Two-Step Hub Mechanism for Solid Reflector Deployment

Final Design Package

EML 4551C – Senior Design – Fall 2011 Final Deliverable

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Table of Contents

Introduction

Background

Since the beginning of telecommunications, it has been a priority to develop better, more transportable reflectors. Reflectors that focus electromagnetic energy are used in applications such as radio-frequency (RF) antennae, solar collectors, cameras, and other optical devices. The reflectors used in these applications are typically shaped to focus electromagnetic energy at a particular point or area. In the case of an antenna feed mounted on or proximate to the reflector, the reflector is shaped to have a parabolic surface to focus the electromagnetic energy in a particular direction.

In the past, reflectors have been divided into two material categories: solid and mesh. Rigid solid reflectors usually allow for a higher performance than mesh reflectors because the mesh material generally experiences a loss in the focused electromagnetic energy due to decreased rigidity. For this reason, solid reflectors are more efficient in the fact that a majority of the electromagnetic energy is absorbed and stored rather than deflected or attenuated. Throughout the production and deployment process, the mesh of a mesh reflector requires an extensive amount of human interaction in order to maintain correct positioning. This is because a reflectors require a surface roughness deviation from an ideal surface profile of less than 0.010-inch. Although these required adjustments can be carried, it is sometimes very difficult to achieve them with the needed precision. In addition, the mesh reflector cannot be used to focus high-frequency RF signals such as Ka and Ku-band transmissions. For this reason, solid reflectors are more commonly used in space application.

The solid reflectors generally perform better than a similarly sized mesh reflector, but the mesh reflectors can be easily folded for efficient transportation. If an application demands that the reflector be easily folded for storage, performance expectations and specifications are lowered. The reason mesh reflectors are used, however, is because they are very dynamic in their ability to be stored. Mesh reflectors can be folded into a compact configuration, allowing them to be stowed in relatively small areas. A solid reflector cannot typically be stowed in a folded configuration, resulting in a larger ratio of stowed-to-deployed volume. In applications that are space-based, the sizes of the fairings in which the reflectors are stowed prior to deployment are limited in size. As a result, the reflectors used in space-based applications or any airborne or mobile applications are normally mesh reflectors. In completing this project, it is our goal to prove that, although solid reflectors lack in space-saving, they make up for in performance, efficiency, and automaticity.

Motivation

The optimal and ideal reflector would be one that combines the high performance capability and automaticity of a solid reflector with efficiency of transportation of a mesh reflector. Thus, the solution lies in a deployable solid reflector that will create a balance between these characteristics. Since this type of solid reflector has not been designed before, it is our job to prove that it is possible. In the final stage of this project, our hub mechanism will deploy, retract, and interlock six solid reflector panels. It is also desired that our design ultimately increases the performance, decreases the amount of potential maintenance, and increases the transportation efficiency as compared to other solid or mesh reflectors deployment systems.

Problem Statement

The challenge of this project is to develop a two-step hub mechanism for Harris Corporation that allows for the deployment and retraction of six segmented solid reflector panels. This involves creating a 3D CAD model, along with a dynamic simulation, of the deployment process to better understand the motion of the system.

Objective

The goal of this project is to design the hub deployment mechanism for a solid reflector that proves its functionality. This entails creating a CAD model, complete with kinematic and dynamic analysis, and constructing a working scaled prototype. The final prototype should demonstrate the mechanism's functionality by deploying and retracting into the same plane surface six solid reflectors. The prototype reflector system is to be comprised of a reflector formed from rigid panels mounted on a centrally-located hub. The panels must be able to be stowed in a relatively compact arrangement in which the panels overlap. The panels are to be configured to translate with a combination of rotational and linear motion so that the panels become disposed in a side by side relationship. While our team is responsible for the hub mechanism that will accomplish these motions, we must work together with the panel team to ensure that our motion will allow for their locking mechanisms to triumph.

Our sponsor, Harris Corporation, has provided a very basic, preliminary design for the hub that we are to update and edit as we see fit. Pro/ENGINEER CAD drawings of this beginning design have been created so that our team can produce a 3-D dynamic simulation of the prototype hub mechanism we create. Along with a preliminary CAD drawing, we have been given all the patent documents relating to this project. The patent outlines the functionality requirements we are to meet in designing a hub deployment mechanism. Preliminary drawings of a basic hub deployment mechanism were provided along with the patent.

Methodology

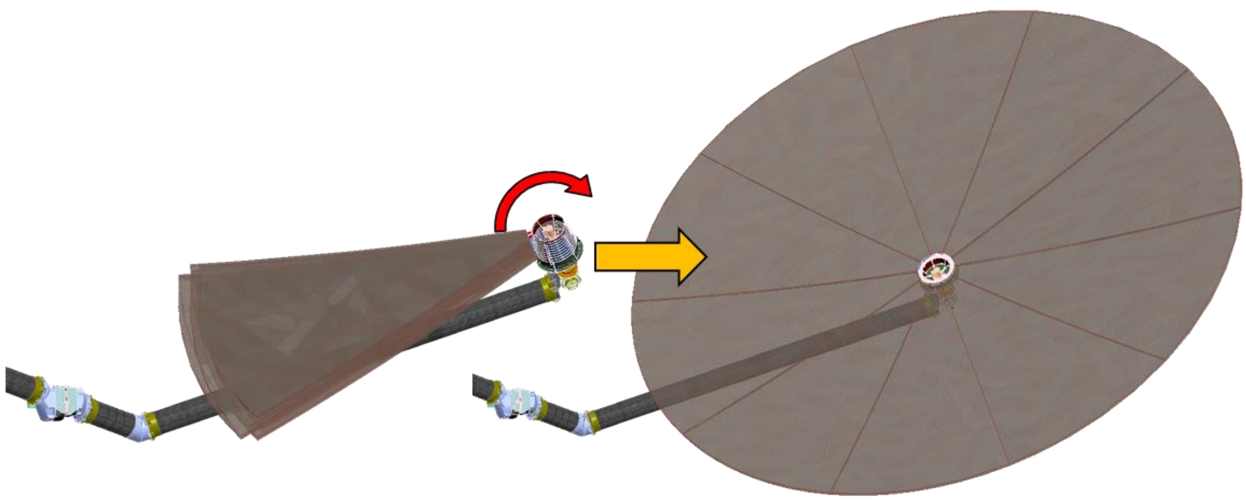


Figure 1: Conceptual Visualization of Project (Provided by Harris Corporation)

The first task was to read and understand all preliminary information received from Harris Corporation and to research existing and previous hub deployment designs. This not only allowed for additional understanding of previous designs, but also ensured that the new design was unique and will withstand testing that caused previous designs to fail. This research revealed to us important parameters that needed to be considered while in the construction stage. Harris Corporation provided detailed drawings, videos, and explanations of past designs (figure 1); therefore, it was our duty to take them, refine them, and turn them into a tangible, working hub deployment mechanism.

After extensive research, we brainstormed many ideas of how to (1) deploy all reflective panels with respect to one another and (2) to pull the panels axially to interlock them to one another in order to form a solid parabolic surface. Since these two tasks could be achieved using many different procedures, it was important to choose a design that could be easily implemented and was not too bulky since size and geometry are important. The chosen design needed to include all desired measurements and had to implement all limiting factors and important parameters in order to ensure avoidance of possible modes of failure. After the design was optimized and refined, materials had to be chosen for each component of the hub. Parameters that needed to be considered included, but were not limited to, robustness, mechanical strength and durability, thermal stability, and cost of materials used.

Following selection of optimal design and materials, CAD drawings of all parts were produced in Pro/ENGINEER. Existing drawings were edited as needed. A 3-D model of the hub mechanism was also produced within Pro/ENGINEER so that a working, moving hub could be seen virtually. This allowed us to get an idea of how each component of the hub deployment mechanism moved. Since the interface between the hub deployment mechanism and the interlocking panels was important, it was important to have a 3-D model of the whole system to ensure that there were no problems between the two.

After the CAD drawings were completed, we began looking into the construction for the components of the hub deployment mechanism. Since a full-sized deployable solid reflector can span up to 30 feet in diameter, a much smaller prototype will be built for the purposes of this project. The parts will either be machined in local shops or bought from online sources. A thorough and complete cost analysis will be kept to ensure that all expenses are kept within budget. During this stage, it is important to keep in touch with Team 6 (the interlocking panel team) in order to ensure that the two systems will work together properly.

The last stage in this project will be to test our hub deployment mechanism. This will be done by first attaching the interlocking panels Team 6 will construct then analyzing the deployment and retracting process. If the system is in working order and is problem free, then the project is complete.

Constraints

There are several constraints to consider while constructing the hub deployment mechanism. In no particular order, below is a summary of such constraints:

- There is a $2,500 budget
- Since a full-size, working solid reflector will be modeled after the prototype built for this project, there are numerous material constraints that need to be considered
    - Some materials cannot take the extreme temperatures imposed in outer space
    - A material needs to be selected so that the stresses imposed by the panels do not cause the rings to bind (titanium would most likely be used in a real application but is out of our budget in making the prototype)
- This hub deployment mechanism should be designed so that it can be used in space and on the ground for the purposes of communication
- Size constraints have been set in place (4 inch maximum diameter for the hub mechanism)
- The hub should be constructed mainly of concentric rings each having a mounted panel
- Panel alignment is important
- Design needs to restrict or eliminate panel-to-panel contact as to reduce friction
- The motor and all parts must be below the deployed panels as to not interrupt the signal

Design and Analysis

Customer Needs versus Engineering Specifications

A Quality Function Deployment Chart was created to relate customer needs to engineering specifications. Harris Corporation stressed the need for our hub deployment mechanism to maintain panel alignment, to rotate the panels into position, to retract the panels into the same surface plane, to be reliable, and to contain redundancies. The customer wanted to hub mechanism to deploy the panels from the stowed position then retract them into the same plane surface. In order to ensure that these needs were met, material strength, motor/ driver setup, panel interface, motion synchronization, and retraction methods are important needed to be considered as engineering specifications.

QFD		Engineering Specifications				
		Material Strength	Motor/Driver Setup	Panel Interface	Motion Syncronization	Retraction Method
Customer Needs	Maintain Panel Alignment			X		X
	Rotate the Panels into Position	X	X	X	X	X
	Retract the Panels into Same Surface Plane		X			X
	Contain Redundancies	X	X			X
	Reliable	X	X		X	X

Figure 2: Quality Function Deployment chart relating customer needs to engineering specifications

Decision Matrix

Decision Matrix		Concepts					
		Synchronized Two Step Deployment		Spring Implementation		Guide Slots	
Specification	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Reliability	0.400	4.000	1.600	3.000	1.200	4.000	1.600
Durability	0.050	4.000	0.200	2.000	0.100	4.000	0.200
Weight	0.100	3.000	0.300	3.500	0.350	4.000	0.400
Efficiency	0.200	5.000	1.000	4.000	0.800	3.000	0.600
Ease of Construction	0.150	2.000	0.300	3.000	0.450	2.500	0.375
Cost	0.100	3.000	0.300	3.500	0.350	4.000	0.400
Total	1.000	3.700		3.250		3.575	

Ratings: 1 (worst) to 5 (best)

Figure 3: Decision Matrix

Each concept we constructed satisfies the costumer's main requirement that the hub mechanism must rotate the solid reflector panels into position and retract them into the same surface plane. We came up with additional concepts as well but were told by our project sponsor that they would not achieve the desired motions. Based on our current views of our concepts, we have come up with a decision matrix that rates each concept based on theoretical workability. We weighted the importance of the concept specifications based on our views as well as the views of our sponsor at Harris Corporation.

The reliability of our hub mechanism is the most important specification because the mechanism will be deployed in space. If the hub mechanism does not deploy correctly or if the rings bind during deployment, there is no way to recover the device to fix or maintain the hub. Our synchronized two step deployment design along with the guide slots design were determined to be the most reliable. They both depend on only one motor to perform the rotational and/or linear motion needed to fully deploy the panels. Harris Corporation has a motor that they traditionally use for space application that has been tested and used multiple times in space, and thus has been deemed extremely reliable. Unfortunately for this project, we will be unable to use the motors they traditionally use due to our cost constraint. We concluded that, as long as the selected motor has a high torque and low speed, it will be reliable enough achieve the main goal of the project. Although it also uses only one motor, the spring implementation concept is slightly less reliable. The spring located at the center of the hub has the potential of being knocked out of place during the turbulent ride into space. Also, since only one spring would be used, the downward force applied by the spring to retract the panels into place would decrease as the panels are deployed. There is a possibility that the spring would not impose enough retracting force to fully pull the panels into the same surface plane. If this happened, the main goal of the hub deployment mechanism would not be achieved.

The durability of the hub mechanism is less important since it only needs to deploy the solid reflector panels once. The concept implementing a spring to retract the rotated panel rings was rated below the concepts of a synchronizer two step deployment and guide slots because it involves a spring that can be jarred loose during ascent. The robustness and rigidity of the guide slots and the synchronized two step deployment helped in the durability rating. In both of these concepts, there should be very little linear movement of the panels once they are in the deployed position; on the other hand, the spring implementation concept would not fully restrict linear panel motion.

The weight of our hub mechanism is not as important because each of the concepts should weigh about the same. Since a full scale model will ultimately be deployed into space, weight is not our main concern. According to Team 6 (the interlocking panel team), the weight of the panels are being kept as low as possible; therefore, the majority of the weight will come from the weight of the hub. This has been taken into consideration, and lightweight, strong materials such as aluminum and various types of steel are being evaluated and analyzed.

Efficiency of the hub mechanism is important as it is closely related to the reliability of the system. Ideally, an efficient mechanism will be created as to reduce the strain on the motor and to reduce friction imposed by the rotation of the rings. A low speed, high torque motor should be the most efficient option. In order to reduce friction imposed by rotation of the rings, bearings or lubricant in-between each ring might be essential. A layer of sprayed on Teflon is also being considered.

We thought that ease of construction would be important because of our time constraints in prototype production. The concept using the synchronized two step deployment would be the easiest to produce because it requires less machining as compared to the other concepts. For the synchronized two step deployment concept, straight vertical slots will be machined into the rings while angled slots will be machined for the guide slot concept. Machining angled slots will be much more difficult, especially since they need to be angled and placed in precise predetermined spots along the rings with very little tolerance for error.

The cost of the hub mechanism is important since we have been given a budget. The concept using a spring to retract the hub would be cost effective because it will not require extra machining and bearings. The guide slot concept would be least expensive because it does not require the purchasing of a ball screw or a spring. The two step deployment concept was found to be the most expensive because of the addition of a ball screw and a synchronizer.

Actuator Control Analysis

The device we have chosen to power the motions of the hub mechanism is a dual motion actuator. Haydon Kerk, a company that has many products for motion solutions, makes a line of dual motion actuators that provide independent linear and rotary motion. Using a dual motion actuator to accomplish our desired motions is more efficient than using a motor and a ball screw with a synchronizer. Instead of machining many different parts and having a bulky design, the dual motion actuator is a more compact unit that simplifies our design. The actuator has a stepper motor built in that will power the rotational motion. Once the rotational motion is complete, the stepper motor turns to powering the linear motion to pull the rings, and consequently the panels, of the mechanism into place.

Haydon Kerk’s dual motion actuators are available in varying sizes and performance. For our hub mechanism, we will be using the series 43000 dual motion actuator. The actuator can be fitted with an L/R drive (L/R stands for the relationship of inductance to resistance) or a chopper drive. We will be using a chopper drive as it allows the stepper motor to maintain greater torque than the L/R drive.

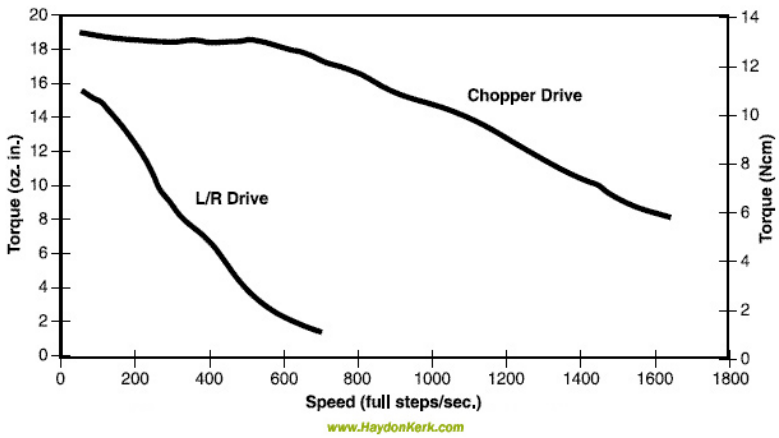
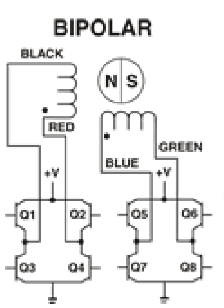


Figure 4: Performance Curve - Speed vs. Torque

Equipped with the chopper drive, the size 17 dual motion actuator can achieve 55 pounds of thrust and a torque of about 19 oz. in. (about 1.19 lb. in.) at low speeds (figure 4). The chopper drive is a constant current drive that gets its name because of the way it rapidly turns the output power on and off to control the motor current. The chopper drive uses a two phase stepper sequence known as bipolar winding. Bipolar winding works by reversing the current in the windings, which reverses the electromagnetic polarity. The electrical schematic diagram and stepping sequence of a bipolar winding stepper motor (figure 5) shows that switching reverses the current flow through the winding which causes the phase polarity to change.



CW Rotation ↓	BipolarStep	Q2-Q3	Q1-Q4	Q6-Q7	Q5-Q8	CCW Rotation ↑
	1	ON	OFF	ON	OFF	
	2	OFF	ON	ON	OFF	
	3	OFF	ON	OFF	ON	
	4	ON	OFF	OFF	ON	
	1	ON	OFF	ON	OFF	

Figure 5: Electrical Schematic Diagram and Stepping Sequence

The dual motion actuator comes in 3, 5, and 12 volt models. To deliver the greatest performance by using the chopper drive, the ratio of the supply voltage rating compared to the motor voltage needs to be at least five to one. Since our dual axis controller can have a voltage up to 35 volts, we have decided to go with a 5 volt motor in the actuator. This makes the ratio seven to one which is close to the ideal ratio of eight to one.

The series 4300 dual motion actuator comes in standard stroke sizes of ½, 1, 2, and 4 inches. Because our hub mechanism consists of six rings, five rings need to be linearly retracted into the same plane as the bottom ring. Each ring has a height of 0.75 inches which means we need a stroke of at least 3.75 inches. Therefore, the actuator that we purchase will have a stroke of 4 inches.

Controlling the actuator can be done using a standard two axis stepper motor driver.

Dual Axis Stepper Motor Driver

To control the motions of the actuator, a standard two-axis stepper motor driver is needed. This allows the independent control of the rotary and linear motions that need to be accomplished. We selected the 2035XD (figure 6) from Applied Motion Products. It is a DC dual-axis step motor driver that can operate as a full, half, or microstep drive. The drive controls the step and direction of the stepper motor and has an oscillator mode, which allows for velocity control of the motor.

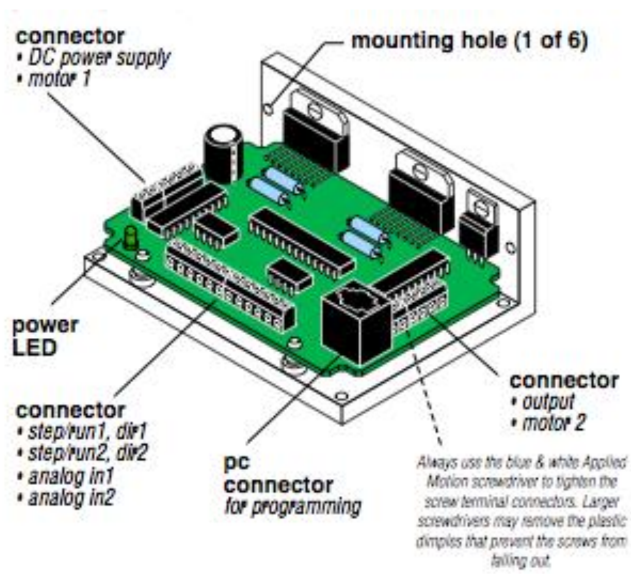


Figure 6: 2035XD - Two Axis Step Motor Drive

The controller allows for a power supply of 12-35 volt DC power to be attached. We will be attaching the maximum 35 volts so that our actuator can achieve the greatest amount of torque. The 2035XD provides constant current to the actuator's motor, which also enhances performance. The drive is equipped with idle current reduction so that the stepper motor in the actuator doesn't burn out when not providing motion.

The drive comes with eXposition software to program the drive. By using the software, we will be able to program the drive so that the actuator's linear and rotary motions are accomplished independently and sequentially.

The motor control has 15 different step resolutions ranging from 200-50800 steps/revolution. These step resolutions include full,half, and 13 microstep resolutions and can be set using the included software. The precision of the control drive can be increased by using microstepping which will have a higher end step resolution.

Numerical Analysis

ProEngineer was used to create a kinematic simulation of the deployment process. Through this analysis, the desired two step motion was achieved and there proved to be no frictional or collisional problems with the rings or panels. A build-in feature of ProE, called Mechanica, was used to conduct a finite element analysis on the rings of the hub. It was determined that the maximum possible panel weight was 5lbs. While this may not seem particularly heavy, when combined with the length of the panels it results in a high bending moment at the connection tab. This was used to calculate an equivalent loading of 346 N. This was applied to the base ring and the top ring. These are the largest and smallest rings at 4" and 2.75" in diameter respectively.

The primary concern is the stresses in the top ring as it has the longest panel mounting tab. It was determined that the stresses due to panel weight on the base ring were 19,520 psi and the stresses on the top ring were as high as 28,430 psi. However, these peak values were limited to corners and other areas of high stress concentration. The rest of the structure did not see anything greater than 10,000 psi.

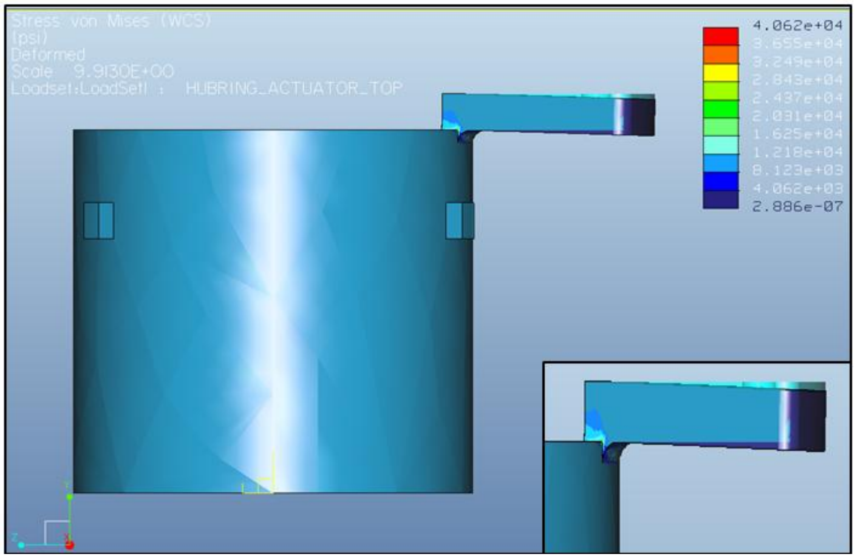


Figure 7: Deformation of Top Ring

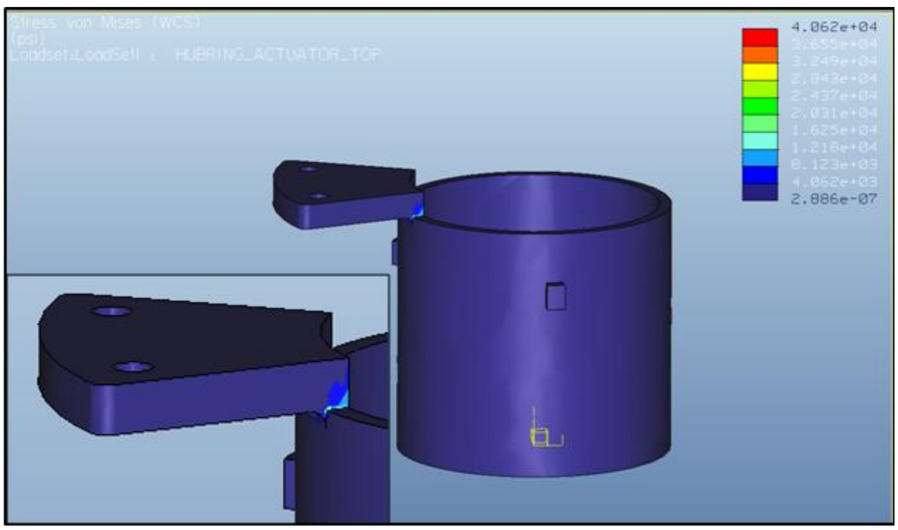


Figure 8: Stress distribution of Top Ring

Figures 7 & 8 are the results of the finite element analysis of the top ring. Figure 8 shows the areas where the stresses are concentrated. In Figure 6, the lower-right corner image shows the deflection of the connector tab. Although it looks like a substantial amount of deformation, it is all elastic and will not cause permanent deformation. Any permanent deformation would alter the panel alignment and would be considered a failure

Figures 9 & 10 detail the base ring. The stresses were much lower in this ring due to the larger diameter and shorter tab length. Similarly to the top ring in Figure 7, there is some deformation, but it remains in the elastic region so there will be no permanent deformation. An alteration to the design of the ring that resulted from this analysis was the addition of a fillet to tab-ring intersection underneath the tab as seen in Figure 10. This was added because this area previously had high stress concentrations. This simple addition greatly reduced the peak stresses seen in the component.

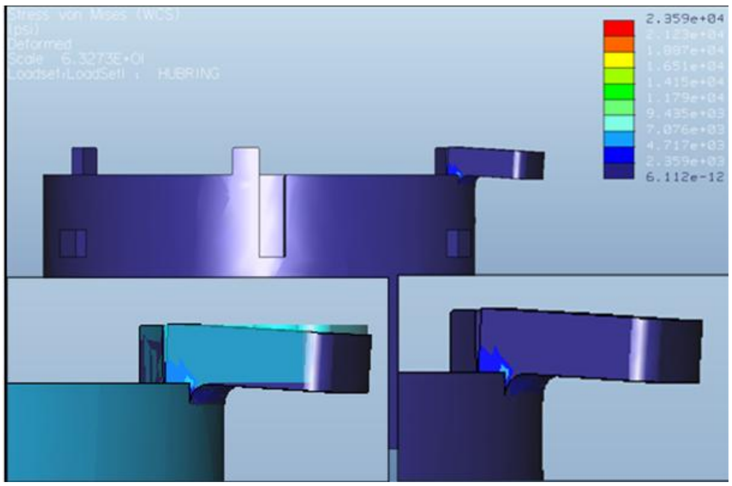


Figure 9: Deformation of Base Ring

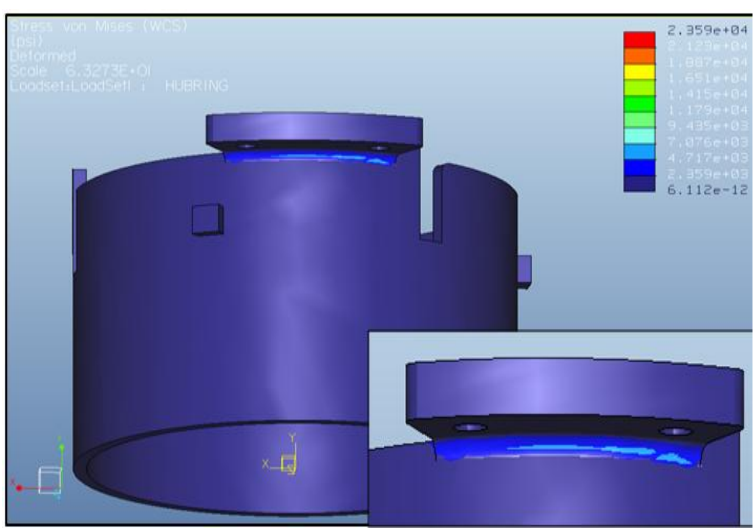


Figure 10: Stress Distribution of Base Ring

Material Selection

The material choice for this project is key to its success. If Harris were to build a full scale, orbit ready version of this mechanism, the clear choice is Titanium with its high strength to weight ratio. However, Titanium is not a feasible option with our budget, so for our application we will be primarily interested in one that can sustain the loading and facilitate the motion. We want to keep it as lightweight at possible, but it is a secondary requirement.

There were several key factors that determined what material would be used to construct the hub. The first concern was strength. We need a material that is sufficiently within the elastic region with the given loading. Since the stresses did not appear to go any higher than 30,000 psi, the natural first choices where high strength aluminum. Aluminum fits the strength requirements but the hardness was a concern. Due to the offset load of the panels, we were concerned with the possibility of galling and high friction levels. Both of which could result in binding or mechanism failure. The solution to this problem is anodizing. Anodizing is a treatment that creates a hard protective layer of Aluminum Oxide on the surface of Aluminum. It greatly increases the surface hardness and wear resistance. Stainless steel has a hardness of 170 on the Brinell scale while hard anodized aluminum can be as high as 360 on the Brinell scale. In addition, Teflon can be impregnated into the surface to greatly increase the lubricity of the material. There are several kinds of anodizing to consider. They are generally described as types I, II, & III as defined by MIL-A-63576A & MIL-A-8625F. The type we would use is type III, this is also known as hard anodizing. It produces a much thicker layer of Aluminum Oxide than that of type I or II. MIL-A-63576A states that hard anodized, Teflon infused should have a coefficient of friction between 0.16-0.20. This is significantly lower than that of raw aluminum at 1.05-1.35. This exceptionally low coefficient of friction will combined with the high surface hardness will greatly reduce the chance of binding or jamming. The anodizing process does add some thickness to the base material which can change some dimensions, but they are held to tight tolerances and can easily be accounted for when machining the parts.

Various steel alloys are viable and potentially cheaper alternatives, but it was decided that hard anodized, Teflon infused, AL 2024 is the best material for the construction on the hub. It is lightweight, has high surface hardness and wear resistance, has a low coefficient of friction, and is readily available and easy to machine.

ProEngineer Flow of Motion

The following flow chart depicts the motion our design. As you can see from the following picturtes, the panels, which are initially in the stowed position, will first deploy and then retract into the same surface plane. This two-step motion corresponds to one of the customer needs as outlined in the "Customer Needs vs Engineering Specifications" section. Deploying the panels, then retracting them into the same plane surface ensures that the panels will not collide during deployment. This is important, since collision of the panels could result in permanent damage to the panels and to the hub mechanism

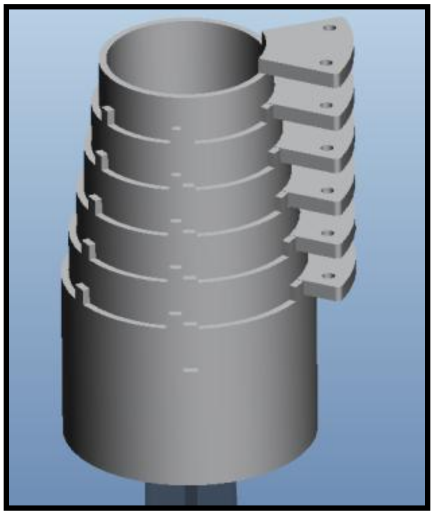


Figure 11 : Stowed position

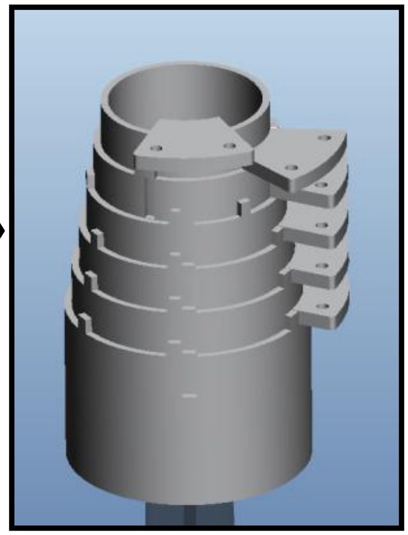


Figure 12: One Panel Deployed

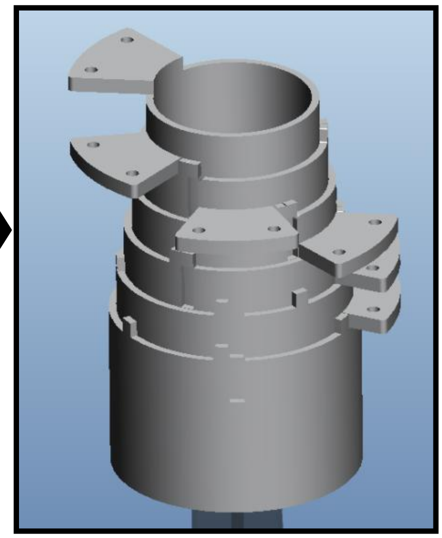


Figure 13 : Four Panels Deployed

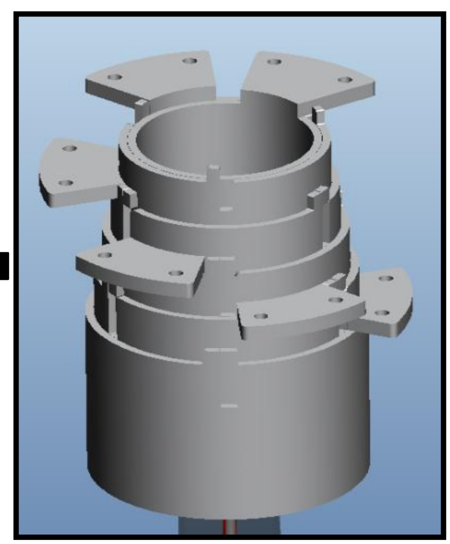


Figure 14 : All Panels Deployed

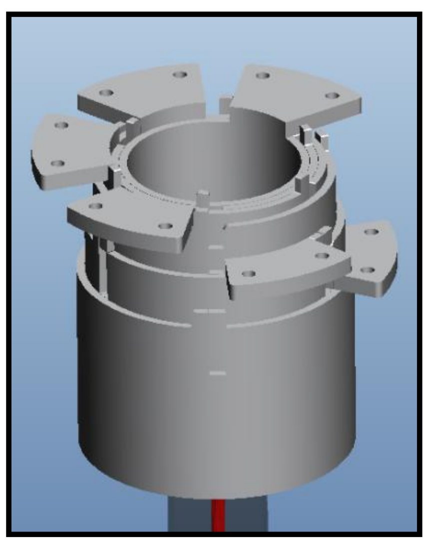


Figure 15 : Four Panels Retracted

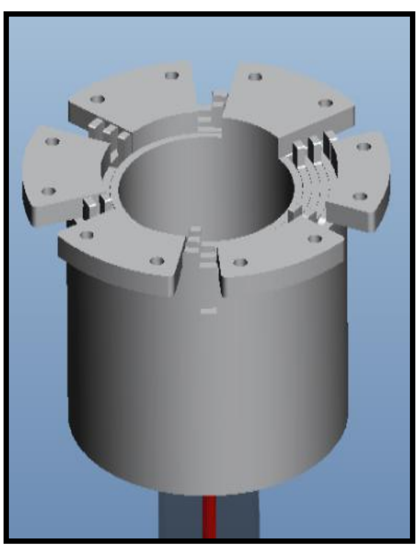


Figure 16 : All Panels Retracted

Connection Tab/Panel Interface

We have worked extensively with the Interlocking Panel Team (Team 6) to construct an interface between the rings and the panels. After brainstorming different ways to do so, a simple pie-shaped connection tab was designed so that the panels could easily be bolted to the rings. Since the two holes in the connection tabs are threaded, bolts and nuts can be used to secure the panels to the rings. Between each connection tab is ½ an inch; each tab is 1/4 inches thick. This allows each panel to have approximately ¾ of an inch to fit comfortably. Since the panels are not this thick, there is plenty of clearance for the panels to deploy without colliding.

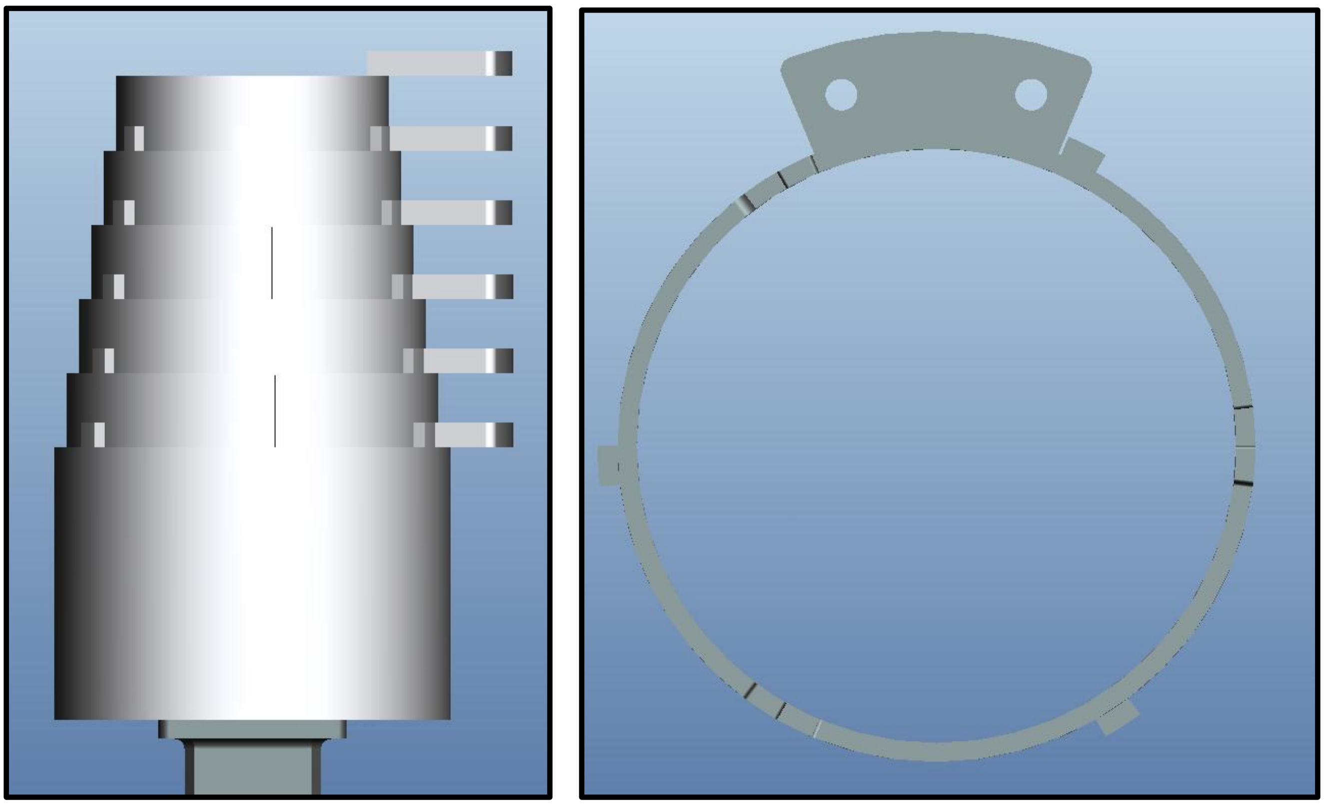


Figure 17 and 18: Hub Rings 1

Bill of Materials & Cost Analysis

Our allotted budget for our project is $2500. We have decided to purchase a 1 foot, 4.5 inch diameter solid rod of high strength aluminum 2024. The rod will be cut into four sections of length 3 inches each. A water-jet will be used to extrude out the rings from the rod. The sections we use to extrude out the largest two rings will also be re-used to extrude the smallest two rings. This will save us money in material costs. We will also be purchasing a 3 foot rectangular bar of high strength aluminum 2024. The bar will be 3/16 inch thick and 1/2 inch wide. This bar will be used to connect the top ring to the actuator. The final material we will be ordering is a 1 foot rectangular bar of high strength aluminum 2024 that will be 1/4 inch thick and 1 ¼ inch wide. This rectangular bar will be cut up and used to create the tabs that the panels will attach to. We will be buying all of our material from McMaster Carr.

We have decided to have the aluminum parts hard anodized with a Teflon coating. Based on our research of pricing, we have come up with a best estimate of $200.00. If it does cost more than our estimate, we have plenty of room in our budget. There are various vendors that we can send our parts to for them to anodize them.

The actuator will be purchased from Haydon Kerk, a motion control company. In order to control the actuator, we need to also purchase a two-axis step motor control. We have decided upon the 2035XD two-axis step motor drive by Applied Motion Products.

We will be machining the rings in the FSU machine shop. There is no cost involved with this; however we have come up with an estimate of the man hours required. We are estimating that each ring will take roughly 3 hours to machine. Because we have 6 rings, we are estimating about 18 man hours of machining.

The total cost estimate is $1024.02. Since our budget is $2500, we are currently $1475.98 underbudget.

Cost Analysis				
	Quantity	**Cost/Unit**	**Total Cost**	**Place of Purchase**
High Strength Aluminum 2024	1 - [1 ft rod (4.5" diameter)]	229.65	229.65	Mcmaster
High Strength Aluminum 2024	1 - [3/16" thick, 1/2" wide rectangular bars (3 feet)]	14.19	14.19	Mcmaster
High Strength Aluminum 2024	1 - [1/4" thick, 1 1/4" wide recatangular bars (1 ft)]	14.18	14.18	Mcmaster
Hard Anodizing with Teflon Coating	All aluminum parts	200.00*	200.00*	various
Actuator	43000 Series (Size 17) Dual Motion : 4 inch stroke	297.00	297.00	haydon kerk
Acutator Control	1- [2035XD Dual Axis Drive]	269.00	269.00	Applied Motion Products
Machining Costs	3 hours/ring with 6 rings	18 hours	18 hours	FSU machine shop
Total ($)			**$1,024.02**	

Figure 19: Cost Analysis

Conclusion

After completing all analysis of the rings and determining the amount of stresses imposed on the rings due to the panels, it was concluded that we have selected the correct material for our rings. The yield stress of the Aluminum 2024 is far greater than the stresses imposed on the rings, which means that deformation of the connection tabs will not be an issue. Although the exact weight of the panels is still unknown, the 5lb value that was used in the finite element analysis is still considered to be an extreme. The key characteristics of our design include the ring design, ring material, and the actuator and actuator control. It is certain that the combination of these characteristics will work together to ensure that our design succeeds in proving the functionality of the two step hub mechanism.

The final process, using a two-step deployment of rotary followed by linear motion, will be integral in ensuring that the panels do not collide or rub together during deployment. This motion corresponds to the customer needs, and relates to our engineering specifications for a reliable model. Because the motions will need to work with the panel curvatures, we will be working extensively with team 6 when programming the actuator's motions.

Our next step moving forward will be to order all the parts and materials. We will then be able to machine the rings and construct a prototype to begin testing.

Health and Safety

It is important to always consider health and safety issues when dealing with any kind of mechanical device. Our final design (the synchronized two step deployment concept) has multiple moving parts, thus has the potential to harm a human being. For ground application, it is advised that no individual stands in the way of the panels as they are deploying. Although the panels will not be moving at a high velocity, an individual standing in the panel deploying circumference could get cut by the panel's reinforced aluminum edge. It is also possible that they disrupt the motion of the panels. In space application, the hub mechanism will operate completely autonomously; therefore, there will be a low risk of injury.

This was found in relation to anodized aluminum:

> "Environment, health and safety - Anodizing is favorable towards current governmental regulations because it is one of the most environmentally friendly industrial processes and is typically not harmful to human health. An anodized finish is chemically stable, will not decompose, is nontoxic, and is heat-resistant to the melting point of aluminum. Since the anodizing process is a reinforcement of a naturally occurring oxide process, it is non-hazardous and produces no harmful or dangerous by-products. Chemical baths used in the anodizing process often are reclaimed, recycled, and reused."

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Appendices

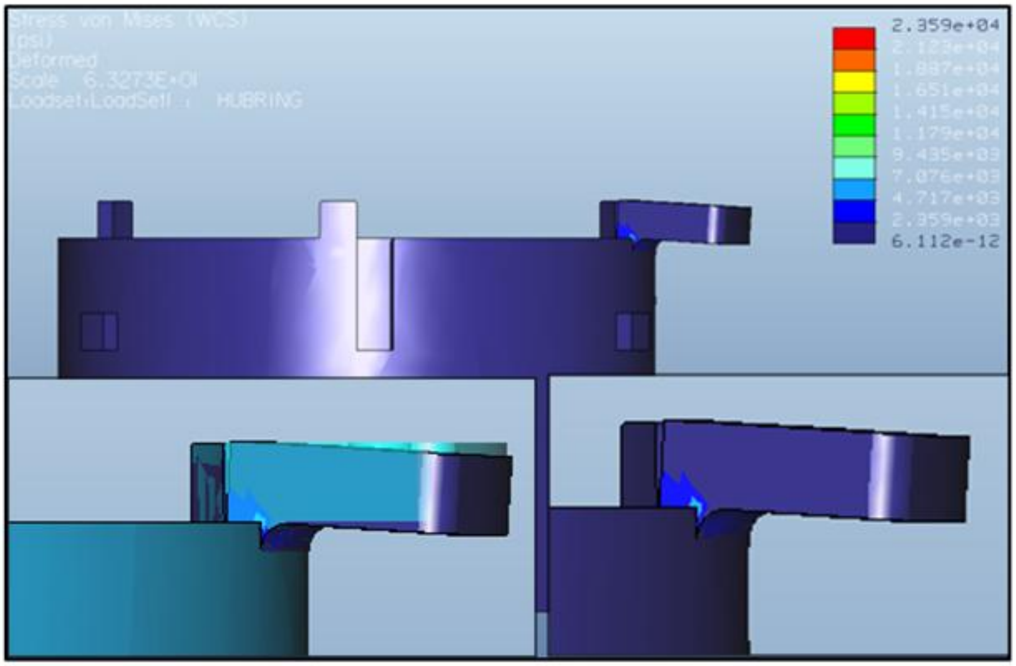

Figure 20: Bottom most ring

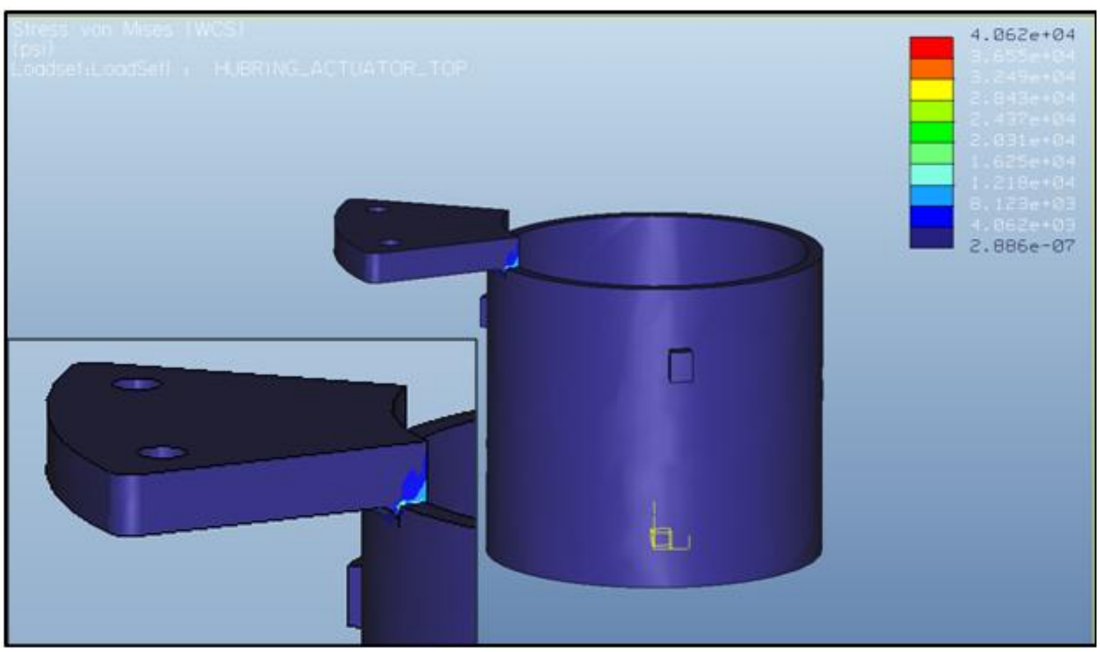

Figure 21: top most ring

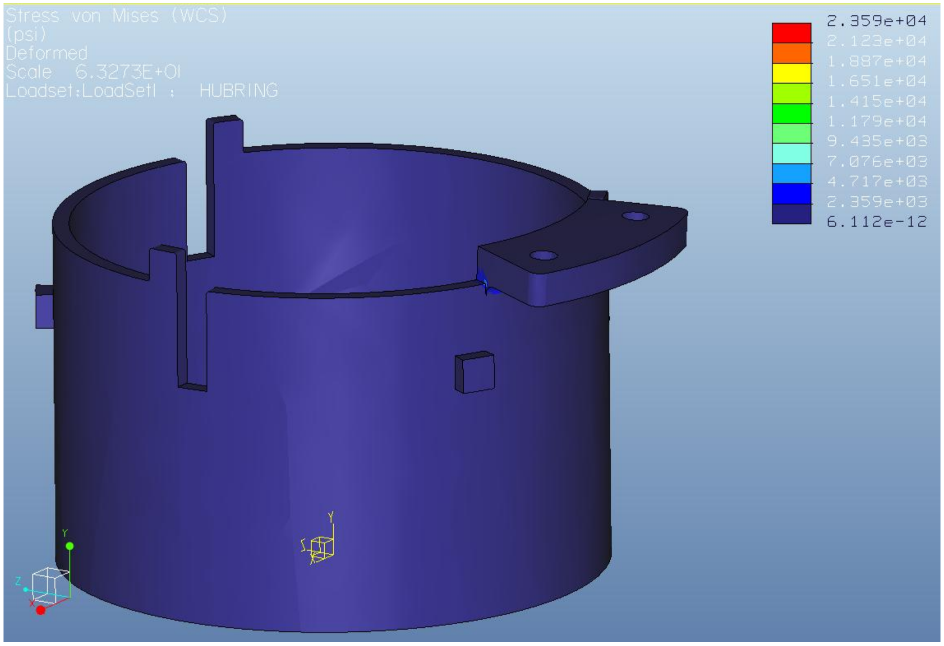

Figure 22 : Bottom most ring

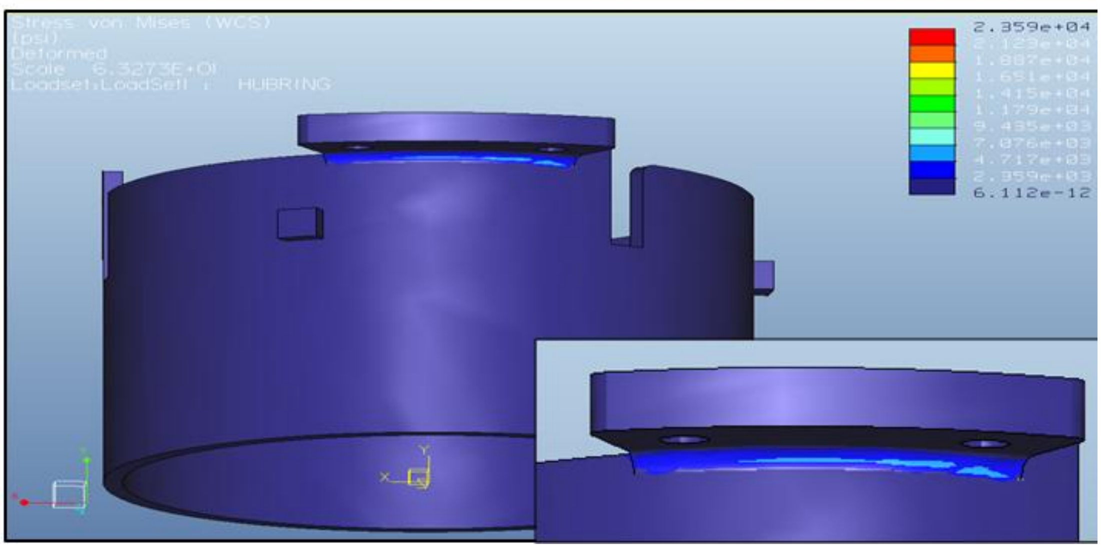

Figure 23: Middle ring

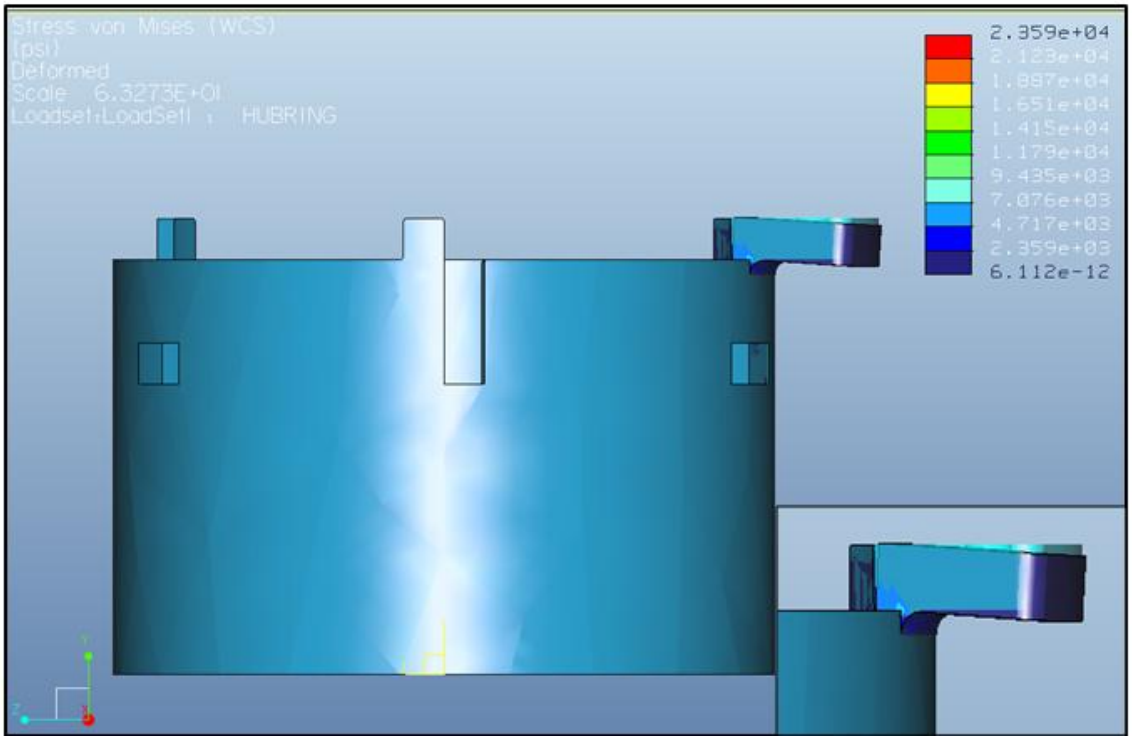

Figure 24 : Deformation of the base ring connection tab

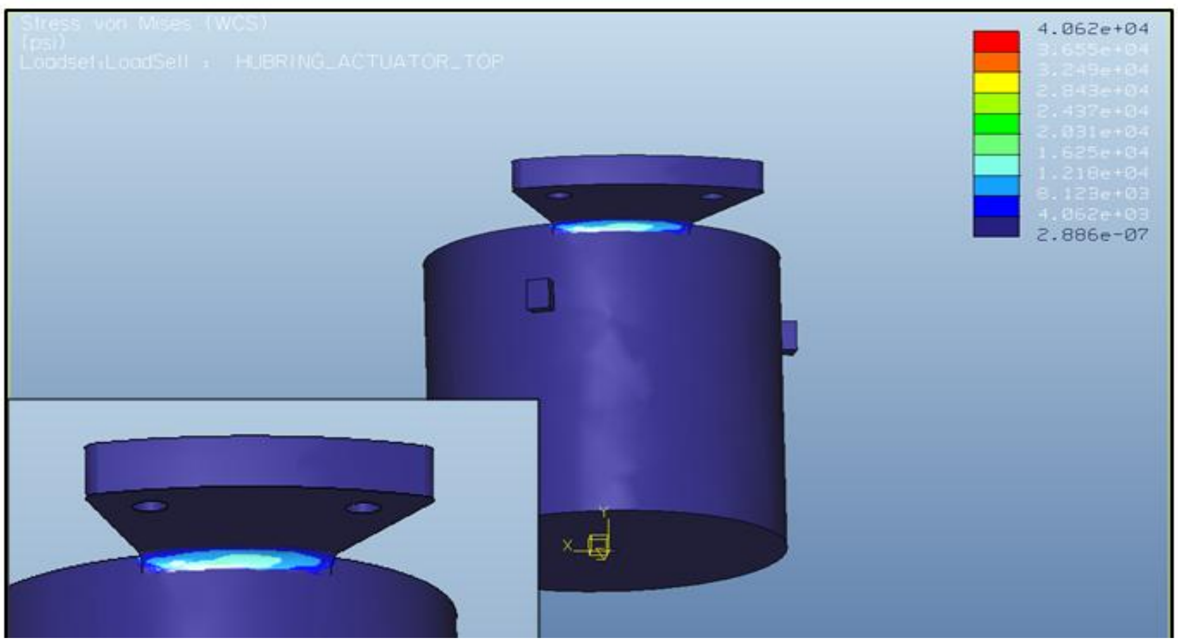

Figure 25 : Bottom most ring

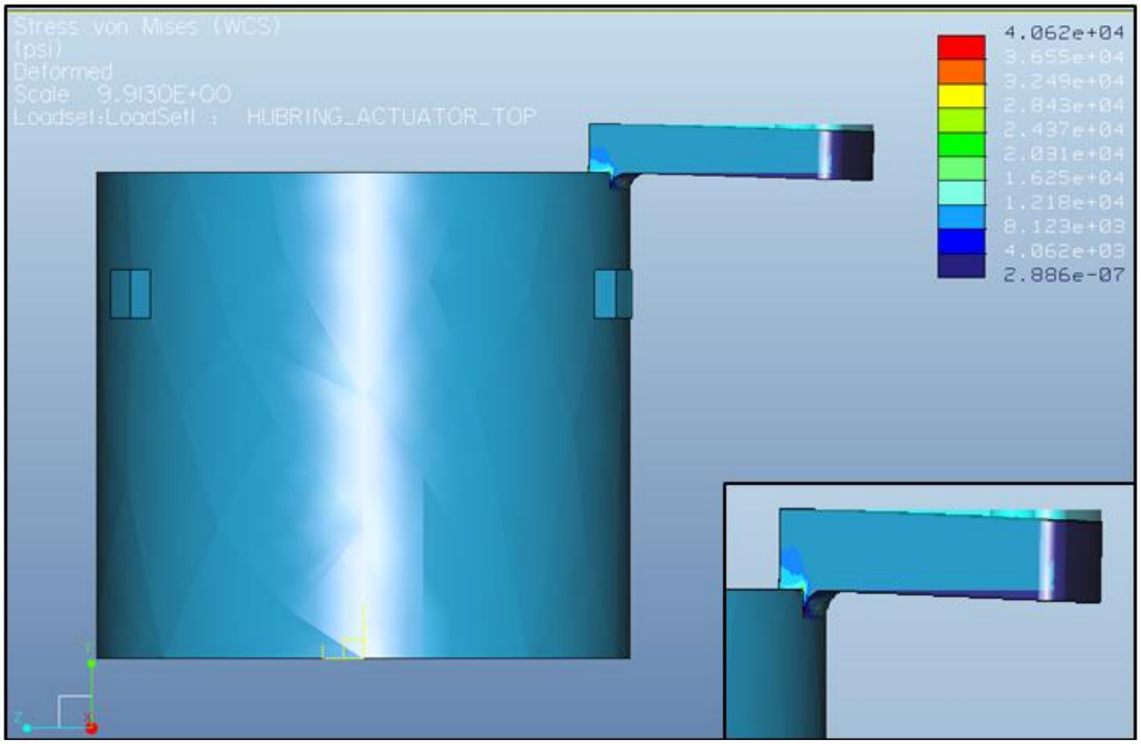

Figure 26: smallest ring. Top most ring.

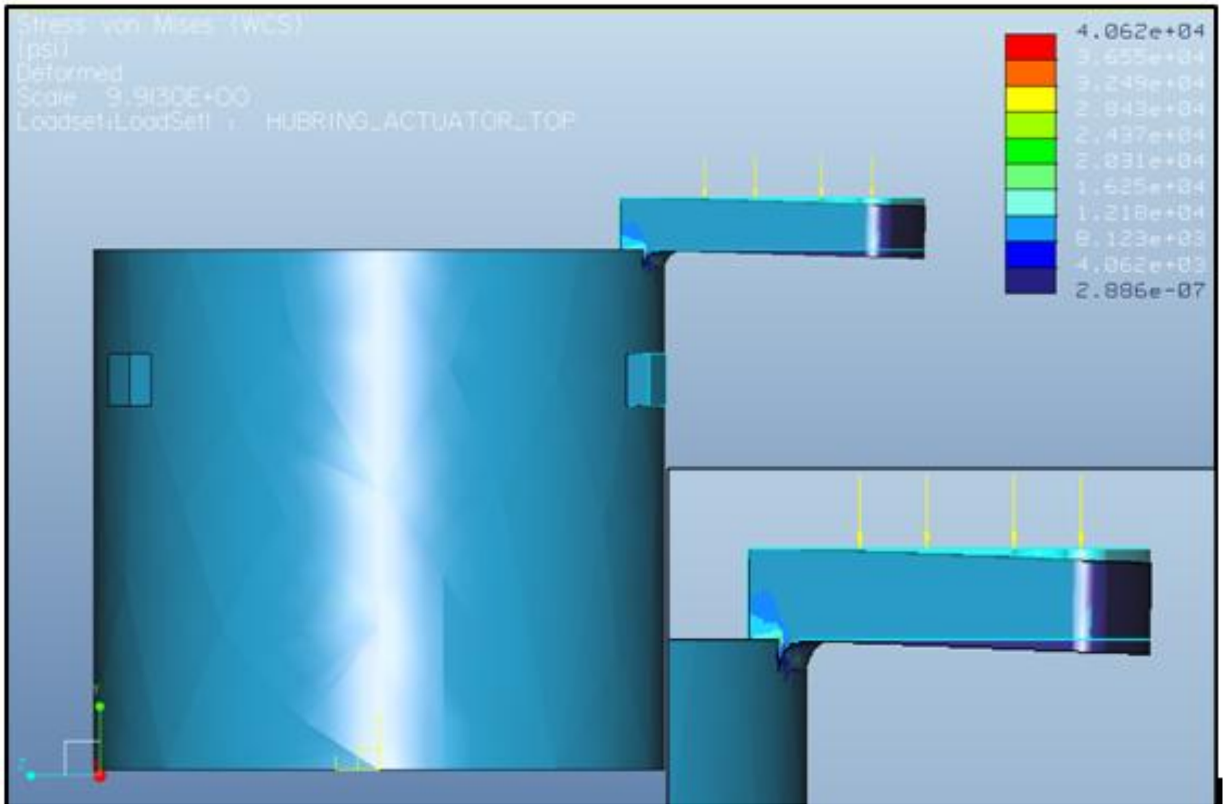

Figure 27 : smallest ring. Top most ring

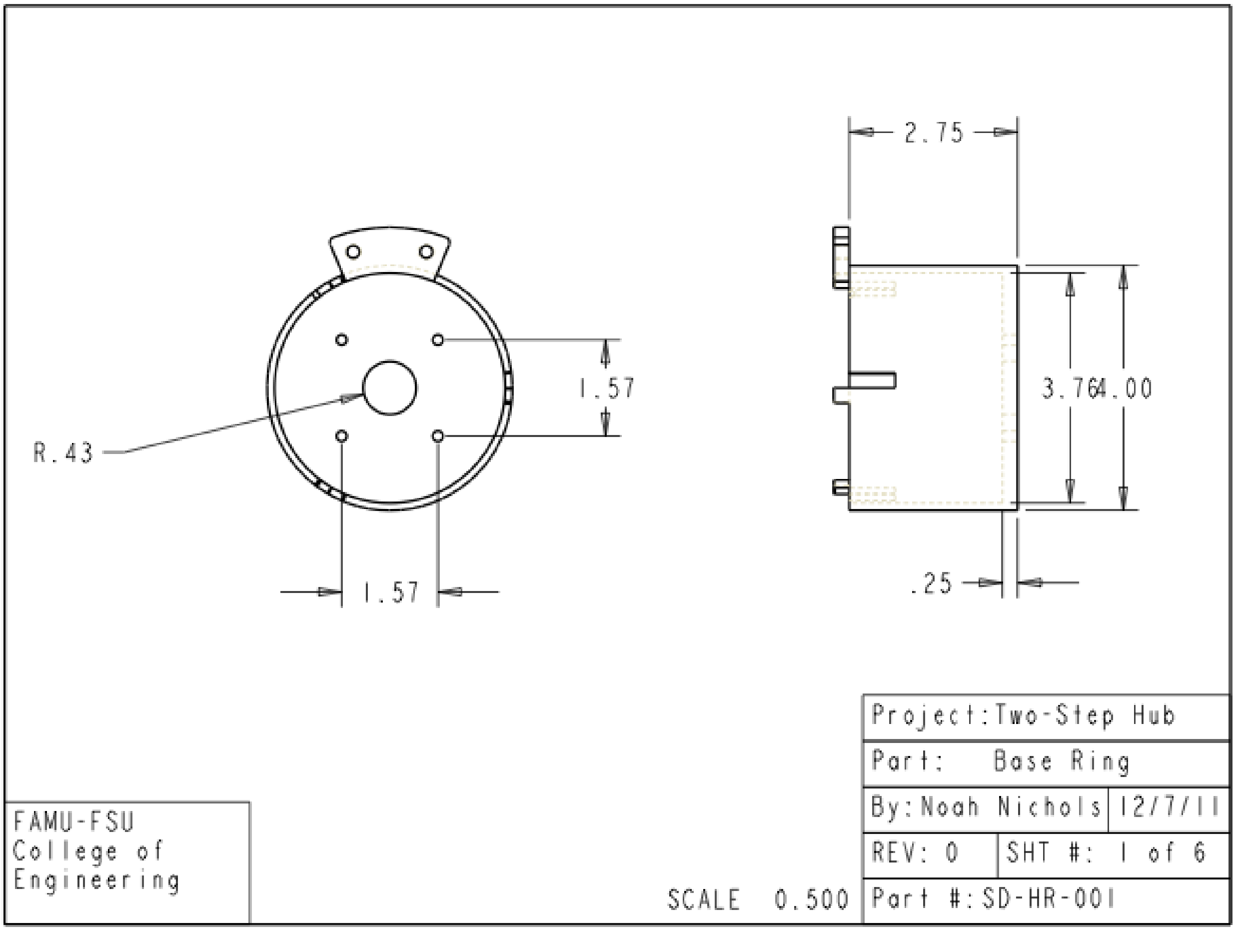

Figure28 : Top view of Pro E drawing of base ring

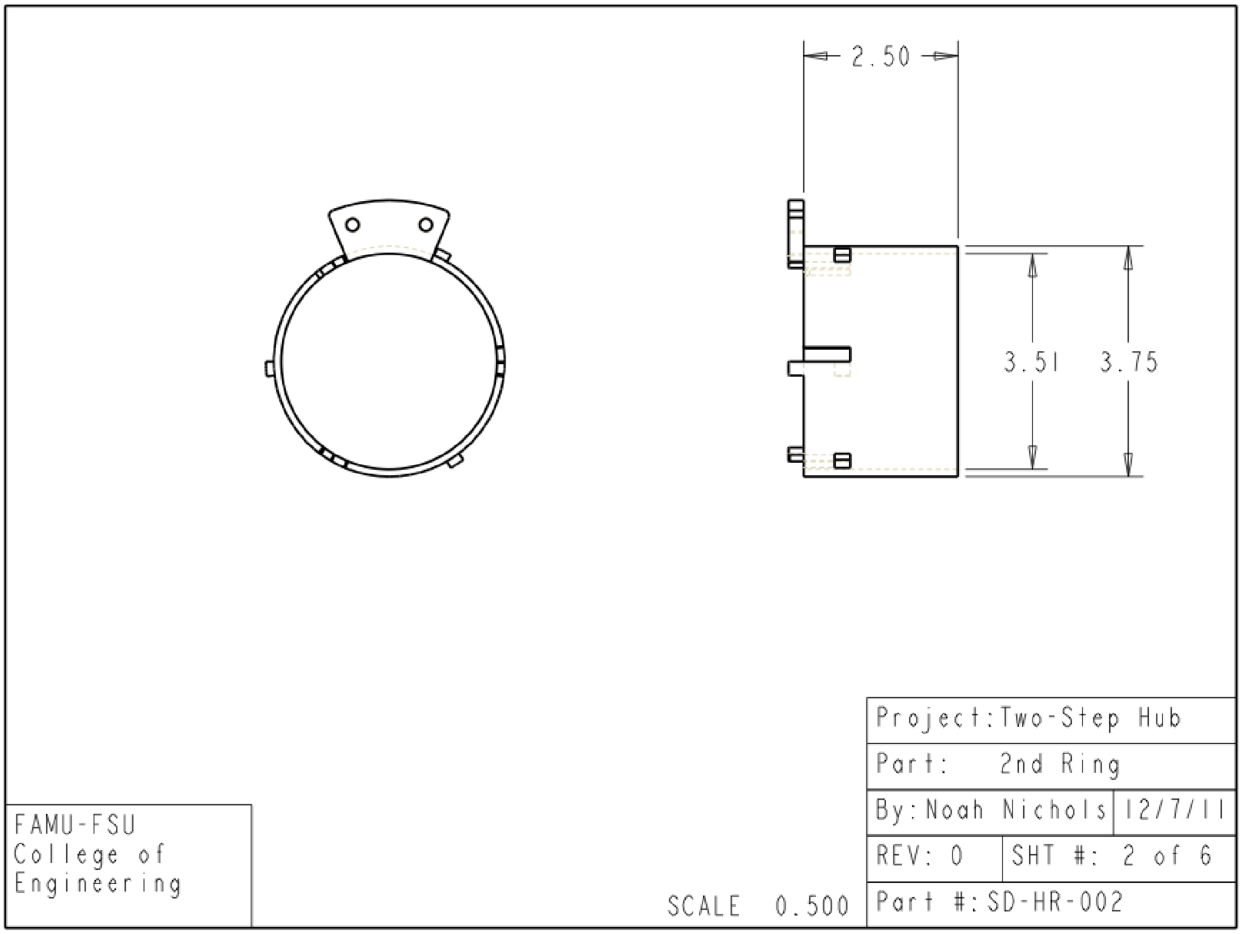

Figure29 : Top view of Pro E drawing of 2nd ring

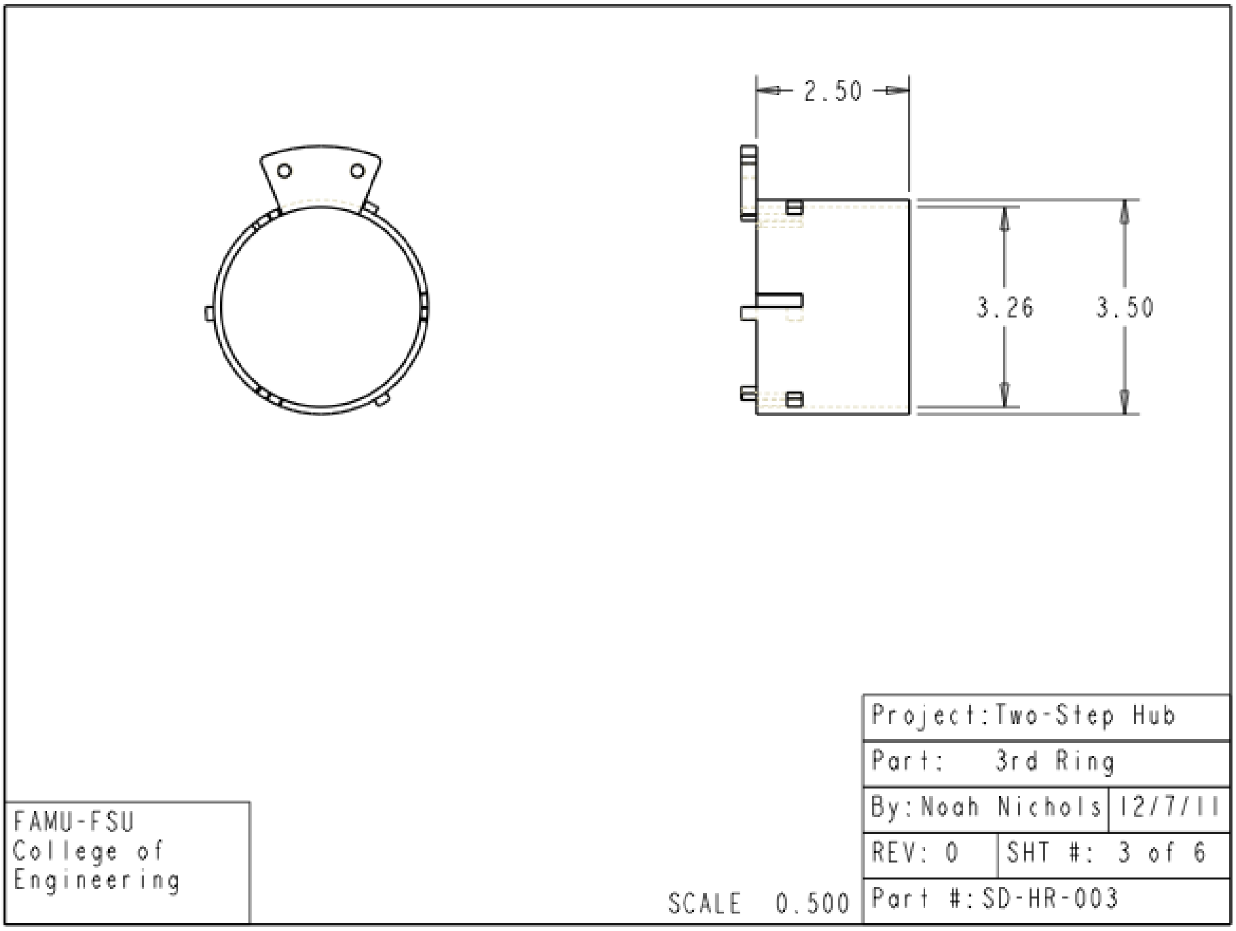

Figure30 : Top view of Pro E drawing of 3rd ring

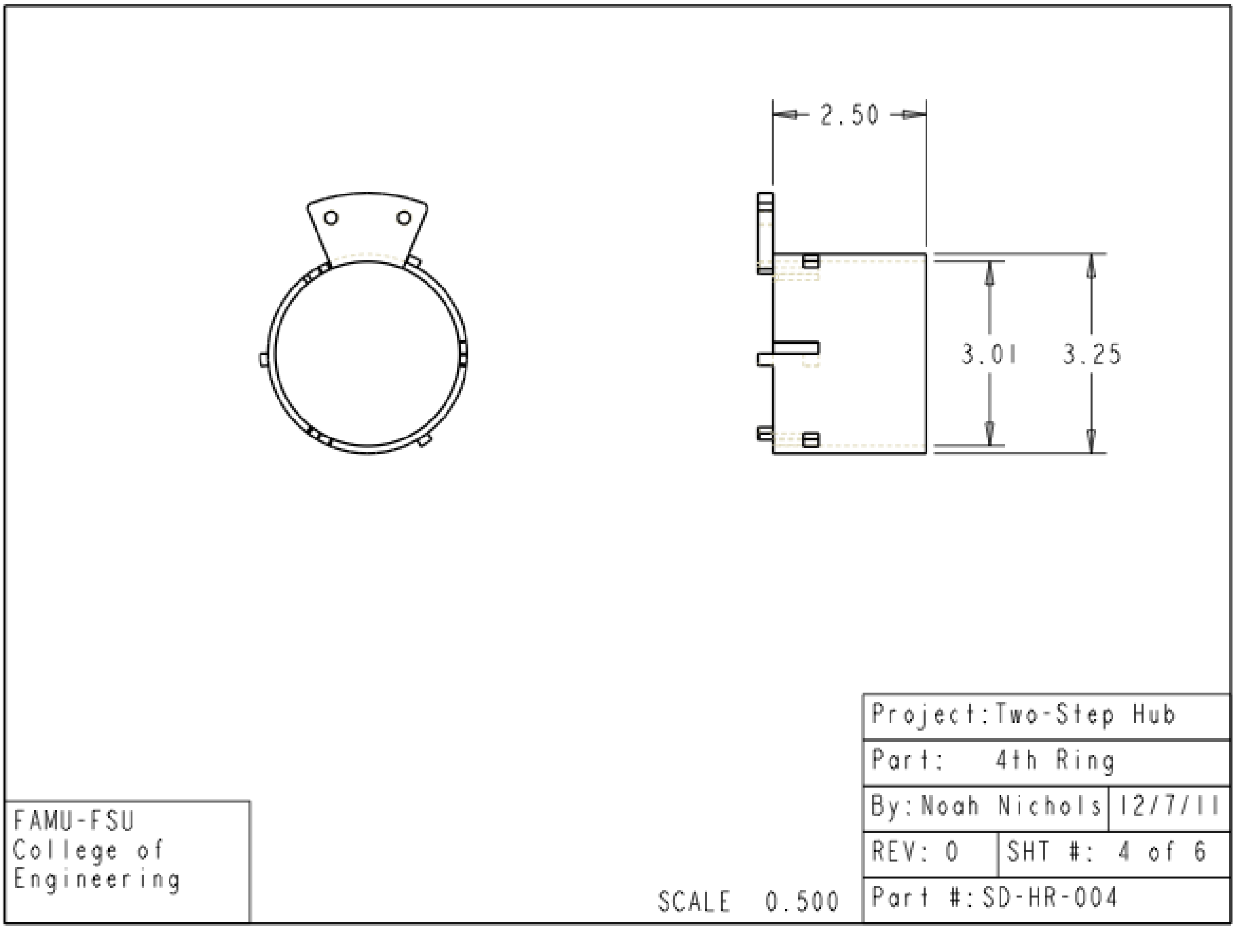

Figure31 : Top view of Pro E drawing of 4th ring

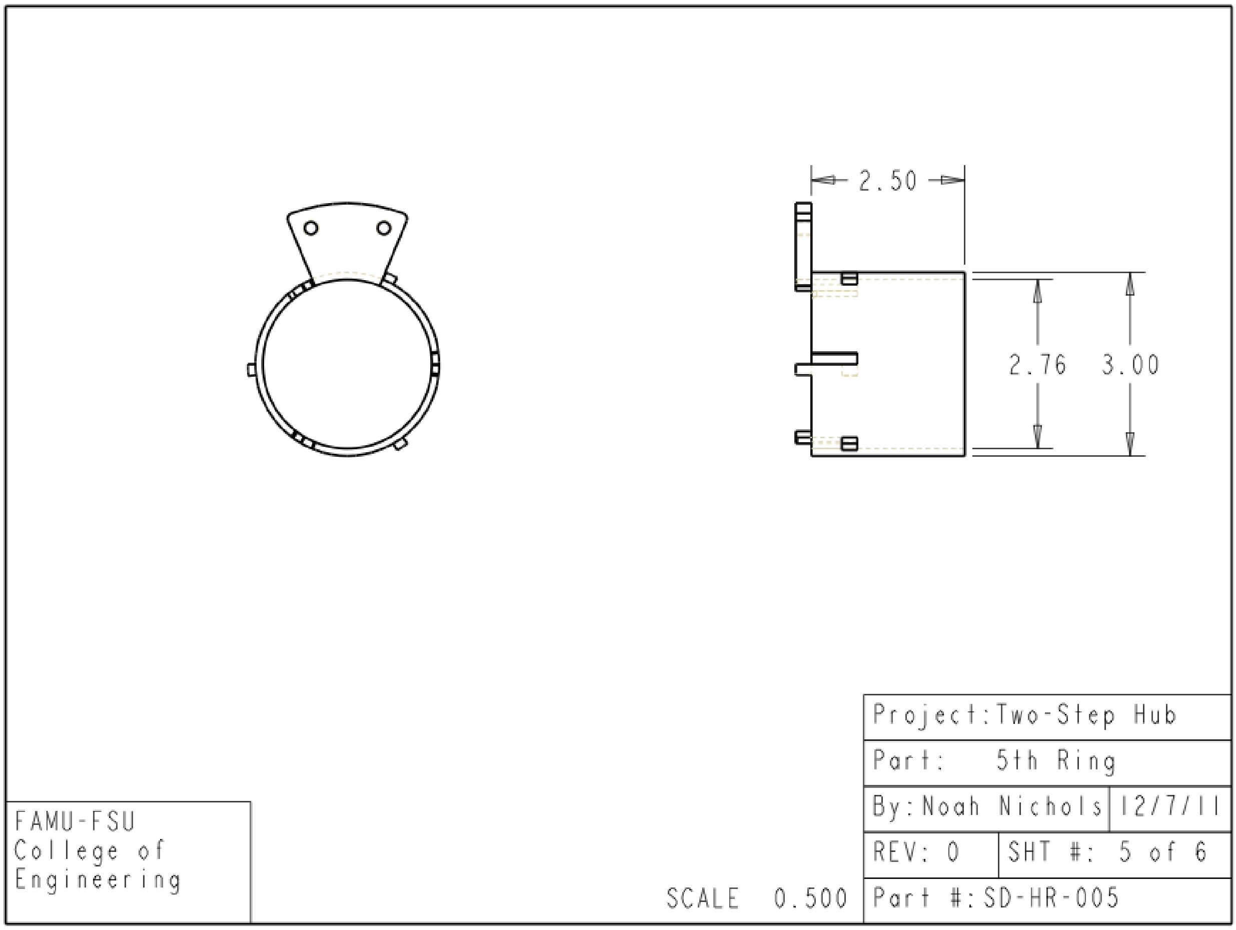

Figure32 : Top view of Pro E drawing of 5th ring

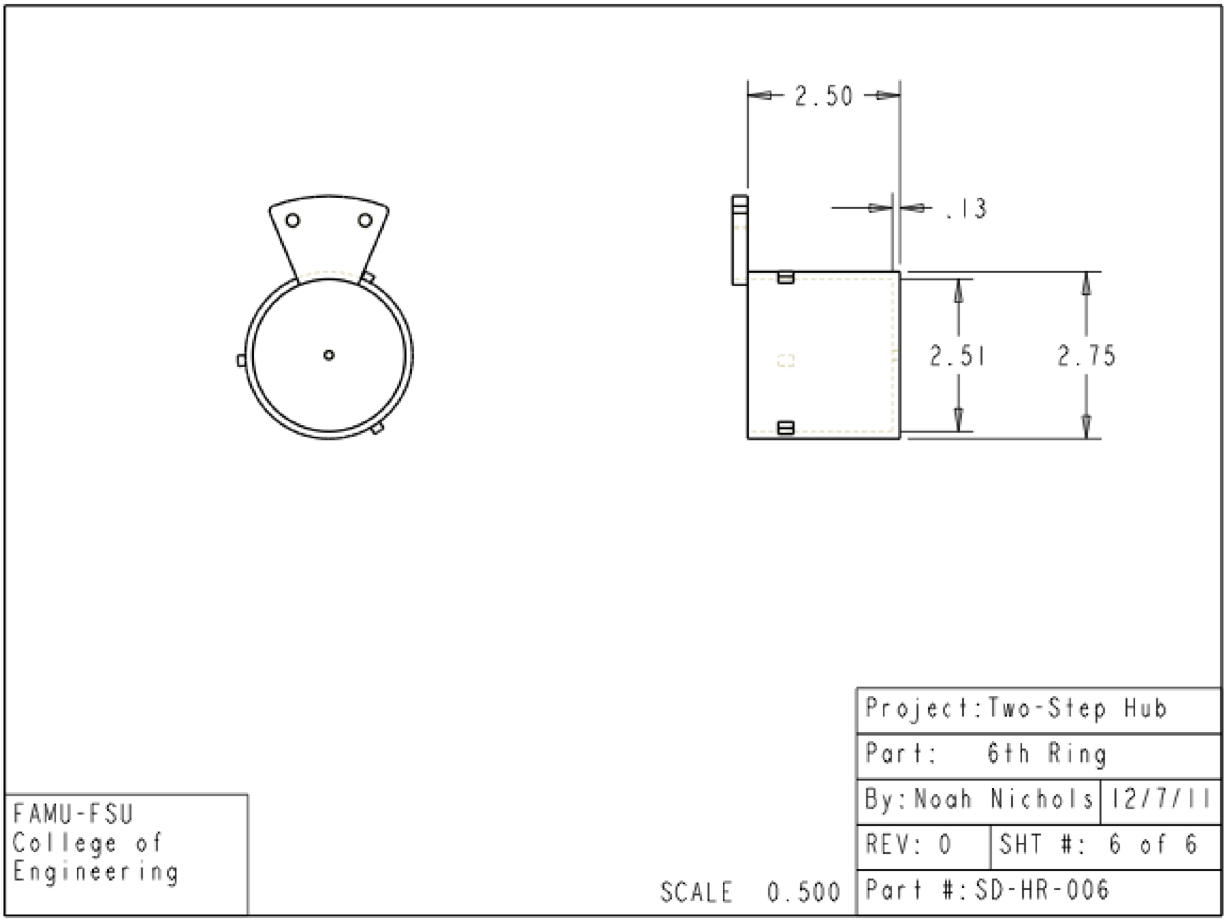

Figure33 : Top view of Pro E drawing of 6th ring