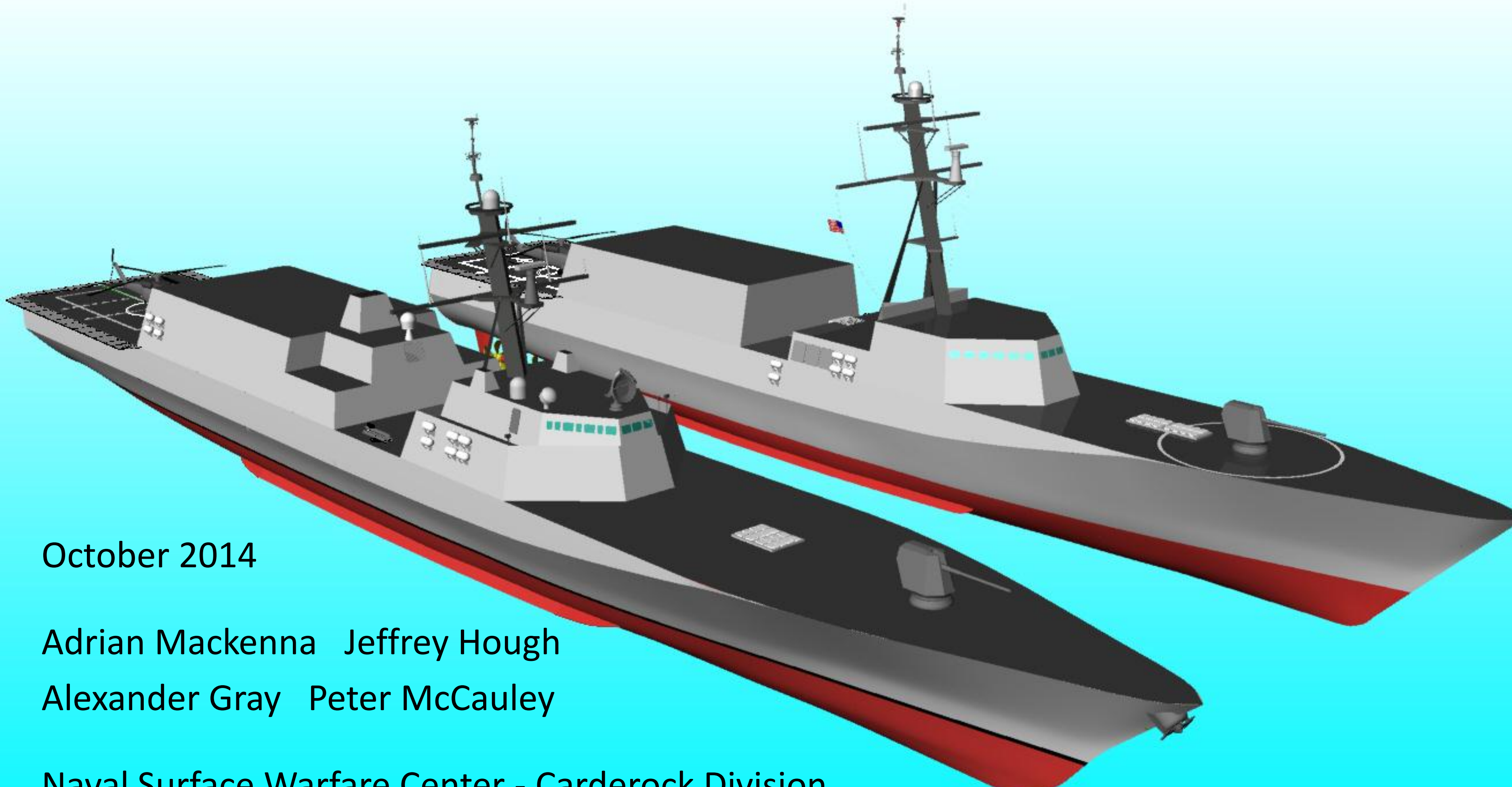
Engineered Resilient Systems (ERS) for Ship Design& Acquisition



October 2014

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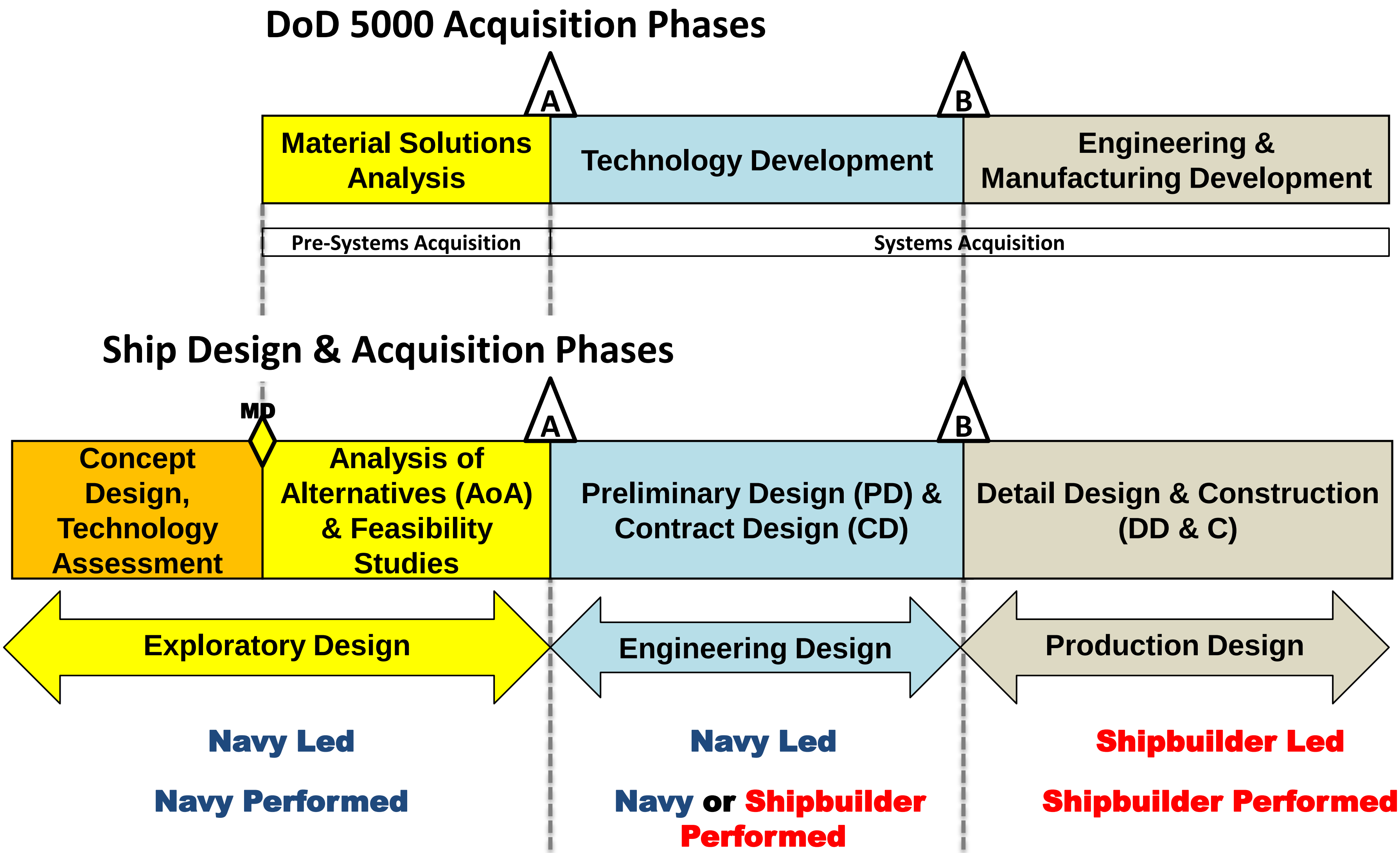
Naval Surface Warfare Center - Carderock Division

DoD 5000 & Ship Design Phases



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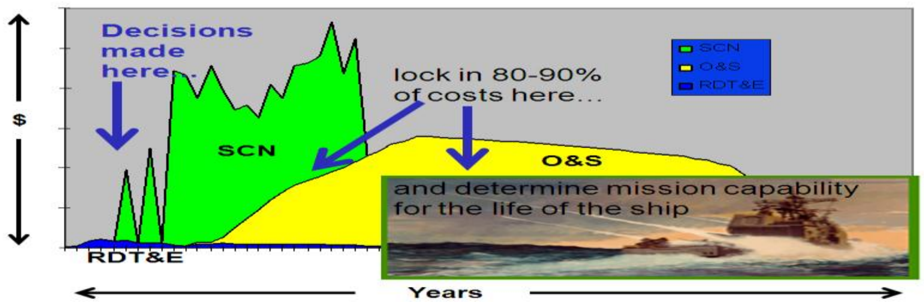
ERS BENEFITS: SMART BUYER

AFFORDABLE MISSION CAPABLE SHIPS & SUBMARINES

- Explore Requirements – Ensure can be Achieved Technically & Affordably *(Pre-Milestone A)*
- Evaluate Potential Cost-Performance Benefits of New Technologies before Investment & During Investment/Development *(Pre-Program & Pre-Milestone A)*
- Perform Government Led Designs *(Milestone A to B)*
- Evaluate Industry Led Designs *(Milestone A to C)*
- Explore Options for Mid-Life Upgrades &/or Technology Insertion *(Post Acquisition / In-Service)*

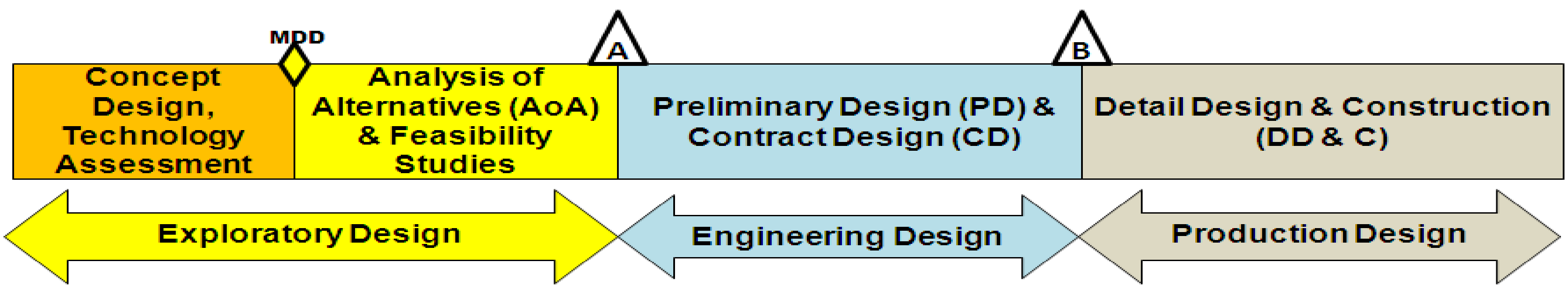
ERS Applied to Ship Design

Successful Acquisition Starts with Solid “Framing Assumptions” in Pre-Milestone A Efforts - Early Decisions Drive Significant And Expensive Results



During Pre-Milestone A Efforts Employ Resilient Engineering Process with

- **Physics Based Data-Driven Trade Space Exploration**
- **Robust Analysis of Requirements – Design Concepts – CONOPS – Mission Effectiveness – Technology – Cost**



High Leverage to Achieve Total Ownership Cost Savings

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Challenge:
Reduce Risk, Vet Requirements & Achieve Affordability

HISTORICALLY:

- Early Ship Design Decisions Determine Fundamental Architecture of Ship & Its Systems
- Early Design Decisions Made at a Time when Fidelity of Information is Low, and Requirements are Still in Development
- Only Later in Design Process does Fidelity of Ship Design Information Support Physics Based Analysis
- When Detailed Analysis Reveals Design Deficiencies, Must Relax Requirements , Use High Risk Solutions, Use Costly Solutions, or Mix of All Three To Retain an Acceptable Ship Design
- Naval Ship Designers have Used their Experience to Overcome these Limitations. - Note: We (Navy & Industry) are Losing these Experienced Ship Designers!

Proposed Solution: Resilient Design Process using Physics Based Modeling Data-driven Trade Space Exploration and Analysis

ERS Ship Design Demo Task

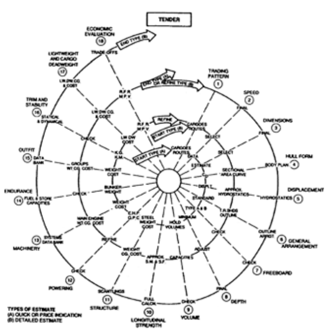
PURPOSE:

Demonstrate Ability to Design a Resilient Ship, with a Resilient Process, through Application of Physics Based Modeling & Trade Space Informed Set-Based Design

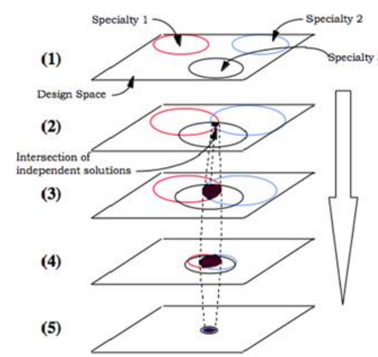
Set-based design is an design approach where:

- broad sets of design parameters are defined
- these sets are kept open (no decision) until the tradeoff information is fully defined
- as the sets narrow, the level of detail (design fidelity) increases
- the sets are gradually narrowed to the best solution*

Point Design Process (spiral design)



Set-Based Design Process



*SINGER, D. J., DOERRY, N. and BUCKLEY, M. E. (2009), What Is Set-Based Design?. Naval Engineers Journal, 121: 31–43. doi: 10.1111/j.1559-3584.2009.00226.x

ERS Ship Design Demo Task

Approach:

Scenario Simulation
- Early Stage Design Phase
- Service life Phase of a ship's life

Baseline Ship

Two independent ship design teams
- Point design process team
- Set-based design process team

Provided a Baseline Ship Design as a Starting Point
Each Team Independently Developed a Ship Design

At the Conclusion of Each Phase, Each Team came up with a Final Ship Design
Each Design was Evaluated for Measure of Effectiveness & Cost

Each Design Team was Subjected to Stressing Design Challenges:
- Requirements changes imposed during design tested resiliency of design method to a dynamic acquisition environment
- Mid-Life Upgrade Scenario tested the resiliency of the final ship designs

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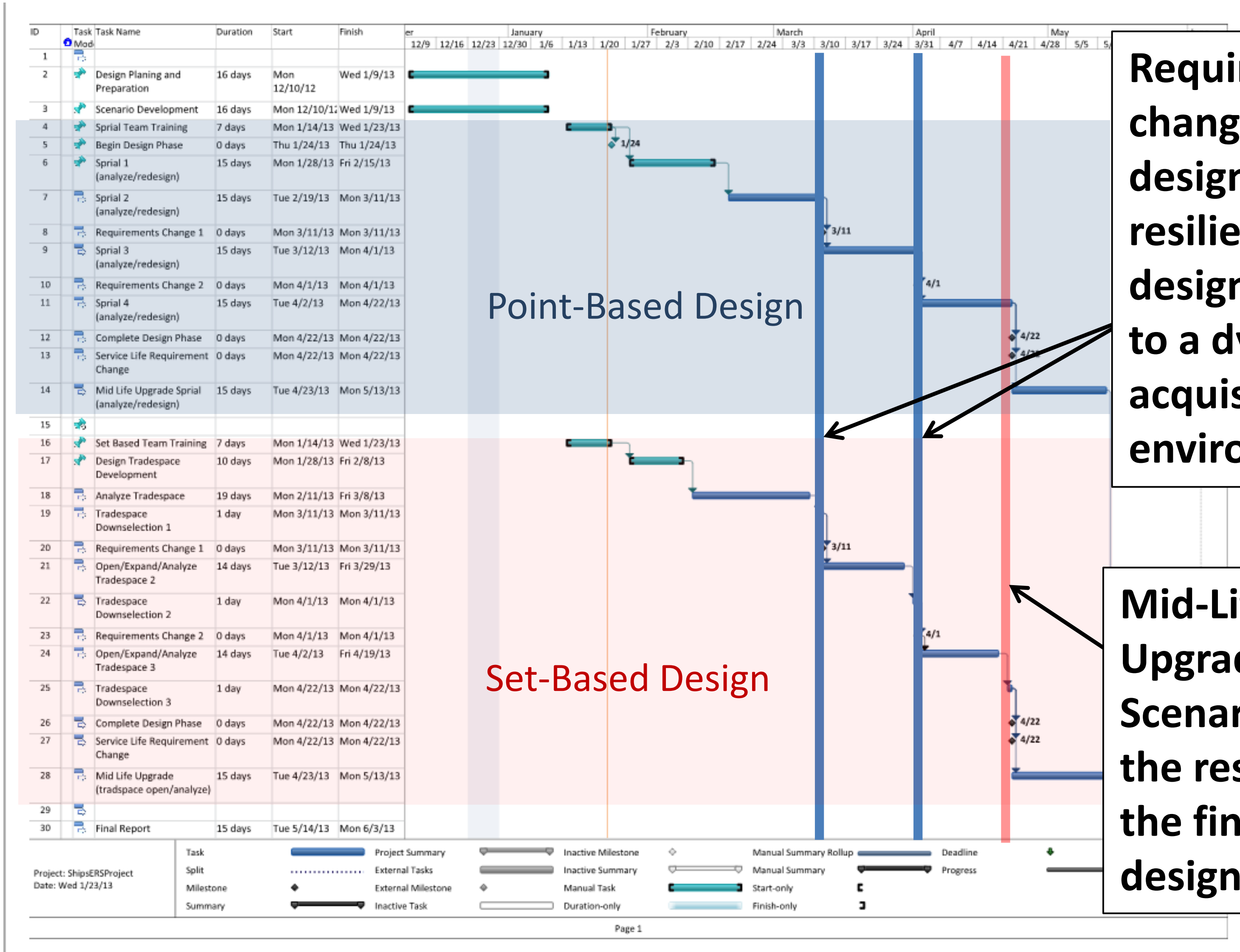
Overall Project Plan - Mimics an Actual Ship Design Effort:



ID	Task Mode	Task Name	Duration	Start	Finish
1					
2		Design Planing and Preparation	16 days	Mon 12/10/12	Wed 1/9/13
3		Scenario Development	16 days	Mon 12/10/12	Wed 1/9/13
4		Sprial Team Training	7 days	Mon 1/14/13	Wed 1/23/13
5		Begin Design Phase	0 days	Thu 1/24/13	Thu 1/24/13
6		Sprial 1 (analyze/redesign)	15 days	Mon 1/28/13	Fri 2/15/13
7		Sprial 2 (analyze/redesign)	15 days	Tue 2/19/13	Mon 3/11/13
8		Requirements Change 1	0 days	Mon 3/11/13	Mon 3/11/13
9		Sprial 3 (analyze/redesign)	15 days	Tue 3/12/13	Mon 4/1/13
10		Requirements Change 2	0 days	Mon 4/1/13	Mon 4/1/13
11		Sprial 4 (analyze/redesign)	15 days	Tue 4/2/13	Mon 4/22/13
12		Complete Design Phase	0 days	Mon 4/22/13	Mon 4/22/13
13		Service Life Requirement Change	0 days	Mon 4/22/13	Mon 4/22/13
14		Mid Life Upgrade Sprial (analyze/redesign)	15 days	Tue 4/23/13	Mon 5/13/13
15					
16		Set Based Team Training	7 days	Mon 1/14/13	Wed 1/23/13
17		Design Tradespace Development	10 days	Mon 1/28/13	Fri 2/8/13
18		Analyze Tradespace	19 days	Mon 2/11/13	Fri 3/8/13
19		Tradespace Downselection 1	1 day	Mon 3/11/13	Mon 3/11/13
20		Requirements Change 1	0 days	Mon 3/11/13	Mon 3/11/13
21		Open/Expand/Analyze Tradespace 2	14 days	Tue 3/12/13	Fri 3/29/13
22		Tradespace Downselection 2	1 day	Mon 4/1/13	Mon 4/1/13
23		Requirements Change 2	0 days	Mon 4/1/13	Mon 4/1/13
24		Open/Expand/Analyze Tradespace 3	14 days	Tue 4/2/13	Fri 4/19/13
25		Tradespace Downselection 3	1 day	Mon 4/22/13	Mon 4/22/13
26		Complete Design Phase	0 days	Mon 4/22/13	Mon 4/22/13
27		Service Life Requirement Change	0 days	Mon 4/22/13	Mon 4/22/13
28		Mid Life Upgrade (tradspace open/analyze)	15 days	Tue 4/23/13	Mon 5/13/13
29					
30		Final Report	15 days	Tue 5/14/13	Mon 6/3/13

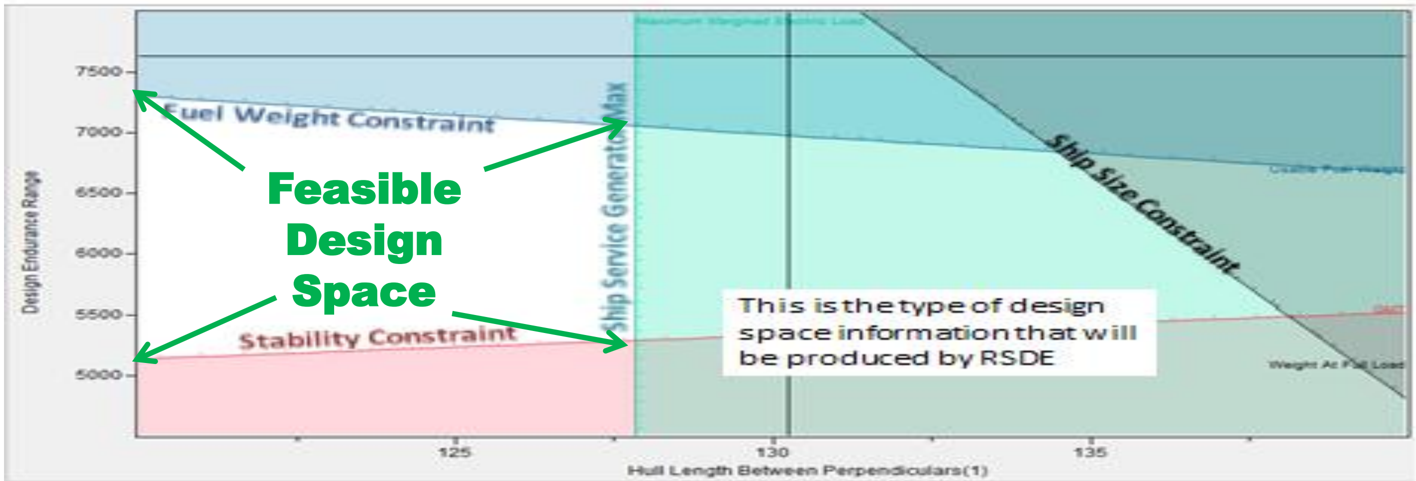
Requirements changes during design: test the resiliency of the design method to a dynamic acquisition environment

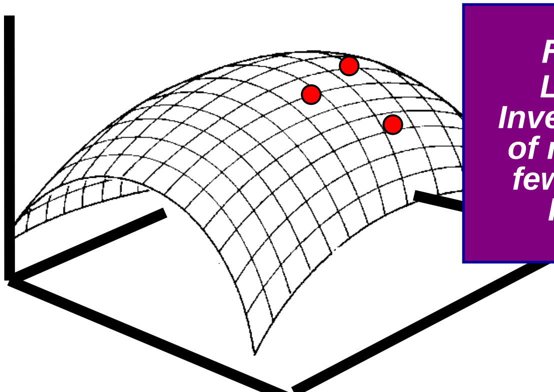
Mid-Life Upgrade Scenario: tests the resiliency of the final ship designs

ERS Ship Design Demo Task

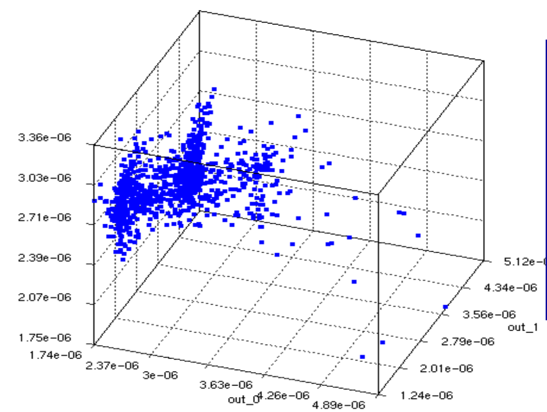
Process:

Set Based Design Space Exploration Versus Point Based





From…
Limited Investigation of relatively few Design Points



To…
Full Investigation of Concepts throughout the Design Space

POINT BASED DESIGN

SET BASED DESIGN

ERS Ship Design Demo Task

Tools:

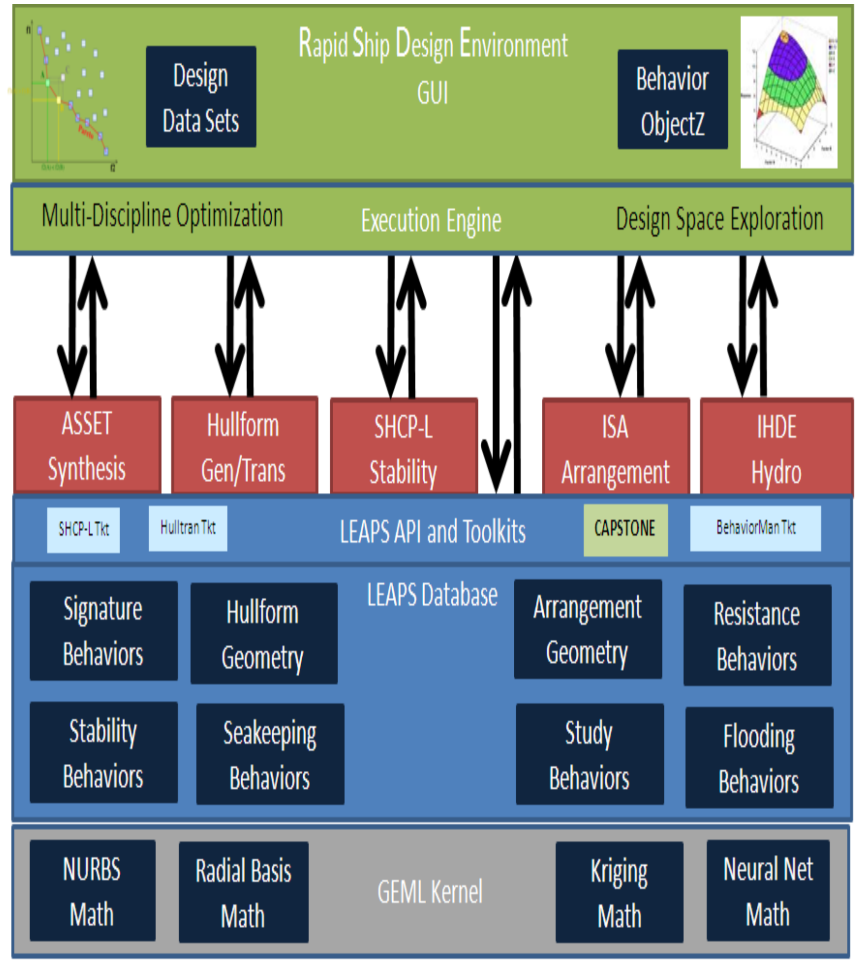
ASSET-LEAPS Early Stage Ship Design Tool Suite

- Used by Both Teams
- US Navy Developed
- Used in Navy Design/Acq Programs Today
- Includes Semi-Empirical & Physics-Based Analysis Tools
- Includes Performance-Based Cost Model
- "Breadboard" MS-Excel Spreadsheets for Measure of Effectiveness & Risk Assessment

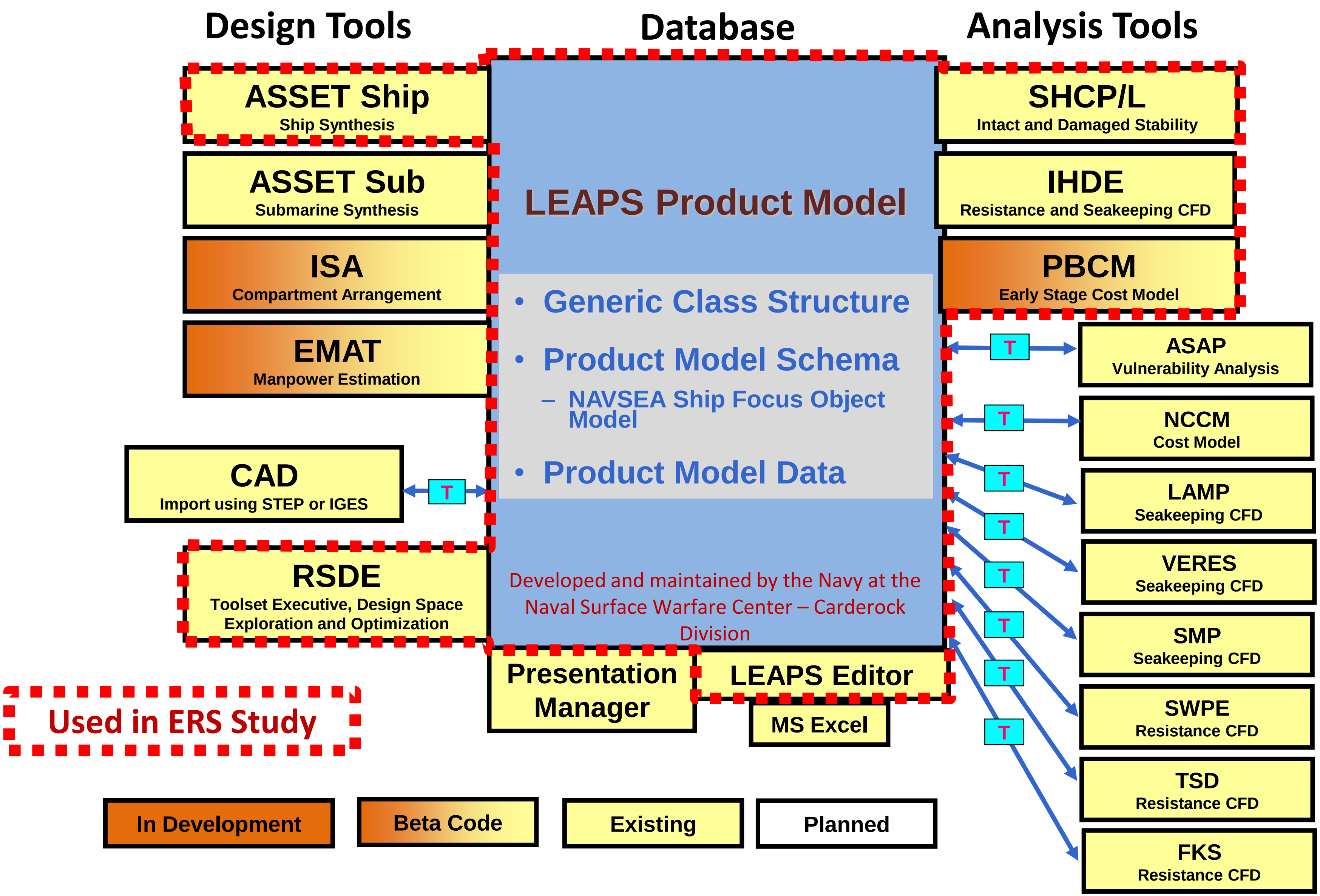
Set-Based Team Also Used Rapid Ship Design Environment (RSDE)

- Initial Tool with Limited Capabilities
- Under Further Development in HPCMP CREATE Program

RSDE Envisioned Tool Architecture



US Navy's ASSET/ LEAPS Toolset



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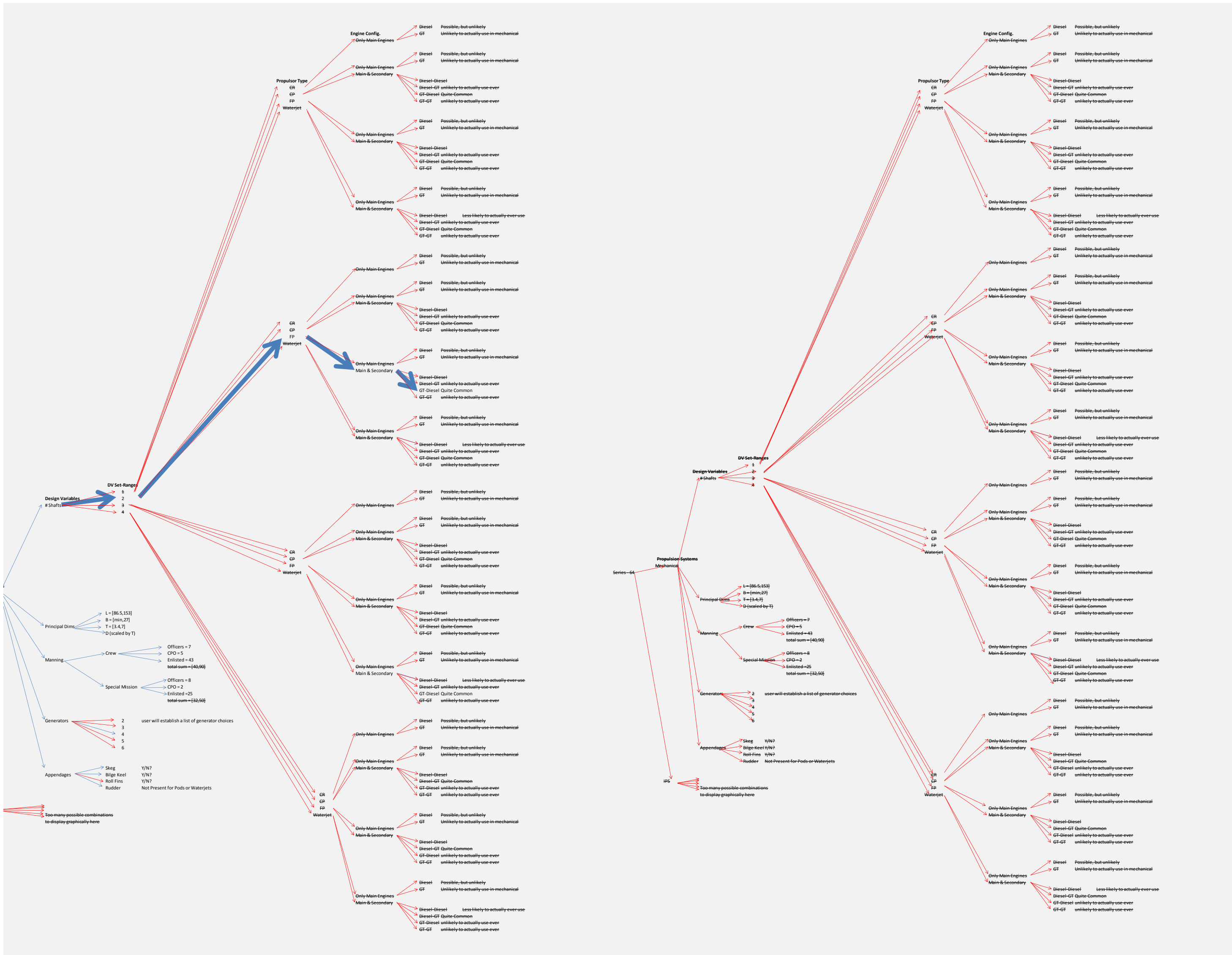
Map of the Design Space for the Set-Based Design team



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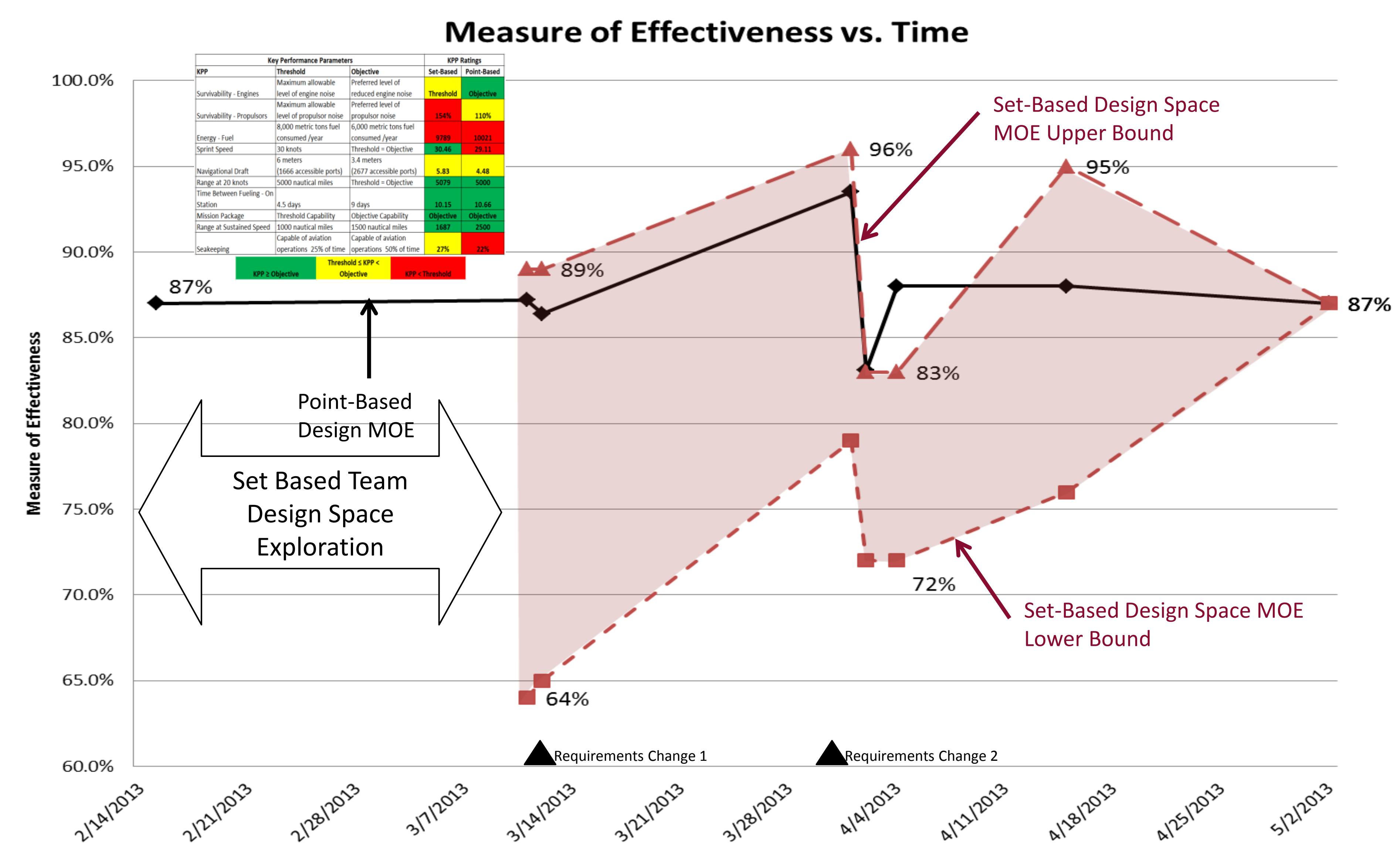
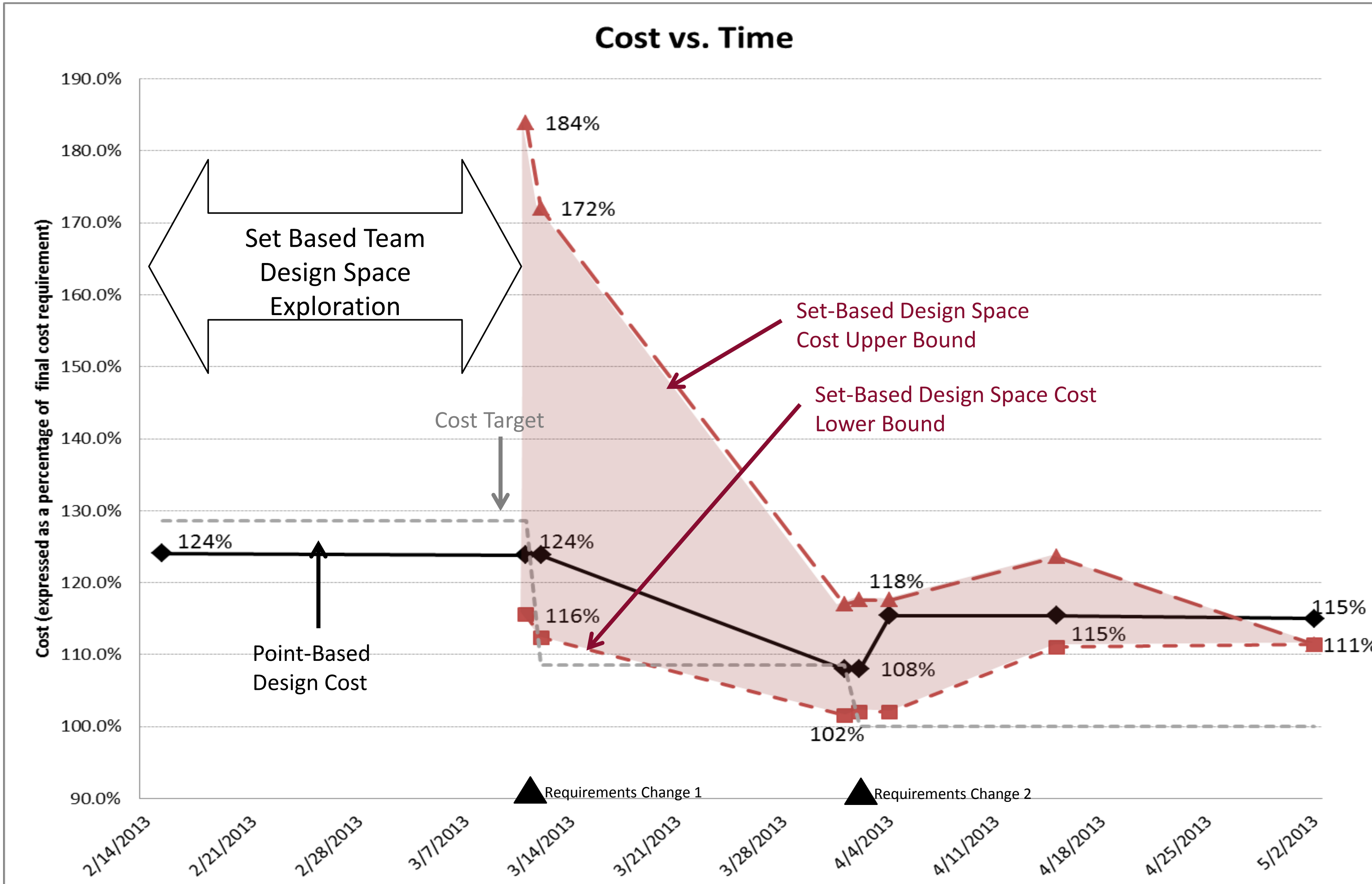
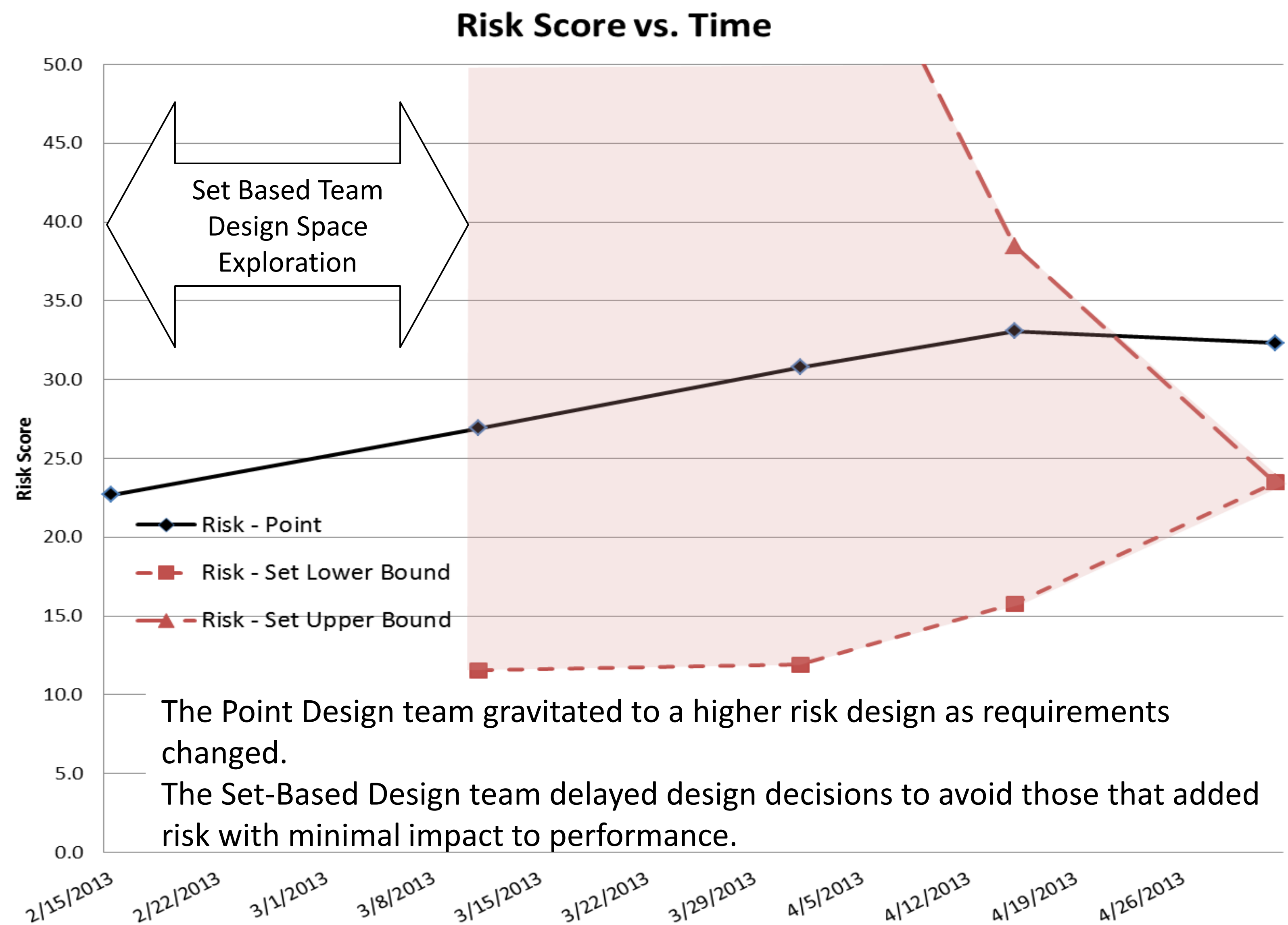


Key Performance Parameters			KPP Ratings	
KPP	Threshold	Objective	Set-Based	Point-Based
Survivability - Engines	Maximum allowable level of engine noise	Preferred level of reduced engine noise	Threshold	Objective
Survivability - Propulsors	Maximum allowable level of propulsor noise	Preferred level of propulsor noise	154%	110%
Energy - Fuel	8,000 metric tons fuel consumed /year	6,000 metric tons fuel consumed /year	9789	10021
Sprint Speed	30 knots	Threshold = Objective	30.46	29.11
Navigational Draft	6 meters (1666 accessible ports)	3.4 meters (2677 accessible ports)	5.83	4.48
Range at 20 knots	5000 nautical miles	Threshold = Objective	5079	5000
Time Between Fueling - On Station	4.5 days	9 days	10.15	10.66
Mission Package	Threshold Capability	Objective Capability	Objective	Objective
Range at Sustained Speed	1000 nautical miles	1500 nautical miles	1687	2500
Seakeeping	Capable of aviation operations 25% of time	Capable of aviation operations 50% of time	27%	22%

ERS Ship Design Demo Task



ERS Ship Design Demo Task



The Point Design team gravitated to a higher risk design as requirements changed.

The Set-Based Design team delayed design decisions to avoid those that added risk with minimal impact to performance.

Design Process Comparison

Point-Based Design	Set-Based Design
Design decisions largely driven by the designer's preference	Design decisions were driven by design/analysis data, with each design decision formally documented
Design Decisions that were made early were largely set through the process. (ship sizing and system architectures)	Decision space was open until the end of the design process. Subsystem design was done before the ship was sized, ship sizing was one of the last steps
Design progressed rapidly, with iterations on detailed analysis happening early	Design progressed slowly at first, with significantly more work done up front, with lower fidelity tools, to reduce the design space to a point where more detailed analysis could be performed in an economical manner
Requirements change caused significant rework	Requirements changes caused no rework, and actually facilitated the set reduction process.
As cost requirement decreased during the experiment, there was not much flexibility to adapt. Without exploration of the design space, the point based team had to guess how to achieve cost reduction	Set based process provide the team with robust information to do MOE versus aggressive cost goal tradeoffs
Resulting design: high performance, complex, high risk design with lower reliability	Resulting design: high performance, simple, low risk, and higher reliability

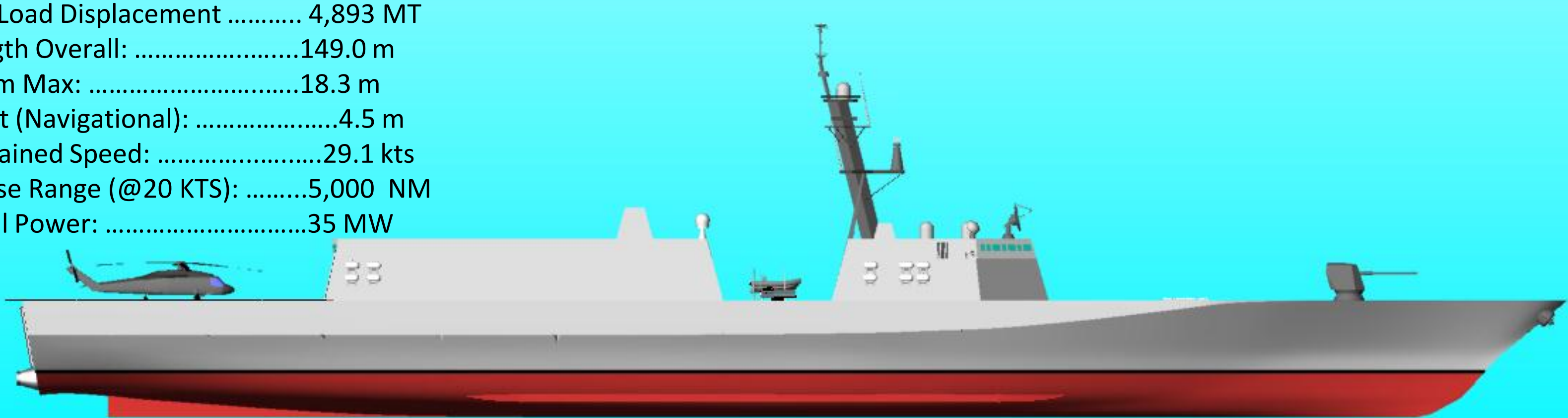
ERS Ship Demo - Final Ship Concepts

Set-Based Design Characteristics

Full Load Displacement …………4,359 MT
Length Overall: ……………….......129.3 m
Beam Max: ……………………….....16.7 m
Draft (Navigational): ……………......5.8 m
Sustained Speed: …………….…… .30.5 kts
Cruise Range (@20 KTS): ………..5,079 NM
Total Power: ……………………….….47 MW

Point-Based Design Characteristics

Full Load Displacement ……….. 4,893 MT
Length Overall: ……………........149.0 m
Beam Max: ……………………......18.3 m
Draft (Navigational): ……………....4.5 m
Sustained Speed: …………………..29.1 kts
Cruise Range (@20 KTS): ……...5,000 NM
Total Power: ……………………….35 MW



ERS Ship Design Demo Task - Conclusions

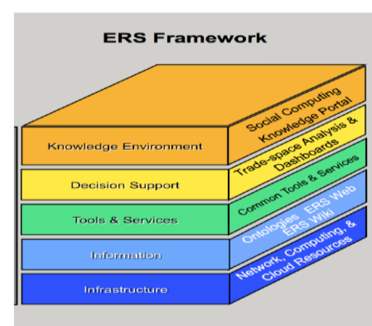
- **Development of Trade Space Facilitates Rigorous Requirements Analysis**
  - Could Allow Government to Make Deliberate Cost vs. Capability Decisions at Earliest Stages of Design Acquisition (pre-Milestone A)
- **Physics Based Analysis Tools provide Basis for Early Identification of Unobtainable or Unaffordable Requirements**
- **Trade Space Information Allows Government to Identify Key Technologies Needed to Reduce Risk or Meet Requirements**
- **Synthesized Ship Design Tools with Physics-Based Modeling Facilitates Understanding of Total Ship Impacts of Systems-of-Systems**
- **Design Space Exploration Educates Inexperienced Ship Designers**

Vision for ERS Ship Design

- **Decision Making Tool**
  - Uses Physics Model Based Data
  - Shows Requirements Tradeoffs
  - Shows Measure of Effectiveness
  - Shows Cost Versus Requirements,
  - Risk, & Measure of Effectiveness

- **Incorporate More Physics-Based Modeling into Early Stage Ship Design Decision Making Loop**
  - Survivability / Topside Integration / Manning / other tech areas
  - Producibility / Other "ilities"
  - Needs S&T and R&D Efforts

- **Develop ERS Framework Functionality/Capability**



ERS Ship Design - Future Work

More Physics-Based Modeling into Early Stage Ship Design

- Complete RSDE Toolset Development
  - Continue to Exercise Toolset during Development
  - Add Additional Technical Areas to Toolset

Decision Making Tool

- Integrate Mission Effectiveness Tool
- Integrate Higher Fidelity Cost Tools (Acquisition & TOC)
- Develop Visualization of Set-Based Design Process Generated Data (Requirements vs. MoE vs. Cost vs. Risk)
- Develop Formal Tool for Robust Risk Assessment

- Demo Set-Based Process with Larger Ship Design Team – (Team of Teams with More People)

BACKUPS

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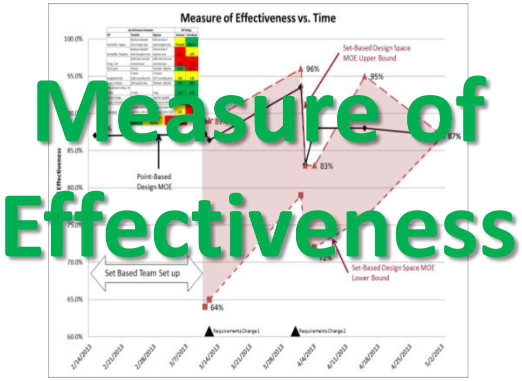
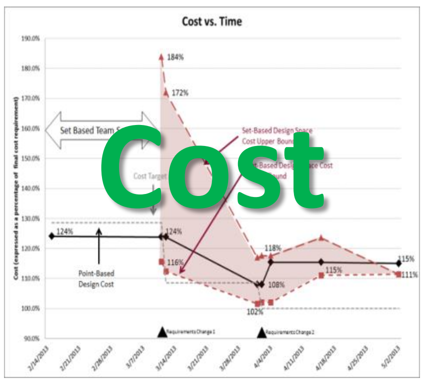
ERS Ship Design Demo Task

Measure of Effectiveness – Cost – Risk Comparison Conclusions:



- Both Approaches Resulted in Technically Feasible Designs
- Point-Based Approach Zeroed in on Optimal Design to Meet Requirements, However Required Complete Design Iteration with Requirements Changes
- Set-Based Team Able to Select Ship Systems First & then Fit these into Total Ship Selection – Required No Design Re-Work for Requirements Changes



- Both Teams Challenged to Achieve Cost Target for Given Requirements Set
- Point-Based Team had to Guess on Way to Achieve Cost Goal Based on Experience of Team Members
- Set-Based Team Gained Knowledge of Design & Cost Drivers – Had Knowledge on How to Meet Cost Goal

- Point-Design Team Gravitated to Higher-Risk Design as Requirements Changed
- Set-Based Approach Developed Lower-Risk Design, Able to Delay Decisions to Avoid Higher Risk Options with Minimal Performance Impact