Compactable Stool

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Abstract*– The objective of the paper is to reveal a design for a portable and sturdy stool. The approach that was taken to solving the problem dividing the seat and the support into three key assemblies, each with their own components, such that they fold onto one another when in the collapsed position. The most important criteria for success, was if the stool could withstand a compressive force of 300lbs. For preliminary testing, the stool was designed, modelled, and tested using a Computer Aided Design software called CATIA V5. A Finite Element Analysis (FEA) was computed on the stool assembly to determine the maximum stress and displacement when a downward 1500N (337.2 lbs.) distributed load was placed on the seat. The results concluded that our design was successful as the maximum stress values given by the simulation were lower than the yield strength of aluminum, which is the assumed material being used. The maximum displacement of the structure was found to be 0.0327 mm (0.00129 in.) Based on the results of the simulation, our design can approach the next step in manufacturing and testing a prototype.

Keywords—Portability, shear stress, bending stress, normal stress, compactibility.

I. INTRODUCTION

For many commuters, walking to a destination or standing for extended periods of time can be tiring and frustrating. Areas to sit while waiting are not always present at every bus stop or on every street. Therefore, the need for portable and convenient seating for locations without such seating arises. Our design for a portable stool is aimed at being slim, convenient, and comfortable, while being sturdy enough to withstand the weight of an average American adult male. [1]

II. ENGINEERING REQUIREMENTS

The goal of the project is to eventually create a finished product for consumer use. Therefore, we determined that meeting the following criteria would set safety standards and appeal to the most number of consumers:

1. The stool must support the weight of a 300 lb. (136 kg) which is approximately 1.5 times more than the weight of an average adult male human.

2. The seat should allow for the consumer to comfortably sit. This is done in two ways:
   (1) Allowing for the height of the seat to be adjusted to the user's preference. The typical range for a stool chair height is around 16 in. to 30 in. (40.64 cm to 76.2 cm) or more.
   (2) Providing enough surface area on the seat for the user to rest on. Most circular stools measure approximately 14 inches to 21 inches (~35.5cm – 53 cm) in diameter.

3. The stool should be compact enough when folded, such that it can be easily carried around, and not burden the consumer. When compacted, the stool should be comparable to the size of a 1 Liter water bottle, or roughly 8 in. height x 4 in. diameter (20.42 cm height x 10.16 cm diameter).

III. DESIGN

The stool was designed so it could be portable when collapsed yet sturdy and comfortable when used. The stool can be divided into 3 key structures:

1. Seat
2. Central Rods
3. Legs

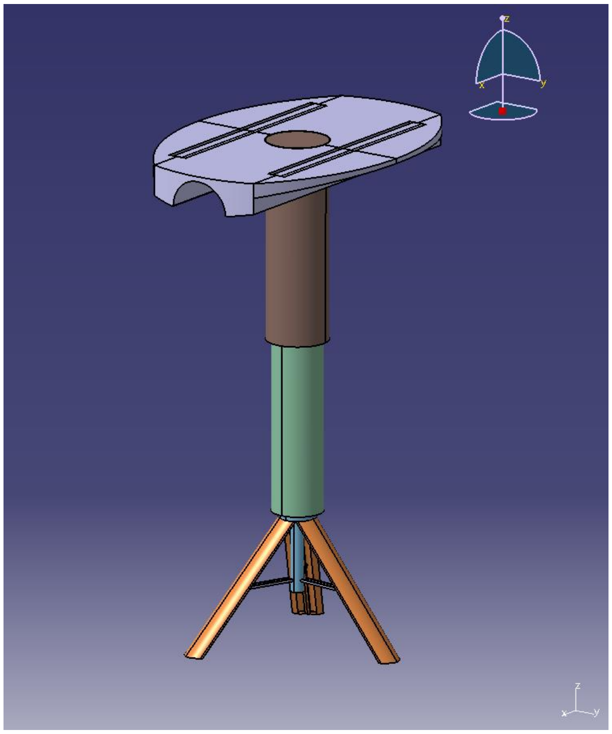

Fig. 1 Assembled Stool, Isometric View

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A. Seat

The shape of the seat was chosen to be ovular rather than circular to reduce the volume of the seat for folding. The ovular shape also provides enough surface area for seating when unfolded. A circular design with a diameter of 16 in. (40.64 cm), would have provided a sitting surface area of 615.44 in^2 (3971 cm^2). The downside to having a large surface area is the problem of folding it in such a way that it does not add significant thickness. An ovular design, however, circumvents that issue, by reducing surface area. The seat dimensions have a major radius of 8 inches (20.32 cm) and a minor diameter of 5.5 in. (~14 cm) which provided a drastic reduction in surface area, of around 138 in^2 (890 cm^2). The seat is comprised of two main sections, with each section containing two flaps. The flaps are meant to fold onto the main section, which is then meant to fold onto the outer support rod, when collapsed.

B. Central Rods

The support consists of three main rods connected to each other: the outer rod, the central rod, and the inner rod (brown, green and blue respectively from Fig. 1). The outer rod is hollow with an outer diameter of 2.5 in. (6.35 cm) and an inner diameter of 2.1 in. (5.33 cm). It's attached to the seat via hinges. The outer rod contains three sets of grooves which will enable the simple "twist and lock" mechanism which is controlled through the central rods.

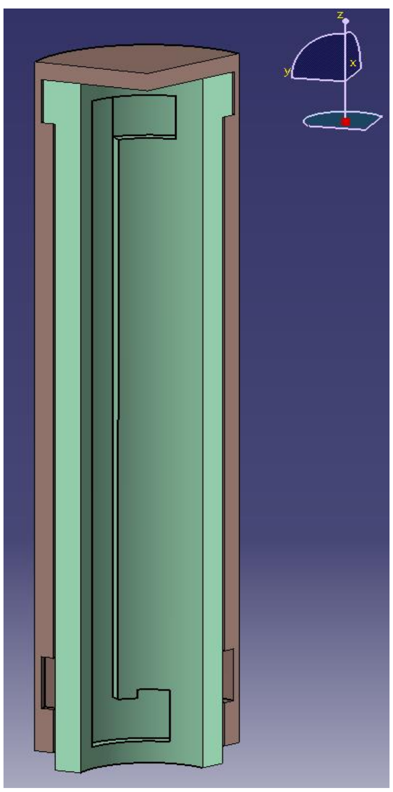


Fig. 2 Compacted Outer Rod and Central Rod

The central rod is also a hollow structure with an outer diameter of 2.05 in. (5.2 cm) and inner diameter of 1.51 in. (3.84 cm). It contains three small rib protrusions that fit into the grooves of the outer rod (as seen in Fig. 2), allowing it to slide and lock up or down, depending on whether the stool is unfolded or compacted. This design is intended to save volume when compacted, while being able to extend into a structure that is strong and comfortable to sit on.

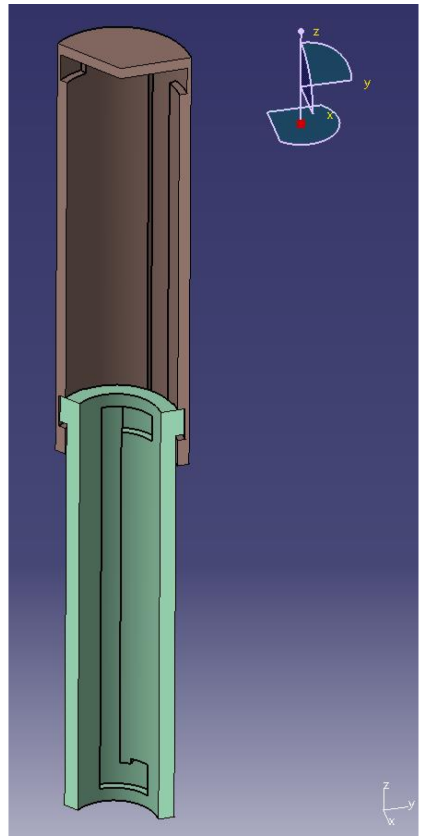


Fig. 3 Assembled Outer Rod and Central Rod

Having three sets of grooves and ribs, allows for the structure to distribute the weight in a symmetrical manner. Although not visually explicit in Fig. 3, the rods connect at three points around the structures at an evenly spaced distance from one another. Apart from having the rib protrusions, the central rod also contains three sets of grooves to connect with the inner rod, the grooves of the central rod were specifically designed so they are not located at the same position where the ribs were designed, this way the amount of material will not affect the integrity of the structure when loads are being applied.

Finally, the inner rod is a solid structure with two different cross-sectional areas. The first section has a diameter of 1.5-inch (3.81 cm) and contains three rib protrusions to fit in the central rod's grooves. The second section of the inner rod is a 0.5 inch (1.27 cm) smaller rod which will enable the legs support.

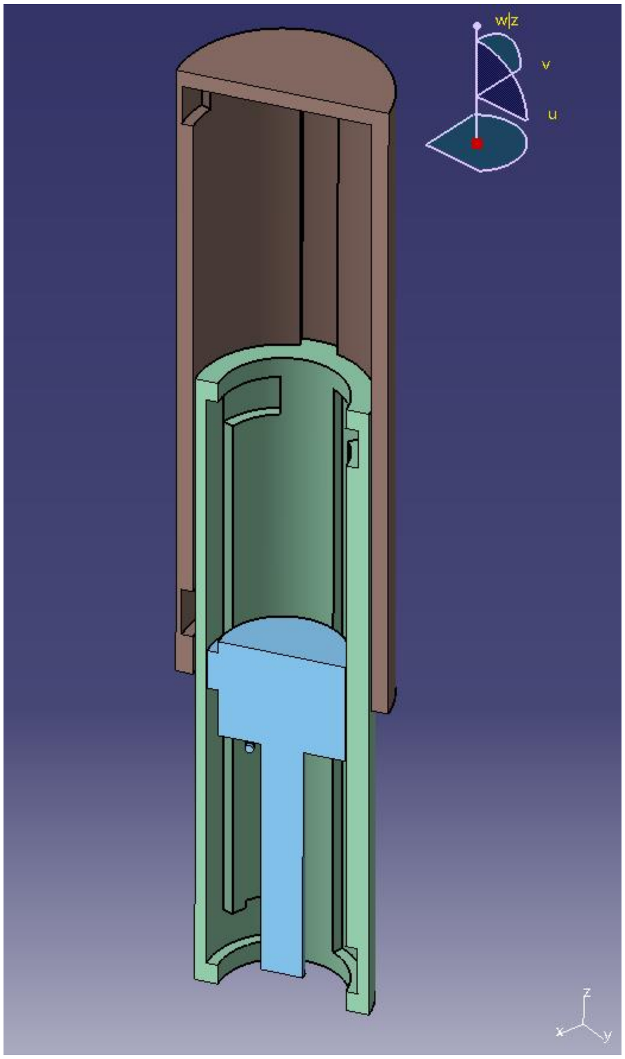


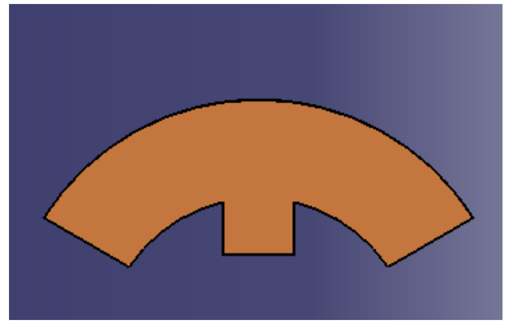
Fig.4 Central Rods being assembled

This design is intended for easy user assembly and great compatibility. From Fig.4 it is visually explicit that all three rods fit perfectly inside each other, saving a lot of space, and can be assembled with ease.

C. Legs

The Stool will be supported with three legs, able to fold up into the central rods. We wanted to create a structure that can stand on its own and be well balanced. The three legs are hinged at the inner rod and will also have a structural mechanism able

The small section of the inner rod will contain a sliding ring, which will have three structural hinges attached to the legs and will be able to move up and down, controlling this way the position of the three legs. When this ring is moved down, the legs will change from being in a vertical position, to be spread into a sort of tripod structure with an angle of 40-degrees with respect to the vertical axis of the stool. Because the legs were designed to be at an angle, we designed the cross section to be



able to withstand the stresses of the applied load; particularly the bending stress.

Fig. 5 Cross Sectional Area of Stool Leg

The cross-sectional area of the legs is shown in Fig. 5, was designed to withstand a higher bending stress value due to incorporating a web, or the part of a beam that is connected to the flange. The flange in this case is the arc shown in the cross-section of fig. 5, and the web would be the piece sticking out of the arc shape.

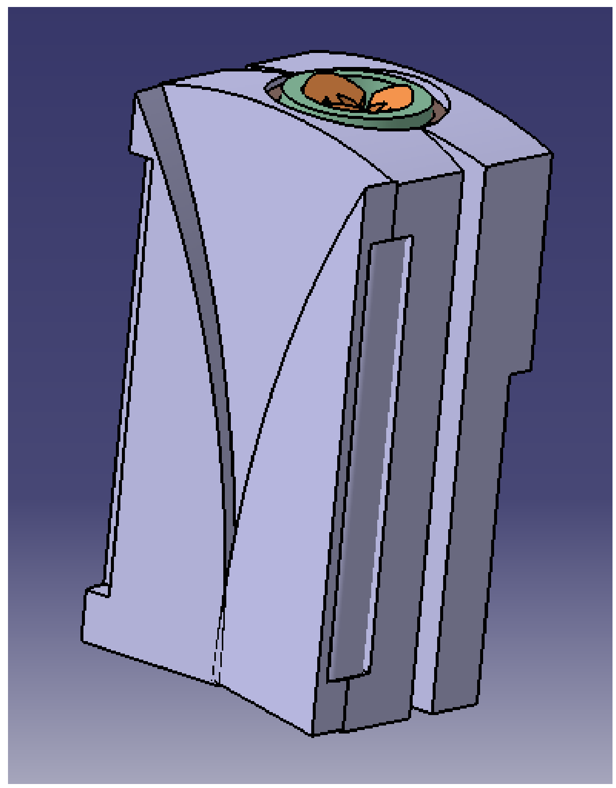


Fig. 6 Compacted Seat

IV. Failure Analysis

The stool will be subjected to various kinds of stresses when the distributed load of a person sitting on it is applied. The stool was designed to be able to withstand an ultimate load of

337 lb. (1500N) while restricting the maximum allowable weight to 300 lb. (1334.47 N) to maintain a margin of safety.
The three main rods will experience mainly shear stress and normal stress at the groove's cross section where the part locks when assembled. To calculate for the shear stress, we used the shear stress formula:

$\tau = (V*Q)/(I*t)$

τ – Shear Stress [Pa]
V – Shear Force [N]
Q – First Moment of Area [m^3]
I – Moment of Inertia [m^4]
t – Thickness of material perpendicular to shear [m]

To calculate for Normal Stress, we used the Normal Stress Formula

$\sigma = (P/A)$

σ – Normal Stress [Pa]
P – Axial Force [N]
A – Cross Sectional Area [m^2]

The three legs will experience bending stress and normal stress, since they are each at an angle of 40 degrees the force component parallel to the legs will generate a normal stress and the component of the force normal to the legs will generate bending stress. For bending stress analysis, we first need to calculate the moment at the hinge that the normal force creates, using the moment formula

$M = F*r$

M – Moment [N-m]
F – Normal Force [N]
r – Distance from hinge to pivot [m]

Finally, we calculate the bending stress using the bending stress formula

$\sigma_B = (M*c)/I$

σ_B – Bending Stress [Pa]
M – Moment [N-m]
c – Perpendicular Distance to Neutral Axis [m]
I - Moment of Inertia about the neutral axis [m^4]

As mentioned before, the legs have a cross sectional area that can withstand more bending stress (See Fig. 5)

V. Simulation Testing

The support and the seat parts were assembled in the CATIA V5 workbench and were then treated as a single part in the generative structural analysis workbench, which is a Finite Element Analysis tool (FEA).

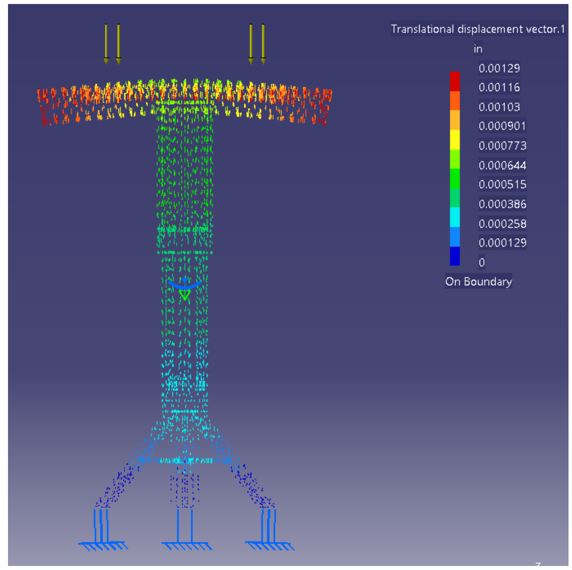


Fig. 7 Maximum Displacement of seat in side view

The structure was also assumed to be made of aluminum in the simulation, due to the desirable quality of being relatively lightweight and strong. The support legs were clamped to a fixed position and a distributive force of 1500N was added to the entire top portion of the seat. As shown in Fig. 7 and Fig. 8 the analysis found that the maximum Von Mises stress was found to be 4.15 MPa and the maximum displacement in the seat was 0.0327 mm, respectively. The stress and displacement values found were indicative a successful design so far.

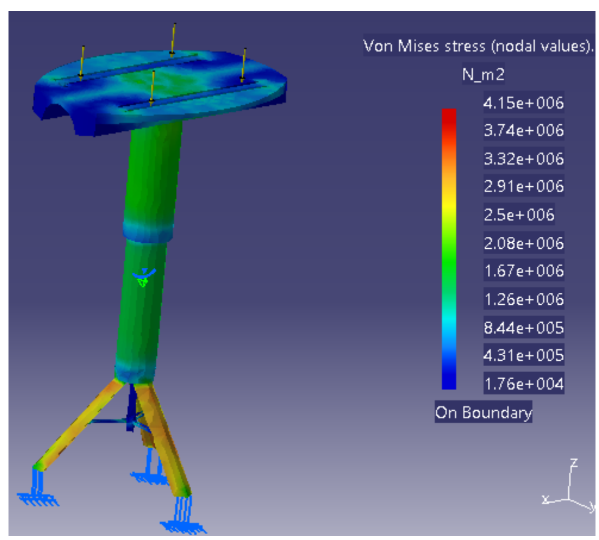


Fig. 8 Von Mises Stress FEA analysis of seat

VI. Conclusion

The compactable stool design, is a feasible structure that can withstand the weight of a person sitting on it. Although we must continue testing this structure, we are sure that it can be built and enjoyed by a large variety of consumers. We will continue to develop our design and proceed to a manufacturing phase where we can develop our first prototype.

ACKNOWLEDGMENT

We would like to thank Dr. Y. Budhoo, Professor at Vaughn College, for guiding us through this project and sharing his knowledge of mechanics and CATIA.

REFERENCES

[1] National Center for Health Statistics. (2017, May 03). Retrieved March 20, 2018, from https://www.cdc.gov/nchs/fastats/body-measurements.htm