FAMU-FSU College of Engineering

Final Report: Spring 2016

Team #18

SAR Imager

Instructors:	*Dr. Nikhil Gupta and Dr. Chiang Shih*
Sponsor:	*Michael Blue*
Faculty Advisor:	*Dr. Dorr Campbell*

Members:	*ID:*
Luke Baldwin	*lrb11e*
Josh Dennis	*jad11d*
Kaylen Nollie	*kn11e*
Desmond Pressey	*drp14*

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ABSTRACT

Synthetic Aperture Radar is an advance technique of measuring a high resolution radar signature with a smaller antenna. The purpose of this project is to use SAR technology to create a low-resolution image for homeland security applications. Our product will be able to scan individuals for metal objects in order to designate people who need additional security screening. From contact with our sponsor, Northrop Grumman, our team has developed a concise problem statement: "Design an improved housing structure for the SAR Radar array." This project is a continuation from last year's senior design group. New objectives for this year include lowering the weight, making the structure more stable, fixing the antenna horn mounting and alignment, and reducing cost. This report will cover the entire design and manufacturing experience of the 2015-2016 team.

1. Introduction

In partnership with the FAMU/FSU College of Engineering and Northrop Grumman, the objective of the Synthetic Aperture Radar (SAR) Imager Project is to develop a low-cost weapon detection system that provides suitable imagery resolution for physical security and military force protection applications.

Current detection technologies commonly employed in the security industry such as metal detectors, Advanced Imaging Technology (AIT) scanners, and x-ray scanners can be expensive, obtrusive, and require the subject to be inside the apparatus. An imager based on SAR technology, composed primarily of commercial-off-the-shelf (COTS) components, can be implemented at a lower cost than many industry-standard scanners; it may be placed behind a barrier, out of view from subjects; and most importantly, it can identify concealed metal objects from a distance.

In environments with multi-layered physical security protocols, the SAR imager’s superior range can alert security professionals to potential threats before they reach an access control point, or before they progress further into a secure area, depending in which security layer the SAR is deployed. Some environments may be vulnerable to physical attack, but conventional AIT body scanners are too obtrusive or inefficient. An amusement park, for instance, might have high-level security needs, but their customers would not tolerate stepping into a full-body scanner.

Furthermore, random screening protocols have been widely criticized for being culturally or racially biased in practice. With SAR capability, guests can be discreetly imaged while queuing, and persons of interest can be identified for additional screening based on the presence of metal signatures rather than the caprice of a human screener.

This project is a continuation from last year. The first team to work on the project made major progress in pathfinding for this very unique, challenging project. While the work done by last year’s team was an impressive feat for a first generation product, there are many things that can be improved upon this year. Two engineering teams are assigned to this project: one Electrical, and one Mechanical team. While the two groups work in tandem, this report will primarily consider the scope of the mechanical engineering team.

2.Background

2.1 Northrop Grumman

The fifth largest defense contracting company in the world, Northrop Grumman employs more than 68,000 people worldwide. In 2013, its reported revenue was $24.6 billion. In 2011, the company was placed at number 72 on the Fortune 500 list of America's biggest corporations. Northrop Grumman has four business sectors: Aerospace Systems, Electronic Systems, Information Systems, and Technical Services (1).

Perhaps one of the most widely recognizable achievements by Northrop Grumman is the construction of the B-2 Spirit Bomber, as seen in Figure 1. Each one of these aircraft costs $2 billion, and represents the pinnacle of high-tech, highly priced aircraft that makes the United States military such an unparalleled force worldwide.

Figure 1: Northrop Grumman B-2 Spirit Bomber (2)

Northrop Grumman has been the contractor for a number of recent high-budget projects. In 2013, a contract with the U.S. Air Force to develop a new aerial warfare training simulation network was awarded, worth $490 million. In 2014, Northrop Grumman "is the primary contractor for the James Webb Space Telescope," a project worth an estimated $8.7 billion (3). In 2015, the Pentagon announced that Northrop Grumman won a contract over a cooperative effort by Lockheed Martin and Boeing to develop the next long range bomber for the U.S. Air Force. The initial value of this contract is $21.4 billion, and could yield nearly four times that throughout the life of the project (4).

2.2 SAR Overview

A Synthetic Aperture Radar System (SARS) is a radar system that generates a high resolution remote sensor imagery using multiple antennas and each antenna stores its' data electronically (5). A SARS normally is used by the military in aircrafts and are used to find targets such as ships by taking Doppler's Effect into account and having the antennas in time multiplex over a certain length (6). This means that the systems are usually used from the sky, looking downward toward the earth. Signal processing uses magnitude and phases of the received signals over successive pulses from elements of synthetic aperture and it then creates an image.

SARS are primarily used by mounting the system to an aircraft. Because the aircraft moves as it scans, this time-based displacement creates a synthetic length of a radar, giving it its name, as seen in Figure 2.

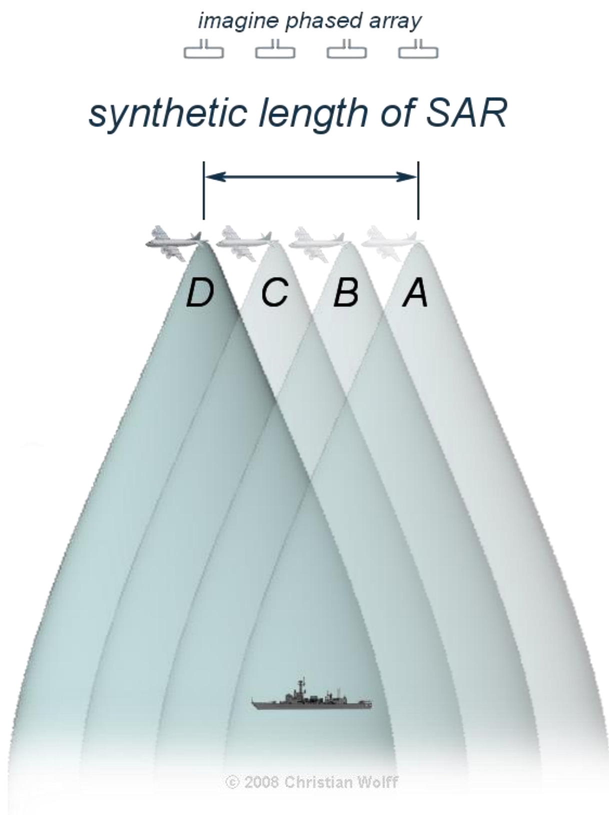


Figure 2: Mobile SARS (5)

SARS is used for military use primarily but there are also some non-military uses as well. The "Blackbird's Eye" is where an aircraft pilot uses SARS to establish a location of an object. SARS is used for the 24/7 missions in hostile territories for reconnaissance and counter terrorism, this is specifically called the TRACER and are for unmanned and manned. This system can operate in any type of weather, day or night, wide area-surveillance capabilities, and has a long endurance. For non-military uses SARS is also used for GEO mapping, which is a mapping system to map areas all over the world. These three applications of the Synthetic Aperture Radar System were all created by Lockheed Martin and all are mobile (7).

Our objective is to make a SARS imager with a purpose of creating a strong security system to protect against threats in public places such as movie theaters and stadiums. People are able to conceal weapons such as handguns or even bombs in public areas without anyone having any knowledge that someone has a weapon and could be a potential perpetrator of mass murder or anything with malicious intent. The difference between a tradition SARS imager is that this device will be on the ground with a target that is horizontal and also that the device will have multiple stationary antennas that is sending data to be stored electronically by taking images of a target that is moving, specifically a human being. Instead of using it in the air, this will be used on the ground and taking images horizontally. The imager should be fully functional, uses materials that are commercially used and low in cost, and also creates a low but useful resolution of an image that can detect concealed weapons.

Because this is a stationary SAR, multiple antennas must be used to create the synthetic length of the radar. There are 16 antennas that transmit radar, and 4 that receive – the 4 outermost antennas. The received signal will be passed to the electrical components for modification, and that data will be sent to a laptop for post-processing. The output will be low-resolution displace of the 40x40 inch scene. This system is shown in Figure 3.

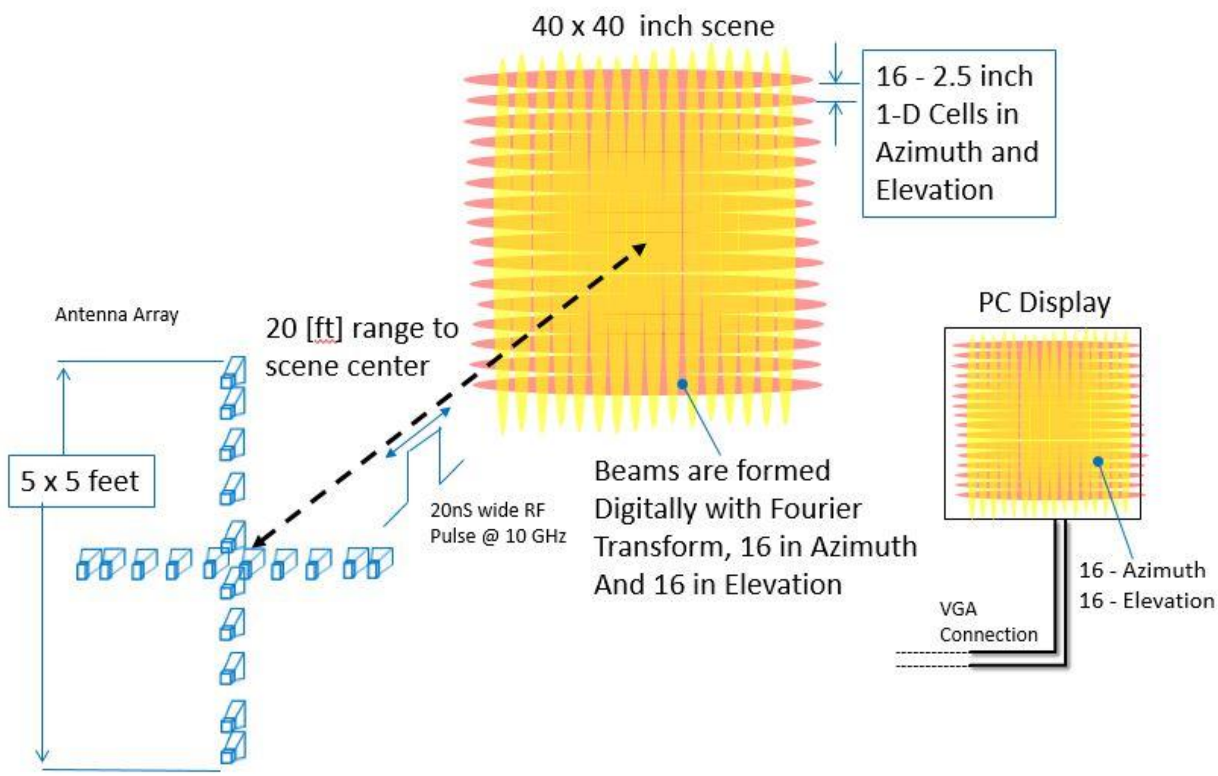


Figure 3: Antenna Array Creating Image (8)

2.3 First Generation

The dictating factor in the SAR design is the electrical engineering requirements. As such, the mechanical aspects of the project are there to supplement the electrical operation. Because of the unique and challenging nature of this project, the electrical engineers spent a considerable amount of time initially determining how to start with designing the layout of the system. This constrained the mechanical engineers by giving them less time to develop a prototype design. Once a final mechanical design was chosen for the system, the team proceeded by submitting the design package to various fabricating shops for quotation. The mechanical engineers chose the quote from a fabrication shop that was considerably cheaper than the average quote. Many of the problems of last year's design was introduced by the selected fabricator. These problems included not clearly understanding the design drawings and incorrectly fabricating parts which then must be re-fabricated, providing an estimated completion date that was not met, and subsequent lack of fabrication quality. The delays that were created in fabrication totaled three weeks. The poor fabrication quality also caused the horn holders to not fit onto the horn assembly properly, and the entire structure, as shown in Figure 4, is very unstable. Simply placing a hand on the side of the horizontal bar would cause the structure to wobble. This is detrimental to the operation of the SAR, causing a considerable amount of error to be introduced into the readings whenever it was bumped.

Figure 4: First Generation Project and Team, Faculty (9)

Additional constraints were placed on the mechanical engineers because throughout the life of the project, the electrical requirements consumed more and more of the budget. Although there was a significant amount of money not budgeted to be spent, most of that had to be spent on electrical components and renting test equipment. Because of budget, seen in Figure 5, a design that would have had the structure made out of aluminum had to be changed to steel. This cause the weight of the structure to increase so much that it was difficult to move, totaling over 220 pounds.

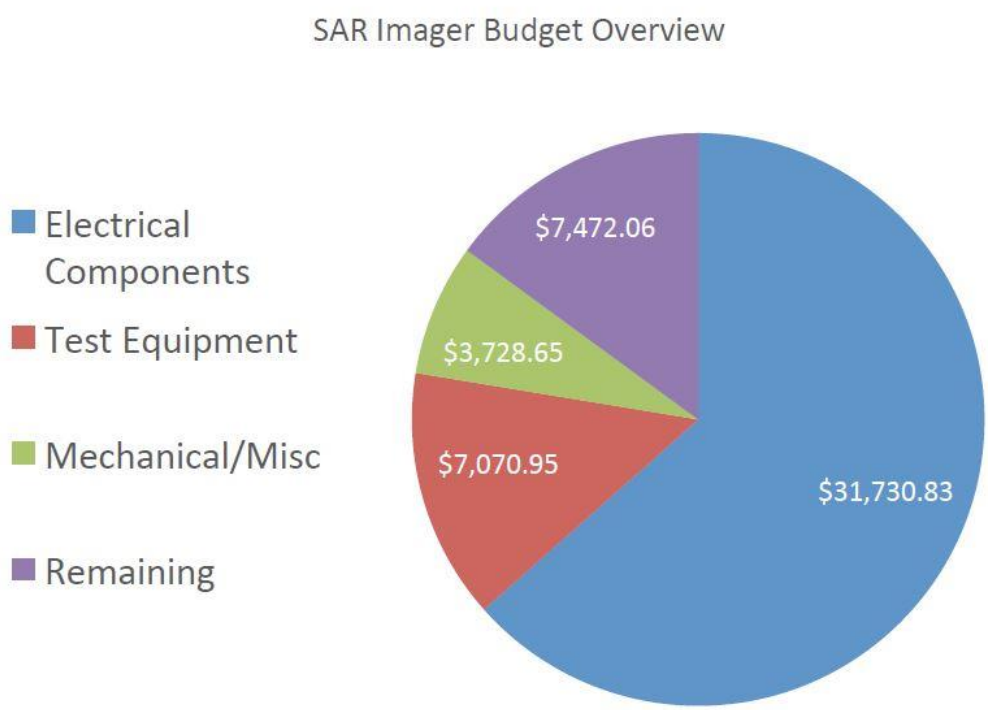


Figure 5: First Generation Final Budget (9)

3. Project Definition

Compared to other senior design projects, the SAR Imager is a project with open ended goals. It was difficult to initially get a clear idea of the direction of the project. The open nature is partially because it is difficult to assess what is achievable in nine months' time. Information regarding project definition has been outlined, but it is important to note that the scope can be changed as needed throughout the life of the project.

3.1 Need Statement

This is a second generation project; the sponsor being Northrop Grumman and the Mechanical Engineering team from the previous year has demanded some key changes in the aspects of the previous design. These include, improving the rigidity of the frame, changing the method of aligning the antenna horns, increasing mobility, reducing weight to under 150 lbs., changing the material of the structure, and increasing the pointing accuracy of the laser of the horn antenna. These changes are needed because, the horn alignment caused errors in the collection of data and target sensing. The changes are also needed because the current design was extremely too heavy and difficult to transport.

Need Statement:

"The structure of the current SARS is producing too much of an error and isn't efficient or effective for sensing targets."

3.2 Goal Statement & Objectives

From our sponsor meeting, our team was able to create the following goal statement:

"Design an improved housing structure for the SAR Radar array."

During our meeting, our sponsor stated very clearly what his concerns with last year's prototype and what we could do to make it better. The first requirement was improved stability, the 1st-Gen prototype would wobble upon the application of a small force. Operationally this is not acceptable because the SAR takes radar images of a fixed region in space and a small adjustment would mess up the accuracy of what is being read. Another element to help improve the accuracy is improved horn alignment and mounting. The first generation of the imager had a problem with precisely mounting the horn holder to the frame and in some cases JB Weld was used hastily used. It is important to finely adjust the angle of each antenna and lock it into place since errors of even 1/10" can propagate to major errors in the phase angle of the radar signal.

Reducing the total weight is another major concern for Gen1 was made of solid steel and weigh roughly 300lbs. However, this was to save cost as lightweight Aluminum would have been more expensive. A goal of making it a Mil-Spec standard two person carry weight of 80lbs was given. Lowering the weight would also make the device more portable another of our client desires. However, portability can also include easy of breakdown and assembly which is not a main focus of our 2nd Gen design. Design of the hardware box to protect the circuitry from the elements and Electromagnet Interference was given to the two ME students on the EE team, however, we still need to make a way to attach their box to our structure.

From the design requirements, our team produced and House of Quality (HOQ) matrix as shown in Table 1. We took the design requirements provided by our client and ranked them in terms of importance. By brainstorming, our team created the engineering characteristics of structural thickness, specific material used, horn locking mechanism and adjustment, physical size of the base, height of the structure above ground, number of cross support beams and a Mil-Spec weight standard.

Table 1: House of Quality

Customer Requirements	Customer Importance	Engineering Characteristics								
		Structural Thickness	Material Used	Locking Mechanism	Axis Adjustability	Mounting Mechanism	Base size	Height Above Ground	Number of Crossbeams	Weight
Increased Stability	5	9	3	6		3	9	6	6	
Lower Weight	5	3	9				6	3	6	9
Good Images	5			6	9	9		3		
Better Horn Mounting	5			9	9	9				
Cost	4	3	6	3		3	3		3	
Hardware Box	2	3	6							3
Portability	2		6				9	6		9
Score		18	30	24	18	24	27	18	15	21
Relative Weight		78	108	117	90	117	105	72	72	69
Rank		6	3	1	5	1	4	7	7	9

Based on the HOQ, the most important engineering characteristics are the locking mechanism and mounting mechanism for the horns, followed by the material used in construction of the structure and the base size.

3.3 Constraints

Some engineering constraints have been proposed by Northrop Grumman. These are preliminary goals to aim for, but may need to be revised throughout the project since it is still a young, evolving product.

3.3.1 Stability

A main drawback of the first generation of the design was stability. A slight bump of the structure could cause significant wobbling, affecting the accuracy of the SAR. The stability is required because the radar being sent out and received by the antenna has a wavelength of 1 inch. Any movement of the structure will cause the received phase to be artificially shifted to the left or the right. It was determined that the maximum allowable phase shift is 5 degrees. In terms of horizontal movement, this corresponds to 1/72 of an inch in maximum deformation.

3.3.2 Weight and Mobility

The first generation product weighed over 220 pounds. Although this system is designed to be stationary, it is desirable that it can be both lifted and moved by two people, as well as having wheels so it is easy to move. Per military specifications, two people are generally considered to being able to lift an object of 80 pounds easily, so that will be the goal weight of the project. This weight goal may be revised as the project comes closer to actualization if needed.

3.3.3 Horns

The entire purpose of the structure is to facilitate the collection of data by the antenna horns. This will be the most critical design feature, so it will be given priority in design. The sponsor clearly outlined all requirements of the horn: the horns need to be adjustable through rotation in the left to right direction and through rotation in the up and down direction, all horns must be focused within a 1 feet circle that is 20 feet away, and there must be some method of alignment. Last year, the method of alignment was by using a mounted laser pointer to determine the alignment direction. A similar method will be considered this year.

3.3.4 Cost

Although the budget for the mechanical engineering aspects of the project is $5000, the team's goal will be to find a satisfactory price to performance balance that will be below this amount. The methods to reduce cost will be to use commercial-off-the-shelf (COTS) hardware, and to keep design as simple as possible while still meeting engineering requirements.

4. Concept Generation and Overview

The various designs by the mechanical engineering team have already undergone multiple revisions through input by the sponsor and electrical team. The intention of this report is not to propose a final design, but to show the team's progress in the design process.

4.1 Structure Designs

The design of the structure is strictly dictated by the geometry of the antenna array. As long as the structure can support the 20 antenna horns and hardware box, the secondary goal of reducing weight and cost was pursued in design.

4.1.1 Design S-1: 80/20 Structure

The first design, Structure S-1, focuses around the use of 80-20, an industrial grade building structure and test platform as shown in Figure 6. 80-20 is very modular due to its extruded aluminum profile and con be combined to other pieces through a variety of connectors. This design is also very flexible because different sized pieces of 80-20 with different channel numbers can be selected if more strength or surface area is desired.

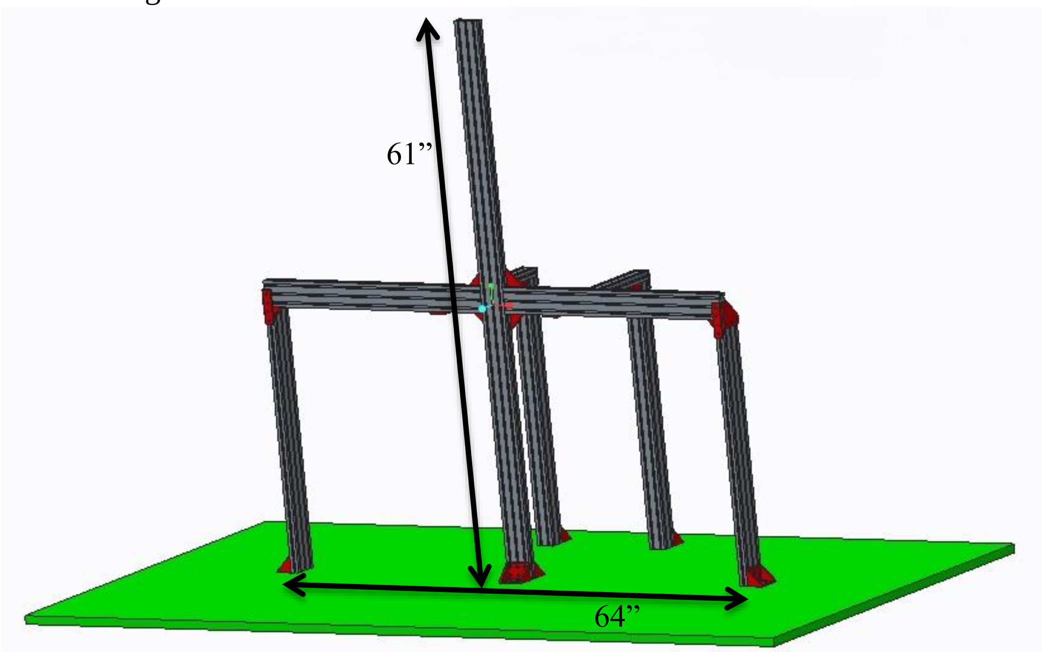


Figure 6: Design S-1, 3D (inches)

From the particular SAR radar array specified by Northrop Grumman, a 3x1channeled piece of 80-20 was used as the main vertical and horizontal bars which hold the antennas in place. Four angled brackets are used on the back of the structure to provide rigidity to the structure. This allows for near endless translation of the waveguide holders so that they can be aligned relative to each other. 80-20's modular nature allows support beams to be attached anywhere. At the end of each horizontal beam, another 3x1 piece is used to support the far side. In order to keep the device from toppling forwards or backwards, two legs are added to each horizontal beam. This leg also serves to balance the weight of a central rear mounted control box if this location becomes specified by the EE team. The green base plate is an arbitrary ground; it shows how the structure would be mounted to a cart surface or floor with 45 angle brackets in red.

Structure S-1 stands 64" tall and 61" wide from the extreme ends of the cross beams. The top of the 3" wide arm is 33.5" above the ground making the center exactly at 32" above the ground. The rear leg stands 19" away from the front and connects to the very bottom channel of the horizontal arm at 31.5" high.

4.1.2 Design S-2: Custom Aluminum Structure

Design S-2 features influences from last year's design or Generation 1 (Gen1) and is shown below in Figure 7. Four pieces of Aluminum are bent or welded into an L shape and are attached together at their ends. The connectors at each horizontal end extend down to the floor to provide stability and weight relief to the center ground piece. Each waveguide adapter is sandwiched between two different pieces with a rectangular cutout placed in the proper distances for the antennas. There are four plastic gutters which protect and conceal the wires and are shown to be clear attached to the rear of the L beams.

Figure 7: Design S-2, 3D (inches)

Detailed drawings of this design concept can be found in Appendix B. Each L beam is made of 0.375” Aluminum and is spaced 4 inches apart from each other to offer clearance for the waveguide to rotate freely without interference. The rectangle which anchors the waveguide adapter and rotation mechanism are spaced 1.5” x 0.5” to all some adjustment room to fine tune their translation. This structure stands 64.55” tall and 63.65” wide with each arm 29” long. At the side of the structure, each end cap stands 35.85” tall and 29.075” away from the downward side of the center. The inside of each gutter is 4.75” apart and 26” long so that it doesn’t interfere with the end caps. The component box will be mounted to the back the horizontal sections of the L beams.

4.2 Horn Holder Designs

The most critical aspect of the mechanical engineering design of the project was the horn holders. The first generation design performed very poorly in this area, so the main improvement for the second generation is to improve on this aspect.

4.2.1 Design H-1: Bracket Enclosure

Design 1, as shown in Figure 8, will be mounted onto the 80-20 structure by the screw-to-clamp structure available from the 80-20 providers. This screw-to-clamp structure will be used on the back of the horn holding brackets. The outer rectangular brace of the structure will be fastened onto the braces by a thumb screw, rubber washer, and a nut. This outer brace will control the azimuth rotation of the horn. The outer brace is also connected to the flange by another set of thumb screws, rubber washers, and nuts. This rotational point controls the elevation of the horn. The flange is fastened onto the back of the waveguide along the same screws that connect the waveguide to the horn.

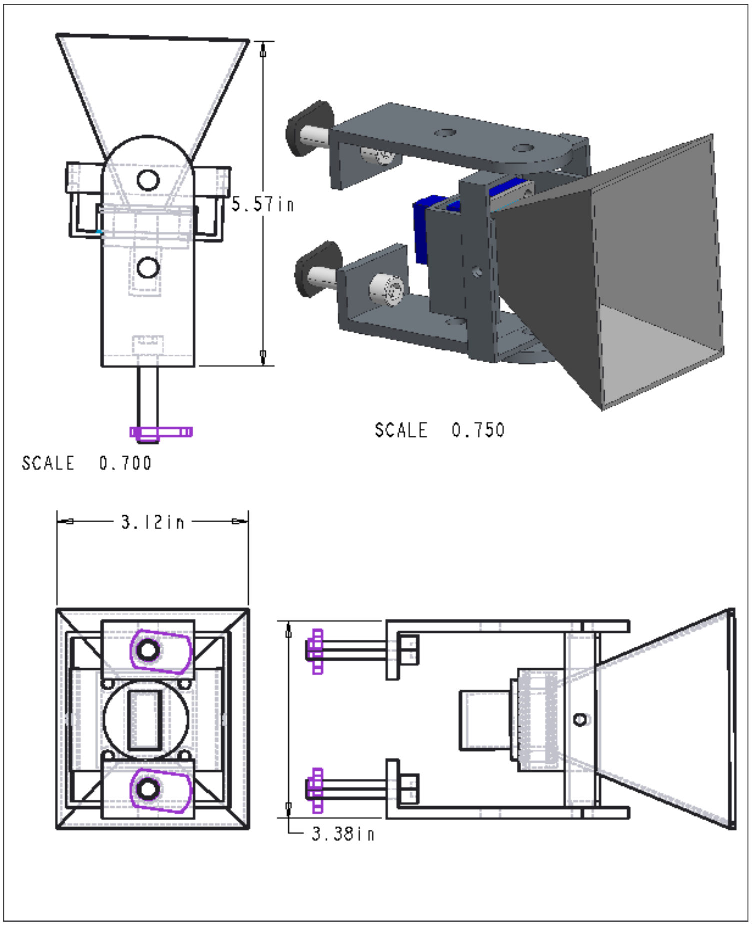


Figure 8: Design H-1, 3D and Dimensioned Drawings in Inches

4.2.2 Design H-2: Articulating Arm

Design 2, seen in Figure 9, copies that of a computer monitor; this is called an articulating arm. It is connected with three separate parts. There is a plate that is connected to a rod. This controls the rotation along the elevation and the rod rotates along the azimuth. The rod is then connected to the 80-20, 15 series, pivot nub that enables the design to connect to the 80-20 structure. In order for each degree of freedom to lock, disabling any adjustments in either the azimuth or elevation, depending which is trying to be adjusted, we have decided to use pins that will be able to tighten or loosen the design so that it can be altered by the user. The pivot nub that slides into the structure will also be able to become fixed by the pins used by loosening and tightening.

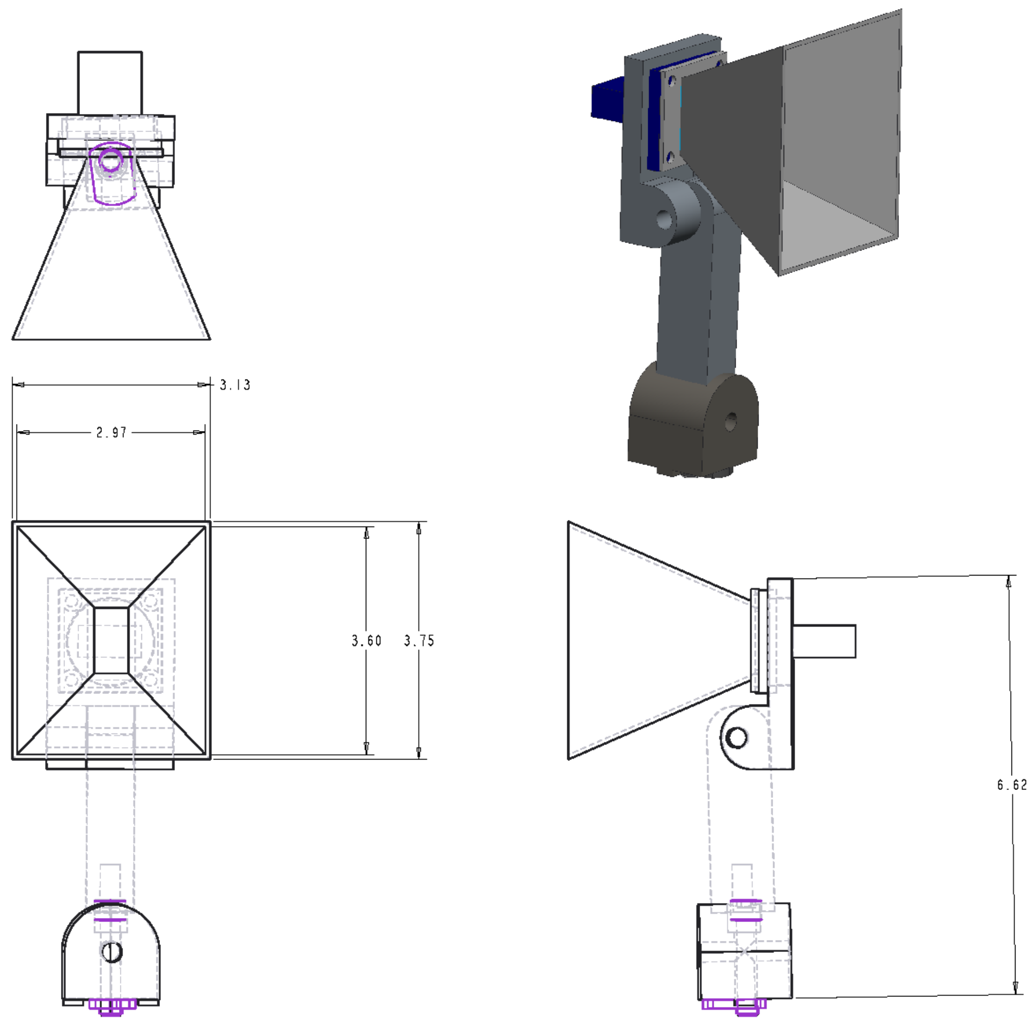


Figure 9: Design H-2, 3D and Detailed Drawings in Inches

4.3 Base Designs

The designs of the base are currently early in the design stages. Because both the horn holder and structure design are under heavy revision, the team is waiting on proposing detailed designs of the base. Although the team believes the design will be trivial to complete after the other aspects are finalized, there have been two proposed methods of constructing a base.

4.3.1 Design B-1: 80/20 Castors

The first base design is based off of structure design S-1 which uses the 80/20 product. The requirements of the operation of the SAR dictate that the system must be placed on a level floor. The mobility requirements of the project require that it have wheels to be easily moved. The team is considering a part that satisfies both of these requirements, seen in Figure 10.

Figure 10: Design B-1, 80/20 Leveling Castors (#2714)

The general idea will be to create a rectangular frame on the bottom of the structure and attach four leveling castors.

4.3.2 Design B-2: Pre-Fabricated Cart

An additional idea proposed would be to purchase a pre-fabricated cart, and simply attach the structure to the cart. Many options are available from McMaster-Carr depending on the final geometry of the structure. One of these options is shown below.

Figure 11: Design B-2, Aluminum Platform Truck (10)

The advantage this design brings is that there will be little time required for assembly – possibly only installing a few bolts to mount the structure. There may be cost savings depending on the final cost of B-1. Less time will be spent on designing something that is already commercially available. There is a smaller likelihood that an unforeseen problem will arise because the vendor performs their own quality checks on their products.

5. Concept Selection

5.1 Structure Selection

After these rough designs were constructed, pros and cons were analyzed to select the superior design. For the S-1, the modular nature of the 80-20 makes it very easy to assemble and modify. Ordering is also easy and it takes very little machine shop time to fabricate. However, the ¼ - 20 hardware used to fasten the pieces together might not carry extreme stress and shear. In its basic form, the structure offers little protection for the waveguides from the elements or accidental bumps. Considering the weight of the support box from last project, it could deform the beams if the supports are not strong enough.

Structure S-2 also has its own advantages. The thicker cross section of Al used allows more rigidity to stress and strain. Additionally, larger bolts than ¼-20 can be used in assembly which will give more strength and rigidity to the connections. There is also a larger surface area for ground or cart contact which will aid in stability. But, the size and complexity of the four L brackets will take a lot of time and money to assemble. This design is also substantially heavier than S-1 with the back mount control box can cause additional deformations.

In addition to these pros and cons, a Pugh decision matrix was constructed with the engineering characteristics to further guide us to the optimal solution. For this matrix, last year's design Generation 1 (Gen 1) was used as a baseline of 0 all around the board. A value of 2 was assigned for the design that offered a great improvement over Gen1 while a score of 1 was used for a slight improvement. Zero was assigned if there was not real improvement upon the original. The results can be seen below in Table 2.

Table 2: Decision Matrix, Structure Design Selection

Categories	Gen 1	S-1	S-2
Horn Accesability	0	2	0
Mounting Position	0	2	1
Locking Movement	0	0	2
Material Used	0	2	1
Base Dimensions	0	1	0
Cost to Produce	0	2	0
Total	0	9	4

In terms of accessing the horns for adjustment, S-1 excels because the waveguides extend out of the front of the structure and offer access from any angle. Gen1 and S-2 have the waveguide sandwiched between two pieces for limited access. In terms of mobility and mounting position, S-1 offers limitless opportunities and S-2 has a slot for changes much better than the solid holes of last year's design. S-1 also performs excellently for materials used and cost to produce since it's cheap and lightweight yet strong. It earns a nine over a four from the S-2 design, which in reality is mostly a copy from Gen1 just made with aluminum to be lightweight. From this Pugh matrix, Structure S-1 is the general format with which our team will go forward.

5.2 Horn Holder Analysis and Selection

5.2.1 Design H-1 Analysis

Advantages:

Design H-1 offers a great deal of adjustability where it is needed most. The horn holder allows horizontal translation through its screw-to-clamps at the ends of the brackets. It also offers over 90 degrees of rotation on the axis between the brackets and rectangular brace. It also restricts some of the rotational range on the opposite axis between the brace and flange. This is ideal for the prospective column that each horn is mounted on, whether that is the horizontal or vertical column of the structure. Design H-1 also keeps its rotation about a center point with increases the ease of use and potential accuracy.

Drawbacks:

Design H-1 offers a challenge is its control of adjustability. Because each rotation axis will be screwed in at two opposite ends, it will require both ends to be loosened to adjust, then both to be tightened to keep it in place. This can open up room for error in accuracy. Further fastening concept generation can improve this design.

5.2.2 Design H-2 Analysis

Advantages:

Design H-2, is a very simple design because it is taken straight from a design that is already made and is in use for mounts for TV’s, antennas, and computer monitors. Because it is similar to the designs of multiple mounts already being used, we know that the design already works and is effective.

Drawbacks:

Design H-2 is easier to deal with on the horizontal column. If you refer to Figure 9, the 80/20 component slides into the 80/20 structure piece where a pin will tighten or loosen to either fix or enable translational movement for the antenna respectively. On the vertical component of the structure, this may pose as an issue because of how that 80/20 pivot nub is connected to the rod that keeps the antenna upright. This may also be an issue because the pivots are not on the centerline.

5.2.3 Horn Design Selection

While the team currently has not formerly proposed a final design for the horn holders to the sponsor, a decision matrix as shown on the next page in Table 3 was created to guide us to the favorable design which we believe is design H-1. Design H-1 has the superior structure compatibility because it can be mounted on the vertical or horizontal columns with equal ease. Design H-2 has an ideal horizontal mounting compatibility but lacks in the vertical mounting capability. Because Design H-1 mounts about to slots, its translation is easier and more stable.

Whereas Design H-2 is mounted in one slot and will be less stable when translating. Design H-2 has superior rotational lock-ability over Design H-1 because it rotates about one pin on each axis. Design A extends very far from the frame structure and thus has a non-ideal size. Because of this size and off center axes, its ease of adjustability does not score as high as Design H-1.

Table 3: Decision Matrix, Horn Holder Designs

Attribute	Gen 1	Design H-1	Design H-2
Structure compatibility	0	2	1
Ease of translation	0	2	1
Lock-ability	1	1	2
Size	1	1	0
Ease of adjustability	0	2	1
Total	2	8	5

5.3 Base Selection

The selection for the base is not going to be determined at this time. The team has proposed multiple options and their possible benefits, but there is not enough information to make an informed decision. It is preferred to wait on creating detailed designs so that there are not multiple, unnecessary revisions to this aspect since it will be a trivial design.

6. Finite Element Analysis

At this point in the design process, the senior design team has created a second generation concept. The use of finite element analysis is intended to provide insight into the structural integrity of the design. If the FEA shows the structure goes through excessive stresses, modifications or potential redesigns will be made to effectively mitigate these effects.

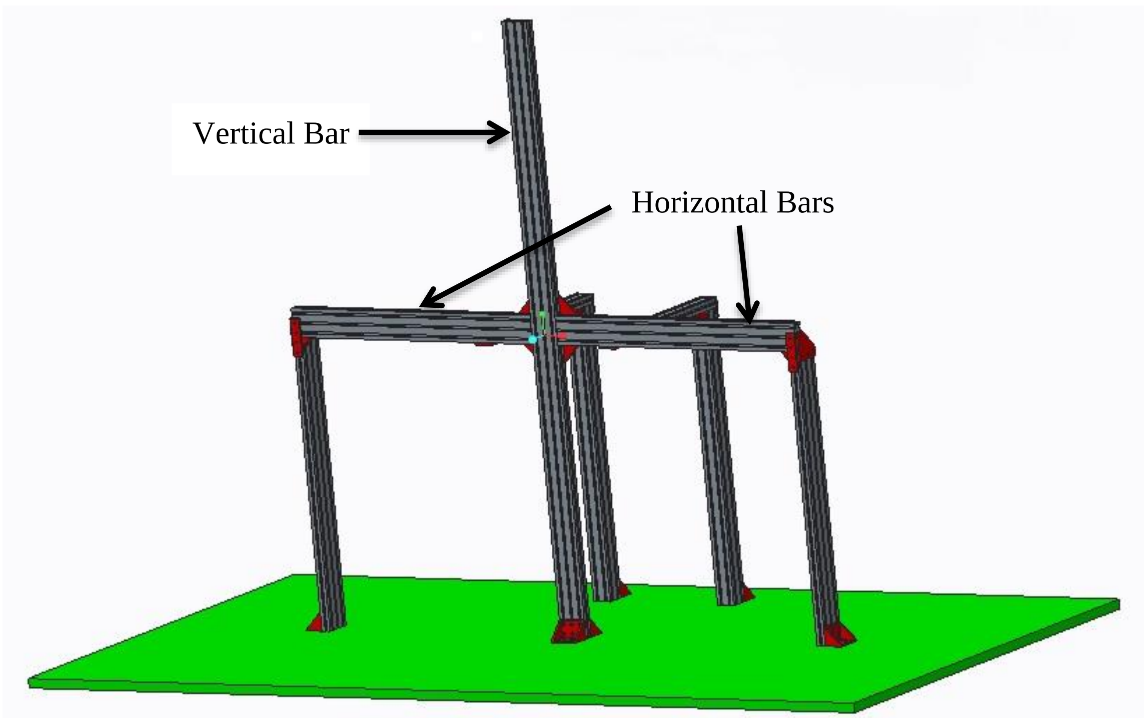


Figure 12: 3D Structure Design

6.1 1-Dimensional Model

The primary concern is that both horizontal bars will deflect downwards, and that the top half of the vertical bar causes deflection due to its unsupported nature. The signal processing done to the received signal requires the structure to be very rigid, as any deflection of the structure would cause the received signal to be processed off of its true phase, causing significant error.

In order to produce some preliminary values for the analysis, the 3D model will be simplified to a 1D model. Since the longest unsupported span is on the top half of the structure, this will be analyzed. It will be represented as a cantilevered beam, analyzed using the Euler-

Bernoulli beam theory. The transverse deflection of the beam is governed by the fourth-order differential equation:

$$\frac{d^2}{dx^2}\left(EI\frac{d^2w}{dx^2}\right) + c_f w = q(x) \quad \text{for} \quad 0 < x < L \qquad \textbf{(1)}$$

At the very top of the beam, a 100 pound force will be applied on the top of the beam along the weak axis of the cross section.

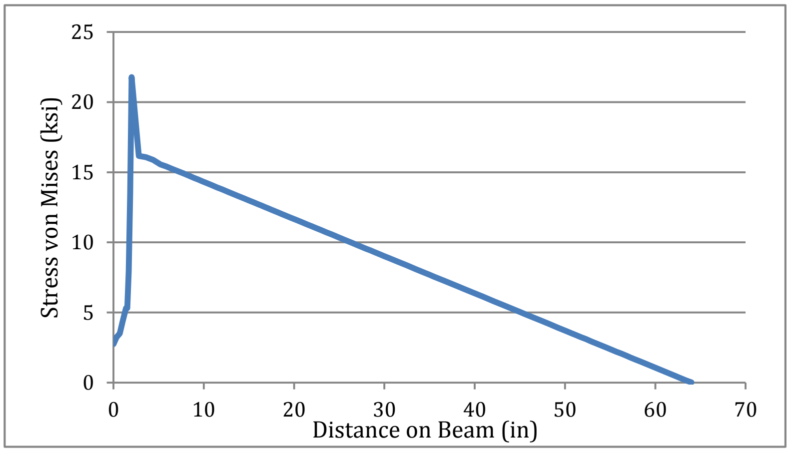


Figure 13: 1-Dimensional model stress

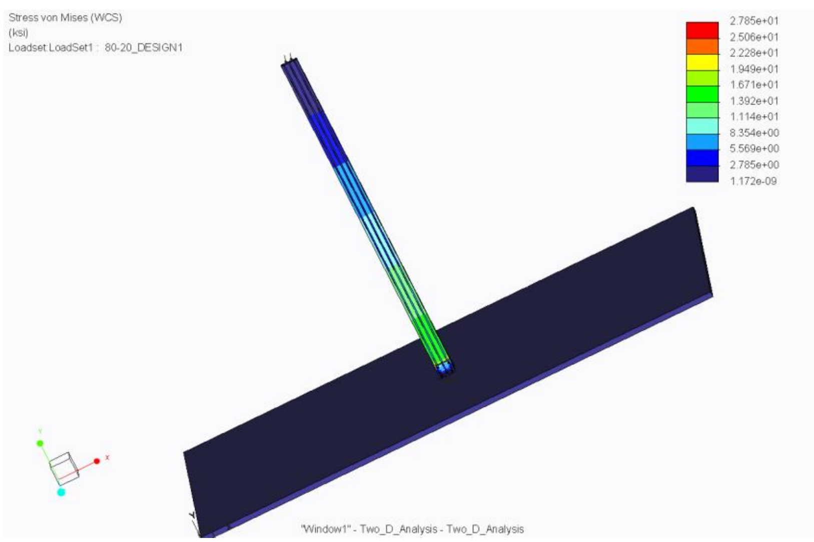


Figure 14: von Mises Stress for vertical bar

The area of primary interest is the bottom portion of the structure. Stress concentrations could develop in the bottom few inches because that is where it is physically clamped to the bottom surface. In the 0 to 5 inch range, there is a spike in the stress where the bracket attaches to the structure. The curve shown indicates that the mesh should be refined due to the drastic changes in slope. This region will receive further attention in subsequent analysis.

6.2 3-Dimensional Model

The full design will be testing using a 3D model. The forces applied will be the 100 pounds on the top vertical bar (same as 1D), as well as 100 pounds on each of the top of the rear supports going downwards, and 100 pounds in the downward direction on each of the horizontal arms that are in-plane with the radar array.

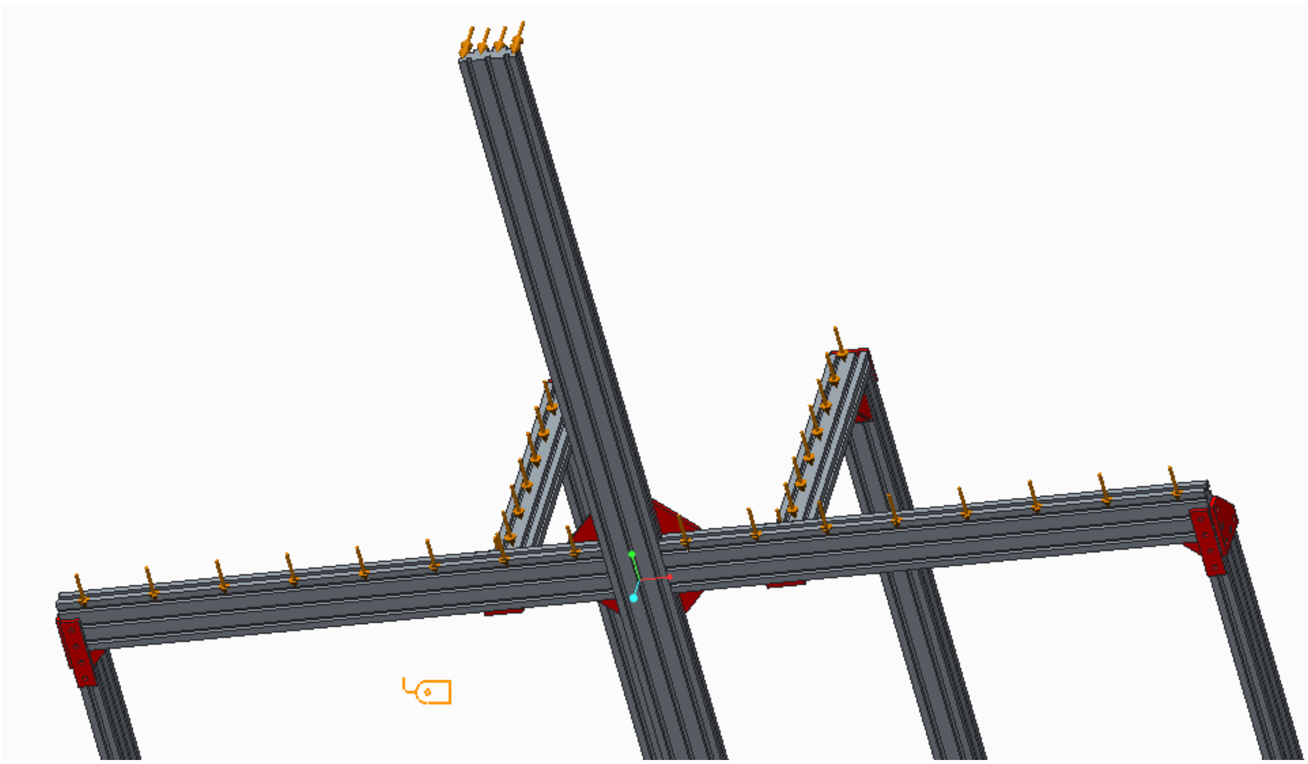


Figure 15: 3D FEM Analysis Loading. The arrows along each surface indicates a 100 pound distributed load. A combined loading for 400 pounds in the vertical, and 100 pounds in the horizontal.

The maximum stress obtained was 7.5 ksi. In regards to the design of the project, this was very optimal considering the maximum allowable stress of the material is 60 ksi. The stress values of the computer analysis on the three dimensional are shown on Figure 16. This tells us that the addition of the horizontal cross beams and legs offer increased rigidity to the center vertical beam.

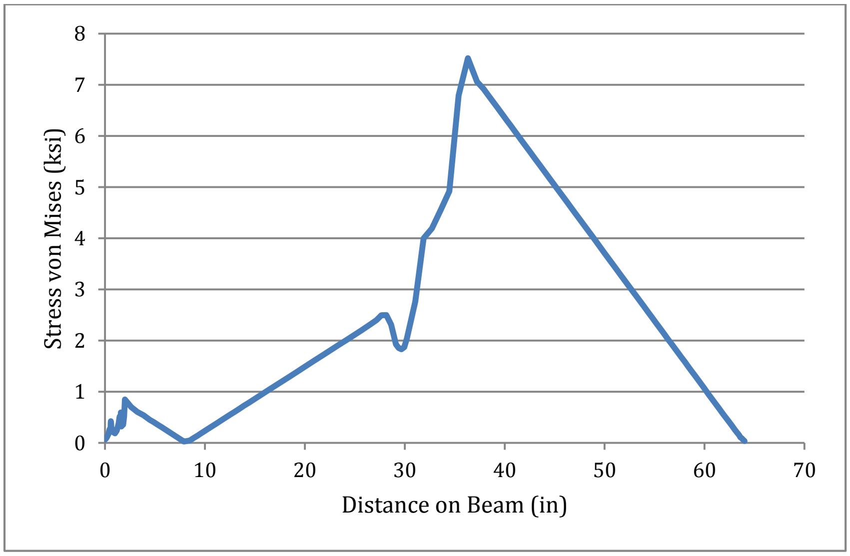


Figure 16: Stress values along vertical beam

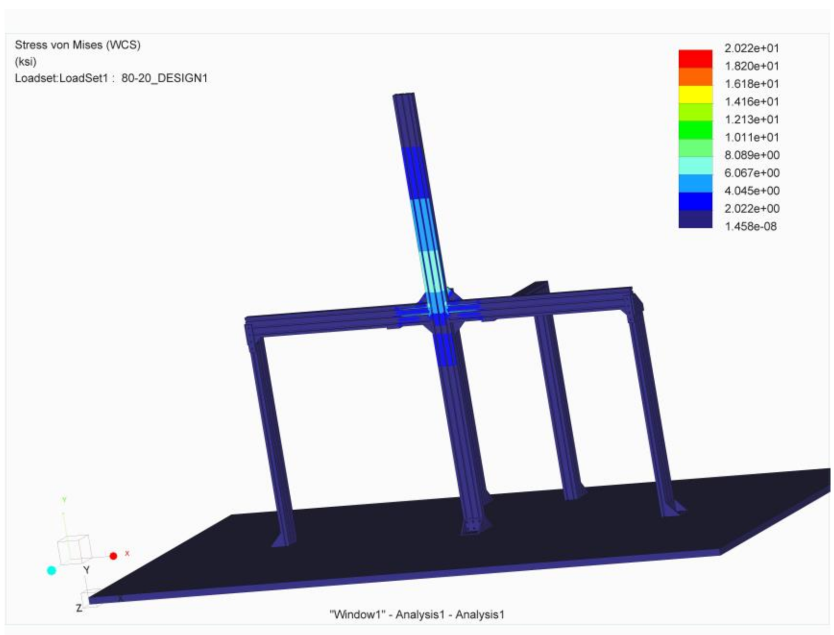


Figure 17: FEM Analysis

The important difference between the 1D and 3D analysis is that the maximum stress is significantly less (7.5 ksi instead of 21.8 ksi) because there were additional supports added to the model. Instead of the center vertical beam having to support all of the load, the other in-plane bars and rear support bars share the load. Another difference about the analysis shown in Figure 17 is that the mesh was greatly refined. There are 146 data points along the line selected to be plotted in Figure 16, and 110 in Figure 13. Considering that this is examining a line within a 3 dimensional structure, the number of meshes increase exponentially.

The data obtained from the analysis was very predictable. The comparison between the computational model and the theoretical model shown in Figure 18 revealed that the values for the computational model had higher stress. Ideally, the stress analysis would have relatively the same values for the maximum stress. The max von Mises stress is 21.8 ksi in 1D, and 7.5 ksi in 3D.

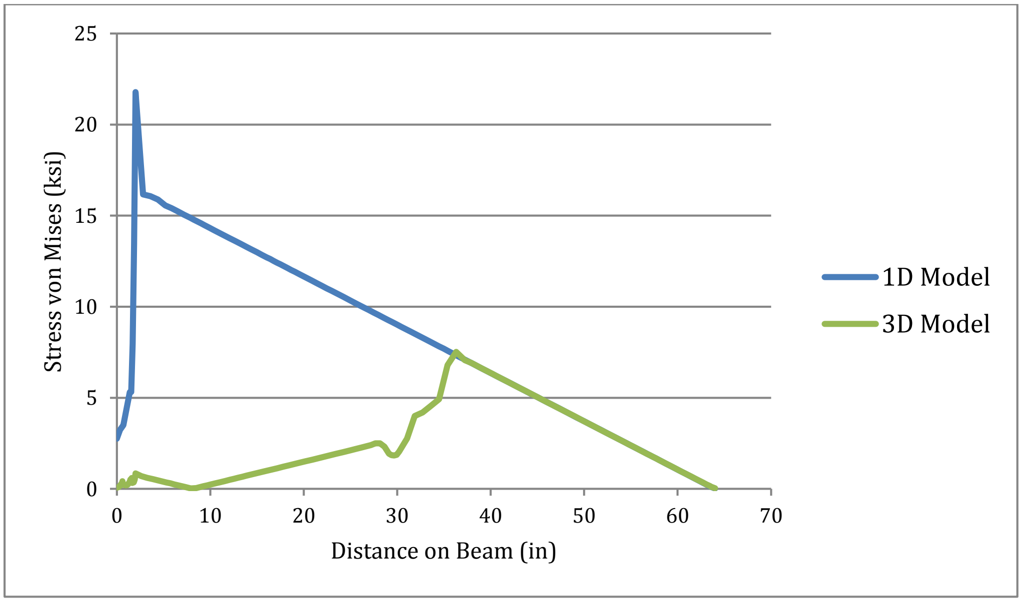


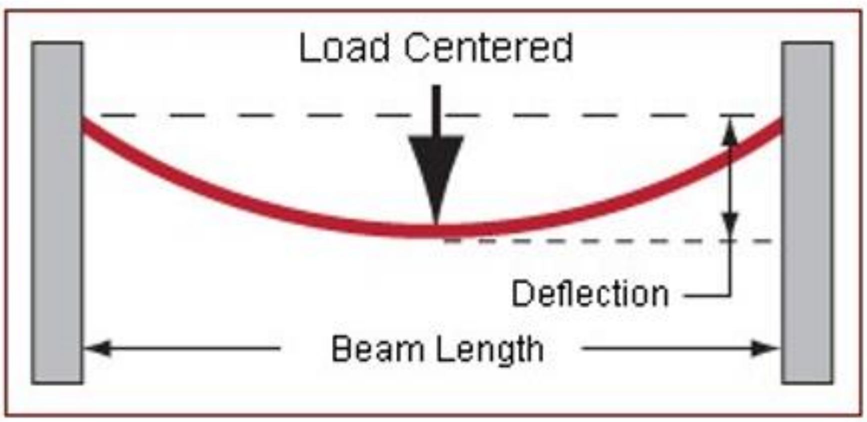
Figure 18: Comparison of values obtained from different methods

6.3 Error and Convergence

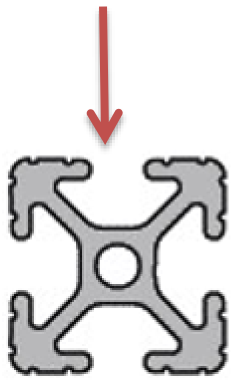
An understanding of finite element analysis must be applied to any results obtained from software. Although a computer is a useful tool, it does not have an inherent understanding of the concepts involved. Results must undergo a "sanity check." Because all of the results shown in Figure 18 are very similar, it is unlikely that one method of analysis introduced an extraordinary amount of error. When the computational analysis was conducted, it was specified in the application that the convergence should reach within 3% at the final iterations. Additionally, the analysis was done using a 6 degree polynomial. Although a higher degree does not always mean a better result, often it does--especially in complex geometries or loadings. Because the results were consistent, and the safety factor used was very high, any small errors are acceptable for this application.

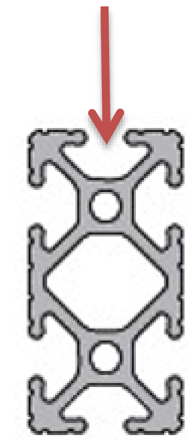
6.4 Beam Analysis

After the structure was fully built, any design flaws or component quirks could be identified. Due to the length of the horizontal chassis beams, it is easy to place a foot on the middle of the structure and apply weight to it. There was a slight amount of deformation that could come of this so analysis of the strength of this pieces cross section was performed. The official 8020 website features a beam deformation calculator. Since the pieces of 1020 are rigidly connected to the four casters which take the whole weight of the structure, it was found appropriate to make the beam rigidly connected at the two endpoints as shown in Figure blah.



The following inputs were made to match our structure requirements including, length of the beam set to 62”, force application to the exact middle due to the presence of the vertical arm. The weight of the Force applied was set to 20lbf to account for the full component box weight at 12.5lbf and the whole vertical beam at 8lbf. To find a beam with more deformation resistance, it was decided to add a second X channel on top of the original one giving us a 1020 piece instead of the 1010. As shown below in Figure blah, the second X on the right adds more material in the vertical direction with the original to the left. Force is applied in the direction of the red arrow at 20lbf.





From the beam analysis, the original beam deforms a total of 0.0623" while the new 1020 piece deforms 0.0098". This results in a six fold reduction of deformation from the 1020 over the 1010 giving us a value of safety that we need.

6.5 Summary

Because the motivation of this research was to offer insight into a creating a product for a senior design project, the impact and usefulness of the report is measured by whether it offers accurate and helpful information of this system. In all versions of the stress analysis, the stress on the structure is well within acceptable bounds. Not only is the calculated stress low, the forces applied to produce that stress were above anything the structure would normally experience. An argument could be made to reduce the material used in the structure to lower cost or weight, but upon the beam analysis it was determined to add more material to increase the rigidity and longevity of the structure. The current design has been verified to be able to endure any stresses applied.

7. Design Iteration

7.1 Structure, S-1

7.1.1 S-1, Version 1

See Section 4.1.1.

7.1.2 S-1, Version 2

While there were no issues with the stress analysis of the structure, additional components were added for convenience. The main horizontal and vertical bars were increased in thickness to accommodate the new horn holder design. There were additional horizontal bars added in the middle of the structure in order to act as something to grab in order to move the structure. The bottom of the structure was framed as well so that castors can be mounted. Figure 19 shows a rough representation of what these addition look like.

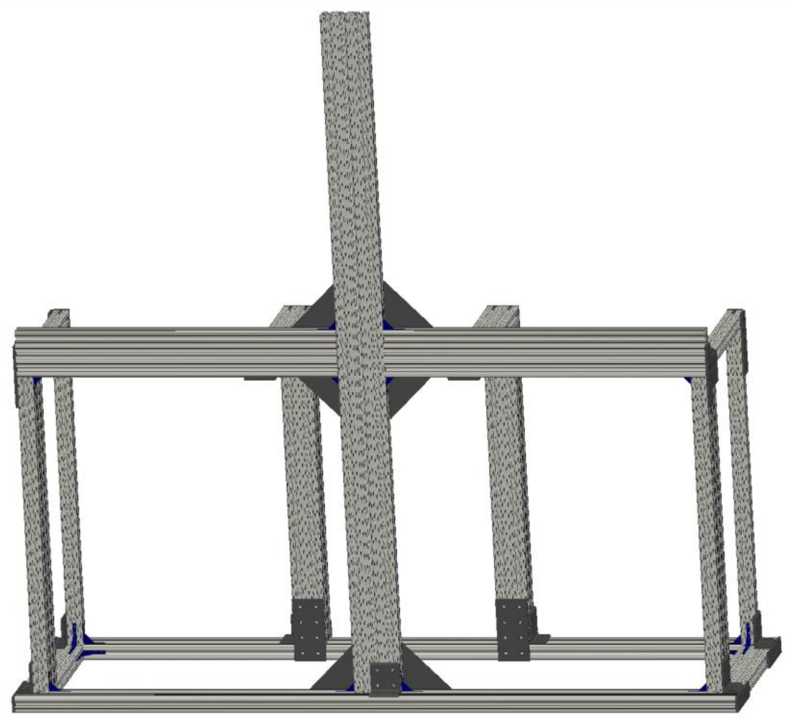


Figure 19: Design S-1 V2

7.1.3 S-1, Version 3

A slight modification was added to Version 2 was to extend the bottom forward bar out from the structure. This addressed a few areas of concern:

- Sponsor requested a laser pointer based testing system that could be mounted to the structure. The bottom platform could be used to mount this to.
- Although tipping would not be a problem when stationary, the extended bar would ensure that if any unexpected forces were applied (i.e., in transit being rolled on wheels), there would be no risk of tipping
- More structure if design were to change

To account for this potential issue, the front of the base was extended 9” forward, while the cross remain in the same position with respect to the rack of the base. This also increase the wheel base depth to 30” which would increase stability of the structure rolling over a tilled floor as shown in Figure 20 below. A piece of 1545-8020 was added in the middle of the rectangular base to give the bottom of the vertical horn beam support. Due to the restructuring, different attachment plates T-slotted nuts can be used to secure the parts together. This results in a cost difference of $233.17.

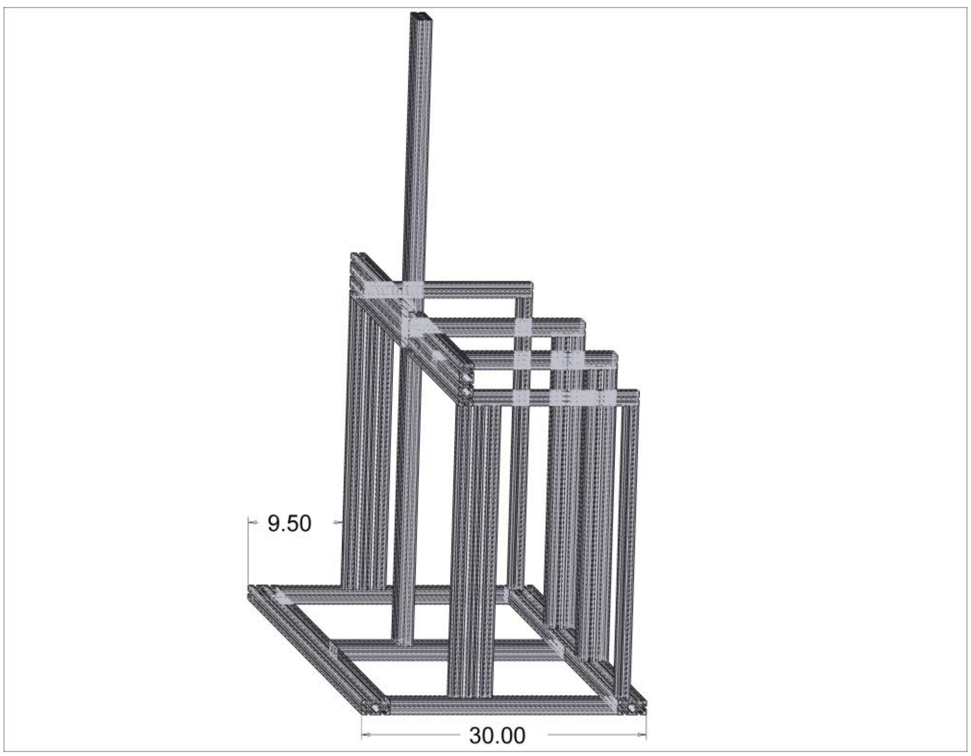


Figure 20: Structure Version 3

7.1.4 S-1, Version 4

To quantify the improvements in weight achieved by this year's project over last year, weight analysis of all the 8020 beams and needed attachment plates was performed. From the numbers given on the 8020 website, the weight of Version 3 was calculated to be 174lbs. This value was not a drastic improvement over the structure of last year at 220lbs. As a result, the structure was changed back to 10 series to get the weight closer to the 80lbs two person Military goal. This design iteration can be seen in Figure 21.

Figure 21: Structure Version 4

One key addition to this design is moving the forward most chassis beam to directly under the Vertical horn holding beam. After talking with the electrical, having any metal in front of the antennas would cause radar reflections and produce inaccurate measurements. The 30" wheelbase was kept to keep the stability of the structure high. The weight of the simple handles on the sides of the structure was also reduced to a lighter series. Leveling casters were implemented as the preferred leveling and movement solution. Additional 45 deg cut pieces of 1010 Aluminum were order to give more rigidity to the structure.

7.1.5 S-1, Version 5

In order to progress with our project, the physical prototype of Version 4 needed to be constructed. After the prototype was completed some key problems arose. Economy Tnuts can only be inserted in the end of the 8020. The nature of how some beams are joined together blocks of the end of some pieces. Slide in nuts from the top face of the channel should be used if any other 8020 beams are to be added later to give more rigidity. The Beam Analysis as performed in an earlier section came about due to the fact that the center beams were drooping down in the middle. Also upon the application of a force, the Rear chassis beam would vibrate in a different motion than the front beam. Going forward is it paramount that we connect these two different pieces to make sure the structure acts as one entire unit.

Even though the leveling casters were a nice in that they took care of the relative mobility of the structure and leveling portion, the small heavily grouted tiles in the A-Side of the Engineering Building did not go together well with the small 2" hard plastic wheels of the caster. During transit over this type of tile flooring, the entire structure would shake violently and even cause some hardware to fall out. All of these problems were taken car of in a final iteration Version 5 as shown below in Figure 22.

Figure 22: Structure Version 5

The Front and Rear Chassis Beams are upgraded to 1020 with the second X channel in the vertical direction. Since the front and back have the same new height, the other beams do not need to be cut but just get raised one inch higher above the bottom of the structure than before. The leveling casters were replaced with 4" soft rubber wheels to give much better mobility over a variety of surfaces. As a result, new leveling hardware needed to be used since the leveling casters did not have a bigger wheel size.

To resolve the problem of not having a leveling option to the structure a two part solution was devised. First, a locking foot that could be locked in a used adjusted position was chosen to rise the rear of the structure above the casters. Next, Special Mitey Mount Anti Vibrational feet as shown in yellow were used to individually align the front of the structure on both the left and right sides. These feet are adjusted by a common socket wrench. The resulting tripod is much easier to adjust than the four leveling casters which is actually an improvement over Version 4. Also to connect the Front and Back chassis beams, a 18" piece of 1030 is used, which conveniently doubles as extra mounting holes for the lockdown foot. Finally a decent amount of milled 45 degree 1010 beams were added to the stricter to resist the Vertical Horn Holder Beam vibration and moment of inertia. These parts have yet to be included on the new structure since the electrical team is performing last minuet tests but they have been delivered to the Engineering College.

7.2 Horn Holders

7.2.1 H-1, Version 1

See Section 4.2.1.

7.2.2 H-1, Version 2

Design H-1 has been modified slightly to be fully compatible with the updated structure iteration. The two 'L' brackets have been replaced by one solid bracket to provide more assurance to the holder's strength. To secure the azimuth and elevation positions, four combinations of a wing bolt, star washer, and lock washer will be used. Recently, the ideal distances between the horns for optimal performance were received from the electrical team. To satisfy those distances, the width of the outer bracket piece was reduced so that there will not be any clearance issues. The shortest distance between horns will be between the transmitter and adjacent receiving horns. To be sure that there will be no clearance issues between these horns, smaller thumb bolts will be used instead of the wing bolts. A total CAD model of this final assembly is shown in Figure 20.

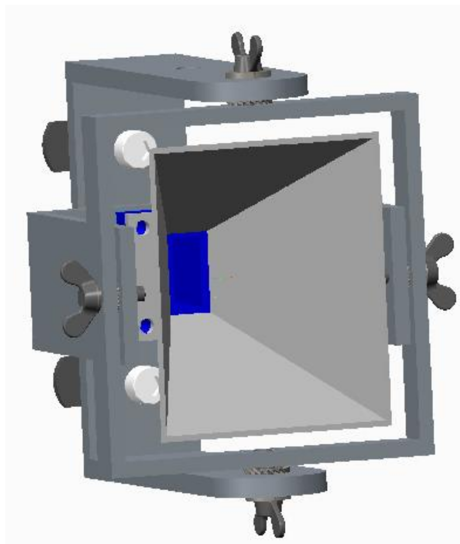


Figure 23: Design H-1, V2

7.2.3 H-1, Version 3

The final horn holder design is shown in Figures 24 and 25. The axes of rotation were moved to the back of the antenna so that the outer bracket dimensions could be reduced to remove all clearance issues. The wing nuts were replaced by thumb screws and the T-nuts were updated to fit the 10-series 80-20 aluminum slots. The back brace, which was originally design to be welded to the upper and lower pieces of azimuth rotation, was change to have clearance holes for screws to go into the threaded upper and lower rotational pieces. All of the components in the horn holder, minus the fasteners, were made out of 0.25-inch aluminum 6061 plates.

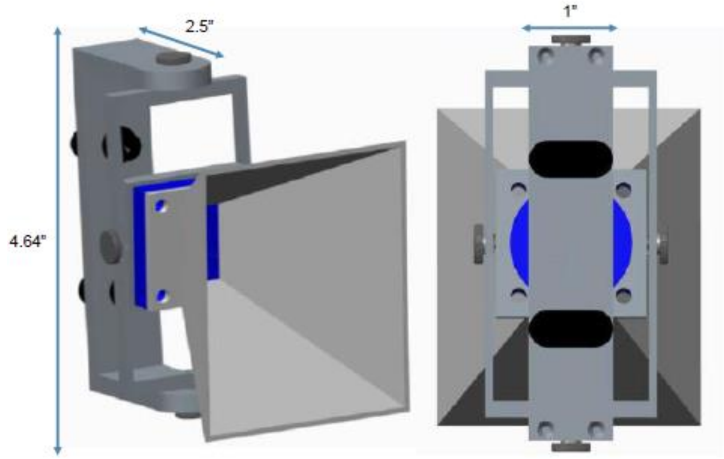


Figure 24: Final horn holder design

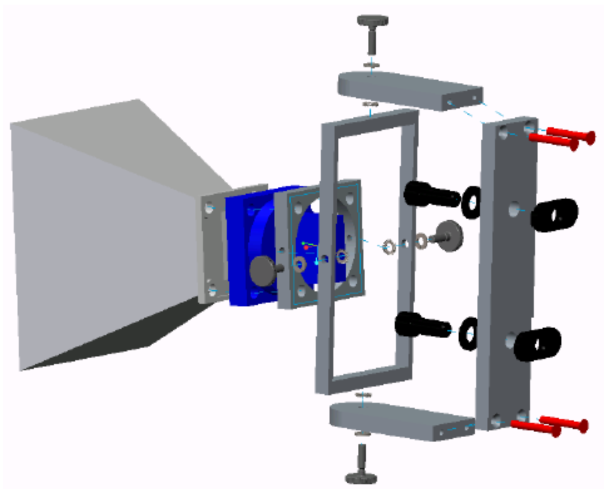


Figure 25: Final horn holder design (exploded)

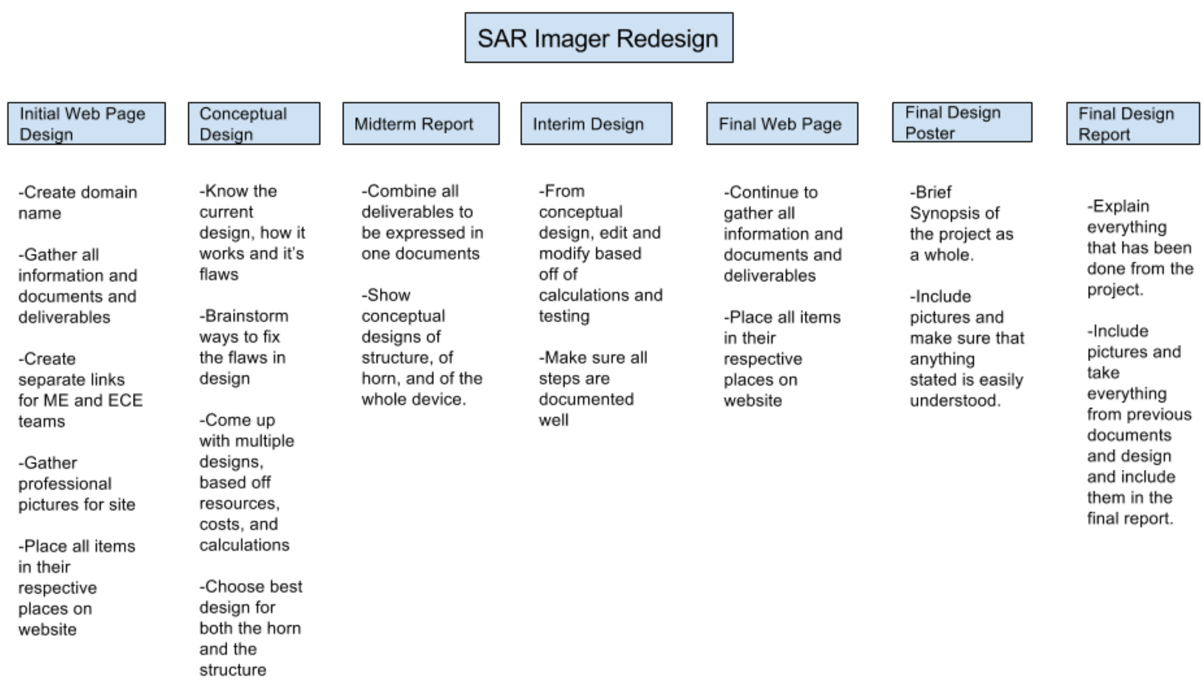
8. Methodology

In order to ensure all parties are up to date and involved in the project process, we will have weekly team meetings, weekly sponsor meetings, and bi-weekly meetings with faculty. The project manager has been tasked with keeping documentation on the process so it can be referred to by the team later in the process, or by another interested party. To apply structure to the project, the following methods have been employed.

8.1 Work Breakdown Structure

In an effort to break down the project into more manageable parts, it has been partitioned in the following sections shown in Table 4:

Table 4: Work Breakdown Structure



There are requirements placed on the team by both the course and the project. Meaning there are deliverables required to obtain grades to pass the course, and also there is an expectation by the sponsors that the project will be completed to a satisfactory level. The work breakdown structure reflects the course requirements. For information on the project requirement breakdown, see

Task Name	Duratio	Start
Design Selection	**27 days**	**Tue 10/13/15**
Procurement	**14 days**	**Thu 11/12/15**
Deliverables	**76 days?**	**Thu 9/3/15**
Procurement	**6 days**	**Mon 1/11/16**
Prepare Drawings for Manufacturing	2 days	Mon 1/11/16
Bill of Materials	2 days	Wed 1/13/16
Submit for Quotation	1 day	Fri 1/15/16
Submit Purchase Order	1 day	Sun 1/17/16
Fabrication	**31 days**	**Fri 1/22/16**
Prepare Schematics	5 days	Fri 1/22/16
Prepare Drawings for machining	5 days	Fri 1/22/16
Fabricate 2 horn holders for testing	7 days	Mon 2/1/16
Submit remaining HH for fabrication	2 days	Mon 2/8/16
Submit 8020 Parts to COE Shop	2 days	Mon 2/8/16
Begin Assembly of Structure	11 days	Thu 2/11/16
Attach Horn Holders to Structure	8 days	Sun 2/14/16
Complete Assembly, Propose Plans for Improvement	[illegible] days	Mon 2/22/16
Implement any improvements	5 days	Mon 2/29/16
Deliverables	**67 days**	**Thu 1/14/16**
Restated Project Definition and Scope/Plan	5 days	Mon 1/11/16
Presentation I	3 days	Fri 1/15/16
Team Evaluation Report I	4 days	Tue 1/19/16
Web Page Update	11 days	Fri 1/22/16
Midterm Presentation I	10 days	Fri 2/5/16
Team Evaluation Report II	2 days	Wed 2/17/16
Midterm Presentation II	20 days	Fri 2/19/16
Team Evaluaion Report III	3 days	Wed 3/16/16
Operational Manual, Design Report	11 days	Fri 3/18/16
Walk Through Presentation	5 days	Fri 4/1/16
Final Report	6 days	Fri 4/1/16
Final Web Page	6 days	Fri 4/1/16
Final Presentation	5 days	Fri 4/8/16
Team Evaluation Report IV	6 days	Fri 4/8/16

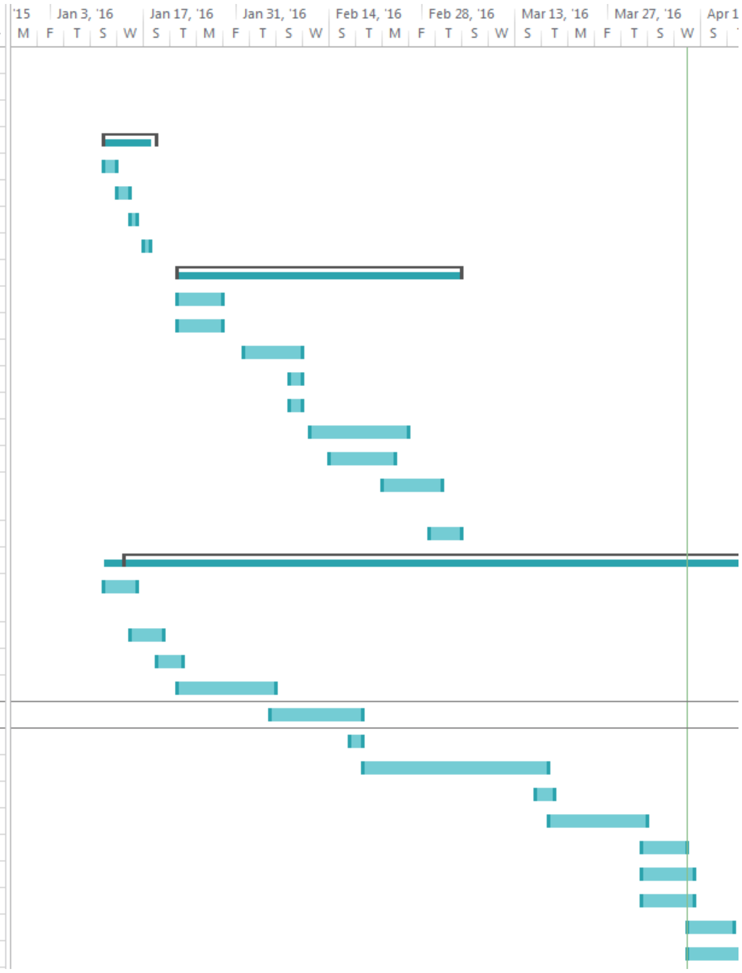


Figure 26.

8.2 Schedule

In order to have a successful project, a clear plan must be laid out. Because there are so many steps in between starting the project and completing it, creating a rigid schedule for every task along the way is difficult. Figure 26A and 26B shows the schedule for the full year broken down into Fall Semester and Spring Semester.

ID	Task Name	Duration	Start	Finish
1	**Planning**	**27 days**	**Thu 9/3/15**	**Fri 10/9/15**
2	Schedule Regular Meetings	7 days	Thu 9/3/15	Fri 9/11/15
3	Agree on Scope of Work with Sponsor	17 days	Thu 9/3/15	Fri 9/25/15
4	Project Plans and Product Specs	11 days	Fri 9/25/15	Fri 10/9/15
5	**Concept Creation**	**16 days**	**Mon 9/28/15**	**Tue 10/20/15**
6	Preliminary Ideas	11 days	Mon 9/28/15	Mon 10/12/15
7	Refine/Eliminate Ideas	1 day	Tue 10/13/15	Tue 10/13/15
8	Detailed Designs	4 days	Wed 10/14/15	Mon 10/19/15
9	Propose Concepts to Sponsor	0 days	Tue 10/20/15	Tue 10/20/15
10	**Design Selection**	**21 days**	**Tue 10/13/15**	**Tue 11/10/15**
11	CAD Modeling	17 days	Tue 10/13/15	Wed 11/4/15
12	Failure Modes Effects Analysis	6 days	Fri 10/23/15	Fri 10/30/15
13	Finite Elements Analysis	10 days	Mon 10/26/15	Fri 11/6/15
14	Propose Final Design	0 days	Tue 11/10/15	Tue 11/10/15
15	**Procurement**	**8 days**	**Wed 11/11/15**	**Fri 11/20/15**
16	Bill of Materials	8 days	Wed 11/11/15	Fri 11/20/15
17	Purchase Orders	5 days	Wed 11/11/15	Tue 11/17/15
18	**Deliverables**	**76 days**	**Thu 9/3/15**	**Thu 12/17/15**
19	Code of Conduct	7 days	Thu 9/3/15	Fri 9/11/15
20	Needs Assessment	17 days	Thu 9/3/15	Fri 9/25/15
21	Project Plans and Product Specs	10 days	Mon 9/28/15	Fri 10/9/15
22	Initial Web Page Design	8 days	Thu 10/8/15	Mon 10/19/15
23	Midterm Presentation I	9 days	Mon 10/12/15	Thu 10/22/15
24	Midterm Report I	15 days	Mon 10/12/15	Fri 10/30/15
25	Peer Evaluation	0 days	Tue 11/3/15	Tue 11/3/15
26	Midterm Presentation II	12 days	Mon 11/2/15	Tue 11/17/15
27	Peer Evaluation	0 days	Tue 11/24/15	Tue 11/24/15
28	Final Web Page Design	12 days	Mon 11/9/15	Tue 11/24/15
29	Final Design Poster Presentation	10 days	Wed 11/18/15	Tue 12/1/15
30	Final Report	22 days	Wed 11/18/15	Thu 12/17/15

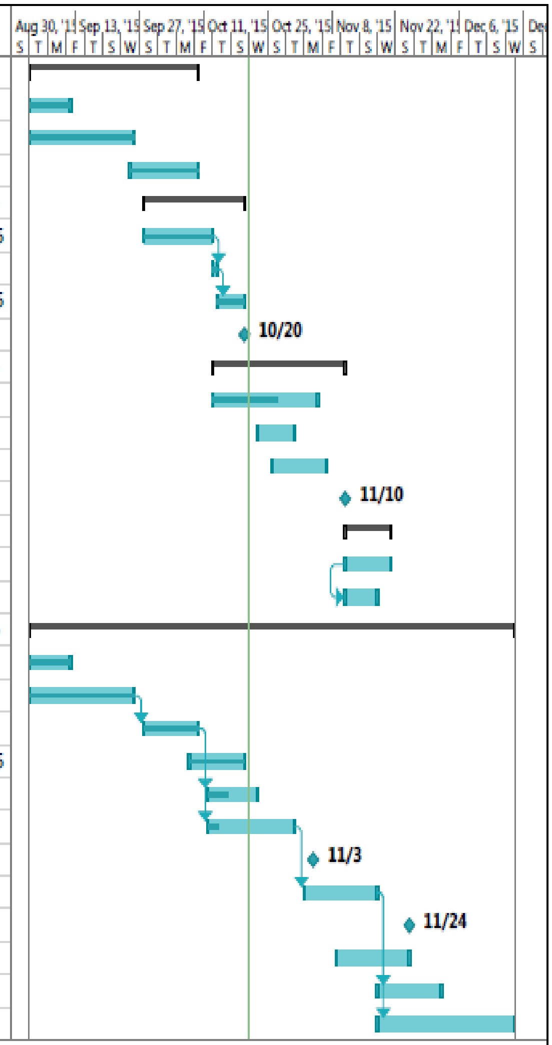
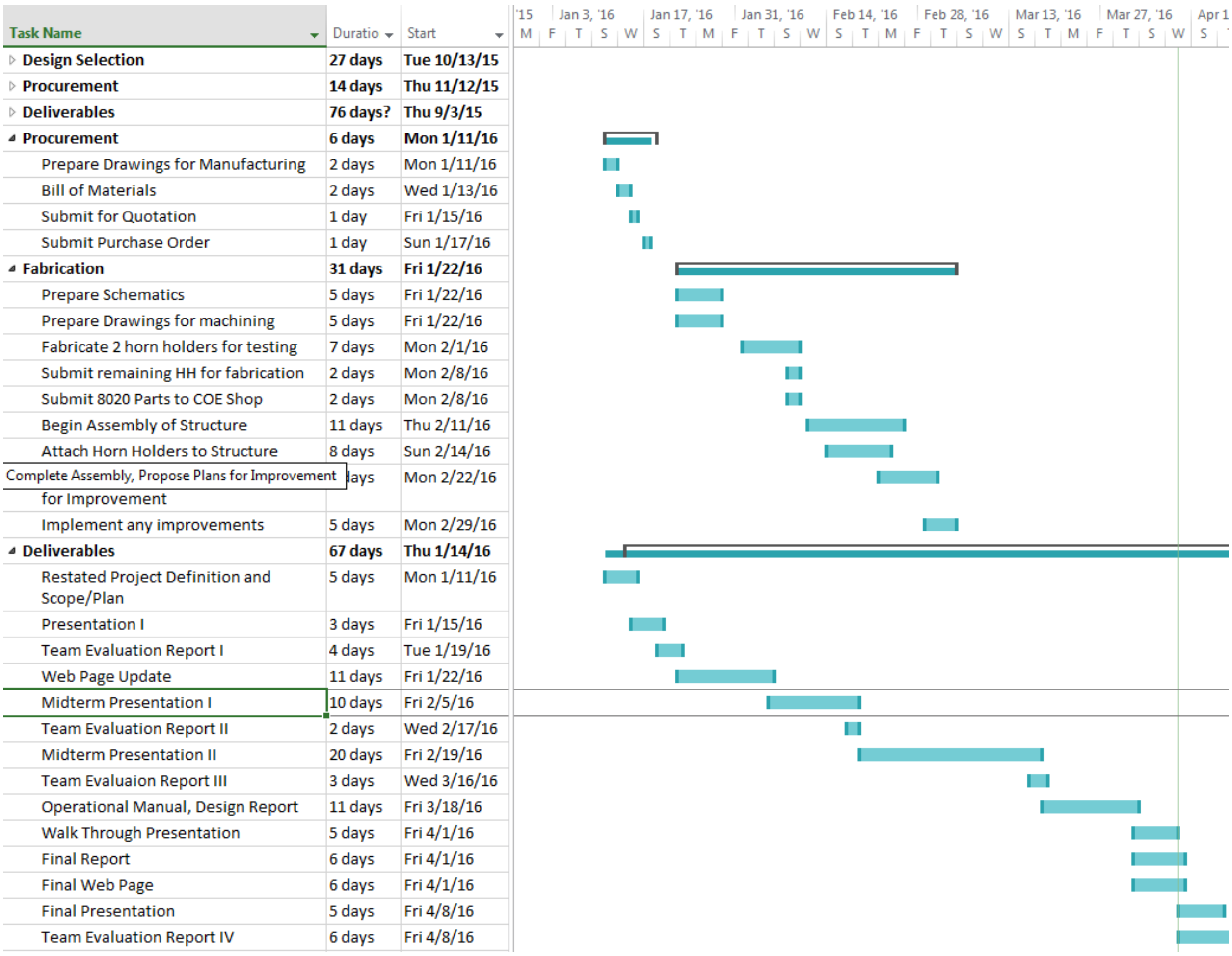


Figure 26A: Gantt Chart for Fall Semester



Task Name	Duration	Start
Design Selection	27 days	Tue 10/13/15
Procurement	14 days	Thu 11/12/15
Deliverables	76 days?	Thu 9/3/15
Procurement	6 days	Mon 1/11/16
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Bill of Materials	2 days	Wed 1/13/16
Submit for Quotation	1 day	Fri 1/15/16
Submit Purchase Order	1 day	Sun 1/17/16
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Operational Manual, Design Report	11 days	Fri 3/18/16
Walk Through Presentation	5 days	Fri 4/1/16
Final Report	6 days	Fri 4/1/16
Final Web Page	6 days	Fri 4/1/16
Final Presentation	5 days	Fri 4/8/16
Team Evaluation Report IV	6 days	Fri 4/8/16

Figure 26B: Gantt Chart for Spring Semester

8.3 Resource Allocation

In order to have a successful project, roles must be assigned and clearly defined for each member. While the group will strive to work cooperatively on all parts of the project, a member has been assigned leadership of specific aspects of each part of the project:

A. Josh Dennis - Team Leader

He is the person responsible for setting all meetings with sponsors, advisors, teachers, and ensures that the group is completing the project based off of what the sponsors are requesting and in an efficient manner. He also keeps track of all documents and ensures that each group member is doing their fair share.

B. Luke Baldwin – Structure Design

It is his responsibility to modify the existing structure by redesigning based off of the needs of sponsors, errors from the previous group, and constraints that are set.

C. Kaylen Nollie - Horn Holder Design

Kaylen has been placed in charge of designing a method to hold the antenna assemblies in a manner that meets all requirements of the operation of the SAR.

D. Desmond Pressey - Web Design, Budget

Has the duty of creating, editing, and translating all relevant information to the web page. Additionally, all purchasing will be handled by Desmond, including obtaining quotes from vendors and submitting purchase orders.

8.4 Ethical Implications

The issue of implied consent will be relevant to the deployment of the SAR Imager. The Imager will search individuals without any direct interaction, so it is important that the individual knows they are being searched. Since the main consideration for deployment is in airports or similar locations where security is already in place, there should not be a need for any additional measures than those already in place.

8.5 Environmental Impacts

This structure does not have any continuous input or output besides power. Any effect on the environment occurs in the production of the specific parts of the product. Since nearly all of the components will be purchased from vendors, the environmental impacts fall outside the scope of the project. The tooling and handling required to operate or maintain this machine is design to be simple. Only Allen wrenches and screwdrivers will be needed, thus eliminating the need for other complicated and potentially harmful materials on the environment.

8.6 Procurement and Budget

A primary goal of the team was to purchase commercial, off the shelf (COTS) components. This would give the benefits of being cheaper and reducing time needed to design and fabricate custom parts. The structure parts were purchased from an 80/20 distributor and all machining was done on their end. This saved time on waiting on the college of engineering machine shop, as well as having faith in the accuracy in the work of 80/20 Inc.

All of the horn holders were fabricated out of aluminum plate. A uniform thickness was used to reduce the number of materials that must be purchased.

There were many "miscellaneous" parts that had to be purchased for this project as well. Whether it was tools, hardware, or testing equipment. These items were purchased from local sources or bought online with 2-day delivery.

Below is the overall budget for this project:

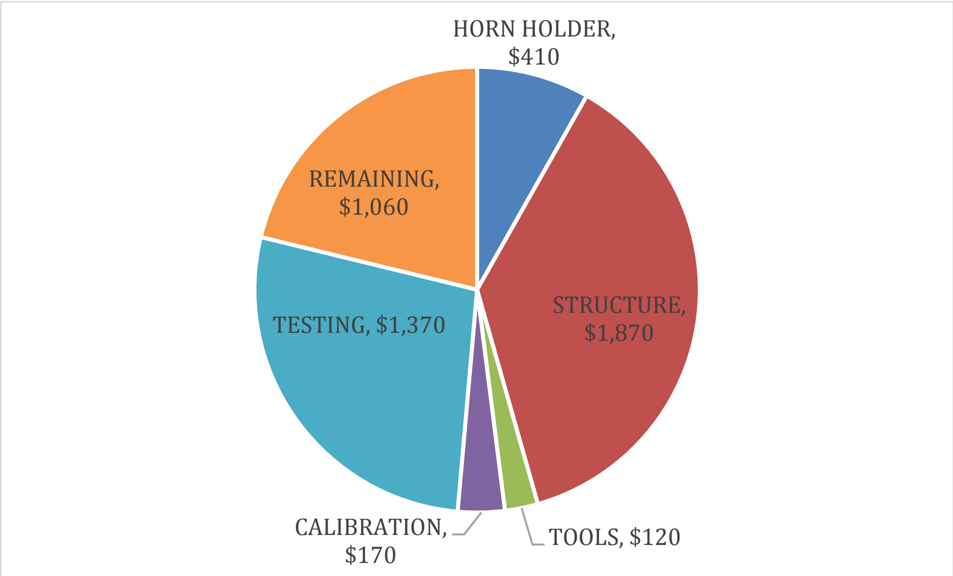

Figure 27: Budget Overview

And the broken down parts list:

Table 5: Parts List

No.	Item	Distributor	QTY	Unit Price	Shipping/Tax	Total Price
1	.249 3003 H14 Aluminum Sheet, 12" x 12"	Amazon	1	$17.57	$0.00	$17.57
2	.125 6061 T6 Aluminum Sheet 12" x 12"	Amazon	1	$14.78	$0.00	$14.78
3	6" DIGITAL CALIPER	Home Depot	1	$34.96	$2.62	$37.58
4	5" DIGITAL PROTRACTOR	Home Depot	1	$19.97	$1.50	$21.47
5	MACH SCR FL HD PH ZINC #6-32X1/2"	Home Depot	2	$1.18	$0.18	$2.54
6	MACH SCR RND HD CMB ZINC #8-32X3/4"	Home Depot	1	$1.18	$0.09	$1.27
7	WASHER LOCK EXT TOOTH ZINC #6	Home Depot	1	$1.18	$0.09	$1.27
8	WASHER LOCK MED SPLIT SS #6 18-8	Home Depot	1	$1.18	$0.09	$1.27
9	100 FT. LINE REEL - TWISTED GOLD	Home Depot	1	$2.98	$0.22	$3.20
10	8020 Products	Adams Air				$828.39
11	Aluminum 6061, 0.125" x 2" x 36"	Online Metals	1	$9.22	$10.41	$19.63
12	Aluminum 6061, 0.125" x 12" x 24"	Online Metals	1	$24.28	$10.41	$34.69
13	Aluminum 6061, 0.25" x 24" x 24"	Online Metals	2	$76.68	$10.41	$163.77
14	JLPS-20B <5mW Green Laser Pointer	Apinex	3	$35.00	$13.00	$118.00
15	AmazonBasics 60-Inch Lightweight Tripod with Bag	Amazon	1	$22.26	$1.67	$23.93
16	AmazonBasics 60-Inch Lightweight Tripod with Bag	Amazon	1	$22.26	$1.67	$23.93
17	HDE Laser Eye Protection Safety Glasses	Amazon	2	$8.99	$0.00	$17.98
18	43 PC Tool Set	Walmart	1	$9.88	$0.74	$10.62
19	25 ft Measuring Tape	Walmart	1	$8.88	$0.68	$9.56
20	22 PC Hex Key Set	Walmart	1	$14.88	$1.12	$16.00
21	Bubble Level	Walmart	1	$3.88	$0.29	$4.17
22	3D Printed Laser Clamp	Shapeways	1	$33.31	$0.00	$33.31
23	8020 Products	Adams Air				$1,042.86
24	Thumb Screw, Knurled, 6-32x3/8 L, Pk5	Grainger	4	19.52		$78.08
25	Thumb Screw, Knurled, 6-32x1/2 L, Pk5	Grainger	4	19.87		$79.48
26	Machine Screw, Phillips, Oval Head, 6-32x3/8 L, Pk100	Grainger	1	5.06		$5.06
27	Machine Screw, Phillips, Oval Head, 6-32x1/2 L, Pk100	Grainger	1	0.91		$0.91
28	Mach Scr, Flat, SS, 4-40x1 L, Pk100	Grainger	1	5.87		$5.87
29	External Tooth Lock Washer, Pk100	Grainger	1	4.42		$4.42
30	Standard Split Lock Washer, Pk100	Grainger	1	2.9		$2.90
31	Mach Screw, Pan, 8-32x3/4 L, Pk100	Grainger	1	$10.54		$10.54

32	C-RAM FAC-3 W/Velcro	PPG Aerospace	16	$68.00	$179.00	$1,267.00

9. Risk Assessment

For the purpose of this report, all risks considered will be limited to safety-related risks. After analysis by the mechanical engineering team, the overall risk of the design was considered to be very low due to the following reasons:

- The structure must weigh under 80 lbs
- There will be no moving parts with high energy in the system
- Low voltages will be needed to operate the components
- The radar was designed to meet federal safety regulations
- The structure will be stationary unless manually relocated
- The structure has decent vibration resistance and resistance to tipping moments

While inspection yielded no major sources of risk, a detailed list of possible risks were outlined in Table 6.

Table 6: Risk Analysis

No.	Description of Risk	Possible Consequences	Probability	Severity	Overall Risk	Plan
1	Electrical components are not properly housed	User is electrocuted	M	M	M	Ensure any component carrying electricity is properly insulated and cannot be accidently touched.
2	Structural failure	Structure could fall on someone nearby	L	L	L	Because it is a low-weight design, proper construction should prevent this failure.
3	Hazardous edges, corners of structure	A sharp edge or corner could cut the operator	M	L	M	Any fabricated components edges' will be smoothed over. Protruding edges will be avoided in design.

10. Summary

The first generation of the SAR project was an achievement in pathfinding, but left much to be desired. This year's mechanical engineering team has been tasked with making significant improvements to mechanical aspects of the project, including cutting weight, lowering cost, increasing stability, and allowing for a better method of horn adjustment.

The hard work of last year's design work and analysis came into fruition. Choosing to use 8020 hardware gave both the Antenna and Structure designers a common goal to make a product that would fit together. The iterative design process for both pieces was validated with the production of a successful prototype. We learned a great deal about product and screw placement from the consulted machinists and physically assembling the unit. Some structure simplifications were overlooked when reducing the weight causing independent vibrations. From these problems, we have found an optimal horn alignment pattern and a set of structure modifications which have yet to be installed due to electrical testing.

One of the most challenging steps was the final system integration of the ME Teams structure and horn holder with the component box design and wire connections from the EE Team. Our two Northrop Grumman sponsors flew in for 3 days to answer our questions and guide both teams to the final completion. Their help has been invaluable to our coherency. Communication between the ME's on both teams ensured that the EE's had their connections in the correct spot despite a fabrication issue with the Machine Shop. From this the ME Team has tackled issues for testing and power wiring so the EE's can spend more time developing their code. Our Team feels confident that we have produced a secure working SAR platform to make a dependable base for the EE Team to send and receive SAR images as accurate and complete as they are able to.

11. Future Work

One of the most important things that made this project success was communication between the two different the Mechanical and Electrical Teams. During wire placement for the power and 16P1T switch, I know how to lay down the wires to low noise and good connections but I had no idea where all the components would end up and where they would connect to the power supply. Without one of the lead EE helping me along I wouldn't know what to do wasting precious time. The next most important lesson was learning physical constraints to building the waveguide adapters. After consulting the machinists, we learned the most cost effective solution would be to water jet all the components together out of one plate and then used machine hardware to assemble all the sides. Even so, some of our tolerances were off from piece to piece which would be a good thing to improve upon for next year's project.

If the project were to continue for next year, our Team agrees with the lead EE in that there should be a focus of Software Engineers and little on Mechanical. The progress our team made over the structure of last year is immense not only is horn alignment and freedom of motion but also Structure mobility and compactness. This basic platform can be expounded upon with future ME's but the structure is already able to be used in radar testing. Despite some complications with reflections in early testing, there is much too learn and be fixed in the coding portion. Image processing can be developed as well as signal path and reflection control. If there were students to devote completely to this task, they might actually be able to get knowledge and find a working solution. After convening with the Lead EE, and our electrical sponsor, they feel like a lot of growth has come in the overall system knowledge and how RF fundamentally works, but as a result they have not been able to dive the software specifics. There is not enough time to learn the theory to a decent level and develop the code. Overall this project should be continued because it involved all the engineering aspects of developing a project from understand customer desires, to initial design work with iterations, to fabricating and making prototype modifications and finally system integration to complete a working product.

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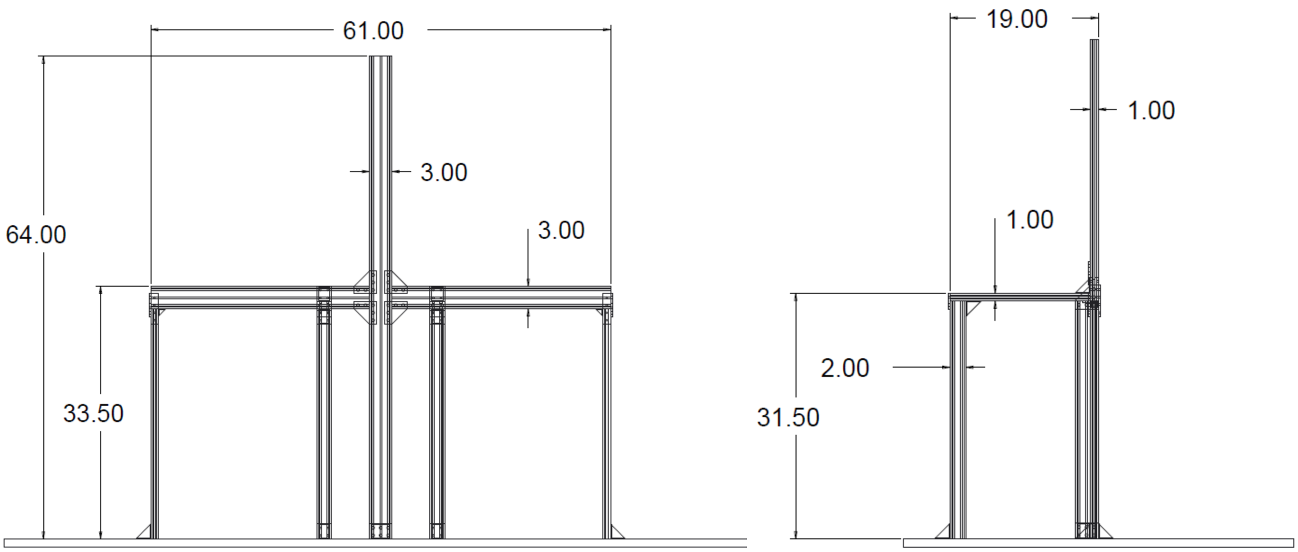
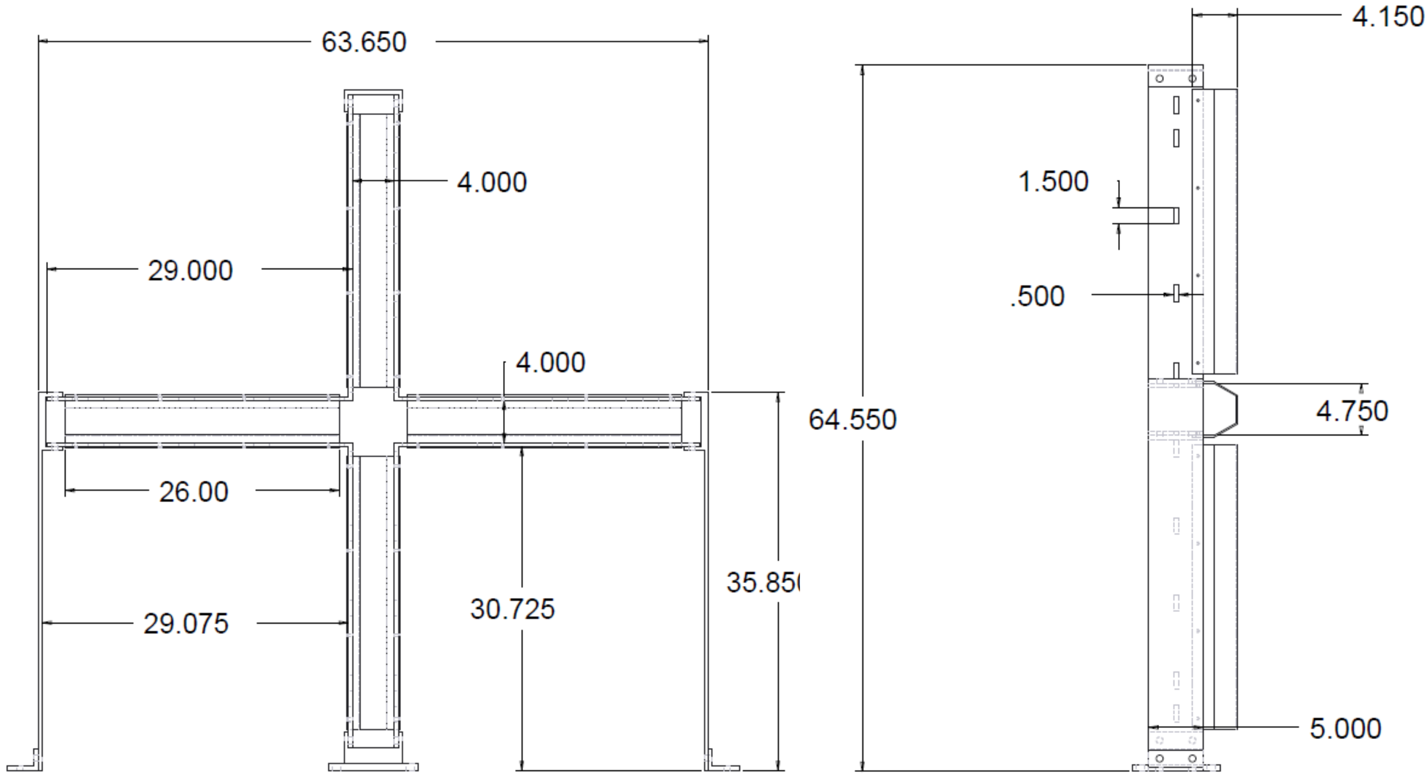
Appendix



Appendix A: Detailed drawings of design S-1 in Inches



Appendix B: Detailed drawings of design S-2 in Inches

Biography

Luke Baldwin, Structure Designer:

Luke Baldwin is a senior in the Mechanical Engineering department pursuing a speciality in Aerospace Engineering. He is working part time as a Research Assistant at the Florida Center for Advanced Aero Propulsion learning about the experimental techniques of PIV and Shadowgraphy.

Josh Dennis, Project Manager:

Josh is a Mechanical Engineering major with a concentration in Material Science. Josh will graduate in April 2016 with his Bachelors of Science degree. He is currently employed at an engineering firm in town working on industrial plant design and construction management. His significant contributions include developing proprietary programs that assist in automating database management.

Kaylen Nollie, Antenna Designer:

Kaylen Nollie is a Mechanical Engineering student from Richmond, VA. She has previously worked as a mentor to incoming Engineering students as well as tutored in Calculus I, Calculus II, Calculus III, Physics I, and Physics II for the College of Engineering. She is also a Naval ROTC student who is graduating and commissioning as a Naval Officer in Spring 2016.

Desmond Pressey, Financial Advisor and Website Administrator:

Desmond Pressey is a senior Mechanical Engineering major from Orlando, FL, enrolled at Florida A&M University. Desmond is currently involved with a number of clubs and organizations including, NSBE, Theta Tau Engineering Fraternity, and is the president of the Society of Engineering Entrepreneurs. He is also a mentor for pre-engineering students.

FAMU-FSU College of Engineering

Operation Manual

Team #18

SAR Imager

Instructors:	***Dr. Nikhil Gupta and Dr. Chiang Shih***
Sponsor:	***Michael Blue***
Faculty Advisor:	***Dr. Dorr Campbell***

Submitted:
April 1st, 2016

Members:	***ID:***
Luke Baldwin	***lrb11e***
Josh Dennis	***jad11d***
Kaylen Nollie	***kn11e***
Desmond Pressey	***drp14***

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ABSTRACT

Synthetic Aperture Radar is an advance technique of measuring a high resolution radar signature with a smaller antenna. The purpose of this project is to use SAR technology to create a low-resolution image for homeland security applications. Our product will be able to scan individuals for metal objects in order to designate people who need additional security screening. From contact with our sponsor, Northrop Grumman, our team has developed a concise problem statement: “Design an improved housing structure for the SAR Radar array.” This project is a continuation from last year’s senior design group. New objectives for this year include lowering the weight, making the structure more stable, fixing the antenna horn mounting and alignment, and reducing cost. The purpose of this document is to provide the reader with the knowledge to build and operate the design.

1. Functional Analysis

1.1 Introduction

In partnership with the FAMU/FSU College of Engineering and Northrop Grumman, the objective of the Synthetic Aperture Radar (SAR) Imager Project is to develop a low-cost weapon detection system that provides suitable imagery resolution for physical security and military force protection applications.

Current detection technologies commonly employed in the security industry such as metal detectors, Advanced Imaging Technology (AIT) scanners, and x-ray scanners can be expensive, obtrusive, and require the subject to be inside the apparatus. An imager based on SAR technology, composed primarily of commercial-off-the-shelf (COTS) components, can be implemented at a lower cost than many industry-standard scanners; it may be placed behind a barrier, out of view from subjects; and most importantly, it can identify concealed metal objects from a distance.

In environments with multi-layered physical security protocols, the SAR imager's superior range can alert security professionals to potential threats before they reach an access control point, or before they progress further into a secure area, depending in which security layer the SAR is deployed. Some environments may be vulnerable to physical attack, but conventional AIT body scanners are too obtrusive or inefficient. An amusement park, for instance, might have high-level security needs, but their customers would not tolerate stepping into a full-body scanner.

Furthermore, random screening protocols have been widely criticized for being culturally or racially biased in practice. With SAR capability, guests can be discreetly imaged while queuing, and persons of interest can be identified for additional screening based on the presence of metal signatures rather than the caprice of a human screener.

This project is a continuation from last year. The first team to work on the project made major progress in pathfinding for this very unique, challenging project. While the work done by last year's team was an impressive feat for a first generation product, there are many things that can be improved upon this year. Two engineering teams are assigned to this project: one Electrical, and one Mechanical team. While the two groups work in tandem, this report will primarily consider the scope of the mechanical engineering team.

1.2 Project Objective

Our objective is to make a SARS imager with a purpose of creating a strong security system to protect against threats in public places such as movie theaters and stadiums. People are able to conceal weapons such as handguns or even bombs in public areas without anyone having any knowledge that someone has a weapon and could be a potential perpetrator of mass murder or anything with malicious intent. The difference between a tradition SARS imager is that this device will be on the ground with a target that is horizontal and also that the device will have multiple stationary antennas that is sending data to be stored electronically by taking images of a target that is moving, specifically a human being. Instead of using it in the air, this will be used on the ground and taking images horizontally. The imager should be fully functional, uses materials that are commercially used and low in cost, and also creates a low but useful resolution of an image that can detect concealed weapons.

Because this is a stationary SAR, multiple antennas must be used to create the synthetic length of the radar. There are 16 antennas that transmit radar, and 4 that receive – the 4 outermost antennas. The received signal will be passed to the electrical components for modification, and that data will be sent to a laptop for post-processing. The output will be low-resolution displace of the 40x40 inch scene. This system is shown in Figure 1.

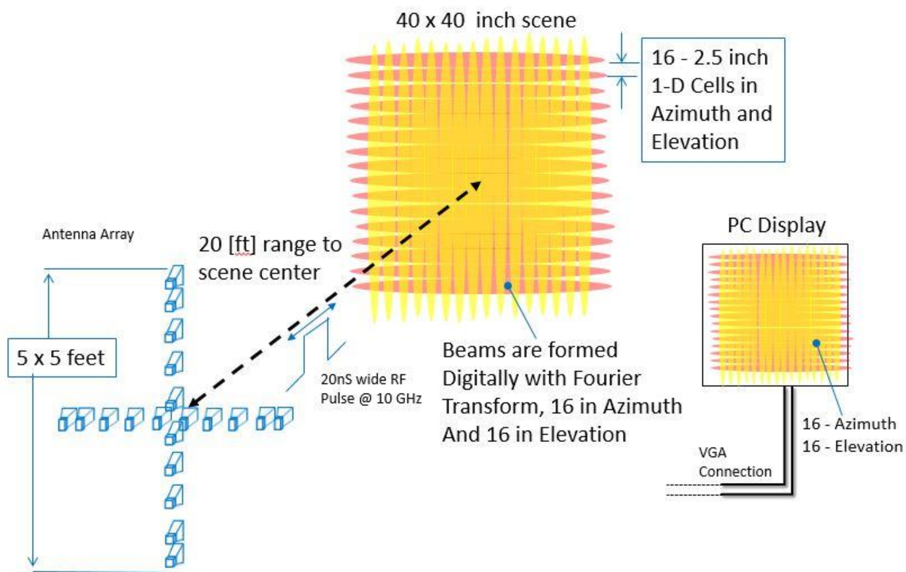

Figure 1: Antenna Array Creating Image (1)

2. Project/Product Specification

Table 1 is the parts list which includes the dimensions for each part used for design for the Synthetic Aperture Radar System.

Table 1: Parts and Description

1	.249 3003 H14 Aluminum Sheet, 12" x 12"	HORN HOLDER	Amazon	1
2	.125 6061 T6 Aluminum Sheet 12" x 12"	TESTING	Amazon	1
3	6" DIGITAL CALIPER	TOOLS	Home Depot	1
4	5" DIGITAL PROTRACTOR	TOOLS	Home Depot	1
5	MACH SCR FL HD PH ZINC #6-32X1/2"	HORN HOLDER	Home Depot	2
6	MACH SCR RND HD CMB ZINC #8-32X3/4"	HORN HOLDER	Home Depot	1
7	WASHER LOCK EXT TOOTH ZINC #6	HORN HOLDER	Home Depot	1
8	WASHER LOCK MED SPLIT SS #6 18-8	HORN HOLDER	Home Depot	1
9	100 FT. LINE REEL - TWISTED GOLD	TESTING	Home Depot	1
10	8020 Products	STRUCTURE	Adams Air	
11	Aluminum 6061, 0.125" x 2" x 36"	TOOLS	Online Metals	1
12	Aluminum 6061, 0.125" x 12" x 24"	TESTING	Online Metals	1
13	Aluminum 6061, 0.25" x 24" x 24"	HORN HOLDER	Online Metals	2
14	JLPS-20B <5mW Green Laser Pointer	CALIBRATION	Apinex	3
15	AmazonBasics 60-Inch Lightweight Tripod with Bag	TESTING	Amazon	1
16	AmazonBasics 60-Inch Lightweight Tripod with Bag	TESTING	Amazon	1
17	HDE Laser Eye Protection Safety Glasses	CALIBRATION	Amazon	2
18	43 PC Tool Set	TOOLS	Walmart	1
19	25 ft Measuring Tape	TOOLS	Walmart	1
20	22 PC Hex Key Set	TOOLS	Walmart	1
21	Bubble Level	TOOLS	Walmart	1
22	3D Printed Laser Clamp	CALIBRATION	Shapeways	1
23	8020 Products	STRUCTURE	Adams Air	
24	Thumb Screw, Knurled, 6-32x3/8 L, Pk5	HORN HOLDER	Grainger	4
25	Thumb Screw, Knurled, 6-32x1/2 L, Pk5	HORN HOLDER	Grainger	4
26	Machine Screw, Phillips, Oval Head, 6-32x3/8 L, Pk100	HORN HOLDER	Grainger	1
27	Machine Screw, Phillips, Oval Head, 6-32x1/2 L, Pk100	HORN HOLDER	Grainger	1

28	Mach Scr, Flat, SS, 4-40x1 L, Pk100	HORN HOLDER	Grainger	1
29	External Tooth Lock Washer, Pk100	HORN HOLDER	Grainger	1
30	Standard Split Lock Washer, Pk100	HORN HOLDER	Grainger	1
31	Mach Screw, Pan, 8-32x3/4 L, Pk100	HORN HOLDER	Grainger	1
32	C-RAM FAC-3 W/Velcro	TESTING	PPG Aerospace	16

Following are dimensions of the basic structure:

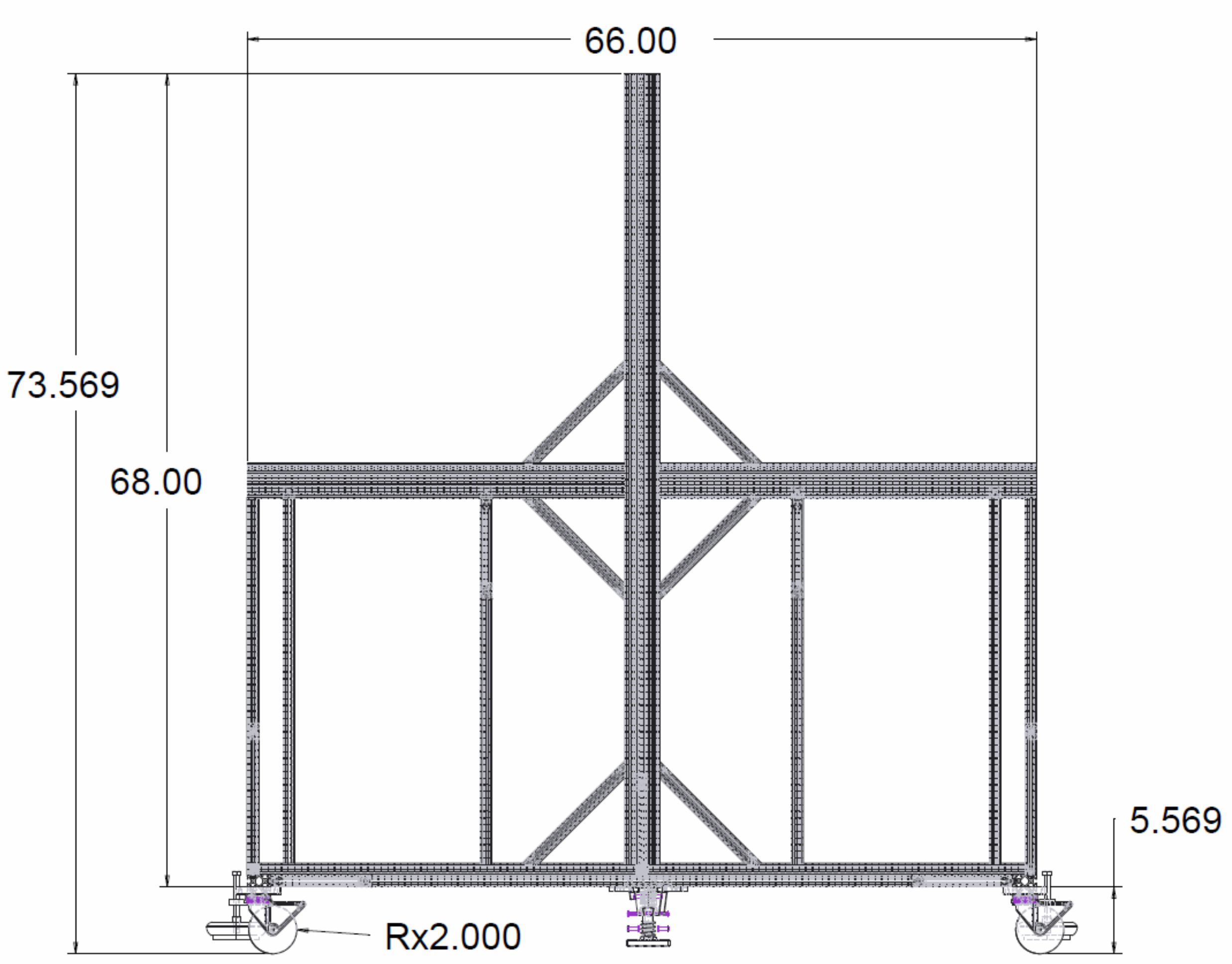

Figure 2: Structure - Front View

3. Product Assembly

3.1 Structure Assembly

As a general note, the design of the 8020 structure and the use of economy T-nuts forces all of the nuts to be inserted into the respective Aluminum before it is bolted together. After some pieces are joined, it will be impossible for economy nuts to be inserted through the end of the given 8020 piece. During assembly, it was found efficient to use two set of hands for alignment/assembly and to pre-connect all the connecting plates with the maximum screw and T-nut number. Two hex keys were required to assemble the structure sized 5/16" and ¼". In terms of geometric channel convention, top refers to the channel that faces the sky, bottom for the channel facing the floor, front for channel facing the target circle--as if you were looking into the open antennas--and finally rear for the channels that points away from the back of the structure. Each paragraph explains the details for spacing connector plates and a subsequent assembly step for multiple beam sub-assemblies.

3.1.1 Assembly of Base Back Connection Bar

To assemble the structure first take one of the long 1010 Al pieces 62" long spanning from left to right. Then slide only one screw of the 4117 plate on the rear face with the examining screws faced upward about 10 inches from the center on either side. Take two of the 4136 connector plates and slide both of the screws on one side in on the top channel. Make sure that the vertical portion of unused connections points towards the middle of the beam right next to the 4117's. Next slide a 2570 piece of bracing 8020 through the front channel right near the end. Finally take a 4017 plate and slide one screw through the front face right after the 2570 with the other open screw pointing upwards.

3.1.2 Assembly of Baes Front Connection Bar

Take the second piece of 62" long 1010 and slide onto the rear channel the bottom row five screws of the 4201 plate. Leave the remaining 2x3 grid of screws facing upwards, this will be used to secure the main center beam. As on the Back Connector, take two 2570 brace's and slide one screw on to the front channel of each end. Take two more 2570 connectors and slide them through the top channel of the 1010 for additional center beam support. Finally take two holes of a 4117 plate and slide them into the bottom channel. The other open two screws will be used to connector to the wheel supports. Then slide one screw of a 4136 plate with the vertical open screws pointing away from the center of the beam.

3.1.3 Assembly of Base Wheel Supports (x2)

Two of these pieces will be made to a mirror image of the other. DO NOT make two of the same piece. Take a 30” piece of 1020 with the two x channels making a plane with a normal in the vertical direction. The length goes from front to back. On the very end of the top channel, slide two of the screws of a 4117 plate through the two parallel channels. Make sure that there are two screws on one side; do not split the 4117 in the middle of the 1020. To make the second Wheel Support, slide the other two end screws of the 4117 on the top of the channel with the open screws on the other side of the Aluminum bar.

3.1.4 Joining the Back Connector and Wheel Supports

The base of the SAR structure can now be completed. Take the pieces assembled in Steps 1 and 3. The Wheel Support 1020 with the open 4117 screws facing to the right will become the leftmost wheel base and vice versa. Take the hanging 2570 bracket on the 1010 piece and slide the open screw through the front of the right channel. Then slide the wheel base out to slide the open two screws of the 4117 piece through the top of the 1010 piece. Make sure that the rear of the 1020 and 1010 pieces are flush with each other. Then repeat this step on the other side. Tighter down these plates loosely so that the structure can be moved to slide the Base Front Connector Bar through the front.

3.1.5 Completing the Base

This piece is difficult to get into position due to the many connection points of Step 2 to the two Step 3 parts. First, slide the other open end of the 4136 plate hanging of the top of the 1010 into the inside top channel of the 1020 part 3 on each side. Simultaneously, align the exposed two screws of the 4117 on the bottom of the 1010 piece with the two parallel bottom channels of the 1020. This needs to be done on each side of the piece. Slid the Front Beam backwards and align the open side of the 2570 bracket mounted to the front face with the inside channel of the 1020 Wheel Base. Then slowly shimmy each side until the rear face of the Front Beam is 19” away from the rear face of the Back Beam. Immediately tighten down all the screws on the Back Beam and two Wheel Base Beams followed by those of the Front beam. The base is complete.

3.1.6 Mounting the Vertical Beam

Take the 66” long 1030 beam with the three parallel channels facing normal to the target in a vertical orientation. Align the two 2570 brackets attached to the top channel of the Front Beam to the left and right channels of the 1030 piece. Once threaded through, make sure the 2x3 set of open screws form the 4201 on the rear face of the Front Beam to the rear face of the Vertical Beam.

3.1.7 Horizontal Arm Legs (x2)

Now take on of the 31.5" pieces of 1010 and slide a 4117 connector with three screws into the left face. Slide the one remaining screw through the left face of the 1020 Wheel Support beam. Then slide the 1010 piece up to fit the right face through the open end of the 4136 joining the 1020 Wheel Support and 1010 Front Beam. Repeat this process for the other le making sure the 4117 is on the outside and the 4136 is on the inside.

3.1.8 Horizontal Arms (x2)

Again we will make two mirror image parts. First slide a 2570 brace through the left and right faces of the Vertical Beam. Then in the rear face of the Vertical Beam, Slide the five screw row of a 4201 through the left most channel with the 2x3 grid of open screws. Now slide a 4136 on the inside face of the Part 7 addition with the unused nuts facing up and toward the inside of the structure. Now slide two screws of a 4117 on the top of the rear face of the Part 7. Now slide the 1030 Horizontal Arm of 31.5" from the outside toward the center with the bottom channel through the 4136 and two of the three rear face channels through the two open screws for the rear faced 4117. Now slide one end of a 4107 through the bottom channel with the open screw pointing backwards. Bring up the dangling 2570 Brace and slide the open end through the bottom face of the Horizontal Arm. Slide one more 4117 plate like the first before lining up the same way as the previous one. Next slide a 4136 on the bottom rear face channel with the open screws pointing towards the inside of the structure. Now you can slide the Horizontal Arm onto the open 2x3 grid of the 4201. Repeat this process on the other side making sure the vertical symmetry is preserved. This step will prove complicated in aligning the piece to make a perfect cross due to the tolerance in the Tnuts and plates. Make sure that the arms are level with each other and perfectly orthogonal to the center beam and you will complete this step.

3.1.9 Component Box Legs (x2)

Now take the 19" 1010 and the 31.5" piece of 1010 to make the back legs. Slide a 4136 on the front face of the 31.5" piece at the top with the other screws on the bottom face of the 19". Then take a 4117 plate and slide three of the screws onto the outside of the 31.5" leg. Then slide the 19" horizontal portion of the leg onto the final screw of the 4117 also on its outside face. Repeat this process with the 4117 plate on the other side. The legs can now be attached to the structure. Slide the left leg through the open two nuts of the 4136 brace on the left face of the leg. Simultaneously slide the open three screws of the 4117 on the rear face of the leg from the Rear Beam. Now slide the front of the 19" Box Leg through the 4136 on the back of the 1030 Horizontal Arm and the three open screws of the bottom face 4117. After these are in place tighten everything down.

3.1.10 Arm Handles (x2)

Both of these pieces are identical and slide on the farthest from center open 4107 pieces of the Part 8 and the open 4107 pieces on the Rear Beam. It is important to note that 1050 series 8020was ordered to save weight and offer a smoother grip for people to move the structure. However, the right length pieces were given to us in a 1030 cross section, impossible to make into a handle so extra 1010 was sacrificed to make this piece. Take a 19" piece of 1010 and join a 4136 plate to the bottom face with the unused nuts point toward the rear. Then slide the 31.5" 1010 piece through these holes so that the rear plane of the 31.5" piece is flush with the rear plane of the 19" piece. Attach these arms to the open two 4107 plate and tighten down everything. At this point the structure is completed

3.1.11 Castors and Plates (x4)

First make sure that the 2406 Caster Plates have 4 screws in a 2x2 grid to match up with the 1020 Wheel Base Beam. Rotate the structure face up to add the top casters. Slide the 2x2 grid onto the bottom face of the 1020 arm aligning the edge of the 1020 with the edge of the 2406 and tighten. Then take the 2714 Leveling Caster and screw it onto the four screws of the plate. Repeat this step on the other 1020 Wheel Base. Then rotate the structure with the face down and repeat the same process on the back two casters making sure that the edge of the 2406 is lined up with the edge of the 1020 Wheel Base. Once this is completed, the structure is fully assembled.

Figure 3: Fully assembled structure

3.2 Horn Assembly

The Synthetic Aperture Radar System has two main components that are the focus for the mechanical aspects of the design: the structure and the horn holders. The structure is made of 8020 material and the horn holder's attachment piece is also made of this material. The attachment piece is shown in Figure 4 and slides in the slots of the structure's design, which is shown in Figure 3. The horn holders are also able to move in both azimuth and elevation while still being able to be locked, using screws, without affecting any degree of freedom. The components of the horn holders which causes movement in the azimuth and elevation are also shown in Figure 4.

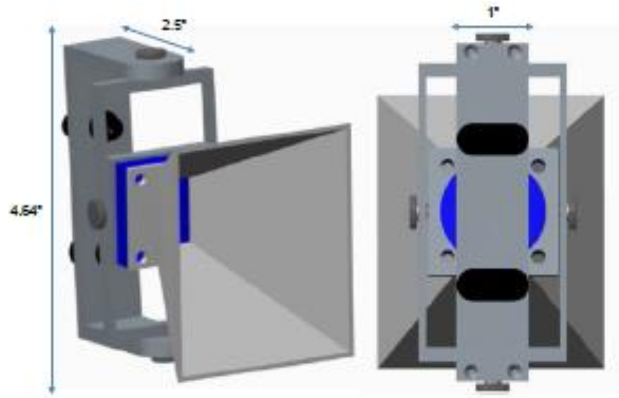

Figure 4: Horn holders

4. Operational Instructions

Operations for the structural portion of the project include attachments of the horns to the structure, alignment of horns, and adjusting of horns in desired degrees of freedom.

4.1 Attaching Horns to Structure

Figure 3, is an illustration of the structure's design. The design is already assembled, the only assembly needed is that of the attachments of the horns onto the structure. In order to attach the horns to the structure there is a piece, as referred to in the *Product Assembly* portion of the operation manual, that is compatible with the 8020 structure and that piece slides in the T slots of the extruded aluminum of the structure pieces. All 20 horns have this attachment piece and is placed on the structure at the users desired location which is based off of the requirements needed on the electrical portion in order for the horns to be able to transmit, receive signals, analyze them, and produce the low resolution image as needed.

4.2 Adjusting Horns

The horns are able to move in 3 degrees of freedom. One degree is where the horn is able to slide on the structure's surface. Another degree of freedom is in the azimuth direction and the other is in elevation. All degrees of freedom are free from one another meaning they are able to be locked in place while the other degree can be adjusted as need be. To adjust each degree of freedom you must either loosen or tighten the screws on the horns which is shown in Figure 4.

4.3 Alignment of Antennas

The laser calibration device is shown in Figure 5. A 3D Printed parts was created to fasten to the antenna horns during calibration by attaching the outer brackets to the horns. Once the brackets are attached then the laser can be put inside the device and attached to the horn. The laser can then be adjusted, and is calibrated once the laser is within the 1ft circle.

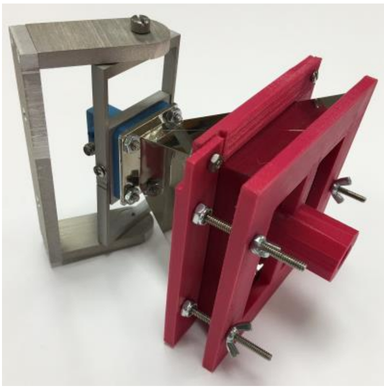

Figure 5: Laser Horn Alignment

5. Troubleshooting and Spare Parts

For the mechanical aspects of the project, there may be a few potential problems. In order to prevent these problems, there are methods put in place.

The design of the Synthetic Aperture Radar System is made up of 20 horn holders and a single structure that each horn is attached to. The horns are able to be adjusted and taken off of the structure. In the adjusting and removal of the horns from the structure, the horns could potentially be damaged or misplaced. To prevent no function ability in the design, there must be a spare horn that is fully operational carried around with the Synthetic Aperture Radar System. There will also be some sort of case that is used for all parts not attached to the structure and for transporting and protecting important components.

Another potential problem is with the screws. Since the horn holders on the structure will be adjusted, which means that the screws that are used for attachment and adjusting will be loosened and tightened. The chances of the screws being lost or dropped is very high so extra screws are to be carried along with the full structure.

6. Regular Maintenance

The Synthetic Aperture Radar System has a design which needs little maintenance after being built. The structure is made mostly of extruded aluminum and the material properties of aluminum are ideal for the project scope. The system will not be dealing with any extreme climate change or any great deal of stress and aluminum is high in strength, highly resistant to corrosion, and has great workability for the mechanical aspects of the design.

The only maintenance needed for the mechanical aspects of design should be annual checkups making sure that every component is still in place. The person checking the material should check for any possible structural or horn damages and loose screws that hold key components in place.

Appendix

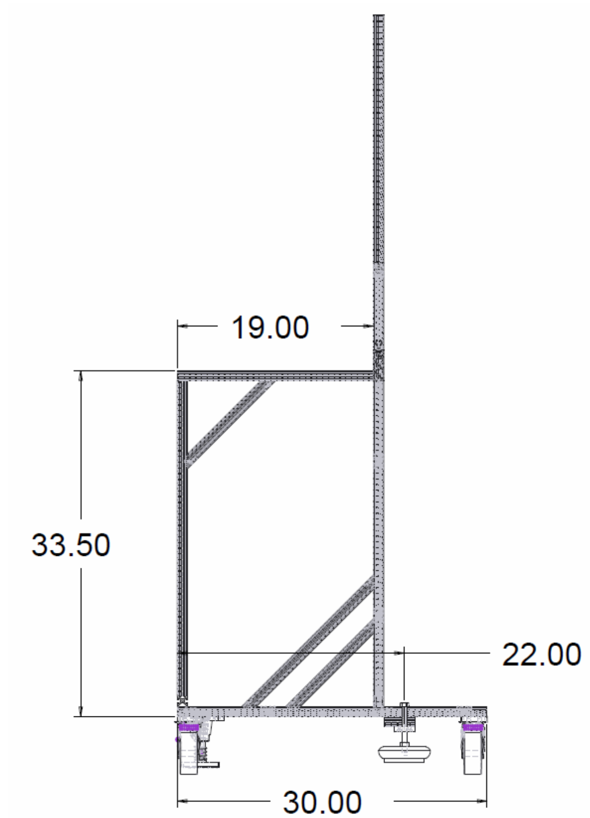

Figure 6: Structure - Side View

FAMU-FSU College of Engineering

Design for Manufacturing: Spring 2016

Team #18

SAR Imager

Instructors:	*Dr. Nikhil Gupta and Dr. Chiang Shih*
Sponsor:	*Michael Blue*
Faculty Advisor:	*Dr. Dorr Campbell*

Members:	*ID:*
Luke Baldwin	*lrb11e*
Josh Dennis	*jad11d*
Kaylen Nollie	*kn11e*
Desmond Pressey	*drp14*

Submitted:
April 1, 2016

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1. Introduction

This report covers the basis of the design process. This includes the manufacturing and assembly, the reliability, and the economics of the design. The purpose of this design is to produce a working, reliable prototype using the synthetic aperture radar concept for homeland security.

2. Design for Manufacturing

2.1 Structure Design

The design for manufacturing started with a very extensive 3D modeling process to allow the team to assemble the structure and horn holders with minimal issues. The team utilized multiple manufacturing processes and sources to accomplish our assembly. To begin, the team ordered all of the parts for the structure from an 80-20 aluminum supplier. The beams for the structure were pre-cut to fit the dimensions determined by our 3D model. The structure was built by first building the bottom frame without the caster wheels, then adding the middle brace, followed by the horizontal brace, support braces, and diagonal braces. The assembly of the structure only took approximately 5 hours, which was slightly shorter than anticipated. There are many components to the structural design. The reasoning for this is to provide our team with the maximum amount of flexibility and adjustability with the structure. Where a commercial product would most likely have less components, this design allows for the team to be able to make changes on the fly to complete our goal.

Figure 1: Structure Design

2.2 Horn Holder Design

As with the structure, the horn holder design was completed first using 3D modeling. The horn holder components were made out of .25 inch aluminum plates that were water jetted to the shapes indicated by the 3D model. The pieces were then tapped and threaded to fit the determined fasteners. The fastening process included thumb and flat-head screws as well as lock and star washers. The assembly process can be seen in the exploded view in Figure 2. The design for the horn holders was altered over time to include more components and fasteners. The reasoning for this was to allow for flexibility as well as save time in the machine shop. Instead of having parts welded together and rick misalignment, it was decided to add fasteners to the back to have control over the assembly time and alignment.

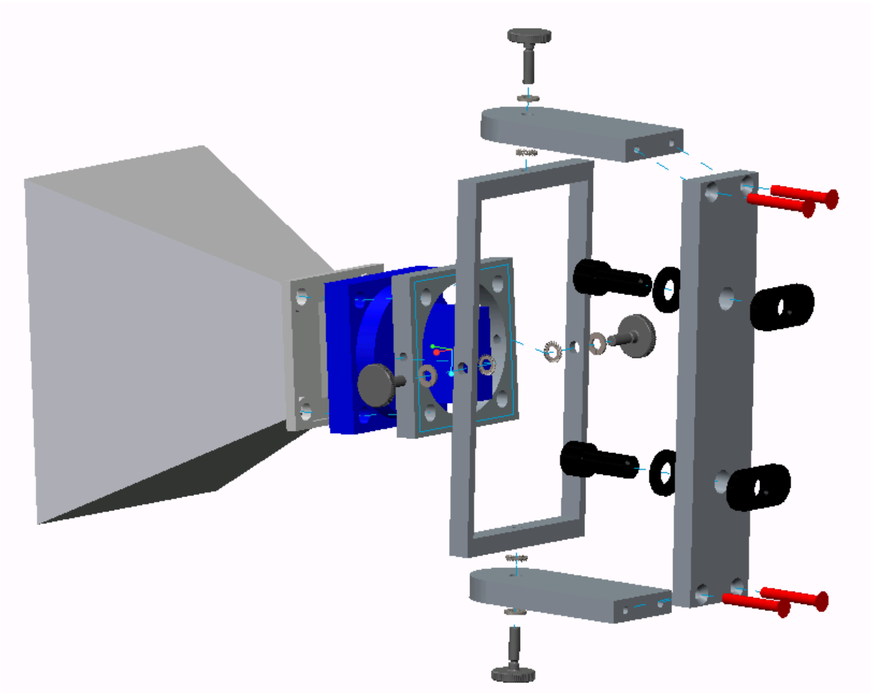

Figure 2: Horn Holder Design Assembly

3. Design for Reliability

3.1 1-Dimensional Model

The primary concern is that the horizontal bar will deflect downwards, and that the top half of the vertical bar causes deflection due to its unsupported nature. The signal processing done to the received signal requires the structure to be very rigid, as any deflection of the structure would cause the received signal to be processed off of its true phase, causing significant error.

In order to produce some preliminary values for the analysis, the 3D model will be simplified to a 1D model. Since the longest unsupported span is on the top half of the structure, this will be analyzed. It will be represented as a cantilevered beam, analyzed using the Euler-Bernoulli beam theory. The transverse deflection of the beam is governed by the fourth-order differential equation:

$$\frac{d^2}{dx^2}\left(EI\frac{d^2w}{dx^2}\right) + c_f w = q(x) \quad \text{for} \quad 0 < x < L \qquad \textbf{(1)}$$

At the very top of the beam, a 100 pound force will be applied on the top of the beam along the weak axis of the cross section.

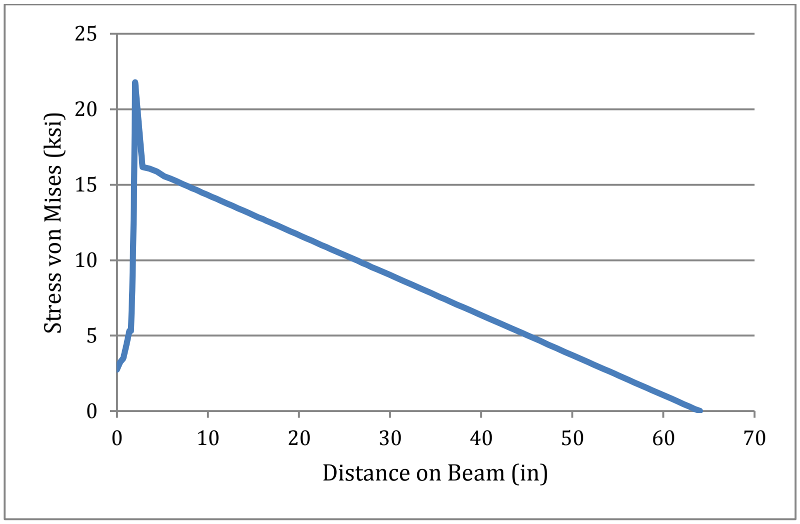

Figure 3: 1-Dimensional model stress

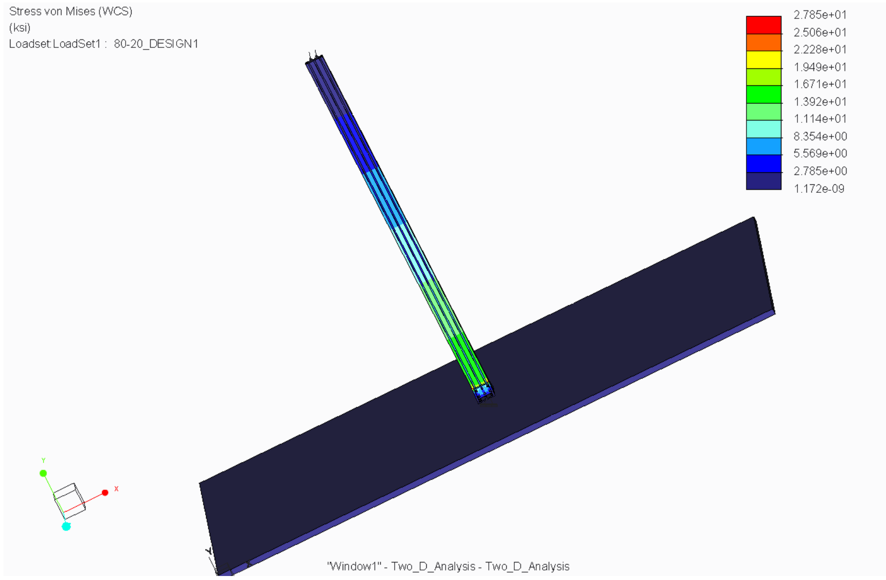

Figure 4: von Mises Stress for vertical bar

The area of primary interest is the bottom portion of the structure. Stress concentrations could develop in the bottom few inches because that is where it is physically clamped to the bottom surface. In the 0 to 5 inch range, there is a spike in the stress where the bracket attaches to the structure. The curve shown indicates that the mesh should be refined due to the drastic changes in slope. This region will receive further attention in subsequent analysis.

3.2 3-Dimensional Model

The full design will be testing using a 3D model. The forces applied will be the 100 pounds on the top vertical bar (same as 1D), as well as 100 pounds on each of the top of the rear supports going downwards, and 100 pounds in the downward direction on each of the horizontal arms that are in-plane with the radar array.

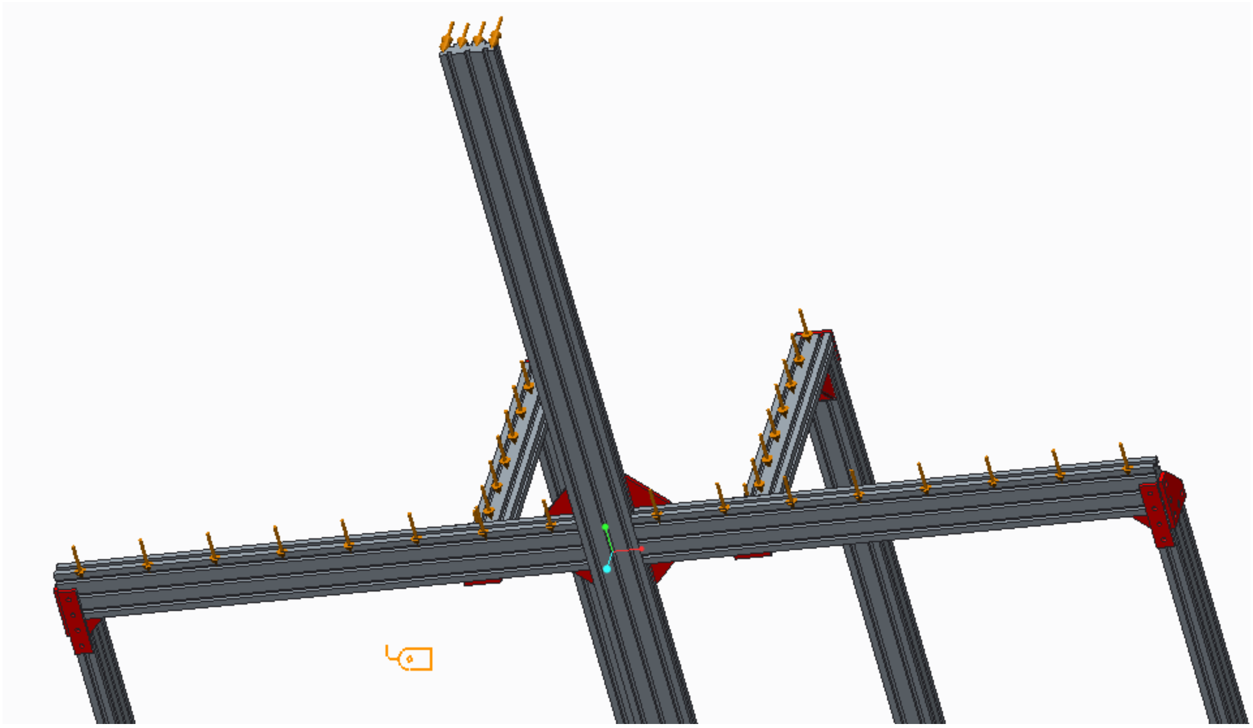

Figure 5: 3D FEM Analysis Loading

The arrows along each surface indicates a 100 pound distributed load. A combined loading for 400 pounds in the vertical, and 100 pounds in the horizontal.

The maximum stress obtained was 7.5 ksi. In regards to the design of the project, this was very optimal considering the maximum allowable stress of the material is 60 ksi. The stress values for the computer analysis is also shown on **Error! Reference source not found.**.

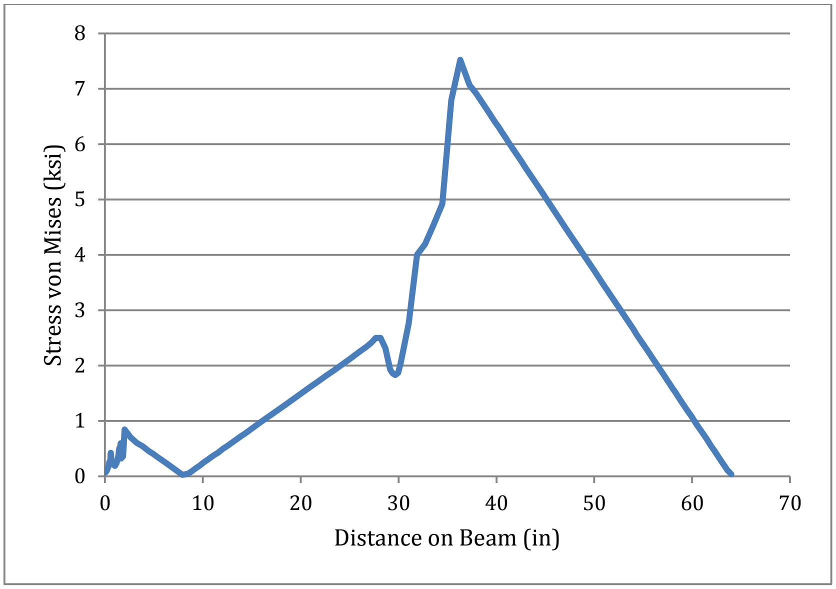

Figure 6: Stress values along vertical beam

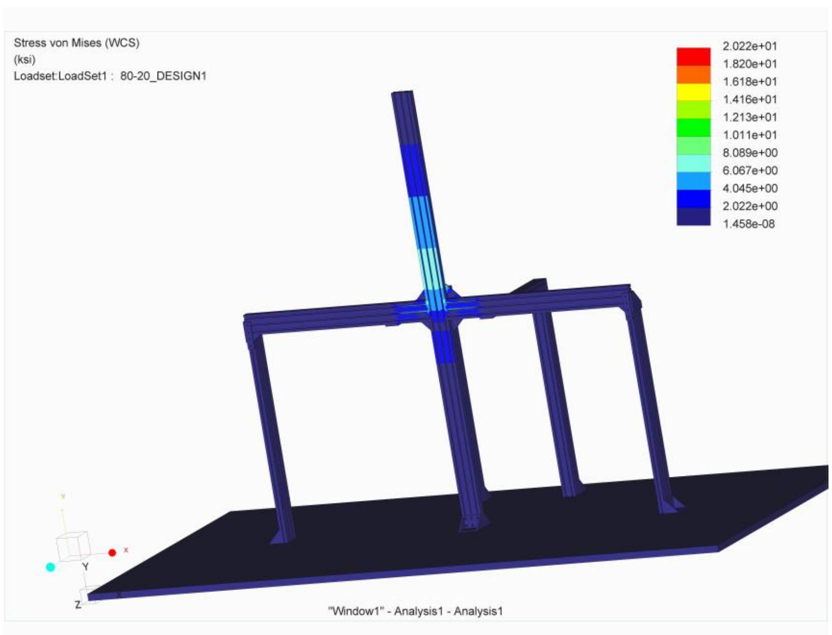

Figure 7: FEM Analysis

The important difference between the 1D and 3D analysis is that the maximum stress is significantly less (7.5 ksi instead of 21.8 ksi) because there were additional supports added to the model. Instead of the center vertical beam having to support all of the load, the other in-plane bars and rear support bars share the load. Another difference about the analysis shown in **Error!**

Reference source not found. is that the mesh was greatly refined. There are 146 data points along the line selected to be plotted in **Error! Reference source not found.**, and 110 in **Error! Reference source not found.**. Considering that this is examining a line within a 3 dimensional structure, the number of meshes increase exponentially.

The data obtained from the analysis was very predictable. The comparison between the computational model and the theoretical model revealed that the values for the computational model had higher stress. Ideally, the stress analysis would have relatively the same values for the maximum stress. The max von Mises stress is 21.8 ksi in 1D, and 7.5 ksi in 3D.

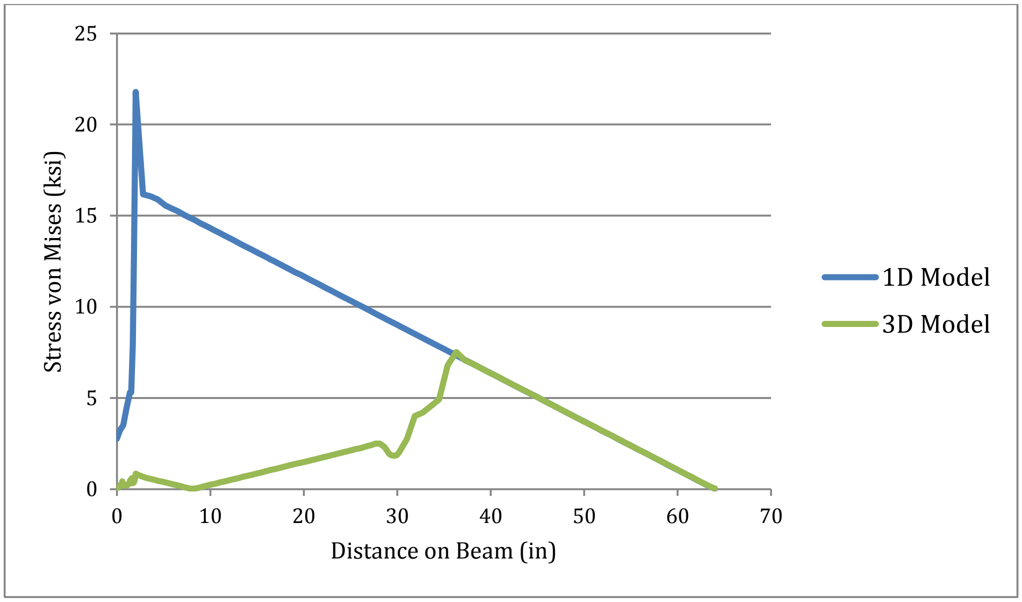

Figure 8: Comparison of values obtained from different methods

3.3 Error and Convergence

An understanding of finite element analysis must be applied to any results obtained from software. Although a computer is a useful tool, it does not have an inherent understanding of the concepts involved. Results must undergo a "sanity check." Because all of the results shown in **Error! Reference source not found.** are very similar, it is unlikely that one method of analysis introduced an extraordinary amount of error. When the computational analysis was conducted, it was specified in the application that the convergence should reach within 3% at the final iterations. Additionally, the analysis was done using a 6 degree polynomial. Although a higher degree does not always mean a better result, often it does – especially in complex geometries or loadings. Because the results were consistent, and the safety factor used was very high, any small errors are acceptable for this application.

3.4 Summary

Because the motivation of this research was to offer insight into a creating a product for a senior design project, the success of the report is measured by whether it offers useful information. In all versions of the analysis, the stress on the structure is well within acceptable bounds. Not only is the calculated stress low, the forces applied to produce that stress were above anything the structure would normally experience. Also final structure has more support than the tested 3D model, thus there is not expected issues. The minimum design has been verified to be able to endure any stresses applied.

4. Design for Economics

The project was sponsored with $5,000 dollars to complete the mechanical team's objectives. Thus far we have been able to complete our designs using $3,940. The breakdown of the costs is in Figure 9 below. Compared to other high end homeland security metal detectors, out design cost is very comparable. The graphic comparison is in Figure 10.

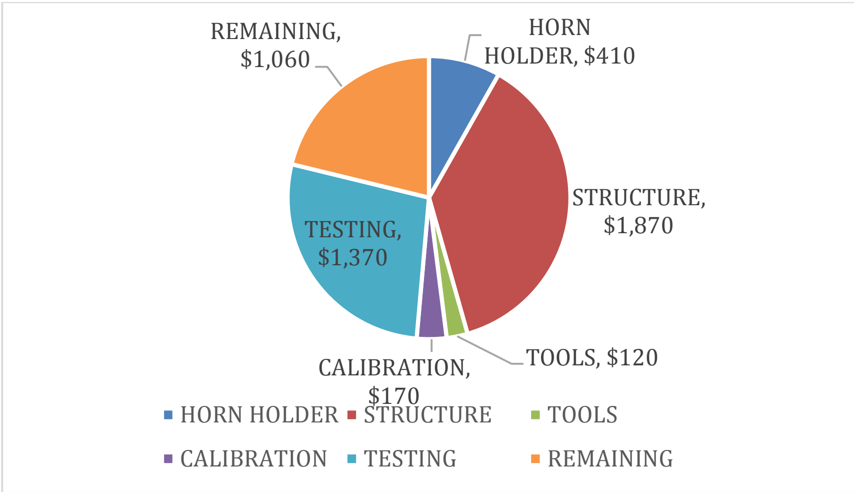

Figure 9: Mechanical team cost breakdown

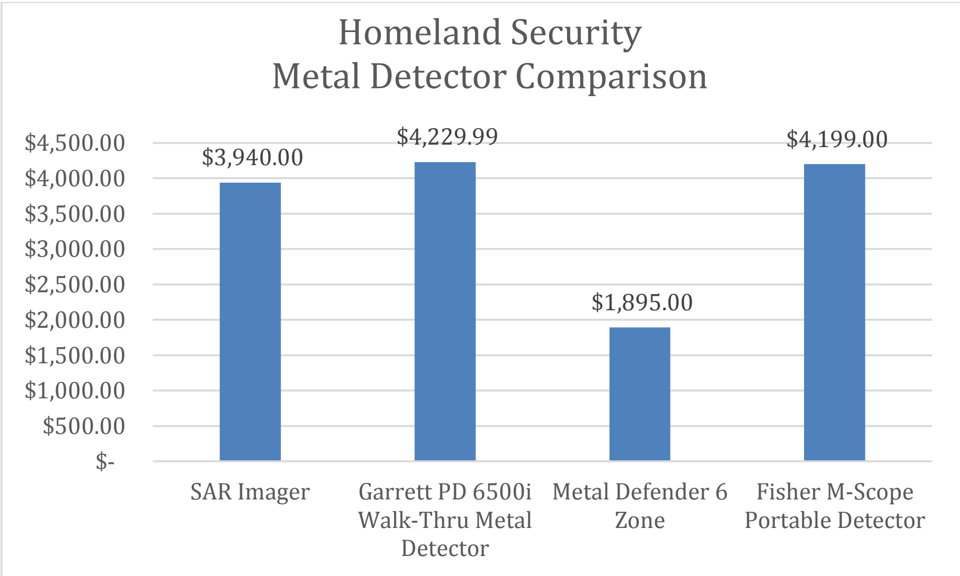

Figure 10: Comparison of competitive homeland security devices

5. Conclusion

This second generation design process has refined what was accomplished last year by allowing for flexibility to achieve results. The structure is much more lightweight and the manufacturing process has been much more punctual. The design has also been analyzed using the 3D model stress tests and deemed to be reliable. The project will also be completed with excess money left over and at a cost that should produce a product that is competitive on the market. He next order of business is to assemble the electrical equipment and test the functionality.

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