



**3DEXPERIENCE®**

# The Tosca Tuesdays

# Tosca Tuesday #4

## Basics: Shape optimization

### Example: Shape optimization of a wheel rim



# Basics | Shape optimization

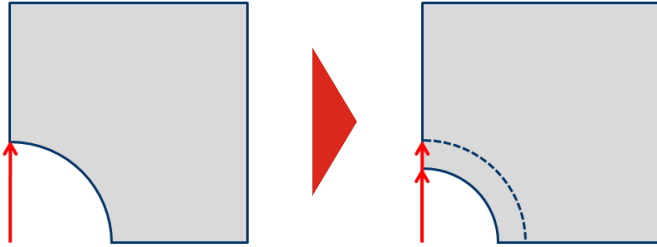
## Fundamental concept

- **Design variables:** Position of each surface node from a given design area
- **Goal:** Calculate an optimal surface geometry of a given model under consideration of all boundary conditions, constraints and geometric restrictions
- **Result:** Optimization displacements for all corresponding design nodes
- **Examples of possible tasks (controller strategy):**
  - Minimize local stress /strain peaks
  - Minimize local stress / strain peaks under a volume equality constraint
  - Minimize local fatigue hotspots / nodal damage peaks
  - Minimize local fatigue hotspots / nodal damage peaks under a volume equality constraint
  - ...

# Basics | Shape optimization

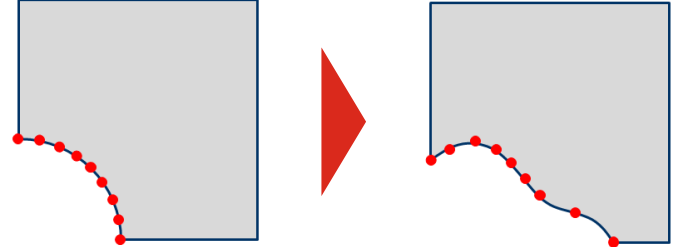
## Different approaches

Parametric concept (→ Isight)



e.g. Variation of a radius

Non-parametric concept (→ Tosca)

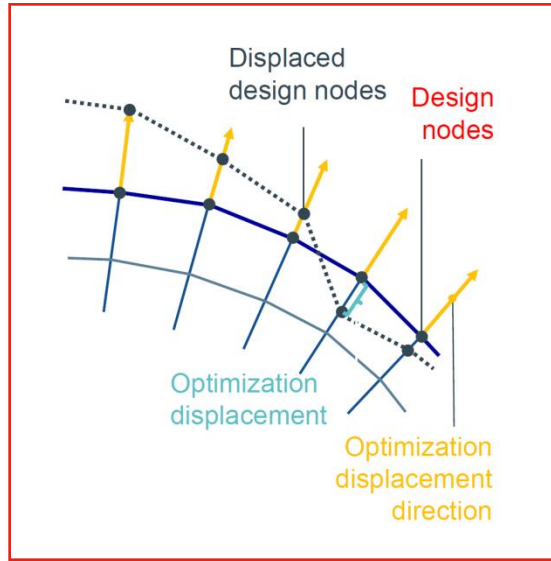


Modification of each surface node

→ Flexibility of possible shapes

# Basics | Shape optimization

## Non-parametric concept



### Terminology

- “**Growth**”: Design node is moved outwards in normal direction (positive displacement)
- “**Shrinkage**”: Design node is moved against normal direction (negative displacement)
- The **design variables** are more specifically the optimization displacement values of the corresponding design nodes.

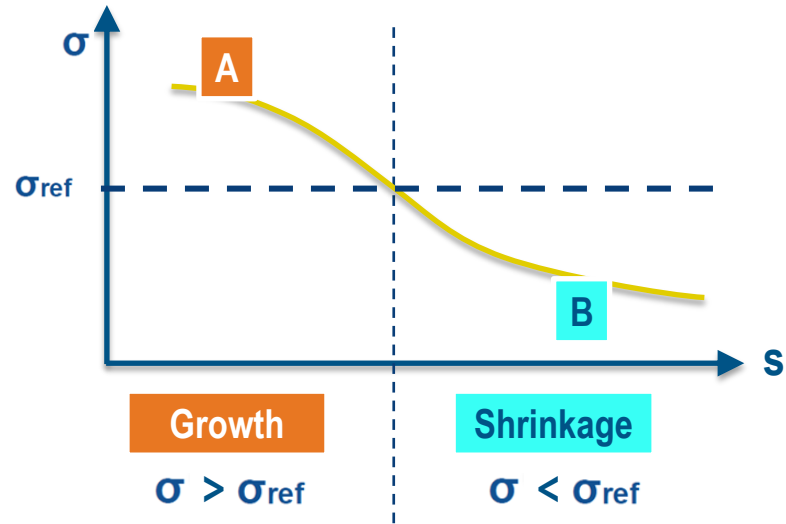
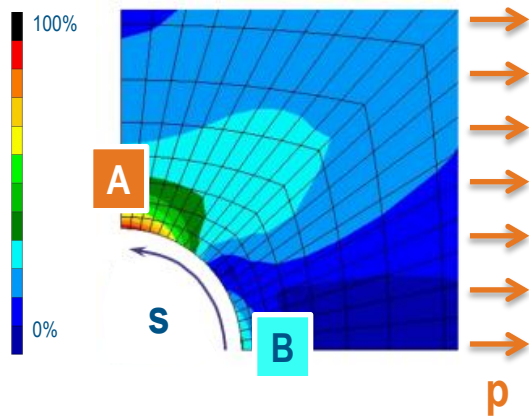
# Basics | Shape optimization

## Controller strategy

- **Goal:** Minimize local stress peaks on the surface of a structure
- **Controller strategy:**
  - Homogenization of the surface stress distribution
  - “Growth” in regions of high stress → leads to local stress decrease
  - “Shrinkage” in regions of low stress → leads to local stress increase
  - Characterization of a certain region by using a reference stress (~ average stress of all design nodes)
- **Result:** Homogeneous (uniform) stress distribution without any stress peaks
- The concept is in a similar manner applicable to strain or damage peaks (fatigue analysis).

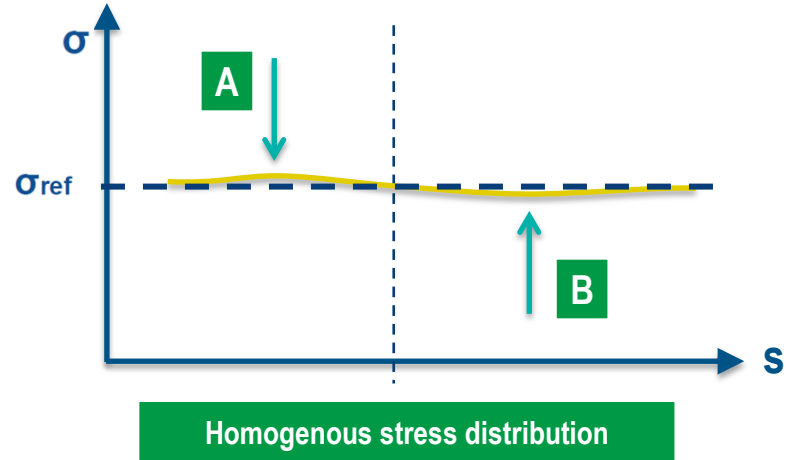
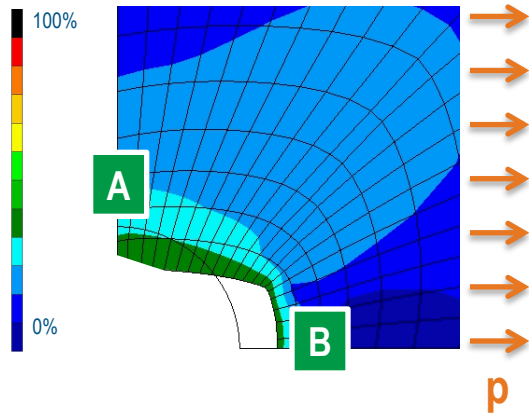
# Basics | Shape optimization

## Controller strategy – Example of a hole plate



# Basics | Shape optimization

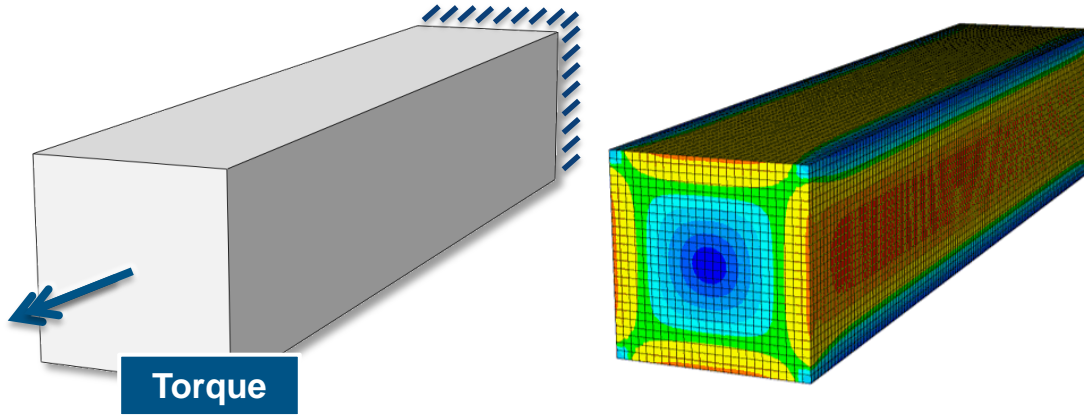
## Controller strategy – Example of a hole plate





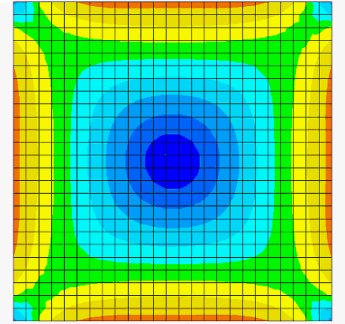
# Basics | Shape optimization

Controller strategy – Example of a rectangular beam under torsional loading



Shrinkage

Growth



Homogenous stress distribution

# Tosca Tuesday #4

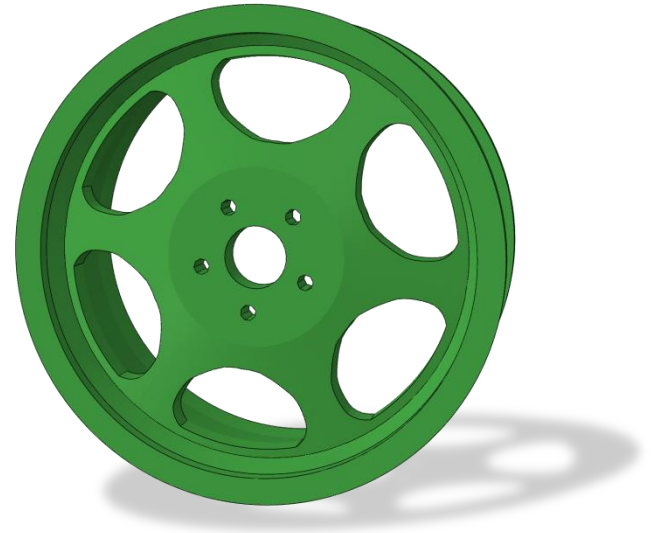
**Basics:** Shape optimization

**Example:** Shape optimization of a wheel rim

# Example | Wheel rim

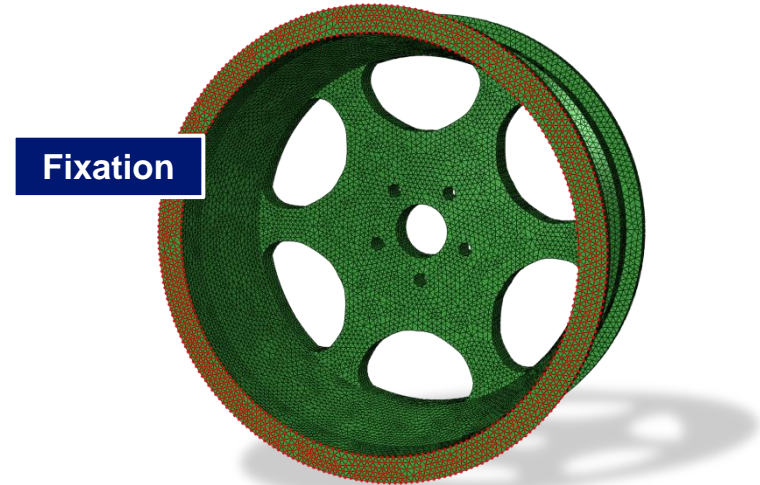
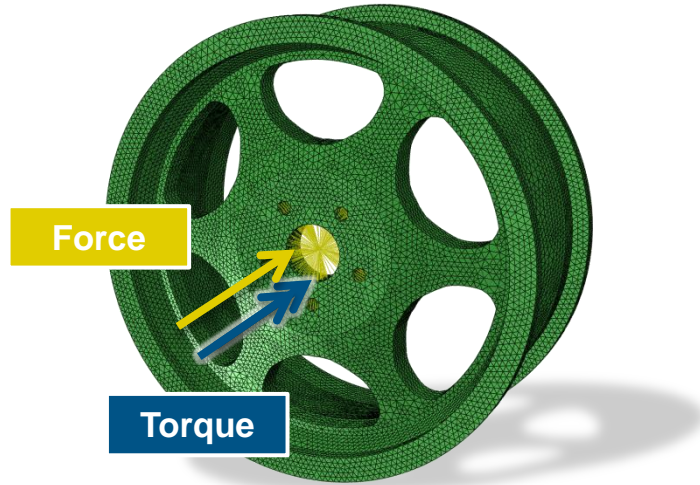
## Get started ...

- ▶ Start Abaqus CAE (at least version 6.13, preferable 6.13-4)
- ▶ File → Import → Model → “rim.inp”
- ▶ File → Set Work Directory → Choose Directory



# Example | Wheel rim

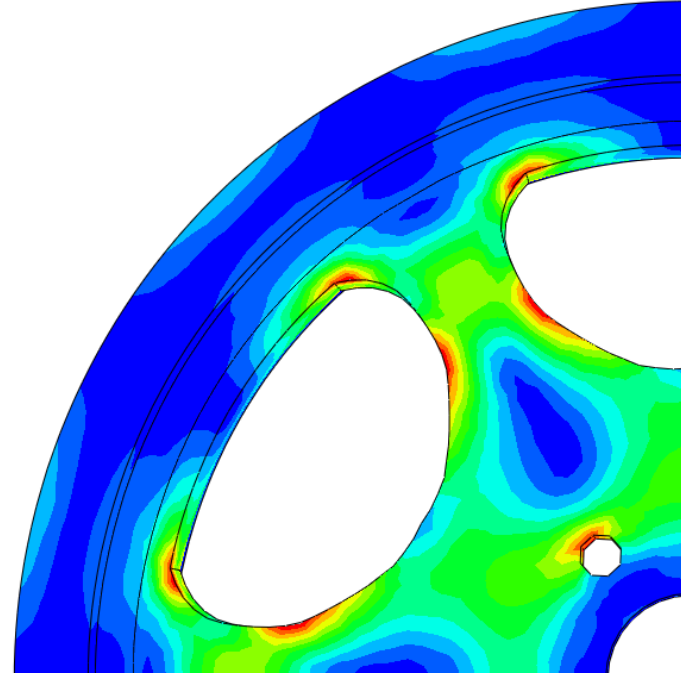
**Basic model:** Loading and boundary conditions



# Example | Wheel rim

## Shape Optimization: Setup

- **Objective function**
  - Minimize maximal stress peaks (v. Mises)  
→ Controller strategy
- **Geometric restrictions**
  - Rotational symmetry
  - Planar symmetry for each segment
  - Stamp restriction (manufacturing)



# Example | Wheel rim

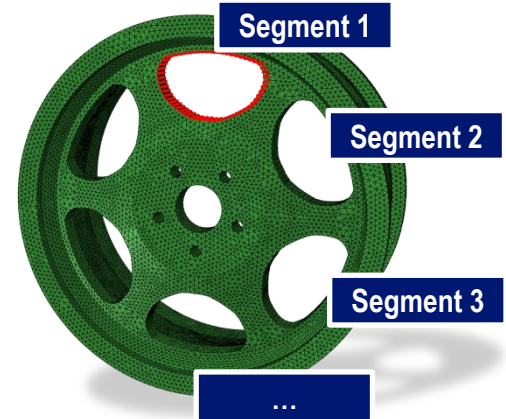
Shape Optimization: Used node sets



Complete model



Design nodes



Segment 1

Segment 2

Segment 3

...

# Example | Wheel rim

Shape Optimization: Used node sets



Pair A



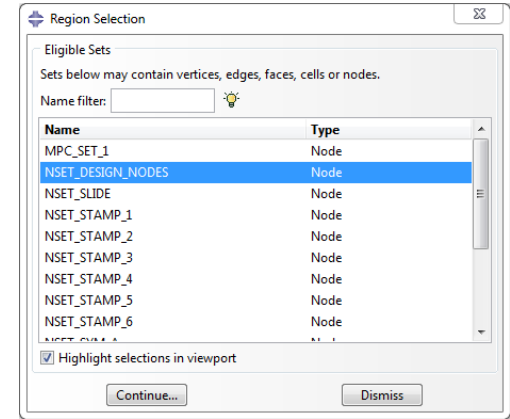
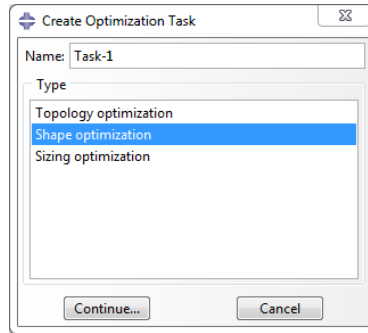
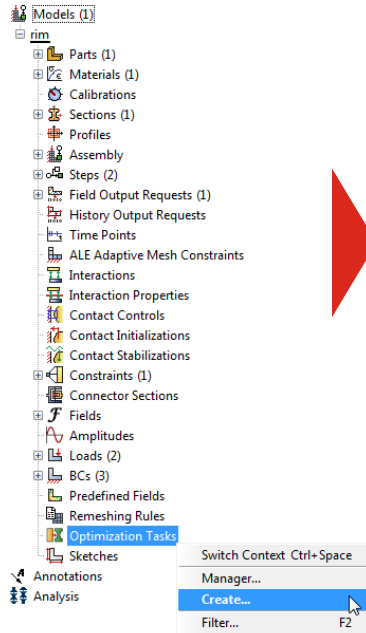
Pair B



Pair C

# Example | Wheel rim

## Step 1: Shape optimization task





# Example | Wheel rim

## Step 1: Shape optimization task


Edit Optimization Task

Name: Task-1  
Type: Shape  
Region: NSET\_DESIGN\_NODES

Basic Mesh Smoothing Quality Advanced

☐ Freeze boundary condition regions  
Restrict to those within region: (Whole Model)

Mesh Smoothing

Region: ☐ Specify smoothing region: (Not Picked)   
☒ Specify first layer: NSET\_DESIGN\_NODES  
Number of layers to smooth: 5  
☐ Smooth six layers using the task region

Number of node layers adjoining the task region to remain free:  
☐ Fix all ☒ Fix none ☐ Specify:

OK Cancel

Edit Optimization Task

Name: Task-1  
Type: Shape  
Region: NSET\_DESIGN\_NODES

Basic Mesh Smoothing Quality Advanced

☒ Target mesh quality: Low  
☐ Report poor quality elements  
☐ Report solver quality criteria violation  
☐ Halt optimization upon criteria violation

	Min Angle	Max Angle	Taper	Skew
Tri	20	140		
Quad	20	160	0.5	30

	Min Aspect	Max Aspect	Aspect Ratio	Skew
Tet	0.222	8	100	10

Smoothing Strategy

Strategy: ☒ Constrained Laplacian ☐ Local gradient

Convergence level: Low

Frequency of evaluating geometric restrictions: Low

OK Cancel

Edit Optimization Task

Name: Task-1  
Type: Shape  
Region: NSET\_DESIGN\_NODES

Basic Mesh Smoothing Quality Advanced

Algorithm: Condition-based optimization

Growth scale factor: 1

Shrink scale factor: 1

Update shape basis vectors: ☒ Every cycle ☐ First cycle

Step size determined by: ☒ Min. displacement ☐ Average displacement

Interpolation of midside nodes:  
☒ Linearly by position  
☐ By optimization displacement of corner nodes

☒ Edge length for movement vector: 5

☐ Max. influence radius for equivalent stress:

Surface bending radius reduction: 0.2

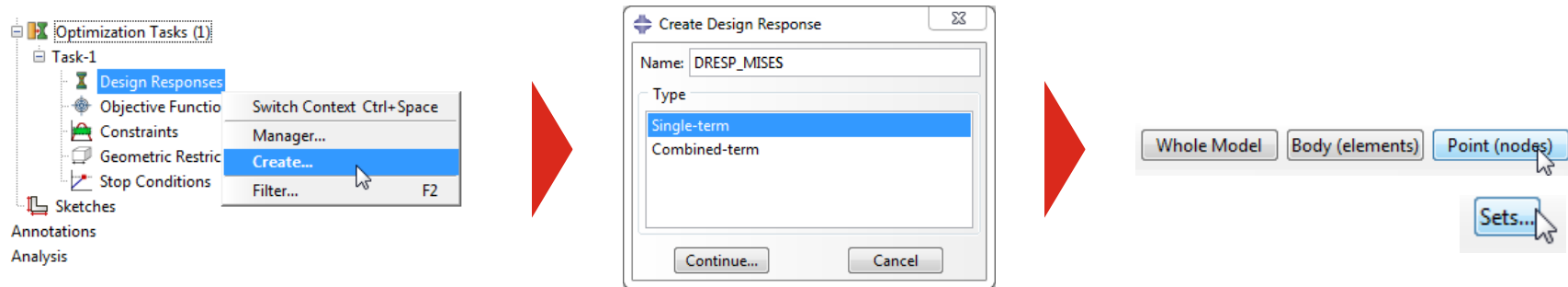
Weighting depending on radius: 1

Equality constraint tolerance: 0.001

OK Cancel

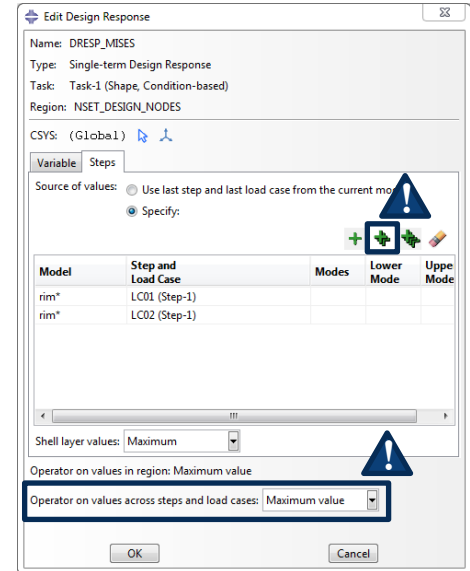
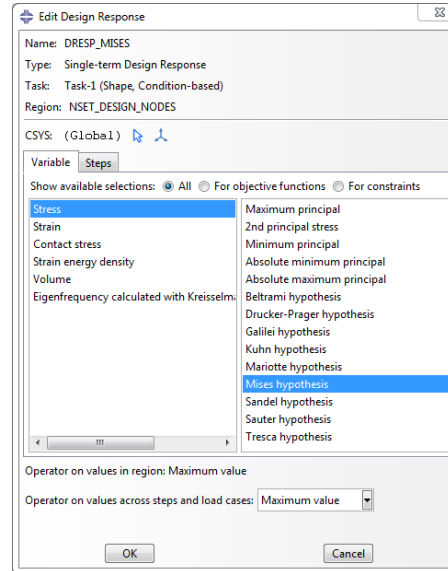
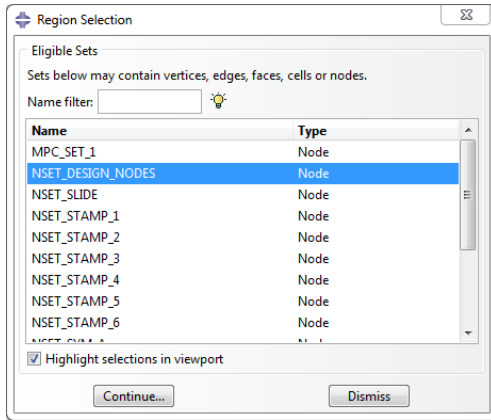
# Example | Wheel rim

## Step 2: Design response for maximal v. Mises stress



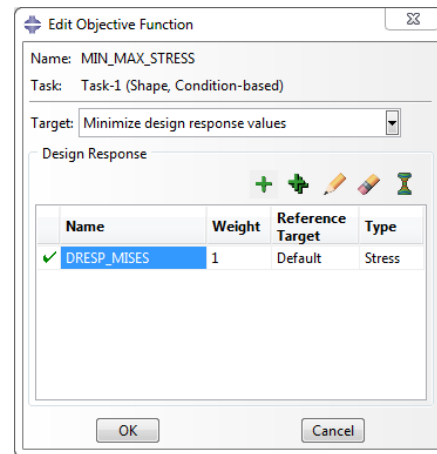
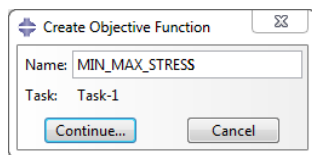
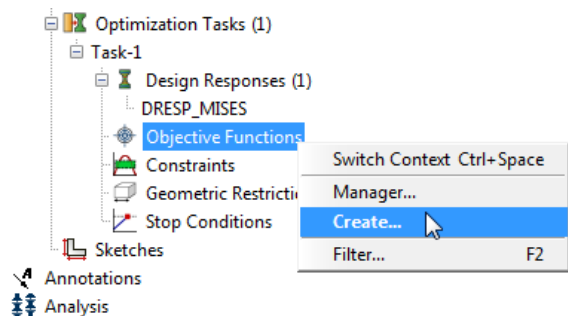
# Example | Wheel rim

## Step 2: Design response for maximal v. Mises stress



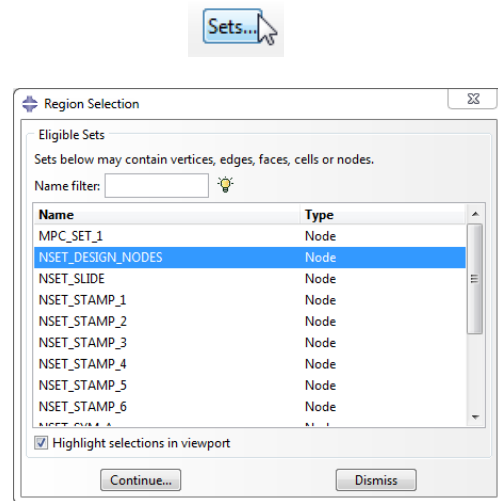
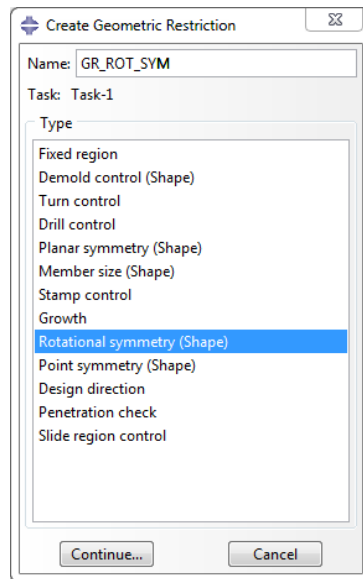
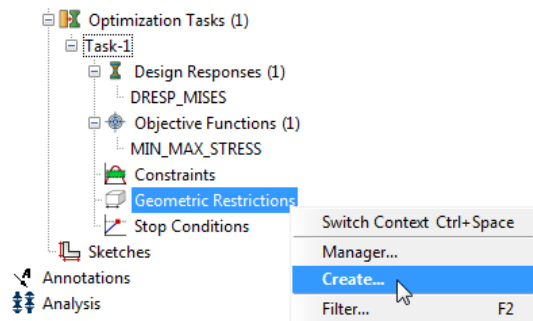
# Example | Wheel rim

**Step 3:** Objective function (→ minimize maximal v. Mises stress peak)



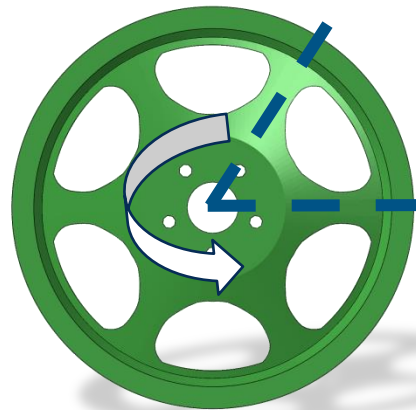
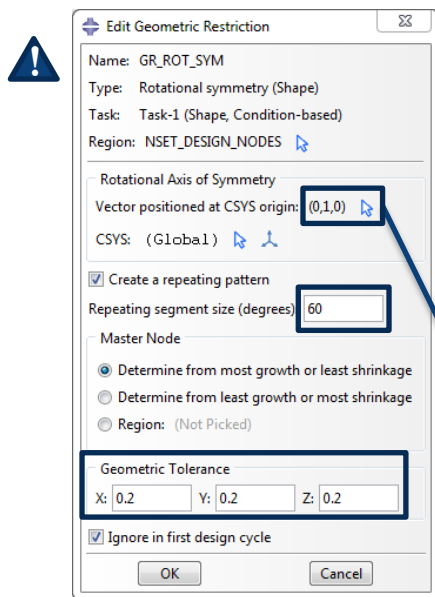
# Example | Wheel rim

## Step 4: Geometric restriction for rotational symmetry



# Example | Wheel rim

## Step 4: Geometric restriction for rotational symmetry

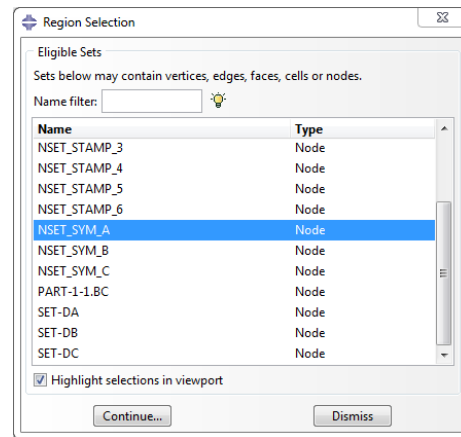
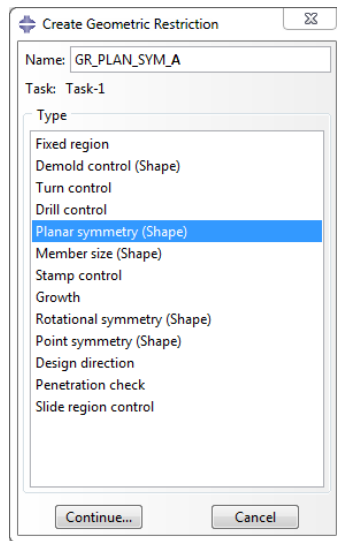
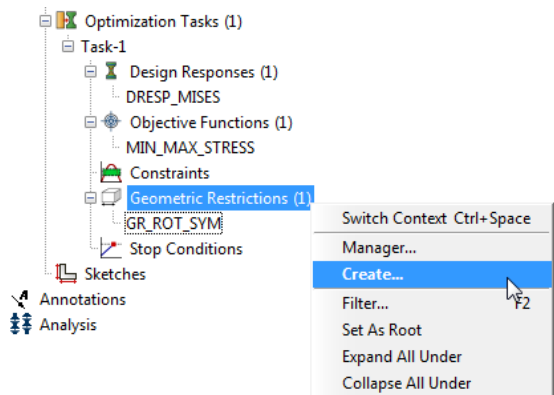


Pick the first point of the vector: 0,0,0,0,0

Pick the second point of the vector: 0,0,1,0,0,0

# Example | Wheel rim

## Step 5: Geometric restriction for planar symmetry (pair A)



# Example | Wheel rim

## Step 5: Geometric restriction for planar symmetry (pair A)

The diagram illustrates the process of applying a planar symmetry geometric restriction to a wheel rim model. It includes three main components: the 'Edit Geometric Restriction' dialog box, the 'Datum CSYS List' dialog box, and a 3D model of the wheel rim.

**Edit Geometric Restriction Dialog Box:**

- Name: GR\_PLAN\_SYM\_A
- Type: Planar symmetry (Shape)
- Task: Task-1 (Shape, Condition-based)
- Region: NSET\_SYM\_A
- Normal to Symmetry Plane
- Vector positioned at CSYS origin: (1,0,0)
- CSYS: Transform\_\_csys-A
- Master Nodes
  - ☒ Determine from most growth or least shrinkage
  - ☐ Determine from least growth or most shrinkage
- Geometric Tolerance
  - X: 0.2
  - Y: 0.2
  - Z: 0.2
- ☒ Ignore in first design cycle

**Pick the first point of the vector:** 0.0,0.0,0.0

**Pick the second point of the vector:** 1.0,0.0,0.0

**Datum CSYS List Dialog Box:**

- Names
  - Transform\_\_csys-A
  - Transform\_\_csys-B
  - Transform\_\_csys-C
  - Datum csys-1

The 3D model of the wheel rim shows a green rim with a blue dashed line indicating the plane of symmetry. A yellow arrow points to the center of the rim, and a blue arrow points to the plane of symmetry.



# Example | Wheel rim

## Step 5: Geometric restriction for planar symmetry (pair B & C)



Repeat for pair B  
and pair C



**Edit Geometric Restriction**

Name: GR\_PLAN\_SYM\_B  
Type: Planar symmetry (Shape)  
Task: Task-1 (Shape, Condition-based)  
Region: NSET\_SYM\_B

Normal to Symmetry Plane  
Vector positioned at CSYS origin: (1,0,0)  
CSYS: Transform\_\_csys-B

Master Nodes  
☒ Determine from most growth or least shrinkage  
☐ Determine from least growth or most shrinkage

Geometric Tolerance  
X: 0.2 Y: 0.2 Z: 0.2

☒ Ignore in first design cycle

OK Cancel

**Edit Geometric Restriction**

Name: GR\_PLAN\_SYM\_C  
Type: Planar symmetry (Shape)  
Task: Task-1 (Shape, Condition-based)  
Region: NSET\_SYM\_C

Normal to Symmetry Plane  
Vector positioned at CSYS origin: (1,0,0)  
CSYS: Transform\_\_csys-C

Master Nodes  
☒ Determine from most growth or least shrinkage  
☐ Determine from least growth or most shrinkage

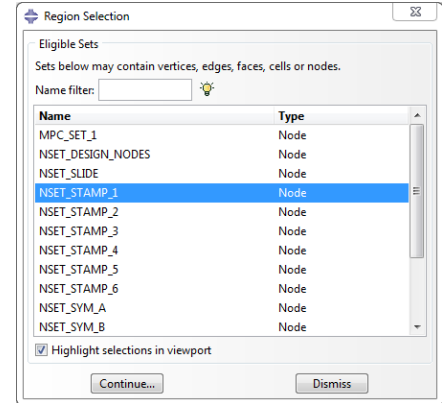
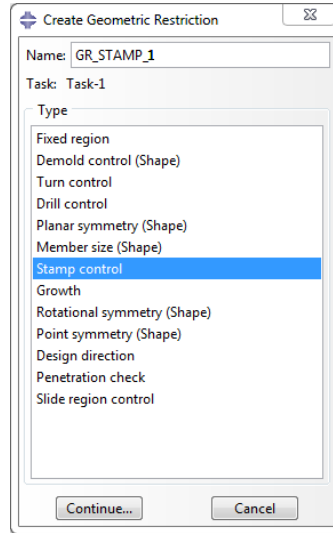
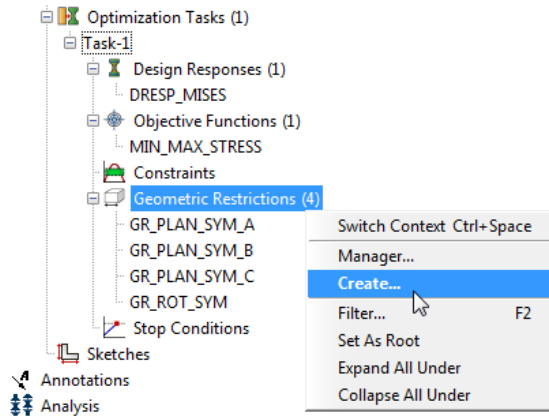
Geometric Tolerance  
X: 0.2 Y: 0.2 Z: 0.2

☒ Ignore in first design cycle

OK Cancel

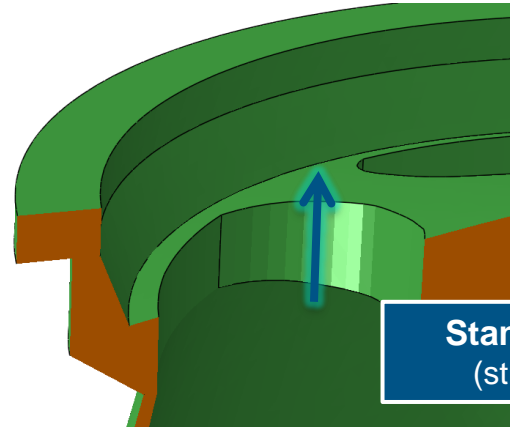
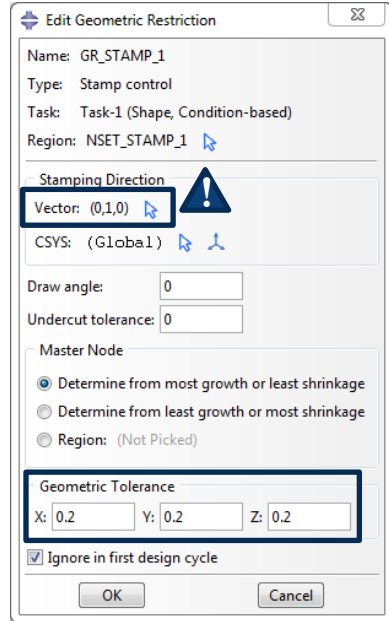
# Example | Wheel rim

## Step 6: Geometric restriction for stamping process (segment 1)



# Example | Wheel rim

## Step 6: Geometric restriction for stamping process (segment 1)



**Stamp direction**  
(straight edge)

# Example | Wheel rim

## Step 6: Geometric restriction for stamping process (segments 2-6)



Repeat for  
segments 2-6

**Edit Geometric Restriction**

Name: GR\_STAMP\_2  
Type: Stamp control  
Task: Task-1 (Shape, Condition-based)  
Region: NSET\_STAMP\_2

Stamping Direction  
Vector: (0,1,0)  
CSYS: (Global)

Draw angle: 0  
Undercut tolerance: 0

Master Node  
☒ Determine from most growth or least shrinkage  
☐ Determine from least growth or most shrinkage  
☐ Region: (Not Picked)

Geometric Tolerance  
X: 0.2 Y: 0.2 Z: 0.2

☒ Ignore in first design cycle

OK Cancel



**Edit Geometric Restriction**

Name: GR\_STAMP\_6  
Type: Stamp control  
Task: Task-1 (Shape, Condition-based)  
Region: NSET\_STAMP\_6

Stamping Direction  
Vector: (0,1,0)  
CSYS: (Global)

Draw angle: 0  
Undercut tolerance: 0

Master Node  
☒ Determine from most growth or least shrinkage  
☐ Determine from least growth or most shrinkage  
☐ Region: (Not Picked)

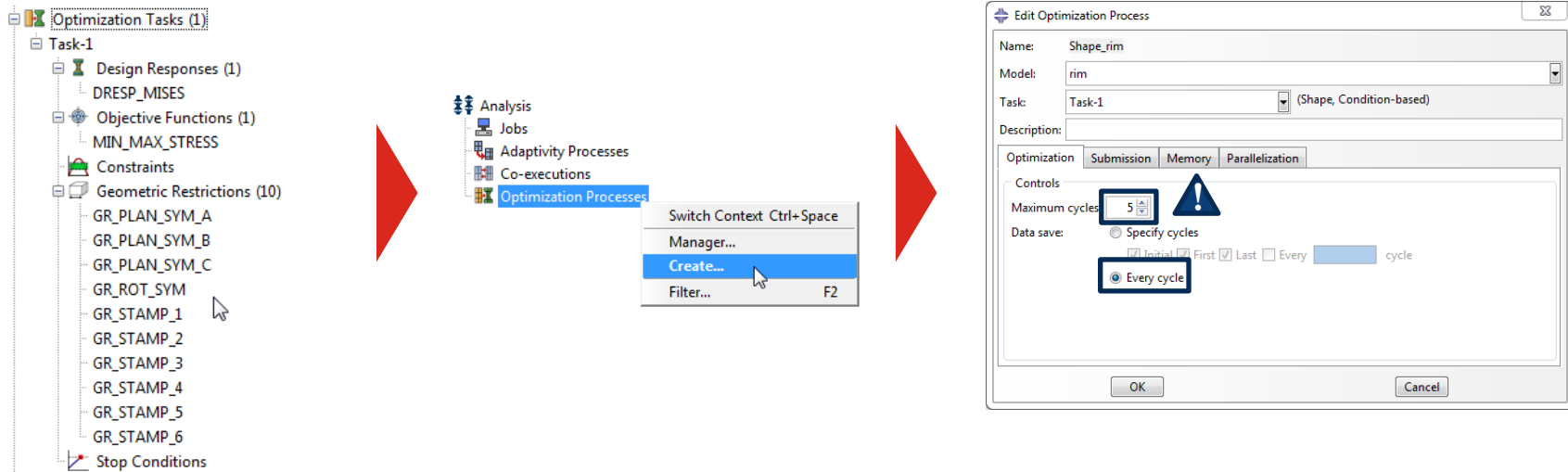
Geometric Tolerance  
X: 0.2 Y: 0.2 Z: 0.2

☒ Ignore in first design cycle

OK Cancel

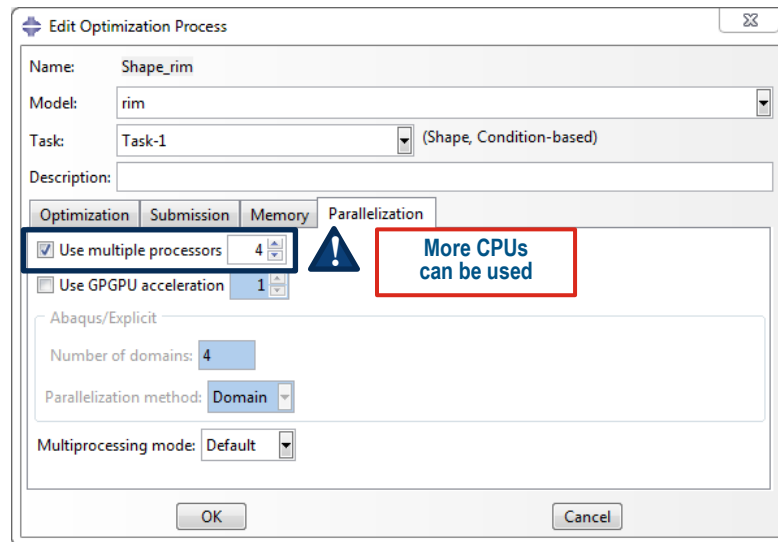
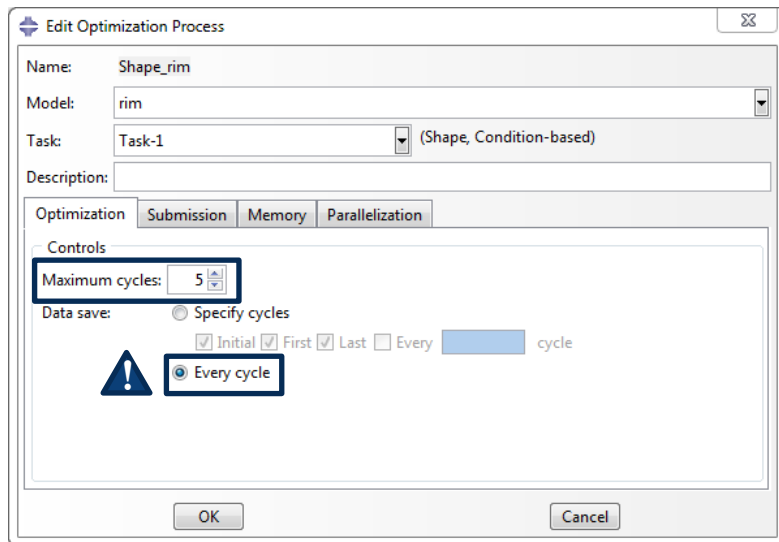
# Example | Wheel rim

## Step 7: Submission of the optimization task



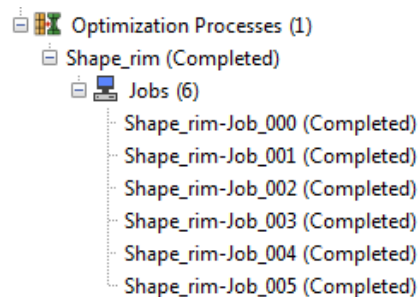
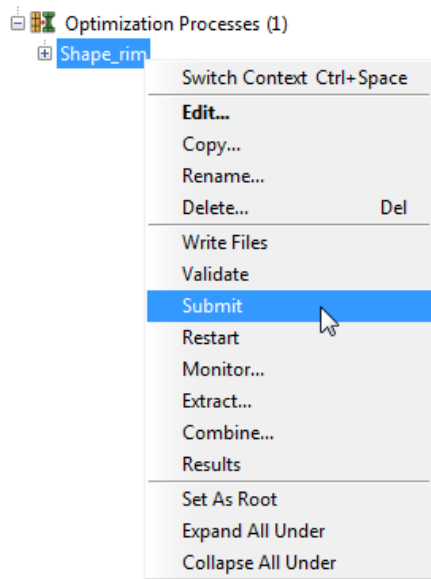
# Example | Wheel rim

## Step 7: Submission of the optimization task



# Example | Wheel rim

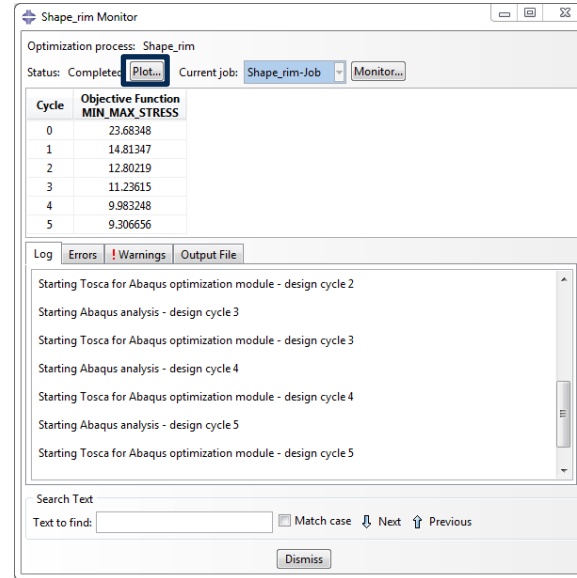
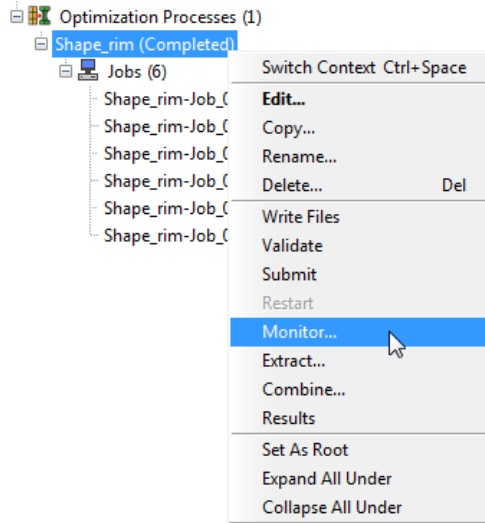
## Step 7: Submission of the optimization task



**Computational time:**  
~ 15min with 4 CPUs

# Example | Wheel rim

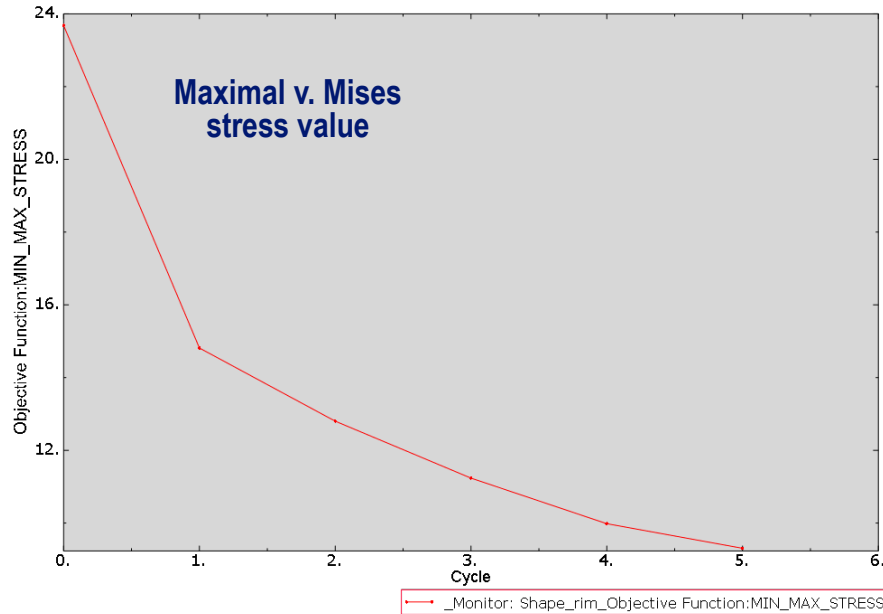
## Step 8: Submission of the optimization task





# Example | Wheel rim

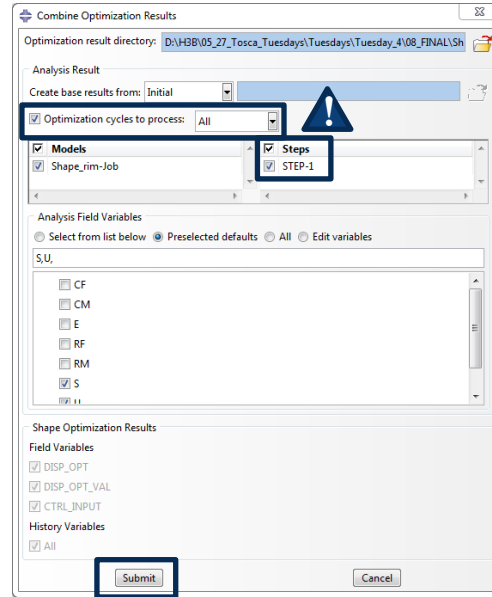
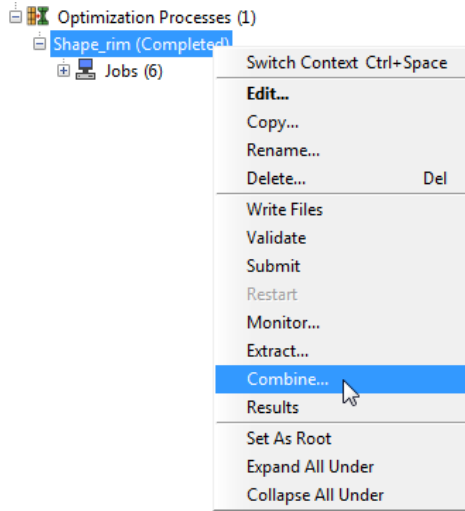
## Step 8: Submission of the optimization task



**Modify axis display options (font, size, color) by double-clicking**

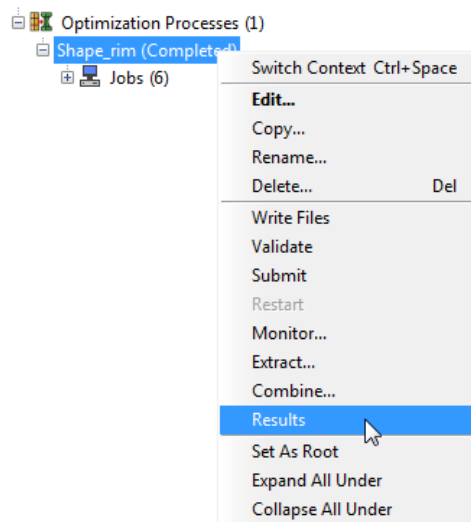
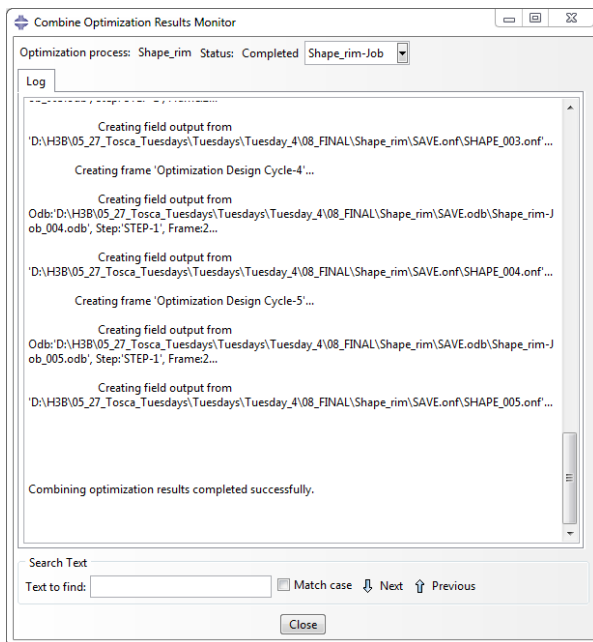
# Example | Wheel rim

Step 9: Visualization ( ⚠ Optimization has to be completed)



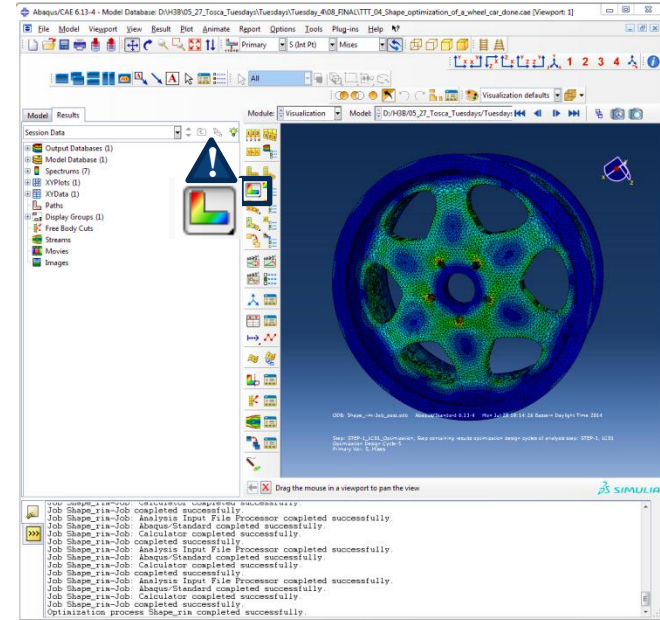
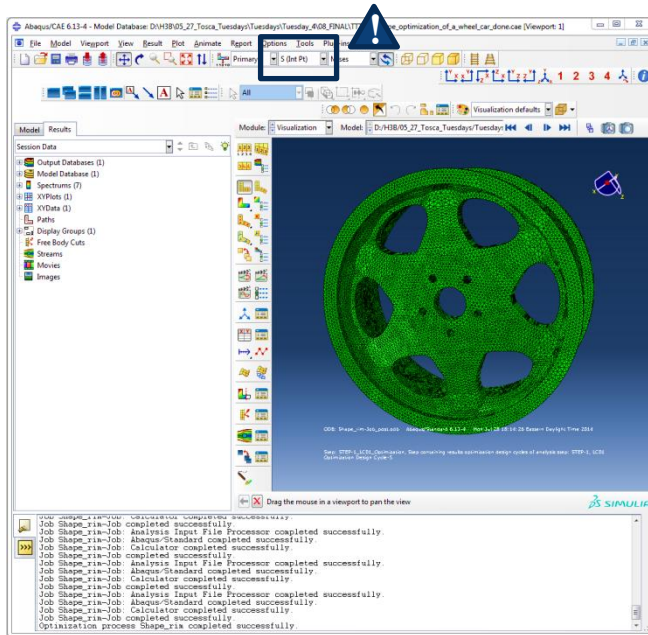
# Example | Wheel rim

## Step 9: Visualization



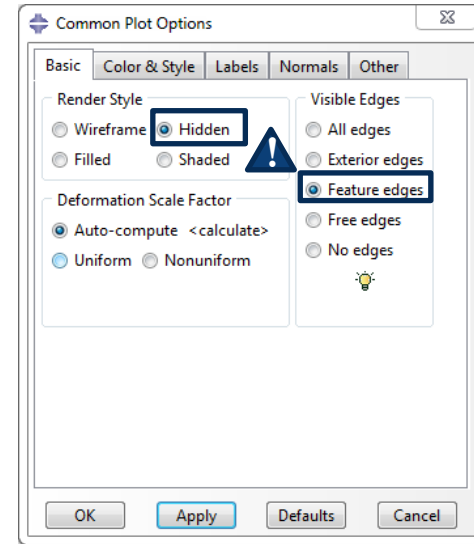
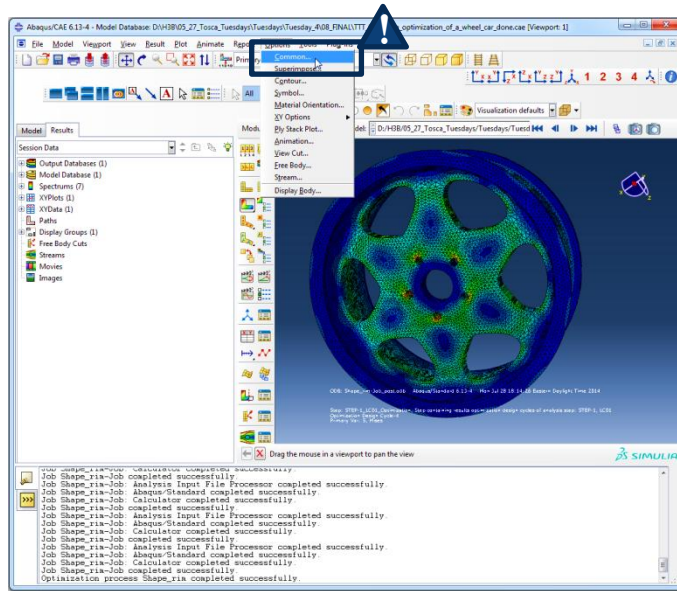
# Example | Wheel rim

## Step 9: Visualization



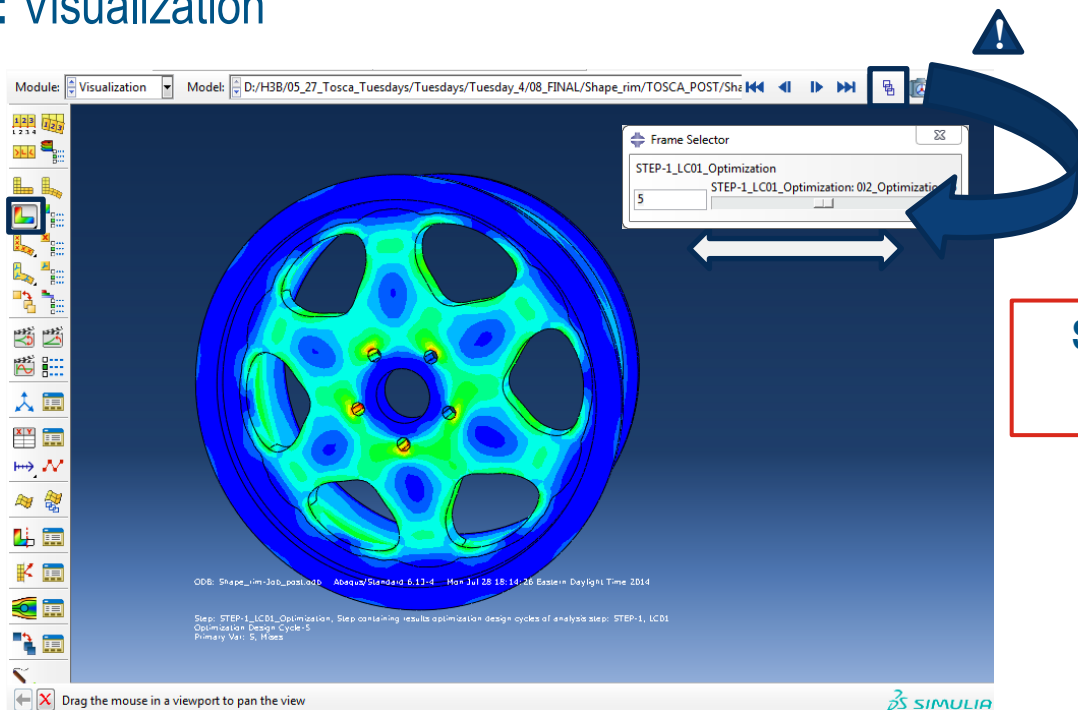
# Example | Wheel rim

## Step 9: Visualization

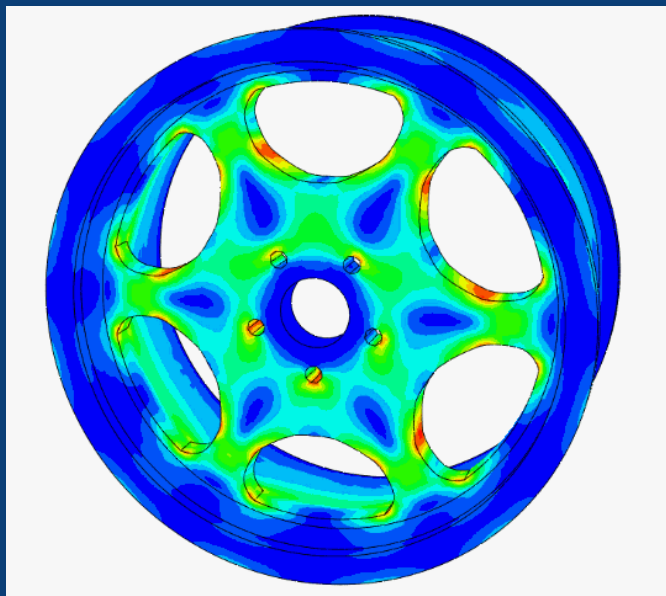


# Example | Wheel rim

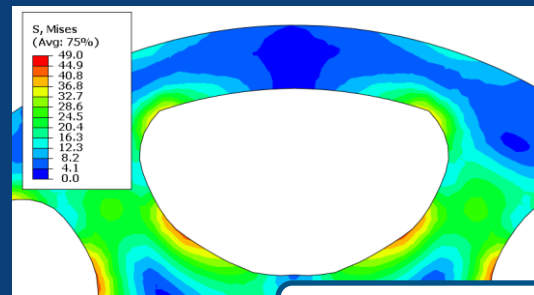
## Step 9: Visualization



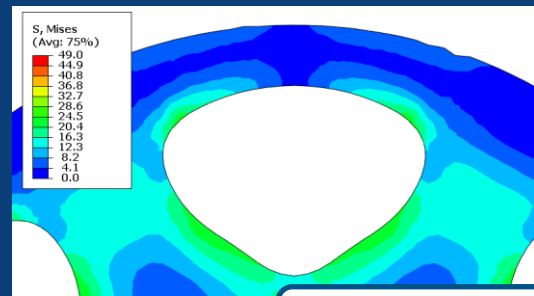
Scroll through each  
optimization cycle



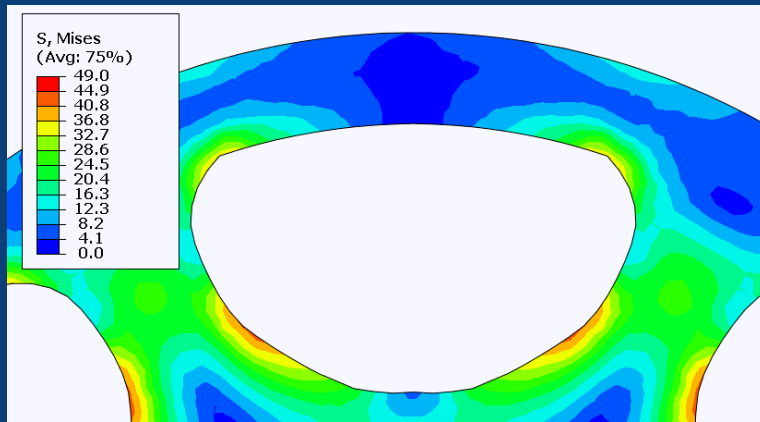
Shape Optimization



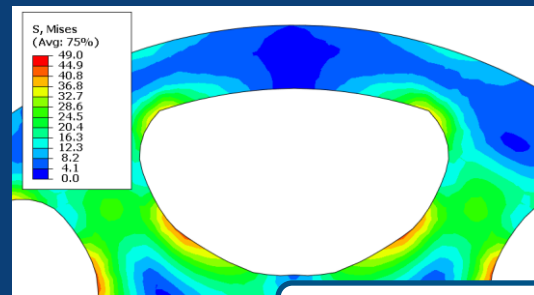
Original Design



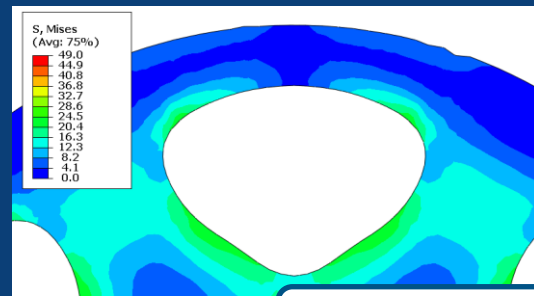
Optimized Design



Shape Optimization

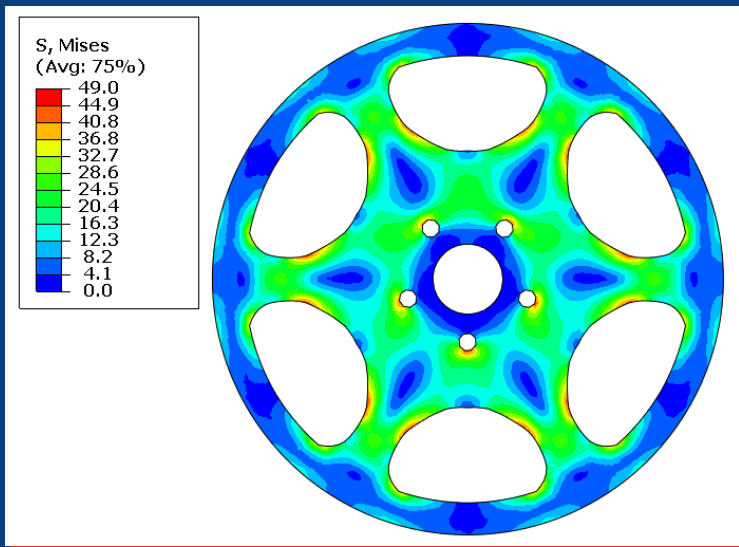


Original Design

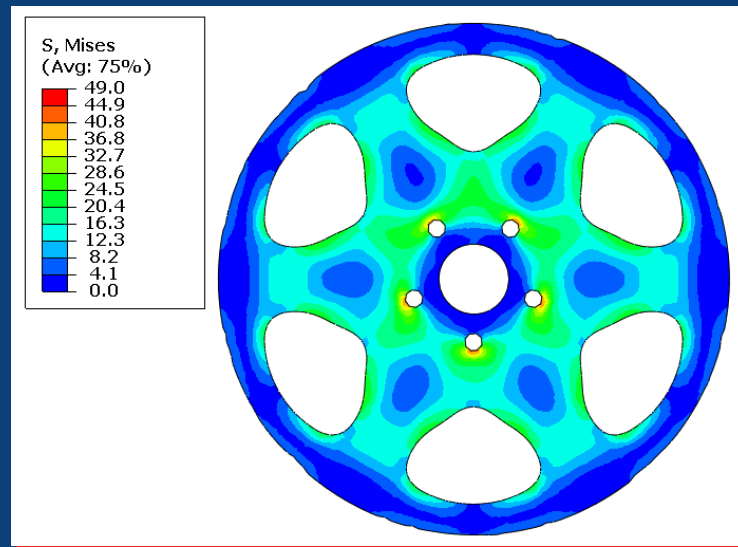


Optimized Design





Original Design



Optimized Design

