Design Challenge III: Topology Optimization

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SUPPORT BRACKET
EDSGN562 – DESIGN FOR AM

For this design challenge, Topology Optimization (TO) will demonstrate its effectiveness in weight reduction. ULA's rocket hardware challenge posted on Grab CAD will serve as a reference (https://grabcad.com/challenges/3-2-1-liftoff-ula-rocket-hardware-challenge). The redesign is for a launch support attachment bracket for ULA's Atlas V rocket (Figure 1); minimizing its weight increases payload weight to orbit. This paper will discuss an intuitive design, a TO design, and their manufacturability analysis.

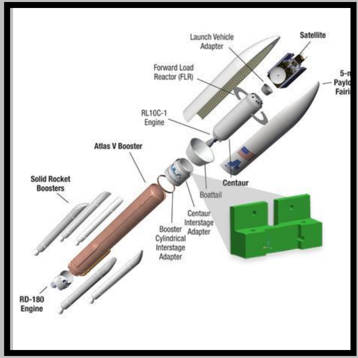

Figure 1: ULA Atlas V rocket (emphasize on bracket)

Intuitive Design

In this section, the bracket's redesign will be done using simple material removal processes (no lattice structures involved). The symmetry of this part made this process easier. Sketches of circles with two times the diameter of all six bolt holes ensured the preserved regions restriction (Figure 2). The final part should have the following characteristics:

- Remains within the original part envelope
- Preserved regions (2x diameter of all six holes, does not have to go all the way through)
- Maximum weight of 0.1 lbs.
- Minimum Wall thickness of 0.04 in
- The ultimate load of 600 lbf (uniform along the negative z-direction on the plane that has only two screw holes)
- Made out of ULTEM 9085
- Max stress smaller than Yield stress (<4500 psi)

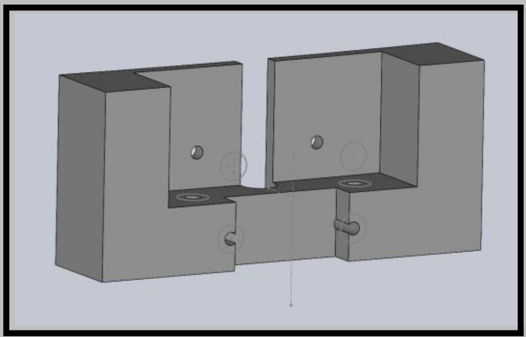

Figure 2: Intuitive preserved regions

Figure 3: Intuitive design rendering

After trimming unnecessary material regions, the intuitive design (Figure 3) satisfied all the required criteria. This part weighed 0.0997 lbs. (volume of 2.06 in^3 with a density of 0.0484 $lbs./in^3$) and showed maximum stress of 1940 psi (Figure 4). Additionally, the maximum displacement was 0.013 in which is almost negligible.

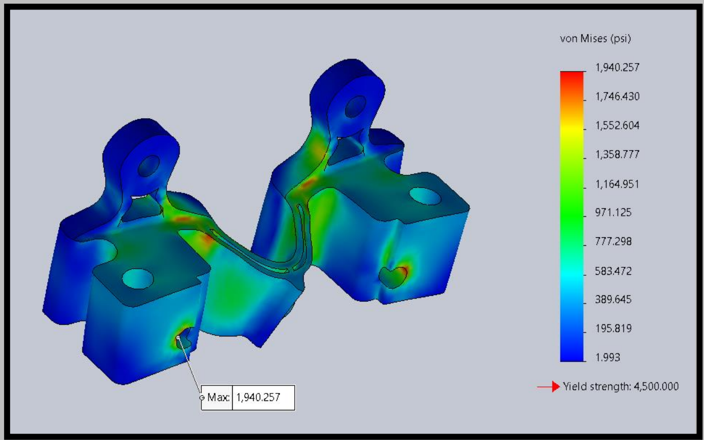

Figure 4: Static stress analysis on intuitive design

Topology Optimized Design

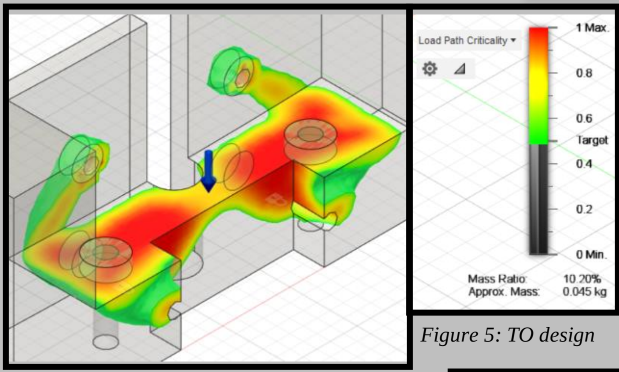

Figure 5: TO design

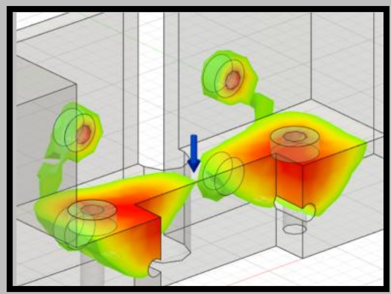

Figure 6: 34g result

In order to set up this problem, the characteristics stated in the Intuitive Design section should define the requirements (design space, loading conditions, constraints). The software used for this application is Autodesk Fusion 360. The original bracket had a weight of 440g (0.97lb), while the final design weighed 45g (0.0997lb). The new weight represents around 10% of the old one, showing genuine progress (Figure 5, also surfaces with loads and constraints were not preserved). Additionally, this number could have gone to 34g, but the structure would end up being cut into two parts (Figure 6, this might cause issues with assembly, and thin features might cause problems as well; additionally both designs should have the same weight).
For this next section, both designs will involve a manufacturability analysis.

Manufacturability Analysis

The goal was to have both intuitive and TO designs reach the same weight so that comparison would make sense. With a final weight of 0.0997 lb., the analysis is represented below:

Intuitive

After sending the .stl file to the slicer (MakerBot Print is used for this application), the preferred orientation had to be default (Figure 7). This orientation had the least support material needed, with a total PLA weight of 25.98g and an estimated print time of 3h 35min.

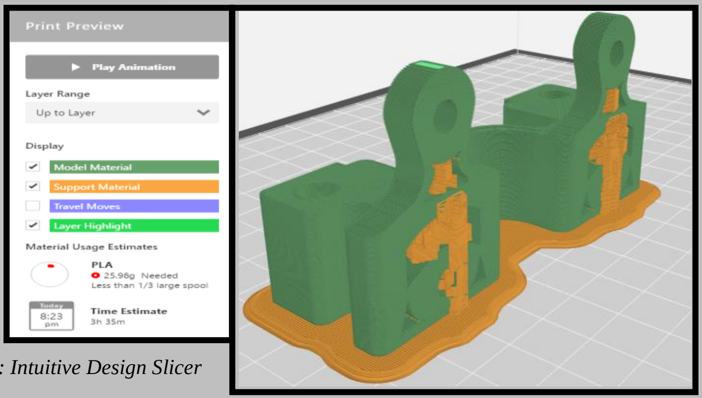

Figure 7: Intuitive Design Slicer

TO

For the TO part, the mesh used had an absolute size of 2mm (overly fine). For the preferred orientation, a +90deg in the x-direction was applied (Figure 8). The total PLA weight was 24.11 g with an estimated print time of 3h 37min.

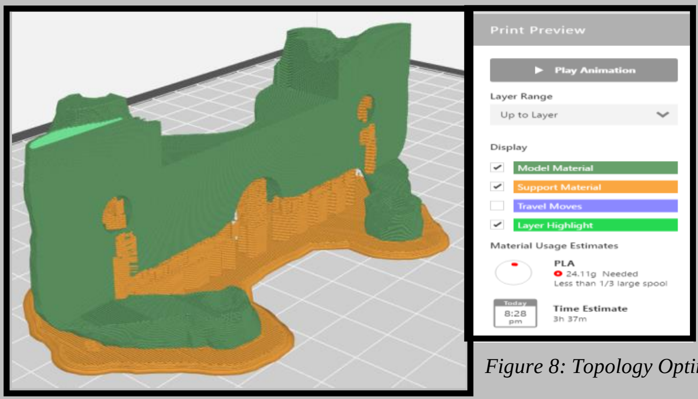

Figure 8: Topology Optimized Slicer

Note: For both Intuitive and TO design all of MakerBot Print's settings were kept on default (the print mode was balanced, extruder temperature of 215° C , breakaway supports and raft turned on, infill density of 10% ...)

Reflection

In most applications, TO designs are difficult to manufacture because of their unusual shapes. In this study, both designs behaved almost similarly when it came to AM. The time and support material needed are nearly identical.
With stress analysis being unavailable for the TO part of this study, comparing stress states was not an option. On the weight reduction side, TO has shown how easy (and faster) it is for a program to work it out rather than doing it manually.
TO still has drawbacks that should be considered when comparing it to the intuitive design. To be able to achieve optimal results, the meshes should be as fine as possible. The transition from a mesh to a part that can be modified is not straightforward. It is also harder to generate smooth structures with geometries that do not consider AM drawbacks (bridging, self-supporting angles, …).
For future work, I would suggest improving Topology Optimization algorithms to incorporate Restrictive Design for Additive Manufacturing. This way, the TO design would involve less work when it comes to engineering intuition and post-processing.