Ship Distortion Control and Production Process Improvements of Thin plate Structures

NSRP Planning, Production Processes and Facilities Panel Meeting
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Ingalls Shipbuilding
Ingalls Shipbuilding has been designing, building, overhauling and repairing a wide variety of ships for the U.S. Navy, the U.S. Coast Guard and world navies. Today, Ingalls builds more ships, in more ship types/classes, than any other U.S. naval shipbuilder.

- Multi-Purpose Amphibious Assault Ships (LHAs)
- Amphibious Transport Dock (LPDs)
- Aegis Destroyers (DDG 51)
- USCG National Security Cutters (NSC)
USS America (LHA-6)

- The latest multifunctional and most versatile amphibious assault ship

- Enhanced aviation capabilities centered on (STOVL) F35B Joint Strike Fighter Jets and MV-22 Osprey tilt-rotor

<table>
<thead>
<tr>
<th>LHA-6 Class Specs</th>
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<tbody>
<tr>
<td>CREW SIZE</td>
<td>3,075</td>
</tr>
<tr>
<td>LENGTH</td>
<td>844 feet</td>
</tr>
<tr>
<td>WIDTH</td>
<td>106 feet</td>
</tr>
<tr>
<td>SPEED</td>
<td>22 knots</td>
</tr>
<tr>
<td>DISPLACEMENT</td>
<td>45,000 tons</td>
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Crew Breakdown

<table>
<thead>
<tr>
<th>Crew</th>
<th>Troops</th>
</tr>
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<tbody>
<tr>
<td>1,204</td>
<td>1,871</td>
</tr>
</tbody>
</table>
LPD 17 (San Antonio Class) Amphibious Platform Dock

- Transports Marines, their equipment, and supplies by conventional landing craft and assault vehicles, augmented helicopters or other rotary wing aircraft.

- Support amphibious assault, special ops, or expeditionary warfare and humanitarian missions.

Crew Breakdown

<table>
<thead>
<tr>
<th>Sailors</th>
<th>360</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marines</td>
<td>800</td>
</tr>
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</table>

LPD 17 Class Specs

<table>
<thead>
<tr>
<th>CREW SIZE</th>
<th>1,160</th>
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<tbody>
<tr>
<td>LENGTH</td>
<td>684 feet</td>
</tr>
<tr>
<td>WIDTH</td>
<td>105 feet</td>
</tr>
<tr>
<td>SPEED</td>
<td>22 knots</td>
</tr>
<tr>
<td>DISPLACEMENT</td>
<td>25,000 tons</td>
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</table>
Arleigh Burke (DDG 51 - Flight 1)

- Surface combatants built for the U.S. Navy
- Destroyers are the backbone of the Navy surface fleet

<table>
<thead>
<tr>
<th>DDG 51 Class Specs</th>
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<tbody>
<tr>
<td>CREW SIZE</td>
<td>303 sailors</td>
</tr>
<tr>
<td>LENGTH</td>
<td>505 feet</td>
</tr>
<tr>
<td>WIDTH</td>
<td>67 feet</td>
</tr>
<tr>
<td>SPEED</td>
<td>30 knots</td>
</tr>
<tr>
<td>DISPLACEMENT</td>
<td>8,230 tons</td>
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</table>
USCG National Security Cutter (NSC)

- Centerpiece of the U.S. Coast Guard fleet replacement program
- Flag Ship of U.S. Coast Guard
- Most technically advanced high endurance cutter in existence

**USCG NSC “Legend” Class Spec**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>CREW SIZE</td>
<td>120 sailors</td>
</tr>
<tr>
<td>LENGTH</td>
<td>418 feet</td>
</tr>
<tr>
<td>WIDTH</td>
<td>54 feet</td>
</tr>
<tr>
<td>SPEED</td>
<td>28 knots</td>
</tr>
<tr>
<td>DISPLACEMENT</td>
<td>4,500 tons</td>
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</table>
Thin Steel by Ship Type

Thin Steel Proportions by Erected Weight and Square Footage of Plates Processed

Defined as ≤ 3/8" (15.3#) Plate

- LHD/LHA: 33% by Weight, 45% by SQ. FT.
- LPD: 31% by Weight, 61% by SQ. FT.
- DDG: 43% by Weight, 58% by SQ. FT.
- NSC: 76% by Weight, 80% by SQ. FT.
Thin Steel Ships Require New Thinking

- Stronger HY and HSLA steel alloys allow thinner plates to reduce weight while maintaining tensile and shear strength requirements.

- Buckling strength dominates thin panel construction.

- Need best practices to control distortion in all operations:
  - Engineering design needs to focus on the producibility of thin steels.
  - Ship production needs to focus on optimized processes.
Modern Naval Ship Design Construction

- Thin steel hulls have become a current trend in Naval Surface Combatant designs
  - Incorporates thinner and higher strength steel panels and structures
  - Designs increasingly becoming more light weight to increase mission capabilities
  - Meet operational objectives and improve vessel performance
  - Counteracts increase in weight due to automated equipment and weaponry
  - Naval vessels will increasingly trend toward use of thinner, light weight/high strength steel designs

- Thin steel designs cause significant fabrication difficulties
  - Residual weld stress induced-distortion due to high heat input on thin steel
  - Panel shrinkage and dimensional control issues
  - Workforce training with techniques needed to mitigate thin steel construction difficulties
  - Need to overcome the challenges of implementing newer unfamiliar technologies to aid in reducing production costs and schedule issues with thin steel fabrication
Project Team Members and Roles

- Ingalls Shipbuilding: Project lead
- The Ohio State University: ICME material modeling, residual stress
- University of Michigan: Distortion measurement and modeling
- Mass. Institute of Technology: Cost and process flow modeling
- Edison Welding Institute: Residual stress, shop floor implementation
- ESI – North America: ICME, distortion model software developer
- NSWC – Carderock Division: ICME material modeling, structural testing
- American Bureau of Shipping: Classification and design consulting
- Comau: Innovative fixturing support

Linking leaders in fabrication, technology, and manufacturing innovation
Project Objective and Strategy

- This LIFT project will bring together world class engineering and manufacturing experts in distortion modeling, distortion mitigation, cost modeling, and production innovation.

- Identify areas of lightweight steel manufacturing that present the greatest challenges to the shipboard application of lightweight structures.

- Develop novel, multi-scale, integrated computational materials engineering (ICME) based prediction tools for modeling applications in lightweight material manufacturing.

- Validated ICME tools can be used to quantify distortions associated with the build process to improve:
  - Storage, lifting, and handling of structures
  - Fitting and welding processes
  - Design of unit structures and erection joints
  - Weld and build sequencing
Project Technical Subgroups

- In order to efficiently manage the work on the project, five technical subgroups were created based on the critical tasking related to the project’s goals
  - Dimensional Control & Measurement team
    - UM and HII
  - Cost Modeling & Process Development team
    - MIT and HII
  - ICME Modeling, Testing, and Validation team
    - ESI, EWI, OSU, NSWCCD, UM, ABS, and HII
  - Residual Stress Measurement team
    - EWI, NSWCCD, OSU, UM, ABS, and HII
  - Lightweight Structures Manufacturing Training & Implementation team
    - UM, ESI, MIT, EWI, and HII
1) Build unit 4130 for NSC 8 (April – Aug 2016) - Complete
   • Measure structural distortion data and some residual stresses as baseline
   • Develop process characteristics and ICME/cost models for process improvements

2) Build sub-assembly test panels (July – Nov 2016) - Complete
   • Measure distortion and residual stress variation of design of experiment (DOE) test data
   • Update ICME and cost models based on DOE panel test results

3) Analyze distortion data and model process improvement changes (Oct 2016 – June 2017)
   • Use updated ICME models, distortion measurements to validate process-by-process distortion changes
   • Model welding and production processes to determine strategies for test “mock up” unit fabrication plan
   • ABS DH36 steel alloy complete, HSLA-65 and 80 alloys in progress ECD: 8/31/17

4) Build “mock up” unit with process changes (April 2017 – Sept 2017)
   • Predict distortion, residual stress, and buckling reactions of test unit
   • Measure unit to validate distortion models
   • W/S 200, 210 & Panel Line W/S 220 complete, W/S 225 and Shell Shop in progress

5) Comprehensive High Strength Material Classification and Testing (July 2017 – June 2018)
   • Evaluate HSLA 100, HY80/100 with material testing and build/measure test panels for future modeling
   • Build new test panels with HSS materials if budgeting allows for fabrication and analysis
   • HSS material ordered, no-cost extension thru 6/30/18 approved from LIFT

6) Workforce Training for Lightweight Material Training Implementation (June 2017 – Dec 2017)
   • Apply best practices developed from ICME modeling and testing to shop-floor level work being performed daily at Huntington Ingalls
   • Preliminary training development held with end-users at Ingalls 6/2/17
Workforce Training and Implementation

- **Engineer Training for ICME**
  - Lead: ESI (Lead), UM, HII (Co-Lead)
  - Train Hull Tech and Production Engineers on use of the ICME software to improve design for producibility (DFP) and predict optimum production procedures based on the computer modeling output.

- **Production Craft Training**
  - Lead: EWI (Lead), UM, HII (Co-Lead)
  - Train production craft personnel on best practices for various hull structural conditions. Leverage past Thin Steel Welding Curriculum and build on this training tool to add other procedures developed through the DOE and ICME tasking.

- **Industrial Engineering and Cost/Pricing Personnel Training**
  - Lead: MIT (Lead), HII (Co-Lead)
  - Train industrial engineers and cost/pricing personnel on how to utilize the cost model developed throughout the project and weigh various production procedure options from the ICME modeling tool to determine the most economical and cost efficient solutions.
Cost Modeling Development

Introduction

- Specific quality related costs are difficult to capture accurately, prior to this project the main quantitative costs linked to distortion was flame straightening.
  - Additional costs associated with distortion (fitting, trimming, increased welding time, remediation activities to account for unfairness) were not disaggregated from cost data.

Approach

- Disaggregate cost/rate data to a detailed activity level at each workstation.
- Downstream cost predictions were made based on the addition or elimination of activities resulting from upstream quality/distortion changes.
- UM is aiding by executing a Bayesian Network analysis from historical data to help predict distortion levels and occurrences.
- The project is expected to achieve unprecedented levels of distortion mitigation, controlling dimensional accuracy and cost confidence in order to increase quality and efficiency of hull production at Ingalls.
Full-Scale Mock-Up Unit Construction Status

Mock-Up has completed:
- Blasting, painting, and cutting for all steel
- Pre-Fabrication of built-up structural pieces
- Deck seams and longitudinal stiffener welding

Current Status:
- Fitting transverse structure on deck plates
- Material and shop preparation for shell plates

Accuracy Control Measurements:
- Raw Plates (Deck Panels)
- Post Seam Welding
- Post Longitudinal Stiffener Welding
Summary

Current Activities

- Baseline NSC-8 unit 4130 has completed production and all data necessary for modeling has been collected and is being analyzed by UM and ESI.
- The DOE for the test-articles has been completed and distortion scans have been completed by UM for analysis of design variables.
- Material model has been developed for ABS Grade DH36 alloy with HSLA-65 and HSLA-80 steel expected to be completed by August 2017.
- Preliminary cost models have shown great accuracy at predicting costs in early fabrication processes while later stages are continuing to be disaggregated.

Future Activities

- Continue build full-scale mock-up test unit using the recommended process changes for distortion data and production cost comparison with NSC-8 baseline unit 4130.
- MIT team will continue validating cost and distortion model accuracy based on the full-scale mock-up unit data upon test completion in September 2017.