Aishwarya Ledalla

MAE 598: Design Optimization

Dr. Max Yi Ren

Project 2:

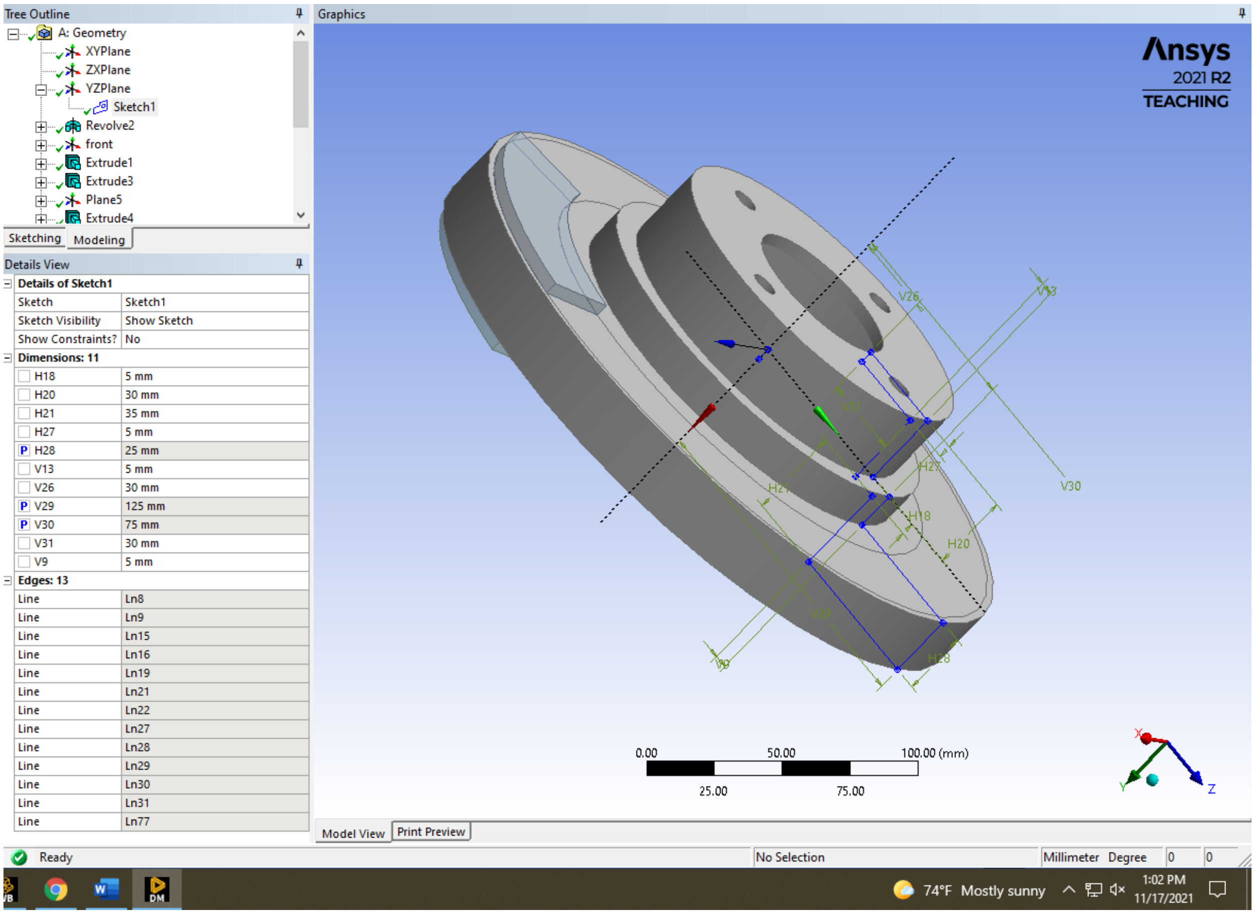
ANSYS DOE and Design Optimization

11/17/2021

Objectives:

- **Design a brake disc for emergency braking conditions with minimal volume**
- **Minimize the maximum stress in the brake disc**
- **Maximize the first natural frequency of the brake disc**
- **Minimize the maximum temperature in the brake disc**

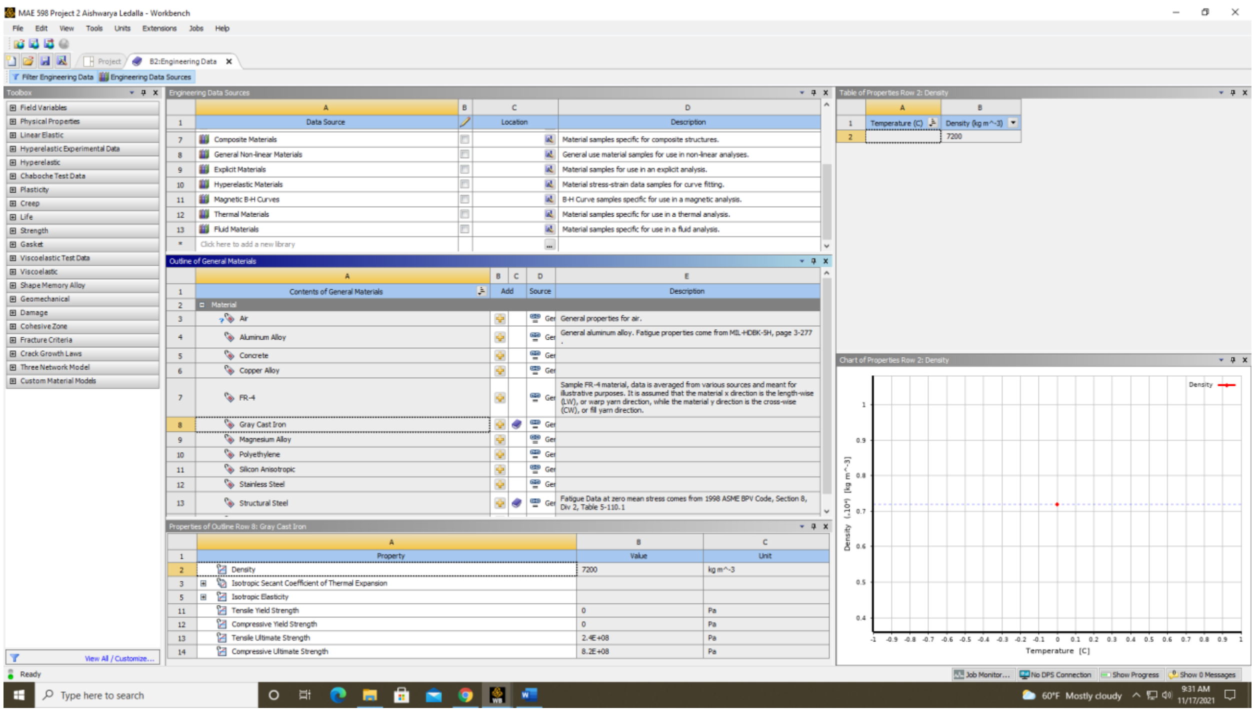
Define Input Parameters:



Static Structural Setup:

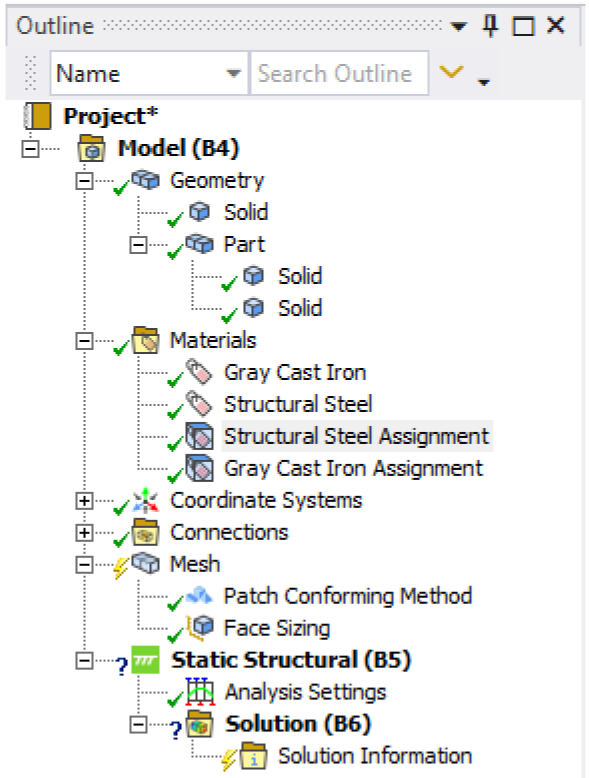
Given:

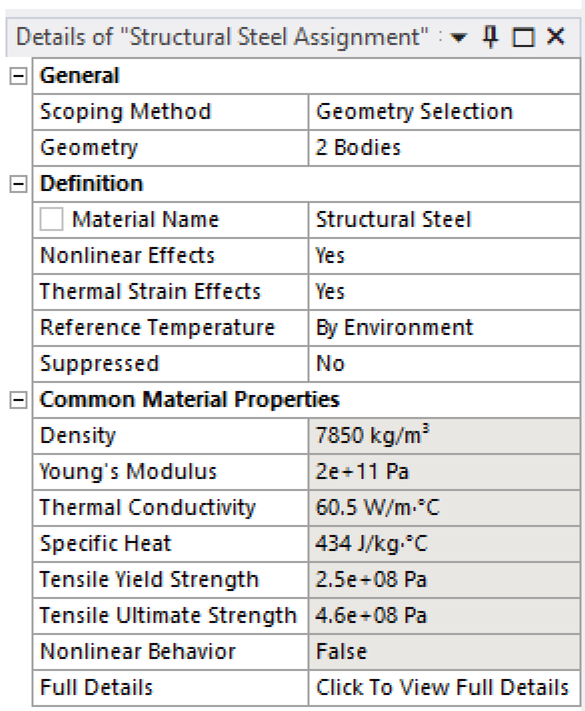
The brake disc has to sustain the pressure from the hydraulically actuated brake pads during sudden braking conditions. Stresses are induced due to friction between the brake pads and the disc. The disc also experiences centrifugal body forces due to its rotation. Resultant stresses generated due these forces can lead to material failure. Therefore, it is of prime importance to make sure that the stresses in the disc are minimized.



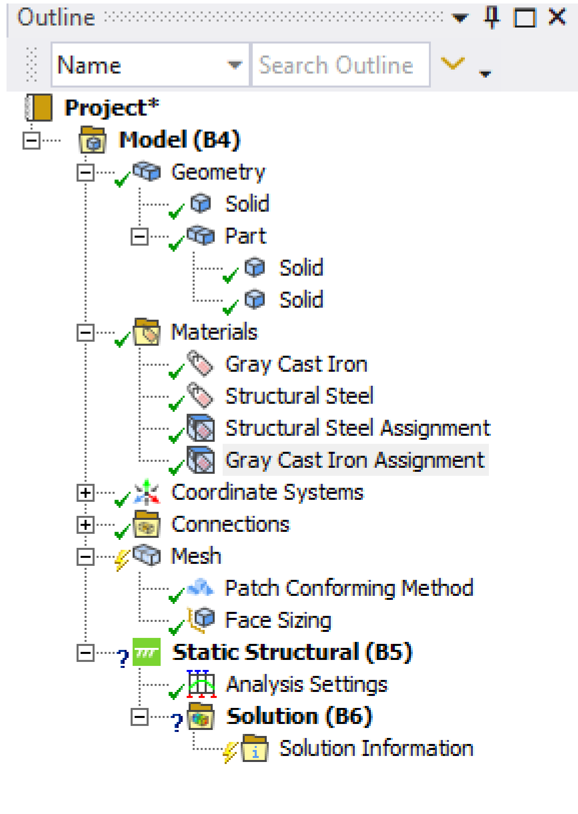
Details of "Patch Conforming Method" -	
Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Suppressed	No
Method	Tetrahedrons
Algorithm	Patch Conforming
Element Order	Use Global Setting

Details of "Face Sizing" - Sizing	
Scope	
Scoping Method	Geometry Selection
Geometry	2 Faces
Definition	
Suppressed	No
Type	Element Size
Element Size	3.e-003 m
Advanced	
Defeature Size	Default
Influence Volume	No
Behavior	Soft



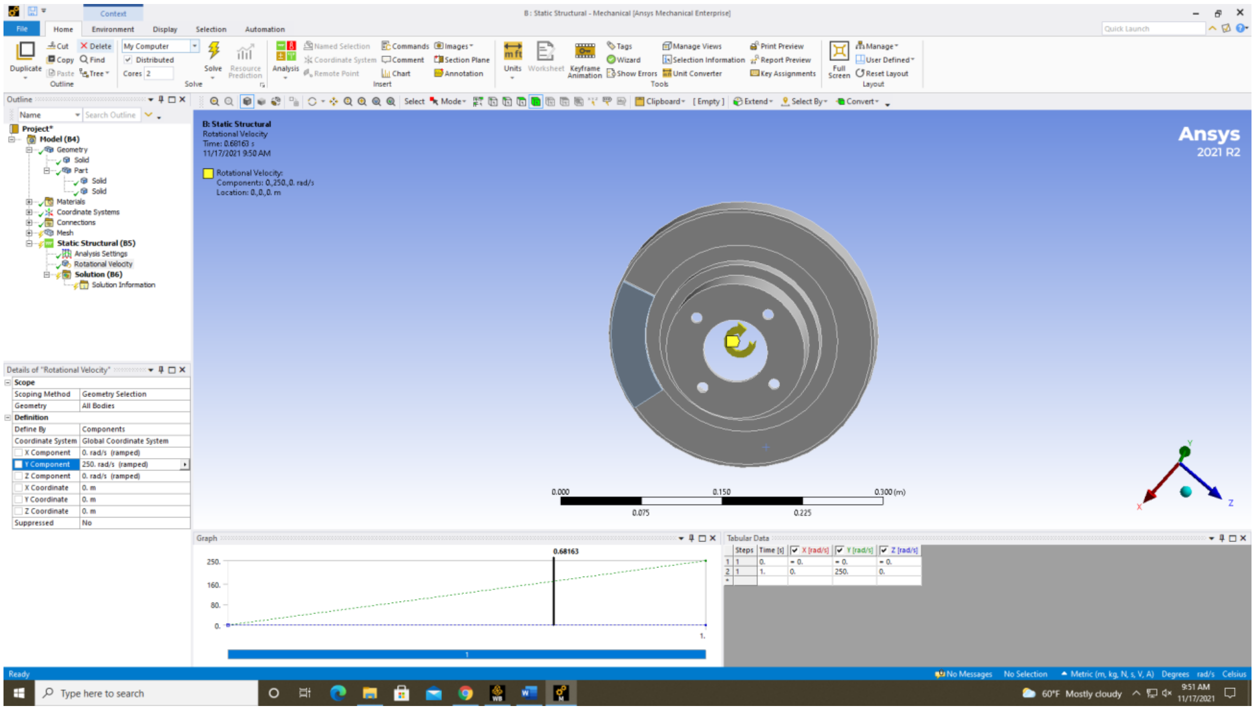


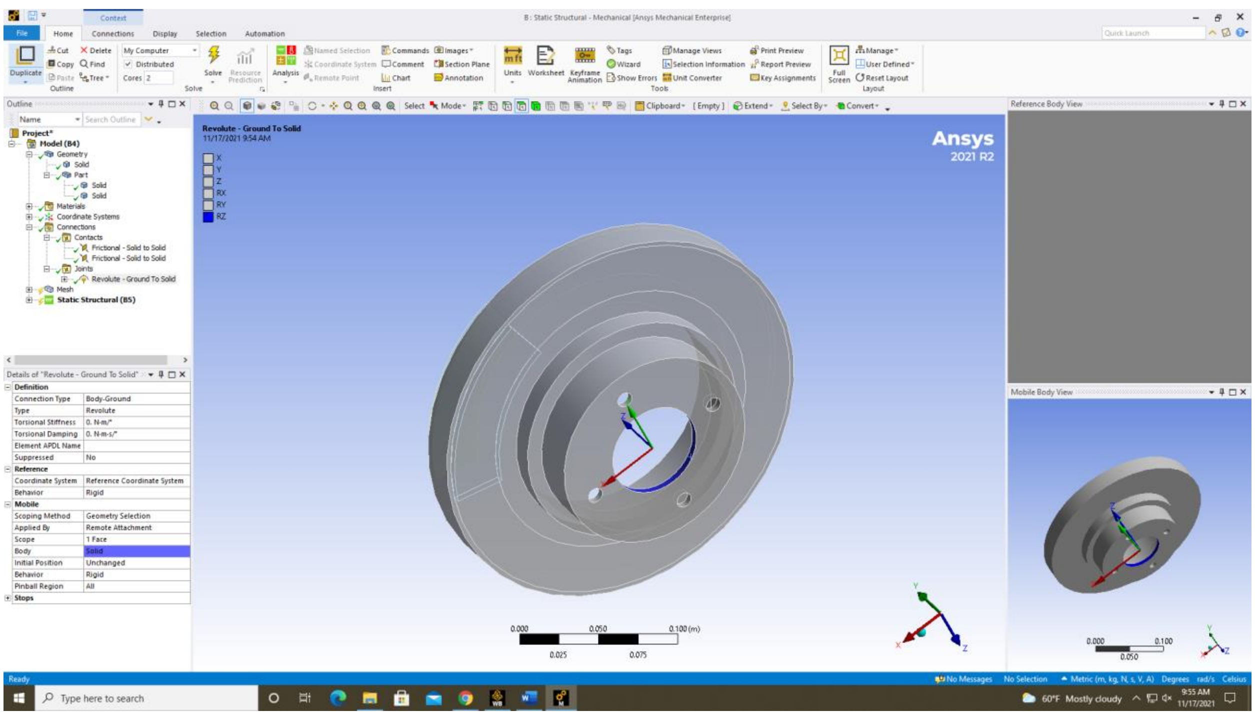
General	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Material Name	Structural Steel
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Reference Temperature	By Environment
Suppressed	No
Common Material Properties	
Density	7850 kg/m^3
Young's Modulus	2e+11 Pa
Thermal Conductivity	60.5 W/m·°C
Specific Heat	434 J/kg·°C
Tensile Yield Strength	2.5e+08 Pa
Tensile Ultimate Strength	4.6e+08 Pa
Nonlinear Behavior	False
Full Details	Click To View Full Details

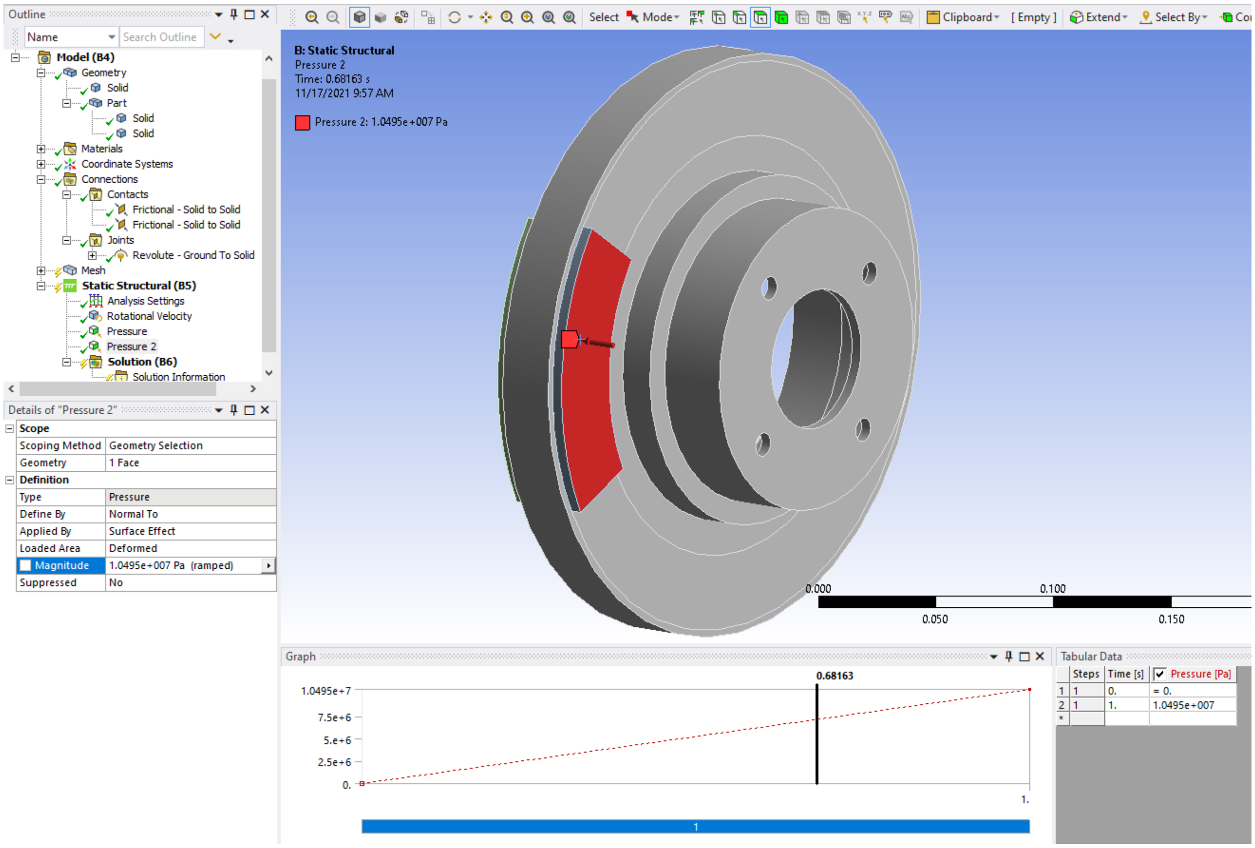


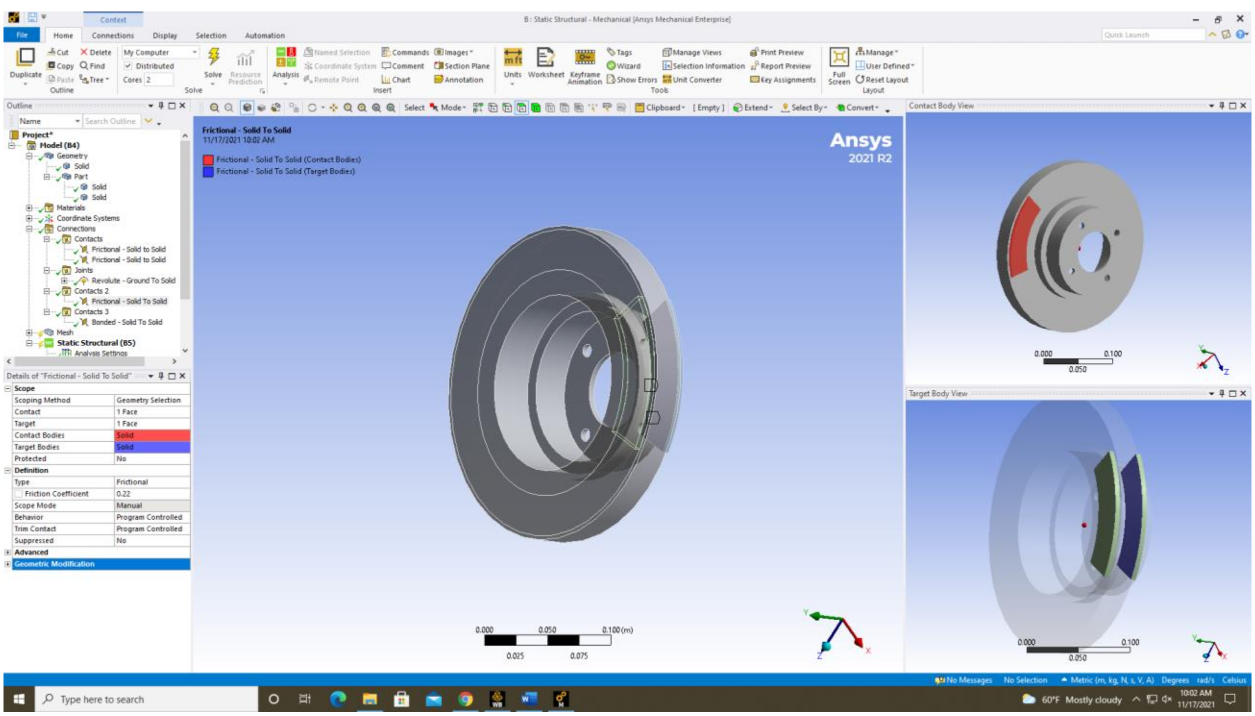
Details of "Gray Cast Iron Assignment"

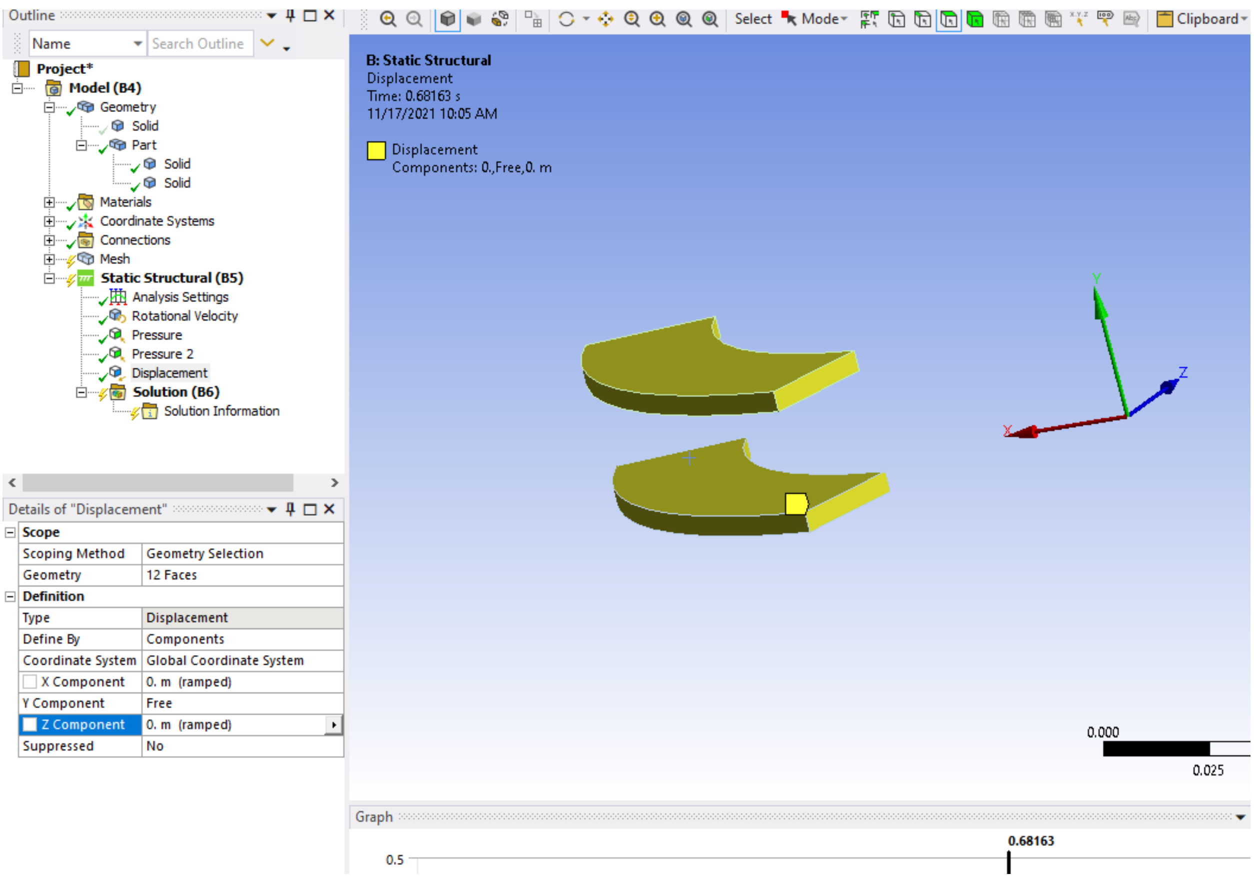
General	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Material Name	Gray Cast Iron
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Reference Temperature	By Environment
Suppressed	No
Common Material Properties	
Density	7200 kg/m³
Young's Modulus	1.1e+11 Pa
Thermal Conductivity	52 W/m·°C
Specific Heat	447 J/kg·°C
Tensile Yield Strength	0 Pa
Tensile Ultimate Strength	2.4e+08 Pa
Nonlinear Behavior	False
Full Details	Click To View Full Details

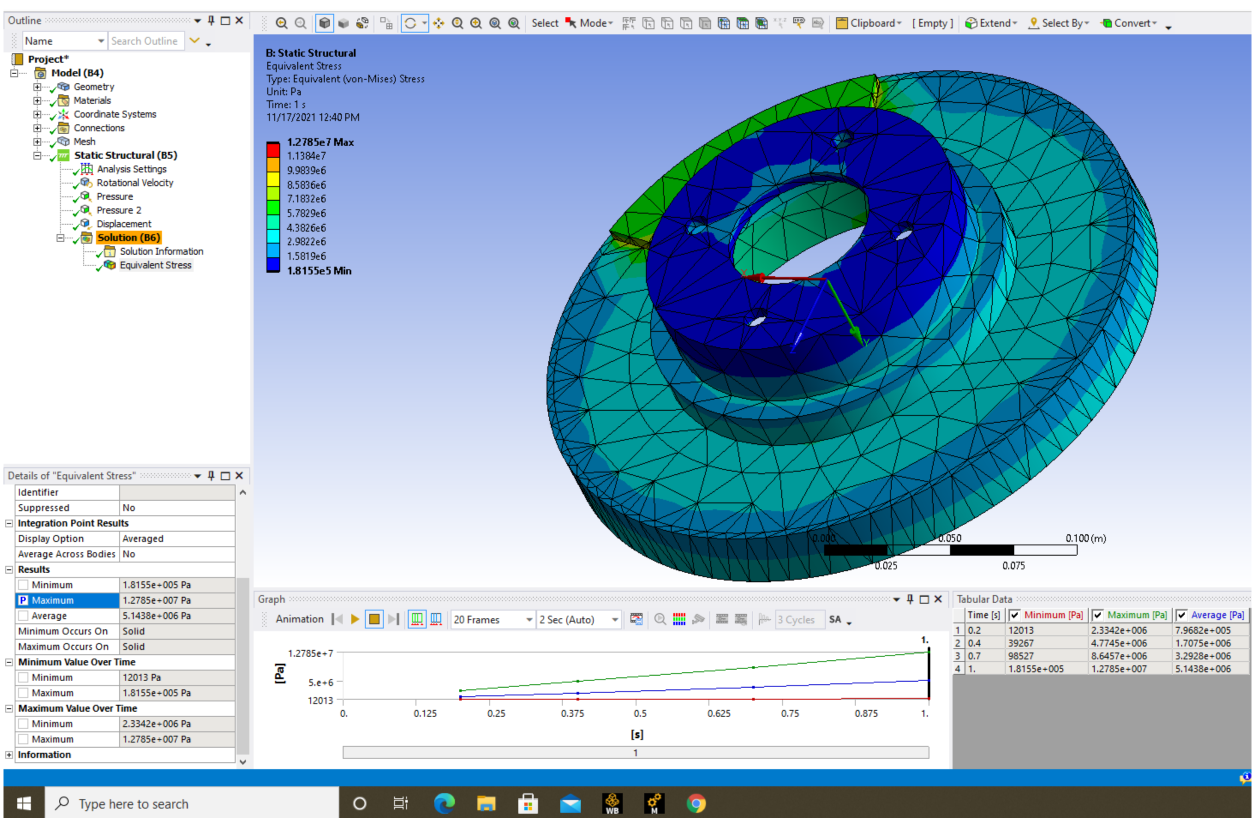





Outline
Model (B4)
Geometry
Solid
Part
Solid
Solid
Materials
Coordinate Systems
Connections
Contacts
Frictional - Solid to Solid
Frictional - Solid to Solid
Joints
Revolute - Ground To Solid
Mesh
Static Structural (B5)
Analysis Settings
Rotational Velocity
Pressure
Pressure 2
Solution (B6)
Solution Information
Details of "Pressure 2"
Scope
Scoping Method Geometry Selection
Geometry 1 Face
Definition
Type Pressure
Define By Normal To
Applied By Surface Effect
Loaded Area Deformed
Magnitude 1.0495e+007 Pa (ramped)
Suppressed No
B: Static Structural
Pressure 2
Time: 0.68163 s
11/17/2021 9:57 AM
Pressure 2: 1.0495e+007 Pa
0.000
0.050
0.100
0.150
Graph
0.68163
1.0495e+7
7.5e+6
5.e+6
2.5e+6
0.
1.
Tabular Data
Steps Time [s] Pressure [Pa]
1 1 0. = 0.
2 1 1. 1.0495e+007


B : Static Structural - Mechanical [Ansys Mechanical Enterprise]
Frictional - Solid To Solid
11/17/2021 10:02 AM
Frictional - Solid To Solid (Contact Bodies)
Frictional - Solid To Solid (Target Bodies)
Ansys
2021 R2
Contact Body View
Target Body View
Details of "Frictional - Solid To Solid"
Scoping Method Geometry Selection
Contact 1 Face
Target 1 Face
Contact Bodies Solid
Target Bodies Solid
Protected No
Type Frictional
Friction Coefficient 0.22
Scope Mode Manual
Behavior Program Controlled
Trim Contact Program Controlled
Suppressed No
Advanced
Geometric Modification

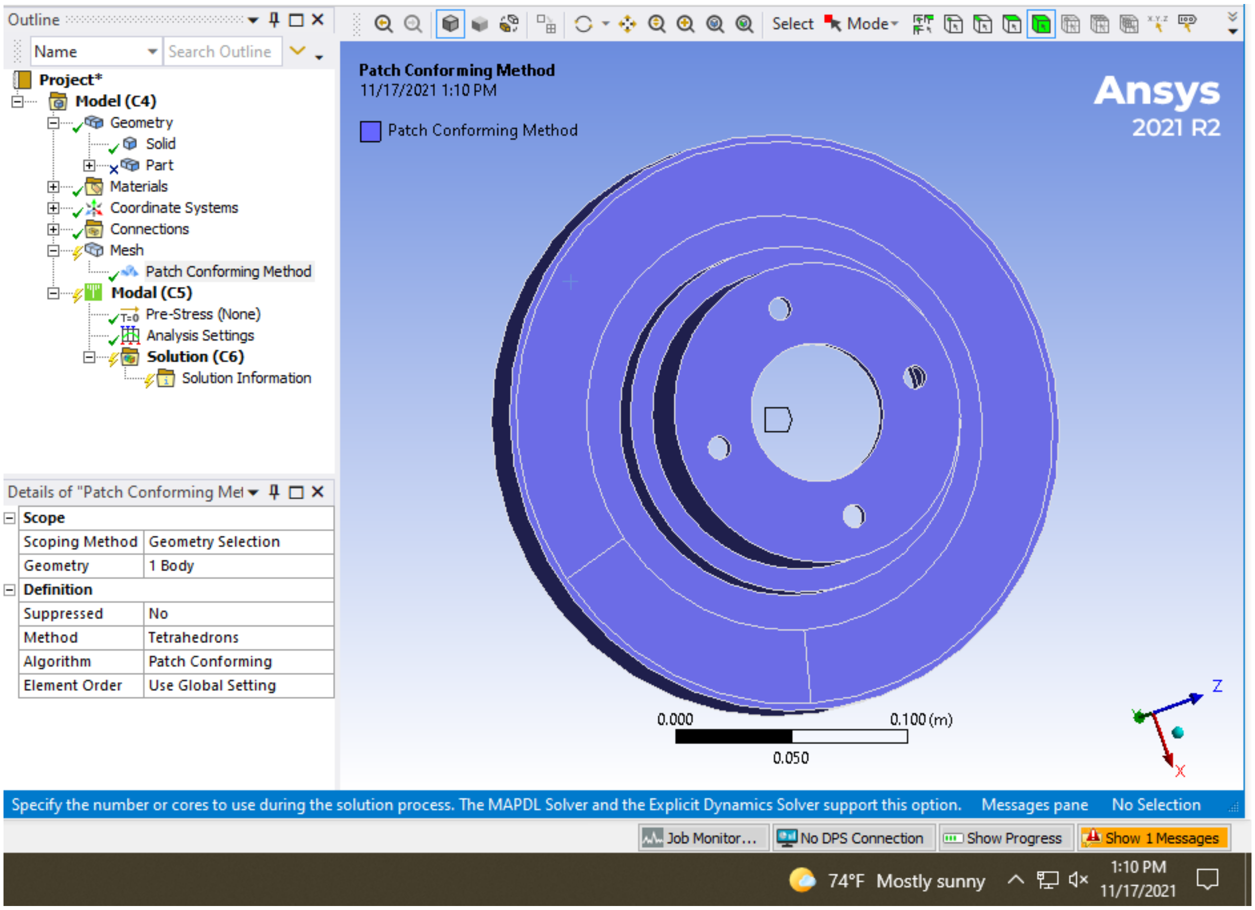

Outline
Project*
Model (B4)
Geometry
Solid
Part
Solid
Solid
Materials
Coordinate Systems
Connections
Mesh
Static Structural (B5)
Analysis Settings
Rotational Velocity
Pressure
Pressure 2
Displacement
Solution (B6)
Solution Information
Details of "Displacement"
Scope
Scoping Method Geometry Selection
Geometry 12 Faces
Definition
Type Displacement
Define By Components
Coordinate System Global Coordinate System
X Component 0. m (ramped)
Y Component Free
Z Component 0. m (ramped)
Suppressed No
B: Static Structural
Displacement
Time: 0.68163 s
11/17/2021 10:05 AM
Displacement
Components: 0.,Free,0. m
0.000
0.025
Graph
0.68163
0.5

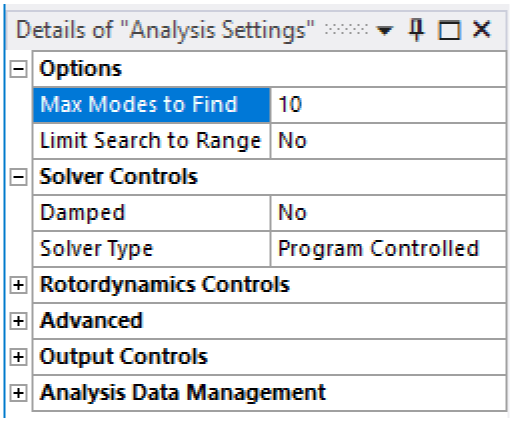

Outline
Project*
Model (B4)
Geometry
Materials
Coordinate Systems
Connections
Mesh
Static Structural (B5)
Analysis Settings
Rotational Velocity
Pressure
Pressure 2
Displacement
Solution (B6)
Solution Information
Equivalent Stress
B: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1 s
11/17/2021 12:40 PM
1.2785e7 Max
1.1384e7
9.9839e6
8.5836e6
7.1832e6
5.7829e6
4.3826e6
2.9822e6
1.5819e6
1.8155e5 Min
Details of "Equivalent Stress"
Integration Point Results
Display Option Averaged
Average Across Bodies No
Results
Minimum 1.8155e+005 Pa
Maximum 1.2785e+007 Pa
Average 5.1438e+006 Pa
Minimum Occurs On Solid
Maximum Occurs On Solid
Minimum Value Over Time
Minimum 12013 Pa
Maximum 1.8155e+005 Pa
Maximum Value Over Time
Minimum 2.3342e+006 Pa
Maximum 1.2785e+007 Pa
Information
Graph
Animation
20 Frames
2 Sec (Auto)
Tabular Data
Time [s] Minimum [Pa] Maximum [Pa] Average [Pa]
1 0.2 12013 2.3342e+006 7.9682e+005
2 0.4 39267 4.7745e+006 1.7075e+006
3 0.7 98527 8.6457e+006 3.2928e+006
4 1. 1.8155e+005 1.2785e+007 5.1438e+006
Type here to search

Modal Setup:

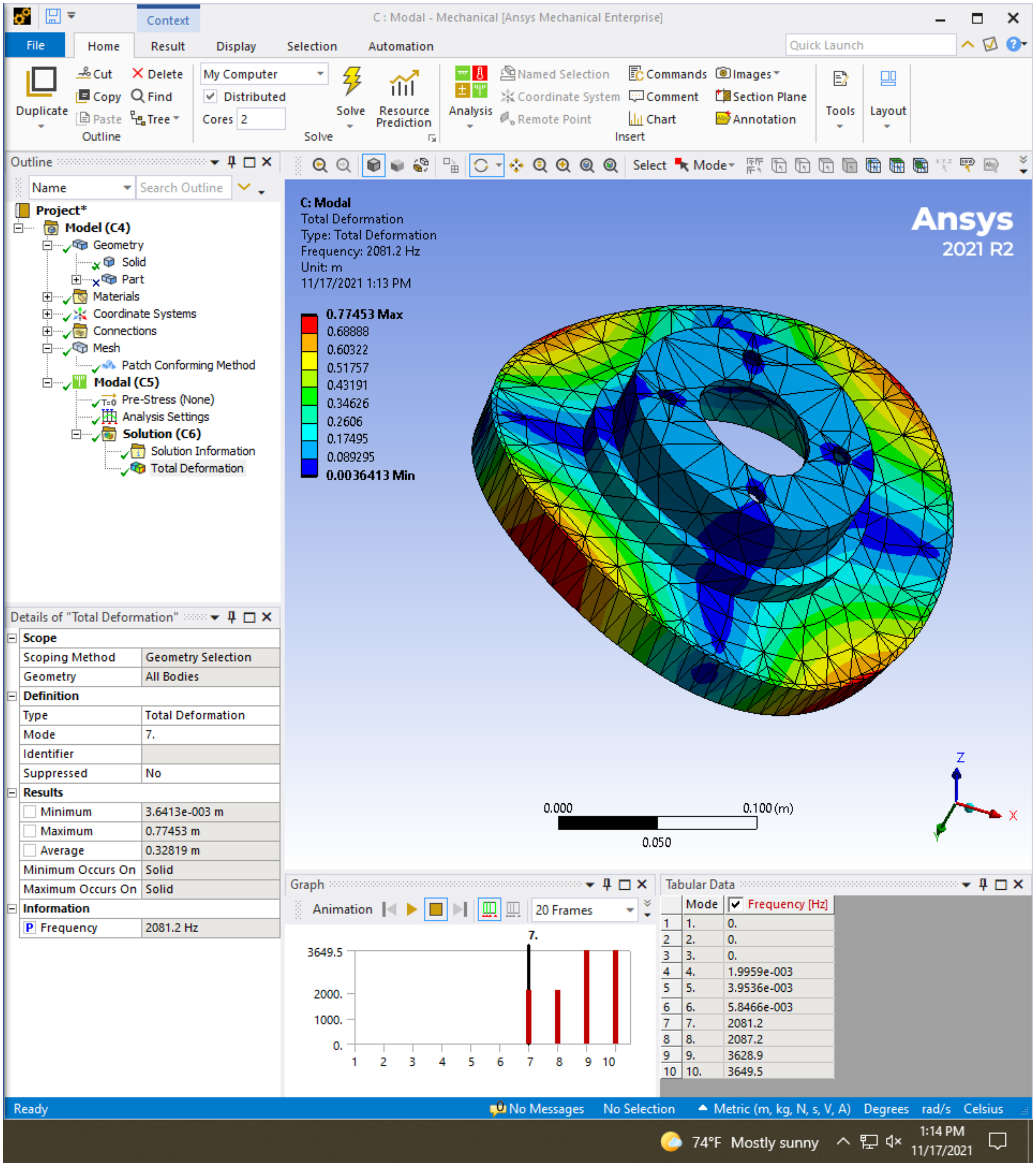
Given:

Free modal analysis is performed to ensure that the disc's first natural frequency is higher than the engine firing frequency. This guarantees that the disc does not experience failure due to resonance.




Details of "Analysis Settings"

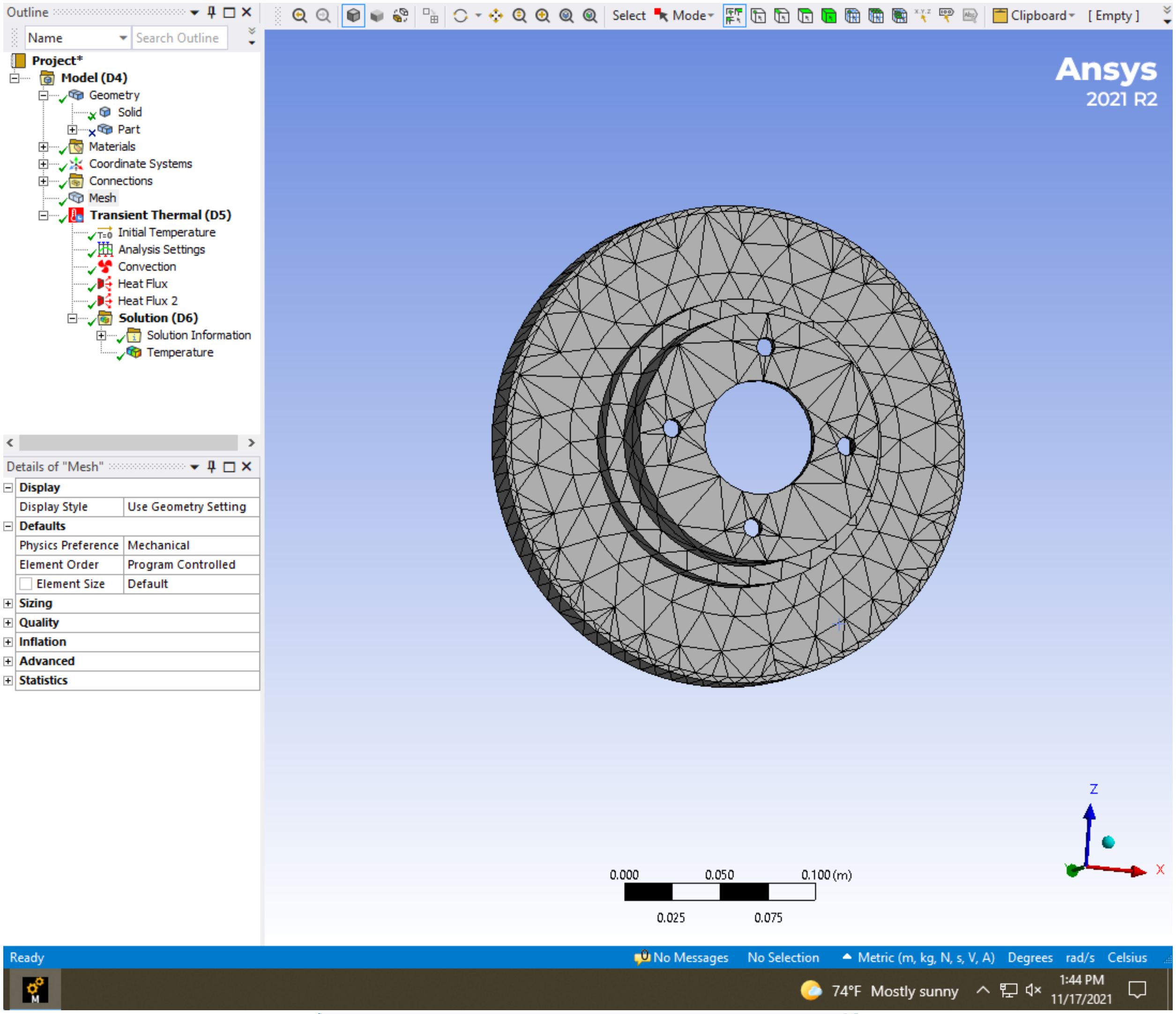
Options	
Max Modes to Find	10
Limit Search to Range	No
Solver Controls	
Damped	No
Solver Type	Program Controlled
Rotordynamics Controls	
Advanced	
Output Controls	
Analysis Data Management	

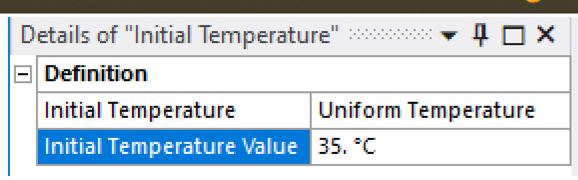


Transient Thermal Setup:

Given:

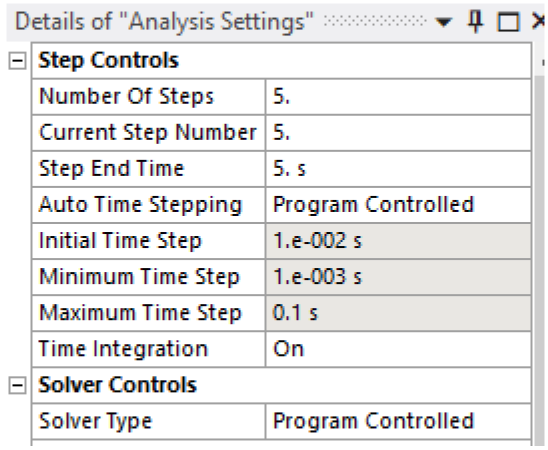
Braking in a vehicle takes place due to friction between the brake pads and the rotor disc. This leads to heat flux generation in the disc which consequently results in increase in its temperature and thermal stresses. Emergency braking conditions induce high temperatures that damage the *contact surfaces. It is therefore essential to minimize the temperature to prevent disc wear and tear.*





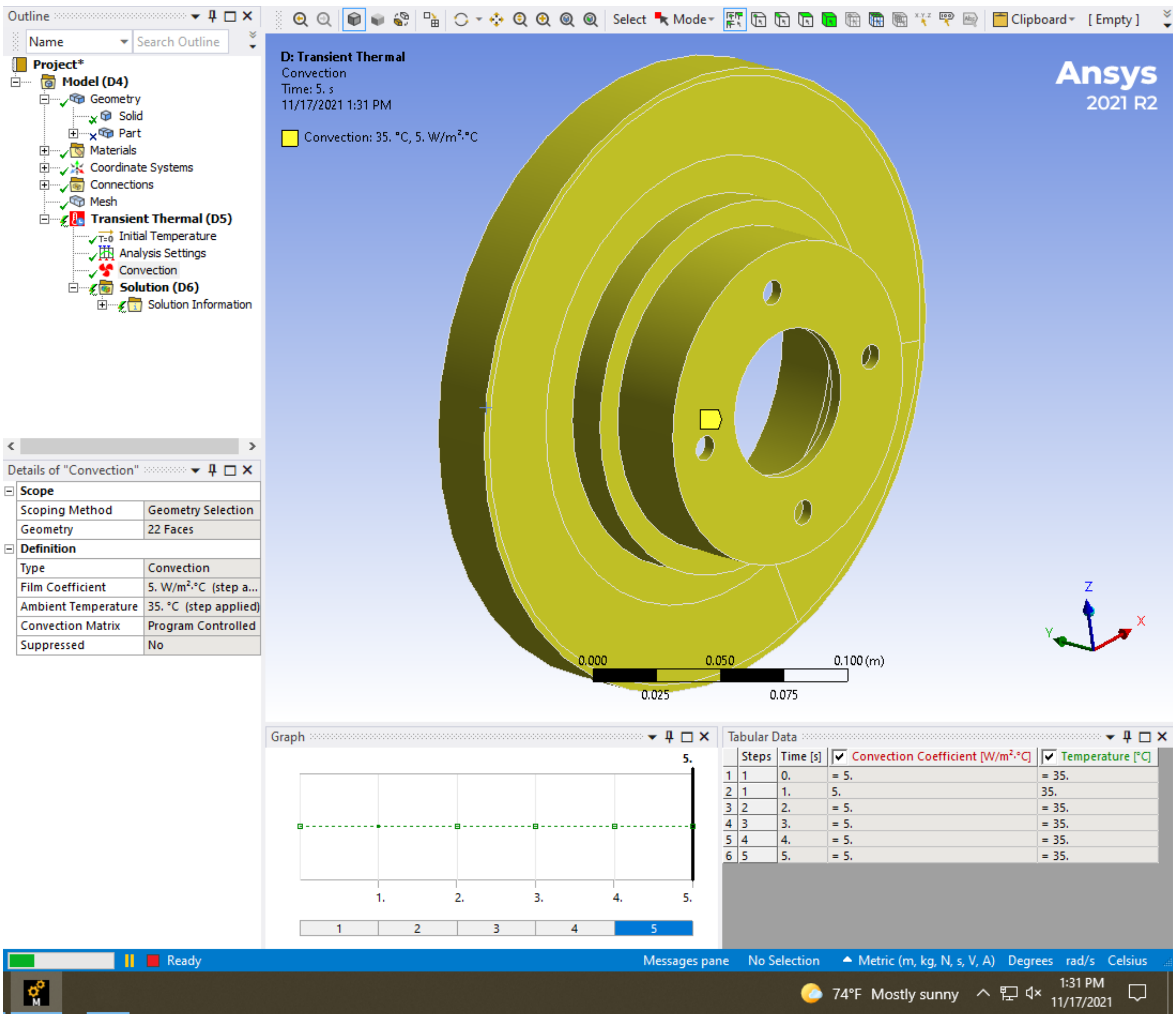
Details of "Initial Temperature"

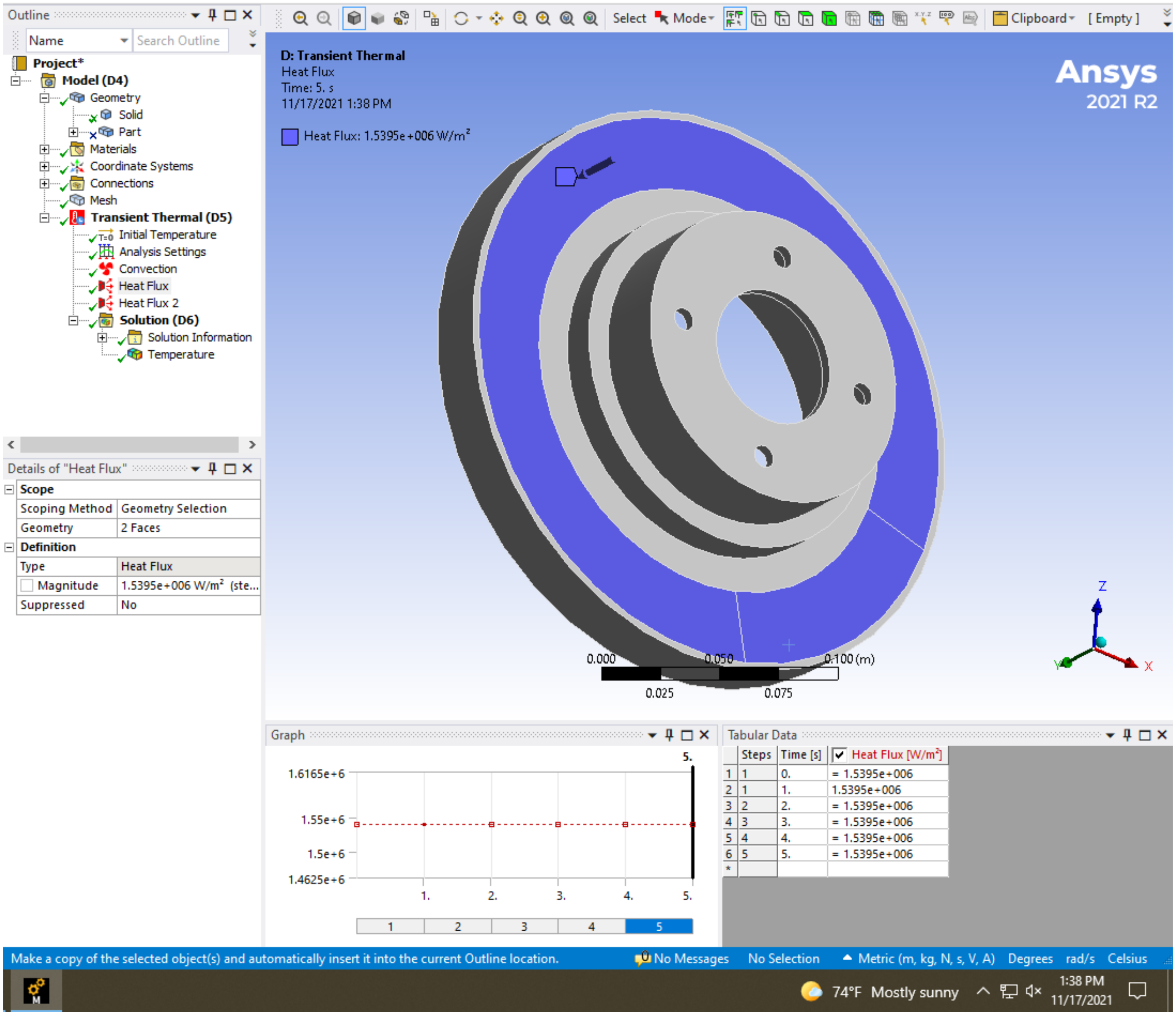
Definition	
Initial Temperature	Uniform Temperature
Initial Temperature Value	35. °C

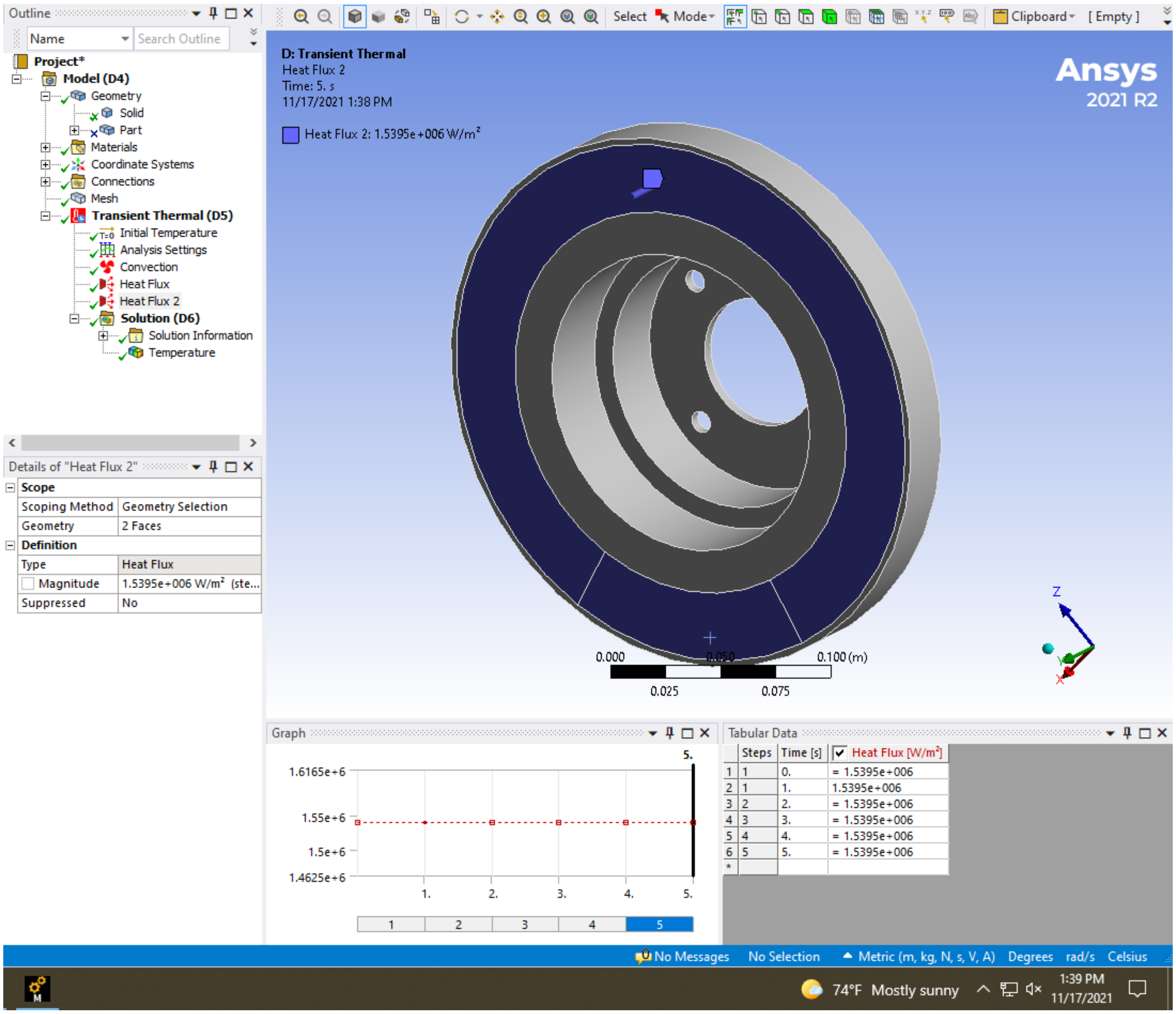


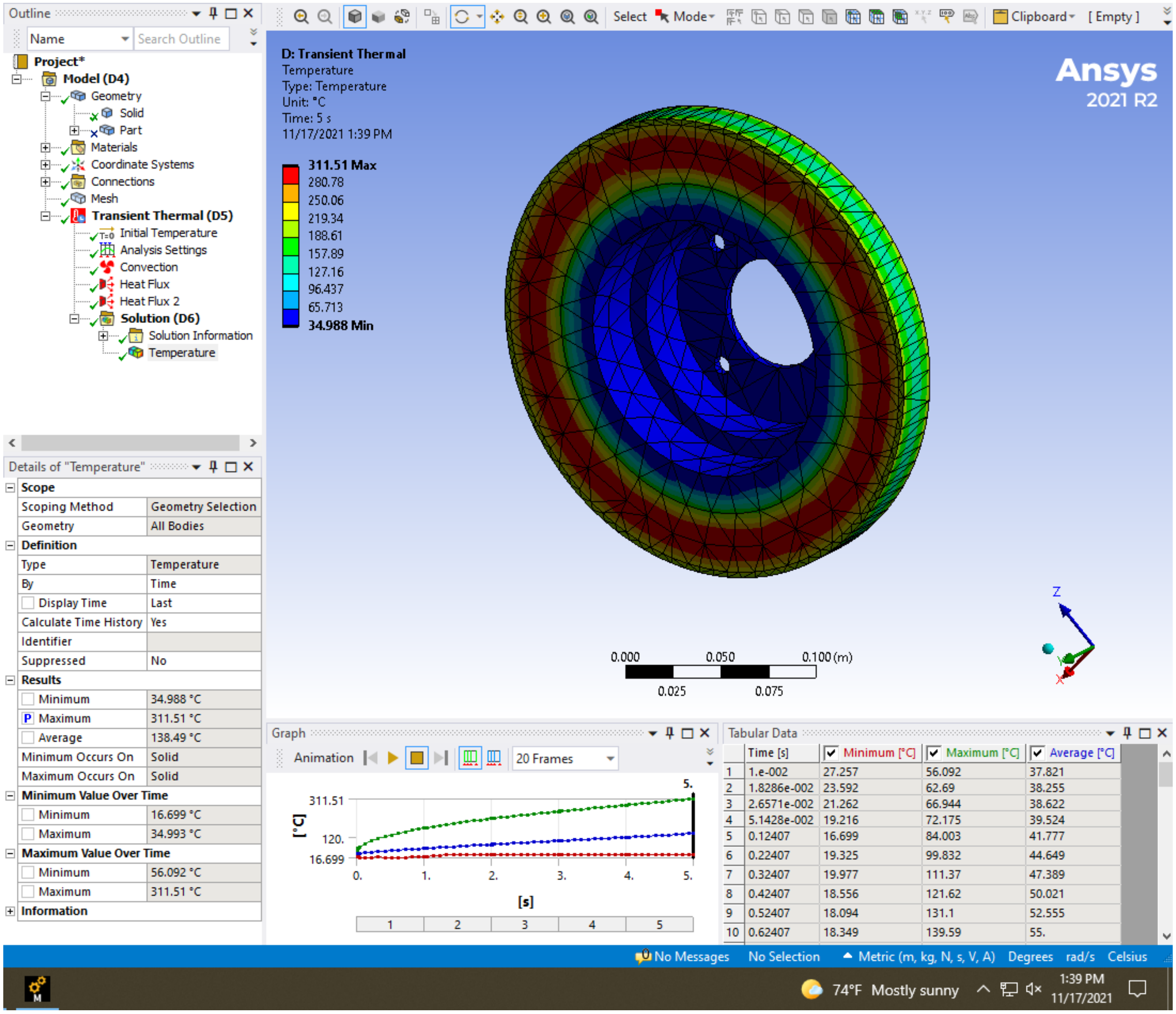
Details of "Analysis Settings"

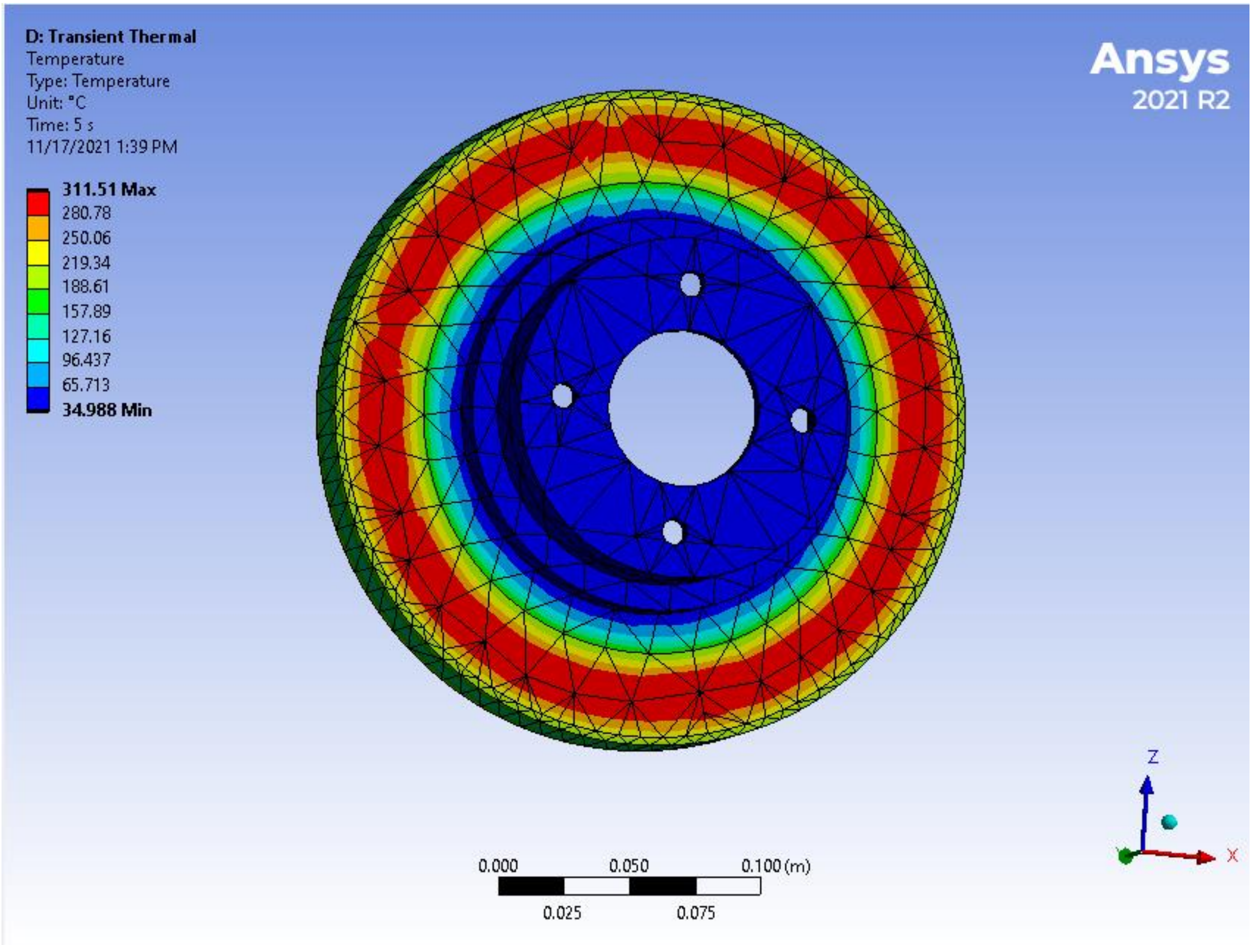
Step Controls	
Number Of Steps	5.
Current Step Number	5.
Step End Time	5. s
Auto Time Stepping	Program Controlled
Initial Time Step	1.e-002 s
Minimum Time Step	1.e-003 s
Maximum Time Step	0.1 s
Time Integration	On
Solver Controls	
Solver Type	Program Controlled



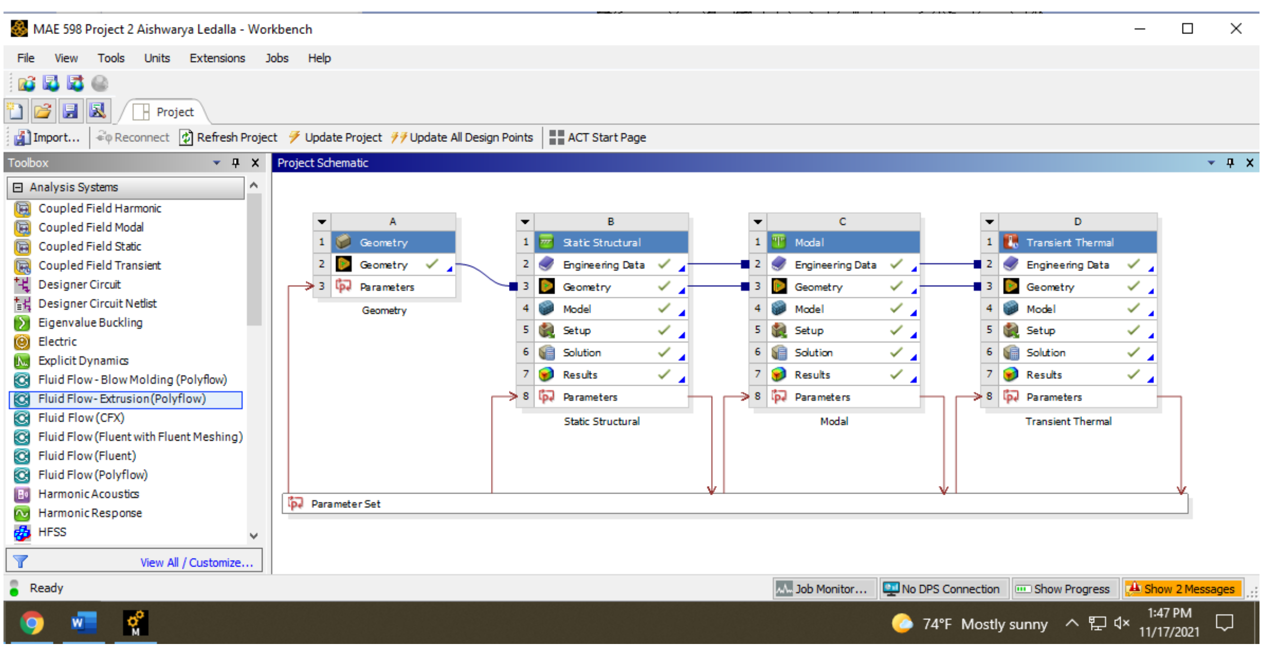

Outline
Project*
Model (D4)
Geometry
Solid
Part
Materials
Coordinate Systems
Connections
Mesh
Transient Thermal (D5)
Initial Temperature
Analysis Settings
Convection
Heat Flux
Heat Flux 2
Solution (D6)
Solution Information
Temperature
Details of "Heat Flux"
Scope
Scoping Method Geometry Selection
Geometry 2 Faces
Definition
Type Heat Flux
Magnitude 1.5395e+006 W/m² (ste...
Suppressed No
D: Transient Thermal
Heat Flux
Time: 5. s
11/17/2021 1:38 PM
Heat Flux: 1.5395e+006 W/m²
Ansys
2021 R2
Graph
Tabular Data
Steps Time [s] Heat Flux [W/m²]
1 1 0. = 1.5395e+006
2 1 1. 1.5395e+006
3 2 2. = 1.5395e+006
4 3 3. = 1.5395e+006
5 4 4. = 1.5395e+006
6 5 5. = 1.5395e+006
Make a copy of the selected object(s) and automatically insert it into the current Outline location.
No Messages No Selection Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
74°F Mostly sunny
1:38 PM
11/17/2021


Outline
Project*
Model (D4)
Geometry
Solid
Part
Materials
Coordinate Systems
Connections
Mesh
Transient Thermal (D5)
Initial Temperature
Analysis Settings
Convection
Heat Flux
Heat Flux 2
Solution (D6)
Solution Information
Temperature
Details of "Heat Flux 2"
Scope
Scoping Method Geometry Selection
Geometry 2 Faces
Definition
Type Heat Flux
Magnitude 1.5395e+006 W/m² (ste...
Suppressed No
D: Transient Thermal
Heat Flux 2
Time: 5. s
11/17/2021 1:38 PM
Heat Flux 2: 1.5395e+006 W/m²
Ansys
2021 R2
0.000
0.050
0.100 (m)
0.025
0.075
Graph
1.6165e+6
1.55e+6
1.5e+6
1.4625e+6
Tabular Data
Steps Time [s] Heat Flux [W/m²]
1 1 0. = 1.5395e+006
2 1 1. 1.5395e+006
3 2 2. = 1.5395e+006
4 3 3. = 1.5395e+006
5 4 4. = 1.5395e+006
6 5 5. = 1.5395e+006
No Messages
No Selection
Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
74°F Mostly sunny
1:39 PM
11/17/2021


Outline
Project*
Model (D4)
Geometry
Solid
Part
Materials
Coordinate Systems
Connections
Mesh
Transient Thermal (D5)
Initial Temperature
Analysis Settings
Convection
Heat Flux
Heat Flux 2
Solution (D6)
Solution Information
Temperature
D: Transient Thermal
Temperature
Type: Temperature
Unit: °C
Time: 5 s
11/17/2021 1:39 PM
311.51 Max
280.78
250.06
219.34
188.61
157.89
127.16
96.437
65.713
34.988 Min
Ansys
2021 R2
0.000 0.050 0.100 (m)
0.025 0.075
Details of "Temperature"
Scope
Scoping Method Geometry Selection
Geometry All Bodies
Definition
Type Temperature
By Time
Display Time Last
Calculate Time History Yes
Identifier
Suppressed No
Results
Minimum 34.988 °C
Maximum 311.51 °C
Average 138.49 °C
Minimum Occurs On Solid
Maximum Occurs On Solid
Minimum Value Over Time
Minimum 16.699 °C
Maximum 34.993 °C
Maximum Value Over Time
Minimum 56.092 °C
Maximum 311.51 °C
Information
Graph
Animation 20 Frames
311.51
120.
16.699
[°C]
0. 1. 2. 3. 4. 5.
[s]
Tabular Data
Time [s] Minimum [°C] Maximum [°C] Average [°C]
1 1.e-002 27.257 56.092 37.821
2 1.8286e-002 23.592 62.69 38.255
3 2.6571e-002 21.262 66.944 38.622
4 5.1428e-002 19.216 72.175 39.524
5 0.12407 16.699 84.003 41.777
6 0.22407 19.325 99.832 44.649
7 0.32407 19.977 111.37 47.389
8 0.42407 18.556 121.62 50.021
9 0.52407 18.094 131.1 52.555
10 0.62407 18.349 139.59 55.
No Messages No Selection Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
74°F Mostly sunny 1:39 PM 11/17/2021



Project Schematic:



Design of Experiments:

Sensitivity Analysis:

Optimization:

Checks:

1. **What are your design variables, constraints, and objectives?**

2. **What are the potential trade-offs between your objectives?**

3. **Are your variables continuous? Or are they discrete/integer?**

4. **Do you have analytical objective/constraint functions? And are they differentiable?**

5. **Based on the above answers, what optimization methods will you choose?**

6. **Perform a sensitivity analysis and comment on the importance of your variables? Also, do you observe monotonicity (i.e., the objective always goes up or down with a variable)?**

7. **Compare your optimal design against the initial one (e.g., see the following comparison on the brake disc design) AND comment on whether the optimal design is reasonable.**