

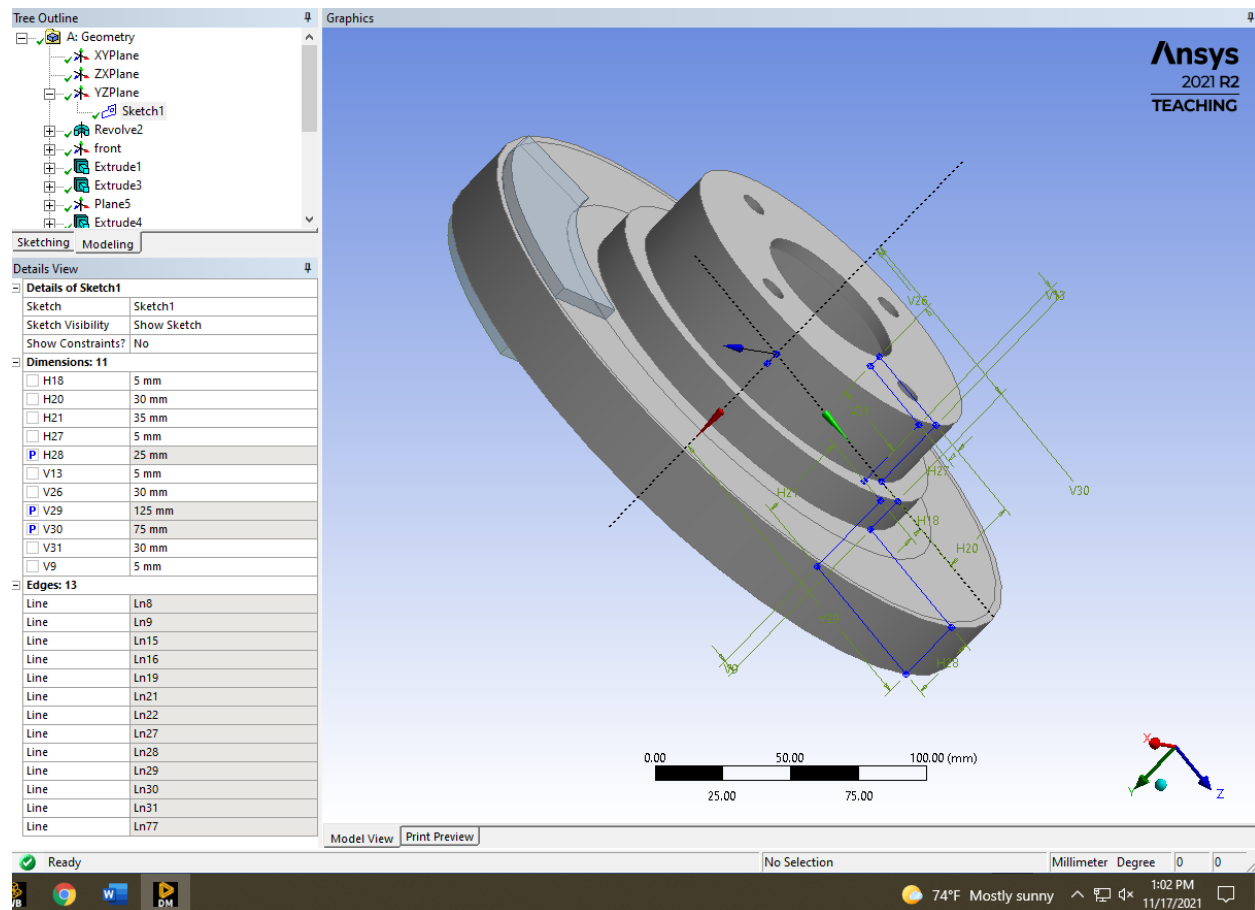
Aishwarya Ledalla
MAE 598: Design Optimization
Dr. Max Yi Ren

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.

MAE 598 Project 2 Ashwarya Ledalla - Workbench

File Edit View Tools Units Extensions Jobs Help

Project B2-Engineering Data

Filter Engineering Data Engineering Data Sources

Toolbox

- Field Variables
- Physical Properties
- Linear Elastic
- Hyperelastic/Experimental Data
- Hyperelastic
- Chaboche Test Data
- Plasticity
- Creep
- Life
- Strength
- Gasket
- Viscoelastic Test Data
- Viscoelastic
- Shape Memory Alloy
- Geomechanical
- Damage
- Cohesive Zone
- Fracture Criteria
- Crack Growth Laws
- Three Network Model
- Custom Material Models

Engineering Data Sources

A	B	C	D
Data Source	Location	Description	
7	Composite Materials		Material samples specific for composite structures.
8	General Non-linear Materials		General use material samples for use in non-linear analyses.
9	Explicit Materials		Material samples for use in an explicit analysis.
10	Hyperelastic Materials		Material stress-strain data samples for curve fitting.
11	Magnetic S-H Curves		S-H Curve samples specific for use in a magnetic analysis.
12	Thermal Materials		Material samples specific for use in a thermal analysis.
13	Fluid Materials		Material samples specific for use in a fluid analysis.

Click here to add a new library

Outline of General Materials

A	B	C	D	E
Material	Add	Source	Description	
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				

Properties of Outline Row 8: Gray Cast Iron

A	B	C
Property	Value	Unit
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

Table of Properties Row 2: Density

A	B
Temperature (C)	Density (kg m ⁻³)
1	
2	7200

Chart of Properties Row 2: Density

Ready

Type here to search

Job Monitor... No DPS Connection Show Progress Show 0 Messages

60°F Mostly cloudy 9:31 AM 11/17/2021

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
<input type="checkbox"/> Element Size	3.e-003 m
Advanced	
<input type="checkbox"/> 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	
<input type="checkbox"/> 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

Outline

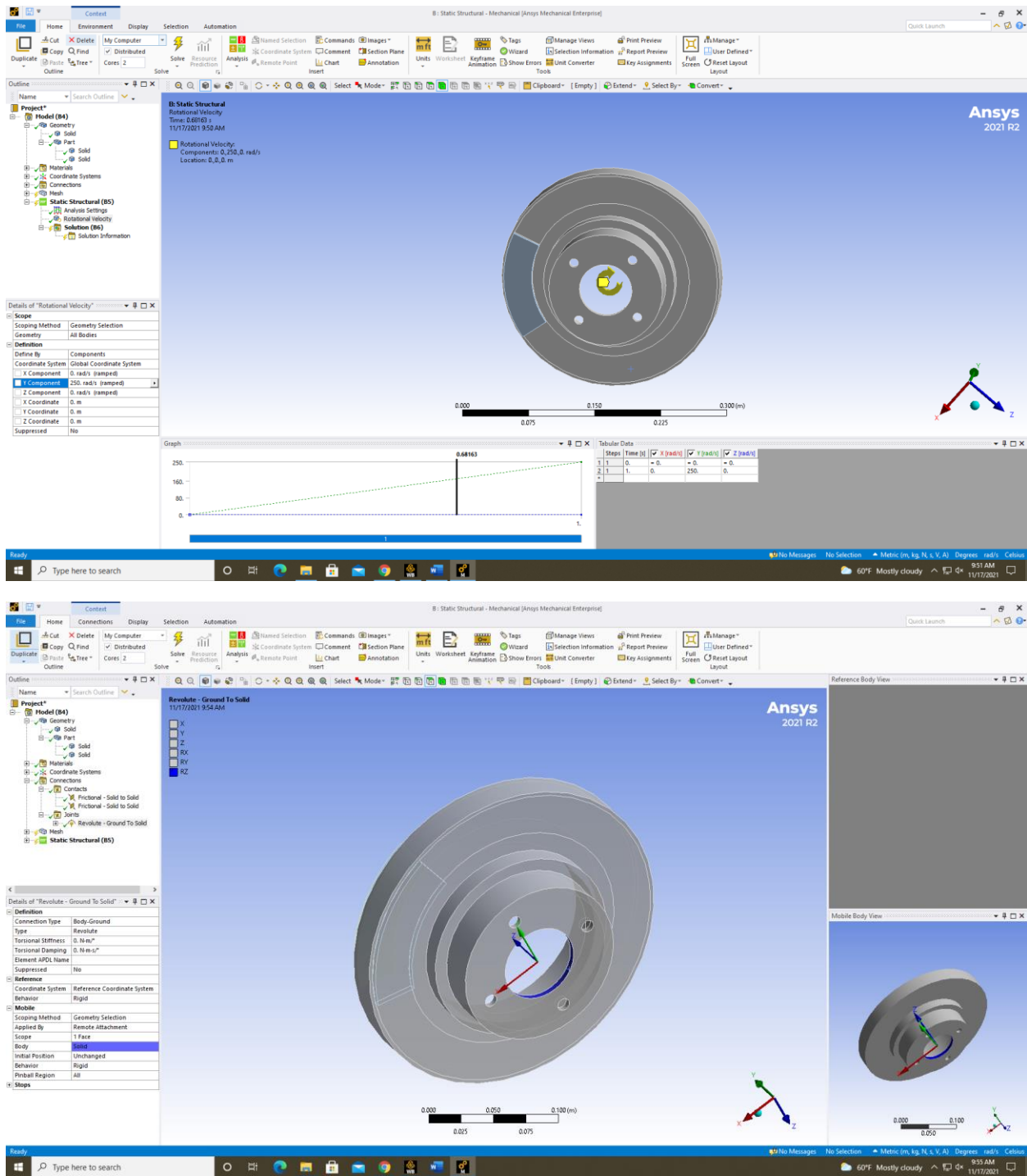
Name Search Outline

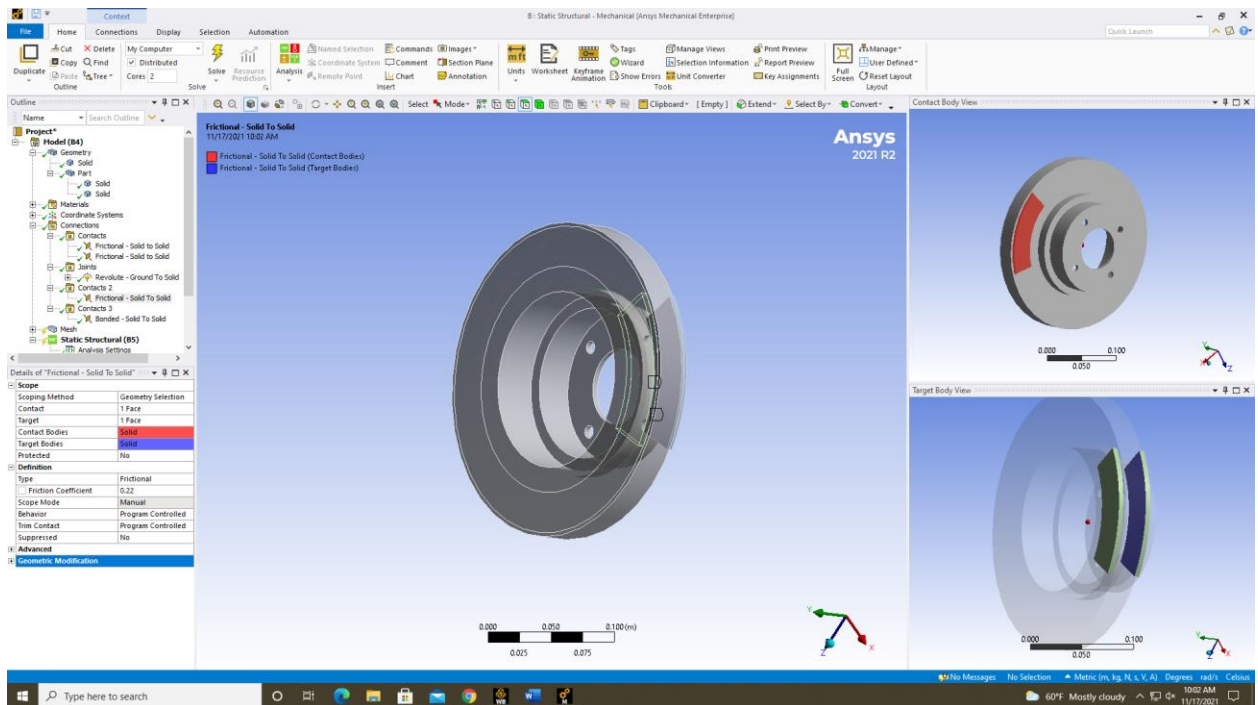
Project*

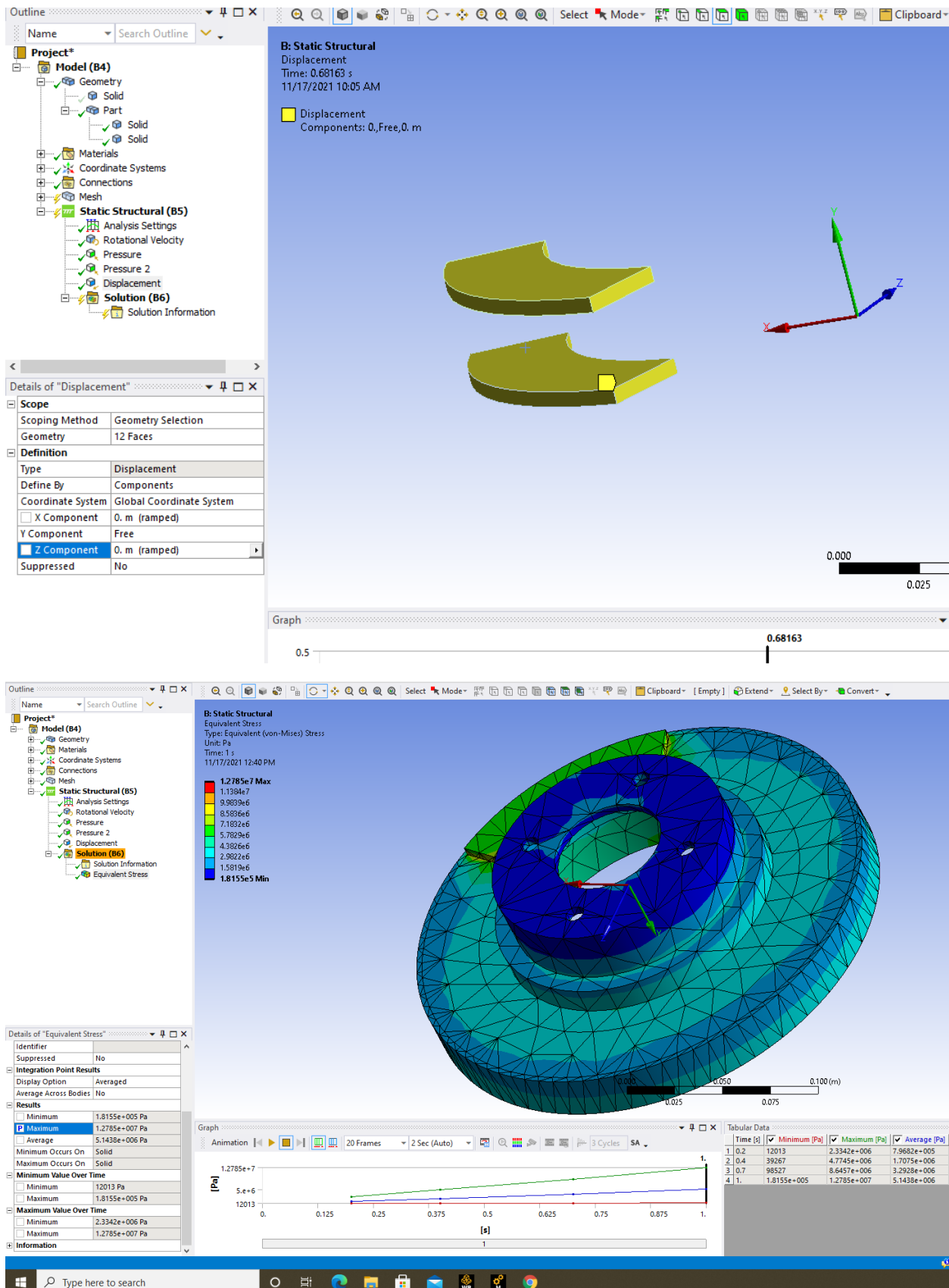
- Model (B4)**
 - Geometry
 - Solid
 - Part
 - Solid
 - Solid
 - Materials
 - Gray Cast Iron
 - Structural Steel
 - Structural Steel Assignment
 - Gray Cast Iron Assignment
 - Coordinate Systems
 - Connections
 - Mesh
 - Patch Conforming Method
 - Face Sizing
 - Static Structural (B5)**
 - Analysis Settings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

Details of "Gray Cast Iron Assignment"

General	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
<input type="checkbox"/> Material Name	Gray Cast Iron
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Reference Temperature	By Environment
Suppressed	No
Common Material Properties	
Density	7200 kg/m ³
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



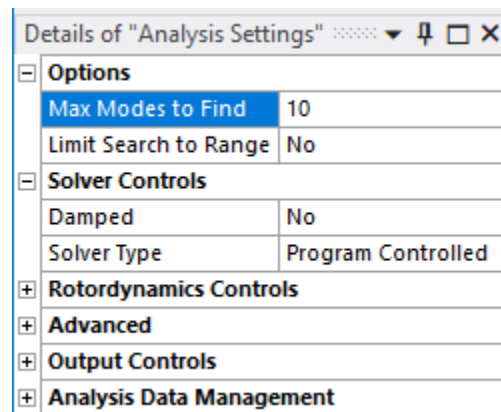
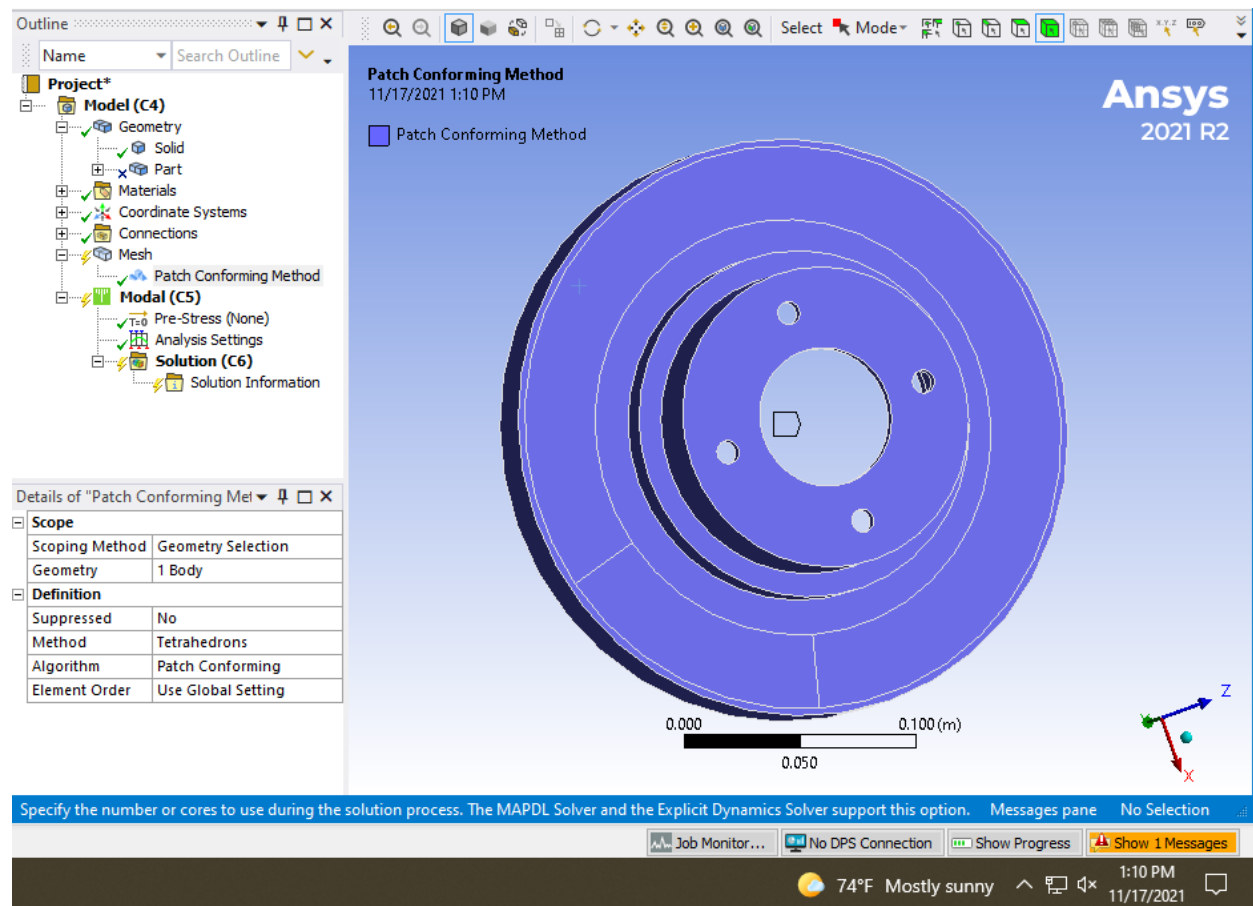


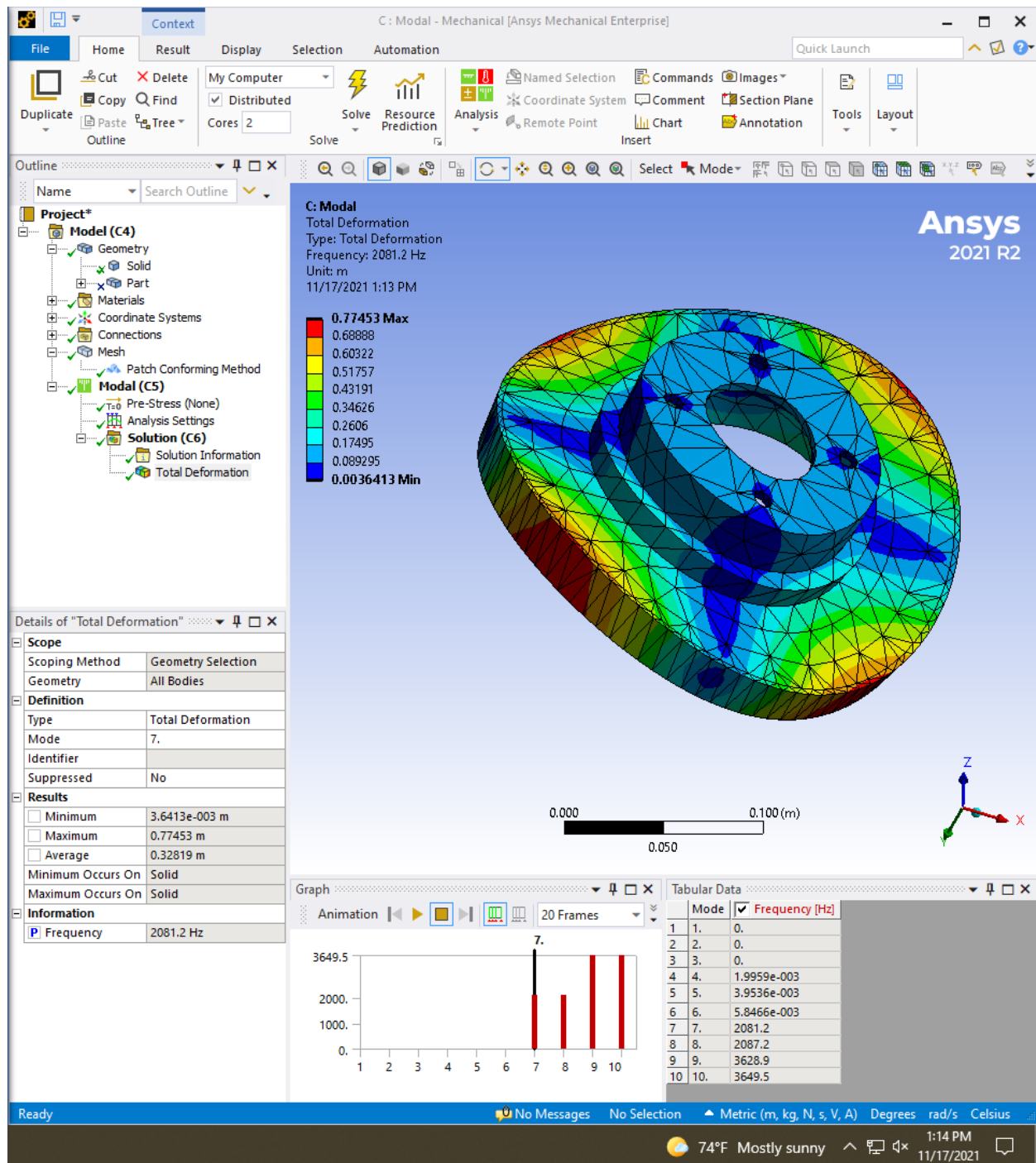


Modal Setup:

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.



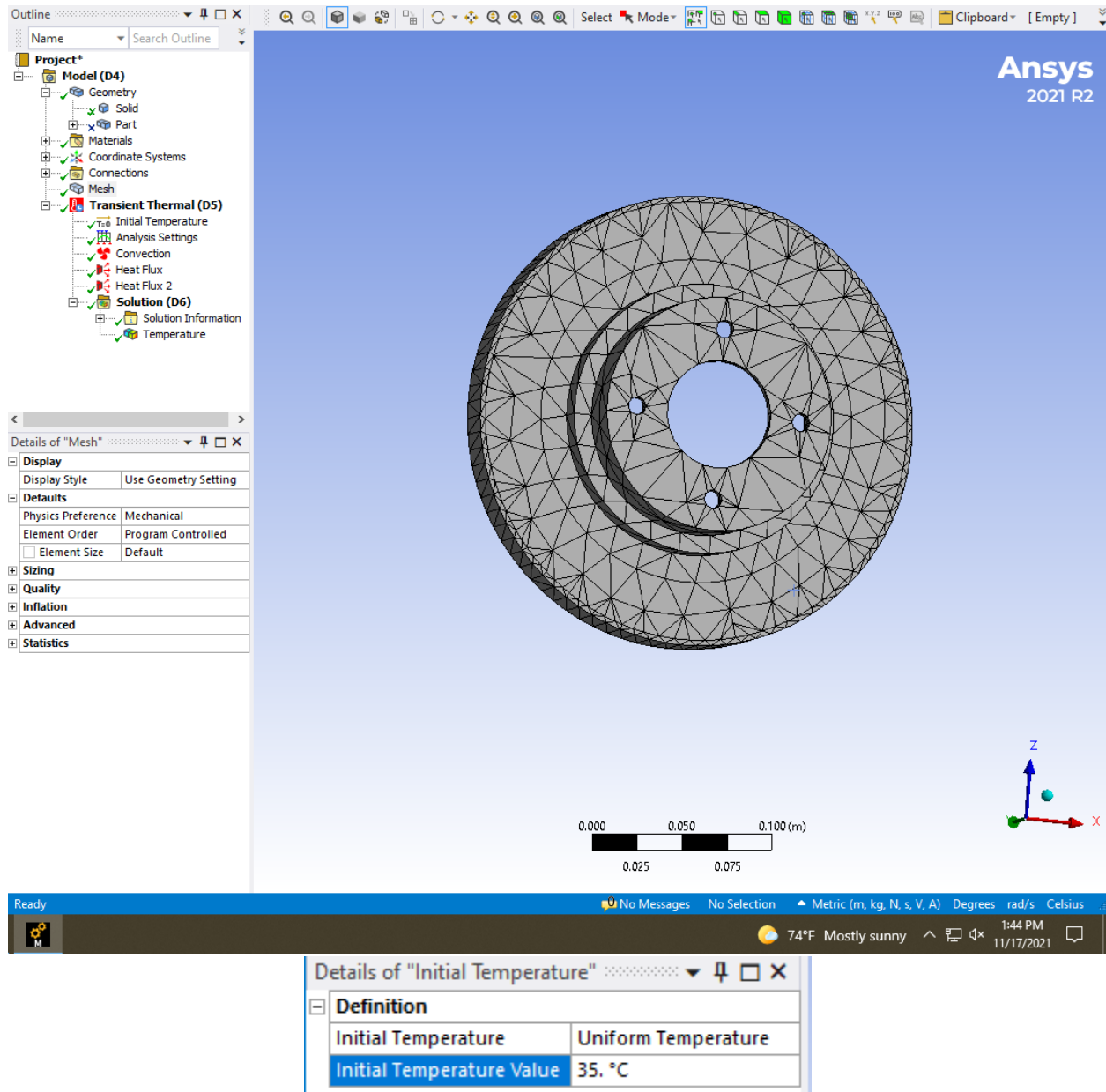


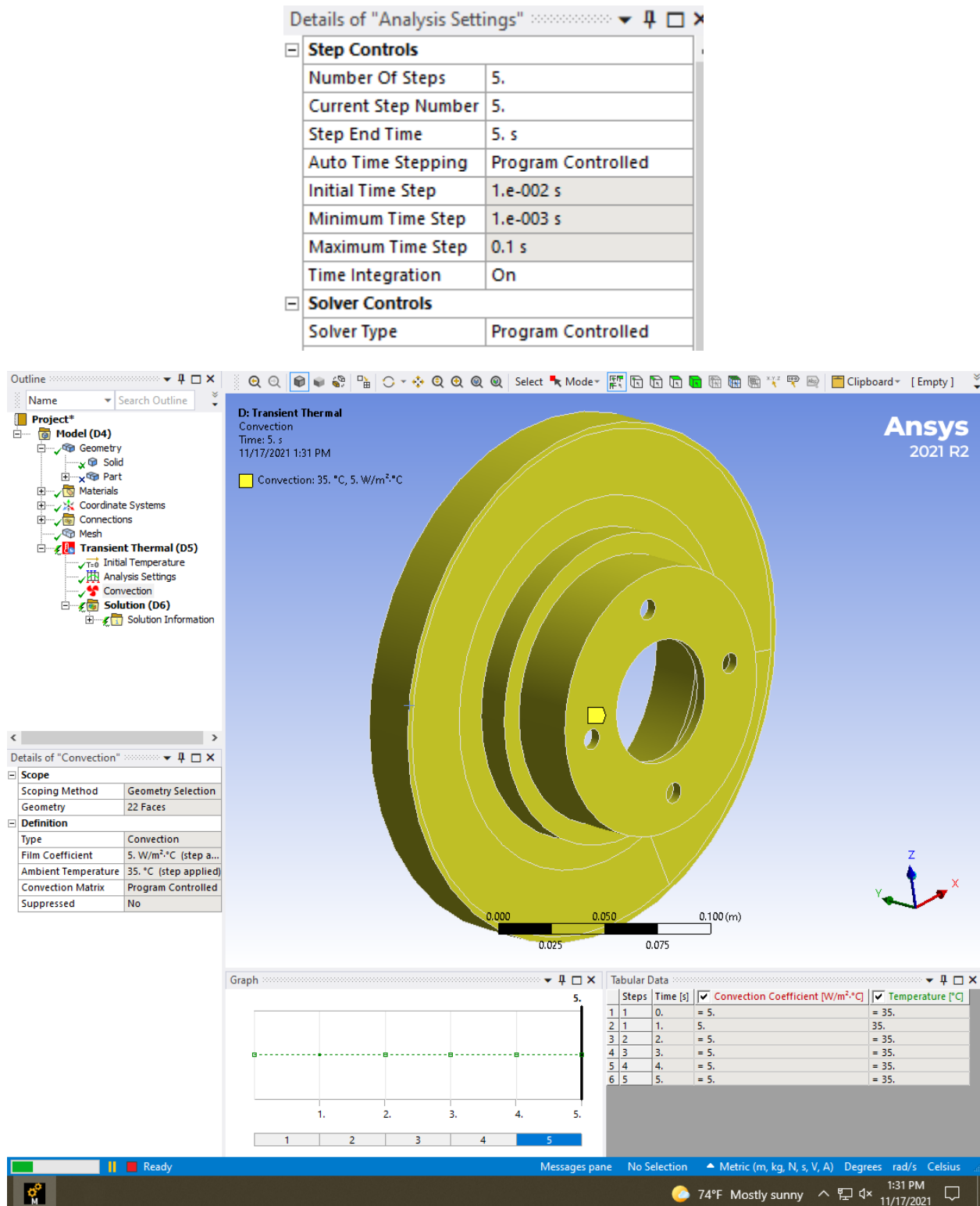
Transient Thermal Setup:

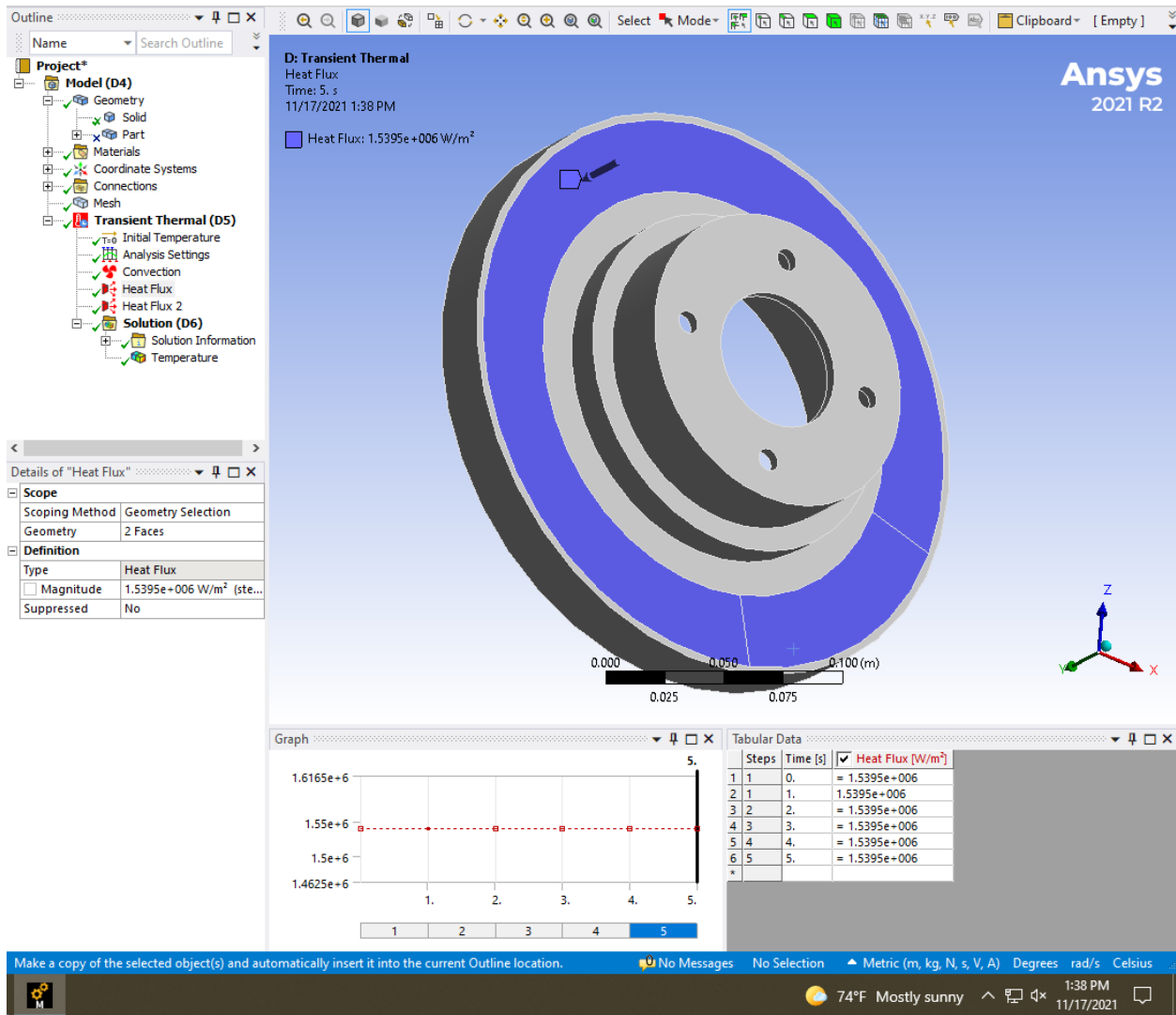
Given:

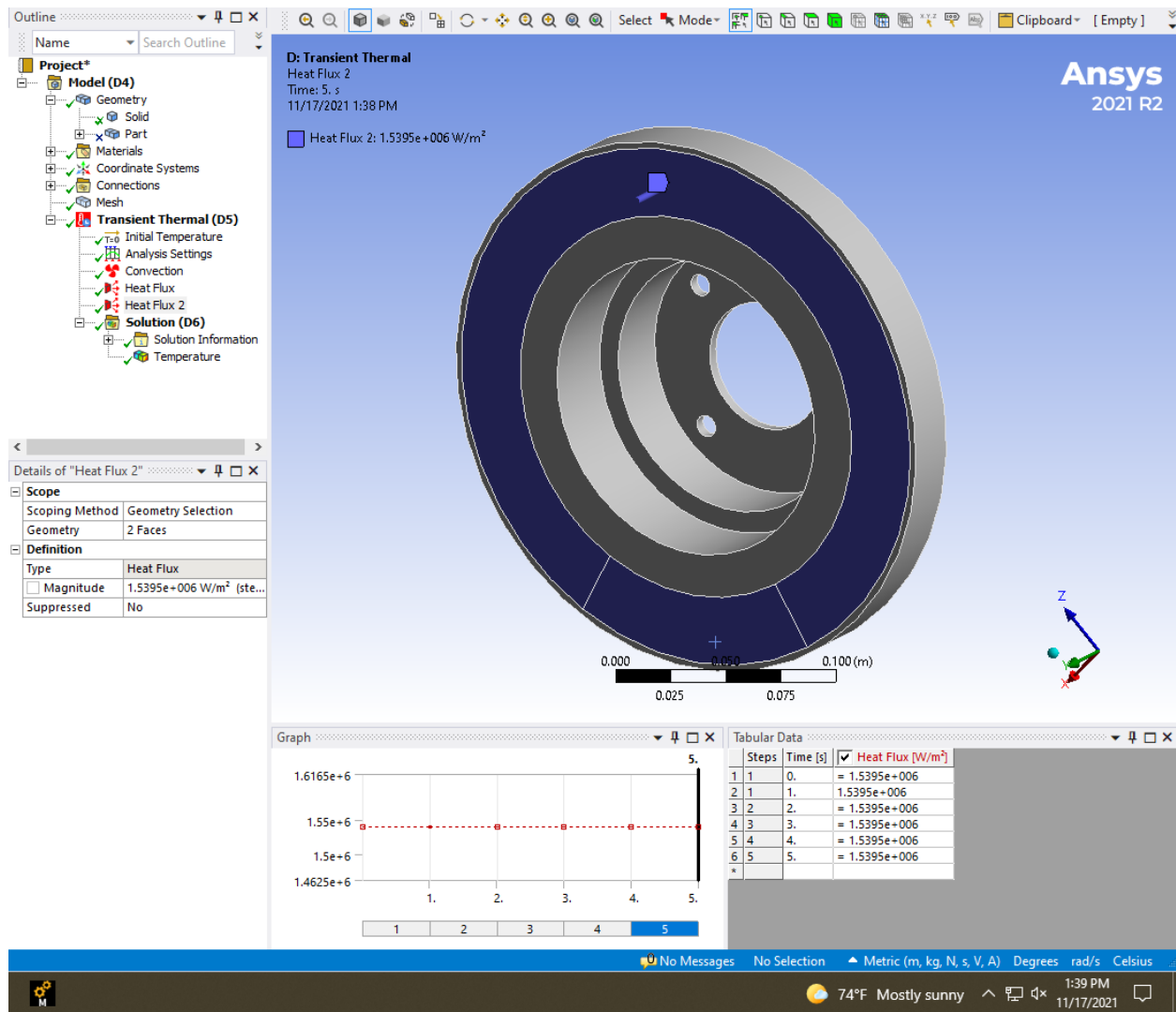
Braking in a vehicle takes place due to friction between the brake pads and the rotor disc. This leads to heat flux generation in the disc which consequently results in increase in its temperature and thermal stresses. Emergency braking conditions induce high temperatures that damage the

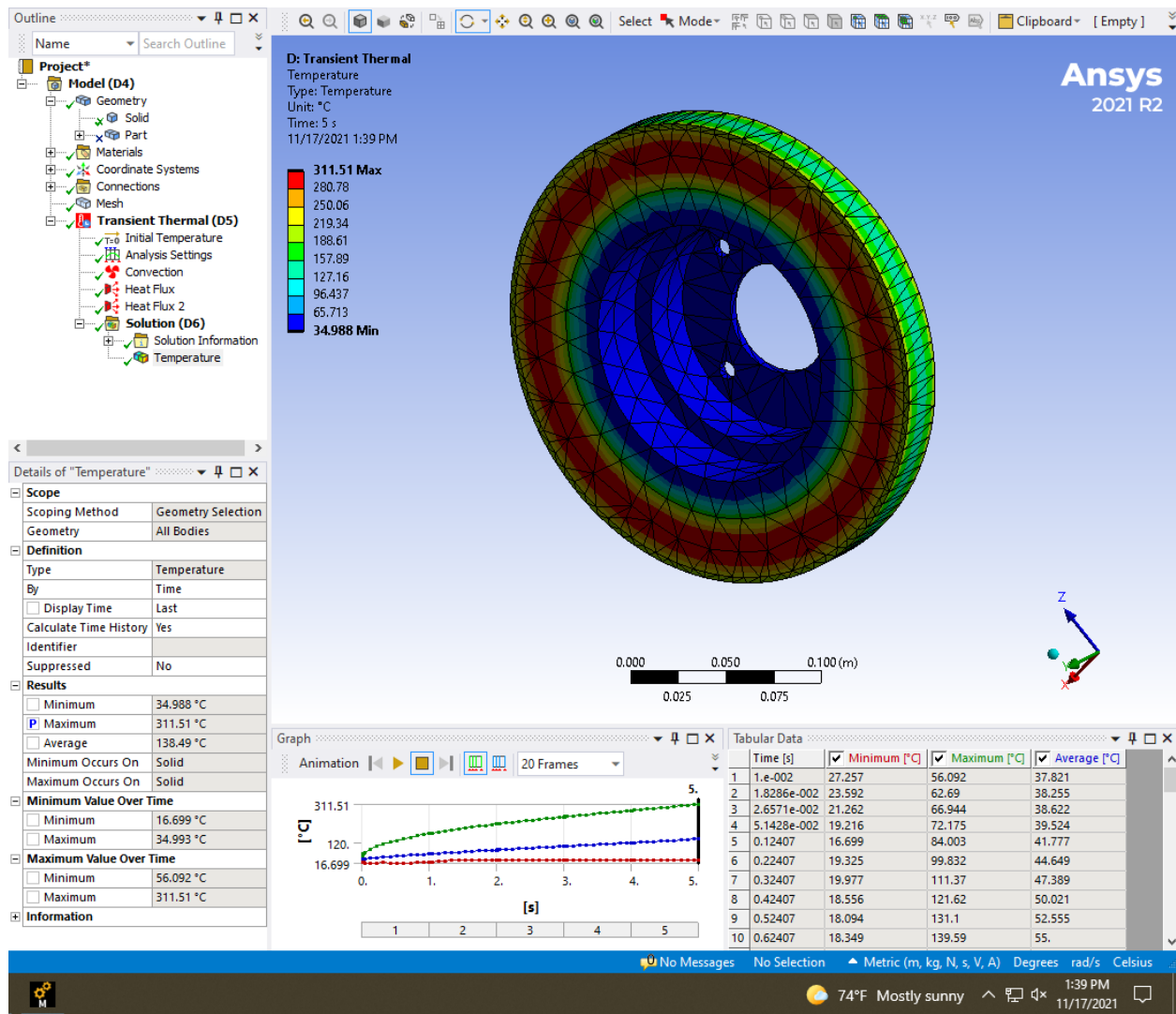
contact surfaces. It is therefore essential to minimize the temperature to prevent disc wear and tear.

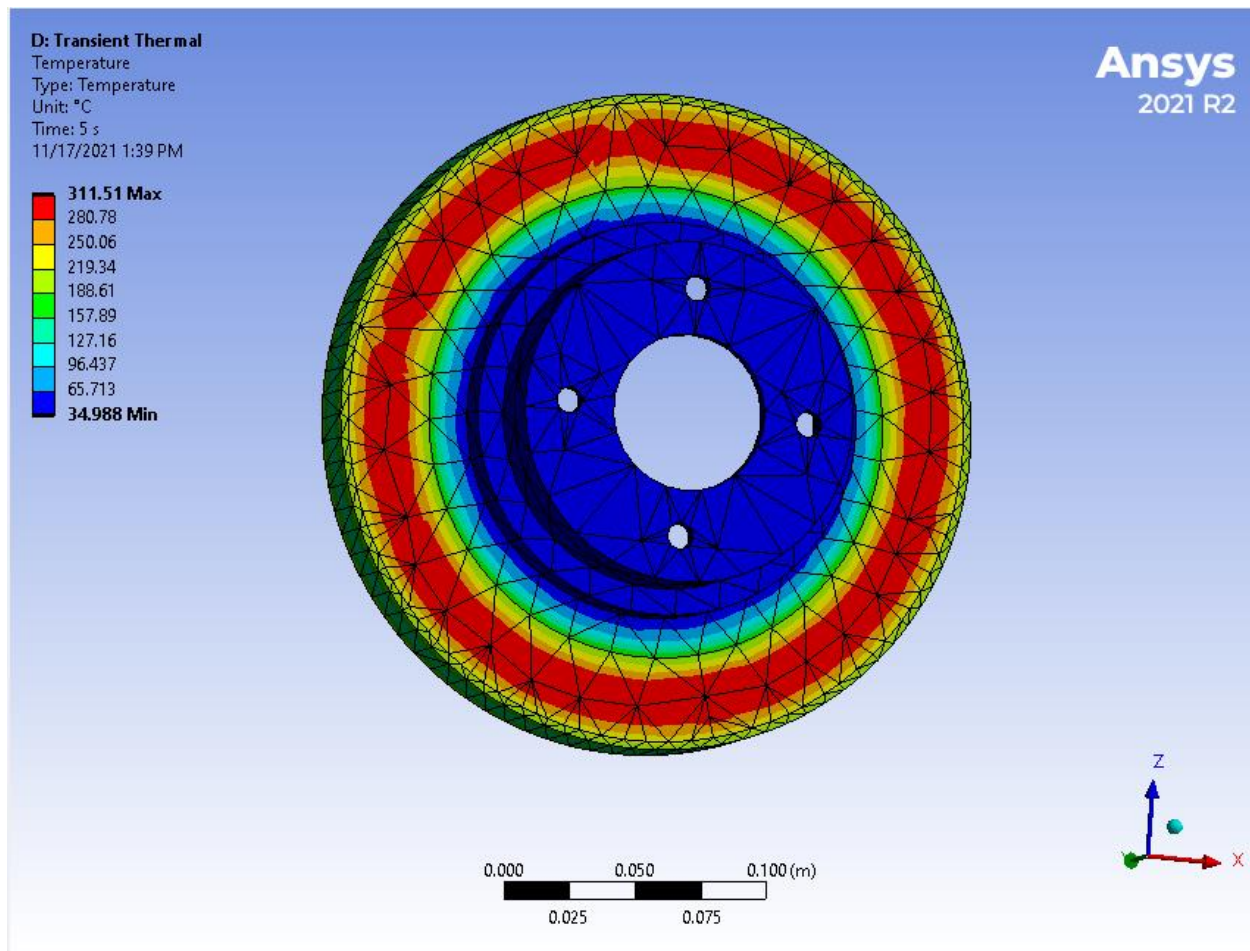












Design of Experiments:

- 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:

Outline of Schematic E2: Design of Experiments

1	A
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 Maximum
11	Modal (C1)
12	P6 - Total Deformation Reported Frequency
13	Transient Thermal (D1)
14	P7 - Temperature Maximum
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

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

Properties of Outline A7: P5 - rotor_thickness

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

Outline of Schematic G2: Design of Experiments

1	A	Enabled
2	Design of Experiments	
3	Input Parameters	
4	Geometry (A1)	
5	P8 - rotor_thickness	<input checked="" type="checkbox"/>
6	P9 - rotor_OD	<input checked="" type="checkbox"/>
7	P10 - rotor_ID	<input checked="" type="checkbox"/>
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	<input checked="" type="checkbox"/>
17	Design Points vs Parameter	<input checked="" type="checkbox"/>

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 1	25.333	131.67	76	1.1189E+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	27.333	115	69	1.139E+07	1808.4	309.16
6	DP 5	25.667	135	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	24.667	121.67	73	1.0849E+07	1887.4	316.59
9	DP 8	23.333	133.33	72	1.7312E+07	2138.4	312.04
10	DP 9	26.667	136.67	68	1.1992E+07	1883.7	306.6
11	DP 10	24.333	120	78			

Properties of Outline A2: Design of Experiments

A		B
1	Property	Value
2	Design Points	
3	Preserve Design Points After DX Run	<input type="checkbox"/>
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

- I initially had 18 points experimental data but I removed the ones Ansys could not evaluate using the custom sampling DOE type:

	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	<input type="checkbox"/>
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	<input checked="" type="checkbox"/>
12	Number of Verification Points	3
13	[-] Design Point Report	
14	Report Image	None

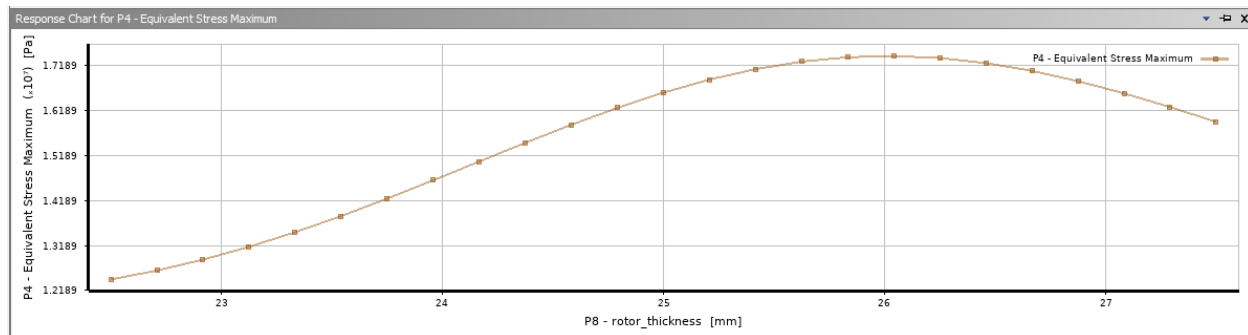
Table of Outline A2: Response Points

	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	Response Point	25	125	75	1.6577E+07	2112.8	312.65
*	New Response Point						

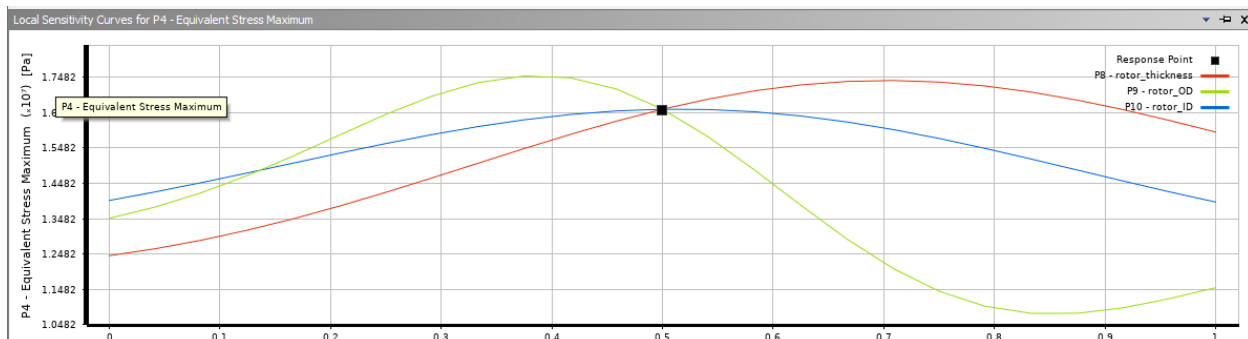
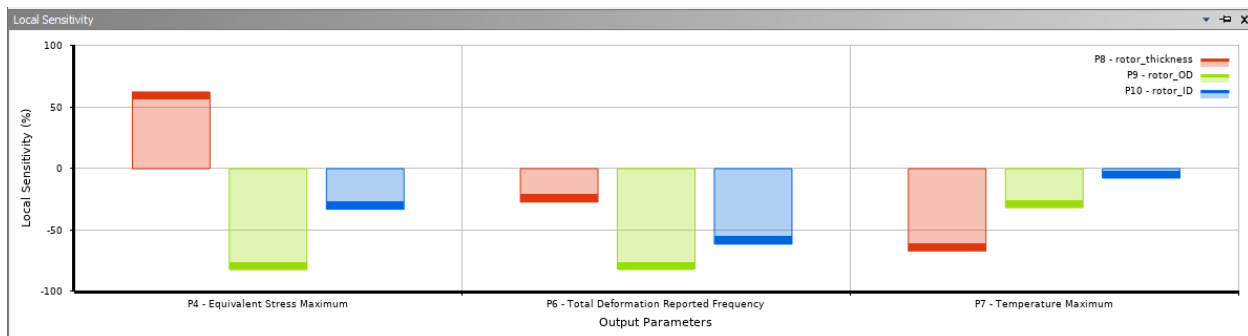
Table of Schematic G3: Response Surface

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

	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	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 not have the option to use Adaptive Multi-Objective Optimization (AMO) or Adaptive Single-Objective Optimization (ASO), otherwise I would have chosen AMO.

	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							

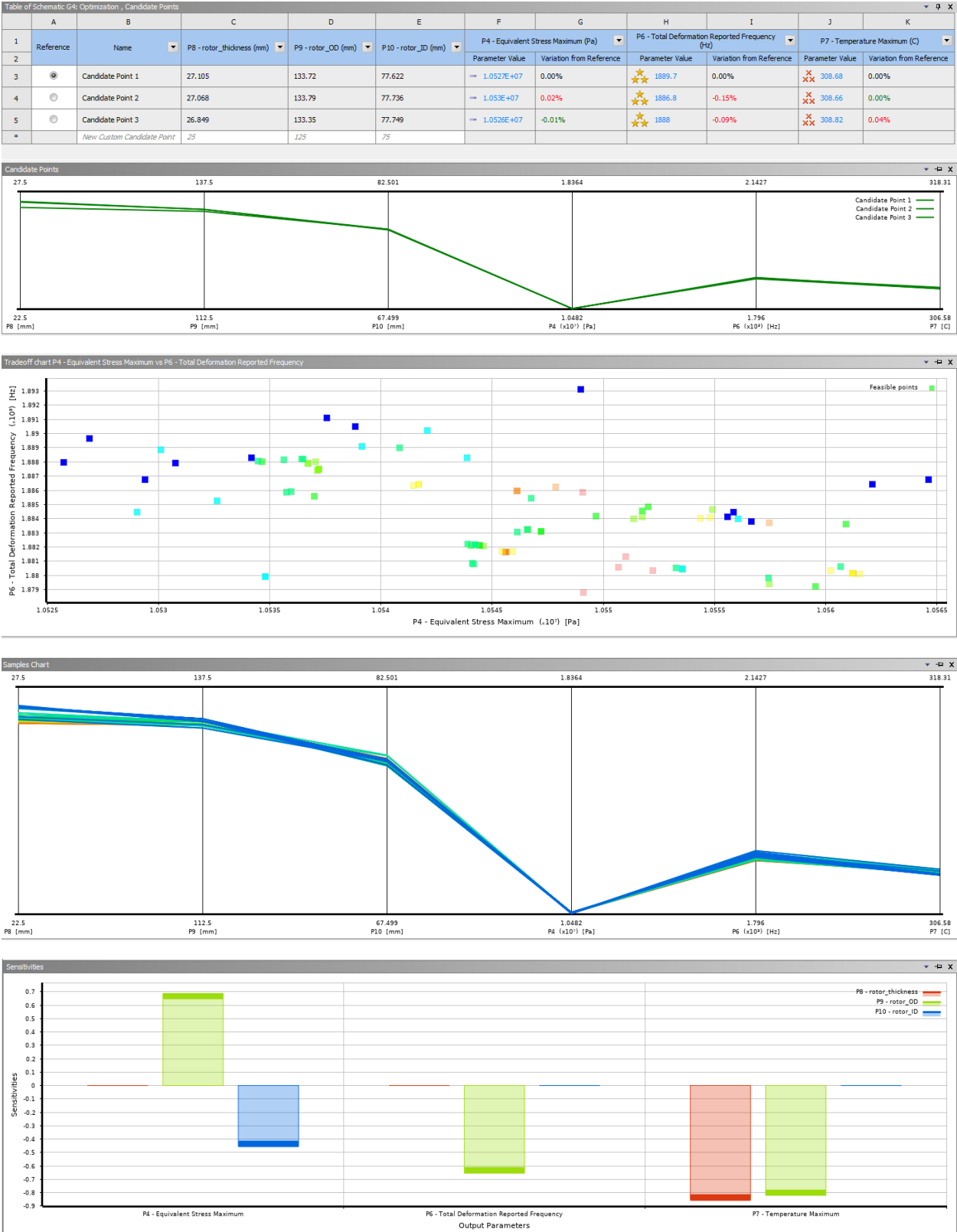
Properties of Outline A2: Optimization		
	A	B
1	Property	Value
2	[-] Design Points	
3	Preserve Design Points After DX Run	<input type="checkbox"/>
4	[-] Failed Design Points Management	
5	Number of Retries	0
6	[-] Optimization	
7	Method Selection	Manual
8	Method Name	MOGA
9	Estimated Number of Evaluations	2000
10	Tolerance Settings	<input checked="" type="checkbox"/>
11	Verify Candidate Points	<input type="checkbox"/>
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	1.3355
22	Number of Iterations	8
23	Number of Evaluations	687
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	[-] 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 100 samples initially, 100 samples per iteration and find 3 candidates in a maximum of 20 iterations.		
8	Status	Converged after 687 evaluations.		
9	[-] Candidate Points			
10		Candidate Point 1	Candidate Point 2	Candidate Point 3
11	P8 - rotor_thickness (mm)	27.105	27.068	26.849
12	P9 - rotor_OD (mm)	133.72	133.79	133.35
13	P10 - rotor_ID (mm)	77.622	77.736	77.749
14	P4 - Equivalent Stress Maximum (Pa)	[-] 1.0527E+07	[-] 1.053E+07	[-] 1.0526E+07
15	P6 - Total Deformation Reported Frequency (Hz)	★★★ 1889.7	★★★ 1886.8	★★★ 1888
16	P7 - Temperature Maximum (C)	✖✖✖ 308.68	✖✖✖ 308.66	✖✖✖ 308.82

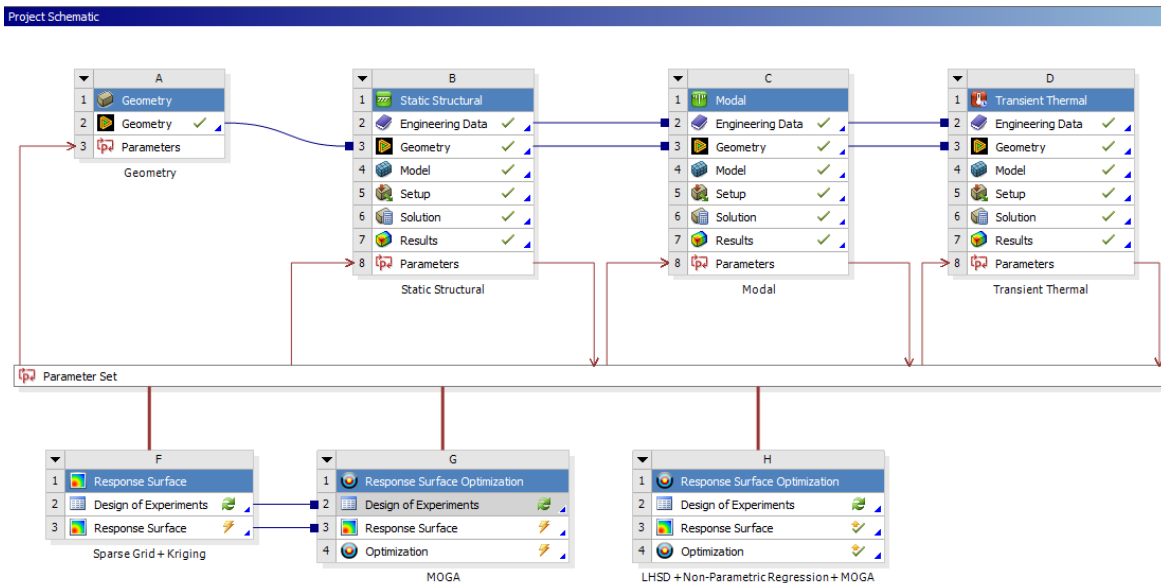
- Volume of each candidate:

Candidates	Volume of Brake Disk
Initial	9.9667e+05 mm ³
Optimal 1	1.23e+06 mm ³
Optimal 2	1.2291e+06 mm ³
Optimal 3	1.2109e+06 mm ³

- 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.

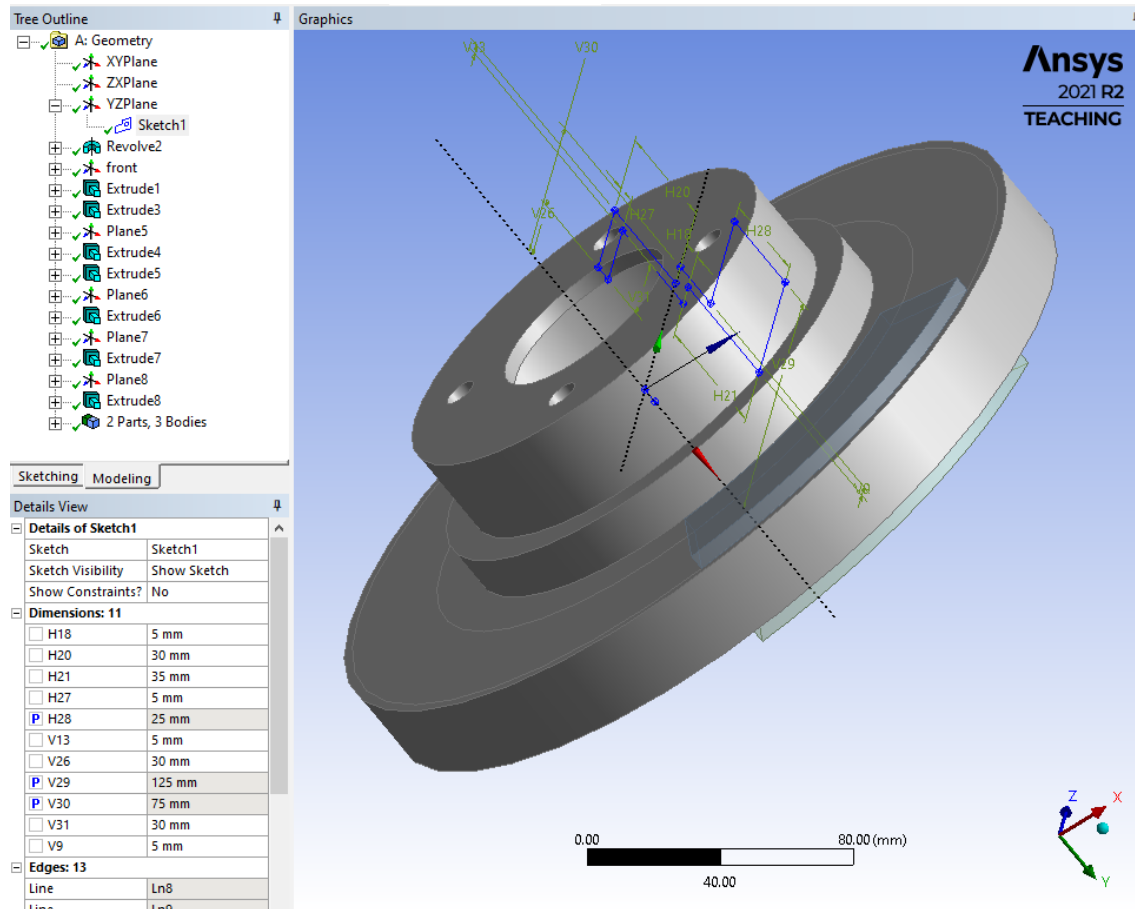


Project Schematic:

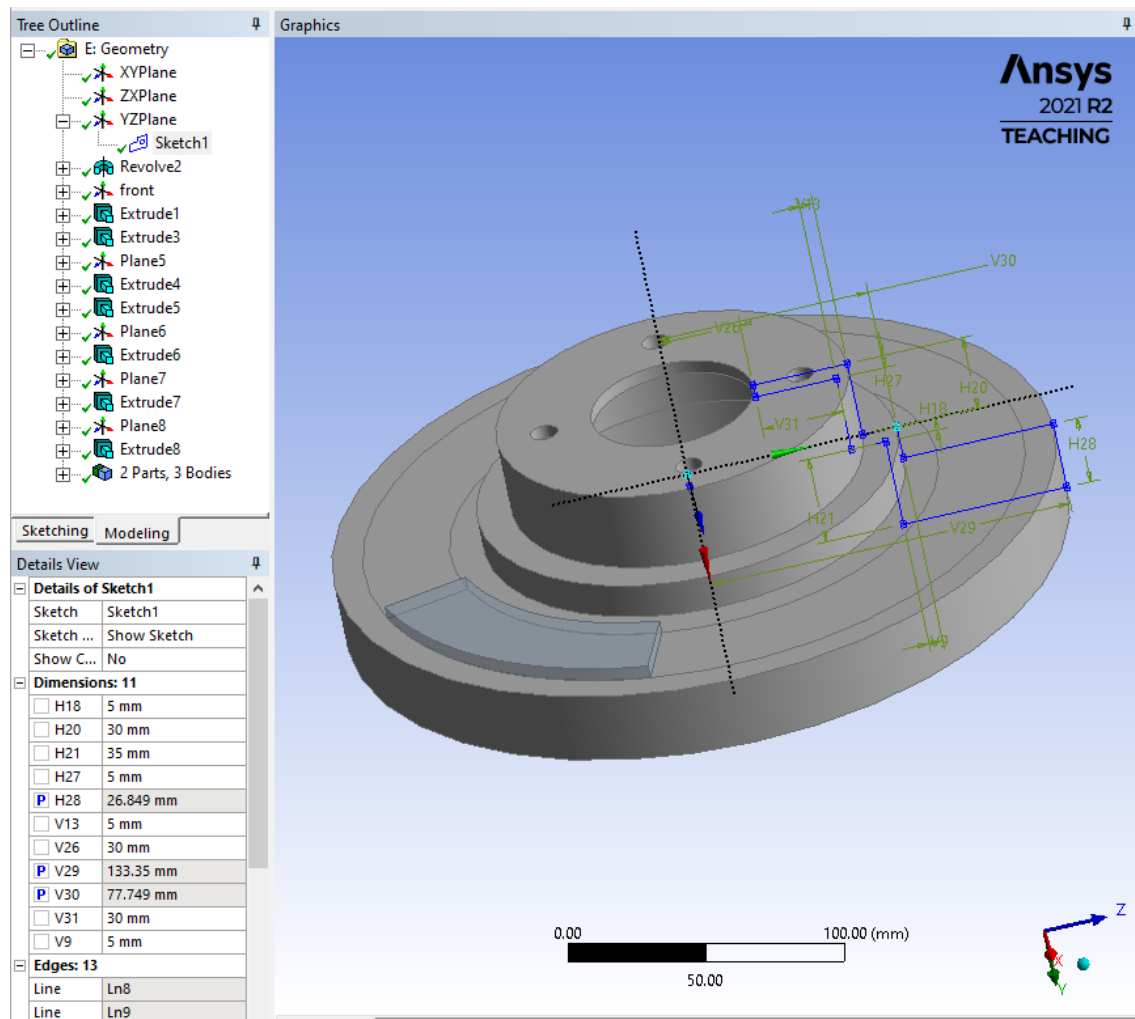


Optimal Design:

Initial:



Final:



Volume reduction: - 19.409%

- The volume increased by 19.4% after it was optimized for the other objectives.

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.
- And finally, the maximum thickness is highly insensitive to the thickness of the disk.

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 had a larger volume than the original design. It is not a reasonable design to consider. The major source of error came from not including the volume objective in my DOE and not optimizing with respect to the volume.
- To fix this issue and to get a better design, I can re-perform my design optimization while including volume as an output parameter.

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	<input type="checkbox"/>
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 Experiments		
	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 Experiments		
	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 Experiments		
	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_thickness		
	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

Update Preview Clear Generated Data

Outline of Schematic E2: Design of Experiments

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	1.278E+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	⚡	⚡	⚡

Properties of Outline A7: P5 - rotor_thickness

	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

Chart: No data

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

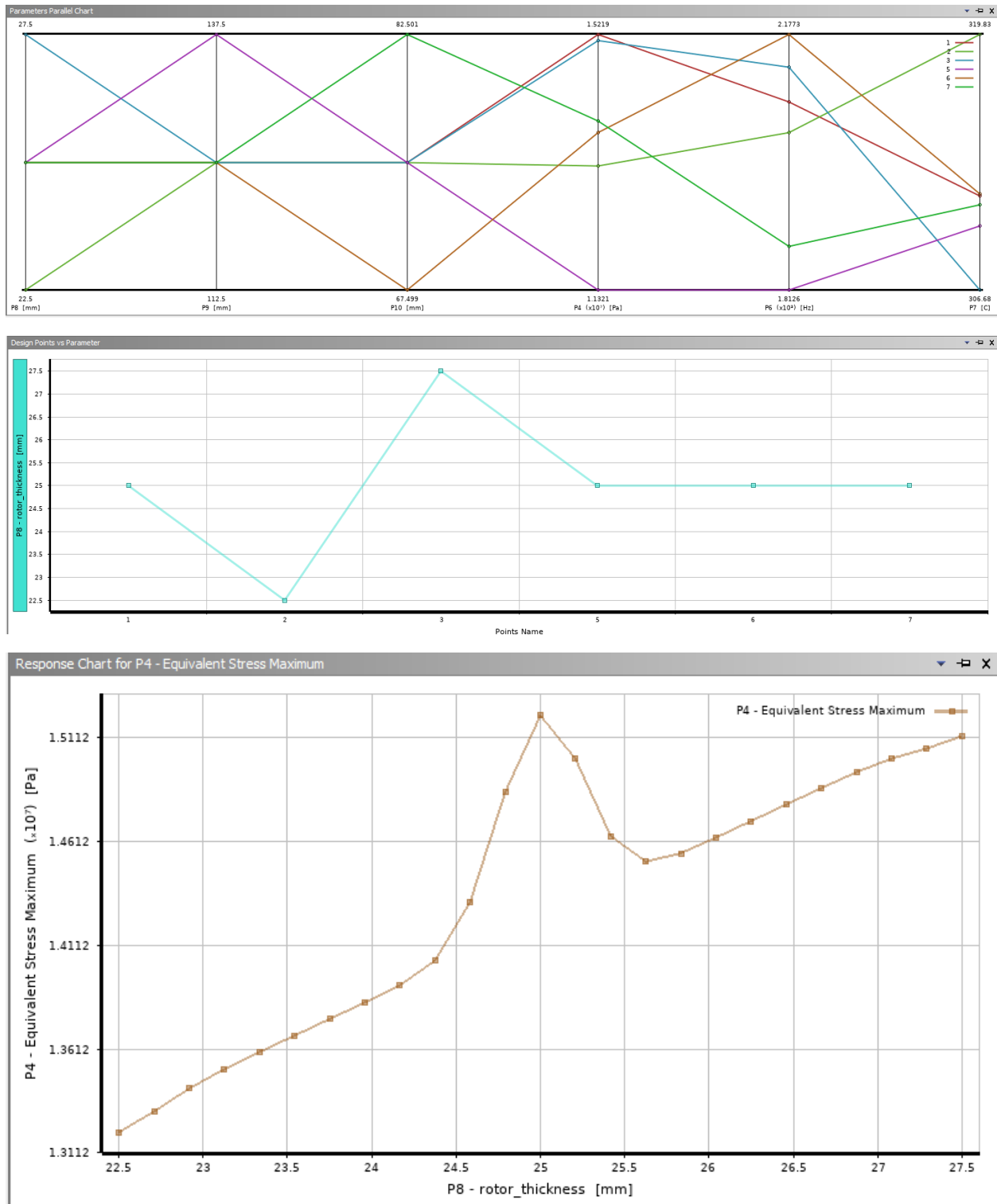
Properties of Outline A2: Design of Experiments

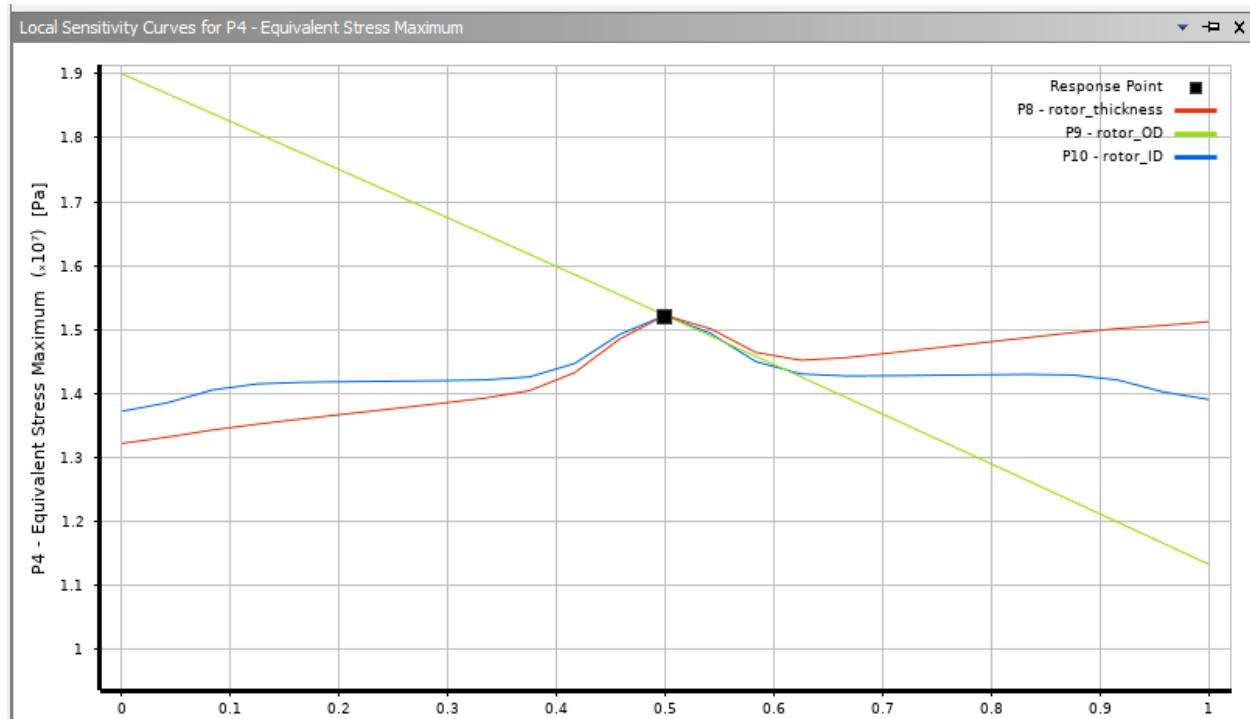
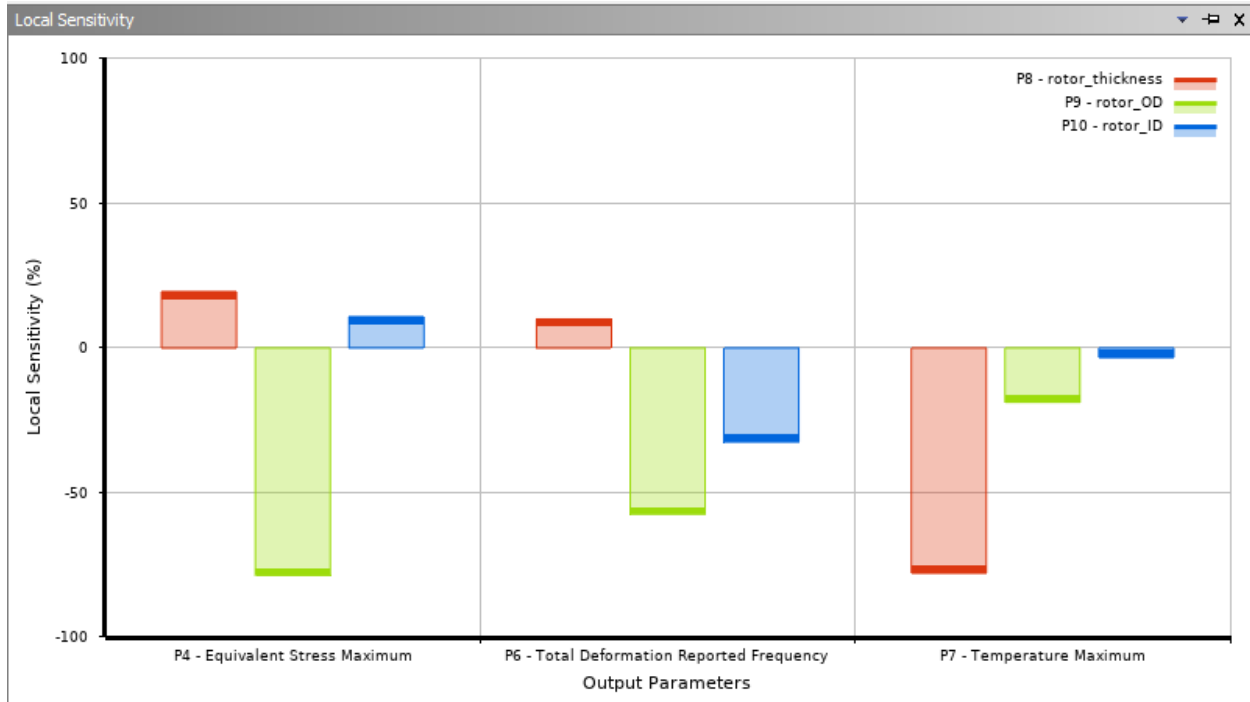
	A	B
1	Property	Value
2	Design Points	
3	Preserve Design Points After DX Run	<input type="checkbox"/>
4	Failed Design Points Management	
5	Number of Retries	0
6	Design of Experiments	
7	Design of Experiments Type	Custom
8	Design Point Report	
9	Report Image	None

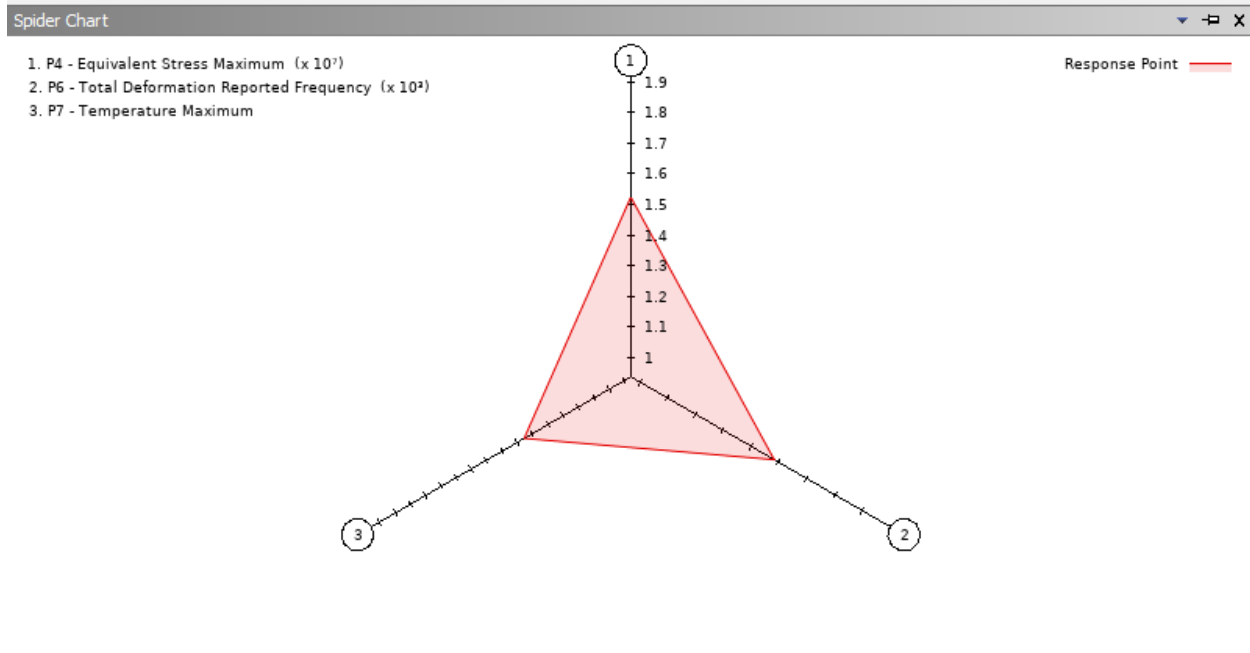
Table of Outline A2: Design Points of Design of Experiments

	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:







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							

	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