Washington University in St. Louis
James McKelvey School of Engineering

Exam II: Structural Design Contest

I, Benjamin Horine, understand that this exam must be individual work. I will not show or discuss my exam work with anyone else.

MEMS 3110: Machine Elements, Spring 2021

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Introduction

Bit braces are useful tools that can be used by a variety of users. An example of what one looks like is shown below in Fig. 1. The main issue with these braces are that they come in standard sizes and only accept specific types of bits. This is difficult to an user that requires a smaller size or for the user that uses a variety of bits. This paper explores the solution to this problem using waterjet-cutting technology on an aluminum block. These blocks can be scaled depending on the user and be more useful for different types of bits.

The U-shape of this part, which allows for the rotational motion, produces large bending stresses. This paper will work through possible designs that could reduce these stresses ad increase stiffness while removing material from the aluminum block. The goal of this project is to obtain a final bit brace design that is less than 0.7lbs and have at least a factor of safety of 2 using FEM analysis.

Each concept design is inspired by the strength of shapes and explore the benefits and challenges of applying each shape to the bit brace. All braces have excess material from the left side and upper right corner. These locations will not add any structural support, they will only add mass to the object.

Figure 1: A standard bit brace. This images was taken from and is available at amazon.com.

Design #1: Circles Can Be Strong Shapes Too?

Sketch

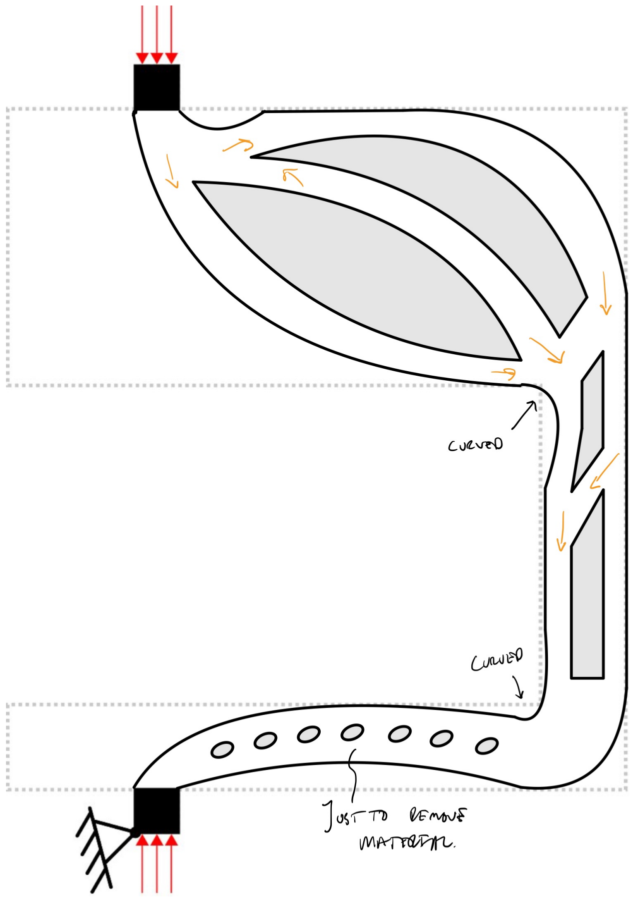


Figure 2: This is a schematic of a bit brace inspired by circles and curves, labeled in yellow for desired loading directions for the structure based off (S)WAGs.

Discussion

It is arguable that the circle can be one of the strongest shapes, which happens to be my favorite argument. The circle has no edges, therefore the stress is distributed equally along the shape instead of at at specific point. Fundamentally this shape is the solution to every structural design that requires less material with evenly distributed stress. However, in practice, this shape is very weak and hard to use as there is not a convenient way to attach or distribute a load on the shape.

This is where the arc comes in, as it is not a circle but is still able to equally distribute stress and have convenient loading ends. The two main arcs at the top are designed to distribute load while reducing material. Inverse arcs, or curves, are applied in the corners of the handle. This location is where the most stress is experienced without these curves due to the sharp edge. Another arc is found in the lower part of the brace bit also used to distribute load evenly from the top part of the bit. Note how there are cut outs in the handle and small circles in the lower section. These are present to remove material. There is very little structural intention.

Design #2: Triangles Make More Sense

Sketch

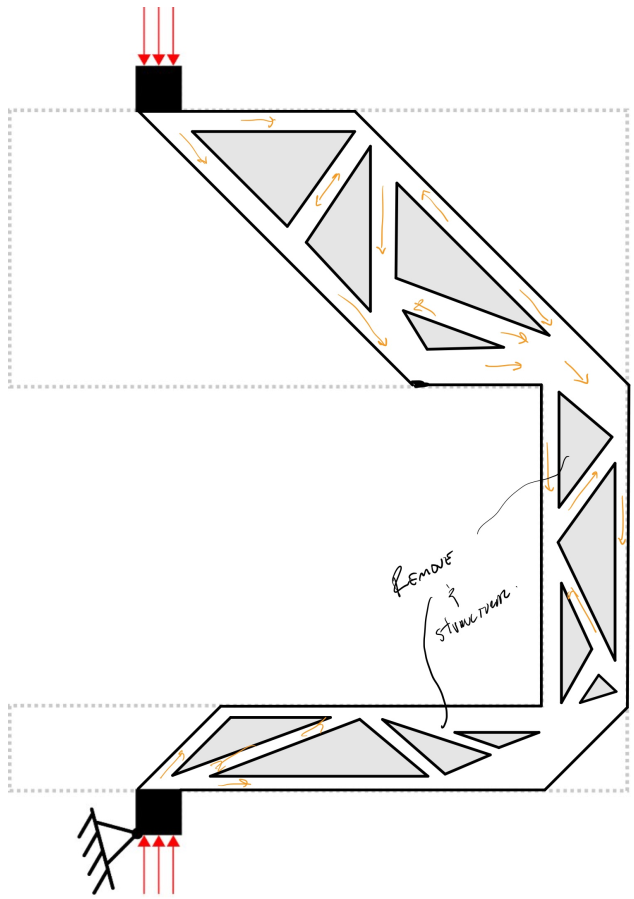


Figure 3: This is a schematic of a bit brace inspired by the triangles and trusses, labeled in yellow for desired loading directions for the structure based off (S)WAGs.

Discussion

Triangles are useful shapes to distribute multiple loads. They can be used to create a truss structure, which is what is seen in this design in Fig. 3. Each Triangle has a specific orientation in order to gain advantage from tension and compression forces on each truss section. This will add stiffness to the brace as the force will be distributed evenly throughout the entire brace. The even distribution will reduce bending stresses.

The corners are sharp in this design and the purpose is to exploit the benefit and strength solely from the triangles and truss structure. There are locations where it seems important to have material. These locations are at the top and bottom of the "handle" location. However, the handle itself is does not seem to need to have a lot of support material. This is likely due to the fact that the handle itself does not experience a lot of bending stress. Again, the top and bottom will experience bending due to the lower and upper sections.

Design #3: What about both?

Sketch

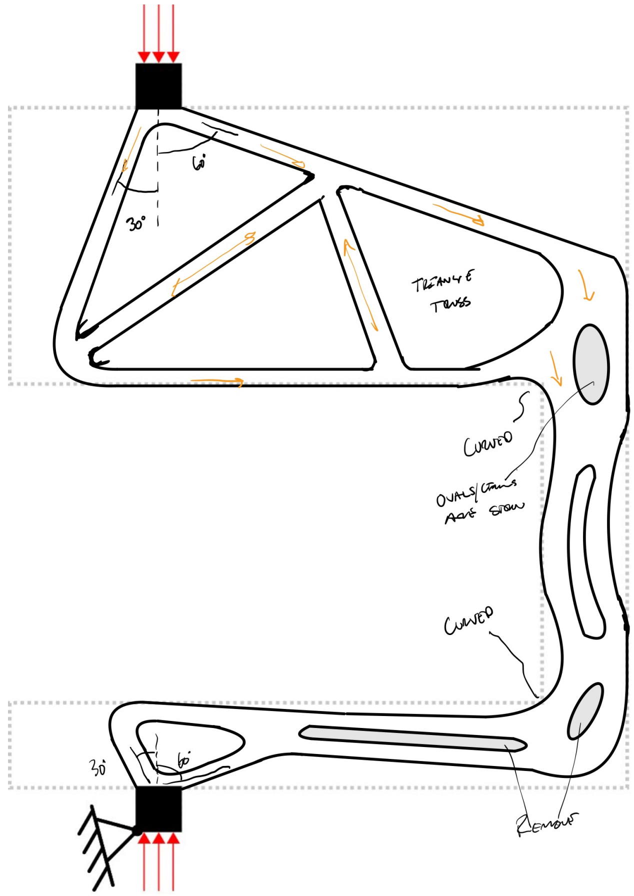


Figure 4: This is a schematic of a bit brace inspired by combining the previous two designs, labeled in yellow for desired loading directions for the structure based off (S)WAGs.

Discussion

This last design is a combination of the two previous designs. It takes the best components of each design. The triangle truss supports are beneficial to the bit braces structure. This design goes a step further in applying useful angles to the overarching truss triangle as a 30-60-90 triangle. The 90° angle is split into 30° and 60° angles to distribute some load to the left and more the right. This is aimed at reducing the stress at the handle.

The next component taken is from the first design, and applying curves and arches. The arches in the handle act as fillets and will greatly reduce the bending stress because it will be able to evenly distribute the load. Again, there is no need to have material at the middle of the handle due to no bending stress. This just needs to be strong enough translate force. The triangular arc in the lower section is able to distribute load and remove material from the lower section. The handle is also arced itself to help reduce the bending stress from the lower and upper sections.

Contest Entry

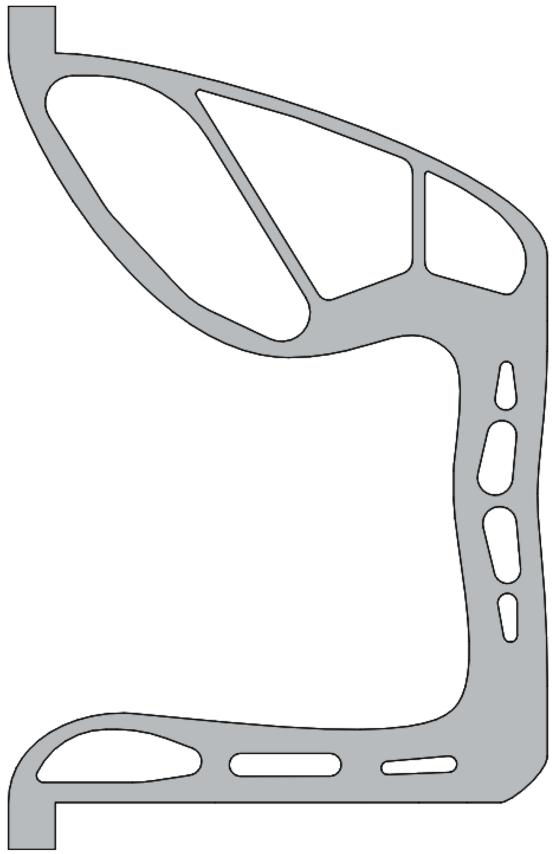


Figure 5: This is an image of the entry sketched design.

This design, seen in Fig. 5, is an adaptation from design #3. The use of arcs are more prevalent than the use of triangles. However, the use of trusses help stiffness and removal of material. As predicted earlier, the material at the top and bottom of the handle is very important. However, I did not expect the material to be so important or ”sensitive”. At the top of the handle, if any more material is taken away from the underside or the truss side it will have a large stress. Likewise, the same happens at the lower side of the handle. Even so much that the lower corner of the brace cannot be modified or “shaved off” too much.

Based off of the results from Table 1 I am very proud of this design as it has such a high factor of safety at 3.27, and only experiences a maximum stress of 2,752psi. The maximum stress experienced is in the corner of the bit brace, however, it is much lower than the original “edge” corners without an arc curvature. This proves that the arc design is able to evenly distribute the stress and further stiffen the structure.

Lastly, this design was significantly under the expected weight of 0.7lb at a feathery 0.5528lb. In all honesty, I was able to reduce this weight to about 0.47lbs, however, it was too good to be true. Each time I got close to this weight, and still over a factor of safety of 2, I accidentally ran the study while the sketch was open and forgot to save it. Therefore, this is the best, and lightest, design I have on file that was not ruined. To further reduce the material, I took more out of the handle and added a truss structure to the lower section to increase stiffness and decrease the material present.

Table 1: Weight, factor of safety, and maximum deflection

Weight in pounds:	0.5528 lb
Minimum factor of safety: (must be greater than 2.0)	3.27
Maximum deflection in inches: (must be less than 0.025")	0.022"

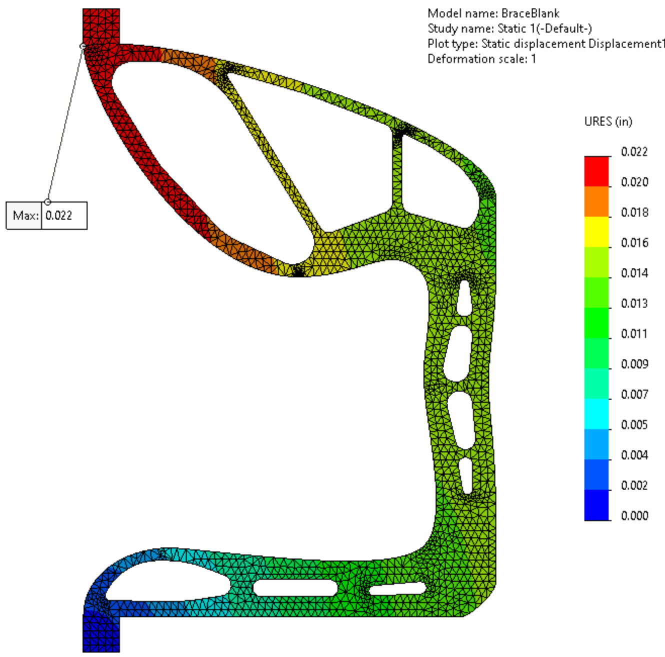
Conclusion

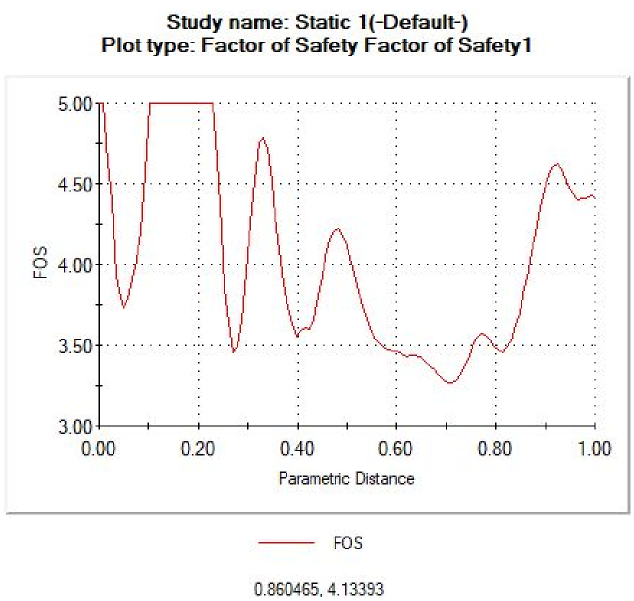
Being in the great city of St. Louis there are numerous places to observe the arc at work. The two most common that I've had the pleasure of seeing are the Gateway Arch and the Jewel Box in Forest Park. This design is mostly inspired from the Jewel Box as it was one of the very first times that an arc was used as a structural support in a building. I was inspired to use arcs in one way or another with this project. I am thrilled and excited by how effective they are in my entry design

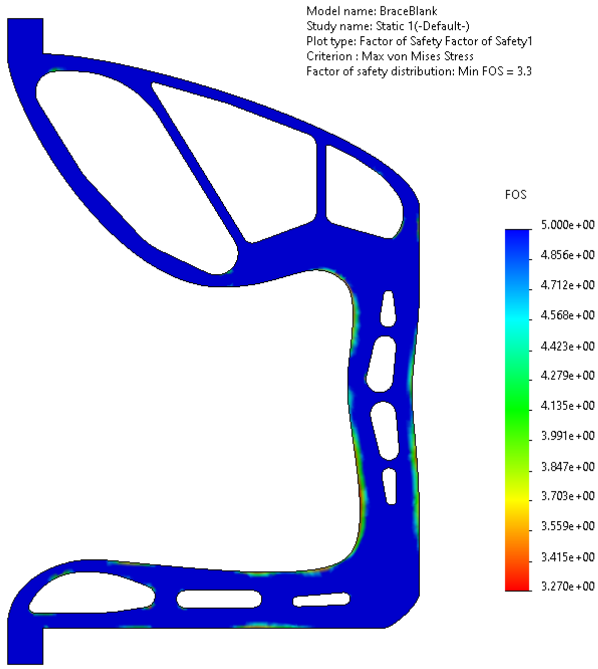
Thank you (:

This class has been wonderful, and the design parts have been extremely beneficial and enjoyable. I love the use of SolidWorks on the exam and the ability to design our own tool. I think that students in the future classes would also really benefit from this exam structure! Thank you!

Some more images from my study







Model name: BraceBlank
Study name: Static 1(-Default-)
Plot type: Factor of Safety Factor of Safety1
Criterion : Max von Mises Stress
Factor of safety distribution: Min FOS = 3.3
FOS
5.000e+00
4.856e+00
4.712e+00
4.568e+00
4.423e+00
4.279e+00
4.135e+00
3.991e+00
3.847e+00
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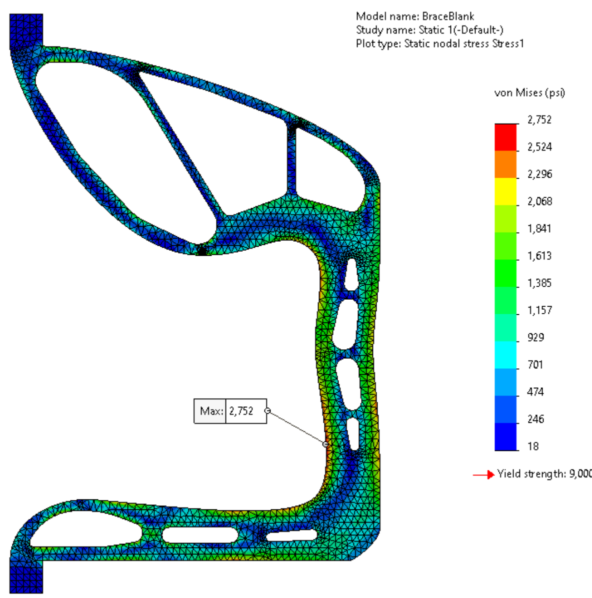
3.415e+00
3.270e+00



Model name: BraceBlank
Study name: Static 1(-Default-)
Plot type: Static nodal stress Stress1
von Mises (psi)
2,752
2,524
2,296
2,068
1,841
1,613
1,385
1,157
929
701
474
246
18
Yield strength: 9,000
Max: 2,752