Workshop - Automated Optimization of a Composite Laminate

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

Objective: Minimize the weight of this cylinder composed of a composite laminate

Before Optimization
- Weight: 1.60 lbf⋅s²/in
- Layup: [85/-85/60/-60/60/-60/85/-85]
- Thickness: .0100 in
- Plies are initially in failure

After Optimization
- Weight: 1.04 lbf⋅s²/in
- Layup: [90/-90/0/0/0/0/90/-90]
- Thickness: .0065 in
Details of the Structural Model

Allowed to translate in x and y

Translation prevented in z direction

Internal pressure load of 400 psi
Details of the Structural Model

-85°  
85°  
-60°  
60°  
-60°  
60°  
-85°  
85°
Optimization Problem Statement

Design Variables
- x1: T of lamina 1 of PCOMP 1
- x2: T of lamina 2
- x3: T of lamina 3
- x4: T of lamina 4
- x5: T of lamina 5
- x6: T of lamina 6
- x7: T of lamina 7
- x8: T of lamina 8
  \[ .001 < x_i < 10 \]
- x9: Orientation of lamina 1 of PCOMP 1
- x10: Orientation of lamina 2
- x11: Orientation of lamina 3
- x12: Orientation of lamina 4
- x13: Orientation of lamina 5
- x14: Orientation of lamina 6
- x15: Orientation of lamina 7
- x16: Orientation of lamina 8
  \[ -90 < x_i < 90 \]

Variable Linking
- x2, x3, ..., x8 = x1
- x15 = x9
- x10, x16 = -1.0 * x9
- x13 = x11
- x12, x14 = -1.0 * x11

Design Objective
- r0: Minimize weight

Design Constraints
- r1: Failure index of lamina 1 of element 1
- r8: Failure index of lamina 8 of element 1
  \[ r1, ..., r8 < .9 \]
More Information Available in the Appendix

The Appendix includes information regarding the following:

◦ Frequently Asked Questions
◦ What are the ways of specifying allowable discrete values for design variables?
◦ Why do the orientation angles not change?
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

- **Discrete Values for Design Variables**: This example has a requirement where the design variables can only take on specific values. Instead of an optimization solution where the values may be 45.23423 or 15.90234, the use of Discrete Values will allow specific values to be obtained such as 45.0 or 16.0. This tutorial showcases a feature to specify specific values that can be taken by the design variables.

- **Design Variable Linking**: In some situations, one design variable will drive the values of other design variables. For example, the thickness of one section will be the same for other sections. This tutorial demonstrates the use of Design Variable Linking to address such examples.

\[
x_2 = x_1 \\
x_4 = x_1 \\
x_5 = x_1
\]
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.

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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.
Open the Correct Page

1. Click on the indicated link

MSC Nastran can perform many optimization types. The MSC Nastran SOL 200 Web App includes dedicated web apps for the following:
- 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 d200c01.bdf
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.
Create Design Variables

1. In the filter box, type ‘t’
2. Click twice on the Property column header to sort the column in decreasing order
3. Type in 16 to show only 16 rows
4. Click + Options
5. Click Create

- There are 2 methods to create the 16 design variables: Click each blue plus icon, which requires 16 mouse clicks, OR click the yellow Create icon, which requires 1 mouse click.
- Each step has hidden functionality for advanced users. The visibility is controlled by clicking + Options.
- If the property entry, e.g. PSHELL, was given a name in Patran, e.g. Car Door, the name can be shown by marking the checkbox titled Entry Name.
Create Design Variables

1. Click 20 on the pagination bar

2. For design variable x1 (The thickness of ply 1)
   1. Set the lower bound as .001
   2. Set the upper bound as 10.

3. For design variable x9 (The angle of ply 1)
   1. Set the lower bound as -90.
   2. Set the upper bound as 90.
   3. Set the allowed values as: -90., THRU, 90., BY, 5.0

4. For design variable x11 (The angle of ply 3)
   1. Set the lower bound as -90.
   2. Set the upper bound as 90.
   3. Set the allowed values as: -90., THRU, 90., BY, 5.0

• In some instances, the optimizer will vary a positive design variable and make it negative, e.g. a thickness of .08 becomes -.01 in a weight minimization optimization. Certain properties, such as thickness or beam cross sections should never be negative. The lower bound in this example is set to .001 to avoid a negative variable during the optimization.

• In some scenarios, the use of 0 degrees for the initial value of an orientation angle may be unsuccessful. An alternative is to use 360 degrees as the initial value.
Create Design Variables

1. Click 5 times on +Create DLINK
2. Create design variables links for the thicknesses
   1. Dependent Design Variables: x2, x3, x4, x5, x6, x7, x8
   2. Equation: x1
3. Create design variables links for the -85 degree plies
   1. Dependent Design Variables: x10, 16
   2. Equation: x9 * -1.0
4. Create design variables links for the 85 degree plies
   1. Dependent Design Variables: x15
   2. Equation: x9 * 1.0
5. Create design variables links for the -60 degree plies
   1. Dependent Design Variables: x12, x14
   2. Equation: -1.0 * x11
6. Create design variables links for the 60 degree plies
   1. Dependent Design Variables: x13
   2. Equation: x11 * 1.0 + 0.0

• It is important to verify the Equation is configured properly. For example, the variable x10 is initially equal to -85 degrees. When the Equation is configured, it should also produce an initial value of -85. The resulting value of the Equation is displayed on the column titled Value of Equation and can be used to validate the Equation is configured properly.

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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 scalar response. A response such as weight and volume are single responses 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.

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Create Design Constraints

1. Click Constraints
2. Filter the table by typing ‘fa’
3. Select the plus(+) icon 8 times for Composite Failure Criterion to create 8 constraints
4. Click 10 on the pagination bar
5. Configure the constraints as shown to the right
   - Example: Configure the following for r1
     - Property Type: ELEM
     - ATTA: 5 - FP (failure index)
     - ATTB: 1 (lamina 1)
     - ATTI: 1 (element 1)
     - Upper Allowed Limit: .9
   - Repeat the same for r2, r3, ... r8, but note that ATTB will be different for each row
   - This example requires 8 constraints to be created. If there is a need to create hundreds of constraints, the web app includes a CSV export/import capability and is available by clicking + Options. With the use of CSV and Excel, constraints can be quickly generated.
   - In prior versions of this tutorial, the Lower Allowed Limit was set to .001. The failure index can actually be lower, e.g., .0002, and is still valid, but with the lower bound set to .001, the optimizer would see .0002 as a violated constraint. In this version of the tutorial, the lower allowed limit is left blank to avoid this issue.

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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 u+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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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.

- Both the thicknesses and orientation angles have changed during the optimization. The plot can be manipulated to view specific variables.
- On some occasions, the orientation angles may not change during the optimization. See the Appendix for additional details.

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Results

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After Optimization
- Weight: 1.04 $\text{lb}_f \cdot \text{s}^2/\text{in}$
- Layup: [90/-90/0/0/0/0/90/-90]
- Thickness: .0065 in
Update the Original Model

1. Click Results
2. Click PCH to BDF
Update the Original Model

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: d200c01.bdf
3. A summary of updates that will be performed are shown
4. Click Download and a new updated BDF file is downloaded
Update the Original Model

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

- Frequently Asked Questions
  - What are the ways of specifying allowable discrete values for design variables?
  - Why do the orientation angles not change?
Frequently Asked Questions

Question:
- What are the ways of specifying allowable discrete values for design variables?

Answer:
- There are two methods
- Suppose you want to specify allowable values: 1.0, 2.0, 3.0, ..., 10.0

Method 1
- Type in each value with commas separating each value

Method 2
- Use the THRU and BY method

<table>
<thead>
<tr>
<th>Allowed Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Allowed Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0, 2.0, 3.0, 4.0, BY 10, THRU 1.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DDVAL</th>
<th>2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>9.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DDVAL</th>
<th>2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>1.0</td>
<td>3.0</td>
</tr>
<tr>
<td>1.0</td>
<td>4.0</td>
</tr>
<tr>
<td>1.0</td>
<td>5.0</td>
</tr>
<tr>
<td>THRU 10</td>
<td>BY 1.0</td>
</tr>
</tbody>
</table>

Specifies range of values
Specifies increment between values
Why do the orientation angles not change?
Why do the orientation angles not change?

For some optimizations, the orientation angles remain unchanged.
Why do the orientation angles not change?

The orientation angles will only change when an angle dependent constraint is violated.

In this example, the normalized constraint at each design cycle is negative, indicating satisfied constraints. There are no violated constraints, i.e. positive normalized constraints, therefore, there is no change in orientation angles.

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Why do the orientation angles not change?

Thickss influences both weight and angle dependent responses.

Orientation angles only influence angle dependent responses.

The optimizer cares most about the objective. The optimizer only takes action against the constraints when the constraints are violated. This is why you see the thickness change often, but sometimes see the orientation angles unchanged.

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Why do the orientation angles not change?

The reader may be tempted to state, “Intuition suggests the orientation should still change regardless.”

In this example, the thickness variable starts at 1.0 and eventually ends at its lower bound of .01. Even when the thickness is at its thinnest, the normalized constraints remain negative. The moment when the normalized constraint is positive is never achieved, therefore the orientation angles are not changed.

If the normalized constraints are positive, i.e. violated constraints, the angles will change.
Why do the orientation angles not change?

A change in orientation angles can be forced by reducing the lower bound of the thickness design variables.

During the optimization, the design can become very thin and cause constraints to become violated, which cause a change in orientation angles.

### Before:

<table>
<thead>
<tr>
<th>Label</th>
<th>Status</th>
<th>Property</th>
<th>Property Description</th>
<th>Entry ID</th>
<th>Initial Value</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
<th>Allowed Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>x1</td>
<td></td>
<td>T1</td>
<td>Thickness of ply</td>
<td>PCOMP</td>
<td>1</td>
<td>1.0</td>
<td>10.0</td>
<td>Allowed discrete values, example 1.5, 2.0</td>
</tr>
<tr>
<td>x2</td>
<td></td>
<td>T2</td>
<td>Thickness of ply</td>
<td>PCOMP</td>
<td>1</td>
<td>1.0</td>
<td>.61</td>
<td>Upper Allowed discrete values, example 1.5, 2.0</td>
</tr>
<tr>
<td>x3</td>
<td></td>
<td>T3</td>
<td>Thickness of ply</td>
<td>PCOMP</td>
<td>1</td>
<td>1.0</td>
<td>.61</td>
<td>Upper Allowed discrete values, example 1.5, 2.0</td>
</tr>
</tbody>
</table>

### After:

<table>
<thead>
<tr>
<th>Label</th>
<th>Status</th>
<th>Property</th>
<th>Property Description</th>
<th>Entry ID</th>
<th>Initial Value</th>
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</thead>
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<td>x1</td>
<td></td>
<td>T1</td>
<td>Thickness of ply</td>
<td>PCOMP</td>
<td>1</td>
<td>.0001</td>
<td>10.0</td>
<td>Allowed discrete values, example 1.5, 2.0</td>
</tr>
<tr>
<td>x2</td>
<td></td>
<td>T2</td>
<td>Thickness of ply</td>
<td>PCOMP</td>
<td>1</td>
<td>.0001</td>
<td>Upper</td>
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<td>1</td>
<td>.0001</td>
<td>Upper</td>
<td>Allowed discrete values, example 1.5, 2.0</td>
</tr>
</tbody>
</table>
Why do the orientation angles not change?

After reducing the lower bound on the thickness variables, the normalized constraint become positive, indicating a violated constraint, during design cycle 6. Note that the orientation angles also change in the same design cycle.

The reader may notice that after design cycle 7 and 8, the constraints are violated, but the orientation angles are now unchanging. At this point, the thickness is the variable being dominantly changed but is not shown in the variable plot.

To conclude, the orientation angles will change if an angle dependent constraint is violated.

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