Optimization of Spacecraft Metallic Primary Structure with OptiStruct

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Introduction

- The primary structure of a spacecraft serves as the main structural support during launch environments and it can serve as a mounting point for primary payloads, secondary payloads, and auxiliary hardware.

- The following slides present a study where mathematical optimization was applied to a typical spacecraft primary structure metallic panel with a mounted secondary payload.

- The objective of the study was to improve the strength and stiffness characteristics of the primary structure panel with a limited mass budget.

- Altair HyperWorks 2014 and OptiStruct 2014 were used to perform the structural optimization.
Objective

- Increases in primary structure mass reduce the amount of useful payload to orbit, so significant design efforts are undertaken to reduce the primary structure mass while preserving the strength and stiffness characteristics.

- Balancing these characteristics can be challenging due to the extensive number of load cases and requirements applicable to primary structure.

- The study focused on maximizing the 1st bending mode of the secondary payload and meeting launch environment strength requirements without exceeding a mass budget.
Approach

• The study started with topology optimization to understand the panel regions that most influenced the secondary payload 1st bending mode.

• After topology optimization, a panel design was conceived to incorporate the topology results, address manufacturing concerns, and address other requirements.

• Once a preliminary panel design was completed, a size (gauge) optimization was used to fine tune the panel thicknesses.

• Nastran DMIG mass and stiffness matrices were used to accurately capture the spacecraft boundary of the panel.

• The load steps applied included typical launch vehicle quasi-static load factors, typical quasi-static load factors to envelope dynamic secondary payload environments, and a modal analysis step.

• A buckling analysis and final size optimization cycle was completed to complete the study.

• Results were characterized relative to a heritage uniform isogrid panel and by strength margins of safety.
Analysis Model: Topology Optimization

- 2D, 3D, and Rigid elements were used to create a topology optimization model.
- The light blue topology design variable region was made up of 2D elements.
- Rigid elements were used to model the secondary payloads on the panel.
- The orange region was previously defined based on prior evaluation.
Analysis Approach: Topology Optimization

• **DRCO**
  – **Design Variables**
    • Elements in Light Blue Area
  – **Responses**
    • Mass
    • Weighted Frequency Compliance
  – **Constraint**
    • Mass
  – **Objective**
    • Minimize Weighted Frequency Compliance
      – Modes 1, 2, and 3 Equally Weighted

• **Load Step(s)**
  – Modal
Analysis Results: Topology Optimization

Contour Plot
Element Densities (Density)
1.000E+00
8.889E-01
7.778E-01
6.667E-01
5.556E-01
4.444E-01
3.333E-01
2.222E-01
1.111E-01
7.506E-15

Max = 1.000E+00
Min = 7.506E-15

Model info: 1
Result: H:\P05\T7\Opt1\Opt1_des.h3d
Design: Iteration 0
Frame 1

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Analysis Results: Topology Optimization

Blue: Void
Red: Solid
Transition from Topology to Size Optimization

- After topology optimization, other considerations like manufacturability, integration and testing were used to define a preliminary panel CAD design.

- Primary structure is typically used by other subsystems that impact the design:
  - Thermal
  - Propulsion
  - Electrical
Analysis Model: Size Optimization

- 2D, 3D, and Rigid elements were used to create a size optimization model
- The green ribs and grey back surface were grouped with symmetry and insights from the topology optimization to reduce the number of design variables.
Analysis Approach: Size Optimization

- **DRCO**
  - Design Variable
    - Discrete Variables Linked to Thickness
  - Responses
    - Mass
    - Stress
    - Weighted Frequency Compliance
  - Constraint
    - Mass
    - Stress
  - Objective
    - Minimize Weighted Frequency Compliance
      - Modes 1, 2, and 3 Equally Weighted

- **Load Step(s)**
  - Modal
  - Quasi-Static Typical Launch Vehicle
  - Quasi-Static Secondary Payload Dynamic Envelope
Analysis Results: Size Optimization

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Buckling Analysis

- Adding buckling analysis into the optimization loop significantly increased runtime.
- Early evaluations of the panel indicated that the back surface thickness was the primary driver for buckling margins of safety.
- After the initial size optimization was completed, a linear buckling analysis was run, the back surface thickness was updated, and a final rib size optimization was completed.
Optimization Results

Reference Design

Final Design

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Optimization Results

- 23% Secondary Payload Bending Mode Improvement
- Yield, Ultimate, and Buckling Margins of Safety Preserved or Improved
- No Panel Mass Increase
• A primary structure metallic panel was successfully optimized to increase a mounted secondary payload’s 1st bending mode by 23%
  – Yield, Ultimate, and Buckling margins are the same or better
  – No Increase in Mass

• OptiStruct can be used apply mathematical optimization to spacecraft primary structure designs and improve performance

• Future Work
  – Application to other metallic and non-metallic primary structure
  – Process definition for secondary structure components
  – Build, Test, and Fly an optimized primary structure panel
THE VALUE OF PERFORMANCE.

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