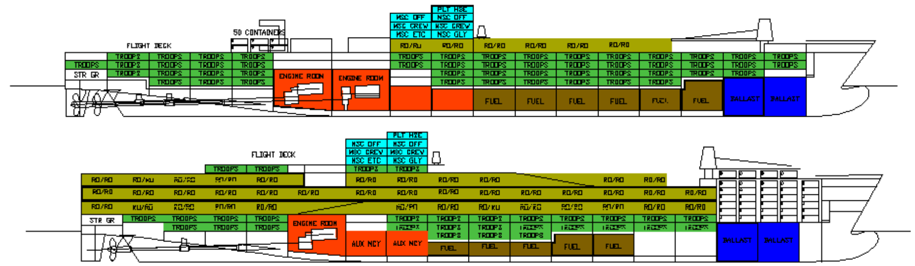
High Speed Sealift (HSS) Family

Family Members

All 6000-naut mile range -- loaded

Name	Speed	Vehicle	Cargo	Troop
FEST	40 kt	9290 m^2	90 TEU	1150
FEFT	40 kt	12,080 m^2	100 TEU	1100
FEAT	40 kt	(aircraft only)	250 TEU	1625
FETT	40 kt	2320 m^2	50 TEU	3300
FSS	30 kt	17,650 m^2	230 TEU	2000

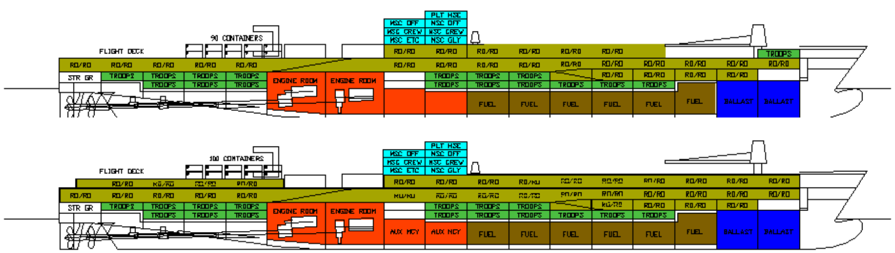
FETT/FSS Monohull



LOA: 294 m BMAX: 32 m
LWL: 280 m BWL: 32 m
Draft FL: 11.0 / 10.7 m
PANAMAX Dimensions

Disp FL: 58,766 / 64,208 mton
Four / Two Screws
8 x LM6000 / 4 x LM6000
298,280 kW → 38/30 kt

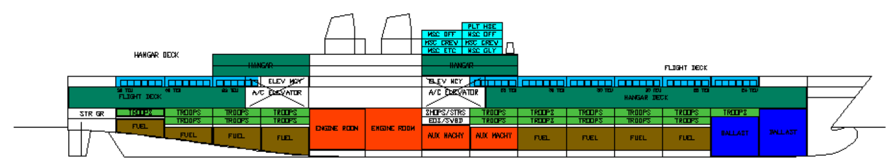
FEST/FEFT Monohull



LOA: 294 m BMAX: 32 m
LWL: 280 m BWL: 32 m
Draft FL: 11.0 / 11.0 m
PANAMAX Dimensions

Disp FL: 52,155 / 56,898 mton
Four Screws
8 x LM6000
298,280 kW → 38 kt

FEAT Monohull



Particulars:

LOA: 300 m BMAX: 40 m
LWL: 285 m BWL: 40 m
Draft FL: 11.0 m
Post PANAMAX Dimensions

Disp FL: 66.590 mton
Four Screws
8 x LM6000
298,280 kW → 36 kt

High Speed Connector (HSC) Family

- Characteristics
  - FNB = Fast Non-Beachable
  - HCMB = High Capacity Medium-Speed Beachable
  - HCFB = High Capacity Fast-Speed Beachable

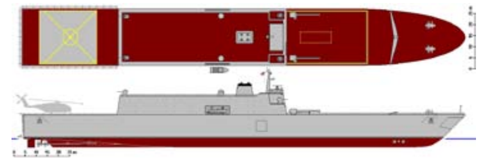
High Speed Connector (HSC) Family

Family Members

All 2000-nautical mile range

Name	Speed	Vehicle Stow	Troop Accom
Fast **N**on**B**each	40 kt	3250 m^2	125 + 375 Airline
Hi **C**ap **M**ed **B**each	25 kt	4180 m^2	405
Hi **C**ap **F**ast **B**each	45 kt	4180 m^2	105 + 300 Airline

Hi Cap Medium Beachable (Mono)

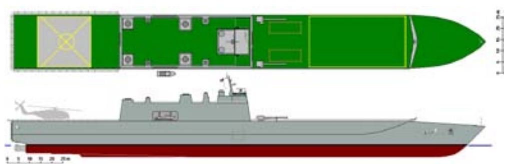


LOA: 200.4 m
LWL: 191.0 m
Draft: 4.9 m FL

BMAX: 22.2 m
BWL: 22.2 m
Depth: 15.4 m

Disp FL: 11825 tonne
Quad Screw
4 x Med Speed Diesel
31000 kW → 26.8 kt
sustained at 80% MCR

Fast Non-Beachable (Slender Mono)



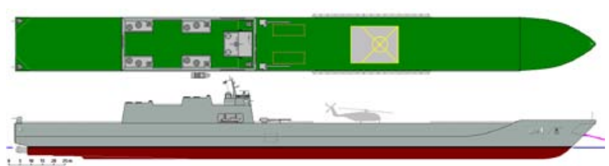
LOA: 215.4 m
LWL: 205.1 m
Draft: 5.1 m FL
4.8 m Arrival

BMAX: 22.6 m
BWL: 22.6 m
Depth: 16.3 m

Disp FL: 15527 tonne
Quad Waterjets
4 x LM6000 GT
149100 kW → 40.2 kt
sustained at 90% MCR

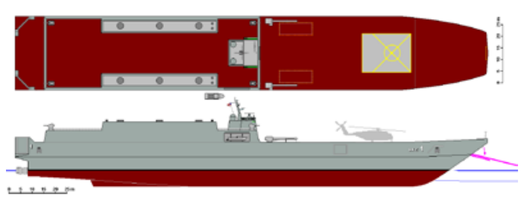
Hi Cap Fast Beachable

(Slender Monohull and Catamaran Alternatives)



LOA: 262.7 m
LWL: 249.8 m
BMAX: 24.0 m
Draft: 5.5 m FL
5.2 m Arrival

Displacement FL: 21231 tonne
4 Waterjets -- 8 x LM2500+ Gas Turbines 208800 kW → 43.2 kt @ 90% MCR



LOA: 235 m
LWL: 215 m
BMAX: 32.2 m
Draft: 6.9 m FL
5.0 m Arrival
(with Cushion-Assist)

Displacement FL: 20292 tonne
6 Waterjets -- 6 x LM6000 Gas Turbines 223700 kW → 43 kt @ 90% MCR

High Speed Assault Connector (HSAC) Family

- Characteristics
  - MCMB = Medium Capacity, Medium Range, Beachable
  - FWDB = Fast, Well-Deck Capable, Beachable
  - MCSB = Medium Capacity, Short Range, Beachable

High Speed Assault Craft (HSAC) Family

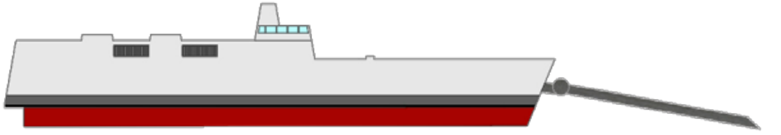
Family Members

(All Beachable)

Name	Speed (kts)	Mission Range (nm)	Ferry Range (nm)	Mission Area (m^2)	Mission load (mt)	Troops
MCMB	30	1000	4000	1115	300	110
MCSB	20	1000	4000	1115	300	110
FWDB	45	150	NA	372	145	125

MCMB

Hybrid Catamaran / Surface Effect Ship (SES)



LOA: 95.6 m BMAX: 23 m
LWL: 88.6 m BWL: 23 m
Displ: 1637 m tons
Draft (off cushion): 2.9 m
Draft (on cushion): 1.5 m

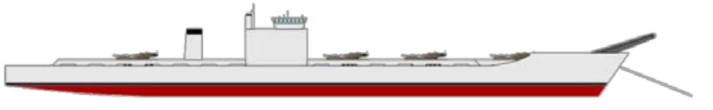
FWDB

Surface Effect Ship

LOA: 60 m BMAX: 14.6 m
LWL: 54 m BWL: 14.0 m
Displ: 472 m tons
Draft (off cushion): 2.0 m
Draft (on cushion): 0.9 m

MCSB

Conventional Monohull



LOA: 126 m BMAX: 13 m
LWL: 122 m BWL: 13 m
Displ: 2473 m tons
Draft FL: 2.3 m

Connector Study Conclusions

- Ships in the three families are feasible in the 2010 timeframe.
- The HSS Family has the highest confidence level relative to the HSC and HSAC Families.
- HSS: FEST, FEFT, FETT, and FEAT are feasible but rely on LM6000 propulsion plant and four shaft configuration that is unproven at this time; FSS is feasible but requires only twin screw due to reduced speed requirement.
- HSS Family interface issues are high priority; resolving satisfactory at-sea cargo transfer is critical to success.
- HSC: HCMB is feasible and has least risk of HSC alternatives. FNB requires powerplant development. HCFB is high risk and only marginally feasible and potentially too large for austere ports.
- HSAC: MCSB is feasible using proven technologies. Both MCMB and FWDB require development of skirt technology and ramp systems. Shallow draft and beaching requirements for high performance small craft are challenging.

Interface Considerations

Interface Issues

Interfaces Considered

	Ship or Craft Interfacing with HSS		
Type of Interface Mechanism	**HSC**	**HSAC**	**MPF(F)**
Shipboard Cranes for Cargo Transfer	X	X	X
Ramps, Crane Deployed	X	NA	Potential
Ramps, Self-Deploying	X	NA	Potential
RRDF or equal	X	X	X
ILP	NA	X	NA
X indicates that interfaces have been investigated to minimal level.			

Notional Matrix for Force Architecture Trade-off

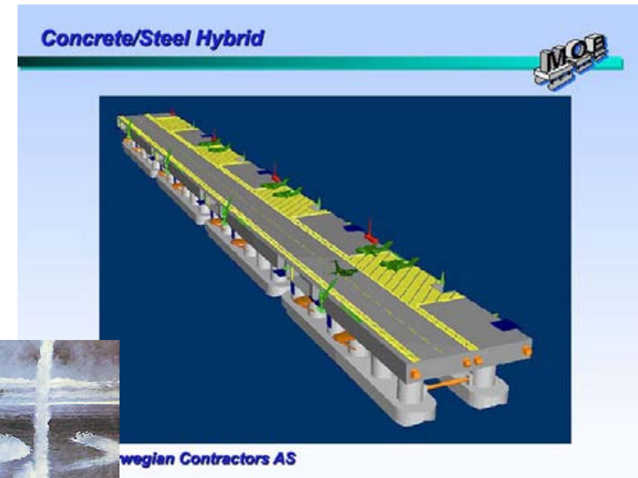
- Develop matrix (SCENARIOS by CONNECTOR CLASSES) to explore force architecture options
- Run EXTEND for each force architecture combination
- Compare OMOEs (time to objective, CPI) for various combinations of Connectors

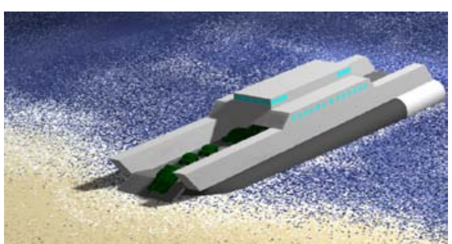
Notional Matrix for Force Architecture Trade-off

	MPF(F)-Centered		RFP		CONUS-Based		WPP	
options	1.1	1.2	2.1	2.2	3.1	3.2	4.1	4.2
HSS								
HSC								
HSAC								
Other Assets								
Time to Objective								
Combat Power Index								

TASK IS TO IDENTIFY COMBINATIONS OF VESSELS TO PERFORM REQUIRED MISSION UNDER EACH SCENARIO – COULD POTENTIALLY HAVE TWO OR MORE 'OPTIONS' OR COMBINATIONS UNDER EACH SCENARIO

How to 'Evaluate' (?) this Mix of Platforms / Sub-systems and Missions?





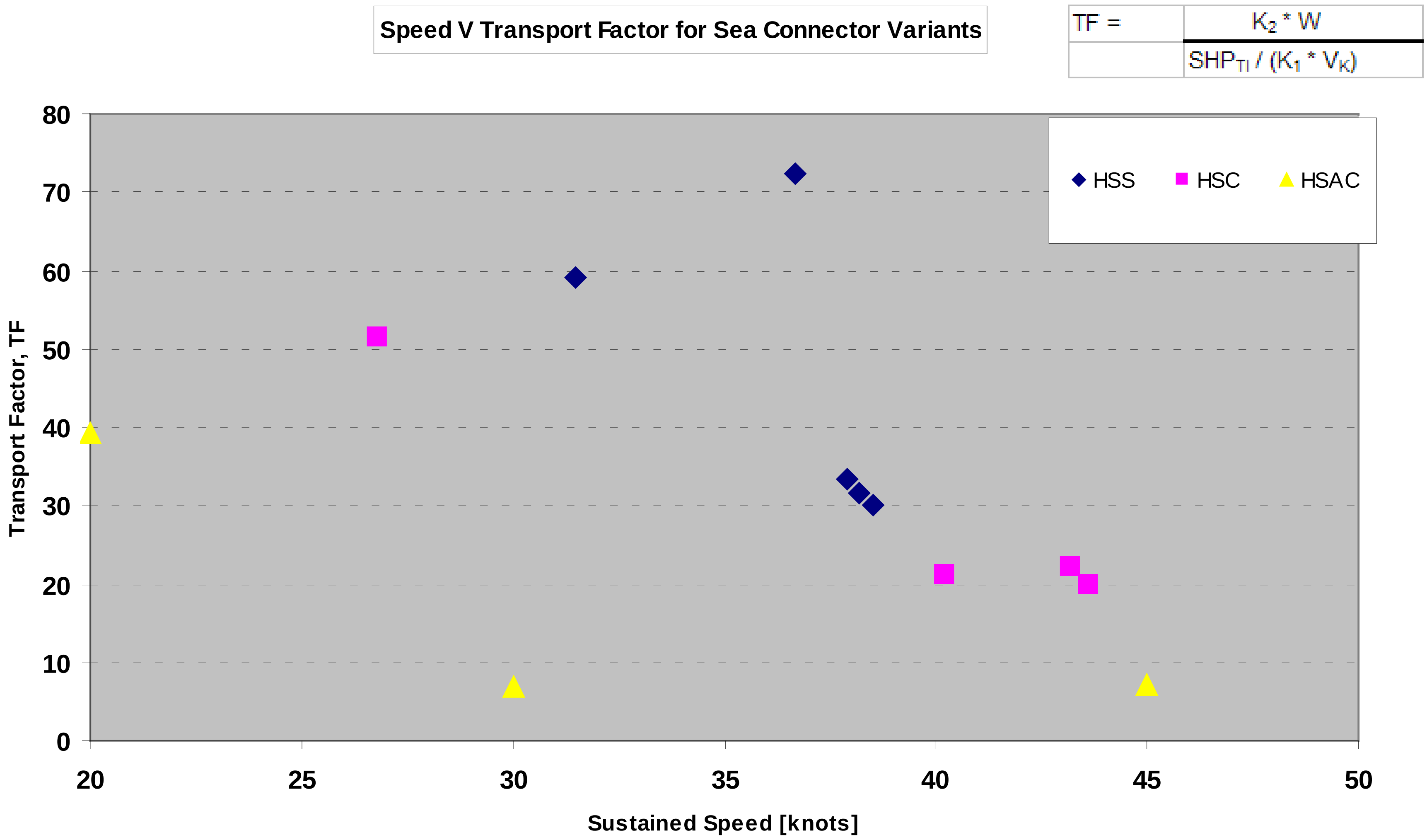
Some Initial 'Composite' Metrics for Sea Connectors

- Transport Factor and Other Metrics for Sea Connectors
  - Speed vs Transport Factor

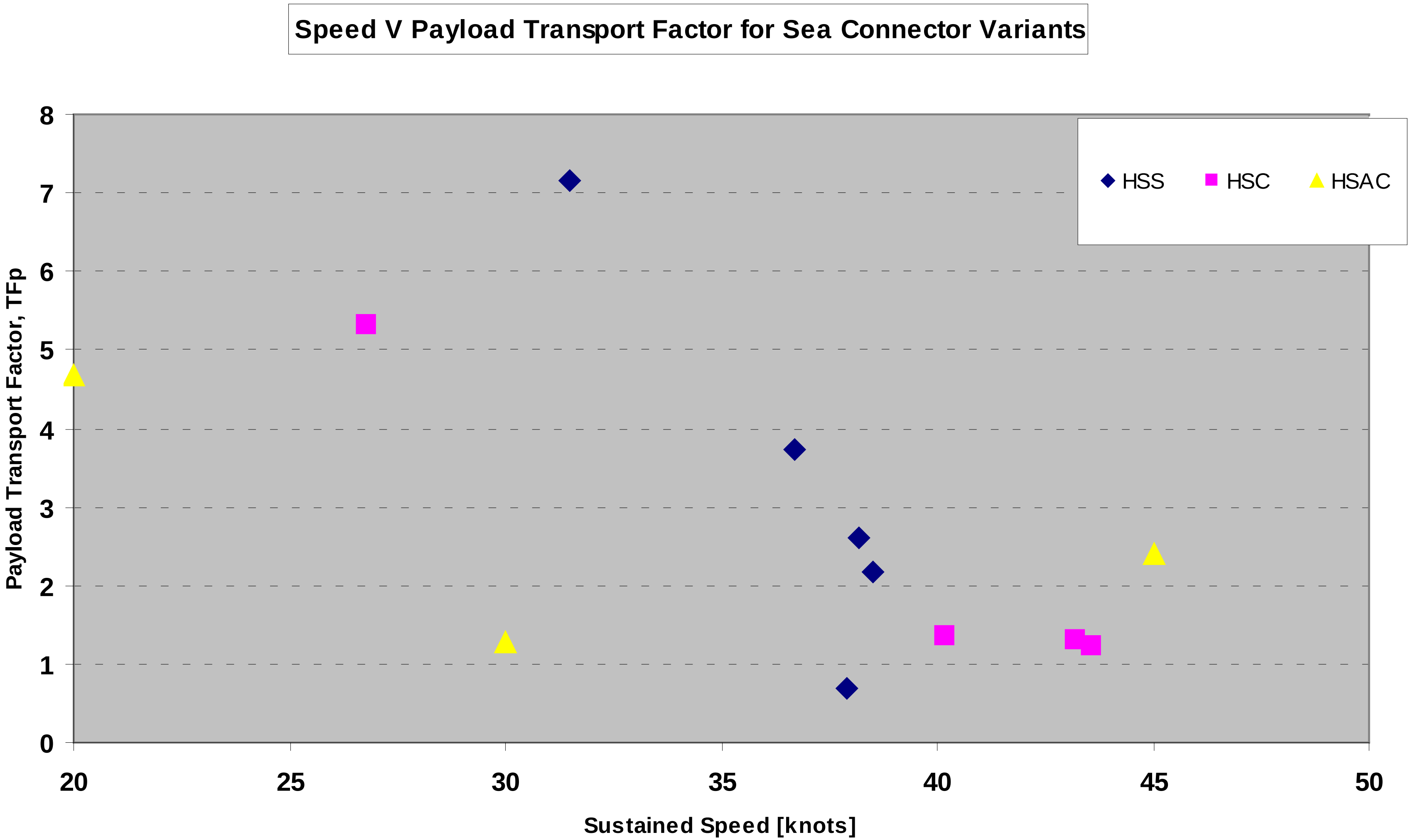
TF =	$K_2 * W$
	$SHP_{TI} / (K_1 * V_K)$

  - Speed vs Payload Transport Factor
  - Payload vs '8 hour' Range
  - Number of Sea Connectors required to transport 1 surface BLT
    - Using following limiting criteria
      - Number of persons
      - Vehicle area
      - Vehicle weight

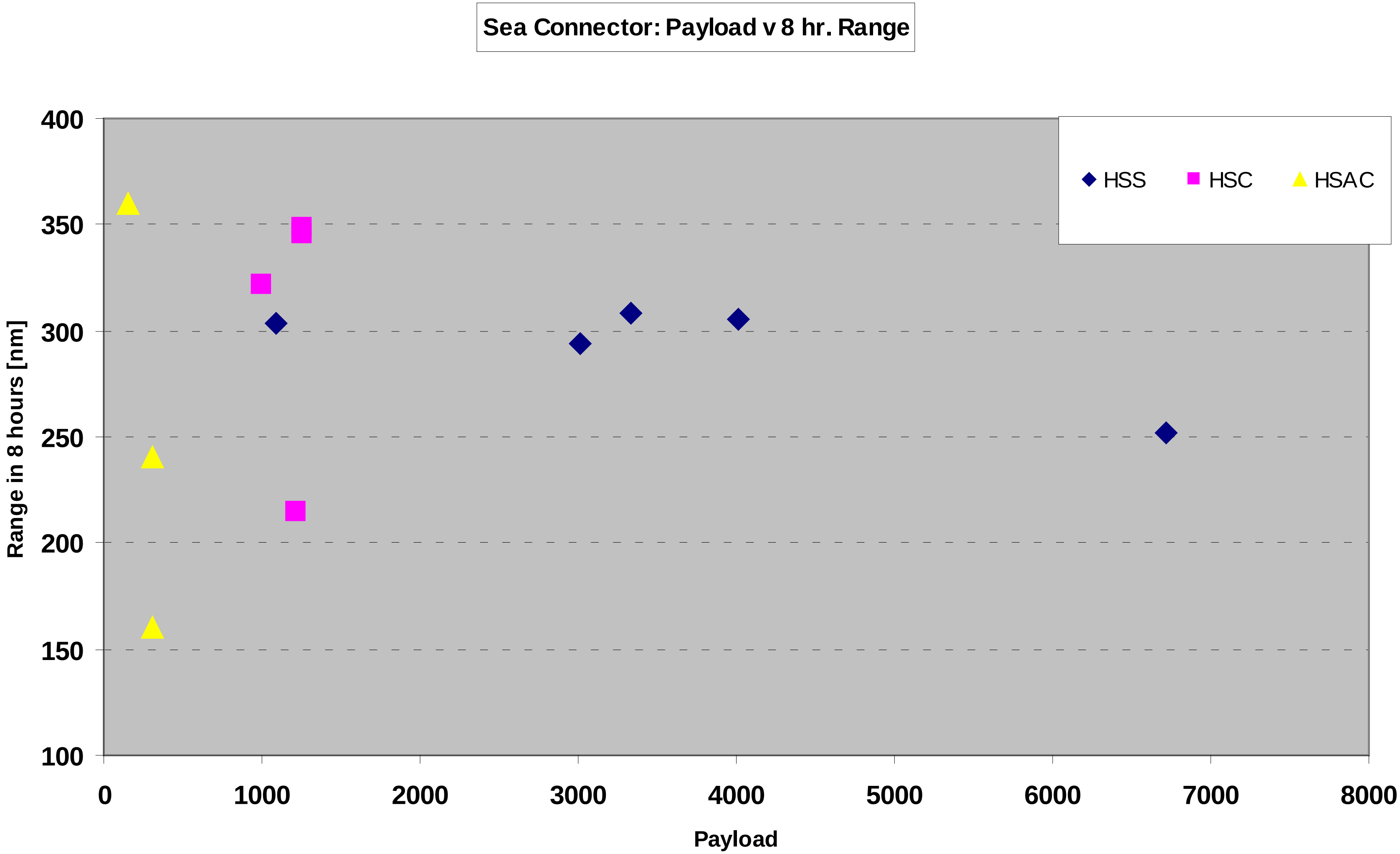
Speed Vs Transport Factor



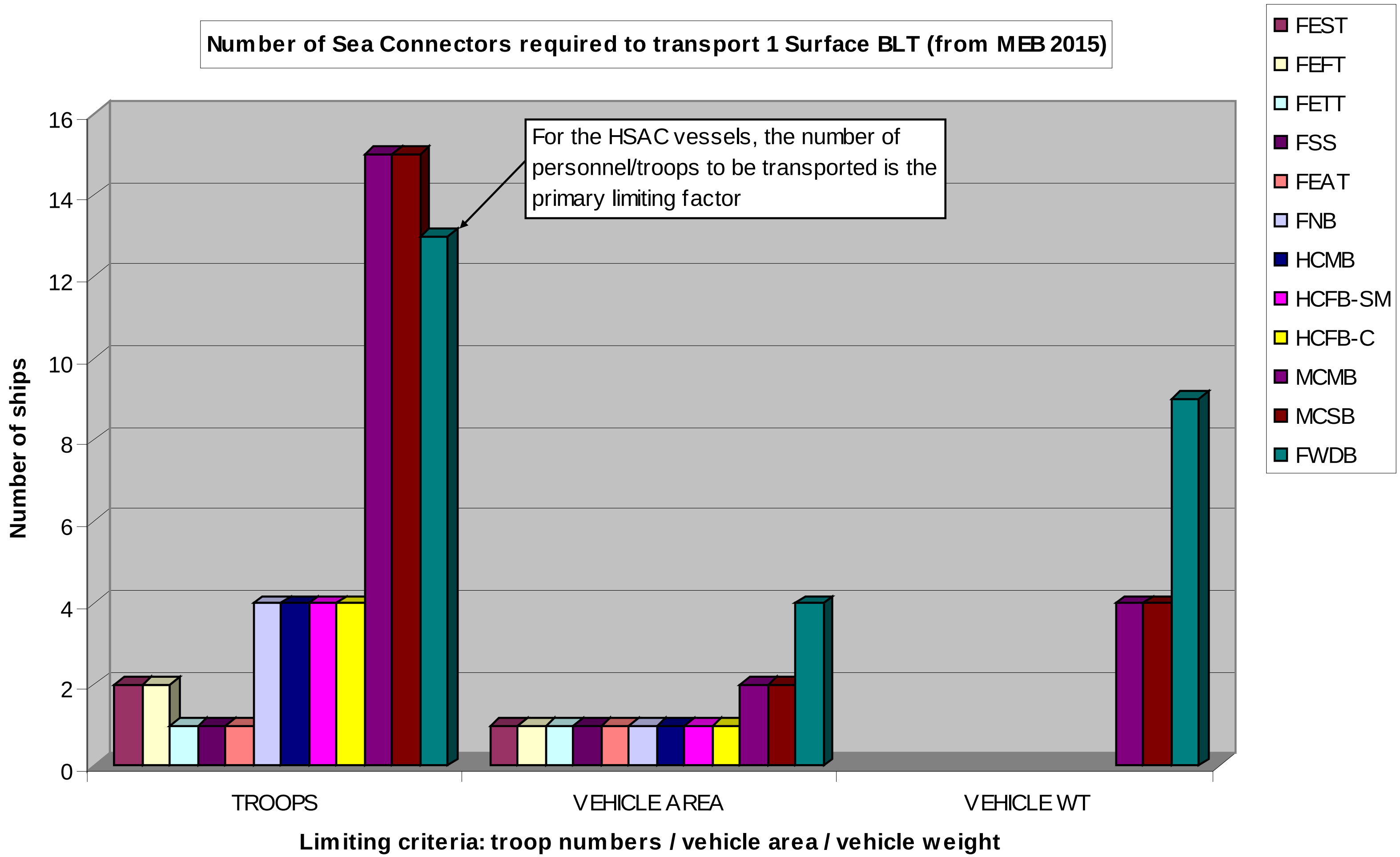
Speed Vs Payload TF



Payload Vs ‘8 hour’ Range



Sea Connectors Required to Transport 1 BLT



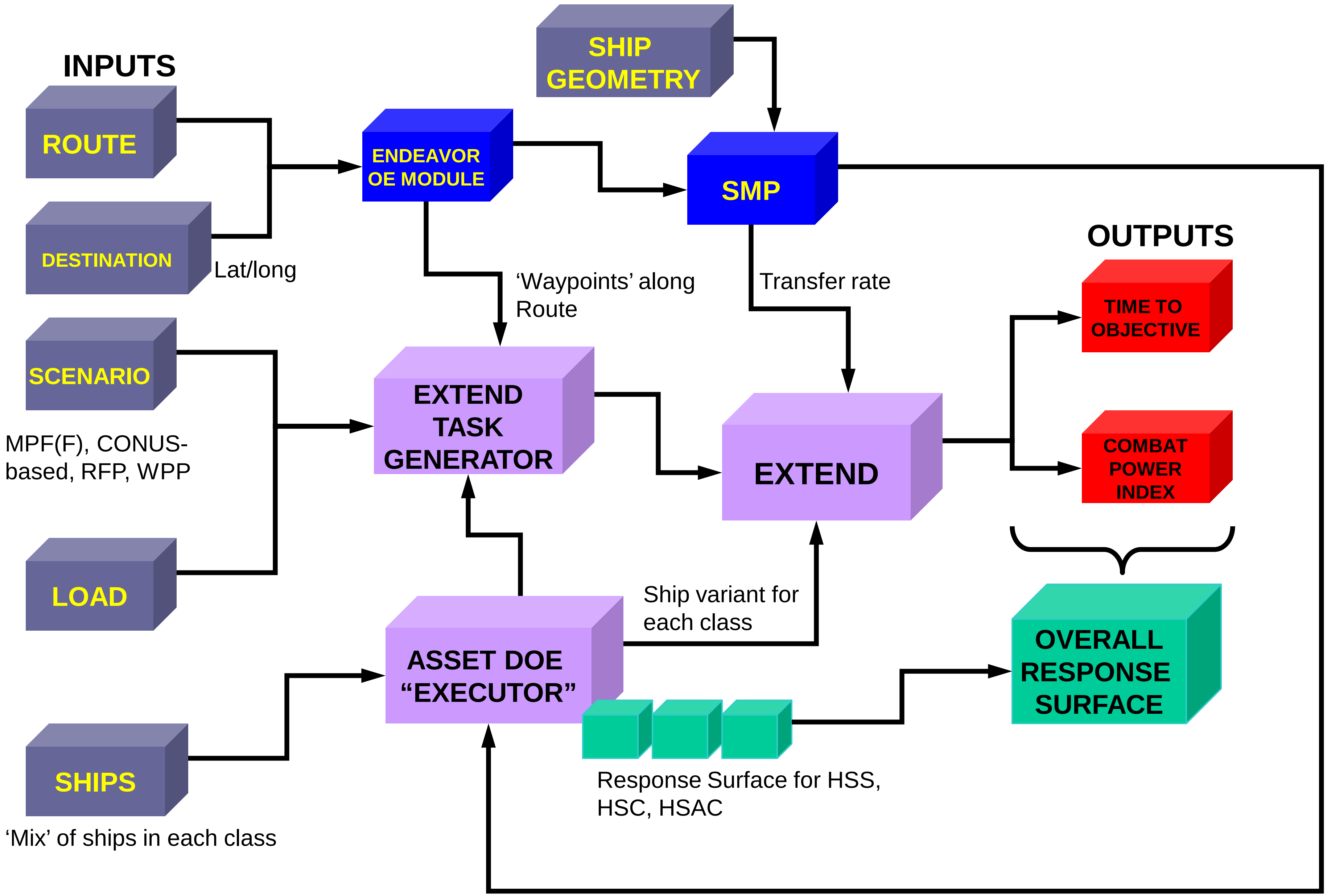
Overall Objective of Modeling Mission Effectiveness

To provide traceable linkages (bi-directional) between measures of performance associated with individual ship- and sea-base platforms (including the constituent subsystems), and measures of effectiveness associated with the required mission

Mission Effectiveness

- OMOE = Overall Measure of Effectiveness
- MOE = Measure of Effectiveness
    - A measure of the effectiveness of the system in performing a particular mission
- MOP = Measure of Performance
    - Physics- and design-based attributes of platform AND payload
- In simple form …
  – A weighted summation of MOP
- TRACEABILITY is paramount!!

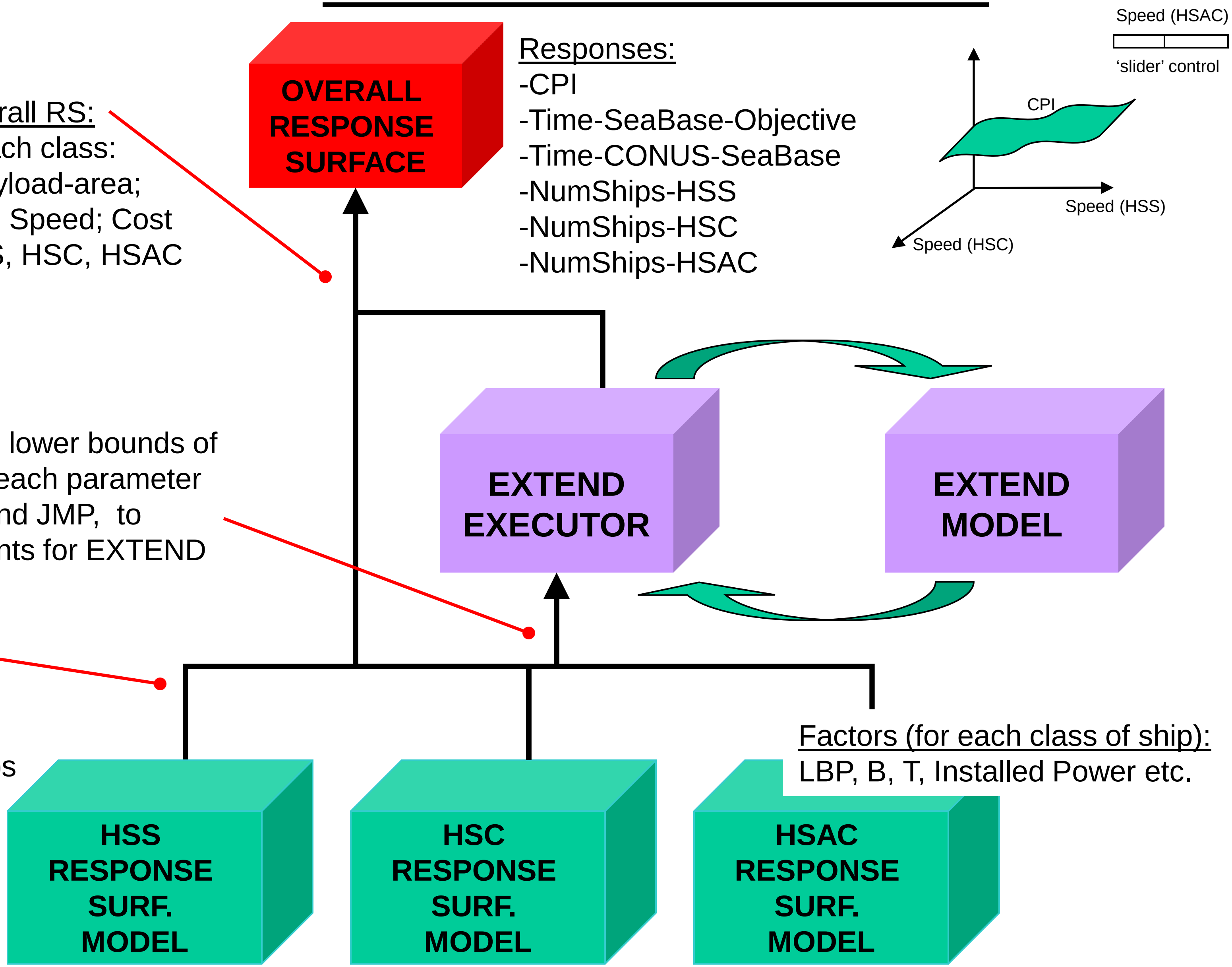
CISD Sea Connector Trade-off Space: Task Module Flowchart



Hierarchy of Response Surface Models for SeaBase-SeaConnector Architecture Trade-off

Factors for Overall RS:
-5 factors for each class:
Payload-wt; Payload-area;
Payload-troops; Speed; Cost
-3 classes: HSS, HSC, HSAC
== 15 factors.

Responses:
-CPI
-Time-SeaBase-Objective
-Time-CONUS-SeaBase
-NumShips-HSS
-NumShips-HSC
-NumShips-HSAC



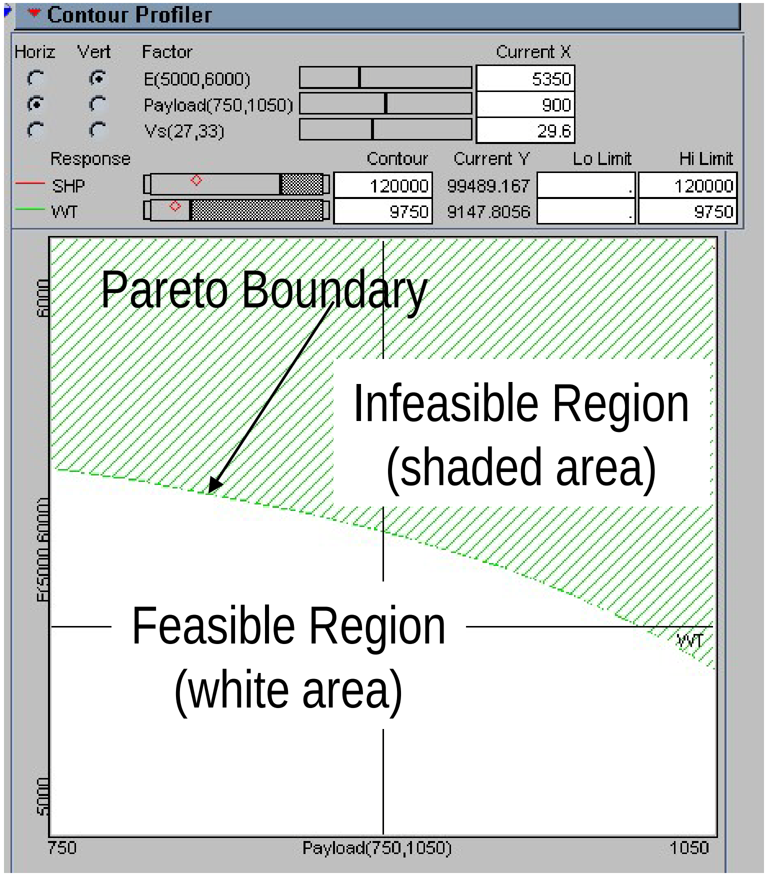
Use upper and lower bounds of responses for each parameter (speed etc.), and JMP, to generate variants for EXTEND executor

Responses:
-Payload-wt
-Payload-area
-Payload-troops
-Speed
-Cost

Factors (for each class of ship):
LBP, B, T, Installed Power etc.

System-based Trade Environment

- System Level
  - Complexity
    - Emergent properties can become more critical than subsystem performance properties
    - Only need 80% solution for Concept Design Level
- Trade Environment
  - Use meta-models for trade-off studies
  - Shared space among stakeholders
    - Design
    - Decision Making
- "Shared Space" can mitigate
  - Ambiguity
  - Uncertainty
  - Exclusion of innovative solutions



Use of Response Surface Methods (RSM)

- Provides capability to assess and visualize changes in mission effectiveness based on changes in MOPs
- For this will need to develop RS model for MOE—MOP relationships
  - – This may be separate to the RSM modeling of platform performance in terms of specific MOPs

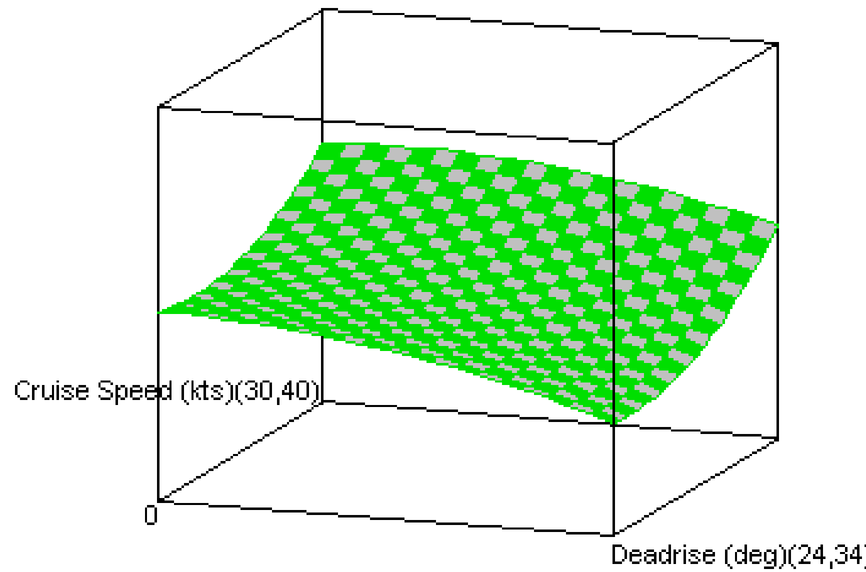
Therefore …

- Two possible levels of usage for RSM
  - To explore inter-relationships between platform MOPs
  - To map MOE-MOP relationships

Response Surface Designs

- 3 Level Design Analysis Creates Mathematical Model
  - Empirically based
  - From experimental data
- Response Function
  - Interpolated function predicts response between factor points tested in experiment
  - Visualized as a “surface”
- Typical Designs
  - Box-Behnken
  - Central Composite Design (CCD)
    - Also known as Box-Wilson design

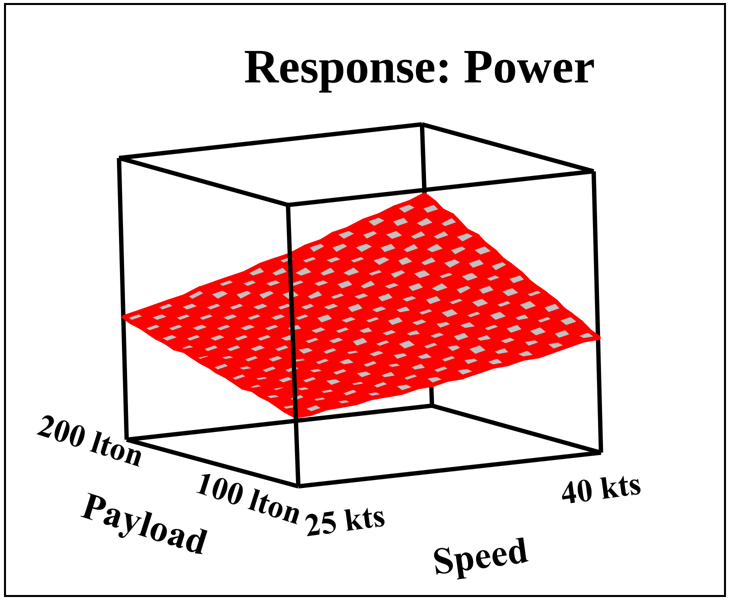
Response: Vertical Acceleration



Example shown is from: Optimal Deadrise Hull Analysis and Design Space Study of Naval Special Warfare High Speed Planing Boats, LT Todd E. Whalen, USN, MIT Masters Thesis, 2002

Response Surface

- Estimate relationship between factors and responses
- Example
  - Factors
    - Speed (s)
    - Payload (p)
  - Response
    - Installed Power
  - Result
    - Can estimate power for any speed-payload combination

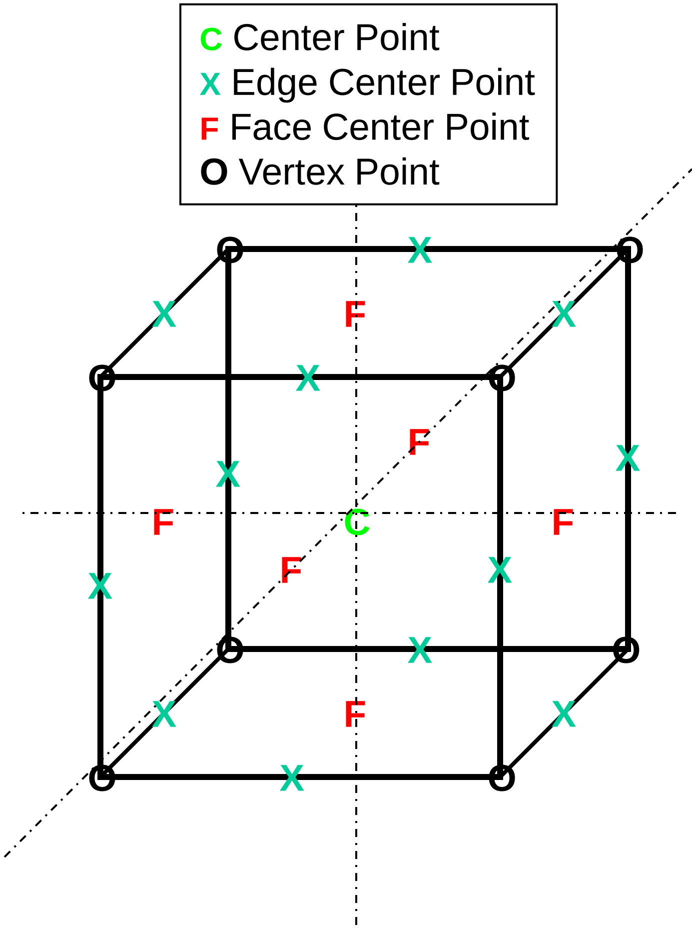


$$Power = 13{,}855 + 4{,}239 \cdot s + 4{,}689 \cdot p + 1405 \cdot p \cdot s + 436.8 \cdot s^2 - 0.2 \cdot p^2$$

Example shown is from: Integrating Response Surface Methods and Uncertainty Analysis into Ship Concept Exploration, LT Shelly Price, USN, MIT Masters Thesis, 2002

DOE - Define Design Space

- Design space defined by ranges of input variables (factors)
- Set the factors to a number of levels
- Total number of variants needed for an experiment
  - $\#\ \text{levels}^{\#\ \text{factors}}$
  - ex: 3 factors with 3 levels each would need 27 variants for a full factorial design
- Can reduce the number of variants using Box-Behnken, Central Composite (Box-Wilson), or Taguchi reduction methods



Cartesian Coordinate System

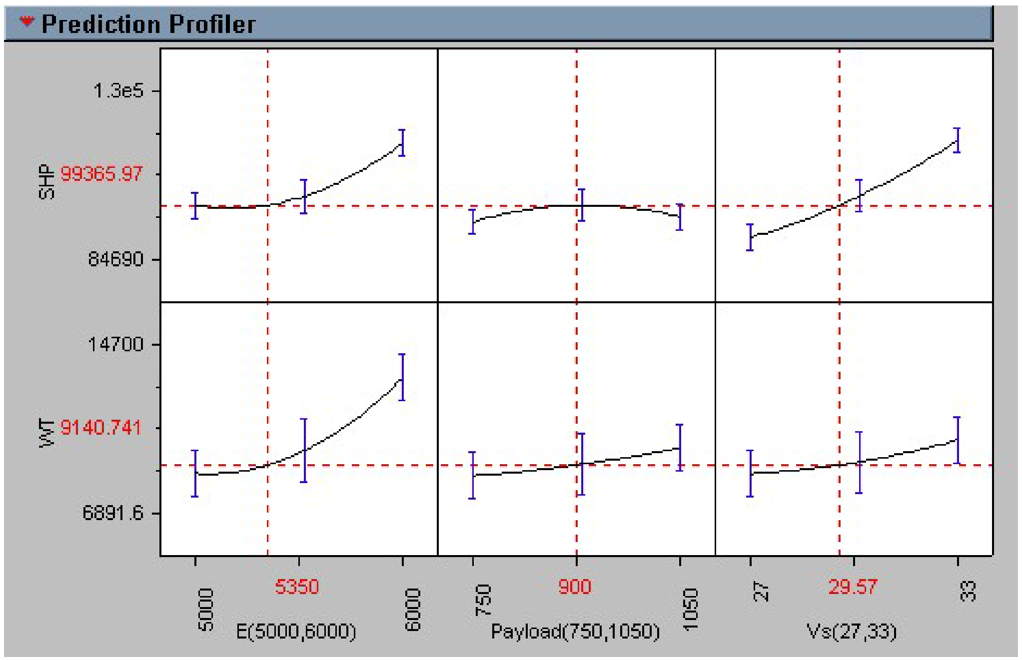
Curve Fit Points from Design Space

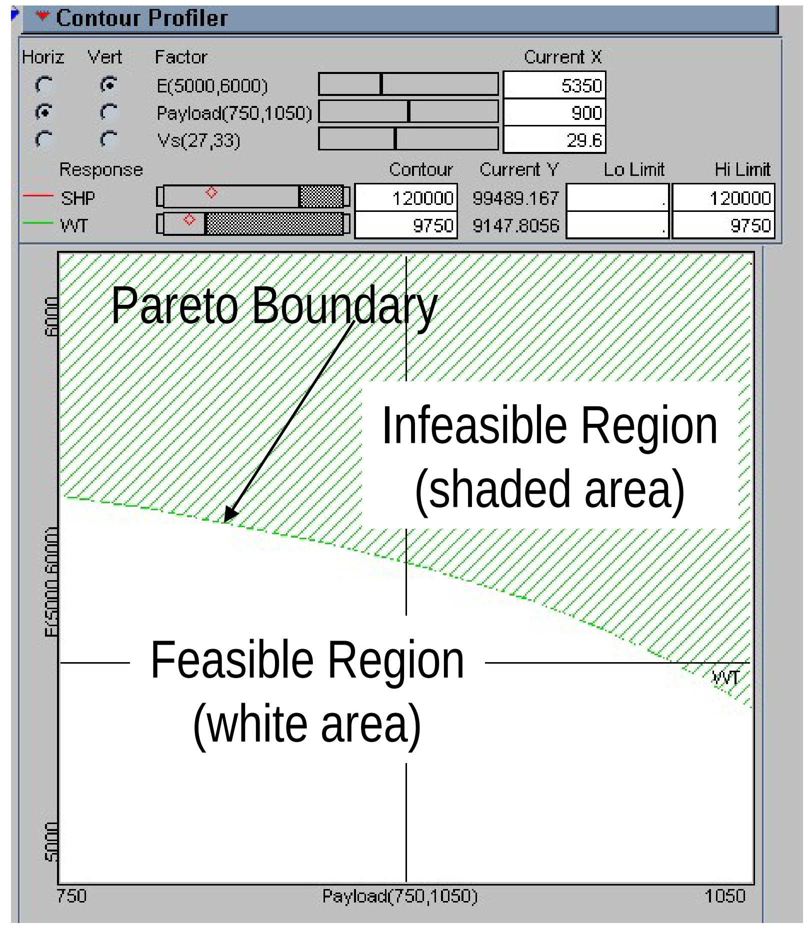
Create Response Surface Equations

$$y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{i=1}^{k} \sum_{j=i+1}^{k} b_{ij} x_i x_j + \varepsilon$$

Interpolated Curve Fit Creates Response Surface

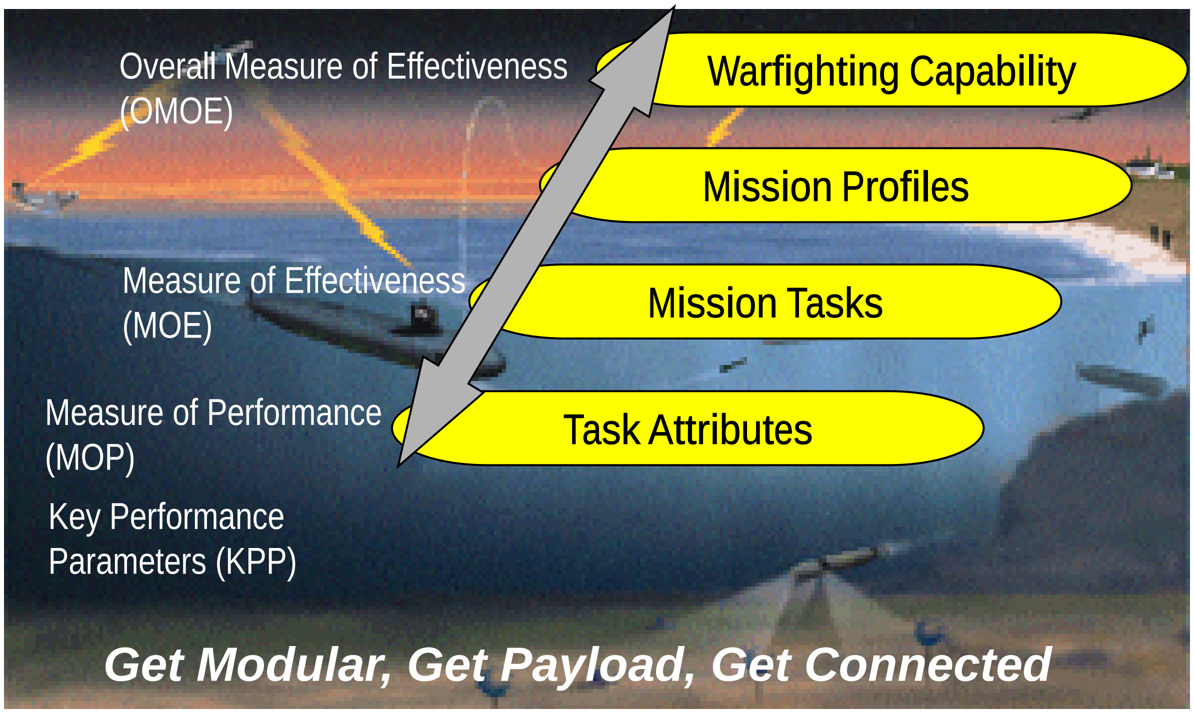
Investigate Response Surfaces Using JMP





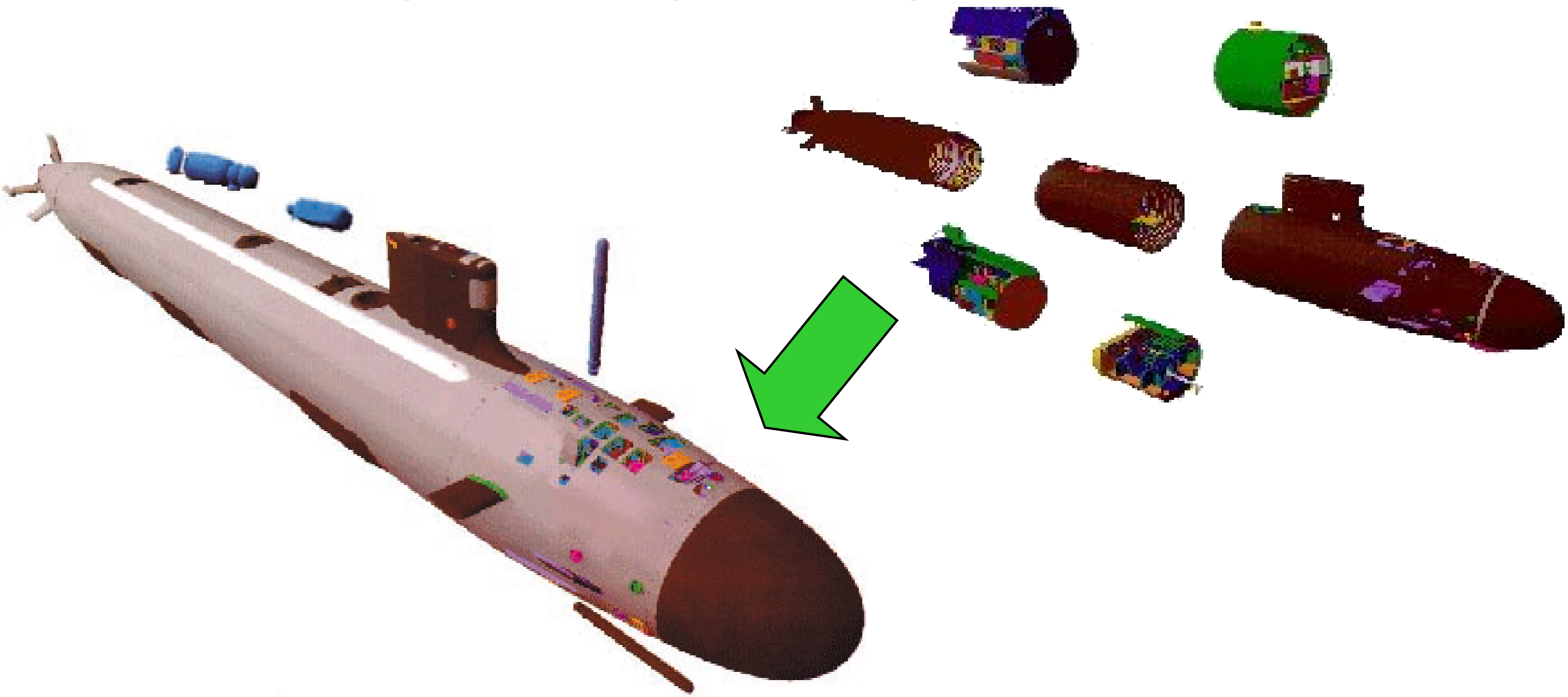
Analyze DOE Case Study
Improved Payload Submarine

- Submarine Design Study Tasking
  - Redesign Virginia class submarine
  - Allow for insertable payload modules for rapid reconfigurability
    - ISO standard size (20 ft x 20 ft)
    - Up to 3 modules



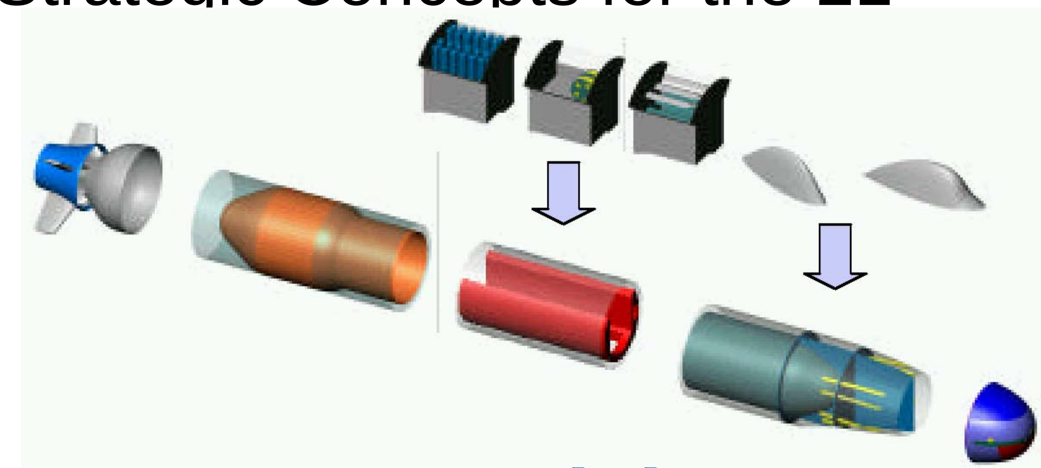
Analyze DOE Case Study Overview

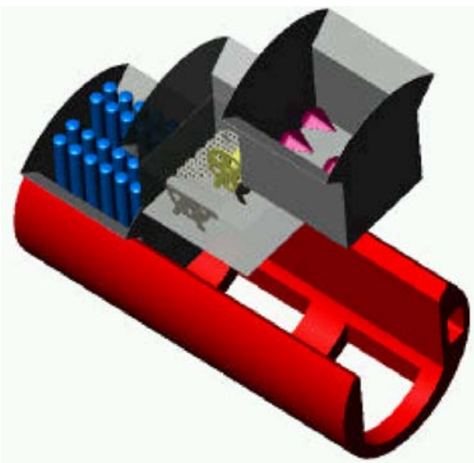
- Create a “Modular and Affordable” submarine
- What payload could be carried?
- What is the impact on Depth and Speed?

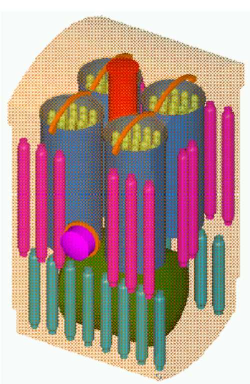


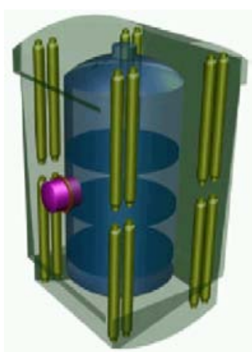
Analyze DOE Case Study
Modular Payloads

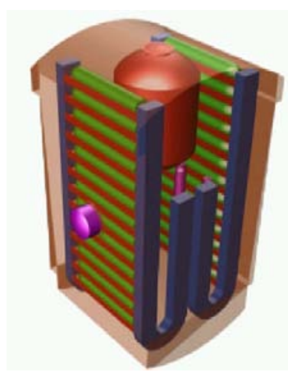
- Submarine Joint Strategic Concepts for the 21st Century

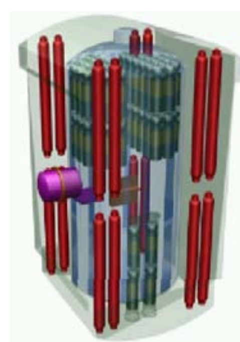


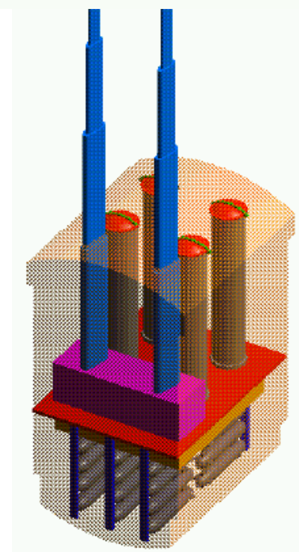






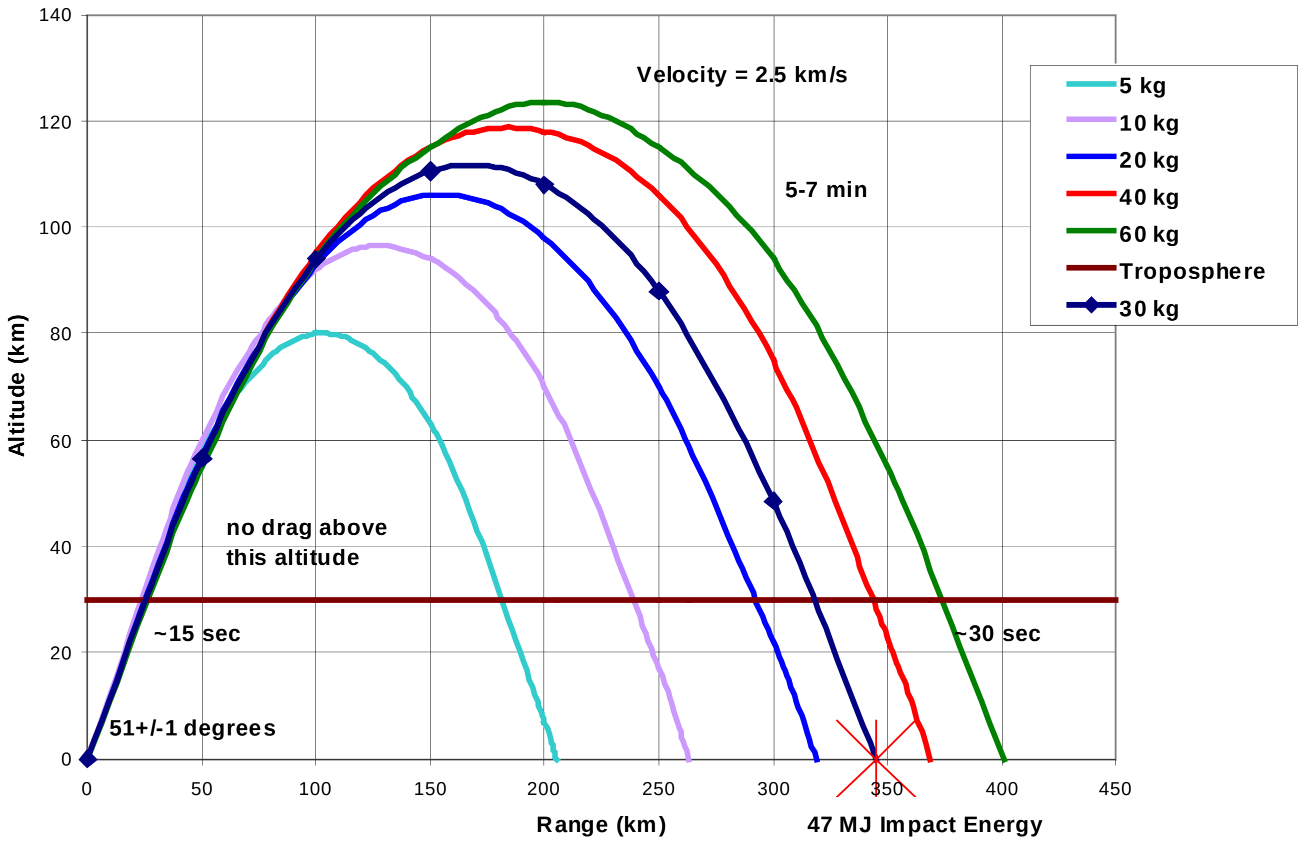






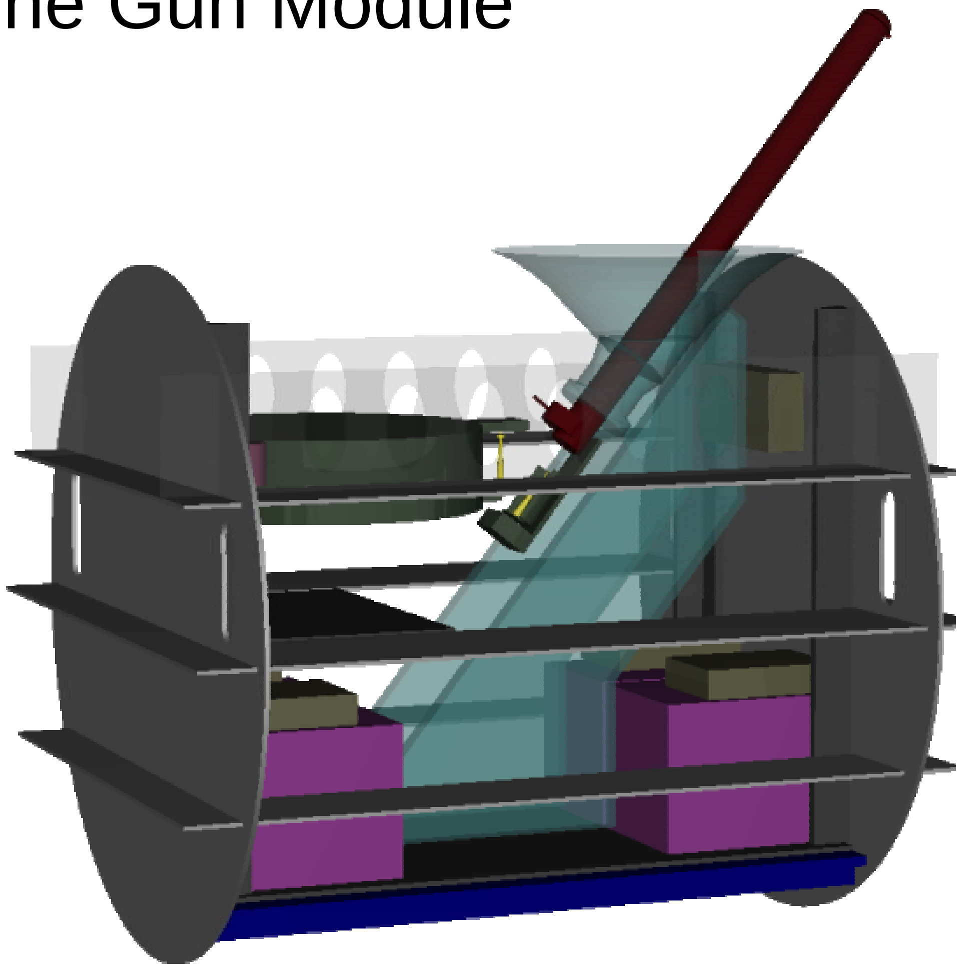
Analyze DOE Case Study Electromagnetic Rail Gun

- EM Gun Performance Plot



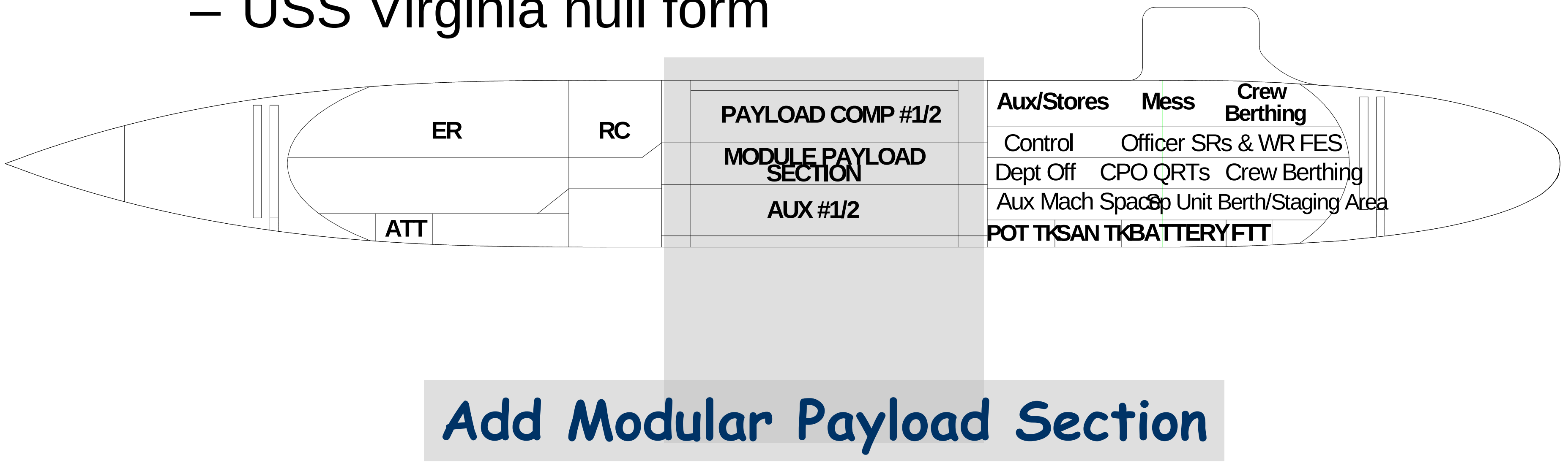
Analyze DOE Case Study
Electromagnetic Rail Gun Module

- Submarine Gun Module



Design Summary

- Need
  - Submarine Payload Capacity Improvement
- Allowable Compromise
  - Top Speed, Maximum Diving Depth
- Constraint
  - USS Virginia hull form



Translate User Needs to Design Requirements

- Establish Needs (VoC)
- Translate to Requirements (AHP and QFD)
- Select Key Performance Parameters (KPP)
- Determine Goals and Thresholds
- Model Using DOE

1. Transit time (days) for rapid surge deployment
   - East Coast to Persian Gulf conflict or West Coast CONUS to Southeast Asia conflict
   - Mark desired goal time (**G**) and ***maximum*** acceptable threshold (**T**)

Time (days)	5	6	7	8	9	10	11	12	13	14	15	20	25	30
Scoring							*G*					*T*		

2. Test Depth
   - Mark desired goal test depth (**G**) and ***minimum*** acceptable threshold (**T**)

Test Depth (ft)	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500
Scoring					*T*		*G*					

Translate User Needs to Design Requirements

3. In-Theater Maximum Speed
   - i.e. in Persian Gulf, Southeast Asia region, Med, etc,
   - Mark ***maximum*** speed (**G**) and ***minimum*** acceptable (**T**) once *in-theater*

Max Speed (kts)	16	19	22	26	29	32	35	38	42	45	48
Scoring				T			G				

4. In-Theater Speed Profile
   - Use GOAL ***maximum*** speed from question #5 (Q5) as max speed
   - Fill-in % of time at each specified speed

% Max speed (Q4 G)	< 60	61-70	71-80	81-90	91-100
% time at specified speed	80	15			5

$\underbrace{\hspace{10em}}_{\textbf{Note: Total must = 100\%}}$

AHP Method: Rank Relative Importance

Compare the *importance* of the following submarine parameters.

1=Equal 3=Moderate 5=Strong 7=Very Strong 9=Extreme

Parameters	**Pairwise Comparisons**																	**Parameters**
Transit Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Test Depth
Test Depth	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Payload
Payload	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Transit Time

Measure acceptance of:

Trading *speed* and *depth* for **Payload**

Computing Effectiveness

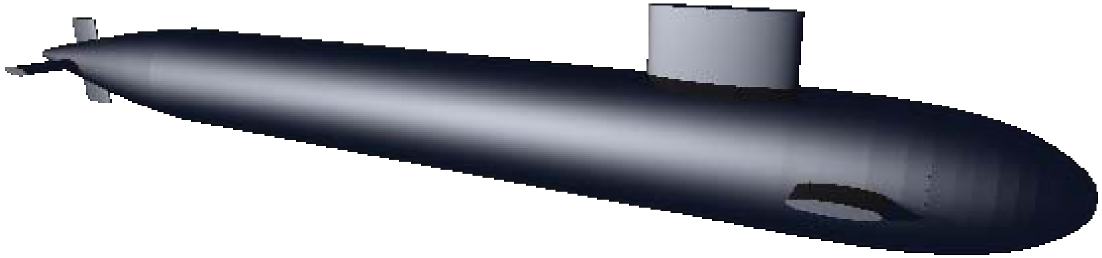
<u>Weighting Factors</u>

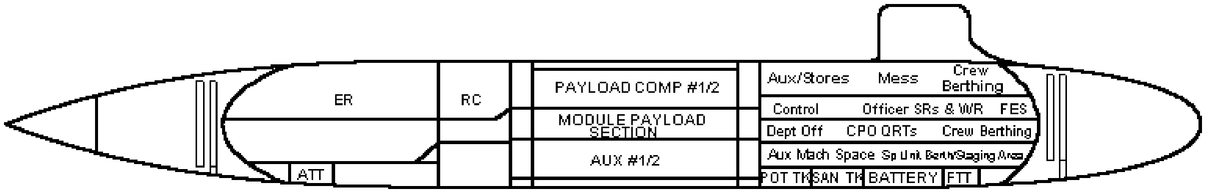
w_{Speed}	0.4105	*Computed Using AHP*
$w_{Test\ Depth}$	0.1360	
$w_{Payload}$	0.4535	

	Min	Max	
Max Speed (kts)	26	35	*Operator Survey*
Test Depth (ft)	850	1100	
Payload Length (ft)	43	88	*Variant Study Limit*

$$OMOE = \frac{Speed - 26}{35 - 26} \times w_{Speed} + \frac{TestDepth - 850}{1100 - 850} \times w_{TestDepth} + \frac{PayloadLength - 43}{88 - 43} \times w_{Payload}$$

Analyze Case Study
Submarine Baseline Concept



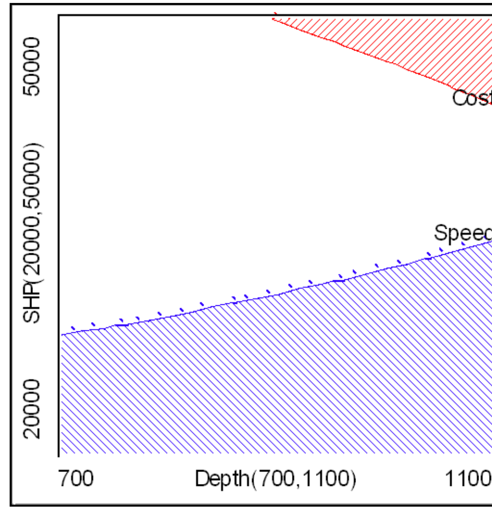


Parameter	Baseline Design
Displacement (surfaced)	8499 ltons
Displacement (submerged)	9562 ltons
Length	372.4 feet
Diameter	40 feet
SSTG’s (combined)	7200 kW
Payload Section Length	64 feet
Installed Shaft Horse Power	28,100 shp
Speed (submerged)	28.08 knots
Endurance Range	90 days
Compliment	100

Case Study: Response Surface Results

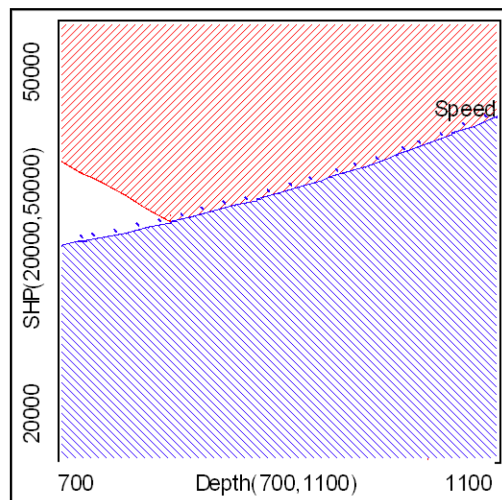
Ship Concept Design Exploration

- Response Surface Methods (RSM) techniques allow multiple variable parameterization and visibility



<u>Factors</u>
PC = 0.79
Payload = 65 ft.
Diameter = 38 ft.

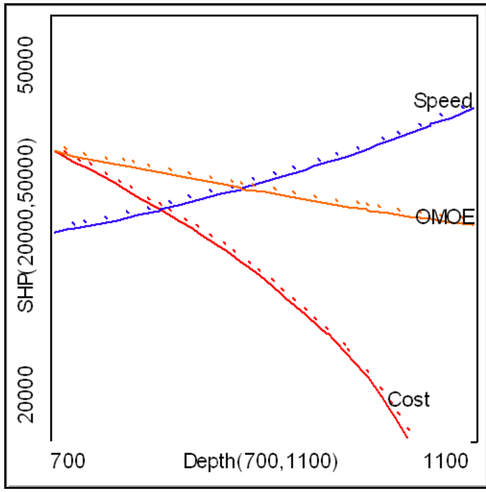
<u>Response Constraints</u>
Cost < $2.0 billion
Speed > 28 knots



<u>Factors</u>
PC = 0.79
Payload = 88 ft.
Diameter = 42 ft.

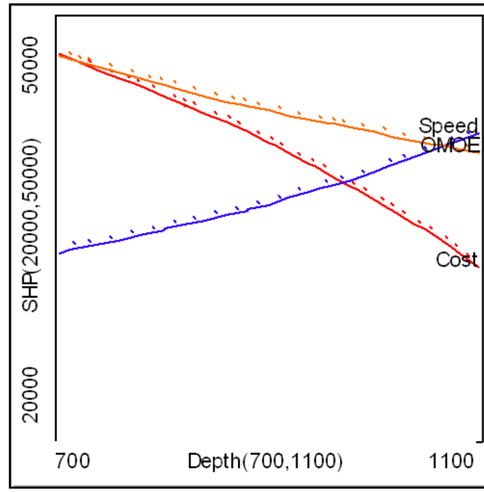
<u>Response Constraints</u>
Cost < $2.0 billion
Speed > 28 knots

Case Study: Trade Off



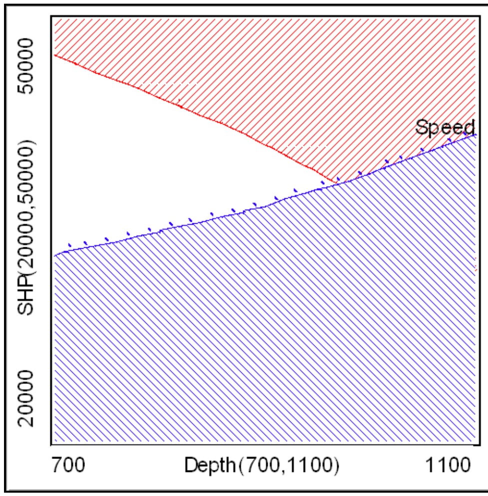
Factors
PC = 0.79
Payload = 88 ft.
Diameter = 42 ft.

Response Contours
Cost = $2.0 billion
Speed = 28 knots
OMOE = 0.72



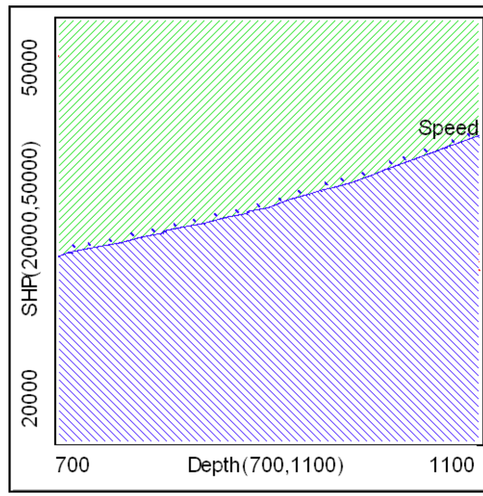
Factors
PC = 0.79
Payload = 88 ft.
Diameter = 38 ft.

Response Contours
Cost = $2.0 billion
Speed = 28 knots
OMOE = 0.784



Factors
PC = 0.79
Payload = 88 ft.
Diameter = 38 ft.

Response Constraints
Cost < $2.0 billion
Speed > 28 knots



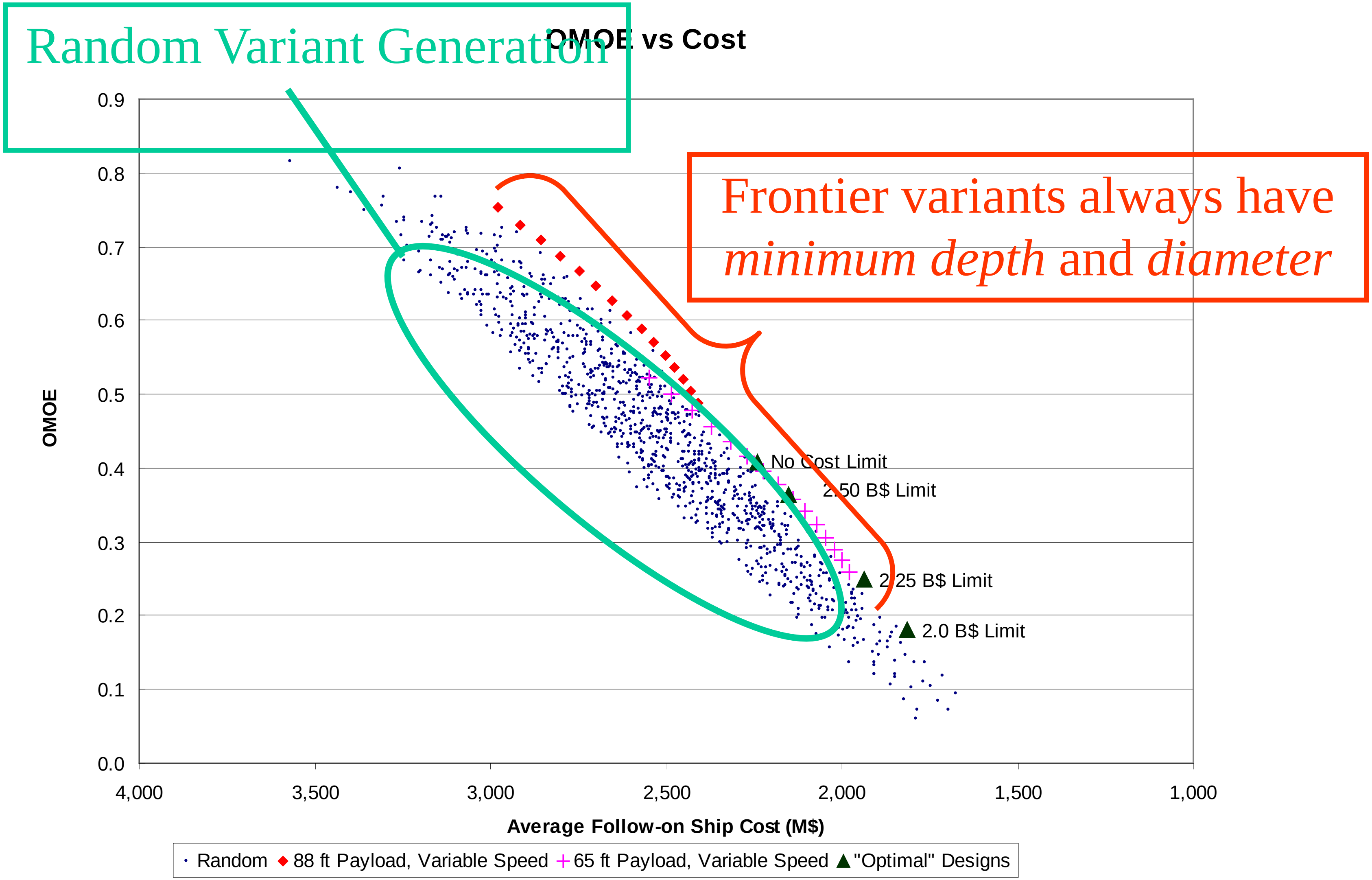
Factors
PC = 0.79
Payload = 88 ft.
Diameter = 38 ft.

Response Constraints
Cost < $2.0 billion
Speed > 28 knots
Submerged Displacement
< 10000 ltons

Case Study: Cost Constrained Optimality

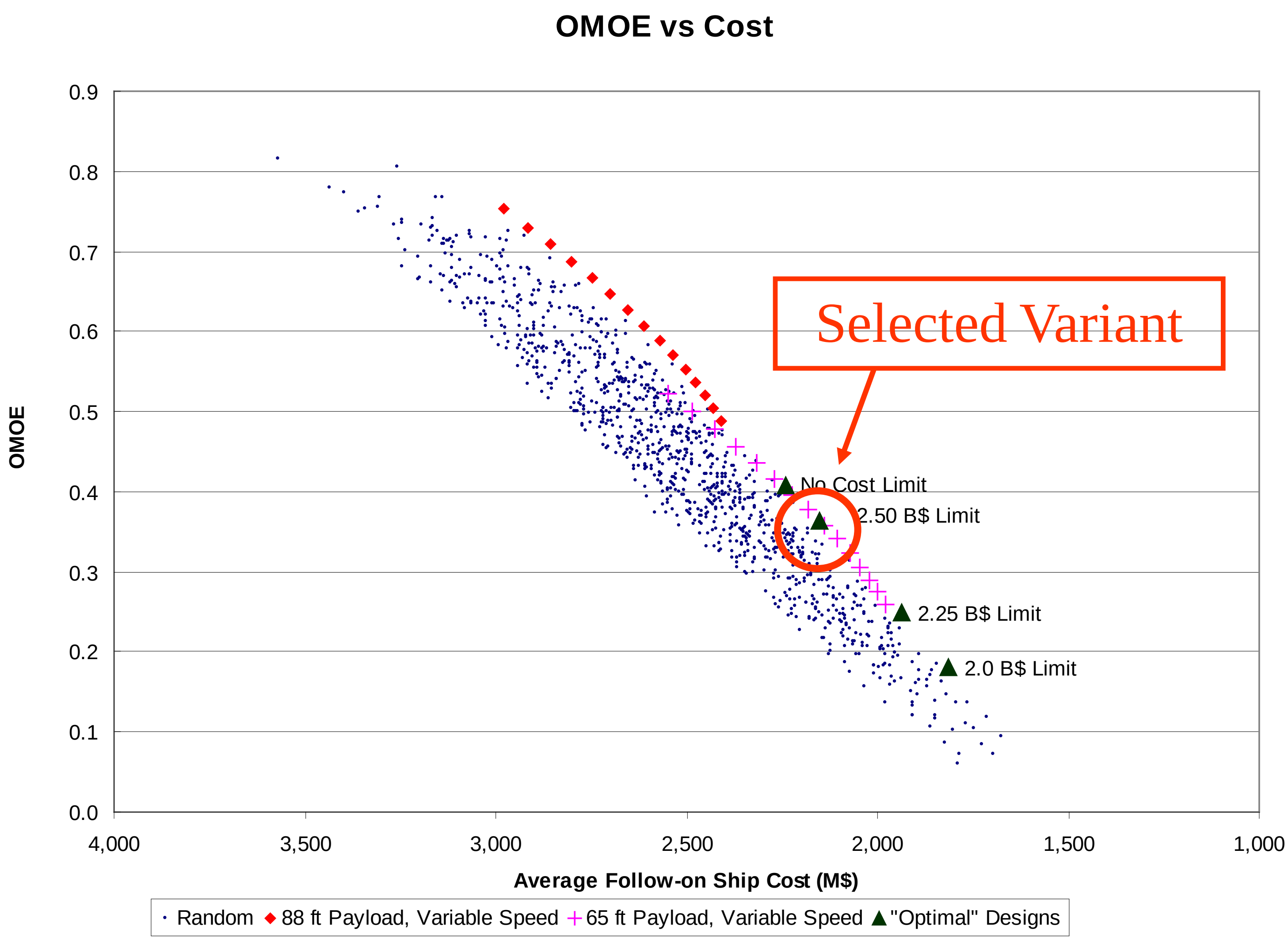
Case Study: Pareto Plot

Solution Comparison



Case Study: Pareto Plot

Solution Comparison



Seaconnector Project Issues

- Identified MOPs and MOEs for each class of Connector
- Defined ‘generic’ ships in EXTEND
- How to link between RS models and EXTEND RS?
- How to ‘fit’ surface BLT (priority loading) components with known available payload weights/areas for Connectors?
- Determine how best to track Combat Power Index (CPI) in EXTEND
- How to include survivability / sustainability / beaching capability, etc ???

Additional Detailed Information

HSS Family Conclusions

- FEST, FEFT are feasible pending development of high power CPP and marinized version of LM6000.
- FETT is feasible under similar conditions but may be a better design at greater than PANAMAX beam for stability.
- FSS is feasible under similar conditions but may be a better design at greater than PANAMAX beam for stability. Ten thousand tons of fixed ballast required at 32 m beam.
- FEAT is feasible, although it doesn’t quite achieve 37 knot speed under conditions above.
- All but FEAT subject to satisfactory development of multiple interface issues.

HSC Family Conclusions

- FNB is feasible but has moderate development risks.
  - Requires development in areas of powerplant (turbines and waterjets).
  - Risk area is design for acceptable hull structural responses.
- HCMB is minimal risk concept.
  - HCMB is basically a conventional design, despite need for triple or quad-screw plant; several alternative propulsion options are attractive.
  - ”Economical” (in context of military Sea Basing) at 25 knots threshold speed.
  - 30-knot speed objective can be met with LM2500 gas turbines , either with electric drive and propellers, or with waterjets.
- HCFB is potentially feasible, but presents high development and operational risks in several areas.
  - Monohull and multihull variants both near 45 knots (but not quite: best so far 43.2 kt at 90%)
  - Catamaran draft is too high (without cushion-assist).
  - Monohull variants likely to be considered “too big for Port Austere”.

HSAC Conclusions

MCMB

- Feasible with some design development required
  - Propulsion plant within current technologies
  - Auxiliary systems (except for bow ramp) non-developmental
  - Aluminum construction already heavily used in commercial sector
  - Bow ramp will be developmental but not outside current technologies
  - Retractable cushion skirts will require design development investment

MCSB

- Feasible and readily within current technology
  - Propulsion plant within current technologies
  - Auxiliary systems non-developmental
  - Aluminum construction already heavily used in commercial sector

HSAC Conclusions

FWDB

- Feasible with design development required
  - Propulsion plant within current technologies
  - Auxiliary systems (except for bow ramp) non-developmental
  - Shallow draft and high speed benefit from composite construction. Not a proven technology for US Navy Craft.
  - Complex structural design required to reduce wave slamming while keeping overall depth small enough to interface with well deck.
  - Seakeeping expected to be acceptable, but requires further analysis to model interaction with well deck.
  - Bow ramp will be developmental but not outside current technologies
  - Retractable cushion skirts will require design development investment
  - Folding navigation and communication antenna will be developmental, but there are already applications of this capability in the US Navy.

HSS Family Recommendations

- Begin seakeeping studies to establish structural loads and added resistance in a seaway and motion limits to set sustained speed definition.
- Longitudinal strength and scantling calculations should be performed to confirm there is enough ship at baseline forward to give required strength with producible thickness of steel.
- Begin looking at fatigue considerations – since these ships will not be in constant service may be able to design to relaxed standards.
- Should bring propeller manufacturers into program to determine ability to design and build controllable pitch propellers at this power level.
- Initiate tradeoffs to determine optimum proportions and form coefficients for speed-power considerations.

HSC Family Recommendations

- Refine the definition of "Port Austere"
  - Draft
  - Length and "handiness"constraints
- Consider appropriate survivability requirements for HSC Family
  - Self-defense
  - Susceptibility (especially MIW)
  - Vulnerability and recovery (Are 15% length of hit and CPS worth it?)
- Initiate propulsion system development for FNB
  - LM6000 turbines and compatibly rated waterjets
- Initiate hull form and structural trades for FNB
  - Wave-piercing bow variant
  - "Exotic" content in hull structural materials
- Begin development of a bow ramp system design for HCMB
  - Would also be applicable to a beachable (new) variant of FNB
- Begin machinery trades for HCMB
  - Integrated electric (diesel or turbine)

HSAC Recommendations

MCMB

- Investigate retractable skirt cushions
- Mature lightship weight estimate
- Conduct preliminary seakeeping assessment
- Investigate and develop at-sea cargo transfer operations
- Develop conceptual design for folding bow ramp

MCSB

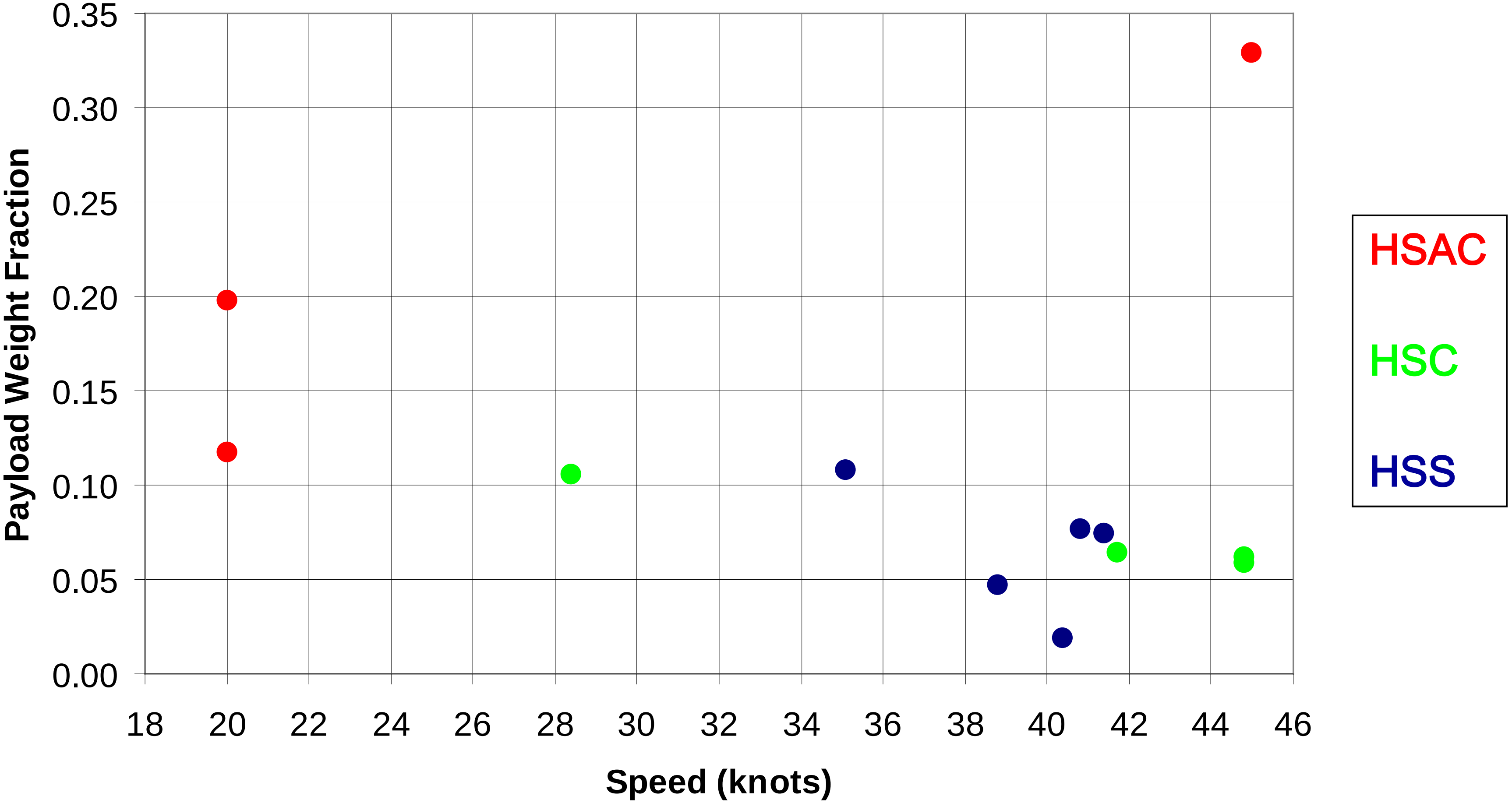
- Develop conceptual design for folding bow ramp
- Develop conceptual general arrangements and machinery arrangements
- Investigate required C4 items
- Validate manning estimate

HSAC: Recommendations

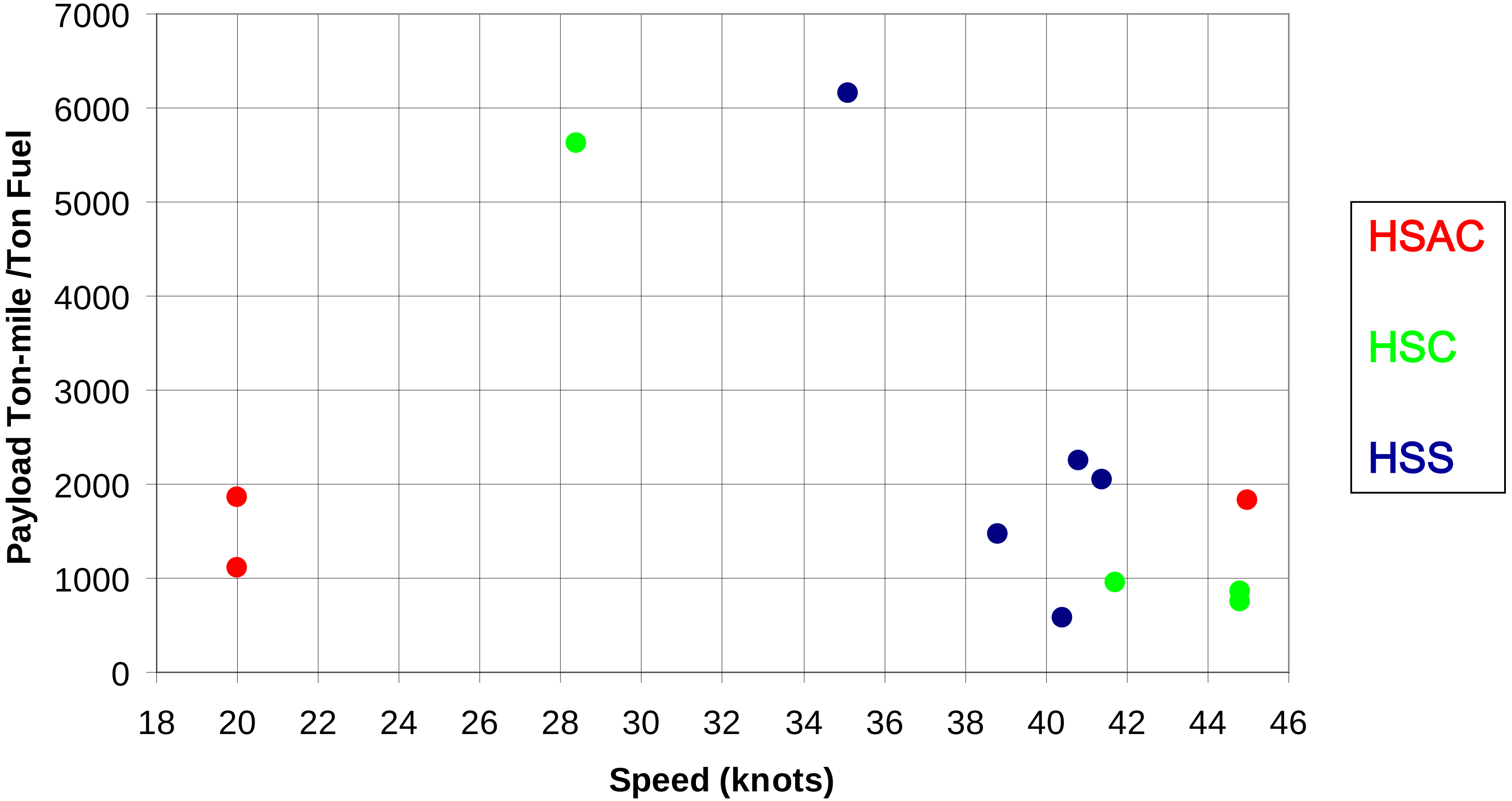
FWDB

- Refine structural design. Develop notional details and conduct materials trade-off study.
- Conduct preliminary seakeeping assessment
- Investigate well-deck interface in high sea states
- Mature lightship weight estimate

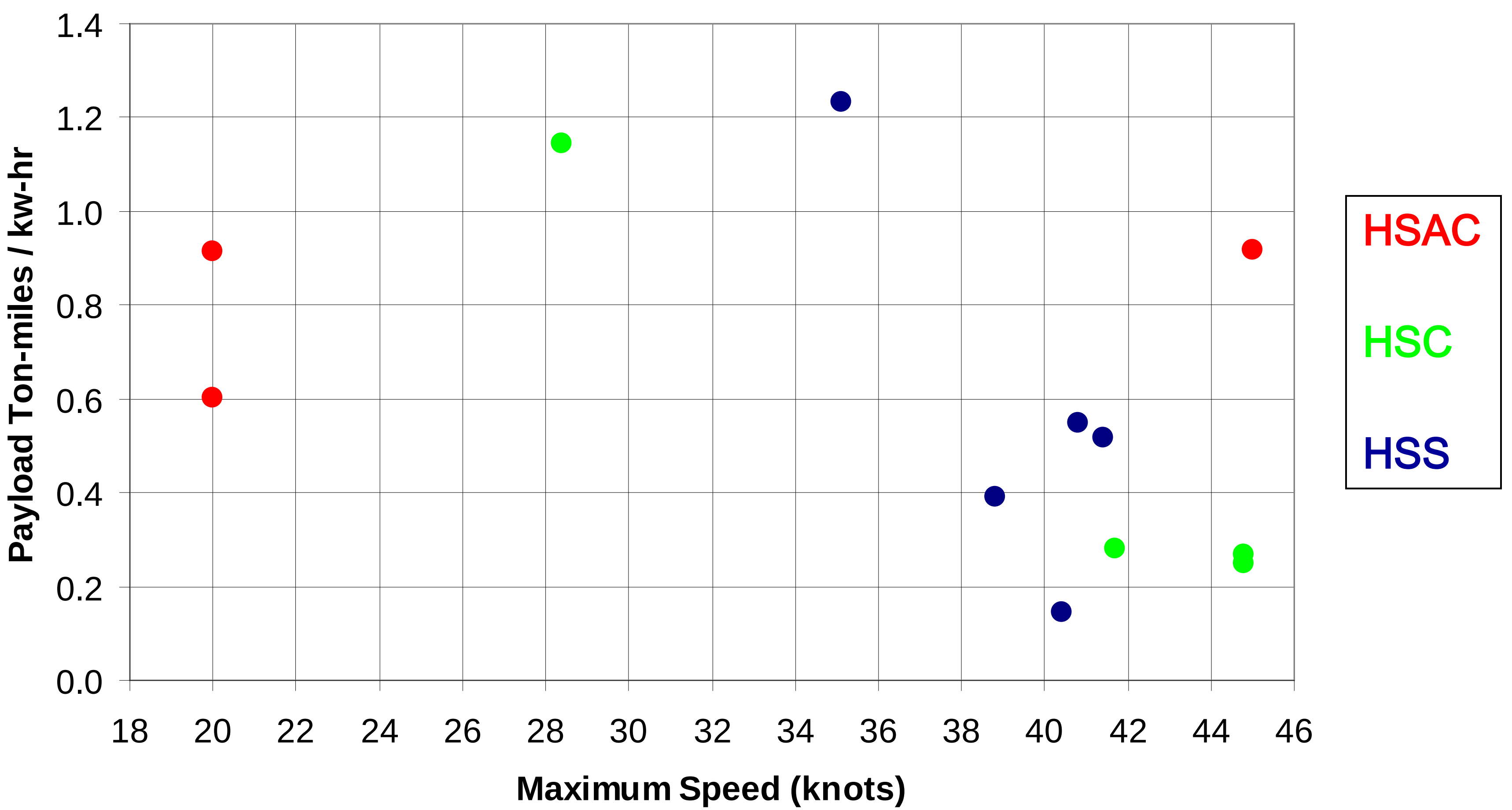
Comparative Payload Fractions



Comparative Transport (Fuel) Efficiencies



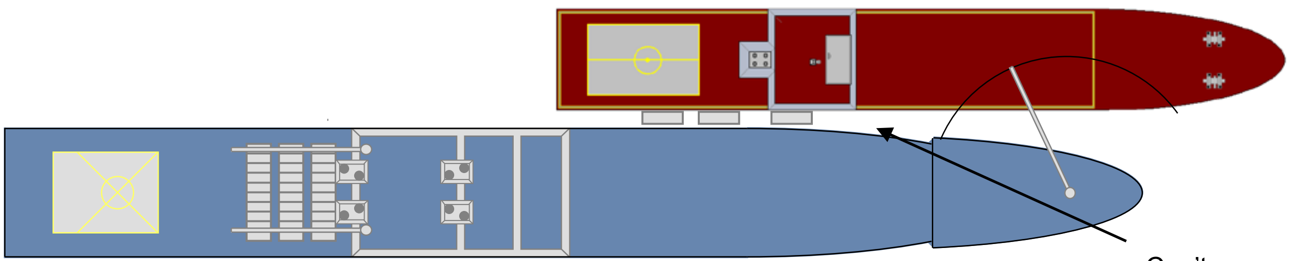
Comparative Transport Specific Power



Skin to Skin, Bow Crane Interface

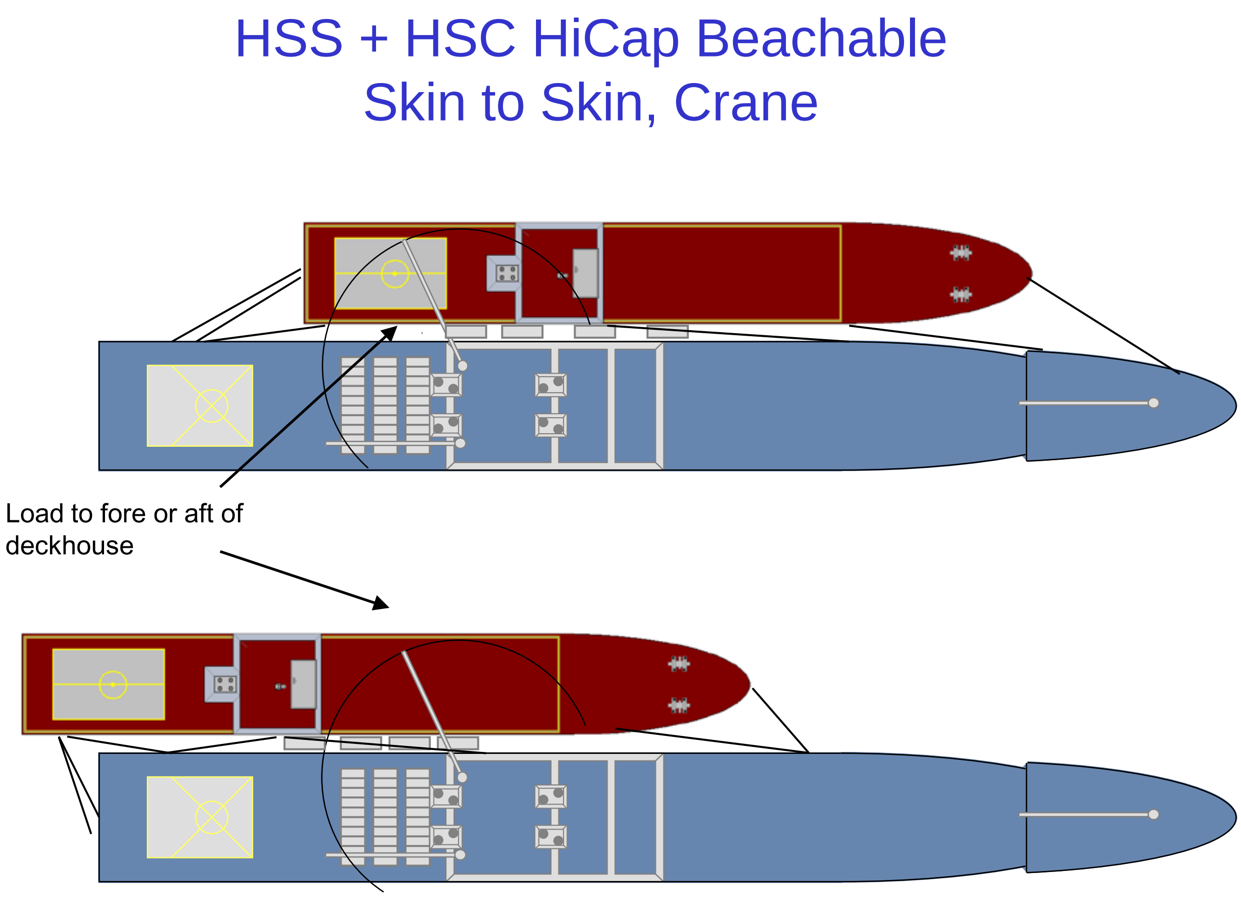
HSS + HSC HiCap Beachable
Skin to Skin, Bow Crane

Not Practical or Safe



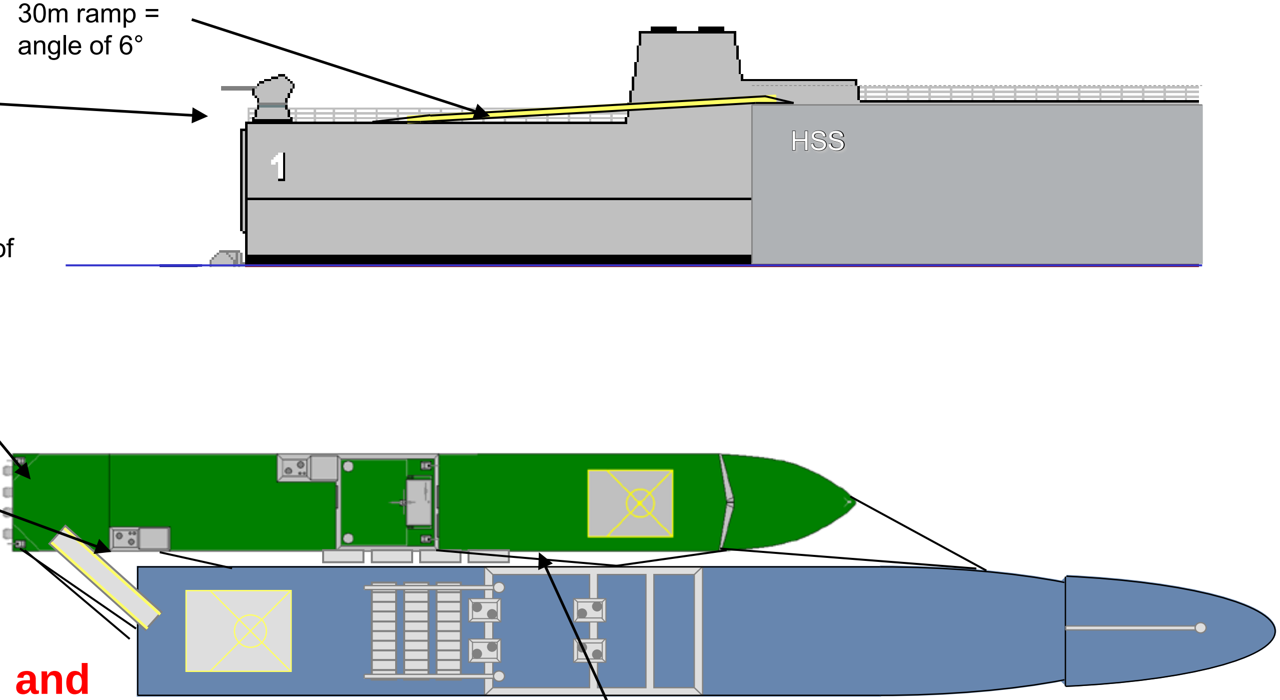
Can't moor while using bow crane

Skin to Skin, Crane Interface



Skin to Skin, Ramp From Stern Interface

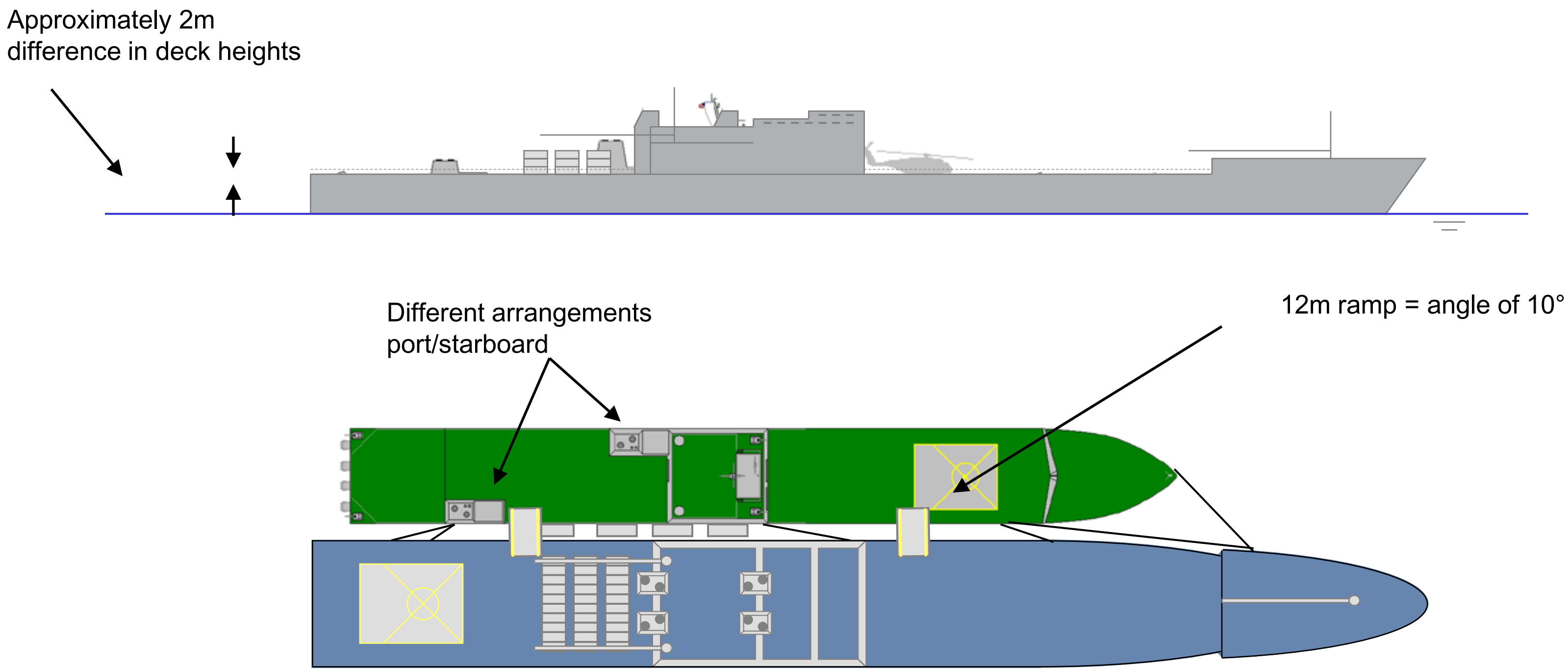
HSS + HSC NonBeach Slender Monohull
Skin to Skin, Ramp From Stern



Ramp Design and Deployment TBD

Skin to Skin, Ramp From Side Interface

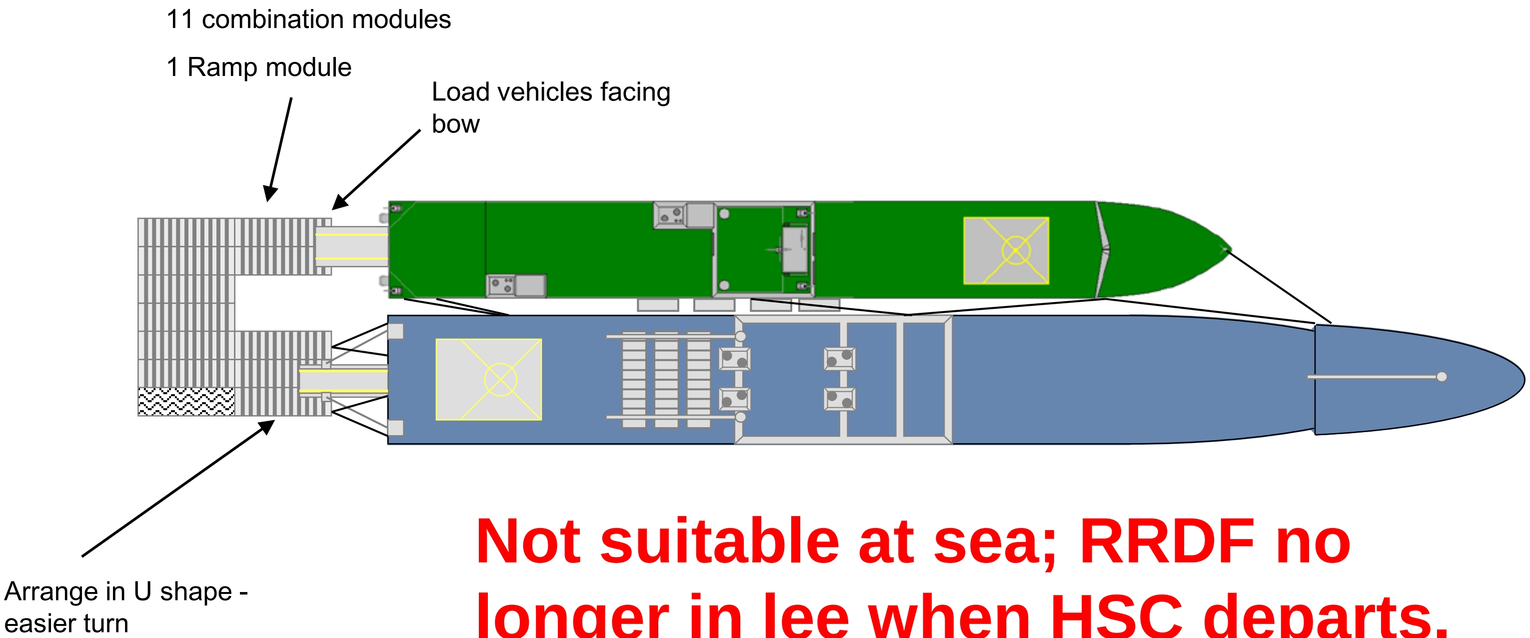
HSS + HSC NonBeach Slender Monohull
Skin to Skin, Ramp From Side



Ramp Design and Deployment TBD

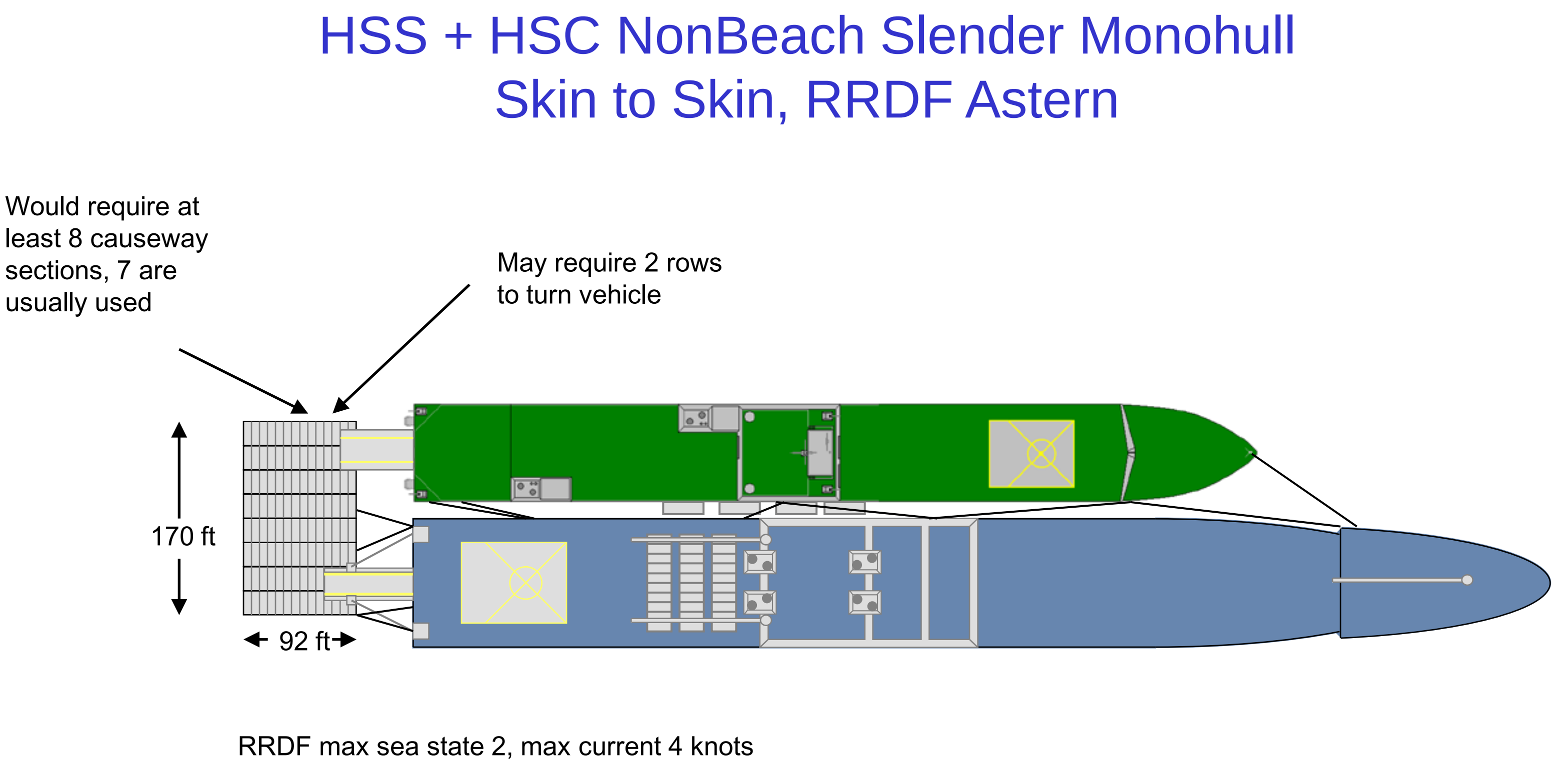
Skin to Skin, INLS RRDF Astern Interface

HSS + HSC NonBeach Slender Monohull
Skin to Skin, INLS RRDF Astern



Not suitable at sea; RRDF no longer in lee when HSC departs.

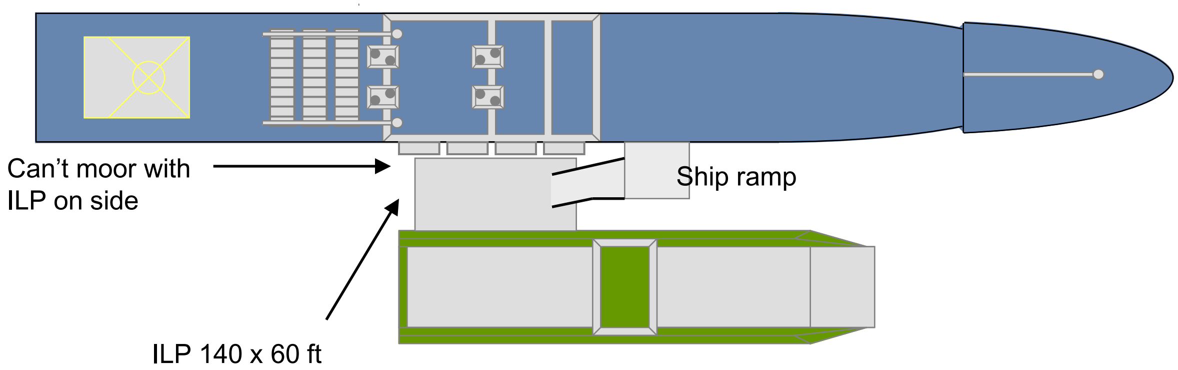
Skin to Skin, RRDF Astern Interface



Not suitable at sea; RRDF no longer in lee when HSC departs.

Integrated Landing Platform Interface

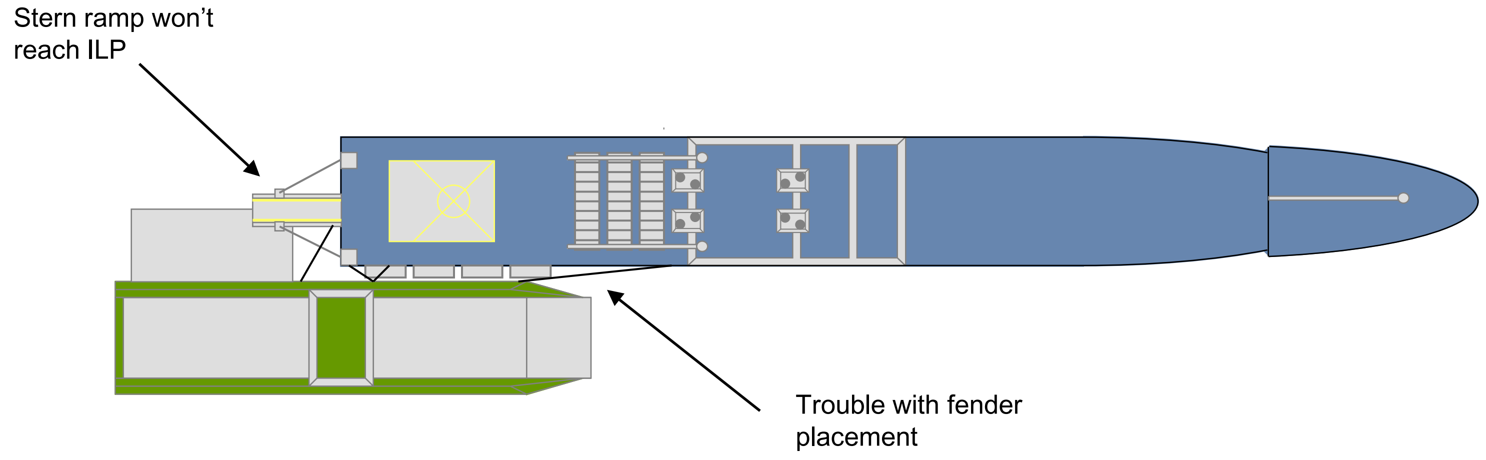
HSS + HSAC SES with Integrated Landing Platform



Not suitable at sea; HSAC mooring to ILP is not practical in this configuration.

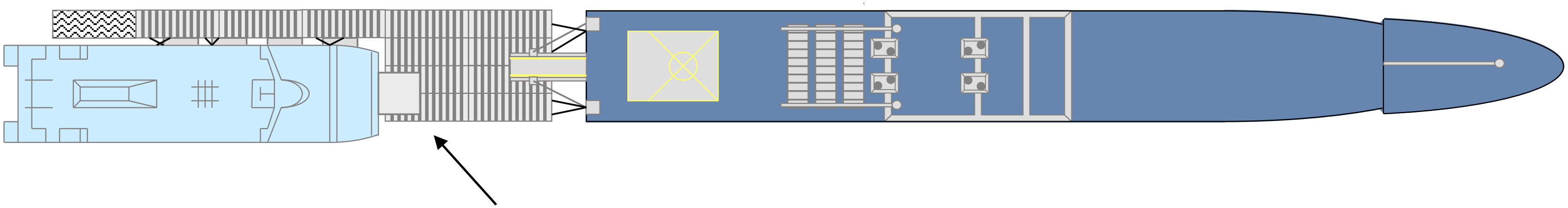
Stern Ramp and ILP Interface

HSS with Stern Ramp + HSAC SES with ILP



Interface

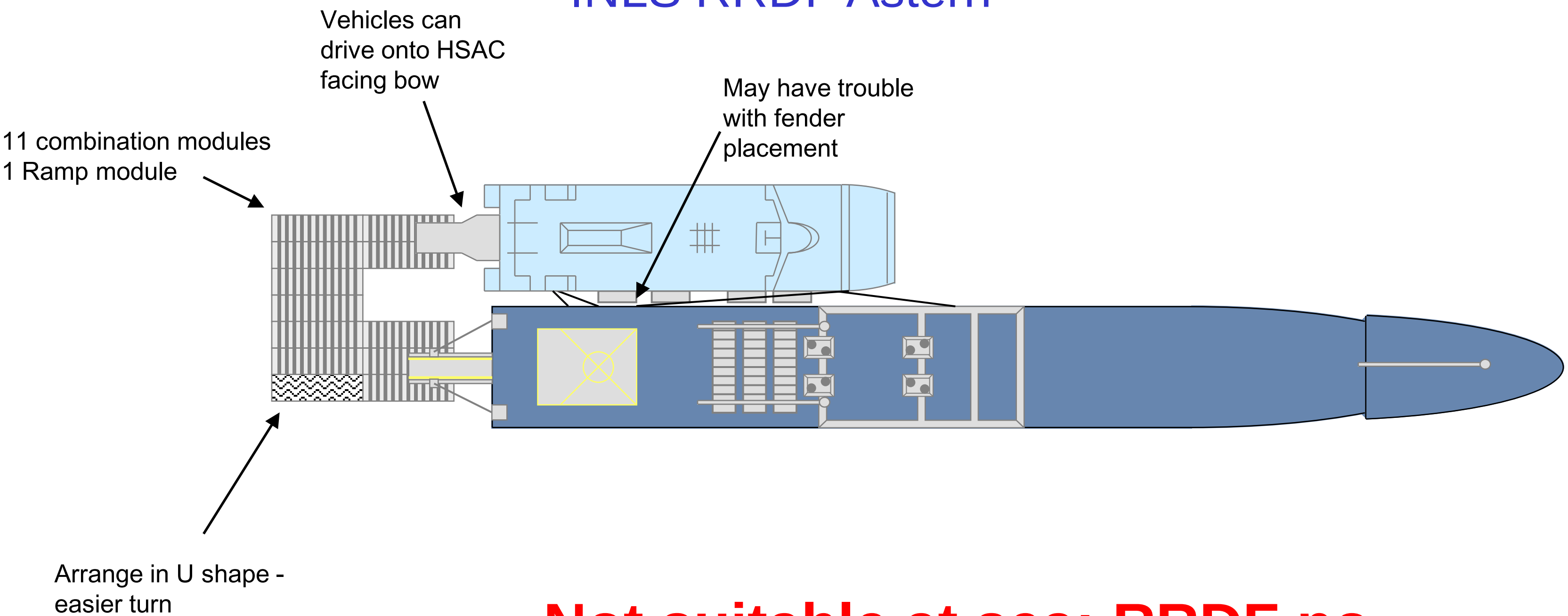
HSS with INLS RRDF Astern + HSAC Catamaran with Bow Ramp



Vehicles have to turn and reverse onto HSAC to face bow

Interface

HSS + HSAC Catamaran Skin to Skin, INLS RRDF Astern

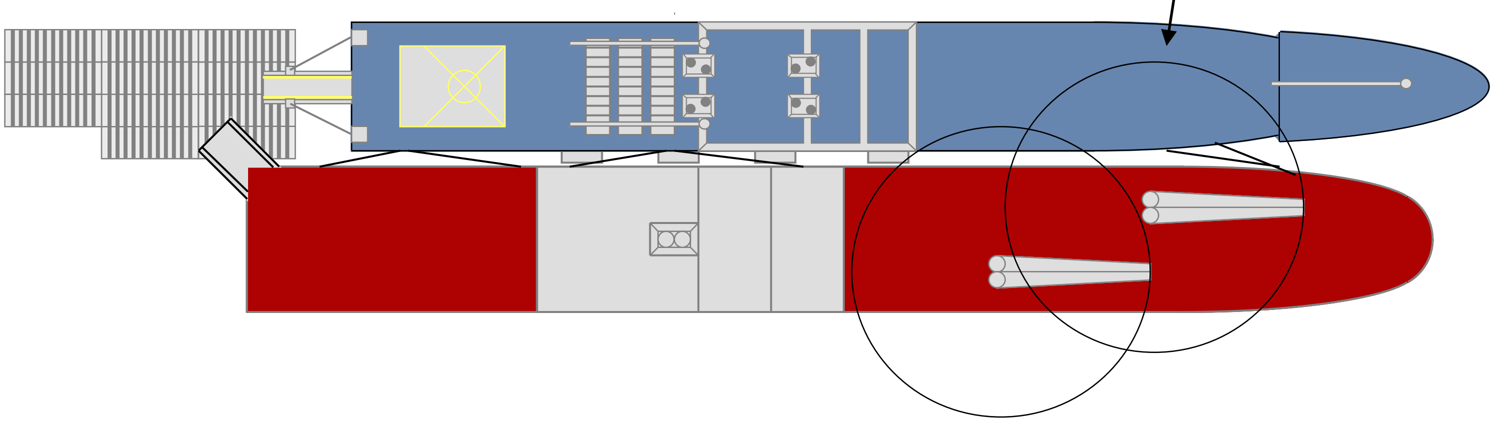


Not suitable at sea; RRDF no longer in lee when HSAC departs.

Interface

HSS + MPF(F) Skin to Skin, INLS RRDF Astern

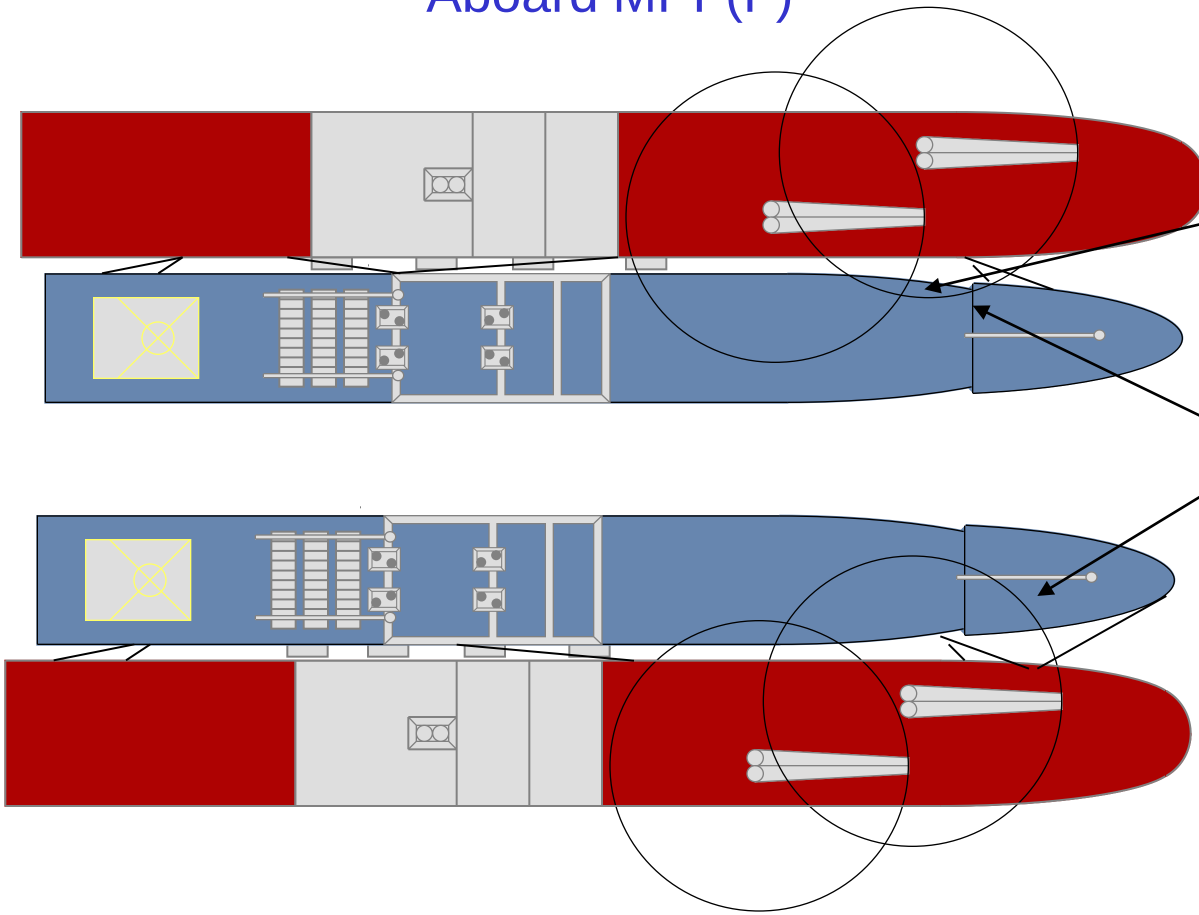
Can also use MPF(F) crane when interfacing with RRDF



RRDF should be associated with MPF(F) rather than HSS; when HSS departs, configuration is not stable.

Interface

HSS + MPF(F) Skin to Skin, Using Crane Aboard MPF(F)



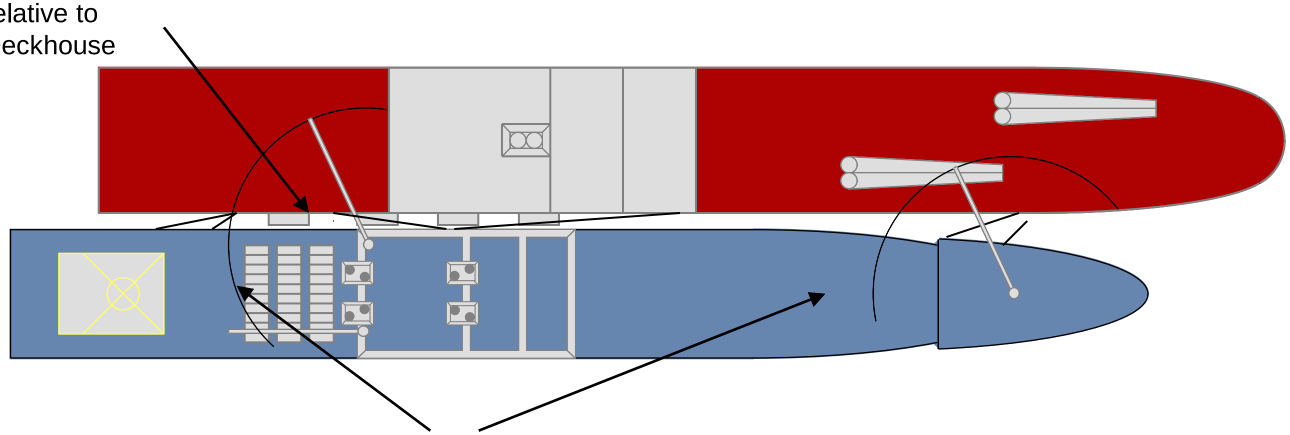
May be difficult to use both cranes

Differences depending on which side of MPF(F) HSS is moored on

Interface

HSS + MPF(F) Skin to Skin, Using Crane Aboard HSS

May be difficult to moor
because of HSS crane
location relative to
MPF(F) Deckhouse



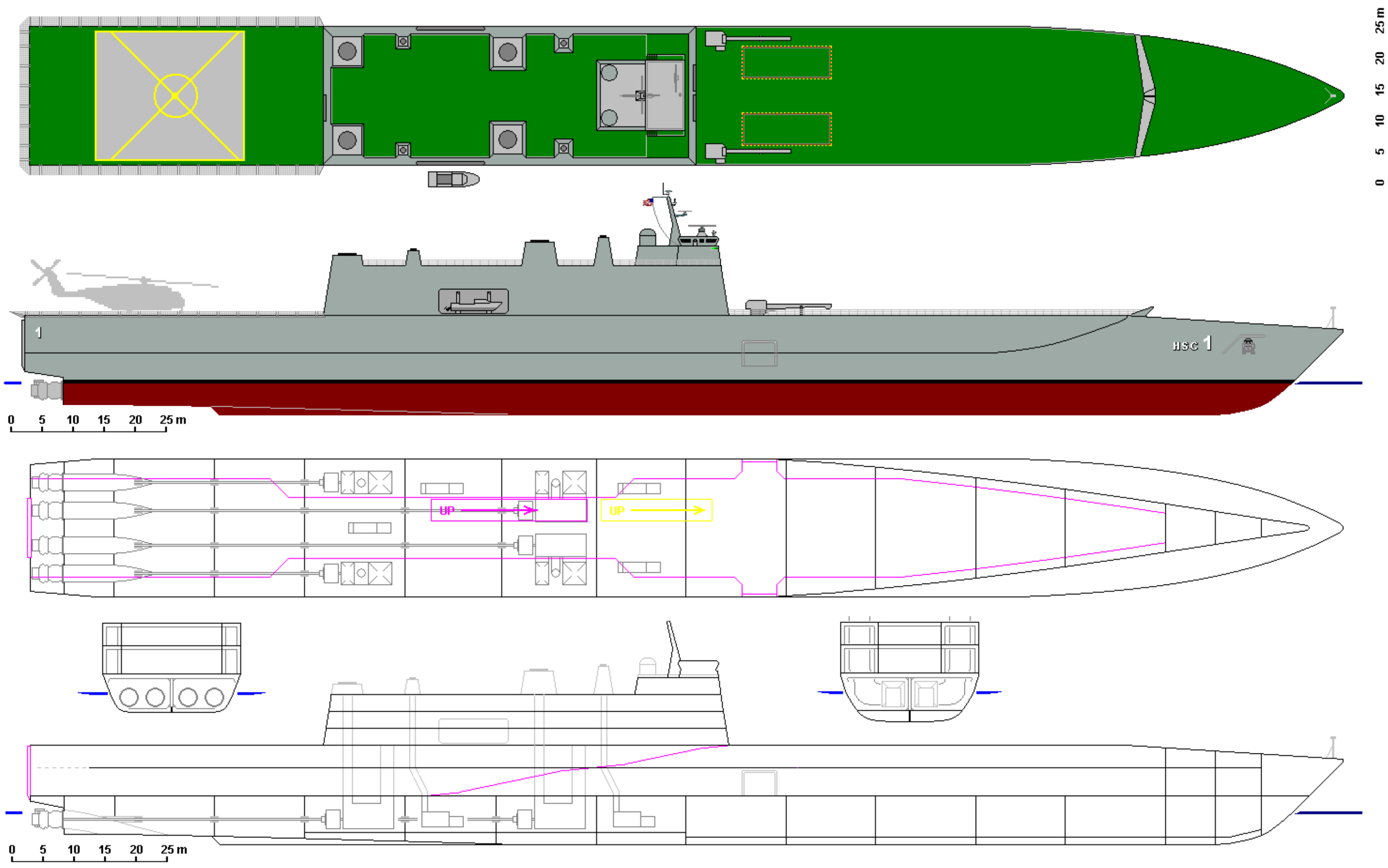
Possible to use both cranes

Interface Issues

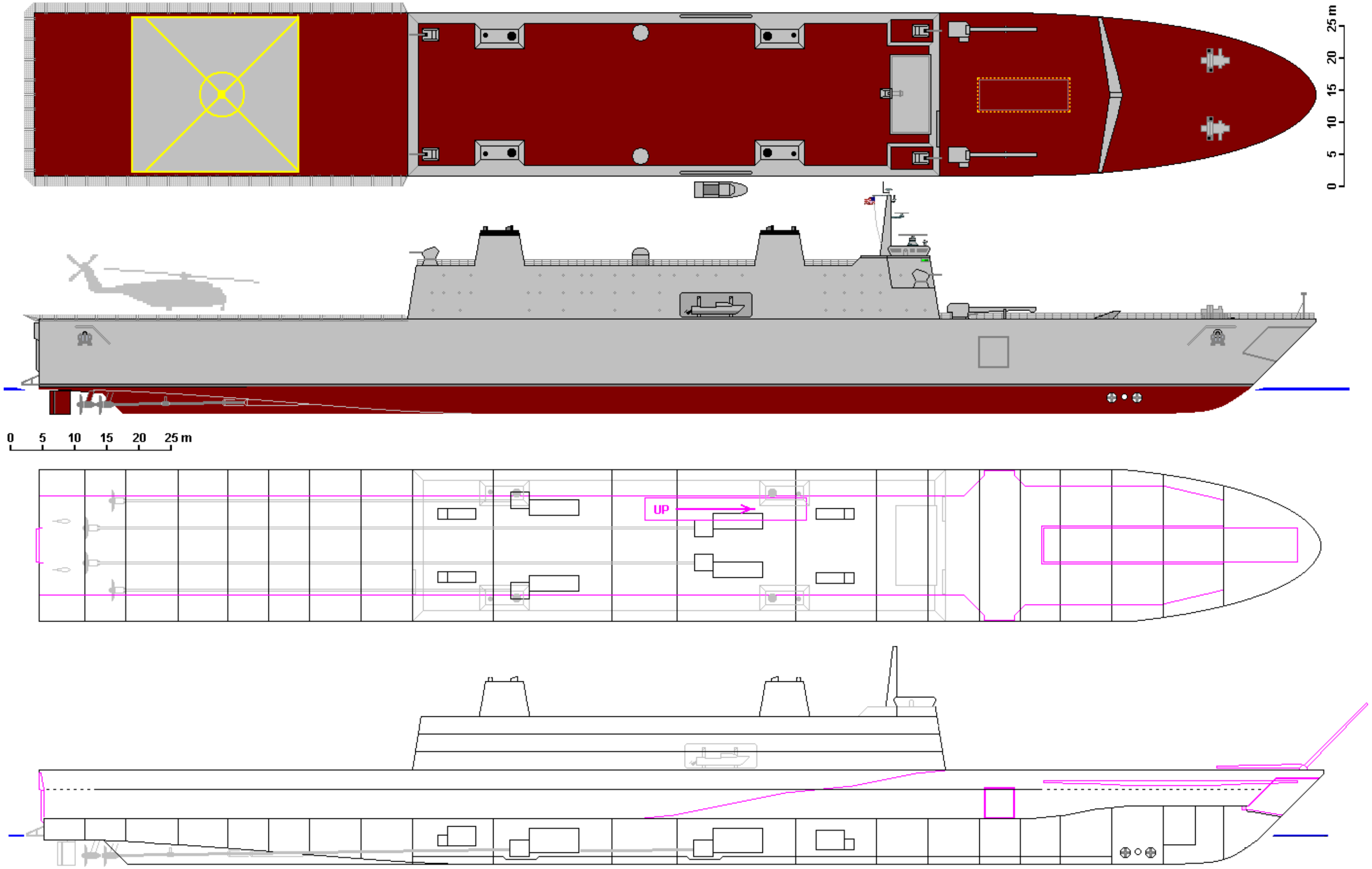
Miscellaneous Interface Data and Assumptions

- Ro/Ro Discharge Facility - Old
  - 21’3” by 92’
  - 7 causeway sections
  - Sea State 2, max current 4 knots
- Improved Navy Lighterage System RRDF
  - 24’ by 80’
  - 11 combination modules
  - 1 ramp module
  - Sea State 3
- Max angle 12 - 15 for Ro/Ro ramps
- ILP 140’ by 60’
- Fender size assumed for sketches - 28’ length 10’ diameter

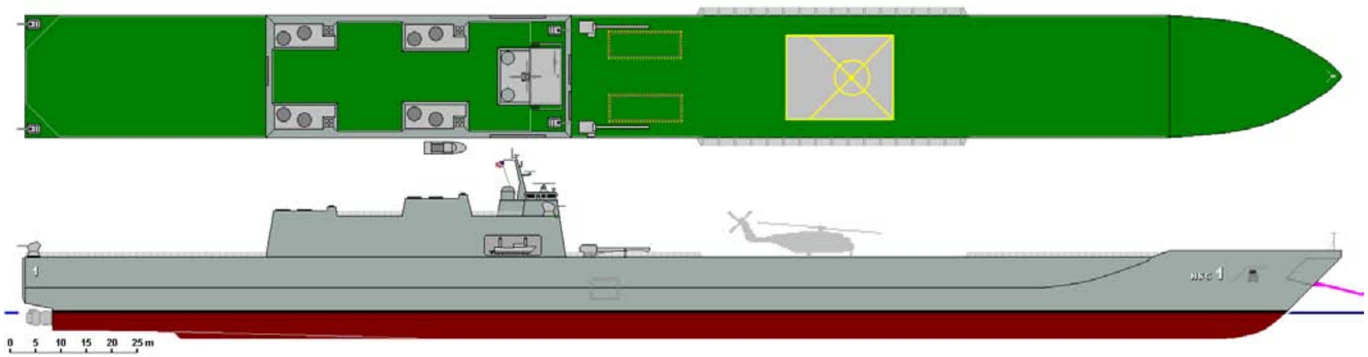
FNB

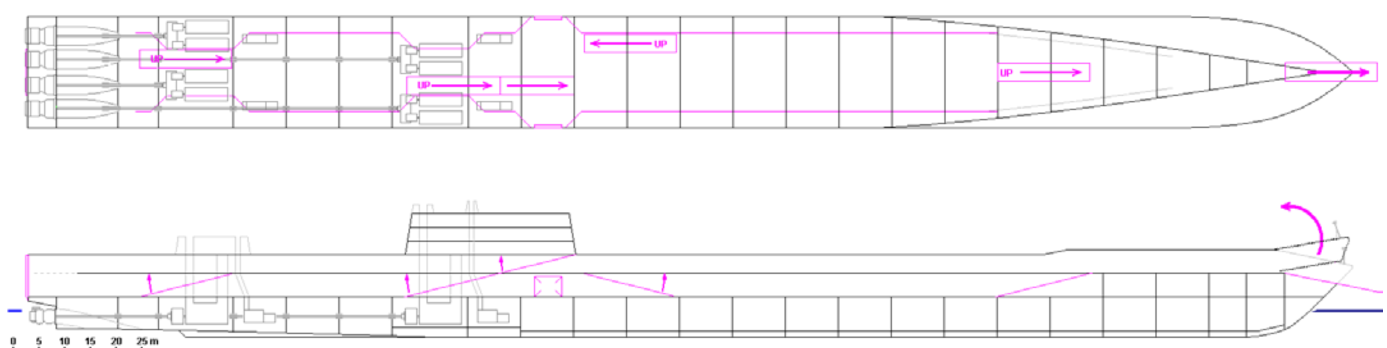


HCMB

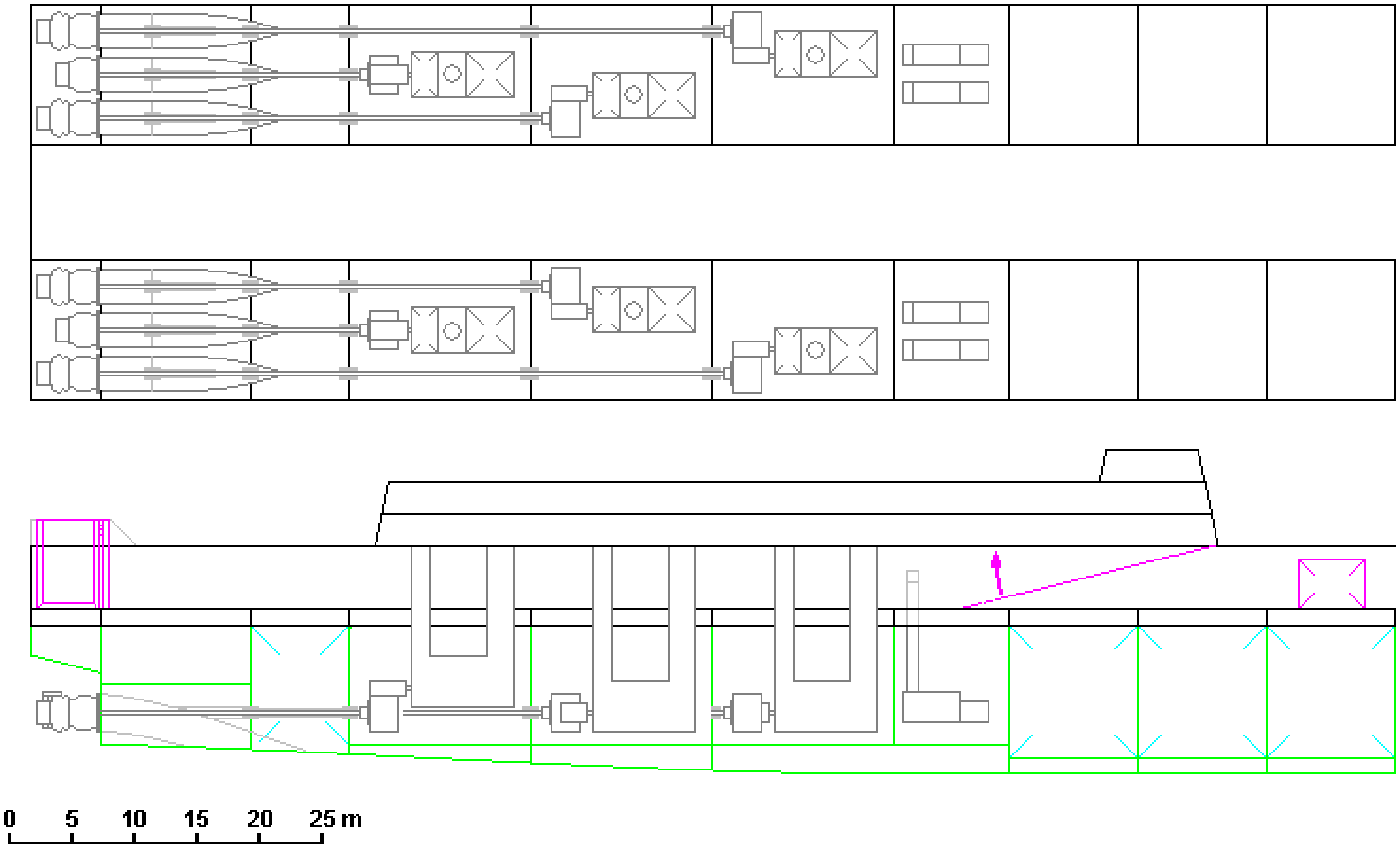


HCFB Layout Sketches



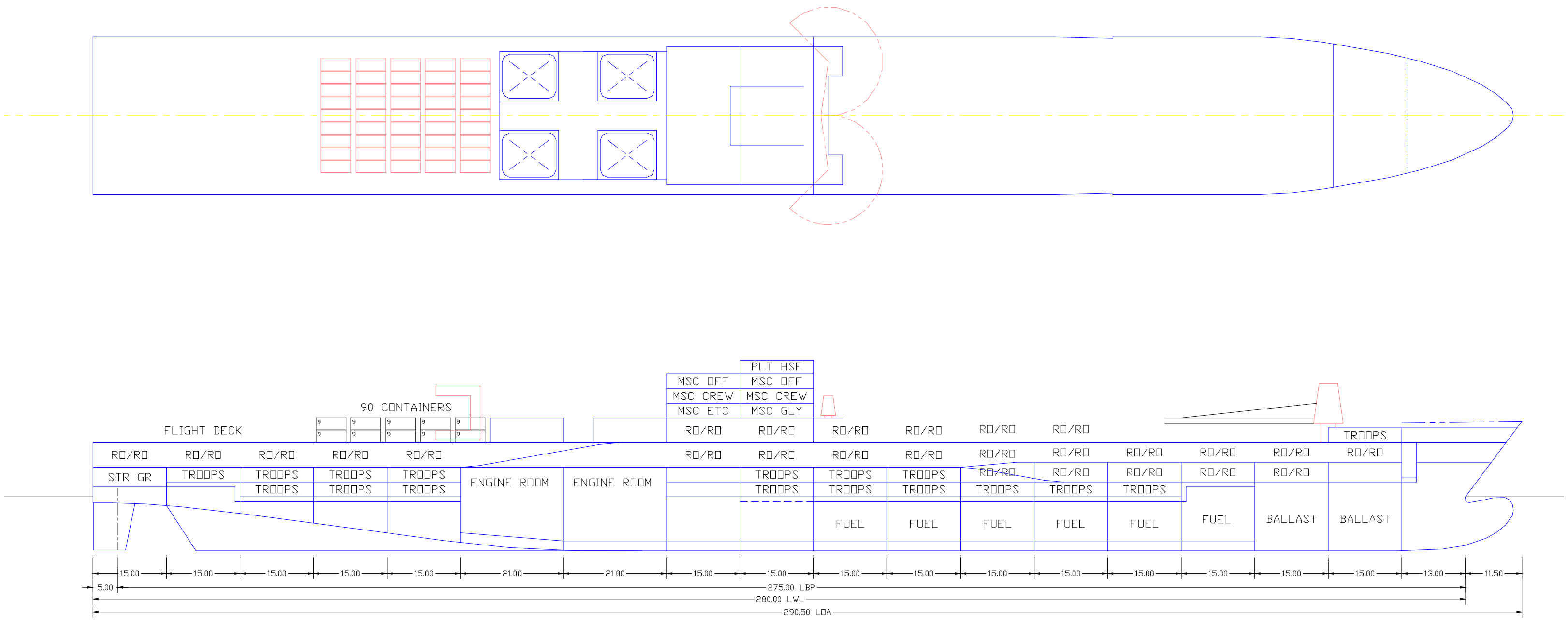


HCFB-Catamaran
Machinery Arrangement Concept



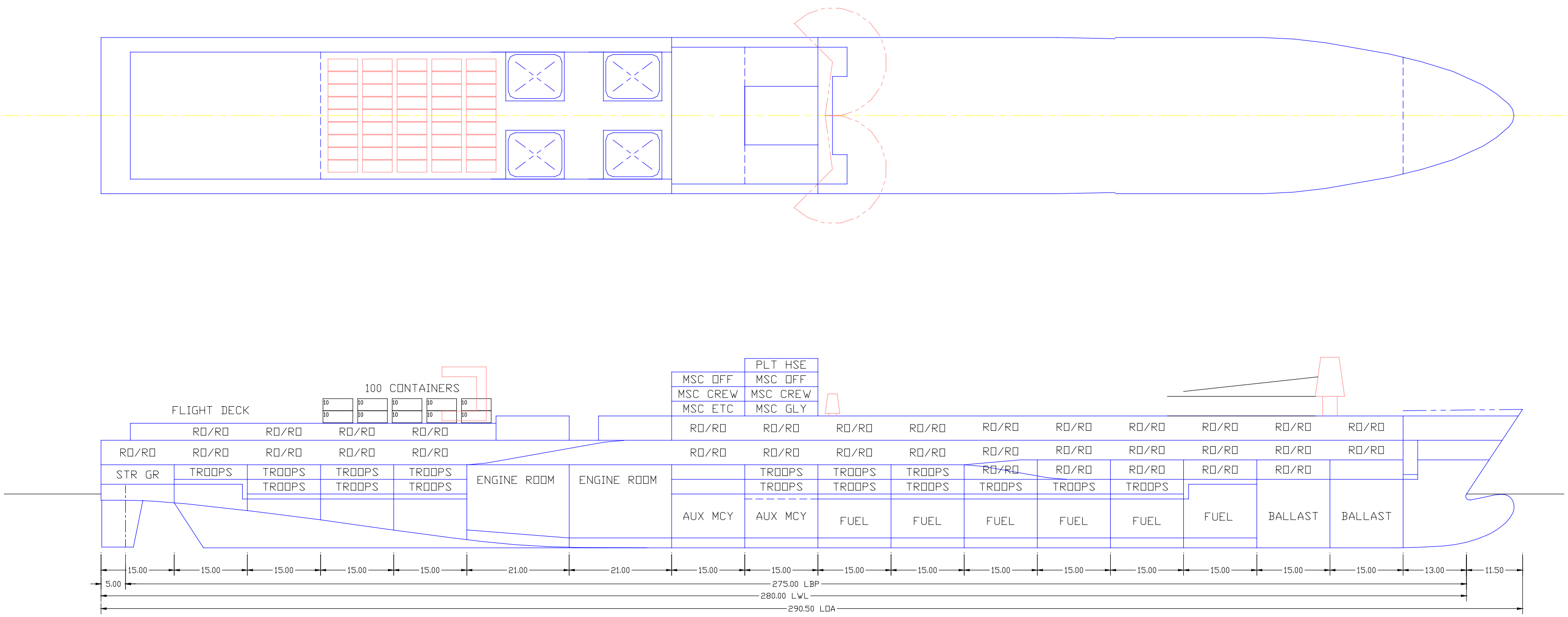
High Speed Sealift (HSS) Family

Fast Expeditionary Sealift Transport



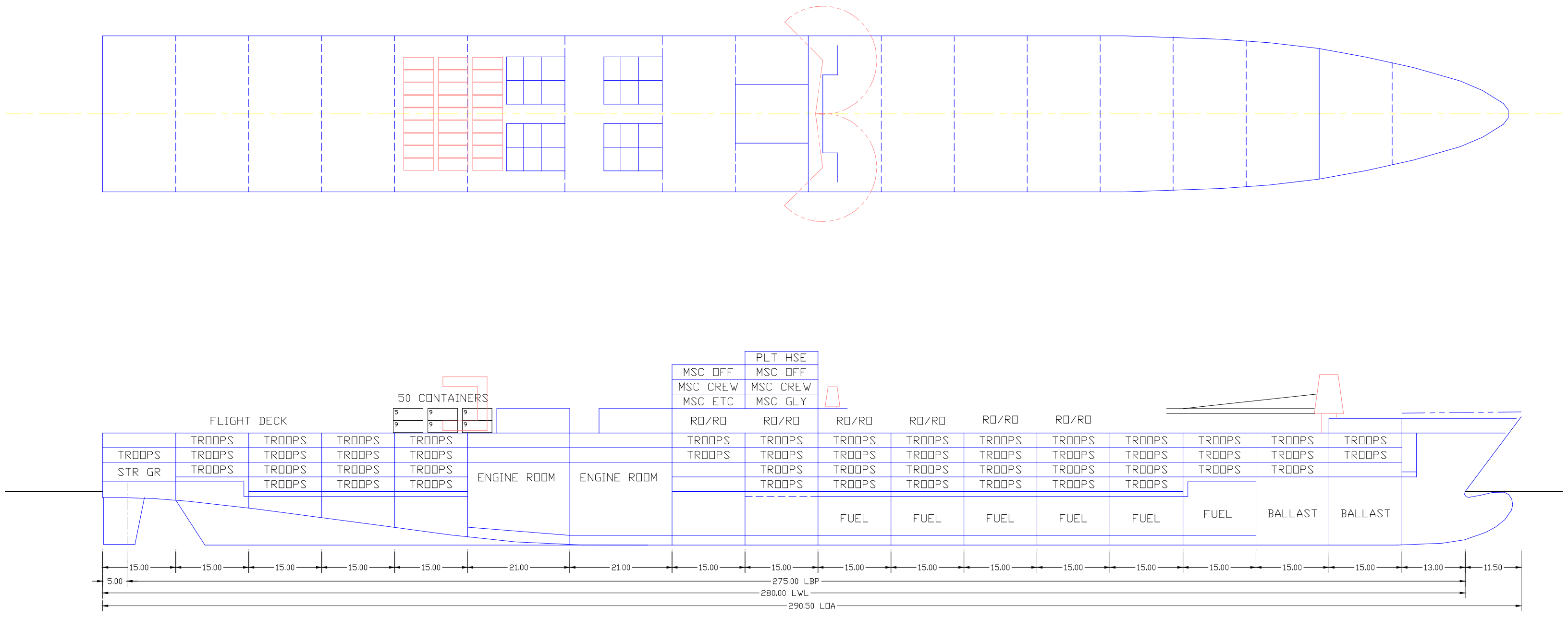
High Speed Sealift (HSS) Family

Fast Expeditionary Force Transport

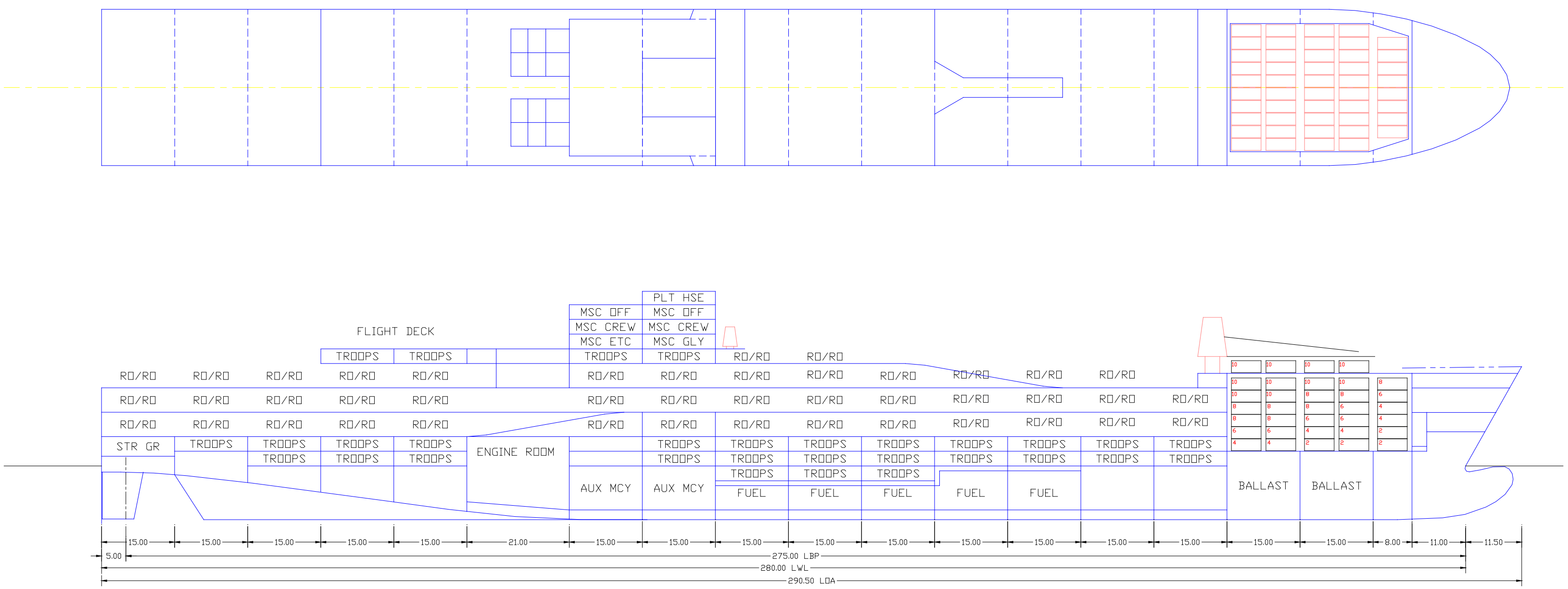


High Speed Sealift (HSS) Family

Fast Expeditionary Troop Transport



Fast Sealift Ship



High Speed Sealift (HSS) Family

Fast Expeditionary Aviation Transport