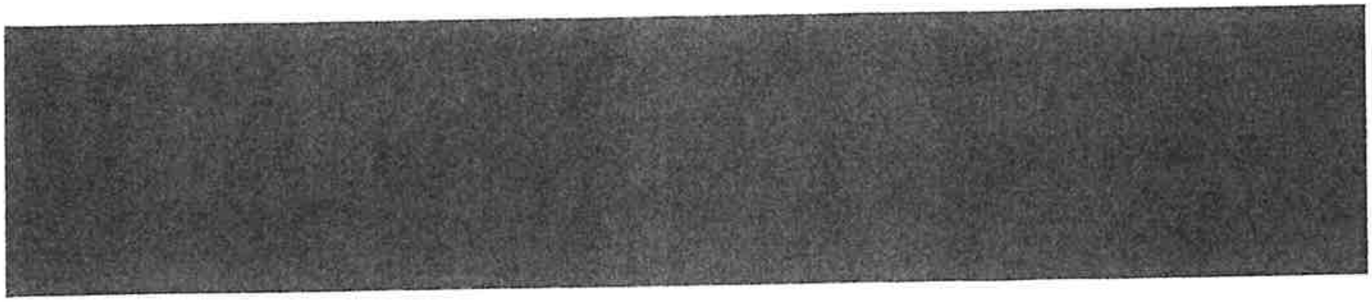
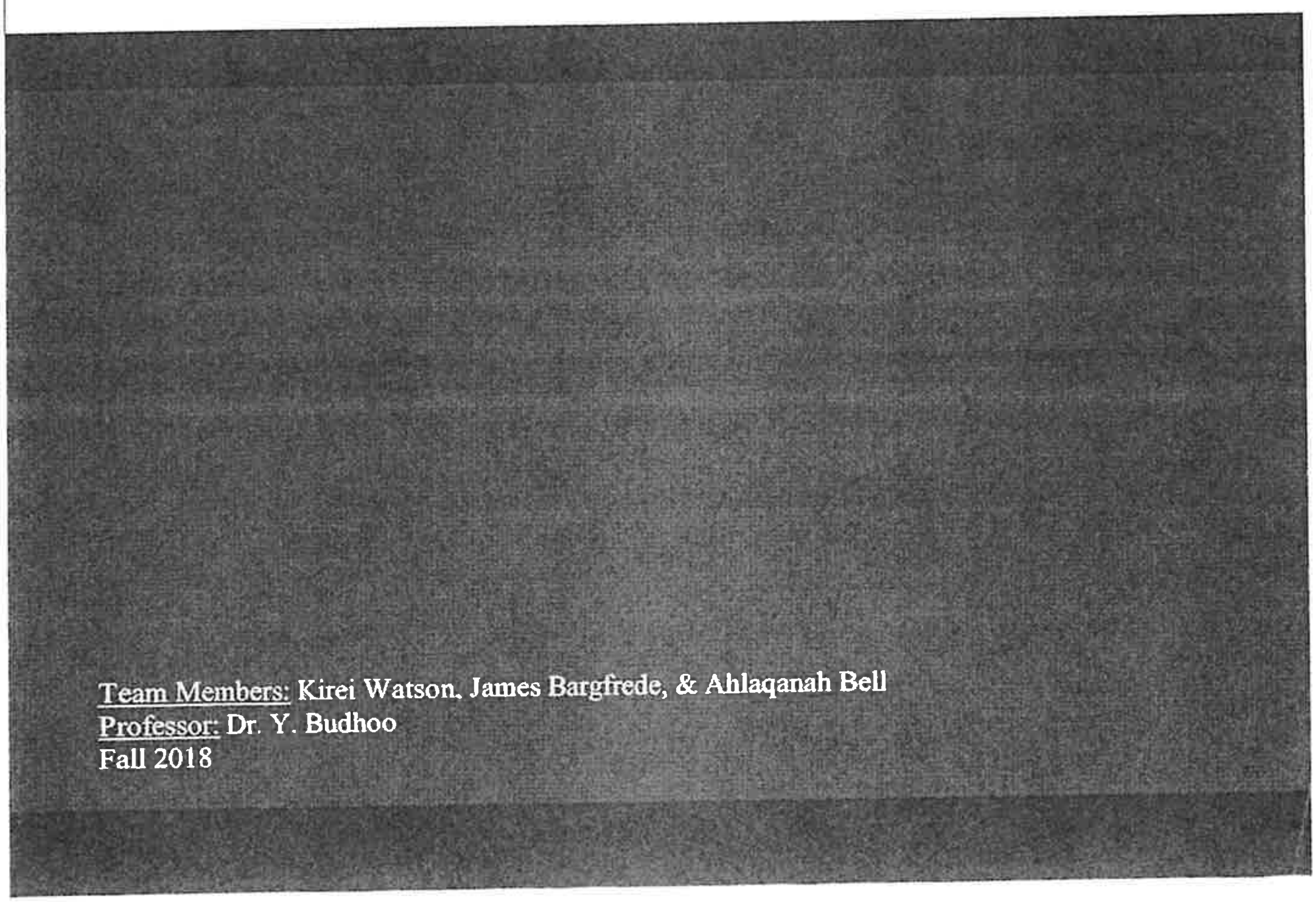


VAUGHN COLLEGE OF AERONAUTICS AND TECHNOLOGY

MET 409: Capstone Degree Project

Dual-Position Rotating Cosmic Ray Detector



Team Members: Kirei Watson, James Bargfrede, & Ahlaqanah Bell
Professor: Dr. Y. Budhoo
Fall 2018

Abstract

There are energetic particles from outer space comes into our atmosphere; happening less than every second. These energetic particles are commonly called "Cosmic Ray;" a misnomer that kind of stuck. When the cosmic ray, an extraterrestrial particle, comes in contact with our atmosphere, muons are then "created." To identify the rate at which the cosmic rays are coming the atmosphere, a "light" detector is used. These detectors analyze the muons that come into contact with the instrument. Since this particle carries an electric charge, it can then be converted into electrical reading with the right equipment.

The majority of these detectors are heavy and stationary causing an inaccurate analysis of the cosmic rays coming from specific locations. Since the earth is similar to the shape of a sphere the location of the stars and planets in outer space based on the time of day varies. A stationary detector can't produce the data that's conducive enough to understand the relationship of Earth and the universe. It was then determined that a dual positioned rotator was the solution for an effective cosmic ray detector.

A dual position rotator will rotate at the azimuth and elevation angles, these angles are specific based on the shape of our planet. The altitude and azimuth can be adjusted simply based on the location of a star of interest. A design was sought to support a substantial amount of weight. The challenge was to ensure the stability as well as a smooth transition of adjusting the position based on the location of interest.

Table of Contents

Introduction

What are Cosmic Rays?

"Cosmic Rays" the term used to describe energetic (charged) particles that travel throughout the galaxy nearing the speed of light. . These particles come from various galaxies; coming from black holes, dead stars, or even the Sun [3]. These Rays are nothing new in discovery; in fact, scientists have known about them for over five decades. One of the ways that provide evidence of Cosmic Rays on Earth is the existence of the auroras; they are also known as polar, northern or southern lights due to the fact that that is where they primarily appear. This is a result of a disturbance to the magnetosphere (Earth's protective magnetic field) by solar winds. The Protons from the Cosmic Rays that breaches Earth's Atmosphere is what allows for the reading of the Rays from a Cosmic Ray Detector. (***Fig. 1***).

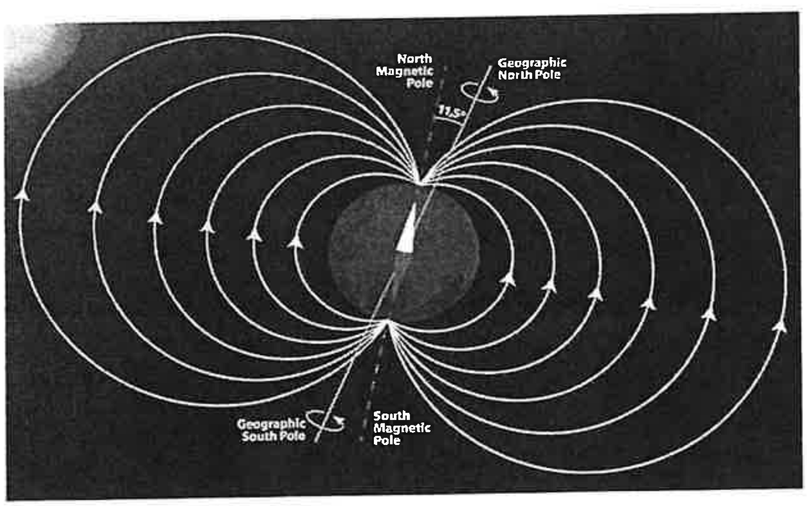


Figure 1 - Earth's Magnetic Field

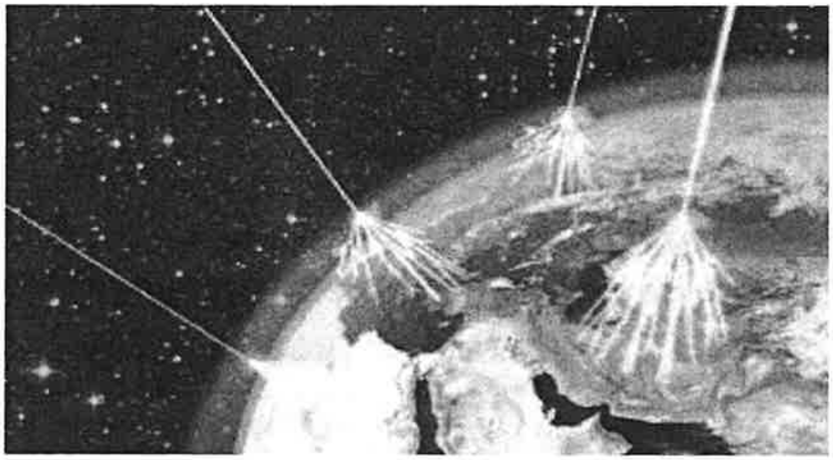


Figure 2: Comic Ray's transition into muons

This protectant prevents many of the solar winds from deteriorate our ozone layer. The particles that come into contact with our Earth's magnetic field are usually sent to the North Pole where the Northern lights primarily occur [1]. When the cosmic rays actually are able to penetrate into our earth's atmosphere they change their chemical composition because of the particles that already exist in this planet's atmosphere [4]. The protons are what is actually penetrating the Earth's atmosphere, and is then transformed into muons (***fig.3***) as shown in ***figure 2***. This is a result of a chemical change that occurs to the proton atom. This information is important because muons are the "Cosmic Rays" that the Cosmic Ray detector is detecting.

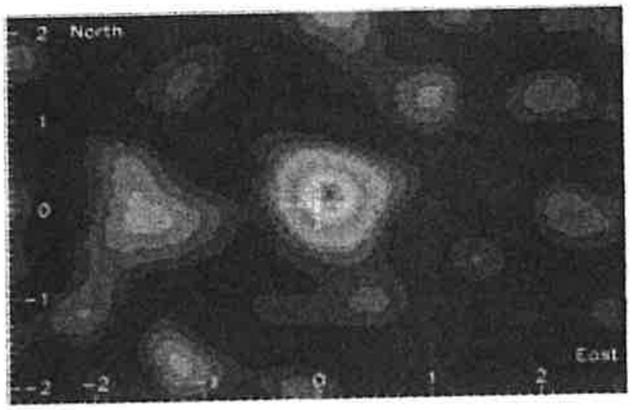


Figure 3: Muon particle

Since muons produce more energy than gamma radiation, a plastic scintillator is used to determine if the particle that passes through it is a muon from Outer-Space [2]. Once the muons pass through the scintillator it is then sent to the Photomultiplier Tube, also known as a PMT, which converts this energetic particle into an electronic reading. The electron reading is then displayed in the oscilloscope in terms of voltage, due to it working like a Digital Multi-meter, DMM, in nature. The oscilloscope can produce the rate of muons the scintillator comes in contact with. Based on the rate of the readings and further analyses, it is then determined whether or not it was a particle form a cosmic ray or other particles. A simplified layout of this process is depicted in ***figure 4***; μ is the symbol used to represent a muon. What is shown in ***figure 5*** is a diagram of what is happening inside of the PMT. The particle goes through a process that converts it into an electrical signal.

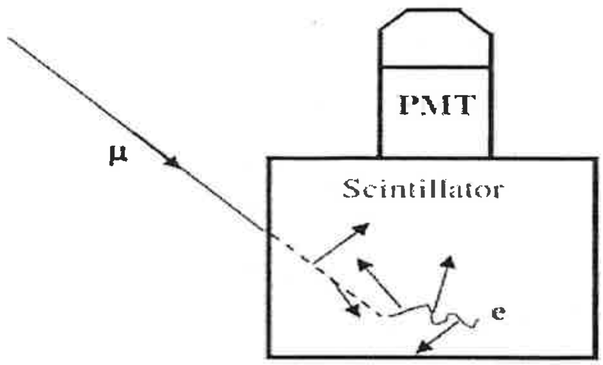


Figure 4: Scintillator and PMT collecting muons

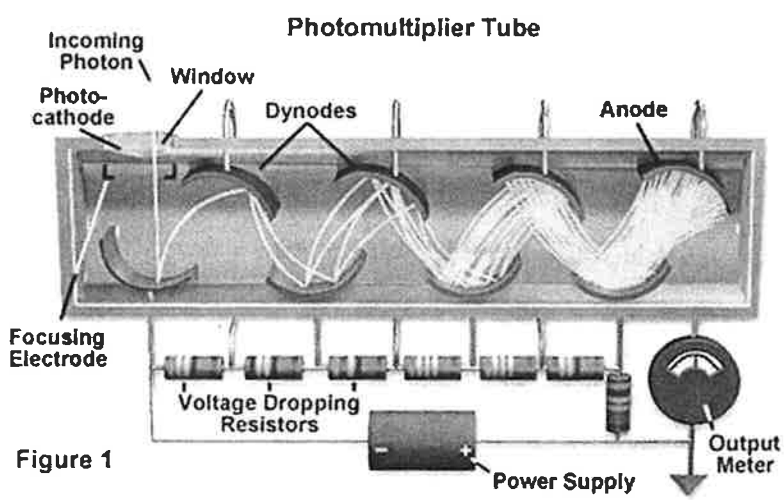


Figure 5 – Inside of Photomultiplier Tube

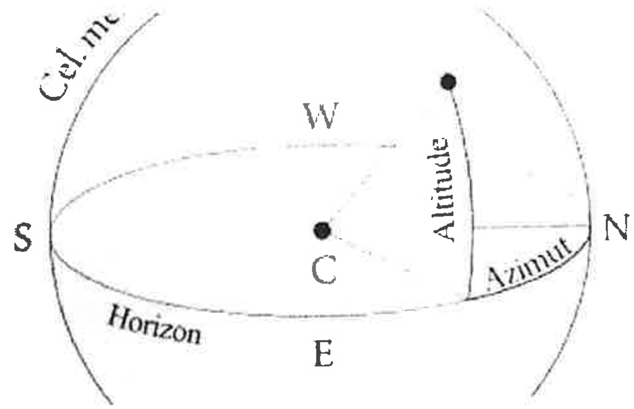


Figure 6: Dual angles (planes) of rotation

Tracking System

There are various forms of tracking systems that locate the position of satellites, the Sun, planets, moons, and stars. There are telescope, solar, and satellite trackers that can convert their specific location on Earth and focus the system to the point of interests. There isn't, however, a dual position rotating mechanism that exists for the sole purpose of tracking and detecting cosmic rays. This will optimize the amount of data in regards to the rate at which cosmic rays are coming to specific areas from space. These areas of interest can be a Black Hole, the Sun, and even a dying star. This rotation is occurring along two planes of rotation (***fig. 6***) to better locate the point of interest as shown.

Competition

Considering this is the first time that a dual positioned rotator existed in order to track terrestrial objects, there has yet to be made a mechanism like this. The only dual position rotators that exist are used for telescopes and satellite tracking. Depending on the purpose of the rotator the price begins to vary. The price can range from $400 to $2,000. The dual position rotator telescopes tend to be in the higher price range bracket, because it locates various extraterrestrial objects based on GPS location. Therefore, comparison of prices and structural components is unachievable. Also, having the ability to provide a visual display of other products is inconclusive as well. But there is a product that does dual positioning rotation solely to track extraterrestrial objects it's called the "Meade Instruments LX90-ACF Telescope" as shown in ***figure*** *7*. The retail price for this product is $1,599.00; which is close to the budget expected to manufacture this product.

Figure 7: Meade Instruments LX90- ACF Telescope

Project Objective

The main objective of this project is to design a mechanism that involves dual position rotation, which will rotate a cosmic ray detector at along both the both an azimuth and elevation plan. These angles are specifically based on the shape of our planet. The altitude and azimuth angles can be adjusted simply based on the location of the star of interest.

This mechanism was designed to support a substantial amount of weight, being hold the actual materials for the detector. The challenge was to ensure the stability as well as a smooth transition of adjusting the position based on the location of the star of interest; moreover, a design that would be structurally supportive enough so that the mechanism would not tip over from the torque of the rotators moving the detector.

Software Used

The software programs used in the modeling process of the design were CATIA and SolidWorks. Modeling in CATIA and SolidWorks provided for a good visual of the mechanism, without having to repeated manufacture when a new design concept was developed. In regards to the interface program, a software program Named EQUIP (*see **A.1.1***) was used. The complete set up (*see **A.1.2***) involved the PMT (*see **A.2.1***) connected to an oscilloscope (*see **A.2.2***). The oscilloscope is similar to Digital Multiplier, providing a voltage reading for the flow of current in a wire. The oscilloscope was then connected to the DAQ (Data Acquisition) Board (*see **A.3.1***) to convert rate of incoming "signals" into data. The DAQ Board was used to obtain the physical readings of the "rate" at which the charged particles where "striking" the scintillator.

A GPS receiver (*see **A.3.2***) was attached to convey the "message" of the day and time of day the PMT recognized the energized particle. The receiver had to pick up multiple satellite signals in order for it to record data. The time is UTC, and the numeral system is hexadecimal.

Without this set up, the PMT would be useless, because there would be know way to track and record the rate of the rays; hence this being a Cosmic Ray Tracker.

Application

This Dual Position Cosmic Ray Tracker will be used as a means of more efficiently tracking energized particles from a specific location. Before, only stationary cosmic ray detectors existed; not really optimizing the capabilities of it. This mechanism can be targeted to specific to location to receive the data of the rate at which cosmic rays are coming from that position.

Specific Design Objectives

i. **Azimuth Rotation**
   a. Obtained a motor that possesses the capabilities of rotating along the azimuth plane

ii. **Elevation Rotation**
   a. Obtained a motor that possesses the capabilities of rotating along the altitude plane

iii. **Withstand a Dynamic force of 50lbs**
   a. Designed and manufactured a stand that could support both the weight of the Dual position motor (*Yeasu G5500*) and PMT/Scintillator support Bracket.

Modeling/ Mathematical Formulation

The mathematical formulations used throughout the experiment regardless of the design being revised were:

I. Stress

$$\sigma = \frac{F}{(W)\,(T)} \qquad \textbf{Eq. (1)}$$

F= force
(W)(T)= Width x Thickness

II. Ultimate strength

$$\sigma = \frac{P}{A} \qquad \textbf{Eq. (2)}$$

P= max load where specimen breaks
A= area

III. Maximum Bending Stress

$$\sigma = \frac{MC}{I} \qquad \textbf{Eq. (3)}$$

M= moment= P x L (Force X Length)
C= Distance from Neutral Axis (N.A.) to the surface (C=r)
I= Moment of Inertia

IV. Shear Stress

$$\tau = \frac{VQ}{It} \qquad \textbf{Eq. (4)}$$

V =Calculated Shear at Specific section
$Q = AY$= Calculated Static Moment
$I = \frac{1}{12}(b)(h^3)$Moment of Inertia around the Neutral Axis
t =Width of Beam at Depth of Specific Section

V. Shear Torsional Stress

Eq. (5)

$$\tau = \frac{Tr}{J}$$

T= Torque
R= Radius
J= Polar Moment of Inertia

Engineering Requirements

Within this section the various constraints involved in this project is as follows. Based on the Specific design objectives, there are numerical engineering requirements that have to be met throughout the experiment, they're as follows:

1) Rotator should support a maximum weight of 50lbs
2) The weight of the rotator should be no more than 30lbs
3) The elevation angle has to range from 0 to 90 degrees
4) The azimuth angle should range from 0 to 360 degrees
5) The cost of the rotator has to be less than $1,000
6) Total cost to build mechanism should be less than $2,000
7) Rotation speed should be 3 degree per a second
8) Withstand Corrosion due to passing of time and weather conditions

Engineering Design Process

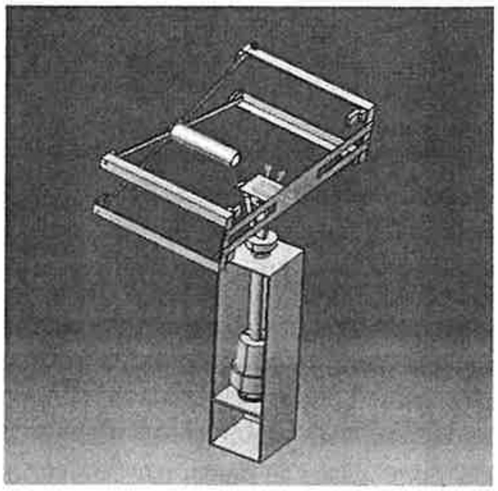
Throughout the process of this project, producing a mechanism that met the requirements of weigh and cost efficiency were very important. The process started from generating a design concept, then selecting a design concept, and finally optimizing that design concept. This is an essential process within this project considering it will be continuously used throughout the years; meaning that the life span has to be optimized as much as possible.

- **Generated Design Concepts**

As mention earlier, the only other cosmic ray detector in existence was stationary; before the design and creation of this one of course. The concept of these designs weren't originally generated from current having a dual positioned rotator in mind. One major influence of the design concept is derived from the highly functioning telescope that tracks the location of the planets, stars, and moon based on the GPS coordinated location; which uses a dual position rotator. The dual positioning rotators that exist did aid in the final design concept before manufacturing process took place. More specifically, one that was made from a DIY project used for satellite tracking (*see **A.4.1***); model for set up made in SolidWorks (*see **A.4.2***). There were various avenues that could have been taken in regard to the entirety of the project. There were various changes within the design from creating a stand that's detachable to using a rigid bar to support the Cosmic Ray Tracker. The reason this changed was to assist in the simplicity of the manufacturing process; such as simply welding the rigid bar to the base. A design which attached the actuator to an angled plate did make it for easier weight distibution and manuverability.

- **Selecting the Design Concept**

During the selection process, a design was needed that would support the PMTs in a manner that would be best suited for the purpose of detecting the cosmic rays on a moving mechanism. The Selection Design Concept was the majority of the Design Process. The reason for this specific concept to be time consuming is because of the various options of creating a mechanism that rotates at two various plans. Analyzing which design was efficient in rotation as well as cost effective was a process. First design concept involved two motors (***Fig. 8***); one inside, and one outside of the box frame. The frame was going to be mounted on a stand (***Fig. 9***), designed in SolidWorks.

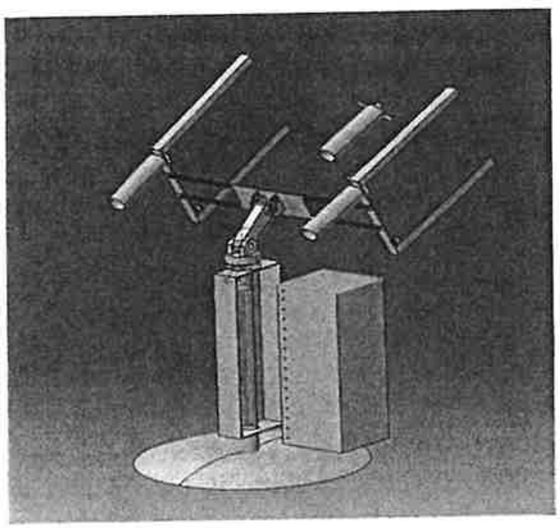


ig. 8: Design concept 1

Fig. 9: Stand for First Design Concept

After the cost estimation was done, there was an understanding that it was not the most cost efficient option. Each motor that had the desired rotation speed and still at reverse polarity was around $1,000; since the budget was $2,000, the motors would have taken up the entire cost of the project. From there a decision was made to use a motor as well as a linear actuator for the elevation rotation, for the majority of this project that was the design of concept (***Fig. 10***). No analysis was done for the first design concept because of the cost. Since it would not be an option-able design, there would be no need to determine the forces or stresses that may have been involved.

When further research and development was conducted, and there was a realization that the software setup would be more complicated. Creating a code in sync with both the movement of the motor (*azimuth*) and the actuator (*elevation*) created another layer of difficulty. The recent change of design was to ensure the software setup was as simple as possible; leading to the selection of EQUIP as the software program of choice, as mentioned earlier. The Yeasu G5500 (*see **image 1***) is known for dual rotation; primarily for antennas. The specification (*see **A.5***) shows that the motor can withstand a vertical load of 440 lbs.; the weight of the box frame being less than 50 lbs. showed, load wise, this was also a good choice. The design was changed multiple times; looking at ***figure 11***, there is a clear indication of the difference. The motor (*Yeasu G5500*) for figure 11 is commonly used and is equipped with a preprogrammed interface that allows it to be controlled remotely. So, this selection led to the optimization process of the design concept.



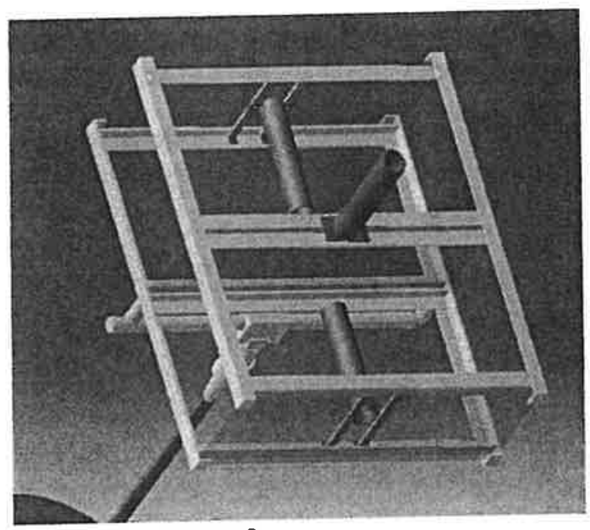


Fig 10: Design concept 2

Fig. 11: Support Bracket for PMT and Scintillator

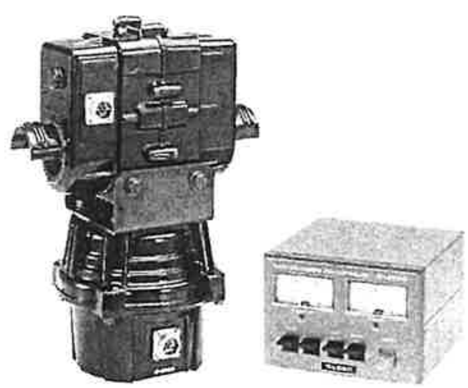


Image 1: Yeasu G5500 with controller box

- **Optimizing the Design Concept**

To optimize the design, it was decided which material would be used based on the concentrated stresses at certain points. The point of stress that is highest is at the bearing, which is connected to the motor. Since we've changed the motor to accomplish both azimuth and elevation rotations, it created an optimization, having the weight acting at one point. Since there's a concentrated stress at the bearing, the material used is steel because the ultimate tensile strength is higher than that of aluminum. For the frame instead, the material is aluminum because it is less dense than steel. Upon revision of the cost analysis, it was shown to be more cost effective. This change in the design ensured that the material used was minimized. Since the Yeasu G5500 is the only motor doing both rotations, it allowed a reduction in material usage throughout the manufacturing; the welding and manufacturing components were drastically reduced. It was the decided that the design in figure 10 was the best option, and from there went into manufacturing. The initial base of the motor were four long pieces of steel. Not only were the heavy, but they were aesthetically unappealing. This was the only designed part that was changed after being manufactured. The X-like base was changed to a cylindrical chair stand, being able to withstand hundreds of pounds. The images of this can be seen in the next section.

Manufacturing Process

Image 2 is showing the beginning process of assembling the box frame; cutting thin aluminum bars down to measurement (*see **A.8 – A.11***).

Image 2: Sawing of aluminum pieces

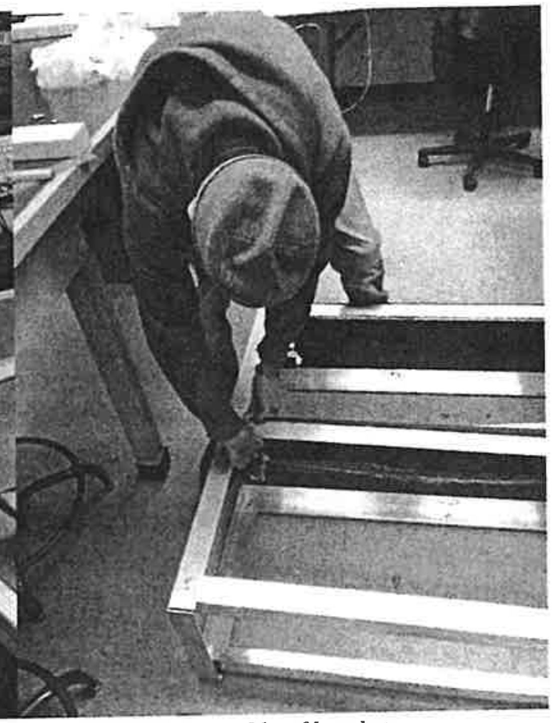


Image 3: Assembly of brackets

Image 3 is showing the brackets being assembled. Holes were drilled in the ends of them according to the design specifications (*see A.7, A.12*). They were then connected by nuts and bolts; simply tightened down with a wrench.

Image 4 is the completed box frame with the scintillators in place. At the top of the frame is the top half of the Yeasu G5500, which was mounted to the frame using nuts and bolts as well. This part of the mechanism allows it to accomplish change in elevation along the altitude plane.

Image 5 was the original stand for the Cosmic Ray Tracker, but was changed for reasons mentioned earlier.

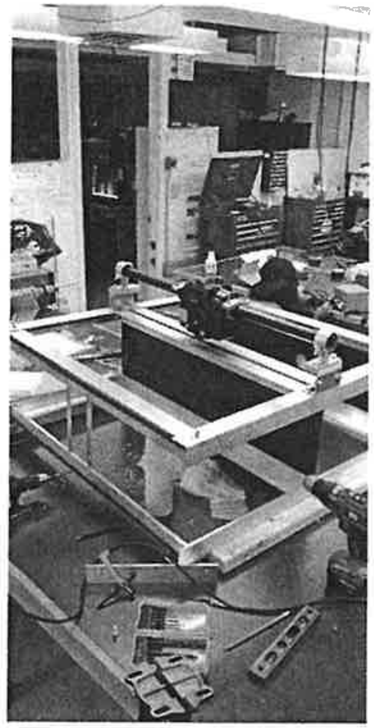


Image 4: PMT Support Box Frame

Image 5: Initial manufactured base

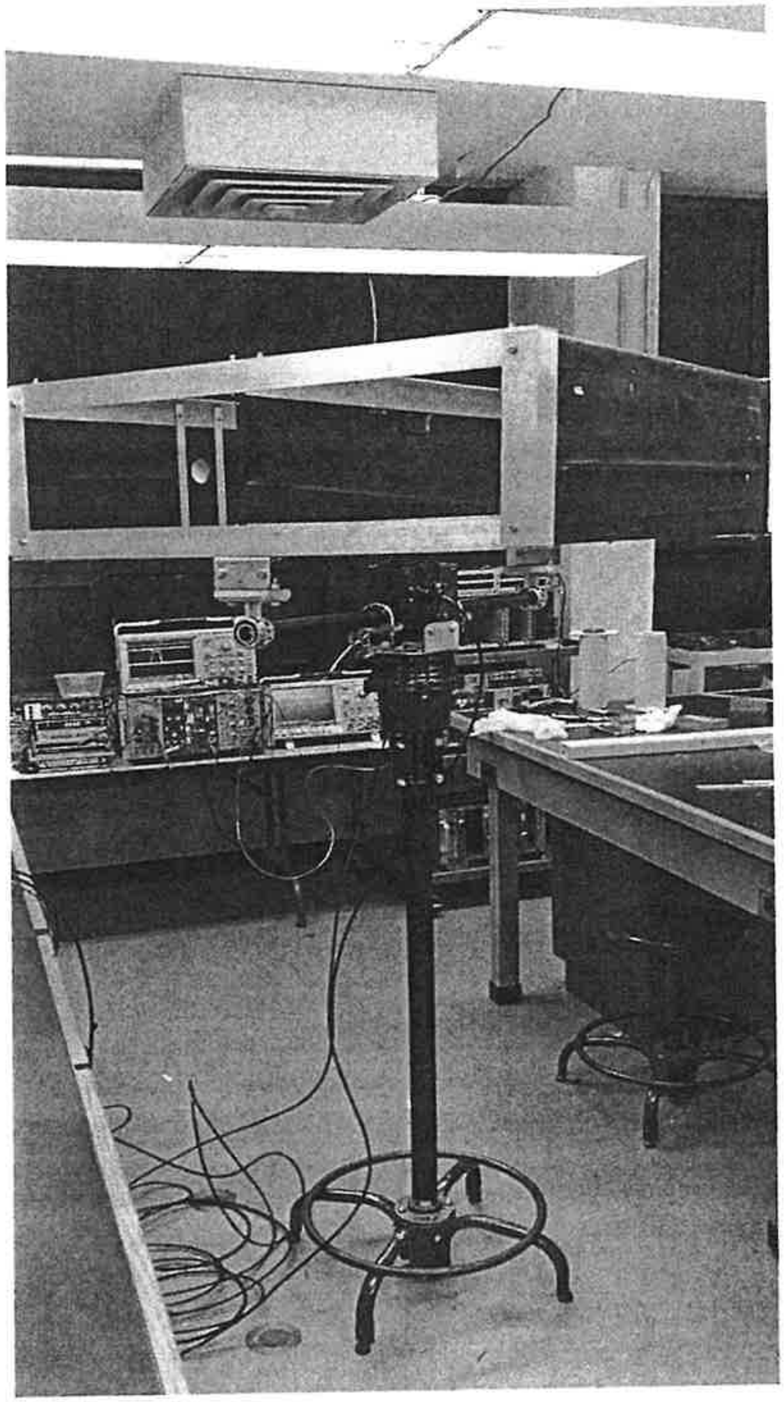


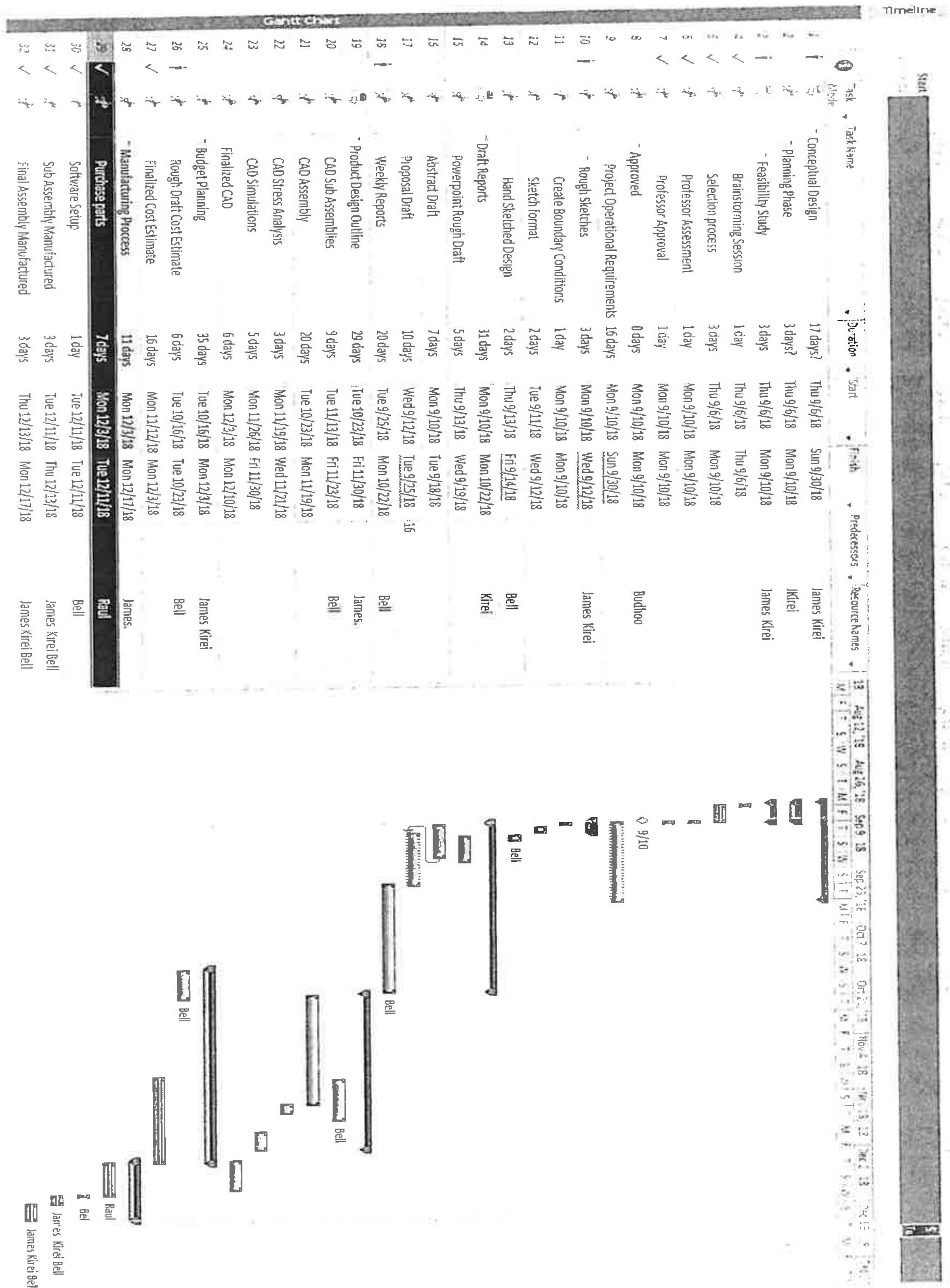
Image 5: Final Assembly

Project Management

As can be seen in table 1, the final cost of the mechanism and software program came up to $1426.64; less than what was estimated to be the cost of the production.

Type of Item	*Supplier*	*Quantity*	*Unit Price*	*Total*
Metals	Metal Depot			
T6 Aluminum Angle Iron		3	$71.88	$215.64
Steel Tube		1	$89.00	$89.00
Stainless 3/8 Bolts and Nuts		14	$0.43	$9.00
Stainless ¼ Bolts and Nuts		10-	$0.40	$5.00
Electronics		1		
Yeasu 5500	Gigaparts	1	$775.00	$775
Computer Interface	Gigaparts	1	$313.00	$313.00
Pst Software	PST Company	1	$20.00	$20.00
			Sum Total	$1,426.64

Table 1: Final Cost Estimate of Parts



ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	- Conceptual Design	17 days?	Thu 9/6/18	Sun 9/30/18		James Kirei
2	- Planning Phase	3 days?	Thu 9/6/18	Mon 9/10/18		JKirei
3	- Feasibility Study	3 days	Thu 9/6/18	Mon 9/10/18		James Kirei
4	Brainstorming Session	1 day	Thu 9/6/18	Thu 9/6/18		
5	Selection process	3 days	Thu 9/6/18	Mon 9/10/18		
6	Professor Assessment	1 day	Mon 9/10/18	Mon 9/10/18		
7	Professor Approval	1 day	Mon 9/10/18	Mon 9/10/18		
8	- Approved	0 days	Mon 9/10/18	Mon 9/10/18		Budhoo
9	Project Operational Requirements	16 days	Mon 9/10/18	Sun 9/30/18		
10	- Rough Sketches	3 days	Mon 9/10/18	Wed 9/12/18		James Kirei
11	Create Boundary Conditions	1 day	Mon 9/10/18	Mon 9/10/18		
12	Sketch format	2 days	Tue 9/11/18	Wed 9/12/18		
13	Hand Sketched Design	2 days	Thu 9/13/18	Fri 9/14/18		Bell
14	- Draft Reports	31 days	Mon 9/10/18	Mon 10/22/18		Kirei
15	Powerpoint Rough Draft	5 days	Thu 9/13/18	Wed 9/19/18		
16	Abstract Draft	7 days	Mon 9/10/18	Tue 9/18/18		
17	Proposal Draft	10 days	Wed 9/12/18	Tue 9/25/18	16	
18	Weekly Reports	20 days	Tue 9/25/18	Mon 10/22/18		Bell
19	- Product Design Outline	29 days	Tue 10/23/18	Fri 11/30/18		James.
20	CAD Sub Assemblies	9 days	Tue 11/13/18	Fri 11/23/18		Bell
21	CAD Assembly	20 days	Tue 10/23/18	Mon 11/19/18		
22	CAD Stress Analysis	3 days	Mon 11/19/18	Wed 11/21/18		
23	CAD Simulations	5 days	Mon 11/26/18	Fri 11/30/18		
24	Finalized CAD	6 days	Mon 12/3/18	Mon 12/10/18		
25	- Budget Planning	35 days	Tue 10/16/18	Mon 12/3/18		James Kirei
26	Rough Draft Cost Estimate	6 days	Tue 10/16/18	Tue 10/23/18		Bell
27	Finalized Cost Estimate	16 days	Mon 11/12/18	Mon 12/3/18		
28	- Manufacturing Process	11 days	Mon 12/3/18	Mon 12/17/18		James.
29	Purchase parts	7 days	Mon 12/3/18	Tue 12/11/18		Raul
30	Software Setup	1 day	Tue 12/11/18	Tue 12/11/18		Bell
31	Sub Assembly Manufactured	3 days	Tue 12/11/18	Thu 12/13/18		James Kirei Bell
32	Final Assembly Manufactured	3 days	Thu 12/13/18	Mon 12/17/18		James Kirei Bell

Table 2: Gantt chart

Team Members and Responsibilities

Name	Responsibilities
Kirei Watson	Mathematical Formulations and Analysis; Project Management; Weekly Reports; Final report
James Bargfrede	Conceptual Design & Construction of Design; Purchase of Parts; Manufacturing and assembly
Ahlaqanah Bell	Conceptual Design; Software Programming/setup, Weekly reports; Aid in assemble; Photos; Final report

Analysis

Analysis of Original Design

a. Shear Stress at pivotal point on the bolt (Eq.

Shear Stress = (45lbs)/ ((π/4) (.25) ^2) = 916.73

b. Location of the center of gravity on the pivot point

$\sum$M (pivot point) = (27 lbs. x 5.5in) – (8lbs x 18.5 in)

c. Angle of extended plate to ensure rotation to 90 degrees

Arc length= 2πr (θ/360)

2πr (90/360) =Stroke Length of Actuator

The radius could then be determined in order to know the needed distance to revolve the scintillator to 90 degrees

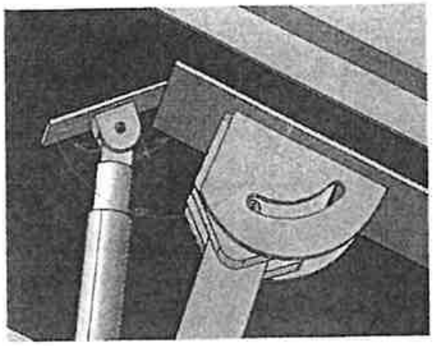


Figure 3.1: 2nd Design Pivot Point

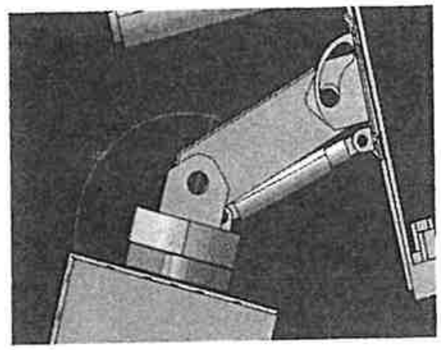


Figure 3.3: 1st Design Pivot Point

Analysis of Final Design

The change of the structure design caused angled aluminum to be used in the final stages. The change in design then causes the weight of the scintillators to be directly applied to the beam. This causes both a shear and bending stress. To ensure the prevention of a fracture the factor of safety was also determined.

Bolt Stress

The elevation rotation is created by a torque from the motor. This motor creates a maximum torque of 110 ft.-lbs. with that information the force can be determined. From the calculated force, the shear stress acting on the bolt will then be calculated. Equation 2 was used to sole this analysis as shown in Figure 4.1 & 4.2, the torque is then considered a force applied to the bolt.

$$Force = \frac{1320lb.-in.}{.5in.}$$

$$\tau = \frac{2640lb}{\pi.375in^2.} = 5975.74\,psi$$

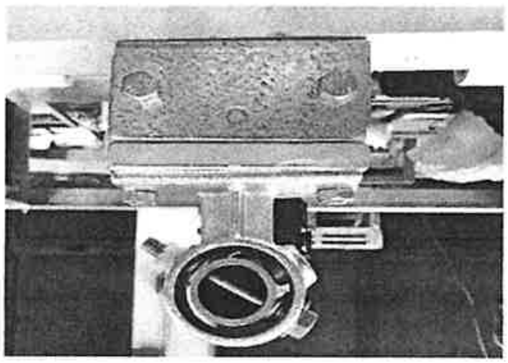


Fig. 4.1: Bolted elevation support

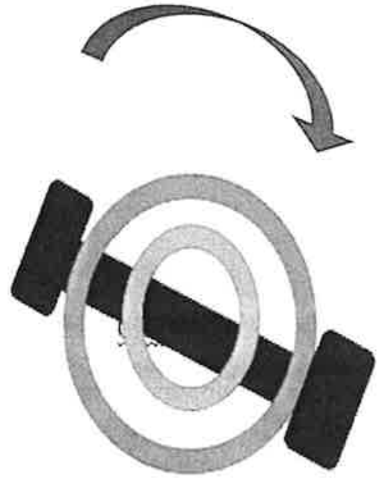


Fig. 4.2: FBD of Bolt Stress

Shear Torsional Stress

As shown in Fig. 4.1 above, the pipe that supports the frame structure will experience 110ft-lbs of torque. For torsional stress equation 5 was used calculating the shear stress created from the torsion will determine if the structure will experience fracture based on the material used.

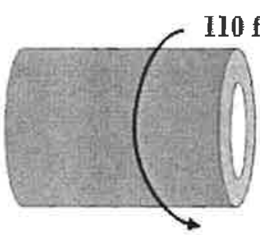


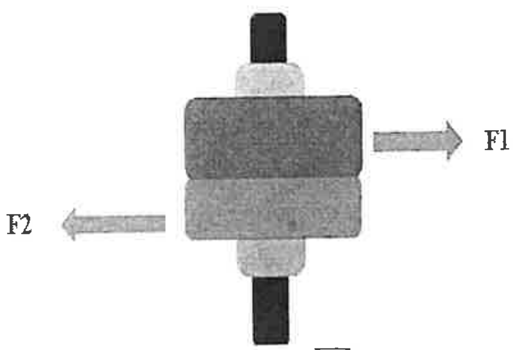
Figure 6.1: FBD Torsional Stress

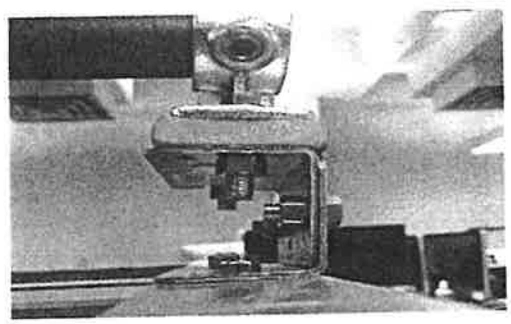
$$T = 110\ ft - lb. = 1320\ \text{in} - \text{lbs.}$$
$$r = .625\ in.$$
$$J = \frac{\pi}{2}(.625^4 - .5^4) = 11.17\ in^4$$
$$\tau = 73.857\ psi$$

Shear Stress Shims

When the rotator is angled at 0 degrees the shear stress is maximized. The shear stress is happening at the shim of the mechanism. A free-body diagram was drawn to represent this (*see A.6*). The shear stress was determined by the bolt being connected to the shim and bracket together. With the known force and measured areas, the shear was calculated using equation 1.

$$Force = 120lbf$$





$$Area = Diameter * \sum(thickness)$$
$$= (\frac{1}{4}in)(.75in.)$$

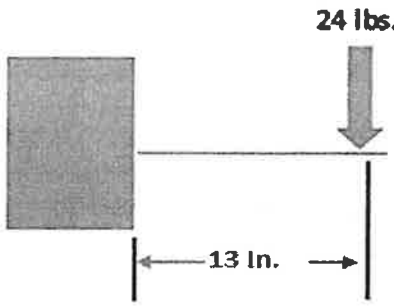
$$\tau = 640\ lb.-in.$$

Figure 6.1: FBD Shim Shear Stress

Figure 6.2: Shim Shear Stress

Pipe BendingStress

A bending stress occurs when there is a normal stress in a body subjected to loads that will cause it to bend. The pipe that supports the weight of the structure will experience bending stress. As shown in equation 3.



$$M = (120lbs)(13in.)$$

$$C = .625in.^4$$

$$I = \frac{\pi}{4}(.625^4 - .5^4)$$

$$\sigma_b = 13{,}732\ psi$$

Figure 6.1: FBD Bending Stress

Shear and Bending Stress of Frame

The support for the scintillators will experience the direct force from the acrylic plates. To ensure the prevention of Fracture the shear and bending stress was calculated. With the use of equations 3 and 4 the stresses were calculated.

$$\tau = \frac{(45lbs)(3.66 * 10^{-3})}{(.3051 * 10^{-3})(.125)} = 4{,}318.58\ psi$$

$$F.S = \frac{21{,}000psi}{4{,}318.58\ psi}$$

$$\sigma_b = \frac{(45lb - in)(.4535)}{(.1752)} = 116.4811\ psi$$

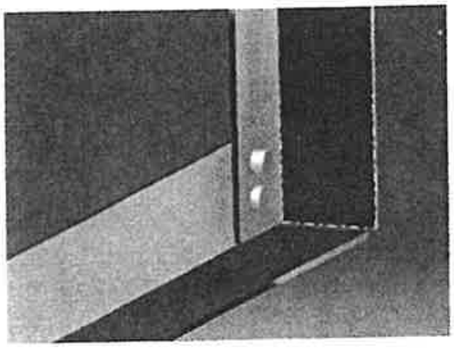


Figure 12 - Bolted Angle Aluminum

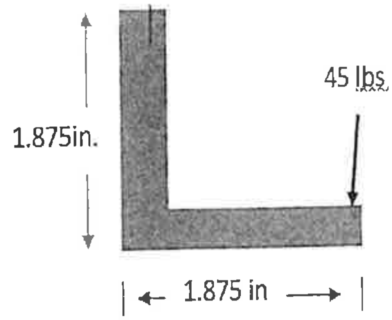


Figure :FBD Angle Aluminum

Ultimate Tensile Strength

To ensure that the mechanism is stable the Ultimate Tensile Strength of the material was assessed. After further analysis, it was determined to use Aluminum for the frame support. While the main support and base was built out of steel. Based on the calculations of the stress, it is evident that the material used would not fracture based on the tensile strength information obtained.

Material	Ultimate Tensile Strength
A36 Steel	58,000–80,000 psi
Aluminum 6061 T6	45000 psi

Table 3: Breakdown of Material's UTS

K Factor

K factor for the Yeasu G5500 is 578 ft.-lbs.

K = [turning radius] x [weight of box frame]

@75 lbs., k = 2.18 ft. x 75 lbs. = 163.5 ft.-lbs.
@90 lbs., k = 2.18 ft. x 90 lbs. = 196.2 ft.-lbs.
@120 lbs., k = 2.18 ft. x 120 lbs. = 261.6 lbs.

Wind Loading Area

As per the specifications, the wind loading area is 1 m^2.
3(*number of brackets*) x 3 ft^2. (*Area of bracket*) = 9 $ft.^2$ = .8361 m^2

Results and Discussion

Based on the conducted analysis above, it was determined that the structure would not experience fracture. After calculating the factor of safety, it will experience stress in the support frame, Rotational aspects of the mechanism.

Table 4: Total Analysis Results

Location	Type of Stress	Calculated	Material	Factor of Safety
Bolts of Elevation Pipe	**Shear Stress**	**5975.94 psi**	**Steel**	**9.71**
Pipe of Elevation	**Torsional Shear & Bending**	**73.86 psi & 13,732 psi**	**Steel**	**4.22**
Angle Aluminum	**Bending & Shear**	**116.48 psi & 4,318.48 psi**	**Aluminum**	**10.42**
Shim and Brackets	**Shear**	**640 psi**	**Steel**	**90.62**

The significance of these results is proof that the mechanism will experience stress, but the material properties used has a higher yield point stress causing th3e factor of safety to be high. Many of the components where's a force applied to it will be successfully supported. Based on the motor used, the dynamic calculations provided in the manual of the Yeasu 5500 ensure the force of the detector will be supported.

Conclusion

In conclusion, the objective of the Cosmic Ray Detector was successfully accomplished. The mechanism does rotate on both the azimuth and elevation plane. This mechanism is able to withstand a weight of over 50 lbs., as well as not tilt over due to the torque created from the rotation of the detector. Also, parts purchased for this experiment were well within budget. Then, to prevent rapid weather corrosion the material used was coated in zinc. The motor used was manufactured to prevent damage from a variety of weather conditions. One of the engineering requirements was that this mechanism should cost less than $2000 to produce. Not only was it less than $2000, but it was ¾ less than that cost limit. The possibility to determine the rate of cosmic rays from specific celestial objects can now be determined using this Dual-Position Cosmic Ray Tracker. This will further the world of science's understanding about energetic particles, by providing a method of tracking the rate these particle from a variety of position without having to move a stationary cosmic ray detector; being able to only operate in one set position at a time.

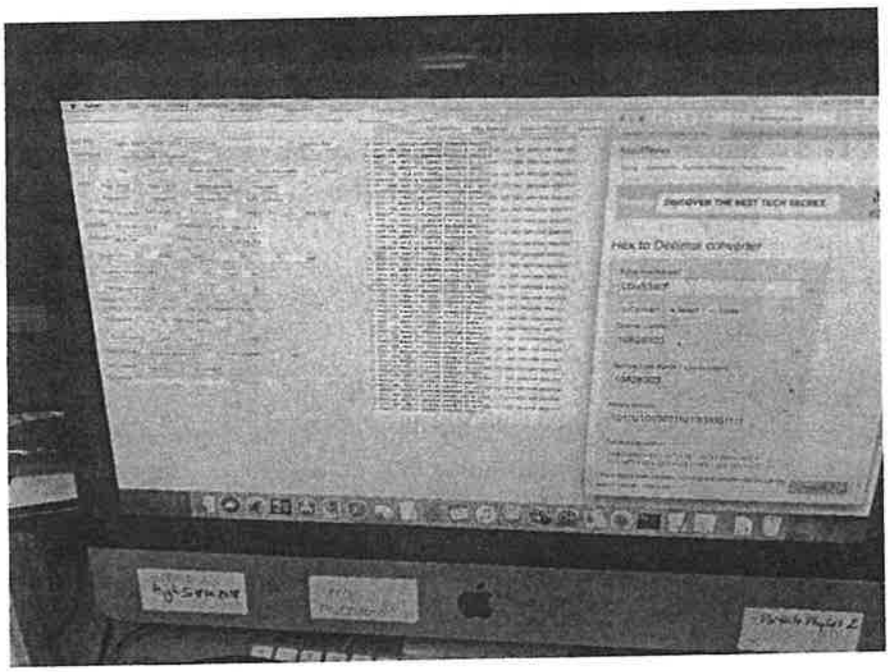
References

[1] Ginzburg, Vitaliĭ Lazarevich, and Sergei Ivanovich Syrovatskii. *The origin of cosmic rays*. Elsevier, 2013.
[2] "Cosmic Ray Detectors." *Cosmic Ray Detectors*, hardhack.org.au/book/export/html/2.
[3] Hart, Robert. "What Is a Cosmic Ray?" *Cosmic Ray Astronomy*, cosmicray.com.au/what-is-a-cosmic-ray.
[4] Tasoff, Harrison. "Discovery of a Cosmic-Ray Source Is a Triumph of 'Multimessenger Astronomy'." *Space.com*, Space.com, 14 Aug. 2018, www.space.com/41156-cosmic-ray-source-multimessenger-astronomy.html.
[5] "LX90-ACF 10' f/10 with Standard Field Tripod." *Meade Instruments*, www.meade.com/lx90-acf-10-f-10-with-standard-field-tripod.html.

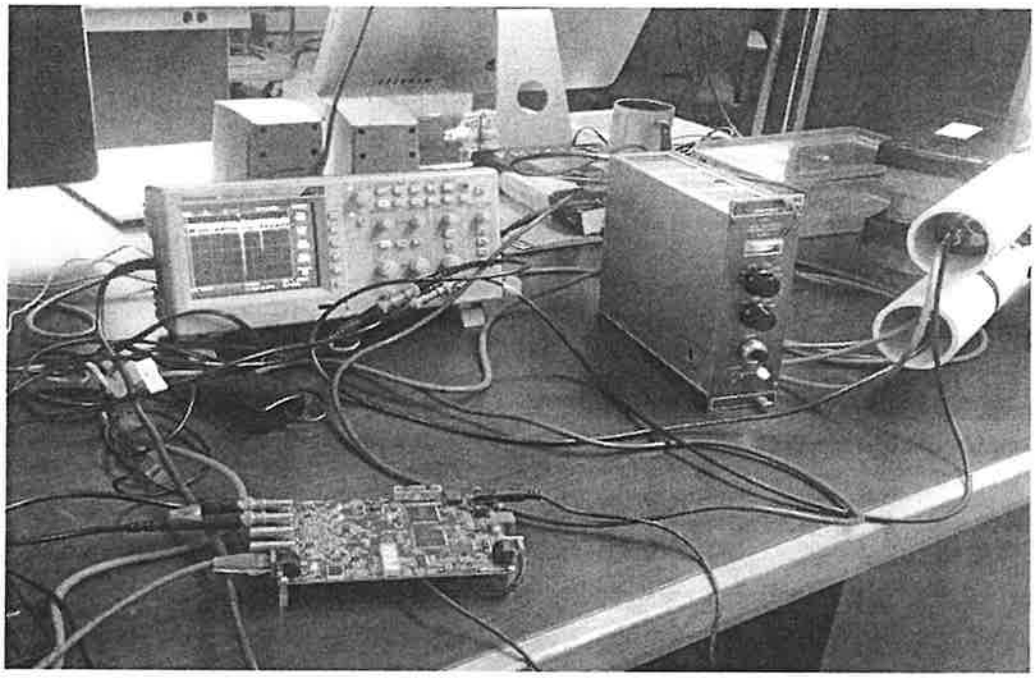
Appendix

A1

A.1.1: Screen Display of EQUIP Software Program



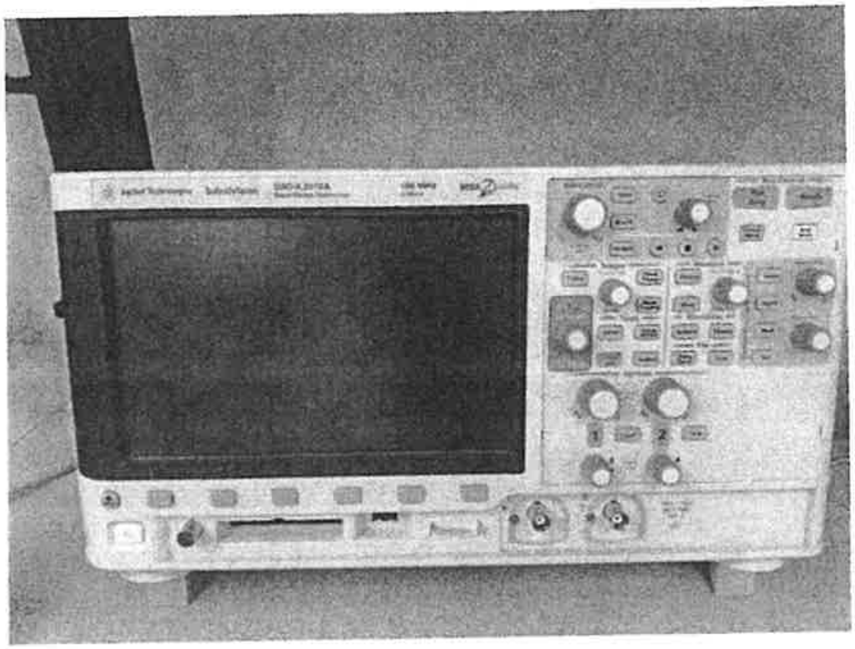
A.1.2: Complete wiring set up for EQUIP program



A2

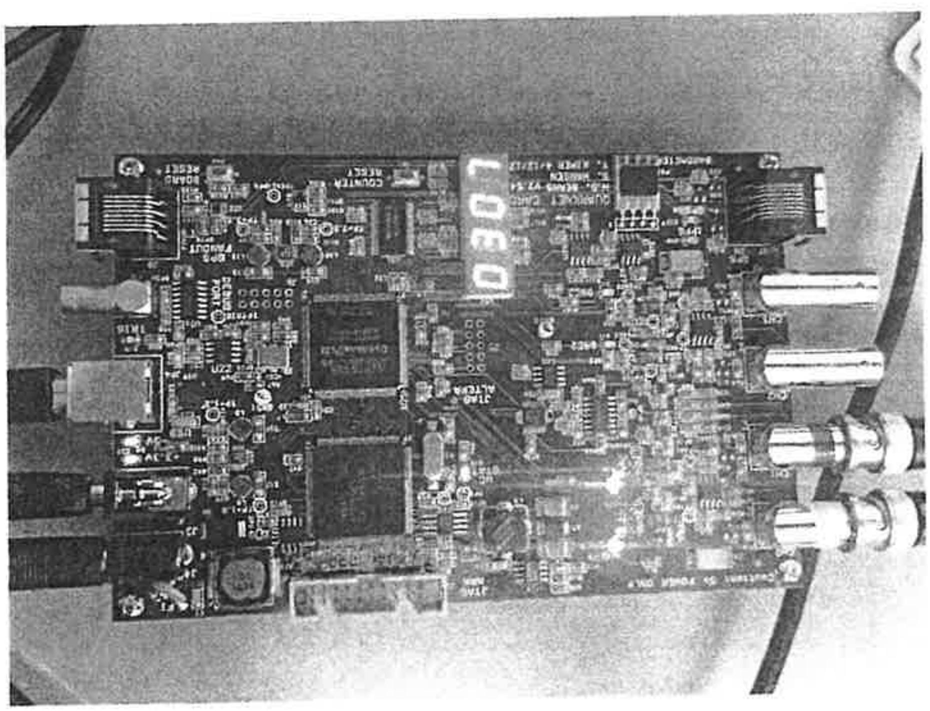
A.2.1: Photomultiplier Tube (PMT)

A.2.2: Oscilloscope (model DSO-X 2012A)



A3

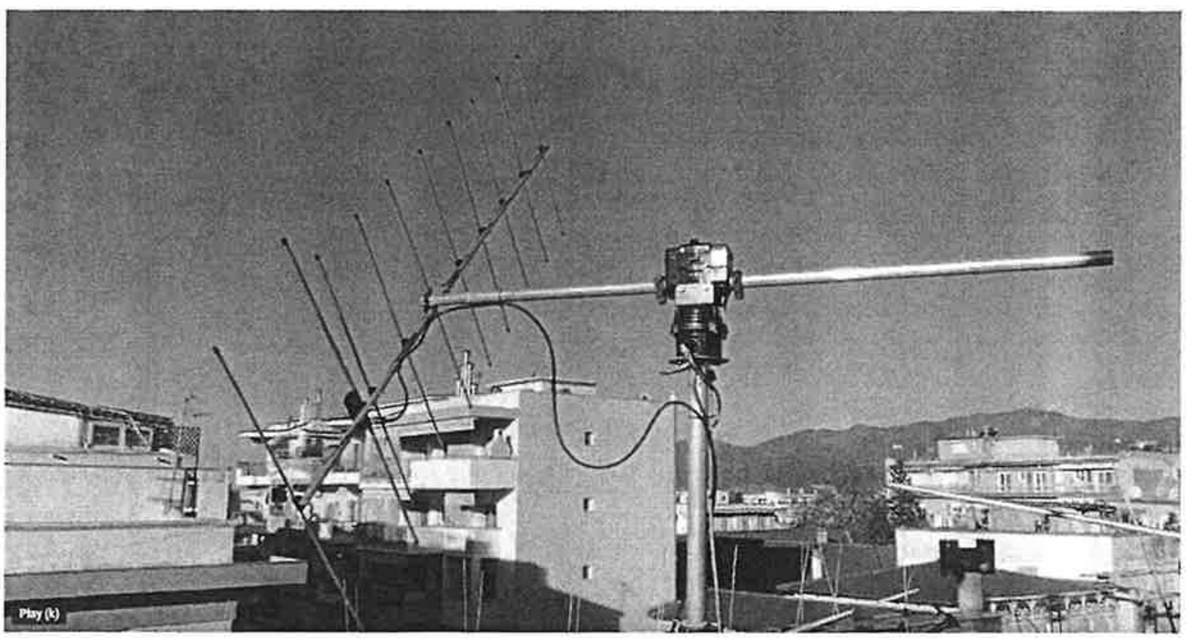
A.3.1: Data Acquisition (DAQ) Board



A.3.2: GPS Receiver

A4

A.4.1: Mounting concept of Yeasu G5500



A.4.2: SolidWorks Model

A.5: Specification of Yeasu G5500

G-5500 Antenna Azimuth-Elevation Rotators & Contoroller Instruction Manual

SPECIFICATIONS

Voltage requirement:	110-120 or 200-240 VAC
Motor voltage:	24 VAC
Rotation time (approx., @60Hz):	Elevation (180°): 67 sec. Azimuth (360°): 58 sec.
Maximum continuous operation:	5 minutes
Rotation torque:	Elevation: 14 kg-m (101 ft-lbs) Azimuth: 6 kg-m (44 ft-lbs)
Braking torque:	Elevation: 40 kg-m (289 ft-lbs) Azimuth: 40 kg-m (289 ft-lbs)
Vertical load:	200 kg (440 lbs)
Pointing accuracy:	±4 percent
Wind surface area:	1 m^2
Control cables:	2 x 6 conductors - #20 AWG or larger
Mast diameter:	38-63 mm (1-1/2 to 2-1/2 inches)
Boom diameter:	32-43mm (1-1/4 to 1-5/8 inches)
Weight:	Rotators: 9 kg (20 lbs) Controller: 3 kg (6.6 lbs)

UNPACKING & INSPECTION

When unpacking the rotator confirm the presence of the following items:

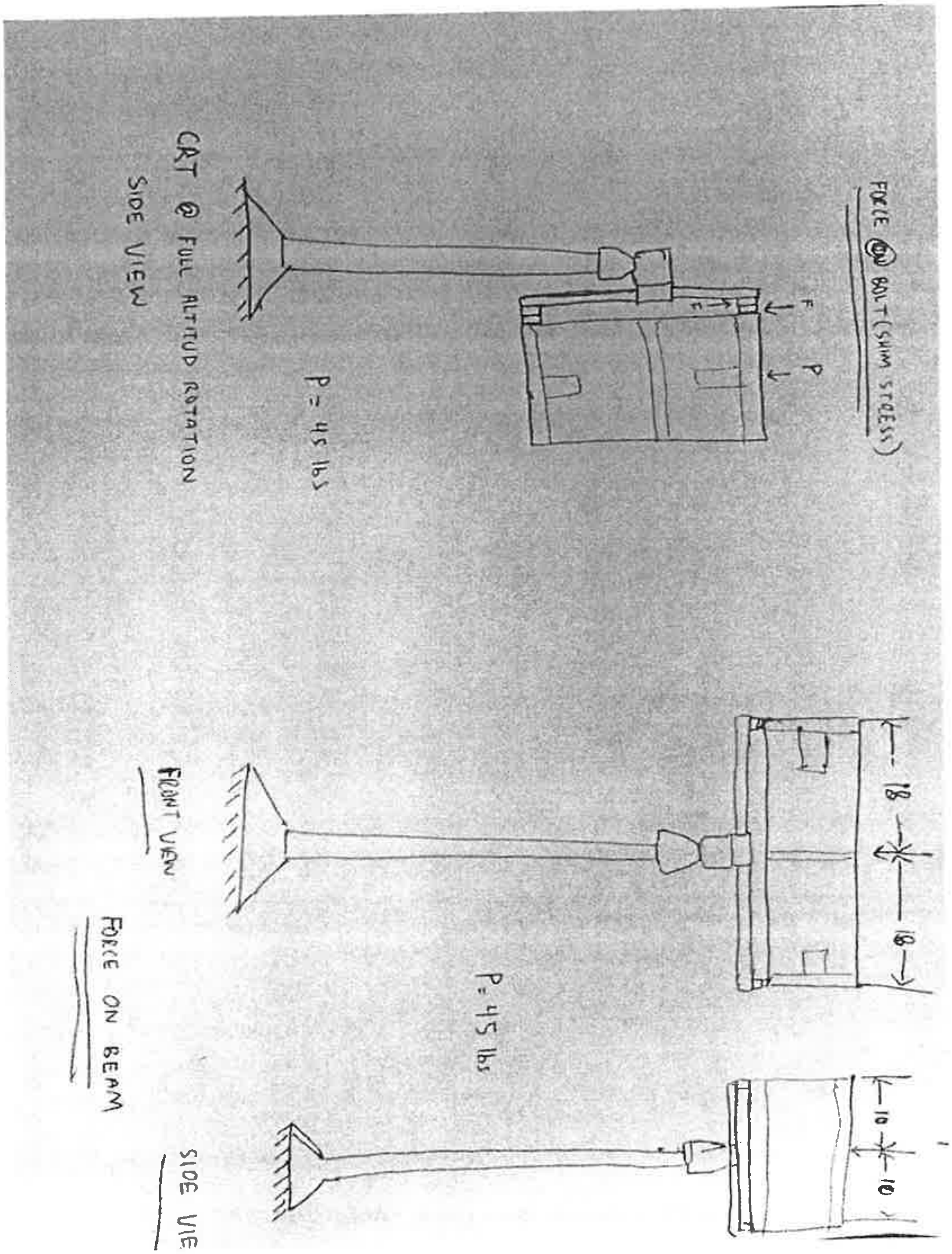
Elevation Rotator Unit	1
Azimuth Rotator Unit	1
Controller Unit	1
Mast Clamp (pair)	2
Pipe clamp	2
U Bracket	1
M8 x 16 Hex. Bolt	4
M8 x 25 Hex. Bolt	8
M8 x 70 Hex. Bolt	4
M8 x 95 Hex. Socket Bolt	1
U-Bolt	2
6mm Spring Washer	4
6mm Flat Washer	4
8mm Spring Washer	18
8mm Flat Washer	12
M8 Square Nut	1
M8 Hex. Nut	4
M6 Hex. Nut	4
8-pin DIN Plug	1
7-pin Metal Connector	2
Water Resist Cap	2
Spare Fuse (117V:2A, 220V:1A)	1
Instruction Manual	1

If any of these items are missing or appear to be damaged, save the carton and packing material and notify the shipping company (or dealer, if purchased directly at his shop).

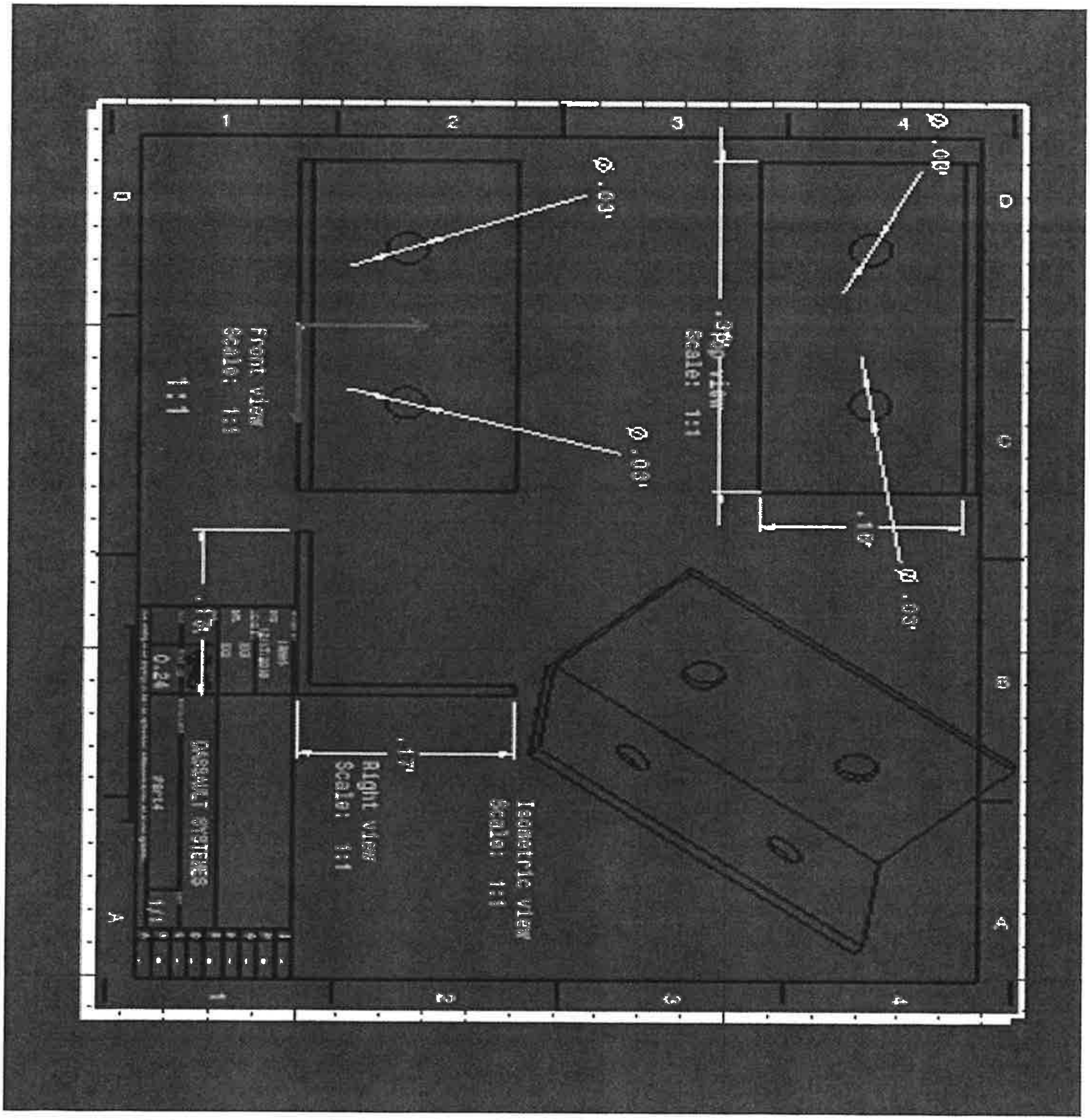
Before proceeding with installation, confirm that the AC voltage label on the rear of the Controller matches your local line voltage: either "117V" for 110 to 120 VAC, or "220" for 220 to 240 VAC. If the labeled voltage range does not match, return the controller to the dealer from whom you purchased it (different power transformers are installed for the different voltage ranges).

Note that cable is not included with the rotator, as the length must be determined case-by-case. Contact your Yaesu dealer to obtain the length of cable your installation requires. For runs of over 100 feet, use #18 AWG instead of #20 AWG.

A.6: Free Body Diagrams

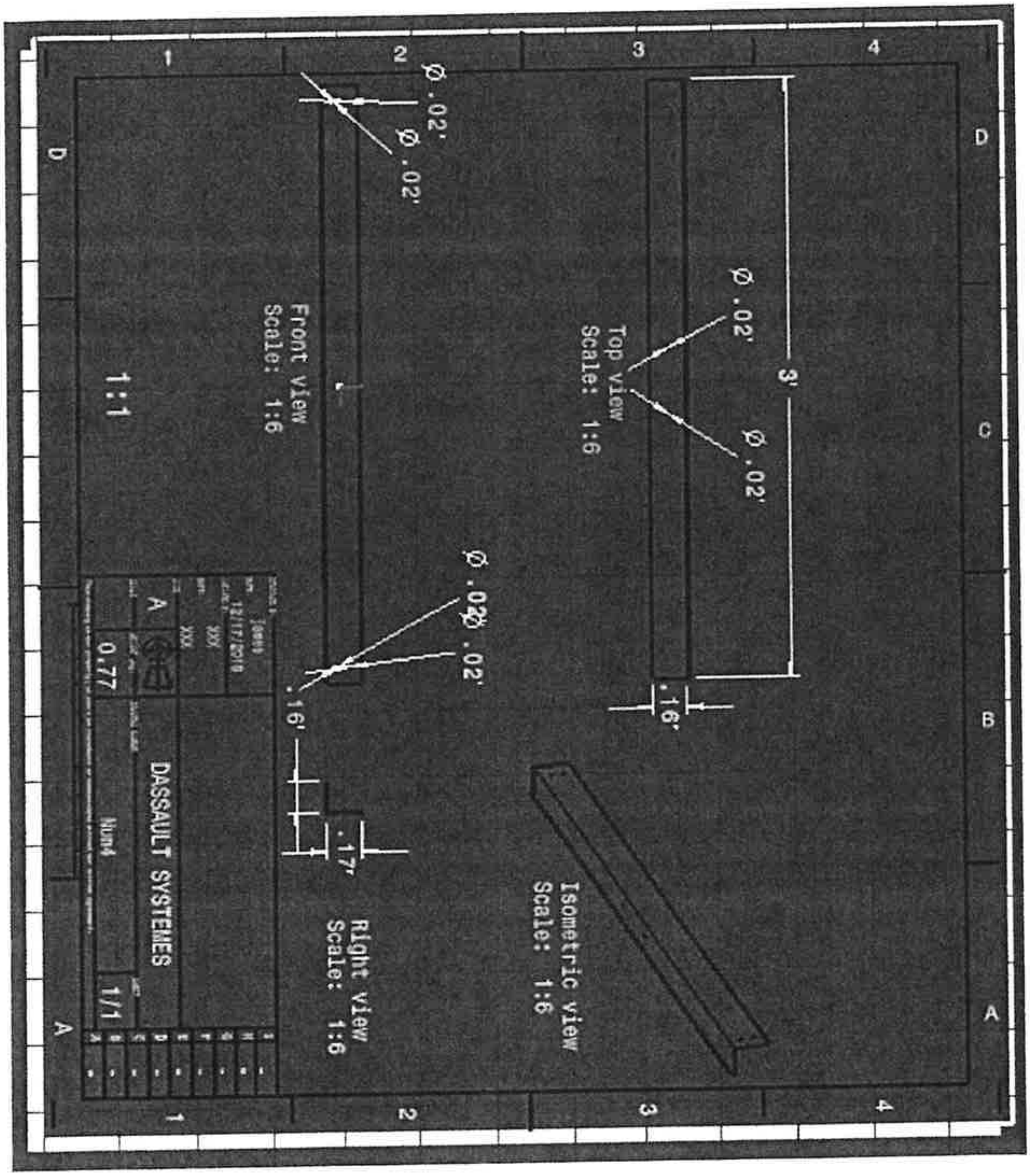


A.7: Upper Box Frame Mount Plate



A8

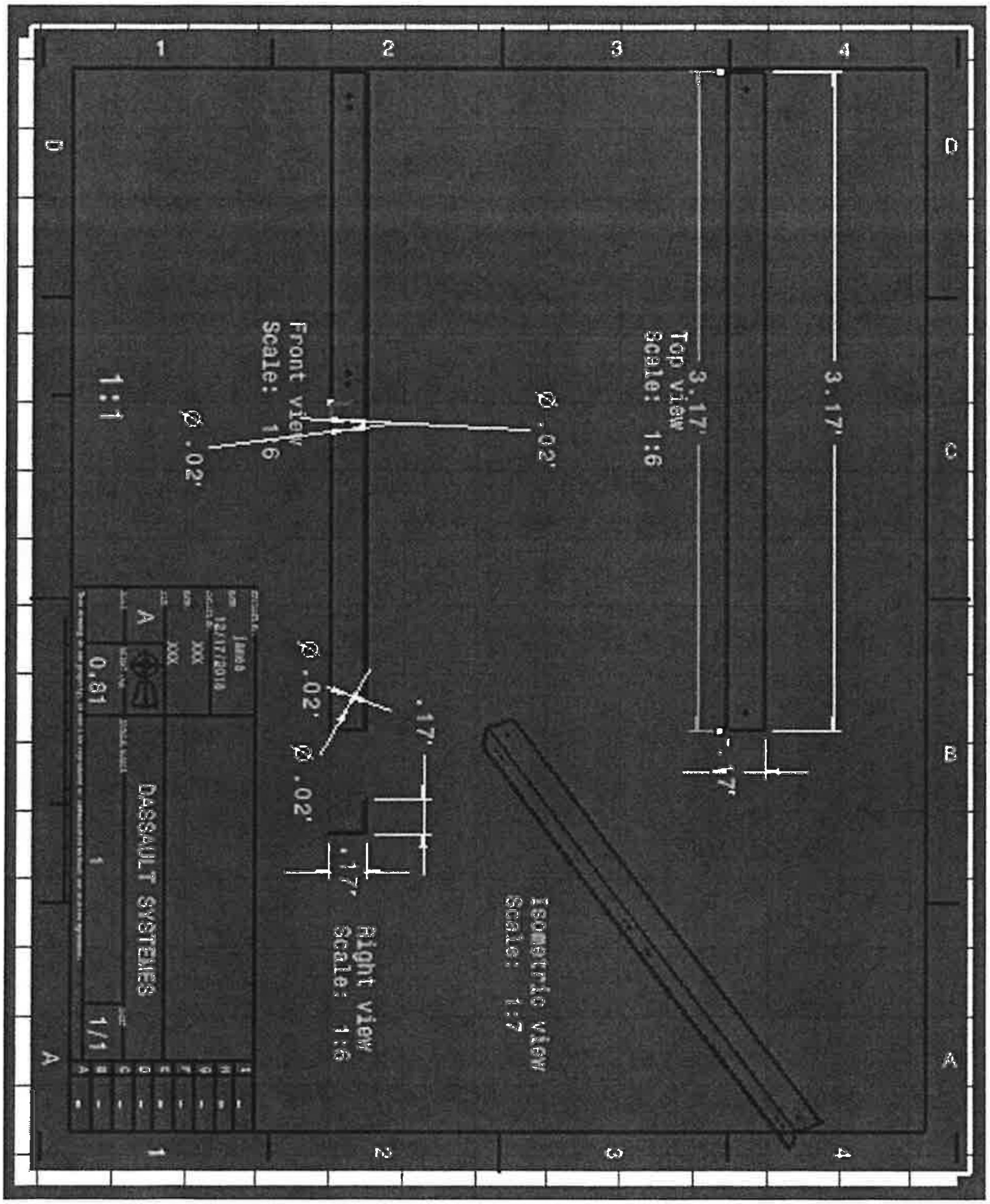
A.8: Middle and Lower Box Frame Support (Left and Right)



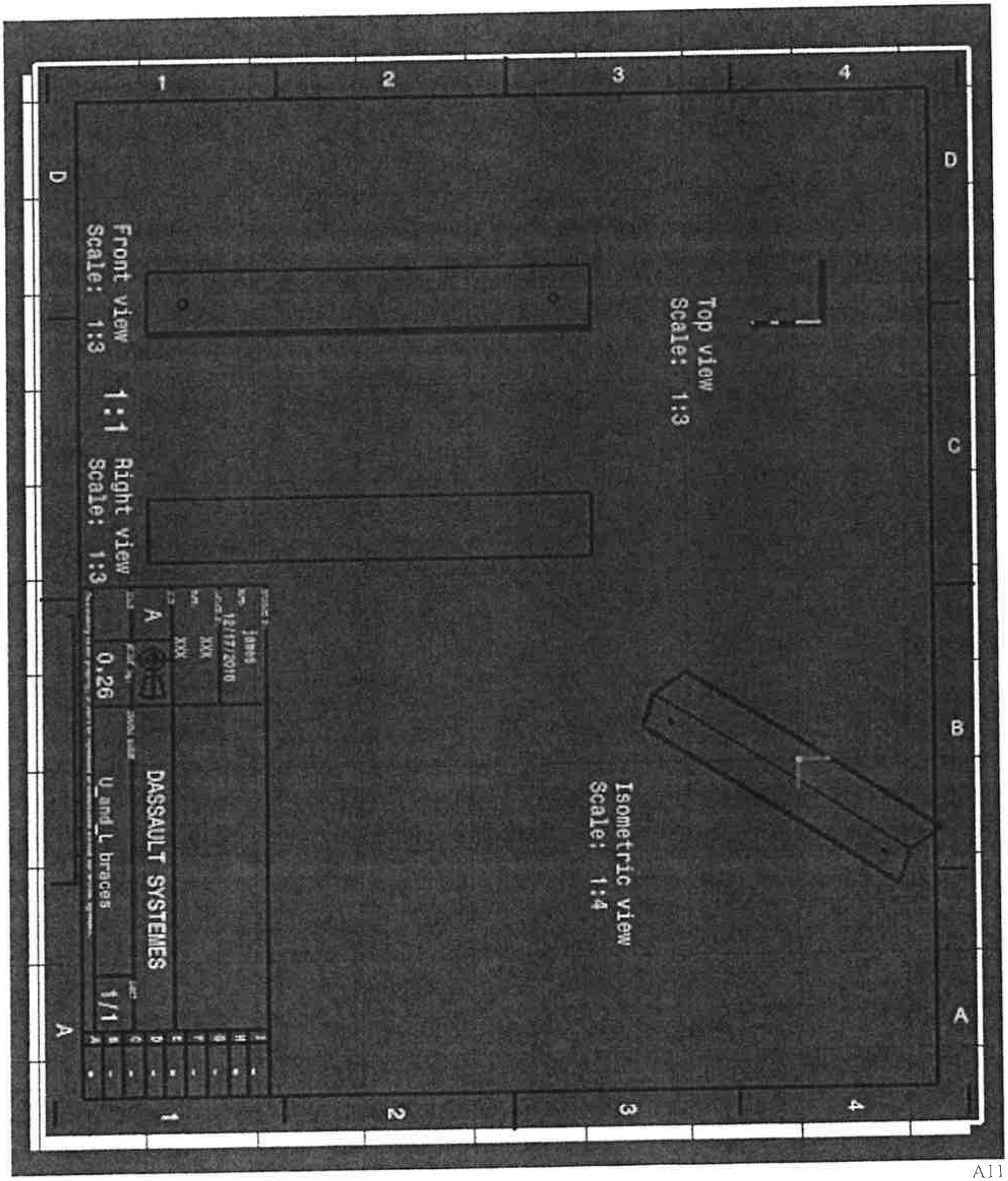
A9

A.9: Top Box Supports (Left and Right)

A10

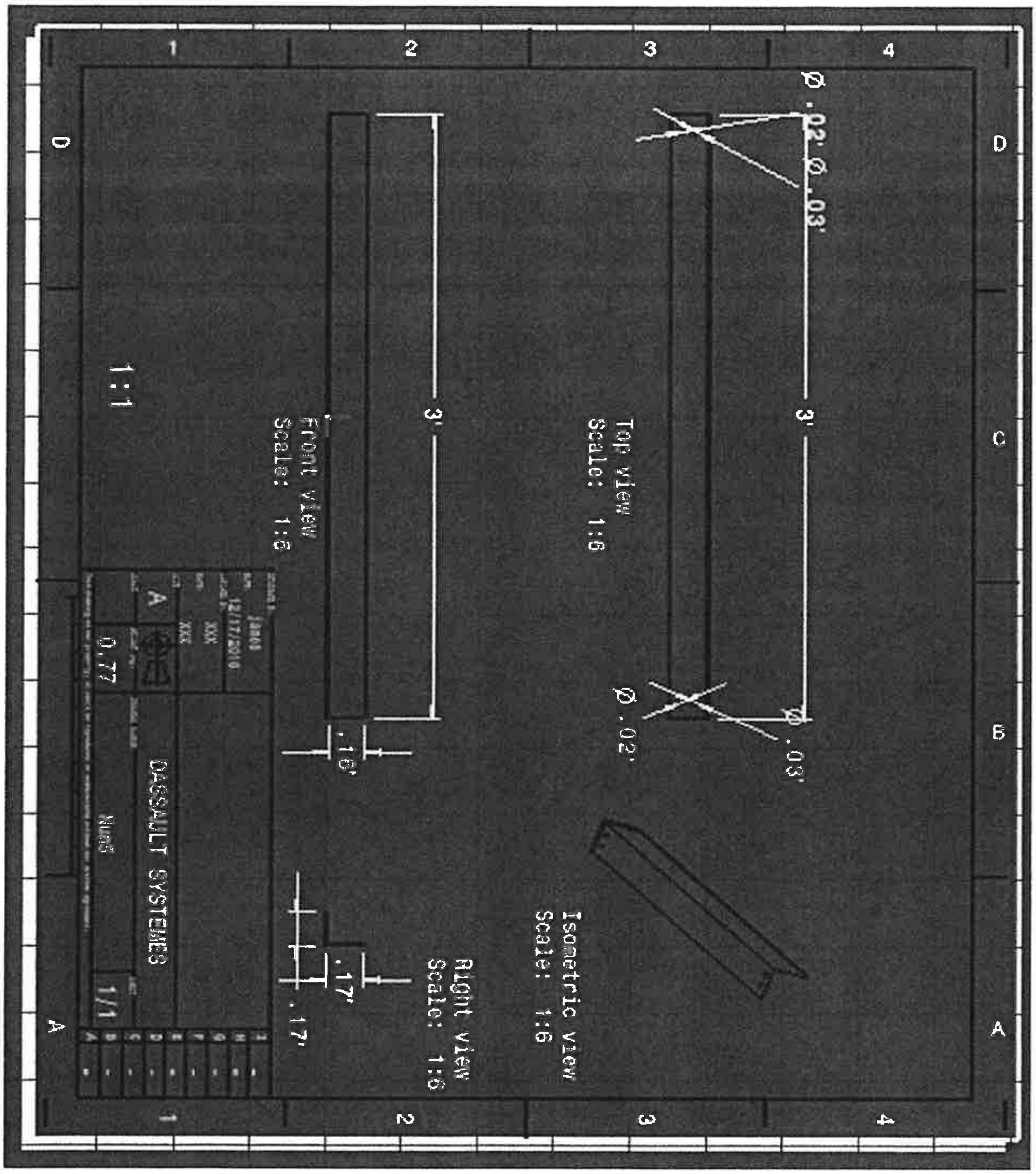


A.10: Upper and Lower End Panels



A11

A.11: Upper and Lower Box Frame Support



A.12: Lower Box Frame Mount Plate