Workshop - Automated Structural Optimization of a Stiffened Plate

AN MSC NASTRAN SOL 200 TUTORIAL
Goal: Use Nastran SOL 200 Optimization

Optimize the weight of this structure while constraining stress and displacement

Before Optimization
- Weight: 6.962
  - $x_1 = T$, thickness of shell
  - $= .15$
  - $x_2 = \text{DIM2}$
  - $= .1 \text{ in.}$

After Optimization
- Weight: 5.477
  - $x_1 = T = .113 \text{ in.}$
  - $x_2 = \text{DIM2} = .0839 \text{ in.}$

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Details of the Structural Model

Stiffened Plate

An effective way to keep the number of independent design variables to a minimum is by grouping designed elements by property type. A smaller set of independent design variables decreases the cost associated with the sensitivity analysis, allows the optimizer to perform more effectively, and makes interpretation of the final results much easier.

A simple example is shown in Figure 8-20 and includes a plate with a hat stiffener. The design goal is to reduce the weight of the stiffened panel subject to stress and displacement constraints under two separate static load conditions. The thickness of the plate and the thickness of the hat stiffener are allowed to vary. The boundary condition creates a simply-supported condition with the plate also restrained in the x-direction along y=9.0. The first load case includes both axial tension in the z-direction and a vertical pressure load in the y-direction. The second load case is a concentrated load applied in the z-direction at grid H103, which is directly under the hat. The example illustrates how the beam library can be utilized to simplify the modeling and design tasks and how the beam output solutions can be adjusted as the structural properties change.

Figure 8-20 Plate with a HAT Stiffener

MSC Nastran Design Sensitivity and Optimization User’s Guide
Chapter 8 - Example Problems - Stiffened Plate
Optimization Problem Statement

Design Variables

x1: T1 of PSHELL 1 | .01 < x1 < 1.
x2: DIM2 of PBARL 3 | .01 < x2 < 1.

W3A,B for each element = 1.5 + x1 / 2.0

Design Objective
r0: Minimize weight

Design Constraints
r1: The max stress at end A of elements related to PBARL 3
r2: The max stress at end B of elements related to PBARL 3
   -25000 < r1, r2 < 25000
r3: The von Mises stress of elements related to PSHELL 1
r4: The von Mises stress of elements related to PSHELL 1
   r3, r4 < 25000
r5: The z component of displacement for node 10302
   -1 < r5 < .1
r6: The z component of displacement for node 10203
   -.03 < r6 < .03
Optimization Problem Statement

Design Variables

- $x_1 = T$, thickness of shell
  
  $x_{1\text{initial}} = .15 \text{ in.} \quad .01 < x_1 < 1.$

- $x_2 = \text{DIM2}$
  
  $x_{2\text{initial}} = .1 \text{ in.} \quad .01 < x_2 < 1.$

- Offset of CBARs = $\text{DIM1} / 2.0 + T / 2.0$
  
  $= 1.5 + x_1 / 2.0$
More Information Available in the Appendix

The Appendix includes information regarding the following:
- Frequently Asked Questions
- How do I avoid the scenario where the offset causes the cross section to interfere with the plate?
Contact me

• Nastran SOL 200 training
• Nastran SOL 200 questions
• Structural optimization questions
• Access to the MSC Nastran SOL 200 Web App

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Tutorial
**Tutorial Overview**

1. Start with a .bdf or .dat file
2. Use the MSC Nastran SOL 200 Web App to:
   - Convert the .bdf file to SOL 200
   - Design Variables
   - Design Objective
   - Design Constraints
   - Perform optimization with Nastran SOL 200
3. Plot the Optimization Results
4. Update the original model with optimized parameters

**Special Topics Covered**

**Creating Hundreds of Equation Driven Parameters** - Certain parameters of the Finite Element Model may need to be adjusted as certain design variables change. For example, as the thickness of a plate changes, an attached stiffener’s offset will depend on the thickness. This tutorials describes the process for automatically generating dozens or hundreds of these equation driven parameters.
MSC Nastran SOL 200 Web App

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Before Starting

1. Ensure the Downloads directory is empty in order to prevent confusion with other files.

- Throughout this workshop, you will be working with multiple file types and directories such as:
  - .bdf/.dat
  - nastran_working_directory
  - .f06, .log, .pch, .h5, etc.
- To minimize confusion with files and folders, it is encouraged to start with a clean directory.

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Go to the User’s Guide

1. Click on the indicated link

• The necessary BDF files for this tutorial are available in the Tutorials section of the User’s Guide.
Obtain Starting Files

1. Find the indicated example
2. Click Link
3. The starting file has been downloaded

- When starting the procedure, all the necessary BDF files must be collected together.
MSC Nastran SOL 200 Web App

Select a web app to begin

- Size and Topometry Optimization
- Topology Optimization
- Global Optimization
- Multi Model Optimization

The web app also features the HDF5 Explorer, a web application to extract results from the H5 file type.

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Upload BDF Files

1. Click 1. Select Files and select dsoug4.dat
2. Click Upload Files

- The process starts by uploading all the necessary BDF files. The BDF files can be files of your own or files found in the Tutorials section of the User’s Guide.

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Create Design Variables

1. In the filter box, type ‘t’
2. Click on the plus (+) icons to set the thickness as a design variable
3. In the filter box, type ‘dim’
4. Click on the plus (+) icons to set DIM2 as a design variable
5. Specify the lower bound as .01 for design variables x1, x2
6. Specify the upper bound as 1. for design variables x1, x2

• The necessary design variables, as detailed in the optimization problem statement, are created.
• The search boxes are used to filter the tables for the T and DIM2 properties.
• Each step has hidden functionality for advanced users. The visibility is controlled by clicking + Options.
Create Design Variables

1. Type 'w3' into the filter box
2. Select '10' in the pagination bar
3. Click +Options
4. Check the DVXREL2 option
5. Type in this equation: • 1.5 + x1 / 2.0
6. Click on Create

In order to avoid interference between the beam cross section and thickness of the plate, a relationship is created between the beam offsets (W3A,B) and the variable representing the plate thickness (x1). A DVXREL2 entry defines this relationship.

Design variables (DVXREL1) and DVXREL2 relationships can be individually created by clicking this icon: .

If dozens or hundreds of variables or relationships must be created, the table can be used create these entries in one click by clicking this icon: . In addition, the bounds, discrete values or equation can be configured rapidly.

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Create Design Variables

1. 8 DVXREL2 entries have been created

- These entries define relationships between the beam offsets (W3A, B) and the plate thickness variable (x1). As the thickness variable changes, the offset is also updated and will avoid the situation where the beam cross section interferes with the plate thickness.
Create Design Objective

1. Click Objective
2. Select the plus (+) icon for weight
3. The objective has been set to minimize the weight, no further modification is necessary

- The objective must always be a single and global response. A response such as weight and volume are single responses, are independent of load case, and can be used as an objective. Other responses require special care when set as an objective. For example, if the objective is stress, only the stress of a single component, e.g. von Mises, of a single element, of a single load case may be used.
Create Design Constraints

1. Click Constraints
2. Filter the table by typing ‘s’
3. Select the plus(+) icon 4 times for Stress to create 4 stress constraints
4. Select the plus(+) icon 2 times for Displacement to create 2 displacement constraints
5. Select ‘10’ in the pagination bar
6. Configure the constraints as shown to the right
   - Example: Configure the following for r1
     - Property Type: PBARL
     - ATTA: 7 - End A maximum
     - ATTI: 3 (PID 3)
     - Lower Allowed Limit: -25000.
     - Upper Allowed Limit: 25000.

   • The r1 label is configured as follows: A stress constraint is created for all elements associated with the entry PBARL 3, for component 7 (End A Maximum). PBARL 3 has 4 elements associated, so 4 stress quantities are constrained.
   • The r3 label is configured as follows: A stress constraint is created for all elements associated with PSHELL 1 for component 9 (von Mises). PSHELL 1 has 16 elements associated, so 16 stress quantities are constrained.

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Assign Constraints to Load Cases (SUBCASES)

1. Click Subcases
2. Click Check visible boxes
3. Unmark the indicated checkboxes

- The following constraints have been applied to SUBCASE 1: r1, r2, r3, r4, r5
- The following constraints have been applied to SUBCASE 2: r1, r2, r3, r4, r6
- When hundreds of SUBCASEs must be configured, the following options expedite the process:

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Export New BDF Files

1. Click on Exporter
2. Click on Download BDF Files

- When the download button is clicked a new file named “nastran_working_directory” is downloaded. If the file already exists in your local folder, the folder name is appended with a number, e.g. “nastran_working_directory (1).zip”
Perform the Optimization with Nastran SOL 200

A new .zip file has been downloaded

1. Right click on the file
2. Click Extract All
3. Click Extract on the following window

- Always extract the contents of the ZIP file to a new, empty folder.
Perform the Optimization with Nastran SOL 200

1. Inside of the new folder, double click on Start MSC Nastran
2. Click Open, Run or Allow Access on any subsequent windows
3. MSC Nastran will now start

- After a successful optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- One can run the Nastran job on a remote machine as follows:
  1) Copy the BDF files and the INCLUDE files to a remote machine.
  2) Run the MSC Nastran job on the remote machine.
  3) After completion, copy the BDF, F06, LOG, HS files to the local machine.
  4) Click “Start MSC Nastran” to display the results.

Using Linux?

Follow these instructions:
1) Open Terminal
2) Navigate to the nastran_working_directory
   cd /nastran_working_directory
3) Use this command to start the process
   ./Start_MSC_Nastran.sh

In some instances, execute permission must be granted to the directory. Use this command. This command assumes you are one folder level up.

sudo chmod -R +x /nastran_working_directory

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Status

While MSC Nastran is running, a status page will show the current state of MSC Nastran.

The status of the MSC Nastran job is reported on the Status page. Note that Windows 7 users will experience a delay in the status updates. All other users of Windows 10 and Red Hat Linux will see immediate status updates.

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<table>
<thead>
<tr>
<th>Name</th>
<th>Status of Job</th>
<th>Design Cycle</th>
<th>RUN TERMINATED DUE TO</th>
</tr>
</thead>
<tbody>
<tr>
<td>model.bdf</td>
<td>Running</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>
Review Optimization Results

After MSC Nastran is finished, the results will be automatically uploaded.

1. Ensure the messages shown have green checkmarks. This is indication of success. Any red icons indicate challenges.

2. The final value of objective, normalized constraints (not shown) and design variables can be reviewed.

- After an optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- After the first design cycle, the weight is minimized from 7 to ~4.8, but after the second design cycle, the weight increases to ~5.4. This drop in weight, then slight increase is sometimes an indication a constraint was violated or near violation when minimizing weight, but then corrected by increasing weight. The normalized constraint at the initial design, after design cycle 1 and 2 are, -.1.64, .654 and .087, respectively, note the increase to .654, then drop to .087. The normalized constraint plot is not shown on this page but is visible to you when viewing the web app.

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Results

Before Optimization
- Weight: 6.962
  - $x_1 = T$, thickness of shell
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After Optimization
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Update the Original Model

1. Click Results
2. Click PCH to BDF
The original .bdf/.dat file has old information about the properties. The properties will be updated.

1. Select the model.pch file
2. Select the original file: dsoug4.dat
3. A summary of updates that will be performed are shown
4. Click Download and a new updated BDF file is downloaded

On download, the PCH entries will replace older BDF entries.
Update the Original Model

1. Note the entries have been updated with the optimized properties
End of Tutorial
Appendix
Appendix Contents

◦ Frequently Asked Questions
  ◦ How do I avoid the scenario where the offset causes the cross section to interfere with the plate?
Frequently Asked Questions

Question:

◦ How do I avoid the scenario where the offset causes the cross section to interfere with the plate?

The offset (W3A and W3B) in this example causes the beam cross section to interfere with the plate.
Frequently Asked Questions

Answer:
- In ‘Step 4 - Adjust DVXREL2’, specify bounds that the offset property can take
- In this tutorial, this step was not necessary because the offset is in terms of x1 and x1 already has bounds applied

<table>
<thead>
<tr>
<th>Label</th>
<th>Status</th>
<th>Property</th>
<th>Entry</th>
<th>ID</th>
<th>Initial Value</th>
<th>Minimum Allowed Value</th>
<th>Maximum Allowed Value</th>
<th>Equation</th>
</tr>
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<tbody>
<tr>
<td>C1</td>
<td></td>
<td>W3A</td>
<td>CBAR</td>
<td>31</td>
<td>1</td>
<td>Maximum</td>
<td>1.5 * x1 / 2.0</td>
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<td>C2</td>
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<td>W2B</td>
<td>CBAR</td>
<td>31</td>
<td>1</td>
<td>Maximum</td>
<td>1.5 * x1 / 2.0</td>
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<td>W3A</td>
<td>CBAR</td>
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<td>W2B</td>
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<td>1</td>
<td>Maximum</td>
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<td>W3A</td>
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<td></td>
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<td>W2B</td>
<td>CBAR</td>
<td>33</td>
<td>1</td>
<td>Maximum</td>
<td>1.5 * x1 / 2.0</td>
<td></td>
</tr>
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<td>C7</td>
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<td>W3A</td>
<td>CBAR</td>
<td>34</td>
<td>1</td>
<td>Maximum</td>
<td>1.5 * x1 / 2.0</td>
<td></td>
</tr>
<tr>
<td>C8</td>
<td></td>
<td>W2B</td>
<td>CBAR</td>
<td>34</td>
<td>1</td>
<td>Maximum</td>
<td>1.5 * x1 / 2.0</td>
<td></td>
</tr>
</tbody>
</table>