MAE 598 - Design Optimisation

Project II

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Problem Description:

We have been given a disc brake and braking pads. Out task is to perform analysis on the disc for the following:

1) Minimise the maximum stress in the disc brake
2) Maximise the first natural frequency of the disc brake
3) Minimise the maximum temperature in the disc brake

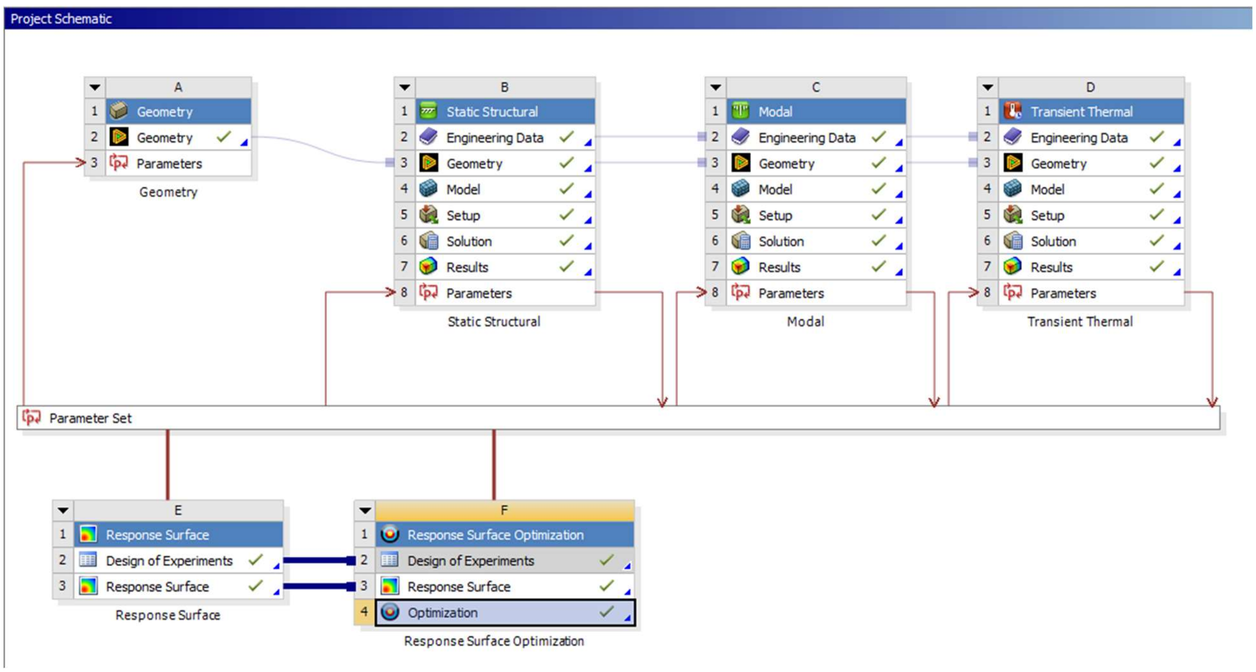

Figure 1: Project Schematic page

We start by applying material to the disc and the pads. In our project we have chosen structural steel for the brake pads and gray cast iron for the disc. Later meshing the components at 0.003m

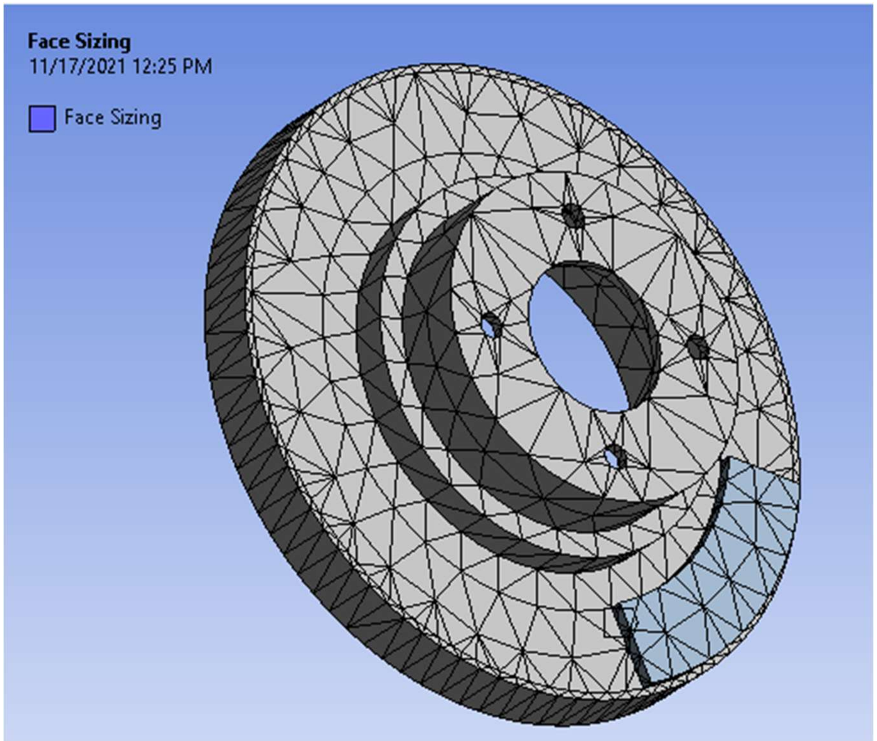

Figure 2: Meshing with element size 0.003m

Task 1: *Structural Analysis*

In real life we know that brakes are applied in order to stop the vehicle, during this process there are forces acting on the disc exerted by the brake pads. These force/pressure induce stress on the disc at the same time, the rotation of the disc at high-speed cause centrifugal forces. Hence the resultant stress is quite large. Hence, we try to minimize the stresses induced the disc.

<u>Model setup:</u>

- Rotation of disc: 250 rad/s
- Pressure on face of disc: 10496 KPa
- Connection: Revolute Joint→Body to Ground→Scope
- Boundary Conditions: Fix x and z-axis displacement for brake pads

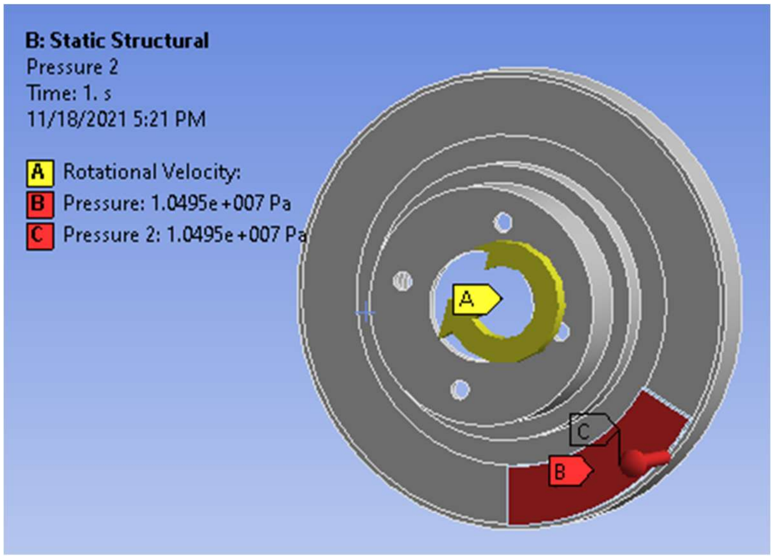

Figure 3: Setup for static structure, with ω=250rad/s and pressure of 10.496 MPa

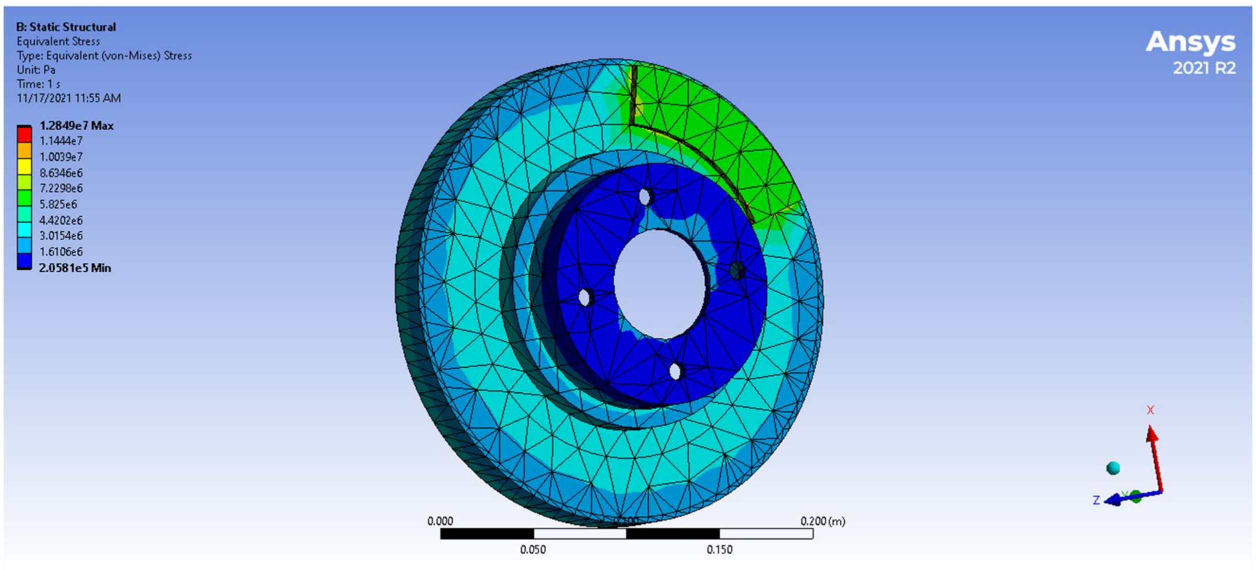

Figure 4: Static Structure analysis for max principle stress

Task 2: *Modal Analysis*

A vehicle in motion has vibration in all the parts. Even the disc is vibrating at a certain frequency. We should ensure that disc's first natural frequency is higher than that of engine vibrating frequency to avoid failure.

Model setup:

We suppress the geometry of the brake pads as we are supposed to determine the natural frequency of the disc brake.

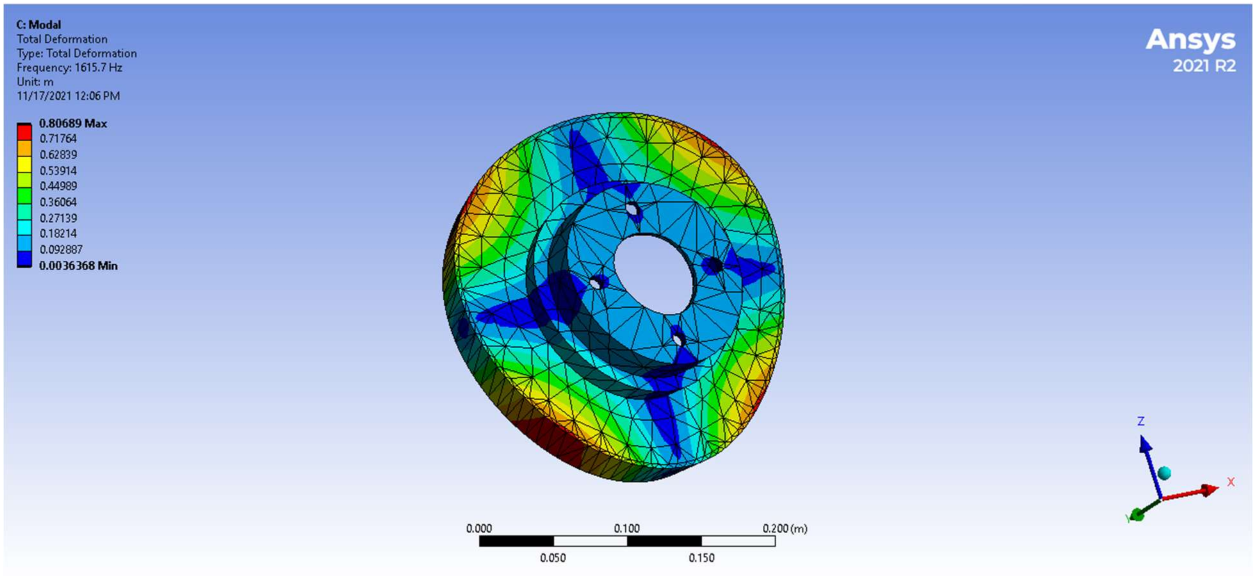

Figure 5: Modal analysis for natural frequency

Task 3: *Thermal Analysis*

Along with structural stresses there are thermal stresses induced in the disc during the braking action. We know that, braking takes places due to friction between the disc and pads. This friction in-turn causes heat generation and induces thermal stress. This heat generation depends on the speed of the disc and amount of pressure applied by the pads. High heat generation causes damage on the surface of the disc.

Model setup:

- Heat flux applied to the area on the disc that is swept by the pads is taken as 1.5395e6 W/m^2
- Heat convection is applied on the entire disc with a convection coefficient of $5 W/m^2K$
- Initial Temperature: 35^oC

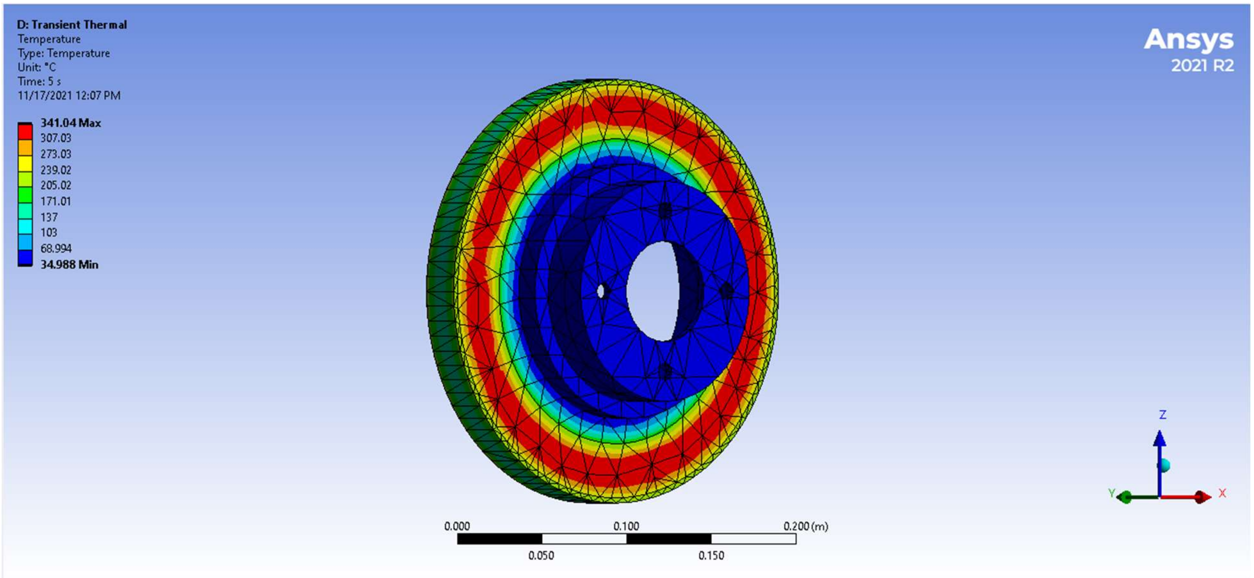

Figure 6: Thermal analysis for max temperature

Task 4

Design of Experiments:

Once the initial analysis is done. We find out the relation between output parameters and design variables. With the help of this data we create a response surface over design parameter. For our analysis we have used Latin Hypercube Sampling (LHS) method with user defined sample points of 32 points. In LHS we are given the option to manually set the no. of sample points and also the no. of samples is independent of number of parameters. CCD is not recommended as a quadratic function cannot be approximated and requires large no. of samples.

Table of Schematic F4: Optimization

	A	B	C	D
1	⊟ Input Parameters			
2	Name	Lower Bound	Upper Bound	
3	P1 - rotor_thickness (mm)	23	28	
4	P2 - rotor_OD (mm)	123	140	
5	P3 - rotor_ID (mm)	65	85	
6	⊟ Parameter Relationships			
7	Name	Left Expression	Operator	Right Expression

Table 1: Lower and Upper bounds/limits for design parameters

Table of Outline A14: Design Points of Design of Experiments

	A	B	C	D	E	F	G
1	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P5 - Temperature Maximum (C)	P6 - Total Deformation Reported Frequency (Hz)
2	1	25.109	127.52	69.063	1.1308E+07	340.79	1648.6
3	2	25.891	136.02	80.938	1.1656E+07	340.34	1378
4	3	23.078	126.98	75.313	1.1398E+07	347.31	1547.9
5	4	25.422	125.39	84.688	1.197E+07	340.35	1405.6
6	5	23.391	139.73	73.438	1.118E+07	346.1	1348.5
7	6	27.609	136.55	84.063	1.1719E+07	340.08	1354.3
8	7	25.266	130.7	76.563	1.1784E+07	342.91	1506
9	8	27.453	138.67	67.813	1.1993E+07	334.23	1442.8
10	9	24.172	130.17	82.813	1.1989E+07	346.29	1391.9
11	10	23.859	128.58	66.563	1.1449E+07	346.29	1576.7
12	11	24.484	133.36	75.938	1.1232E+07	344.77	1454.8
13	12	23.703	125.92	74.063	1.171E+07	340.18	1596.6
14	13	24.953	134.95	72.188	1.1206E+07	340.56	1458.4
15	14	26.203	132.3	67.188	1.1567E+07	339.83	1546
16	15	24.328	137.08	72.813	1.1297E+07	342.44	1406
17	16	27.141	131.23	79.063	1.169E+07	340.1	1484.6
18	17	26.828	124.86	82.188	1.394E+07	338.72	1488.1
19	18	25.734	123.8	80.313	1.4396E+07	337.91	1523.8
20	19	23.547	124.33	74.688	1.4292E+07	346.31	1613.4
21	20	23.234	135.48	78.438	1.1519E+07	346.68	1382.1
22	21	24.797	137.61	79.688	1.1836E+07	341.28	1354.1
23	22	27.297	132.83	65.938	1.162E+07	338.91	1554.7
24	23	27.766	126.45	77.188	1.2118E+07	335.68	1590.1
25	24	24.016	129.11	71.563	1.1515E+07	344.94	1570.1
26	25	26.359	134.42	65.313	1.1843E+07	339.66	1485.5
27	26	25.578	133.89	83.438	1.1937E+07	340.64	1360.3

Table 2: LHS values for parameters and variables

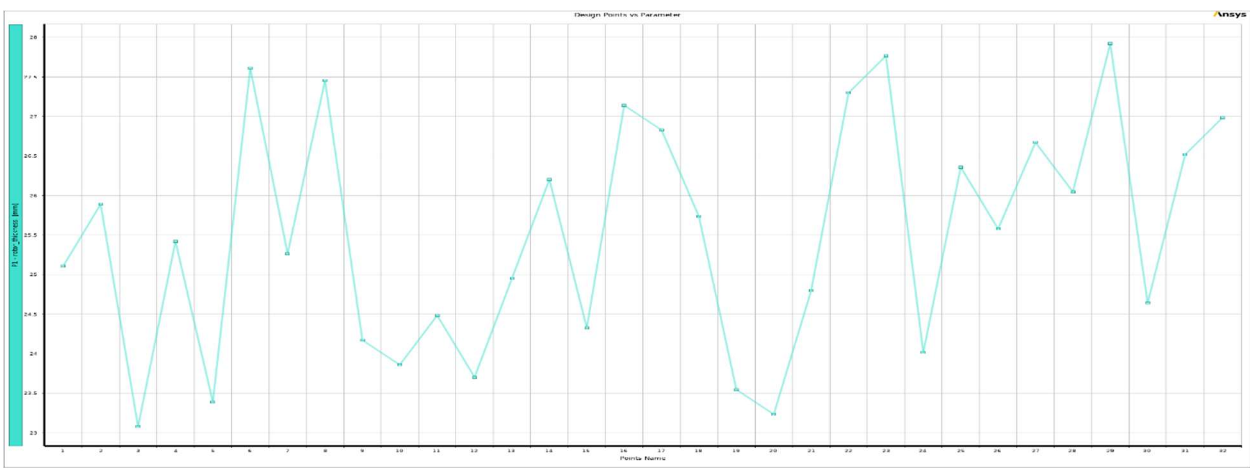

Figure 7: Design Points v/s Parameters

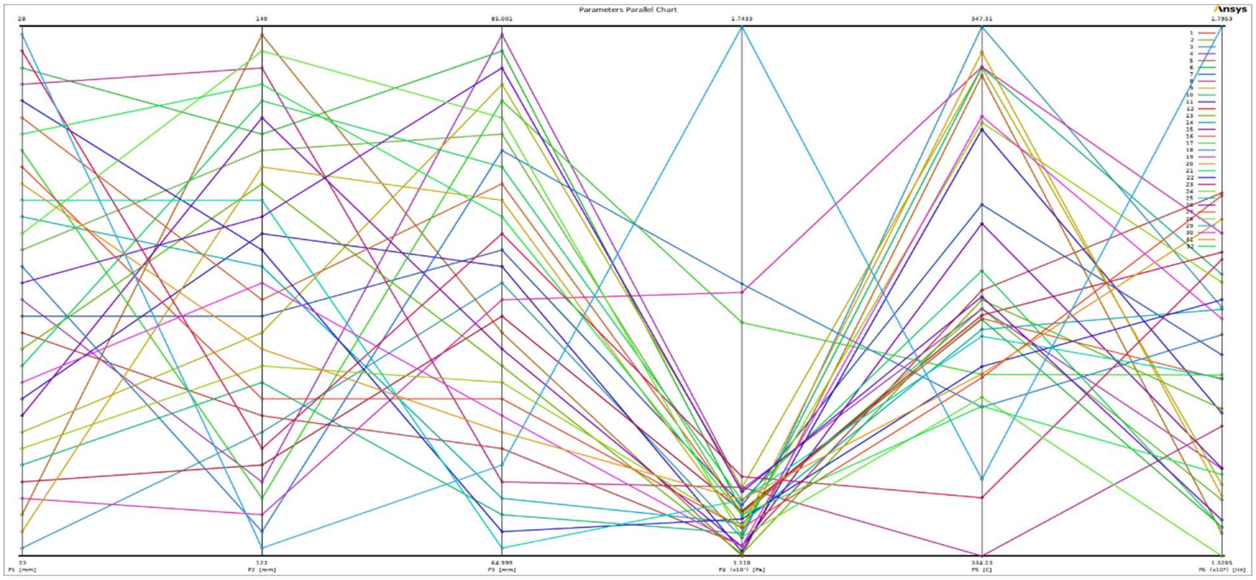

Figure 8: Parallel Parameters

Response Surface:

DOE results are used to create a response surface. There are multiple methods to create this, in our analysis we have used Aggregation method.

Table of Outline A15: Min-Max Search

	A	B	C	D	E	F	G
1	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P5 - Temperature Maximum (C)	P6 - Total Deformation Reporte Frequency (Hz)
2	Output Parameter Minimums						
3	P4 - Equivalent Stress Maximum	24.235	132.96	67.799	**1.1235E+07**	344.58	1496.2
4	P5 - Temperature Maximum	28	140	68.472	1.1939E+07	**334.36**	1434.8
5	P6 - Total Deformation Reported Frequency	23	140	85	1.1649E+07	347.24	**1248.7**
6	Output Parameter Maximums						
7	P4 - Equivalent Stress Maximum	28	123	65	**1.8293E+07**	335.81	1809.3
8	P5 - Temperature Maximum	23	131.83	65	1.142E+07	**349.26**	1468.4
9	P6 - Total Deformation Reported Frequency	28	123	65	1.8293E+07	335.81	**1809.3**

Table 3: Min-Max search for parameters

Table of Outline A21: Verification Points

	A	B	C	D	E	F	G
1	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P5 - Temperature Maximum (C)	P6 - Total Deformation Reported Frequency (Hz)
2	1	23.014	123.16	84.132	1.5324E+07	348.92	1404.5
3	2	23.326	137.63	65.024	1.1125E+07	347.29	1331.7
4	3	25.269	139.6	66.118	1.1519E+07	339.53	1358.1
5	4	23.478	139.57	84.486	1.3119E+07	346.21	1240.6
*	New Verification Point						

Table 4: Verification point for the below Response Surface

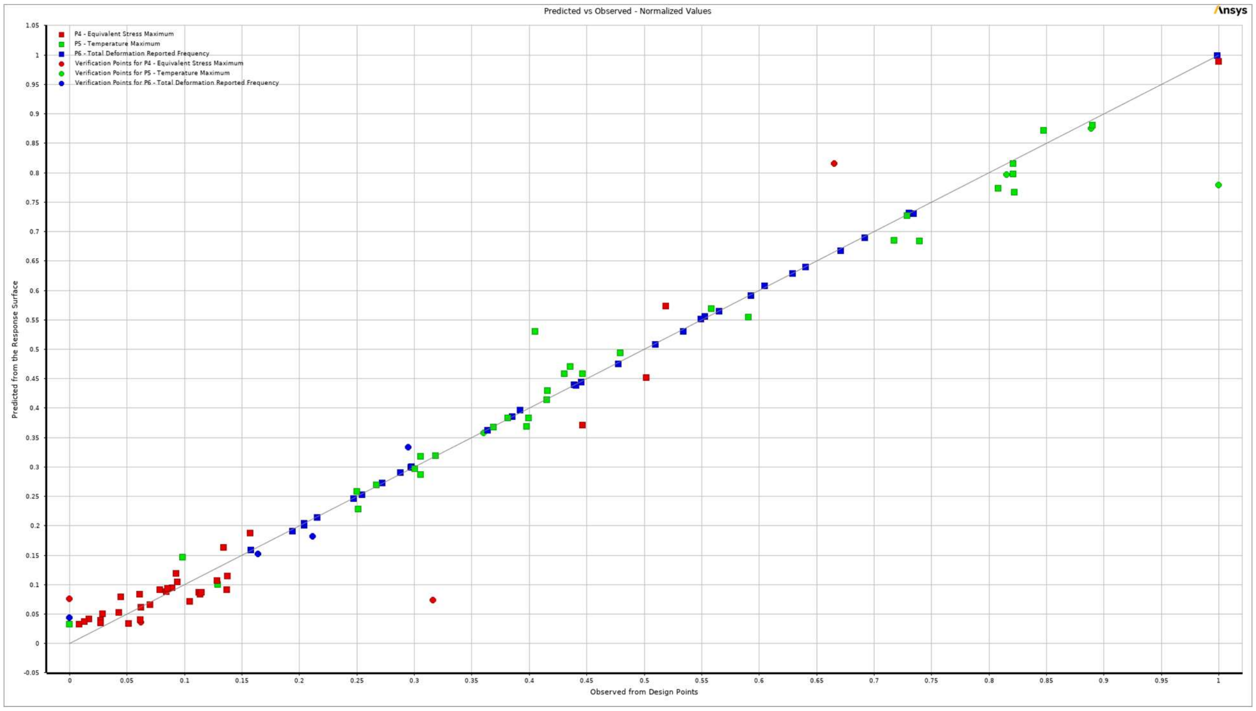

Figure 9: Response Surface with verification points

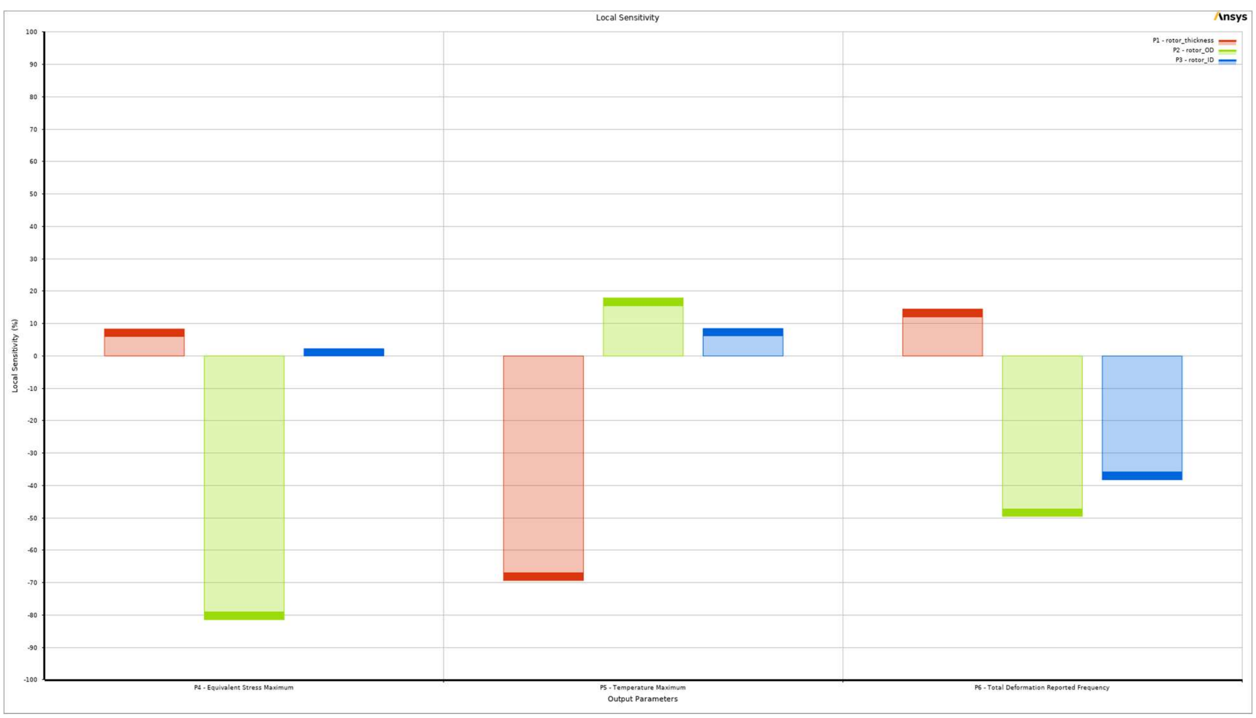

Figure 10: Local Sensitivity

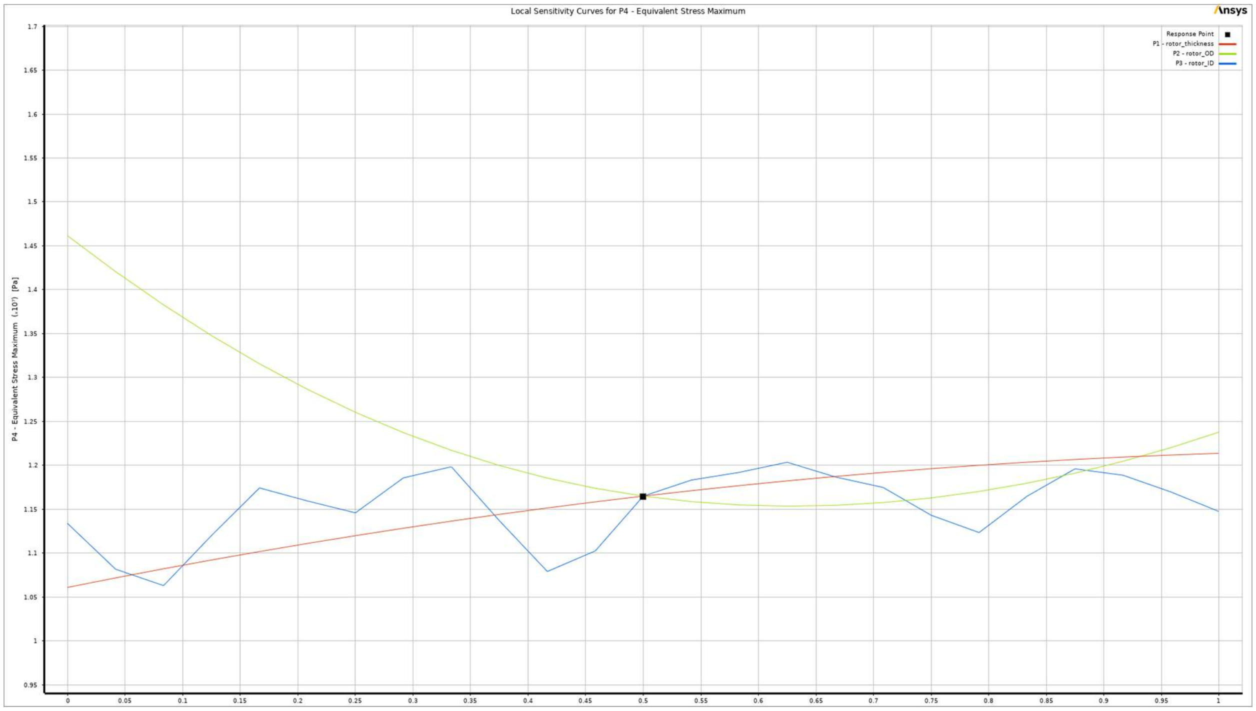

Figure 11: Local Sensitivity Curves

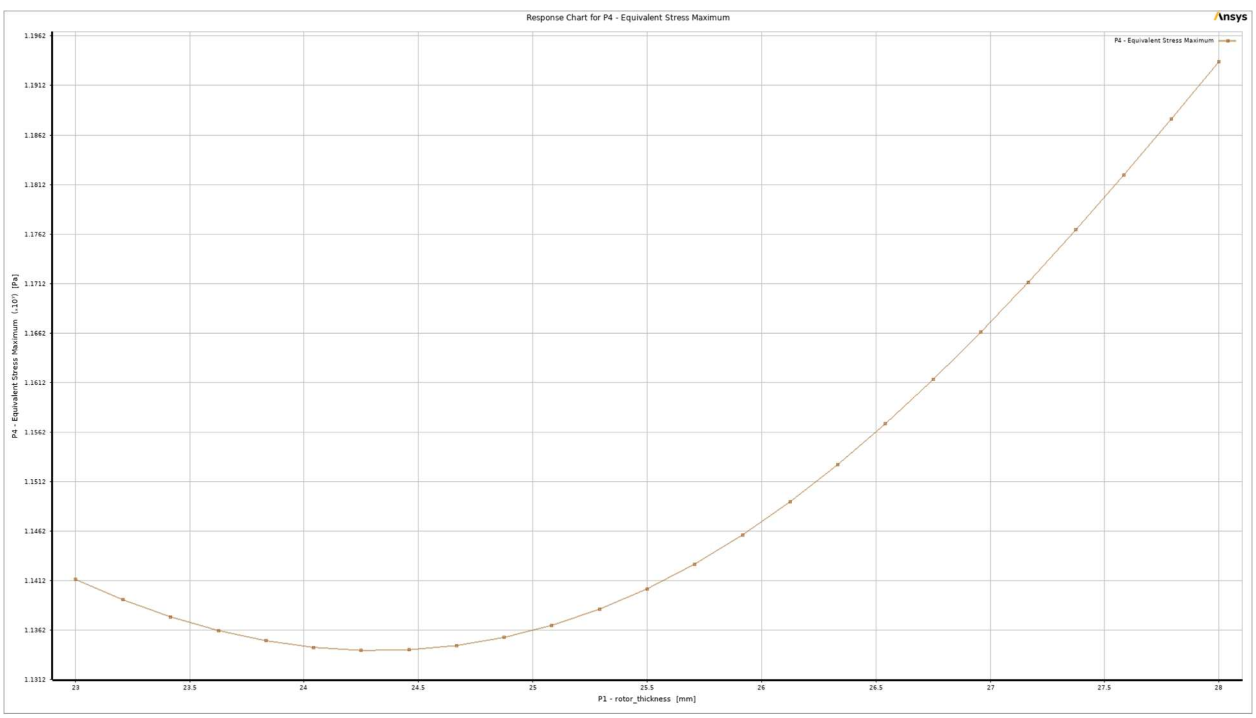

Figure 12: Response Curves

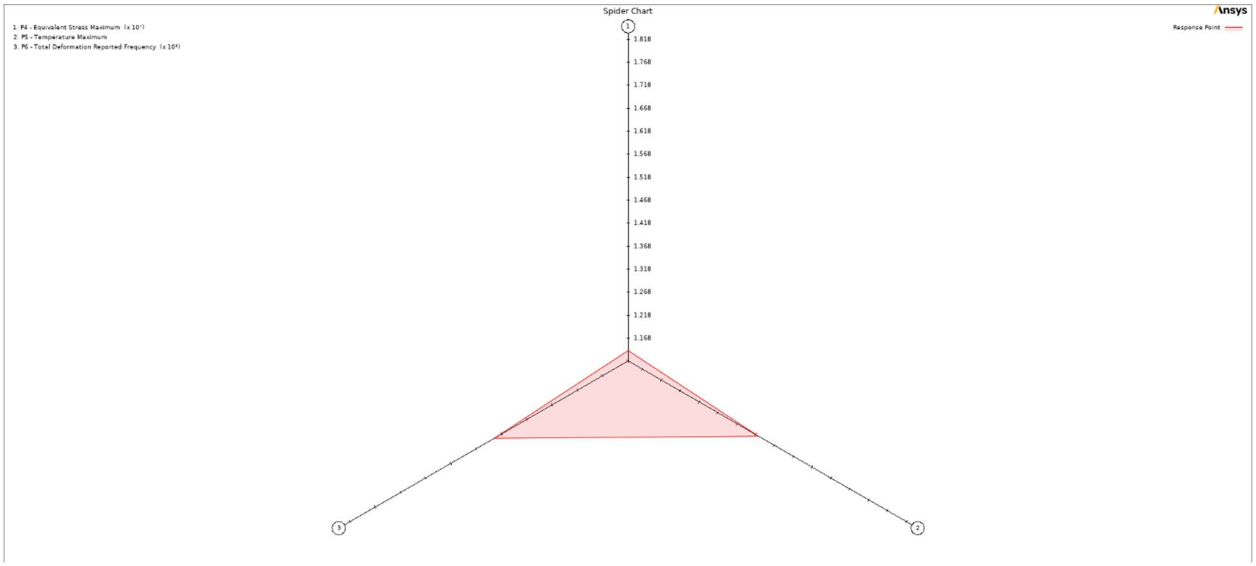

Figure 13: Spider

Optimisation:

Finally, from all the data we collected from the individual analysis, we get the most optimal points of the individual parameter of all the results.

We used Multiobjective Genetic Algorithm (MOGA), as we have multiple objective parameters to optimize. However, we use only of the parameters as the main objective and the other parameters acts as constraints only. For our case, we have taken principle stress as main function.

Table of Schematic F4: Optimization , Candidate Points

	A	B	C	D	E	F	G	H	I
1	Reference	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)		P5 - Temperature Maximum (C)	
2						Parameter Value	Variation from Reference	Parameter Value	Variation from Referenc
3	○	Candidate Point 1	24.201	132.96	68.047	1.1235E+07	0.00%	344.66	0.08%
4	○	Candidate Point 2	24.191	132.96	67.474	1.1235E+07	0.00%	344.76	0.10%
5	◉	Candidate Point 3	24.278	132.95	68.318	1.1235E+07	0.00%	344.4	0.00%
*		New Custom Candidate Point	25.5	131.5	75				

Table 4: Optimality inputs

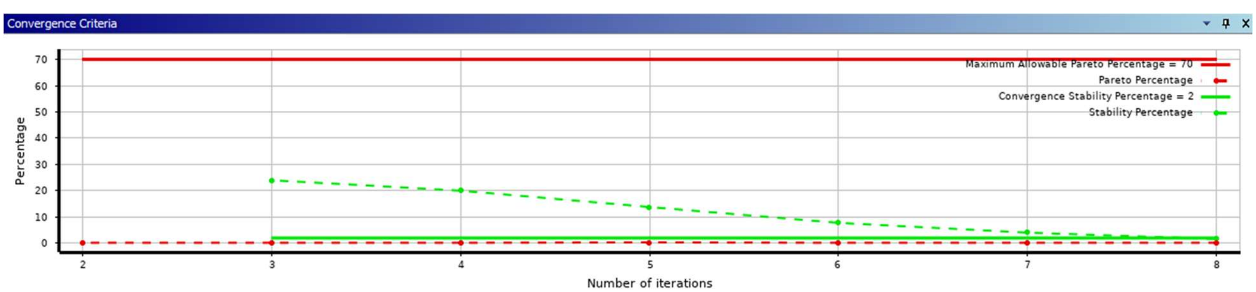

Figure 14: Converge Criteria

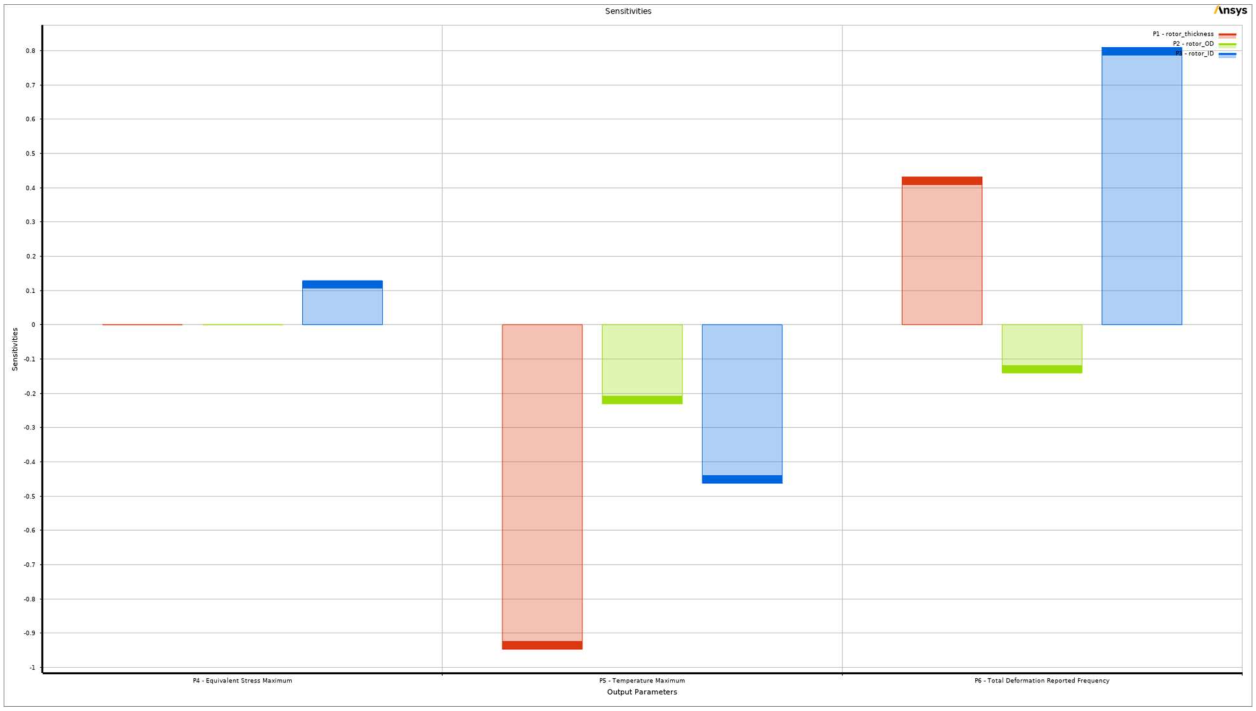

Figure 15: Sensitivities

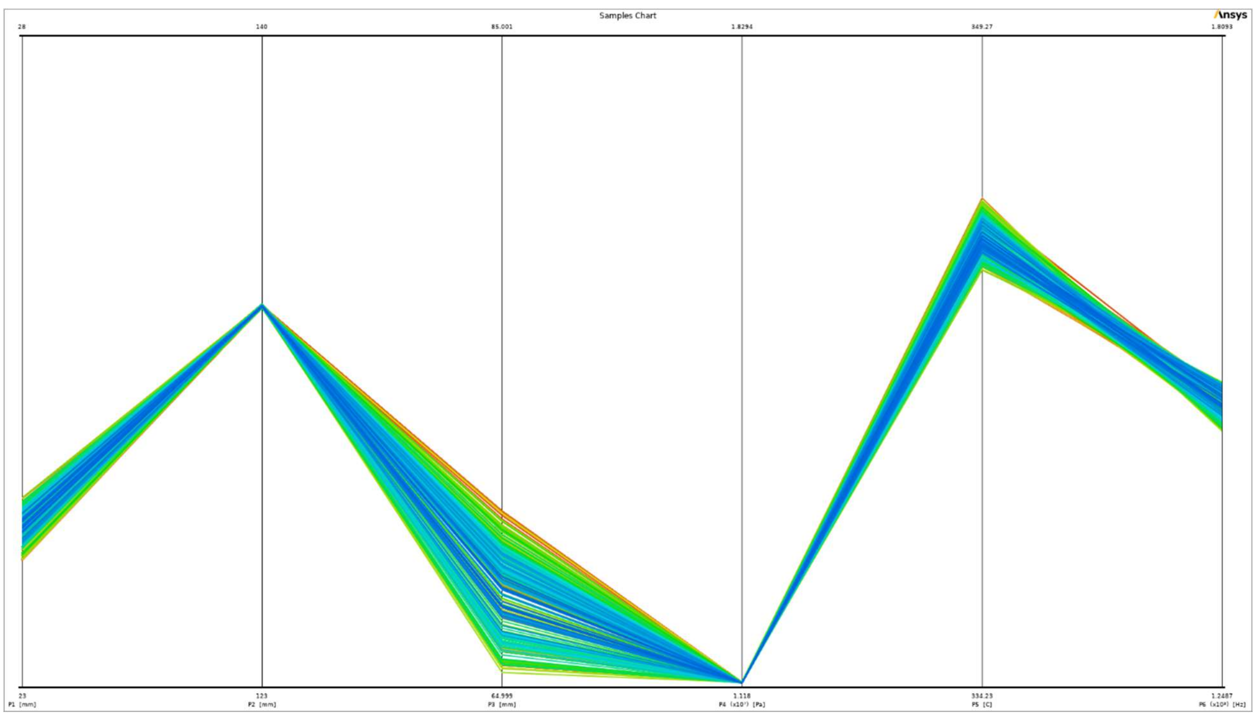

Figure 16: Sampling

Table of Schematic F4: Optimization				
	A	B	C	D
1	⊟ Optimization Study			
2	Minimize P4	Goal, Minimize P4 (Default importance)		
3	P5 <= 347.31 C	Strict Constraint, P5 values less than or equals to 347.31 C (Default importance)		
4	P6 >= 1328.5 Hz	Strict Constraint, P6 values greater than or equals to 1328.5 Hz (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 6609 evaluations.		
9	⊟ Candidate Points			
10		Candidate Point 1	Candidate Point 2	Candidate Point 3
11	P1 - rotor_thickness (mm)	24.201	24.191	24.278
12	P2 - rotor_OD (mm)	132.96	132.96	132.95
13	P3 - rotor_ID (mm)	68.047	67.474	68.318
14	P4 - Equivalent Stress Maximum (Pa)	1.1235E+07	1.1235E+07	1.1235E+07
15	P5 - Temperature Maximum (C)	344.66	344.76	344.4
16	P6 - Total Deformation Reported Frequency (Hz)	1498.8	1490.5	1504

Table 5: Optimised Output chart

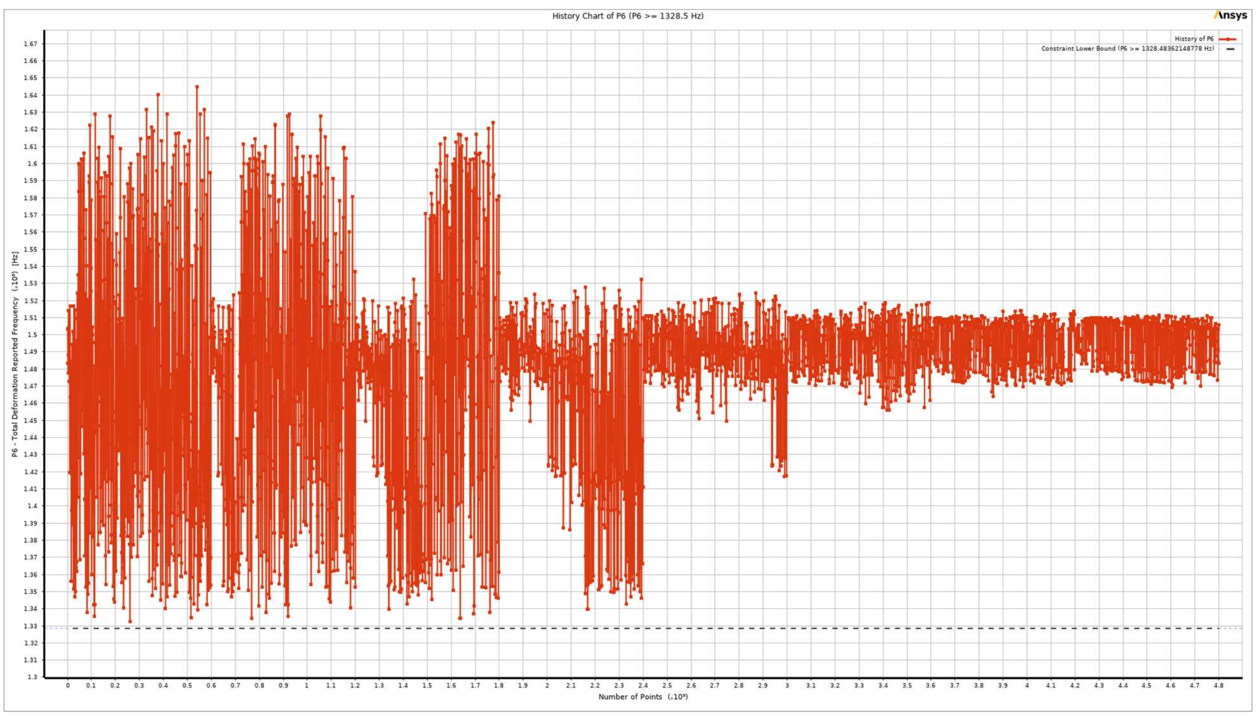

Figure 17: Total Deformation Frequency

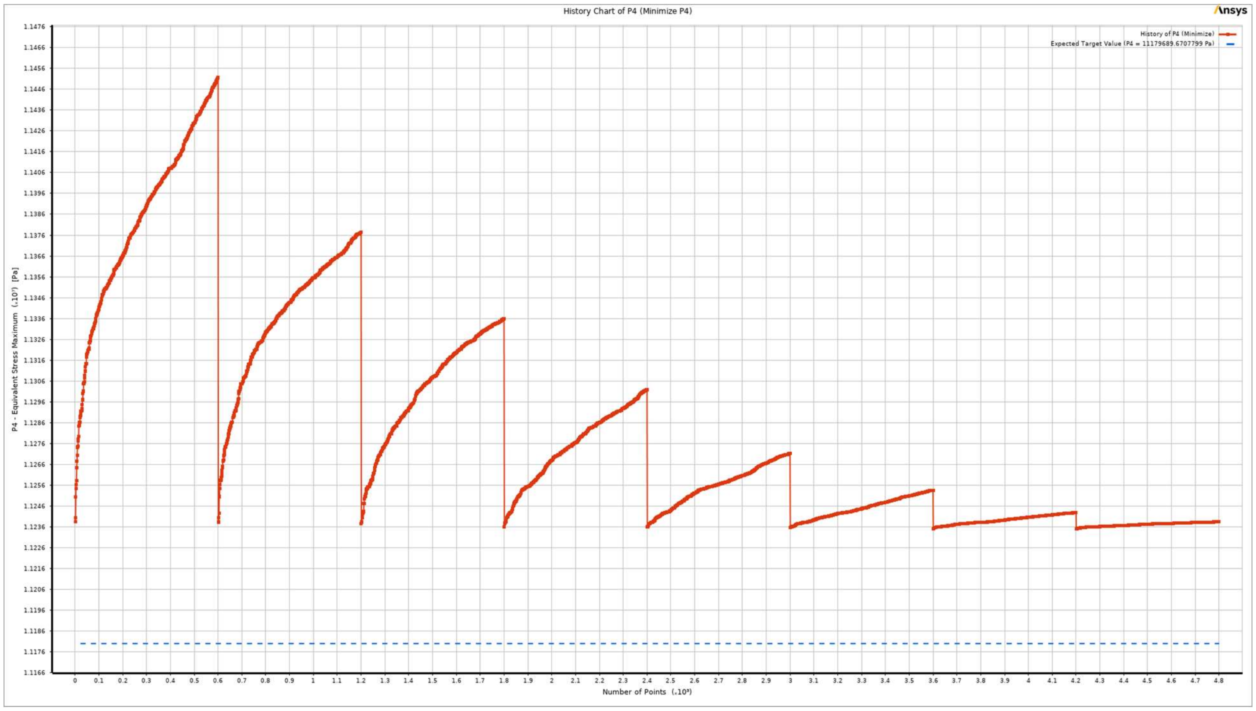

Figure 18: Equivalent Stress

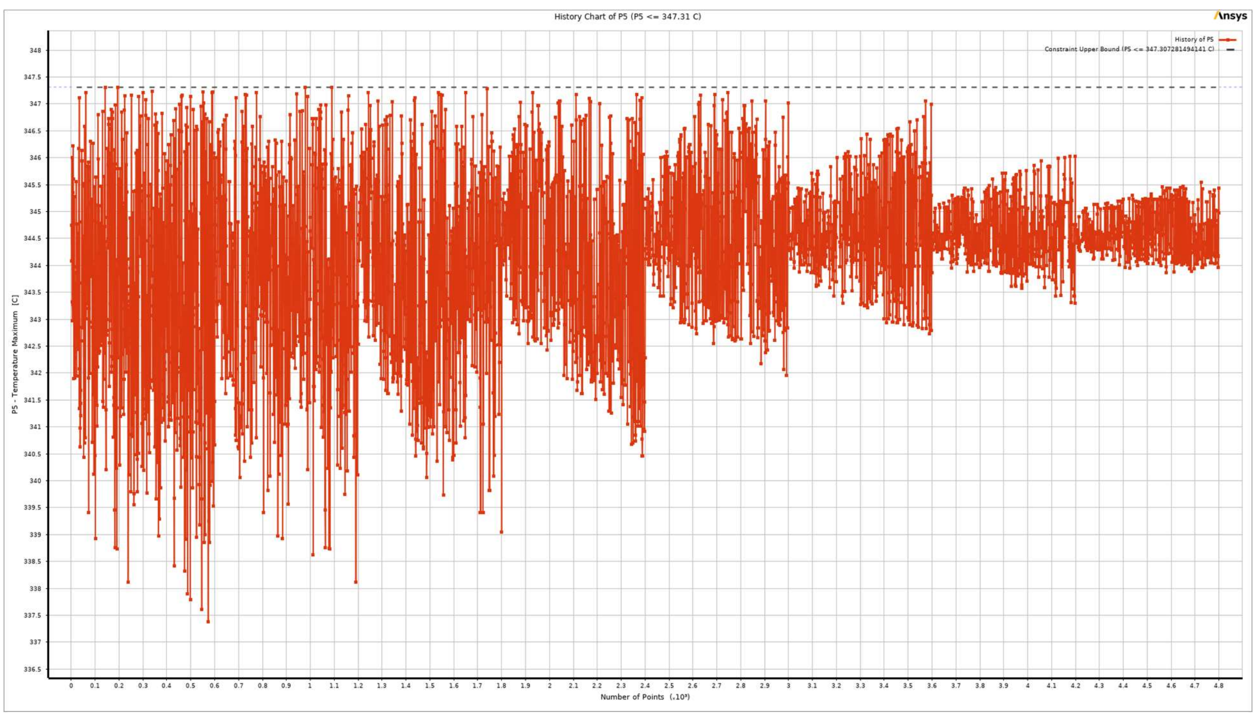

Figure 19: Temperature Maximum

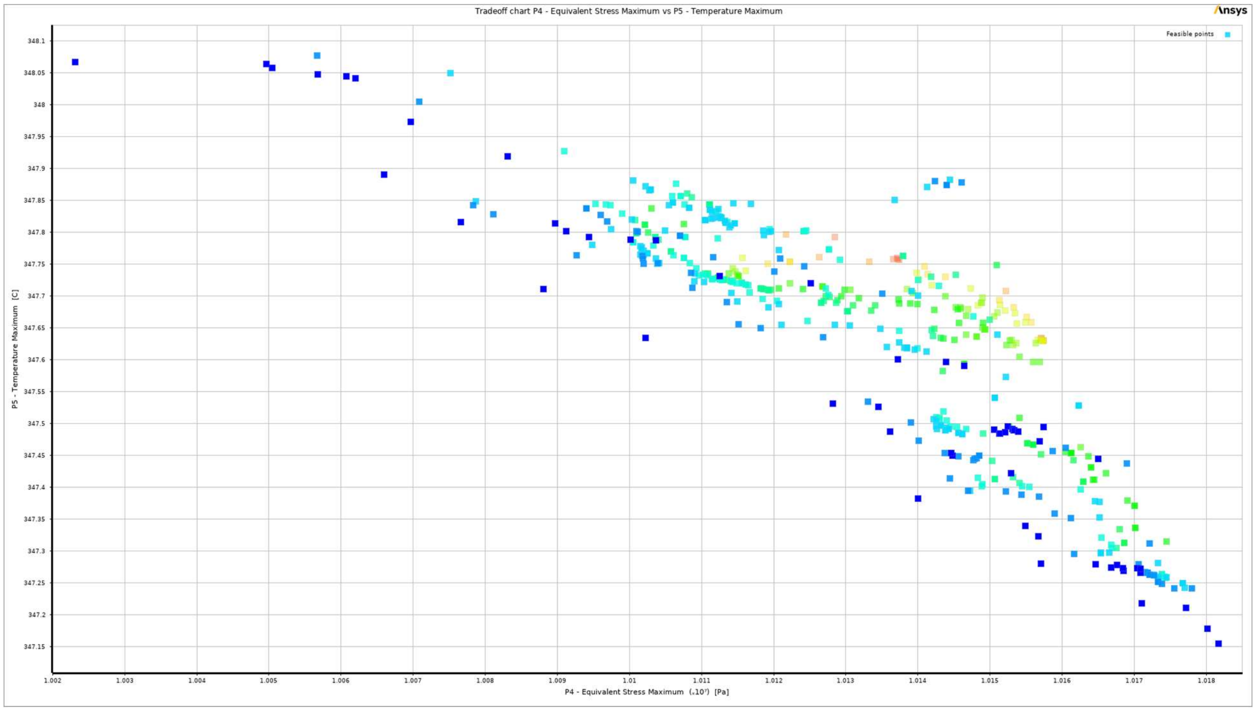

Figure 20: Trade Off