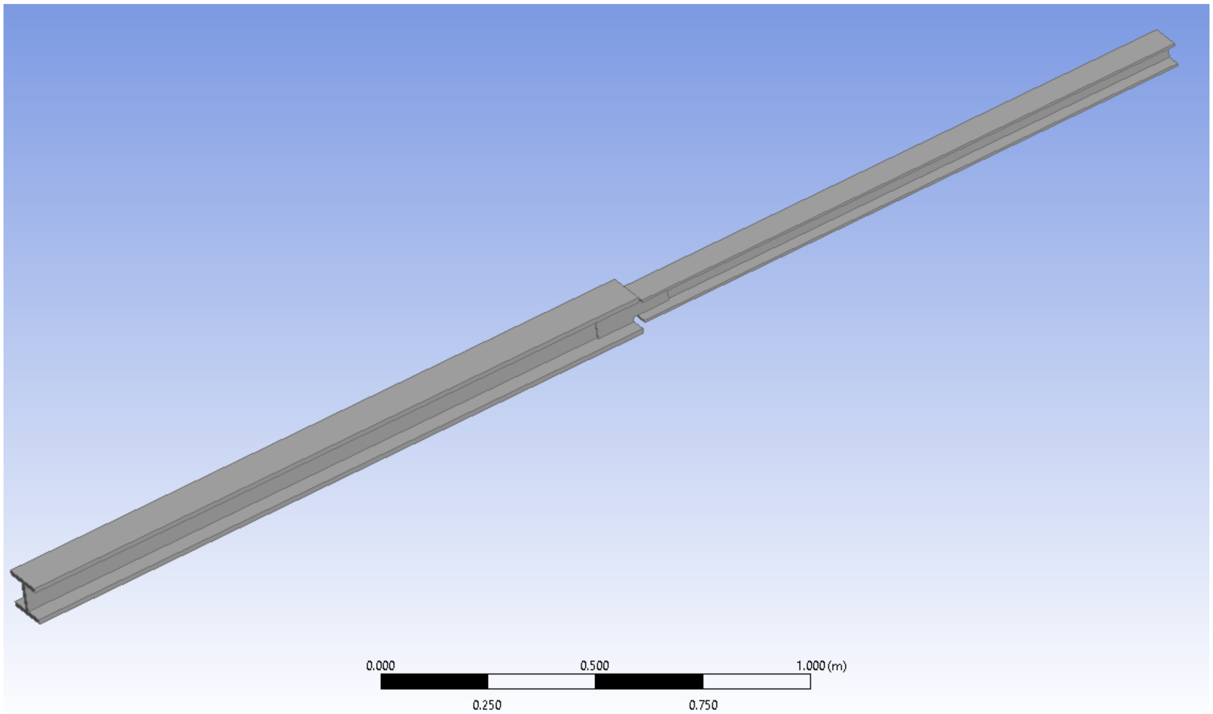
Optimization Project 2

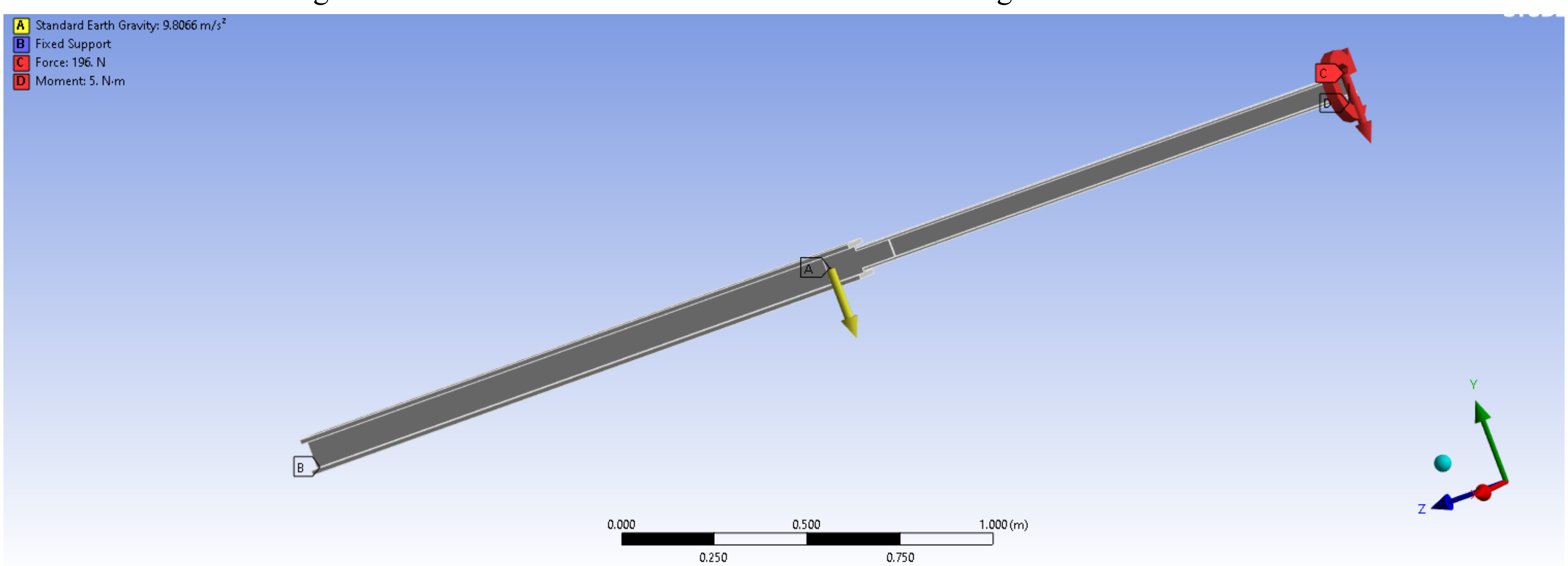
By Eric Weissman

<u>Problem Formulation</u>

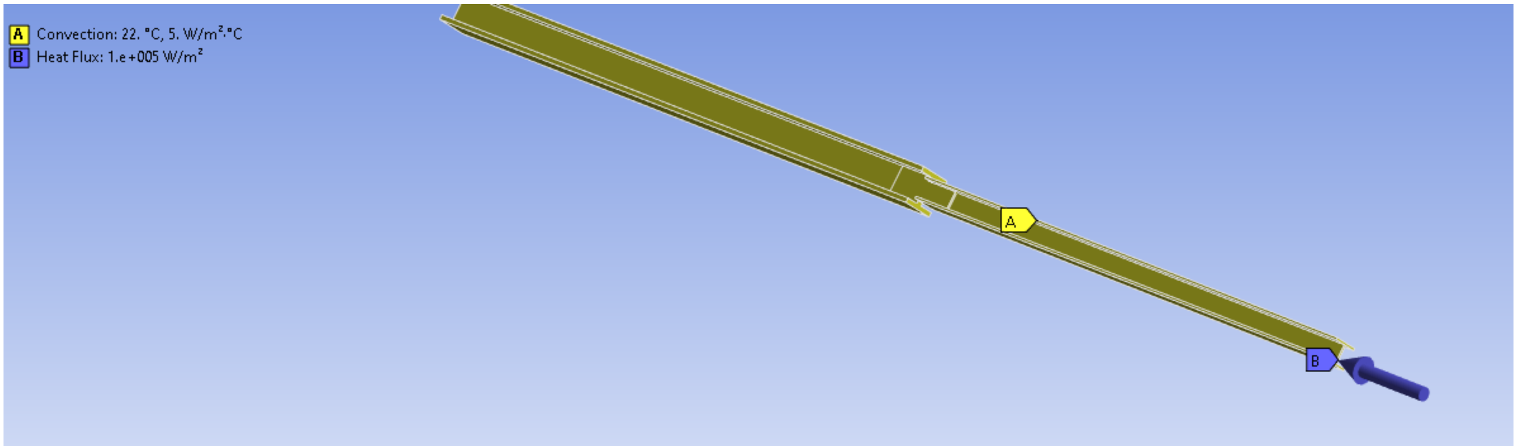
The goal of this optimization is to use Ansys to optimize the dimensions of a series of 2 aluminum I-beams connected together with a 6.35 mm plate as seen in the image below. The total length of the beams is 3.2m.



The loading and constraints on this I-beam can be seen in the image below

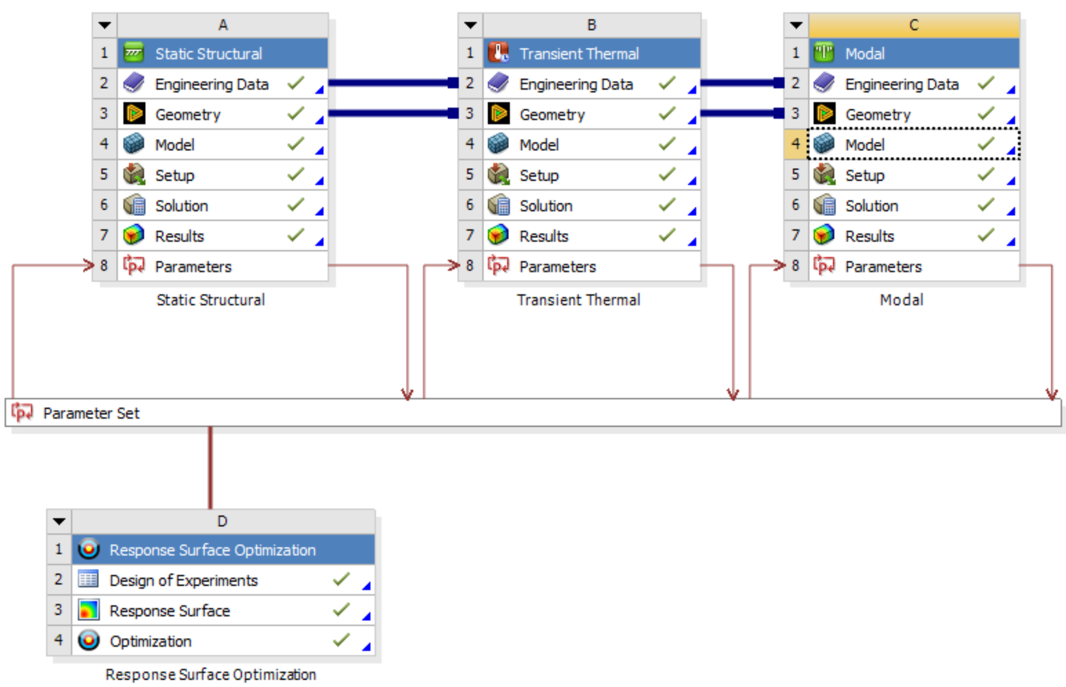


The parameters to be optimized are the width, height and flange of each I-beam, meaning there are 6 geometric parameters in total to be optimized. The design will optimize to minimize the total deformation, to minimize the mass and the moment of inertia Ip1, to minimize the maximum temperature given the convention and heat flux shown in the image below, and to maximize the frequency of maximum deformation.



The motivation for this analysis comes from a problem I recently encountered at my internship. The problem was to design an arm for a large robotic 3d metal printer which would require the smallest possible motors in the joints (related to the moment of inertia) while also deflecting the minimum amount as to not deteriorate the printer's accuracy (related to total deflection). In this problem I simplified the problem by orienting the arm in the configuration where it would experience the highest deformation but would also be a static problem (this simplification is relatively accurate due to the incredibly slow movement the arm would be under during a print.

<u>Project Schematic</u>



DOE

150 samples were created using the latin hypercube sampling design. Points which failed due to mesh issues were deleted from the sample.

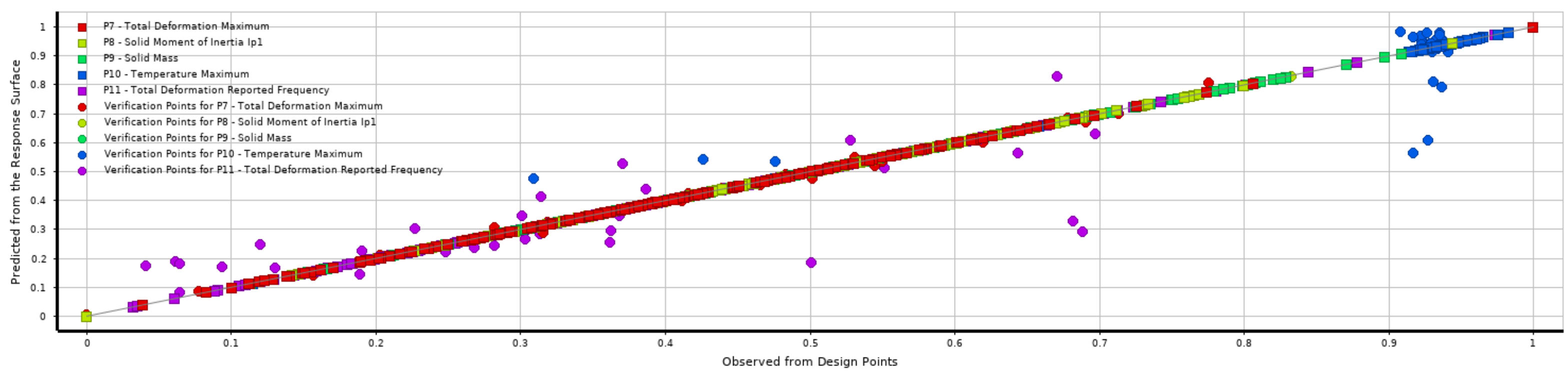
Response Surface

The kriging algorithm was used to create the response surface with 30 points used as verification points with 31 refinement points used.

Table of Schematic D3: Response Surface

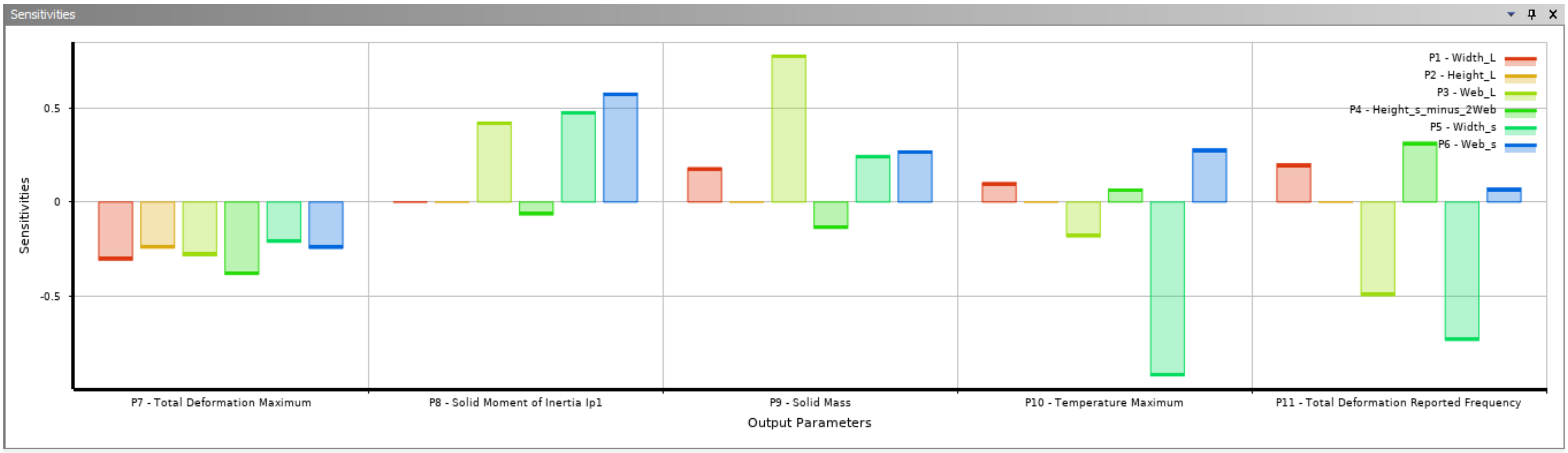
	A	B	C	D	E	F
1		P7 - Total Deformation Maximum	P8 - Solid Moment of Inertia Ip1	P9 - Solid Mass	P10 - Temperature Maximum	P11 - Total Deformation Reported Frequency
2	Coefficient of Determination (Best Value = 1)					
3	Learning Points	1	1	1	1	1
4	Root Mean Square Error (Best Value = 0)					
5	Learning Points	1.4474E-11	2.4062E-08	6.4102E-15	8.0367E-07	1.0234E-07
6	Verification Points	0.00012109	0.00065169	2.1336E-13	0.65677	0.81289
7	Relative Maximum Absolute Error (Best Value = 0%)					
8	Learning Points	0	0	0	0	0
9	Verification Points	19.5	0.22557	0	256.66	203.14
10	Relative Average Absolute Error (Best Value = 0%)					
11	Learning Points	0	0	0	0	0
12	Verification Points	6.8357	0.048708	0	45.127	51.241

Predicted vs Observed - Normalized Values



While this response surface is not perfect, due to the large amount of design parameters and outputs being simulated for, it is to be expected that only 150 points is not enough (120 in reality because of verification points). However due to the limitations of my computer and the fact that this is only a demonstration, I will use this model. Even generating this response plot took the better part of 6 hours.

Sensitivity Analysis



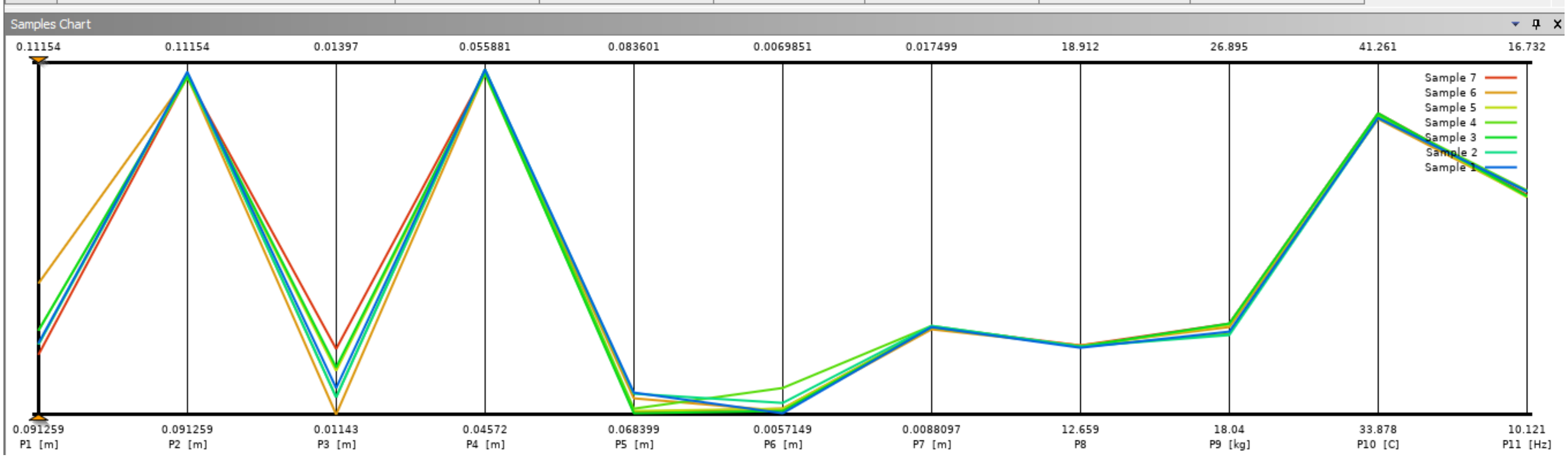
It appears the parameters of the small I-beam disproportionately affect all the parameters other than the deformation. Deformation seems to decrease as any of the parameters increases.

Optimization

For the optimization the MOGA algorithm was used. This was selected as it automatically computes the pareto frontier and finds a selection of optimal parameters.

Table of Schematic D4: Optimization

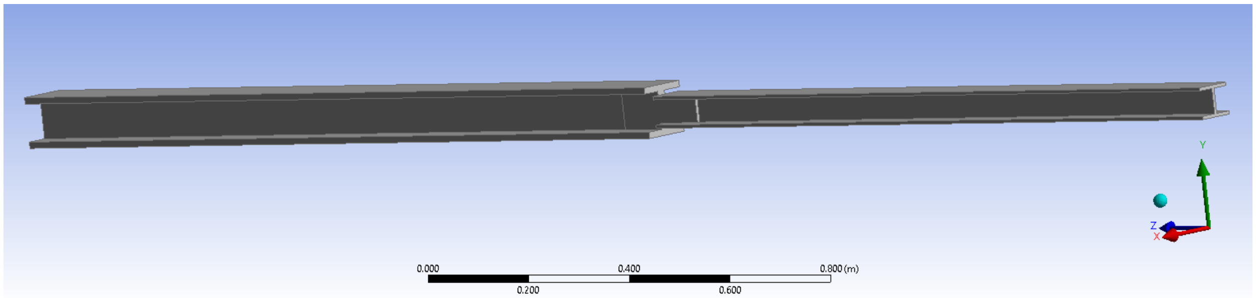
	A	B	C	D	E	F	G
10	Candidate Points						
11		Candidate Point 1	Candidate Point 1 (verified)	Candidate Point 2	Candidate Point 2 (verified)	Candidate Point 3	Candidate Point 3 (verified)
12	P1 - Width_L (m)	0.095377		0.096108		0.098875	
13	P2 - Height_L (m)	0.11101		0.11077		0.11076	
14	P3 - Web_L (m)	0.011629		0.011778		0.011433	
15	P4 - Height_s_minus_2Web (m)	0.055688		0.055609		0.055588	
16	P5 - Width_s (m)	0.069343		0.068481		0.069121	
17	P6 - Web_s (m)	0.0057206		0.0057283		0.0057285	
18	P7 - Total Deformation Maximum (m)	★★★ 0.01099	★★★ 0.010882	★★★ 0.010977	× 0.011027	★★★ 0.010939	★★★ 0.010778
19	P8 - Solid Moment of Inertia Ip1	★ 13.849	★ 13.849	★ 13.881	★ 13.88	★ 13.887	★ 13.887
20	P9 - Solid Mass (kg)	20.124	20.124	20.333	20.333	20.244	20.244
21	P10 - Temperature Maximum (C)	★★★ 40.108	★★★ 40.16	★★★ 40.201	★★★ 40.196	★★★ 40.087	★★★ 40.16
22	P11 - Total Deformation Reported Frequency (Hz)	★★★ 14.319	★★★ 14.249	★★★ 14.24	★★★ 14.464	★★★ 14.236	★★★ 14.26



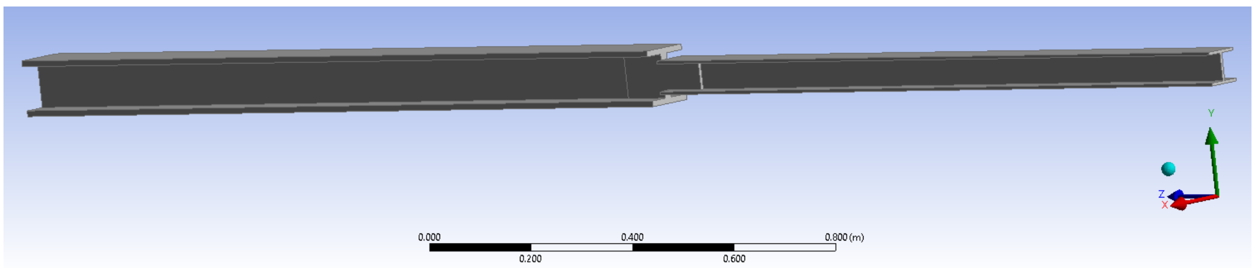
Parameter	Original Value	Optimized value	Percent Change (%)
Width_L (m)	.1014	.098875	-2.490138067
Height_L (m)	.1014	.11076	9.230769231
Web_L (m)	.0127	.011433	-9.976377953
Width_s (m)	.076	.069121	-9.051315789
Height_s (m)	.0778	.067045	-13.82390746
Web_s (m)	.00635	.0057285	-9.787401575
Max Deformation (m)	.0120	.010939	-8.841666667
Mass (kg)	22.247	20.244	-9.003461141
Moment of Inertia of Ip1 (kgm^2)	15.629	13.887	-11.14594664
Max Temperature (C)	40.132	40.087	-0.1121299711
Frequency (Hz)	12.8	14.236	11.21875

Shown by the percent change, the optimization worked at decreasing the mass of arms, the deformation, the mass temperature and the moment of inertia while also maximizing the frequency. The relatively small improvements are to be expected. The initial parameters I input were found through trial and error using beam theory and a very large Excel spreadsheet by one of the other interns on the team, so it's not surprising that the values used were in the ballpark of an optimized value.

Original:



Optimized:



<u>Potential Improvements</u>

The main improvements that this optimization could benefit from would be to improve the response plot. While the moment of inertia and the mass were modeled very accurately, the surface struggled to accurately fit to the maximum temperature, the frequency and the deformation. This could be done with significantly more sample points in the DOE or significantly more refinement points in the fitting of the surface. While maybe a different algorithm could perform better, I did try every algorithm and the kriging worked the best by far. Furthermore, To make these results more useful, an optimization that fits realistic manufactured aluminum dimensions would be more useful. Because aluminum I-beams come from extruded aluminum there are in reality a small set of usable dimensions available.