S92 Gearbox Optimization

HyperWorks Technology Conference 2010

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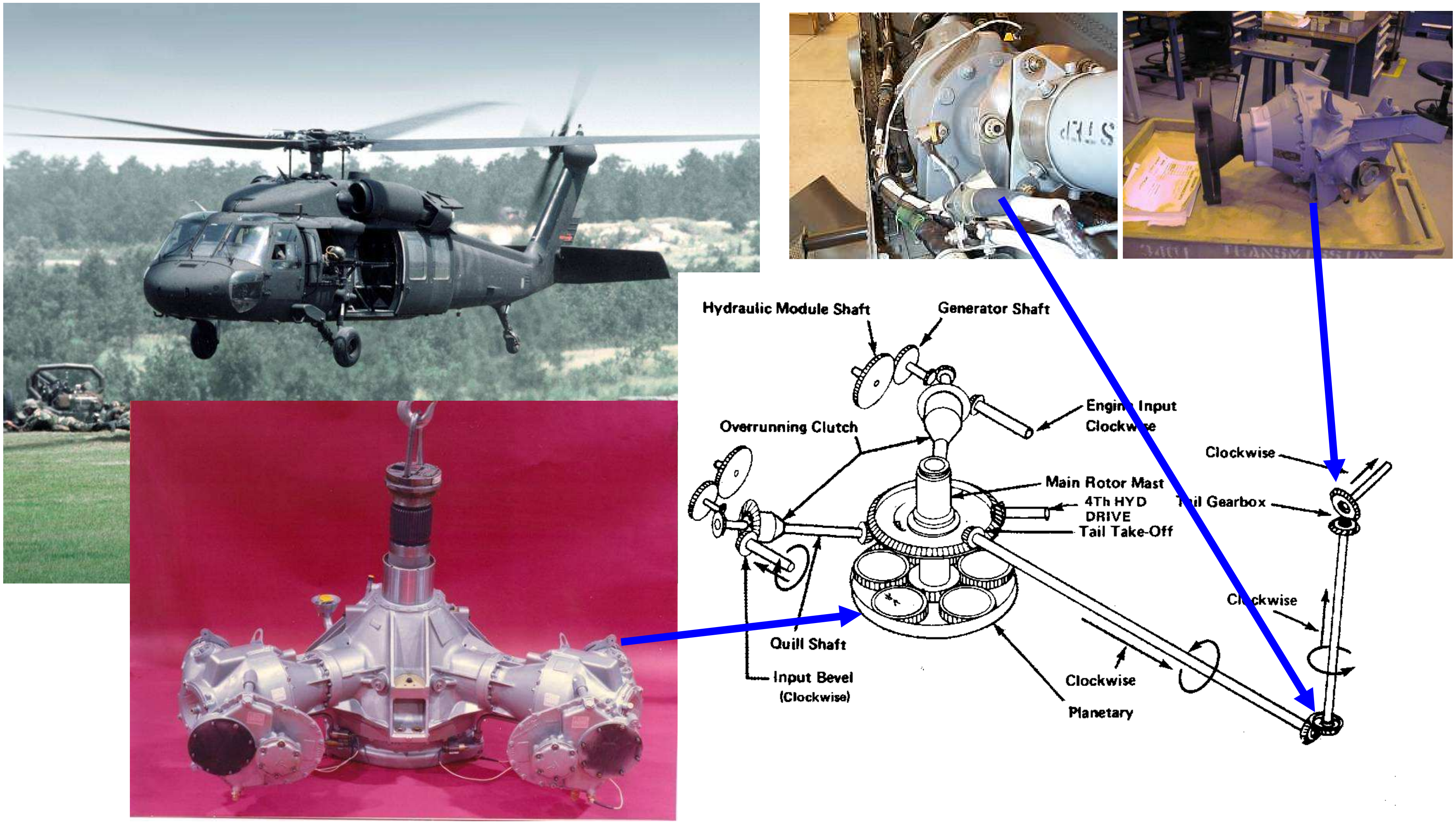
Altair ProductDesign
The shortest distance between concept and reality

Current Production Rotorcraft

H-60 BlackHawk Transmission System



S-76 Transmission System

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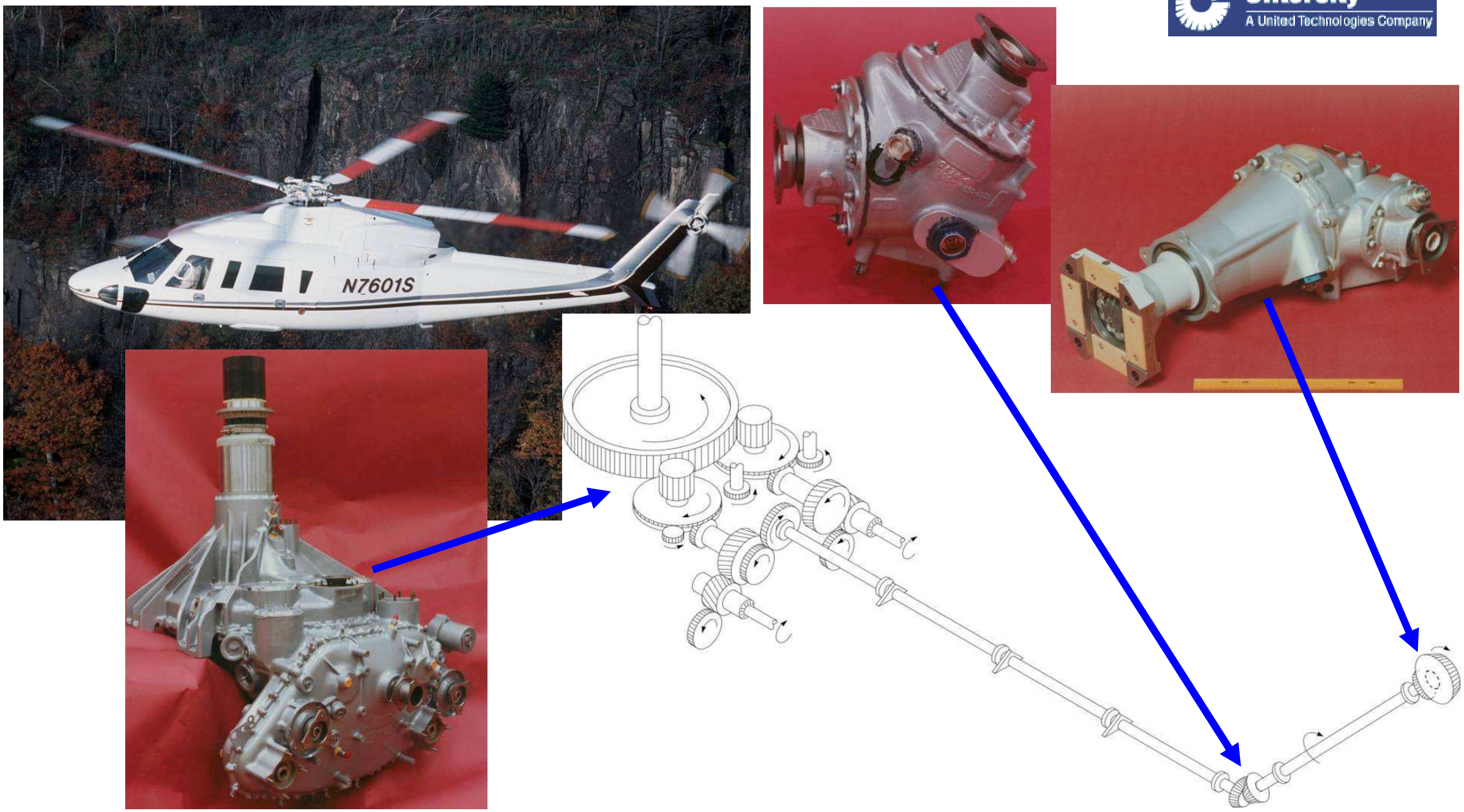
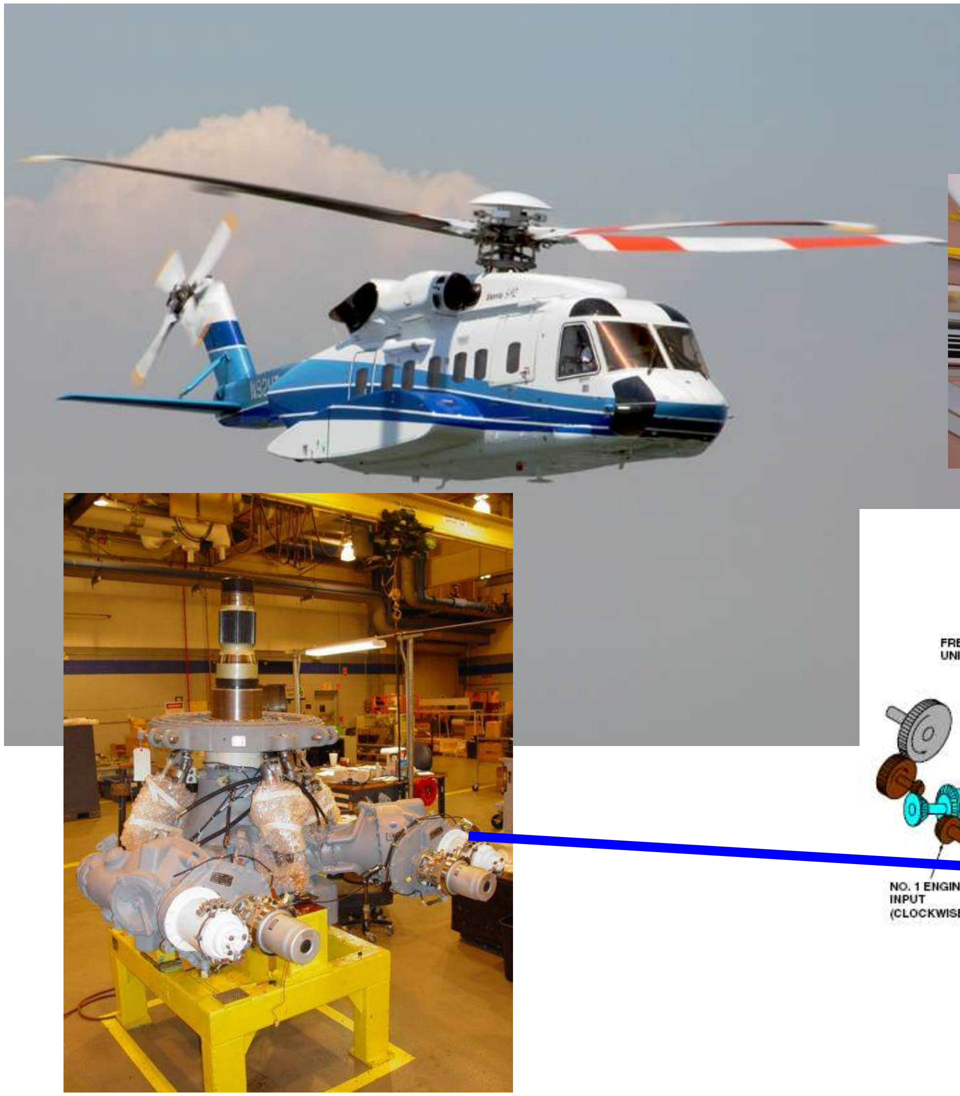
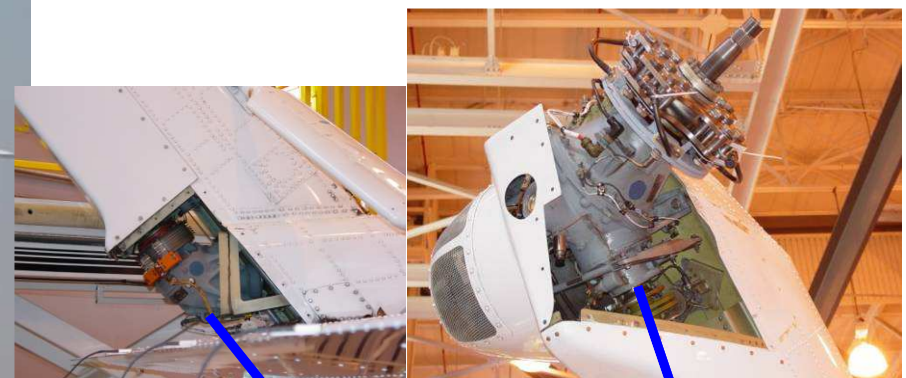
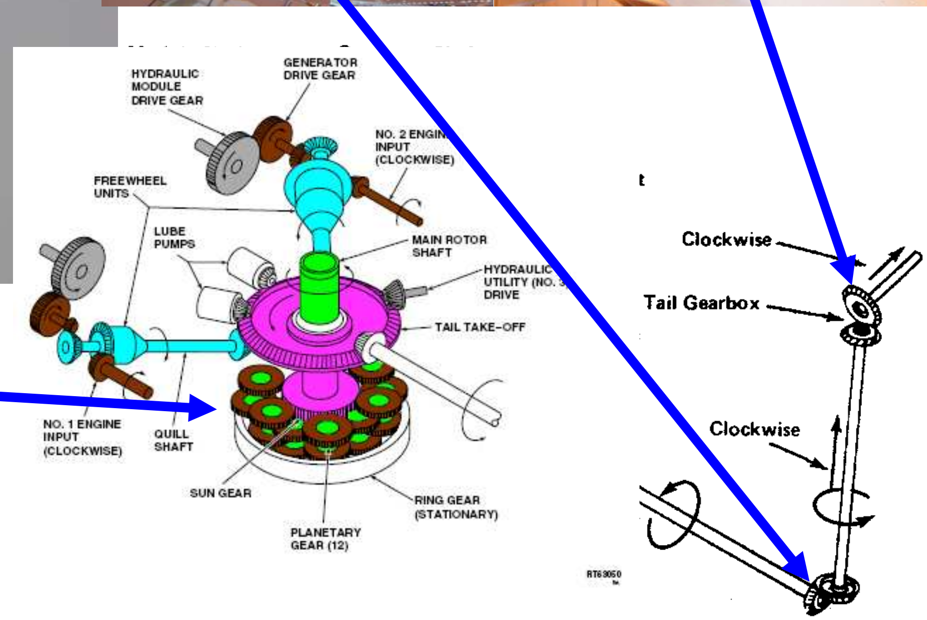


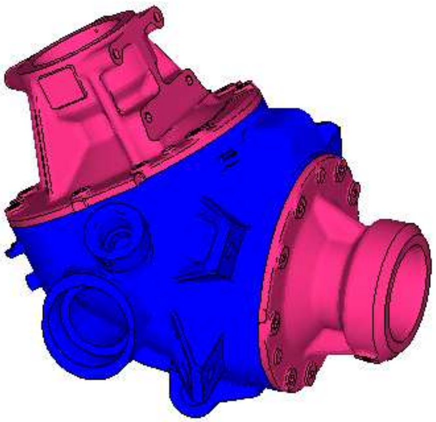
S-92 Transmission System







S-92 Gearbox Optimization



Project Overview

- S-92 Gearbox Optimization Objective
  - Substitute Aluminum for Magnesium in the S-92 gearbox with the overall goal a weight neutral change. This investigation is to address marine air corrosion and frequent maintenance intervals for the current Magnesium design on production aircraft.

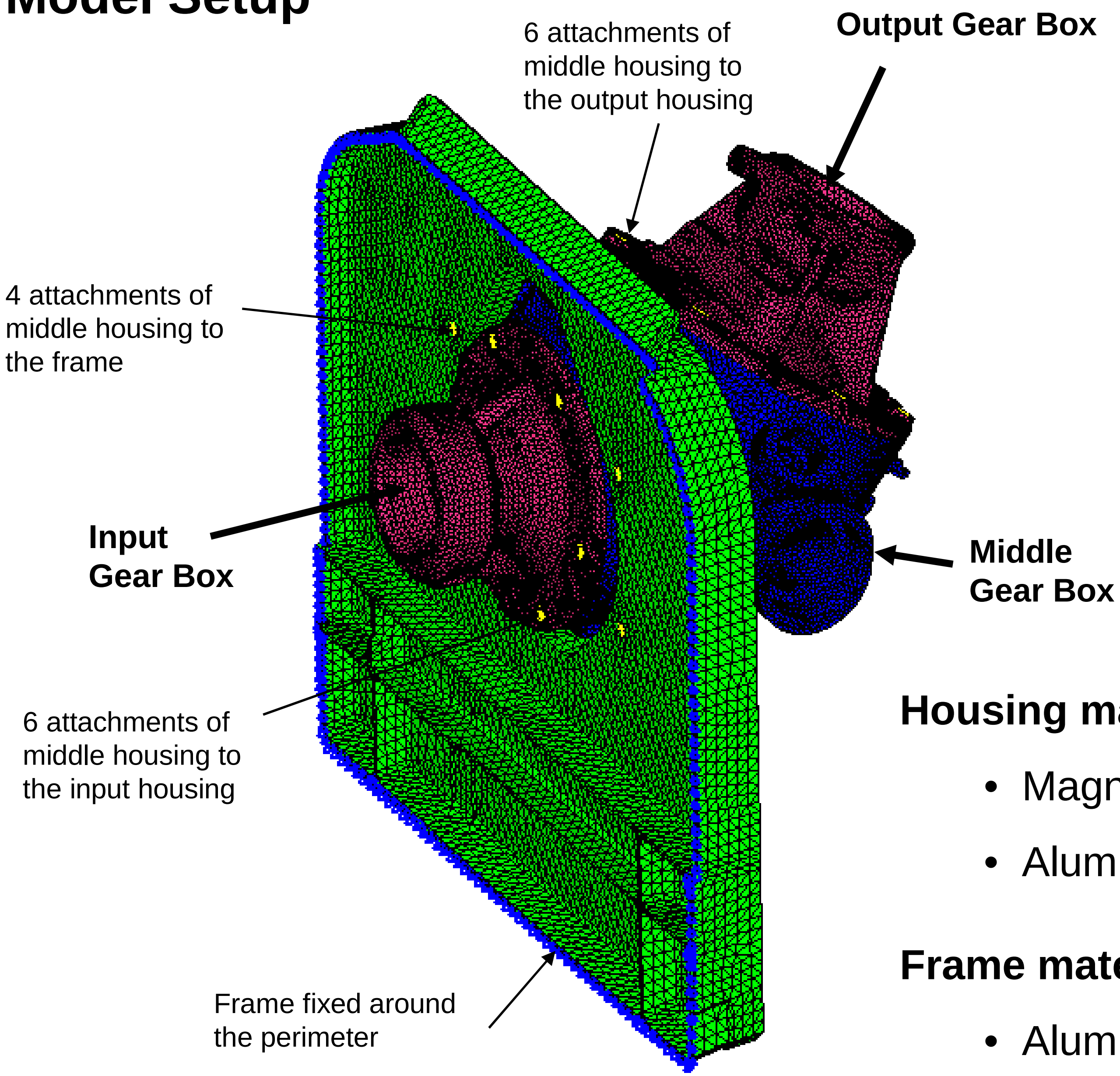
- 2-Phase Optimization Approach
  - The first phase was considered a Proof-of-Concept phase, and the problem statement was kept simple. Optimization was conducted to enhance the stress performance of the housing without further increasing the weight of the baseline Aluminum design.
  - The second phase was to design a minimum-weight aluminum housing with fatigue performance that is better or equivalent to that of the baseline Magnesium design. In order to keep optimization simple, the ratio of $\sigma_{max}/\sigma_{yield}$ was used as a basic measure of fatigue. The second phase is documented in this presentation though both phases follow a similar approach.

Project Overview (cont.)

- Optimization Methodology
  - FE Model Setup
  - Loadcase Details
  - Baseline Results
  - Topology Optimization
  - Design Interpretation
  - Free Shape Optimization
  - Final Design

- Analytical Model Solver Details
  - Baseline Analysis & Design Validation
    - Nonlinear analysis including contacts employing 2nd order elements (C3D10M) using ABAQUS
  - Optimization
    - Linear analysis employing 1st order elements using OPTISTRUCT

FE Model Setup



Housing material:

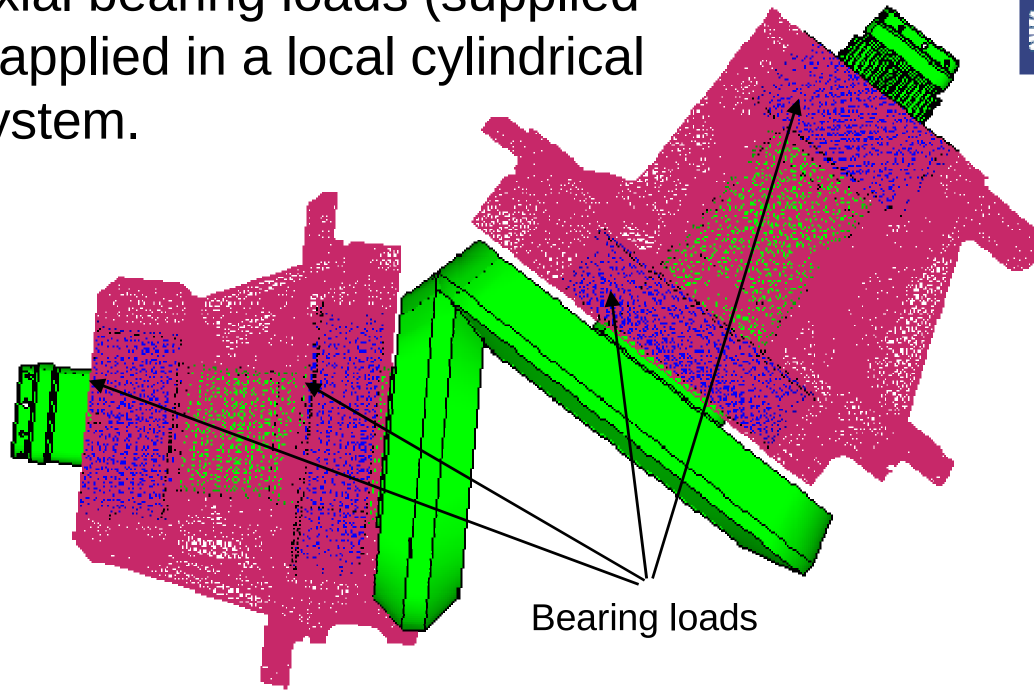
- Magnesium AZ91E
- Aluminum A357

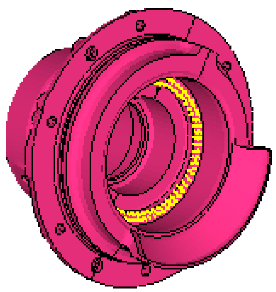
Frame material:

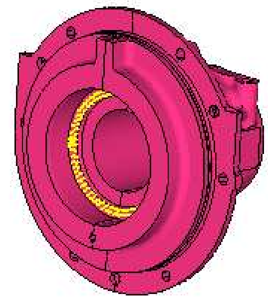
- Aluminum A357

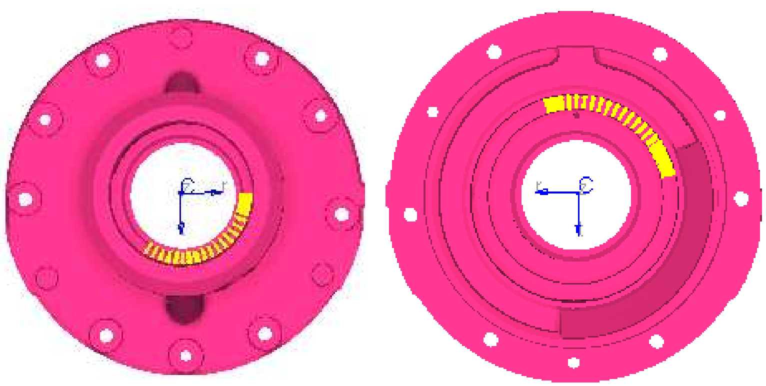
Loadcase Details

- Radial and axial bearing loads (supplied by Sikorsky) applied in a local cylindrical coordinate system.

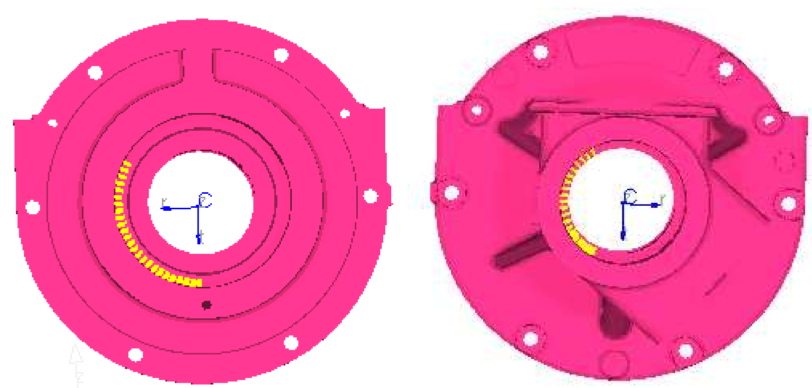








Input Housing

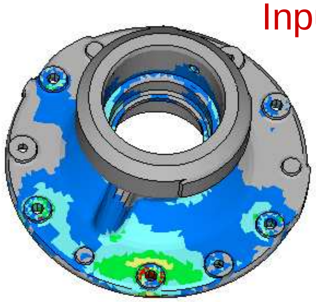


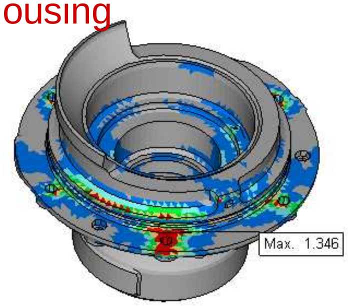
Output Housing

Baseline Results

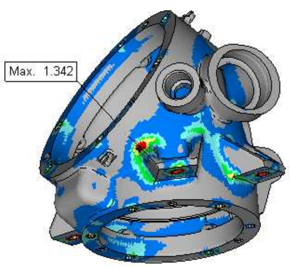
Magnesium

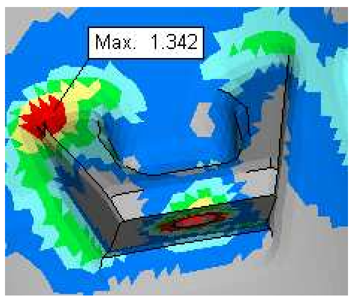
Input Housing



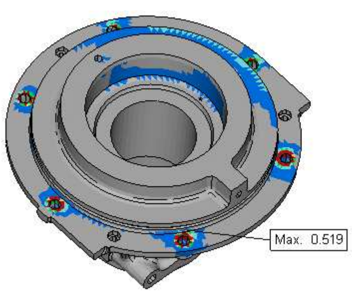


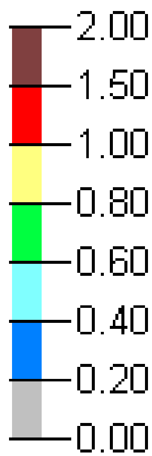
Middle Housing





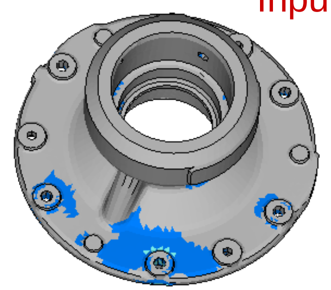
Output Housing

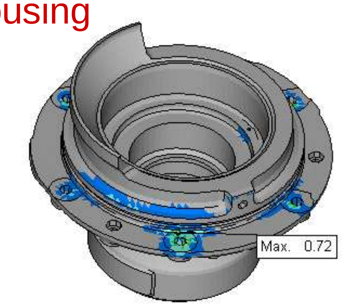




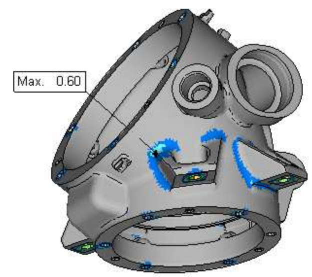
Aluminum

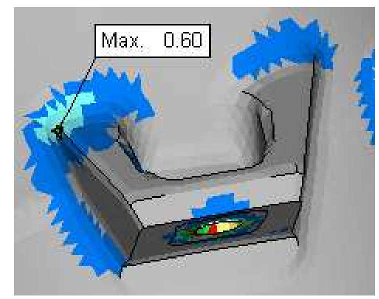
Input Housing



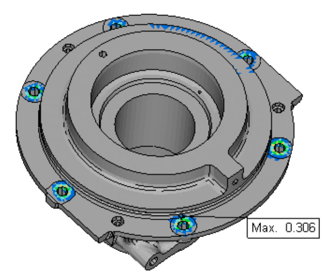


Middle Housing





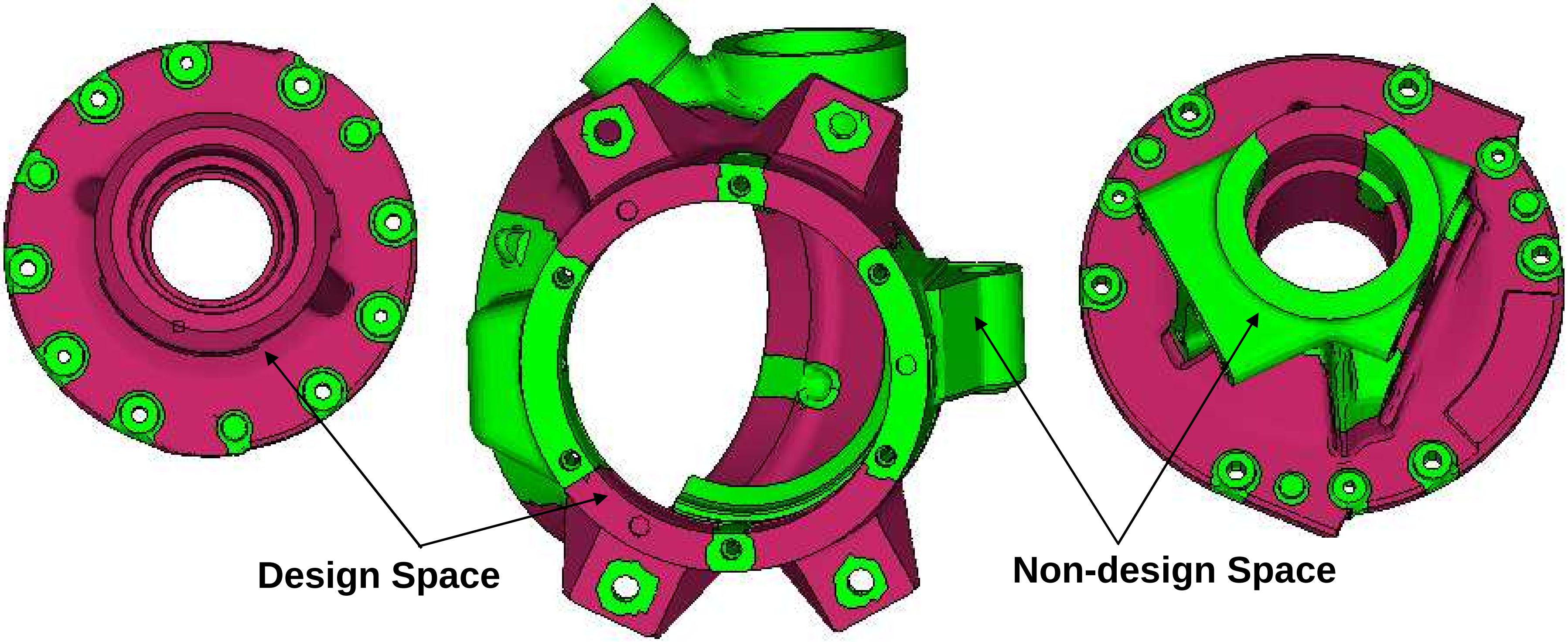
Output Housing



Topology Optimization

Objective: Minimize strain energy of the Aluminum gear box assembly

Constraint: Total mass of the three Aluminum gear boxes ≤ 18.9 lb



Input Housing
Baseline MG: 3.9 lb
Baseline AL: 5.9 lb

Middle Housing
Baseline MG: 7.6 lb
Baseline AL: 11.5 lb

Output Housing
Baseline MG: 7.3 lb
Baseline AL: 10.9 lb

Topology Optimization Results

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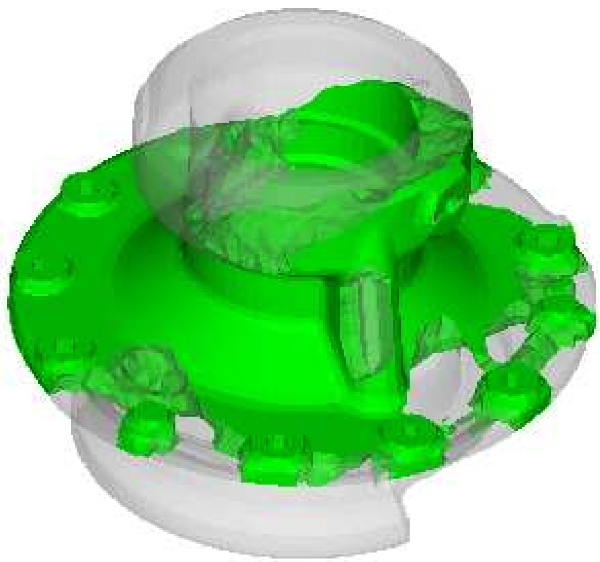

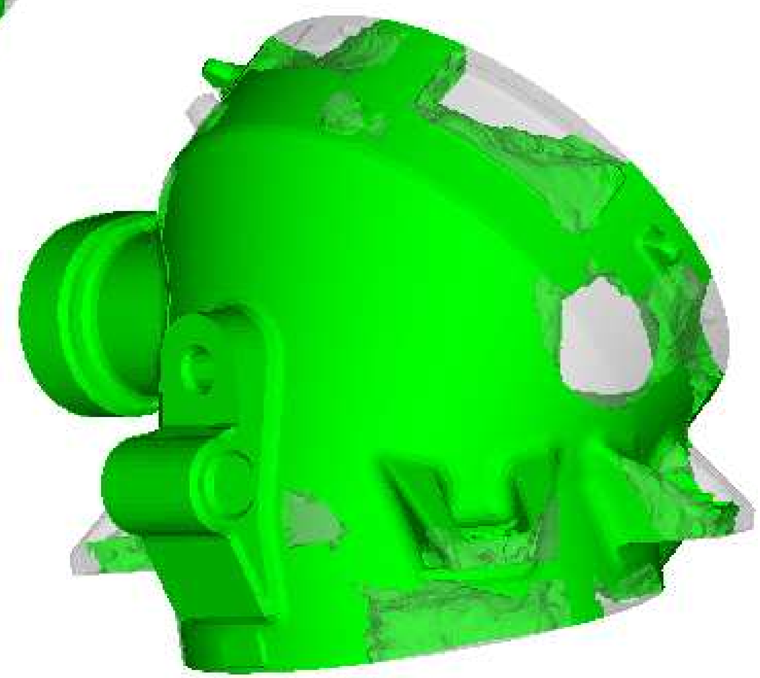

Design Interpretation

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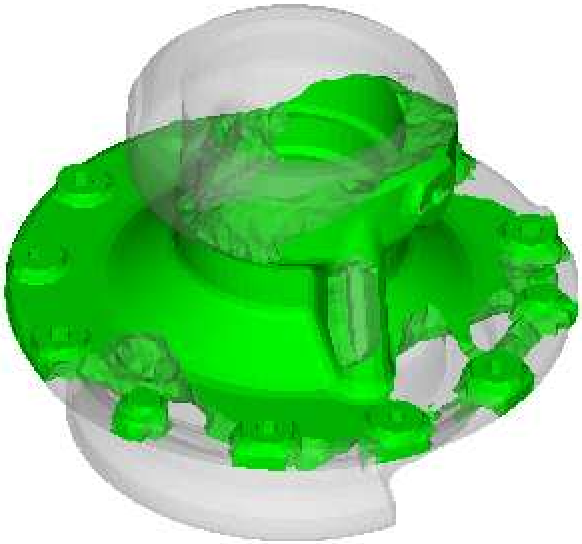
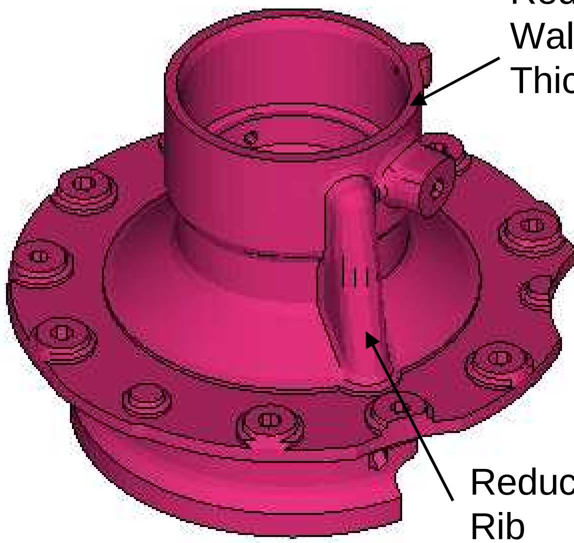
Topology Load Path (Conceptual Design)

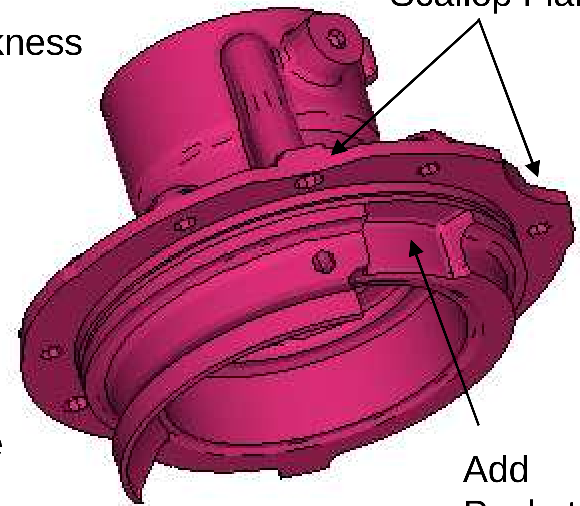


Interpreted Design AL (4.682 lb)



Reduce Wall Thickness

Reduce Rib Thickness

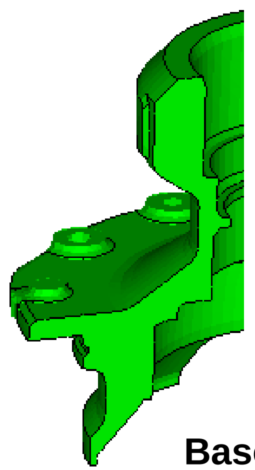


Scallop Flange

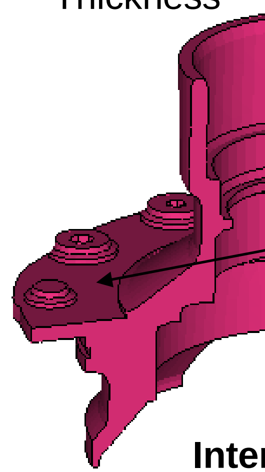
Add Pocket

Input Housing:

Baseline MG: 3.951 lb
Baseline AL: 5.927 lb
Int. Design AL: 4.682 lb



Baseline

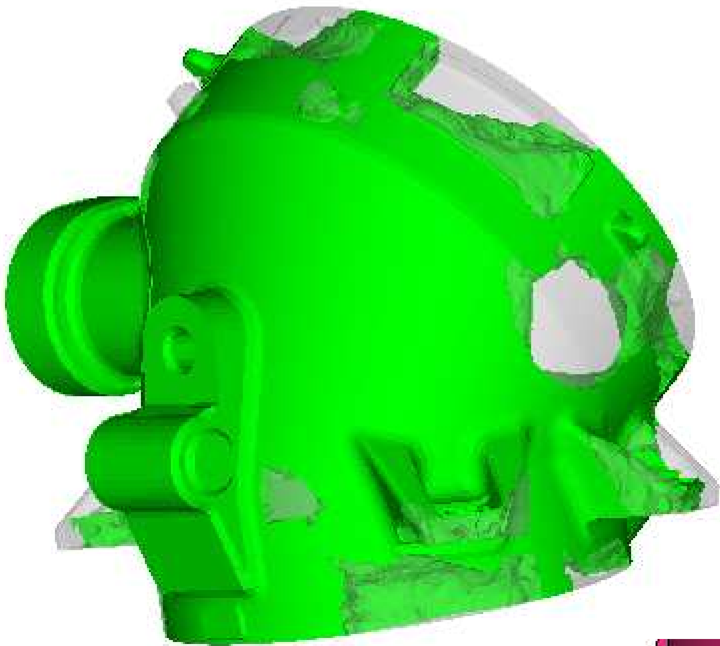


Reduce Flange Thickness

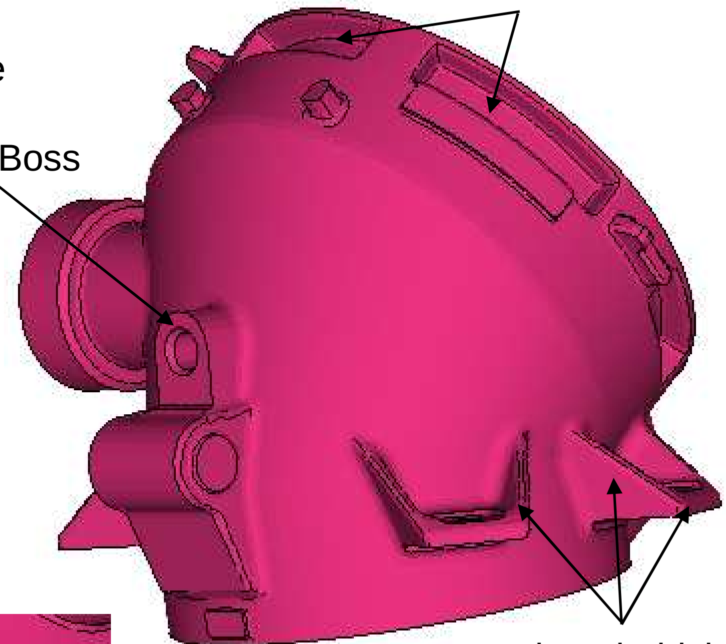
Interpreted Design

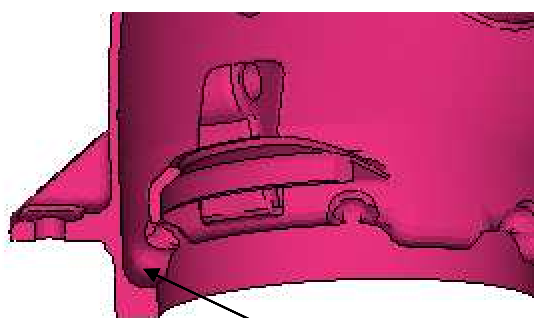
Design Interpretation (cont.)

Topology Load Path (Conceptual Design)



Interpreted Design AL (8.512 lb)



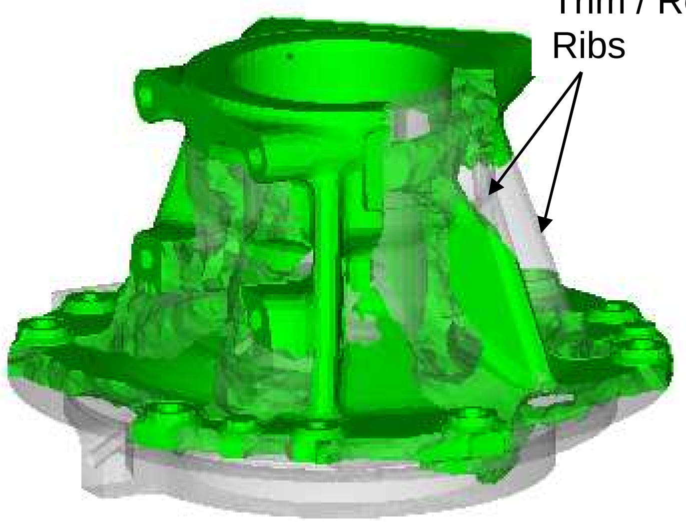


Middle Housing:

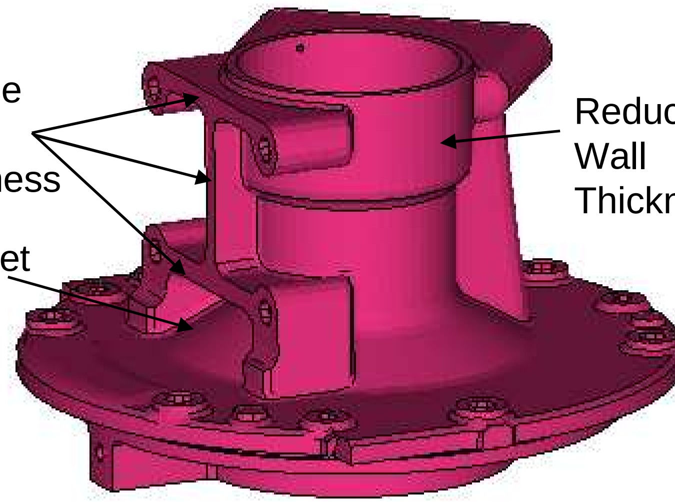
Baseline MG: 7.671 lb
Baseline AL: 11.508 lb
Int. Design AL: 8.512 lb

Design Interpretation (cont.)

Topology Load Path (Conceptual Design)

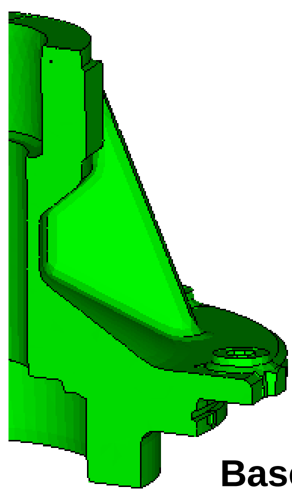


Interpreted Design AL (5.526 lb)

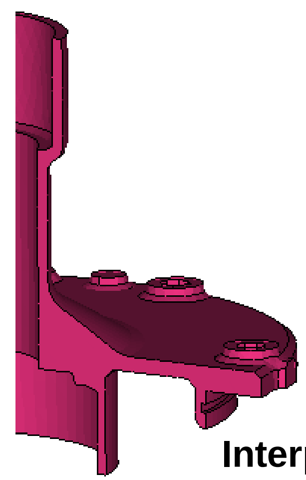


Output Housing:

Baseline MG: 7.269 lb
Baseline AL: 10.903 lb
Int. Design AL: 5.526 lb



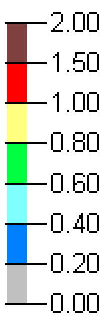
Baseline

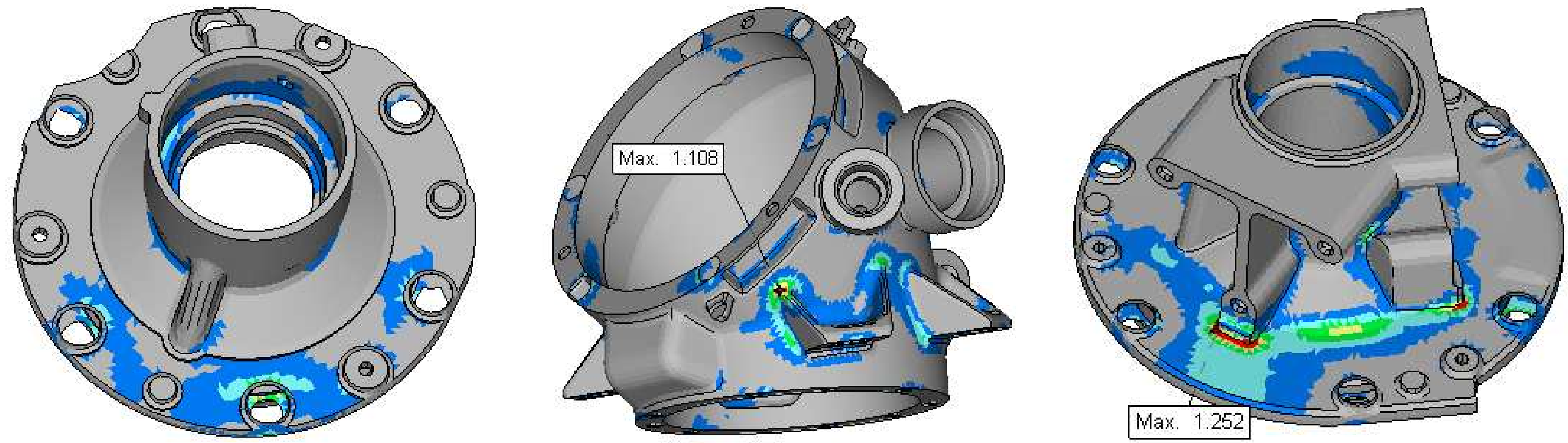


Interpreted Design

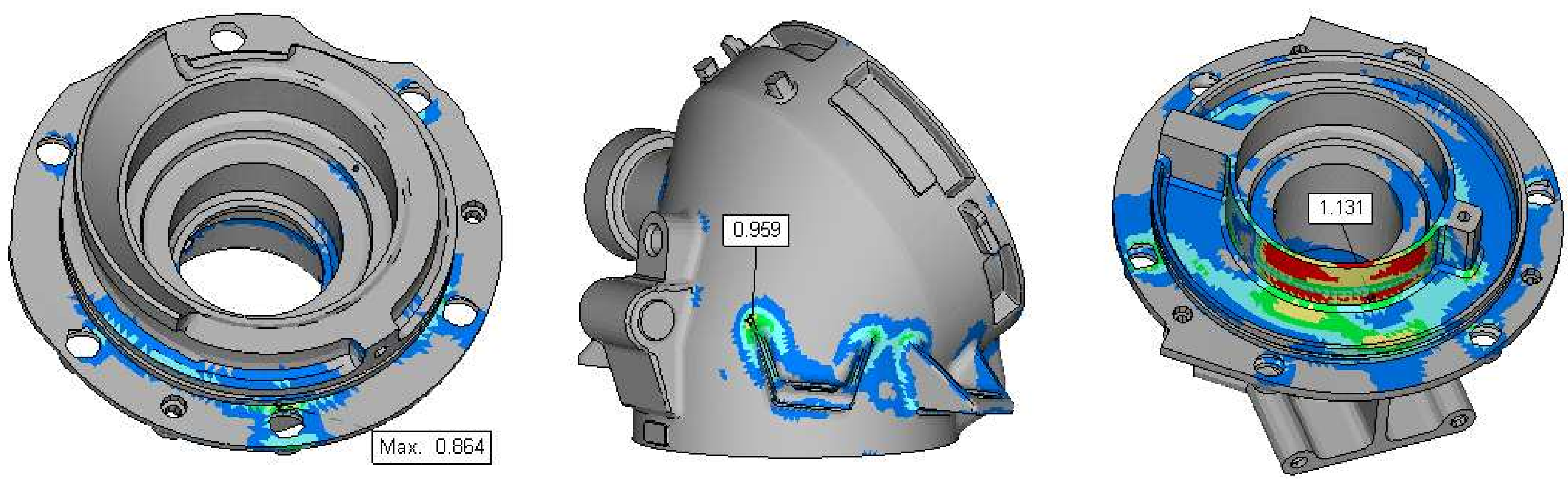
Interpreted Design Evaluation

- Generate FEA models of the interpreted design and evaluate radial and axial bearing loadcase.





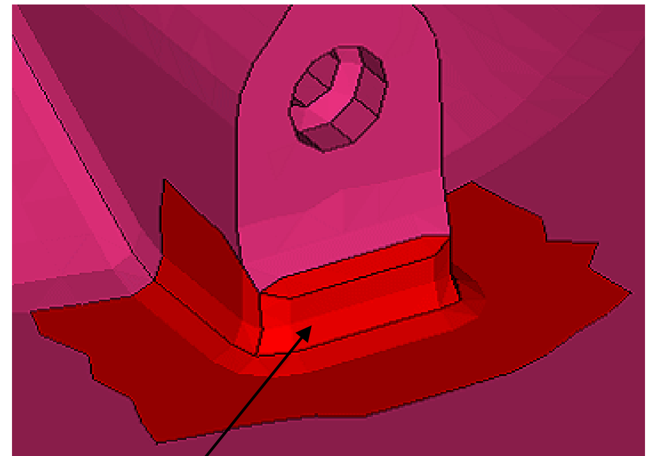
Input Housing **Middle Housing** **Output Housing**



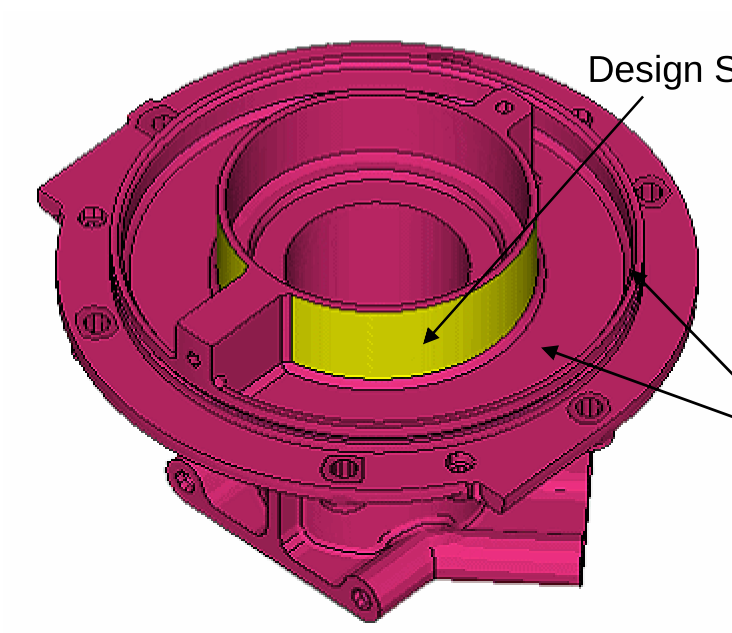
Free Shape Optimization

Objective: Minimize strain energy of the Aluminum gear box assembly (input housing, center housing, and output housing).

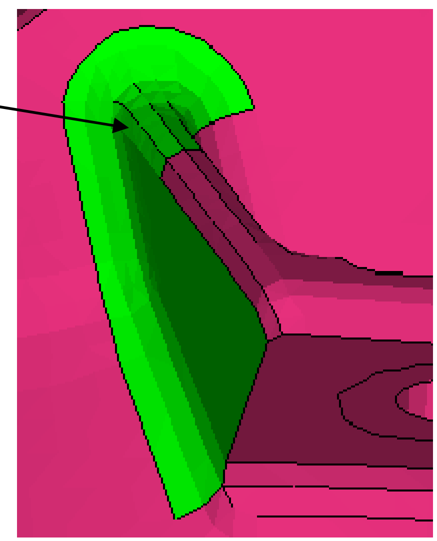
Constraint: Scaled local stress ratio ≤ 0.8



Design Space

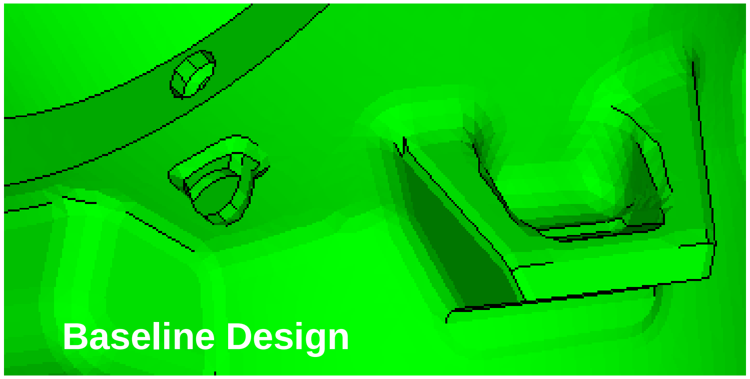


Design Space



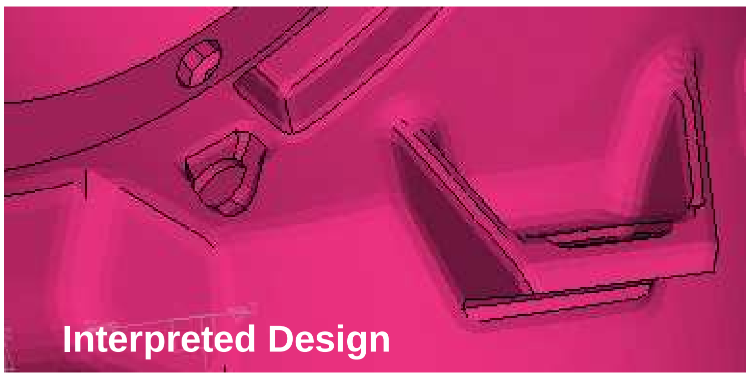
Similar free shape optimization was performed on these areas

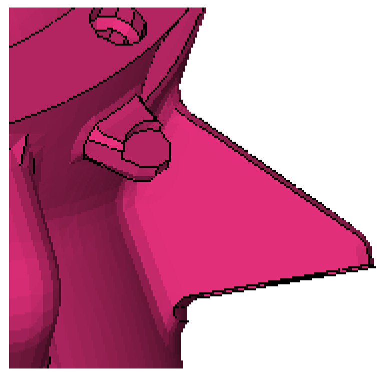
Final Design

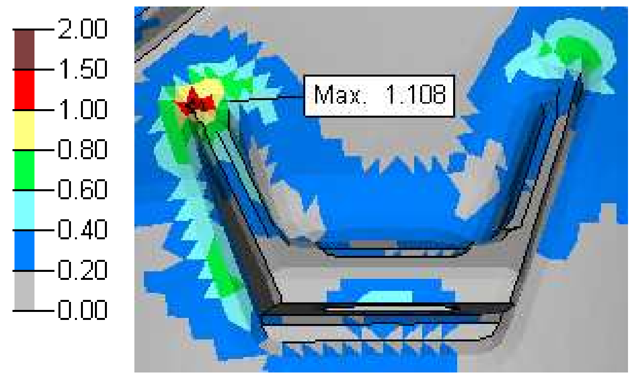


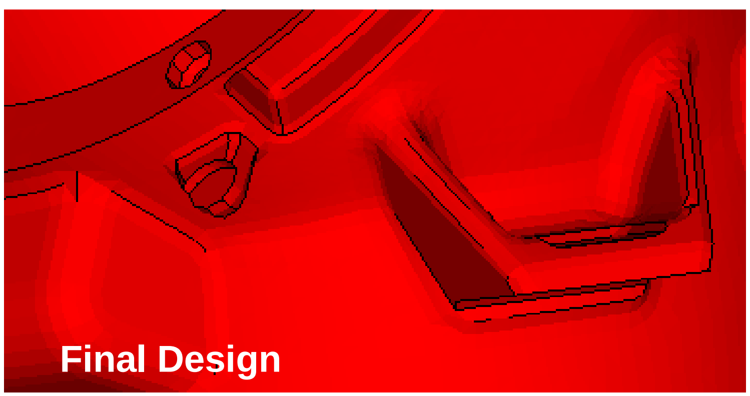
Middle Housing:

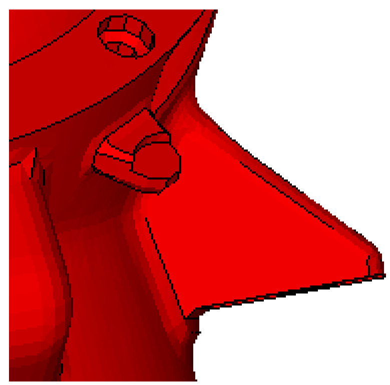
Baseline MG:7.671 lb
Baseline AL:11.508 lb
Int. Design AL: 8.512 lb
Final Design AL: 8.532 lb

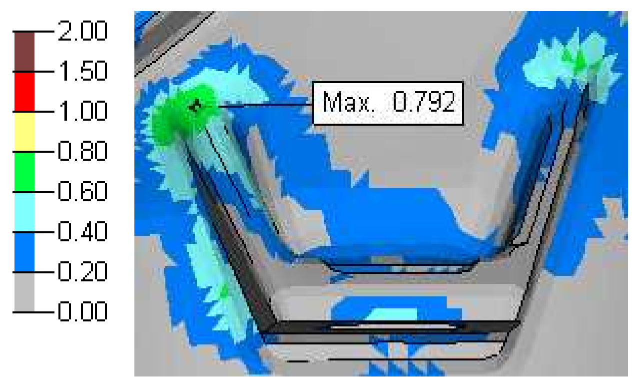




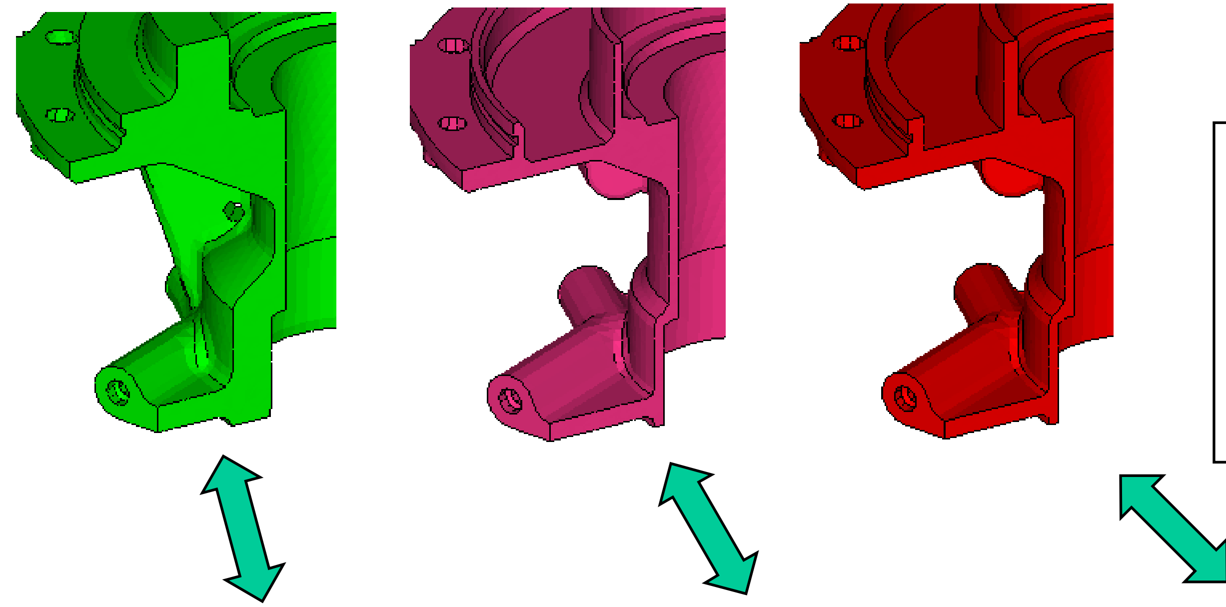








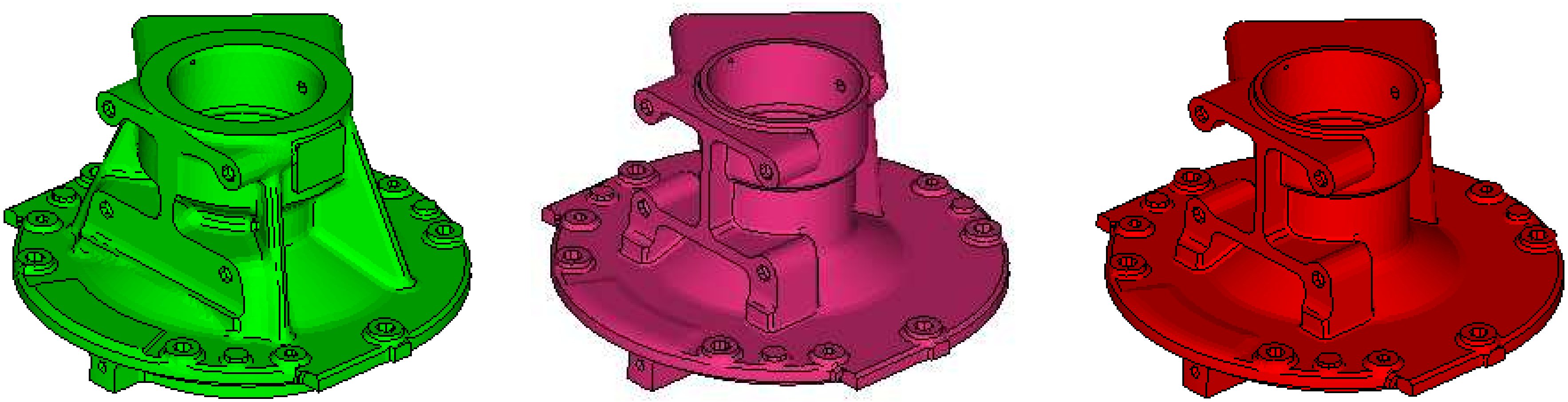
Final Design (cont.)



Output Housing:

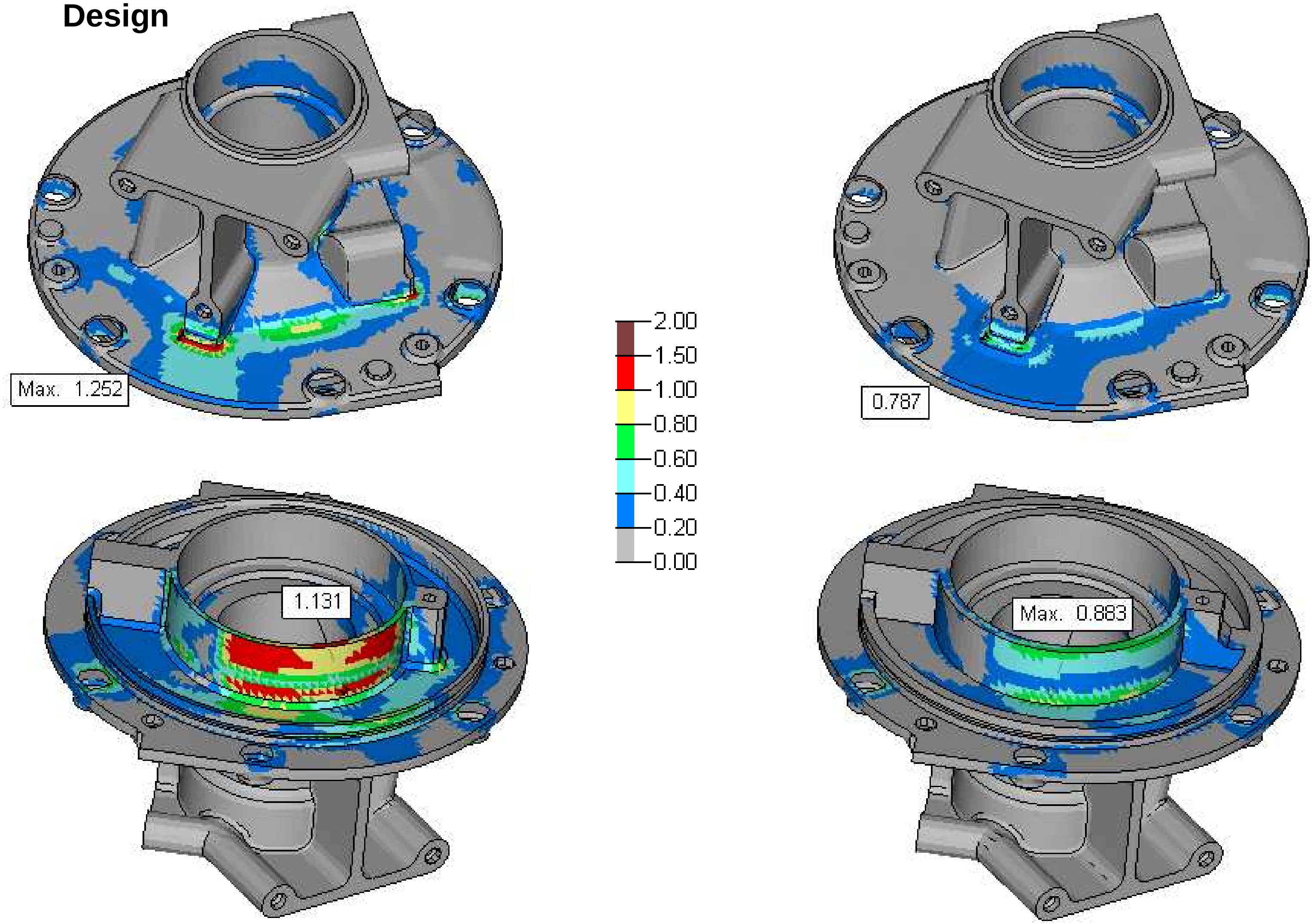
Baseline MG: 7.269 lb
Baseline AL: 10.903 lb
Int. Design AL: 5.526 lb
Final Design AL: 6.257 lb

Baseline Design **Interpreted Design** **Final Design**



Final Design (cont.)

Interpreted Design | **Final Design**



Results Summary

Design	$\sigma_{max} / \sigma_{yield}$		
	Input Gear Box	Middle Gear Box	Output Gear Box
Baseline Design MG	1.34	1.34	0.52
Baseline Design AL	0.72	0.60	0.31
Interpreted Design AL	0.86	1.11	1.25
Final Design AL	0.87	0.79	0.88*

σ_{max} : Maximum Von Mises Stress (elements attached to rigids excluded)
σ_{yield} : Yield stress

* In order to have a balance between weight reduction and performance, the final design of the output housing was targeted to a similar stress ratio as the input and middle housings.

Design	Input Gear Box	Middle Gear Box	Output Gear Box	Total	Change with respect to Baseline MG	Change with respect to Baseline AL
Baseline Design MG	3.951 lb	7.671 lb	7.269 lb	18.891 lb		
Baseline Design AL	5.927 lb	11.508 lb	10.903 lb	28.338 lb	+50 %	
Interpreted Design AL	4.682 lb	8.512 lb	5.526 lb	18.720 lb	-0.9 %	-34 %
Final Design AL	4.682 lb	8.532 lb	6.257 lb	19.471 lb	+ 3%	-31 %

S-92 Gearbox Optimization

- 31% reduction in mass over directly substituting aluminum into the existing design.
- Increased durability, reduced maintenance and downtime
- Savings in design cycle times
  - Typical manual optimization process ~ 6 months
  - S-92 Gearbox Optimization ~ 1 month
- Method viable for wide range of helicopter systems

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The shortest distance between concept and reality