Aishwarya Ledalla

MAE 598: Design Optimization

Dr. Max Yi Ren

Project 2:

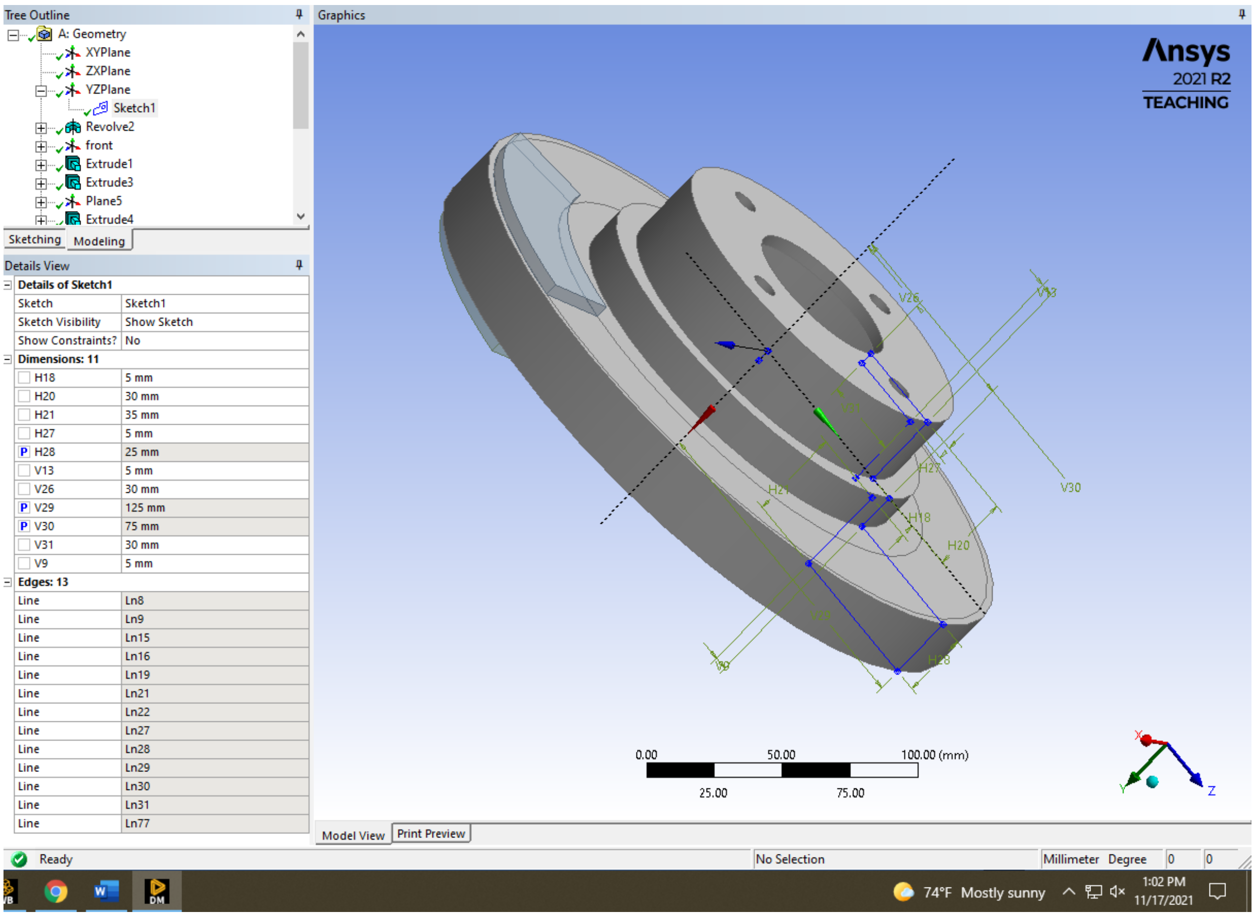
ANSYS DOE and Design Optimization

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:



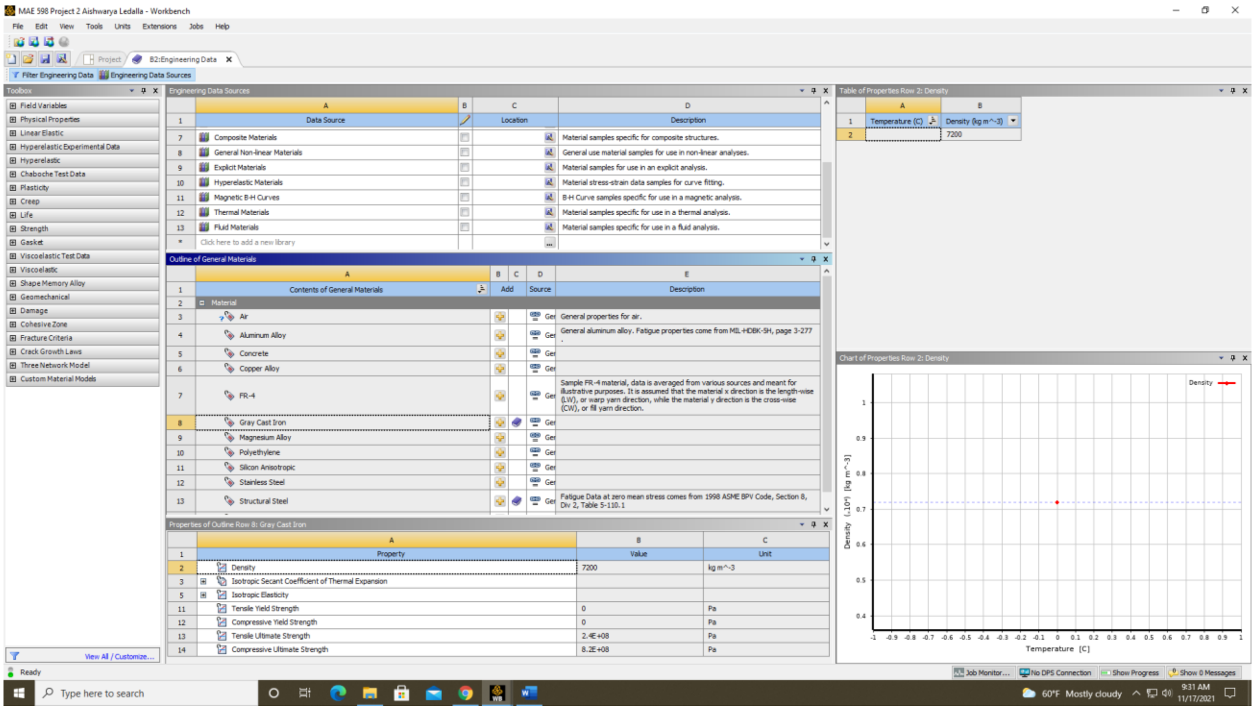
Outline of All Parameters

	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	Input Parameters			
3	Geometry (A1)			
4	P8	rotor_thickness	25	mm
5	P9	rotor_OD	125	mm
6	P10	rotor_ID	75	mm
*	New input parameter	New name	New expression	
8	Output Parameters			
9	Static Structural (B1)			
10	P4	Equivalent Stress Maximum	1.5219E+07	Pa
11	P14	Solid Volume	0.00099667	m^3
12	Modal (C1)			
13	P6	Total Deformation Reported Frequency	2081.2	Hz
14	Transient Thermal (D1)			
15	P7	Temperature Maximum	311.51	C
*	New output parameter		New expression	
17	Charts			

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.

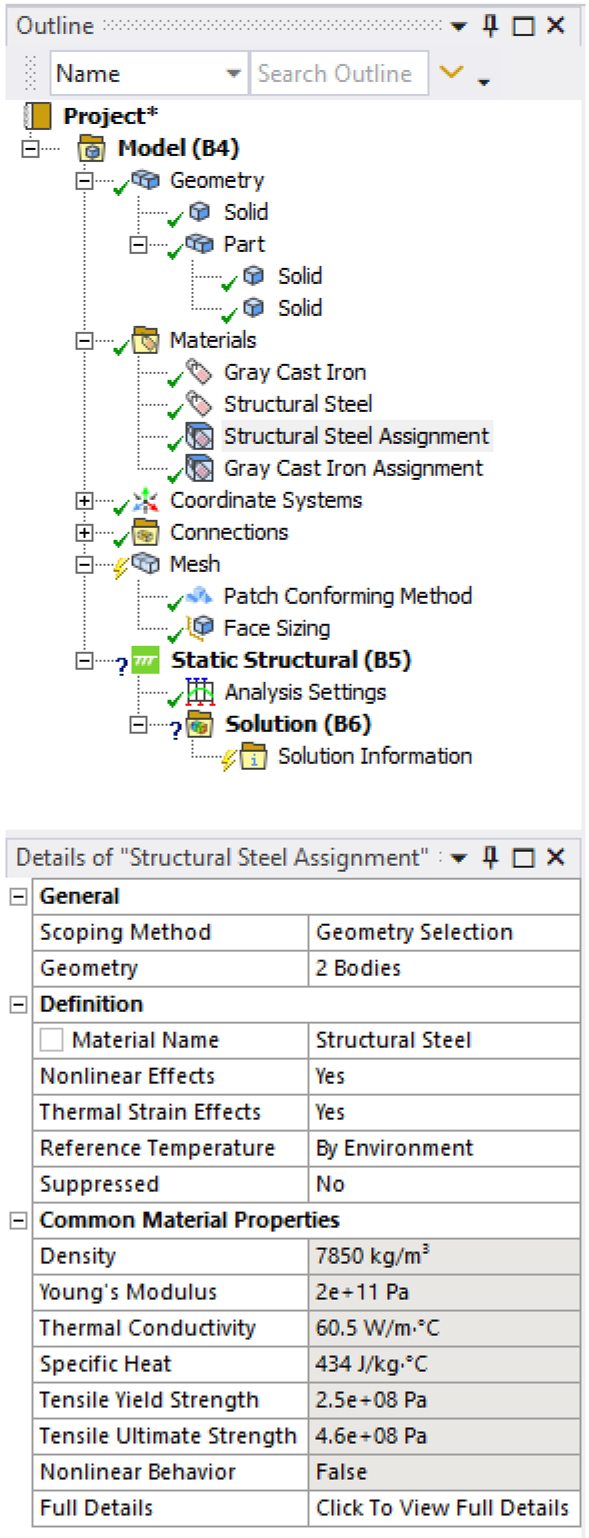


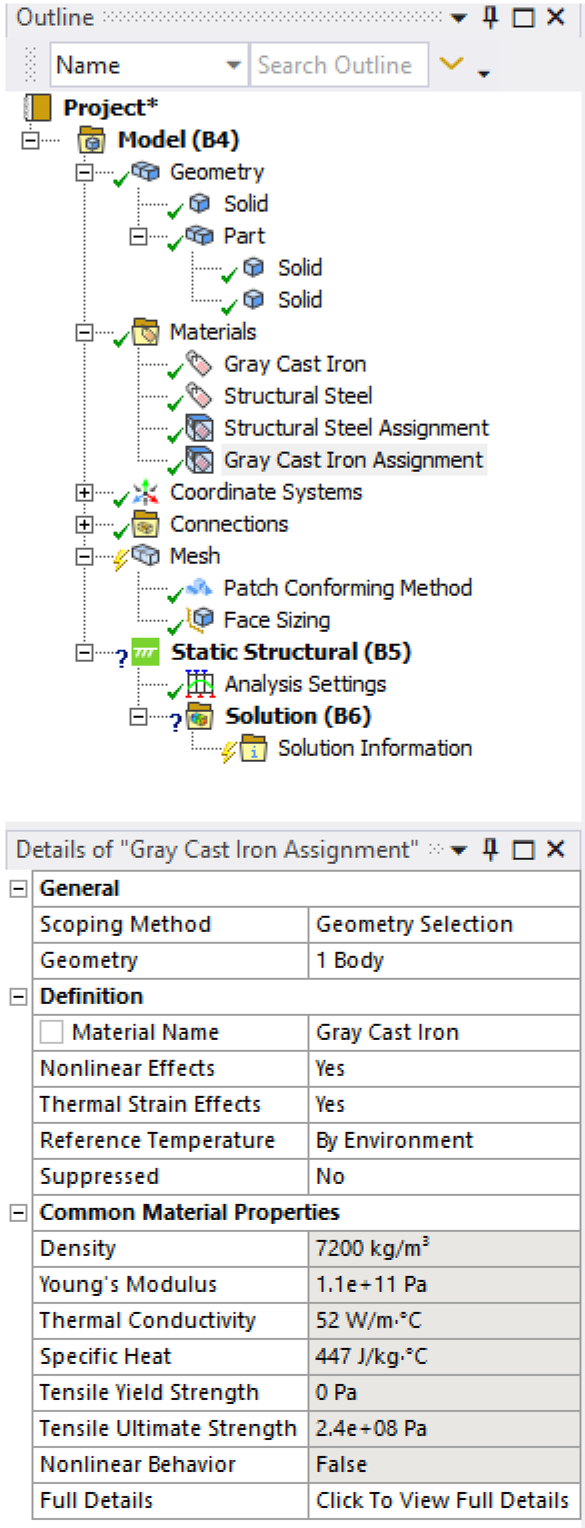
Details of "Patch Conforming Method" -

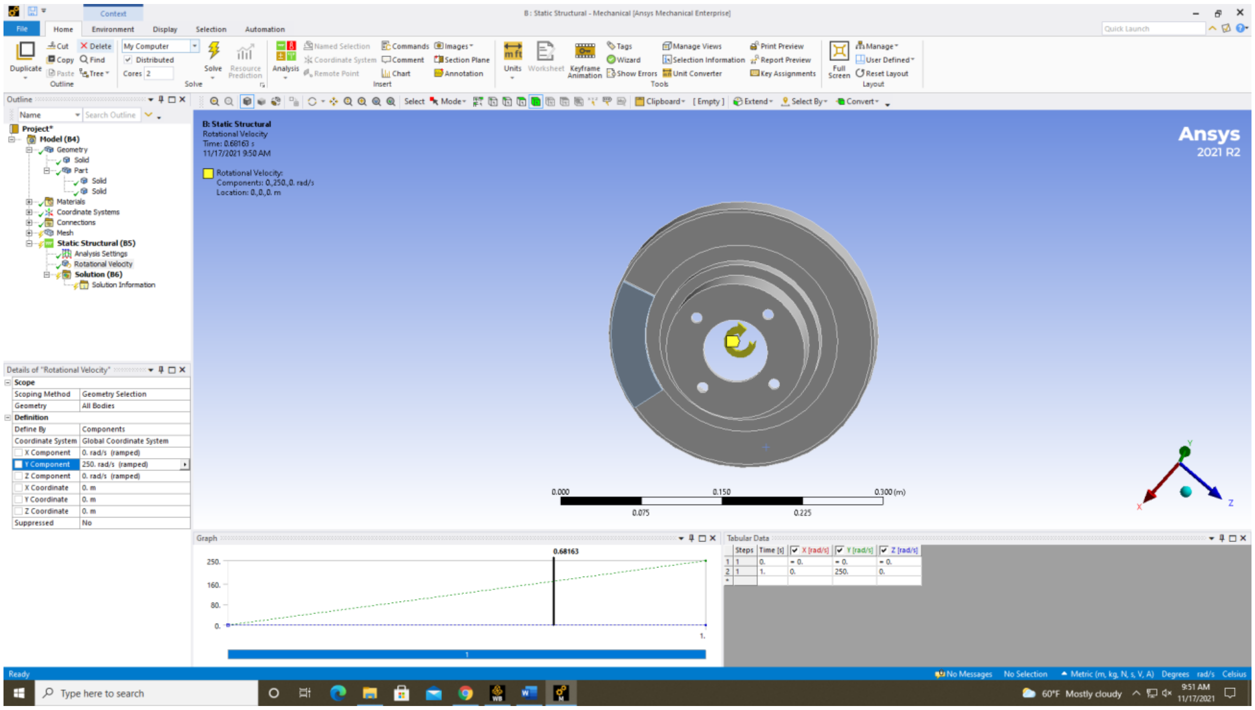
Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Suppressed	No
Method	Tetrahedrons
Algorithm	Patch Conforming
Element Order	Use Global Setting

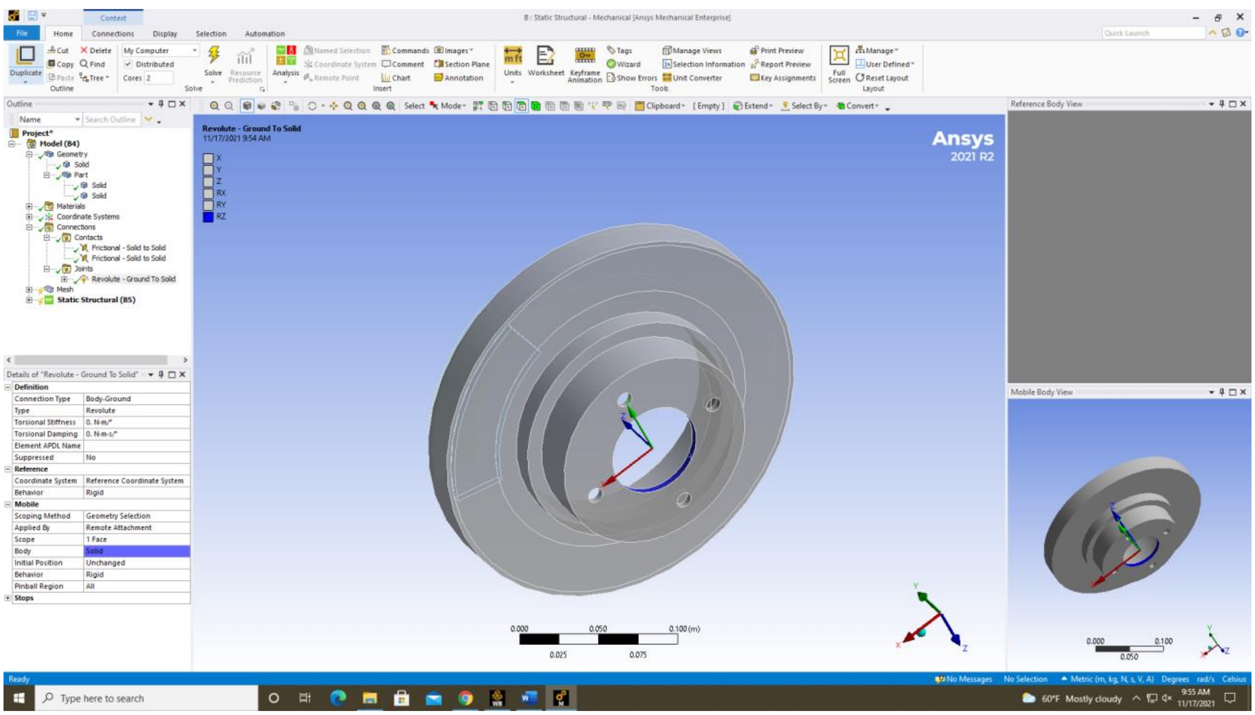
Details of "Face Sizing" - Sizing

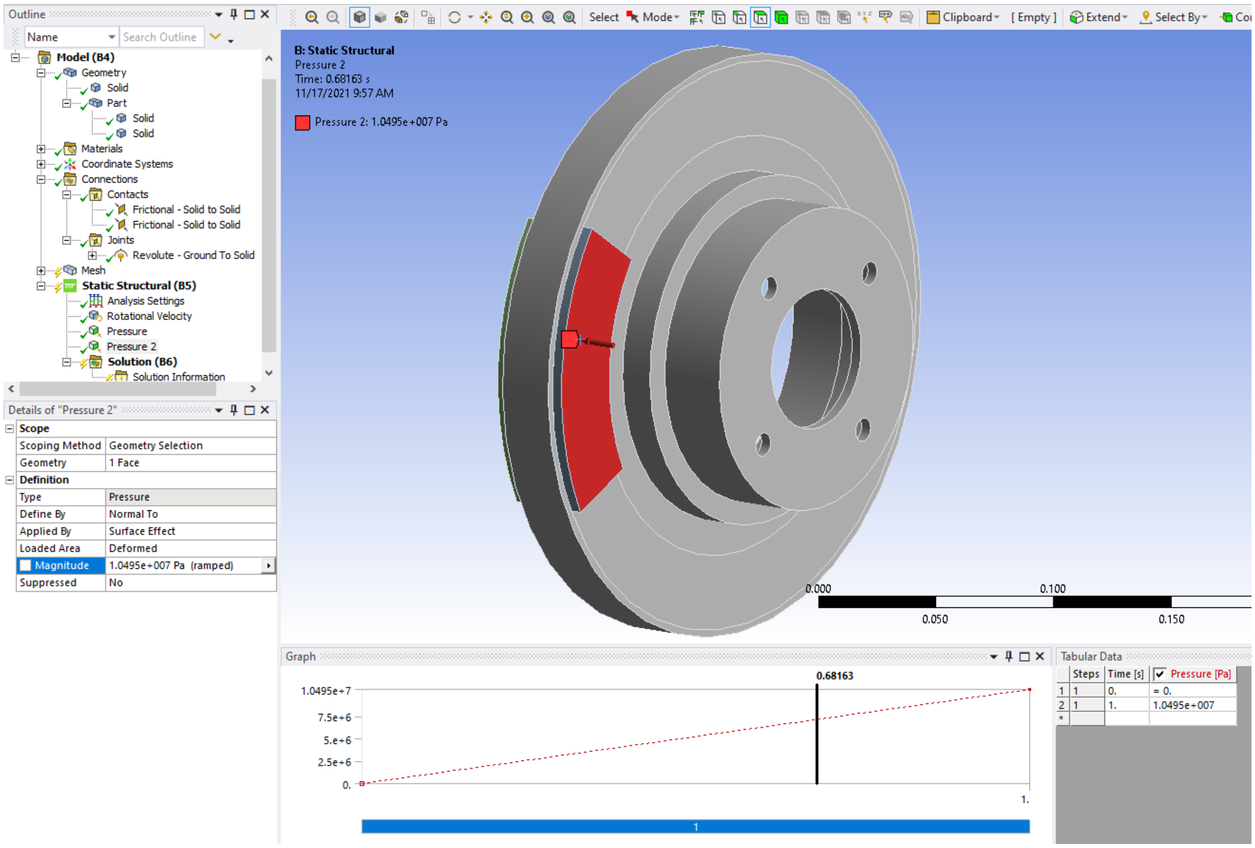
Scope	
Scoping Method	Geometry Selection
Geometry	2 Faces
Definition	
Suppressed	No
Type	Element Size
Element Size	3.e-003 m
Advanced	
Defeature Size	Default
Influence Volume	No
Behavior	Soft

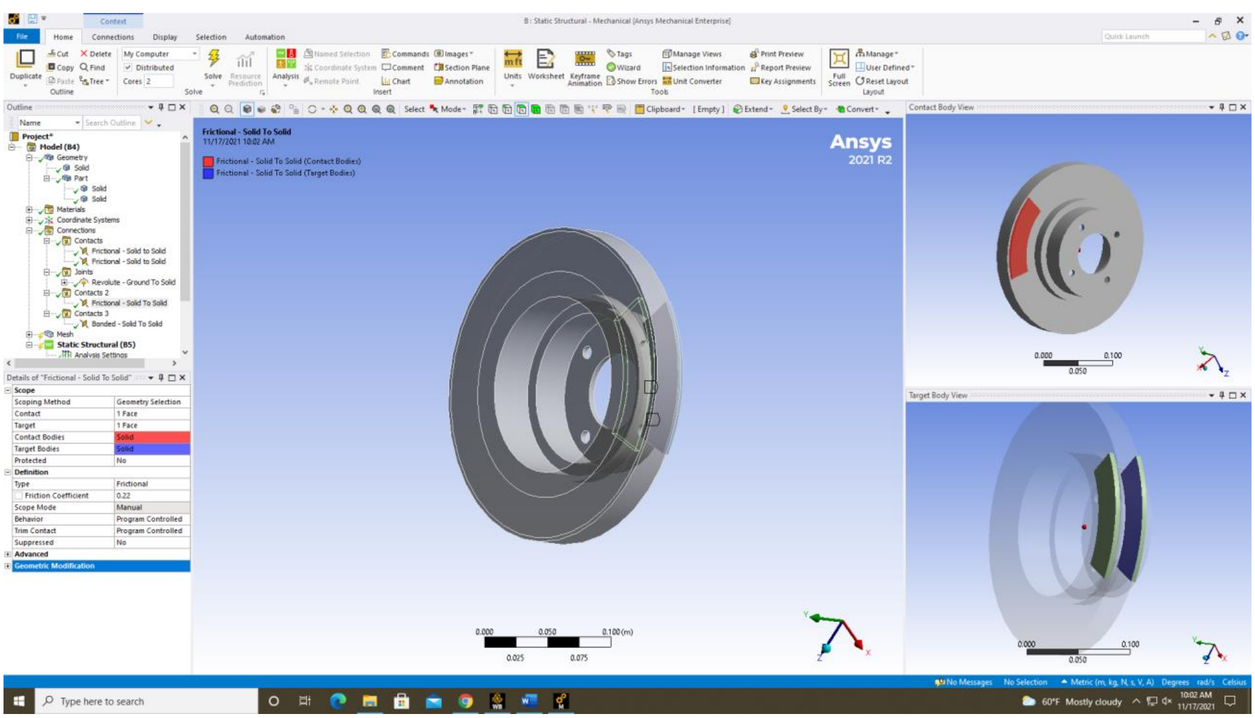

Outline
Name
Search Outline
Project*
Model (B4)
Geometry
Solid
Part
Solid
Solid
Materials
Gray Cast Iron
Structural Steel
Structural Steel Assignment
Gray Cast Iron Assignment
Coordinate Systems
Connections
Mesh
Patch Conforming Method
Face Sizing
Static Structural (B5)
Analysis Settings
Solution (B6)
Solution Information
Details of "Structural Steel Assignment"
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/m³
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

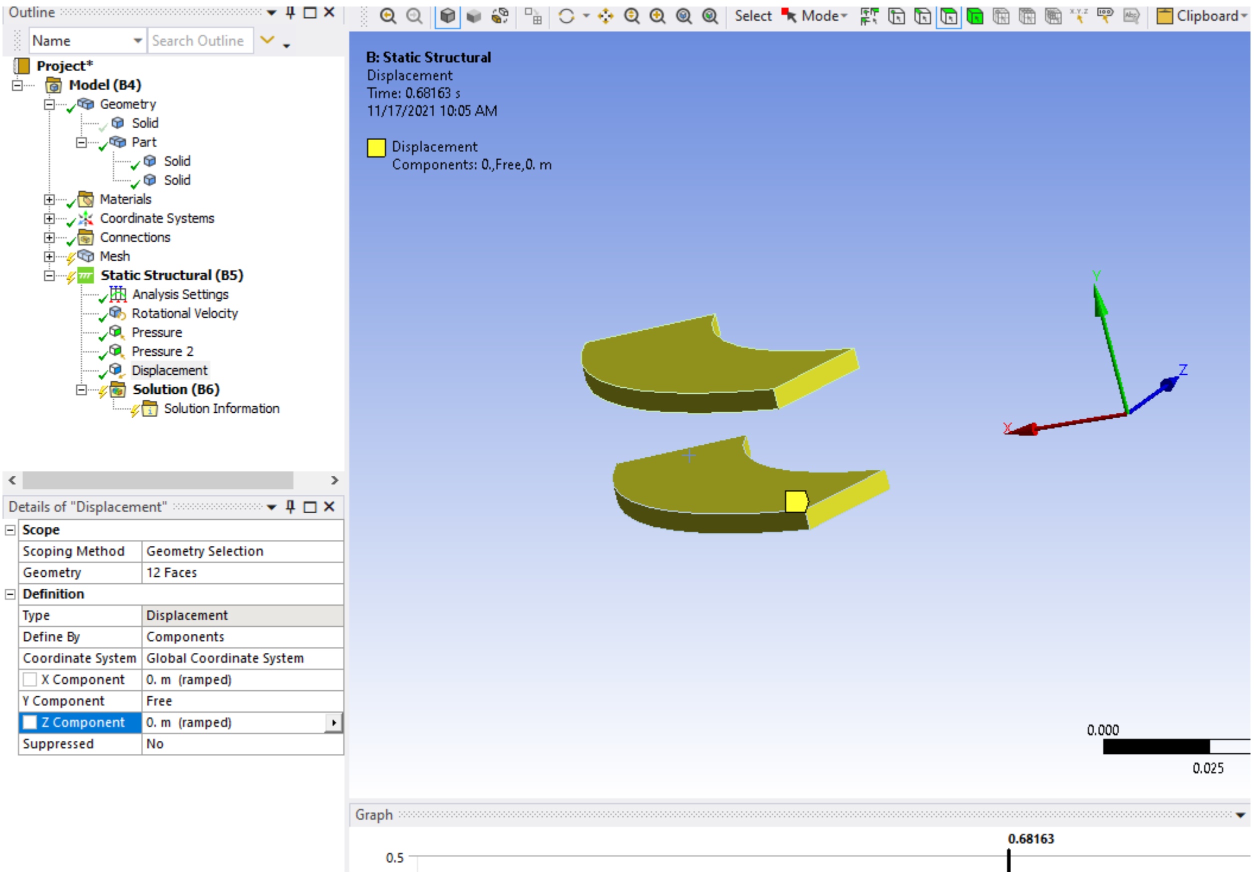

Outline
Name
Search Outline
Project*
Model (B4)
Geometry
Solid
Part
Solid
Solid
Materials
Gray Cast Iron
Structural Steel
Structural Steel Assignment
Gray Cast Iron Assignment
Coordinate Systems
Connections
Mesh
Patch Conforming Method
Face Sizing
Static Structural (B5)
Analysis Settings
Solution (B6)
Solution Information
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

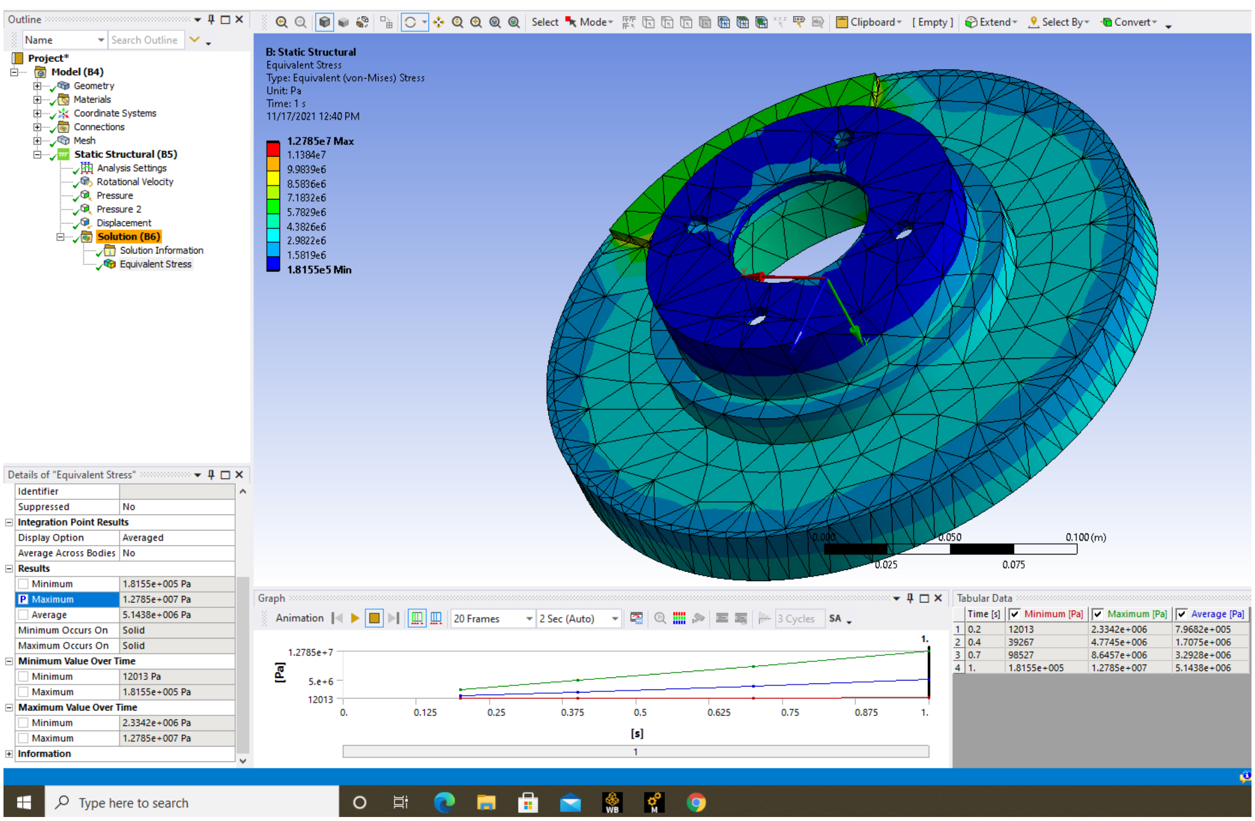

B: Static Structural
Rotational Velocity
Ansys
2021 R2


Revolute - Ground To Solid
Ansys
2021 R2


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


Frictional - Solid To Solid
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"
Type Frictional
Friction Coefficient 0.22

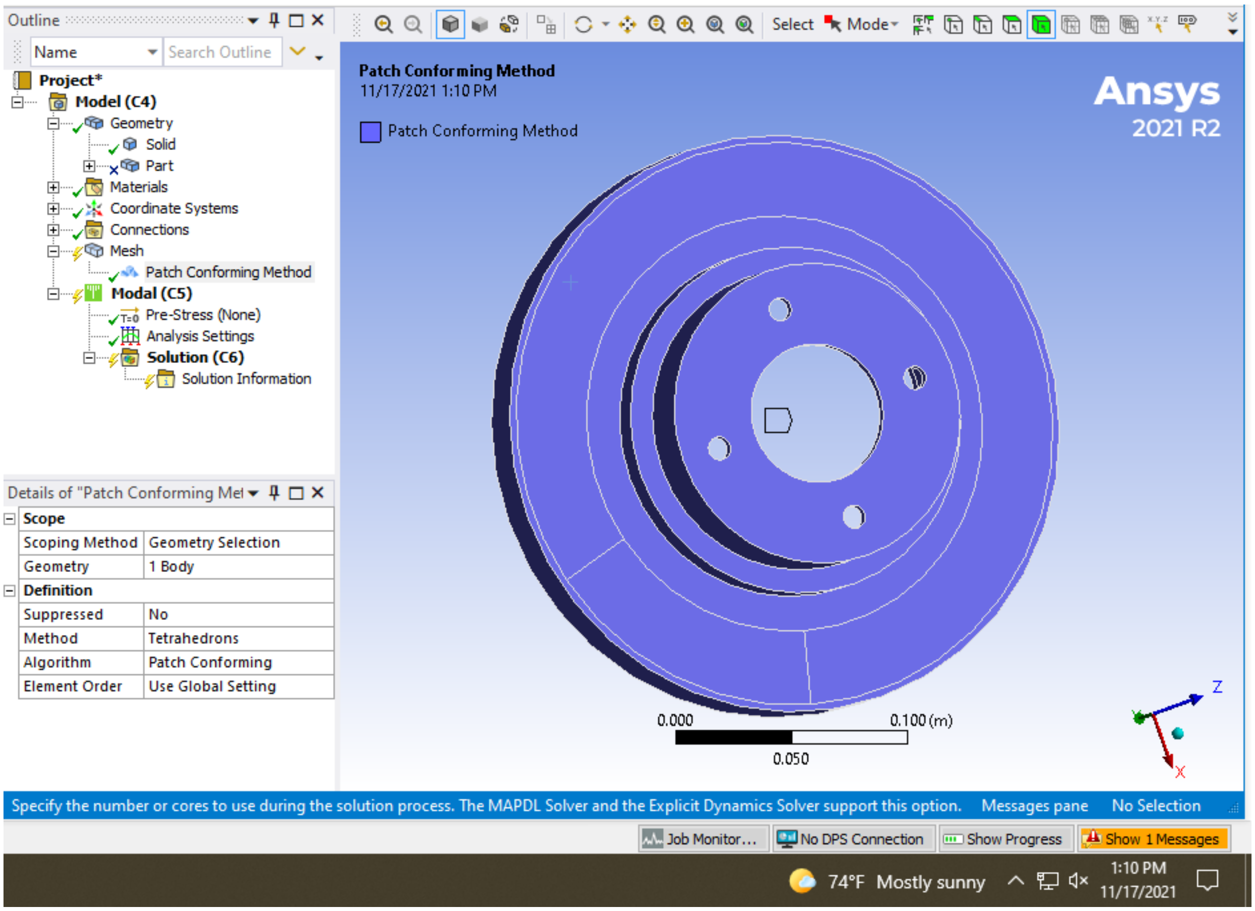


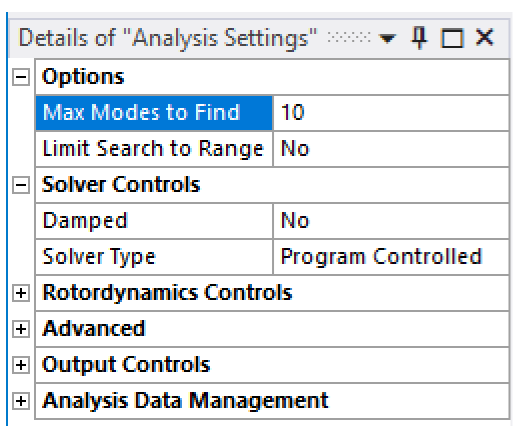


Modal Setup:

Given:

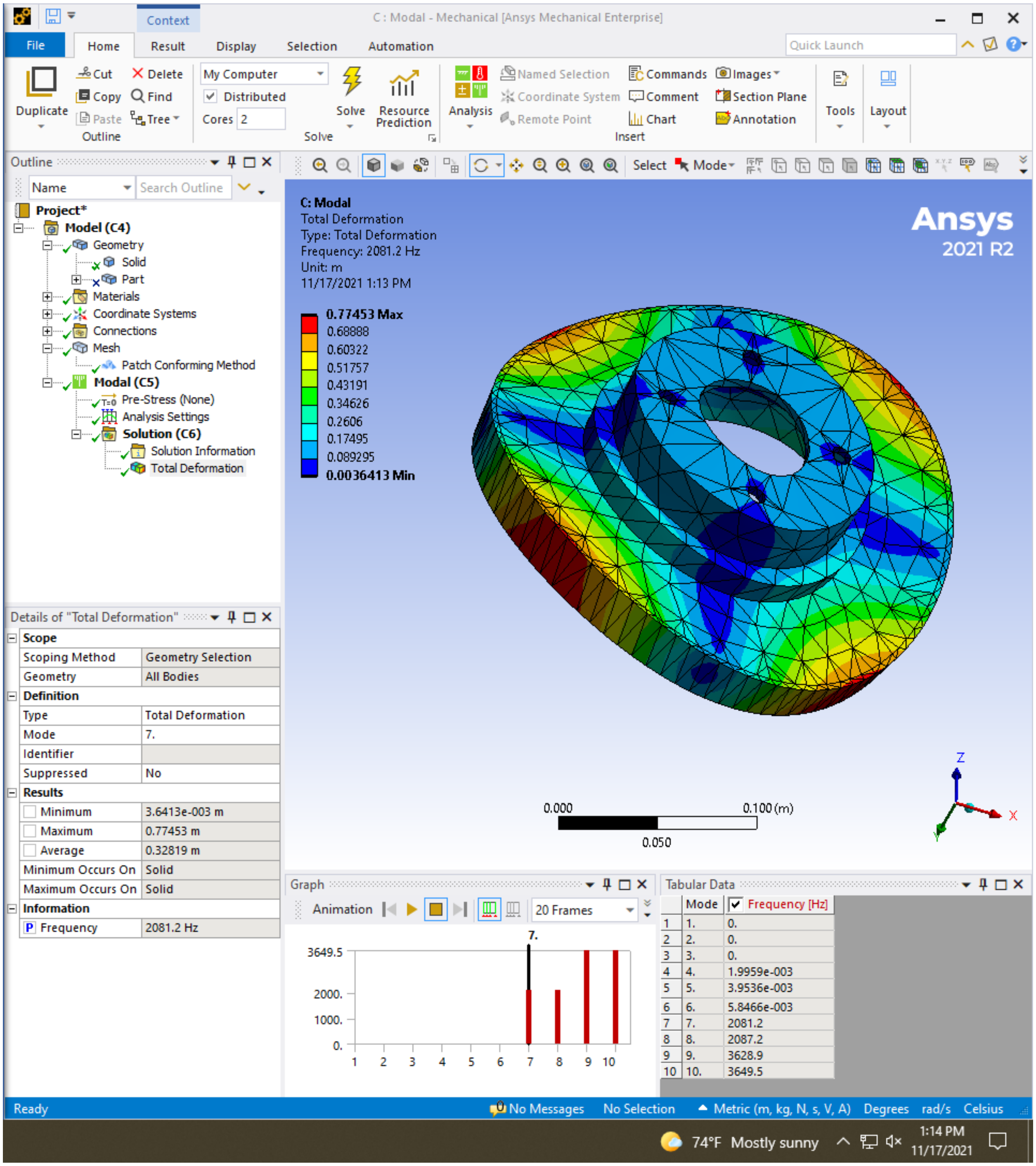
Free modal analysis is performed to ensure that the disc's first natural frequency is higher than the engine firing frequency. This guarantees that the disc does not experience failure due to resonance.





Details of "Analysis Settings"

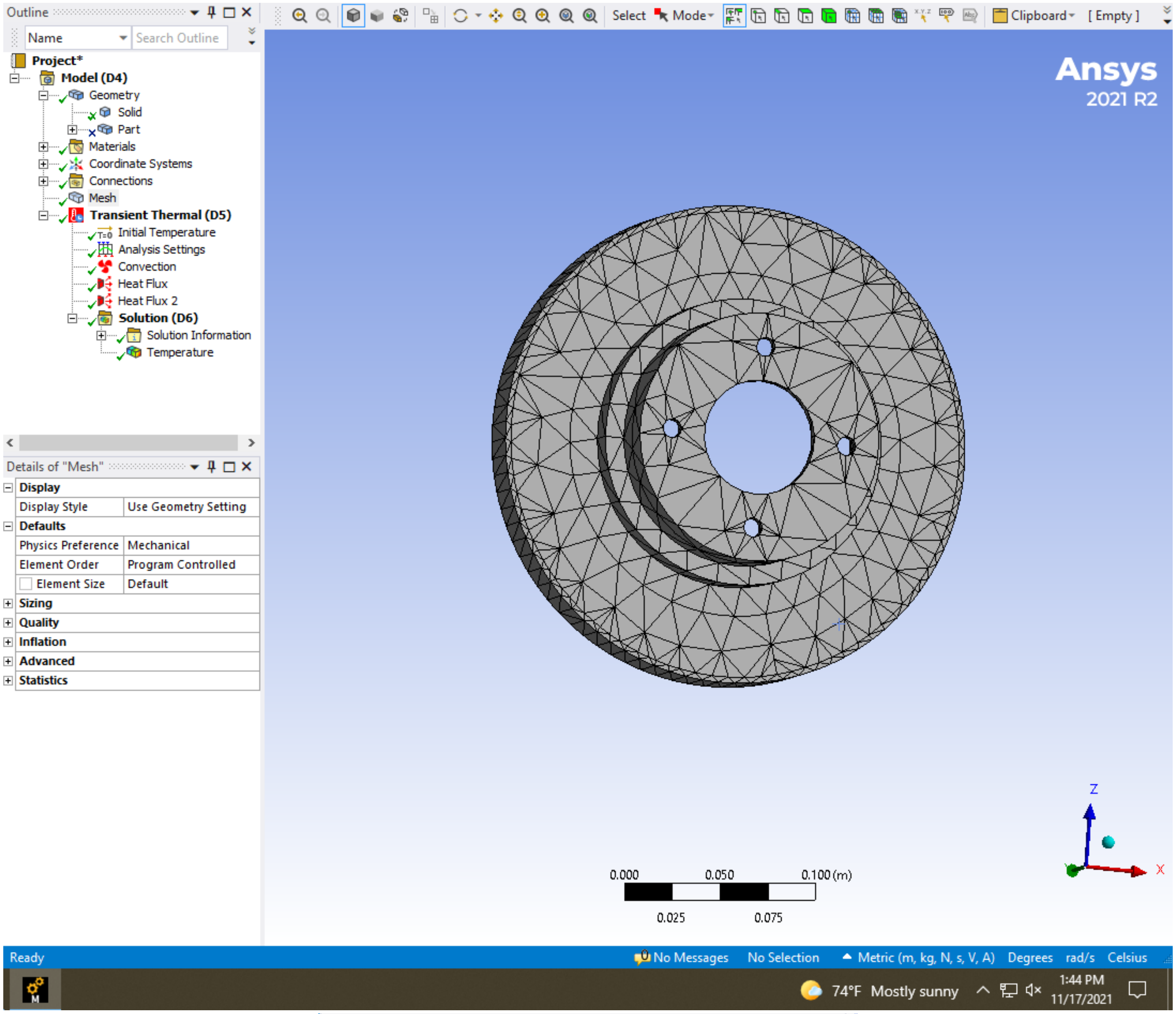
Options	
Max Modes to Find	10
Limit Search to Range	No
Solver Controls	
Damped	No
Solver Type	Program Controlled
Rotordynamics Controls	
Advanced	
Output Controls	
Analysis Data Management	

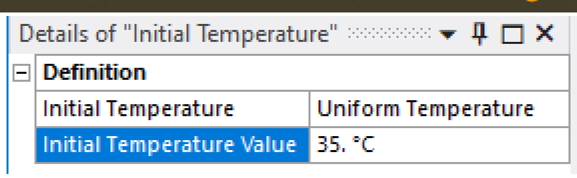


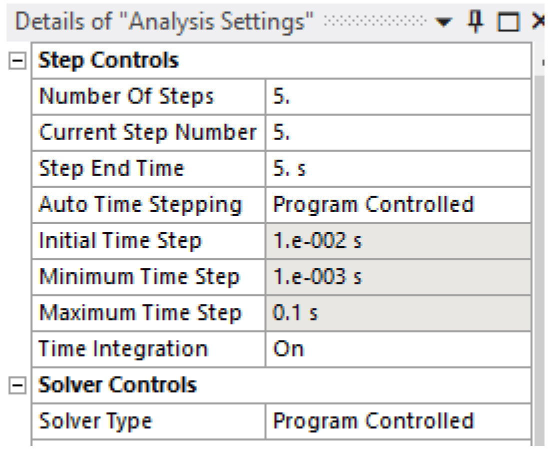
Transient Thermal Setup:

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.*

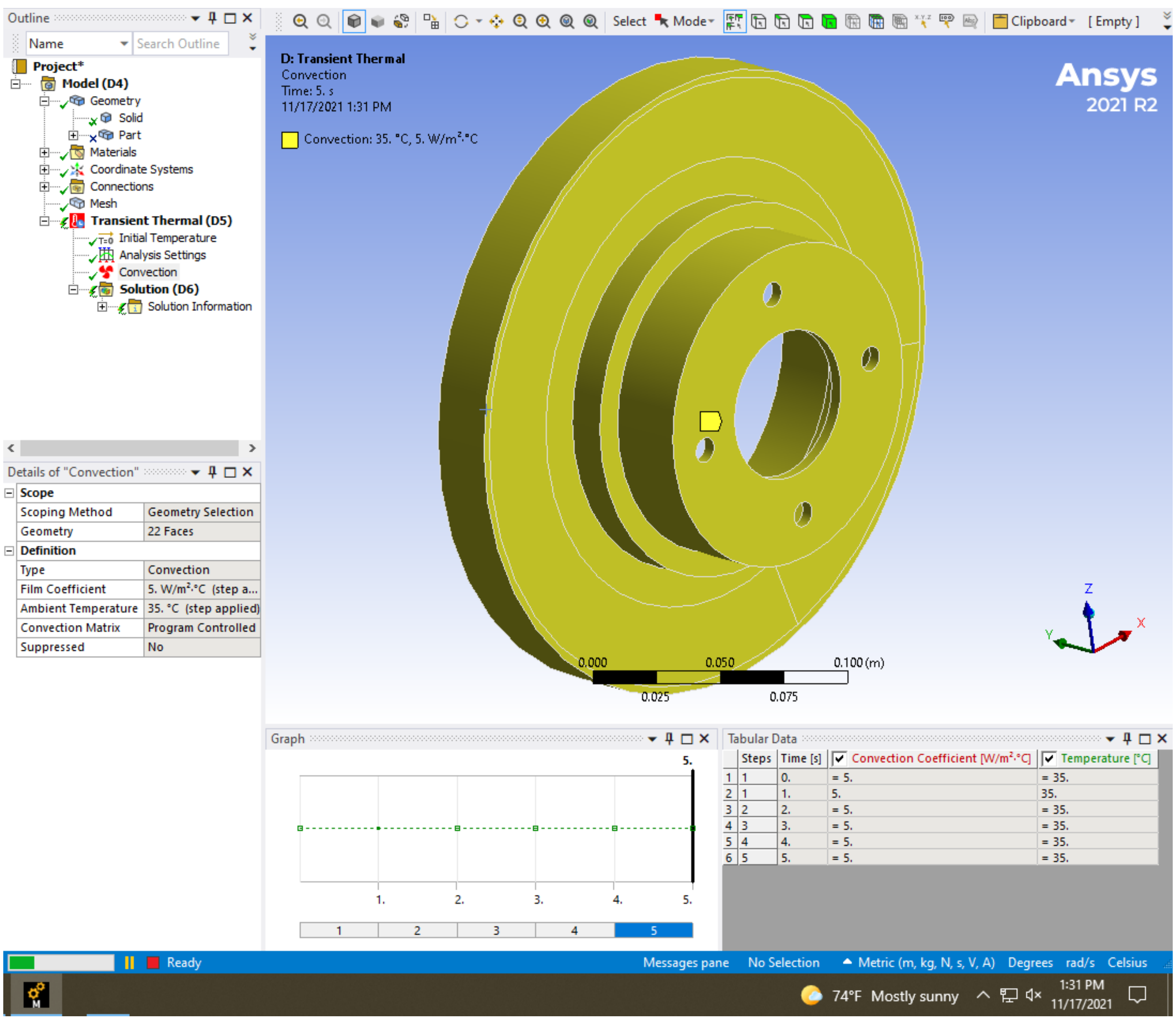


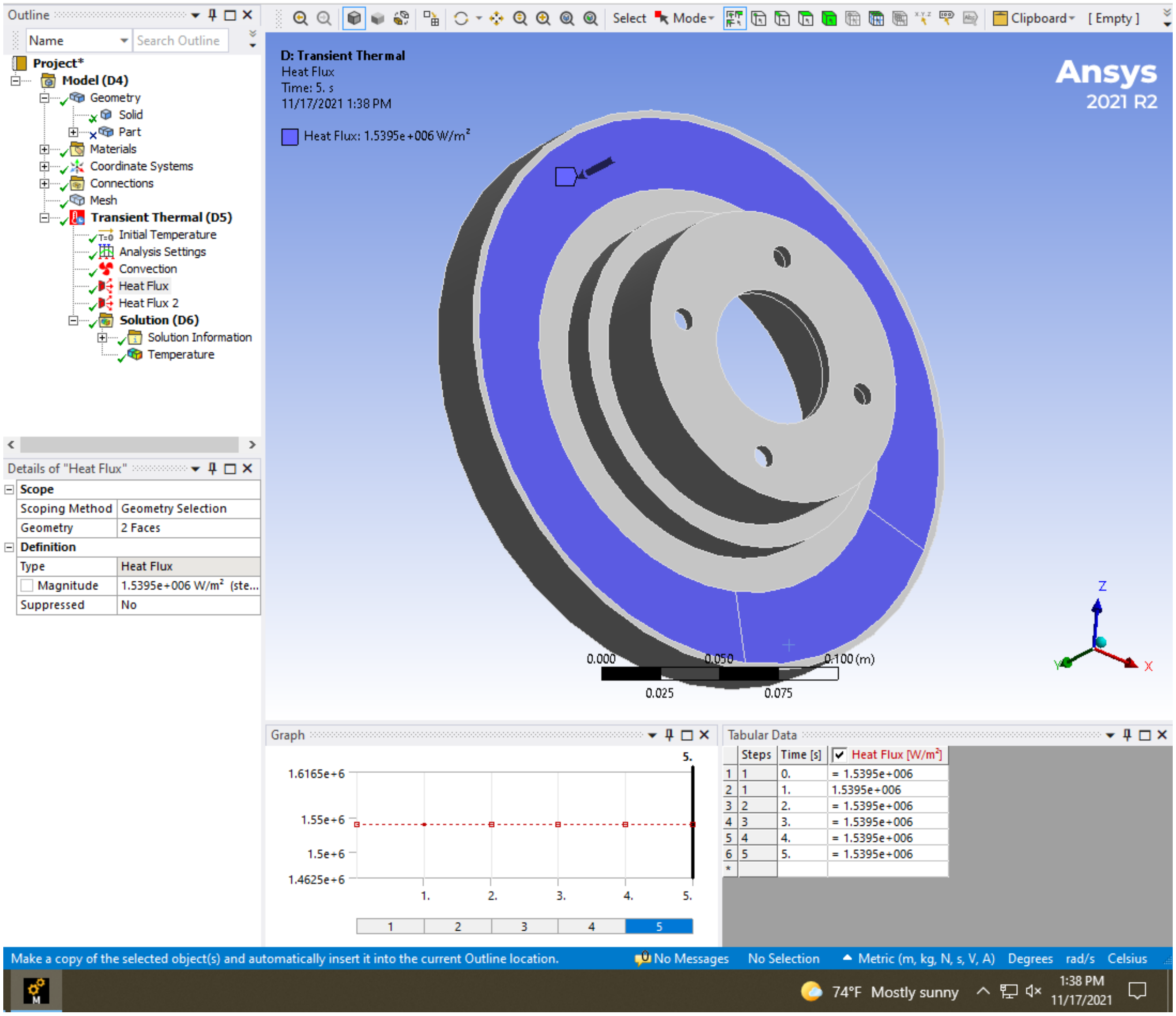


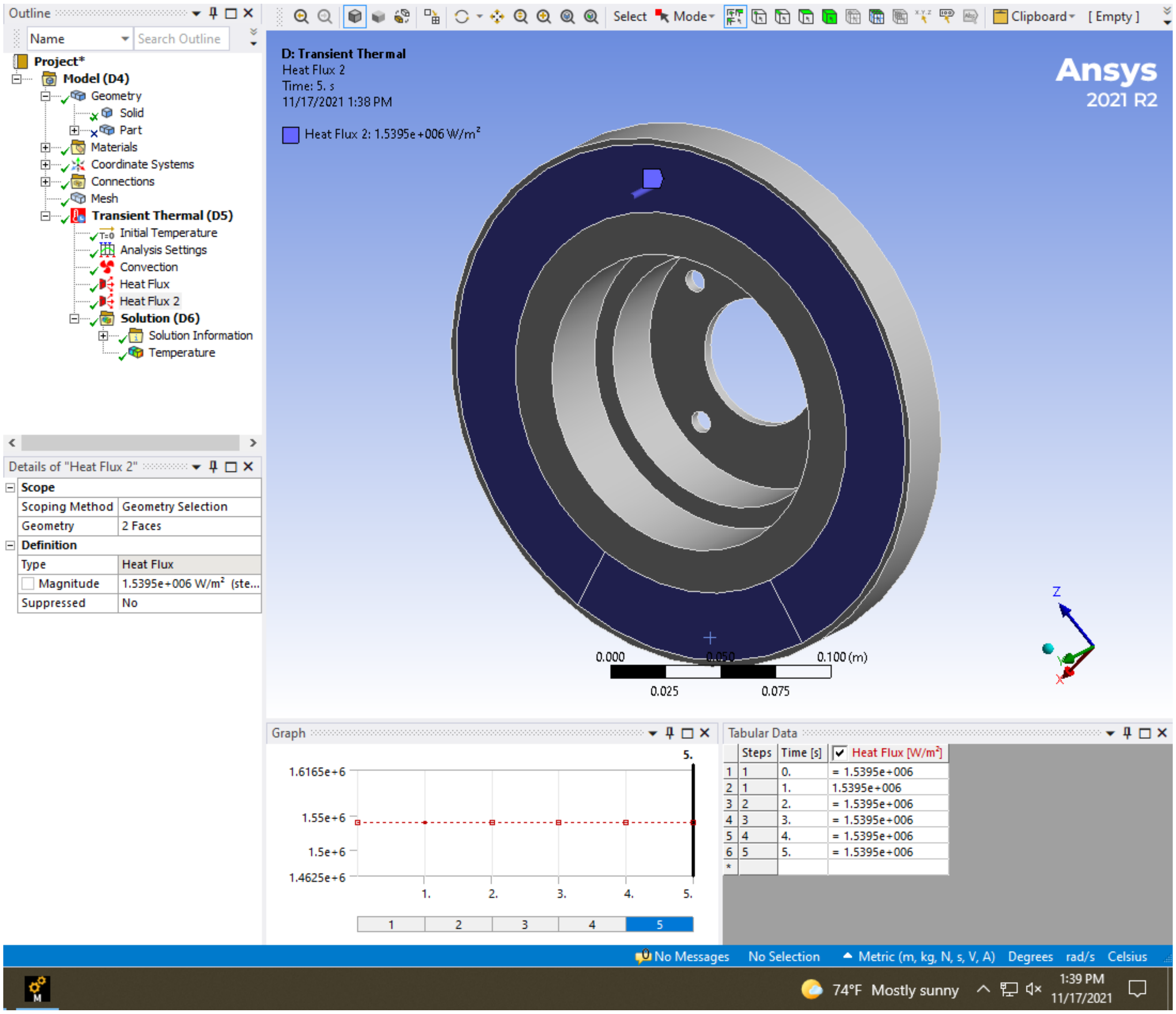


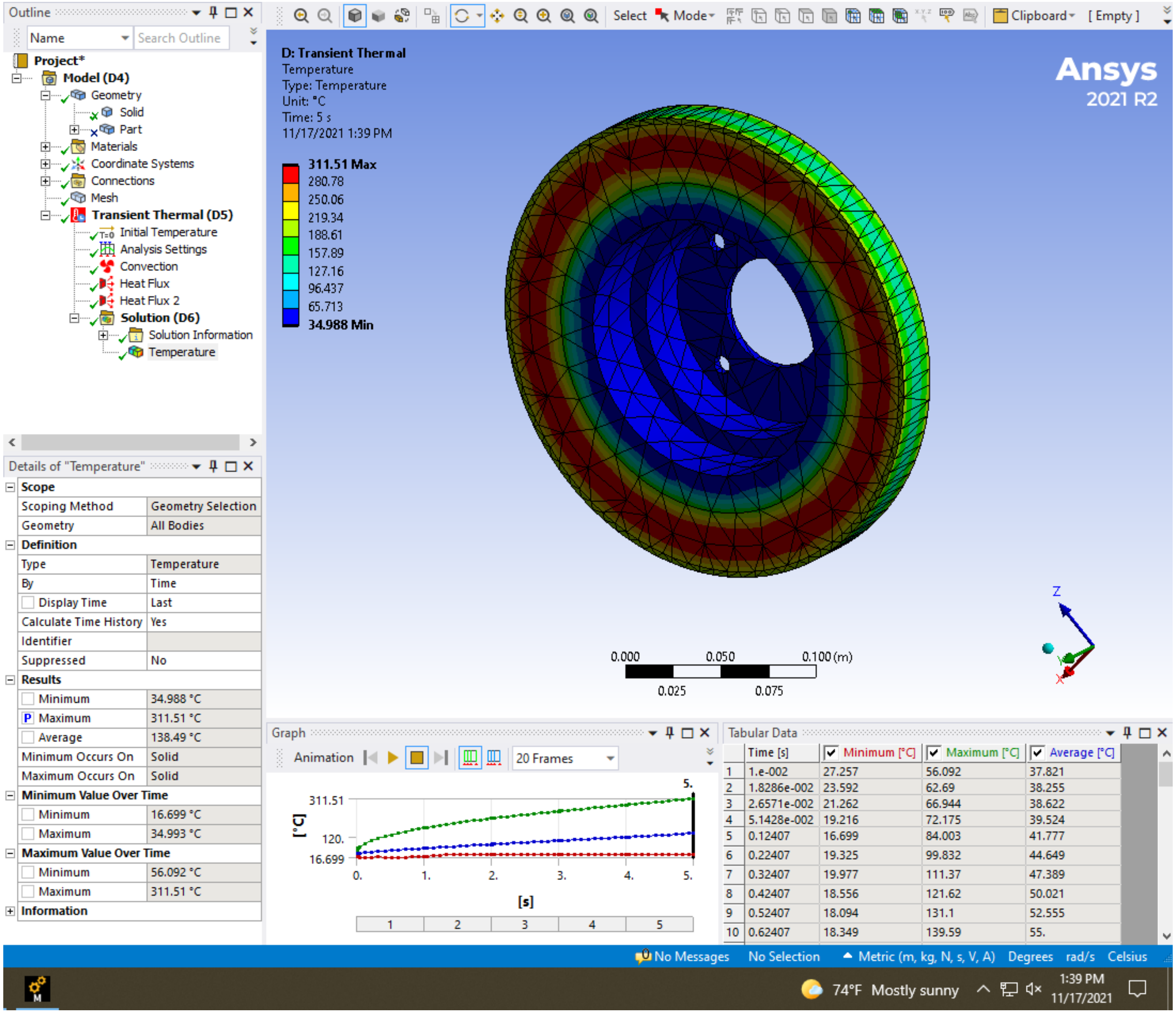
Details of "Analysis Settings"

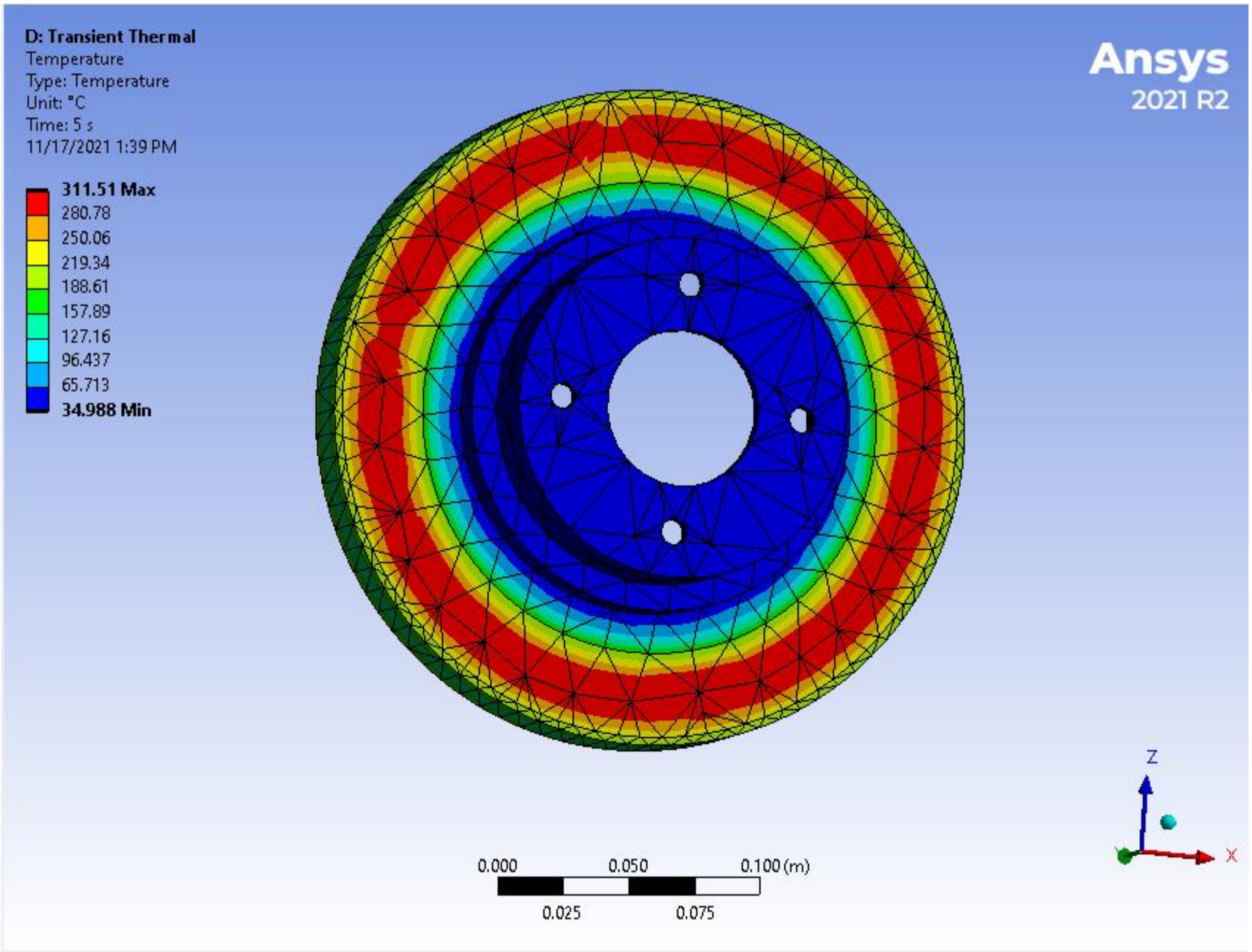
Step Controls	
Number Of Steps	5.
Current Step Number	5.
Step End Time	5. s
Auto Time Stepping	Program Controlled
Initial Time Step	1.e-002 s
Minimum Time Step	1.e-003 s
Maximum Time Step	0.1 s
Time Integration	On
Solver Controls	
Solver Type	Program Controlled




D: Transient Thermal
Heat Flux
Time: 5. s
11/17/2021 1:38 PM
Heat Flux: 1.5395e+006 W/m²
Ansys
2021 R2
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
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


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
1. 2. 3. 4. 5.
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


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
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 "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
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.
Graph
Animation
20 Frames
311.51
120.
16.699
[°C]
[s]
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



Design of Experiments:

- I only evaluated designs which were reasonable and within limitation. For example, I eliminated all experiments which Ansys could not evaluate due to geometrical conflicts, i.e., the design where the disk had a smaller outer radius than the outer radius of the brake pads.
- I first chose the Sparse Grid method because I thought it would be best for Ansys to adaptively sample points as it runs the experiment. But I could not perform a sensitivity analysis, so I switched to the Latin Hypercube Sampling Design (LHSD).
- You can find my DOE using Sparse Grid in Appendix A.
- The upper and lower bounds of input parameters:

Table of Schematic G4: Optimization

	A	B	C	D
1	⊟ Input Parameters			
2	Name	Lower Bound	Upper Bound	
3	P8 - rotor_thickness (mm)	22.5	27.5	
4	P9 - rotor_OD (mm)	112.5	137.5	
5	P10 - rotor_ID (mm)	67.5	82.5	
6	⊟ Parameter Relationships			
7	Name	Left Expression	Operator	Right Expression
*	New Parameter Relationship	New Expression	<=	New Expression

Outline of Schematic G2: Design of Experiments

	A	B
1		Enabled
2	⊟ Design of Experiments	
3	⊟ Input Parameters	
4	⊟ Geometry (A1)	
5	P8 - rotor_thickness	☑
6	P9 - rotor_OD	☑
7	P10 - rotor_ID	☑
8	⊟ Output Parameters	
9	⊟ Static Structural (B1)	
10	P4 - Equivalent Stress Maximum	
11	P14 - Solid Volume	
12	⊟ Modal (C1)	
13	P6 - Total Deformation Reported Frequency	
14	⊟ Transient Thermal (D1)	

Properties of Outline : Design of Experiments

	A	B
1	Property	Value
2	⊟ Design Points	
3	Preserve Design Points After DX Run	☐
4	⊟ Failed Design Points Management	
5	Number of Retries	0
6	⊟ Design of Experiments	
7	Design of Experiments Type	Latin Hypercube Sampling Design
8	Samples Type	CCD Samples
9	Random Generator Seed	0
10	⊟ Design Point Report	
11	Report Image	None

Table of Outline A2: Design Points of Design of Experiments

	A		B	C	D	E	F	G	H
1	Name		P8 - rotor_thickness (mm)	P9 - rotor_OD (mm)	P10 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P6 - Total Deformation Reported Frequency (Hz)	P7 - Temperature Maximum (C)	P14 - Solid Volume (m^3)
2	1	DP 1	25.333	131.67	76	1.1185E+07	1923.5	312.76	0.0011348
3	2	DP 2	26.333	125	77	1.7134E+07	2056.3	309.03	0.0010204
4	3	DP 3	22.667	126.67	70	1.1685E+07	2067.4	317.65	0.00098798
5	4	DP 17	26	113.33	81				
6	5	DP 13	23	116.67	71				
7	6	DP 18	27.333	115	69				
8	7	DP 4	25.667	135	80	1.139E+07	1808.4	309.16	0.0011824
9	8	DP 5	27	130	79	1.1464E+07	1939.9	308.98	0.0011295
10	9	DP 14	24	118.33	75				
11	10	DP 6	23.667	128.33	82	1.1659E+07	1838.6	316.03	0.00096082
12	11	DP 16	24.667	121.67	73				
13	12	DP 7	23.333	133.33	72	1.0849E+07	1887.4	316.59	0.0011242
14	13	DP 8	25	123.33	74	1.7312E+07	2138.4	312.04	0.00097243
15	14	DP 9	26.667	136.67	68	1.1992E+07	1883.7	306.6	0.0013652
16	15	DP 15	24.333	120	78				

Chart: No data

- I initially had 15 points experimental data but I removed the ones Ansys could not evaluate using the custom sampling DOE type:

Table of Outline A2: Design Points of Design of Experiments

	A	B	C	D	E	F	G
1	Name	P8 - rotor_... (mm)	P9 - rotor_OD (mm)	P10 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P6 - Total Deformation Reported Frequency (Hz)	P7 - Temperature Maximum (C)
2	DP 1	25.333	131.67	76	1.1185E+07	1923.5	312.76
3	DP 2	26.333	125	77	1.7134E+07	2056.3	309.03
4	DP 3	22.667	126.67	70	1.1685E+07	2067.4	317.65
5	DP 4	25.667	135	80	1.139E+07	1808.4	309.16
6	DP 5	27	130	79	1.1464E+07	1939.9	308.98
7	DP 6	23.667	128.33	82	1.1659E+07	1838.6	316.03
8	DP 7	23.333	133.33	72	1.0849E+07	1887.4	316.59
9	DP 8	25	123.33	74	1.7312E+07	2138.4	312.04
10	DP 9	26.667	136.67	68	1.1992E+07	1883.7	306.6

Response Surface

- I used Non-parametric Regression as my response surface since my data was highly nonlinear and limited. I also did not trust my data and thought it would be better to not fit right through my DOE data. I chose Kriging as my response surface for the Sparse Grid DOE since I trusted my DOE data.

- You can find my response surface through Kriging in Appendix A.

- I used 1/3 of my experimental data for verification since more points is always good for learning.

Properties of Outline A2: Response Surface

	A	B
1	Property	Value
2	Design Points	
3	Preserve Design Points After DX Run	☐
4	Failed Design Points Management	
5	Number of Retries	0
6	Meta Model	
7	Response Surface Type	Non-Parametric Regression
8	Refinement	
9	Refinement Type	Manual
10	Verification Points	
11	Generate Verification Points	☑
12	Number of Verification Points	3
13	Design Point Report	
14	Report Image	None

Table of Outline A25: Response Points

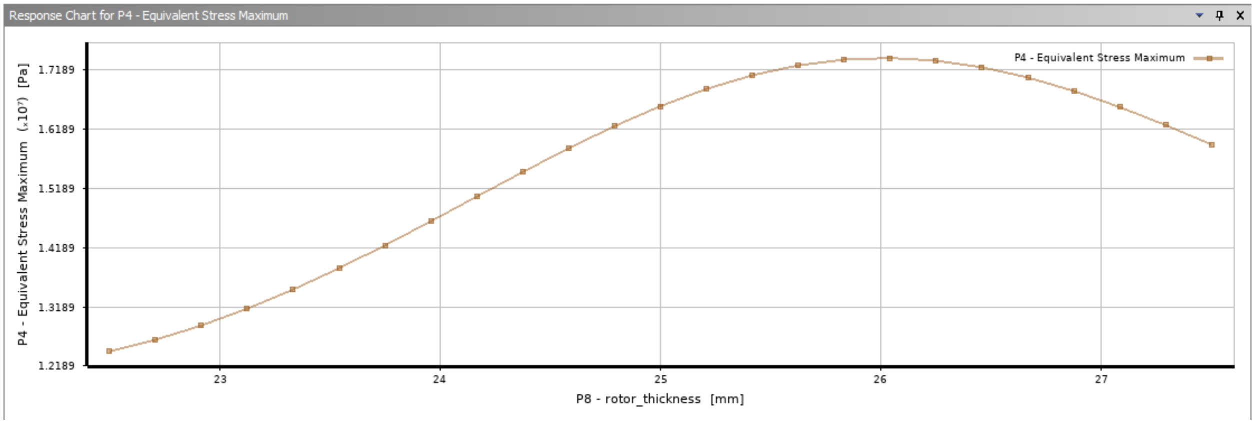
	A	B	C	D	E	F	G	H
1	Name	P8 - rotor_thickness (mm)	P9 - rotor_OD (mm)	P10 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P6 - Total Deformation Reported Frequency (Hz)	P7 - Temperature Maximum (C)	P14 - Solid Volume (m^3)
2	Response Point	25	125	75	1.6577E+07	2112.8	312.65	0.00097294
*	New Response Point							

Table of Schematic G3: Response Surface

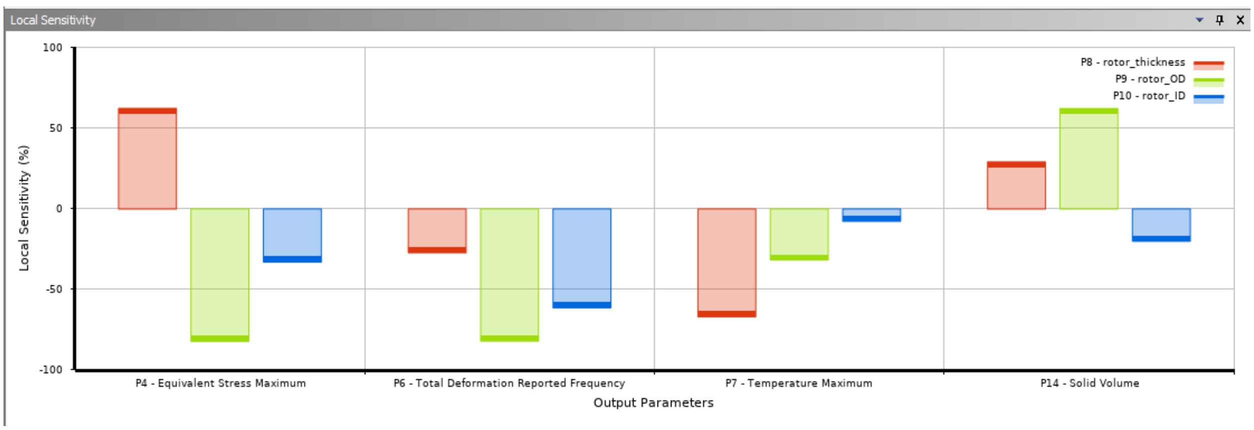
	A	B	C	D	E
1		P4 - Equivalent Stress Maximum	P6 - Total Deformation Reported Frequency	P7 - Temperature Maximum	P14 - Solid Volume
2	Coefficient of Determination (Best Value = 1)				
3	Learning Points	★★★ 0.99936	★★★ 0.99905	★★★ 0.99922	★★★ 0.99902
4	Root Mean Square Error (Best Value = 0)				
5	Learning Points	60973	3.2784	0.10415	3.8243E-06
6	Relative Maximum Absolute Error (Best Value = 0%)				
7	Learning Points	★ 3.3749	★ 3.2499	★ 2.8418	★ 3.2068
8	Relative Average Absolute Error (Best Value = 0%)				
9	Learning Points	★ 2.244	★ 2.8836	★ 2.5196	★ 2.8413

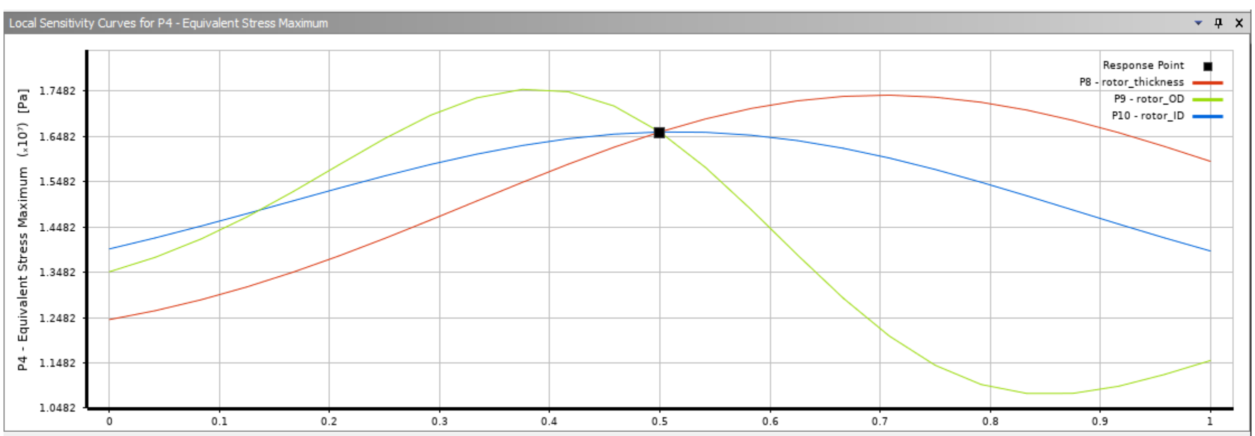
Table of Outline A21: Verification Points

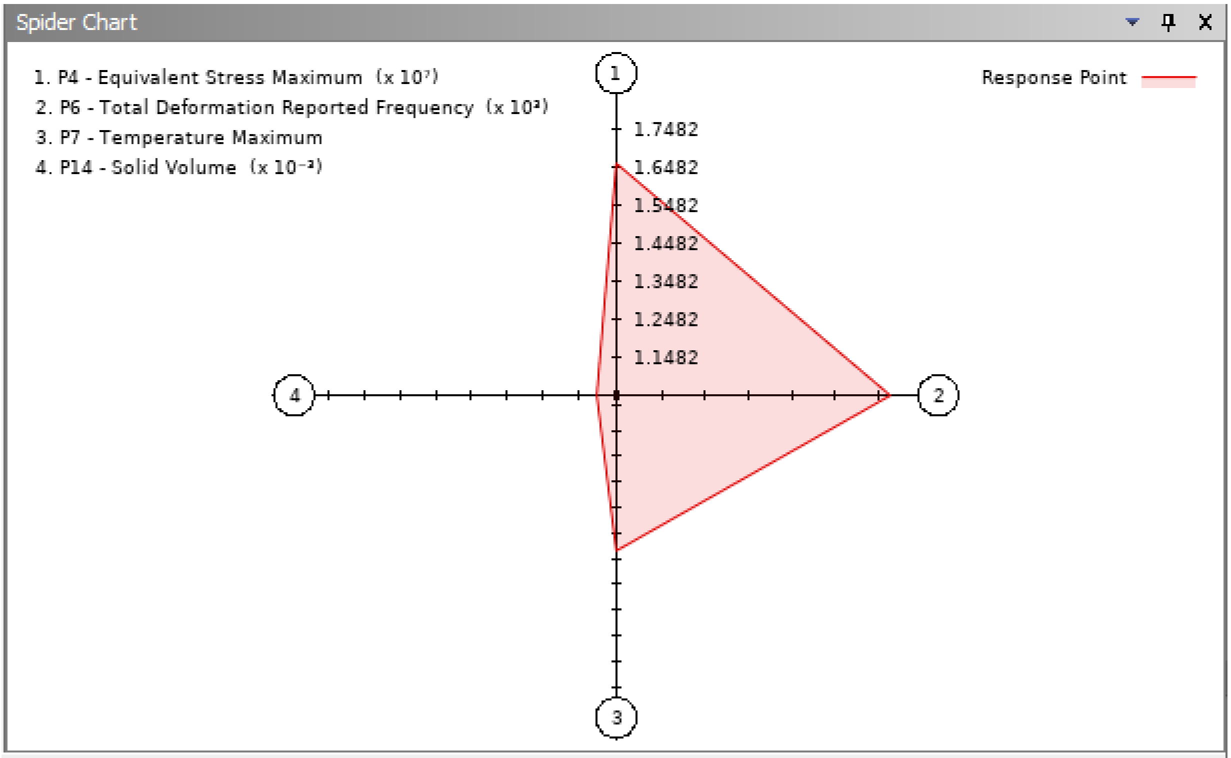
	A	B	C	D	E	F	G	H
1	Name	P8 - rotor_thickness (mm)	P9 - rotor_OD (mm)	P10 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P6 - Total Deformation Reported Frequency (Hz)	P7 - Temperature Maximum (C)	P14 - Solid Volume (m^3)
2	1 DP 12	27.449	113.11	67.79				
3	2 DP 10	22.502	112.67	80.097				
4	3 DP 11	27.012	112.68	82.305				
*	New Verification Point							



Sensitivity Analysis:







Optimization:

- I used Multi-objective Genetic Algorithm (MOGA)to optimize my design since I had multiple objectives. I did not choose to run multiple single-objective simulations using Screening because I trusted my data and thought the results between MOGA and Screening would not be significantly different.

- I used MOGA for my first DOE Optimization as well which is included in Appendix A.

- I unfortunately did to have the option to use Adaptive Multi-Objective Optimization (AMO) or Adaptive Single-Objective Optimization (ASO), otherwise I would have chosen AMO.

Table of Schematic G4: Optimization

	A	B	C	D	E	F	G	H	I
1	Name	Parameter	Objective			Constraint			
2			Type	Target	Tolerance	Type	Lower Bound	Upper Bound	Tolerance
3	Minimize P4	P4 - Equivalent Stress Maximum	Minimize	0		No Constraint			
4	Maximize P6	P6 - Total Deformation Reported Frequency	Maximize	0		No Constraint			
5	Minimize P7	P7 - Temperature Maximum	Minimize	0		No Constraint			
6	Minimize P14	P14 - Solid Volume	Minimize	0		No Constraint			
*		Select a Parameter							

Properties of Outline A2: Optimization

	A	B
1	Property	Value
2	Design Points	
3	Preserve Design Points After DX Run	☐
4	Failed Design Points Management	
5	Number of Retries	0
6	Optimization	
7	Method Selection	Manual
8	Method Name	MOGA
9	Estimated Number of Evaluations	2000
10	Tolerance Settings	☑
11	Verify Candidate Points	☐
12	Number of Initial Samples	100
13	Number of Samples Per Iteration	100
14	Maximum Allowable Pareto Percentage	70
15	Convergence Stability Percentage	2
16	Maximum Number of Iterations	20
17	Maximum Number of Candidates	3
18	Optimization Status	
19	Converged	Yes
20	Pareto Percentage	1
21	Stability Percentage	1.424
22	Number of Iterations	9
23	Number of Evaluations	777
24	Number of Failures	0
25	Size of Generated Sample Set	100
26	Number of Candidates	3
27	Design Point Report	
28	Report Image	None

Table of Schematic G4: Optimization

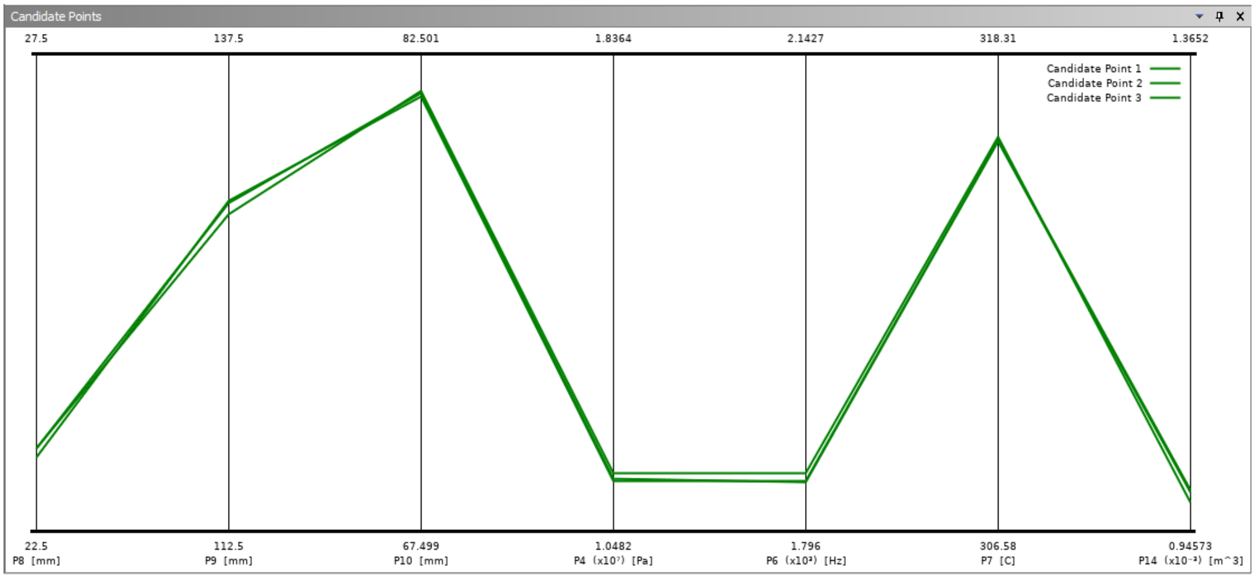
	A	B	C	D
1	⊟ Optimization Study			
2	Minimize P4	Goal, Minimize P4 (Default importance)		
3	Maximize P6	Goal, Maximize P6 (Default importance)		
4	Minimize P7	Goal, Minimize P7 (Default importance)		
5	Minimize P14	Goal, Minimize P14 (Default importance)		
6	⊟ Optimization Method			
7	MOGA	The MOGA method (Multi-Objective Genetic Algorithm) is a variant of the popular NSGA-II (Non-dominated Sorted Genetic Algorithm-II) based on controlled elitism concepts. It supports multiple objectives and constraints and aims at finding the global optimum.		
8	Configuration	Generate 100 samples initially, 100 samples per iteration and find 3 candidates in a maximum of 20 iterations.		
9	Status	Converged after 777 evaluations.		
10	⊟ Candidate Points			
11		Candidate Point 1	Candidate Point 2	Candidate Point 3
12	P8 - rotor_thickness (mm)	23.379	23.369	23.285
13	P9 - rotor_OD (mm)	129.12	129.74	129.85
14	P10 - rotor_ID (mm)	81.368	81.276	81.192
15	P4 - Equivalent Stress Maximum (Pa)	× 1.1453E+07	× 1.1351E+07	× 1.1328E+07
16	P6 - Total Deformation Reported Frequency (Hz)	★★★ 1838.5	★★★ 1832.3	★★★ 1832.6
17	P7 - Temperature Maximum (C)	××× 316.27	××× 316.18	××× 316.21
18	P14 - Solid Volume (m^3)	× 0.00097137	× 0.00098035	× 0.00098231

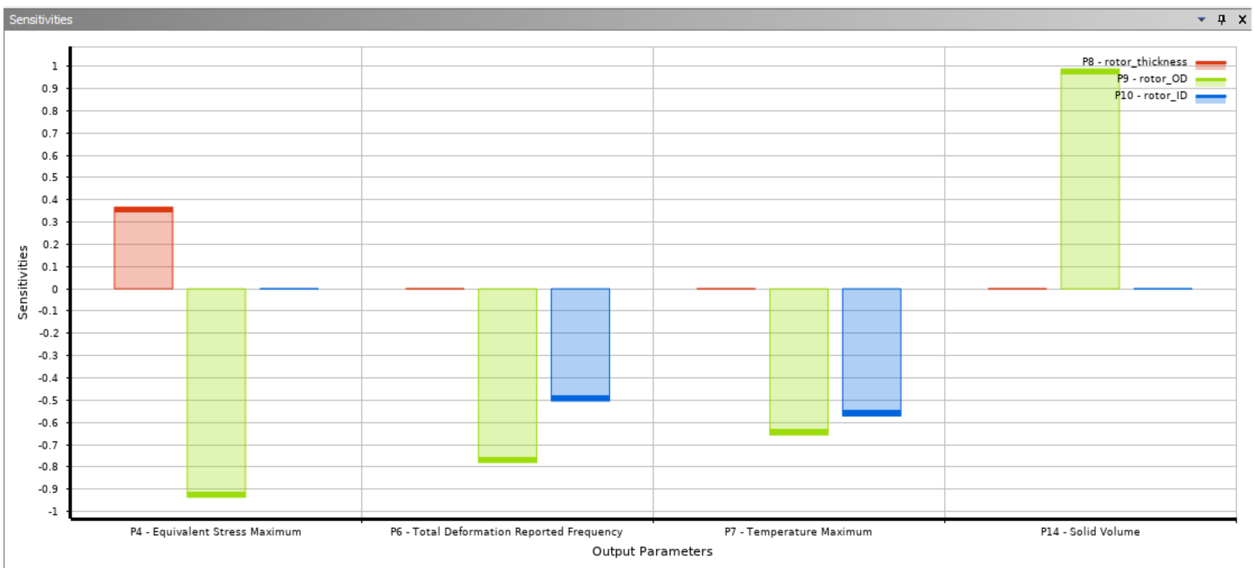
- Candidate 3 is the best since it minimizes volume and maximum stress. The first natural frequency is also the highest. I am willing to tradeoff the slightly higher temperature.

- I included the Candidate Points, Tradeoff, Samples, and Sensitives of the Optimization below.

Table of Schematic G4: Optimization , Candidate Points

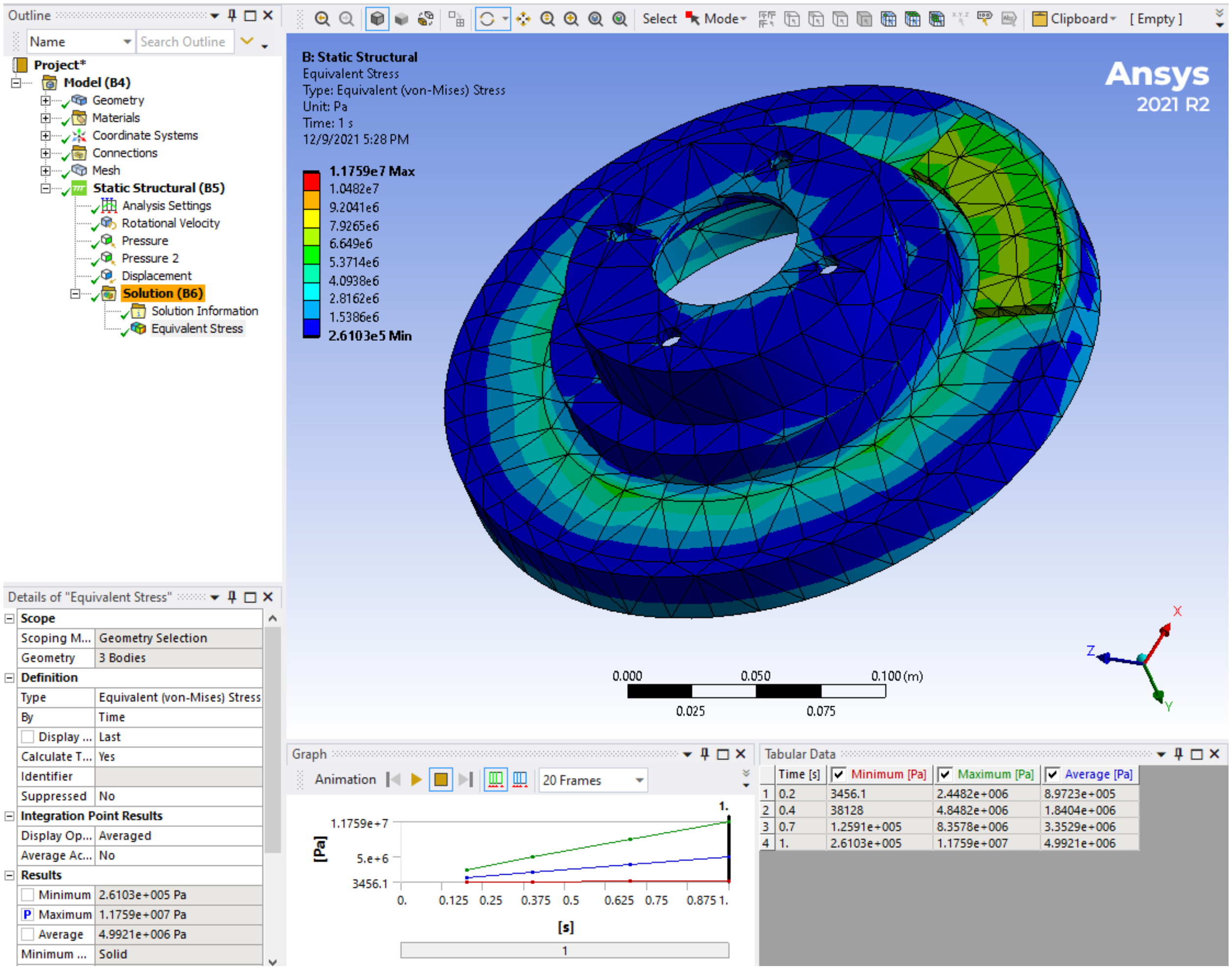
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Reference	Name	P8 - rotor_thickness (mm)	P9 - rotor_OD (mm)	P10 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)		P6 - Total Deformation Reported Frequency (Hz)		P7 - Temperature Maximum (C)		P14 - Solid Volume (m^3)	
2						Parameter Value	Variation from Reference	Parameter Value	Variation from Reference	Parameter Value	Variation from Reference	Parameter Value	Variation from Reference
3	○	Candidate Point 1	23.379	129.12	81.368	× 1.1453E+07	1.11%	★★★ 1838.5	0.32%	××× 316.27	0.02%	× 0.00097137	-1.11%
4	○	Candidate Point 2	23.369	129.74	81.276	× 1.1351E+07	0.21%	★★★ 1832.3	-0.02%	××× 316.18	-0.01%	× 0.00098035	-0.20%
5	◉	Candidate Point 3	23.285	129.85	81.192	× 1.1328E+07	0.00%	★★★ 1832.6	0.00%	××× 316.21	0.00%	× 0.00098231	0.00%
*		*New Custom Candidate Point*	*25*	*125*	*75*								



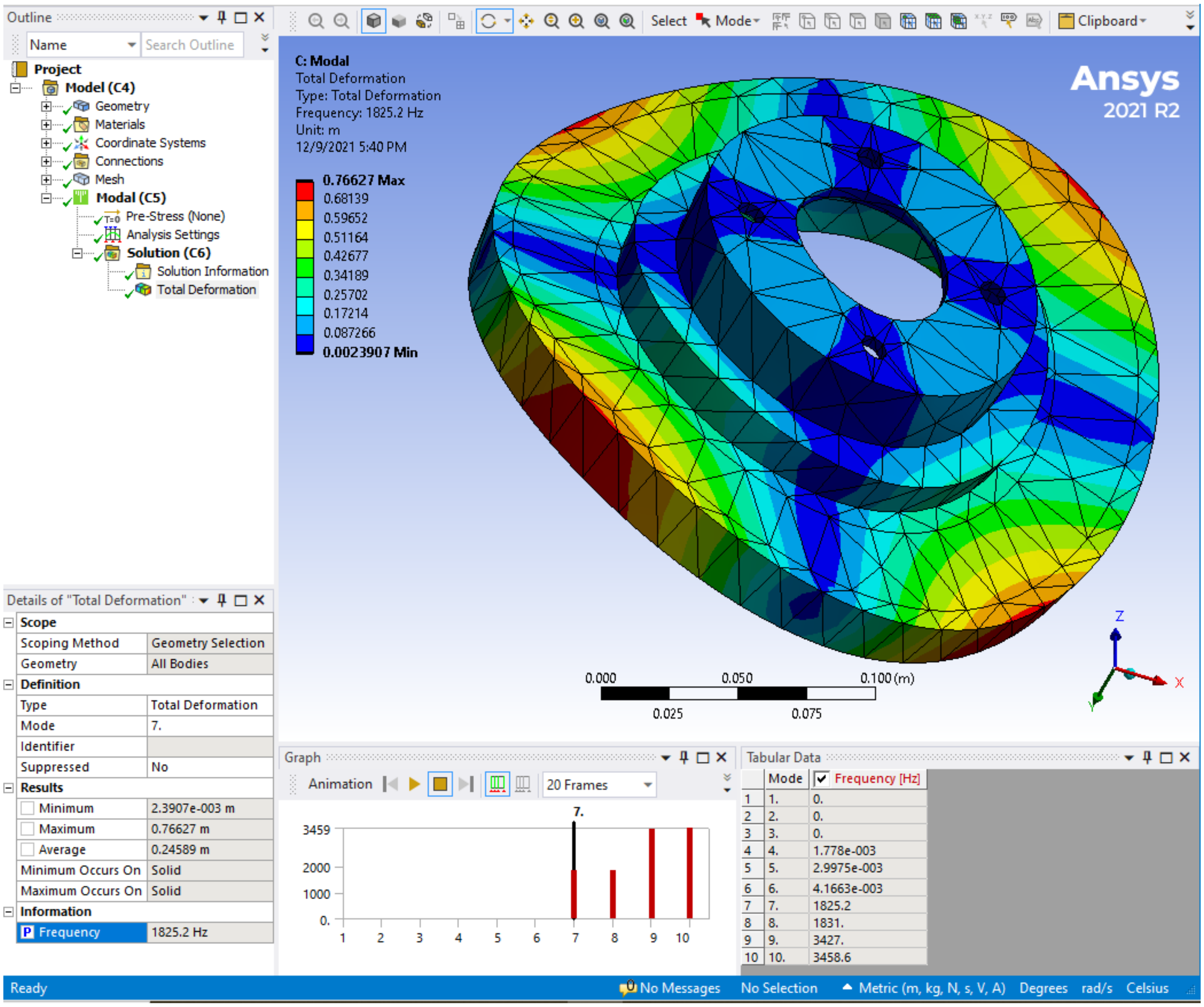


Verification:

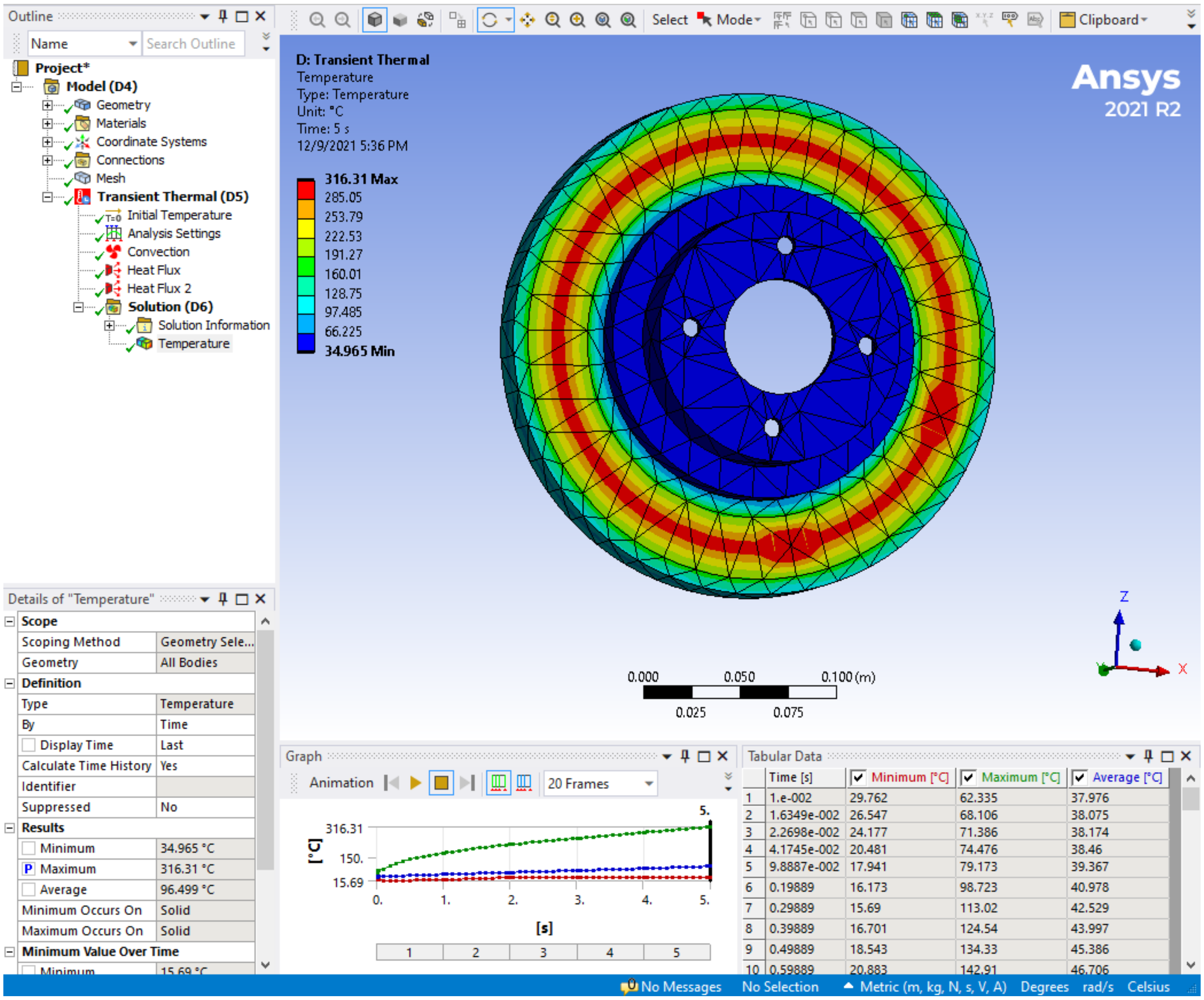
Static Structural:


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
12/9/2021 5:28 PM
1.1759e7 Max
1.0482e7
9.2041e6
7.9265e6
6.649e6
5.3714e6
4.0938e6
2.8162e6
1.5386e6
2.6103e5 Min
Ansys
2021 R2
0.000
0.050
0.100 (m)
0.025
0.075
Details of "Equivalent Stress"
Scope
Scoping Method: Geometry Selection
Geometry: 3 Bodies
Definition
Type: Equivalent (von-Mises) Stress
By: Time
Display Time: Last
Calculate Time History: Yes
Identifier
Suppressed: No
Integration Point Results
Display Option: Averaged
Average Across Bodies: No
Results
Minimum: 2.6103e+005 Pa
Maximum: 1.1759e+007 Pa
Average: 4.9921e+006 Pa
Minimum Occurs On: Solid
Graph
Animation
20 Frames
1.1759e+7
5.e+6
3456.1
[Pa]
[s]
Tabular Data
Time [s] | Minimum [Pa] | Maximum [Pa] | Average [Pa]
1 | 0.2 | 3456.1 | 2.4482e+006 | 8.9723e+005
2 | 0.4 | 38128 | 4.8482e+006 | 1.8404e+006
3 | 0.7 | 1.2591e+005 | 8.3578e+006 | 3.3529e+006
4 | 1. | 2.6103e+005 | 1.1759e+007 | 4.9921e+006

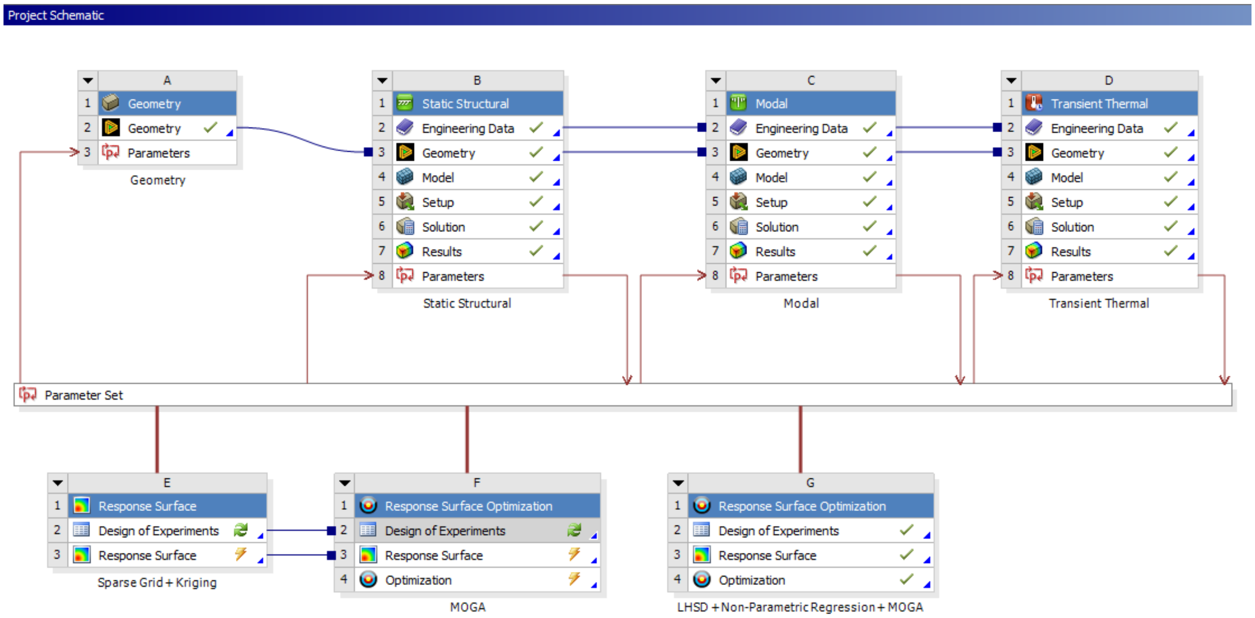
Model:



Transient Thermal:



Project Schematic:

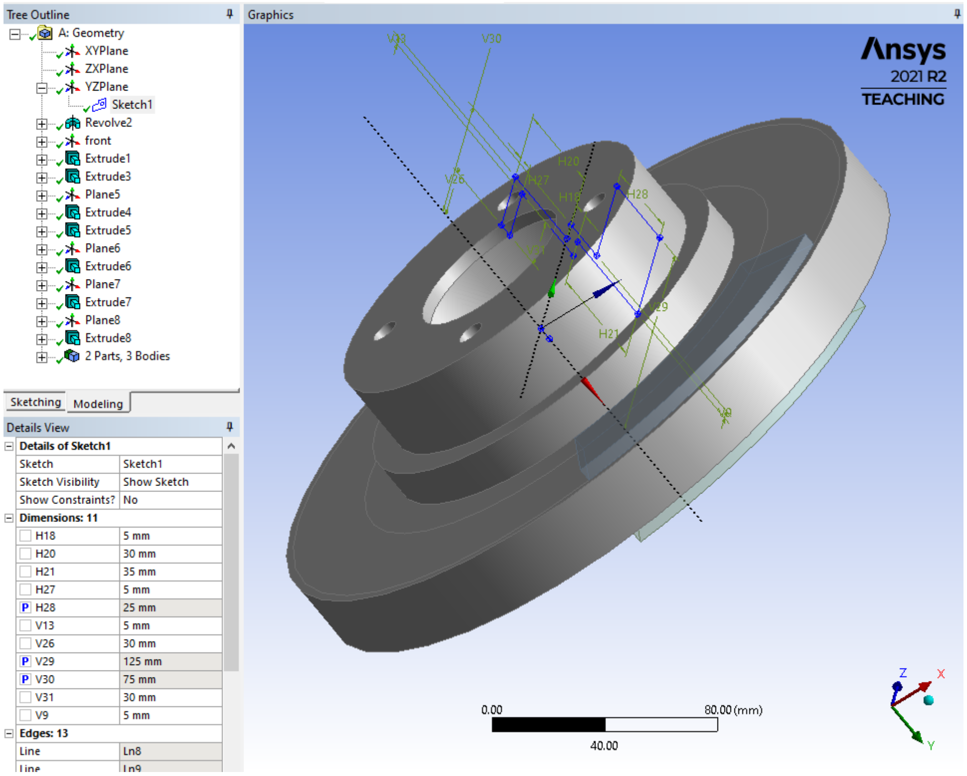


Optimal Design:

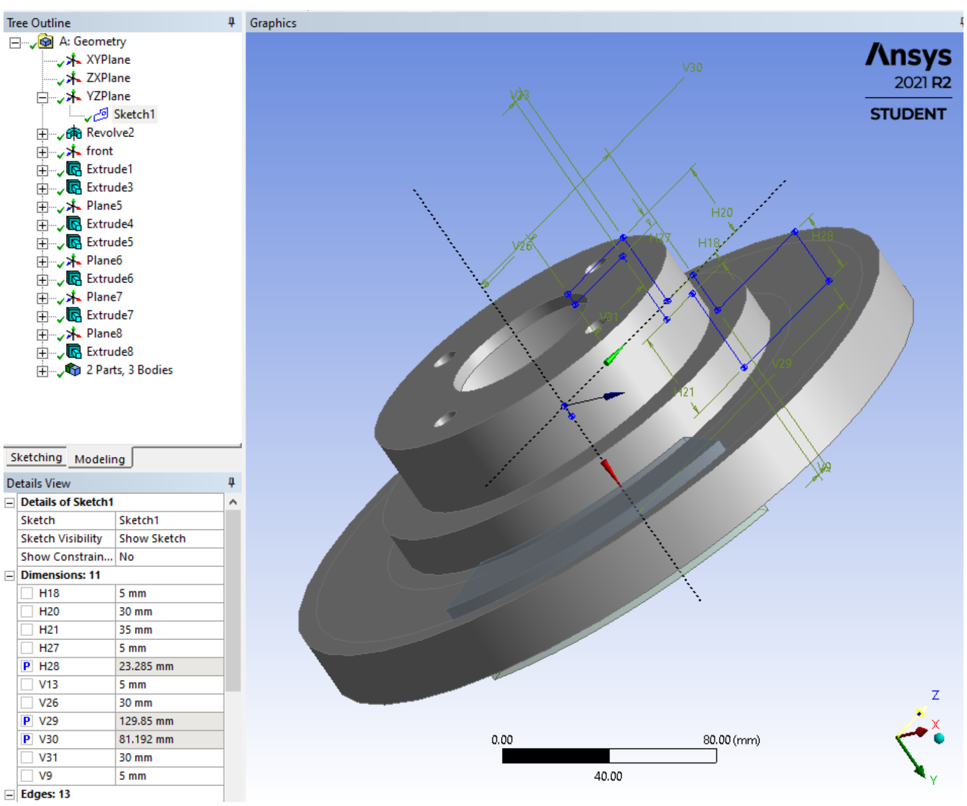
Parameters	Initial	Optimal Solution (Candidate 3)	Verified Optimal Solution
Input:			
Thickness (mm)	25	23.3	23.3
Outer Diameter (mm)	125	129.9	129.9
Inner Diameter (mm)	75	81.2	81.2
Output:			
Volume (cm^3)	9966.7	9823	9843.9
Maximum Stress (MPa)	12.785	11.32	11.759
First Natural Frequency (Hz)	2081.2	1832.6	1825.2
Maximum Temperature (°C)	311.51	316.21	316.31

- Volume Reduction: 1.221% reduction

Initial:



Final:



Discussion:

1. **What are your design variables, constraints, and objectives?**
    - Variables:
        - Thickness, outer radius, and inner radius of break disk
    - Constraints:
        - No given constraints in this project
    - Objectives:
        - Minimize maximum stress, maximize first natural frequency, and minimize maximum temperature in/of the break disk
        - Minimize volume (dependent minimization)

2. **What are the potential trade-offs between your objectives?**
    - There are tradeoffs between the total volume, maximum stress, maximum temperature, and first natural frequency. Larger surface area between the brake pads and the disk would result in lower stress and temperature in the disk but that would increase volume and affect cost and the first natural frequency of the of the brake disk.

3. **Are your variables continuous? Or are they discrete/integer?**
    - All my output and input variables are continuous.

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

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

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)?**
    - There is monotonicity with each objective.
    - The maximum stress is highly sensitive to the disk thickness, and highly insensitive to the outer diameter.
    - The natural frequency is highly insensitive to the outer diameter.
    - The maximum thickness is highly insensitive to the thickness of the disk.
    - The thickness and mostly the outer diameter had a huge impact (highly sensitive) on the total volume.

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.**

- The optimal design does not significantly optimize all the objects but there is a noticeable difference in each of the objective values.
- Using MOGA instead of running single optimization analyses definitely had an impact on the final solution. But there were only 4 objectives which should have had a significant impact on the final solution.
- The first natural frequency is lower in the optimal model compared to the initial model but that is to be expected because the structure’s shape was altered (different dimensions). It is concluded that the natural frequency is the maximum it can be for the optimal disk given the other optimal objectives.
- The highest difference is observed in the maximum temperature the disk experiences.
- All simulations results were average. For more accurate results, the solutions should have been unaverage.
- The mesh was very basic. A mesh convergence analysis should have been conducted to determine the best mesh type and number of nodes. Localizations and singularities should have been accounted for as well.
- The DOE also generated 7 usable points. Generating more experiments would have benefited the optimization.

- Overall, I would conclude the optimal solution is reasonable but further changes, like a better mesh, more DOE points, better optimization methods, must be made for better results.

References:

https://github.com/DesignInformaticsLab/DesignOptimization2021Fall/blob/main/Project/Project%202%20ansys%20design%20optimization.md

Appendix A

Design of Experiments:

Properties of Outline A2: Design of Experiments

	A	B
1	Property	Value
2	Design Points	
3	Preserve Design Points After DX Run	☐
4	Failed Design Points Management	
5	Number of Retries	0
6	Design of Experiments	
7	Design of Experiments Type	Sparse Grid Initialization
8	Design Point Report	
9	Report Image	None

- The upper and lower bounds of input parameters:

Outline of Schematic E2: Design of Experime

	A
1	
2	Design of Experiments
3	Input Parameters
4	Geometry (A1)
5	P2 - rotor_OD
6	P3 - rotor_ID
7	P5 - rotor_thickness
8	Output Parameters
9	Static Structural (B1)
10	P4 - Equivalent Stress Ma:
11	Modal (C1)
12	P6 - Total Deformation Re
13	Transient Thermal (D1)
14	P7 - Temperature Maximu
15	Charts

Properties of Outline A5: P2 - rotor_OD

	A	B
1	Property	Value
2	General	
3	Units	mm
4	Type	Design Variable
5	Classification	Continuous
6	Values	
7	Lower Bound	112.5
8	Upper Bound	137.5
9	Allowed Values	Any

Outline of Schematic E2: Design of Experime

	A
1	
2	Design of Experiments
3	Input Parameters
4	Geometry (A1)
5	P2 - rotor_OD
6	P3 - rotor_ID
7	P5 - rotor_thickness
8	Output Parameters
9	Static Structural (B1)
10	P4 - Equivalent Stress Ma
11	Modal (C1)
12	P6 - Total Deformation Re
13	Transient Thermal (D1)
14	P7 - Temperature Maximu
15	Charts

Properties of Outline A6: P3 - rotor_ID

	A	B
1	Property	Value
2	General	
3	Units	mm
4	Type	Design Variable
5	Classification	Continuous
6	Values	
7	Lower Bound	67.5
8	Upper Bound	82.5
9	Allowed Values	Any

Outline of Schematic E2: Design of Experime

	A
1	
2	Design of Experiments
3	Input Parameters
4	Geometry (A1)
5	P2 - rotor_OD
6	P3 - rotor_ID
7	P5 - rotor_thickness
8	Output Parameters
9	Static Structural (B1)
10	P4 - Equivalent Stress Ma
11	Modal (C1)
12	P6 - Total Deformation Re
13	Transient Thermal (D1)
14	P7 - Temperature Maximu
15	Charts

Properties of Outline A7: P5 - rotor_thicknes

	A	B
1	Property	Value
2	General	
3	Units	mm
4	Type	Design Variable
5	Classification	Continuous
6	Values	
7	Lower Bound	22.5
8	Upper Bound	27.5
9	Allowed Values	Any

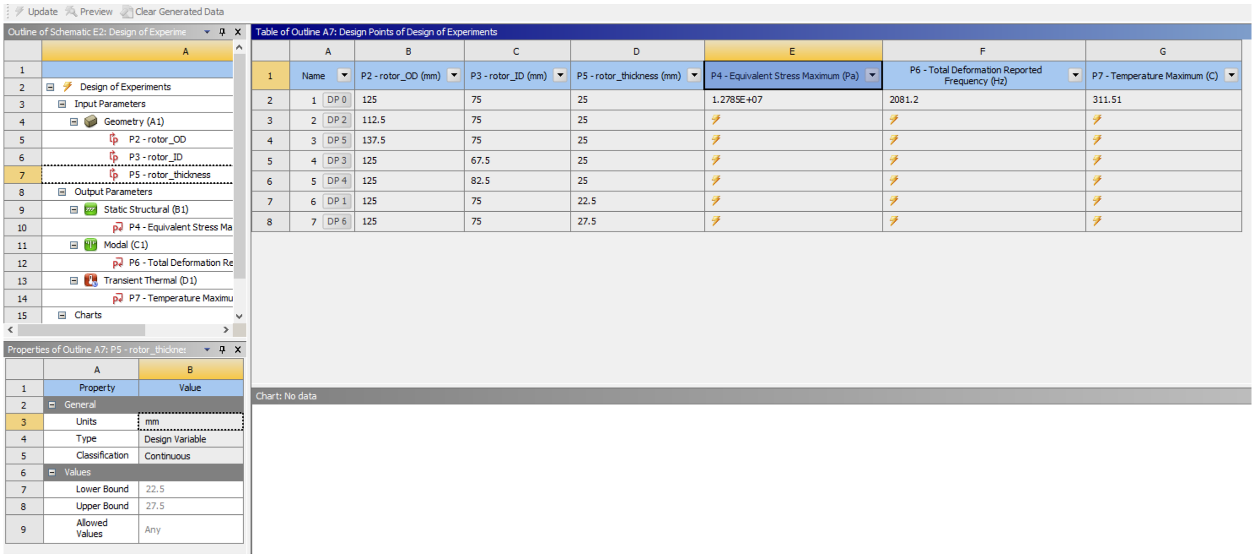
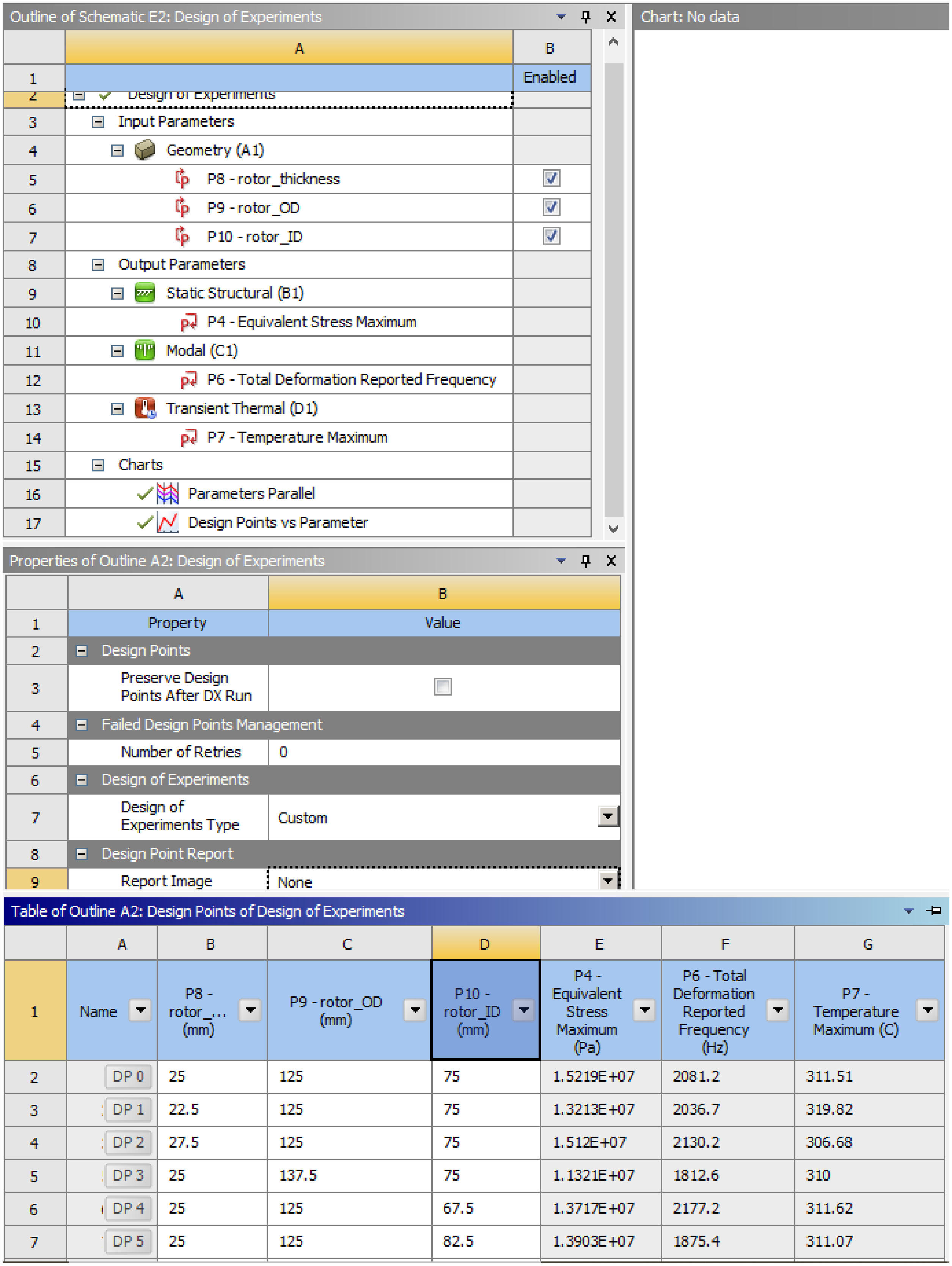


Table of Outline A7: Design Points of Design of Experiments

	A	B	C	D	E	F	G
1	Name	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P5 - rotor_thickness (mm)	P4 - Equivalent Stress Maximum (Pa)	P6 - Total Deformation Reported Frequency (Hz)	P7 - Temperature Maximum (C)
2	1 DP 0	125	75	25	1.2785E+07	2081.2	311.51
3	2 DP 2	112.5	75	25			
4	3 DP 5	137.5	75	25			
5	4 DP 3	125	67.5	25			
6	5 DP 4	125	82.5	25			
7	6 DP 1	125	75	22.5			
8	7 DP 6	125	75	27.5			

Table of Outline A2: Design Points of Design of Experiments

	A	B	C	D	E	F	G
1	Name	P8 - rotor_thickness (mm)	P9 - rotor_OD (mm)	P10 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P6 - Total Deformation Reported Frequency (Hz)	P7 - Temperature Maximum (C)
2	DP 0	25	125	75	1.5219E+07	2081.2	311.51
3	2	22.5	125	75	1.3213E+07	2036.7	319.82
4	3	27.5	125	75	1.512E+07	2130.2	306.68
5	4	25	112.5	75			
6	5	25	137.5	75	1.1321E+07	1812.6	310
7	6	25	125	67.5	1.3717E+07	2177.2	311.62
8	7	25	125	82.5	1.3903E+07	1875.4	311.07



Outline of Schematic E2: Design of Experiments

	A	B
1		Enabled
2	Design of Experiments	
3	Input Parameters	
4	Geometry (A1)	
5	P8 - rotor_thickness	☑
6	P9 - rotor_OD	☑
7	P10 - rotor_ID	☑
8	Output Parameters	
9	Static Structural (B1)	
10	P4 - Equivalent Stress Maximum	
11	Modal (C1)	
12	P6 - Total Deformation Reported Frequency	
13	Transient Thermal (D1)	
14	P7 - Temperature Maximum	
15	Charts	
16	Parameters Parallel	
17	Design Points vs Parameter	

Chart: No data

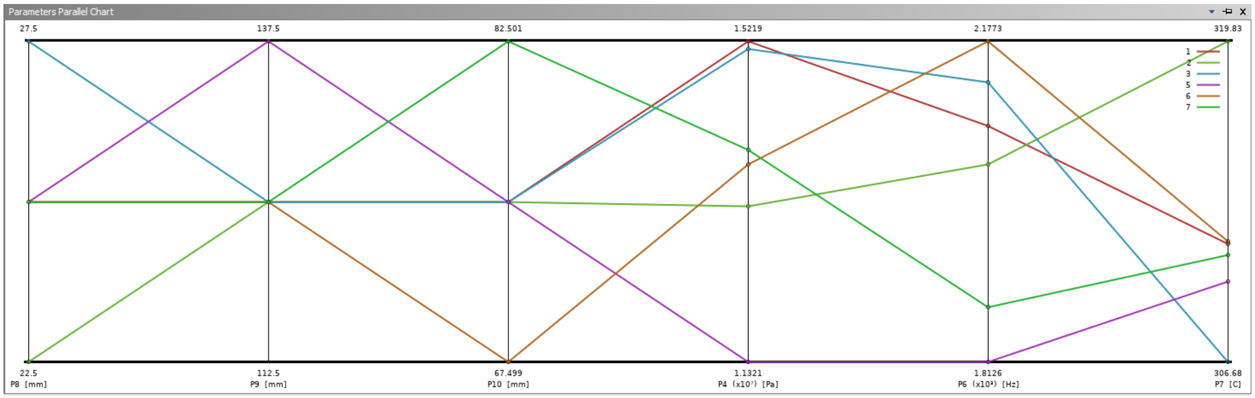
Properties of Outline A2: Design of Experiments

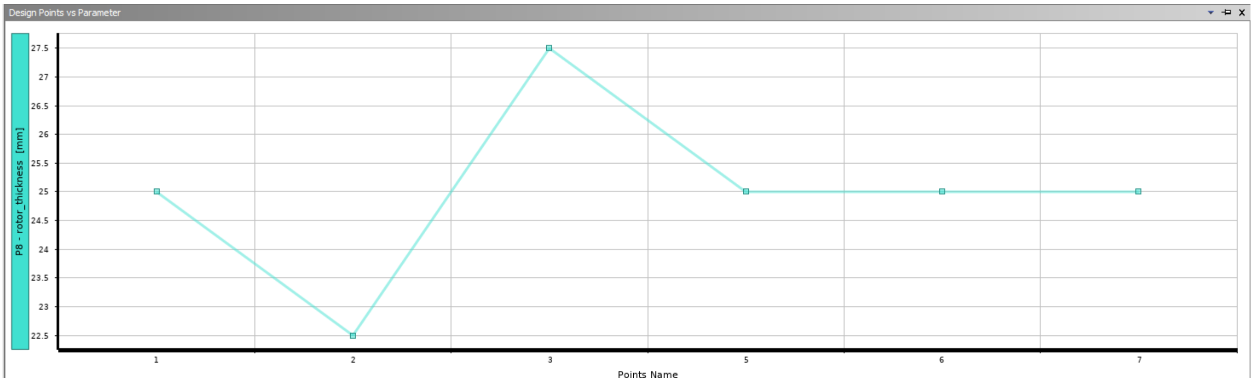
	A	B
1	Property	Value
2	Design Points	
3	Preserve Design Points After DX Run	☐
4	Failed Design Points Management	
5	Number of Retries	0
6	Design of Experiments	
7	Design of Experiments Type	Custom
8	Design Point Report	
9	Report Image	None

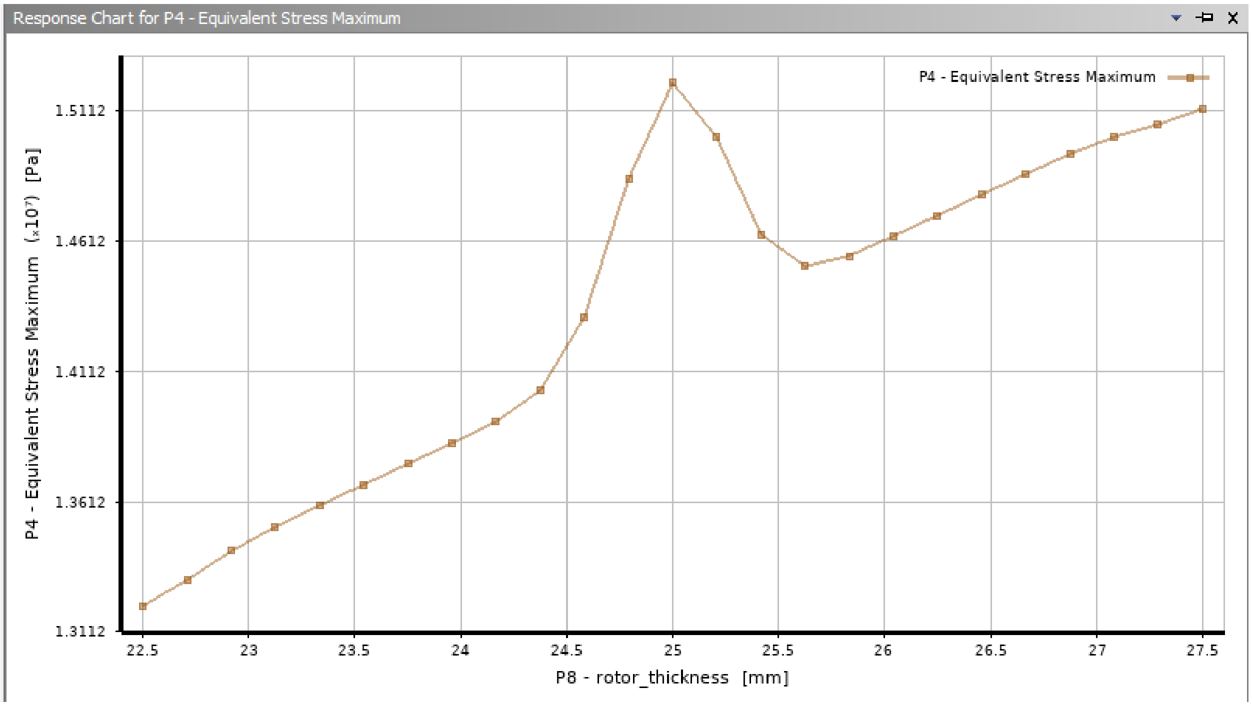
Table of Outline A2: Design Points of Design of Experiments

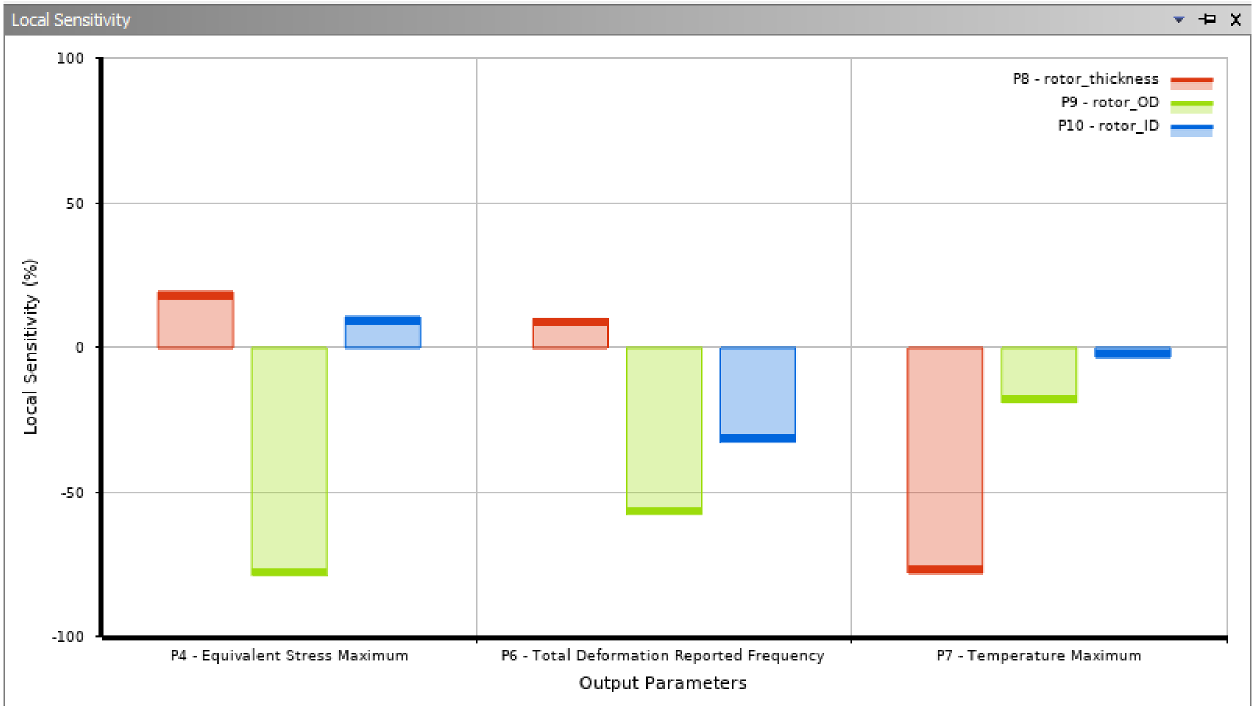
	A	B	C	D	E	F	G
1	Name	P8 - rotor_... (mm)	P9 - rotor_OD (mm)	P10 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P6 - Total Deformation Reported Frequency (Hz)	P7 - Temperature Maximum (C)
2	DP 0	25	125	75	1.5219E+07	2081.2	311.51
3	DP 1	22.5	125	75	1.3213E+07	2036.7	319.82
4	DP 2	27.5	125	75	1.512E+07	2130.2	306.68
5	DP 3	25	137.5	75	1.1321E+07	1812.6	310
6	DP 4	25	125	67.5	1.3717E+07	2177.2	311.62
7	DP 5	25	125	82.5	1.3903E+07	1875.4	311.07

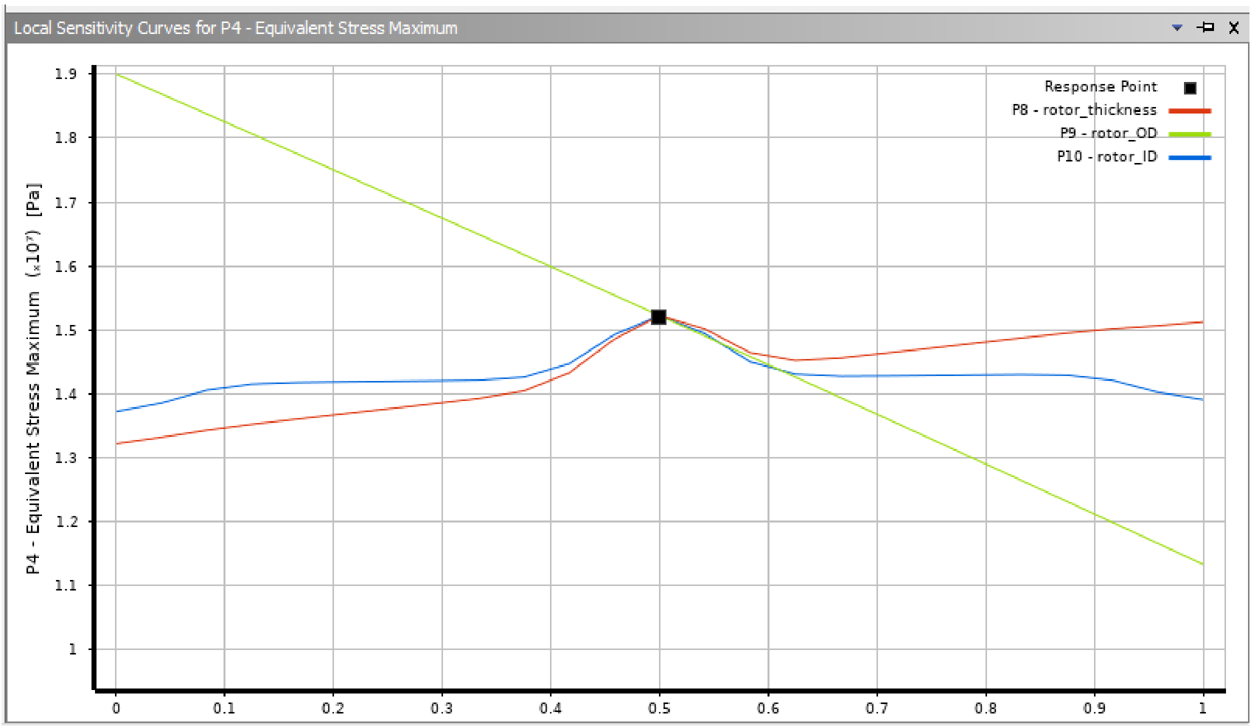
Sensitivity Analysis:

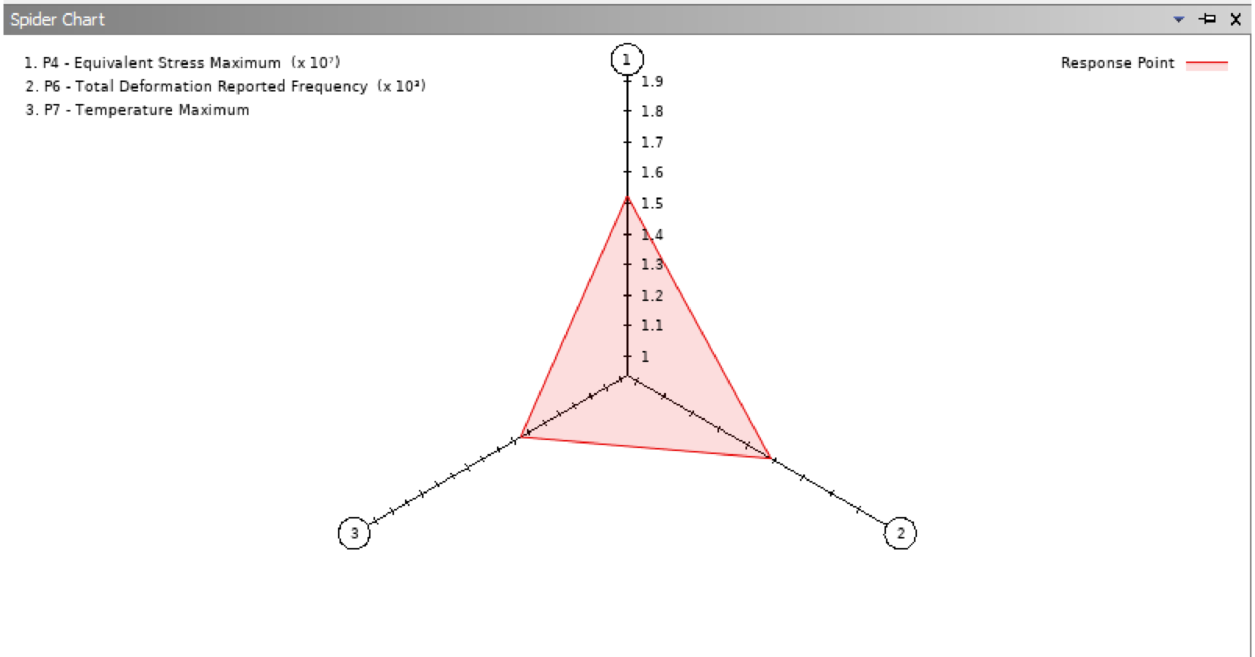







Local Sensitivity
P8 - rotor_thickness
P9 - rotor_OD
P10 - rotor_ID
Local Sensitivity (%)
100
50
0
-50
-100
P4 - Equivalent Stress Maximum
P6 - Total Deformation Reported Frequency
P7 - Temperature Maximum
Output Parameters


Local Sensitivity Curves for P4 - Equivalent Stress Maximum
Response Point
P8 - rotor_thickness
P9 - rotor_OD
P10 - rotor_ID
P4 - Equivalent Stress Maximum (x10^7) [Pa]
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1



Optimization:

Table of Schematic F4: Optimization

	A	B	C	D	E	F	G	H	I
1	Name	Parameter	Objective			Constraint			
2			Type	Target	Tolerance	Type	Lower Bound	Upper Bound	Tolerance
3	Minimize P4	P4 - Equivalent Stress Maximum	Minimize	0		No Constraint			
4	Maximize P6	P6 - Total Deformation Reported Frequency	Maximize	0		No Constraint			
5	Minimize P7	P7 - Temperature Maximum	Minimize	0		No Constraint			
*		Select a Parameter							

Table of Schematic F4: Optimization

	A	B	C	D
1	Input Parameters			
2	Name	Lower Bound	Upper Bound	
3	P8 - rotor_thickness (mm)	22.5	27.5	
4	P9 - rotor_OD (mm)	112.5	137.5	
5	P10 - rotor_ID (mm)	67.5	82.5	
6	Parameter Relationships			
7	Name	Left Expression	Operator	Right Expression
*	New Parameter Relationship	New Expression	<=	New Expression

Table of Schematic F4: Optimization				
	A	B	C	D
1	⊟ Optimization Study			
2	Minimize P4	Goal, Minimize P4 (Default importance)		
3	Maximize P6	Goal, Maximize P6 (Default importance)		
4	Minimize P7	Goal, Minimize P7 (Default importance)		
5	⊟ Optimization Method			
6	MOGA	The MOGA method (Multi-Objective Genetic Algorithm) is a variant of the popular NSGA-II (Non-dominated Sorted Genetic Algorithm-II) based on controlled elitism concepts. It supports multiple objectives and constraints and aims at finding the global optimum.		
7	Configuration	Generate 3000 samples initially, 600 samples per iteration and find 3 candidates in a maximum of 20 iterations.		
8	Status	Converged after 8135 evaluations.		
9	⊟ Candidate Points			
10		Candidate Point 1	Candidate Point 2	Candidate Point 3
11	P8 - rotor_thickness (mm)	24.892	24.892	24.961
12	P9 - rotor_OD (mm)	137.49	137.49	137.46
13	P10 - rotor_ID (mm)	67.553	67.653	67.68
14	P4 - Equivalent Stress Maximum (Pa)	9.9012E+06	9.9078E+06	9.9178E+06
15	P6 - Total Deformation Reported Frequency (Hz)	★★★ 1909.1	★★★ 1907.5	★★★ 1909.2
16	P7 - Temperature Maximum (C)	××× 310.5	××× 310.49	××× 310.24