Acquisition Research Symposium
Naval Postgraduate School

REDUCING WORK CONTENT IN EARLY STAGE NAVAL SHIP DESIGNS

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The Problem

AT&L (2013) analyses of cost and schedule growth on Major Defense Acquisition Programs (MDAPs) over last 20 years:

- Premature contracting without understanding design issues greatly affects contract work content and cost growth
- Early work content stability predicts lower total cost, work content, and schedule growths
- Contract work content growth dominates total cost growth
- Cost-over-target reflects poor performance, poor estimation, or faulty framing assumptions

The Problem: Contract Work Content Growth

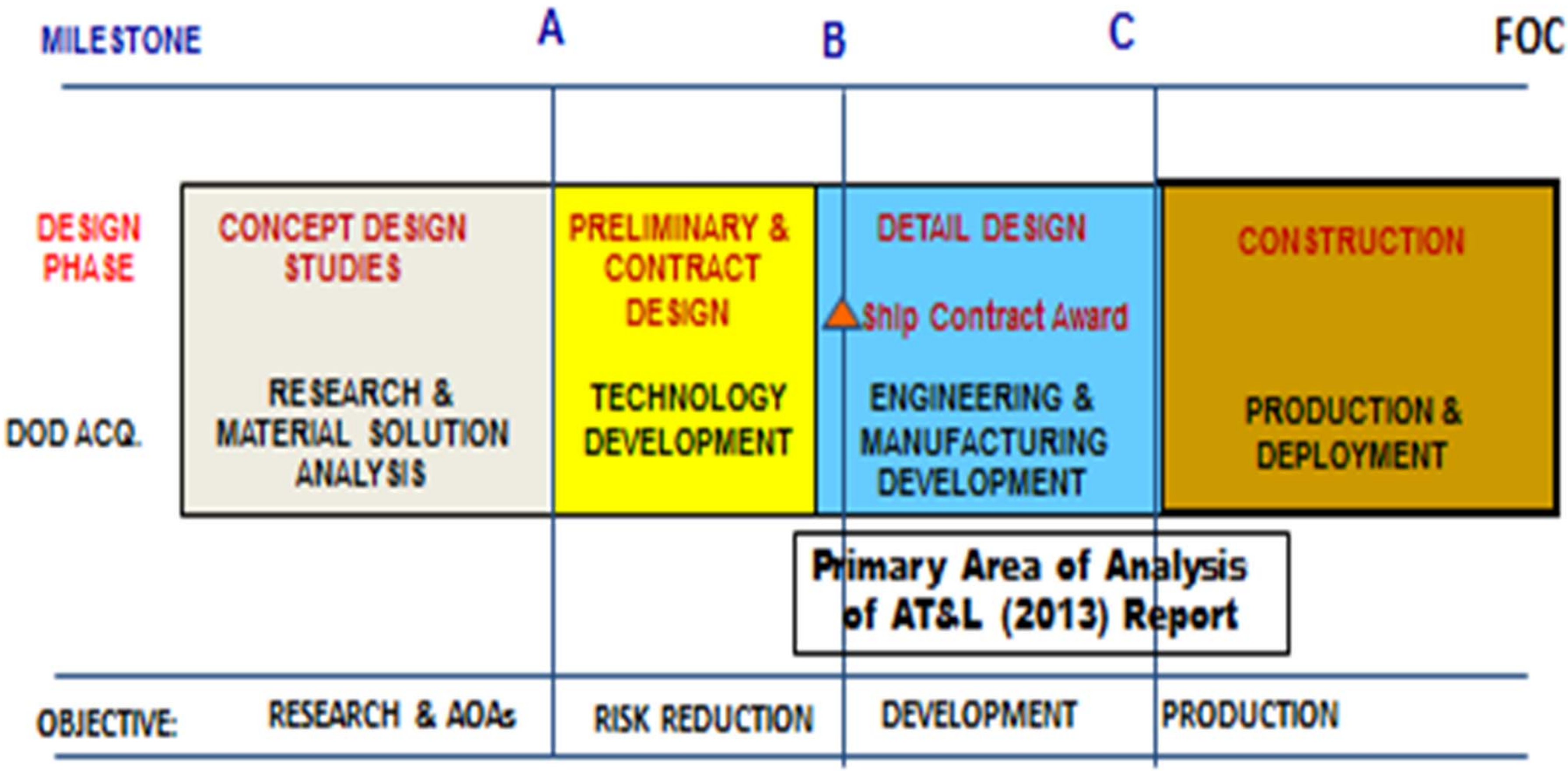


Figure 1. Ship Design & Acquisition Process Compared to the Defense Acquisition System Life Cycle

Contract Cost Growth on Navy Ship Development Contracts (MS B – C)

- AT&L found a statistically significant Undefinitized Contract Action (UCA) effect
  - UCA pertains to contract action for which contract terms are not agreed before performance is begun
- UCAs had a measurable increase on total contract cost growth and also on cycle time
- AT&L warned it could indicate an area of caution and attention for the Navy

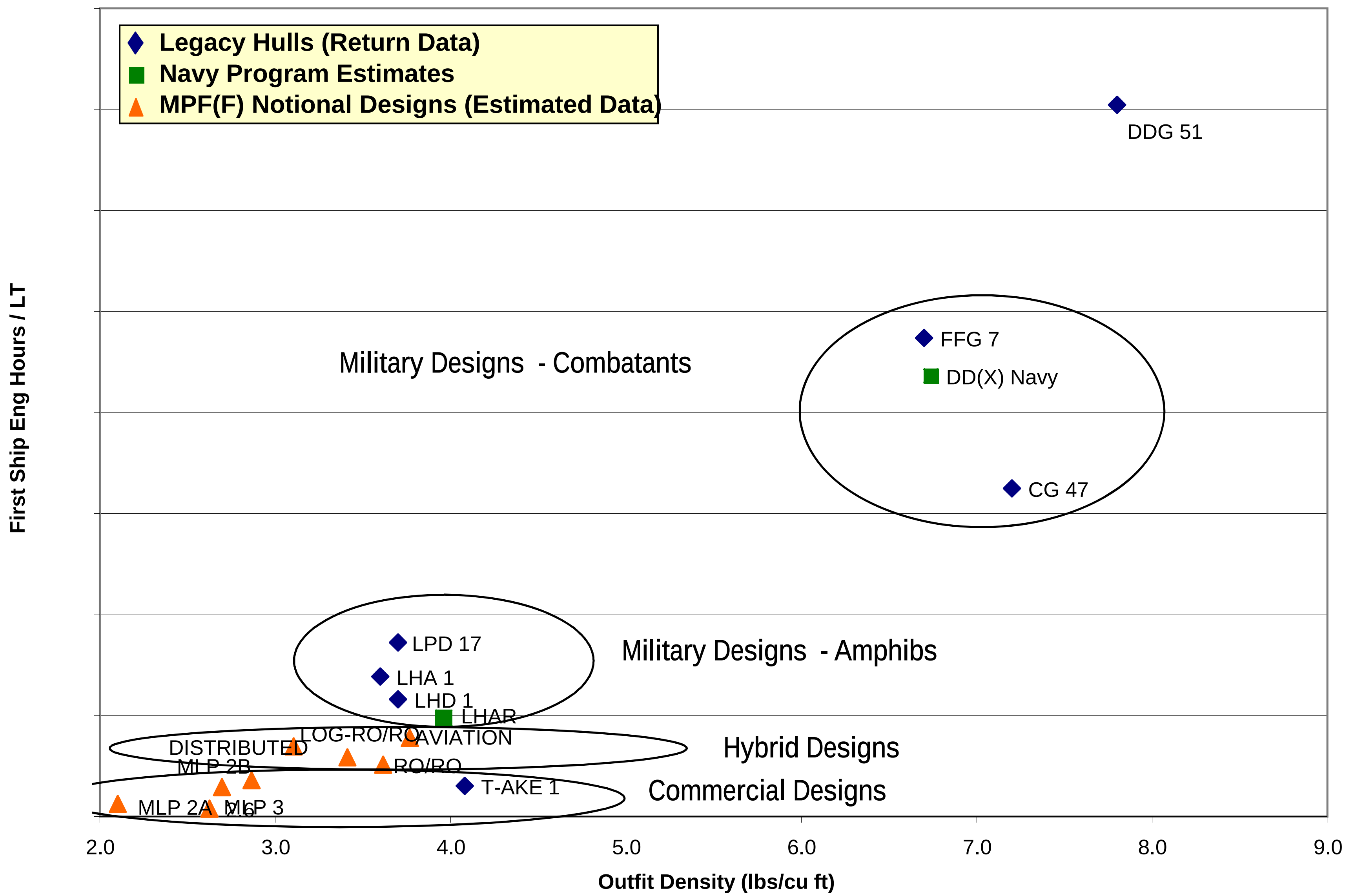
For ship development contracts, UCA effects, or contract work content growth, were significant!

Contract Cost Growth on Early Production Contracts (Post MS C)

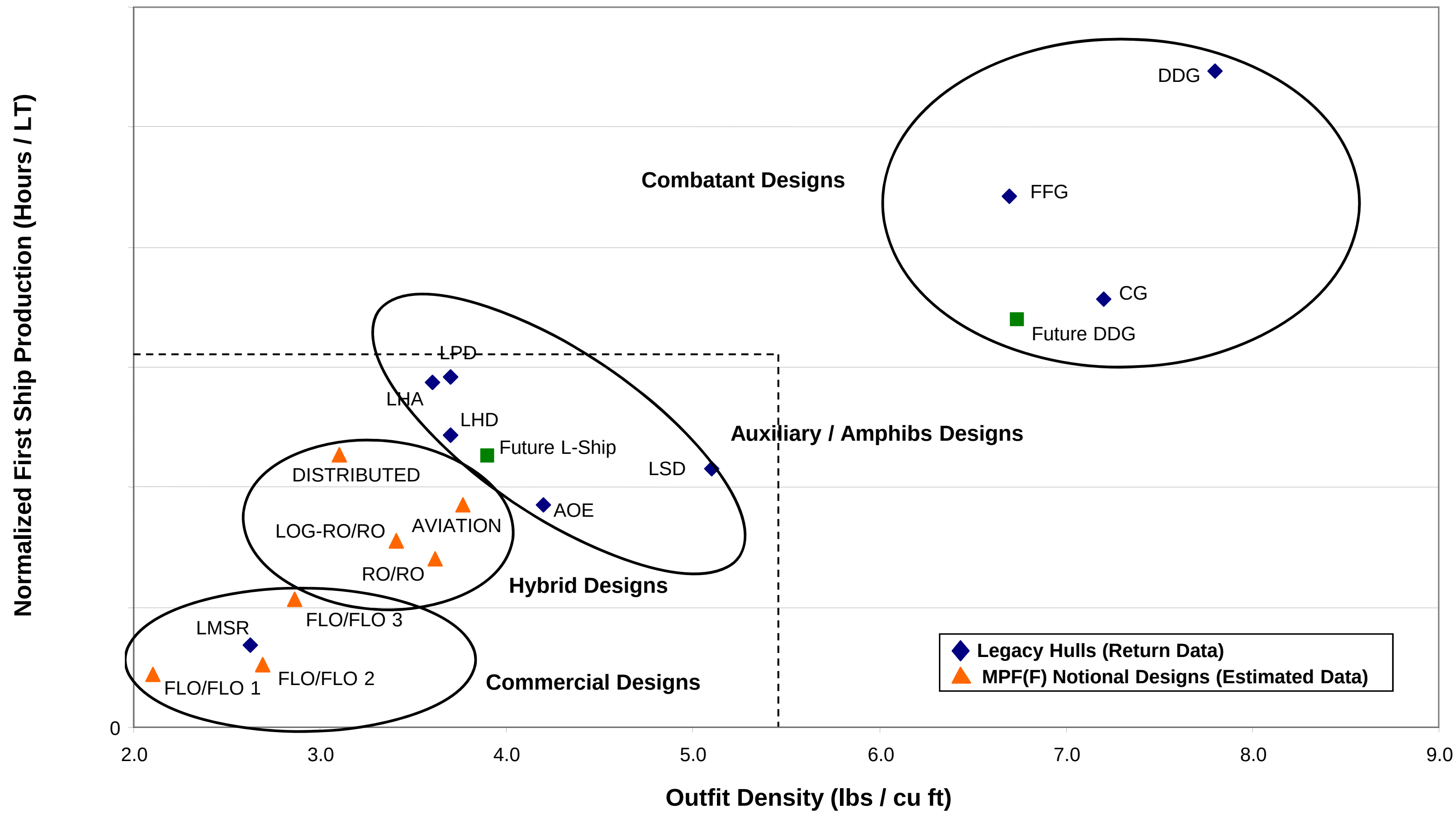
- For total cost growth from 1992–2011:
  - "The dominant statistical correlate of total cost growth was work content growth (as reflected in a higher contract target cost), which explained 95 percent of the variation in the data."
- Concurrent production when designs are unstable can impose added retrofit costs for early production products

AT&L case of early production contract cost growth due to "work added later": a DDG-51 contract

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.

Naval Ships Unnecessarily Cost Too Much to Design and Build

- Cost growth on development contracts correlates strongly with cost growth on production contracts
- NAVSEA Cost Group states Ship Production hours increase with ship outfit density
- National Shipbuilding Research Program report (NSRP, 2011) criticizes US naval ships for:
  - early design decisions that lock in density
  - poor arrangements of piping and ventilation

An overly dense ship with resulting complexity imbeds unnecessary work content in design

A SOLUTION: DESIGN OUT COMPLEXITY EARLY

- Lack of understanding of complexity and how to address complexity during early stage design
- Factors that influence product complexity:
  - number of components,
  - number of interactions/connections,
  - number of subassemblies,
  - geometry, shape, size, accessibility
- Need measures/methods to assess complexity during Design Space Exploration (DSE)

DENSITY ***:*** **best measure to use to reduce total-ship complexity during DSE in concept design**

Outfit Density as a Measure of Complexity

- LT Grant (NPS, 2008) found density is sufficient measure of tightness of ship arrangements
- Based on examination of density as it relates to work content and cost, Grant concludes:
  - weight-reduction efforts to reduce cost often result in opposite effect;
  - unnecessarily dense designs inevitably result in increased cost, schedule, performance risks

<u>DENSITY</u> **represents significant and under-emphasized driver of historic cost growth**

Impacts of Unnecessarily High Outfit Density

- Design tends to have more interferences, rework
- Work sequencing more difficult to plan, schedule
- Negative impacts compounded when combined with weight saving thin steel:
  - Constraints on penetration locations resulting in inefficient routing of distributive systems
  - Distortion and distortion removal impact outfitting
  - Delays and rework to paint and insulation
  - Impact on items requiring completion of paint and insulation behind them before their installation

When productivity decreases, labor hours increase

Impact of Outfit Density on Ship Construction Work Content

- European ship designers actively promote benefits of designing larger hulls (Gelling et al, 2010):
  - Better accommodate equipment and outfit systems
  - Better accommodate Service-Life Allowances for future upgrades
  - Reduce construction work content by making installation of equipment and systems easier
  - Improve access to systems during operations, maintenance and repair

Need a Process-Based not Weight-Based Cost Model to Account for *Density* and *Work Content*

Benefits of Reduced Outfit Density on Cost: A Demonstration

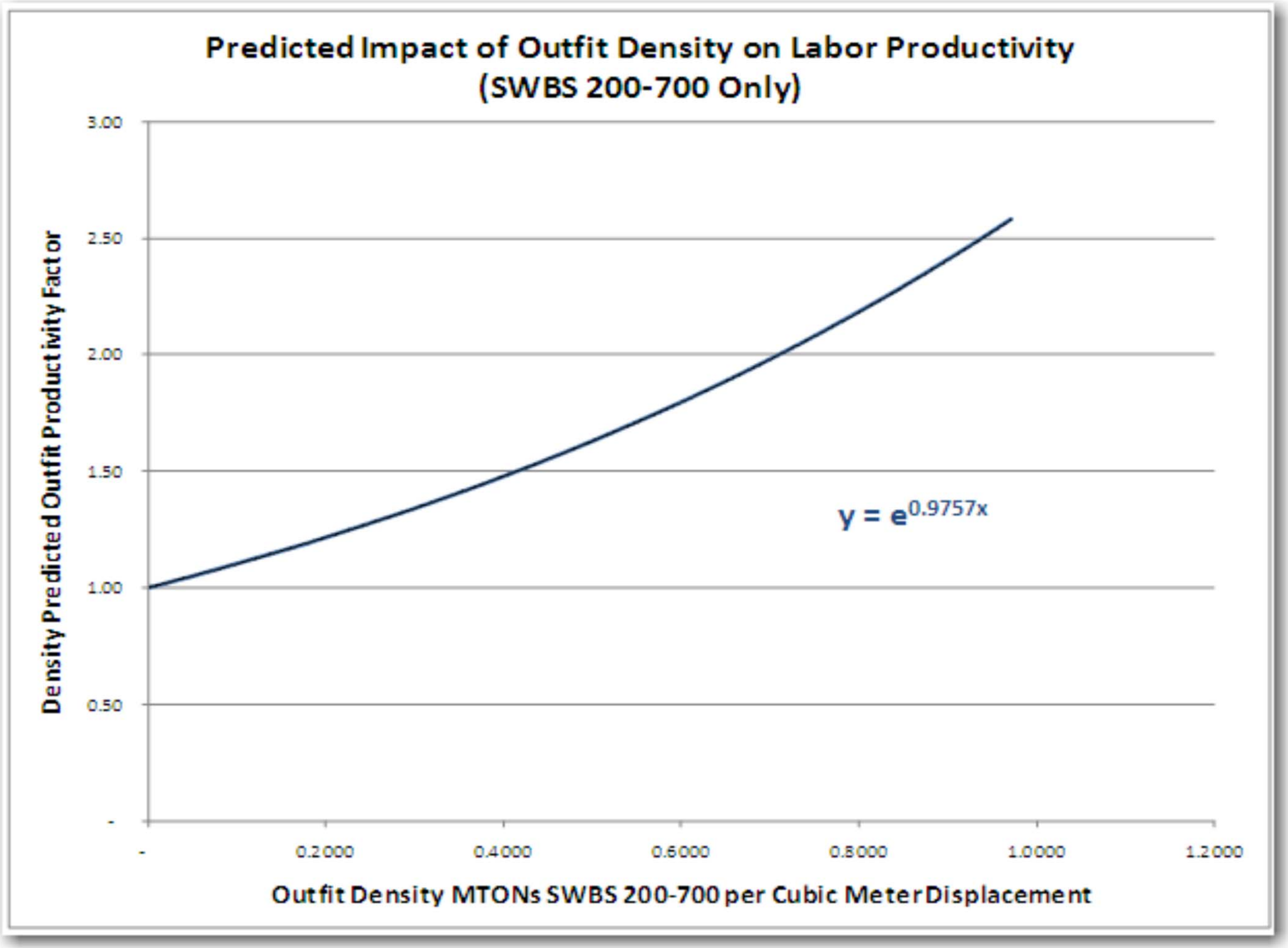
- Evaluated impact of ship density on production hours, material costs and total construction cost
- Based on comprehensive libraries of cost data for medium and high speed naval vessels
- Cost models produce estimates of shipyard manpower requirements by basic trades
- For concept design, cost model substitutes values based on analyses of existing ship designs

Product-Oriented Design And Construction (PODAC) Process-Based Cost Model Used

Shipbuilding Productivity Factors

- Developed 4 types of productivity factors for specific ship construction circumstances:
  - technical support (detail design)
  - structural manufacturing and assembly work
  - outfit manufacturing and assembly work
  - material costs
- Determined productivity factors for different ship types
- Plotted those against density factor for those same ships
- Developed formula that approximates the correlation curve

Produced figure showing predicted impact of outfit density on labor productivity

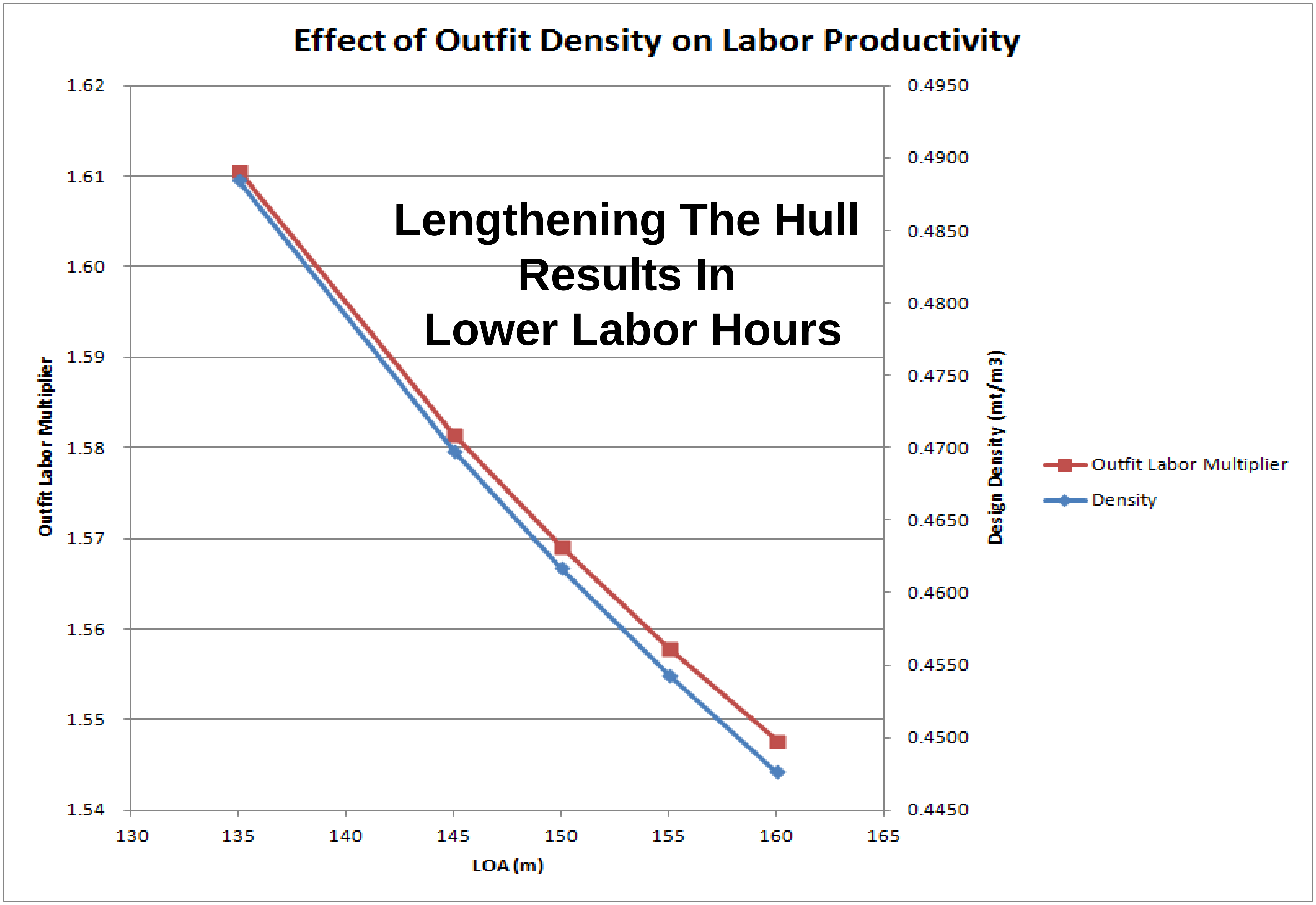


Predicted Impact of Outfit Density on Labor Productivity
(SWBS 200-700 Only)
3.00
2.50
2.00
1.50
1.00
0.50
-
Density Predicted Outfit Productivity Factor
y = e^0.9757x
-
0.2000
0.4000
0.6000
0.8000
1.0000
1.2000
Outfit Density MTONs SWBS 200-700 per Cubic Meter Displacement

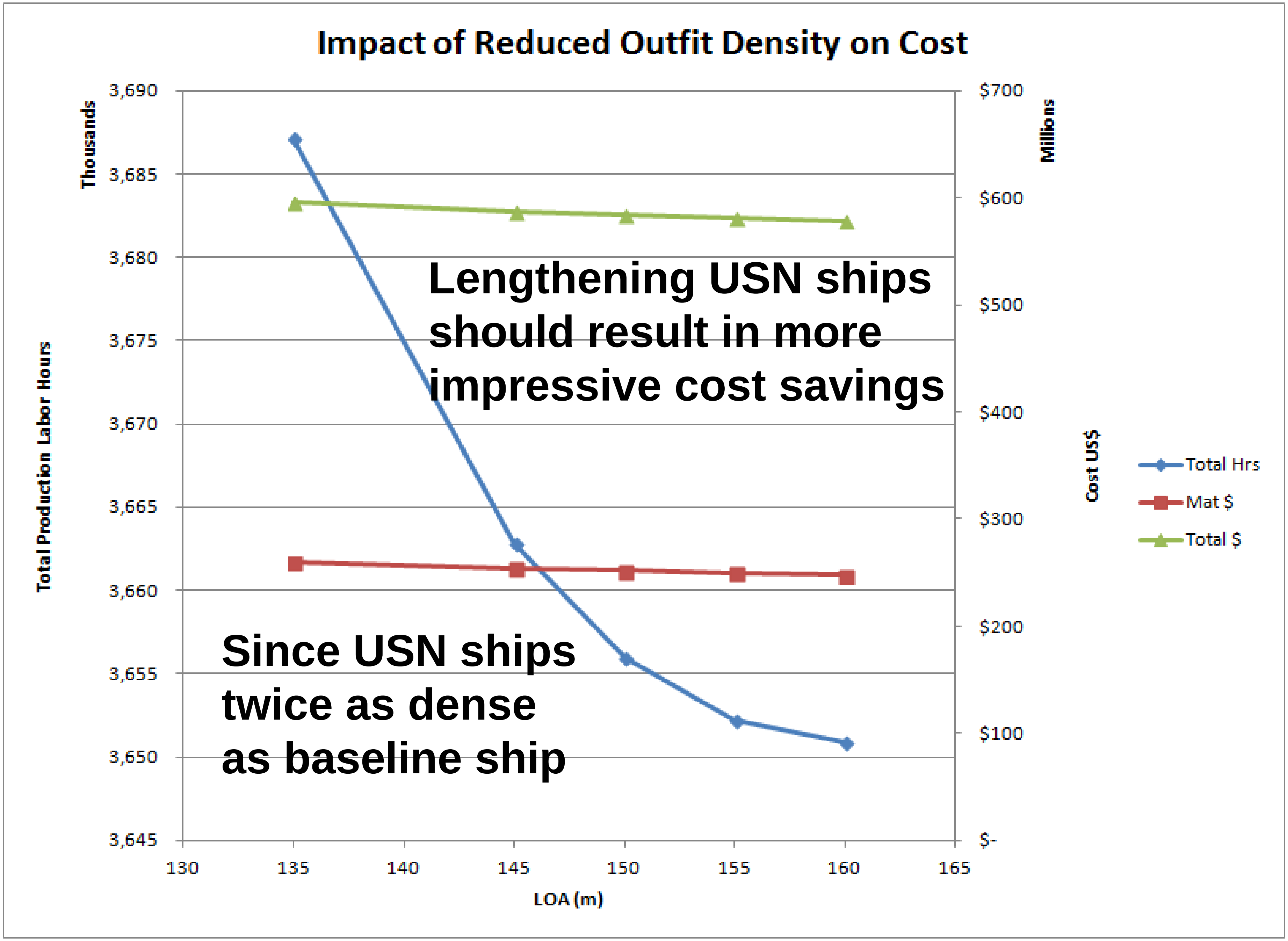
A ROM Parametric Ship Concept Study with PODAC Cost Model

- Varied length from 135 to 160 meters; baseline was 150
- Maintained other principal characteristics (e.g., speed)
- Structures changed with length (superstructure the same)
- Propulsion was variable, expecting with longer length, less power to maintain same speed
- Auxiliary systems followed propulsion system requirements
- General outfit the same except for hull insulation & coatings

Plots of Density and Corresponding Labor Hour Multiplier Versus Length Show Lengthening the Hull Can Result In Lower Labor Hours



Effect of Outfit Density on Labor Productivity
Lengthening The Hull Results In Lower Labor Hours
Outfit Labor Multiplier
1.62
1.61
1.60
1.59
1.58
1.57
1.56
1.55
1.54
Design Density (mt/m3)
0.4950
0.4900
0.4850
0.4800
0.4750
0.4700
0.4650
0.4600
0.4550
0.4500
0.4450
130
135
140
145
150
155
160
165
LOA (m)
Outfit Labor Multiplier
Density



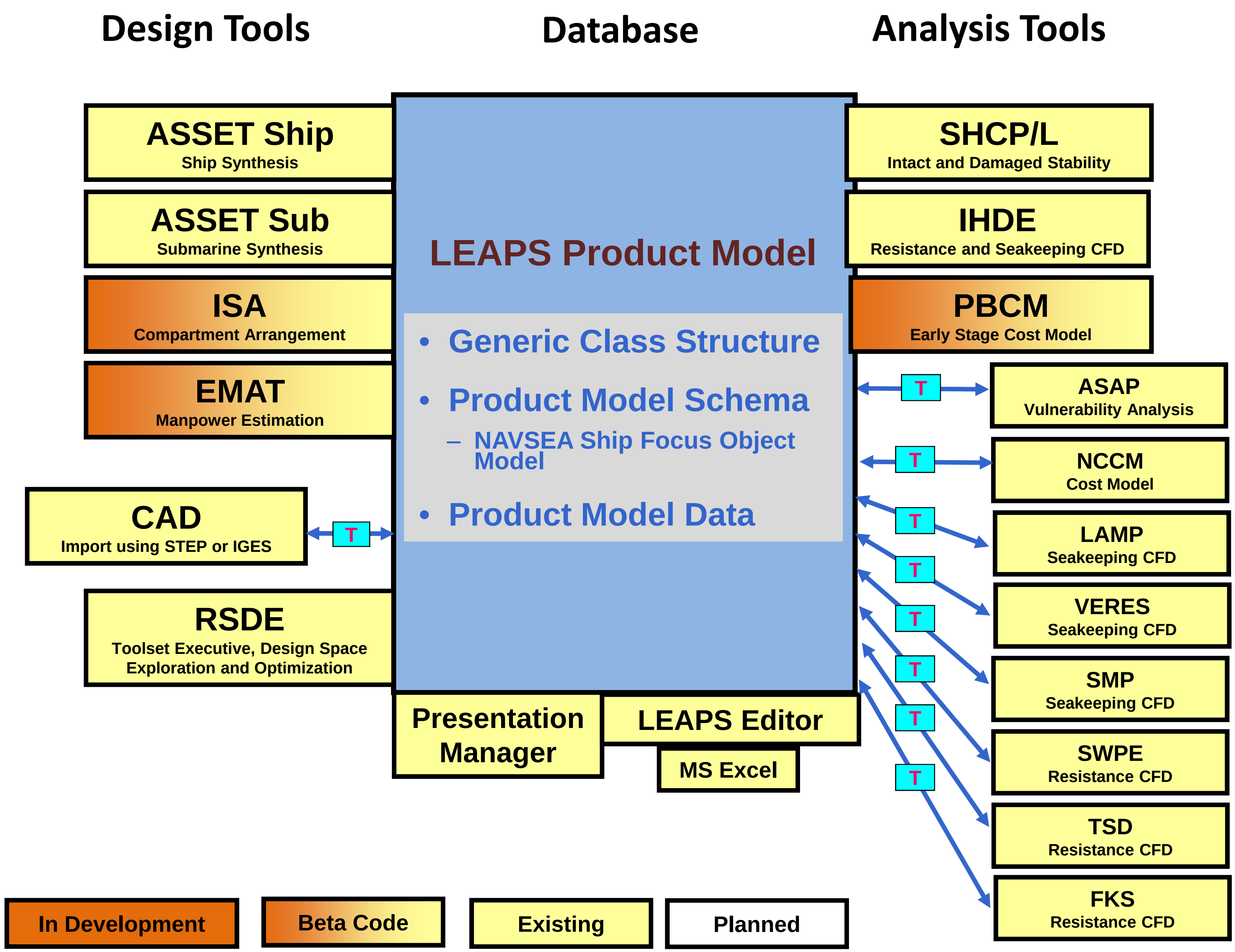
Impact of Reduced Outfit Density on Cost
Lengthening USN ships should result in more impressive cost savings
Since USN ships twice as dense as baseline ship
Thousands
Total Production Labor Hours
3,690
3,685
3,680
3,675
3,670
3,665
3,660
3,655
3,650
3,645
Millions
Cost US$
$700
$600
$500
$400
$300
$200
$100
$-
130
135
140
145
150
155
160
165
LOA (m)
Total Hrs
Mat $
Total $

MAJOR CONCLUSIONS

AT&L finding about contract work content growth combined with results of ROM parametric study:

- density impact on cost important to model early in sizing ship during concept design
- further work needs to relate density to Cost Estimating Relationships (CERs)
- a PODAC process-based cost model needs to be integrated with Navy early stage ship design tools
  - Rapid Ship Design Environment - RSDE
  - Advanced Ship & Sub Evaluation Tool – ASSET
  - Leading Edge Architecture for Prototyping Sys-LEAPS

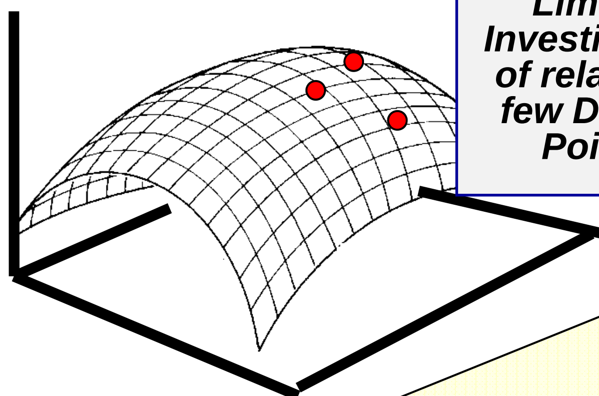
LEAPS Toolset



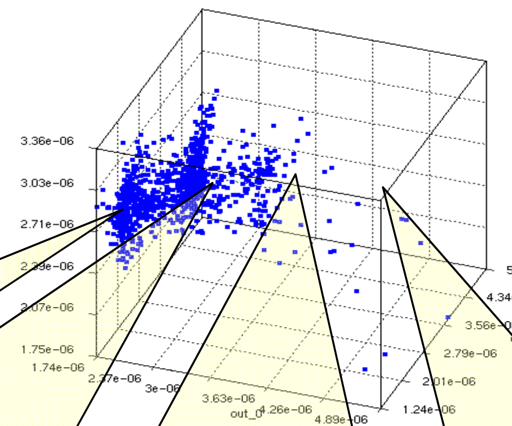
CREATE-SHIPS Project, DoD High Performance Computing Modernization Program (HPCMP)

- Computational Research & Engineering Acquisition Tools & Environments (CREATE)-SHIPS:
  - Build on NAVSEA's LEAPS Product Model and ASSET Total Ship Synthesis Tool
  - 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

Design Space Exploration via HPCMP CREATE-Ships RSDE



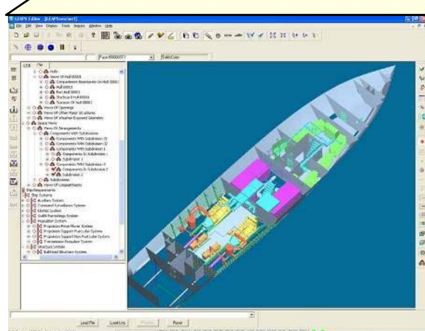
From…
Limited Investigation of relatively few Design Points



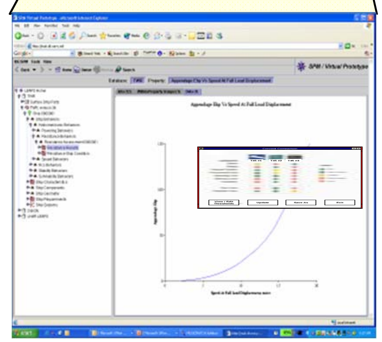
To…
Full Investigation of Concepts throughout the Design Space

HPC Enables Exhaustive Exploration by:

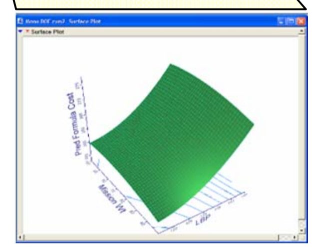
Generating
The Space



Exploring
The Space



Evaluating
The Space



*and **Visualization***

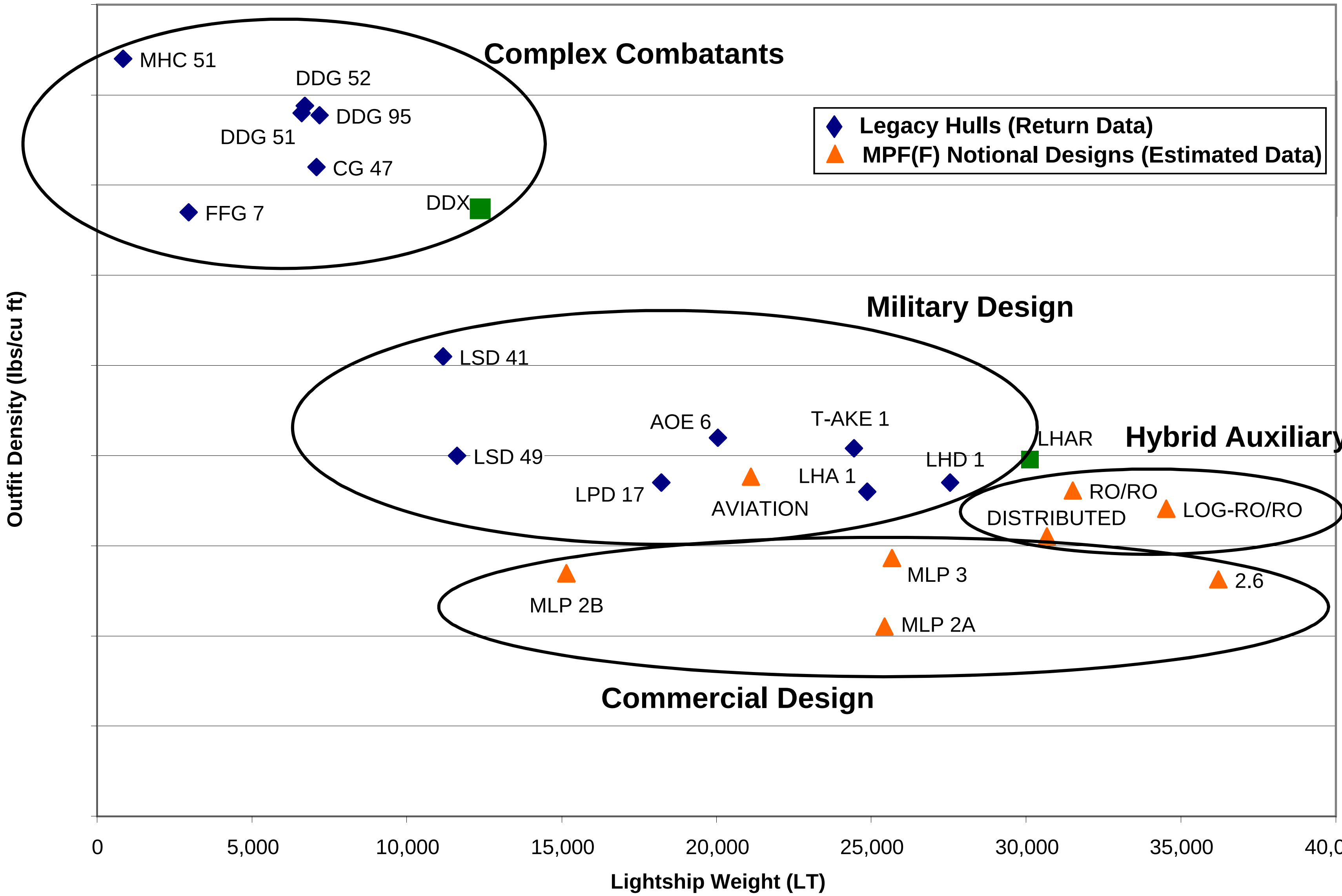
The Way Ahead

- Integrate PODAC model in LEAPS, store results in LEAPS, make work content part of design optimization, RSDE
- Explore wide range of design options to evaluate impact upon detail design and construction (DD&C) work content
- Relate outfit density computations to outfit productivity
- Calculate ship outfit density in ASSET, group by ship type and plot against man-hours for DD&C
- Organize actual man-hour data for range of ships into a relational data base
- Establish ship outfit density as discriminator in early stage naval ship design to reduce DD&C work content

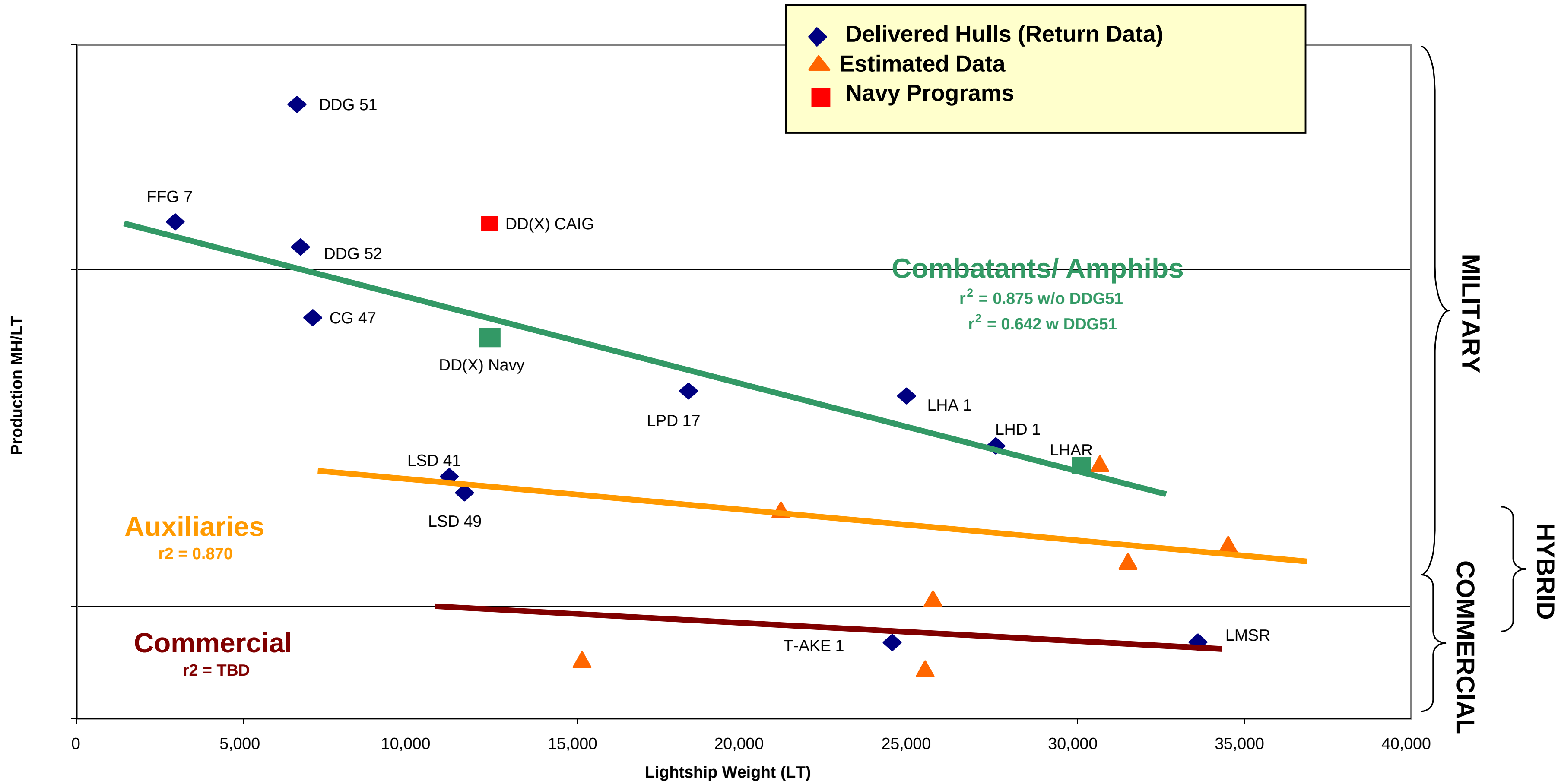
"Steel is cheap and air is free!" Director, Damen Schelde

BACK UP

Outfit Density vs. Lightship Weight (circa 2007)

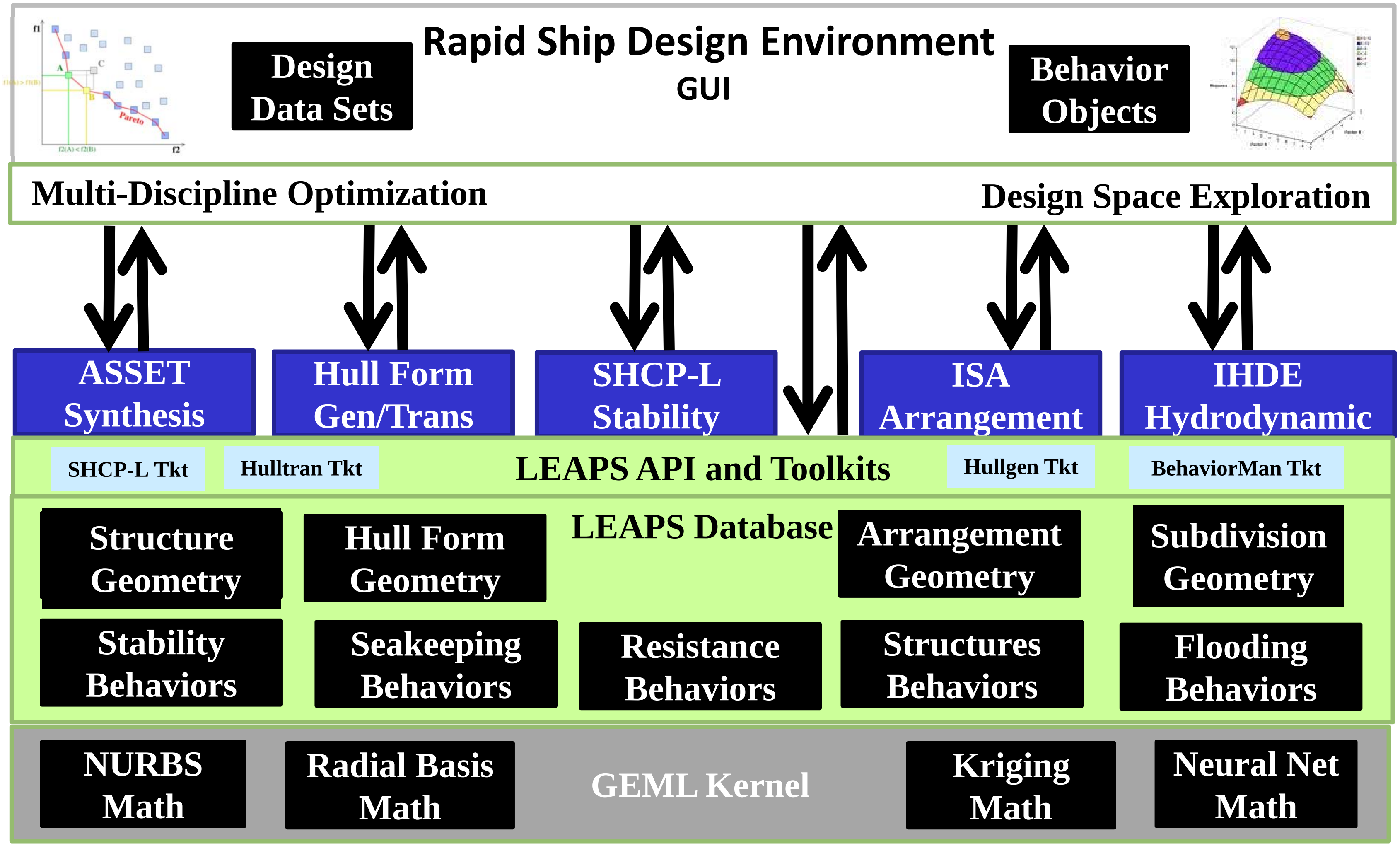


First Ship Production MH / LT vs. Lightship Weight



- *Navy PLCCE Hrs/LT statistically significant with historical lead ship performance…warts and all!*
- *DDG 51 anomaly due to lead ship redesign and 65% ramp up in shipyard personnel during construction.*

RSDE - Product Architecture



Importance of Flexible Ships: Selecting a Hull Sized Appropriately

- Damen Sigma Class modular design philosophy:
  - "***Oversized***" hulls to reduce installation, operations and maintenance costs
    - Increasing hull length by 20% only increases building cost by 1-3%.
    - Cost of larger hull far offset by savings for installation of equipment and distributive systems
  - Customizations by configuring essentially different ships from standard components
- Flexibility must start at ship concept design

Value-Added Design Philosophy: Rigorous Exploration of Larger Design Solution Space

Need for Physics-Based Design Tools in Early Stage Ship Design

- Earlier versions of Navy's Advanced Ship & Sub Evaluation Tool (ASSET) synthesis model inadequately addressed
  - Arrangements Seakeeping
  - Damage Stability Structures
- Leading Edge Architecture for Prototyping Systems (LEAPS) developed to integrate physics-based tools in a common data environment
- Rapid Ship Design Environment (RSDE) being developed by HPCMP-CREATE Program integrates ASSET & LEAPS for exploring trade space leading to large set of designs

RSDE not based on single concept design points such as traditional design spiral method

Ship Cost History since 1980

Navy historically UNDER estimates lead ships by ~20%...

	SHIP Qty	AVG (Qty)	Weighted by Cost
1980s Reagan Build-up	**14**	**10%**	**1%**
1990/2000s Low Rate Production	5	**50%**	**20%**
Overall	19	**20%**	**21%**

Navy historically OVER estimates follow ships by ~6%...

	SHIP	AVG (Qty)	Weighted by Cost
1980s Reagan Build-up	**129**	**-9%**	**-5%**
1990/2000s Low Rate Production	76	**4%**	**1%**
Overall	205	**-4%**	**-6%**

Once the Navy has REALIZED the cost of its warships, they have delivered *under* the original budget set two years before award.

So when does cost realism become cost growth?

Importance of Design Team Experience on Acquisition Outcomes

Lead Ship Cost History Since 1980

Navy historically UNDER estimates lead ship cost growth

	SHIPS Qty	AVG Growth	Weighted by Cost
1980s Reagan Build-up	**14**	**10%**	**1%**
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Outcomes far better with an experienced NAVSEA Design Team

	Contract Type	**No. of Ships**	**Designed by**
1980s Reagan Build-up	**Fixed Price Plus**	**Many**	**NAVSEA**
1990/2000s Low Rate Production	**Cost Plus**	**Few**	**Contractors**

Many factors affect Lead Ship Cost, but obviously the Experience of the Design Team is a major factor.