Lab 4 – Part 2

Simulation Based Optimization

MSE 426:

Introduction to Engineering Design Optimization

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Introduction

The purpose of this lab is to explore simulation based optimization methods using the OASIS [1] and ANSYS[2] toolboxes. Simulation based optimization is a practical solution to not having mathematical formulations. In this case, ANSYS' black-box modelling is used to handle the physics, while OASIS and the ANSYS Design of Experiment module are comparatively used for optimization.

The objective for this lab is to minimize mass of a robot link. This link has eight bounded input variables, three outputs, and two design constraints relating to the safety factor, maximum deformation, and total dimensions. We will find the candidate minima of this problem using metaheuristic software. An image of the robotic link can be seen in Figure 1 below [3]. Following this, Tables 1, 2, and 3 describe the problem's input parameters, outputs, and constraints respectively.

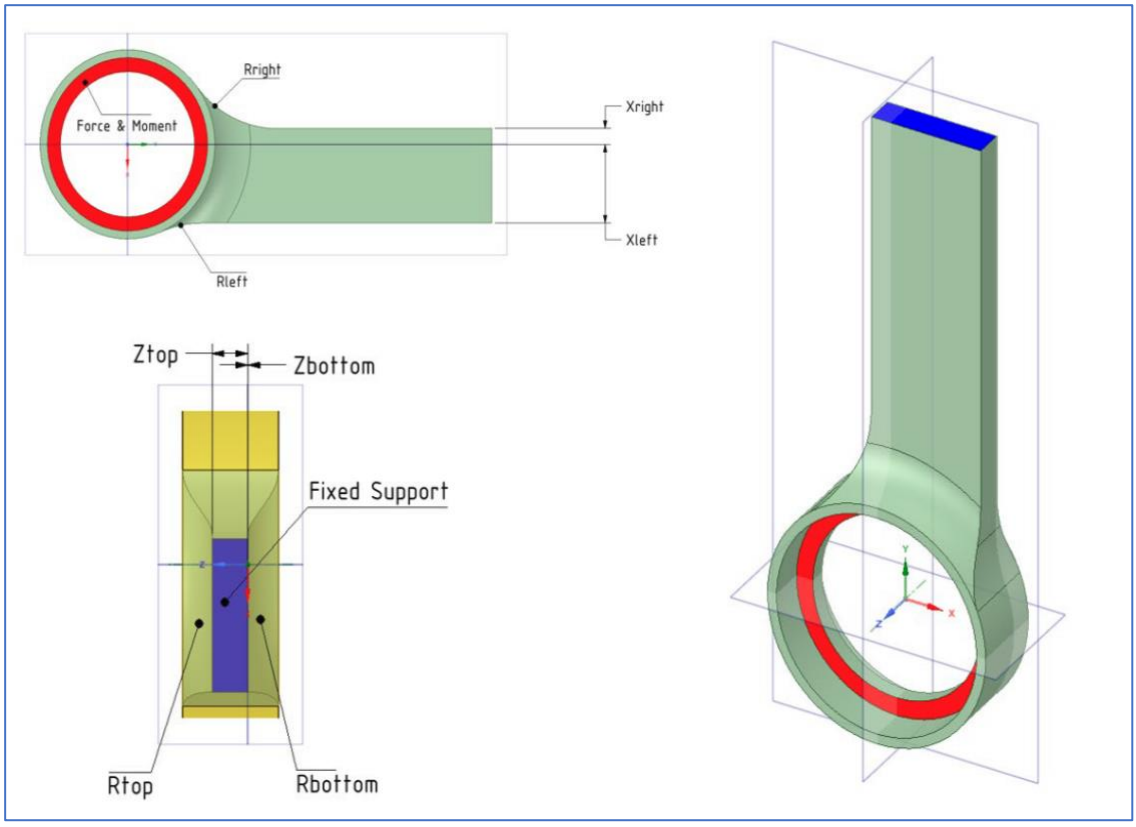

Figure 1 - Simplified link with parameters and boundaries

Table 1 - Input Variables and Boundaries

Variable	Minimum Value (mm)	Maximum Value (mm)
Xleft	-59	59
Xright	-59	59
Ztop	-12	27
Zbottom	-12	27
Rright	1	80
Rleft	1	80
Rtop	1	80
Rbottom	1	80

Table 2 - Outputs and Their Requirements

Variable	Goal
Mass (kg)	Minimize
Safety Factor	>= 2.0
Maximum Deformation (mm)	<= 1.0

Table 3 - Optimization Constraints

20.0 mm <= Xleft - Xright
7.0 mm <= Ztop - Zbottom

Results and Analysis

OASIS Optimization

The numerical results of the optimization using OASIS can be seen in Table 4 and Table 5, visualized in Figure 2. It had a runtime of 2:22:02.227 with an optimum on the 100th iteration. The constraints evaluated at the minimal point are shown in Table 6. Further results and images of iterations throughout the optimization can be found in the appendix.

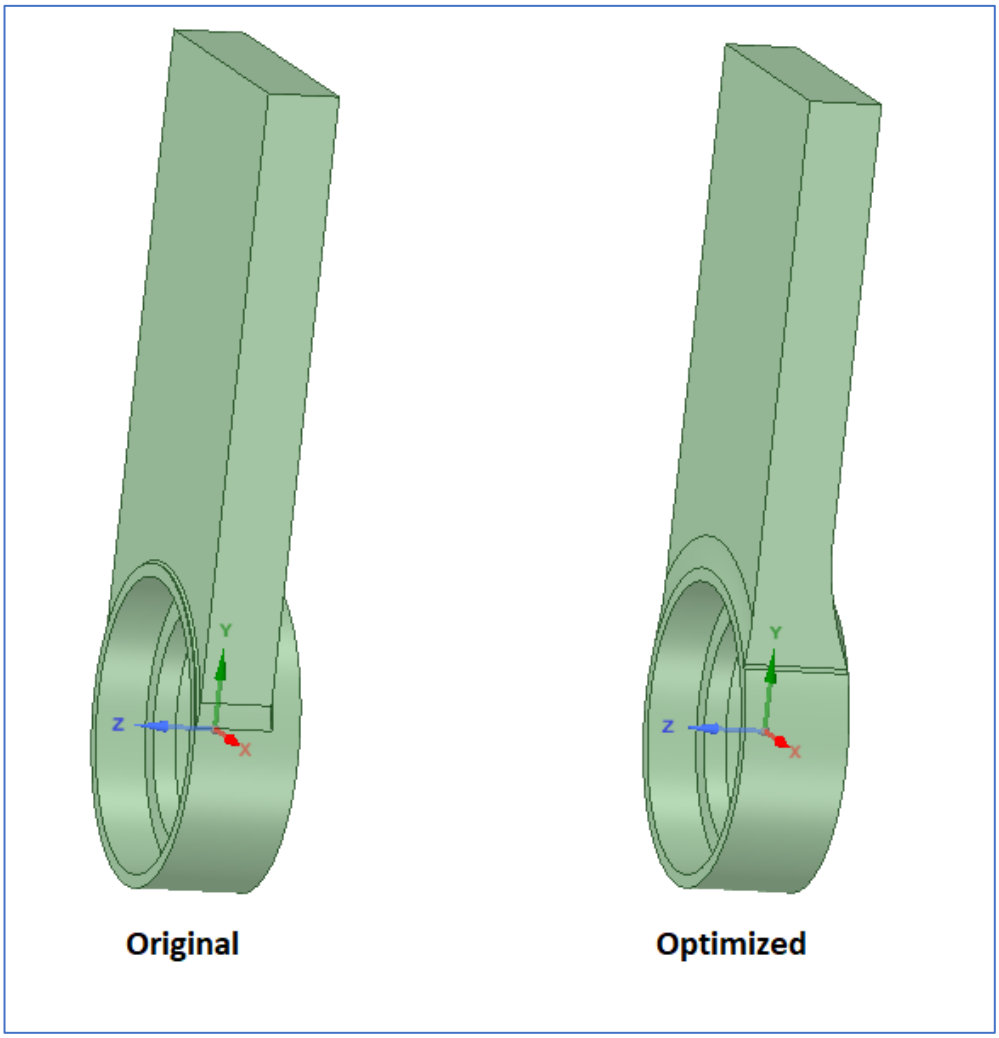

Figure 2 - Original and Optimized link using OASIS

Table 4 - Optimized Input Variables using OASIS optimizer

Variable	Optimized value (mm)
Xleft	-55.48605786
Xright	49.67564863
Ztop	26.273883
Zbottom	-1.544028396
Rright	3.269282718
Rleft	79.10672361
Rtop	59.6065654
Rbottom	63.73828343

Table 5 - Optimized Outputs using OASIS optimizer

Constraint	Optimized Value
Mass (kg)	1.930818488
Safety Factor	2.194344277
Deformation (m)	0.000988338

Table 6 - Constraints Evaluated at Minima using OASIS optimizer

Constraint	Output
2.0 – Safety Factor <= 0	-0.194344277
Max Deformation - 0.001 <= 0	-1.16624E-05
20 + Xright - xleft <= 0	-85.16170649

7.0 + Zbottom - Ztop	-20.8179114

ANSYS Optimization

The results for the optimization using the ANSYS Design of Experiment module can be seen in tables 7 and 8. It had an approximate runtime of 1:27:11.0 and produced three candidate points. The candidate point with the lowest mass is listed here while the other two can be viewed in the appendices.

Clearly, ANSYS completed the optimization process much faster (about one hour), due to its mapping capabilities.

Table 7 - Optimized Input Variables using ANSYS optimizer

Variable	Optimized value (mm)
Xleft	39.333
Xright	-47.154
Ztop	25.311
Zbottom	3.3054
Rright	21.328
Rleft	58.346
Rtop	61.05
Rbottom	76.884

Table 8 - Optimized Outputs using ANSYS optimizer

Constraint	Optimized Value
Mass (kg)	1.3728
Safety Factor	2.2868
Maximum Deformation (m)	0.0019906

Comparing mass results in Table 5 and Table 8, we can see ANSYS Optimizer is much more efficient than OASIS Optimizer. In fact, mass was minimized about 28.9% lower via ANSYS method than OASIS method.

OASIS optimizer was ran with different number of function evaluations, and results are included in tables 9-12. Although ANSIS results (mass) were much better than OASIS, in some scenarios depicted in tables 9-12, mass decreases significantly. For example, in Table 11, mass is roughly 0.9, which is lower than results in Table 8 for ANSIS Optimizer, however, our group predicts there could have been a computational error, since mass values in tables 9-12 oscillate significantly. Therefore, we can say with high degree of certainty that ANSYS is preferred over OASIS, while changing initial variables for OASIS model and improve optimization results.

Conclusion

For this part of Lab 4, optimization process for the function starts within OASIS or ANSYS. Based on results included in the above tables, ANSYS Optimizer seem to be more effective compared to OASIS Optimizer since the final value of mass was about 28.9% lower. However, that alone does not mean it is a better method. The proving factor that turned favors towards ANSYS optimization was runtime, because ANSYS completed optimization in a much shorter period compared to OASIS. This generated result was no accident, since the second and third best ANSIS optimization results were also lower than what was previously generated by OASIS.

References

[1] OASIS. (version 2021.1), Empower Operations. Accessed: March 22nd, 2021. Available: https://empowerops.com/

[2] ANSYS. (version 2020 R2), Ansys. Accessed: March 22nd, 2021. Available: https://www.ansys.com/

[3] G. Wang, “Introduction to Optimum Design: MSE 426/726 Lab Manual.” Canvas.sfu.ca.

Appendices

Detailed OASIS Results

Figure 3 includes OASIS design output for 10, 30, 70, and 100 function evaluations, respectively. Table 9-Table 12 include objective function values for the same order of above function evaluations.

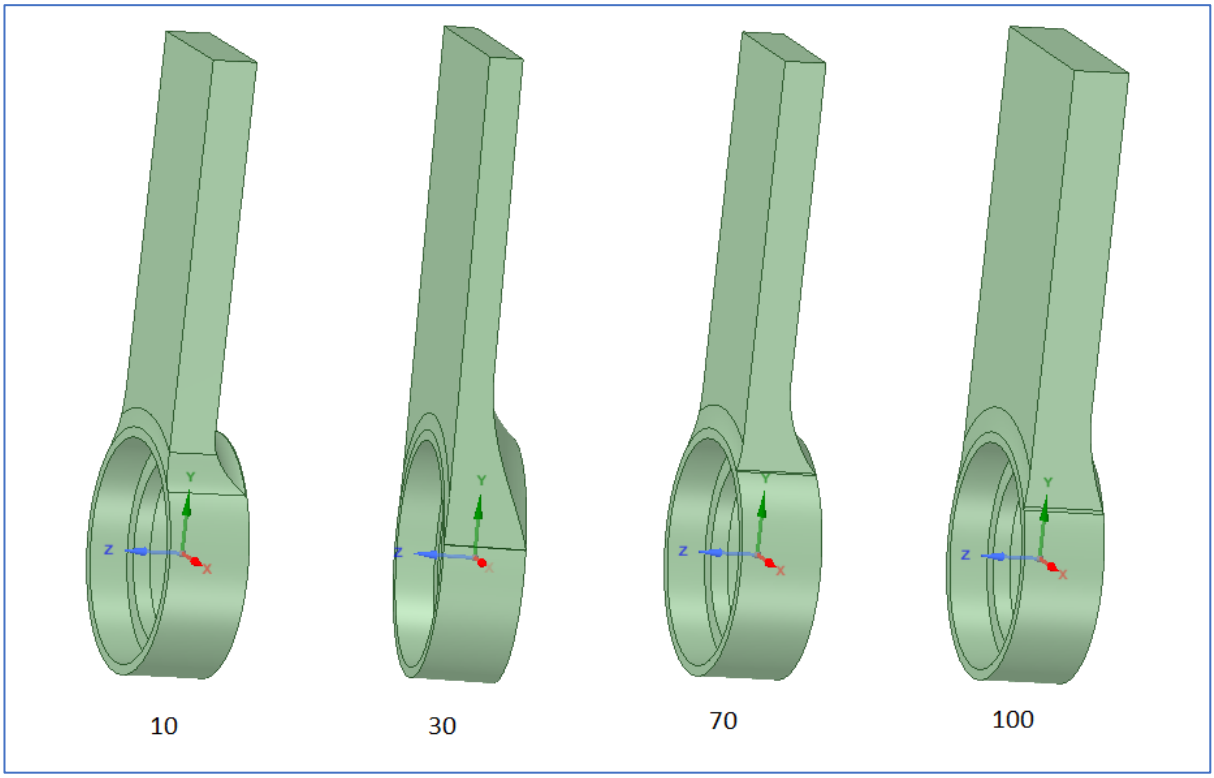

Figure 3 - OASIS results for iteration 10,30,70, and 100

Table 9 - OASIS iteration 10 results

Parameter	Optimized value
Xleft (mm)	57.31462259521746
Xright (mm)	-12.389365193573347
Ztop (mm)	26.67115941440113
Zbottom(mm)	8.055975567038661
Rright (mm)	47.14504726621266
Rleft (mm)	80.0

Rtop (mm)	74.23403726125623
Rbottom (mm)	20.126100052593365
Mass (kg)	1.026176256492236
Safety Factor	1.9674784940718175
Deformation (m)	0.004095328175170147

Table 10 - OASIS iteration 30 results

Parameter	**Optimized value**
Xleft (mm)	58.794507089911036
Xright (mm)	-58.99999999999998
Ztop (mm)	26.96958160279943
Zbottom(mm)	-3.5465676690519548
Rright (mm)	1.0000000000000004
Rleft (mm)	79.9999880924338
Rtop (mm)	64.27519006795978
Rbottom (mm)	68.25174226061506
Mass (kg)	2.325964081616308
Safety Factor	3.8499779020194667
Deformation (m)	6.830715686160945E-4

Table 11 - OASIS iteration 70 results

Parameter	Optimized value
Xleft (mm)	27.4366689805305
Xright (mm)	-30.319270497351056
Ztop (mm)	25.163907730496035
Zbottom(mm)	5.748687788903258
Rright (mm)	13.350602718494638
Rleft (mm)	50.27497110019418
Rtop (mm)	33.15493014109183
Rbottom (mm)	49.461044591297
Mass (kg)	0.9125204436974702
Safety Factor	1.6323088445529315
Deformation (m)	0.0042107620270631155

Table 12 - OASIS iteration 100 results

Parameter	Optimized value
Xleft (mm)	49.675648626887444
Xright (mm)	-55.48605786057148
Ztop (mm)	26.27388300059251
Zbottom(mm)	-1.5440283956409628
Rright (mm)	3.2692827179265898

Rleft (mm)	79.10672360918389
Rtop (mm)	59.60656540076124
Rbottom (mm)	63.73828343339864
Mass (kg)	1.9308184884965502
Safety Factor	2.1943442767905204
Deformation (m)	9.883375532934557E-4

Detailed ANSYS Results

ANSYS optimization produced three candidate points, top one was included in Table 7. Other two candidate points are included here in Table 13 and Table 14.

Table 13 - 2nd ANSYS Candidate Parameters

Variable	Optimized value
Xleft (mm)	39.333
Xright (mm)	-47.154
Ztop (mm)	25.311
Zbottom(mm)	3.3335
Rright (mm)	67.217
Rleft (mm)	58.324
Rtop (mm)	61.05
Rbottom (mm)	77.756
Mass (kg)	1.376

Safety Factor	2.3533
Deformation (m)	0.001972

Table 14 - 3rd ANSYS Candidate Parameters

Variable	**Optimized value**
Xleft (mm)	39.333
Xright (mm)	-47.86
Ztop (mm)	25.843
Zbottom(mm)	4.081
Rright (mm)	67.347
Rleft (mm)	58.324
Rtop (mm)	61.05
Rbottom (mm)	76.911
Mass (kg)	1.3782
Safety Factor	2.309
Deformation (m)	0.0019908