Workshop - Shape Optimization of a Steering Knuckle

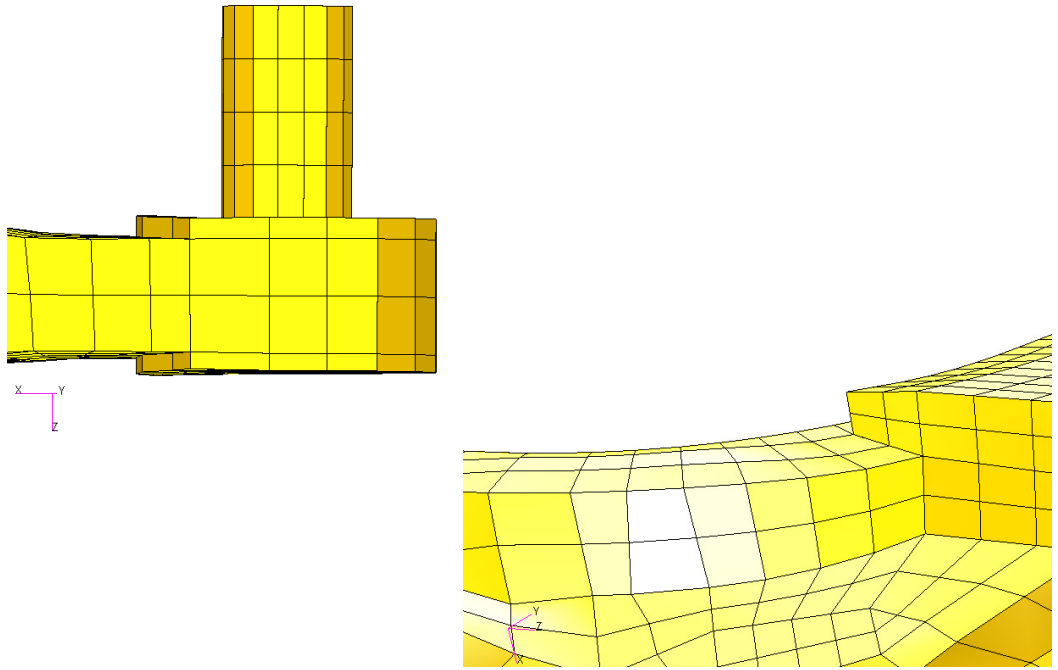
AN MSC NASTRAN SOL 200 TUTORIAL

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

Results

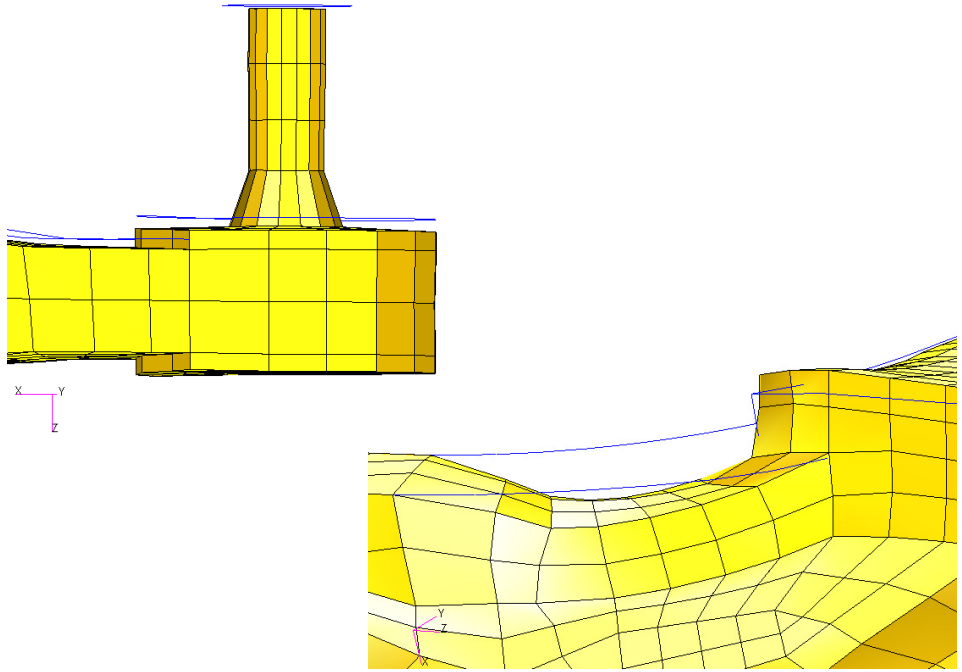
Before Optimization

- Weight: 8.081499E+07
- Max Stress: 36.8



After Optimization

- Weight: 8.019459E+07
- Max Stress: 39.9



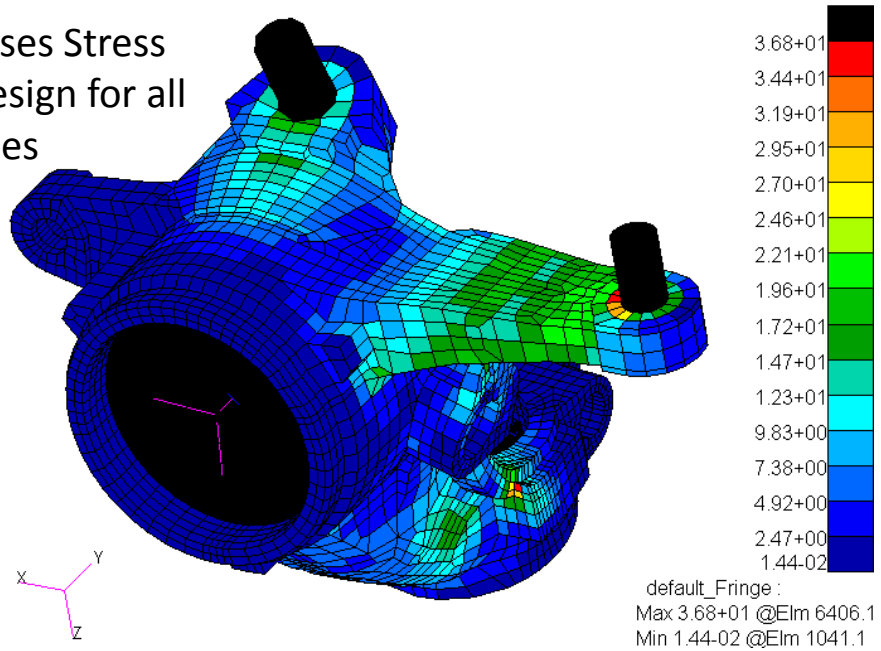
Results

Before Optimization

- Weight: 8.081499E+07
- Max Stress: 36.8

Fringe: Max (Initial), All Subcases, Stress Tensor, , von Mises, (NON-LAYERED)

Max von Mises Stress for Initial Design for all 12 Load Cases

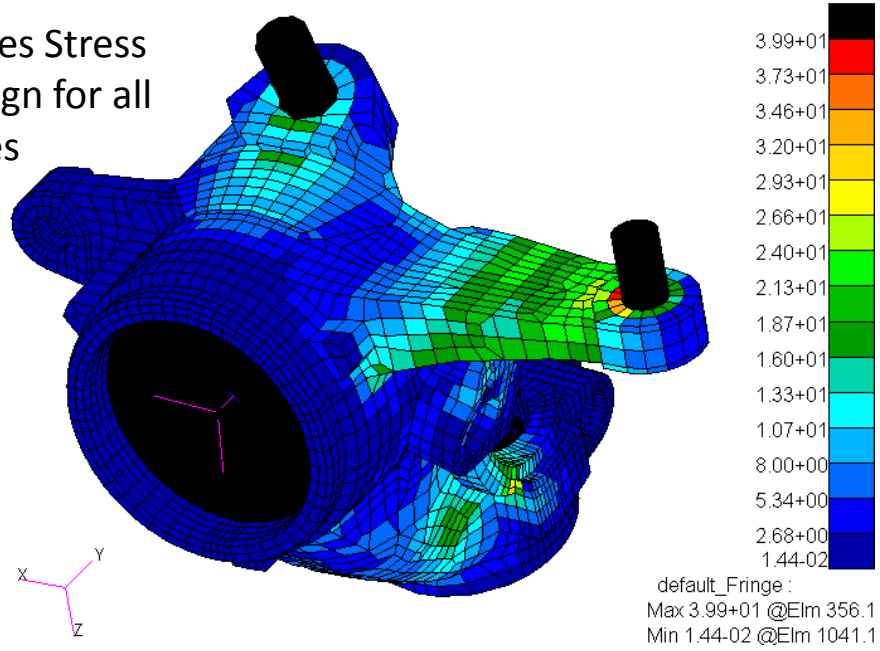


After Optimization

- Weight: 8.019459E+07
- Max Stress: 39.9

Fringe: Max (Final), All Subcases, Stress Tensor, , von Mises, (NON-LAYERED)

Max von Mises Stress for Final Design for all 12 Load Cases

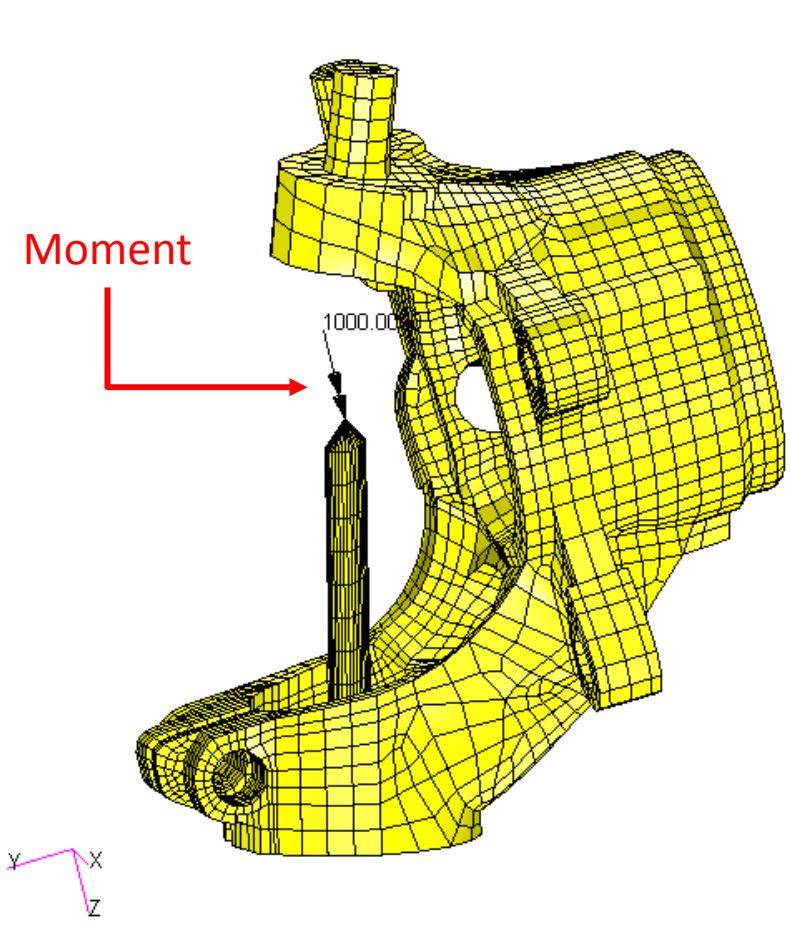


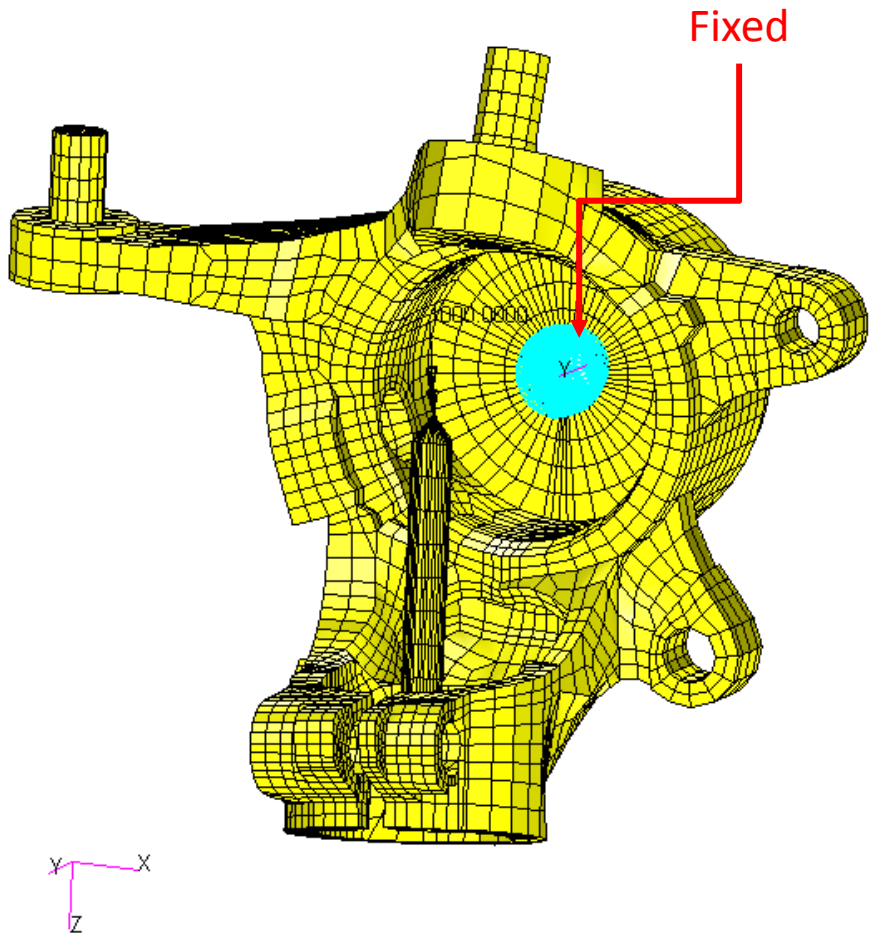
Details of the Structural Model

This model is fixed at the indicated hole.

12 load cases apply point loads and moments.

Only the load of load case 12 is displayed.

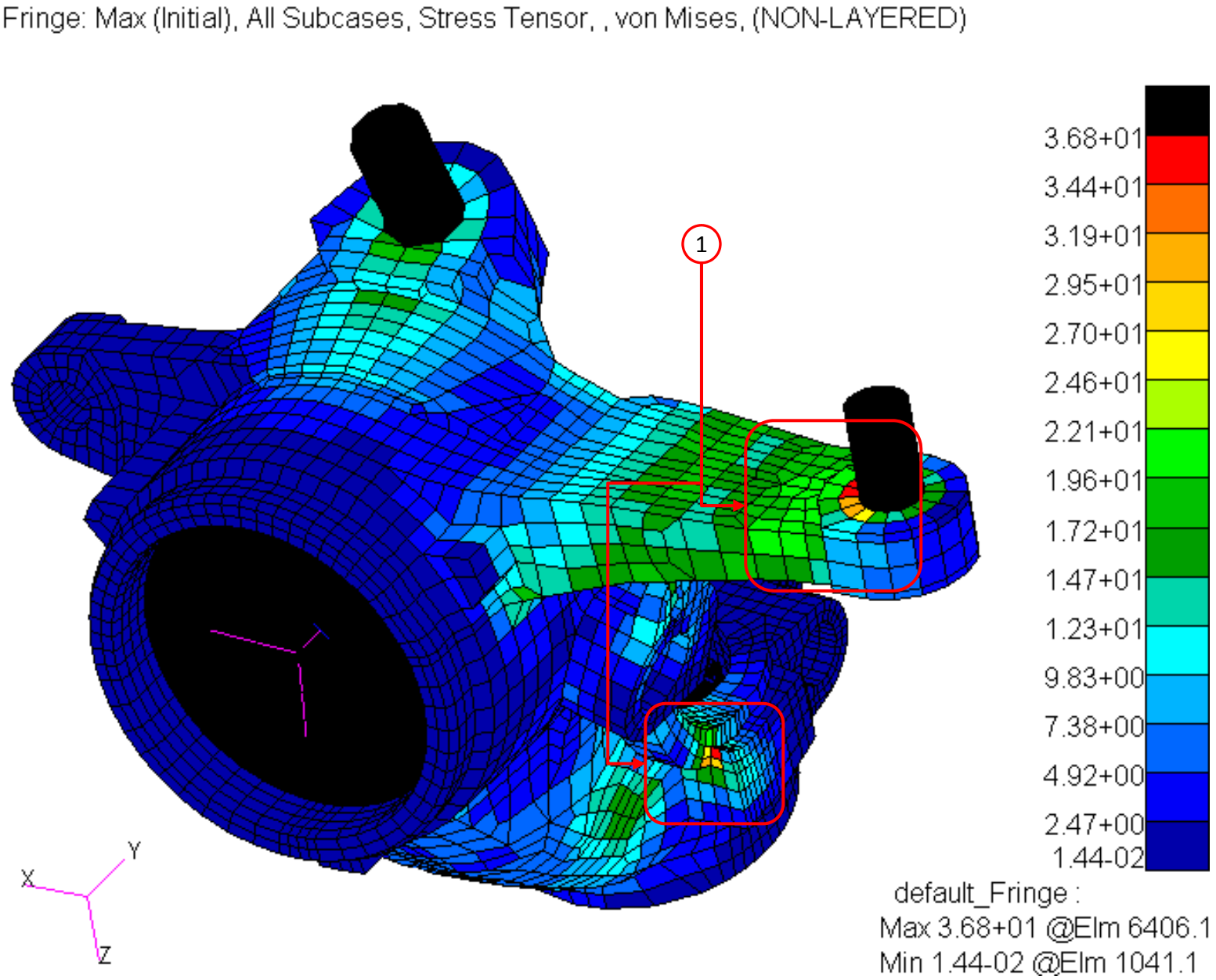




Shape Optimization Strategy

The max von Mises stress across all 12 load cases is plotted.

1. Two regions of the structure have high stresses. The shape in these regions of high stress will be optimized to minimize mass while constraining the stress.



Optimization Problem Statement

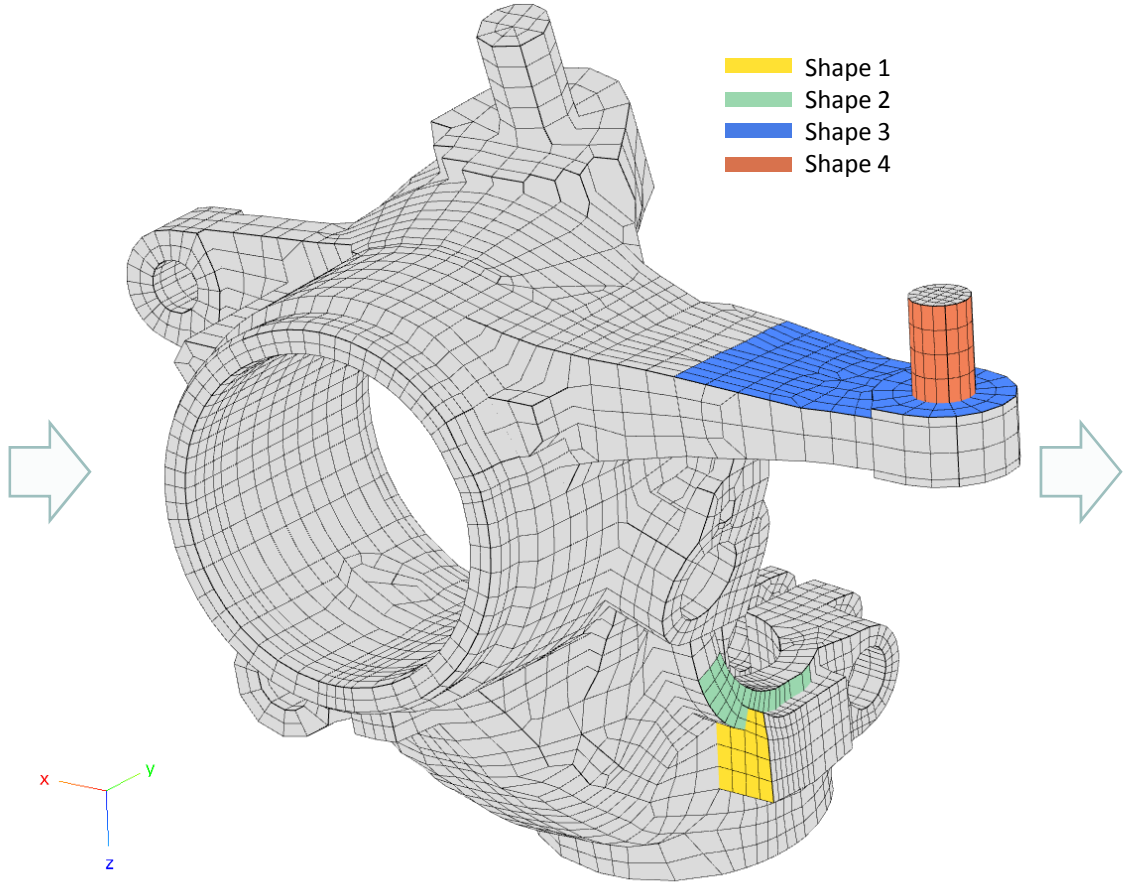
Design Variables

y1: Shape 1 – Expansion/contraction region 1
y2: Shape 2 – Expansion/contraction region 2
y3: Shape 3 – Expansion/contraction region 3
y4: Shape 4 – Expansion/contraction region 4

$4.0 < y1 < 15.0$
$4.0 < y2 < 15.0$
$4.0 < y3 < 13.0$
$7.0 < y4 < 12.0$

When the initial value of the shape variables is 10.0, the equivalent bounds on Δyi are:

$-6.0 < \Delta y1 < 5.0$
$-6.0 < \Delta y2 < 5.0$
$-6.0 < \Delta y3 < 3.0$
$-3.0 < \Delta y4 < 2.0$



Design Objective

r0: Minimize weight

Design Constraints

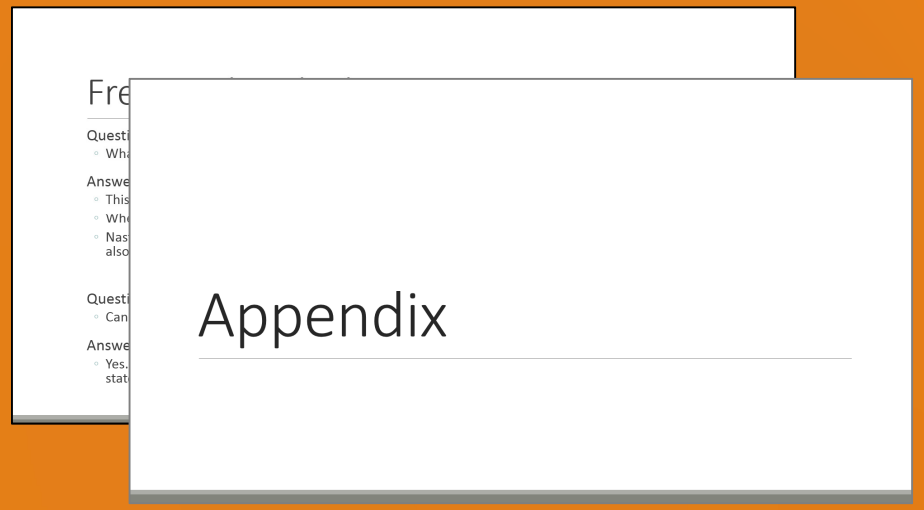
r1: von Mises stress at the center of the elements 356, 355, 6406

$R1 < 40.0$

More Information Available in the Appendix

The Appendix includes information regarding the following:

- Frequently Asked Questions
  - How to view the shape optimization results in Patran?



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

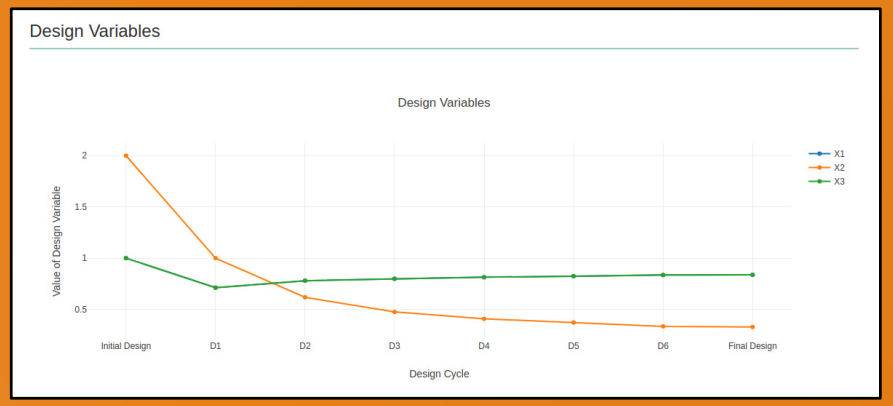
Tutorial

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
     - Design Constraints
   - Perform optimization with Nastran SOL 200
3. Plot the Optimization Results
4. Update the original model with optimized parameters

Special Topics Covered

Automatic Plots - After an optimization is complete and result files are created, the change during the optimization process for design variables and objective may be automatically plotted by the Nastran Web App. This tutorial describes how to create these plots. The plotting capability may also be used to plot design sensitivities.



SOL 200 Web App Capabilities

The Post-processor Web App and HDF5 Explorer are free to MSC Nastran users.

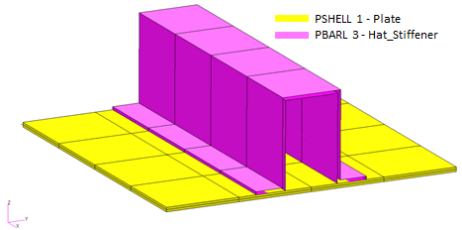
Compatibility

- Google Chrome, Mozilla Firefox or Microsoft Edge
- Windows and Red Hat Linux
- Installable on a company laptop, workstation or server. All data remains within your company.

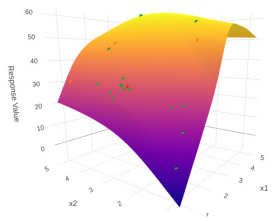
Benefits

- REAL TIME error detection. 200+ error validations.
- REALT TIME creation of bulk data entries.
- Web browser accessible
- Free Post-processor web apps
- +80 tutorials

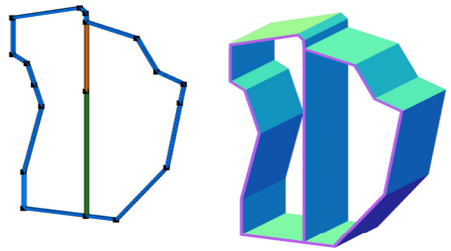
Web Apps



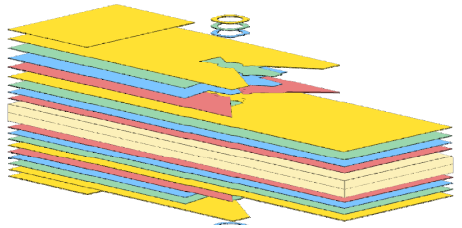
Web Apps for MSC Nastran SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography, multi-model optimization.



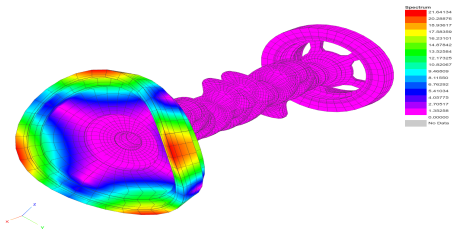
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



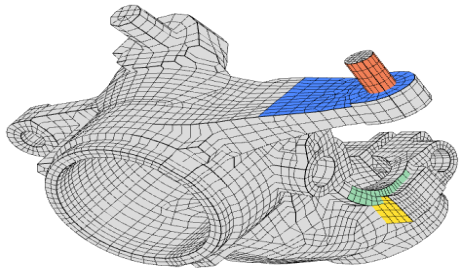
PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



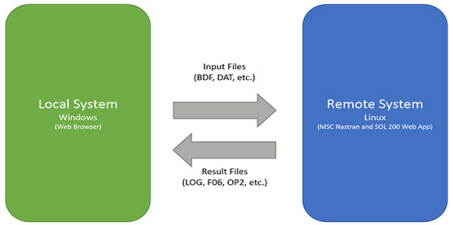
Ply Shape Optimization Web App
Optimize composite ply drop-off locations, and generate new PCOMPG entries



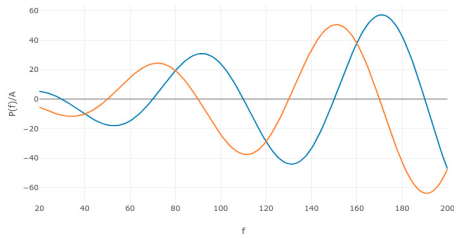
Post-processor Web App
View MSC Nastran results in a web browser on Windows and Linux



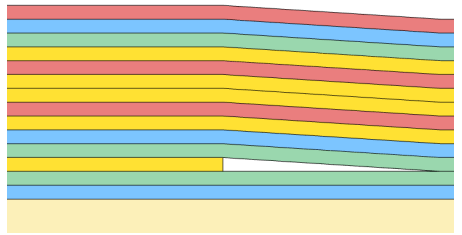
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



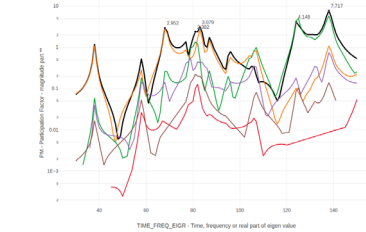
Remote Execution Web App
Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



Dynamic Loads Web App
Generate RLOAD1, RLOAD2 and DLOAD entries graphically



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

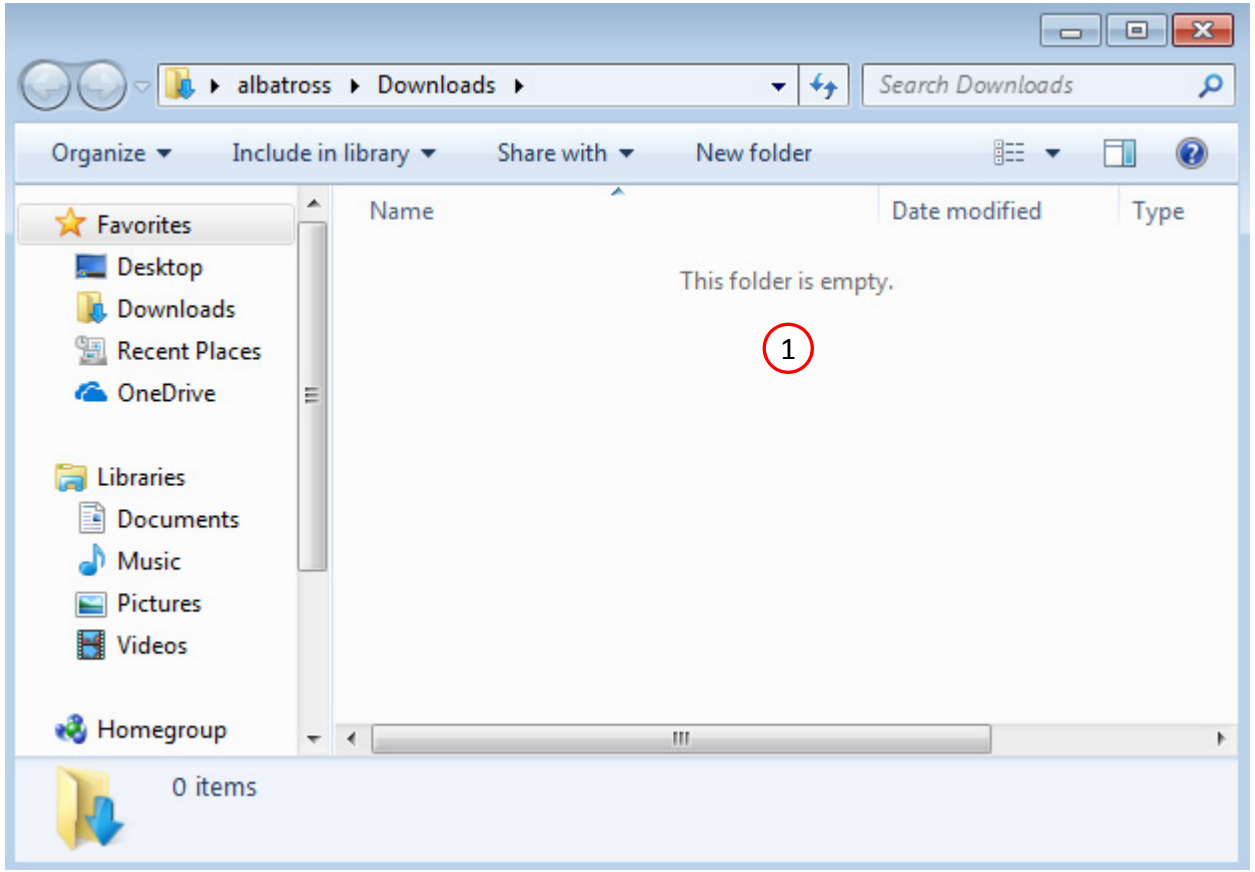


HDF5 Explorer Web App
Create graphs (XY plots) using data from the H5 file

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

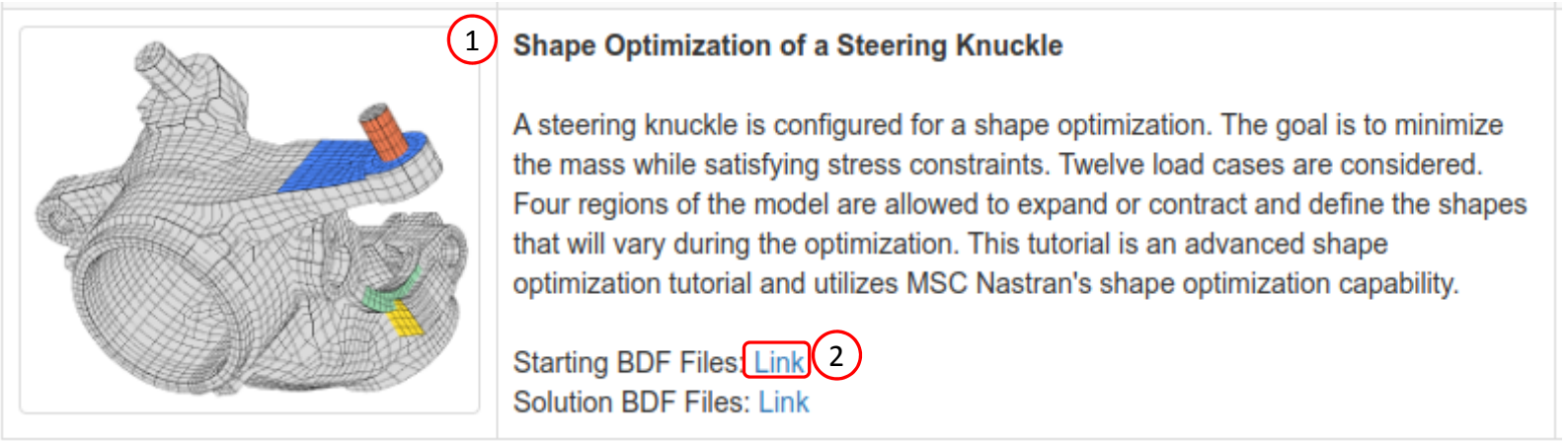
1. Click on the indicated link

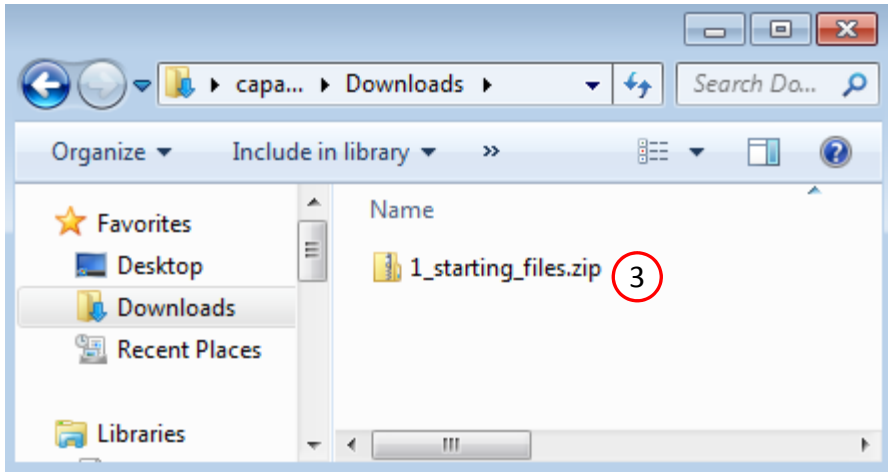
- The necessary BDF files for this tutorial are available in the Tutorials section of the User's Guide.

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.

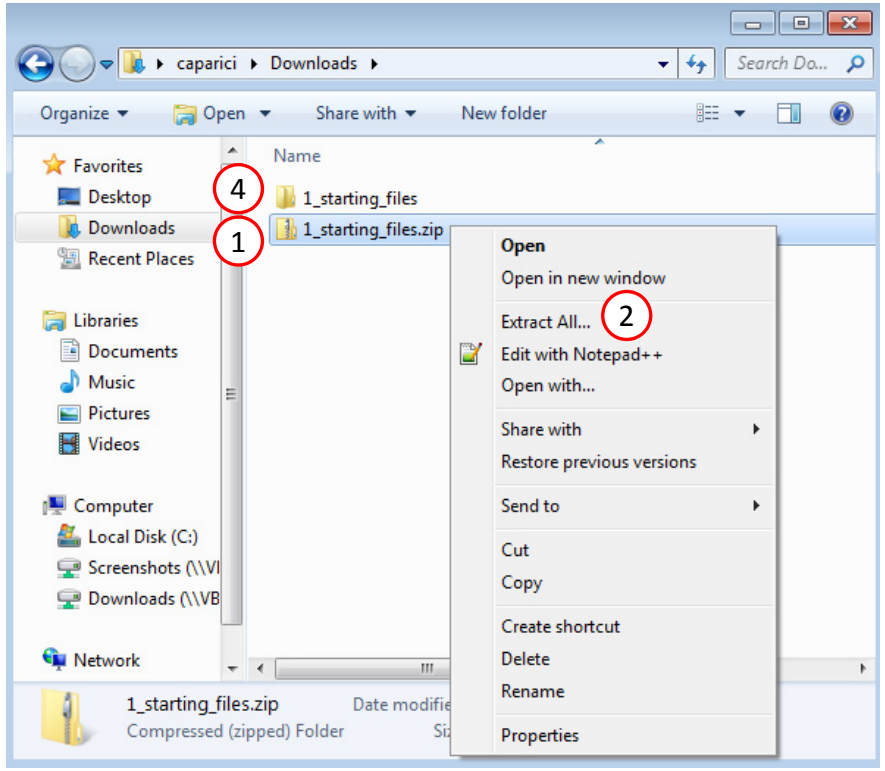


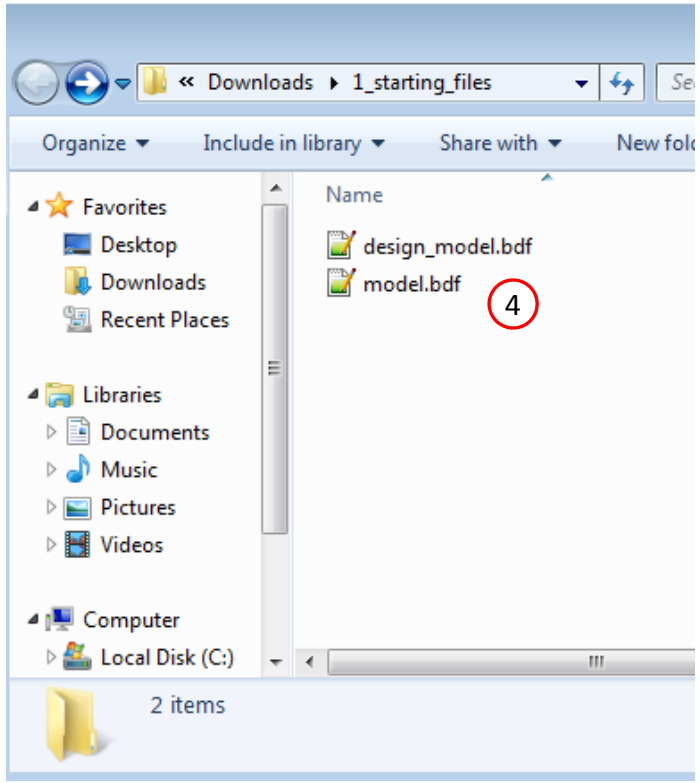


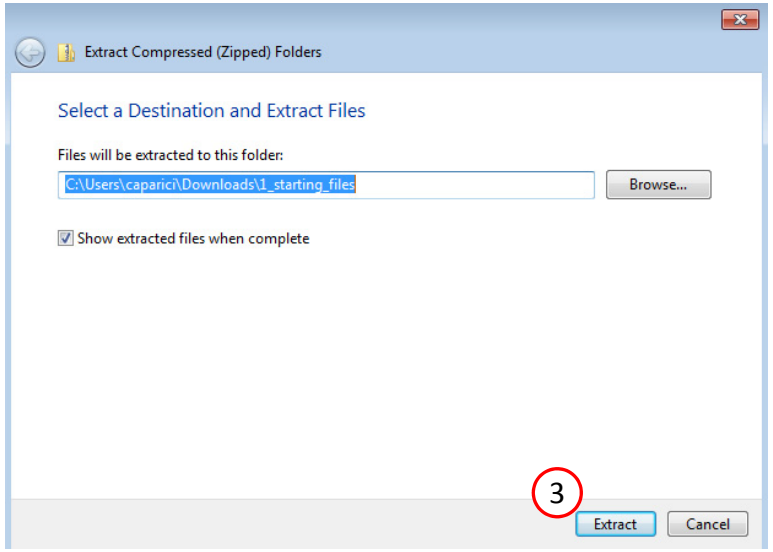
Obtain Starting Files

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

- This example is using a previously created design model. The design model is a model that has been converted to SOL 200 and contains bulk data entries describing the optimization problem statement, e.g. variables, objective and constraints.







Open the Correct Page

1. Click on the indicated link

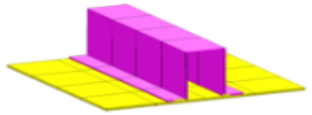
- MSC Nastran can perform many optimization types. The SOL 200 Web App includes dedicated web apps for the following:
  - Optimization for SOL 200 (Size, Topology, Topometry, Topography, Local Optimization, Sensitivity Analysis and Global Optimization)
  - Multi Model Optimization
  - Machine Learning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

Open the Viewer

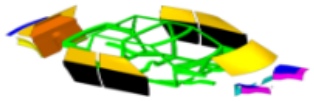
1. Navigate to the Optimization section
2. Click Viewer

1 Optimization (SOL 200)

Pre-processing

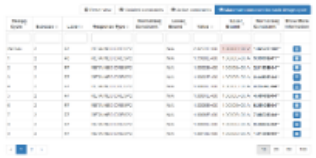


Optimization

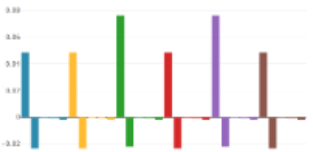


Multi Model Optimization

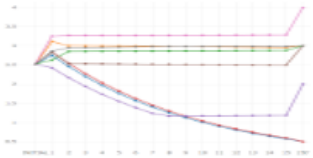
Post-processing



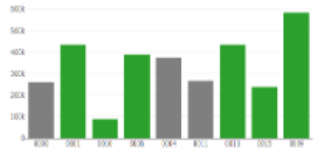
Responses (.f06)



Sensitivities (.csv)

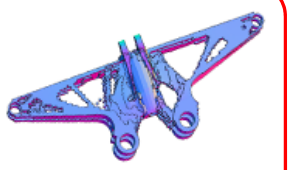


Local Optimization (.f06)



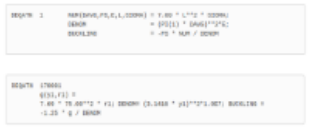
Global Optimization (multiopt.log)

PCH to BDF



Viewer (.des, .ply000i)

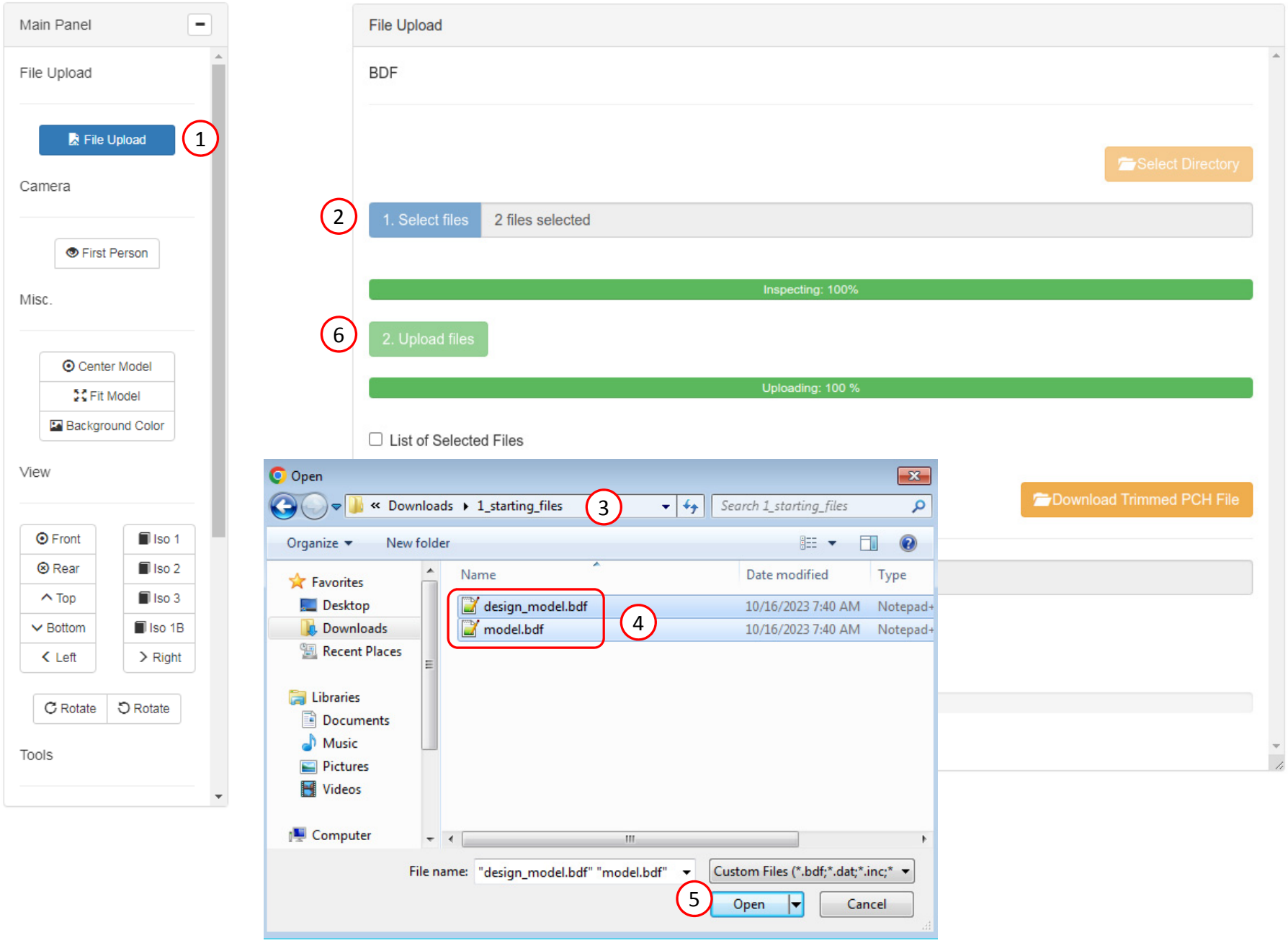
2



Converter

Import BDF Files

1. Click File Upload
2. Click Select files
3. Navigate to directory 1_starting_files
4. Select the indicated files
5. Click Open
6. Click Upload files



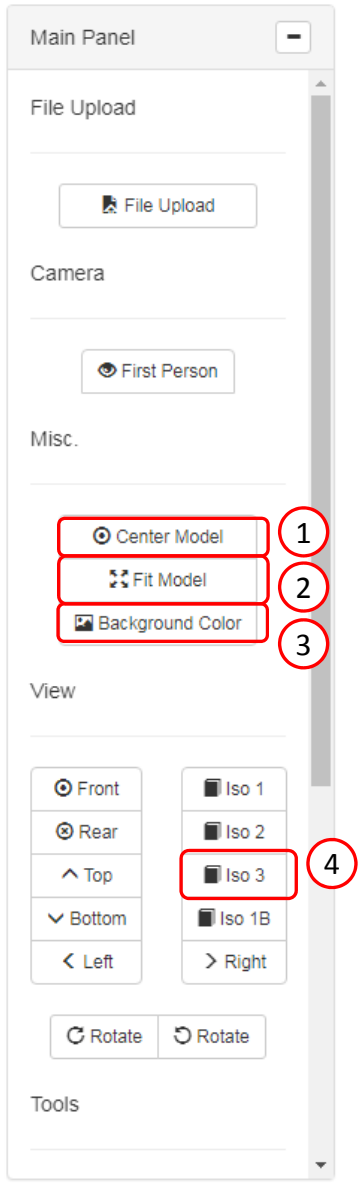
Before Continuing

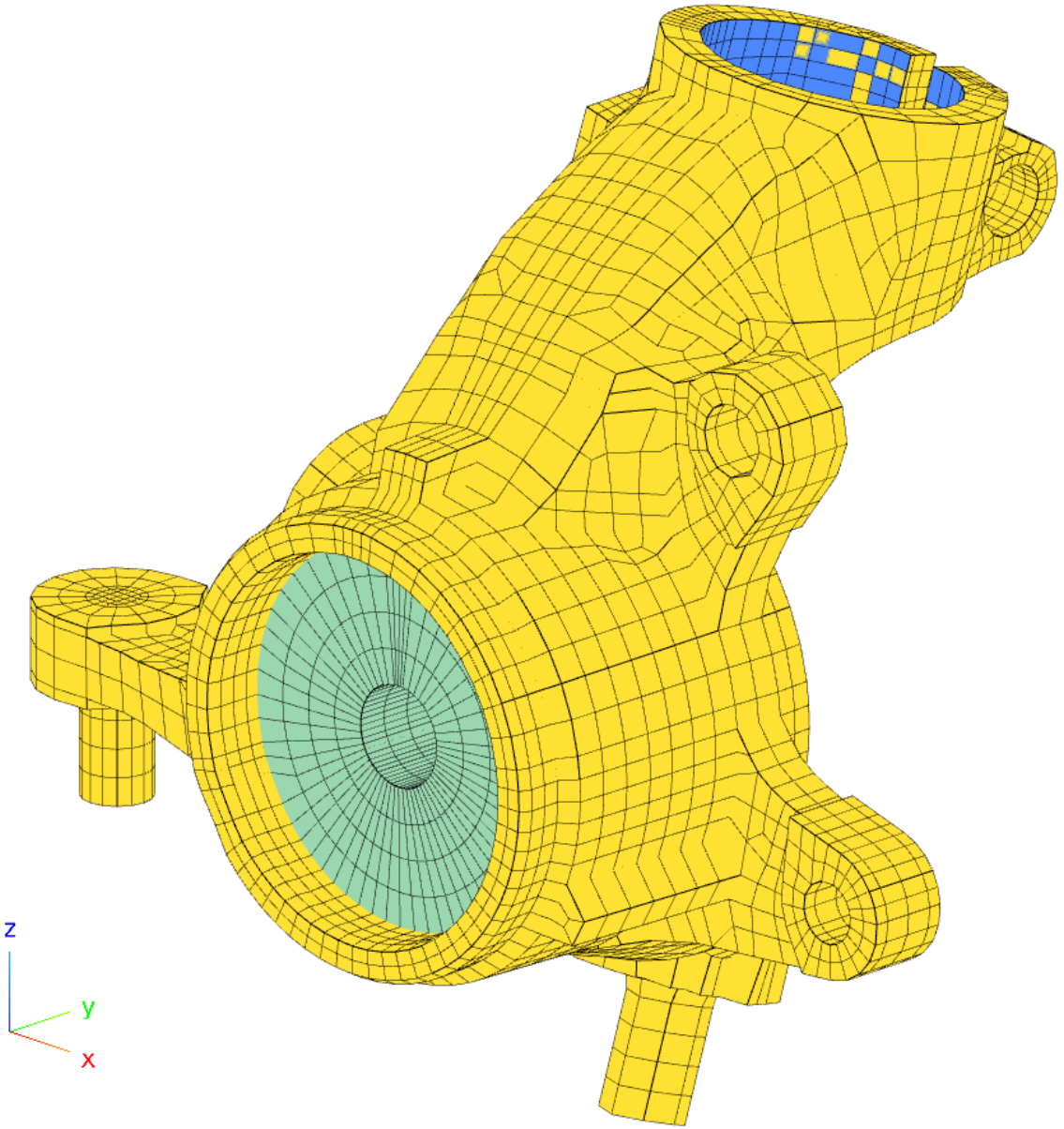
Throughout this exercise, the following buttons will be useful for viewing the model

1. Center Model
2. Fit Model
3. Background Color
4. View Iso 3

The following mouse combinations will orient the model.

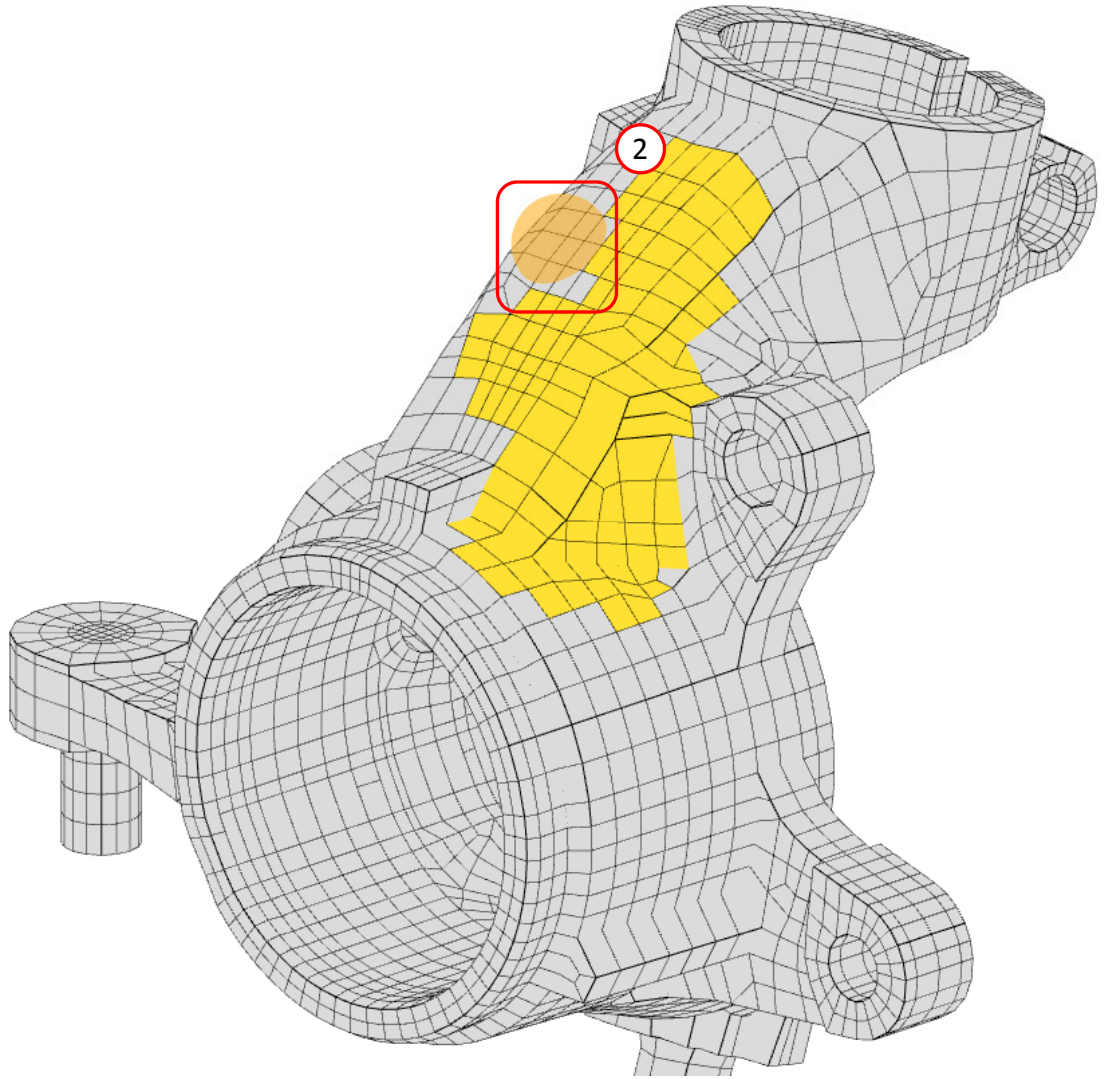
- Rotation: Left Mouse Click + Mouse Drag
  - After rotation, it sometimes helps to click Center Model to restore the center of rotation
- Translation: Right Mouse Click + Mouse Drag
- Zoom: Mouse Scroll Wheel

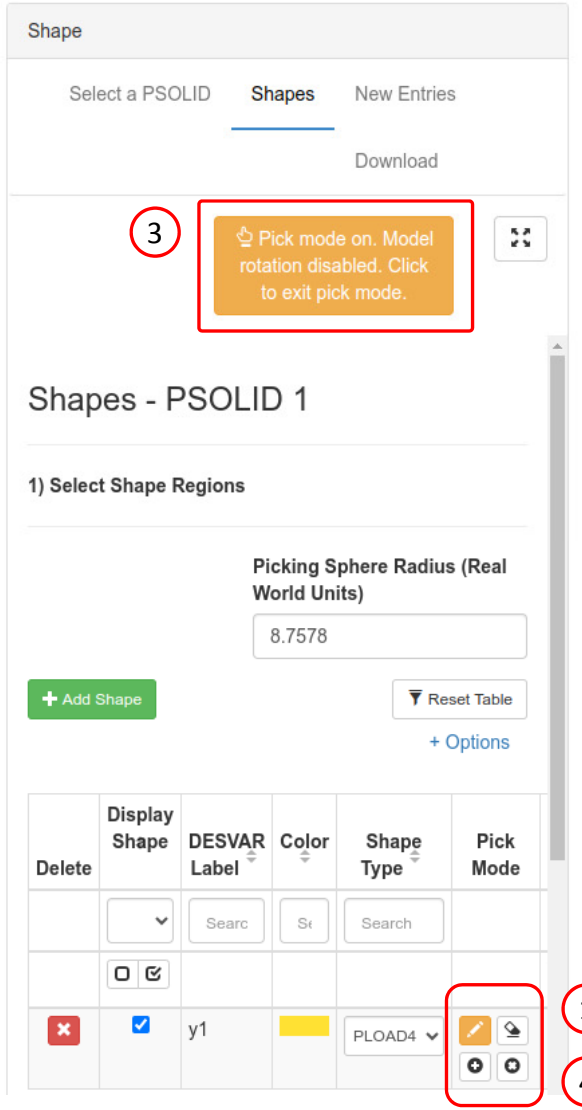




Before Continuing

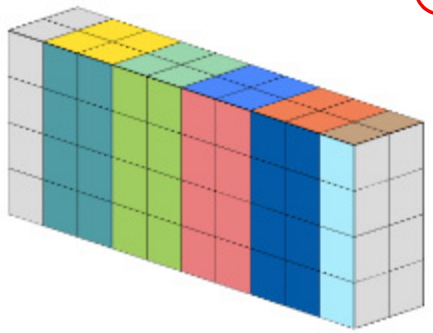
1. The pick modes available include selecting and deselecting element faces and are accessed via the indicated buttons
2. When in a pick mode, a pick sphere appears. Left click and dragging the mouse will select or deselect the element faces.
3. To exit pick mode, click on the indicate button.
4. Alternatively, you can pick on the original pick mode button to exit pick model.





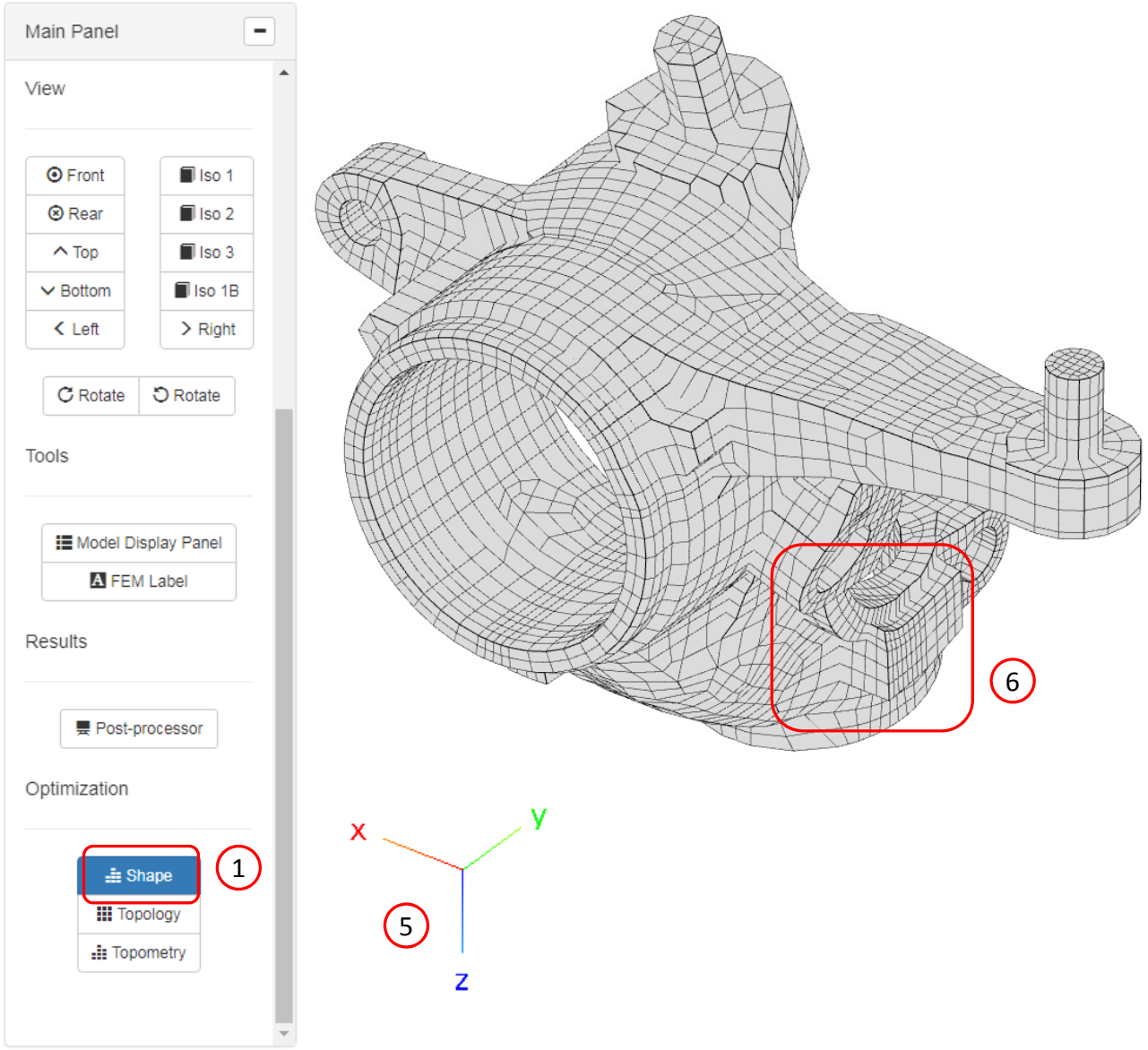
Before Continuing

1. It is assumed that you have thoroughly covered the introductory workshop titled *Shape Optimization of a Cantilever Beam* that is found in the tutorials section of User's Guide. It is assumed you have an understanding of how to create, edit or remove shapes, which is covered in great detail in workshop *Shape Optimization of a Cantilever Beam* .

	Title and Description
	1 **Shape Optimization of a Cantilever Beam** This tutorial is an introduction to MSC Nastran's Shape Optimization capability. A cantilever beam is configured for a shape optimization. The goal is to minimize the mass while satisfying stress constraints. Specified regions of the beam are allowed to expand or contract and define the shapes that will vary during the optimization. This tutorial discusses the following concepts: auxiliary models, shape basis vectors, scaling shape basis vectors, configuring variable bounds, strategies to prevent mesh distortions, results interpretation, updating the model, and more. Starting BDF Files: Link Solution BDF Files: Link

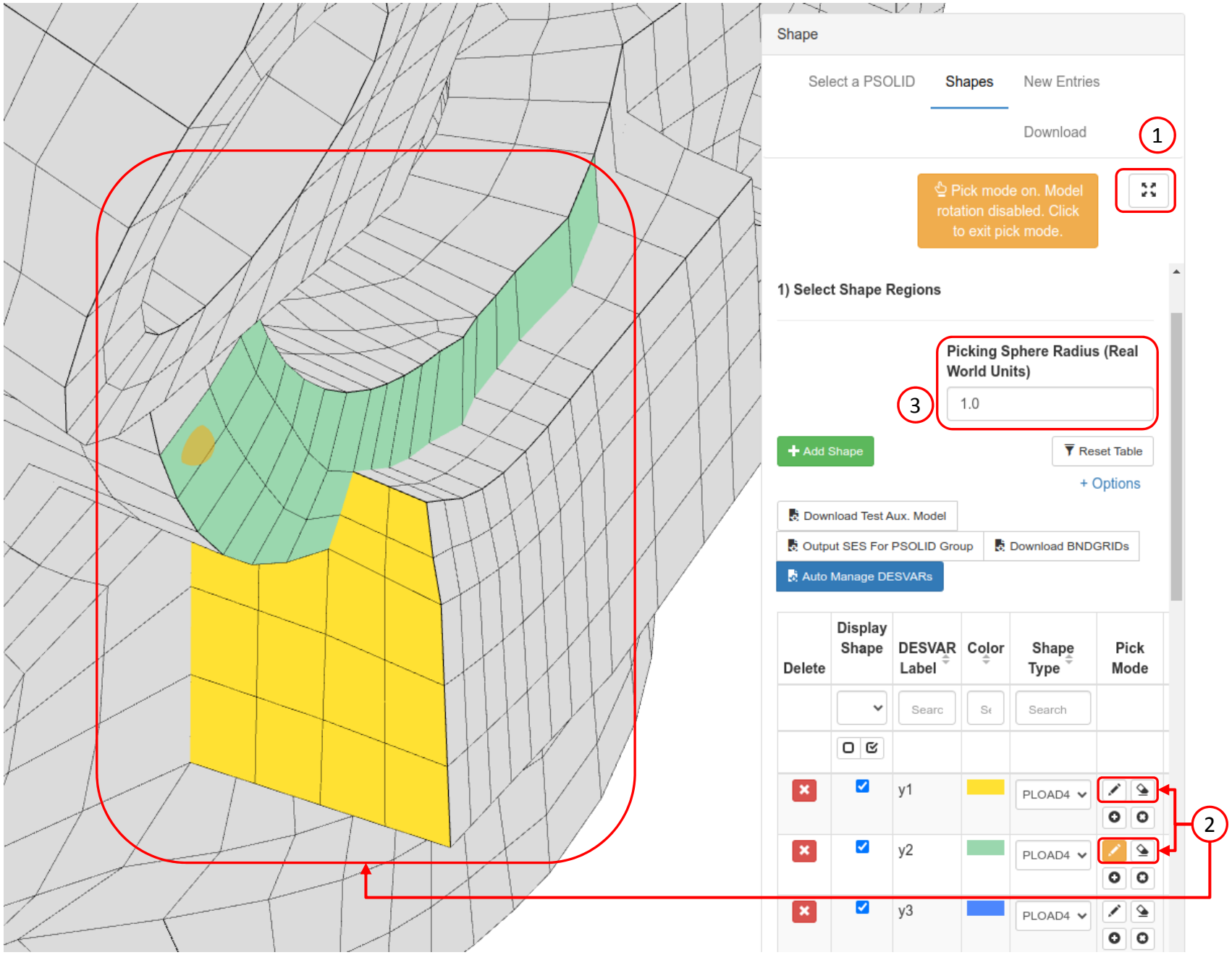
Open the Shape Panel

1. Click Shape
2. Click Shapes
3. Click the Toggle button to adjust the width of the panel
4. Click Add Shape 4 times to create 4 shapes
5. Rotate the model to align to the displayed orientation
6. Zoom in to the indicated region



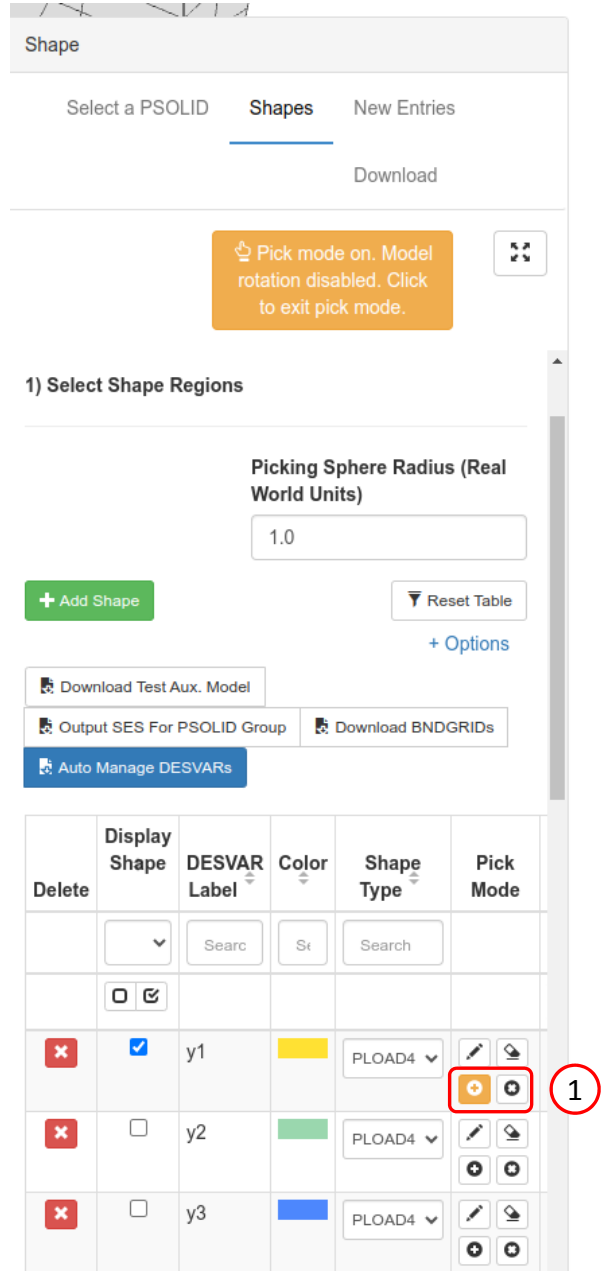
Create Shapes

1. If needed, click the Toggle button to adjust the width of the panel
2. Use the indicated buttons to create the indicated shape regions
3. The size of the pick sphere may be adjusted in the indicated input box. A size of 1.0 is used.



Configure Free Regions

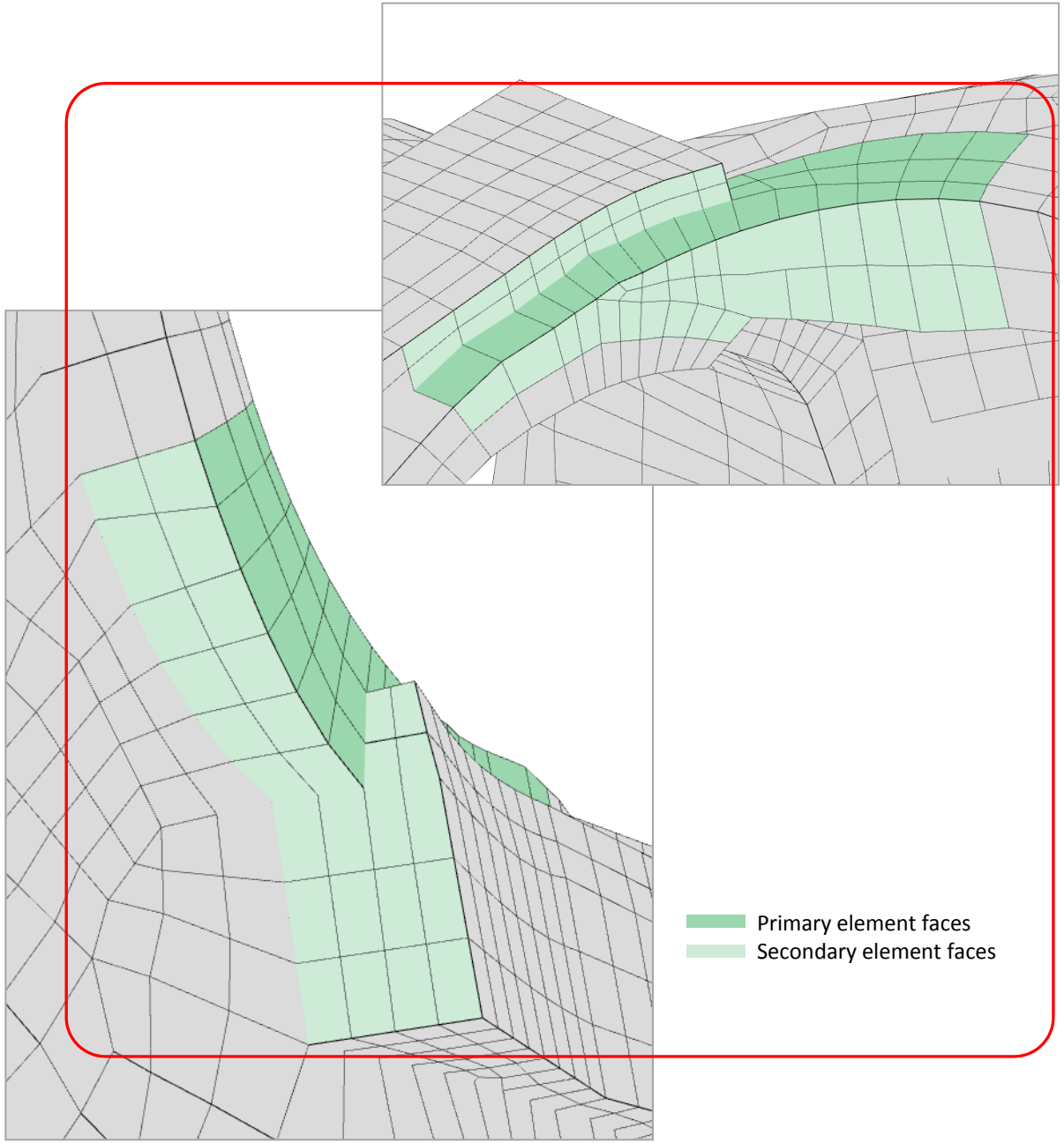
1. Use the indicated buttons to select the secondary faces

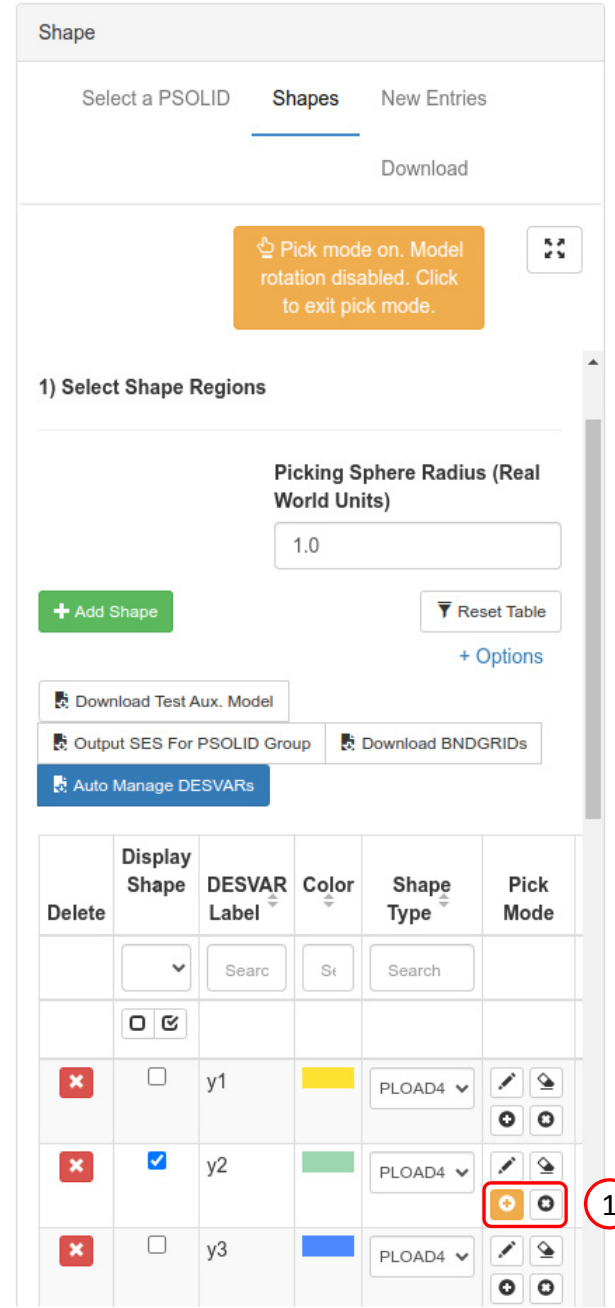


HEXAGON Technology Partner

Configure Free Regions

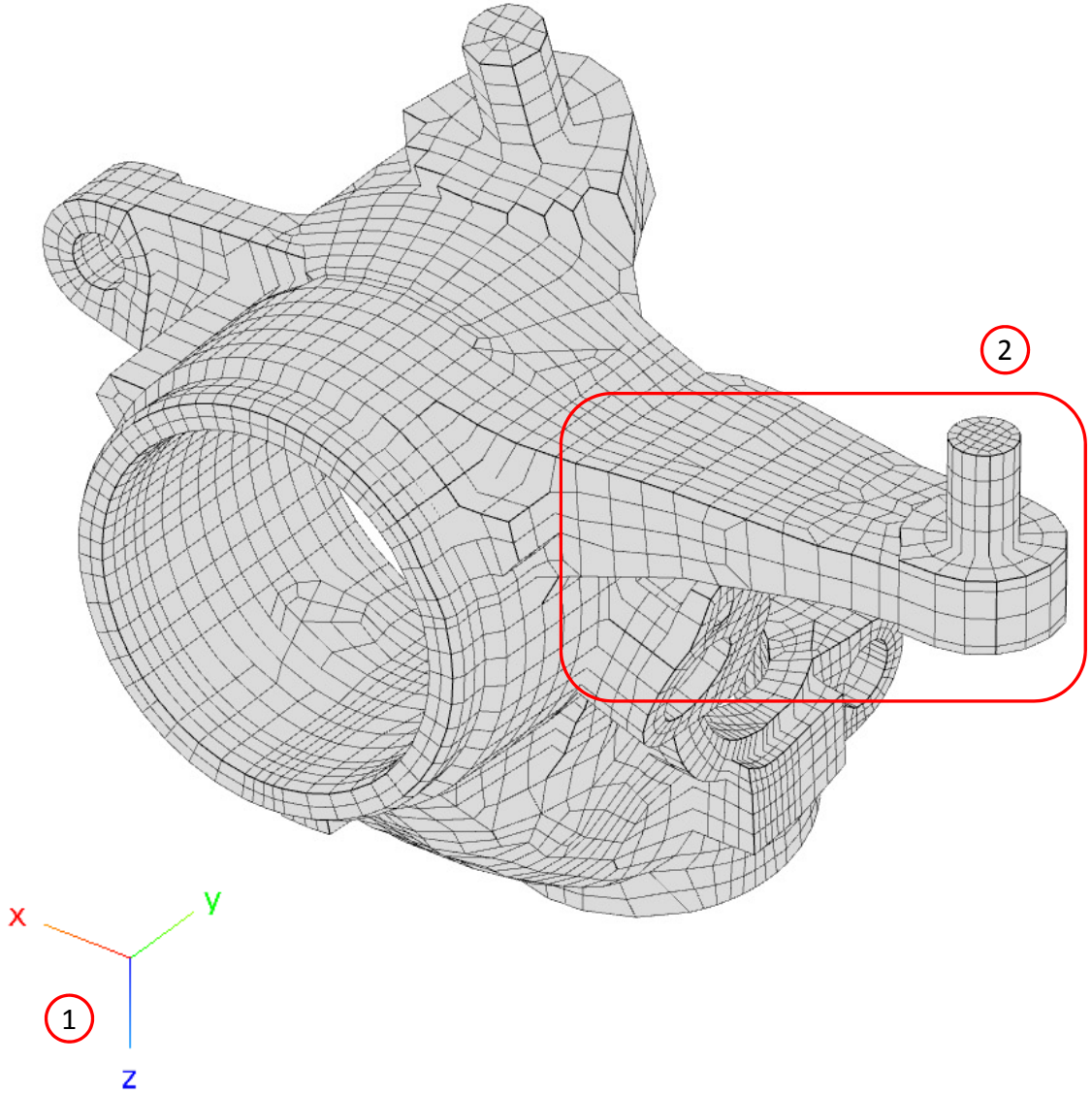
1. Use the indicated buttons to select the secondary faces





Create Shapes

1. Orient the shape as shown
2. Zoom in to the indicated region



Shape

Select a PSOLID | Shapes | New Entries

Download

Shapes - PSOLID 1

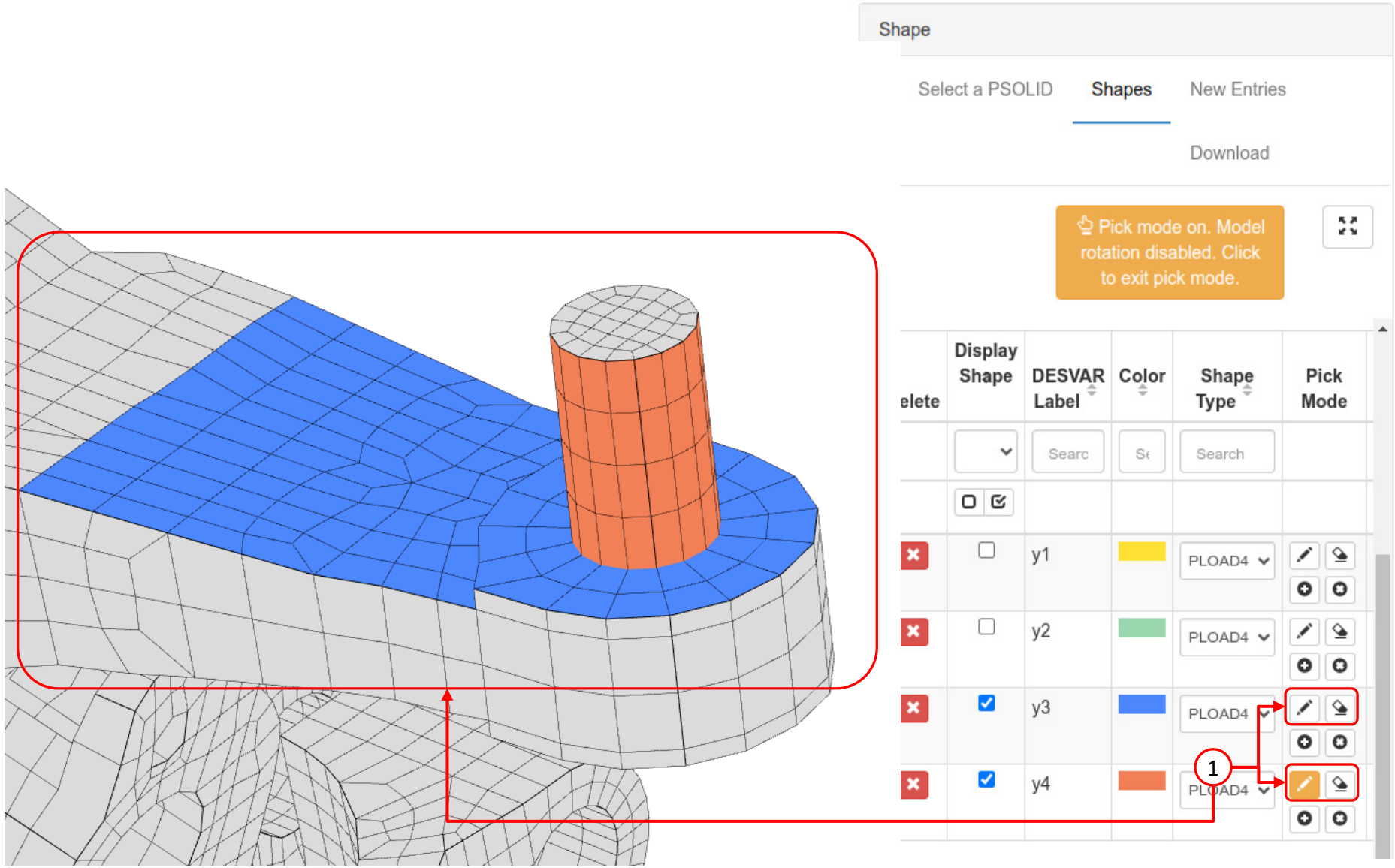
1) Select Shape Regions

+ Add Shape | Reset Table | + Options

Delete	Display Shape	DESVAR Label	Color	Shape Type	Pick Mode
		Searc	Se	Search	
	y1			PLOAD4	
	y2			PLOAD4	
	y3			PLOAD4	
	y4			PLOAD4	

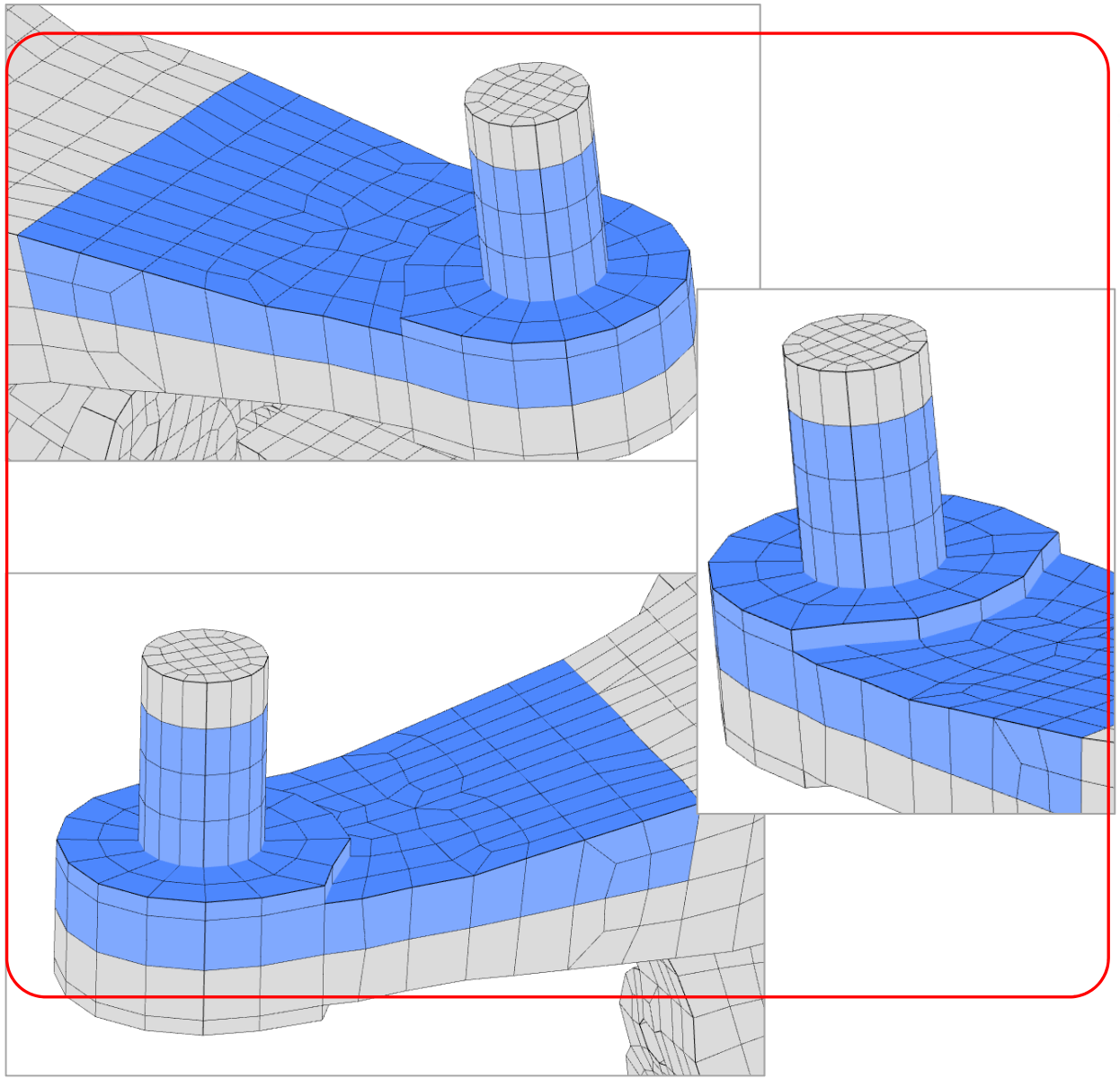
Select Secondary Faces

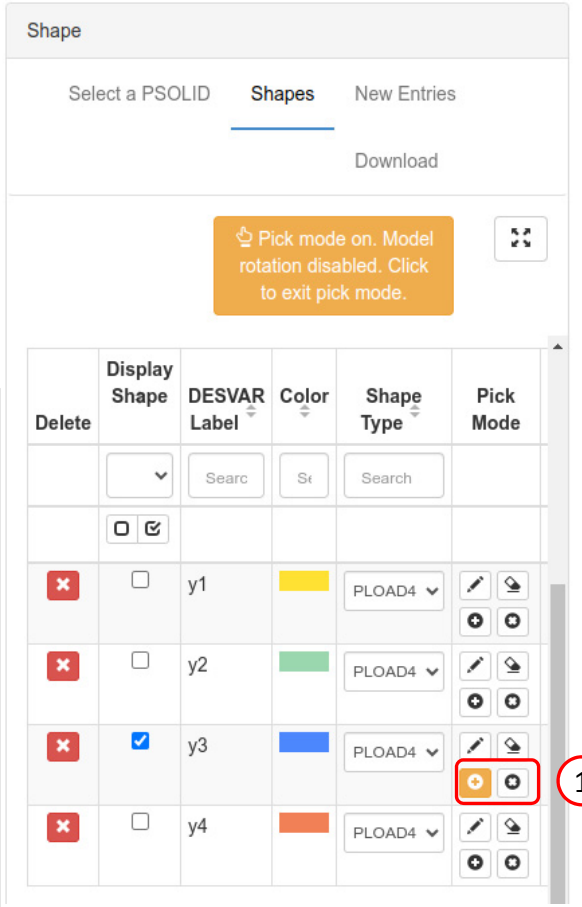
1. Use the indicated buttons to create the indicated shape regions



Configure Free Regions

1. Use the indicated buttons to select the secondary faces

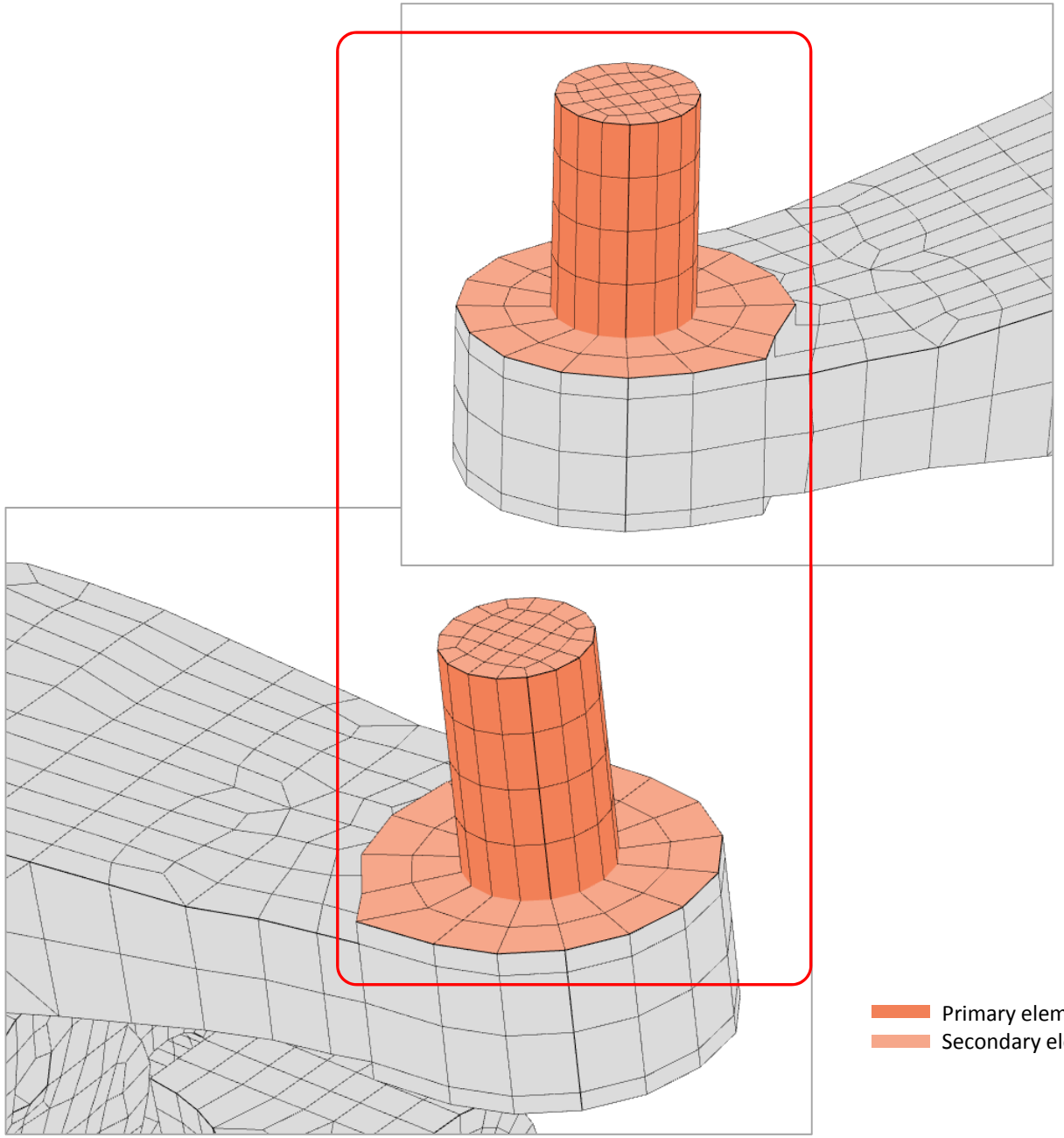


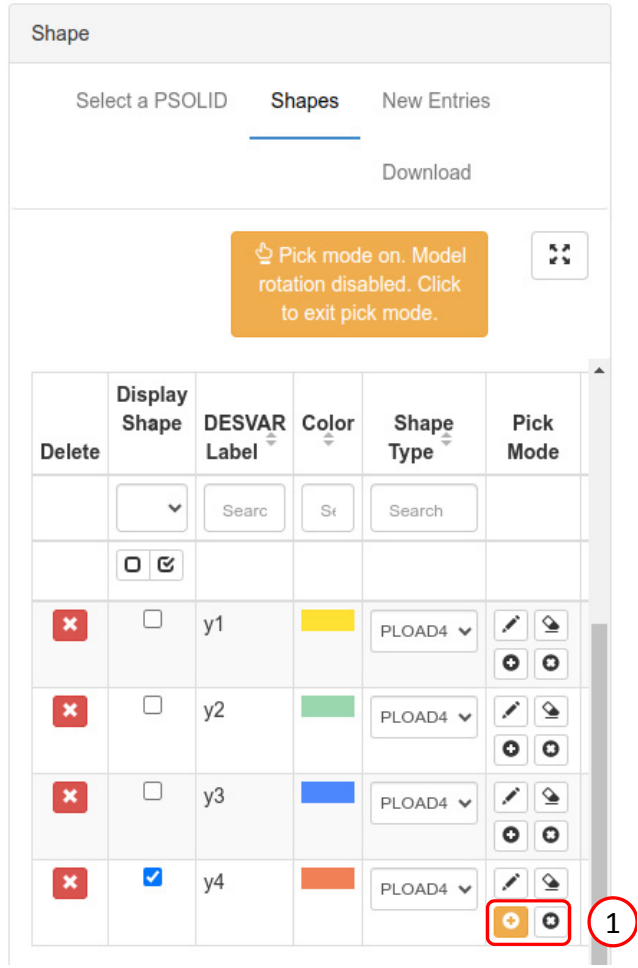


Primary element faces
Secondary element faces

Configure Free Regions

1. Use the indicated buttons to select the secondary faces

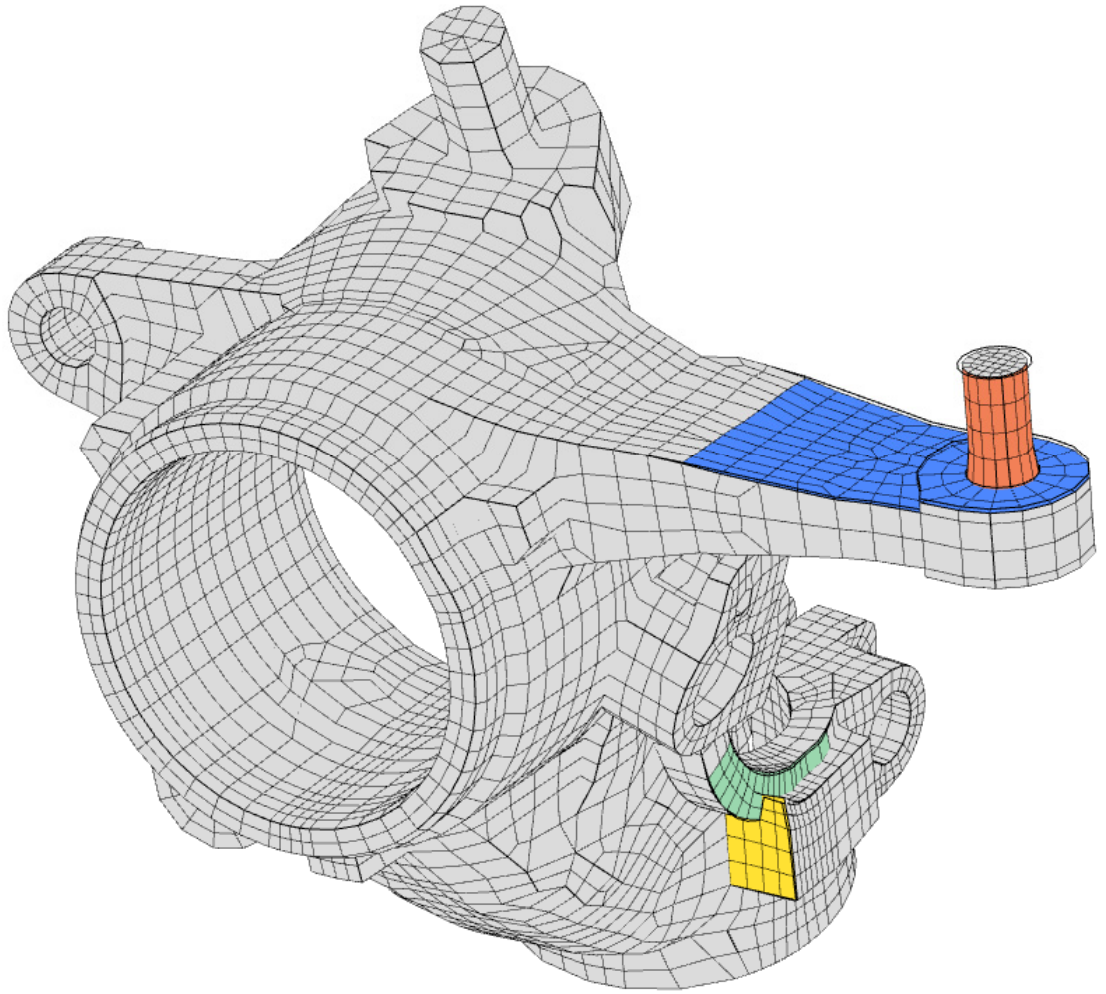


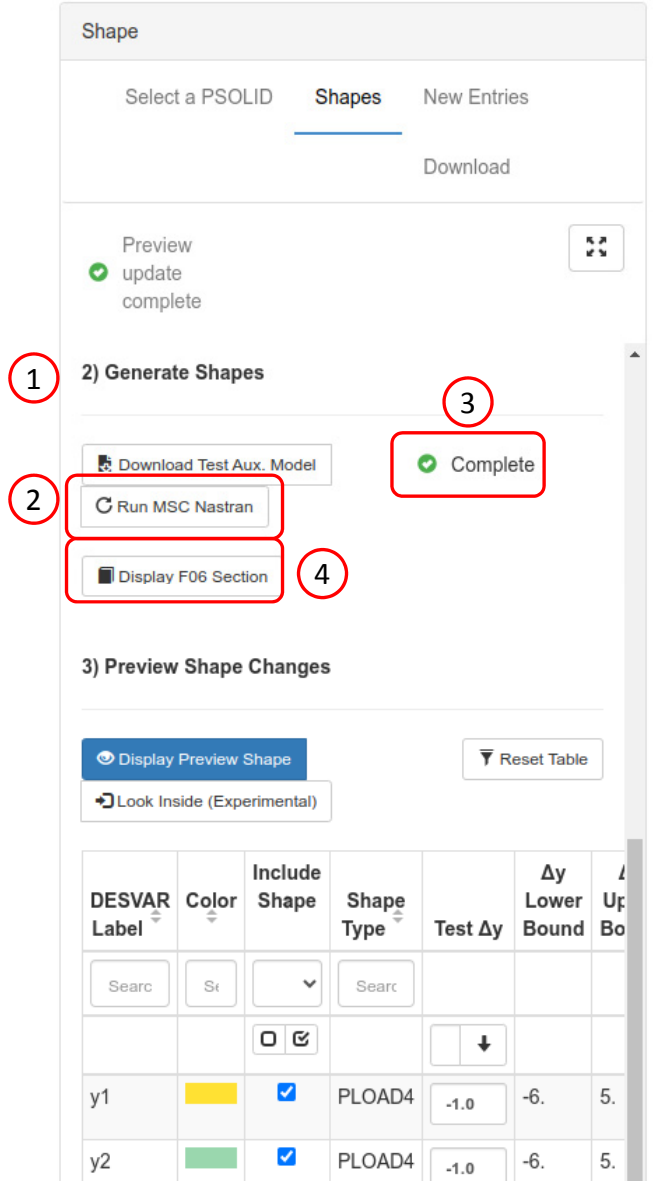


Primary element faces
Secondary element faces

Run MSC Nastran to Generate Shapes

1. Scroll to section 2) Generate Shapes
2. Click Run MSC Nastran
3. Continue after the status reads Complete. The duration of this MSC Nastran run will depend on the size of the model.
4. Optional – Click Display F06 Section to inspect the F06 output.





DVBSHAP

1. After MSC Nastran is complete, the web app will update the scaling factor for each shape defined by DVBSHAP entries. The scaling factor is set in field SF1 (field 5) of the DVBSHAP entry.

- If the scaling factors are 1.0, which will happen if MSC Nastran was not executed, it is suggested that you manually supply ideal scaling factors.

File: design_shapes_psolid_1.bdf

```
$    1   ||    2   ||    3   ||    4   ||    5   ||    6   ||    7   ||    8   ||    9   ||   10   |
DVBSHAP 200001  1       1       2.466e-2
DVBSHAP 200002  1       2       5.601e-2
DVBSHAP 200003  1       3       5.564e-2
DVBSHAP 200004  1       4       .1363515
DESVAR  200001  y1      10.     4.      15.
DESVAR  200002  y2      10.     4.      15.
DESVAR  200003  y3      10.     4.      13.
DESVAR  200004  y4      10.     7.      12.
BNDGRID 123     1       2       3       4       5       6       7
        8       9       10      14      15      17      18      19
        21      22      23      24      25      27      28      29
        30      31      32      33      34      35      36      37
        39      40      41      42      43      44      45      46
        47      48      50      51      52      53      54      55
        56      57      58      59      65      66      67      68
        69      70      71      77      78      84      85      86
        87      88      89      90      91      92      93      97
        98      99      109     112     113     114     119     126
        128     129     135     139     143     144     150     151
```

1

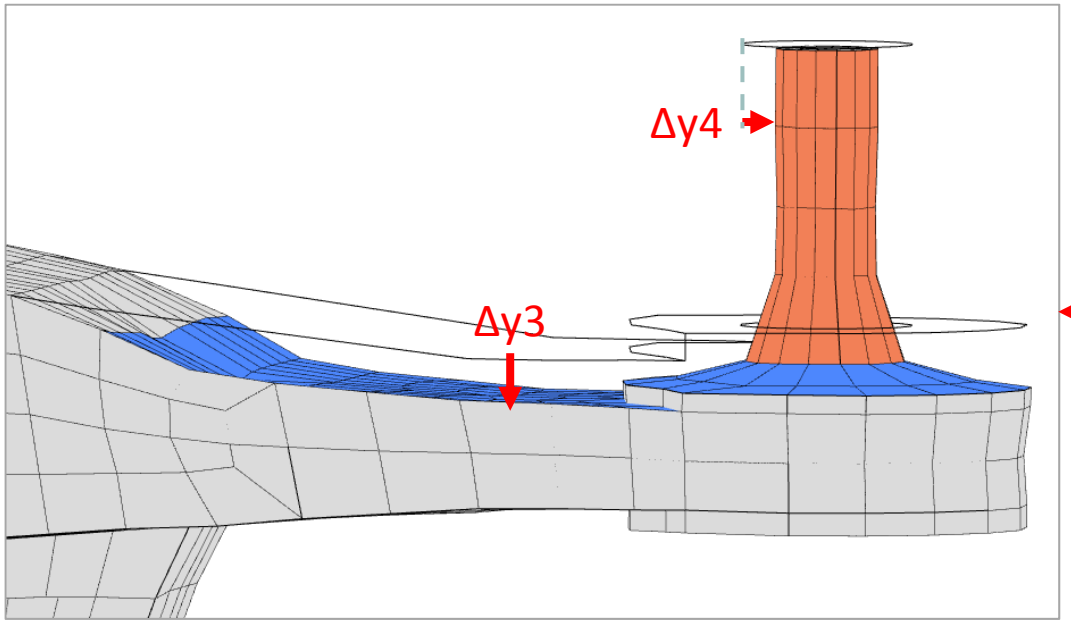
Shape Change Preview

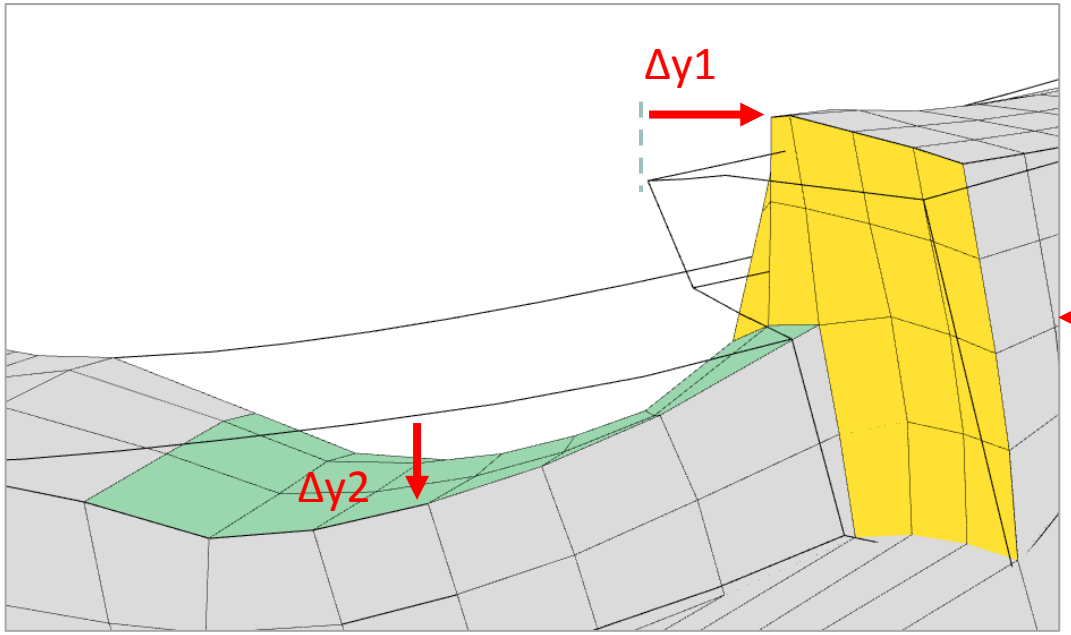
Previewing the shape change is an important step in configuring a shape optimization. A preview of the shape change is inspected in this section.

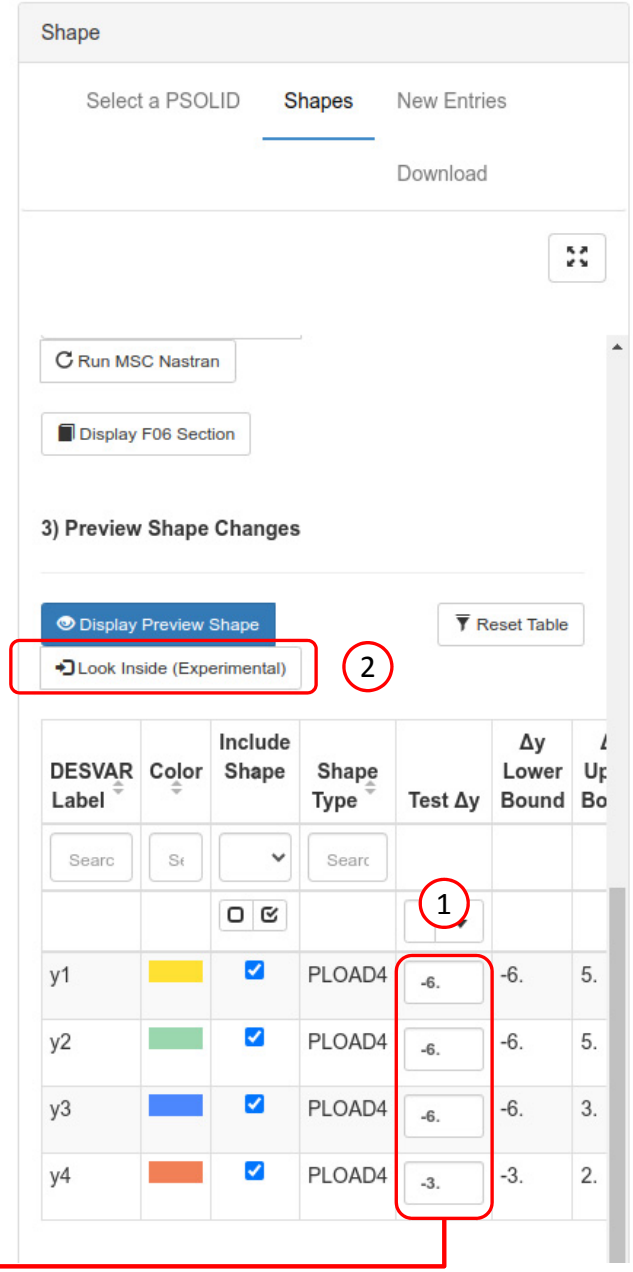
1. Use trial and error to determine which combinations of Δy yield mesh distortions. Below is an example of Δy value combinations that have a high probability of NOT yielding mesh distortions. Δy has real units of length.

2. The indicated button is sometimes useful for inspecting the interior for possible mesh distortions.

Δyi	Lower Bound	Upper Bound
Δy1	-6	5
Δy2	-6	5
Δy3	-6	3
Δy4	-3	2



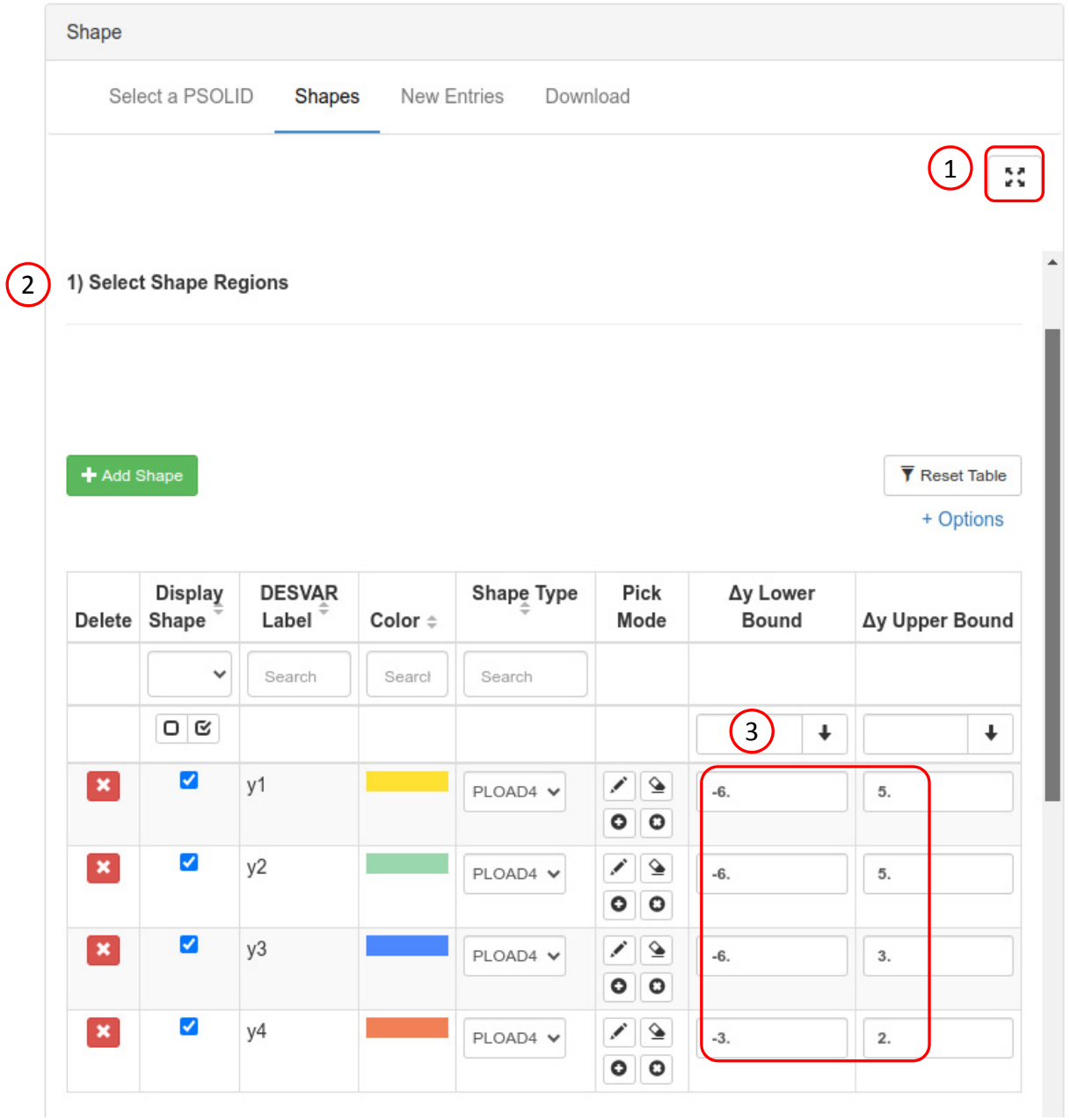




Adjustment of Variable Bounds

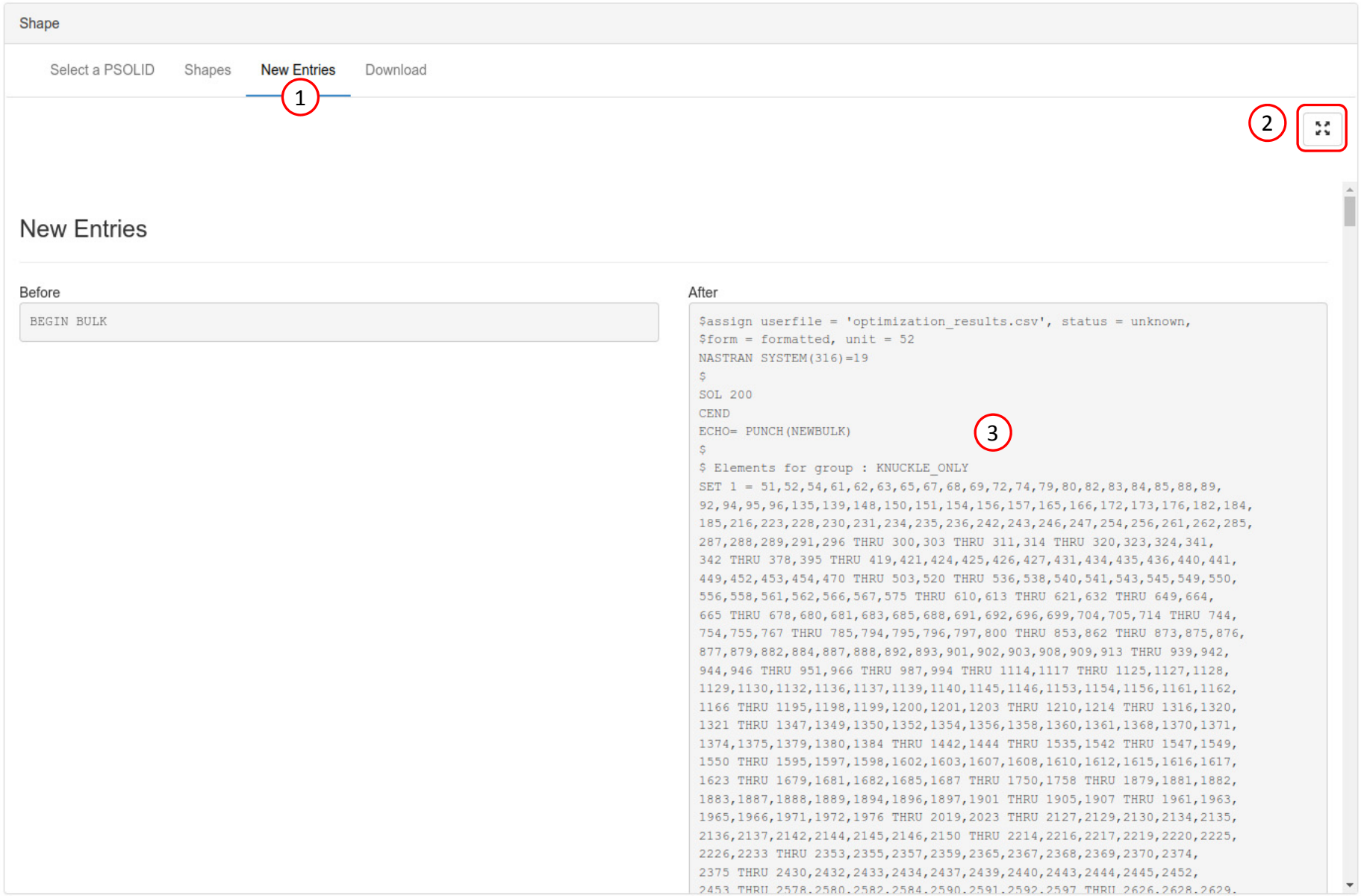
1. Click the toggle button 2 times to restore the width of the panel
2. Return to section 1) Select Shape Regions
3. Use the Δy values determined on the previous page to update the lower and upper bounds in the indicated table.

Δyi	Lower Bound	Upper Bound
Δy1	-6	5
Δy2	-6	5
Δy3	-6	3
Δy4	-3	2



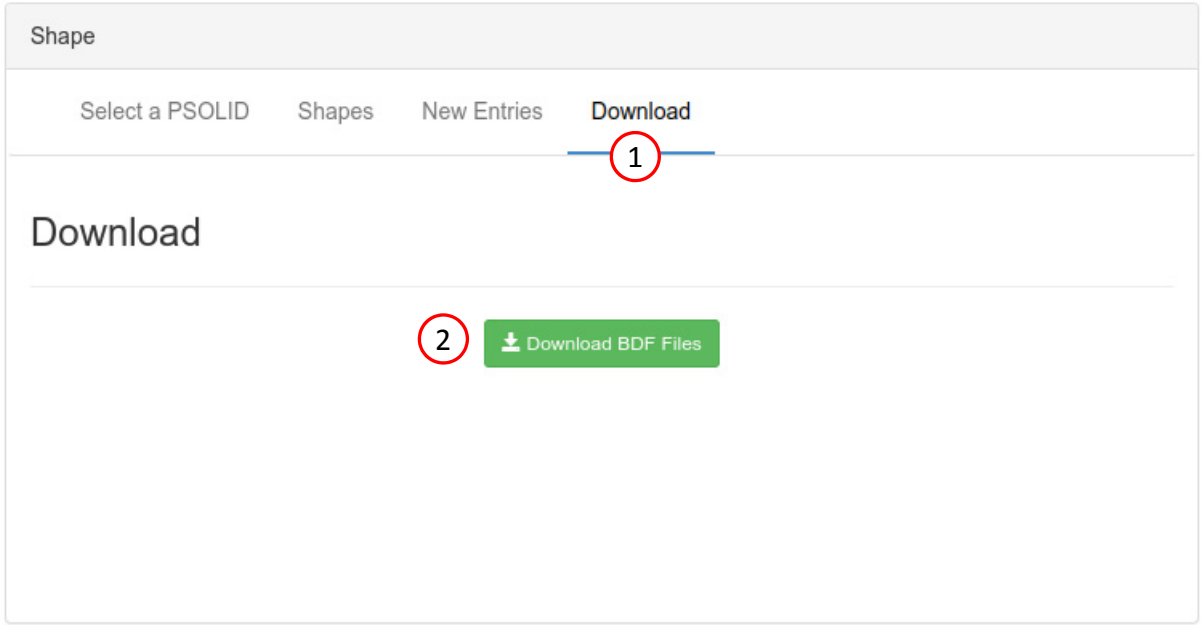
Inspect New Entries

1. Click New Entries
2. Click the toggle button 2 times to expand the width of the panel.
3. The changes that will be performed to the bulk data files are listed.



Export New BDF Files

1. Click Download
2. Click on Download BDF Files

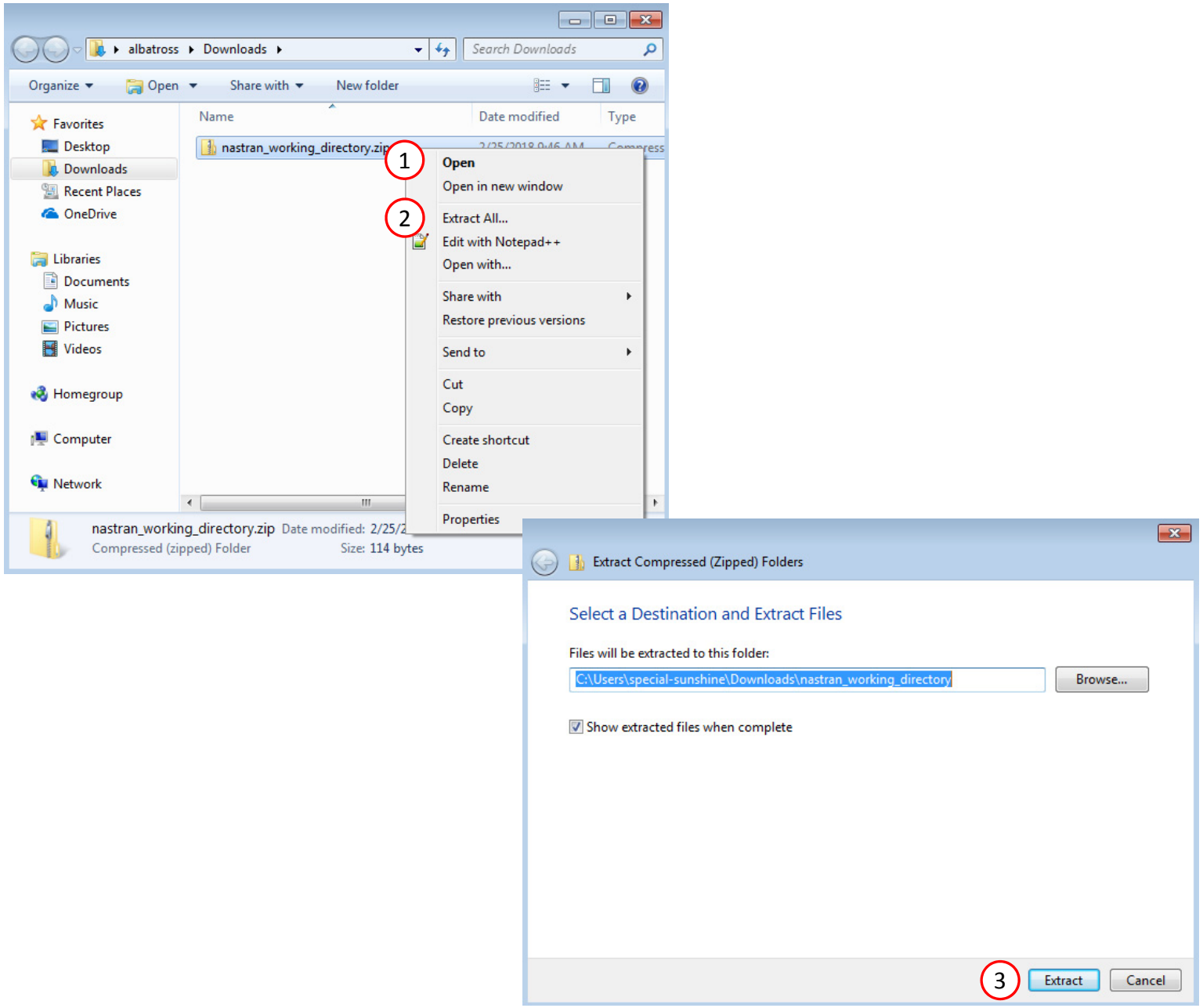


- When the download button is clicked a new file named “nastran_working_directory” is downloaded. If the file already exists in your local folder, the folder name is appended with a number, e.g. “nastran_working_directory (1).zip”

Perform the Optimization with Nastran SOL 200

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

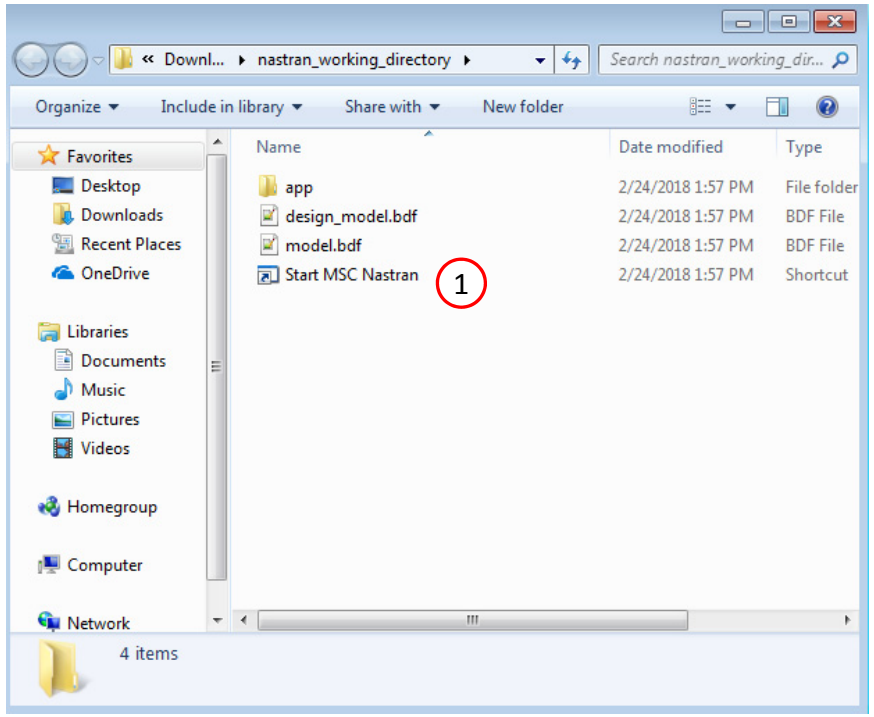
- After a successful optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- One can run the Nastran job on a remote machine as follows:
  1) Copy the BDF files and the INCLUDE files to a remote machine. 2) Run the MSC Nastran job on the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

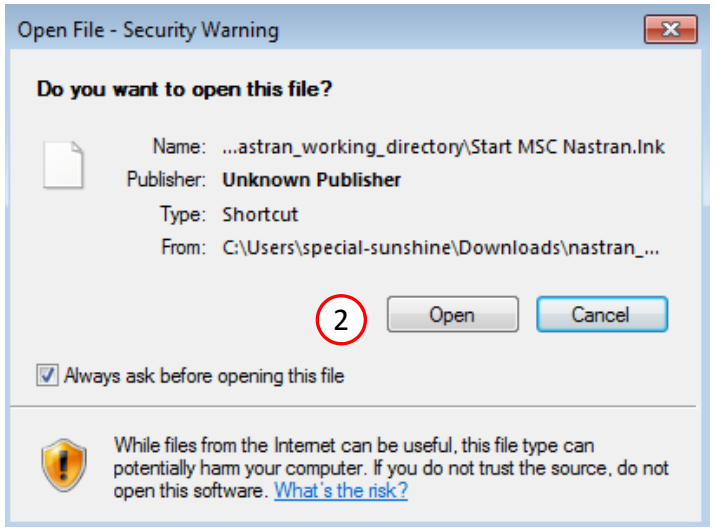
Using Linux?

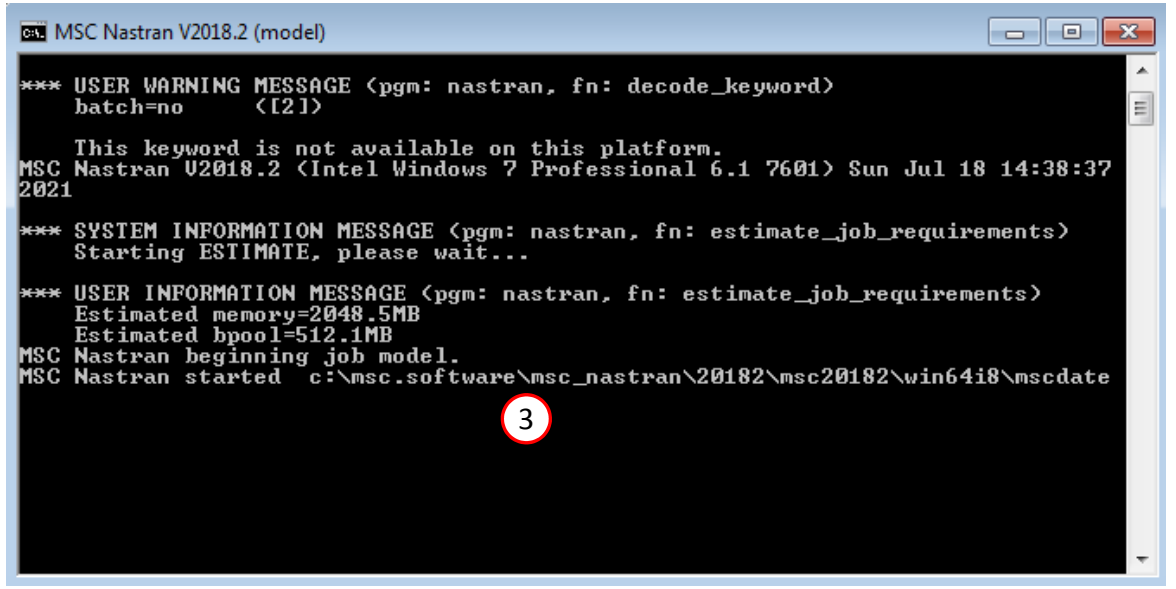
Follow these instructions:
1) Open Terminal
2) Navigate to the nastran_working_directory
cd ./nastran_working_directory
3) Use this command to start the process
./Start_MSC_Nastran.sh

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. The final value of objective, normalized constraints 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.
- The Normalized Constraints plot indicates the final design cycle has yielded a design that has a max normalized constraint very close to zero. Max normalized constraints that are negative or close to zero indicate a feasible design has been obtained. Feasible designs are designs that satisfy all design constraints.

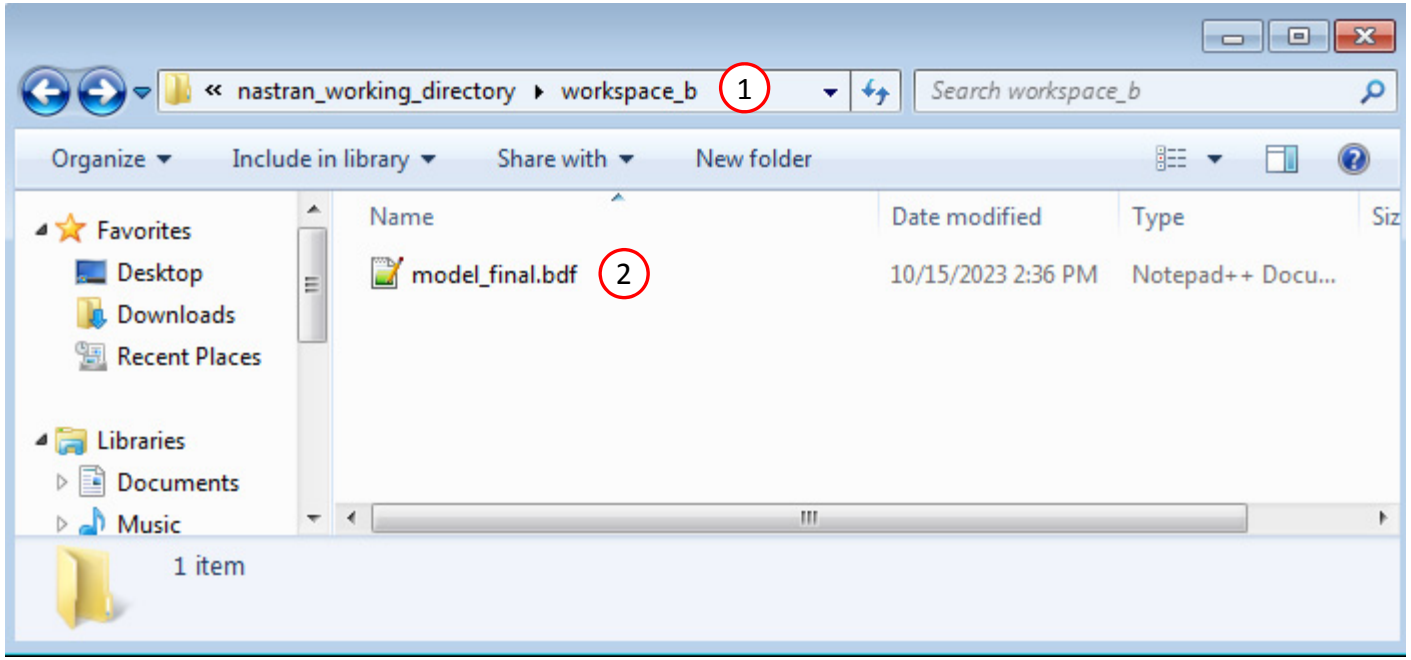
Review Optimization Results

The shape variables are constantly decreasing, indicating the shapes are being contracted during the optimization.

New Updated BDF File

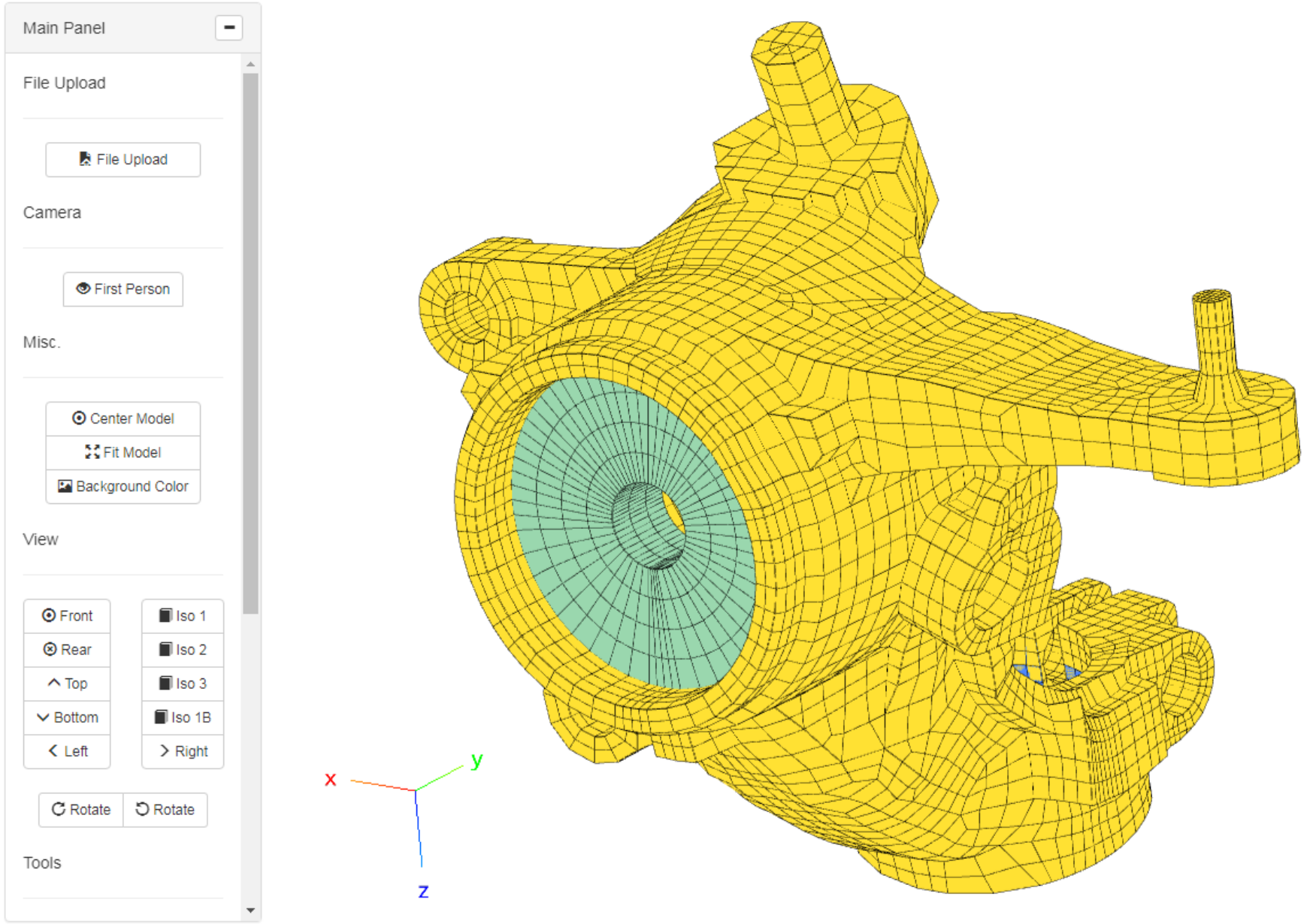
1. After the optimization, a new directory named workspace_b is created

2. This directory contains a new BDF file where the node positions have been updated to reflect the optimized shape. Specifically, the optimized GRID entries found in the file model.pch were used to replace the old GRID entries.



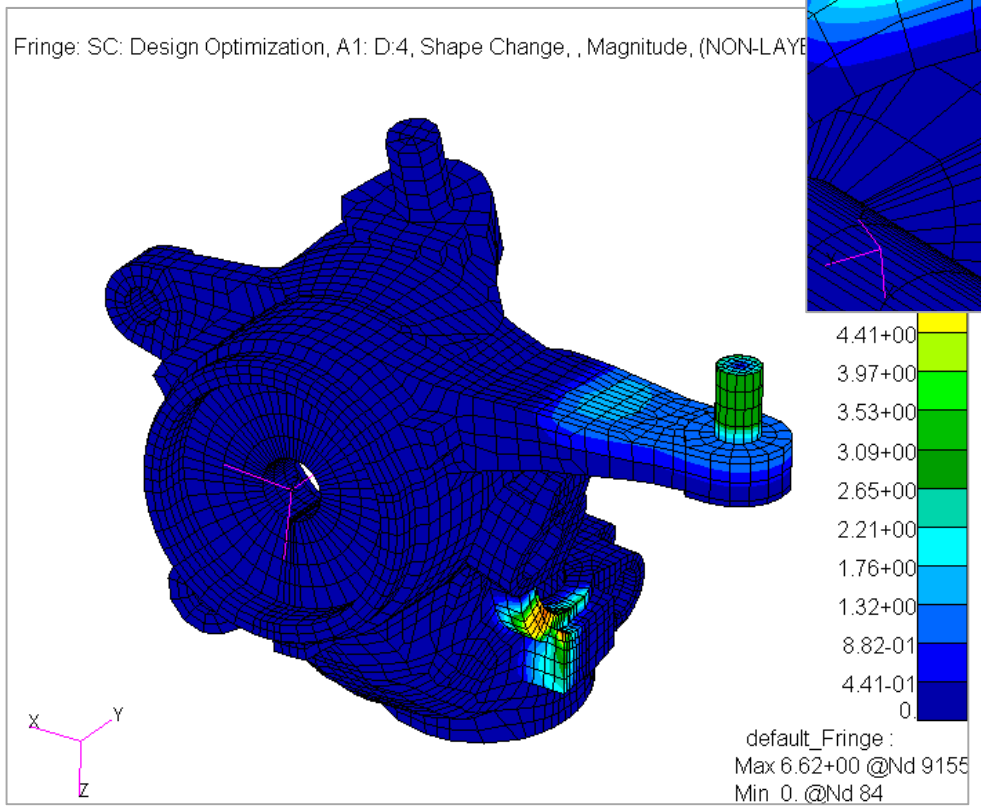
Optimized Shape

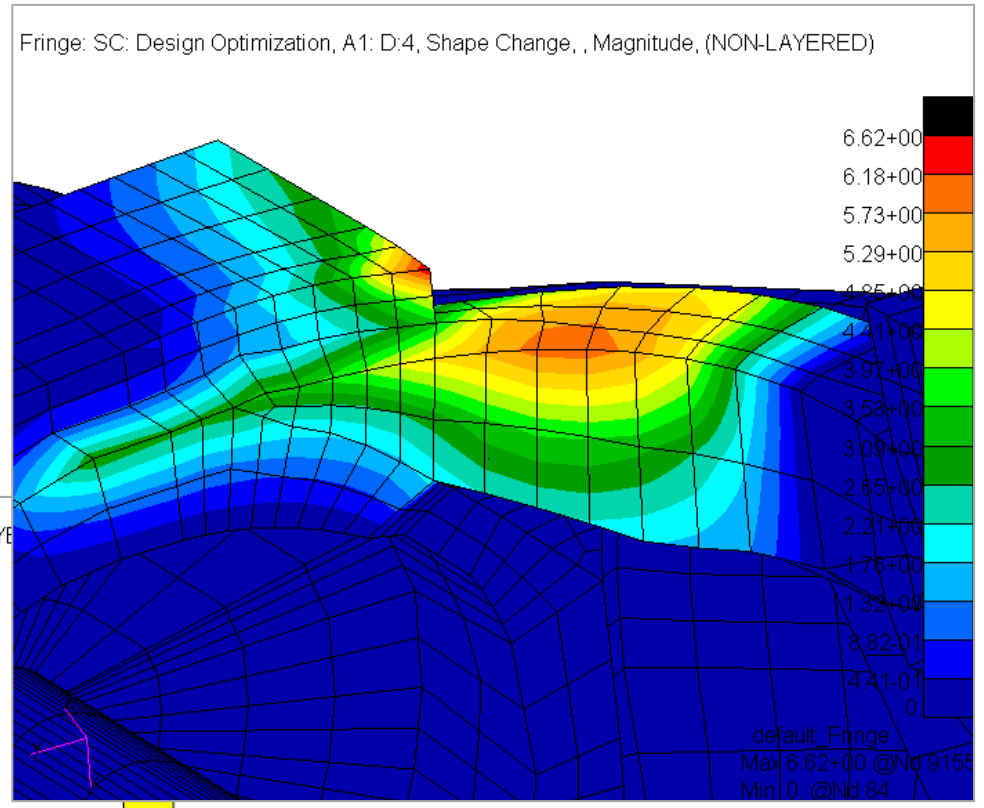
1. The Viewer is used to import the new file model_final.bdf. The shape is confirmed to have changed.



Plot of Shape Change

1. A fringe plot showing the shape change is useful in determining which regions have expanded or contracted the most.



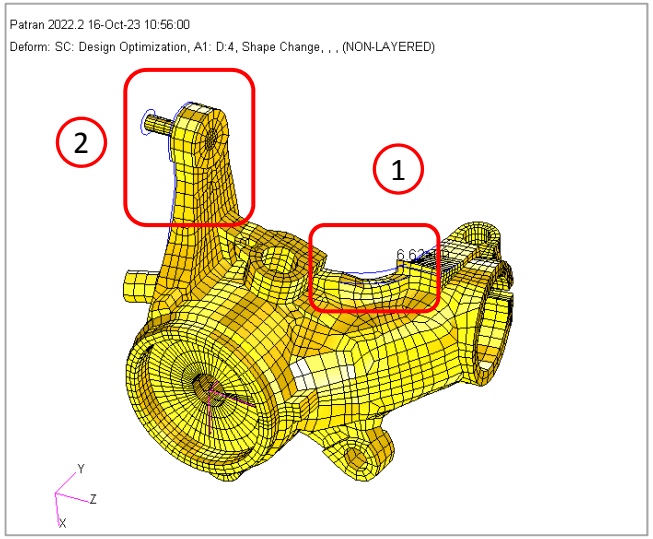


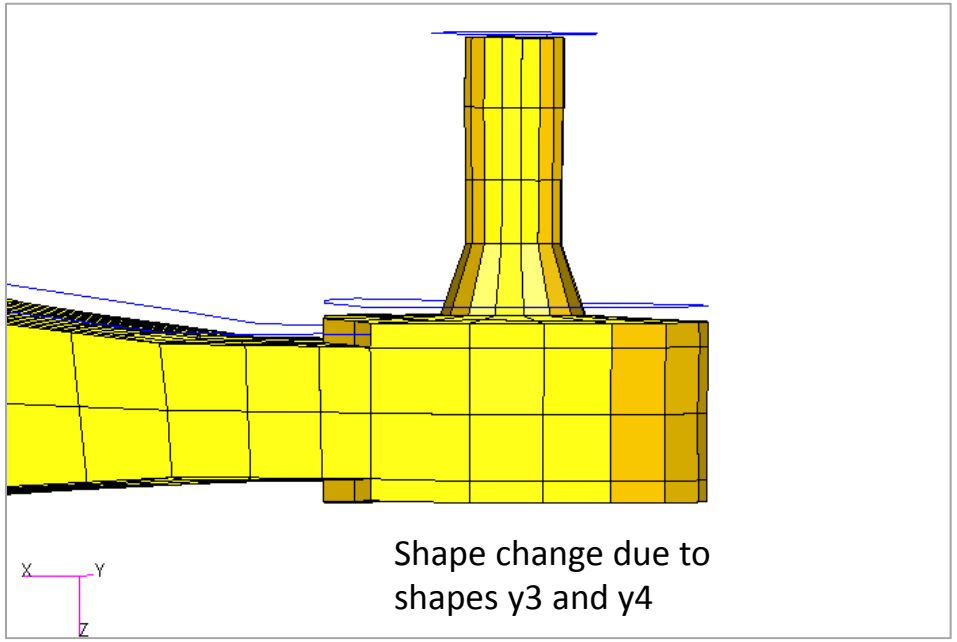
Plot of Shape Change

A comparison between the initial and final design is made.

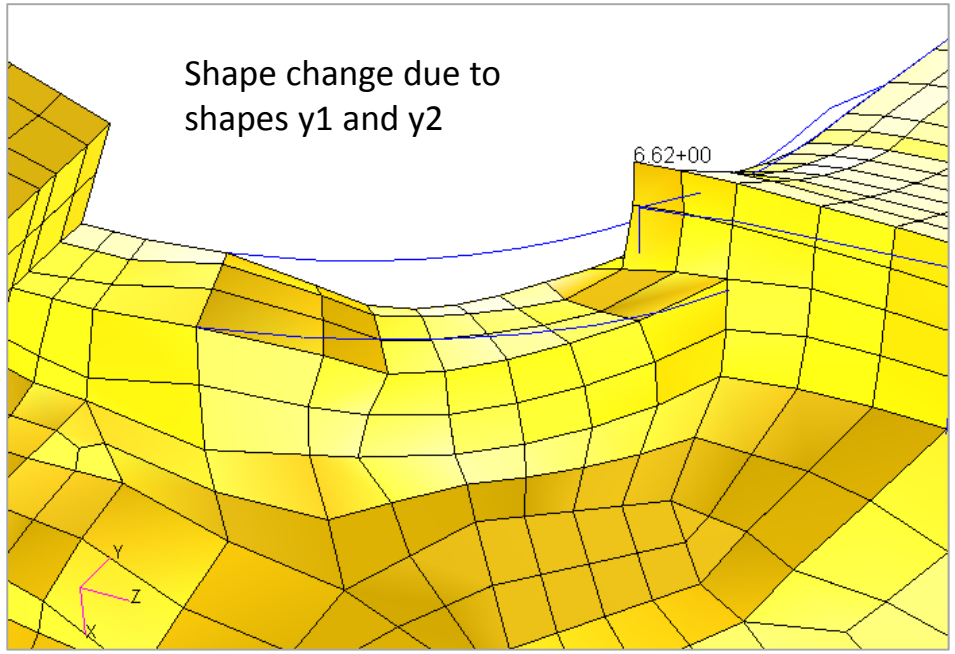
1. Shape change due to shapes y1 and y2
2. Shape change due to shapes y3 and y4

The shape changes are characterized by pure contraction.





Shape change due to shapes y3 and y4



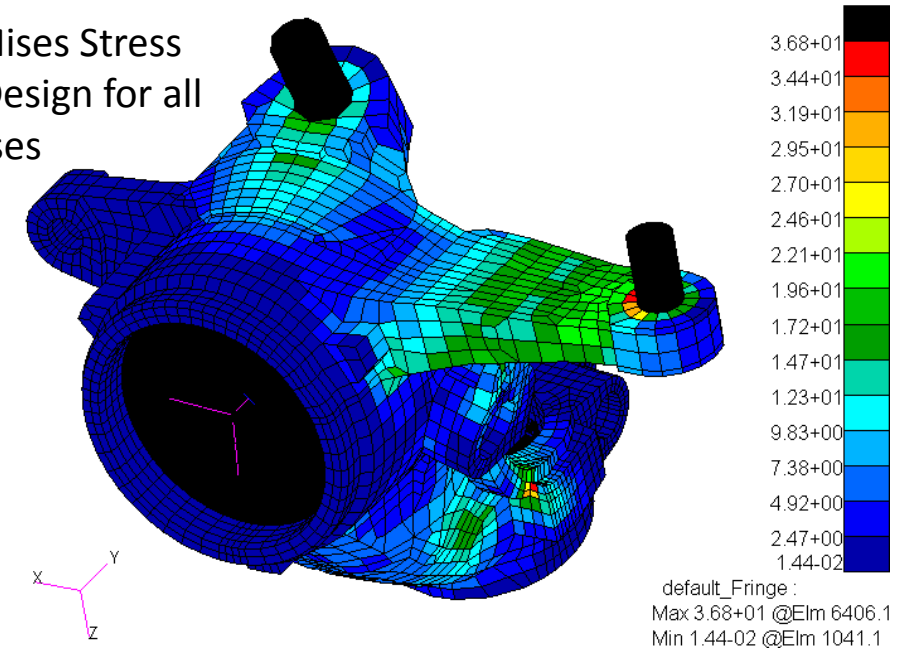
Results

Before Optimization

- Weight: 8.081499E+07
- Max Stress: 36.8

Fringe: Max (Initial), All Subcases, Stress Tensor, , von Mises, (NON-LAYERED)

Max von Mises Stress for Initial Design for all 12 load cases

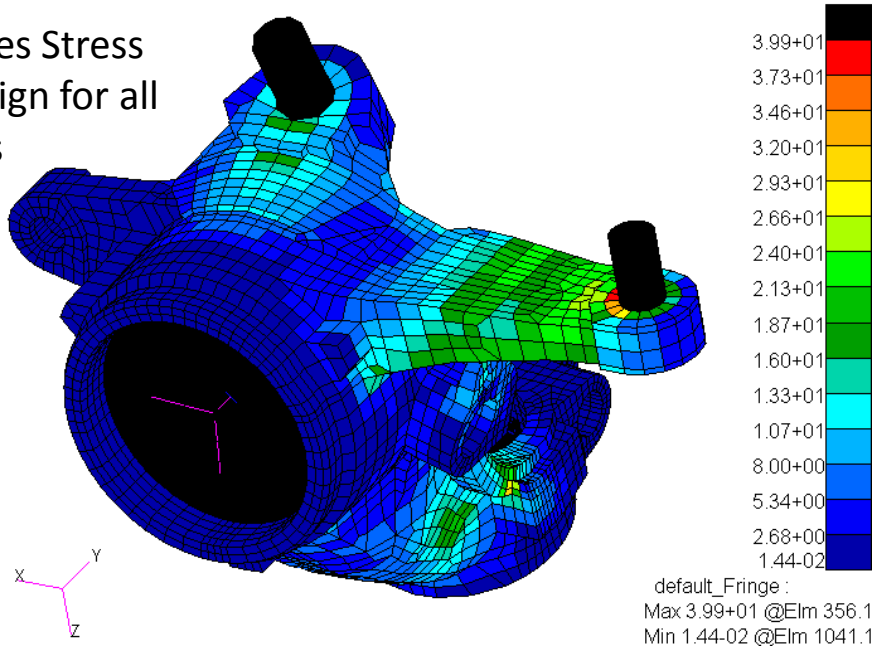


After Optimization

- Weight: 8.019459E+07
- Max Stress: 39.9

Fringe: Max (Final), All Subcases, Stress Tensor, , von Mises, (NON-LAYERED)

Max von Mises Stress for Final Design for all 12 load cases



End of Tutorial

Appendix

Appendix Contents

- Frequently Asked Questions
  - How to view the shape optimization results in Patran?

How to view the shape optimization results in Patran?

Shapes Optimization Results in Patran

Many of the images in this workshop that display the shape optimization results were generated by Patran. The following are steps on how to view the shape optimization results in Patran.

1. Generate an H5 file during the shape optimization. The following entries output an H5 file.

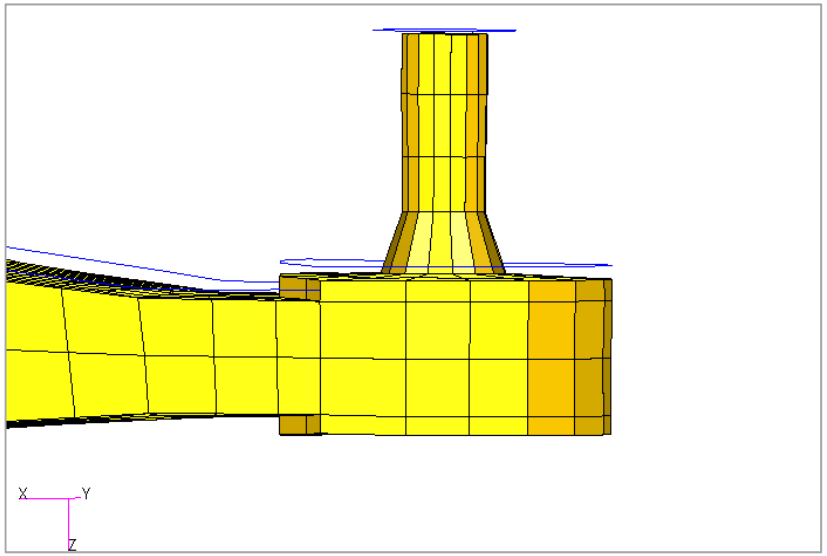
```
HDF5OUT $ MSC Nastran 2022.1 and newer

MDLPRM,HDF5,1 $ MSC Nastran 2016 or newer
```

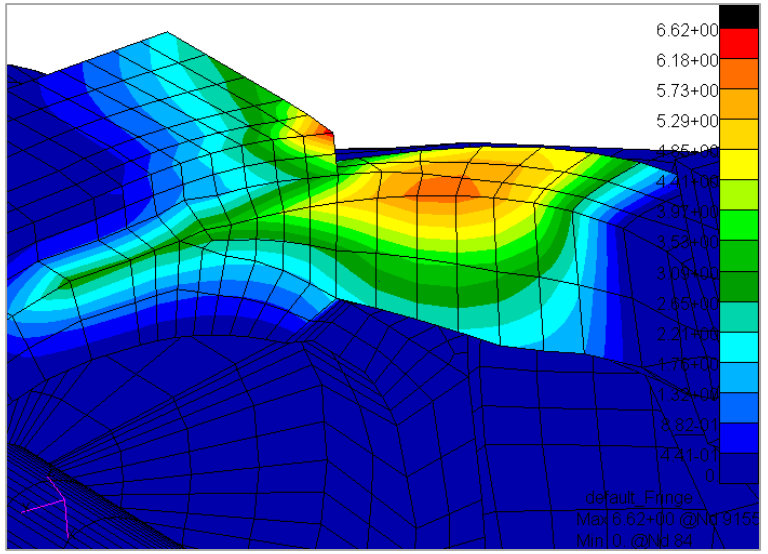
2. Import the H5 file to Patran

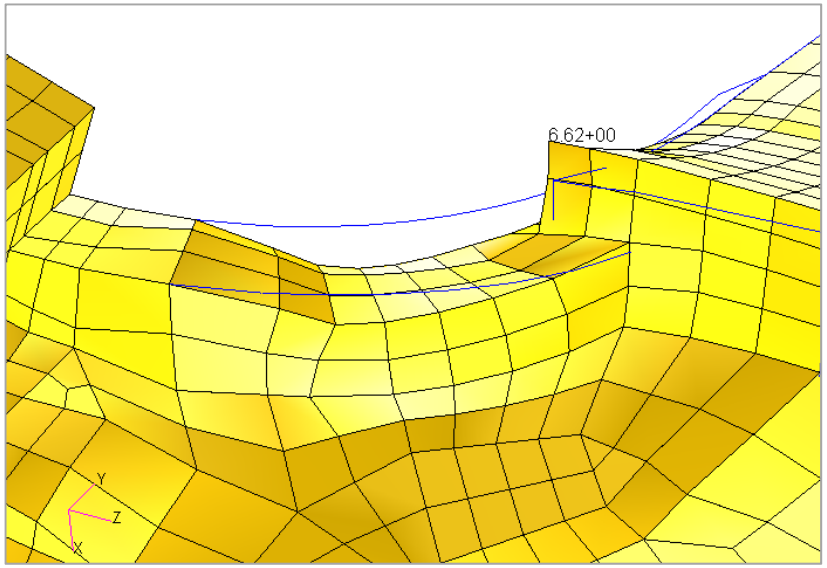
Note that option 2 does not output the shape change data to the H5 file. Use option 1.

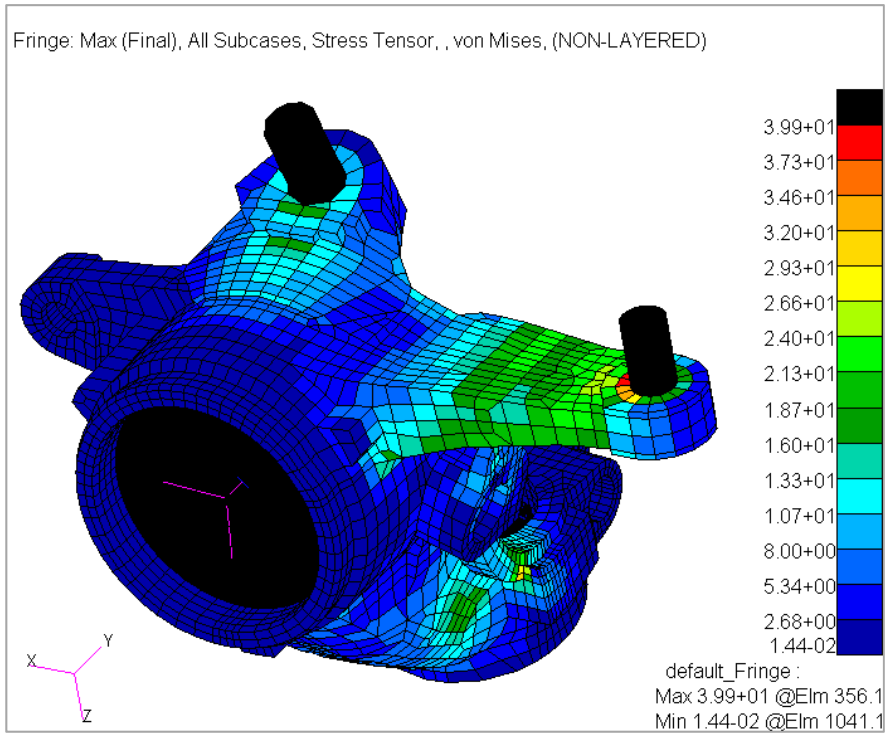
- OK: `MDLPRM,HDF5,1`
- NOT OK: `MDLPRM,HDF5,2`

Alternatively, use HDF5OUT





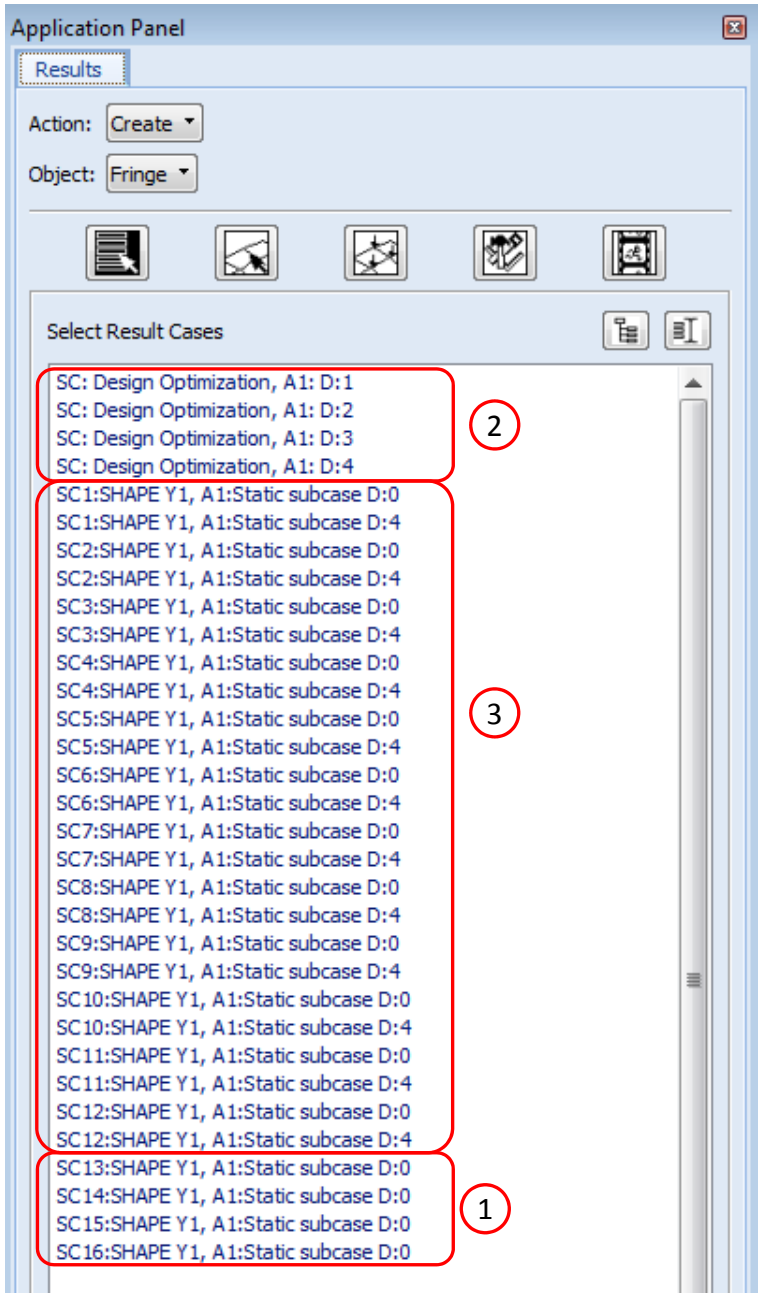




Interpreting the Subcases

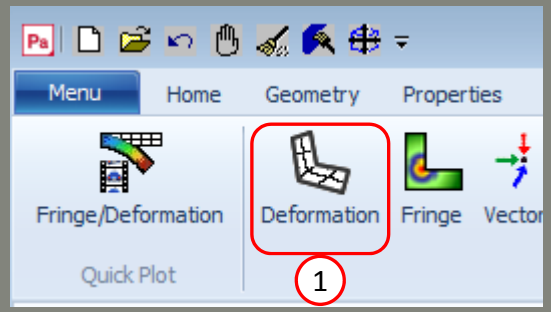
This shape optimization involved 4 shapes , converged in 4 design cycles and 12 load cases.

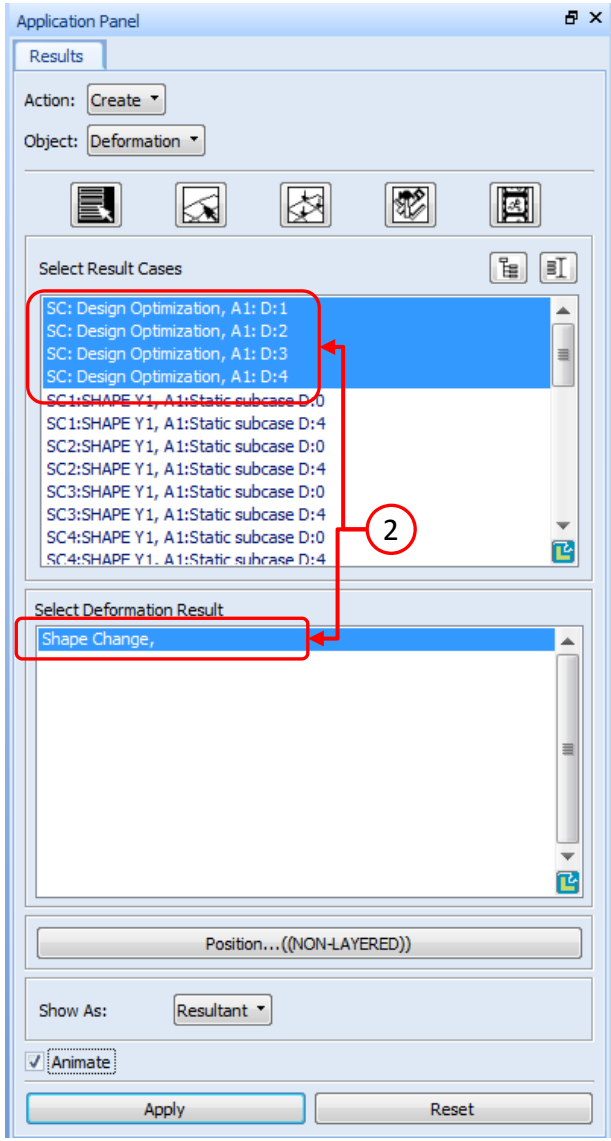
1. The last 4 rows contain the results of the interpolation subcases for the 4 shapes.
2. The first 4 rows contain the shape change results for the first 4 design cycles.
3. The indicated rows contain the results of the 12 load cases. The results of the initial design are indicated by a trailing “D:0” string. The results of the final design are indicated by a trailing “D:4” string. There are a total of 24 rows.

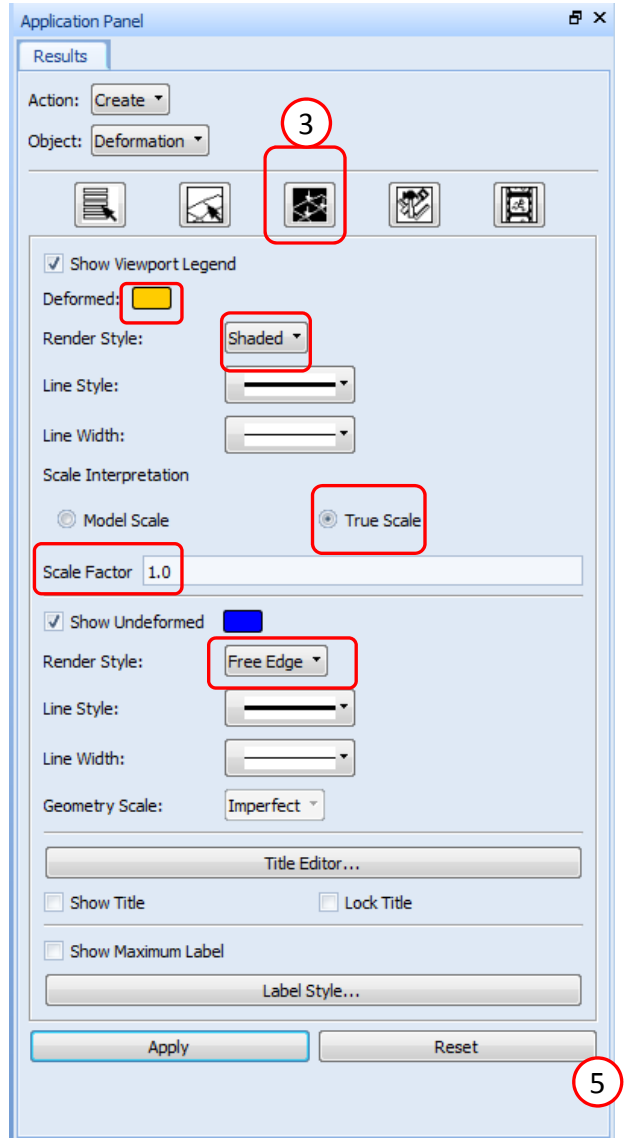


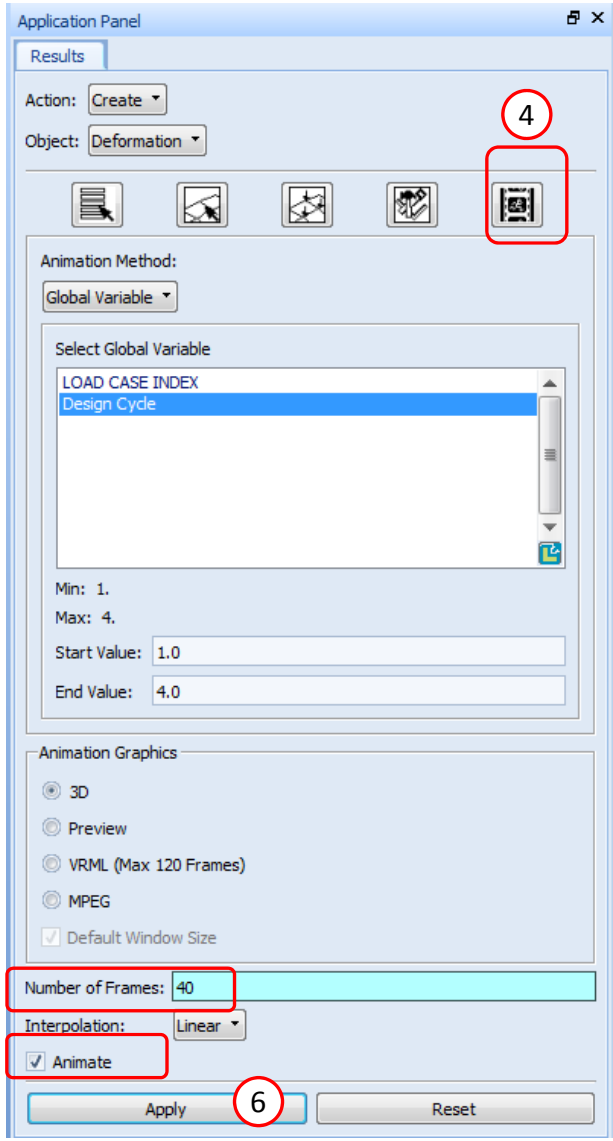
Animating the Shape Change

1. Click Deformation in the top left hand corner of the Patran window
2. Select the indicated rows
3. Click the indicated button and set the following
   - Deformed: Orange or your preferred color
   - Render Style: Shaded
   - Scale Interpretation: True Scale
   - Scale Factor: 1.0
   - Render Style: Free Edge
4. Click the indicated button and set the following
   - Number of Frames: 40
5. Mark the checkbox for Animate
6. Click Apply and the animation will be created



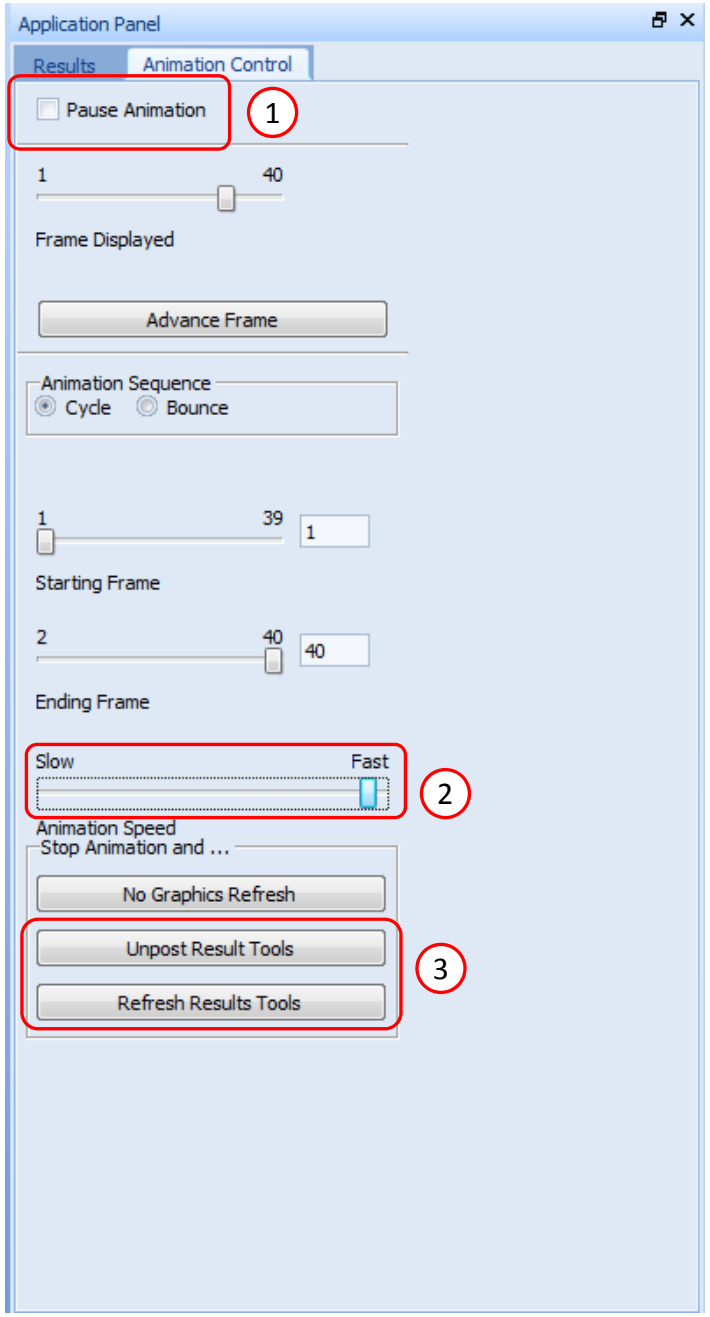


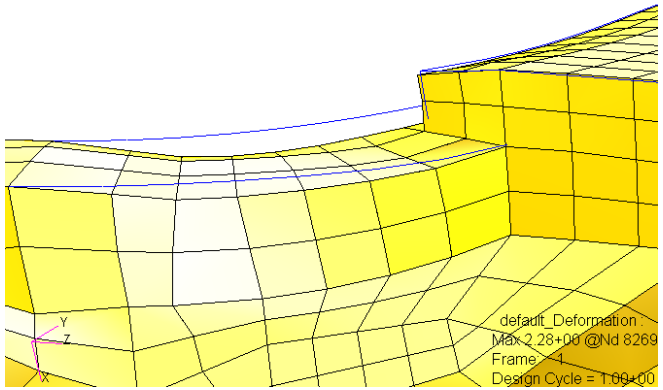




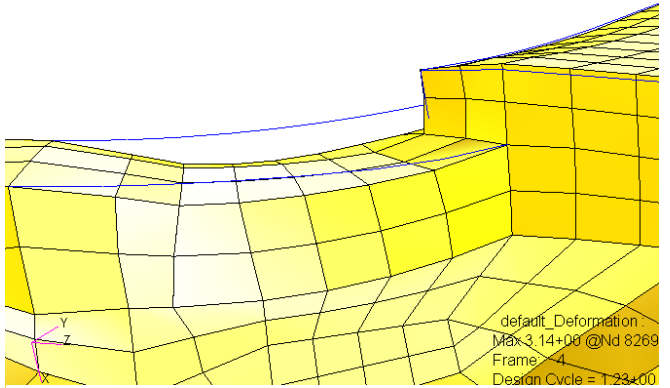
Controlling the Animation of Shape Changes

1. Mark the checkbox Pause Animation to pause or unpause the animation
2. Use the indicated slider to control the speed of the animation
3. To exit the animation click on one of the buttons Unpost Result Tools or Refresh Results Tools

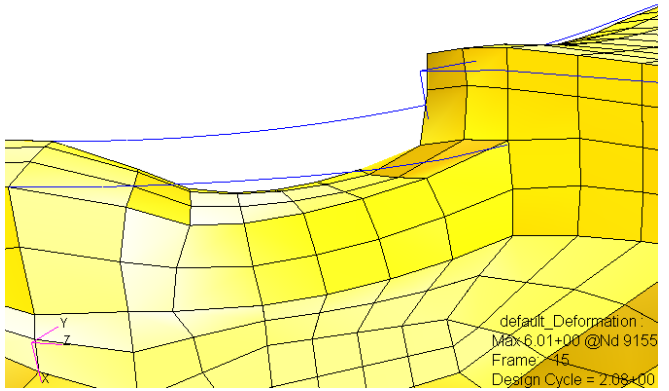




Frame 1



Frame 4



Frame 15