

ACM Assignment 2

by Aimee Davies

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Assignment 2 – ULA Rocket Hardware Design

University of Wales Trinity Saint David

School of Engineering

Aimee Gore

1302416

Date: 24/01/2020

Kelvin Lake



Contents

Table of Figures	3
Abstract.....	4
1 Introduction	5
1.1 Principles of Rocket Flight	5
1.2 Rocket Design	5
1.3 Topology Optimisation	6
2 Pre - Analysis.....	7
2.1 Mesh.....	7
2.2 Material Information.....	8
2.3 Loadings and Boundary Conditions.....	9
2.4 Stress and Strain Analysis.....	9
2.5 Part Definition and Constraints.....	11
3 Analysis of Topology.....	15
4 Recommendations	18
5 Conclusion	20
6 References	22

Table of Figures



Figure 1 – Image of Part for Mesh Calculation (Gore, 2020)	7
Figure 2 – Mesh Size 2.12mm (Gore, 2020).....	7
Figure 3 – Part Drawing (Lake, 2019).....	9
Figure 4 – UDL Representation (Gore, 2020).....	9
Figure 5 – Load Applied to Bracket (Gore, 2020)	10
Figure 6 – Stress Applied to Bracket (Gore, 2020)	11
Figure 7 – Material Data Input (Gore, 2020)	12
Figure 8 – Topology Regions (Gore, 2020)	12
Figure 9 – Front Image of Bolt Hole Area Identified (Gore, 2020)	13
Figure 10 – Rear Image of Bolt Hole Area Identified (Gore, 2020)	13
Figure 11 – Applied UDL (Gore, 2020)	14
Figure 12 – Fabrication Constraints.....	14
Figure 13 – Unneccessary Material (Gore, 2020)	15
Figure 14 – Bolt Holes Not Defined (Gore 2020)	16
Figure 15 – Material Just For Bolt Holes (Gore, 2020)	17
Figure 16 – Final Design (Gore, 2020)	17
Figure 17 – Winning Bracket Design (GrabCad, 2016)	20
Figure 18 – CAE Design Process (Lake, 2019)	21

Abstract

The purpose of this report is to undertake initial topology optimisation on a bracket that will be used to support a work platform on a space rocket. The product specification is detailed and includes the material to be used, Ultem 9085, as well as the required loads that will be exerted on the bracket.

The report includes a brief history of rockets, the principles of space flight and the advantages of topology optimisation. The benefits of topology optimisation include the ability to help speed up the CAE process and how a thorough understanding of the available techniques can help design engineers to carry out efficient and effective changes with minimal cost to a business.

A potential final design has been suggested by the report author however, further analysis would need to be undertaken to ensure that the design is efficient in application and meets all outlined specifications.



1 Introduction

Rockets have been in use for thousands of years. After the development of gun powder, rockets were used as weapons by the Chinese army in 1000-1200's (Van Riper, 2004). However, space rockets as they are more widely recognised, first came into use after World War 2 when German scientists emigrated to the USA and the Soviet Union hence, the start of the 'space race'. The first rocket into space was a Soviet satellite, Sputnik on 4th October 1957 with the USA following shortly on 1st February 1958 with Explorer 1 Satellite (Howell, 2018).

1.1 Principles of Rocket Flight

The principle of space rocket flight is through Newton's third law of motion; for every action there is an equal and opposite reaction. In the combustion engine of a rocket, hot gasses are created which are expelled to propel the rocket upwards for take-off (Hitt, 2011). The main forces acting on a rocket are like those acting on an aeroplane; drag, thrust and weight. However, an aeroplane relies on its wings to help generate lift. The engine of an aeroplane needs to create enough power to move forward, leaving the wings to generate the lift (Woodford, 2019). A rocket is to fly directly upwards, therefore, the force generated by the engine to overcome weight and drag needs to be very large.

Rocket technology and successful space flight involves multidiscipline engineering and technical expertise. The conditions experienced by a rocket during take-off, flight and landing are extreme and all need to be considered during the design and manufacture process. Successful launches are difficult to achieve, and as such catastrophic and fatal launches still occur (Aerospace Engineering, 2016).

1.2 Rocket Design

The design of a rocket is critical to ensure a successful space flight. All elements must be critically evaluated as to how necessary they are and, if deemed essential they must be manufactured to ensure they have minimal effect on the flight. All elements need to be lightweight yet strong enough to withstand the conditions, temperatures and forces that will be experienced throughout the flight, including take-off and landing, without potential to affect the flight.

This report is focussed on a bracket, which is attached to various points throughout the rocket. It is used to help support work platforms while stationary, however they are to remain attached to the rocket during flight and as such needs to be durable yet lightweight while remaining cost effective. Budgets for space flight are generous due to the associated costs for material, research, man power and safety needs, however every extra addition needs to be accounted for as the calculations used to ensure space flight is successful need to be accurate and precise. Every extra kilogram added will end up very costly due to the extra fuel needed to launch the space rocket (Fowler, 2014).

1.3 Topology Optimisation

There are generally three types of structural optimisation of which topology is considered the most general form. There are two main benefits to using topology optimisation in design engineering. The first being the ability to permanently remove material from the design, and secondly, it allows for the elastic property of a material, as a function of its density, to vary over the design domain (Querin et al, 2017). Being able to manipulate the material and structure in this way allows engineers and designers to gain a deep product and material knowledge. Topology optimisation has emerged as a very useful tool in the design of parts and structures. It enables designers and engineers the ability to ensure components are efficiently built and optimised by setting the operating parameters and loadings in the software (Ansys, 2020). An added benefit of using topology optimisation as a form of design analysis is the cost reduction associated with it. Topology optimisation can help reduce costs in material used, shipping, manufacturing and energy. It ensures that the part or structure is produced to be able to withstand any foreseen stresses and conditions but, is efficiently manufactured to reduce costs and wastage.



2 Pre - Analysis

2.1 Mesh

Initial analysis was conducted using 3mm mesh, to ensure that analysis could be undertaken on the part in a suitable time span. As analysis was completed in under five minutes, it was assumed a smaller mesh could be used. The mesh used for optimisation was calculated by using the smallest length on the bracket (6.35mm) and dividing by 3, this is equal to 2.12mm.

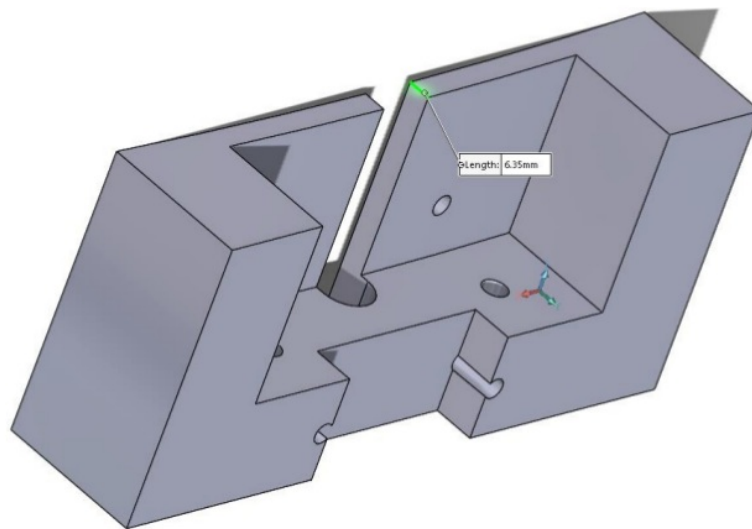


Figure 1 – Image of Part for Mesh Calculation (Gore, 2020)

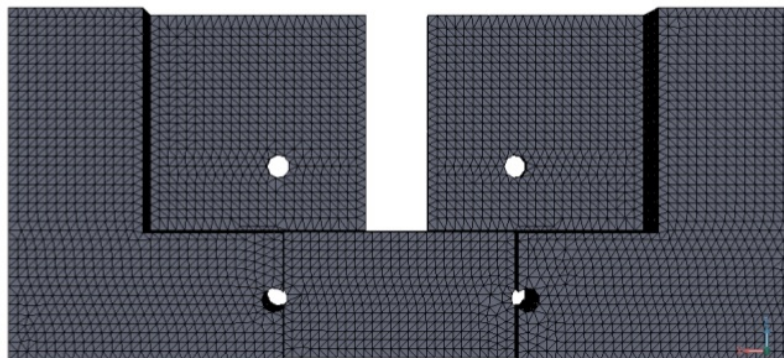


Figure 2 – Mesh Size 2.12mm (Gore, 2020)

2.2 Material Information

The material information for the part was outlined by the product specification and is below:

Material	Ultem 9085
Material Strength Allowable	4500 PSI
Specific Gravity	1.34
Youngs Modulus	325 KSI
Poisson's Ratio	0.41

Ultem 9085 is a polyetherimide thermoplastic. It has high thermal and chemical resistance as well as a high strength to weight ratio, which makes it a very good material for use in aerospace industry (Stratasys, 2019). Ultem 9085 is manufactured via Fused Deposition Modelling (FDM).

FDM, also known as Fused Filament Fabrication, is an additive manufacturing process where heated feedstock plastic filaments are deposited in layers to create a part. FDM is widely used as it is a reliable, affordable and simple way to fabricate parts and prototypes (Mohamed, 2015).

The maximum weight allowance of the part is 0.1lb or 0.045 kg with minimal wall thickness of 0.040 inches or 1.016mm. There is to be a minimum of twice the bolt hole diameter available on the part, this calculates to be 5.59mm diameter for D holes and 6.86mm diameter for E holes shown in Figure 3.

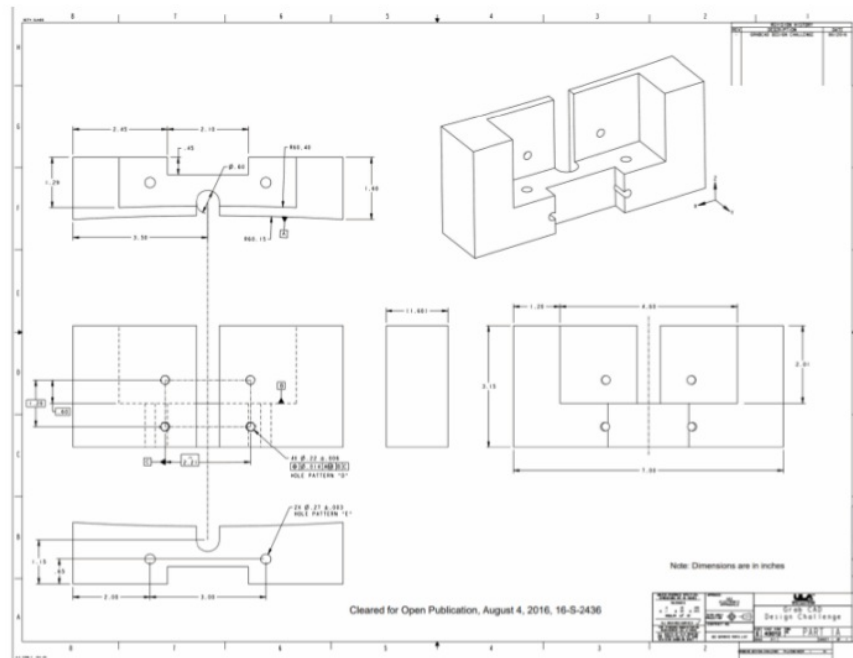


Figure 3 – Part Drawing (Lake, 2019)

2. Creating the UDL

2.3 Loadings and Boundary Conditions

The bracket will be used to support work platforms prior to take off but will remain attached to the rocket during flight. The load applied to the part is a working platform that will be bolted secure to the bracket. It is assumed the load of 600lbf is evenly distributed over the part in the negative Z direction. The initial loading applied to the bracket is represented via the dark nodes shown in Figure 4 below,

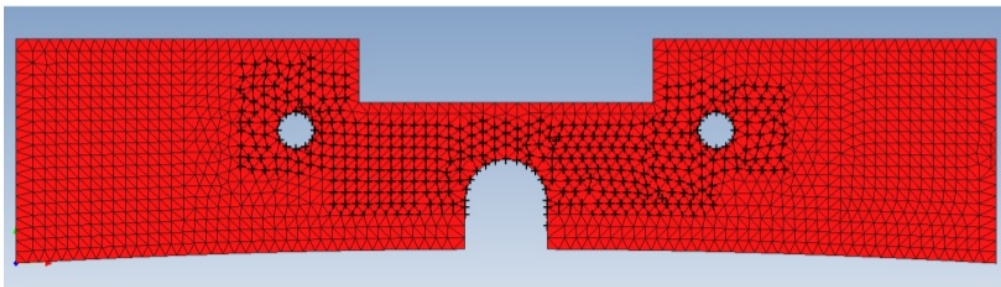


Figure 4 – UDL Representation (Gore, 2020)

2.4 Stress and Strain Analysis

Stress analysis was conducted on the bracket before topology optimisation was simulated. This is to show where the greatest strain and stress would occur on the bracket component

and therefore enable an understanding as to how the bracket might react to the loading. It is shown in Figure 5 below,

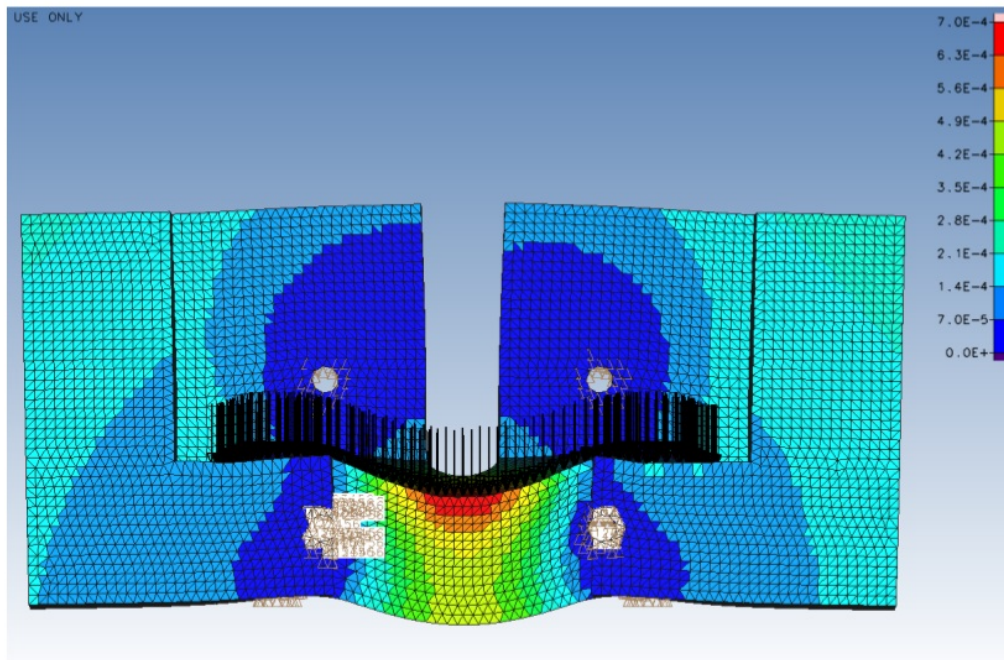


Figure 5 – Load Applied to Bracket (Gore, 2020)

As expected, the weakest part of the bracket is the centre point as there is less supportive material and less rigidity. This would need to be considered when looking at redesigning the part and how this area might need support to reduce the likelihood of failure. As the product specifies the Youngs Modulus of Ultem 9085, the engineer is aware of the material elasticity and therefore can calculate at what point the potential failure of the material is. The designer can therefore ensure that the part will be able to successfully support the calculated load without part failure.

However, Figure 6 shows the part experiencing the calculated forces when the topology constraints have been defined. The image shows that the greatest forces will be on the material defined to remain, as expected. Again, this is to be remembered when designing the final component as there are to be no parts that have potential to cause catastrophic failure.

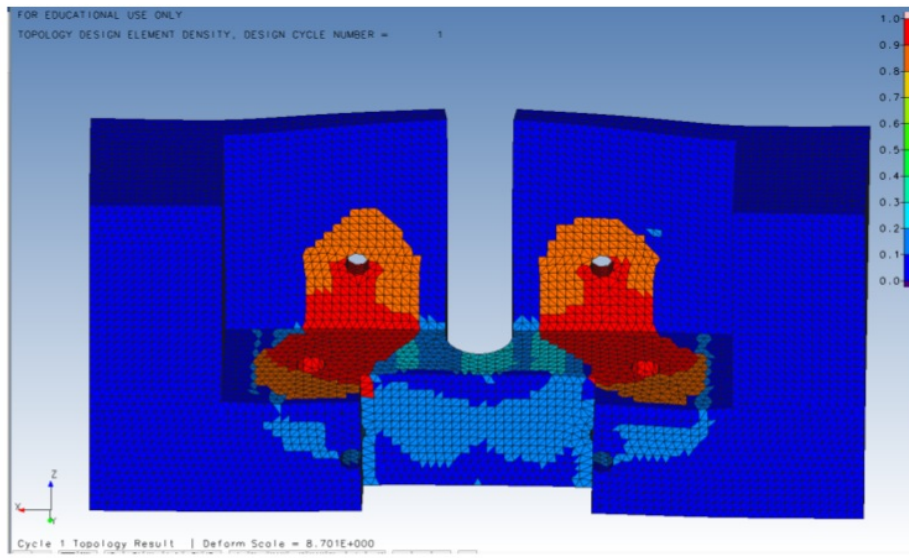


Figure 6 – Stress Applied to Bracket (Gore, 2020)

Unfortunately, although there is a scale visible on both Figure 5 and Figure 6, the scale has been deformed by the software and so an inaccurate representation of stress experienced is used. However, it enables the designer to understand the areas that will potentially experience the most stress. This will need to be overcome in the design of the part to avoid failure.

2.5 Part Definition and Constraints

Before topology analysis can be conducted, a set of constraints and definitions need to be applied to the part. This is to ensure the optimisation meets the design requirements and to guarantee that the optimisation will happen without errors occurring.

The material data needs to be defined to ensure the analysis is completed as effectively as possible. This information was provided in the product specification and was input by the report author into the software. Ultem 9085 data was converted to SI units and from the given data it is possible to calculate the material properties below,

Material	Ultem 9085	SI Units
Material Strength Allowable (ST)	4500 PSI	31.026MPa
Specific Gravity (Rho)	1.34g/cm ³	1340.0 Kg/m ³
Youngs Modulus (E)	325 KSI	2240.8MPa
Poisson's Ratio (Nu)	0.41	0.41
Shear Modulus (G)		2.05MPa



E:	2.2408E+9
G:	2.05e+9
Nu:	0.41
Rho:	1340.0
A:	
Tref:	
GE:	
ST:	3.1026E+7
SC:	
SS:	

Figure 7 – Material Data Input (Gore, 2020)

The loads were then defined, this included the applied load cases and static loads. As the bracket will be attached to the rocket by bolts defined previously in Figure 3, it can be assumed that these will be fixed points and so these were defined as such in the static load section.

Topology regions were then defined. As the product specification required the area twice the bolt hole diameter to remain around the bolt holes, the author therefore, specified this area. These areas were named 'Bolt Holes', represented by the green area, and 'PSOLID 1', represented by the red area.

Topology Regions	
Property ID	Name
PSOLID 1	
PSOLID 3	Bolt Holes

Figure 8 – Topology Regions (Gore, 2020)

Analysis was completed both with the desired bolt hole diameter outlined and without. As expected it produced different results but both can provide information to be used when trying to optimise the bracket design. After several analysis attempts, the design in Figures 9 and 10 was decided upon as the most effective. Both areas have been defined and outlined and enable a more thorough topology analysis to take place.



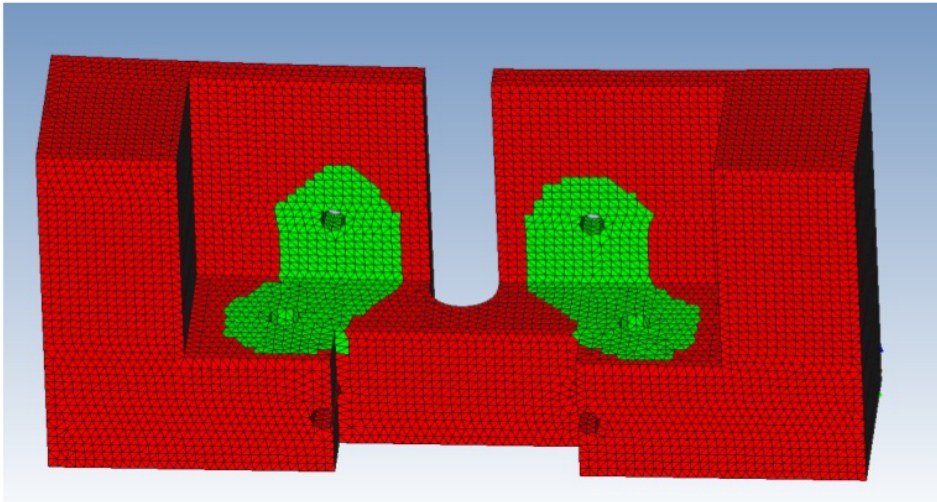


Figure 9 – Front Image of Bolt Hole Area Identified (Gore, 2020)

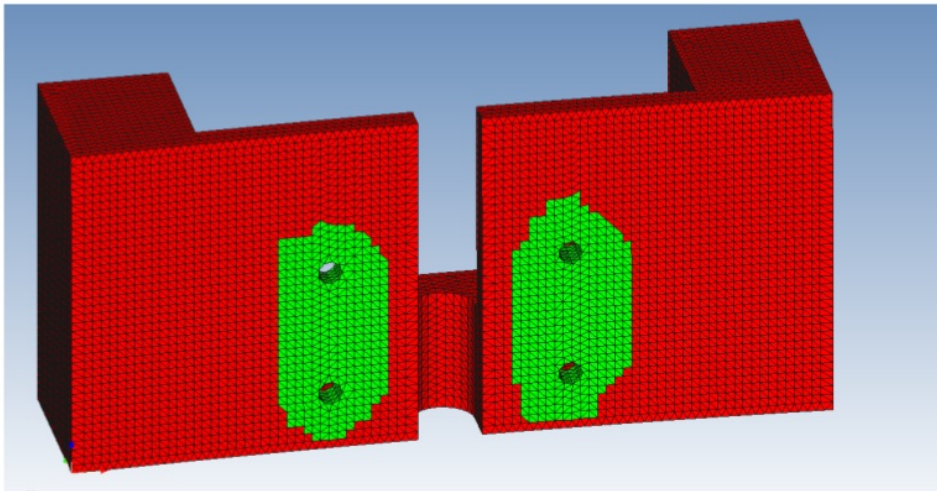


Figure 10 – Rear Image of Bolt Hole Area Identified (Gore, 2020)

The load that the bracket will experience is also given in the product specification. It can be assumed that the whole face will experience the load and so a UDL was calculated and applied to the surface. After the initial UDL was deemed too large a second pattern was decided upon assuming a smaller area is critical to support the platform. Shown in Figure 11 below,

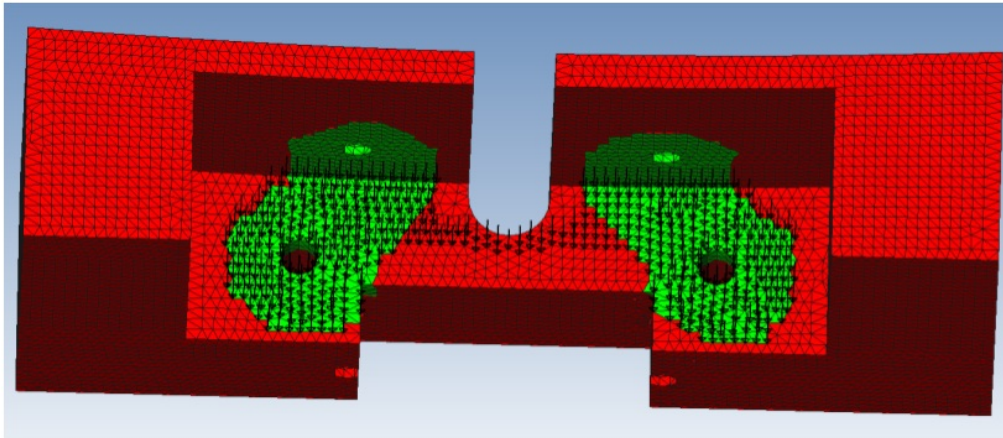


Figure 11 – Applied UDL (Gore, 2020)

Next to be defined was the topology constraints and definitions. As the author had split the bracket into two separate elements for analysis it meant that different constraints could be applied. It was specified that the 'Bolt Holes' were to have no material removed or reduced as it was considered the critical material. However, to 'PSOLID 1' constraints were added.

Fabrication constraints were added for the analysis,

Edit Design Region : Choose Fabrication Constraints	
Coordinate System:	Basic Change
Constraint 1:	MYZ : Mirror about YZ plane ▼
Constraint 2:	FGY : Fill Y axis (inside to out) ▼
Constraint 3:	None ▼
Minimum Size:	0.0042
Spread Fraction:	0.5
Maximum Size:	
Minimum Gap:	

Figure 12 – Fabrication Constraints

Constraint 1 was used to ensure that the part will be optimised symmetrically and constraint 2 used to ensure that the y axis will be filled.

3 Analysis of Topology

Topology was completed on the bracket several times in order to gain an accurate as possible representation of a suitable component.

Figure 13 represents one of the first optimisations that was undertaken. It is apparent there is a large amount of redundant material used in the original bracket design but there was still further optimisation that would improve the final design of the bracket.

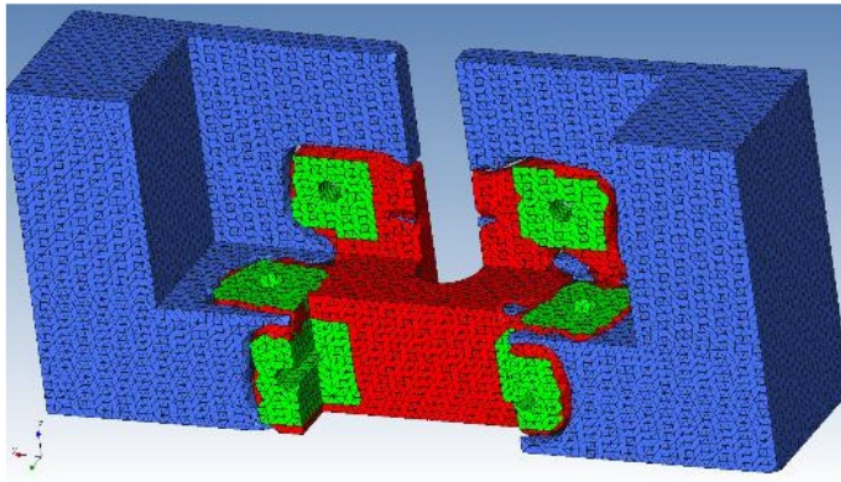


Figure 13 – Unnecessary Material (Gore, 2020)

Topology analysis was then undertaken on the bracket without the bolt holes defined to observe where the most material is required. 10% material usage is close to the optimum design as the original weight of the part is 0.45kg calculated from the part weight available in Solidworks 2019. Therefore, it is assumed that 10% of the material used will weigh 0.045kg which is the desired weight of the product. This analysis is shown in Figure 14, where the material used is 10% of original design.

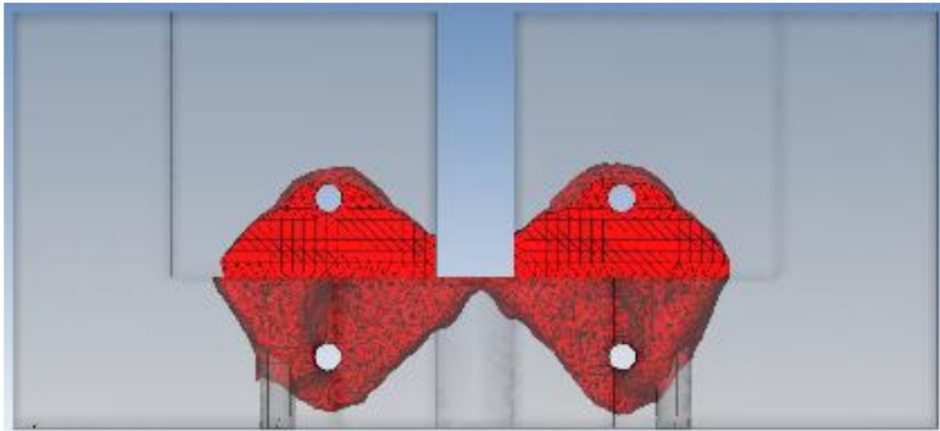


Figure 14 – Bolt Holes Not Defined (Gore 2020)

The design in Figure 14 is a very good potential final design as it uses 10% of original material, which the designer can assume is close to the required weight specified. However, there is still potential for further improvement on the design as it appears to have a lot of material that could be further reduced.

Figure 15 is the defined bolt hole area with very little other material remaining. The engineer can then observe the amount of material that is critical to remain for the product specification. However, the product specification requires the part to be a solid unit. The engineer would need to further develop this design to ensure that the two elements represented are joined together and are one component able to support the work platform.

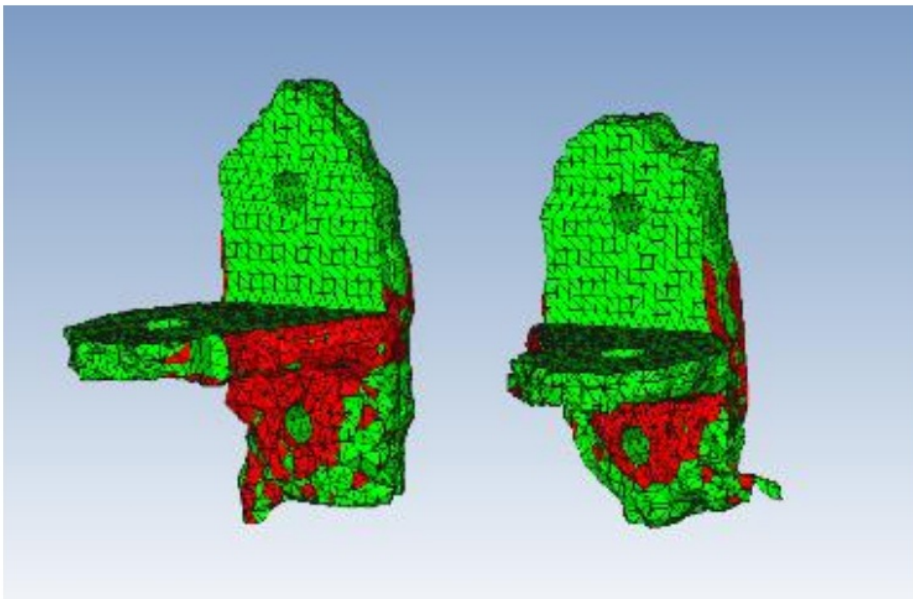


Figure 15 – Material Just For Bolt Holes (Gore, 2020)

The final topology analysis result is shown in Figure 16. Although material is missing from the specified bolt hole area it would be suggested that the engineer design this in the favoured CAD software, along with modifications suggested from the previous attempts. The final design should incorporate the required bolt hole area, with material available to support the platform and join the bolt hole areas together.

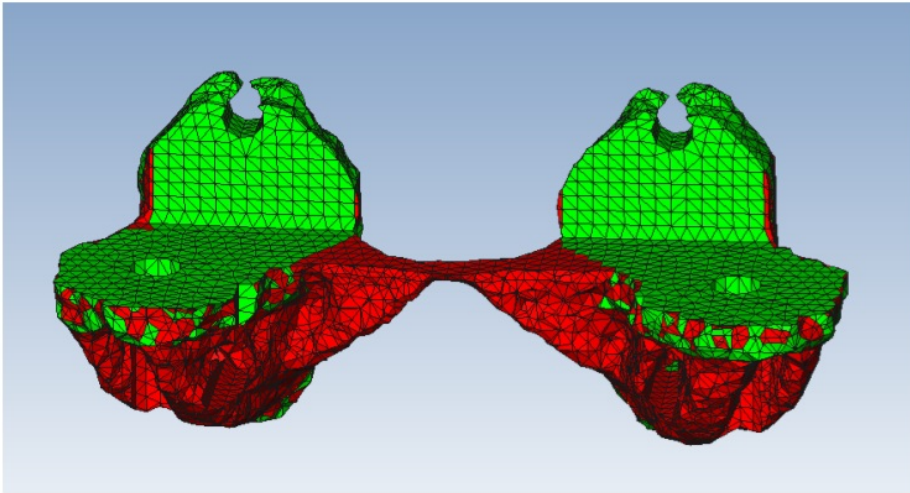


Figure 16 – Final Design (Gore, 2020)

4 Recommendations

From the analysis it is possible to modify the bracket in the relevant CAD software to suit the product specification. The designer can carry out further topology analysis on the modified bracket to establish if any further adjustments are needed on the bracket design.

The most suitable design is shown in Figure 16. The critical material remains with most of the material reduced or removed. It is, however, important to understand where the maximum load and stress will be applied to the bracket and to ensure that this is not compromised in the new design. Although this will be considered in the topology analysis, material has been removed that will weaken the bracket. From Figure 6, it is observed that the greatest stress will be on the identified bolt hole area and as such the design will need to ensure this area is strengthened and able to support the bracket. The designer will need to ensure that the integrity of the support is not compromised by focussing on reducing material used.

As mentioned previously it is beneficial to understand how the part will be manufactured. By understanding the manufacturing method, the design of the part can be altered to ensure all critical requirements are met. The bracket is manufactured via FDM, which is an additive manufacturing method, which can be utilised in the design of the bracket. From Figure 14, it can be observed that the bracket will need support underneath where the platform will be bolted to the bracket. However, Figure 15 displays the critical material, which is the outline of where the bolt holes are. By understanding the FDM process the author can use methods such as fillets and ribs to add strength to the part without adding too much weight. By adding fillets and ribs to the underneath of the part will add strength and support without adding too much weight to the bracket.



It is a requirement for the bracket to remain as one solid entity and as such the design will need to incorporate material to attach both outlined bolt holes together. Although this is not seen as critical material and the material used can be minimal. However, it can be of benefit to ensure the bridge used can also be utilised to strengthen the bracket, support the platform and should be designed to optimise this.

The product specification outlines that the weight of the bracket is to be 0.1lb or 0.045 kg, unfortunately, this cannot be calculated using the chosen topology optimisation software. However, the designer can have the part weighed after making the suggested optimisation recommendations. As the part is made via FDM, a low-cost way to manufacture prototypes, the part can be made and physically tested to establish effectiveness of the bracket in a real-

life scenario. After a successful trial has been completed, the part can be weighed to see if it meets the required criteria or different topology optimisation software used that will have this function available.

5 Conclusion

The final design of the bracket is shown in Figure 17 below,

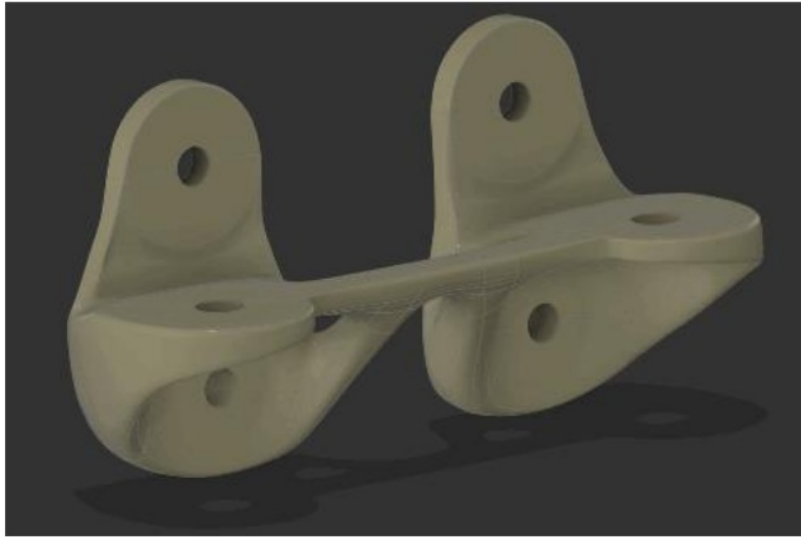


Figure 17 – Winning Bracket Design (GrabCad, 2016)

The design is similar to the report conclusion after initial topology analysis. However, it is assumed that this design was achieved after several optimisation attempts. For optimum design it is always suggested to run several analyses attempts to ensure optimum design is achieved.

The ability to carry out this analysis and optimisation is a great benefit to designers and engineers as it can allow for changes and modifications to be made without the part or prototype being manufactured, thus saving both time and money for companies. The analysis allows for simulated scenarios which will demonstrate how the component will perform and, therefore whether the design is suitable for application.

The use of topology optimisation in engineering applications can help speed up the design process as illustrated in Figure 18. By utilising the tools available design engineers can make changes to parts and prototypes with very little cost associated.

Feedback Look Identifies Problems Early

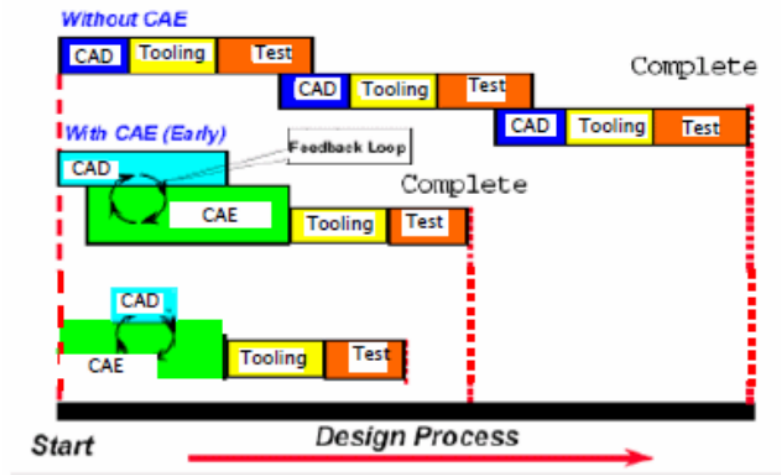


Figure 18 – CAE Design Process (Lake, 2019)

CAE led design process highlights any potential issues that could arise by creating situations and calculated forces to help simulate real life and worst-case scenarios. Therefore, helping to eliminate these situations occurring while in operation. Previously, it has always been a lengthy and costly process as the part would need to be manufactured and tested however with the advancement in technology, CAE designing capability and material knowledge, the associated time and cost of product and part development has dramatically reduced. Many companies are now utilising this to become competitive and sustainable.

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ACM Assignment 2

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

67 /100

PAGE 1

PAGE 2

PAGE 3



Comment 1

There is no need to reference yourself like this when you are presenting information for the first time.

PAGE 4



Comment 2

Good abstract. Yes this is fine. This report asked you to look at a conceptual design, so a final detailed design would require further iterations.

PAGE 5

PAGE 6



Comment 3

Good

PAGE 7



Comment 4

Using what spec machine?



2. Creating the UDL

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.



Comment 5

how have you calculated this?



Comment 6

Good. Yes the topology results give you design DIRECTION, not a final design.



Comment 7

Good



Comment 8

part



Comment 9

It is good to see the final design to see how this compares to your conceptual design. You have demonstrated how powerful Topology can be.

PAGE 21



Comment 10

good

PAGE 22

GRADING FORM: ACM ROCKET BRACKET

AIMEE DAVIES

66.80

RESEARCH-INFORMED LITERATURE



13

KNOWLEDGE AND UNDERSTANDING



12.6

ANALYSIS



PRACT. APP. & DEPLOYMENT



14

SKILLS FOR PROF. PRACT.



6.8