Naval Engineering S&T Needs from Perspective of Ship Designers

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- Total of 45 years of Naval Ship Design experience
  - Leadership positions on 50 Navy Contract Designs (CDs)
  - Navy’s final technical approval authority for 35 CDs
- 35 years at NAVSEA, 21 years of which were as a member of the Senior Executive Service (SES)
  - Chief Naval Architect
  - Total Ship Systems Engineering Technical Authority
  - Chief of Ship Design
  - Director of Ship Survivability
  - Hull Form Design Technical Authority
- Last 6 years, conducted ship design research for Navy’s Center for Innovation in Ship Design (CISD) and OSD’s CREATE-SHIPS Project
- Since 2006, Chair of SNAME-ASNE Joint Ship Design Committee
Session One: Future Needs for S&T Output

- Constituency Represented
  - Naval Ship Design Engineers, Early Stage Design

- How S&T drives our enterprise
  - Provides physics based knowledge to design cost effective warships

- Leading Naval Engineering S&T and Human Capital Needs
  - Integrated, validated physics based design analysis tools
    - developed by subject matter experts,
    - can be used by ship design engineers,
    - pre-processing to reduce time to solution,
    - post-processing to aid decision-making
  - A well spring of highly competent, highly motivated, experienced naval ship design engineers
Problem Statement

- “Unbudgeted cost growth in shipbuilding programs has reached an untenable level” – ASN (RDA)
- “US designs have more complexity for similar type products” – OSD Global Shipbuilding Study
- “U.S. shipbuilders require greater than twice the design labor hours and cycle time” – NSRP Strategic Investment Plan
- “lack of design maturity when introducing new technologies led to rework, increasing growth in labor hours” - GAO

“Greatest Leverage is Design, Engineering, and Production Engineering” - OSD Global Shipbuilding Study
# Need More Integration of Definition and Analysis Tools Throughout Ship Design

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<th>Selection of Other Ship Design Analyses</th>
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Simulation & Analysis Tool Development in bad shape due to years of neglect in investment
S&T to Reduce Cycle Time and Cost Growth

- Need early design tools to estimate/predict ship’s weight and volume

- Hull is sized & shaped based on early design weight estimate and assumption volume is “arrangeable”

- Current practice – “Outside In Design” – design hull form and then try to fit everything in that hull
  - Reason why Ship Arrangements are unstable well into Detail Design

Need Intelligent Ship Arrangements Tool and other Architecture Tools
First Ship Engineering MH / LT vs. Outfit Density

- Legacy Hulls (Return Data)
- Navy Program Estimates
- MPF(F) Notional Designs (Estimated Data)

Legend:
- Military Designs - Combatants
  - FFG 7
  - DD(X) Navy
  - CG 47
- Military Designs - Amphibs
  - LPD 17
  - LHA 1
  - LHD 1
- Hybrid Designs
- Commercial Designs
Ships Possessing Greater Density Increase Production Cost

Ship Production hours increase with density and fall into predictable groupings.
“Inside Out Design”: Create internal arrangement, then fit hull form: NSRP Project 21

Creating the base ship model:
Developing a model requires the internal functional volumes to be bounded by a suitable hull form. As such, the hull form is shrink-wrapped to the required internal volume using the appropriate design rules.

However, while compromises will be made in both compartmentalization and hull performance, the final result will overall be more functionally efficient base design. Which due to being created from product-oriented interim products will be intrinsically producible from the initial concept stage.
Design for Production Technology: “Inside Out Design” Approach


**Community-wide Workshop** (1989). Integration Team Report on **Critical Needs**:  
- Training  
- Design Tools  
- 3-D CAD  
- Cost Models  
- Eval Framework

**Mid-Term Sealift Technology R&D Program** Plan Emphasized Producibility (1989-90)

**Engine Room Arrangement Module (ERAM) Innovation Team** (1992-97) Navy-Shipbuilders-Academia-Collaborative, Multidisciplinary

**ERAM Integrated Product Team (IPT) Explored New Tools & Processes**:  
- Concurrent Engineering Process  
- 3-D Product Model/IPDE  
- Hierarchy of Building Blocks Technology

**Strategic Sealift Ship Acquisition Program Successful Outcomes**

INNOVATION IMPLEMENTED!
**Producibility Depends on Stable Arrangements**

- Sealift (LMSR-Engine Room Arrangement Module only)
  - Engine room cost reduced 57% (from $58M to under $25M)
  - Design time reduced 45% (from 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 ship delivered on time & within budget**
Historical Lead Ship Cost Performance Index (CPI) Trends

Annotations Added
Better Cost Engineering Tools

- NAVSEA standard cost models have limited effectiveness during early stage ship design
- Weight based Cost Estimating Relationships provide limited insight when making subsystem tradeoff decisions
- Legacy ship cost models are particularly limited when estimating cost of software intensive systems
- Design for Producibility changes that are cost effective result in increased cost estimates in weight-based model

**Need ship cost models based on how ships are designed and built: Product Oriented Design & Construction (PODAC)**
S&T to Improve Warfighting in the Ocean Battlespace

“...In time of war, when combat objectives rise above all other priorities, it is not the rule to bestow grave concern on incidental dangers. Planes do not stay grounded and fleets do not run scared because of ugly weather if in doing so they jeopardize military or naval missions.”

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
Navy’s Concern: Large Amplitude Motions in the Ocean Battlespace

- Ability to perform missions in moderately high sea states.

- Ability to survive in extreme sea states:
  - Susceptibility to capsizing
  - Structural integrity
    - Primary structural loads from ship motions
      » including structural fatigue from hundreds of thousands of load cycles over life of ship
    - Secondary loads from wave impacts
      » Including whipping of primary structure that can affect its fatigue life
Seaway Loads for Design of Surface Combatants: Rule-Based

- Structural Design of FFG 7, CG 47, DDG 51 Classes
  - Interested more in extreme loading conditions than in actual working loads
  - Worked with simplified loading envelopes
    - establish maxima of various load conditions
    - which have reasonable probability of occurring simultaneously
  - Deterministic analysis of bending moments and shear forces resulted in scantlings for maximum load expected
  - Highly random wave-induced loads acting on structural members was a simplified set of hydrostatic loads under extreme sea conditions
  - This gross simplification was thought to be adequate for conventional hull girder designs (longitudinally-stiffened, steel monohull)

No Analytical Computations nor Seakeeping Model Tests During PD/CD to Determine Seaway Loads
Lack of Physics Based Tools: Increased Ownership Costs

- **FFG 7 Class**
  - Hull girder doubler plates & ballast added due to weight growth
  - Extensive deckhouse fatigue cracking (seaway load cycles)

- **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 have exceeded design loads**
  - Design loads based on standard rule-based loads
  - Model test data support operational loads

**Ownership Costs:** $100M’s/$B’s in repairs and sustaining service-lives

**Warfighting Capabilities:** months not in service, operational restrictions
Issues with current performance assessment methods

- Analytical/computational tools for prediction of extreme, non-linear motions have been in development for years

- Model experiments conducted in random waves require long test run times to ensure that critical wave events which are probable in the seaway have been encountered

- Panel test pressures to structural design loads – experimental to analytical methodology not well defined

- Intact and Damage Stability computations (like Ship Hull Characteristics Program-SHCP) need to account for variations of waterplane in waves

- No appropriate computer prediction tools to assess damaged ships (progressive flooding, structural integrity)
Modeling Critical Wave Groups to Address Technical Risks Early

- NSWCCD goal is to construct a focused technical test by modeling critical wave events early in design to prototype high technical risks
  - Groups of critical waves can be used to assess both Dynamic Stability and Secondary Structural Loads for ships
    - Design Load Generator (DLG) reduces time to solution
    - Learn more by testing where probability of failure is >50%
  - Develop a deterministic model testing technique
    - Reduces testing time in the model basin
    - Increases confidence in extreme event assessment
    - Can address lack of VV&A of analytical methods
  - Can resolve very complex technical issues early in design

NEED A MULTIDISCIPLINARY APPROACH FOR MODELING WARSHIPS IN THE OCEAN BATTLESPACE
Modeling Warships in the Ocean Battlespace: Vision

Physics based software products developed as part of an Integrated Structural Design Environment (ISDE) being used throughout the Navy, other Government organizations, and industry for:

- Timely Design and Construction of New Ships with Extended Service-Life
- Maintenance and Repair Decisions for Sustaining Service-Life of Ships In-Service
- Operator Guidance for Reduced Ownership Costs of Ships In-Service
- Development of high strength, light weight, low maintenance steel and aluminum alloys
Need an Enterprise Approach as originally conceived for NNRNE-CISD

• ONR, NAVSEA and NSWCCD need to work together more as a Navy Surface Ship Research & Systems Engineering Enterprise

• This type of Enterprise approach of the ONR-NAVSEA-NSWCCD Ship Hydrodynamics leaders worked well in the past
  – Resulted in the Navy’s Ship Motion Program (SMP) and Propulsor Design Codes, which have been industry standards since early 1980’s

• Navy’s Center for Innovation in Ship Design (CISD) should be the forum for such a Collaborative Enterprise
Building a Collaborative US Enterprise

ONR/Universities’ Cooperative Research Program (6.1/6.2 RDT&E)

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<td>Laser &amp; Welding Robot Technologies</td>
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Government - Academia - Industry

Collaborative Ship Product Development Environment

Ship ConForm Innovation Cells

“Winning” Ship Designs

Successful Ship Acquisitions

REDUCE CYCLE TIME

INCREASE THROUGHPUT

Shipbuilders’ NSRP (6.7 RDT&E)
“THE OCEAN IS THE NAVY’S BATTLESPACE” – RADM CARR, CNR

THE WAY AHEAD

INVEST MORE IN SHIP DESIGN/PLATFORM TECHNOLOGIES!
TAKE A COLLABORATIVE, MULTIDISCIPLINARY APPROACH
References on Needs of Ship Designers

- SNAME SPS Paper, “Leading a Sea Change in Naval Ship Design: Toward Collaborative Product Development”, Keane, Fireman and Billingsley, August 2005 (NSRP Best Paper Award)
- NSWCCD Report, “Ship Design Management (SDM)– Human Capital Strategic Plan (HCSP)”, Keane and Hough, 2006
- NAVSEA Seakeeping Workshop Report, 1975
Back Up
Why S&T for Ship Design Tools?

- Reduce design/acquisition cycle time
- Avoid acquisition cost growth
- Reduce ownership costs
  - Maintenance and repair
  - Fuel consumption
  - Modernization
- Increase service-life of warships
- Improve warfighting capabilities
- Increase productivity of design engineers
- Capture intellectual capital of aging workforce
The Technical Challenge of the Ocean Battlespace

- Surface Ships operate at the interface between two media,
  - Subs and Aircraft operate in one medium
- Air-Sea Interface is the technical challenge for Surface Ship designers
- Interface is 3-D, Non-Linear Free Surface Effect
- Design tools must model the physics of the Free Surface
Navy’s Concern: Structural Integrity in the Ocean Battlespace

- Hull structural girder must be designed to withstand primary loads,
  - including structural fatigue that results from experiencing hundreds of thousands of load cycles over life of the ship.

- Secondary and tertiary loads affect local structure and result in failures to local plating and/or substructure due to extreme local pressures.
  - Wave impacts can also result in whipping of primary structure that in turn can affect its fatigue life.
The Chief of Naval Operations’ Ship Operational Characteristics Study (SOCS) of 1988 recommended that ships continue to be able to fight after sustaining damage.

However, there was a lack of ship performance data of partially flooded or flooded ships in waves and wind:
- Progressive Flooding
- Structural Integrity

No appropriate computer prediction tools to assess damaged ships, especially in waves:
- Naval ship designers still do not have these tools

Also important for intact ships to be able to conduct operations in waves, especially over a larger range of wave conditions than an enemy.
Historically, has been a combination of

- practicing established naval architecture rules,
- performing analytical computations and numerical simulations, and
- conducting model experiments.

Model testing became a tool for

- confirming or correlating design decisions,
- investigating nonlinear behaviors which could not be analytically predicted, or
- examining specific problem areas for active fleet assets.
Design of Surface Combatants: Why No Computations/Tests?

- **Analytical Computations:**
  - Serious limitations: linear, 2-D, potential flow, wall-sided hulls (codes available when these designs took place)
  - Large amplitude programs not adequately validated; R&D codes which can only be routinely run with assistance from developers; too long to get results
  - **Inability to rigorously predict local loads**

- **Model experiment techniques:**
  - Regular waves - lack of realism in representing ocean environment
  - Random waves - insufficient test time to ensure exposure to the most extreme waves within a seaway

- **Both require high level of ship definition**
NEED A MULTIDISCIPLINARY APPROACH FOR MODELING WARSHIPS IN THE OCEAN BATTLESPACE
Modeling Warships in the Ocean Battlespace: Mission

Develop A Suite Of Physics Based Analysis Software In The Framework Of An Integrated Structural Design Environment (ISDE)
For The Timely Prediction Of Ship Structure Response To The Ocean Battlespace
Integrated Structural Design Environment (ISDE): Reducing Time to Solution & Ownership Costs

- **STATIC** TENSION
- **STATIC** BUCKLING
- DAMAGE TOLERANCE
- **STATIC** TENSION
- CRACK PROPERTIES

### Design Study Tools

- DESIGN TRADE-OFF STUDIES
- STRUCTURAL OPTIMIZATION
- AUTOMATED VALIDATION CASES

### Simulation Tools

- ULSTR
- SSDP
- DYSMAS II
- SPECTRA
- NASTRAN
- Probabilistic Methods
- SHCP

### Key Features

- **Locally High Performance Computing**
- **Driver/GUI**
- **ASSET/LEAPS**

### Analysis Capabilities

- **.loads:** Seaway, Weapon Effects
- **Material Properties:** Aluminum, Steel
- **Geometry:** Wts, Mfg. Conditions
- **Automated Gridding**

### Additional Tools

- DYSMAS II
- Modeling of Critical Wave Groups
- Integrates Software Developed by CREATE-SHIPS

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**SHOCK/ DAMAGE**

**FATIGUE**
Designing in Costs: Costs committed to product’s lifecycle very early

Figure 9: Designing-in costs. Although the majority of the costs associated with a development program are not incurred until late in the project, costs are committed to the product’s lifecycle very early. (Adapted from Anderson, p. 132)
Warfighting Effectiveness Tools

- Must relate results of analysis programs to ability of ship to perform its missions
  - Post processing of data in form for decision-makers
  - Design enabling communication tools capturing subjective knowledge (expert opinion)

- Ship Mobility is a priority area
  - Comparison of fuel costs for Major Combat Operations
  - Speed and Maneuvering for evading incoming missiles

- Impact of Hull/Integrated Topside Design on Advanced Radar Performance

- Impact of H,M&E Reliability, Availability & Maintainability on Combat System Performance
Declining Naval Ship Design Capability

- Current Status

Staff
Tools
Specs
Process

Communications
Requirements Understanding Evolves During Design but Influence to Impact Decisions Declines

Figure 11: Evolution of design knowledge. Though it increases fairly rapidly, designers’ knowledge about a new product is quite low early in the product’s development. (Adapted from Reimertsen, p. 15)

Figure 10: The diminishing power to make changes. The further a development project progresses, the less power both managers and engineers will have to influence its final outcome. (Adapted from Wheelwright and Clark, p. 33)
Improving DDG 51 Efficiency
A Cost Effective Shipyard For The Future

- Move work/scope to earlier stages
- Reduce duration of Water/Test phase

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<th>Last Inclined Ways Ship</th>
<th>Fab 15%</th>
<th>Pre-Outfit 27%</th>
<th>Ways 22%</th>
<th>Water/Test 36%</th>
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<td>64% of scope prior to Water</td>
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<td>2005 5th LLTF Ship</td>
<td>Fab 16%</td>
<td>Pre-Outfit 34%</td>
<td>LLTF 35%</td>
<td>Water 15%</td>
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<td>85% of scope prior to Water</td>
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<td>2006 9th LLTF Ship</td>
<td>Fab 16%</td>
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<td>First Mega Unit</td>
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<td>85% of scope prior to Water</td>
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Bath Iron Works
A General Dynamics Company

August 2007 40