## Panel #16: Contributions of Systems Engineering to Effective Acquisition

# Robust Systems Engineering: Ensuring Successful Acquisition Outcomes Through "Elegant" Design

**Bob Keane**

**Ship Design USA, Inc.**

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# Problem: Naval Ships Cost Too Much To Produce & Own

- "...lack of design maturity...required to rebuild completed areas of the ship..." (GAO 2005)
- "Starting construction without a stable design...volatility leads to costly out-of-sequence work and rework..." (GAO 2009)
- "Shipboard distributed systems such as … structure… are in wide disrepair throughout the surface force." (Balisle, 2010)
- Poor design decisions are driving TOC (Keane, 2011)
  - Selecting solutions located at the edge of infeasibility and not backing off from edge to find solution that is optimum and robust
  - Robust design will not become infeasible if ship changes a little

**Many ship classes in fleet are at the edge of infeasibility**

# Bottom Line Up Front (BLUF)

1. Less Dense Design

2. Use of Collaborative Physics-Based Design Tools

3. Design-Build Collaboration

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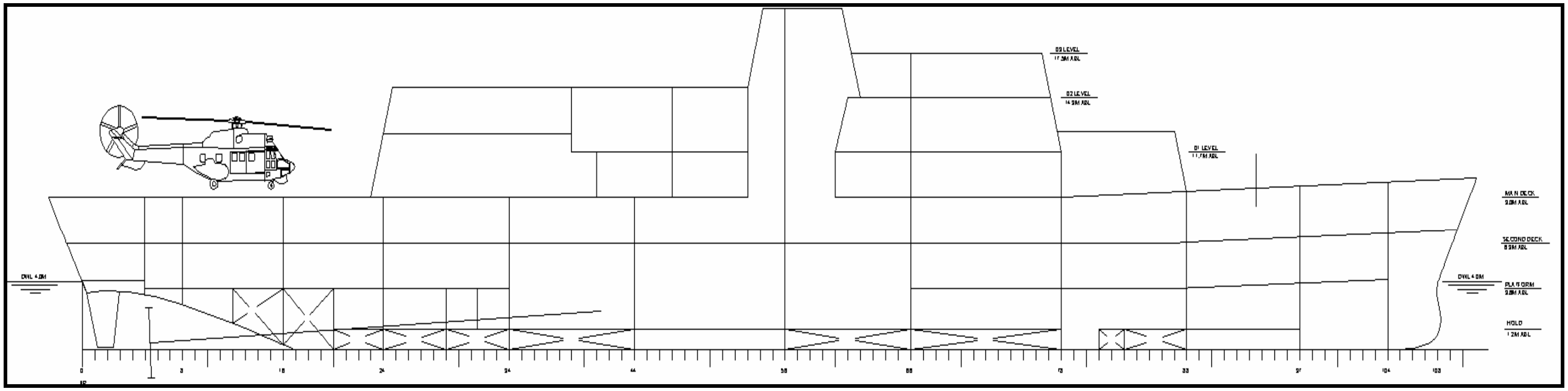
# *"Outside-In Design"* – Start with Hull Form, Then Cram Everything into Hull

- Hull is sized and shaped in early design based on:
  - unreliable weight and area/volume estimates



  - invalid assumption volume is "arrangeable"
  - fallacy that limiting hull size limits ship costs

**Design unstable-cannot freeze arrangements early**

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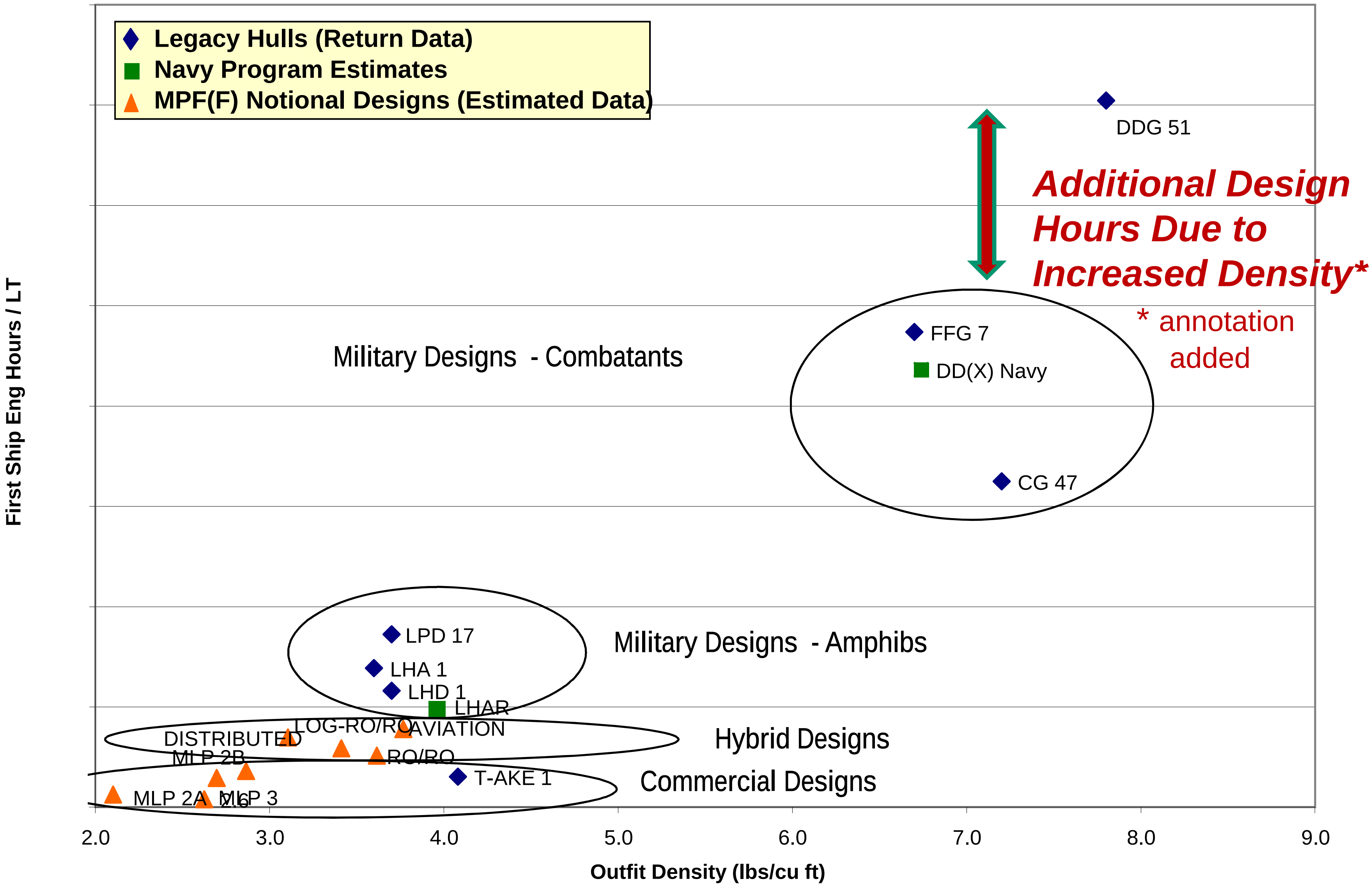
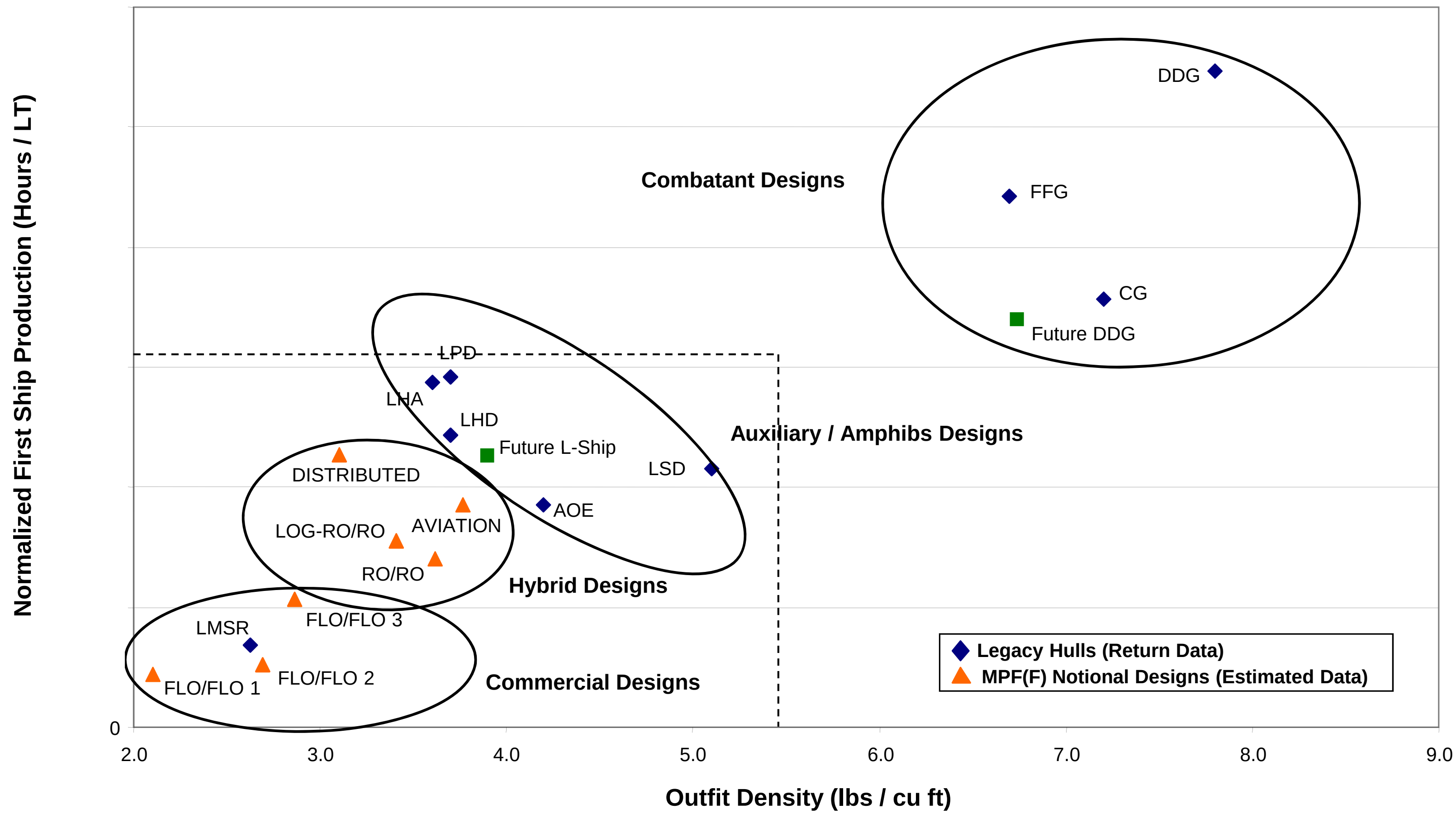
# First Ship Engineering MH / LT vs. Outfit Density



# Ships Possessing Greater Density Increase Production Cost




Ship Production hours increase with density and fall into predictable groupings.

# Seaway Loads for Design of Surface Combatants: Rule-Based Design

- Structural Design of FFG 7, CG 47, DDG 51 Classes
  - Interested more in extreme loading conditions than actual loads which contribute to fatigue
  - Worked with simplified loading envelopes
  - Deterministic analysis resulted in scantlings for maximum load expected
  - Highly random wave-induced loads were set of simplified hydrostatic loads under extreme seas

**No Physics-Based Computations nor Seakeeping Model Tests to Determine Actual Seaway Loads**

# Lack of Physics-Based Design Tools: Increased Ownership Costs

- FFG 7 Class
  - Hull girder doubler plates & ballast added
  - Extensive deckhouse fatigue cracking
- CG 52 Class (with VLS)
  - Serious hull cracking and buckling problem
  - Extensive superstructure fatigue cracking
- DDG 51 Class
  - Bow structure buckling and cracking issue
- **Operational loads exceeded rule-based design loads**

**$100M's in repairs for sustaining service-lives**

# Root Cause of Wrong Technical Decisions: "Outside-In" Design

- Some in the Navy..."*tacitly assumed that ship size could be equated to ship cost..."*
- "*the central assumption, that size and cost inevitably go together, is often false."*
- Based on supposition that "*only a shrunken ship would be sellable"*
- "...*modern warships are much more volume - than weight - critical..."*
- Nevertheless, this philosophy of constraining hull size continues even to today.

Friedman, *U.S. Destroyers: An Illustrated Design History,* 2004

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# Adverse Impacts of "Outside-In" Design Inefficient Designs to Build and Own

- **Increased Detail Design and Construction costs**
- **Costly exotic, lightweight materials, difficult to weld**
- **Increased energy consumption and Fleet fuel costs**
- **Insufficient service-life allowances**
- **Increased maintenance and repair costs**
- **Increased modernization costs**
- **Reductions in years of expected service-life**
- **Many "Band-Aids" to keep ships operating**
- **Operational restrictions**

# WHERE WE NEED TO GO

- According to an old proverb, if we do not change our direction, we might end up where we are headed.

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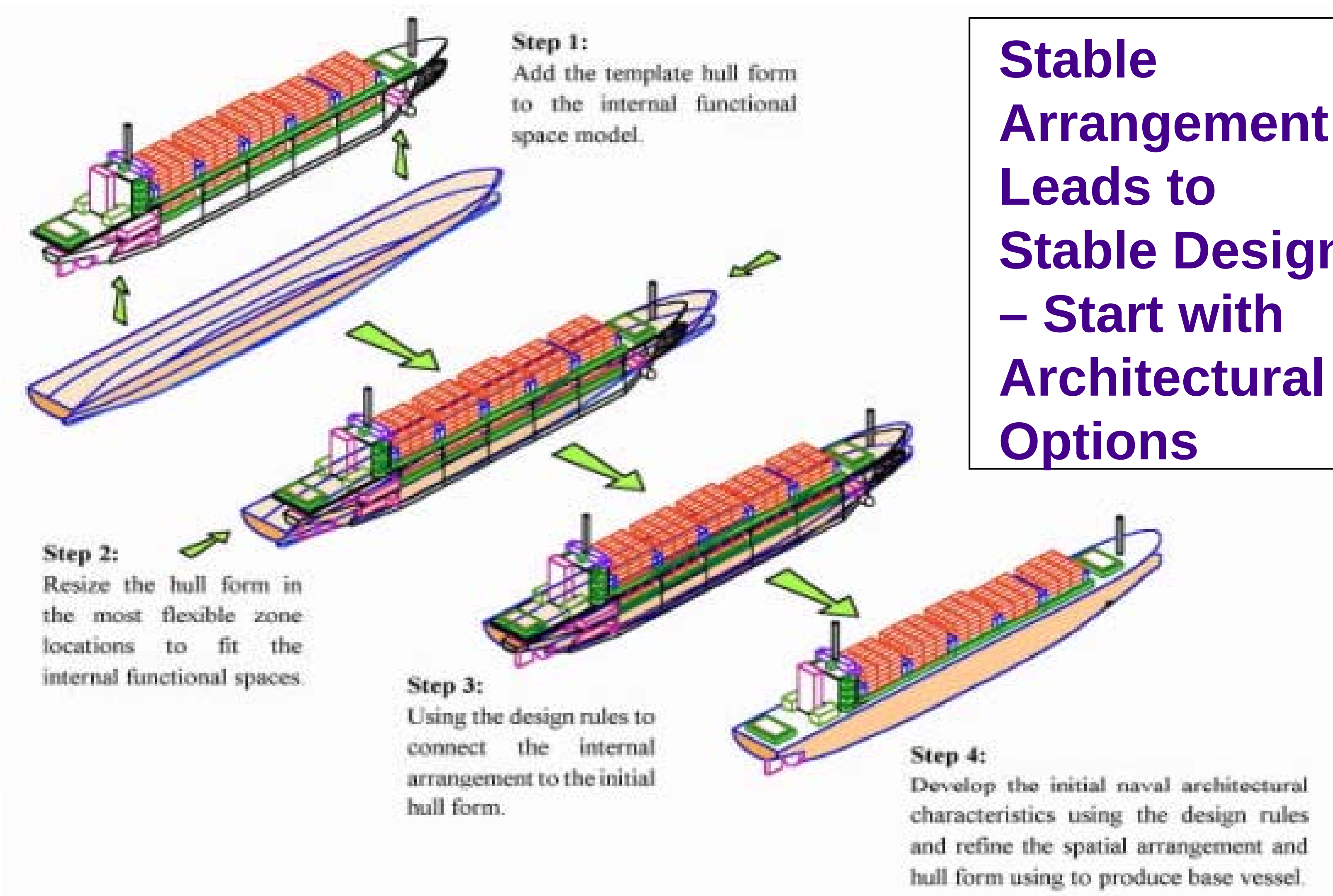
# Systems Engineering – Ensure "Elegant" Designs*

- **Effective** – it does what it is supposed to do
- **Efficient** – to produce, operate, maintain
- **Robust** - insensitive to variations in operations
- **Minimal Unintended Consequences** – few Band-Aids required to fix it in-service

***M. Griffin, Former NASA Director, Dean's Seminar, SIT, "How do we fix System Engineering?", 13 Dec 2010**

# *"Inside Out Design":* Create internal arrangement, then fit hull form: NSRP Project 21




**Stable Arrangement Leads to Stable Design – Start with Architectural Options**

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# Collaborative Design-Build leads to Early Stable Arrangements

- LMSR Engine Room Arrangement Module (ERAM)
  - Sealift engine room cost reduced 57% ($58M to $25M)
  - Design time reduced 45% (27 weeks to 15 weeks)
  - Manufacturing man-hours reduced by 40%
  - Design process supported 18-month build strategy
  - 20% reduction in piping, cabling & equipment realized
  - 60% increase in level of standardization
  - Doubled amount of equipment installed off vessel
  - Off vessel testing increased from 5% to 40%

**Lead LMSR delivered on time, under budget**

# Toward Robust Systems Engineering: CREATE-SHIPS Project

- Computational Research & Engineering for Acquisition Tools & Environments (CREATE):
  - Replace empirical design with validated physics-based computational design
  - Detect and fix design flaws early in design process
  - Develop optimized designs for new concepts
  - Begin system integration earlier in acquisition process
  - Increase acquisition program flexibility and agility to respond to rapidly changing requirements

# CREATE-SHIPS: Leading The Way Toward "Elegant" Design

- **Concept Design High Quality, Physics-Based Software**
  - **Intelligent Ship Arrangements (ISA): a new surface ship architectural optimization system**
  - **Weapons Effects (Shock) & Seaway Loads Predictions**
  - **Integrated Hydrodynamic Design Environment (IHDE): hull form design and evaluation**
  - **Integrated Structural Design Environment (ISDE): incorporate reliability-based structural design**
  - **Rapid Ship Design Environment (RSDE): higher fidelity design definition & physics based analyses**

**A HPCMPO – NAVSEA – ONR Collaboration**

# The Way Ahead: To Efficiently Produce And Own A Warship

- **Less Dense Design**
  - **Develop minimal cost design, not minimal size.**
  - **Size ship to reduce costs due to increased volumetric density and complexity.**
- **Collaborative Physics-Based Design Tools**
  - **Recognize functional arrangements must be developed before hull form is sized and shaped.**
  - **Use architecture to partition high technical risks and define design interfaces.**
- **Design-Build Collaboration between Navy & Builder**

***Invest Early in More Robust Ship Design***

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# Warfighting in the Ocean Battlespace


"…***In time of war, when combat objectives rise above all other priorities ...Planes do not stay grounded and fleets do not run scared because of ugly weather...*"**

CDR George Kosco, ADM Halsey's Chief Meteorologist, *Halsey's Typhoon: The True Story of a Fighting Admiral, an Epic Storm, and an Untold Rescue, 2008*