Modeling and Simulation Tools for Set-Based Design

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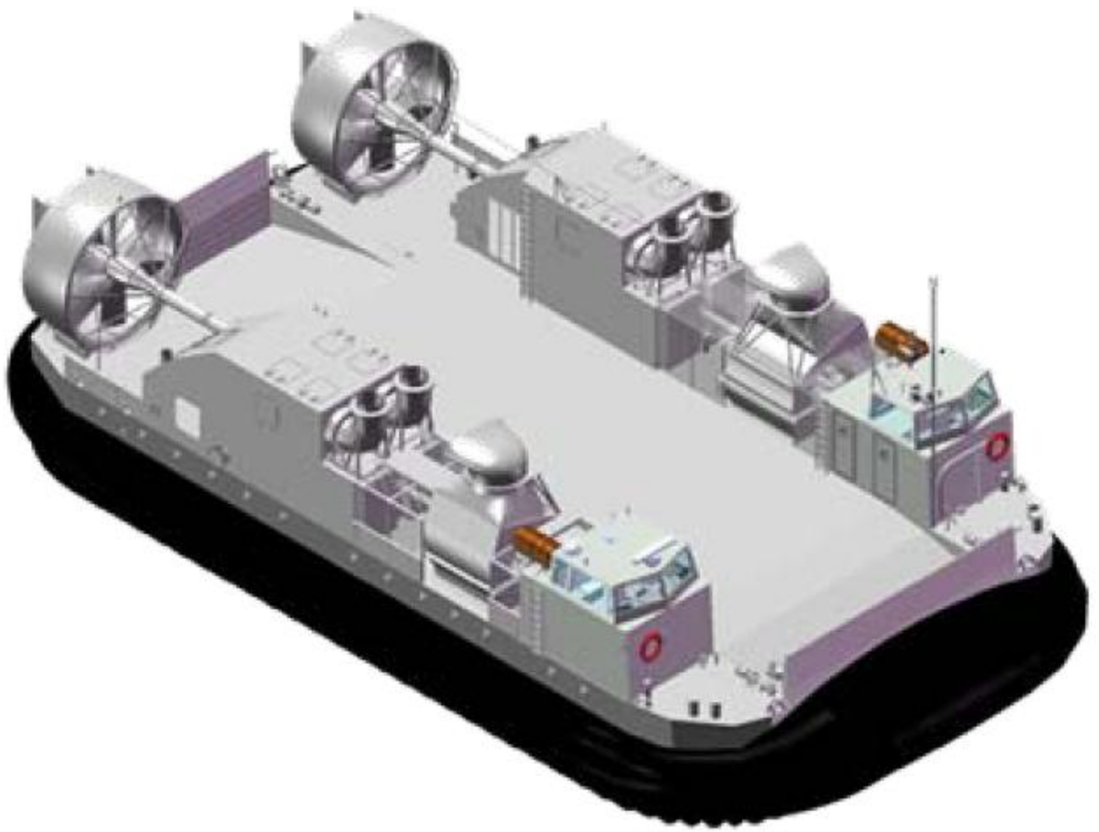
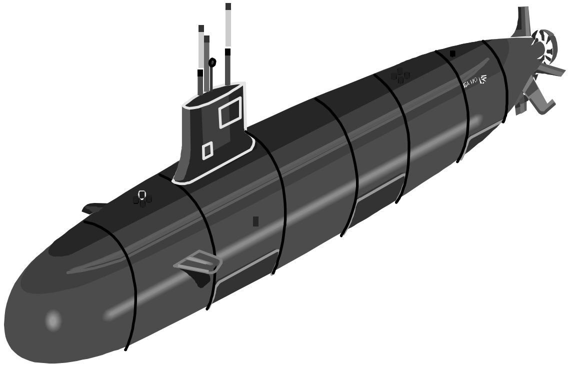
Dr. Norbert Doerry
Technical Director, Technology Group (SEA 05TD)
Naval Sea Systems Command
Norbert.doerry@navy.mil

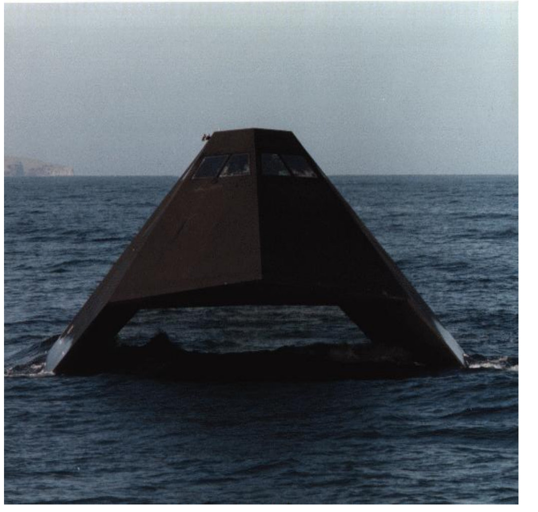
Agenda

- Set Based Design
- Tools for Set Based Design



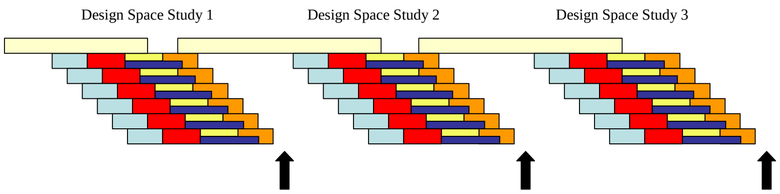
Challenges of Warship Acquisition





- Very low quantities, high unit cost, long lives
- No prototypes, first ship(s) must be fully operational
- Combat / weapons systems developed concurrently
- Government assumes responsibility for meeting requirements
- Extremely high parts count (in the order of 10 million)
- Minimal commercial shipbuilding industrial base
- Intense Congressional/OSD oversight

Motivation



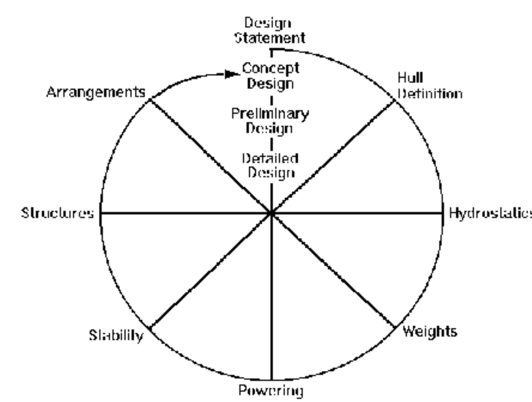
Synthesis Model based Design Optimization

- Great for finding the right part of the design space to look for a solution
- Low level of modeling detail

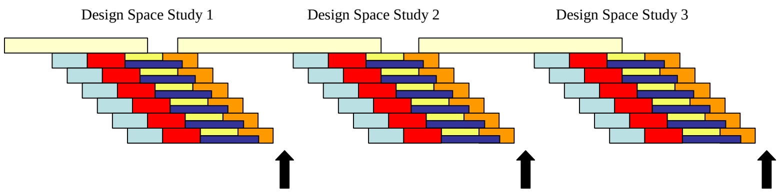
?

Classic Design Spiral (Point Based Design)

- Great for refining a design that nearly meets all requirements, or for optimizing a feasible design
  - Sequence Dependent
  - Convergence Risk
- Can support high level of modeling detail



Motivation



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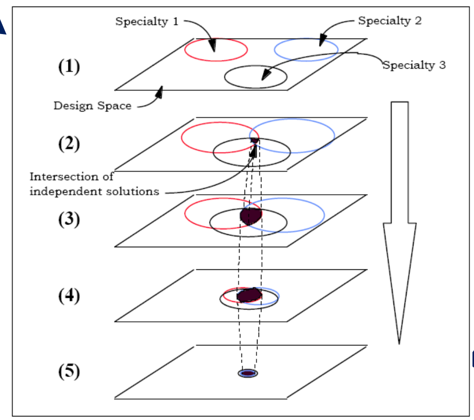
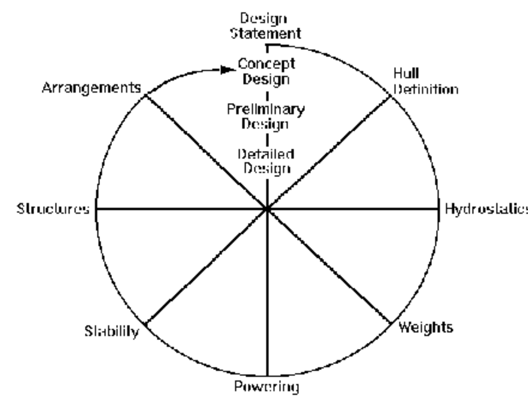


Set Based Design

- Great for finding a converged design solution within a defined Design Space
- Increasing level of modeling detail
- Does not depend on integrated design tools
- Works well with large design teams



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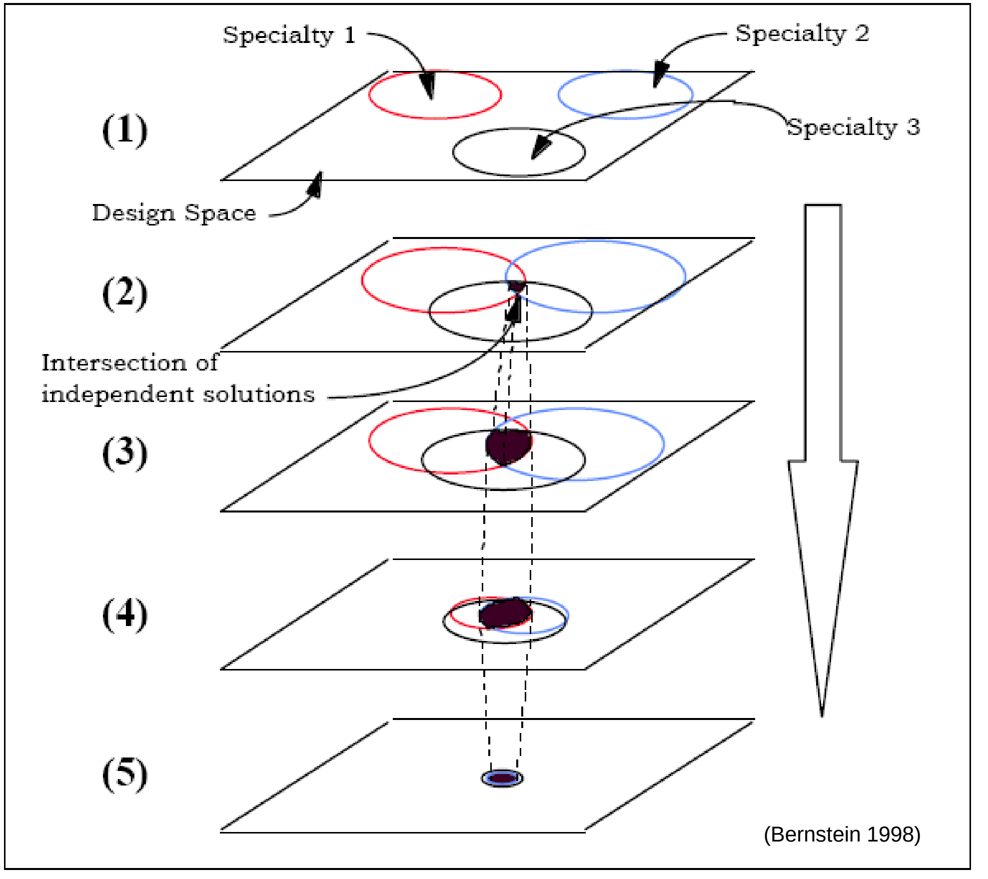
Set Based Design Process

Understand the design space
- Define feasible regions
- Explore tradeoffs by designing multiple alternatives
- Communicate sets of possibilities

Integrate by intersection
- Look for intersections of feasible sets
- Impose minimum (maximum) constraint
- Seek conceptual robustness

Establish feasibility before commitment
- Narrow sets gradually while ***increasing detail***
- Stay within set once committed
- Control by managing uncertainty at process gates

Bernstein, J. I., 1998, Design Methods in the Aerospace Industry: Looking for Evidence of Set-Based Practices, Master of Science Thesis, Massachusetts Institute of Technology, 1998.



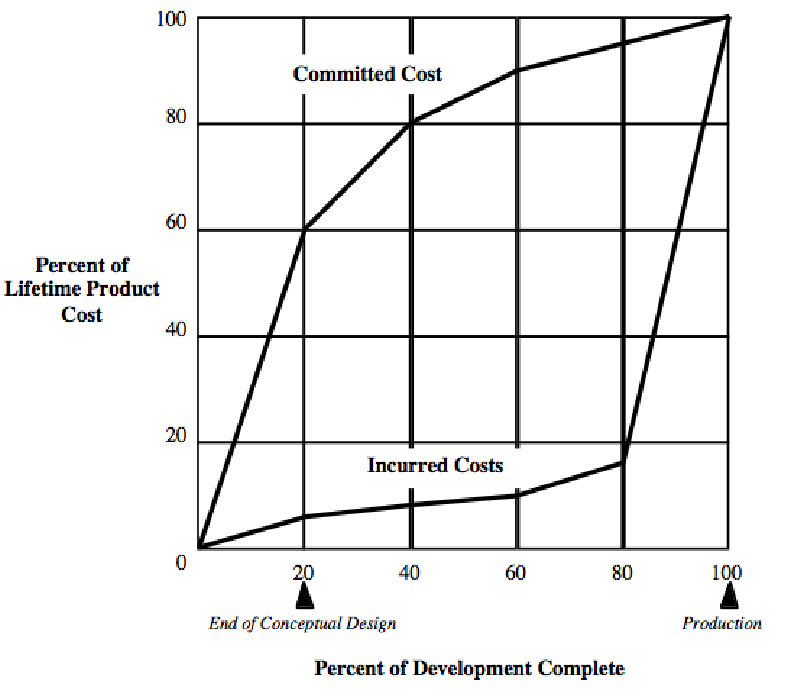
(Bernstein 1998)

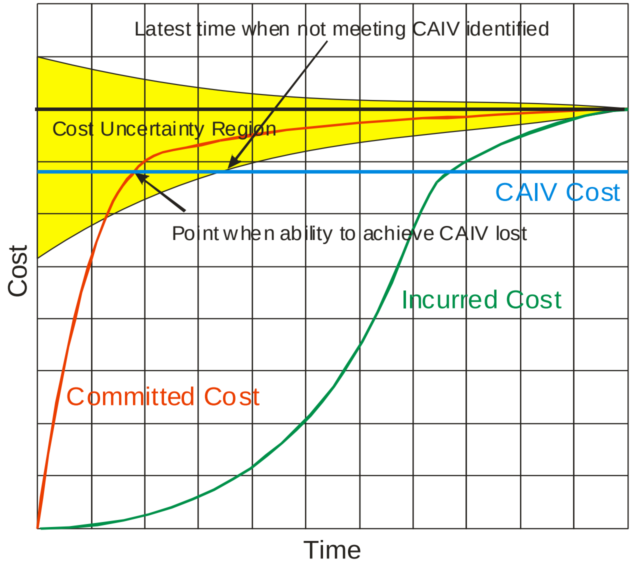
Systematically decide what is NOT the answer

Why not go directly to Spiral / Point Based Design?

- Problem 1: Designing in Cost
  - Costs are committed early, when there isn't sufficient information to accurately predict cost or performance

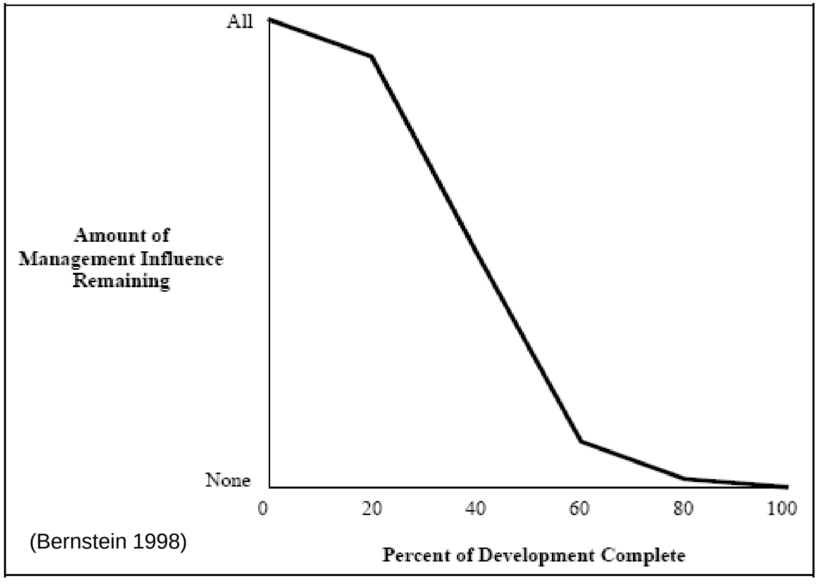
(Bernstein 1998)





Why not go directly to Spiral / Point Based Design?

- Problem 2: Requirements Understanding During Design vs. Influence / Impact on Cost
  - When knowledge is known, remaining Management influence is low



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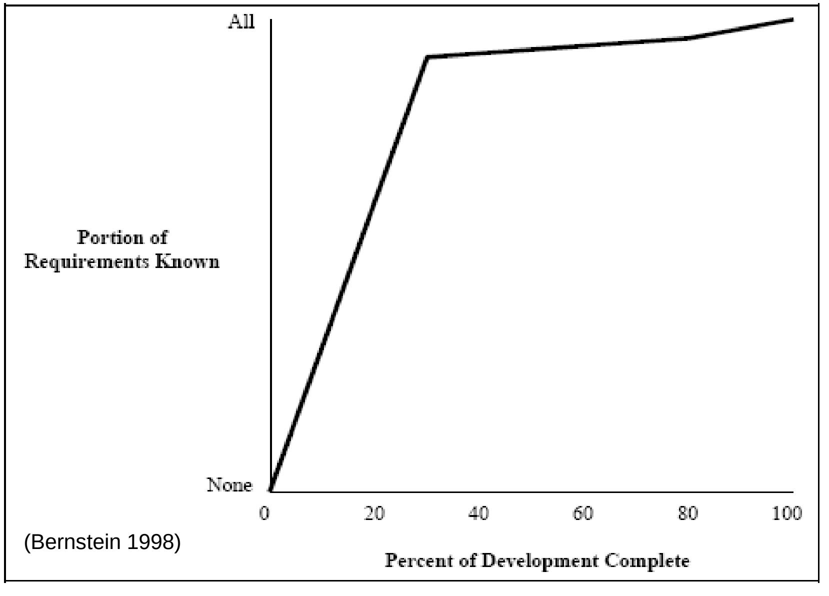

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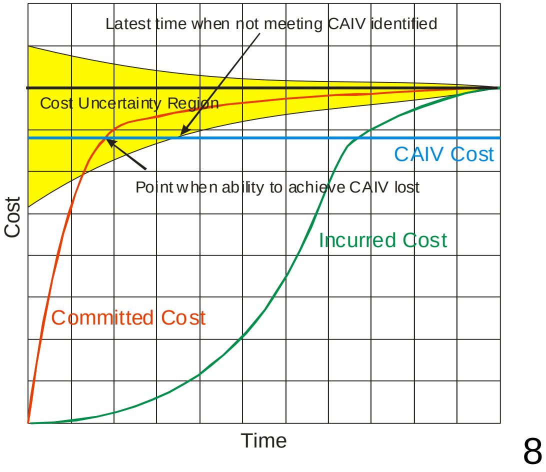
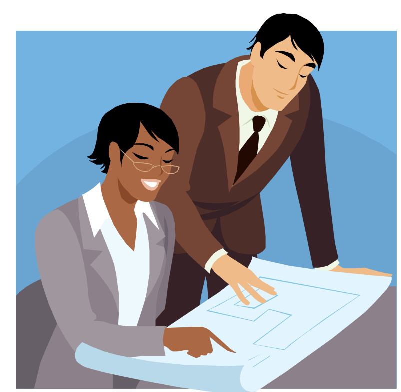


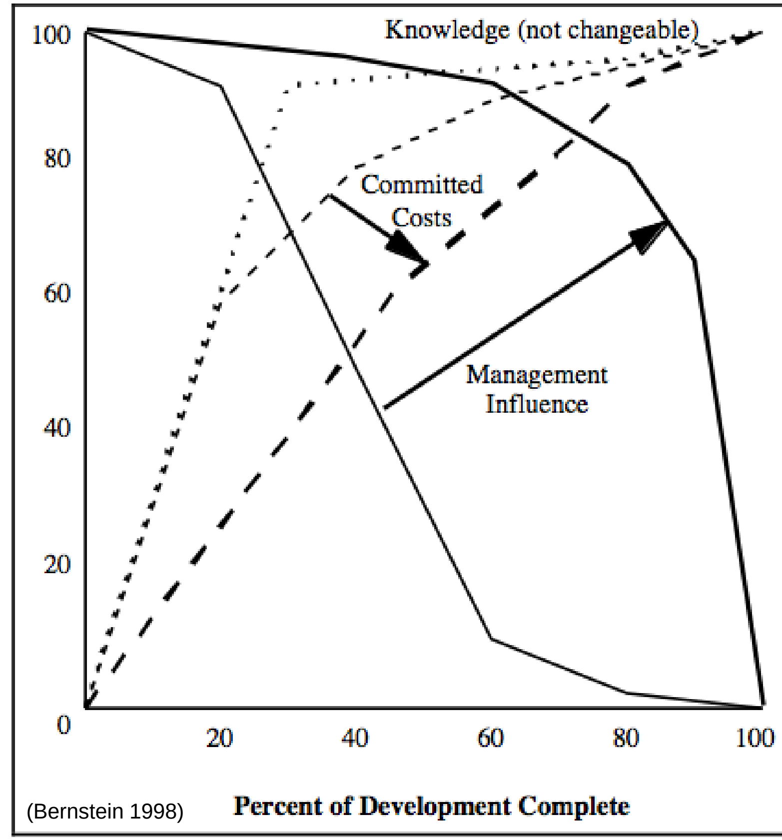
Why not go directly to Spiral / Point Based Design?

- Problem 3: Optimizing a ship design requires both objective knowledge (mathematical models) and subjective knowledge (expert opinion)
  - Objective and subjective knowledge require domain experts
  - In real world domain experts are not collocated
  - Existing design data and knowledge communication tools are generally not rapid and effective enough to support many tightly coupled Spiral Design iterations during the time period typically allocated for a design phase.



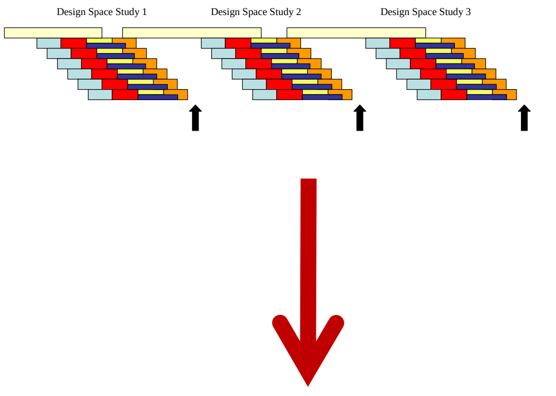
Why Set Based Design is Useful

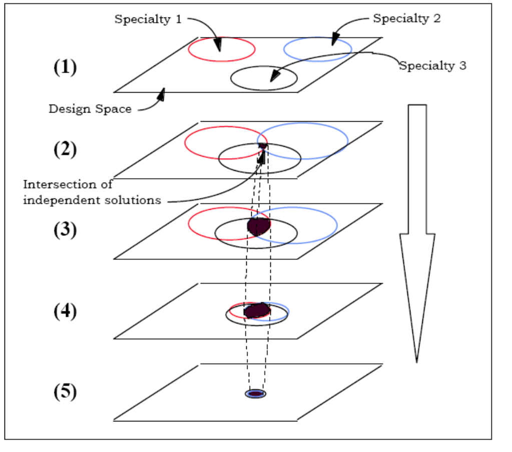
- Delay Cost Commitment until sufficient design detail enables a good choice
- Maximize Management Influence as long as possible
- Enable Stakeholder Consensus – Easier to get agreement on what is NOT the answer than on what IS the answer
- Avoid "Did you consider …?" death spiral!
- Keep options open for innovations while preserving low risk options.



How to start Set Based Design

- Identify the different “Specialties”
- Identify key attributes that define the “set” for each “Specialty”
- Define the initial boundaries for each “set”
- Look for an intersection of the “sets”
- If none exist, or the area of intersection is small, expand the “sets” until the intersection is robust

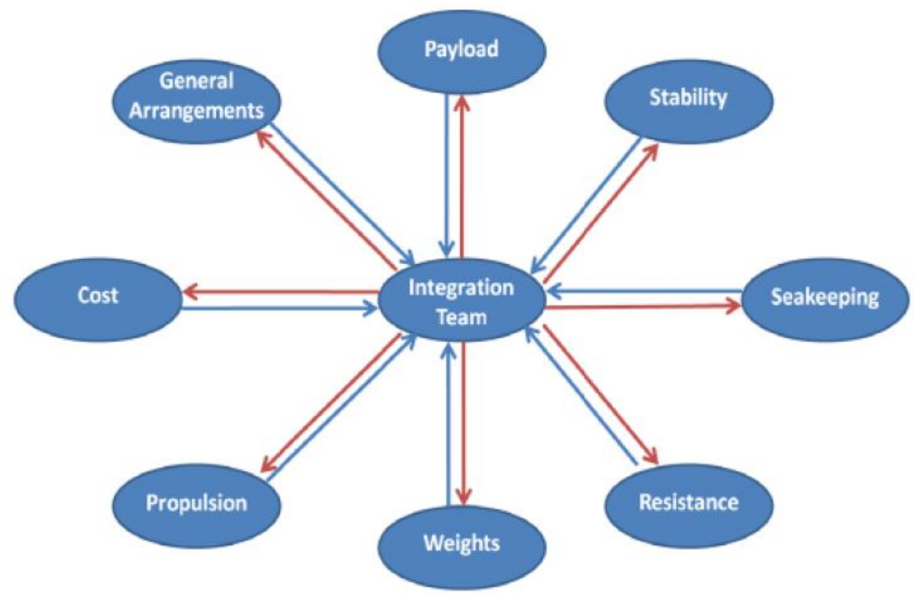




Example of a "Set"

- For an Electrical Plant
  - Scalable from 40 MW to 80 MW
  - Common 4160 V architecture
  - Combination of 4 and 8 MW Diesel Generator sets and 22 MW Gas Turbine Generator Sets
  - Scalable transformers for zonal distribution
- For a hull
  - Scalable hull / family of hulls from 20,000 to 40,000 long tons
  - May also have a variable length to beam ratio and a variable beam to draft ratio.
  - May also have a variable length parallel midbody.

SBD Process Example



McKenney, T.A., Kemink, L.F., and Singer, D.J., 2011, Adapting to Changes in Design Requirements Using Set-Based Design., *ASNE Naval Engineers Journal*, 123 (3), pp. 66-77.

Comparing Point and Set Based Design

Task	Point Based Design	Set Based Design
Search: How should solutions be found?	Iterate an existing idea by modifying it to achieve objectives and improve performance. Brainstorm new ideas	Define a feasible design space, then constrict it by removing regions where solutions are proven to be inferior
Communication: Which ideas are communicated to others?	Communicate the best idea.	Communicate sets of possibilities that are not Pareto dominated.
Integration: How should the system be integrated?	Provide teams design budgets and constraints. If a team can't meet budget or constraints, reallocate to other teams	Look for intersections that meet total system requirements.

David J. Singer, PhD., Captain Norbert Doerry, PhD., and Michael E. Buckley," What is Set-Based Design? ," Presented at ASNE DAY 2009, National Harbor, MD., April 8-9, 2009. Also published in ASNE Naval Engineers Journal, 2009 Vol 121 No 4, pp. 31-43.

Comparing Point and Set Based Design (continued)

Task	Point Based Design	Set Based Design
Selection: How is the best idea identified?	Formal schemes for selecting the best alternative. Simulate or make prototypes to confirm that the solution works	Design alternatives in parallel. Eliminate alternatives proven inferior to others. Use low cost tests to prove infeasibility or identify Pareto dominance
Optimization: How should the design be optimized?	Analyze and test the design. Modify the design to achieve objectives and improve performance.	Design alternatives in parallel. Eliminate alternatives when proven inferior to others.
Specification: How should you constrain others with respect to your own subsystem design?	Maximize constraints in specifications to assure functionality and interface fit.	Use minimum control specifications to allow optimization and mutual adjustment.

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Comparing Point and Set Based Design (continued)

Task	Point Based Design	Set Based Design
Decision Risk Control: How should one minimize the risk of "going down the wrong path?"	Establish feedback channels. Communicate often. Respond quickly to changes.	Establish feasibility before commitment. Pursue options in parallel. Seek solutions robust to physical, market, and design variation.
Rework risk control: How should one minimize damage from unreliable communications? How should the communication process be controlled?	Establish feedback channels. Communicate often. Respond quickly to changes. Review designs and manage information at transition points.	Stay within sets once committed. Manage uncertainty at process gates.

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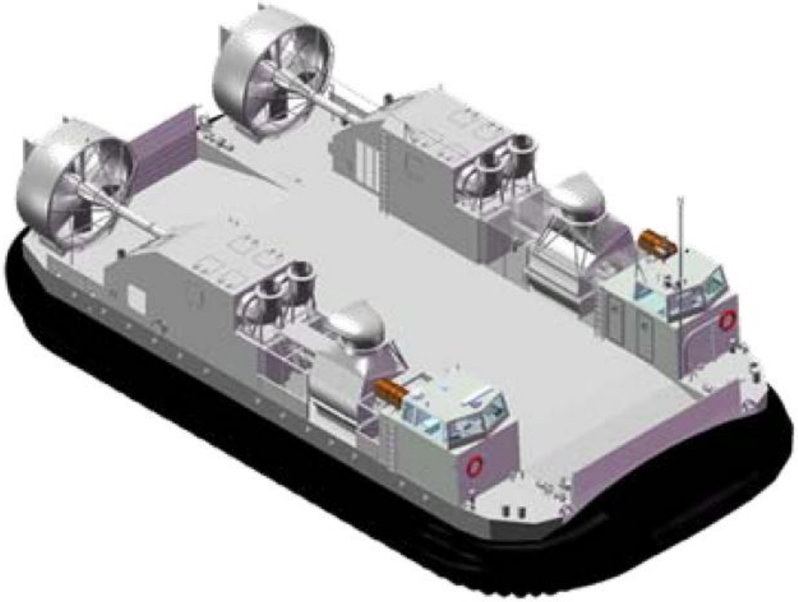
Review of Set Based Design …

- Consider a large number of design alternative by understanding the design space
- Allow specialists to consider a design from their own perspective and use the intersection between individual sets to optimize a design
- Establish feasibility before commitment
  - Narrow sets gradually while increasing detail
  - Stay within a set once committed
  - Maintain control by managing uncertainty at process gates



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Walter L. Mebane, Craig M. Carlson, Chris Dowd, David J. Singer, and Michael E. Buckley, "Set-Based Design and the Ship to Shore Connector," ASNE Naval Engineers Journal 2011 No 3, pp 79-92.

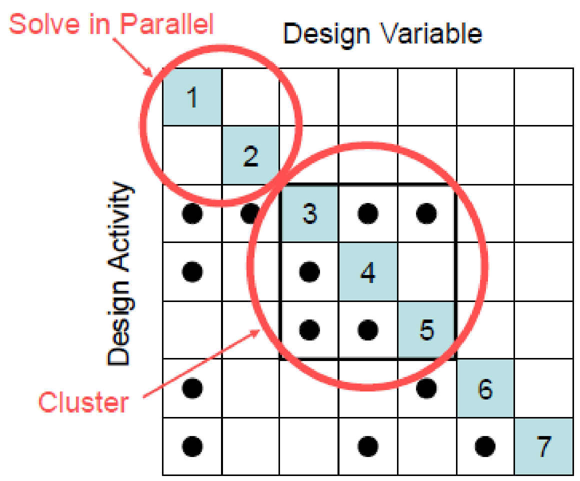
Systematically decide what is NOT the answer

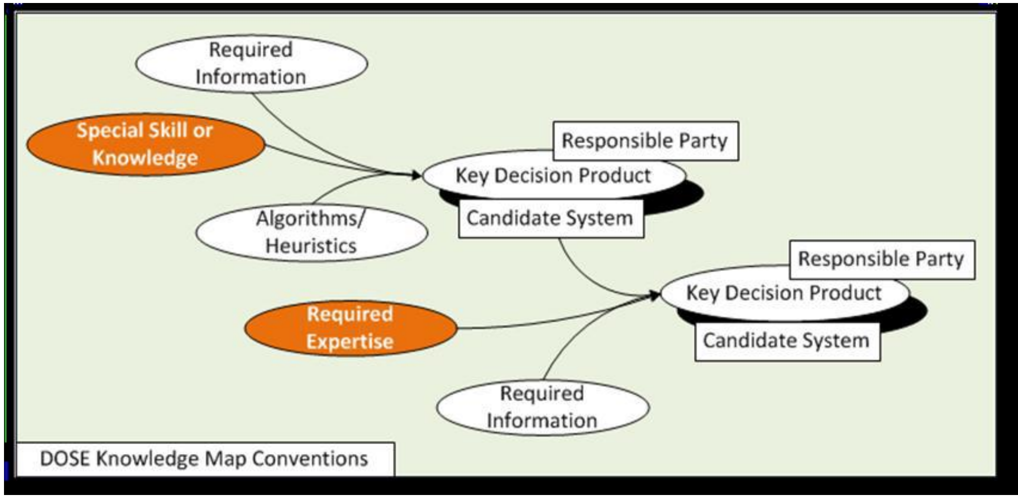
Design Tools for Set Based Design

- Ordering of design decisions
  - Hierarchy of Design Variables
- Capturing ranges of variables in analysis
  - Understanding breakpoints
- Integrating sets
- Changing variables of interest
  - What to do about lesser importance variables.
  - Will the details work out later?
- Visualizing sets / design space
- SBD Management

Ordering of Design Decisions

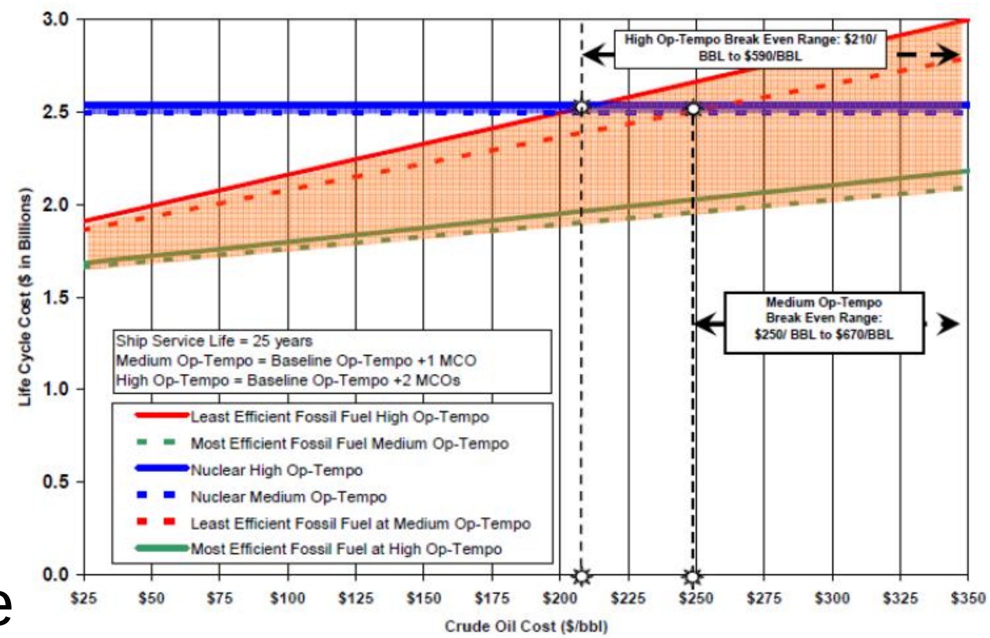
- Decisions interact with one another.
- Important to make decisions in the right order to avoid "back-tracking"
  - Which set of variables should a decision gate consider?
- Some tools and methods:
  - Design Structure Matrix
  - Decision Oriented Systems Engineering





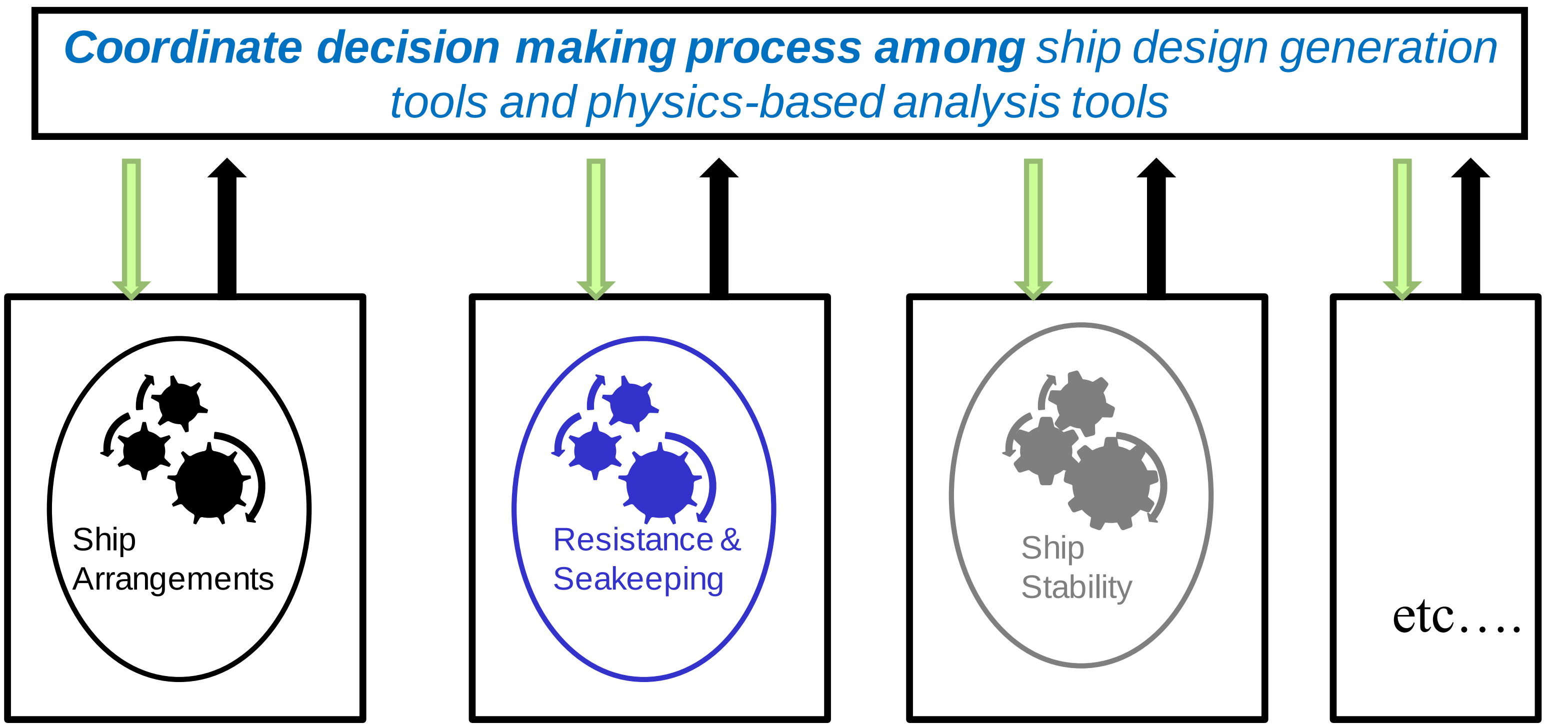
Ranges Instead of Points

- Design and analysis tools typically work on point-designs, not “sets”
- Important to understand within a design space, the location of boundaries between competing design strategies
- Currently we address the problem with methods and tools designed for point designs.



Integrating Sets

- Combine results from each specific design domain
  - Intersection of sets
- CREATE-Ships Rapid Design and Integration:

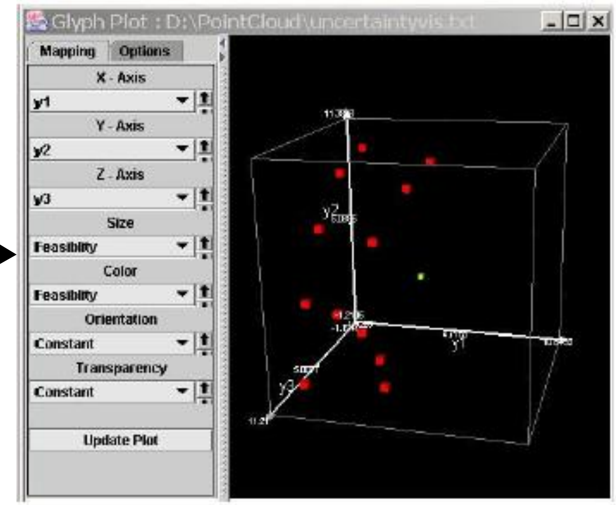


Changing Variables of Interest

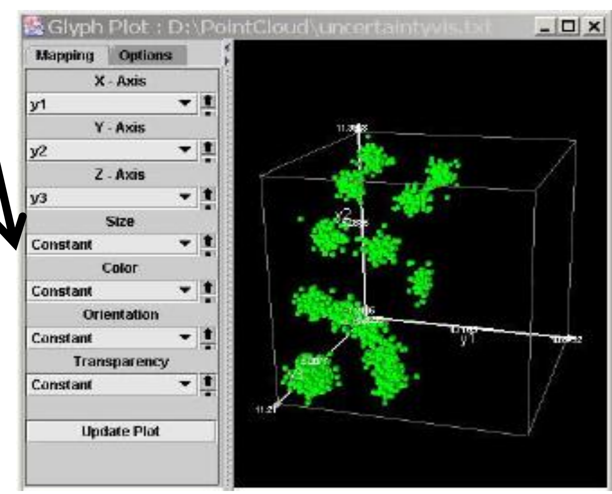
- Normally focus on only a few design variables at a time
- Challenge is what to do about all the “other” design variables
  - Traditionally held them constant
    - May favor one region of the “variables of interest” design space
  - Usually too expensive to model them all exhaustively.
- Possible approach is to use Genetic Algorithms to eliminate inferior sets of the “other” design variables.

Variable 1
Variable 2
Variable 3
Variable 4
….
….
Variable 999,998
Variable 999.999
Variable 1,000,000

Variables of Interest

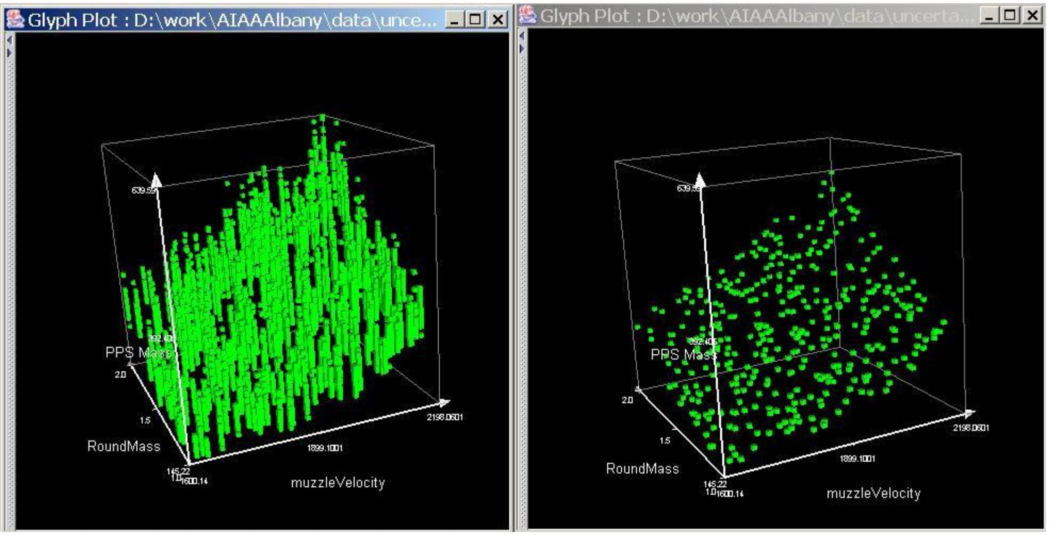


Variables “not of interest” impact shape of response surface



Stump, Yukish, Martin and Simpson, “The ARL Trade Space Visualizer: An Engineering Decision-Making Tool,” AIAA 2004

Design Space Visualization



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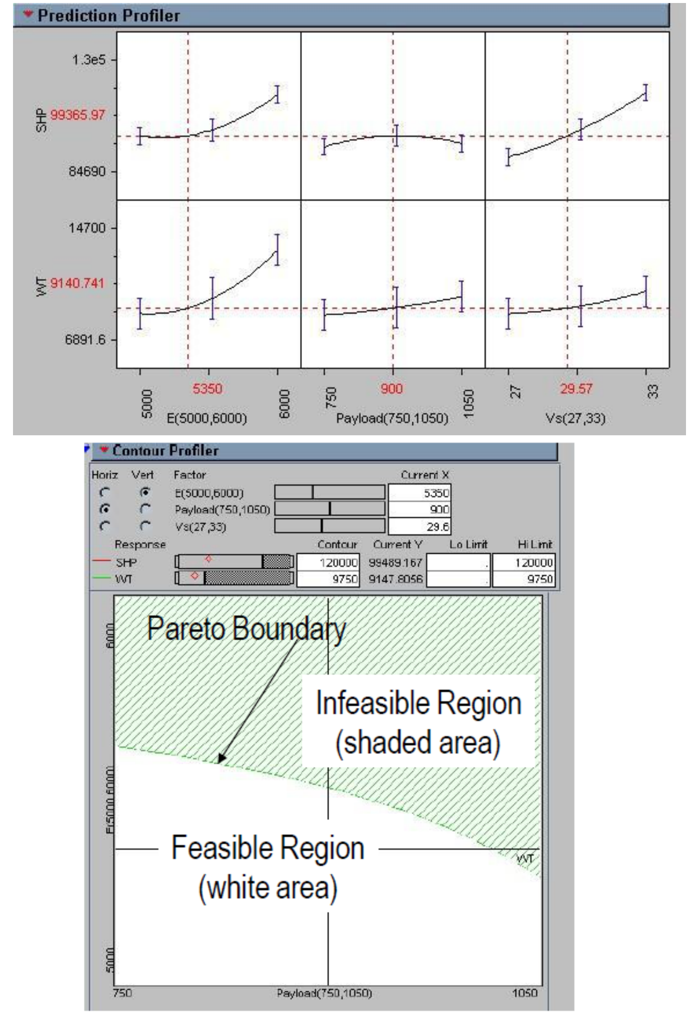

- Many visualization tools exist.
- Most require experience to understand
  - – Difficult for senior leaders to understand nuances

Whitcomb, Dr. Cliff, "Sea Connector Family and Seabase Architecture Systems Engineering and Systems Architecture," Presentation to Naval Postgraduate School SI4000 Fall AY2005, Project Seminar, October 21, 2004.

SBD Management

- Facilitate team negotiations
- Evaluate variable interactions
- Assess risk
- Manage design and decision data

Summary

- Set Based Design
  - Bridge Design Space Exploration & Point Design
  - Delay cost commitment until sufficient design detail exists
  - Systematically decide what is NOT the answer
- Tools for Set Based Design
  - Ordering of design decisions
  - Capturing ranges of variables in analysis
  - Integrating Sets
  - Changing variables of interest
  - Visualizing sets / design space
  - SBD Management