NSRP | National Shipbuilding Research Program

NSRP RA Project 2017-443
“Ship Structural Design Optimization (SSDO) for Improved Producibility and Enhanced Life-Cycle Performance”

SDMT Panel Briefing

October 29, 2020

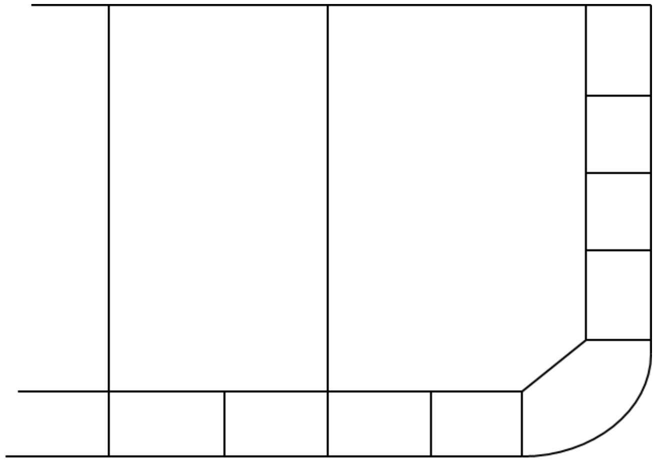
FINCANTIERI MARINETTE MARINE

Rationale – Why Develop Multi-Objective Structural Design Space Exploration for Early-Stage Design

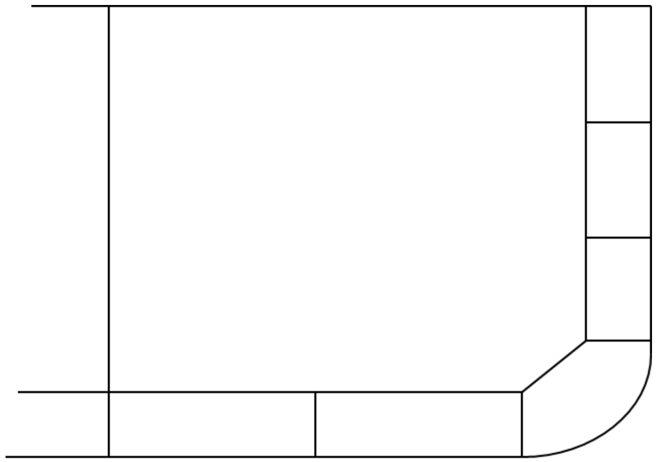
- **Traditional Approaches** – structural design has relied on least weight approaches, correlating with weight-based cost methods, and static design methods in early stage design
- **Resulting Structural Shortcomings** – Lightweight structures that are more complex with higher work content to fabricate, and lack robust qualities causing high in-service damage and repair costs from extreme loads and structural fatigue damage
- **Structural Design Space Exploration** – using automated 3D finite element analysis and higher-fidelity loading in early-design enables design alternatives to be engineered and compared for work content and performance through the life cycle
- **Structural Optimization** – which implements Lean Design principles offers practical tools for effective design space exploration

Lightweight structures lead to high Total Ownership Costs (TOC)

Structural Work Content



Traditional Design
2 long. bulkheads, 9 IB girders, 4 horizontal stringers, and 5 web frames per 12 M tank



Lean Design
1 long. bulkheads, 5 IB girders, 3 horizontal stringers, and 3 web frames per 12 M tank

>50% reduction in structural work scope, >35% reduction in tank coating surface, and improved tank access with ~3% increase in steel weight.

Reduced work content & improved tank access

Ship Structural Design Optimization (SSDO) Program Team

- **Fincantieri Marinette Marine**
  - Project Lead, shipyard implementation
- **MAESTRO Marine LLC**
  - Naval architects & software developers, creators of MAESTRO
- **NSWC-CD Code 65**
  - US Navy lead organization for ship structural design
- **Ship Design USA (Bob Keane)**
  - Former US Navy Chief Naval Architect, advisor on Navy ship design & construction
- **SPAR Associates**
  - SMEs in ship cost-estimating and production planning
- **P. Jaquith & Associates (Pete Jaquith)**
  - SME in Lean Design and Design for Production

SSDO Provides Higher Fidelity Ship Structural Engineering from Concept Design through the Full Life-Cycle

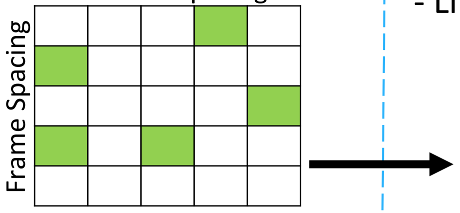
Design Timeline

Concept	Preliminary	Functional/Contract	Life-Cycle

<u>APPLICATION OF MAESTRO OPTIMIZATION & ANALYSIS</u>

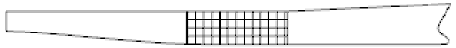
<u>Topology Optimization</u>
Coarse global FEA model

Static Global Loading:
- Automated optimization
- Design space exploration
- Topology search process



Full matrix

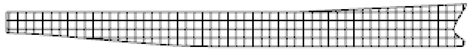
<u>Selected Topology Opt.</u>
Fine mesh midbody model



Loading:
- Secondary & tertiary loads
- Basic hydrodynamic loads
- Extreme Load Analysis
- Spectral Fatigue Analysis
- Life-cycle cost factors

Selected Candidates

<u>Full Optimization</u>
Finer mesh global model

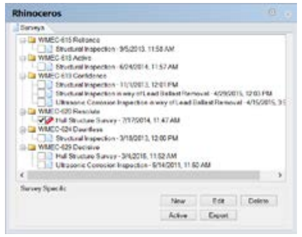


Loading:
- Secondary & tertiary loads
- Full hydrodynamic loads
- Extreme Load Analysis
- Spectral Fatigue Analysis
- Higher fidelity life-cycle cost factors

Final Topology

<u>In-Service Engineering</u>
Fine mesh model & class database

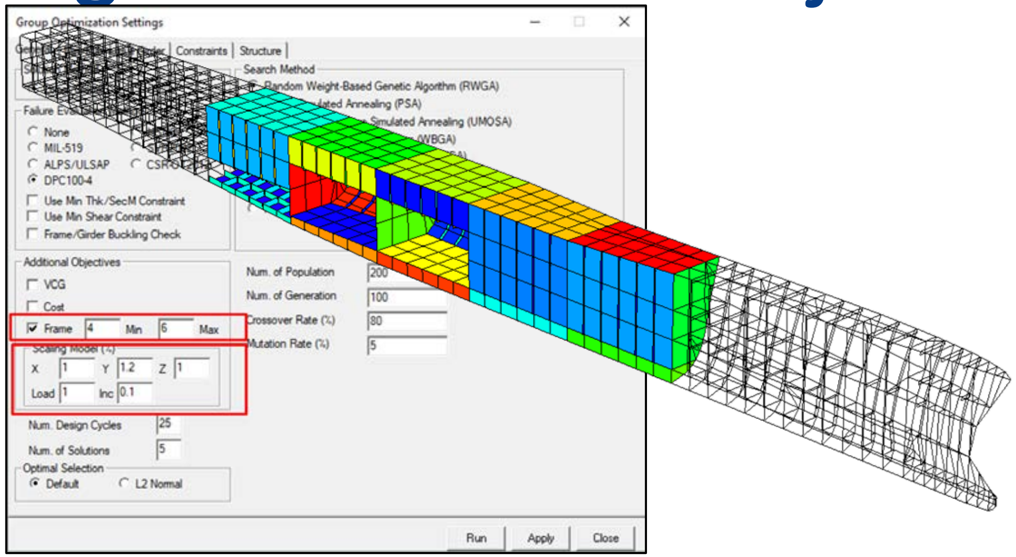
Loading:
- Operational loads
- Extreme loads
- Spectral fatigue
- Damage conditions

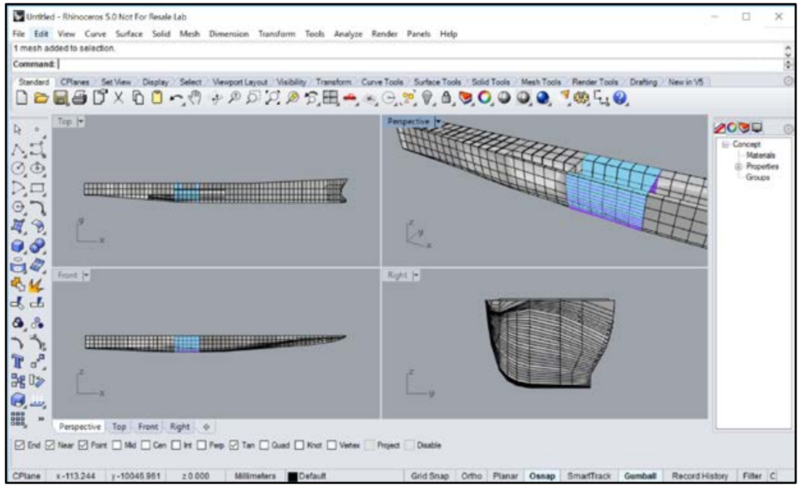


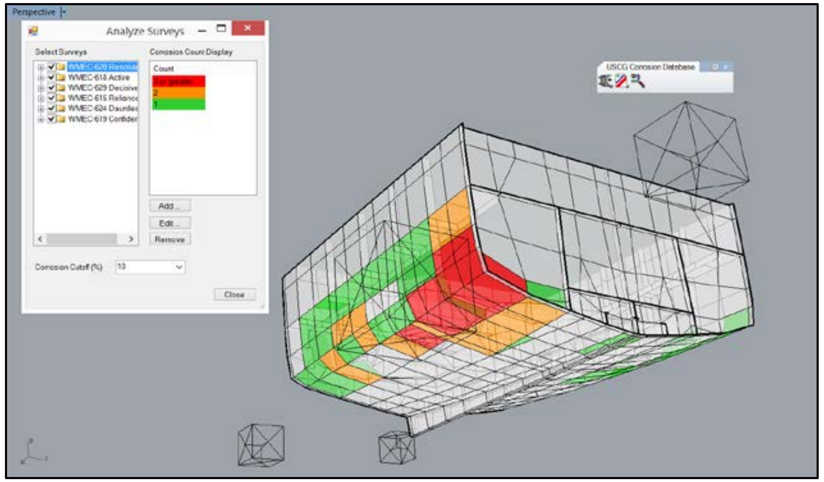
Corrosion database

SSDO Improvements Delivered Through the NSRP RA Project

- Concept Design/Topology Optimization Module
- Cost & Production Engineering Module
- Life-Cycle/Corrosion Module







Concept Design/Topology Optimization Module: Design Space Exploration Approach

- We have successfully developed a capability to conduct an optimization of a coarse mesh MAESTRO finite element model that automatically varies frame spacing and then, for each frame spacing, varies the global stiffener spacing with user defined min/max values.
  - For example, 3 frame spacings x 4 stiffener spacings = 12 optimized designs are automatically generated
- The capability was extended to enable the finite element analysis based automated optimization of structures that have the hull principal dimensions changed
  - Length, breadth, depth can be scaled automatically

Design Space Exploration & Structural Optimization

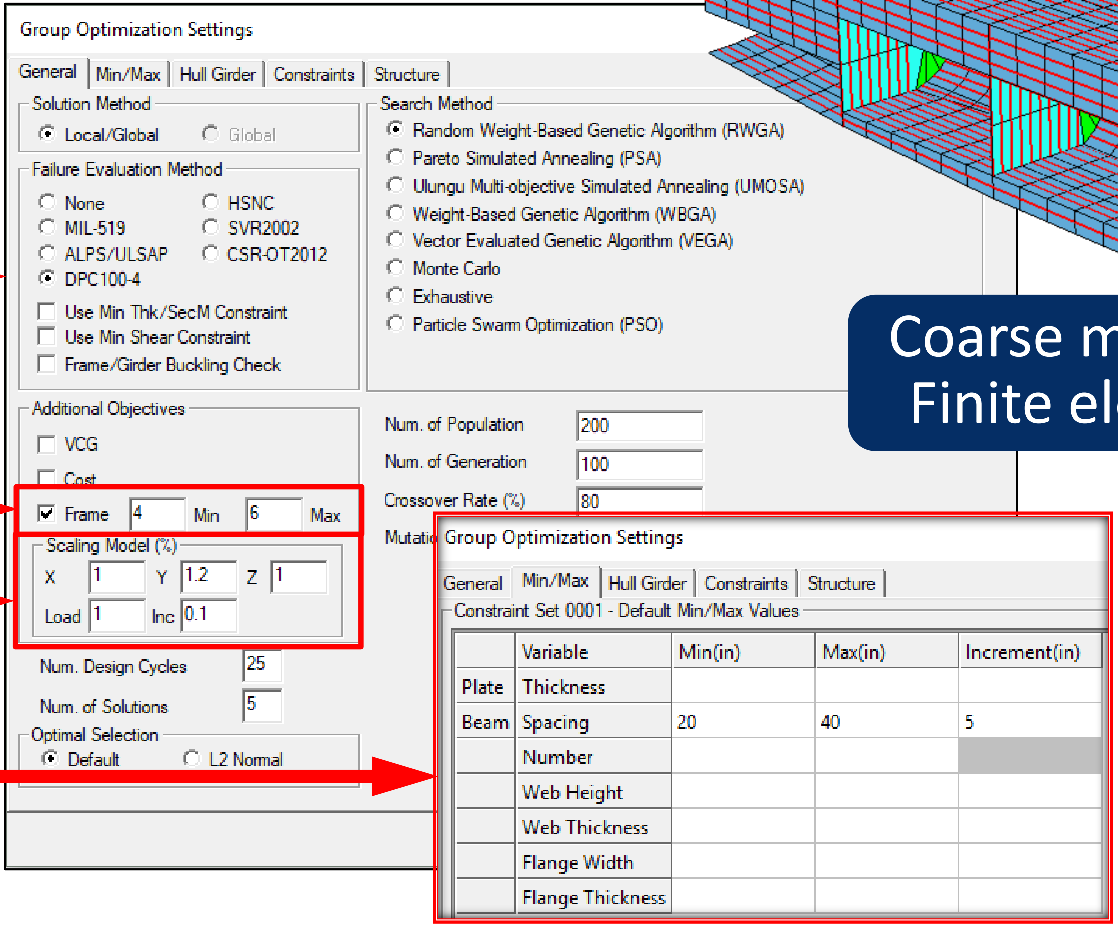
Optimization Settings Interface

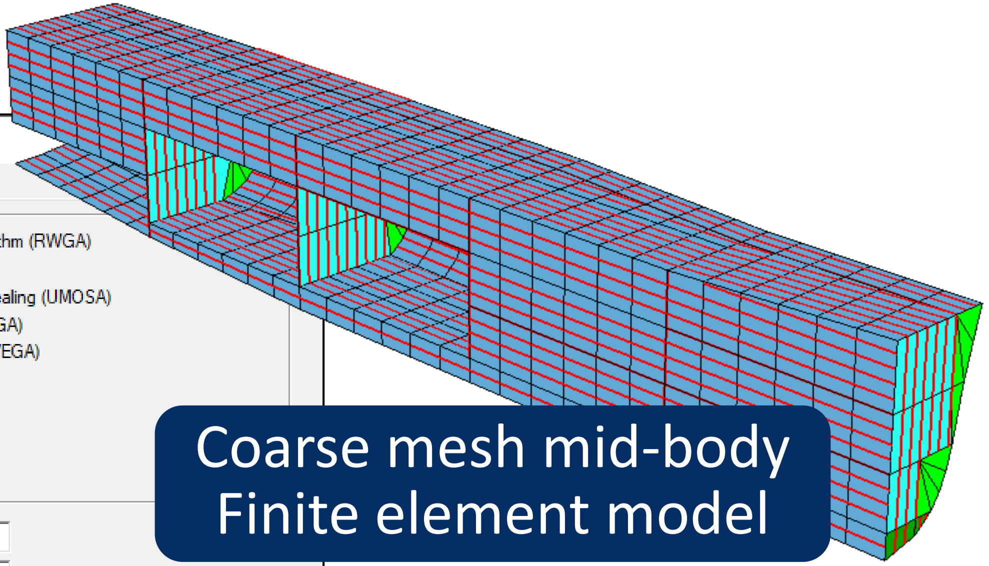
USN safety criteria

Vary frame spacing

Scale global hull

Vary stiffener spacing

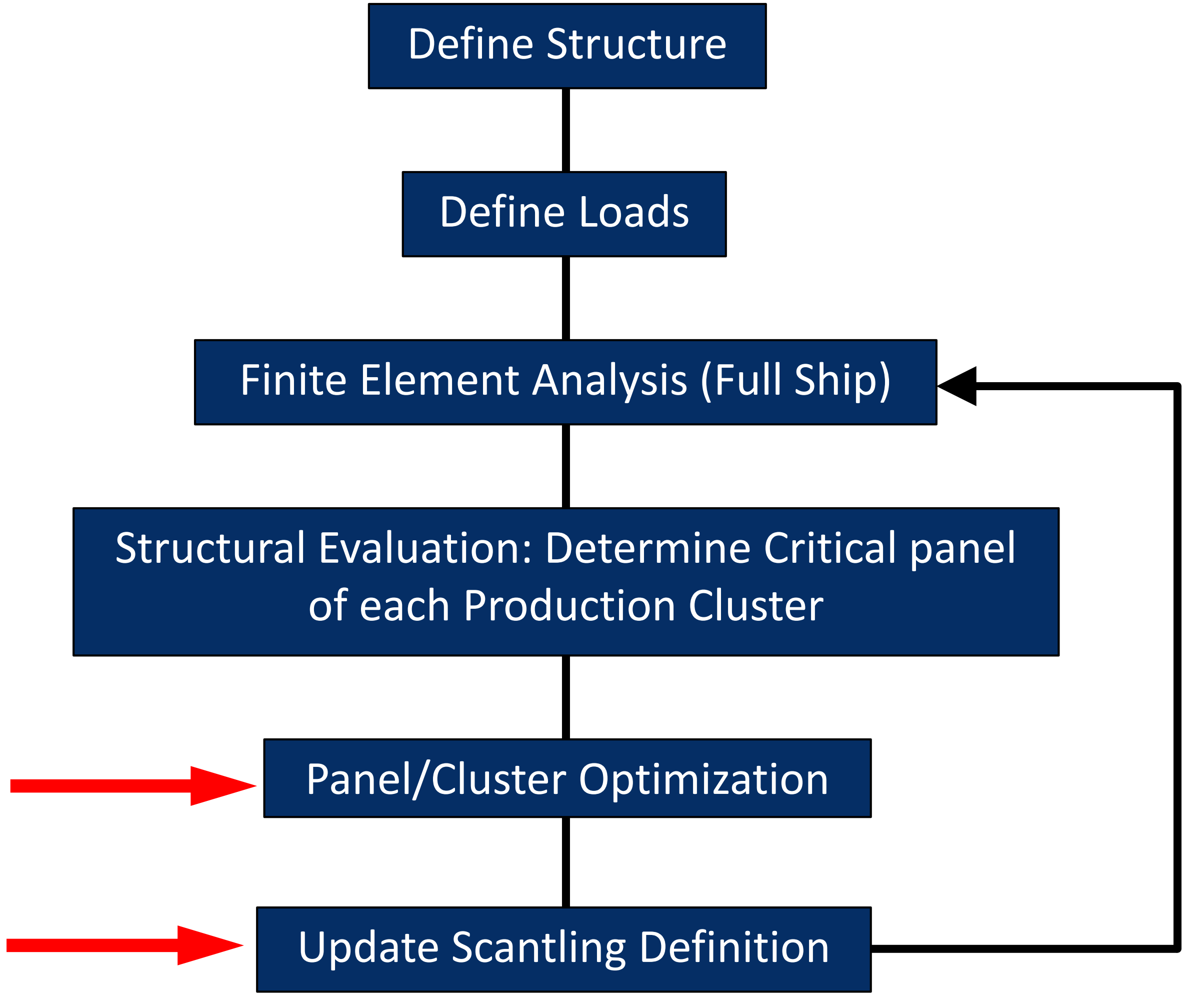




Coarse mesh mid-body Finite element model

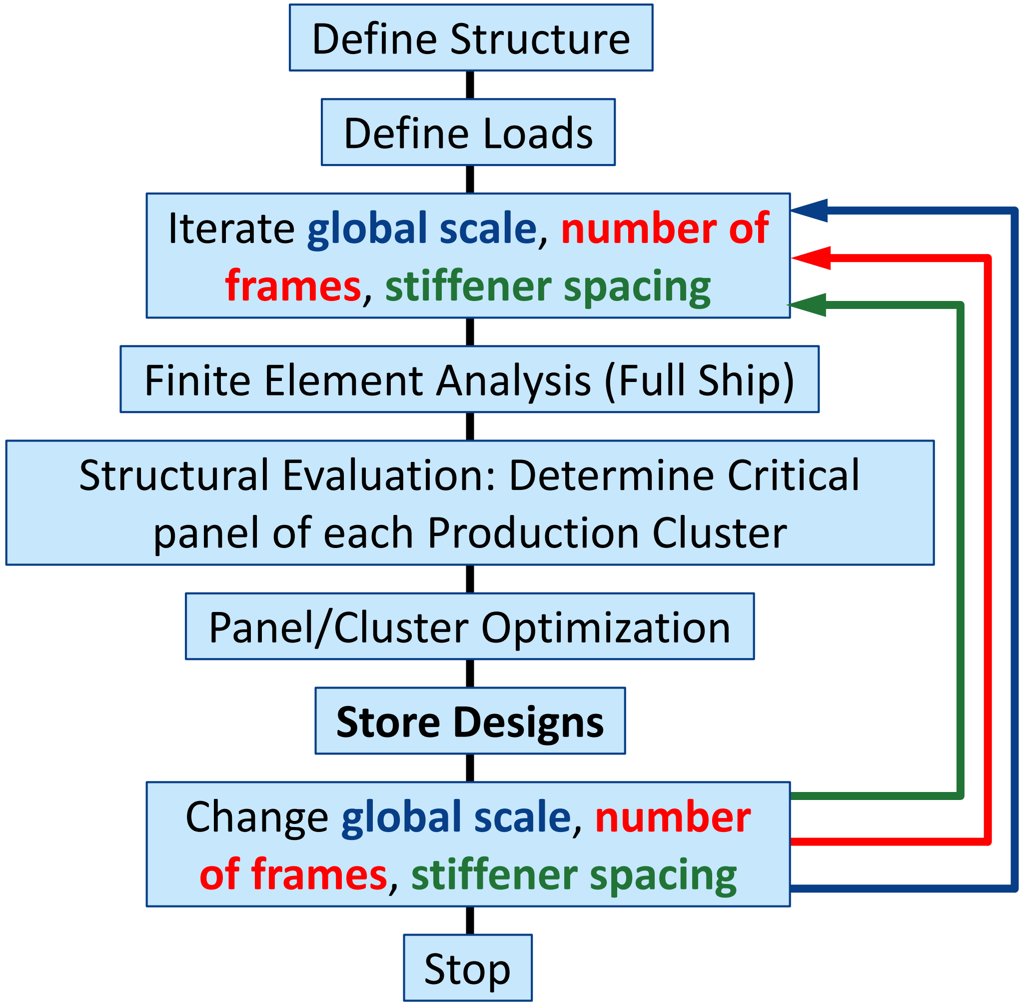
Original Optimization Process

- Process implements "Six Stages of Rational Ship Structural Design" as published by Professor Owen Hughes
- Uses mid-body or full ship finite element modeling and analysis with high fidelity naval architectural loading
- Automates structural failure or limit-state evaluations which serve as constraints for optimization
- Optimizes "manufacturing or design clusters" (inner loop)
- Then re-integrates revised full structure to update structural performance evaluation vs criteria

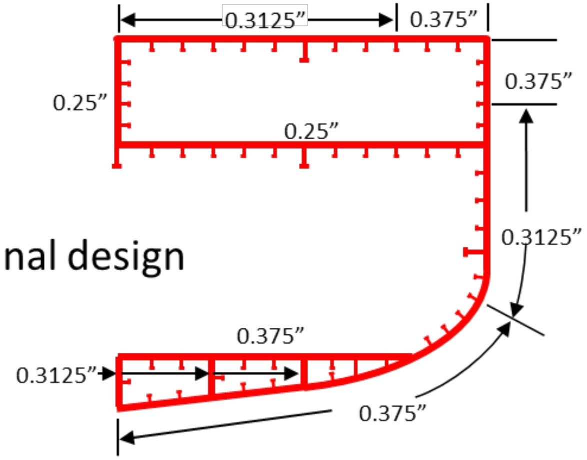


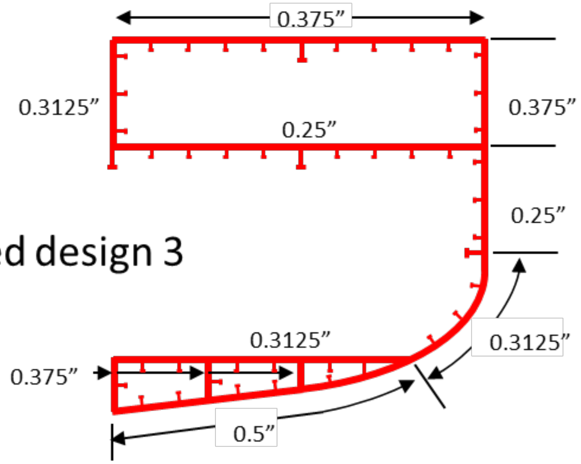
New Topology SSDO Process

- Additional nested global iterations are added to optimize changes of:
  - **Stiffener spacing**
  - **Number of frames**
  - **Global scale/dimensions (length, beam, depth of hull)**
- Automatically generates modified finite element models to support the geometry changes
- Optimizations automatically iterate to convergence
- Each optimized structural design is saved and has metrics extracted for review



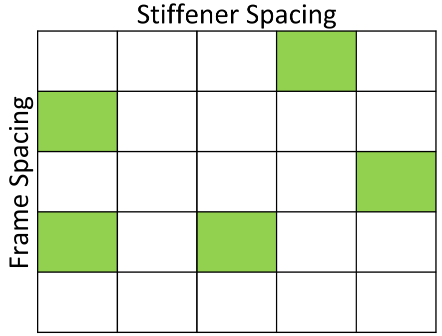
Example Optimization Results
Stiffener and Frame Iterations





Topology Optimization
Level 1 global FEA

Static Global Loading:
- Automated optimization
- Design space exploration
- Topology search process



Full Matrix: 25 Optimized Structural Designs

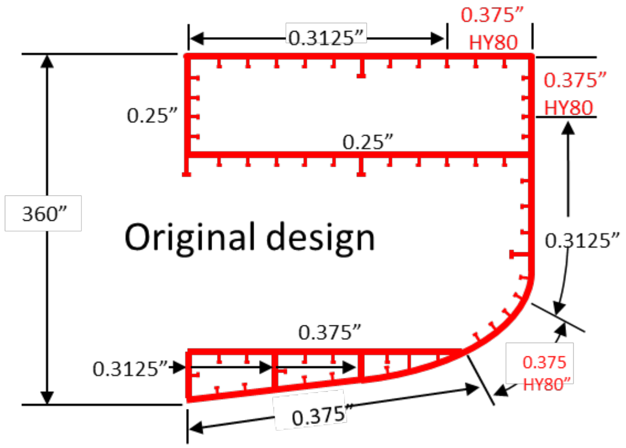
Property per frs 180-220		Original	Optimized Design 1	Optimized Design 2	Optimized Design 3	Optimized Design 4	Optimized Design 5
Trans. Fr. Spacing		80"	96"	96"	96"	96"	80"
Stiffener Spacing		21" - 25"	20"	25"	30"	35"	35"
Weight		45.1 LT	40.8 LT (-9%)	43.1 LT (-4%)	45.7 LT (NC)	47.4 LT (+5%)	48.3 LT (+7%)
Weld Length		39,791"	42,240" (+6%)	36,290" (-9%)	28,920" (-27%)	26,890" (-32%)	28,040" (-29%)
Moment of Inertia		2.29E7 in^4	2.05E7 in^4	2.27E7 in^4	2.41E7 in^4	2.50E7 in^4	2.52E7 in^4
Max Stress	deck keel	-13.3/14.0 ksi 11.4/-15.7 ksi	-14.6/15.2 ksi 12.5/-17.0 ksi	-12.7/13.5 ksi 11.6/-16.1 ksi	-12.5/13.2 ksi 10.4/-14.0 ksi	-12.3/12.7 ksi 10.1/-13.9 ksi	-12.3/12.6 ksi 10.2/-13.4 ksi

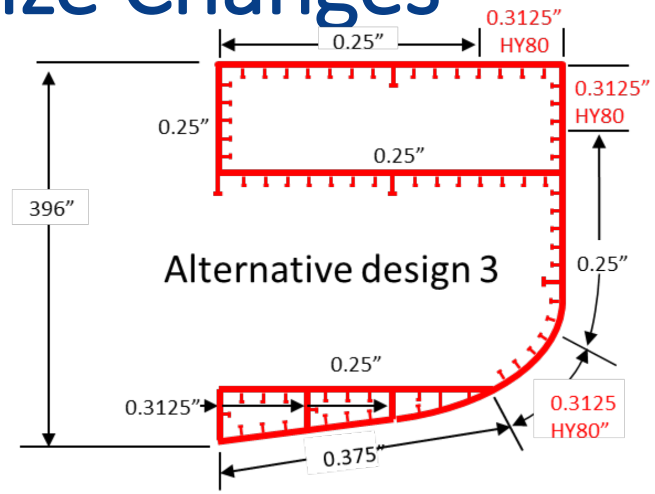
Best case | Worst case

Selected Design

Example Optimization Results, with Hull Size Changes

- This example iterates all three:
  - **Stiffener spacing**
  - **Number of frames**
  - **Global scale/dimensions; this case also changes depth of hull**
- Ship arrangement alternatives
- Production schedule and cost impacts
- Impact SWBS Group 100 as well as other SWBS Group production and cost factors





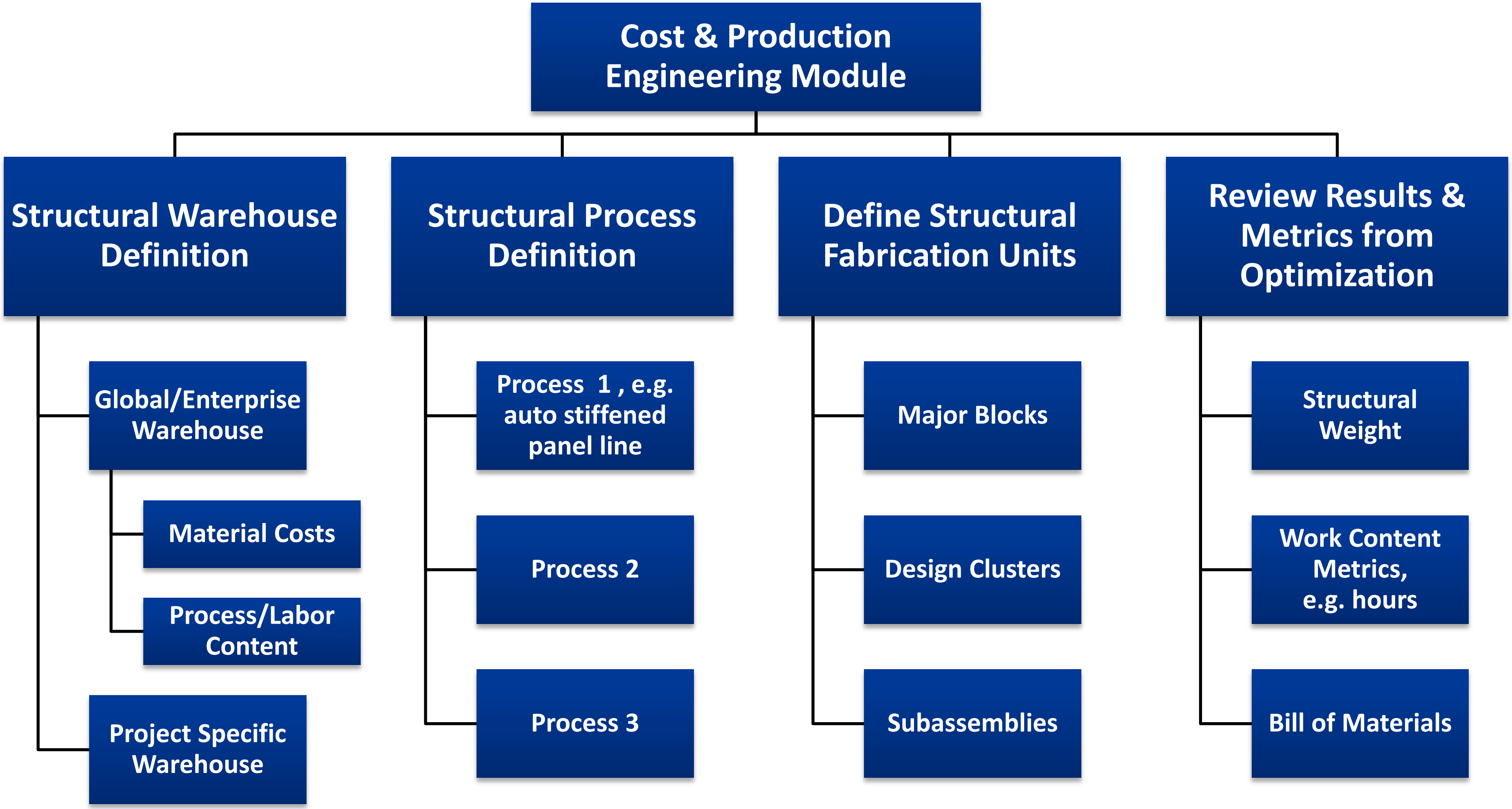
Property per frs 180-220	Original	Alternative Design 1	Alternative Design 2	Alternative Design 3	Alternative Design 4	Alternative Design 5
Trans. Fr. Spacing	80”	80”	96”	96”	96”	96”
Stiffener Spacing	21” - 25”	25”	20”	25”	20”	25”
Height	360”	360”	396”(+10%)	396”(+10%)	360”	360”
Weight	46.27 LT	37.9 LT (-18%)	49.3 LT (+6.5%)	41.1 LT (-11%)	38.8 LT (-16%)	41.5 LT (-10%)
Weld Length	38455”	37879” (-1.5%)	43717” (+13%)	37691” (-2%)	42621” (+11%)	36628” (-5%)
Moment of Inertia	2.28E7 in^4	1.75E7 in^4	3.0E7 in^4	2.27E7 in^4	1.86E7 in^4	1.93E7 in^4
Max Stress deck keel	-13.1/13.9 ksi 11.5/-15.8 ksi	-16.3/17.0 ksi 15.3/-20.4 ksi	-10.1/11.6 ksi 8.9/-13.5 ksi	-12.1/14.7 ksi 11.5/-18.1 ksi	-15.9/15.8 ksi 13.5/-19.4 ksi	-13.9/14.7 ksi 14.7/-20.1 ksi

Cost & Production Engineering Module

- A new MAESTRO software module has been designed to be used by **shipyard cost and production engineers**, not the structural naval architect, for defining cost and production data associated with the structural design and fabrication processes.
  - Specify the plates and shapes in the yard's **"structural warehouse"**
  - Define **structural fabrication processes**, e.g. panel lines and their cost metrics
  - Define the **structural fabrication components** and sequence of assembly
  - **Review results/metrics** for optimized structural alternative designs

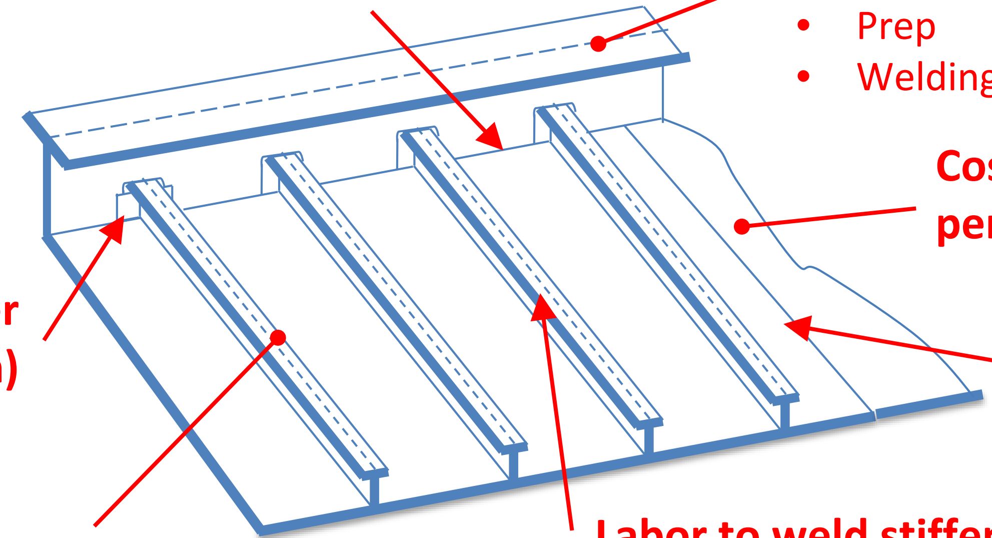
Data from this module will be used in SSDO's work content optimization to facilitate **realistic reductions/trade studies in work content** and **producibility enhancements**

Cost & Production Engineering Module

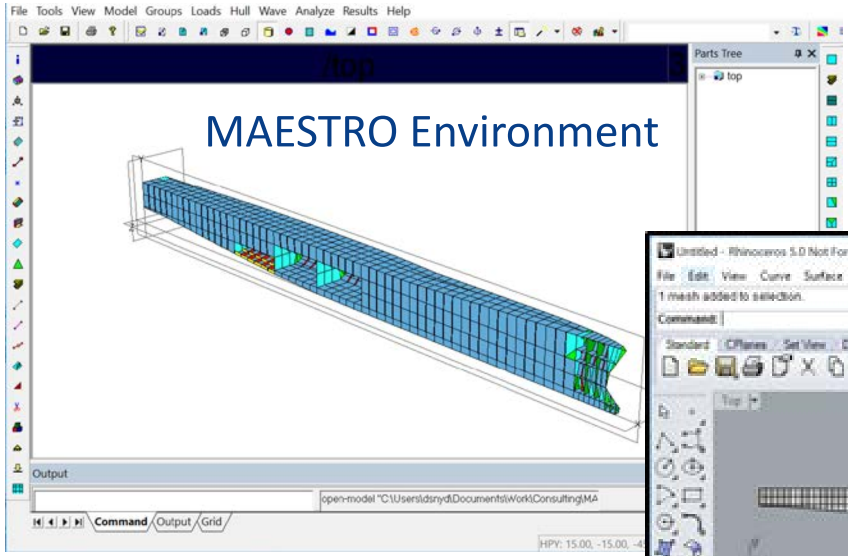


Cost & Production Engineering Module

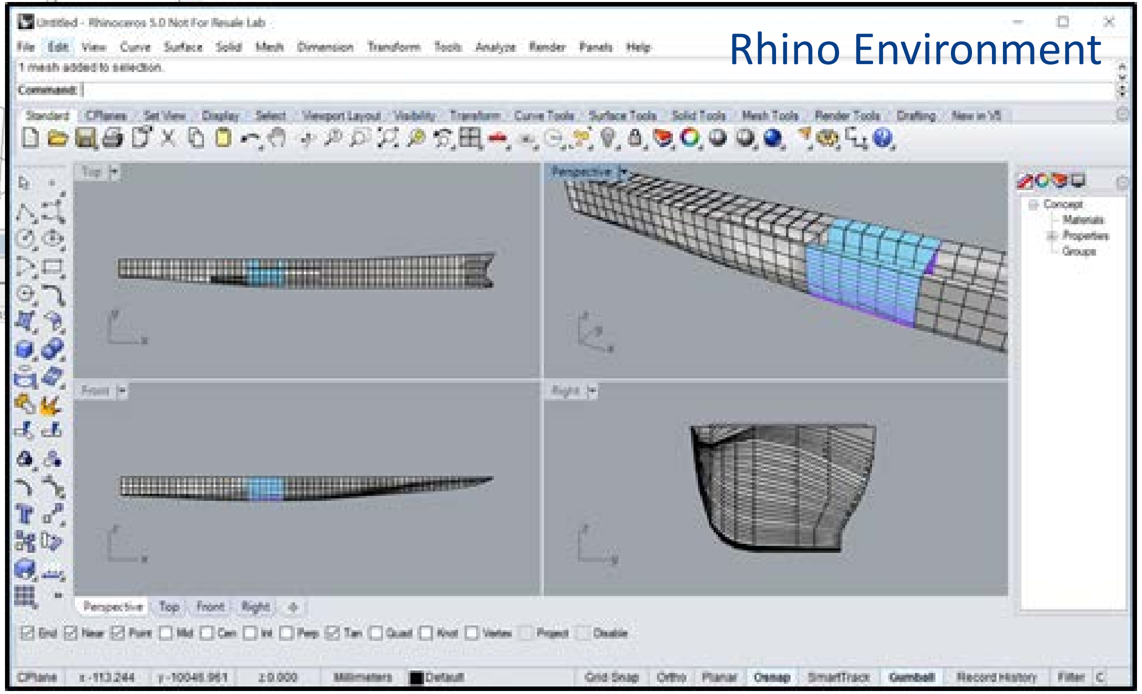
Example Structural Warehouse & Process Definition Metrics



Cost & Production Engineering Module



MAESTRO – Rhino Model And Data Exchange

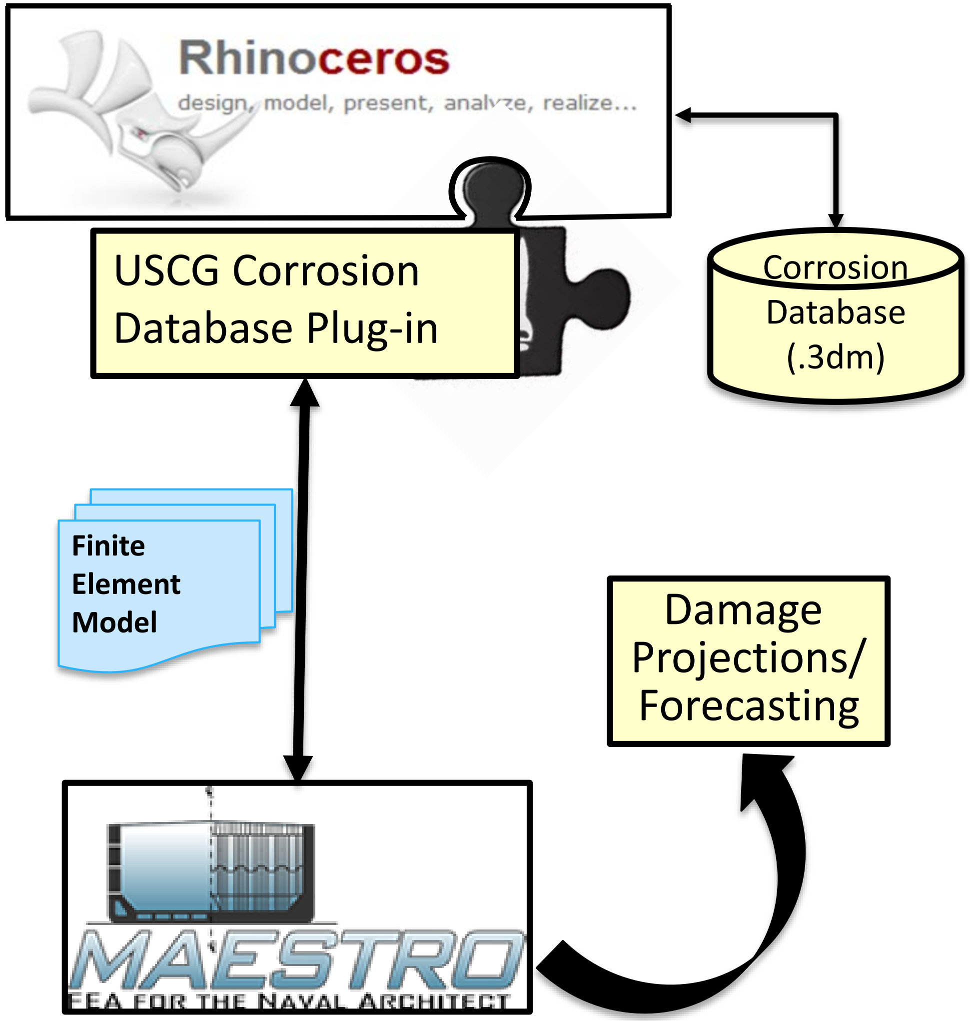


Production engineers work in the user friendly Rhino environment

DISTRIBUTION STATEMENT: Unlimited/Approved for Public Release

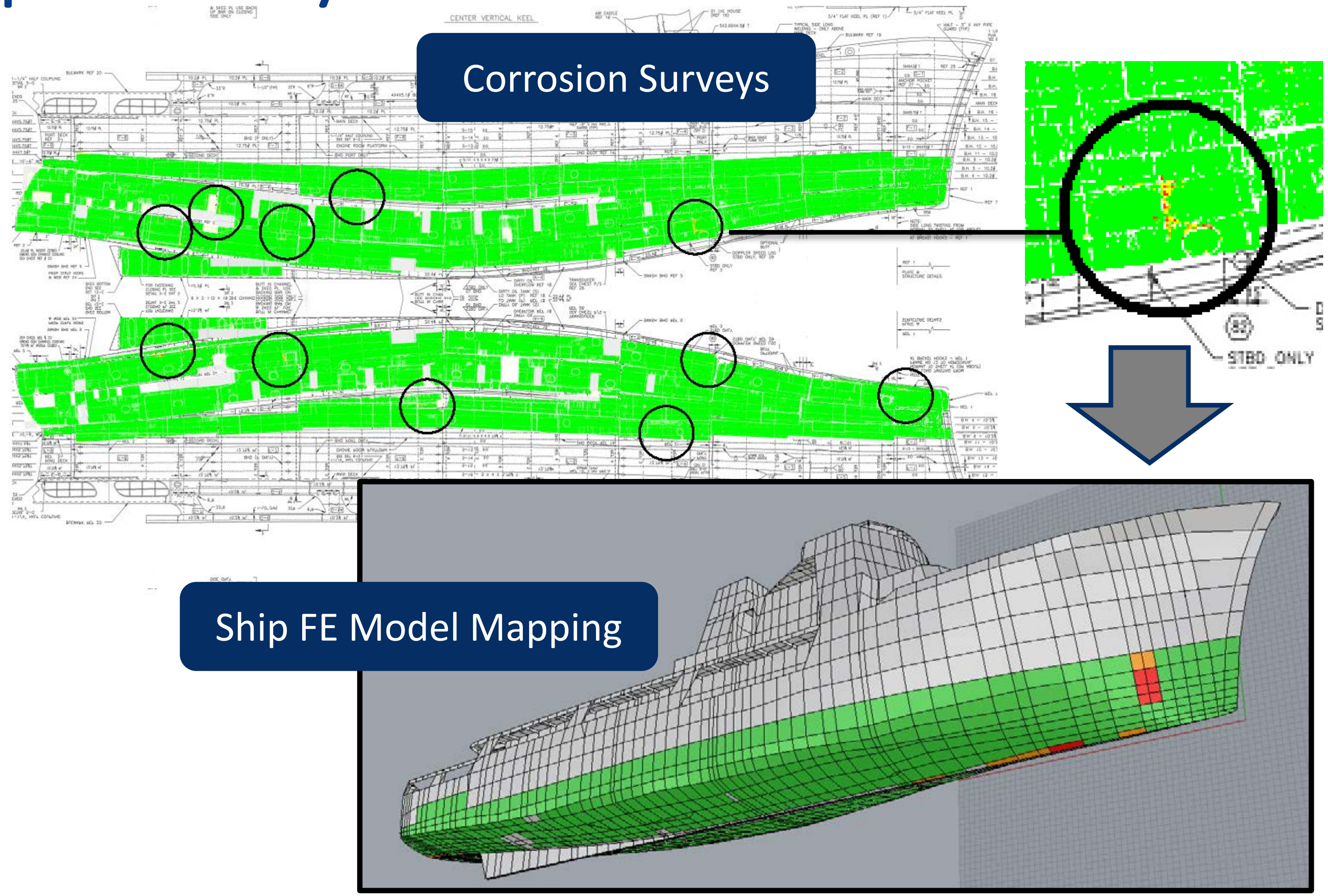
US Coast Guard SFLC Sponsored Corrosion Database Toolset Adaptation to SSDO Life-Cycle Assessment Objectives

- Track corrosion and other damage to a vessel's structure in a Rhino plug-in and database
- Collect, organize, and display data spatially, temporally, and across the fleet
  - Spatially: data displayed on 3D model
  - Temporally: display progression of corrosion/damage over multiple surveys
  - Fleet: examine data across vessels of a class
- Plan future surveys and repairs
- Support structural analysis of the vessel in its corroded/damaged condition
  - Structural Response (yielding/buckling)
  - Hydrodynamic Loads Analysis (MAESTRO-Wave)
  - Extreme Load Analysis (ELA)
  - Spectral Fatigue Analysis (SFA)



Corrosion Database Tool
Conduct Life-Cycle Impact Analyses and Trade Studies

- Corrosion surveys mapped into database that correlates with ship finite element (FE) model
- Corroded/damaged conditions are automatically transferred to ship FE model for analysis
- Support in-service engineering
  - Structural integrity evaluation
  - Fatigue life forecasting
  - Structural margins assessment
  - Structural repair management
  - Damage condition assessment



SSDO Provides Higher Fidelity Ship Structural Engineering from Concept Design through the Full Life-Cycle

Design Timeline

Concept | Preliminary | Functional/Contract | Life Cycle

APPLICATION OF MAESTRO OPTIMIZATION & ANALYSIS

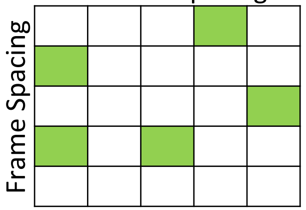
Concept

Topology Optimization

Coarse global FEA model

Static Global Loading:

- Automated optimization
- Design space exploration
- Topology search process

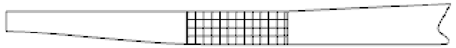


Full matrix

Preliminary

Selected Topology Opt.

Fine mesh midbody model



Loading:

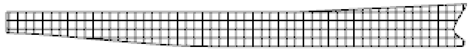
- Secondary & tertiary loads
- Basic hydrodynamic loads
- Extreme Load Analysis
- Spectral Fatigue Analysis
- Life-cycle cost factors

Selected Candidates

Functional/Contract

Full Optimization

Finer mesh global model



Loading:

- Secondary & tertiary loads
- Full hydrodynamic loads
- Extreme Load Analysis
- Spectral Fatigue Analysis
- Higher fidelity life-cycle cost factors

Final Topology

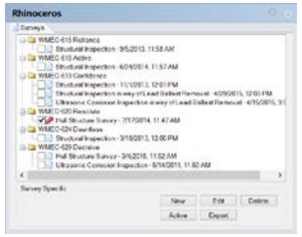
Life Cycle

In-Service Engineering

Fine mesh model & class database

Loading:

- Operational loads
- Extreme loads
- Spectral fatigue
- Damage conditions



Corrosion database

NSRP RA Project 2017-443 Summary
"Ship Structural Design Optimization (SSDO) for Improved Producibility and Enhanced Life-Cycle Performance"

- Early-stage design can rapidly engineer and assess the effects of global changes to frame spacing, stiffener spacing, as well as for changes to hull dimensions
- Production & Cost Engineering have the ability to impact the ship's structural design while it can still be changed during design to optimize cost, weight and production
- Life-cycle factors such as extreme load capabilities, structural fatigue life, and damage tolerance can be engineered during design to effectively improve the life-cycle performance and reduce excessive in-service structural repair costs
- In-Service Engineering can leverage the final design model throughout the ship's life to reduce life-cycle costs, engineer structural repairs, assess damage conditions, and ensure ship structural integrity with minimum downtime and repair costs