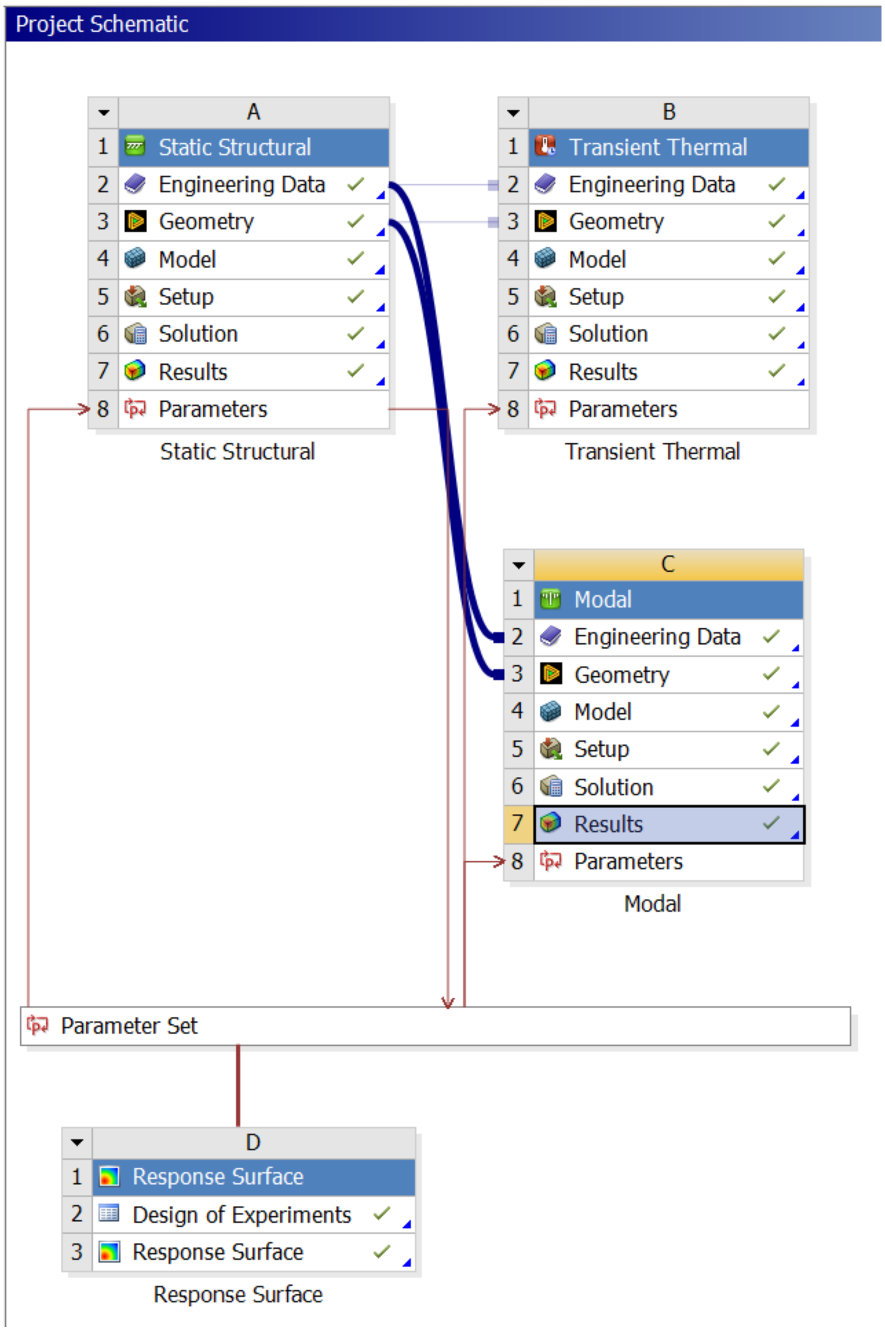
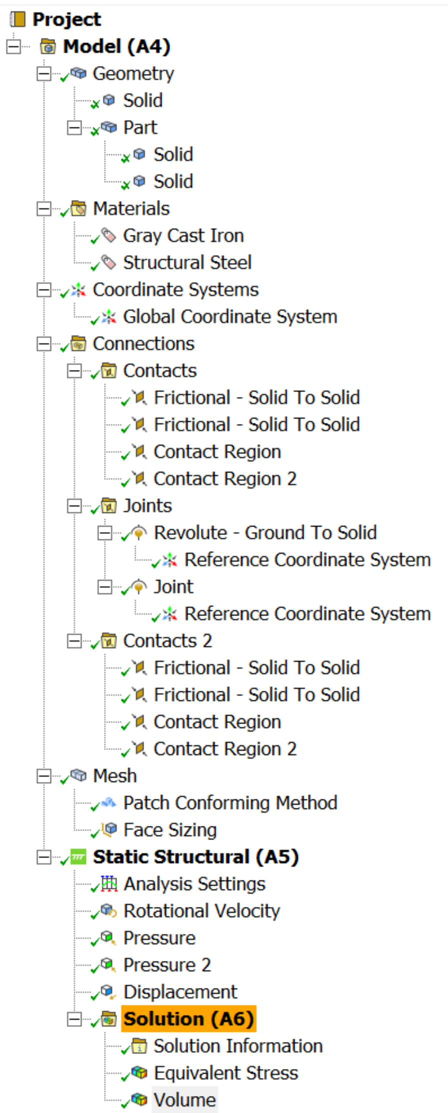
ANSYS DOE and Design Optimization

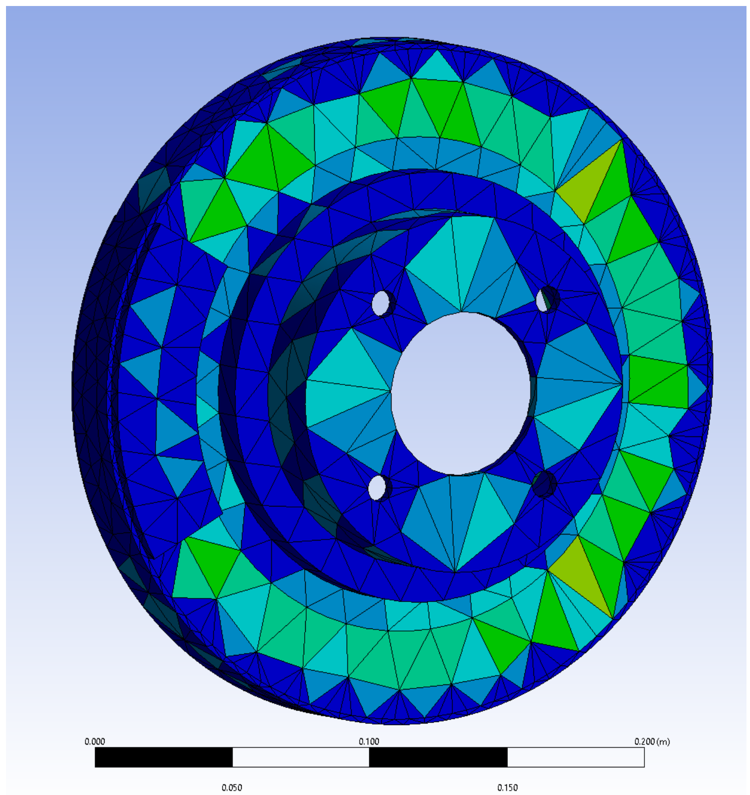
The objective of the project is to utilize the Ansys design of the experiment (ODE) and optimization tools to optimize the design of a brake engineering model.

Project schematic

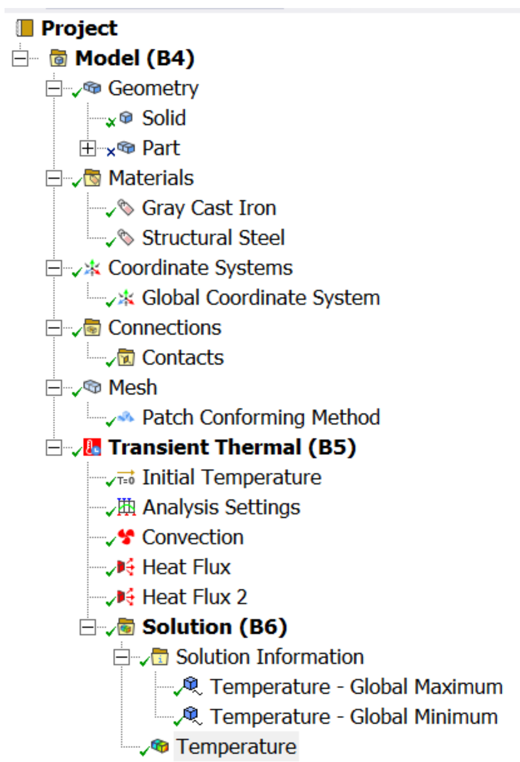


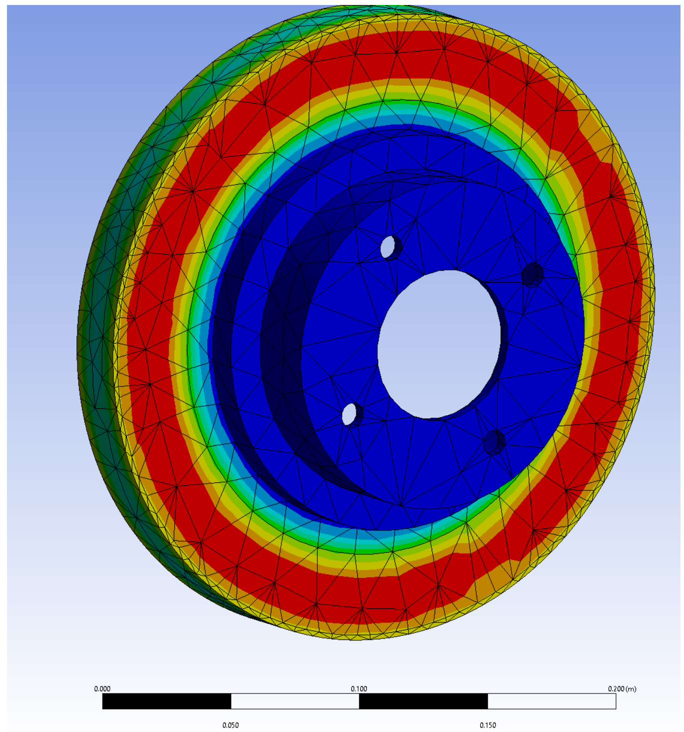
Static structural setup



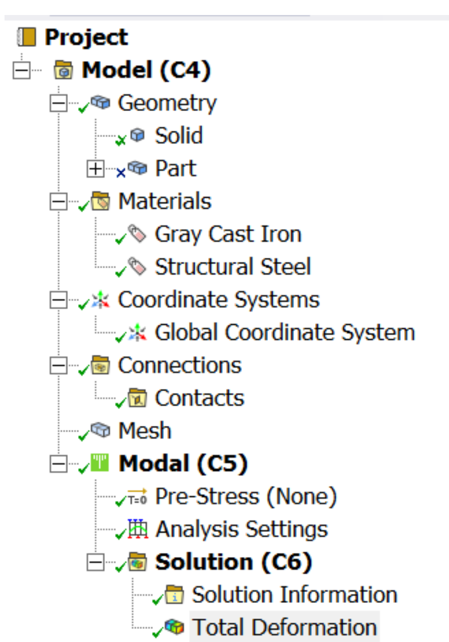


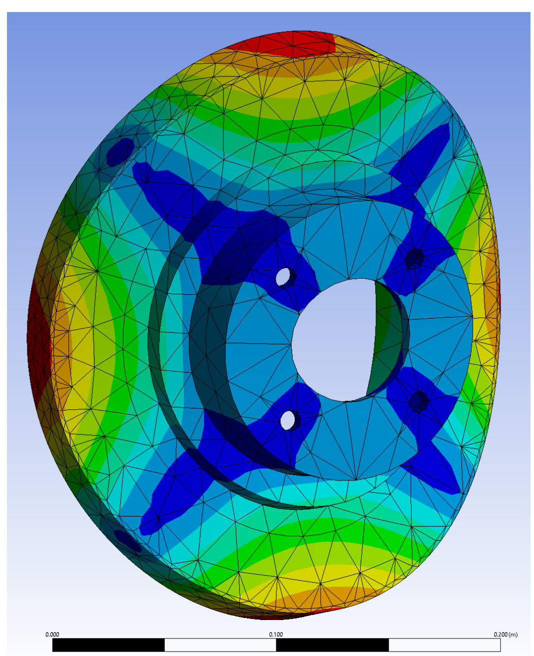
Modal setup



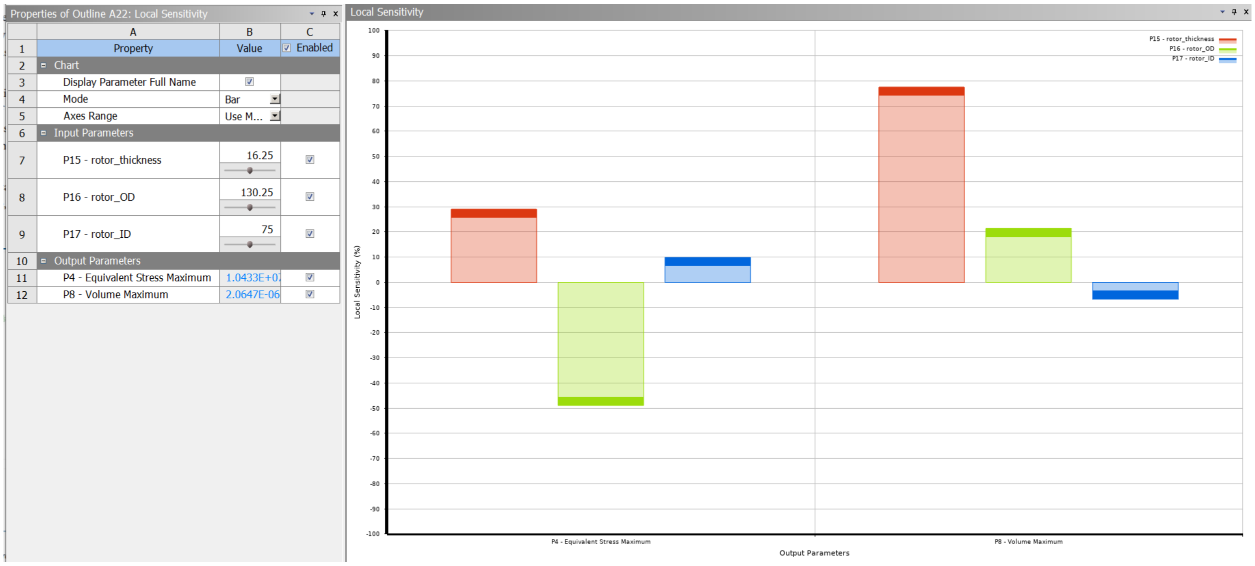


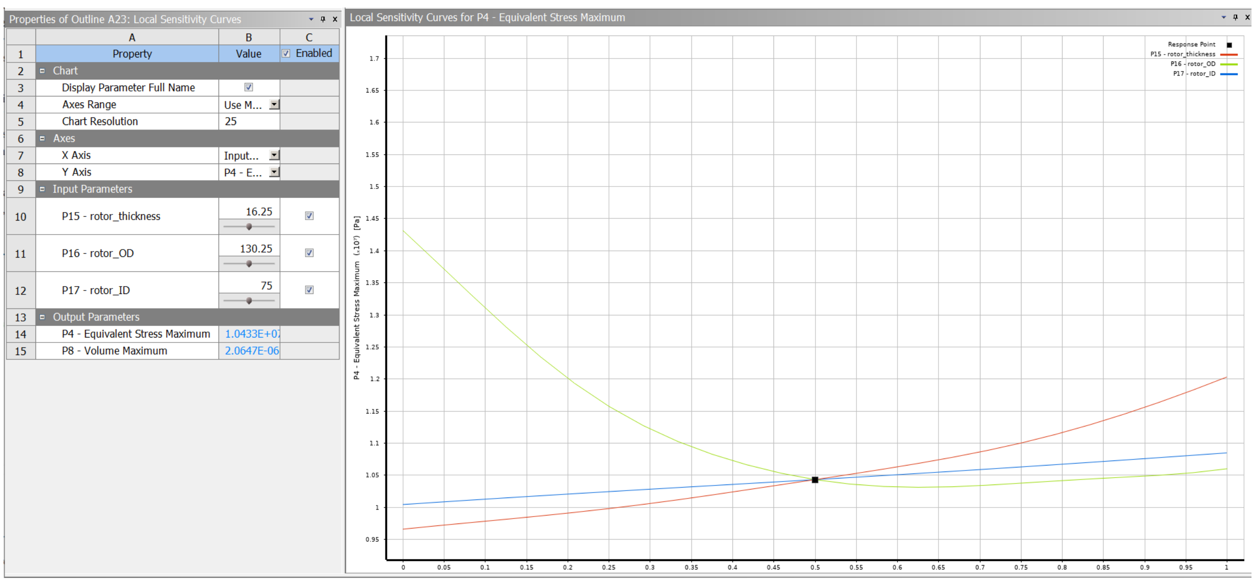
Transient thermal setup





Sensitivity Analysis



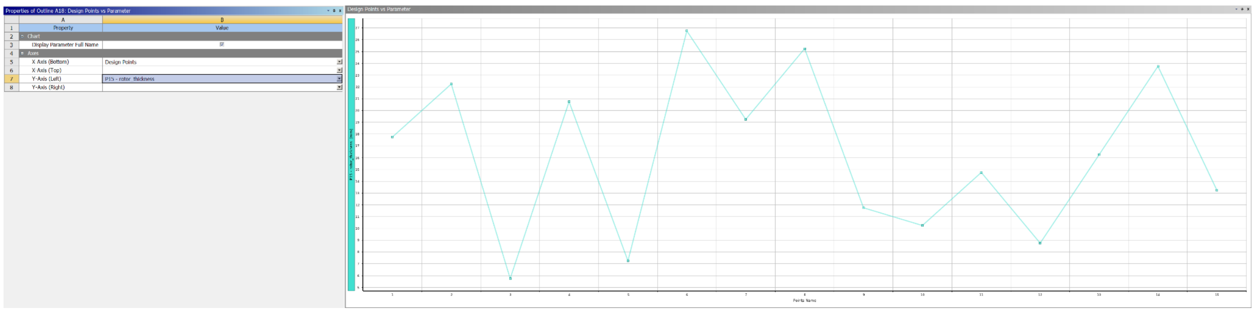


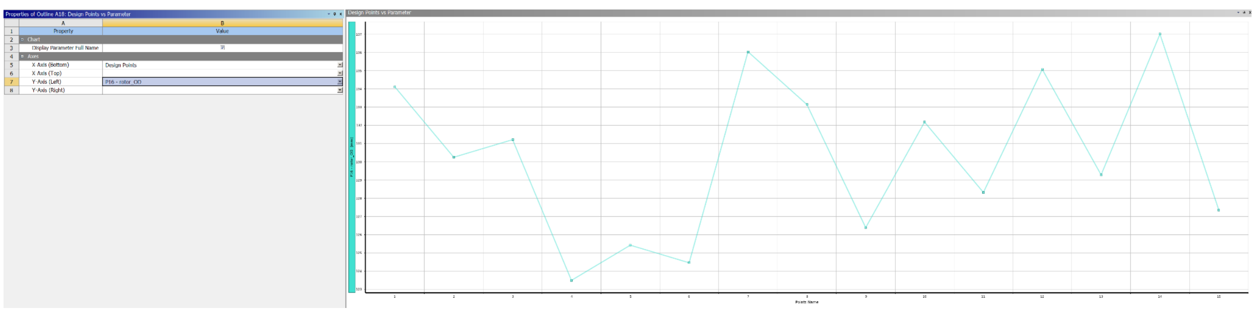
Response surface & optimization

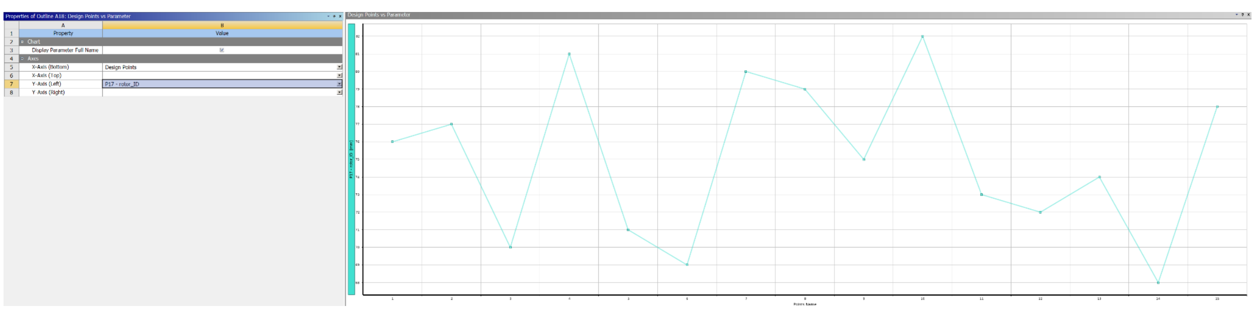
The input settings for rotor thickness, outer diameter, and inner diameter may be viewed in the screenshot. The equivalent stress and total deformation are the output parameters of the static structural surface. It is the total deformation reported frequency from the modal, and the maximum temperature value over time from the thermal. Sparse Grid Initialization was the Design of Experiments type that was employed. Sparse grid sampling is a more sophisticated sampling approach that samples only a few points at first and then adjusts the number of points sampled based on the response surface.

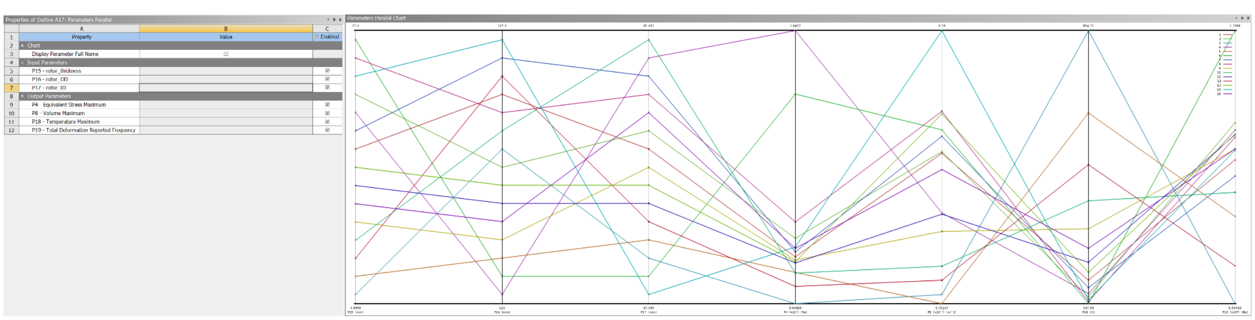
Table of Schematic D2: Design of Experiments (Latin Hypercube Sampling Design : CCD Samples : Random Generator Seed = 0)

	A	B	C	D	E	F	G	H	I
1	Name	P15 - rotor_... (mm)	P16 - rotor_OD (mm)	P17 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P8 - Volume Maximum (m ^3)	P18 - Temperature Maximum (C)	P19 - Total Deformation Reported Frequency (Hz)	P20 - Total Deformation Maximum (m)
2	1	17.75	134.12	76	1.068E+07	2.0715E-06	381.77	1358.7	0.92244
3	2	22.25	130.25	77	1.1152E+07	2.086E-06	350.26	1467.7	0.82573
4	3	5.75	131.22	70	9.4885E+06	7.8716E-07	854.7	934.34	2.0083
5	4	20.75	123.48	81	1.6422E+07	1.5309E-06	356.39	1445.8	0.88278
6	5	7.25	125.42	71	1.0285E+07	7.0148E-07	698.38	1191.4	1.7671
7	6	26.75	124.45	69	1.4811E+07	2.2835E-06	337.03	1739.8	0.7885
8	7	19.25	136.05	80	1.0806E+07	2.2265E-06	367.75	1310.9	0.85496
9	8	25.25	133.15	79	1.1564E+07	2.4549E-06	340.86	1425.1	0.75103
10	9	11.75	126.38	75	1.0596E+07	1.3612E-06	479.11	1390.4	1.2688
11	10	10.25	132.18	82	1.0269E+07	1.0444E-06	532.32	1263	1.2856
12	11	14.75	128.32	73	1.0523E+07	1.5167E-06	415.44	1432	1.1001
13	12	8.75	135.08	72	9.9284E+06	9.163E-07	600.67	1045.7	1.4464
14	13	16.25	129.28	74	1.0554E+07	2.4293E-06	396.39	1434.3	1.0202
15	14	23.75	137.02	68	1.0929E+07	3.19E-06	344.68	1386.9	0.76208
16	15	13.25	127.35	78	1.0895E+07	1.9224E-06	442.08	1390.5	1.1445









I also utilized refinement and verification points to fine-tune the optimization process. The ideal rotor thickness is 16.25mm, the optimal outer diameter is 130.25mm, and the optimal inner diameter is 75mm after operating the response surface for a few minutes. The best maximum equivalent stress was found to be 10.43 MPa, the best total deformation was 0.010132mm, the best total deformation reported frequency was 1406Hz, and the best maximum temperature was found to be 395.97C. The figure below confirms and verifies all of these numbers.

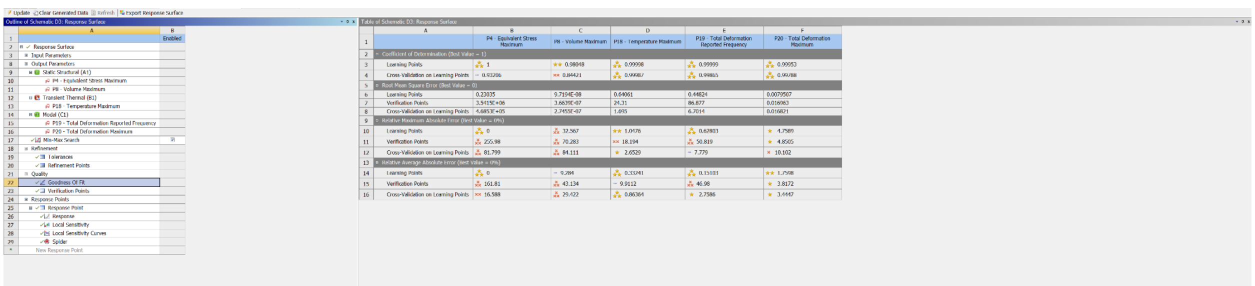
Table of Outline A24: Response Points

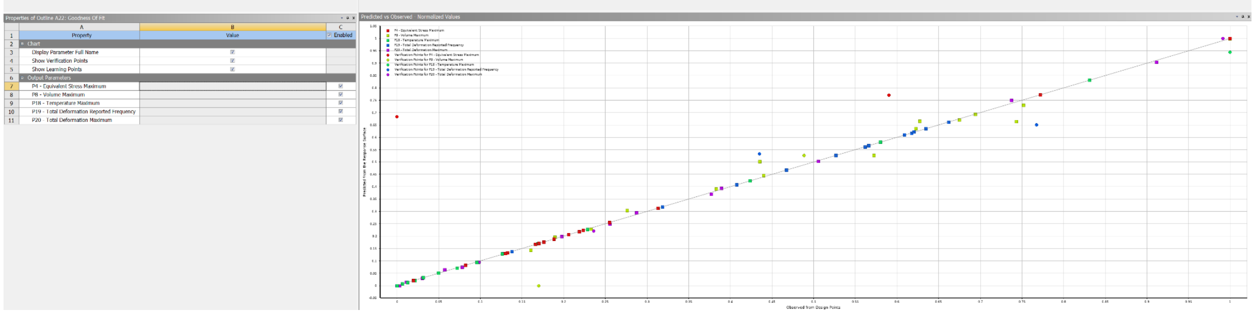
	A	B	C	D	E	F	G	H	I
1	Name	P15 - rotor_thickness (mm)	P16 - rotor_OD (mm)	P17 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P8 - Volume Maximum (m^3)	P18 - Temperature Maximum (C)	P19 - Total Deformation Reported Frequency (Hz)	P20 - Total Deformation Maximum (m)
2	Response Point	16.25	130.25	75	1.0431E+07	1.9182E-06	395.97	1406	1.0132
*	New Response Point								

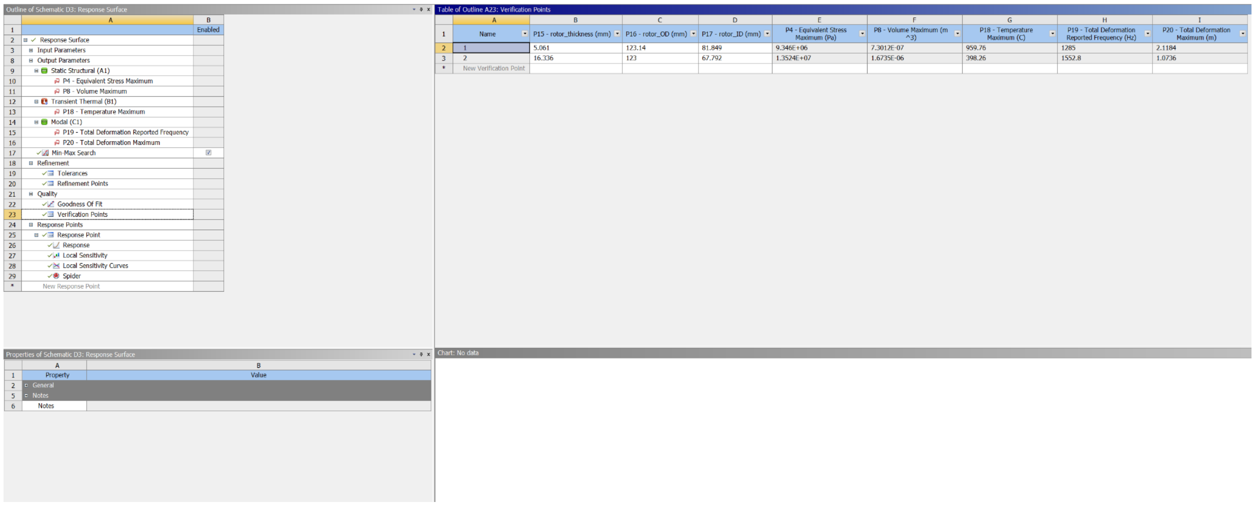
In the images below, you can see some of the results of my response surface analysis:

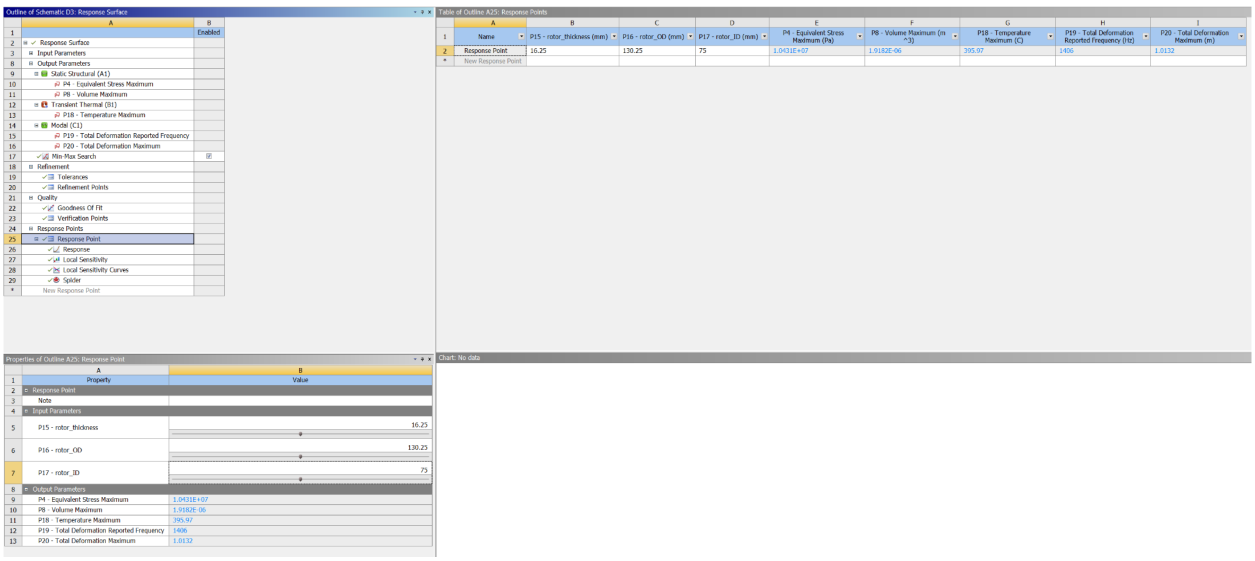
Table of Outline A17: Min-Max Search

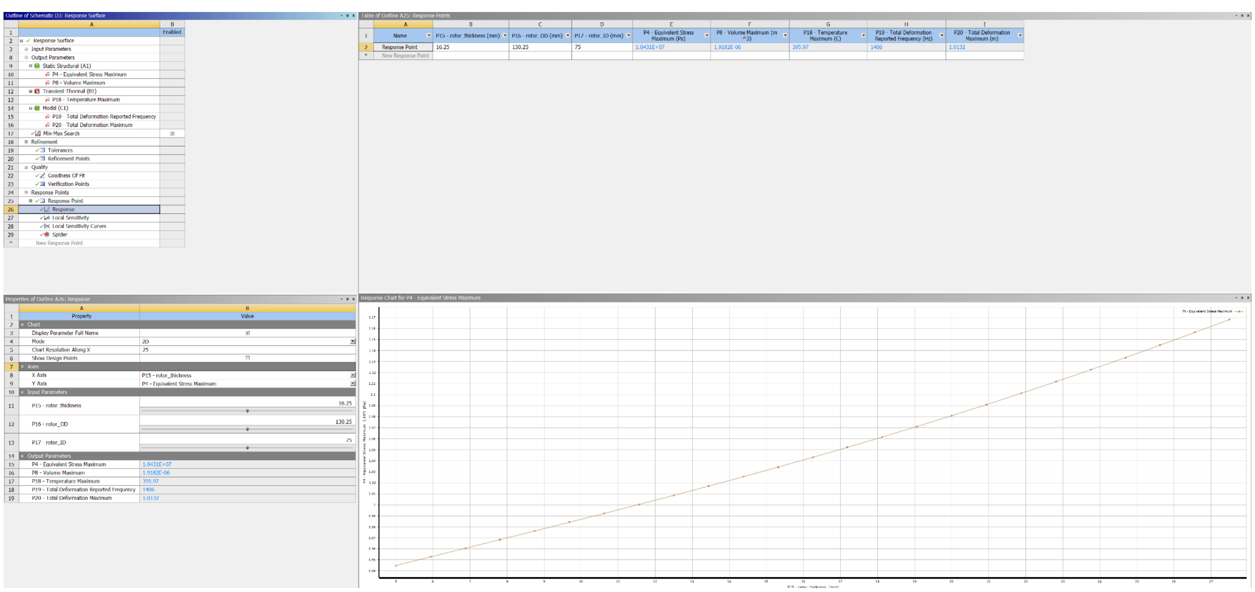
	A	B	C	D	E	F	G	H	I
1	Name	P15 - rotor_thickness (mm)	P16 - rotor_OD (mm)	P17 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P8 - Volume Maximum (m^3)	P18 - Temperature Maximum (C)	P19 - Total Deformation Reported Frequency (Hz)	P20 - Total Deformation Maximum (m)
2	Output Parameter Minimums								
3	P4 - Equivalent Stress Maximum	5	137.5	67.5	**8.892E+06**	1.596E-06	919.07	-43.056	2.0198
4	P8 - Volume Maximum	6.0167	123	82.5	1.4569E+07	**1.3243E-07**	824.05	1280.1	1.9302
5	P18 - Temperature Maximum	27.5	125.49	82.5	1.4951E+07	2.2769E-06	**330.6**	1515.3	0.73271
6	P19 - Total Deformation Reported Frequency	5.7653	137.5	67.5	8.9728E+06	1.5434E-06	834.32	**-56.836**	1.8681
7	P20 - Total Deformation Maximum	27.5	137.5	82.5	1.1447E+07	2.623E-06	338.75	1347.4	**0.65605**
8	Output Parameter Maximums								
9	P4 - Equivalent Stress Maximum	27.5	123	82.5	**1.8207E+07**	1.7716E-06	340.68	1468.8	0.73946
10	P8 - Volume Maximum	27.5	137.5	67.5	1.1153E+07	**3.5019E-06**	332.37	1427.6	0.69664
11	P18 - Temperature Maximum	5	123	70.006	1.3075E+07	2.8256E-07	**945.08**	849.02	2.2403
12	P19 - Total Deformation Reported Frequency	27.5	124.06	68.857	1.5494E+07	2.3784E-06	336.66	**1751.1**	0.77649
13	P20 - Total Deformation Maximum	5	123	67.5	1.2843E+07	8.2836E-07	922.81	141.12	**2.2498**






Outline of Schematic D3: Response Surface
A
B
Enabled
Response Surface
Input Parameters
Output Parameters
Static Structural (A1)
P4 - Equivalent Stress Maximum
P8 - Volume Maximum
Transient Thermal (B1)
P18 - Temperature Maximum
Modal (C1)
P19 - Total Deformation Reported Frequency
P20 - Total Deformation Maximum
Min-Max Search
Refinement
Tolerances
Refinement Points
Quality
Goodness Of Fit
Verification Points
Response Points
Response Point
Response
Local Sensitivity
Local Sensitivity Curves
Spider
New Response Point
Table of Outline A23: Verification Points
Name
P15 - rotor_thickness (mm)
P16 - rotor_OD (mm)
P17 - rotor_ID (mm)
P4 - Equivalent Stress Maximum (Pa)
P8 - Volume Maximum (m ^3)
P18 - Temperature Maximum (C)
P19 - Total Deformation Reported Frequency (Hz)
P20 - Total Deformation Maximum (m)
1 5.061 123.14 81.849 9.346E+06 7.3012E-07 959.76 1285 2.1184
2 16.336 123 67.792 1.3524E+07 1.6735E-06 398.26 1552.8 1.0736
New Verification Point
Properties of Schematic D3: Response Surface
Property
Value
General
Notes
Notes
Chart: No data


Outline of Schematic D3: Response Surface
Table of Outline A25: Response Points
Name
P15 - rotor_thickness (mm)
P16 - rotor_OD (mm)
P17 - rotor_ID (mm)
P4 - Equivalent Stress Maximum (Pa)
P8 - Volume Maximum (m ^3)
P18 - Temperature Maximum (C)
P19 - Total Deformation Reported Frequency (Hz)
P20 - Total Deformation Maximum (m)
Response Point 16.25 130.25 75 1.0431E+07 1.9182E-06 395.97 1406 1.0132
New Response Point
Properties of Outline A25: Response Point
Property
Value
Response Point
Note
Input Parameters
P15 - rotor_thickness 16.25
P16 - rotor_OD 130.25
P17 - rotor_ID 75
Output Parameters
P4 - Equivalent Stress Maximum 1.0431E+07
P8 - Volume Maximum 1.9182E-06
P18 - Temperature Maximum 395.97
P19 - Total Deformation Reported Frequency 1406
P20 - Total Deformation Maximum 1.0132
Chart: No data


Outline of Schematic D3: Response Surface
Table of Outline A25: Response Points
Response Point 16.25 130.25 75 1.0431E+07 1.9182E-06 395.97 1406 1.0132
New Response Point
Properties of Outline A26: Response
Property
Value
Chart
Display Parameter Full Name
Mode 2D
Chart Resolution Along X 25
Show Design Points
Axes
X Axis P15 - rotor_thickness
Y Axis P4 - Equivalent Stress Maximum
Input Parameters
P15 - rotor_thickness 16.25
P16 - rotor_OD 130.25
P17 - rotor_ID 75
Output Parameters
P4 - Equivalent Stress Maximum 1.0431E+07
P8 - Volume Maximum 1.9182E-06
P18 - Temperature Maximum 395.97
P19 - Total Deformation Reported Frequency 1406
P20 - Total Deformation Maximum 1.0132
Response Chart for P4 - Equivalent Stress Maximum

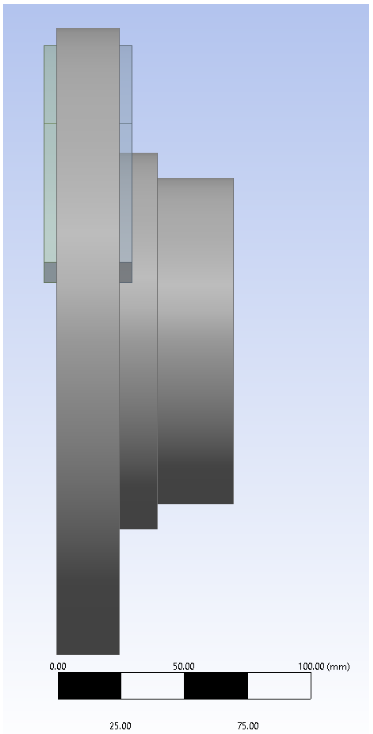
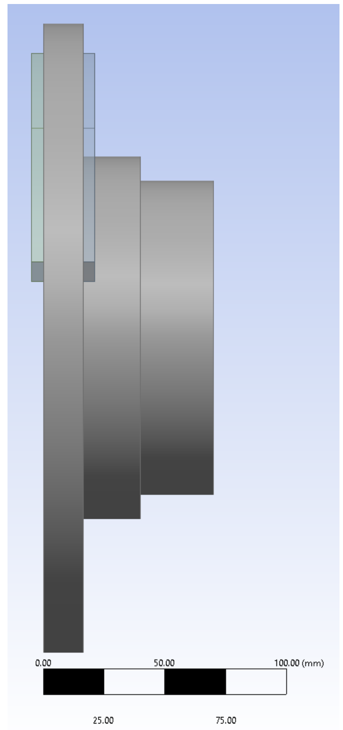
Encountered problem and solution

During the simulation step of the experiment, an error of failing to update the design point occurred. In the beginning, the professor has suggested deleting the design points which failed to update. However, the problem still persists after deleting the design points which failed to update. After consulting the professor again, it turns out that the lower bound of the outer diameter caused the disk to be too small which results in the contact surface of the pad and the disk changing. After trying different parameters in the DesignModular a value of the lower bound has been determined and applied to the setting. Applying new boundaries has eliminated errors during the simulation.

Optimization result & optimization analysis

1. When modifying the settings, there was a trade-off between the objectives. After some trial and error, I discovered that I couldn't keep minimizing the upper bound of the temperature from the thermal analysis without jeopardizing the static structural analysis input parameters. The design parameters that were affected by this problem were unable to be computed.
2. My objective/constraint functions were analytical, however, they weren't always differentiable due to some very steep corners, as shown in the design points versus parameter charts.
3. Sparse Grid Initialization was the optimization approach I picked for the DoE.
4. The local sensitivity graphs and sensitivity curves demonstrate the results of the sensitivity analysis. Only the total deformation and rotor thickness and total deformation showed monotonicity. The overall deformation rises linearly as the rotor thickness increases.
5. The parameters from the first analysis are compared to those after the optimization study is done. The table below summarizes these figures.

	Rotor thickness (mm)	Rotor outer diameter (mm)	Rotor inner diameter (mm)	Volume (mm^3)
Before optimization	25	125	75	9.97e+05
After optimization	16.25	130.25	75	7.09e+05

Before optimization	After optimization
	

There is a 28.8867% decrease in disk volume after the optimization.