Multi-Fidelity Structural Modeling for Set Based Design (SBD) of Advanced Marine Vehicles

by Oliver Raj
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Seongim Choi

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Presentation Outline

• Acknowledgements
• Thesis Focus
• Set Based Design
• HY2-SWATH Requirements
• Machinery, Equipment, Stores Loads
• AMVS Substructures and Plots
• AMVS Design Space Exploration
• AMVS Results
• MAESTRO Model Setup
• MAESTRO Model Results
• Conclusions
• Future Work
• References
Acknowledgements

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• Parents
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Thesis Fundamental Focus

• Development of a parametrically modifiable Advanced Marine Vehicle Structural (AMVS) module
  – Low-fidelity numerical 2D FEA applied to the concept ultra-high-speed Unmanned Surface Vehicle (USV) Hybrid Hydrofoil SWATH (HY2-SWATH)
  – Conduct preliminary design space exploration
    • Varying material, structural member dimensions, and structural member count
    • Demonstrate capability for module incorporation in global software manager for use in Set Based Design (SBD) method
  – Evaluate the structural feasibility of the HY2-SWATH structural design
• High-fidelity MAESTRO 3D FEA comparison of baseline reference HY2-SWATH to that calculated in AMVS module
Set Based Design (SBD)

- SBD is summarized in three steps or phases as follows:
  1. Explore the design space
     A. Design space contains all possible solutions to design problem bounded by current and future-potential capabilities
  2. Identify overlapping solution set regions
  3. Refine feasible design regions

Set-Based Design Process [15]
HY2-SWATH SBD Specialty Groups
HY2-SWATH Requirements

- **Displacement Mode:**
  - 8-25 knots
- **Flying Mode:**
  - 120+ knots
- **Operate in sea state 3**
  - wave heights of 1.67 – 4.08 ft. (0.5 – 1.25 m)
- **Transport 3-5 MT payload**
- **Accomplish 5 day mission**
Structural Analysis Models

- Advance Marine Vehicle Structural (AMVS) low-fidelity model
  - FEA Euler-Bernoulli beam theory code written using 2D frame elements
- MAESTRO Marine high-fidelity model
- Analyzes the HY2-SWATH:
  - Buoyancy Mode
  - Flying Mode
  - Hogging Wave Condition (with slamming)
  - Sagging Wave Condition (with slamming)

Hogging and Sagging [14]
# Reference HY2-SWATH Loads

Table contains the list of machinery loads, equipment loads, stores loads, and structural loads. “Loads” means forces and moments.

<table>
<thead>
<tr>
<th>Load</th>
<th>Quantity</th>
<th>Mass (Each, MT)</th>
<th>Reference Vessel Weight (Each, N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Motor</td>
<td>2</td>
<td>0.255 + 5% allowance</td>
<td>2,316.67</td>
</tr>
<tr>
<td>Payload</td>
<td>1</td>
<td>5</td>
<td>49,030</td>
</tr>
<tr>
<td>Wing-Superstructure</td>
<td>1</td>
<td>Calc. + 5% allowance</td>
<td>76,262.8 (AMVS); 85,866.5 (MAESTRO)</td>
</tr>
<tr>
<td>Cables and Pipes</td>
<td>1</td>
<td>0.65 + 5% allowance</td>
<td>6,692.6</td>
</tr>
<tr>
<td>Struts</td>
<td>1</td>
<td>Calc. + 5% allowance</td>
<td>43,672.6 (AMVS); 62,406.6 (MAESTRO)</td>
</tr>
<tr>
<td>Hull</td>
<td>2</td>
<td>Calc. + 5% allowance</td>
<td>15,799.75 (AMVS); 18,752.1 (MAESTRO)</td>
</tr>
<tr>
<td>Fore foil</td>
<td>2</td>
<td>1.535 + 5% allowance</td>
<td>15,804.8</td>
</tr>
<tr>
<td>Aft foil</td>
<td>2</td>
<td>1.57 + 5% allowance</td>
<td>16,165.2</td>
</tr>
<tr>
<td>Rotating Mech. Fore</td>
<td>2</td>
<td>0.125 + 5% allowance</td>
<td>1,287.04</td>
</tr>
<tr>
<td>Rotating Mech. Aft</td>
<td>2</td>
<td>0.125 + 5% allowance</td>
<td>1,287.04</td>
</tr>
<tr>
<td>Elec. Nav. Equip.</td>
<td>1</td>
<td>0.5 + 5% allowance</td>
<td>5,148.15</td>
</tr>
<tr>
<td>Liquids</td>
<td>1</td>
<td>0.3 + 5% allowance</td>
<td>2,941.8</td>
</tr>
<tr>
<td>Fuel</td>
<td>1</td>
<td>Calculated</td>
<td>157,502.0</td>
</tr>
<tr>
<td>Gas Turbines</td>
<td>2</td>
<td>1.5 + 5% allowance</td>
<td>15,444.5</td>
</tr>
<tr>
<td>Genset</td>
<td>2</td>
<td>0.75 + 5% allowance</td>
<td>7,722.23</td>
</tr>
</tbody>
</table>
AMVS Substructure Frames

• Divided HY2-SWATH into three interdependent substructures.
• Together provide an accurate representation of whole vessel
AMVS Substructure Frames (1)

Divided into 3 substructure frames:
1. Forward two struts connected via the wing-shaped superstructure
2. Aft two struts connected via the wing-shaped superstructure
3. Torpedo-shaped demi-hull
Substructure 1: Loads

Concentrated Loads:
- % of side wing weight aft of this view
- Payload

Concentrated Loads:
- % of side wing weight aft of this view

Distributed Loads:
- % of wing/element,
- % of Cables&Pipes/element,
- % of elecnav/equip/element

Concentrated Loads:
- Strut Weight/element + % of liquids

Concentrated Loads:
- Strut Weight/element

Roller Boundary Condition

Roller Boundary Condition
Substructure 2: Loads

Concentrated Loads: Turbojet

Distributed Loads: % of wing/element
% of Cables & Pipes/element

Concentrated Loads: Turbojet

Roller Boundary Condition

Concentrated Loads: Strut Weight/element + % of liquids

Concentrated Loads: Strut Weight/element + Genset/Batt/Inv

Concentrated Loads: Strut Weight/element

Roller Boundary Condition
Substructure 3: Loads

Buoyancy Mode:

Flying Mode:
Substructure 3: Loads (1)

Hogging Wave Condition with Slamming

Sagging Wave Condition with Slamming
AMVS Module Element Cross-Sections

- Element cross-section parametric inputs:
  - Shell plating thickness
  - Number of longitudinal stiffeners and their dimensions
  - Ring stiffeners and their dimensions
AMVS Module
Reference Vessel Flying Mode Plots

Frame and Final Deflected Frame

Frame and Scaled Moment

Frame and Scaled Shear

Frame
Deflected Frame: Magnified by 50 for Visibility

Frame
Moment
Shear
AMVS Module
Reference Vessel Flying Mode Plots (1)
Design Space Exploration

• Shell thickness varied from 4 – 7 mm
  – Flying mode hull elements 9-13 required an additional 6 mm to input shell thickness
  – Flying mode hull elements 8 & 14 required an additional 3 mm

• Material properties

<table>
<thead>
<tr>
<th>Material Property Parametric Inputs</th>
<th>( \rho ) (kg( \cdot )m(^{-3} ))</th>
<th>( \sigma_{\text{yield}} ) (MPa)</th>
<th>( \tau_{\text{yield}} ) (MPa)</th>
<th>E (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum 7075 - T6; 7075 - T651</td>
<td>2810</td>
<td>503</td>
<td>331</td>
<td>71.9</td>
</tr>
<tr>
<td>316L Steel</td>
<td>8000</td>
<td>205</td>
<td>370</td>
<td>193</td>
</tr>
<tr>
<td>Aluminum 6061 - T6; 6061 - T651</td>
<td>2700</td>
<td>276</td>
<td>207</td>
<td>68.9</td>
</tr>
<tr>
<td>AISI Type S20910 Stainless Steel, high strength</td>
<td>7890</td>
<td>725</td>
<td>570</td>
<td>200</td>
</tr>
<tr>
<td>Titanium Ti - 6 Al - 4 V (Grade 5), Annealed</td>
<td>4430</td>
<td>880</td>
<td>550</td>
<td>113.8</td>
</tr>
</tbody>
</table>

• Longitudinal stiffener count

<table>
<thead>
<tr>
<th>Stiffener Count Parametric Input</th>
<th>Forward Strut Frame Stiffeners</th>
<th>Aft Strut Frame Stiffeners</th>
<th>Hull Frame Stiffeners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>(8, 12, 12, 6, 6, 6, 6, 12, 12, 8)</td>
<td>(8, 12, 12, 6, 6, 6, 6, 12, 12, 8)</td>
<td>6/element (20 elements)</td>
</tr>
<tr>
<td>Run 2</td>
<td>(16, 24, 24, 12, 12, 12, 12, 12, 24, 24, 16)</td>
<td>(16, 24, 24, 12, 12, 12, 12, 24, 24, 16)</td>
<td>12/element (20 elements)</td>
</tr>
<tr>
<td>Run 3</td>
<td>(32, 48, 48, 24, 24, 24, 24, 24, 24, 48, 48, 32)</td>
<td>(32, 48, 48, 24, 24, 24, 24, 24, 48, 48, 32)</td>
<td>24/element (20 elements)</td>
</tr>
</tbody>
</table>
Design Space Exploration (1)

- Data Results (Example)
## Design Space Exploration (2)

- **Constraints (Example)**

| Buoyancy Mode Operating Condition Constraints |  
|-----------------------------------------------|-------------------------------------------------|
| 1 Buoyancy (initial waterline) > 1.1*weight | Initial waterline provides excess buoyancy. Constraint ensures vessel does not sink. |
| 2 Abs(Trim angle) < 0.5°                    | Reduced drag, increased fuel efficiency and range |

### Hull Frame

| Hull Frame |  
|------------|-------------------------------------------------|
| 3 Max vertical deflection of hull < total hull length *x% | Ensure hull vertical deflection does not cause failure |

### Forward Struts Frame

| Forward Struts Frame |  
|----------------------|-------------------------------------------------|
| 4 Max horizontal deflection < forward starboard strut length *x% | Ensure horizontal deflection of starboard strut does not cause failure |
| 5 Max horizontal deflection < forward port strut length *x% | Ensure horizontal deflection of port strut does not cause failure |
| 6 Max vertical deflection < forward wing span *x% | Ensure forward portion of the wing superstructure vertical deflection does not cause failure |

### Aft Struts Frame

| Aft Struts Frame |  
|------------------|-------------------------------------------------|
| 7 Max horizontal deflection < aft starboard strut length *x% | Ensure horizontal deflection of starboard strut does not cause failure |
| 8 Max horizontal deflection < aft port strut length *x% | Ensure horizontal deflection of port strut does not cause failure |
| 9 Max vertical deflection < aft wing span *x% | Ensure aft portion of the wing superstructure vertical deflection does not cause failure |

Where x = 0.25% and 0.20%
Design Space Exploration (2)

- Histograms to help analyze data
Design Space Exploration (3)

- Buoyancy: > Vessel Mass + 10%
- Ref. Mass = 49.0335t > Vessel Mass + 5%
- abs(trim angle): < 0.5°
- DNV $t_s <$ Design Hull Shell Thickness
Design Space Exploration (4)

- Sensitivity plots to help analyze input variables impact on stresses
## AMVS Reference HY2-SWATH Displacement/Stress Results

### AMVS Max Displacement Results Summary

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Forward Frame Location</th>
<th>Forward Frame Displacement (mm)</th>
<th>Aft Frame Location</th>
<th>Aft Frame Displacement (mm)</th>
<th>Hull Frame Location</th>
<th>Hull Frame Displacement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buoyancy Mode</td>
<td>Node 7</td>
<td>-5.33</td>
<td>Node 6</td>
<td>-4.50</td>
<td>Node 10</td>
<td>0.752</td>
</tr>
<tr>
<td>Flying Mode</td>
<td>Node 7</td>
<td>-5.33</td>
<td>Node 6</td>
<td>-4.50</td>
<td>Node 11</td>
<td>-65.1</td>
</tr>
<tr>
<td>Hogging</td>
<td>Node 7</td>
<td>-21.0</td>
<td>Node 6</td>
<td>-17.78</td>
<td>Node 21</td>
<td>-43.0</td>
</tr>
<tr>
<td>Sagging</td>
<td>Node 7</td>
<td>-21.0</td>
<td>Node 6</td>
<td>-17.78</td>
<td>Node 11</td>
<td>-14.9</td>
</tr>
</tbody>
</table>

### AMVS Max Von Mises Stress Results Summary

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Forward Frame Location</th>
<th>Forward Frame Stress, $\sigma_{VM}$ (Pa)</th>
<th>Aft Frame Location</th>
<th>Aft Frame Stress, $\sigma_{VM}$ (Pa)</th>
<th>Hull Frame Location</th>
<th>Hull Frame Stress, $\sigma_{VM}$ (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buoyancy Mode</td>
<td>Element 6</td>
<td>3.931*10^6</td>
<td>Element 5</td>
<td>2.653*10^6</td>
<td>Element 10</td>
<td>1.037*10^6</td>
</tr>
<tr>
<td>Flying Mode</td>
<td>Element 6</td>
<td>3.931*10^6</td>
<td>Element 5</td>
<td>2.653*10^6</td>
<td>Element 11</td>
<td>7.614*10^7</td>
</tr>
<tr>
<td>Hogging</td>
<td>Element 6</td>
<td>1.553*10^7</td>
<td>Element 5</td>
<td>1.047*10^7</td>
<td>Element 7</td>
<td>6.933*10^7</td>
</tr>
<tr>
<td>Sagging</td>
<td>Element 6</td>
<td>1.553*10^7</td>
<td>Element 5</td>
<td>1.047*10^7</td>
<td>Element 6</td>
<td>4.02*10^7</td>
</tr>
</tbody>
</table>

### AMVS Von Mises Stress Statistics

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Stress Range, Max-Min (Pa)</th>
<th>Average, $\mu$ (Pa)</th>
<th>Standard Deviation, $\sigma$ (Pa)</th>
<th>Max Stress Std. Dev. From Avg. ($\mu \pm \sigma$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buoyancy Mode</td>
<td>3.903*10^6</td>
<td>1.332*10^6</td>
<td>1.149*10^6</td>
<td>2.27</td>
</tr>
<tr>
<td>Flying Mode</td>
<td>7.615*10^7</td>
<td>1.622*10^7</td>
<td>2.445*10^7</td>
<td>2.45</td>
</tr>
<tr>
<td>Hogging</td>
<td>6.933*10^7</td>
<td>1.236*10^7</td>
<td>1.562*10^7</td>
<td>3.65</td>
</tr>
<tr>
<td>Sagging</td>
<td>4.020*10^7</td>
<td>1.371*10^7</td>
<td>1.199*10^7</td>
<td>2.21</td>
</tr>
</tbody>
</table>
MAESTRO High-Fidelity Model

- Rhino model was converted to a mesh (quad and tri-elements) and imported into MAESTRO
- Material properties and structural element thicknesses applied
- Same machinery/equipment/stores loads applied to the AMVS module were applied to the HF model.
- Structural loads calculated by MAESTRO
MAESTRO Shell Plating Mesh

- Rhino model discretized into finite element mesh (mostly by hand)
- Imported into MAESTRO as .ply file
MAESTRO Internal Structure Mesh

>12,000 quads and tri-elements to define the stbd side of the vessel
Node Free Edges and Discontinuities
## Aluminum 7075 Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young's Modulus $E$ (N/m$^2$)</td>
<td>7.19e+10</td>
</tr>
<tr>
<td>Poisson Ratio</td>
<td>0.33</td>
</tr>
<tr>
<td>Density (kg/m$^3$)</td>
<td>2950.5</td>
</tr>
<tr>
<td>Yield Stress (N/m$^2$)</td>
<td>5.03e+08</td>
</tr>
<tr>
<td>Ultimate Tensile Strength (N/m$^2$)</td>
<td>5.72e+08</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Material</th>
<th>#Layers</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Null Plate Prop</td>
<td>ST24</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>6mm Al 7075 (default)</td>
<td>Al 7075-T6</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>6.35mm Al 7075 (girders/rings)</td>
<td>Al 7075-T6</td>
<td>1</td>
<td>6.35</td>
</tr>
<tr>
<td>4</td>
<td>9mm Al 7075 (hull shell)</td>
<td>Al 7075-T6</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>12mm Al 7075 (hull shell)</td>
<td>Al 7075-T6</td>
<td>1</td>
<td>12</td>
</tr>
</tbody>
</table>
Concentrated Loads

- The reference vessel loads applied in the AMVS module were applied to the MAESTRO model. (Best for comparison purposes)
  - Concentrated loads remained concentrated and distributed loads remained distributed (which also made logical sense going 2D → 3D)
Distributed Loads

- Cables/Pipes
- Cables/Pipes and Elec. Nav. Equip
- Fuel
- Rotating Mech. Aft and Aft Foil
- Electric Motor

Rotating Mech. Fore and Fore Foil
Boundary Conditions

Flying Mode

Hogging Wave Condition

Sagging Wave Condition
Balance the Vessel (Buoyancy Mode)

***INFORMATION ONLY. No effect on FE-Analysis***
*Displacement= 527529 N. Volume=52.4349 m^3*
*The following parameters are in the Ship Coordinate system:*
*Center of Buoyancy: xCB= 10411.5 mm, yCB=644.096 mm, zCB=0 mm*
*Center of Gravity: xCG= 10391 mm, yCG=1327.82 mm, zCG=0 mm*
*Center of Flotation: xCF= 11748.1 mm, yCF=2252.13 mm, zCF=0 mm*
*Trim Angle(Deg)=-0.375233*
*Fore Draft Point (mm)=(19537.011, 2303.141, 3660.728)*
*Aft Draft Point (mm)=(3764.659, 2199.847, 5299.683)*
*Fore Draft Point at z=0 (mm)=(19537.011, 2303.141, 0)*
*Aft Draft Point at z=0 (mm)=(3764.659, 2199.847, 0)*
*Distance to origin =-2175.143 mm*
*BMT= 7885.98 mm*
*BHL= 10048 mm*
*I_t=4.13501e+14 mm^4*
*I_l=5.26866e+14 mm^4*
*GMT=6702.14 mm*
*GML=8864.16 mm*

Balance Completed
MAESTRO Reference Model Displacement Results (Hogging Condition)

Displacement magnified by 42x factor
Displacement in mm
MAESTRO Reference Model Displacement Results (Hogging Condition) (1)

Max Displacement Node Location (Hogging)
MAESTRO Reference Model Stress Results (Hogging Condition)

Color code modified to show stresses in red when VM stress was 1/6 of yield stress, i.e. SF of 6

Displacement magnified by 42x factor
Stress in N/m²
Stress in N/m²

Stress Results (Hogging Condition) (1)
MAESTRO Reference HY2-SWATH
Displacement/Stress Results

### MAESTRO Max Displacement Results Summary

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Displacement Location</th>
<th>Displacement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buoyancy Mode</td>
<td>FeTag 10693</td>
<td>34.50</td>
</tr>
<tr>
<td>Flying Mode</td>
<td>FeTag 3675</td>
<td>-15.49</td>
</tr>
<tr>
<td>Hogging</td>
<td>FeTag 3675</td>
<td>-54.81</td>
</tr>
<tr>
<td>Sagging</td>
<td>FeTag 3675</td>
<td>-54.34</td>
</tr>
</tbody>
</table>

### MAESTRO Max Von Mises Stress Results Summary

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Stress Location</th>
<th>Max Stress (Pa)</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buoyancy Mode</td>
<td>Strut Stiffener - Tri 298 - FeTag 12042</td>
<td>5.361*10⁷</td>
<td>9.38</td>
</tr>
<tr>
<td>Flying Mode</td>
<td>Hull Stiffener - Tri 56 - FeTag 11968</td>
<td>1.201*10⁸</td>
<td>4.19</td>
</tr>
<tr>
<td>Hogging</td>
<td>Hull Stiffener - Tri 67 - FeTag 11964</td>
<td>2.577*10⁸</td>
<td>1.95</td>
</tr>
<tr>
<td>Sagging</td>
<td>Hull Stiffener - Tri 56 - FeTag 11968</td>
<td>1.939*10⁸</td>
<td>2.59</td>
</tr>
</tbody>
</table>

### MAESTRO Von Mises Stress Statistics

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Stress Range, Max-Min (Pa)</th>
<th>Average, μ (Pa)</th>
<th>Standard Deviation, σ (Pa)</th>
<th>Max Stress Std. Dev. From Avg. (μ ± σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buoyancy Mode</td>
<td>5.361*10⁷</td>
<td>2.858*10⁶</td>
<td>3.528*10⁶</td>
<td>14.39</td>
</tr>
<tr>
<td>Flying Mode</td>
<td>1.201*10⁸</td>
<td>3.106*10⁶</td>
<td>3.755*10⁶</td>
<td>31.13</td>
</tr>
<tr>
<td>Hogging</td>
<td>2.577*10⁸</td>
<td>1.038*10⁷</td>
<td>1.359*10⁷</td>
<td>18.22</td>
</tr>
<tr>
<td>Sagging</td>
<td>1.939*10⁸</td>
<td>9.412*10⁶</td>
<td>1.173*10⁷</td>
<td>15.74</td>
</tr>
</tbody>
</table>
Conclusions

• AMVS module design space exploration of 60 different HY2-SWATH variations for four load cases
  – Flying mode hull stress/displacement largest of four load cases
  – Four feasible solutions found!
    • Limited primarily by the buoyancy provided by the hull, material used, and the hydrofoils’ designed lift
Conclusions (1)

- MAESTRO Reference HY2-SWATH was feasible for all load cases with a minimum stress safety factor of 1.95
  - Hogging wave condition with slamming showed the largest displacement and stress
    - Max displacement in the superstructure at turbojet location
    - Max stress in the hull near aft strut
Conclusions (2)

• The models displacements generally correlated to each other
  – Largest displacements were in the wing-shaped superstructure - location of the turbojets
    • High-fidelity model - turbojets caused largest displacement overall in flying mode, hogging, and sagging load case scenarios.
    • Low-fidelity model – largest displacement overall seen in the hull at midship in flying mode
      – Turbojets caused largest displacement in substructure 2 (aft strut frame) for hogging and sagging load case scenarios.
      – The AMVS module analyzed the hull in a slightly more severe configuration – in absence of strut and superstructure, yet loaded as if they (and all internal machinery) were present.
      – Useful to consider a closed longitudinal frame to include the hull, struts and superstructure.
Conclusion (3)

- The models VM stresses generally correlated to each other
  - MAESTRO model calculates a much larger range of stresses and an order of magnitude greater max stress
  - Average and the standard deviation are similar in their OOM
Future Work

• AMVS Module
  – Conduct larger design space exploration
    • Incorporate in global software manager
    • Incorporate additional ship analysis modules
    • Modify more variables (already capable)
  – Consider analysis of additional frames
  – Reinforce structurally weaker areas
Future Work (1)

- MAESTRO HF model
  - Automate the vessel creation and analysis
  - Reinforce structurally weaker areas
  - Refine mesh
  - Create wave load cases with intrinsic wave functions
    - Compare against DNVGL wave load cases
References


[16] “MAESTRO.” Maestro Marine, maestromarine.com/


Backup Slides

Improved HY2-SWATH Structure in MAESTRO:
HY2-SWATH V2.0

- Goal: Reduce large deflections and high stress areas to achieve SF of 6
  - Addition of flanges in the superstructure and some in hull:
    - Weight: 53.76 MT → 55.12 MT
HY2-SWATH V2.0 (1)

- Hogging Wave Condition w/ Slamming:
  - Stresses in superstructure and hull exceeding allowable to provide SF of 6.

- Max Deflection: -54.8mm → -31.3mm
HY2-SWATH V2.1

- Goal: Reduce large deflections and high stress areas to achieve SF of 6
  - Removal of most flanges in the superstructure
  - Addition of solid bulkheads in superstructure
    - Weight: 53.76 MT → 54.09 MT
HY2-SWATH V2.1 (1)

- Hogging Wave Condition w/ Slamming:
  - Stresses in the hull exceeding allowable to provide SF of 6.

Max Deflection:  
-54.8mm → -16.8mm