SDA Webinar
Introduction to NX Nastran SOL 200
Design Optimization

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Webinar Overview

- About SDA
- What is Design Optimization?
- Demonstrations
  - Thickness optimization of a stiffened rectangular plate
    - Optimization model setup in Femap
    - Post-process optimization results
    - Quick comparison to HyperSizer results
  - Thickness optimization of wing with buckling constraints
    - How to add buckling constraints
    - Adjusting the optimizer’s parameters to improve convergence
- Additional Resources
- Questions

Femap – Model Optimization Dialogue Box

[Image of Femap – Model Optimization Dialogue Box]
About SDA (aka “Structures.Aero”)

• SDA was founded in 1997 and provides expert aerospace structural analysis
• We serve a variety of industries
  • We specialize in composites, and developing strong, lightweight structures that are readily manufacturable
  • Low level support up through developing test plans and advanced stress analysis
  • Typical support programs include small to large UAVs, manned and unmanned spacecraft, naval structures
• Our team consists of over a dozen B.S., M.S., and PhD level engineers
• SDA is located in Sterling, VA, just north of Dulles Airport near Washington DC
Partnerships

• Siemens Value Added Reseller, specializing in:
  – FEMAP
  ★ FEMAP with NX/NASTRAN
  – NX/NASTRAN Enterprise
  – FiberSIM
  – Solid Edge

• Collier Research Corporation Reseller
  ★ HyperSizer, structural analysis and optimization package for composite and metallic structures
Typical Projects we support

• Some of our previous projects include:
  – Aircraft
    • Aurora Excalibur
    • AAI Shadow
    • AAI Aerosonde
    • Lockheed Constellation restoration for Lufthansa
  – Spacecraft
    • NASA NESC Composite Crew Module (CCM)
    • NASA NESC Max Launch Abort System (MLAS)
    • NASA James Webb Space Telescope/IEC
    • NASA Orion Heatshield mass reduction for NESC
    • NASA Orion Crew Module (with Lockheed)
    • NASA WFIRST Telescope for Goddard
What is Design Optimization

- An optimizer is a formal plan, or algorithm, used to search for a “best” design.

- “Best” Design
  - Objective Function
  - Design Variables
  - Constraints

- NX Nastran uses a gradient-based algorithm
  - Uses design sensitivities to find “best” search direction
  - Rate of change of analysis response with respect to changes in the design variables
  - Finds local optimum, not necessarily the global optimum

Geometric Interpretation (Comes from NX Nastran Optimization User’s Manual)
Design Optimization in Femap with NX Nastran

- SOL 200 can be used with...
  - Statics (Femap Supports)
  - Normal Modes (Femap Supports)
    - Buckling
    - Direct and Modal Frequency
    - Modal Transient
    - Acoustic
    - Aeroelastic

- Design variables are defined in relation to property or material entries.
- Design constraints are defined in relation to analysis responses.
- Basically any field on a property or material card can be set as a design variable. *(Limited in Femap)*
- Shape variables, which allow nodes to move can be defined as well. *(Not supported in Femap)*
Stiffened Plate Model

- Orthogrid Stiffened Panel
- Metallic
- 6 psi External Pressure
- Linear Static Analysis

- Optimization Problem
  - Minimize Mass
  - Subject to:
    - Stress Constraints
    - Displacement Constraints
    - Lower and Upper Bounds (side constraints)

Simply-Supported Constraints on all edges
Math Programming Problem

\[
\min_{t \in \mathbb{R}^{42}} \text{Mass}(t) \quad \text{s.t.} \quad g(t) \leq 0
\]

\[
g(t) = \begin{cases} 
\sigma_{VM}(t) - 25,000 \\
\delta_z(t) - 0.35 \\
0.05 - t_i \\
t_i - 0.25 
\end{cases} \leq 0, \quad i = 1, 2, \ldots, 42
\]

- Initial Design → All thicknesses set to 0.10”
- Initial Mass = 22.74 lbs.
- Initial design satisfies all constraints
- Room for improvement

0.148” Max Displacement

15 ksi Max Stress
Optimum Solution – Thickness and Mass Results

- Initial Mass = 22.74 lbs.
- Optimized Mass = 14.54 lbs.
- Percent Relative Decrease of 36%

0.03766 slinches

Shows an active constraint
Optimum Solution – Stress and Displacement Results

Peak stresses close to constraint value in many places

Max displacement = Constraint Value of 0.35”

Properties that show relatively low peak stresses are those at minimum gauge.
Different Initial Design Point

Initialized All Properties at Min Gauge (0.05”)

- Optimized Mass = 14.62 lbs. (slightly heavier)
- Nearly identical optimum design as the first run

HyperSizer Result
Minimum Margin of Safety

- Optimized Weight = 14.08 lbs.
- May need additional iterations with FEA
- Nastran uses 1e-3 default convergence tolerance
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Wing Optimization with Skin Buckling

- Metallic wing with skins, ribs, spars, and stringers
- Uniform pressure load on bottom surface
- Linear Static Analysis and Linear Buckling Analysis

Optimization Problem
- Minimize Mass
- Subject to:
  - Stress Constraints
  - Buckling Constraints
  - Lower and Upper Bounds (side constraints)
Math Programming Problem

\[ \min_{\boldsymbol{t} \in \mathbb{R}^{42}} \text{Mass}(\boldsymbol{t}) \quad \text{s.t.} \quad g(\boldsymbol{t}) \leq 0 \]

\[ g(\boldsymbol{t}) = \begin{cases} 
\sigma_{VM}(\boldsymbol{t}) - 45,000 \\
\lambda_b(\boldsymbol{t}) - 1.15 \\
0.03 - t_{\text{skin},i} \\
0.05 - t_{\text{rib},i} \\
0.05 - t_{\text{spar},i} \\
t_i - 0.5 
\end{cases} \leq 0, \quad i = 1,2, \ldots, 63 \]

- Initial Design \rightarrow Skins are 0.08” and ribs/spars are 0.10”
- Initial Mass = 116 lbs.
- Initial design dramatically violates buckling constraint
- From this alone, it is easy to see that the design will be mostly if not entirely driven by min gauge and buckling.
Best Compromise Infeasible Design

- Design is flat-lining, but the buckling constraint is still violated.
- Small changes in the design variable result in mode switching.
- Only constraining the first buckling mode.
- Optimizer treats buckling eigenvalue as a continuous variable.
- The optimizer has too little information.
Converged Optimum

- Tracking first five buckling modes
- Set looser convergence tolerances

- Initial Mass = 116 lbs.
- Optimized Mass = 93 lbs.
- Percent Relative Decrease of 20%

\[ \lambda_1 = 1.139 \]
\[ \lambda_2 = 1.139 \]
\[ \lambda_3 = 1.145 \]
\[ \lambda_4 = 1.149 \]
\[ \lambda_5 = 1.15 \]
Optimization/Sizing in HyperSizer

- HyperSizer evaluates buckling margins with closed form solutions.
- Buckling margin calculated for every property (component).
- Here I assume simply-supported boundary conditions.
- Iterations with FEA are critical to allow loads to redistribute and converge.
Comparison to HyperSizer Solution

NX Nastran SOL 200
Upper Skin Thicknesses

HyperSizer
Upper Skin Thicknesses

Output Set: Model Data to Contour
Criteria: Plan Element Thickness

SOL 200 Total Weight = 93 lbs

\[ \lambda_3 = 1.145 \]
\[ \lambda_4 = 1.149 \]
\[ \lambda_5 = 1.15 \]
\[ \lambda_1 = 1.139 \]
\[ \lambda_2 = 1.139 \]

HyperSizer Total Weight = 96 lbs
Nastran Buckling Analysis of HyperSizer Solution

\[ \lambda_1 = 1.20 \]
Conclusions and Additional Resources

What We Covered

• Brief introduction to design optimization
• Optimization model setup in Femap
  – Objective function
  – Design Variables
  – Constraints
• General considerations and post-processing
  – Function plotting
  – How to check for convergence
  – How to help account for modal switching
• Comparisons to HyperSizer

Questions?

As a Siemens PLM Software channel partner SDA provides first line support for Femap with NX Nastran

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