Workshop – Composite Coupon – Phase A – Determination of the optimal 0° direction of a composite

AN MSC NASTRAN SOL 200 TUTORIAL

Questions? Email: christian@ the-engineering-lab.com

Composite Workshop

This workshop is phase A of a 5-phase workshop.

Phase A

Workshop – Composite Coupon – Phase A – Determination of the optimal 0° direction of a composite

- Perform an optimization on the angle of ply 1 to maximize stiffness
- Tools Used: MSC Nastran and SOL 200 Web App

Phase B

Workshop – Composite Coupon – Phase B – Baseline Ply Number Optimization

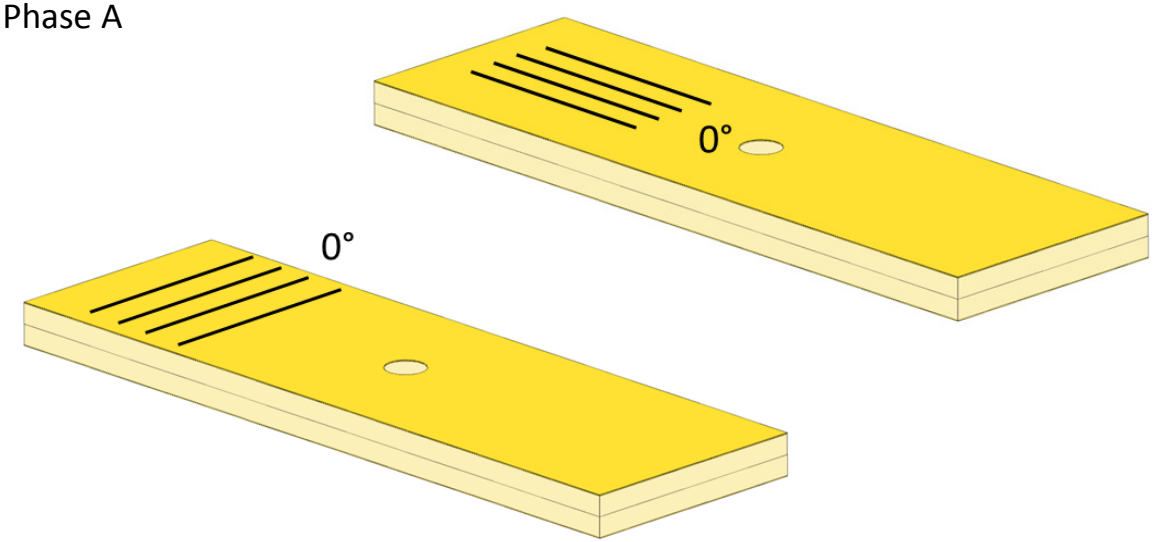
- Perform a ply number optimization with full and continuous ply shapes
- Tools Used: SOL 200 Web App (Viewer and Optimization web apps) and MSC Nastran

0° Direction Optimization → Baseline Ply Number Optimization

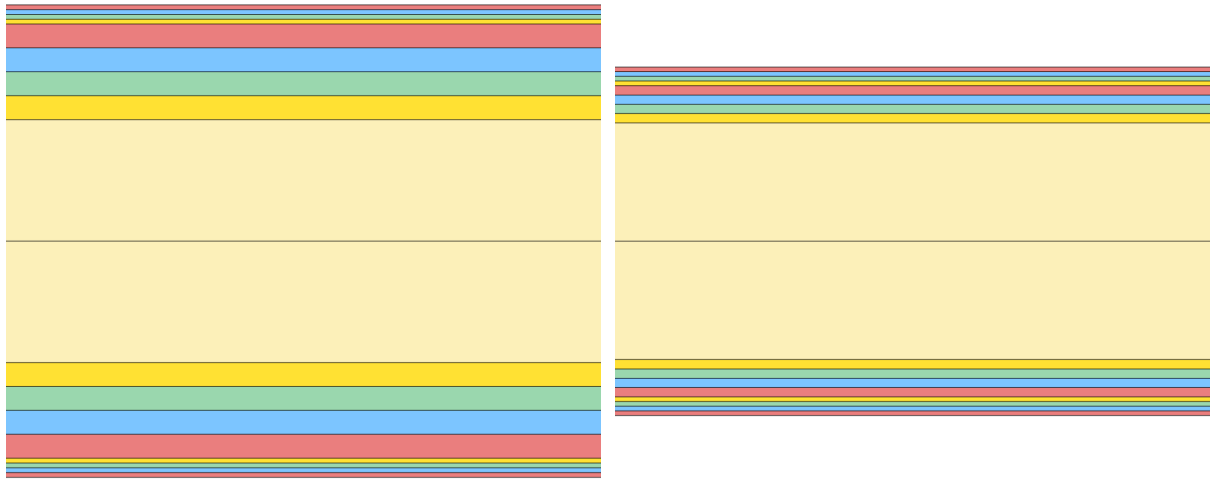
Composite Workshop

This workshop is phase A of a 5-phase workshop.

Phase A



Phase B



0° Direction Optimization

Baseline Ply Number Optimization

Composite Workshop

This workshop is phase A of a 5-phase workshop.

Phase C

Workshop – Composite Coupon – Phase C – Data Preparation for Ply Shape Optimization

- Manually create PLY000i Files
- Tools Used: Patran, MSC Nastran and SOL 200 Web App

Phase D

Workshop – Composite Coupon – Phase D – Ply Shape and Ply Number Optimization

- Input BDF and PLY000i Files
- Create Ply Shapes
- Perform Ply Number Optimization
- Inspect Plies
- Tools Used: SOL 200 Web App (Viewer and Optimization web apps) and MSC Nastran

Phase E

Workshop – Composite Coupon – Phase E – Stacking Sequence Optimization

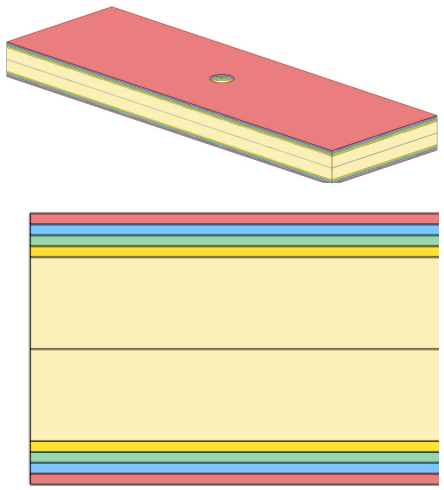
- Input BDF
- Perform Stacking Sequence Optimization
- Validate Performance
- Inspect Plies
- Tools Used: SOL 200 Web App (Stacking Sequence and Viewer web apps) and MSC Nastran

Ply Shape Optimization → Ply Number Optimization → Stacking Sequence Optimization

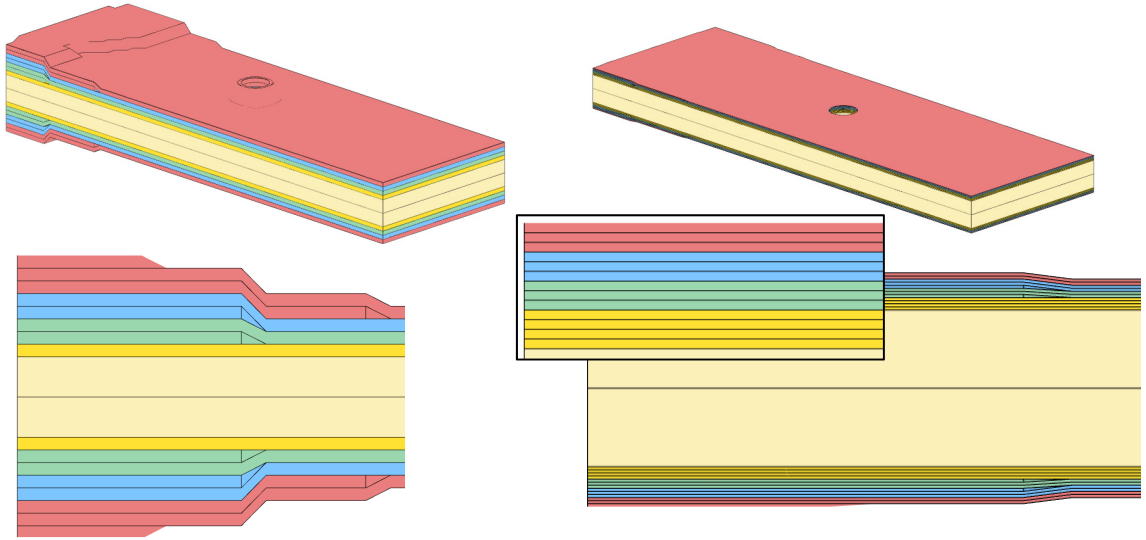
Composite Workshop

This workshop is phase A of a 5-phase workshop.

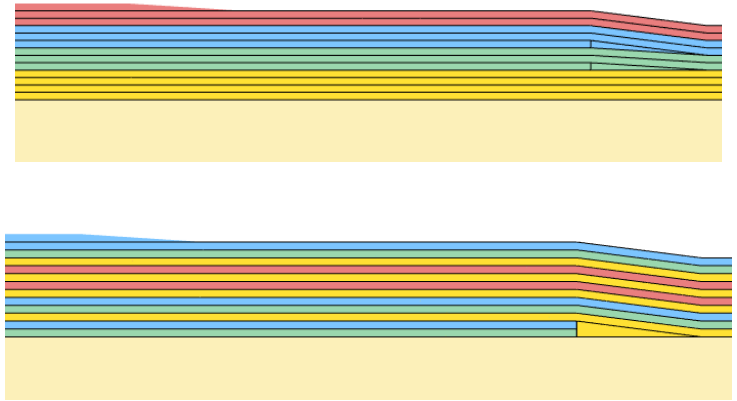
Phase C



Phase D



Phase E



Ply Shape Optimization → Ply Number Optimization → Stacking Sequence Optimization

Goal: Determine the optimal 0° direction of the composite

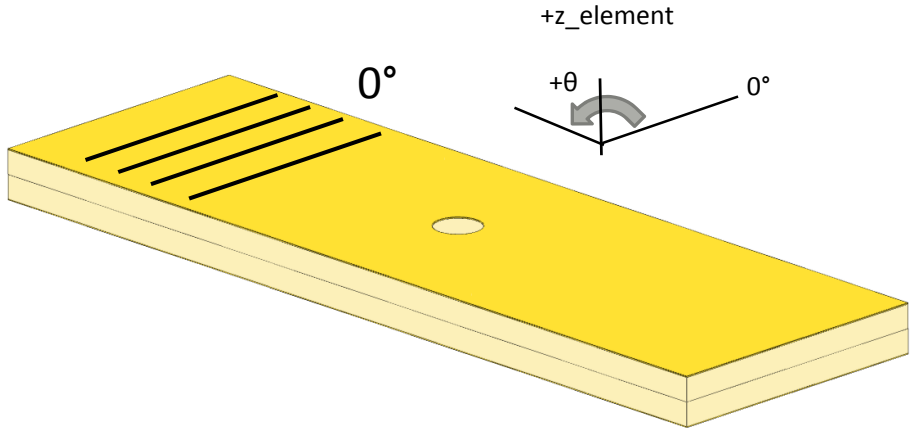
The x-axis of the material coordinate system typically defines the direction of the 0° plies.

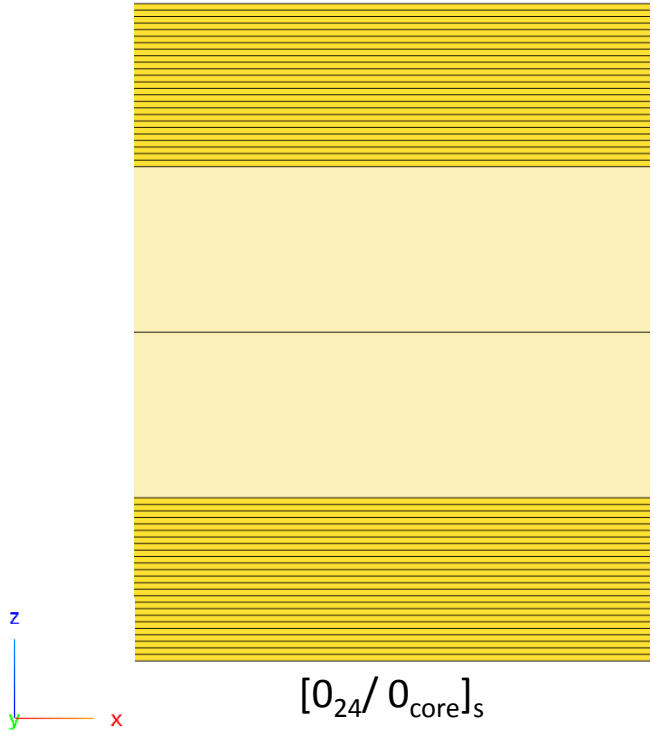
Consider the composite shown, which consists of a core and 0° plies. This composite is to satisfy failure index constraints.

If the 0° direction (x-axis of the material coordinate system) is not optimal, the number of plies determined will be suboptimal. In this example, a total of 48 plies are required if the direction of the 0° plies is suboptimal, but 3 plies are required if the 0° direction is optimal.

This tutorial details how to use the MSC Nastran SOL 200's optimizer to optimize the 0° direction of the composite.

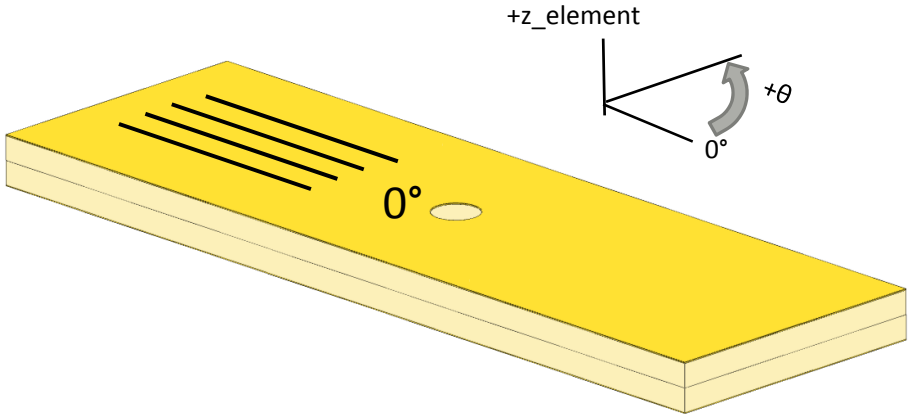
Suboptimal 0° Direction

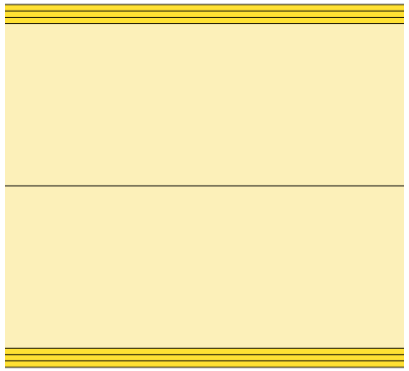




$[0_{24}/\ 0_{core}]_s$

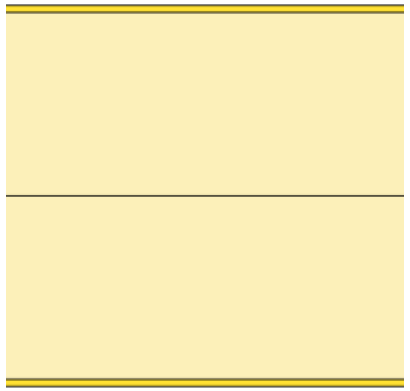
Optimal 0° Direction



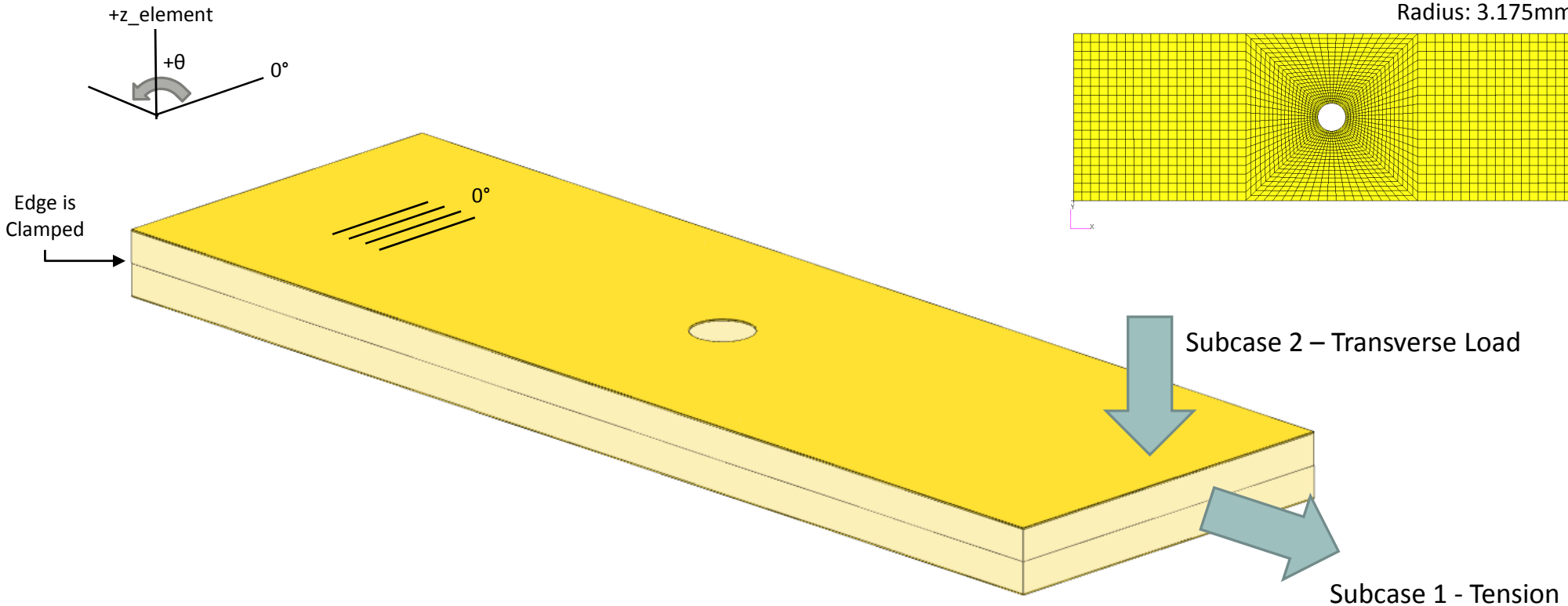


$[0_3/\ 0_{core}]_s$

Details of the structural model



$[0/\ 0_{core}]_s$



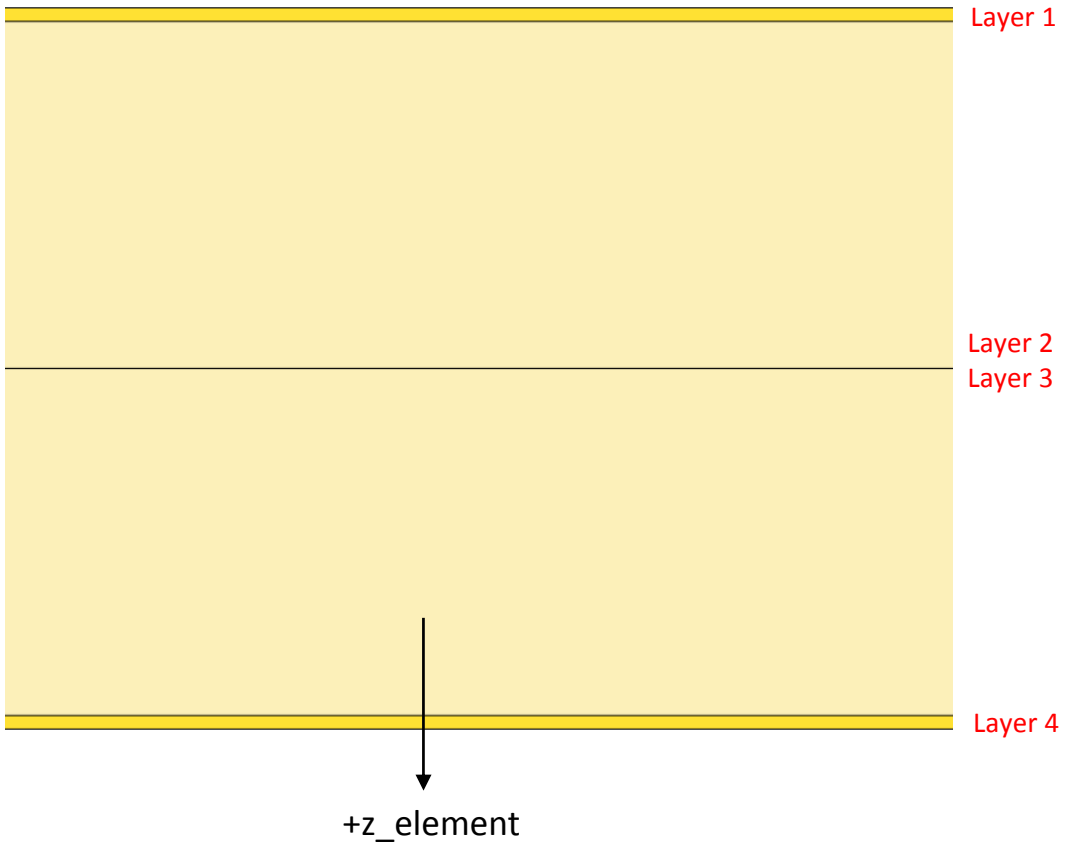
118mm x 38.1mm
Radius: 3.175mm

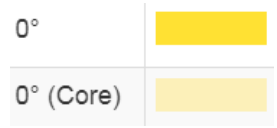
Details of the Composite Layers

This composite consists of 4 layers.

The PCOMP entry defines only 2 layers, but the LAM=SYM option indicates that the composite is symmetric. Internally, layers 3 and 4 are generated and stored.

- Layers 2 and 3 correspond to the core.
- Layers 1 and 4 correspond to the 0° ply.

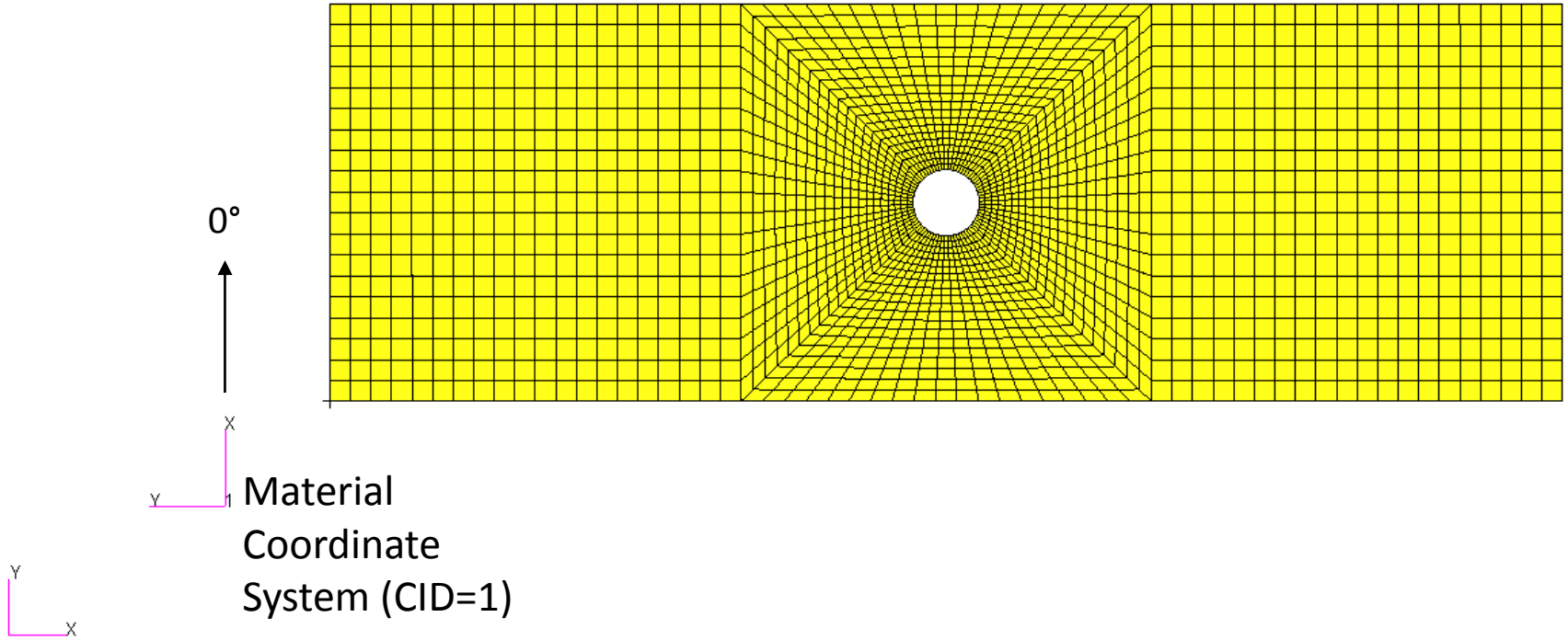





```
PCOMP     1                          90.     HILL                    SYM
          101      .125       0.      YES Layer 1
          501      3.175     0.       YES Layer 2
```

Material Coordinate System

1. The 0° direction corresponds to the x-axis of the material coordinate system.



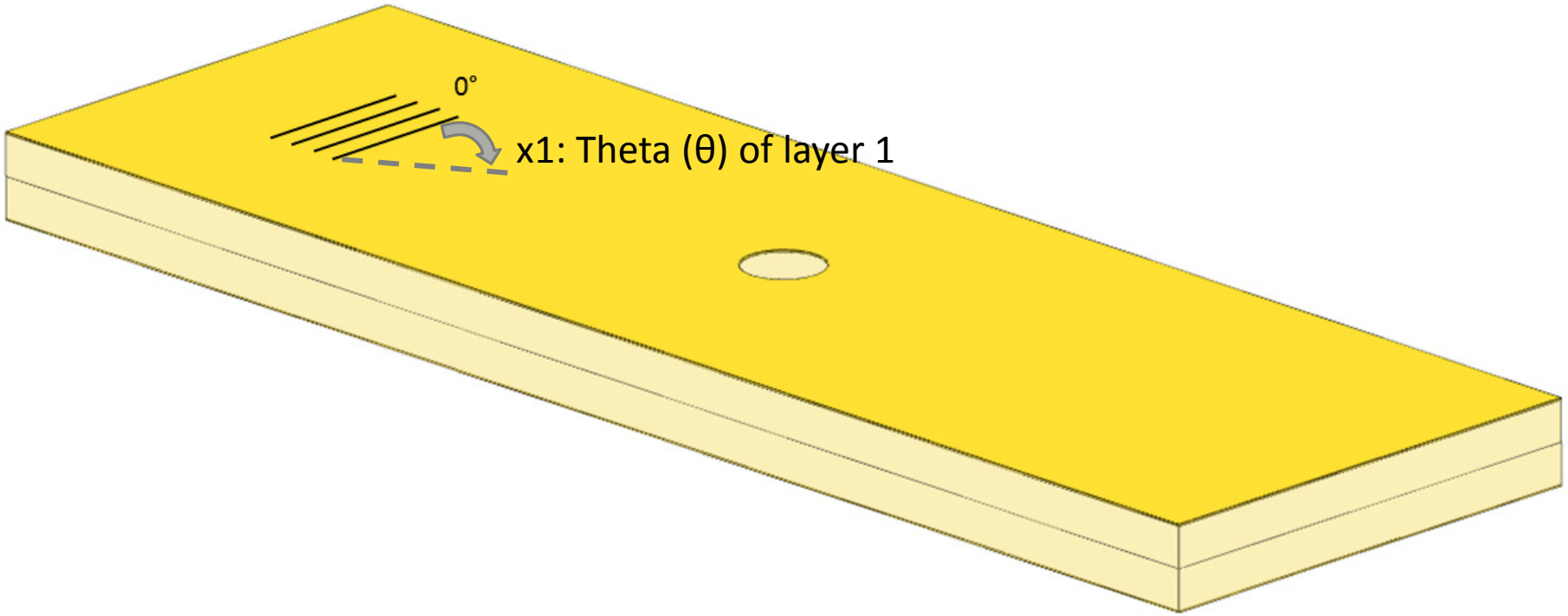
Material Coordinate System

- The material coordinate system is defined by a CORD2R (CID=1) entry and the CQUAD4 entry's 8th field points to CID=1.

```
CQUAD4   1429    1       2393    2374    2452    2411    1       0.
CQUAD4   1430    1       2411    2452    2453    2410    1       0.
CQUAD4   1431    1       2410    2453    2454    2409    1       0.
CQUAD4   1432    1       2409    2454    2455    2408    1       0.
CQUAD4   1433    1       2408    2455    2456    2407    1       0.
CQUAD4   1434    1       2407    2456    2457    2406    1       0.
CQUAD4   1435    1       2406    2457    2458    2405    1       0.
CQUAD4   1436    1       2405    2458    2459    2404    1       0.
CQUAD4   1437    1       2404    2459    2460    2403    1       0.
CQUAD4   1438    1       2403    2460    2461    2402    1       0.
CQUAD4   1439    1       2402    2461    2462    2401    1       0.
CQUAD4   1440    1       2401    2462    2463    2400    1       0.
CQUAD4   1441    1       2400    2463    2464    2399    1       0.
CQUAD4   1442    1       2399    2464    2465    2398    1       0.
CQUAD4   1443    1       2398    2465    2466    2397    1       0.
CQUAD4   1444    1       2397    2466    2467    2396    1       0.
CQUAD4   1445    1       2396    2467    2468    2395    1       0.
CQUAD4   1446    1       2395    2468    2469    2394    1       0.
CQUAD4   1447    1       2394    2469    2431    2412    1       0.
CQUAD4   1448    1       2374    2375    2470    2452    1       0.
CQUAD4   1449    1       2452    2470    2471    2453    1       0.
CQUAD4   1450    1       2453    2471    2472    2454    1       0.
CQUAD4   1451    1       2454    2472    2473    2455    1       0.
CQUAD4   1452    1       2455    2473    2474    2456    1       0.
CORD2R   1               -10.    -10.    0.      -10.    -10.    14.14214
         -10.    4.142136 0.
```

Optimization of the 0° direction

1. This optimization seeks to find the optimal direction of the 0° direction. Variable x1 corresponds to the angle of layer 1 on the PCOMP entry. The final value/angle of x1 represents the offset in which the material coordinate system must be rotated to yield an optimal 0° direction.



Optimization Problem Statement

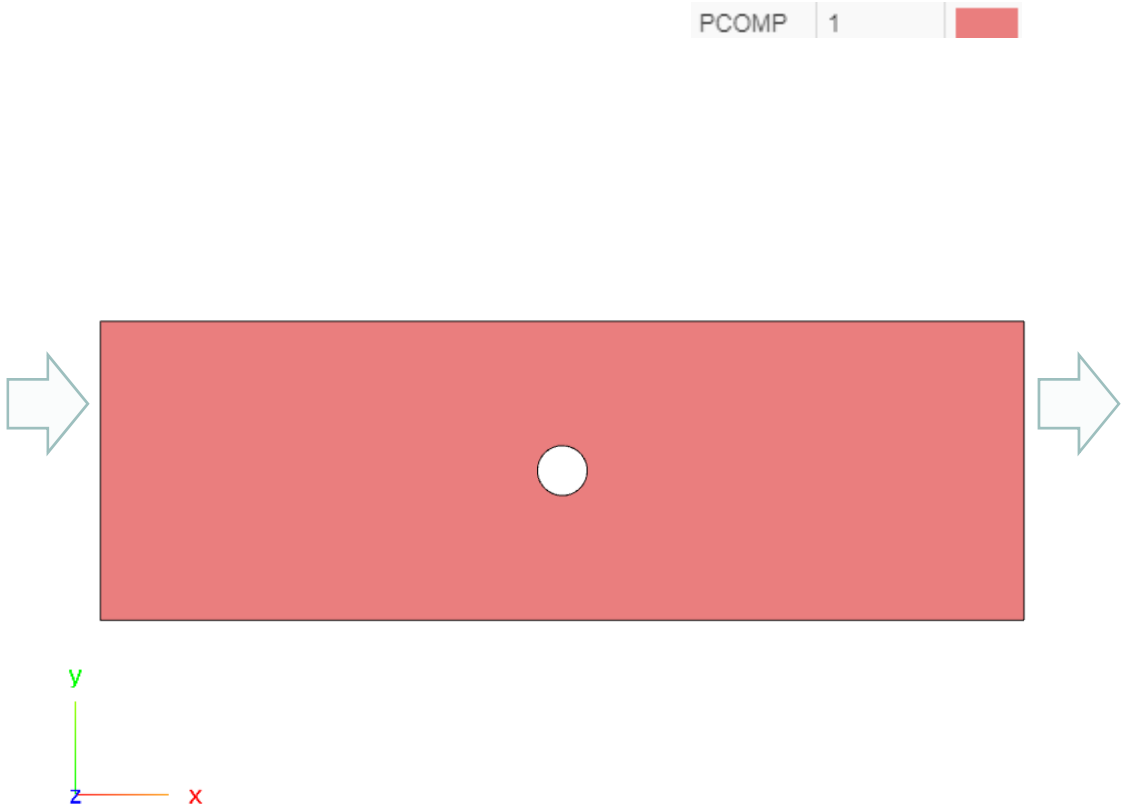
Design Variables

x1: THETA1, Theta of layer 1 (0°), of PCOMP 1 (pcomp.1)

Gradient based optimizers experience difficulties with variable values of 0. Typically, theta is defined between -90° and 90°, but with the initial value equal to 0°, issues are expected during the optimization. Instead, the range between -90 and 90 is offset by +360. The new range of values is between 270° and 450° and the initial value is set to 360°.

270 < x1 < 450

Initial x1 = 360



Design Objective

Minimize R0

R0 = max(a1, a2)

a1: Compliance of subcase 1
a2: Compliance of subcase 2

Contact me

- Nastran SOL 200 training
- Nastran SOL 200 questions
- Structural or mechanical optimization questions
- Access to the SOL 200 Web App

christian@ the-engineering-lab.com

Tutorial

Tutorial Overview

1. Start with a .bdf or .dat file
2. Use the SOL 200 Web App to:
   - Convert the .bdf file to SOL 200
     - Design Variables
     - Design Objective

Special Topics Covered

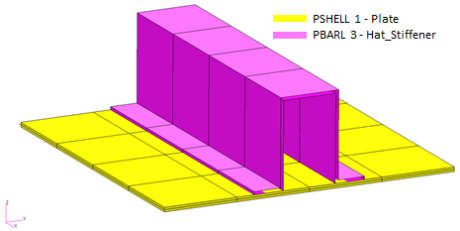
Determination of the optimal 0° direction - The most lightweight composites feature 0° plies in the direction of the load. This tutorial demonstrates how to determine the optimal 0° direction.

SOL 200 Web App Capabilities

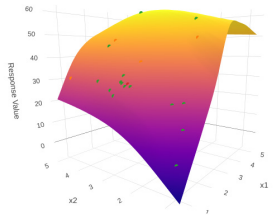
Benefits

- 200+ error validations (real time)
- Web browser accessible
- Automated creation of entries (real time)
- Automatic post-processing
- 76 tutorials

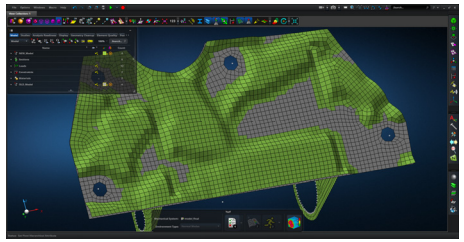
Capabilities



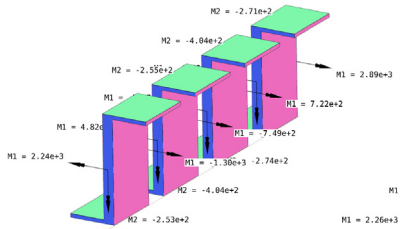
Web Apps for SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography and multi-model.



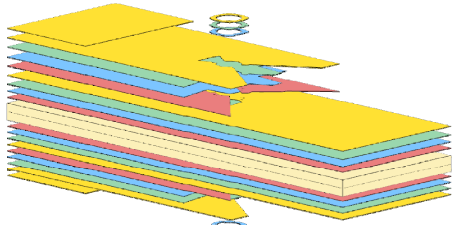
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



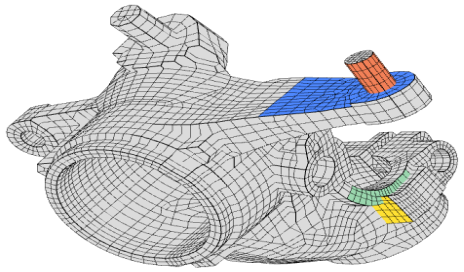
MSC Apex Post Processing Support
View the newly optimized model after an optimization



Beams Viewer Web App
Post process 1D element forces, including shear forces, moments, torque and axial forces

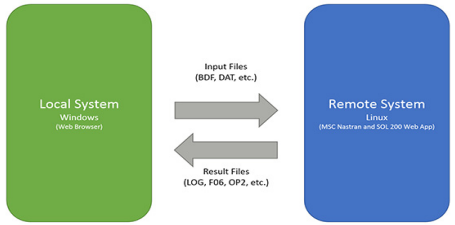


Ply Shape Optimization Web App
Spread plies optimally and generate new PCOMPG entries

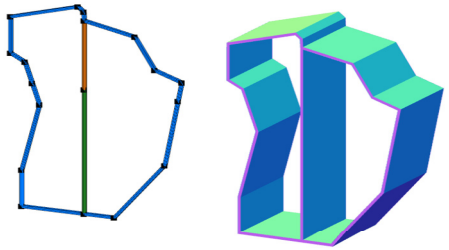


Shape Optimization Web App
Use a web application to configure and perform shape optimization.

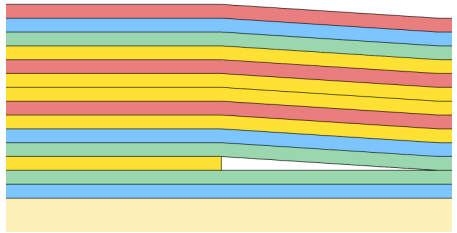
HDF5 Explorer Web App
Create XY plots using data from the H5 file



Remote Execution Web App
Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



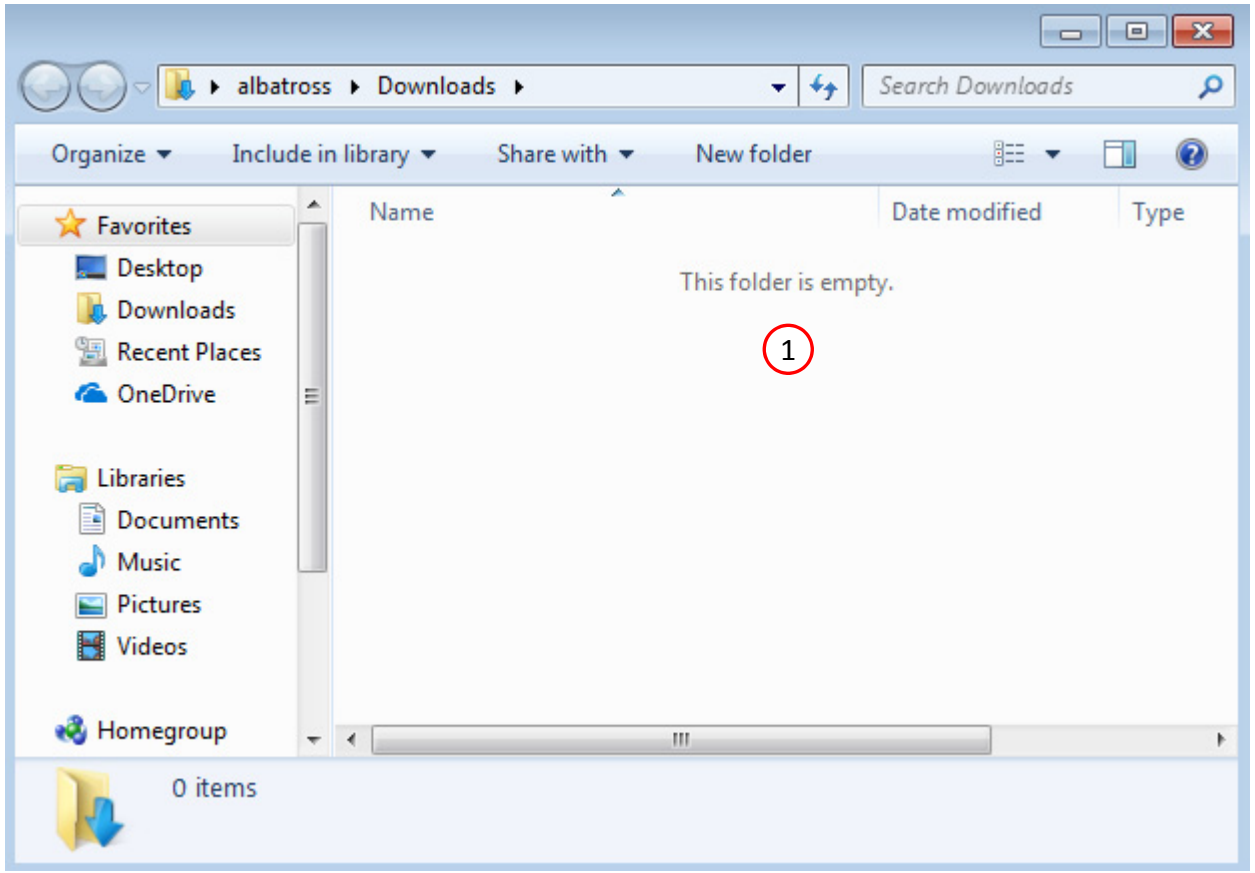
PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



Stacking Sequence Web App
Optimize the stacking sequence of composite laminate plies

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.

Go to the User's Guide

1. Click on the indicated link

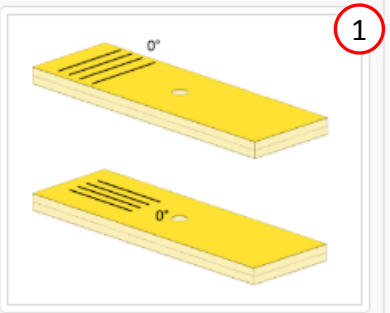
- The necessary BDF files for this tutorial are available in the Tutorials section of the User's Guide.

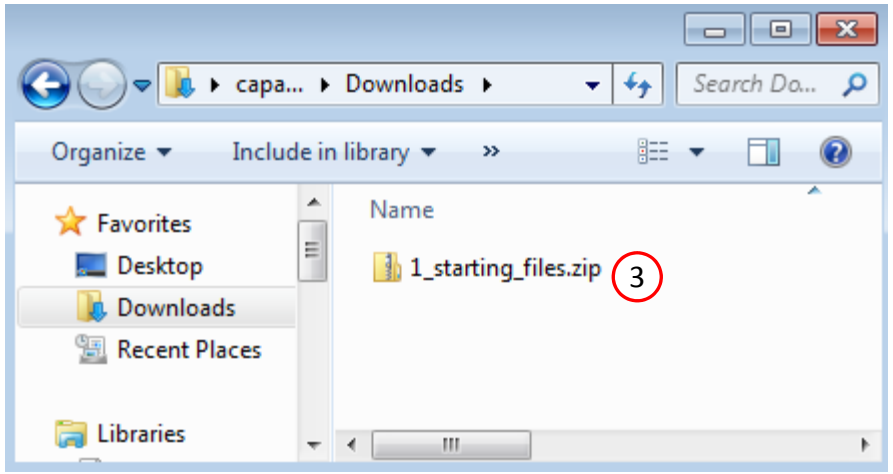
Obtain Starting Files

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.

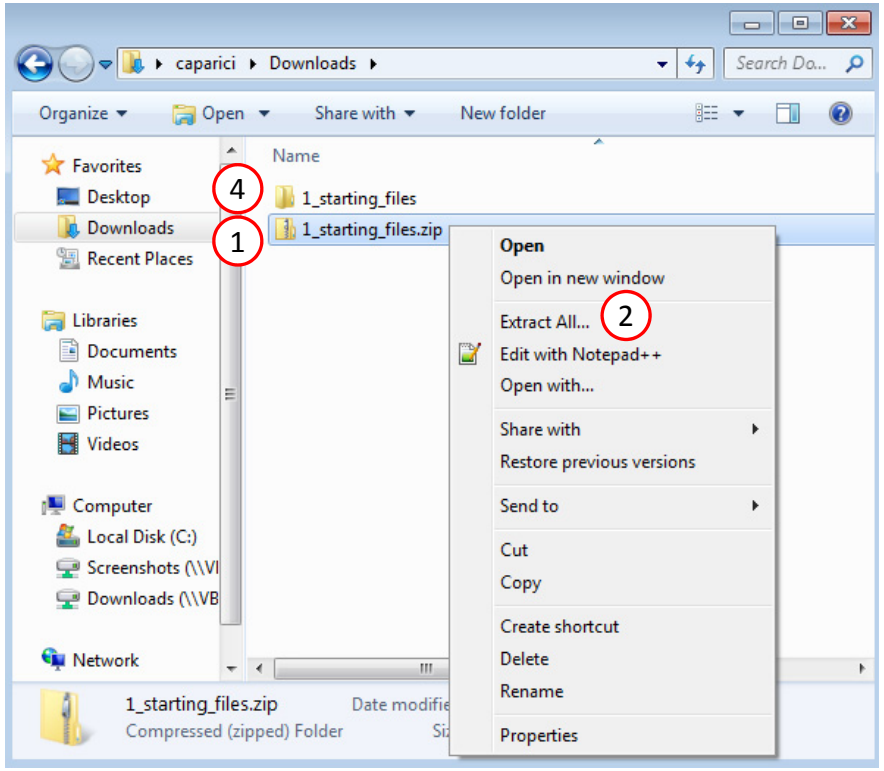
Composites Tutorials

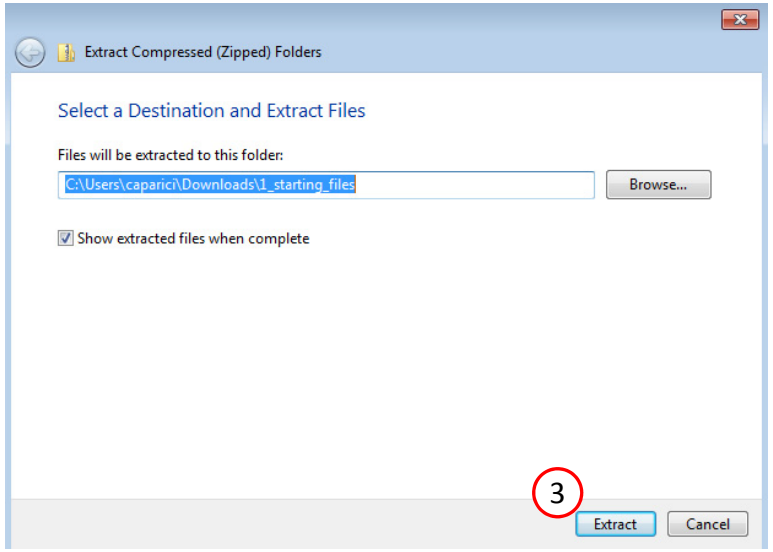
	Title and Description
	**Composite Coupon – Phase A – Determination of the optimal 0° direction of a composite** The goal of this 5-phase tutorial series is to optimize a composite coupon, with a core, and produce a lightweight composite that satisfies failure index constraints. This first phase involves determining the optimal 0° direction of a composite. It is best practice to align the 0° plies in the direction of the load. Not doing so will more than likely produce a suboptimal composite that is heavier than necessary. This tutorial demonstrates the use of MSC Nastran's optimizer to determine the optimal 0° direction of a composite. An optimization is performed to maximize the stiffness of the composite for multiple load cases and while varying the angle of the 0° plies. Ultimately, the best 0° direction is determined. This is the first phase in a 5-phase tutorial series. Starting BDF Files: Link Solution BDF Files: Link

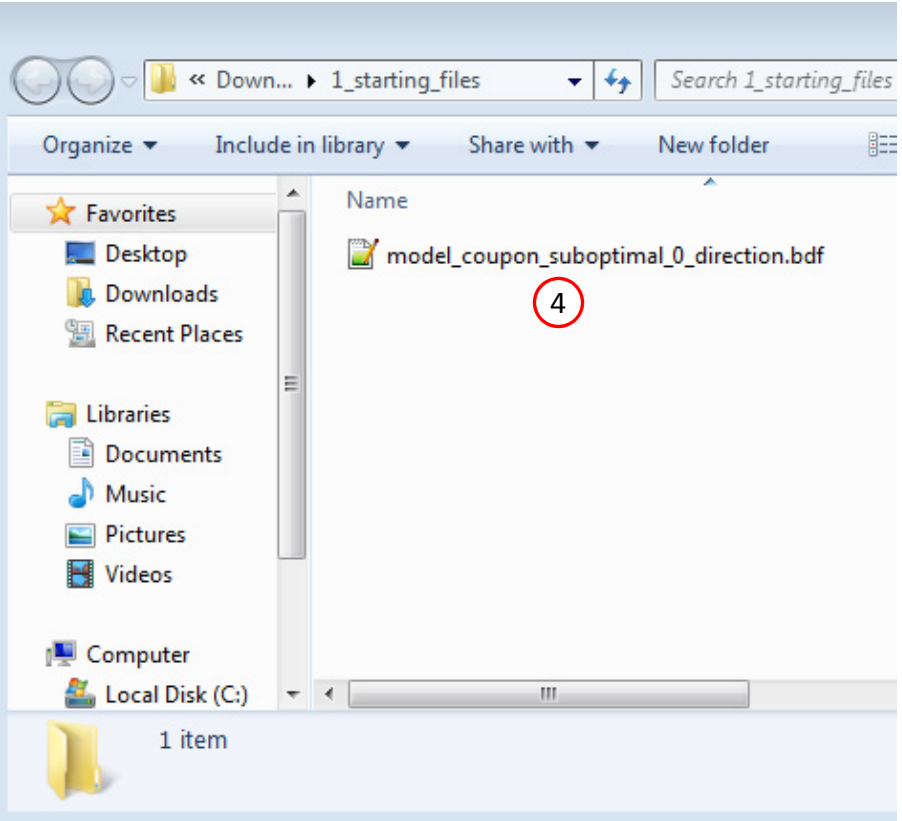


Obtain Starting Files

1. Right click on the zip file
2. Select Extract All…
3. Click Extract
4. The starting files are now available in a folder







Open the Correct Page

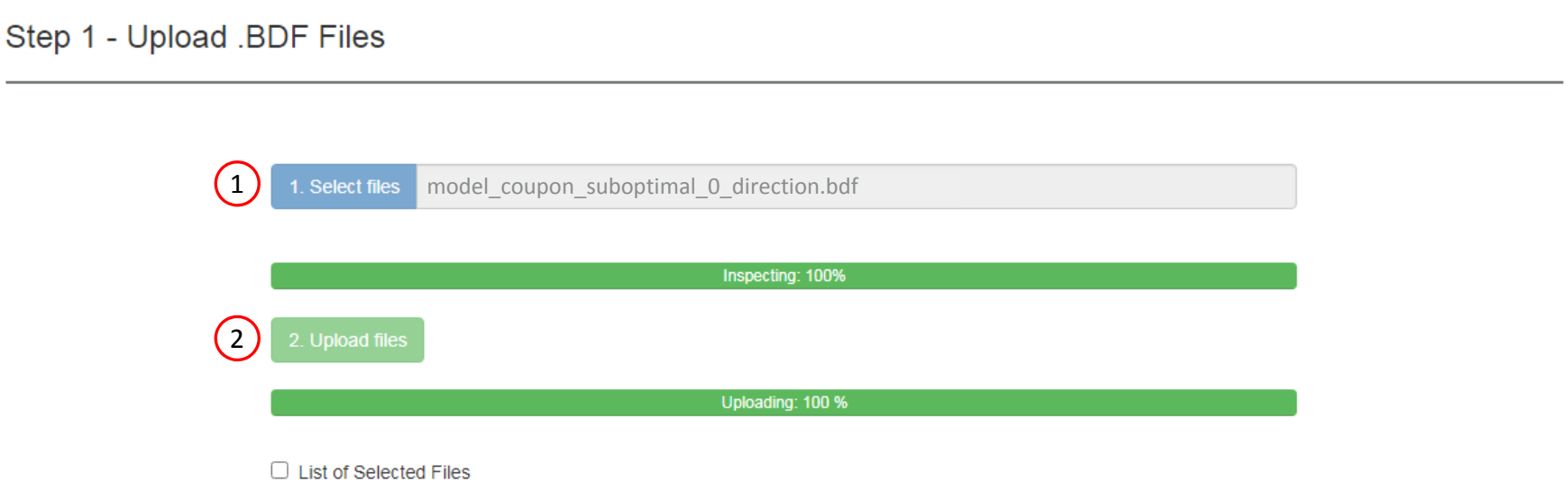
1. Click on the indicated link

- MSC Nastran can perform many optimization types. The SOL 200 Web App includes dedicated web apps for the following:
  - Optimization for SOL 200 (Size, Topology, Topometry, Topography, Local Optimization, Sensitivity Analysis and Global Optimization)
  - Multi Model Optimization
  - Machine Learning
- The web app also features the HDF5 Explorer, a web application to extract results from the H5 file type.

Upload BDF Files

1. Click 1. Select Files and select model_coupon_suboptimal_0_direction.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. Click on the plus (+) icons to set the angle of layer 1 (THETA1) as design variable
2. A new variable x1 is created
3. Configure the following for variable x1
    1. Initial Value: 360.
    2. Lower Bound: 270.
    3. Upper Bound: 450.

- Recall that optimizers have difficulties when the variable approaches or takes on values of zero. Instead of working in the range of values from -90 to 90, the range is offset by +360 degrees to a new range of 270 and 450 degrees. After optimization, the final value of x1 is offset by -360 so that the value is back to the -90 and 90 range.

SOL 200 Web App - Optimization | Upload | Variables | Objective | Constraints | Subcases | Exporter | Results

Size | Topology | Topometry | Topography

Step 1 - Select design properties

+ Options

Create DVXREL1	Property	Property Description	Entry	Entry ID	Current Value
	Search	Search	Search	Search	Search
+	SB	Allowable shear stress of the bondin...	PCOMP	1	90.
+	T1	Thickness of layer 1 (0°)	PCOMP	1	.125
1 +	THETA1	Theta of layer 1 (0°)	PCOMP	1	0.
+	T2	Thickness of layer 2 (0°)	PCOMP	1	3.175
+	THETA2	Theta of layer 2 (0°)	PCOMP	1	0.

« 1 2 3 4 5 6 »

5 10 20 30 40 50

Step 2 - Adjust design variables

✖ Delete Visible Rows

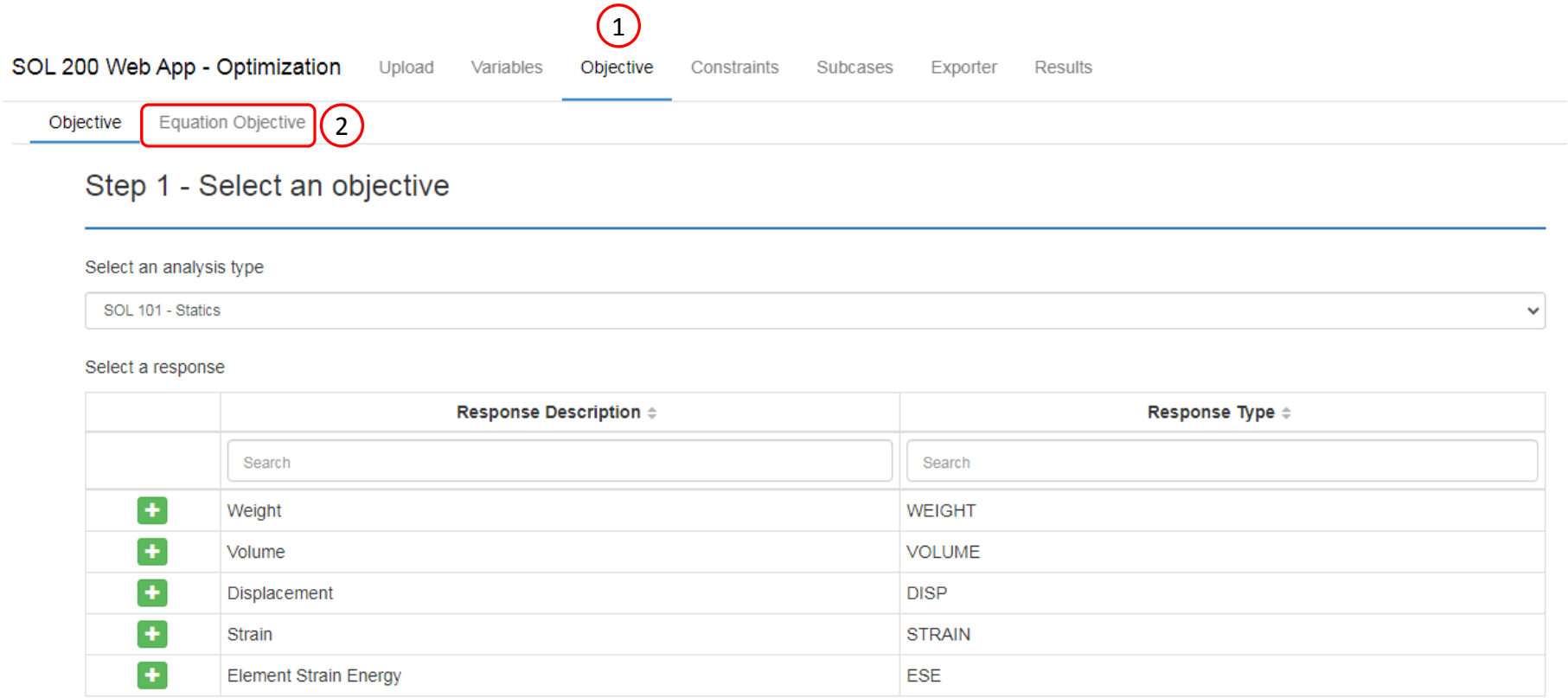
+ Options

	Label	Status	Property	Property Description	Entry	Entry ID	Initial Value	Lower Bound	Upper Bound	Allowed Discrete Values
	Search	Search	Search	Search	Search	Search	Search	3 Search	Search	Search
✖	x1 2	✓	THETA1	Theta of layer 1 (0°)	PCOMP	1	360.	270.	450.	Examples: -2.0, 1.0, THRU, 10.0,

Create Design Objective

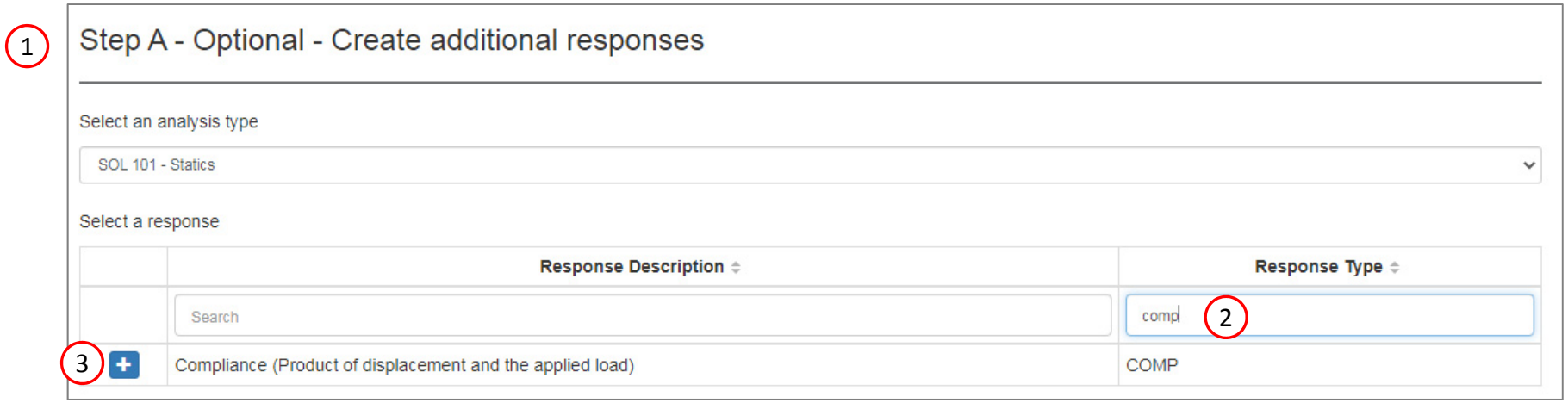
1. Click on Objective
2. Click on Equation Objective

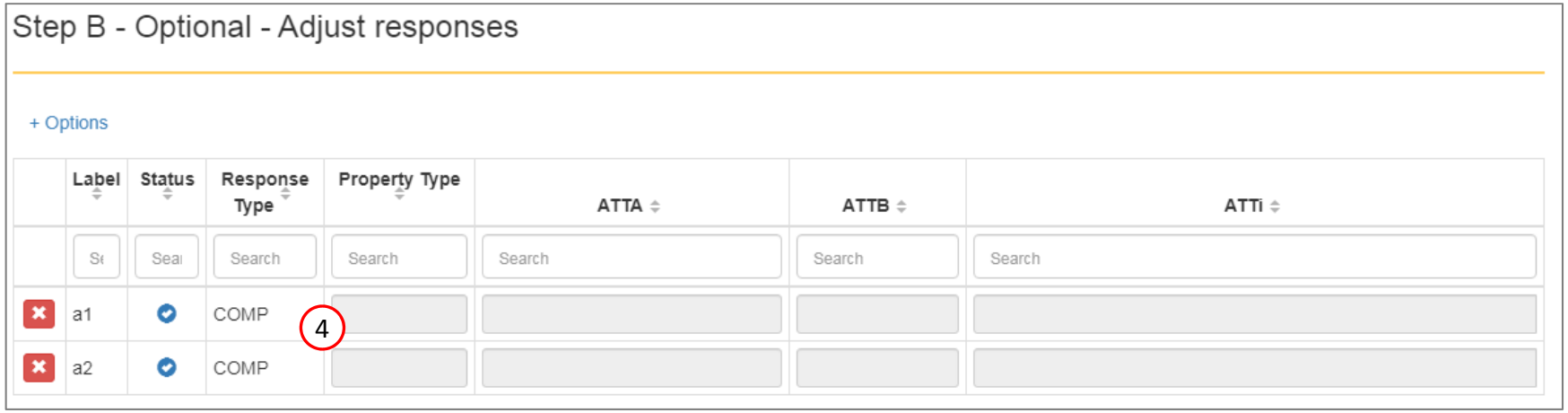
- There are 2 methods of setting an objective.
  - Method 1 – Select a objective from a given list of responses, e.g. Weight, Volume, etc.
  - Method 2 – Create an equation.
- This example uses Method 2 for the objective.



Create Design Objective

1. Scroll down to section Step A - Optional - Create additional responses
2. Type in ‘comp’ to the search box
3. Click the plus (+) icon two times to create two compliance responses
4. Ensure compliance responses a1 and a2 have been created

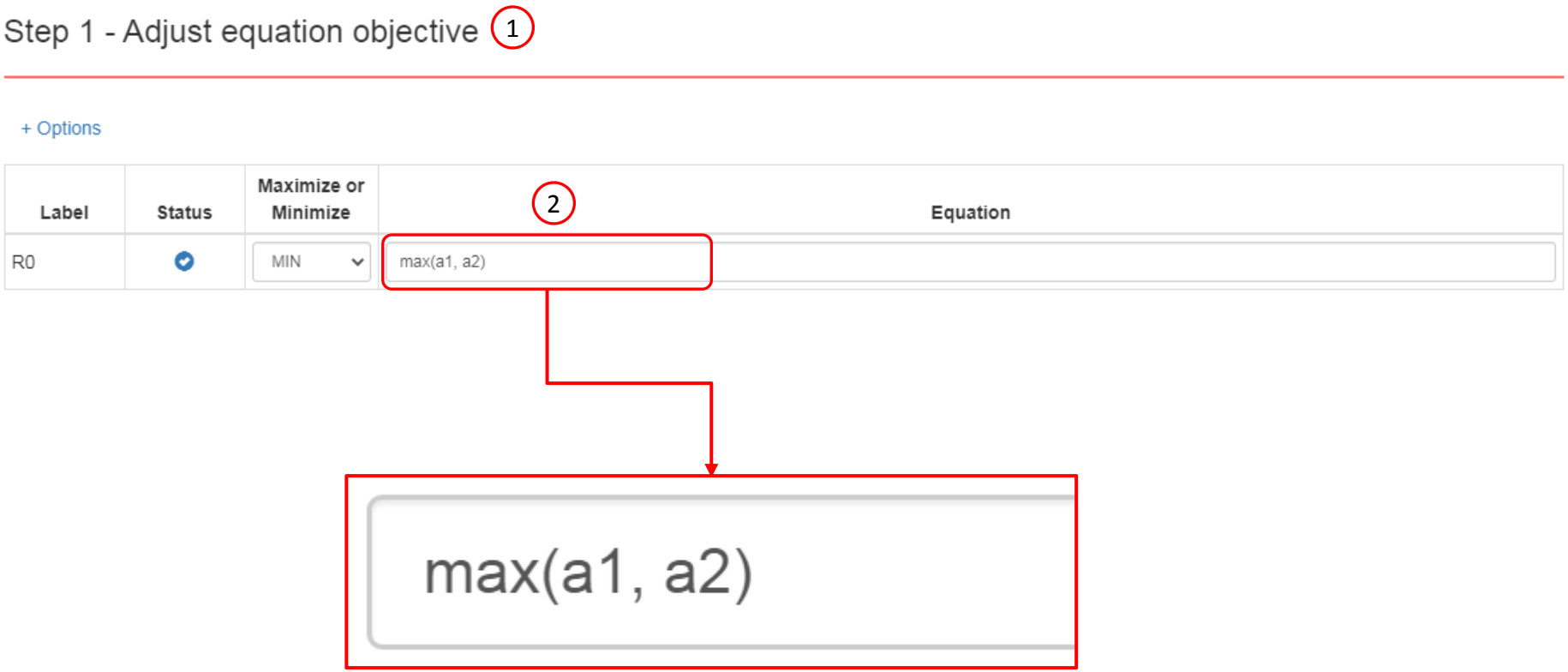




Create Design Objective

1. Scroll to section Step 1 - Adjust equation objective
2. Type this equation into the box
   - max(a1, a2)

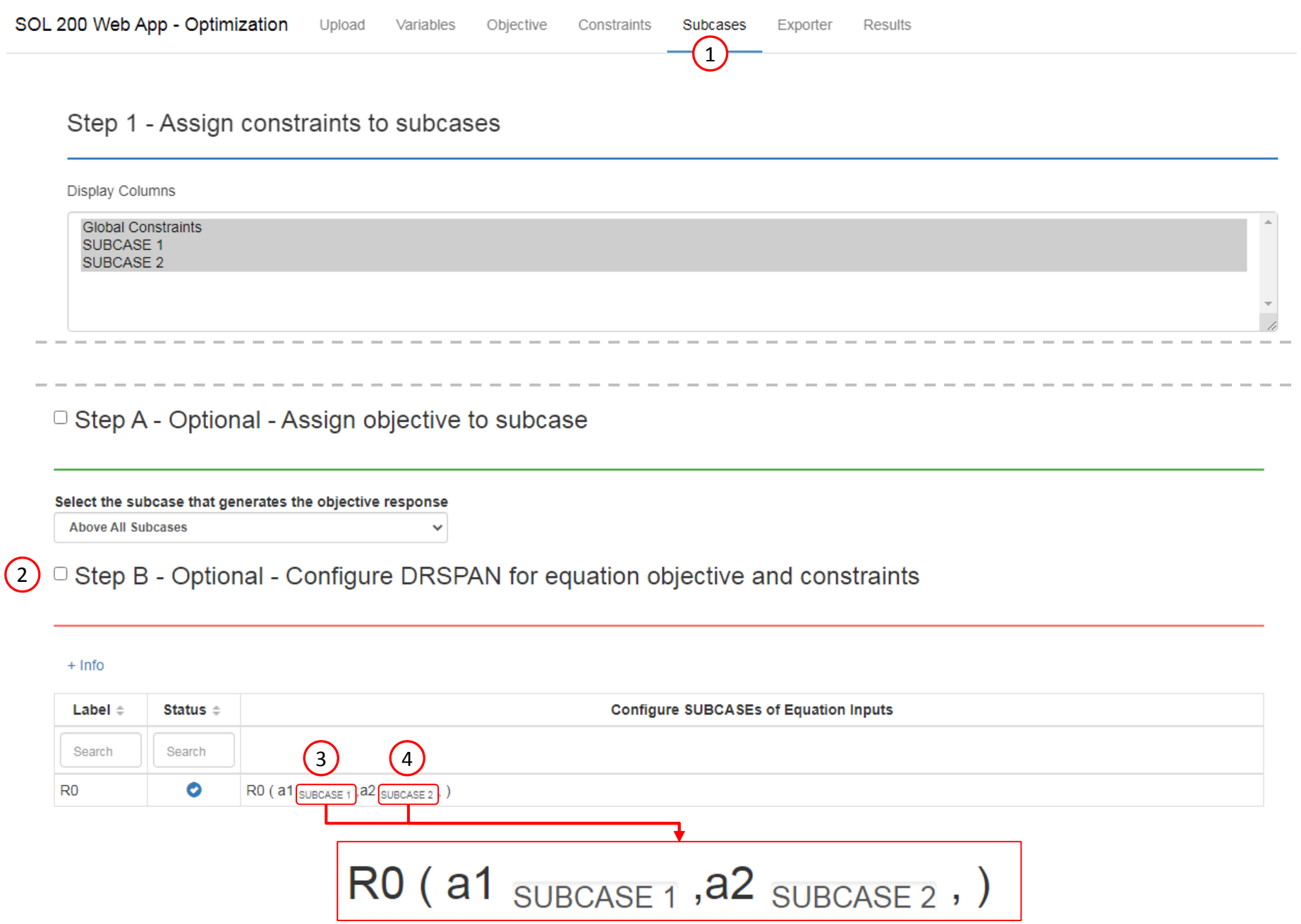
- The objective is to maximize the stiffness of the model by varying the x-axis of the material coordinate system (0° direction). This is achieved by minimizing the compliance response and varying the angle of layer 1 on the PCOMP entry. Since there are multiple load cases in this example, you can either consider the compliance of the most critical load case, e.g. max(a1, a2), or you can consider the average compliance, e.g. avg(a1, a2).



Assign Constraints to Load Cases (SUBCASES)

1. Click Subcases
2. Scroll to section: Step B - Optional - Configure DRSPAN for equation objective and constraints
3. Set a1 to SUBCASE 1
4. Set a2 to SUBCASE 2

- Response a1 is sourced from subcase 1 and response a2 is sourced from subcase 2.



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”

SOL 200 Web App - Optimization | Upload | Variables | Objective | Constraints | Subcases | Exporter (1) | Results

BDF Output - Model

```
assign userfile = 'optimization_results.csv', status = unknown,
form = formatted, unit = 52
$ MSC.Nastran input file created on March     08, 2023 at 12:46:53 by
$ Patran 2022.2
$ Direct Text Input for Nastran System Cell Section
$ Direct Text Input for File Management Section
$ Direct Text Input for Executive Control
$ Linear Static Analysis, Database
SOL 200
CEND

SET 30001 = 6000001
SET 30002 = 6000002
ECHO = PUNCH(NEWBULK)
$ Direct Text Input for Global Case Control Data
   DESOBJ(MIN) = 9000000
   $ DESGLB Slot
   $ DSAPRT(FORMATTED, EXPORT, END=SENS) = ALL
SUBCASE 1
   ANALYSIS = STATICS
   DRSPAN = 30001
   $ DESSUB Slot
   SUBTITLE=Load Case 1
   SPC = 2
   LOAD = 2
   DISPLACEMENT(PLOT,SORT1,REAL)=ALL
   SPCFORCES(PLOT,SORT1,REAL)=ALL
   STRESS(PLOT,SORT1,REAL,VONMISES,BILIN)=ALL
$ Direct Text Input for this Subcase
```

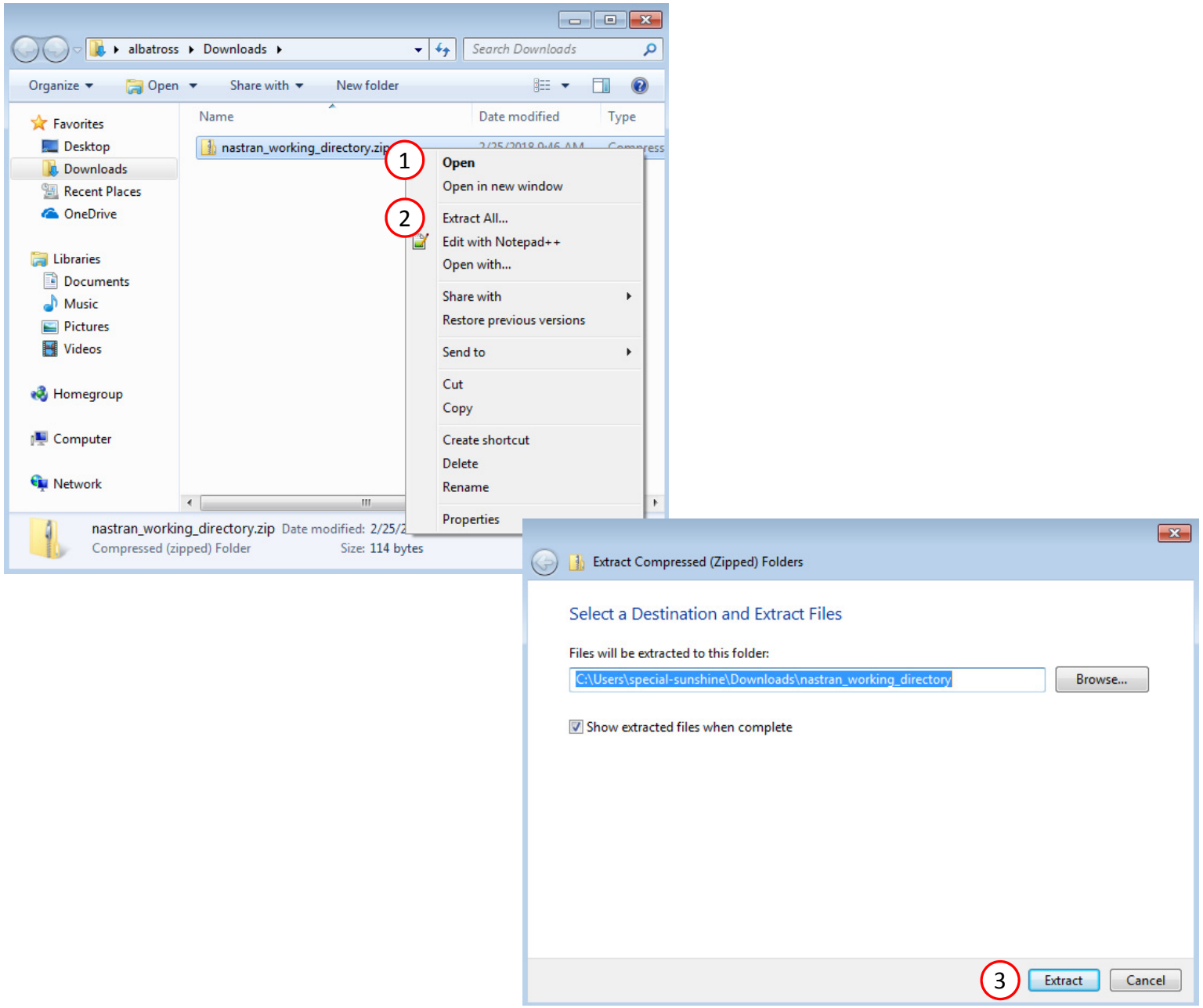
Download BDF Files

Download BDF Files (2)

Perform the Optimization with Nastran SOL 200

1. A new .zip file has been downloaded
2. Right click on the file
3. Click Extract All
4. 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

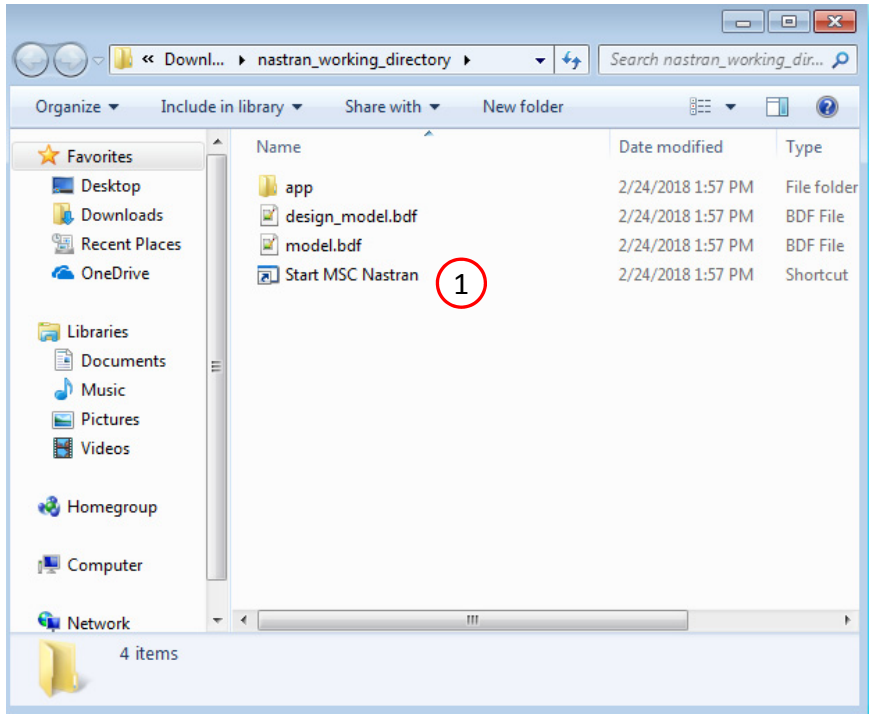
- After a successful optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- One can run the Nastran job on a remote machine as follows:
  1) Copy the BDF files and the INCLUDE files to a remote machine. 2) Run the MSC Nastran job on the remote machine. 3) After completion, copy the BDF, F06, LOG, H5 files to the local machine. 4) Click "Start MSC Nastran" to display the results.

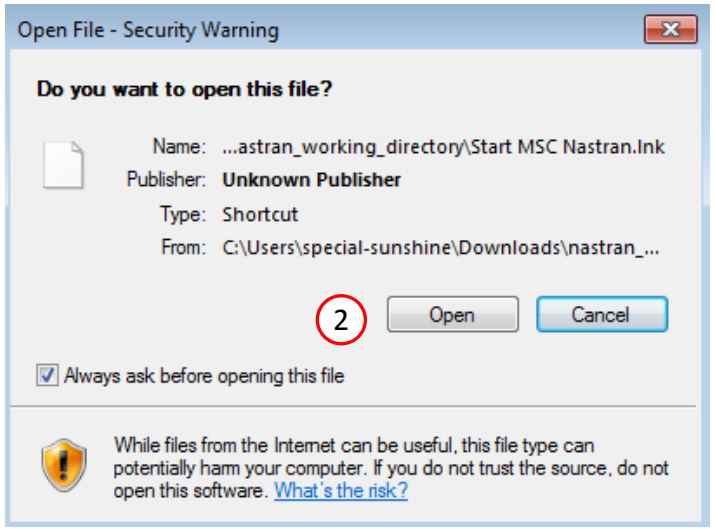
Using Linux?

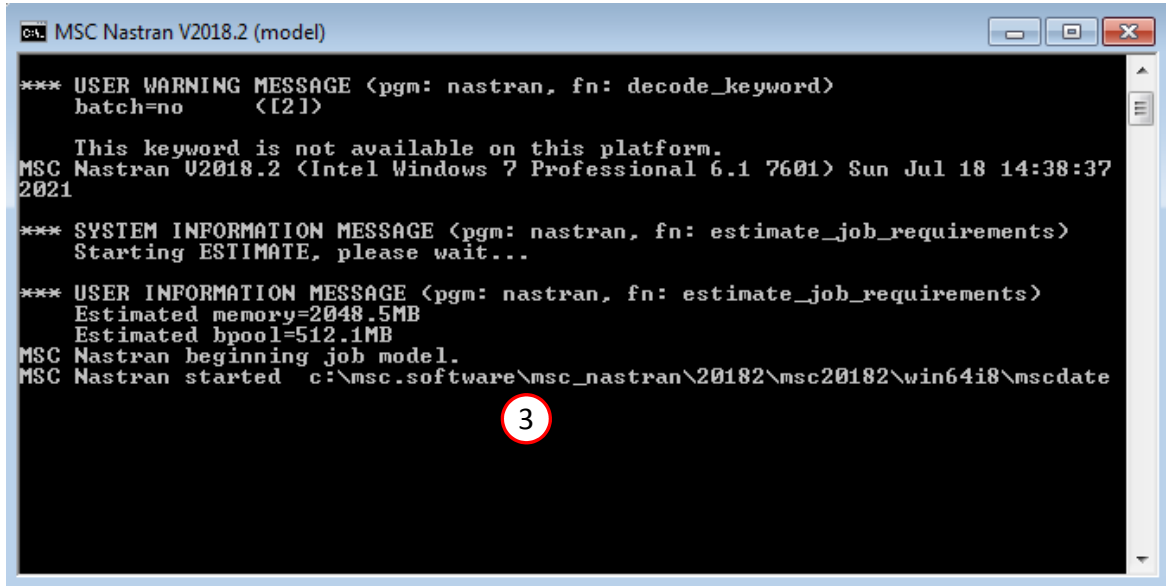
Follow these instructions:
1) Open Terminal
2) Navigate to the nastran_working_directory
   cd ./nastran_working_directory
3) Use this command to start the process
   ./Start_MSC_Nastran.sh

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







Status

1. 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.

SOL 200 Web App - Status

Python MSC Nastran

Status

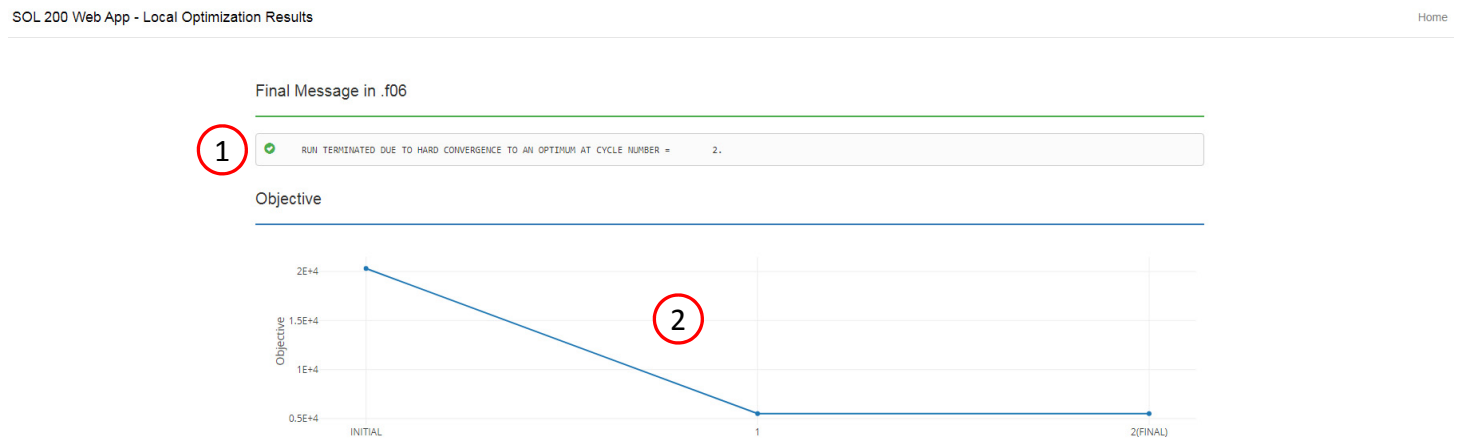
Name	Status of Job	Design Cycle	RUN TERMINATED DUE TO
model.bdf	Running	None	

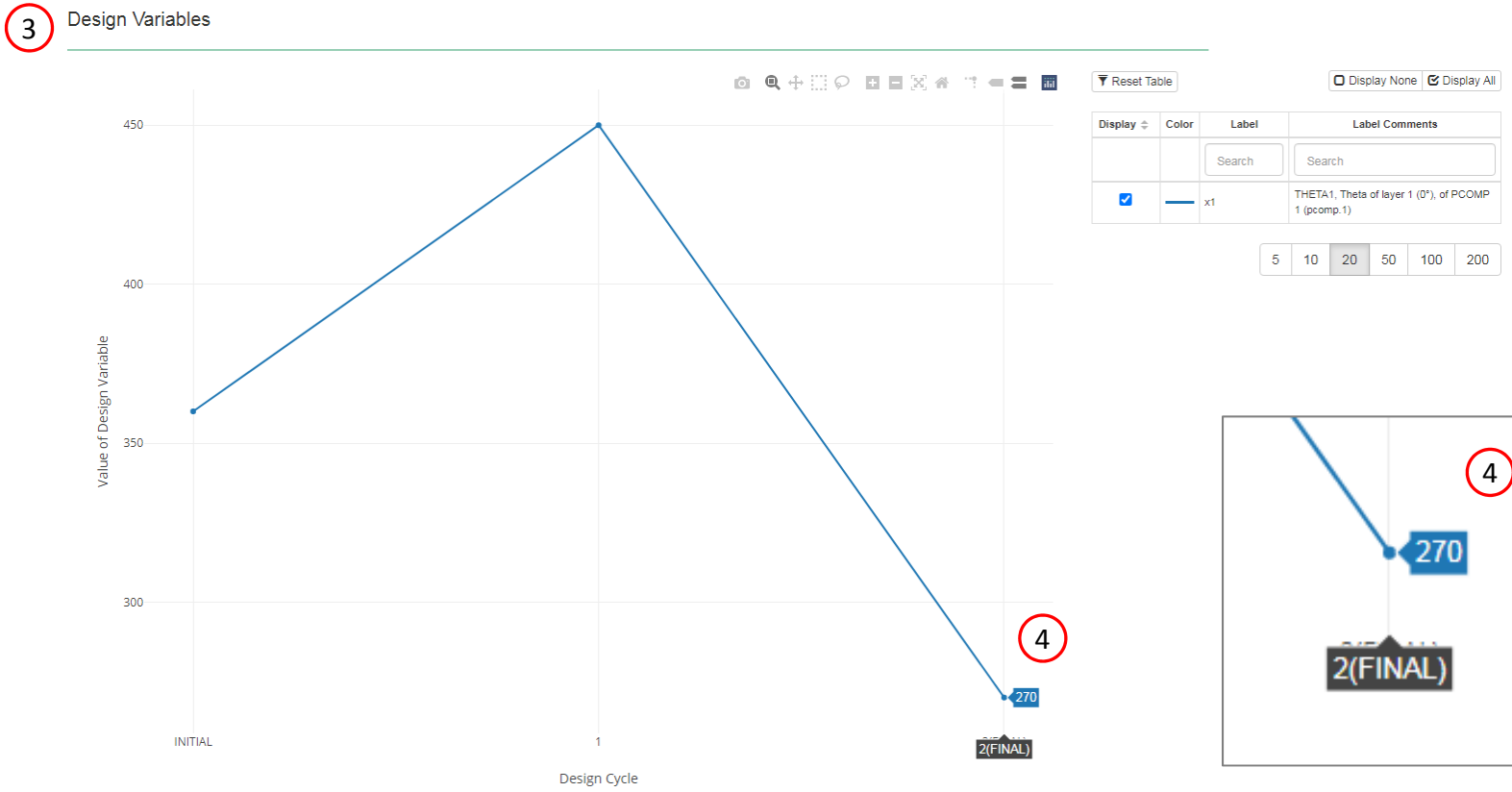
Review Optimization Results

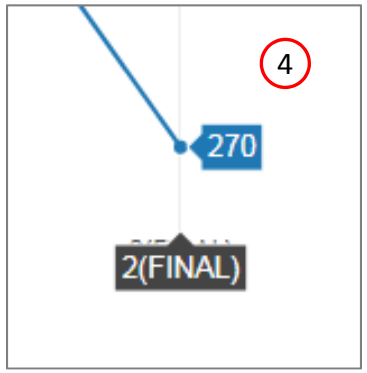
After MSC Nastran is finished, the results will be automatically uploaded.

1. Ensure the messages shown have green checkmarks. This is indication of success. Any red icons indicate challenges.
2. Note that the compliance has been successfully minimized, i.e. the stiffness was maximized.
3. The final value of objective, normalized constraints (not shown) and design variables can be reviewed.
4. The final angle is 270°. Recall that the angle was offset by +360°. The angle 270° is offset by -360° to yield -90°. The x-axis of the material coordinate system should be rotated -90° to maximize the stiffness.

- After an optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- If it is expected that multiple solutions may exist, it is recommended that multiple batch optimizations be configured with different initial values for x1, e.g. -75, -45, -25, 0, 25, 45, 75, or 285, 315, 335, 360, 385, 405, 435. The Machine Learning web app supports configuration of multiple batch runs.

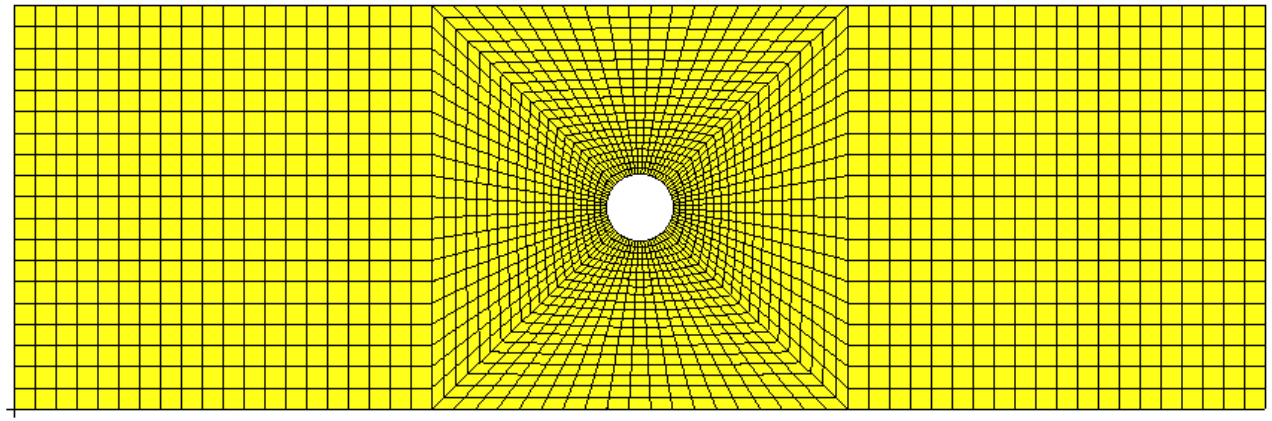


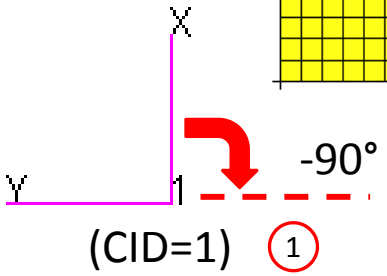


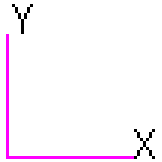


Discussion of Results

1. Coordinate system 1 must be rotated -90°
2. Notice that if CID=1 is rotated -90°, it will align with the default coordinate system (CID=0). CID=0 is used moving forward.







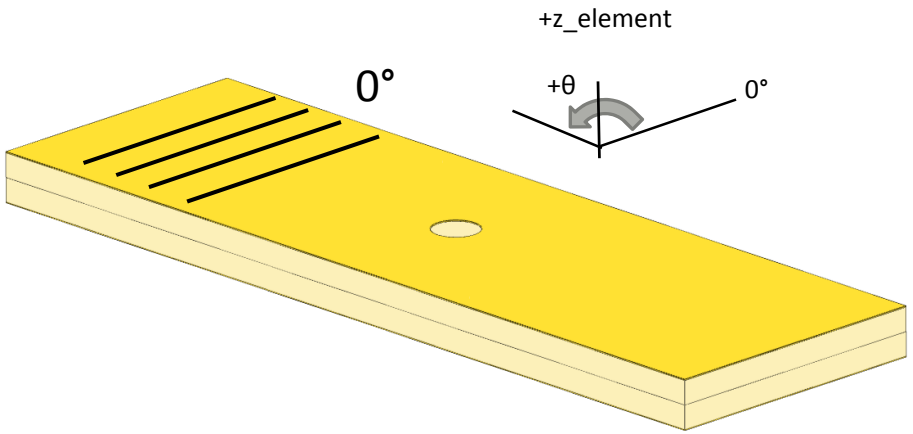
Default Coordinate System (CID=0)

Discussion of Results

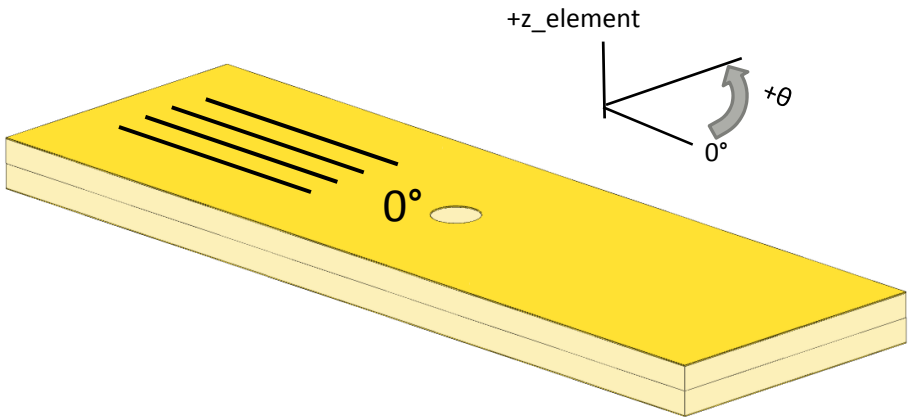
1. The 2D elements are updated to use CID=0, which was found to yield the best stiffness.

This concludes the determination of the optimal 0° direction.

Suboptimal 0° Direction



Optimal 0° Direction



Suboptimal 0° Direction

```
CQUAD4    1429    1        2393    2374    2452    2411    1        0.
CQUAD4    1430    1        2411    2452    2453    2410    1        0.
CQUAD4    1431    1        2410    2453    2454    2409    1        0.
[…]
```

1

Optimal 0° Direction

```
CQUAD4    1429    1        2393    2374    2452    2411    0        0.
CQUAD4    1430    1        2411    2452    2453    2410    0        0.
CQUAD4    1431    1        2410    2453    2454    2409    0        0.
[…]
```

End of Tutorial