

ACM Nathan Jones

by Nathan Jones

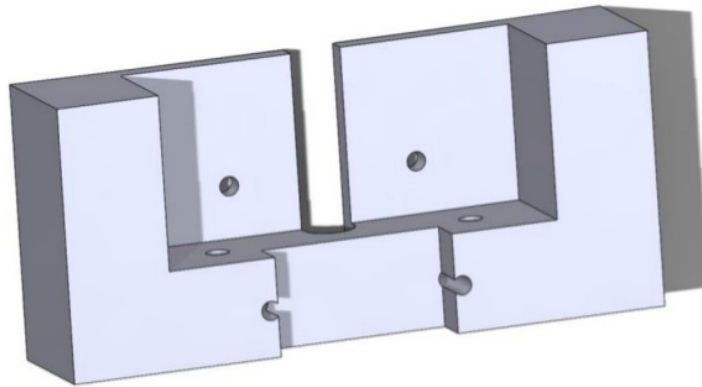
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ADVANCED COMPUTATIONAL METHODS

ULA Rocket Hardware Design

Nathan Jones (P151484)

1. EXECUTIVE SUMMARY



This report is going to look at establishing knowledge and understanding of the use and purpose of topology optimisation, using this knowledge appropriate optimisation of a ULA internal boattail support bracket. 

In order to carry out the topology study, a number of aspects needed to be researched to help understand how the component is loaded and what will need to be accounted for within the optimisation stage. In this report the use of two design softwares will be used to generate the final outcome, these will be Solidworks which will be used to carry out pre-processing and post-processing and Design Studio which will be used to carry out the optimisation.

Once the component has been pre-processed within Solidworks it will then be imported into Design Studio which will be used to apply material properties, fixing and loads which will then help with the topology optimisation in order to generate a conceptual design to help solve the GrabCAD design brief.



Finally a conclusion will be drawn up to justify why certain requirements weren't met, and why others were, as well as recommendations to help improve the study and detailed design stage.

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2. INTRODUCTION

This report is going to take a look at how a conceptual topology study was carried out to create an optimised component for use on the Atlas V rocket. The component in question is a support bracket which will be used to support a working platform to be used in multiple locations around the rocket as specified by GrabCAD in there 2016 3-2-1 LiftOff challenge (GrabCAD, 2016).



Once an initial understanding of what topology optimisation has been established this report will then go onto discuss the aspects of the design which need to be accounted for within the topology study, these included the component having a maximum final weight of 0.045kg, it being able to support a 2668.93N load in the negative Z direction when designed using the supplied technical drawings, having a minmum wall thickness of 0.1cm, it having a diameter of double to bolt hole diameters surrounding each hole and be manufactured using Ultem 9085.



This report will then detail the stages which were carried out to optimise the design such as applying the material, loads and fixings as well as the constraints for the mass and manufacturability of the component.

A conceptual design will then be displayed showing how it has met the design specification and how this would then be carried into a detailed design phase with a number of recommendations of how this will be done in order to generate a final production compoinent.



Finally a conclusion will be drawn up with how the project went and how it would be improved if a similar study was to be completed at a later date.

3. FINDINGS

3.1 BACKGROUND KNOWLEDGE AND UNDERSTANDING

3.1.1 What is Topology Optimization?

Topology optimization is a tool which gives designers the ability to adjust current designs, ensuring that the component entails all essential features and can effectively create a completely different design (Osvaldo, et al., 2017), as long as the new component still achieves the minimum stress, strain and displacement values the original component does (Yunkang & Xirong, 2018), this involves modelling the present forces upon the component to help influence the new design (GENESIS, 2019). This corresponds with what (Christensen & Bastien, 2016) states when discussing topology optimization allowing new components to be designed as long as they fall within the original shape envelope, and also helps to identify load paths within the component to improve its strength and potentially reduce the stresses surrounding the component.

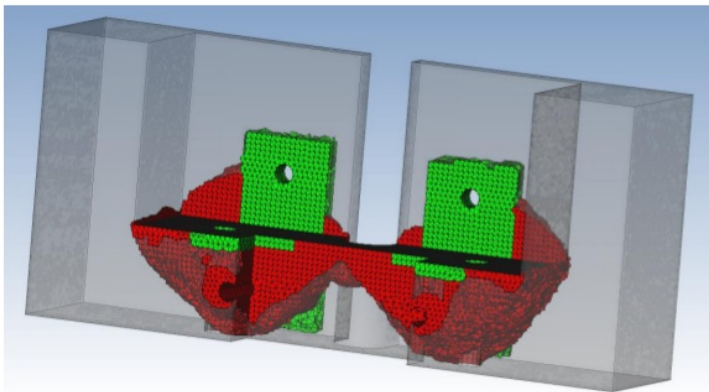


Figure 1 - Example of optimized shape within original envelope (Jones, 2020)

Looking at (Figure 1.) it can be seen that a totally different designed component is present within the original envelope visually interpreting what (Christensen & Bastien, 2016) discussed.

3.1.2 Why is topology used?

Additionally to being used to alter the design of a component it can also be used to change the size, weight and shape, meaning you can reduce the size and weight of a component by a % allowing a design to be generated within “fixed constraints” and using a “prescribed amount of material” (Bruggi & Taliercio, 2015), this gives designers freedom when weight is an issue which needs to be overcome (Wicaksono & Marquardt, 2013), this helps when the brief states that the “launch vehicle weight has a first order effect on the performance of the system, so minimizing weight, such as in this bracket, dramatically improves payload weight to orbit.” (GrabCAD, 2016)

Topology optimisation has predominantly been used in industries for structural design for many years although it is now been found to be used in more diverse industries such as the “electro-magnetism and fluids” industry to optimise design.

3.2 ASPECTS OF DESIGN

3.2.1 The Part

In order to complete topology optimisation it is important to have an initial component, this component can be seen in (Figure 2.), the component is “a launch support attachment bracket for ULA’s current Atlas V rocket” (GrabCAD, 2016), this bracket will be in use at multiple locations around the rocket and will be used “as a support point for work platforms” this will mean that the back plate of the bracket will attach to the side of the rocket with the ledge of the bracket being able to support the work platform.

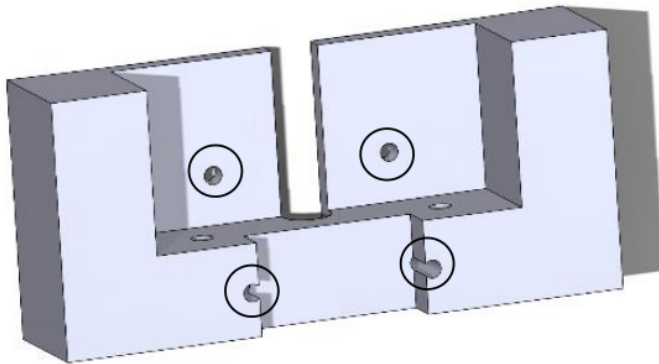


Figure 2 - ULA Support Bracket

Looking at (Figure 2.) it can be seen that the 4 holes along the back plate are the holes which will be used to mount the bracket to the rocket and the work platform ledge can also be seen, this is the original work envelope which will be used to help dictate the optimized design.

In order to generate an optimized component it is important to note the conditions which needs to be met, this means that the weight of the part will not exceed 0.045kg, the minimum wall thickness must surpass 0.1cm, and it must be able to support 2668.93N uniformly along the ledge (GrabCAD, 2016), additionally the component is required to be made out of Ultem 9085 and “the minimum edge distance surrounding all bolt holes shall be 2 times the diameter of the bolt hole” (GrabCAD, 2016).

3.2.2 Manufacturing techniques

Due to the choice of material being required there is only one way in which it can be manufactured, this is because the material is a resin which is used in fused deposition modelling (FDM), this technique is “one of the most widely used additive manufacturing processes for fabricating prototypes and functional parts in common engineering plastics. The process is based on the extrusion of heated feedstock plastic filaments through a nozzle tip to deposit layers onto a platform to builds parts layer by layer directly from a digital model of the part” (Masood, 2014). Due to the way this process builds up layer by layer it is important to understand the orientation and geometry of the part to ensure it is supported properly and doesn’t collapse while being printed.

3.2.3 Pre-Processing

Prior to being able to generate an optimized component it is important to prepare the original design for processing, this was done through the use of Solidworks to generate a 3D model from the given design drawings to, as seen in (Figure 3.) it can be seen that the component has been meshed with a 1.5mm first-order tetrahedral mesh (Dassault Systemes, 2019),

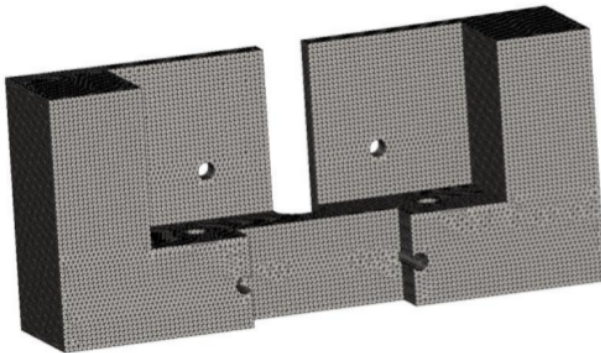


Figure 3 - Meshed component in Solidworks (Jones, 2020)

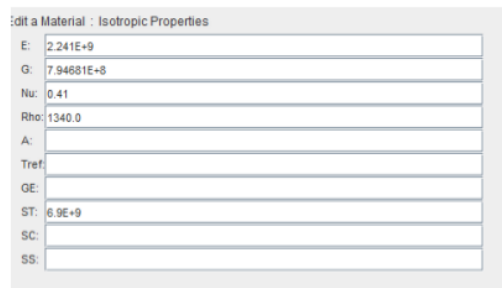
Although it is understood that when meshing a component the optimal element size should be around $1/3^{\text{rd}}$ of the smallest sized wall thickness, with that in mind the recommended element size would be 2.3mm which would provide a balance between run time and accuracy (Lake, 2020),

although a smaller mesh was used in order to help improve the optimization, and create a smoother surface due to the smaller element sizes. Once this was completed the meshed component was then exported into Design Studio which was used to carry out the topology study.  11

3.2.4 Material

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Material selection is an important aspect of topology and design as it can have major influence on the optimized component, this can be due to the size and weight which is different for each material. Using the specification supplied, it can be seen that the required material is Ultem 9085, this material will work well for this component due to Ultem 9085 having a “high strength-to-weight ratio, excellent heat resistance and high impact strength” this also helps meet the maximum weight of 0.045kg (Stratasys, 2019). Using the datasheet supplied by (Stratasys, 2019) the material properties can be seen in (Figure 4.) being applied to the component.



Edit a Material : Isotropic Properties	
E:	2.241E+9
G:	7.94681E+8
Nu:	0.41
Rho:	1340.0
A:	
Tref:	
OE:	
ST:	6.9E+9
SC:	
SS:	

Figure 4 - Material properties for Ultem 9085

As it can be seen in (Figure 4.) some values such as ‘Rho’ (kg/m³) and ‘Nu’ where taken from the brief supplied, but Young’s Modulus (Pa) and Tensile Strength (Pa) was found in the data sheet, ‘G’ (Shear Modulus, Pa) was calculated using the formula:

$$E = 2G (1 + \nu)$$

Equation 1 - Calculating Shear Modulus

It is important to ensure that these values where correctly calculated as these would effect how the model would be affected under the given loads.

3.2.5 Grid Component Selection

Once the material had been applied to the imported component it was important to outline the areas in which material must be kept and not removed in the optimization stage, looking at (Figure 5.) it can be seen that an area of double the diameter of the holes has been selected around the mounting bolts to be kept which is required as per the brief.

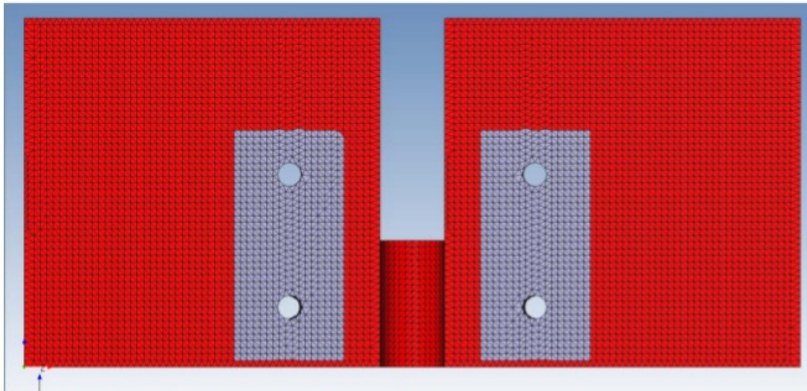


Figure 5 - Grid Component Selection (Jones, 2020)

Additionally it can be seen in (Figure 6.) that an area of double the hole diameter has been accounted for upon the support ledge around the securing holes.

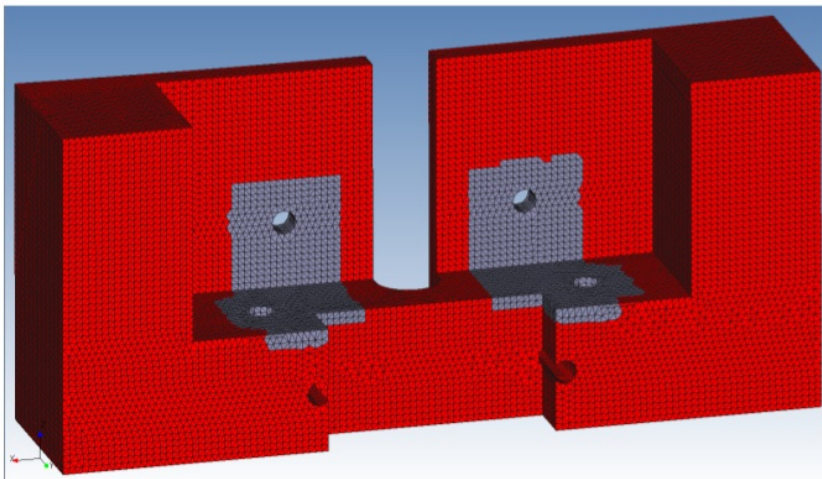


Figure 6 - Grid Component Selection 1 (Jones, 2020)

3.2.6 Load-cases and Fixings

Using the design brief supplied by (GrabCAD, 2016), it is important to understand the sorts of loads which this part is going to encounter in order to model how these affect the part, as stated in the brief the a uniformly distributed load of 2668.93N, will be applied to the ledge of the support bracket (ConvertUnits, 2020), this can be seen in (Figure 7.), this shows the 2668.93N force being distributed over the 1447 nodes along that face, meaning each node would have a force of 1.84N acting upon it in the negative Z direction. The force of 2668.93N is to account for the assumed weight of the working platform which will be attached to the bracket, as well as the engineer which will be using the platform to work on the rocket, additionally a safety factor would also be applied in order to “reduce the risk of failure” and “produce a stronger than required system” (Wilhite, 2018).

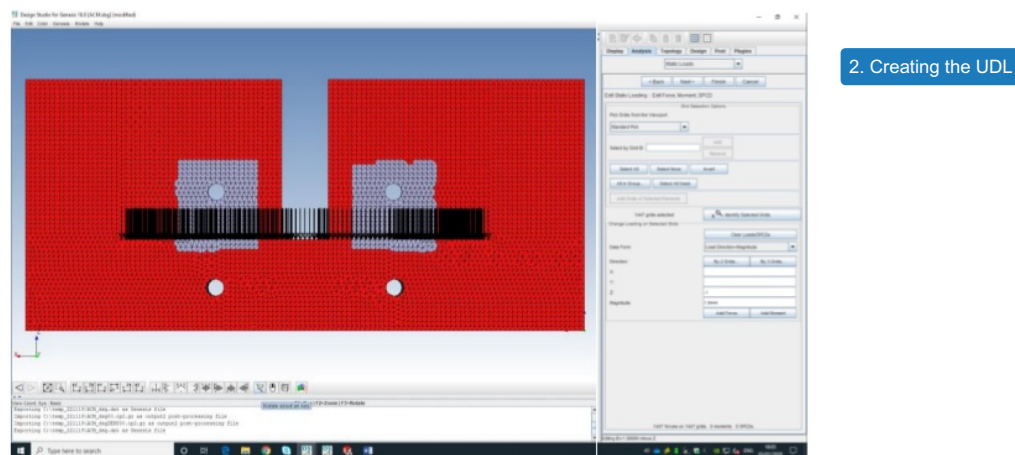


Figure 7 - Uniformly distributed load (Jones, 2020)

Additionally the component needs to be fixed at the back plate so that the bracket can become attached to the rocket, this can be seen in (Figure 8.) showing how each hole is fixed to the rocket, although it is fixed around the nodes surrounding the holes in reality even when fastened using bolts and the friction between the plate and the rocket it still isn't truly 'fixed' but will be suitable for the modelling requirements, it can be seen that the bracket is fixed in 4,560 degrees of freedom on 760 nodes meaning it is totally fixed.

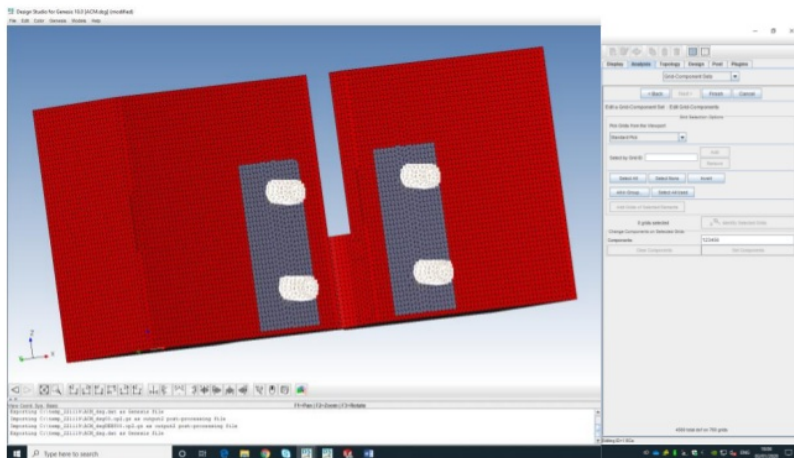


Figure 8 - Fixed holes on bracket (Jones, 2020)

3.3 TOPOLOGY CARRIED OUT

3.3.1 Topology Regions

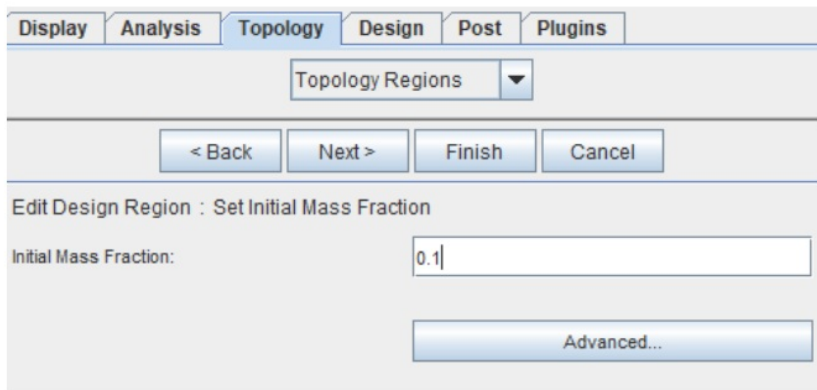


Figure 9 - Topology Regions (Jones, 2020)

In order to start generating a topology run, topology regions need to be set for the design purposes with weight being an issue, an initial mass fraction (INIT) needs to be applied, “it is recommended to set the Initial Mass Fraction as the final value that you want to achieve. For example, if you set Mass

Fraction as a constraint, then you can set the Initial Mass Fraction value to be the same as the constraint upper bound” (PTC, 2020).

It can be seen in (Figure 9.) that the initial mass fraction is 0.1 which means that the mass will be 10% of the original value, which is the value we would like to see from the topology as the brief asks for a component with a weight of 0.045kg.



3.3.2 Topology Constraints

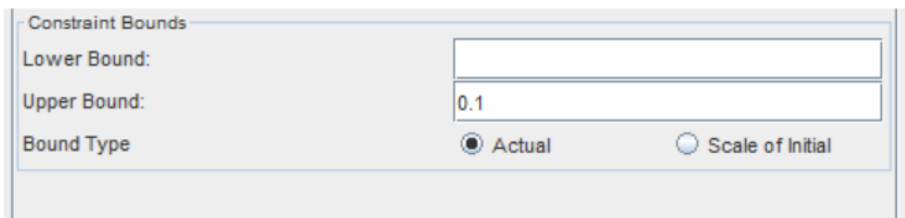


Figure 10 - Topology Constraints (Jones, 2020)

Taking the information from (PTC, 2020) a mass fraction constraint upper bound of 0.1 has been applied to ensure that the optimization doesn't exceed the 10% value and meets the requirement from the brief.

3.3.3 Manufacturing Constraints

When topology optimization is carried out, it “doesn't usually take into account the manufacturability of the optimized geometries, then a heavy further work is required to engineer the product, risking to compromise the mass reduction achieved” (Mantovani, et al., 2017). However, there are additional features which need to be accounted for, and these are in order to be able to make sure that the optimized component can actually be manufactured. Due to the manufacturing process required to create this component, two manufacturing constraints have been applied and that is to ensure that the component is symmetrical along the ZX axis for improved

printing and that the component must be filled from the Y axis to help with the strength of the component (Cai, et al., 2016).

3.4 TOPOLOGY OUTCOME

Once all the variables have been input it is time to run the optimization, this will then use the input data to help drive the optimized design, this will require the software to run through a series of cycles before generating the suitable design. The design cycle graph can be seen in (Figure 11.) showing how 7 cycles passed before the design was fully optimized.

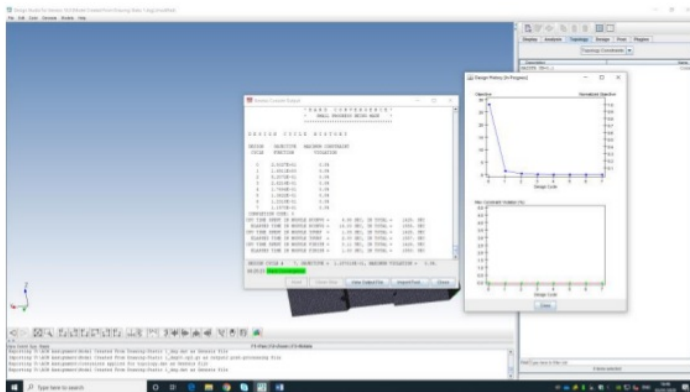


Figure 11 - Design Cycles (Jones, 2020)

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After the results of the optimization had been imported it was time to analysis the results of the design, the design can be seen in (Figure 12.) and (Figure 13.).

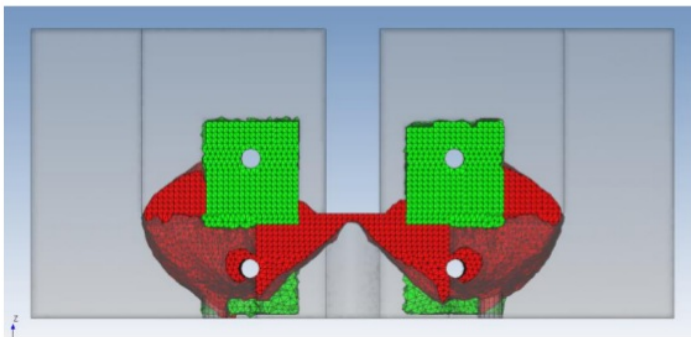


Figure 12 - Optimized Design (Jones, 2020)

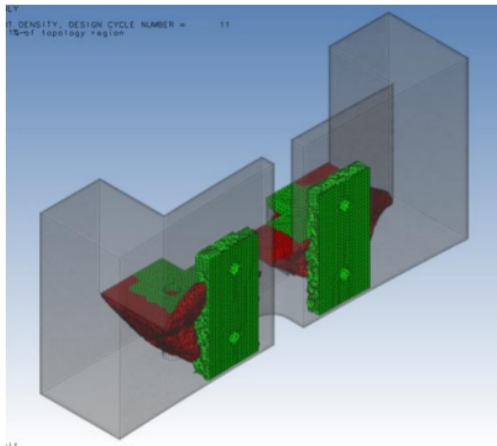


Figure 13 - Optimized Design 1 (Jones, 2020)

It can be seen that the optimized shape now portrays a much smaller area within the original envelope, it can be seen that the selected elements weren't removed which was expected allowing the component to still mount correctly to the rocket, support the work platform and fall within the required weight limit.

3.5 DESIGN STAGES

Once looking at the optimized shape it is important to remember that it was a conceptual study which will be used to help with influencing the final design. This will allow for analysis of the stress points within the component to be reviewed and reduced accordingly by adding features such as radii to remove stress within load paths (Thomas, 2019).

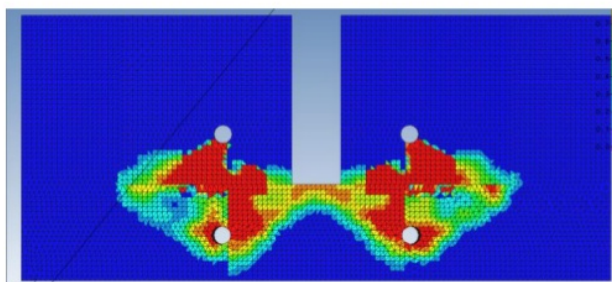


Figure 14 - Load paths within topology region (Jones, 2020)

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Looking at (Figure 14.) and (Figure 15.) it can be identified that the major load paths within the component are at 45° from the mounting holes, meaning that additional material should be applied around those areas.

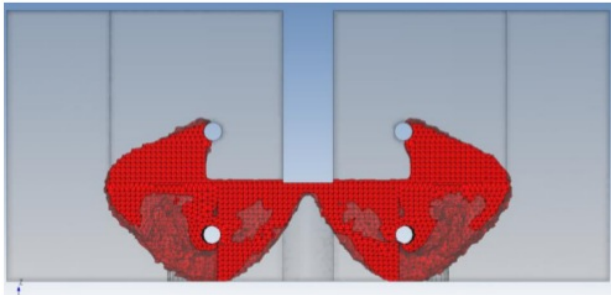


Figure 15 - Load paths within envelope (Jones, 2020)

Once the conceptual design has been optimized it is then time to carry out detailed design in order to further generate the final component.

3.6 REVIEWING THE OPTIMIZED DESIGN

Within the specification the part was required to have a minimum wall thickness of 1mm and a maximum weight of 45g. Once the optimized product has been imported back into Solidworks so the design can be generated to fulfil the needs of the customer.

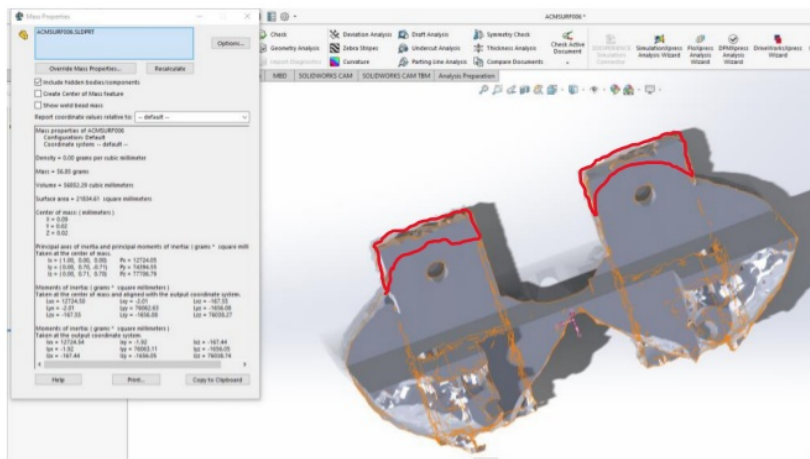


Figure 16 - Component Weight (Jones, 2020)

Using (Figure 16.) it can be seen that the imported component comes in at 56g which doesn't meet the requirement, although this weight can be reduced by removing material highlighted in red. This would be done in the detailed design stage using the advice from the topology study. There is also additional material which could be removed which can be identified in (Figure 17.) meaning the component would reach its required weight and still be able to support the required load.

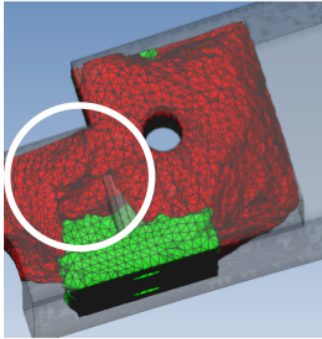


Figure 17 - Material Removal Guide (Jones, 2020)

In (Figure 17.) it can be seen that there is material missing between the non-removable material and the less dense material meaning that some of the material in red could be removed, although this again would be adapted in the detailed design stage.

4. CONCLUSION AND RECOMMENDATIONS

Using the research into the component it can be identified that the component was required to be used to support a work platform which would be used to carry out maintenance on the rocket pre-launch, but would stay secured to the rocket after launch.

Due to the requirements of the component research was needed to understand how the material required was best manufactured which was understood to be a 3D printed resin which was used for its “high strength-to-weight ratio” (Stratasys, 2019).

The component then undertook its optimisation which was carried out with design constraints to help dictate the design outcome.

After reviewing the topology study it can be seen that the component met the requirement for size and load bearing ability, but it didn’t meet the requirement for the weight of 0.045kg which has been discussed within section 3.6.

In order to improve the topology outcome next time, the grid selection would have been carried out to a higher standard around the mounting holes to help generate a finer design. Additionally the grids to the front of the mounting would have been selected to help ensure that the no material would be missing between the back and front of the model, and assumptions would have been made that the bolts required to mount the bracket to the rocket would have already been selected meaning that the thickness between the front and back of the bracket would have had to have remained intact.

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FINAL GRADE

GENERAL COMMENTS

Instructor

57 /100

PAGE 1

PAGE 2

 **Comment 1**
write in past tense.

 **Comment 2**
....is undertaken?

 **Comment 3**
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 **Comment 5**
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Comment 7

This paragraph is one sentence!



Comment 8

Spelling

PAGE 6

PAGE 7



Comment 9

Write your report in third person narrative.



Comment 10

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PAGE 8

PAGE 9

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Comment 11

Good



Comment 12

No. The iterations are relative to each other in the Topology optimisation. Since this is also linear, the material is actually irrelevant for the topology optimisation.

PAGE 11



Comment 13

Why is this area rectangular?

PAGE 12

By applying the force directly to an area that you have defined you are pre-empting the design. Ideally you would apply the load to a 'platform' and then set up contacts between the platform and the bracket. Alternately you could have taken the udl and split this between the two holes. You are then allowing the topology to determine where material should be placed, rather than you defining this by choosing the area that the load is applied over.

PAGE 13

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Comment 14

Use third person narrative.

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GRADING FORM: ACM ROCKET BRACKET

NATHAN
JONES

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RESEARCH-INFORMED LITERATURE



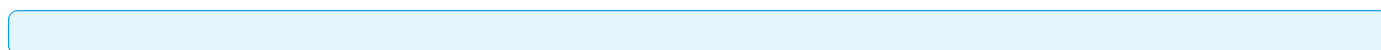
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KNOWLEDGE AND UNDERSTANDING



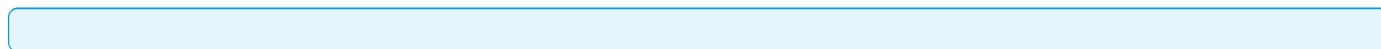
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ANALYSIS



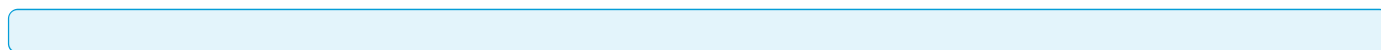
16.5

PRACT. APP. & DEPLOYMENT



11.4

SKILLS FOR PROF. PRACT.



5