Lunar Regolith Excavator

NASA - Corporation 2

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"Critical Design Review"

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1.0 ABSTRACT

The excavation of lunar regolith has been one of NASA's biggest priorities for a considerable amount of time. There have been many past projects that have tried to address this particular concern. Auburn University has been involved in the quest to excavate lunar regolith for the past three years. This year the lunar excavator has been re-designed and improved upon, to yield better results. The new lunar excavator is primarily made of a composite frame, which is unlike last year's model comprised of mostly aluminum tubing. By using a composite material in the fabrication of the excavator frame, the overall mass of the lunar excavator has been drastically reduced. The composite material that was chosen was carbon fiber tubing and G-10 plates. The G-10 plates will be used as gussets to connect the carbon fiber tubing. Not only is the composite material used in the frame, extremely light, it is also very strong. The excavator is now able to excavate lunar regolith and lift the excavated regolith to a height of 0.7m and dump it. This is another improvement between this year's and last year's model.

Last year's model was able to accumulate tremendous loads of regolith but it was unable to dump the excavated regolith in the collection pin. In order to achieve the lifting height of 0.7m, a conventional mechanism was used. We modeled the lifting mechanism after the typical bulldozer design. This design requires the implementation of two linear actuators. There is one actuator connected to the frame and the lifting arms. This actuator's primary objective is to lift the excavated regolith to the desired height. The second actuator is connected to the lifting arms and the bucket. This actuator's responsibility is to dump the excavated regolith. This type of bulldozer mechanism requires more electrical components than the 4-bar mechanism. Although the digger mechanism is totally different, the concept of simple design was implemented. In order to transport the lunar regolith from excavation site to the site of the regolith collector, a tread system was chosen. The tread system was chosen for several reasons. Some of those reasons are it provides better traction than wheeled systems, turning radius of 0^o, and easier to control. The tread system is also another huge improvement over the previous year's model. The main reason why is because last year's model was not self-propelled. The new lunar excavator is self-propelled. The new lunar excavator has a different camera system than the previous year's camera system. Last year's camera system used an expensive camera with a pan and tilt function. The pan and tilt function was unnecessary for our particular application because we are able to rotate completely around on our own axis. Instead of pan and tilt, two cameras are used. One camera is mounted above the frame's tower. This camera is responsible for viewing in front of the excavator. The second camera is mounted on the rear of the excavator, which is responsible for viewing behind the excavator. With the improvement of each individual subsystem, the overall performance of the Lunar Excavator has been improved upon again.

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2.0 INTRODUCTION

Manned and un-manned space exploration was been a hot topic since the ending of the Second World War. There have been many expeditions into the vast regions of outer space. The moon landing in 1969 sparked an increase interest in space exploration. Since the landing on the moon, countries have strived to establish a permanent settlement beyond the gravitational attractions of Planet Earth. One of the few places that are suitable for a manmade settlement is the moon. In order for a settlement to be successful, the basic needs of life must be met. One of the most basic needs of human life is to breath oxygen. In order to breath oxygen, oxygen must be available. Fortunately oxygen is found in one of the most abundant resources on the moon, its soil. The lunar soil, or regolith, is filled with oxygen waiting to be processed. Before the oxygen can be processed it must be harvested and collected. There are two ways in which the oxygen can be harvested. One way is by human effort. The other way is to have a robot harvest the lunar regolith. By using human effort, oxygen is used while harvesting regolith, which would decrease the net amount of oxygen available. By using an autonomous robot, oxygen is not used and the net amount of oxygen is increased. This decision sparked NASA's interest in building a lunar excavator. For several years NASA has tried to design a system to harvest, transport and dump regolith in a processor to create oxygen. Auburn University has been involved in this effort for three years now. This year NASA has decided to host a competition and see which design can harvest the most lunar regolith. Some of the requirements that teams must design for are excavation of 150kg of regolith in 30 minutes, wireless operation, and vehicle should not exceed 80kg.

The objective assignment was presented by Instructor and Supervisor Dr. David Beale at Auburn University. Mr. Rob Mueller, Lunar Surface Systems Lead Engineer, was the sponsor contact who provided basic function requirements to be reached. Midterm Evaluators were Dr. Madsen and Dr. Bevly faculty of the Mechanical Engineering Department at Auburn University.

The original assignment given by Rob Mueller to Dr. Beale was to improve the last design of the Lunar Harvester. With these new functional requirements and the task of entering the design into the Kennedy competition, concepts were revaluated.

3.0 MISSION OBJECTIVE

The mission objective is to create an un-manned lunar device, that while self-propelled, excavates lunar regolith. The vehicle must be able to be driven and operated remotely. It must efficiently excavate 150 kg of regolith per 30 min in semi-lunar conditions.

4.0 Requirements (all are required for competitions)

4.1 **Functional Requirements**

4.1.1 The excavator shall be an un-manned vehicle.

4.1.2 The vehicle shall be operated remotely/wirelessly.

4.1.3 The vehicle shall excavate 150 kg of regolith in less than 30 min.

4.1.4 The mass of the entire vehicle shall be less than 80 kg.

4.1.5 The vehicle shall be able to operate in dusty conditions without the aid of external cleaners.

4.2 **Digger Design Requirements**

4.2.1 The digger shall dump at a height of 0.7 meters or higher from ground.

4.2.2 The digger must dig regolith without using a wall to collect.

4.3 **Power Requirements**

4.3.1 The system shall operate on no more than 40 V DC.

4.3.2 The system shall be limited with a Cooper Bussman BK/AGC-15 fuse.

4.4 **Communication requirements**

4.4.1 The only feedback to the operator will be the data sent back remotely.

4.4.2 The data will be limited to no larger than 1.0 Mbps of bandwidth

4.4.3 The signal shall be delayed by 2.0 sec.

4.4.4 A visual transmitting device shall be employed to operate through data transmission.

5.0 Architectural Subsystem Design

The Functional requirements began a decomposition of all the functions needed to accomplish the design. The systems engineering approach was taken to find function first, and then to find the concepts possible of completing each requirement. This process does not limit the possibilities early on, allowing development of each goal.

"My method is different. I do no rush into actual work. When I get a new idea, I start at once building it up in my imagination, and make improvements and operate the device in my mind… When I have gone so far as to embody everything in my invention, every possible improvement I can think of, I put into concrete form the final product of my brain." *–Nikola Tesla 1856-1943*

5.1 Functional Decomposition

After functions were determined, extensive thought was given on the effectiveness of accomplishing each one.

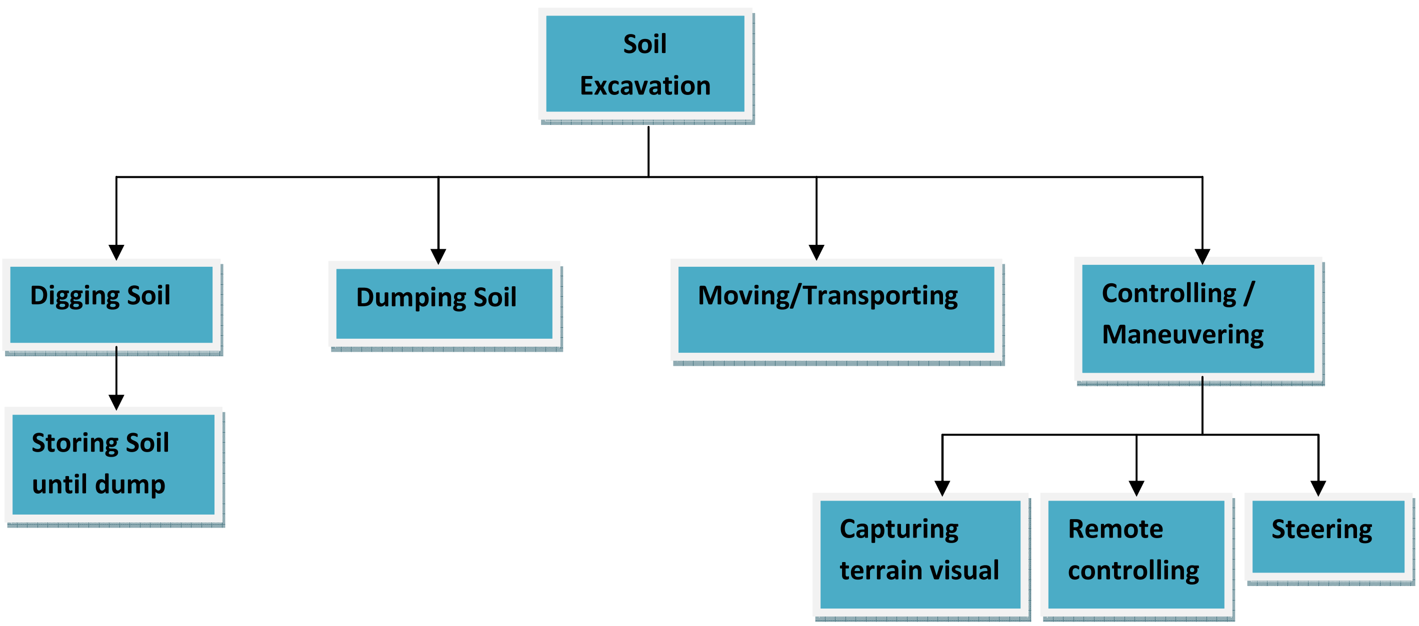


Figure 5.1.1 Functional Decomposition

5.2 System Hierarchy

Concept generation took time to develop which subsystems could carry out which tasks most effectively. A System hierarchy was developed to determine who would lead which subsystem based on skills and strengths of group members. Individual tasks and objectives were then formed to begin conceptual designs of each subsystem.

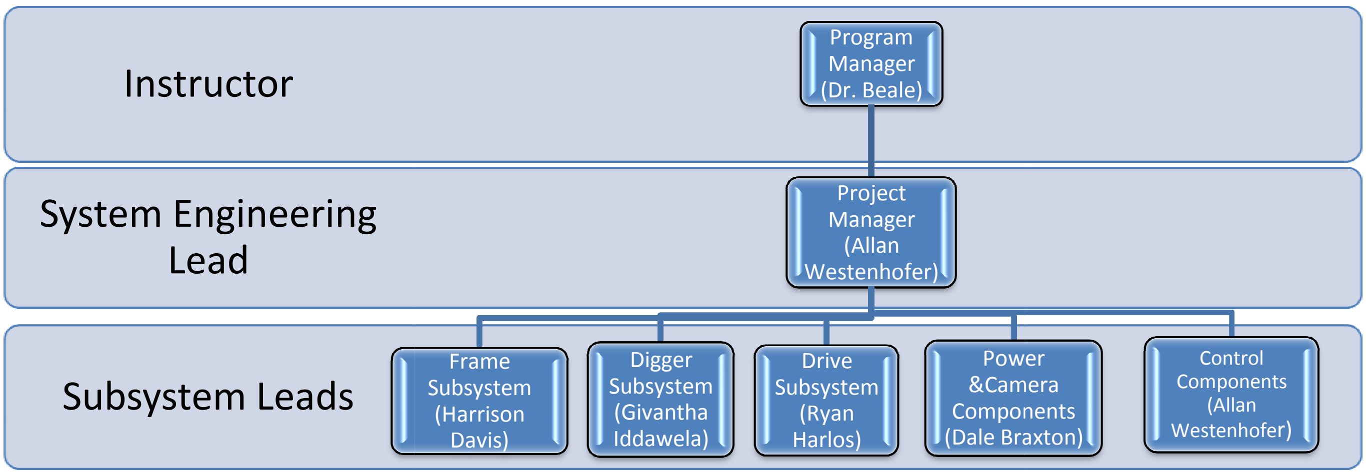


Figure 5.2.1 System Hierarchy

5.3 Navigation Subsystem

5.3.1 Proposed Options

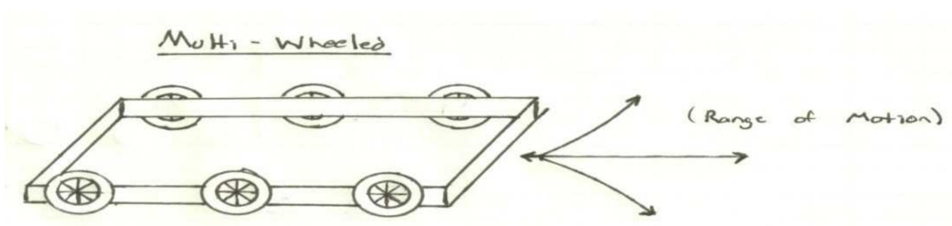


Figure 5.3.1 Multi-Wheeled Option

The proposed option shown is a multi-wheeled vehicle. This approach can, depending on the application, provide more traction than a standard four wheeled vehicle. The vehicle may either be propelled by one motor using a front-steering application as seen in a traditional vehicle or by using two motors to propel each side individually. The two motor approach allows for the vehicle to have a zero-degree turning radius.

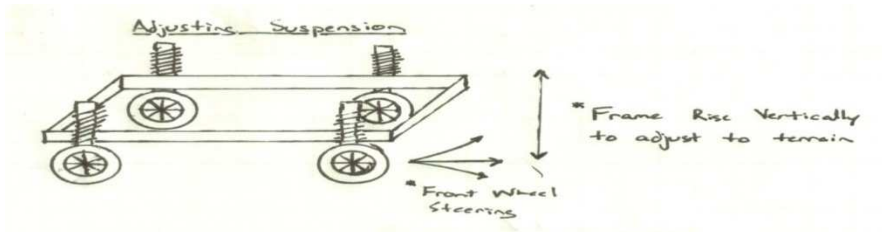


Figure 5.3.2 Adjusting Suspension Option

Another proposed option is the passive adjusting suspension vehicle. In this approach, the wheels are attached to the bottom of adjustable struts. The frame is attached to the upper section of these struts. Using this approach, the user may choose a ride height depending on the height that best fits the terrain to be traversed. This vehicle is powered by one motor and uses front wheel steering to control the direction.

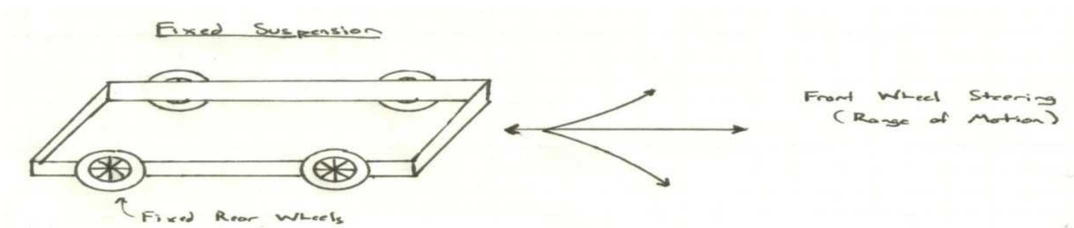


Figure 5.3.3 Fixed Suspension Option

A third proposed option is a fixed or no suspension vehicle. This approach allows for a minimal amount of moving parts. The ride height of the vehicle is fixed according to the specifications desired when assembling the vehicle. This option is powered by one motor and uses front wheel steering to control the direction.

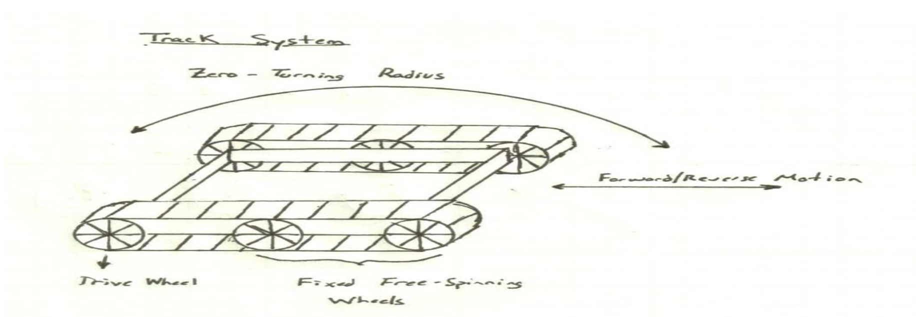


Figure 5.3.4 Track System Option

The final proposed option for the excavator is track system vehicle. This system uses a fixed drivetrain on each side. Each side of the vehicle is controlled by a motor that allows the side to rotate in a forward or reverse direction. The steering is controlled by the motors operating at different speeds for gradual turns or at the same speed in opposite directions to achieve a zero-degree radius turn. The wheels are of a sprocket type with timing to match that of the treads that they are mating with.

5.3.2 Pros and Cons of Each Option

Multi Wheeled

Pros

- Multiple wheels make it harder for the excavator to bottom out in the middle of the frame when traversing varied terrains
- Greater Traction Compared to a traditional two wheel design
- Can still be operable if one of the tires flats

Cons

- Front wheel steering affected by the wheel in the middle
- Larger motors needed to overcome the additional friction forces from added wheels
- Large turning radius

Adjusting Suspension

Pros

- Suspension is adjustable causing the excavator to easily adapt to varying terrain
- Less power to wheels needed due to minimal wheels
- Can be operated with one motor when using front or rear wheel steering

Cons

- Many parts that could fail within the system
- Difficult system needed with a short time span to accomplish the system
- Higher rolling resistance than traditional system due to added weight of suspension
- Large turning radius

Fixed Suspension

Pros	Cons
• Least expensive due to less parts • Can be operated on one motor • Lightweight system	• Large turning radius • Easier to bottom out due to no suspension • Less traction

Track System

Pros	Cons
• Greatest amount of traction possible of all the systems • Zero degree turning radius • Track system makes it harder to bottom out • Wheels are stationary compared to wheel steering design	• Two motors needed • High Torque motors needed to overcome large friction from surface area • Driving inoperable if track slips

5.3.3 Chosen System

After analysis and comparing and contrasting of the available options for the excavator, it was decided that the best choice of the options was the track system. As can be seen from the previous tables of pros and cons, there are reasons why one would choose why or why not to choose from the options listed. The following paragraph will give reasoning behind why the track system was chosen for the design.

The “competition area”, which the excavator will be performing in, is 4 m x 4 m. Four randomly placed rocks (0.2 m – 0.3 m) will also be placed, at random, within the competition area. Due to this small area that the excavator will be performing in along with the randomly placed obstacles, it is an important requirement that the excavator operate with a small turning radius. The track system, with zero radius turns, maximizes the objective to be achieved by this requirement.

Historically, track systems have been used successfully for many different applications. Two of the most recognizable uses are for driving military tanks and for use on heavy machinery seen throughout construction sites. The reason that a track system was chosen for the excavator can be compared with that of the applications mentioned. Military tanks are used on a wide array of surfaces, with the main surface they traverse being dirt areas. The track system for the tanks help them navigate through loose surfaces such as dirt because the added surface areas of the treads allows the tank to have a greater chance of achieving a grip with the dirt. The same comparison can be made with heavy machinery on construction sites. Since the majority of construction sites are on unpaved surfaces, the treads can be considered to be superior in certain applications for their traction with the surfaces. Another advantage the track system has within the construction site, as well as our small competition area is their ability to turn with a zero-degree radius. Since most construction sites are filled with many obstacles throughout them, the track system allows the machinery to navigate through these crowded areas with ease due to its ability of zero-degree radius turns.

The surface that the excavator will be traversing is a simulated lunar regolith. This simulated regolith is very light and composed of many small pieces. In order to navigate across the regolith with ease, a large amount of traction is needed. As compared with traditional wheel systems, the track has superior traction. As can be seen, utilizing the track system achieves another of our two important requirements better than the available options.

5.3.4 Designing Track System

Upon conclusion of deciding on a system of navigation, the next step in the process is designing the track system. Multiple options were looked at from designing a track system from scratch to ordering a complete operable track system for the excavator. The following paragraphs will briefly detail these steps and give reasoning to the final choices.

The first option, which would allow the greatest amount of flexibility, was to design the tread from scratch. Taking this approach, we would be allowed to build the track system to perfectly match up with the frame and/or any other components that it might need to be custom fitted too. When approaching this choice, a few key problems were immediately obvious.

The first problem, and the one that caused most concern, was the timing of the treads. For the excavator, the treads were desired to have holes or notches in the treads which was timed with drive wheels made to fit through this holes. The problem with this involves the cutting of the treads. In order to have the treads match up correctly with the wheels, they must be timed within a very low tolerance at each hole, including the two holes on each side of the splice or joint that connects the tread to itself. When cutting the timed holes into the thread, if one gets out of tolerance just a small amount, and the holes to follow do the same, then after so many holes, your timing will be completely off due to these minimal mistakes in the timing holes compounding as you go along the tread. The reason this is not acceptable is the fact that this would cause the wheels to stop lining up properly with the treads, which could stretch the treads causing the timing to get worse. If the wheel did not cause the tread to stretch, then it would miss the timed holes completely after continuous operation causing the tread to slip, and in turn, deeming that entire side of the excavator and the steering of the excavator inoperable.

A second feasible option, which was looked into, was finding and ordering a fully built track system and drive wheels that would be able to bolt directly to the excavator. If we were to order a system that has been fully built, the dilemma with the timing of a belt and finding a belt suitable for the application would be solved. This would also take care of the problem of designing drive wheels to propel the excavator's treads. After thorough research from manufacturers of these systems, one was found that was the correct size needed for the excavator. See the following image for this product.

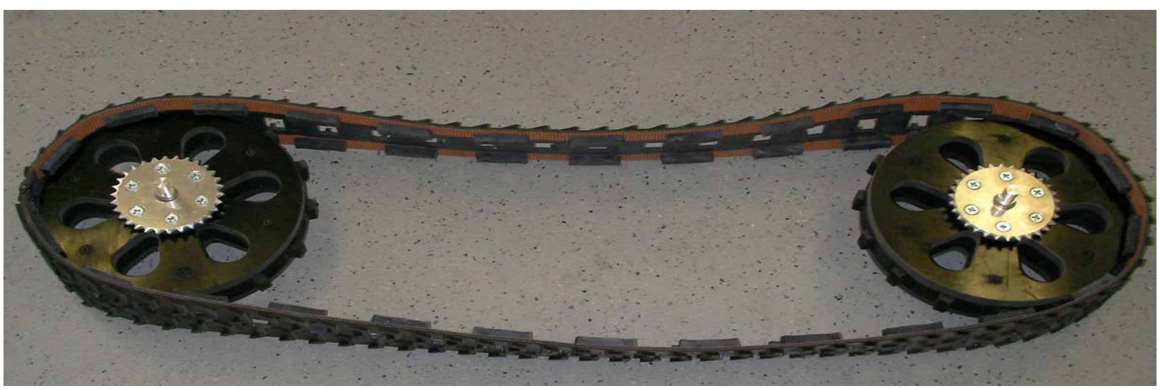


Figure 5.3.5 Combined Tread and Wheel Set

As seen from the image, the track system is a fully timed system with drive wheels matched to the timing. The approximate frame length of the excavator is 1 m. It was ideal to find a system that could either make a track system of a custom length to match this, or find one that was approximately 1 m, which is the case for the system above. See the following sketch for details on the length of the tread system.

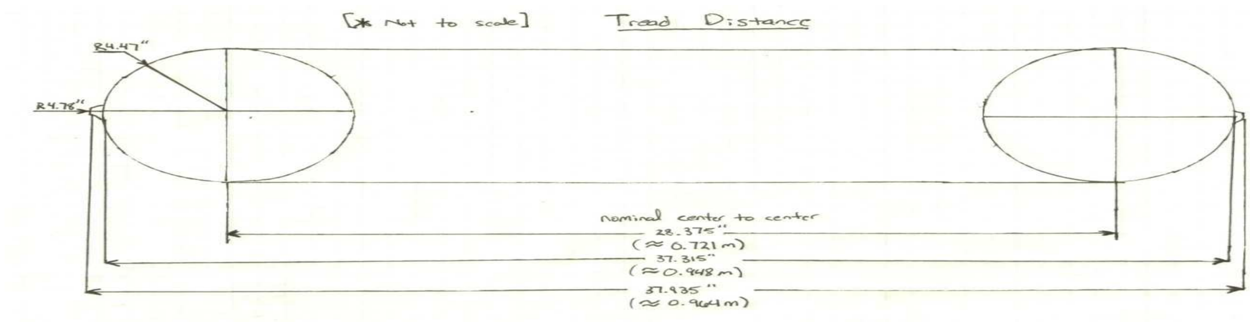


Figure 5.3.6 Tread and Wheel Set Dimensions

The following drawing shows detail of the drive wheels for the system.

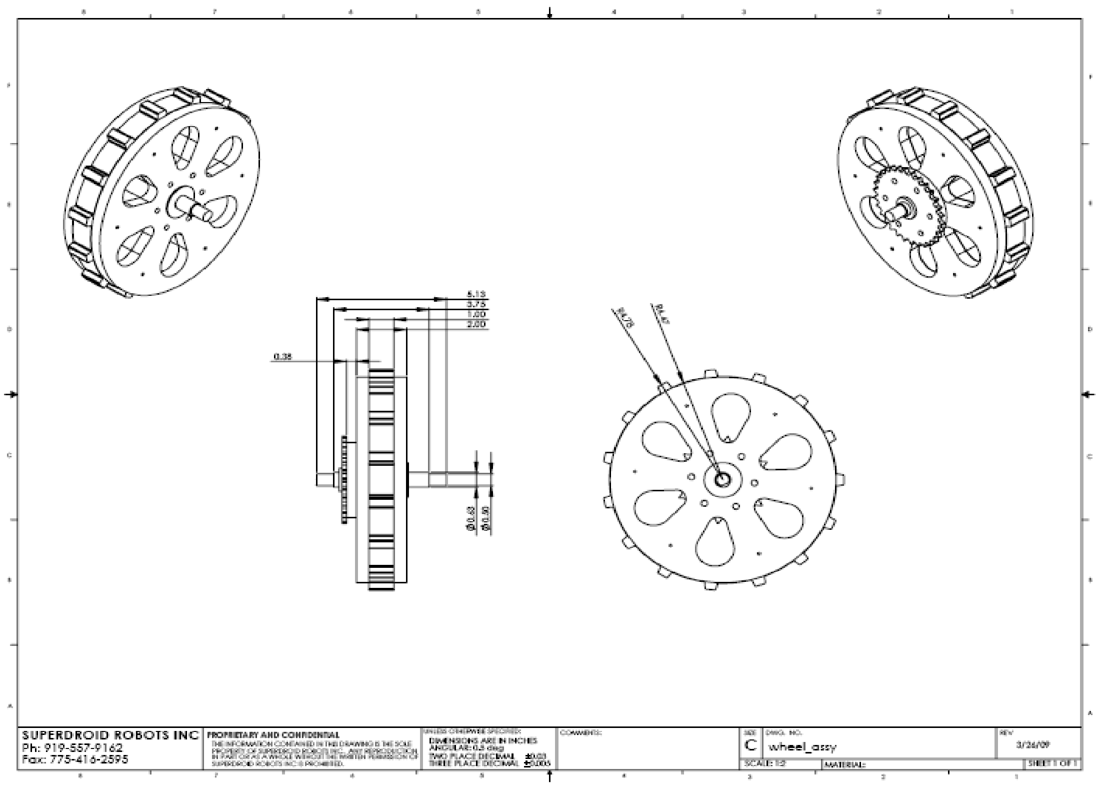


Figure 5.3.7 Draft of Timed Wheel

[Drawing taken from public information on Manufacturer's Website www.superdroidrobots.com]

As can be seen, the tread system, as sold from the manufacturer, is approximately the required distance desired for the excavator. The goal was 1 m whereas the tread system as built is 0.964 m. This difference in the two lengths is considered satisfactory and as a result, is a sufficient design for the excavator.

From a dimensional and functional view, the tread system from the manufacturer, as shown previously, was a sufficient design and fit within the constraints desired. Although, this design fit the physical constraints set forth, upon further research it was shown that the price of the tread system was not satisfactory given the budget for the entire system. The prices that were not acceptable are shown by the following data.

HD2 Track and Wheel Set – $894.96

Note – This price is for two drive wheels and one track. Given this information two sets must be ordered.

Total Price after 2 Sets – $1789.92

If we were to purchase these two sets, then there would be a possibility that we would encounter budget problems in later phases of the excavator design and build. Although this was the tread system that was desired, it was apparent that some compromises or changes would need to be made to lower the budget.

Upon further research it was discovered that a matching set (two tracks) of the timed tracks could be purchased without the wheels. The price of the set of tracks was a significant difference than purchasing the entire tread system from the manufacturer. See the following data to document this.

4 inch wide HD2 Tread Set – $580.63

HD2 Track and Wheel Set Total – $1789.92

Savings in Cost – $1209.29

As shown, the savings in cost is a very significant amount. Another problem presented its self when deciding to take this approach. This problem was that we would not have a drive wheel that is matched up with the timing of the tread set. After further consideration, it was decided that the most feasible and cost reducing choice would be to order the treads and design a wheel to match the timing of these. After conversations with the manufacturer, there is also a possibility to obtain the drawings pertaining to the part of the wheel that has the timing. This would eliminate the need to design a drive wheel to match the timing from scratch if we are able to obtain this drawing. Regardless of whether the drawings are obtained, we will be able to design the drive wheels after receiving the treads with the timing holes cut in them. The tread set is shown in the following image.

Figure 5.3.8 Timed Treads Set

Deciding on this approach, pro active measures have already been taken in order to design the wheel to match up with the tread assembly. Solid Edge parts have been created to give the approximate dimensioning of the tread system. This step was taken in order to provide the subsystem group dealing with the frame to have an approximate idea of what size tread system would be mating to the frame and where it would need to mount to the frame. The following image shows the wheel designed in Solid Edge.

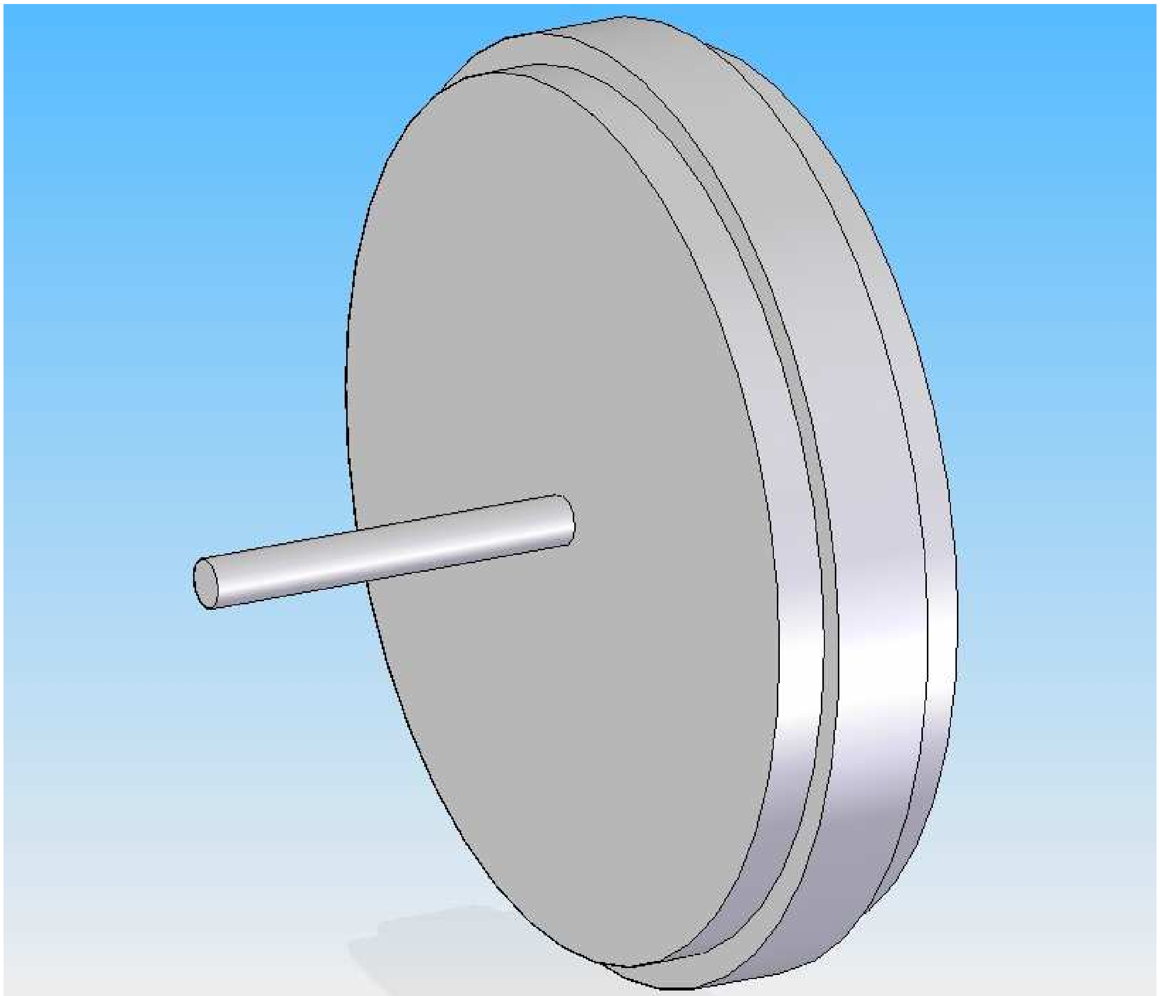


Figure 5.3.9 Preliminary Wheel Design

Note – 1.) The raised section in the middle of the wheel represents the area where timed cut outs will be placed in order to drive the tread.

2.) The material to be used has not been chosen yet. This is the reason behind having no cost estimates on the design of the wheel.

3.) The size of the wheel shaft has not been determined this early in the design phase.

The following image shows the tread designed in solid edge.

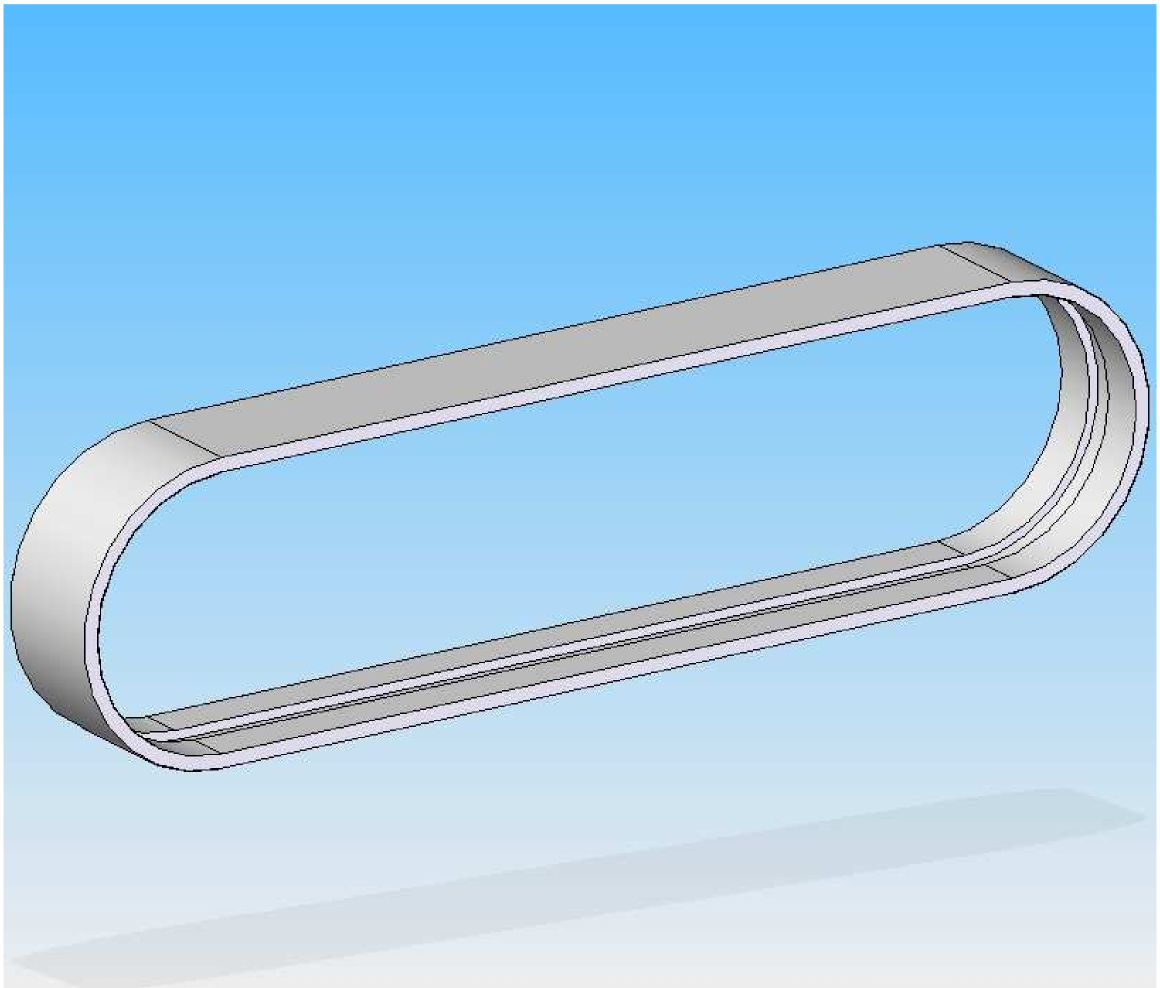


Figure 5.3.10 Preliminary Tread Design

Note – 1.) The notch in the inside-center of the tread represents the area where the timed notches, from the manufacturer, will be placed.

2.) The raised areas on the inside-center of the tread represent the area where raised blocks will be installed, from the manufacturer, to further prevent the wheel from slipping.

As can be seen from the previous images, a grounds for the design have been laid out and will continue to progress through the design and assembly process of the excavator. The following image shows a preliminary assembly of the wheels and tread system combined.

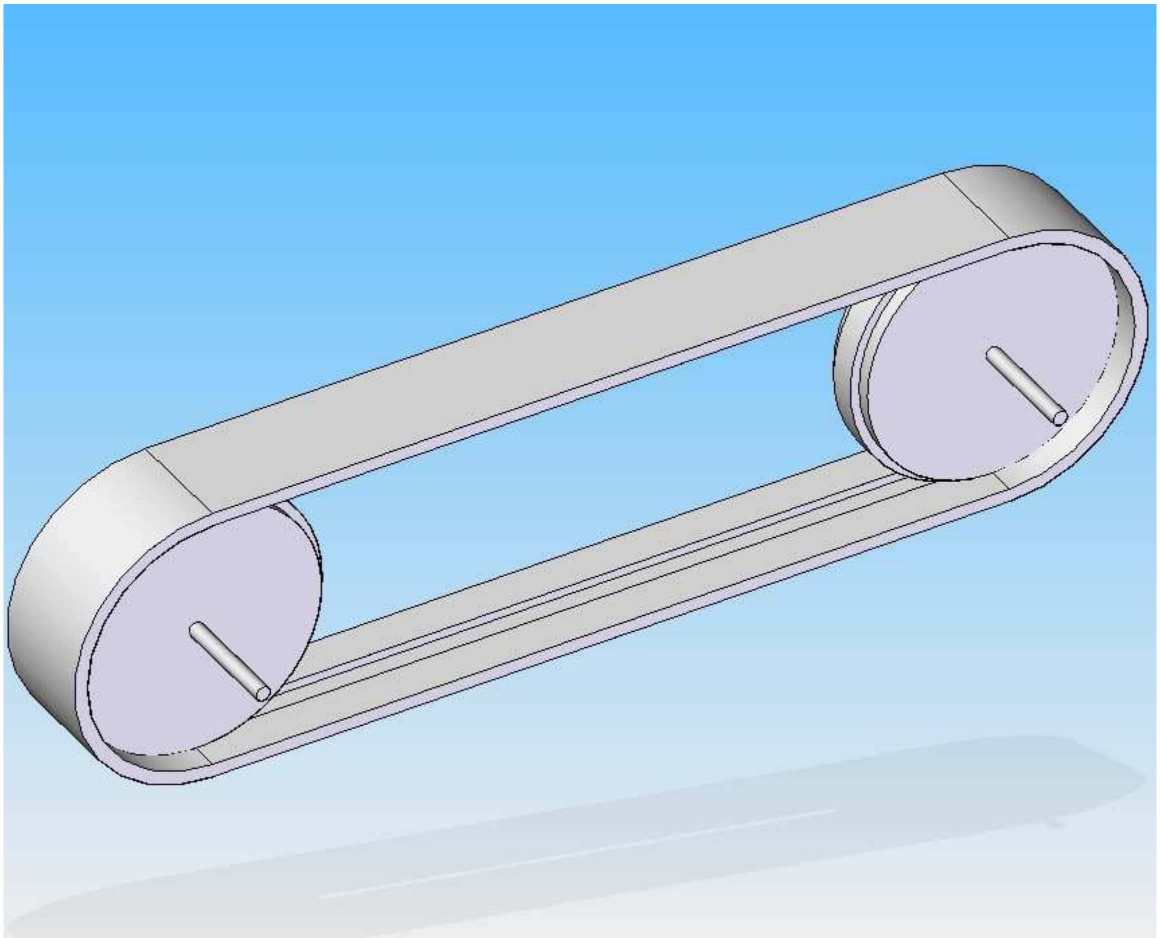


Figure 5.3.11 Preliminary Tread and Wheel Assembly

As the design phase continues to develop, the Solid Edge drawings will continue to be updated until they represent the final design. Although the tread system has been chosen, there are still other items that have to be covered in order to finish the preliminary design of the subsystem.

5.3.5 Choosing Motor

The next required step was to choose a motor that would provide enough torque to propel the excavator. In accordance with the design limits, the motors (independent motors for each size) will be required to propel up to 80 kg plus any load carried by the excavator estimated at 10 to 15 kg.

In order to cut down on weight and cost, the obvious decision was to invest in smaller motors with a gear assembly to provide efficient torque as compared to a non geared motor that would need to be much larger. Upon research of motors, a lightweight and cost efficient motor was found that included different options for gears.

The motor is purchased with the ability to specify your gear ratio according to your desired rpm and torque. The motor model is a 24 Volt IG-52GM sold from www.superdroidrobots.com. The following data shows the weight and price of this motor and gear.

IG-52GM Weight – approx. 2.5 lbs

IG-52GM Price – $106.50 (each)

The following spec sheet gives information pertaining to the motor and available gear ratios.

直流馬達 *(DC Carbon-brush motors)*

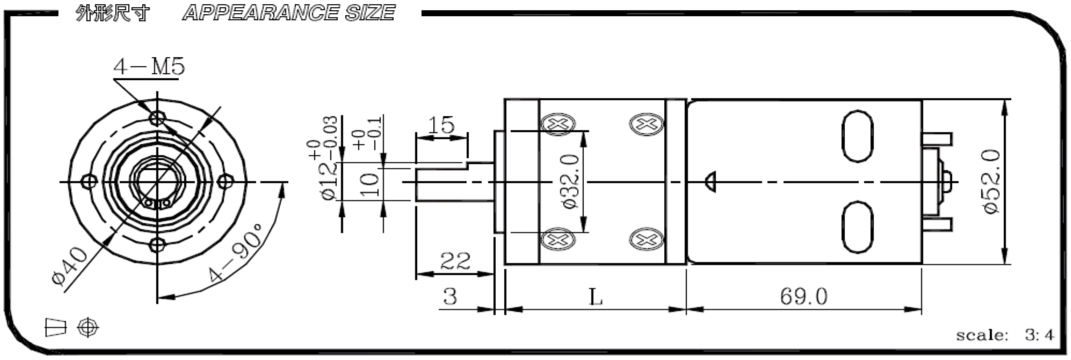
IG-52
GEARED MOTOR
SERIES

IG-52GM

01&02 TYPE

REDUCTION RATIO	L	REDUCTION RATIO	L
1/3~1/4	53.0	1/150~1/676	99.5
1/12~1/19	68.5		
1/43~1/113	84.0		

外形尺寸 APPEARANCE SIZE



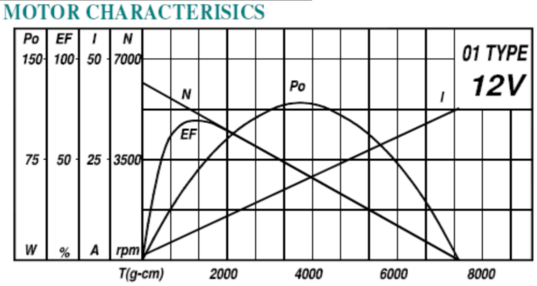
GEARED MOTOR TORQUE/SPEED

	減速比 Reduction ratio	1/3	1/4	1/12	1/15	1/19	1/43	1/53	1/66	1/81	1/100	1/113	1/150	1/230	1/285	1/353	1/488	1/546	1/676
12V	定格扭力(kg-cm) Rated torque	1.3	1.65	4.1	5.0	6.3	12	15	19	23	28	32	36	55	68	84	100	100	100
	定格回轉數(rpm) Rated speed	1600	1290	457	369	305	130.5	122.5	98.5	68.5	55.5	49.5	37	24	19.5	15.5	11.5	10.3	8.3
24V	定格扭力(kg-cm) Rated torque	1.8	2.2	5.5	6.8	8.5	16	20	25	31	39	44	48	74	92	100	100	100	100
	定格回轉數(rpm) Rated speed	1555	1255	444	359	290	127	102.5	82.5	66.5	54	48	36	23.5	19	15.5	11.6	10.4	8.4

馬達單體型式
MOTOR INSTALLATION

定格電壓(V) Rated volt	定格扭力(g-cm) Rated torque	定格回轉數(rpm) Rated speed	定格電流(mA) Rated current	無負荷回轉數(rpm) No load speed	無負荷電流(mA) No load current	定格出力(W) Rated output
12	480	5600	≦5600	6000	≦1750	58.6
24	650	5450	≦2750	6000	≦ 750	48.3

馬達單體特性圖
MOTOR CHARACTERISICS



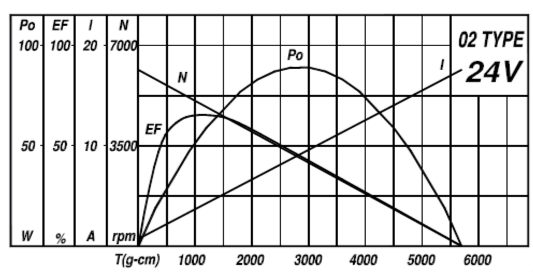
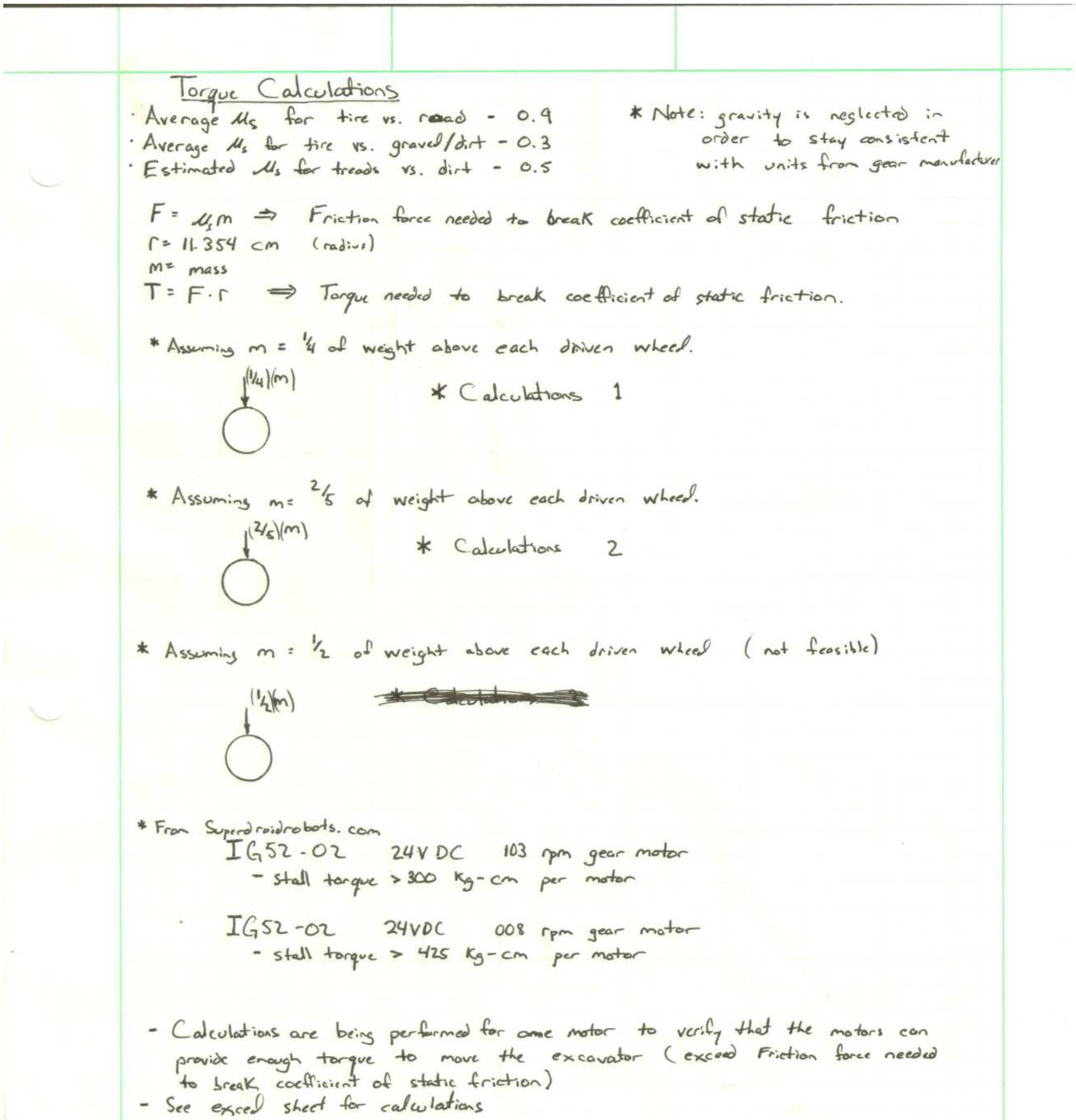


Figure 5.3.12 Geared Motor Spec Sheet

Two options were available that would best fit the application for the excavator. These two options were the 8 rpm and 103 rpm motors listed on the spec sheet for the

IG-52GM motor. In order to make sure that either of these motors will provide enough torque to propel the excavator, calculations needed to be performed to verify their compatibility with the application. See the following for these calculations.



Torque Calculations

- Average μ_s for tire vs. road - 0.9
- Average μ_s for tire vs. gravel/dirt - 0.3
- Estimated μ_s for treads vs. dirt - 0.5

* Note: gravity is neglected in order to stay consistent with units from gear manufacturer

$F = \mu_s m$ ⇒ Friction force needed to break coefficient of static friction
$r = 11.354$ cm (radius)
m = mass
$T = F \cdot r$ ⇒ Torque needed to break coefficient of static friction.

* Assuming m = 1/4 of weight above each driven wheel.

(1/4)(m)

* Calculations 1

* Assuming m = 2/5 of weight above each driven wheel.

(2/5)(m)

* Calculations 2

* Assuming m = 1/2 of weight above each driven wheel (not feasible)

(1/2)(m)

~~* Calculations 3~~

* From Superdroidrobots.com

IG52-02 24V DC 103 rpm gear motor
- stall torque > 300 Kg-cm per motor

IG52-02 24VDC 008 rpm gear motor
- stall torque > 425 Kg-cm per motor

- Calculations are being performed for one motor to verify that the motors can provide enough torque to move the excavator (exceed Friction force needed to break coefficient of static friction)
- See excel sheet for calculations

Figure 5.3.13 Torque Calculations

Notice Calculation 1 (1/4 * m) and Calculation 2 (2/5 * m), these numbers multiplied with the mass represents the amount of mass over one of the rear driven wheels. Calculation 2 is a very cautious approach that if used would be overdesigning for the excavators application. Although it would be considered overdesigning, this calculation is performed so that verification can be made for the motors allowing for a large area of error at the same time. See the following graphs which visualize the calculations in the format of a bar graph. The bar graphs were created in Microsoft Excel and the data associated with them is located within Appendix I.

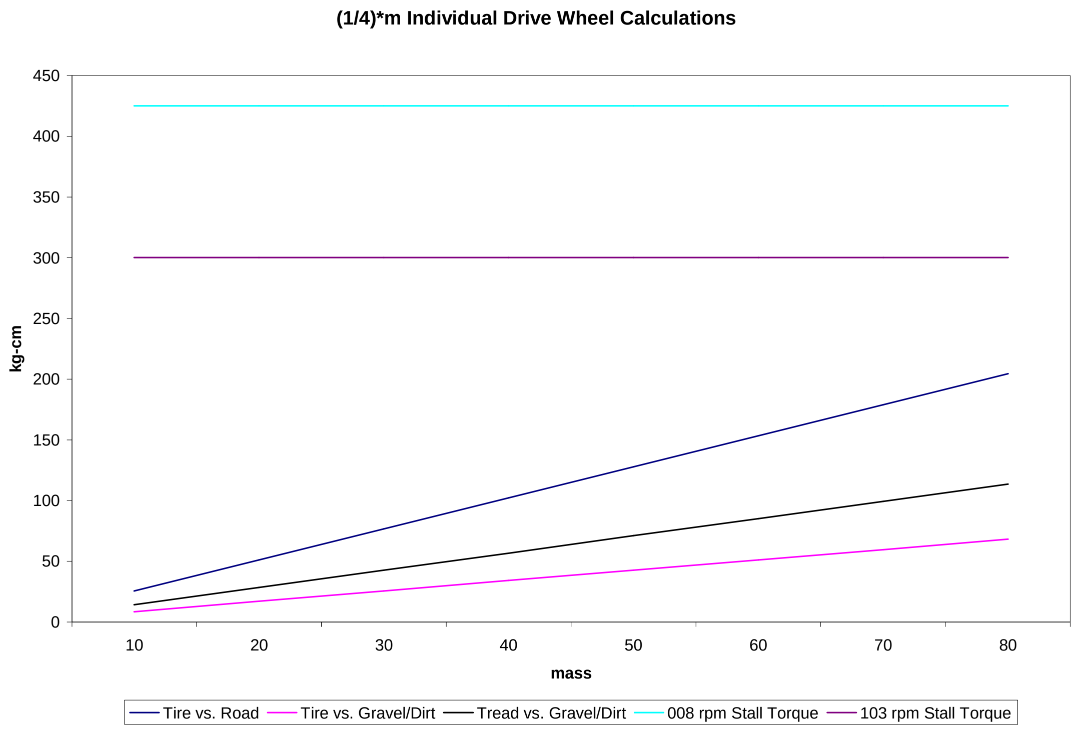


Figure 5.3.14 Torque Calculations 1 Graph

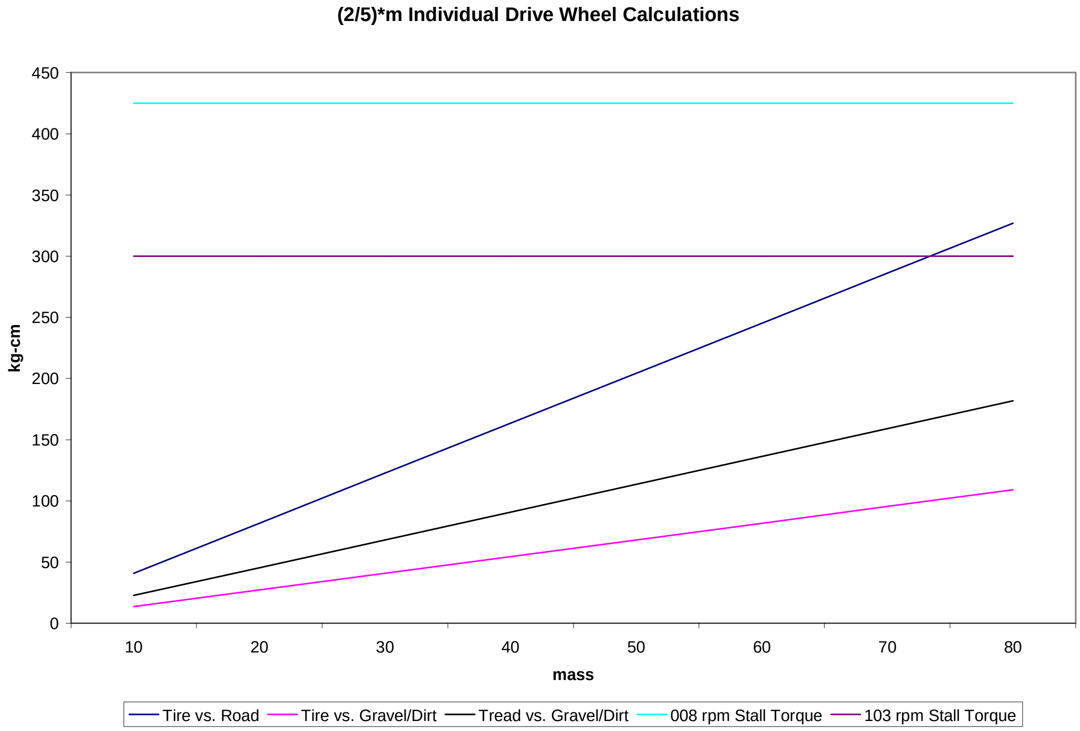


Figure 5.3.15 Torque Calculations 2 Graph

As is shown by the plots, both motors can be used to successfully provide enough stall torque to get the excavator moving. The second set of calculations, although this amount of weight over a drive wheel does not apply directly to the excavator, shows that the 103 rpm motor may not provide enough torque when the gross mass of the excavator is approximately 75 kg. As is shown within this report detailing the weight of the excavator, this calculation does not directly apply due to the fact that the excavator will not way 75 kg but conservatively estimating closer to 50 kg.

The next step, after verifying that both the motor options will successfully propel the excavator was to choose between the 8 rpm and 103 rpm motors. To make this decision the next thing to be performed was to calculate the speed at which each of these motors would propel the excavator at. See the following calculations for these numbers.

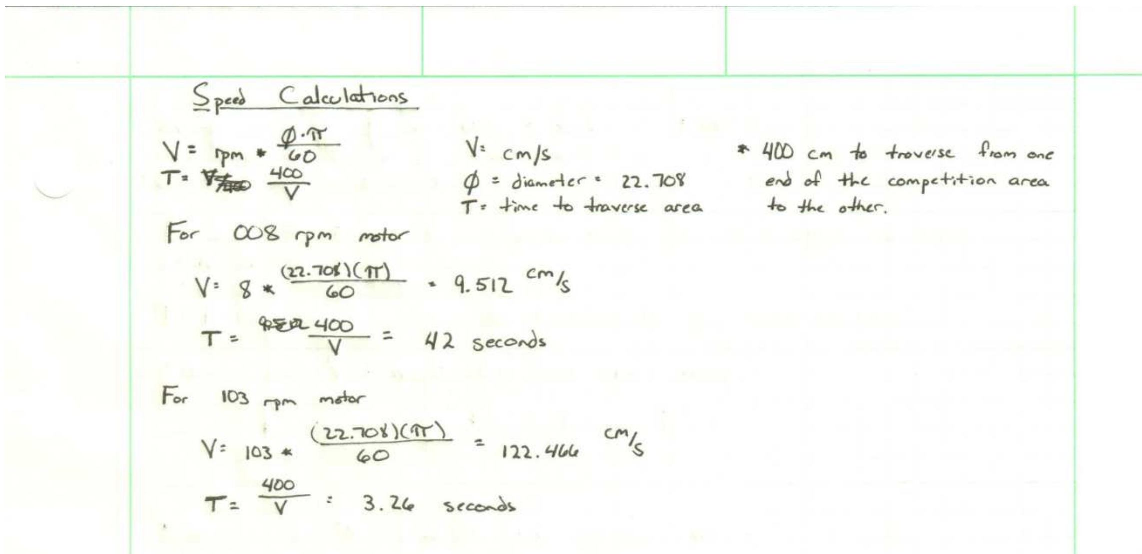


Figure 5.3.16 Speed Calculations

As is shown by the previous calculations the 8 rpm motor would propel the excavator at approximately 9.512 cm/s and the 103 rpm motor at 122.466 cm/s. To gain a better perspective of these numbers, it was calculated how long it would take the excavator to traverse the 400 cm length of the competition area at these rated speeds. As can be seen, the 8 rpm motor would take 42 seconds whereas the 103 rpm motor would take 3.26 seconds to fully cross the competition area. The 8 rpm motors rated speed was considered to be to slow whereas the 103 rpm motors speed too fast for the application. After collaboration with the individuals dealing with the electronics of the excavator, the 103 rpm motor was chosen. It had already been verified that this motor would provide enough torque to propel the excavator and that it could reach speeds faster than necessary. The reason this rated rpm was chosen was due to the electronics used to operate the motor. The motor would be operated with a motor controller, which can control the speed of the motors. Because of this the motors could be operated by the user to move at any speed desired within the competition area.

5.3.6 Assembling the Navigation Subsytem

The next step after choosing the track system and the motors to propel the excavator was to design how the drivetrain would be mounted to the excavator.

The first step in the assembly is to design how the motors will be attached to the frame. To do this, a preliminary design of a motor housing has been modeled. This design allows the motor housing to project from the frame and mount directly to the drive wheels, eliminating a need for extra parts in mounting the motor to the wheels. See the following image for the motor housing.

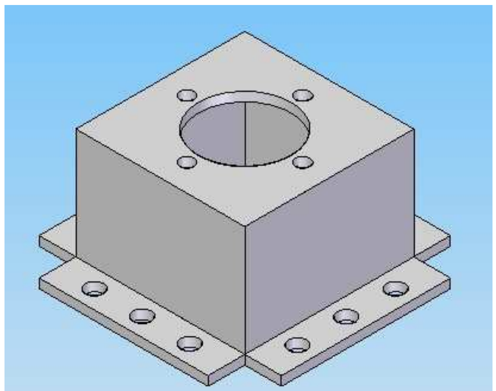


Figure 5.3.17 Motor Housing

Note: This housing will be designed out of either sheet metal or composites (Carbon Fiber or G10)

The following draft shows the preliminary dimensions of the motor. These dimensions may change after receiving the motor and information needed to draft the wheels from the manufacturer www.superdroidrobots.com.

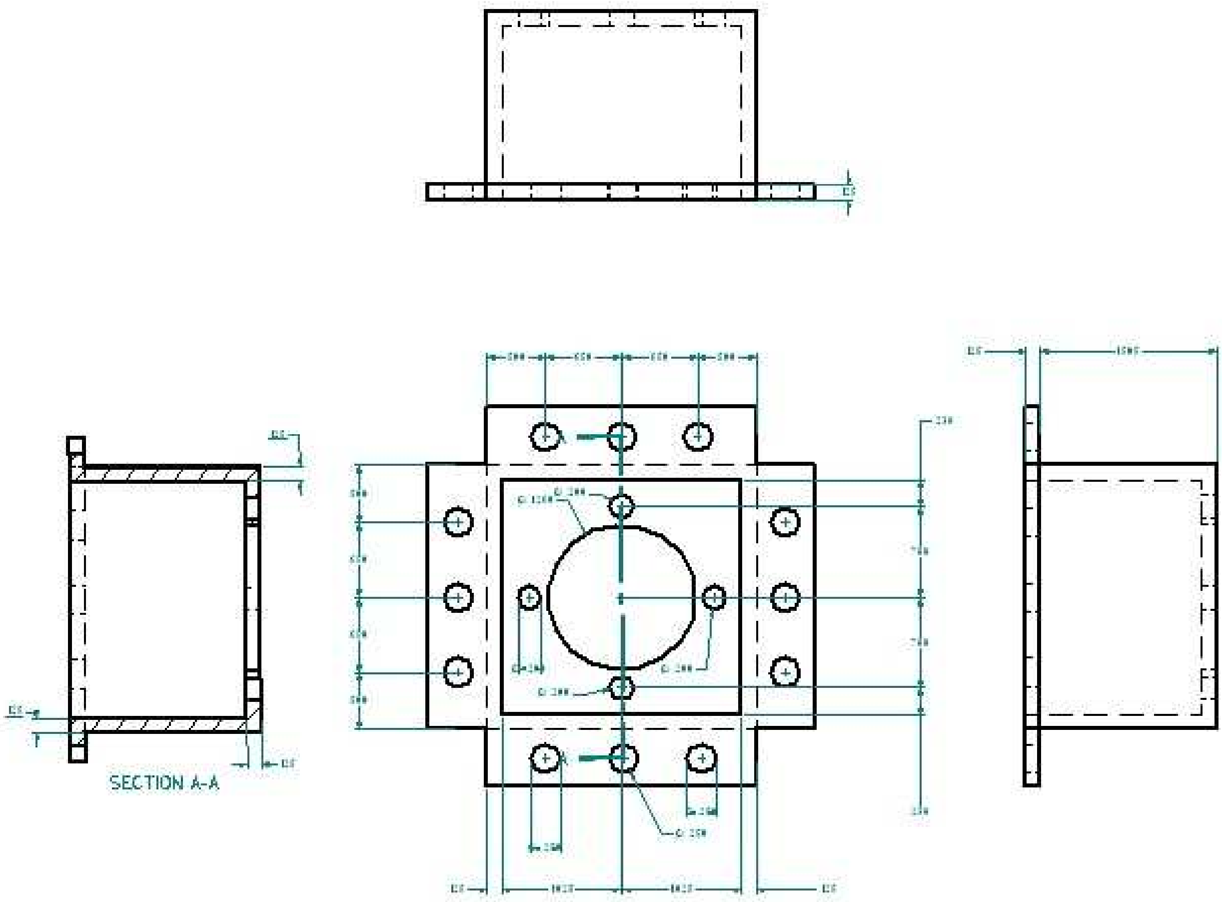


Figure 5.3.18 Motor Housing Draft

Note: All drafts are fully shown in the appendix. Images presented in this section are of dimensions only in order to clearly show all numbers

The following image shows how the motor will mount to the motor housing.

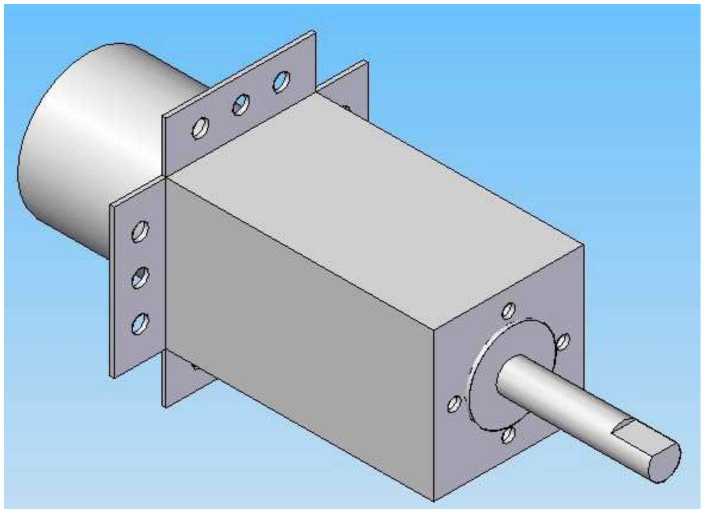


Figure 5.3.19 Motor and Motor Housing Assembly

Note: A more exact housing will be designed once receiving the motor and verifying the dimensions of the motor

After designing a motor housing for the motor, the next step in the assembly was to design how the motor housing would mount to the frames rear side walls. The following image shows the concept for the frame's side wall.

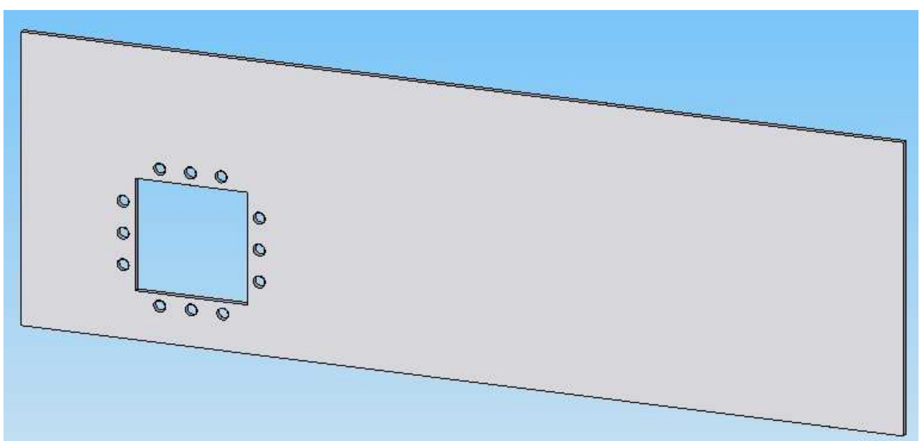


Figure 5.3.20 Frame Side Wall

See the draft following for the dimensions of the frame's side wall.

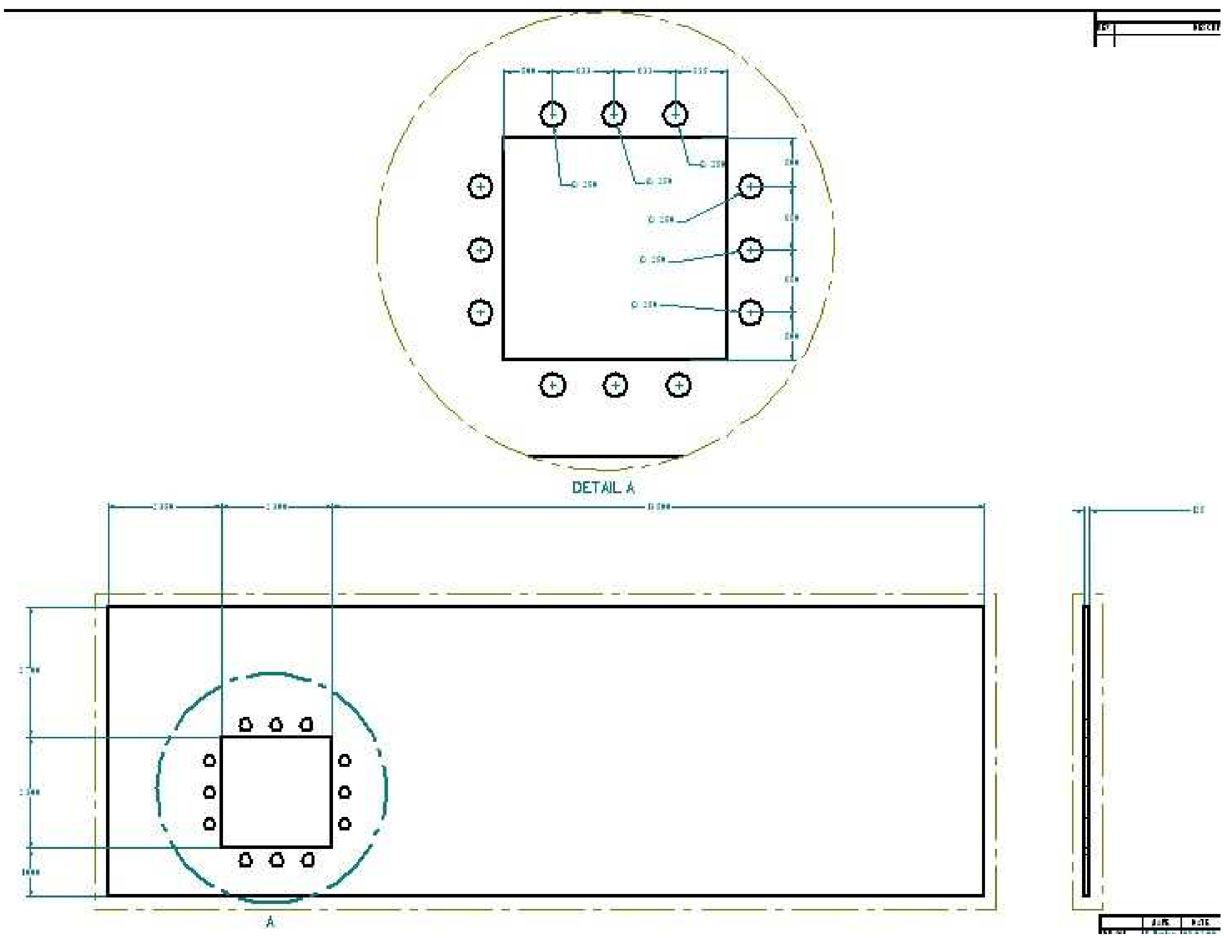


Figure 5.3.21 Frame Side Wall Draft

The following image displays the side wall, motor housing, and motor in their full assembly.

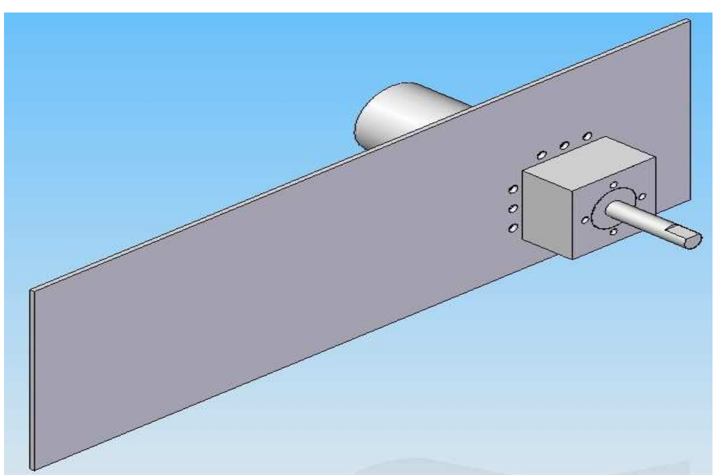


Figure 5.3.22 Rear Navigation Assembly Without Wheel

See the following image showing the previous assembly with the drive wheels attached.

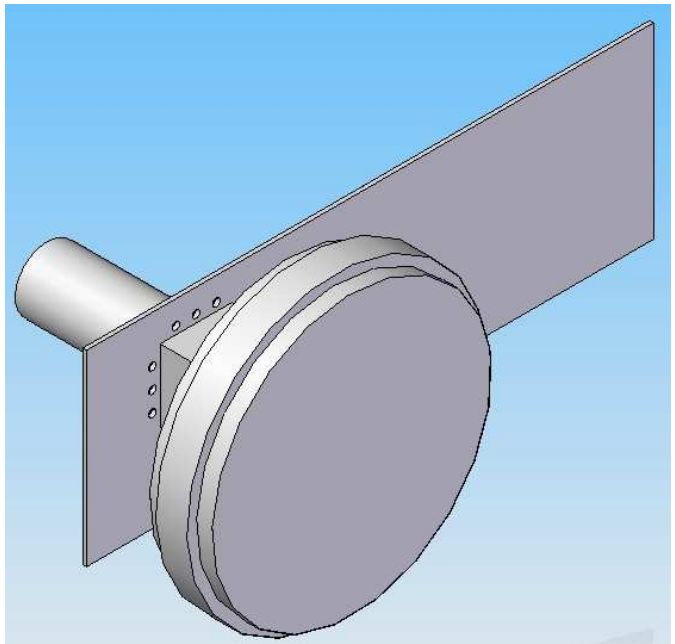


Figure 5.3.23 Rear Navigation Assembly With Wheel

Note: The wheels to drive the treads will be machined according to drawings from the manufacturer. Manufacturer will be sending spec sheets detailing the wheel drawings with the treads. Once these arrive an exact dimensioned wheel will be modeled. Until then, these wheels are considered a preliminary model and not to be considered exactly dimensioned.

After designing how the rear of the Navigation subsytem will be assembled, the next step is to design how the front of the Navigation subsystem will be assembled. Because the excavator will be using a track system, it is necessary for the Navigation subsystem to have a tensioning system added in order to adjust the treads to a proper tension after being mounted onto the wheels.

The base of the tensioning system will be mounted to the front of the excavators frame. The following images show the base plates design and dimensions.

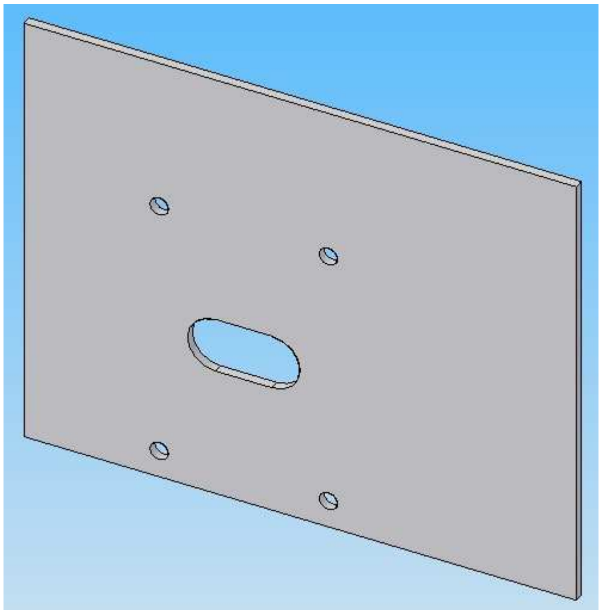


Figure 5.3.24 Tensioning Base Plate

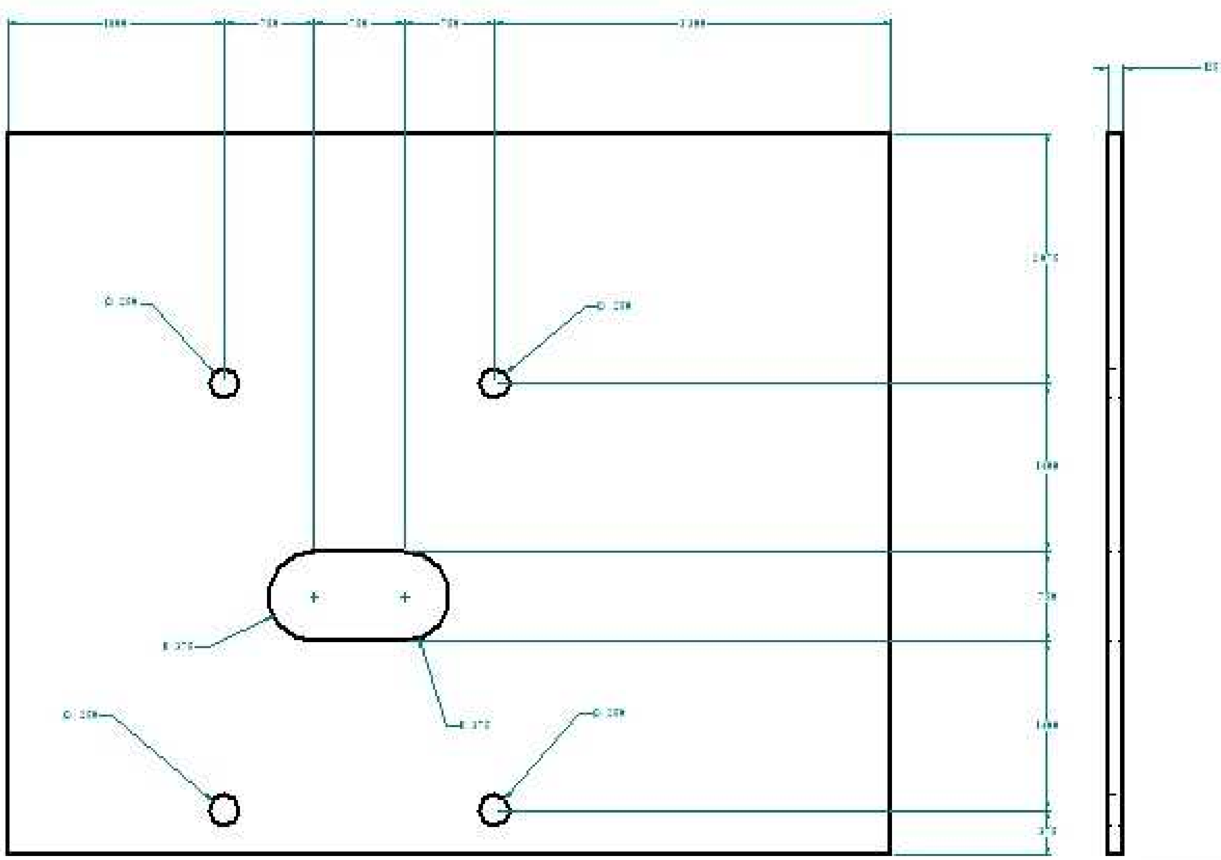


Figure 5.3.25 Tensioning Base Plate Draft

Notice the four 0.25” diameter holes on the base plate, this is where 0.25” fasteners will be inserted through the base plate and the tensioning plate and thus secured to fix the tension plate at a desired position. The cutout in the middle of the plate is where the sleeve bearing, which will be mounted on the tension plate, will protrude through the base plate and be allowed to move freely while tensioning the assembly. See the following images which display the tensioning plate that will be mounted to the frame’s front side wall base plate and the respective dimensions of the tensioning plate.

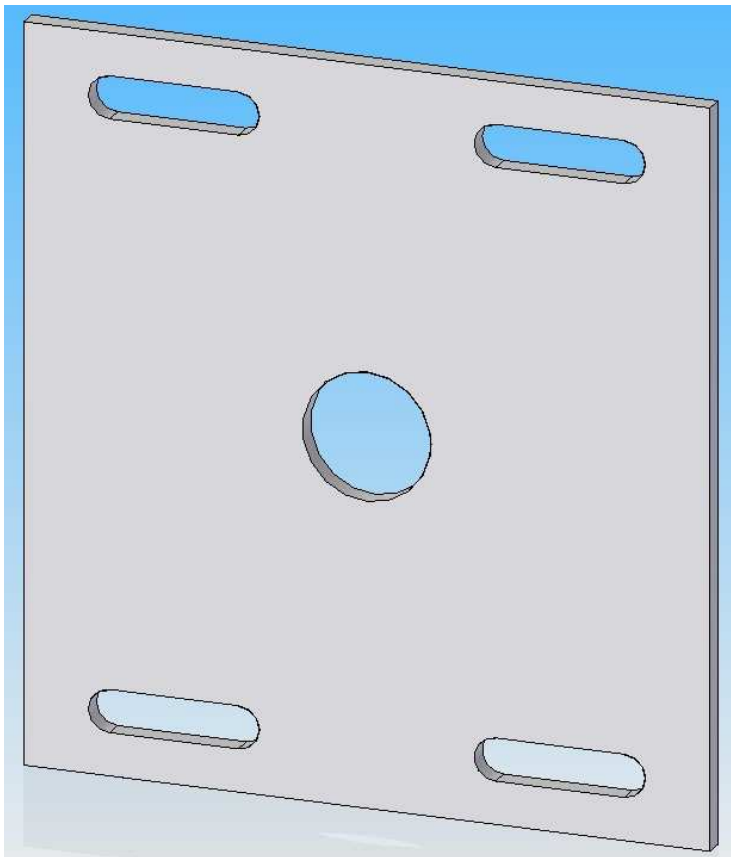


Figure 5.3.26 Tensioning Plate

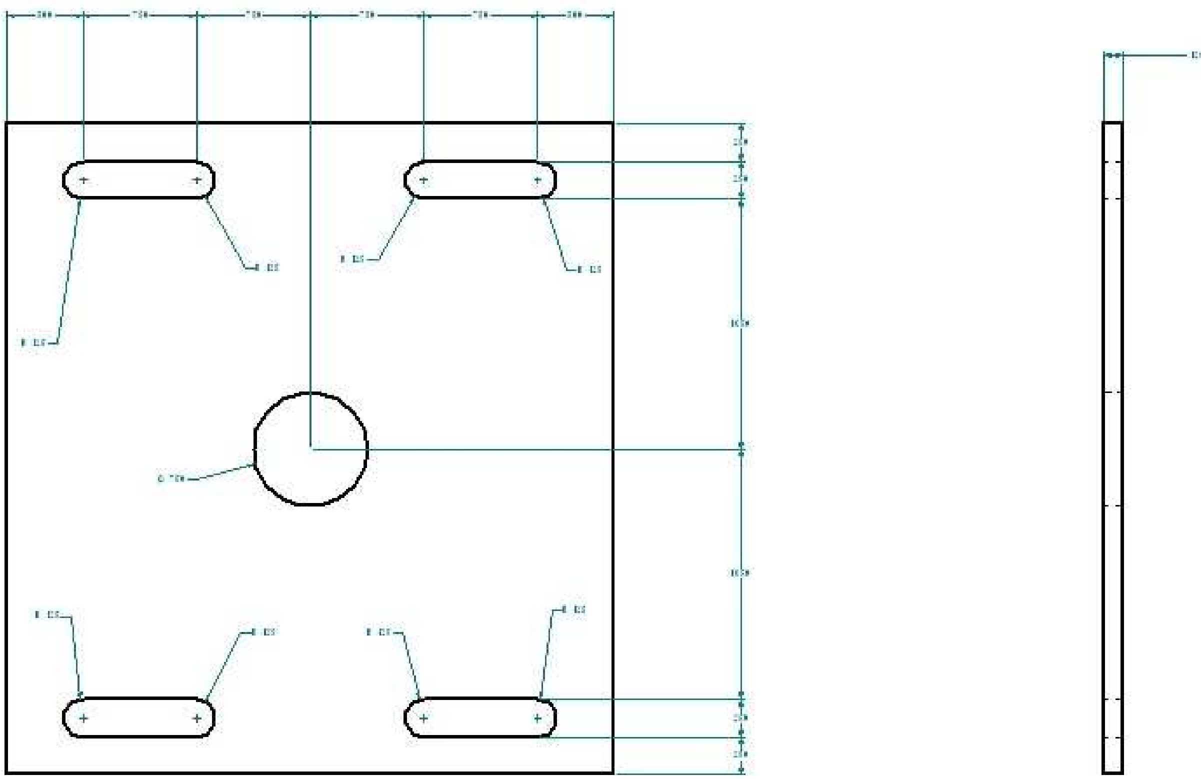


Figure 5.3.27 Tensioning Plate Draft

A self lubricating sleeve bearing has been chosen for the shaft of the front walls. This sleeve bearing is designed to accommodate a 0.5” shaft and made of SAE 863 Bronze (Super Oilite). This is an oil-impregnated material which is maintenance free. The reason this bearing was chosen is for its simplistic design, size, and ease of mounting. The main advantage to this bearing is the small size of it allowing it to be mounted in more locations than most traditional style bearings. The following shows a model of the bearing from the distributer (www.mcmaster.com) and the associated spec sheet.

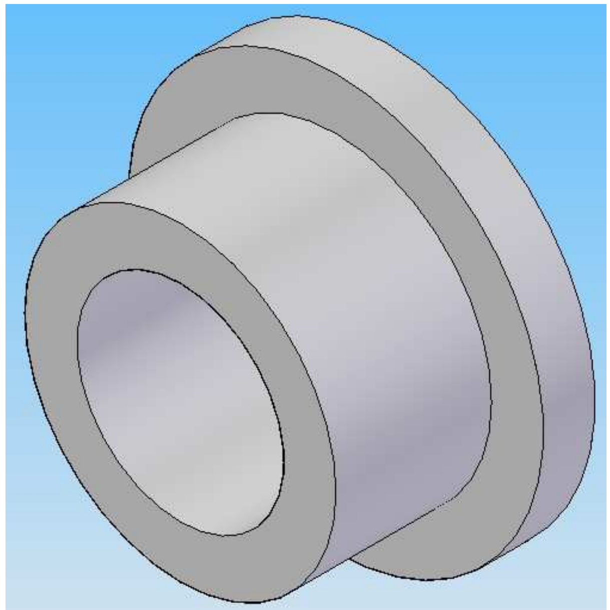
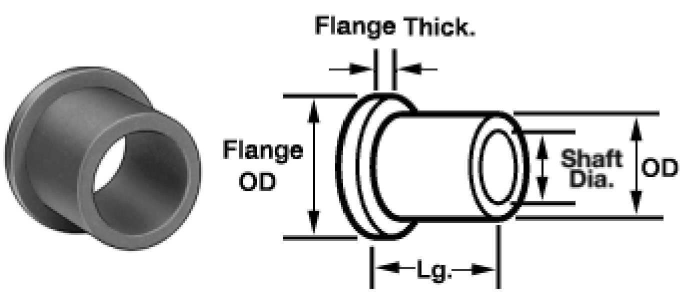


Figure 5.3.28 Sleeve Bearing



Part Number: 2938T15	$0.80 Each
Material	Bronze
Bronze Type	SAE 863 Bronze
Type	Flanged Sleeve Bearings
For Shaft Diameter (Inside Diameter)	1/2"
Inside Diameter Tolerance	+0.0020" to +0.0030"
Outside Diameter	3/4"
Outside Diameter Tolerance	+0.0020" to +0.0030"
Flange Outside Diameter	1"
Flange Thickness	1/8"
Length	1/2"
Length Tolerance	±0.010"
Load (P Max)	4,000
Speed (V Max)	225
Load at Speed (PV Max)	35,000
Temperature Range	+10° to +220° F
Specifications Met	Not Rated

Figure 5.3.29 Sleeve Bearing Specifications

The bearing will be inserted into the tensioning plate with a pressed fit. See the following images for the model showing the sleeve bearing and tensioning plate assembled with the frame's front side wall base plate. The images show both a front and rear view of the assembly.

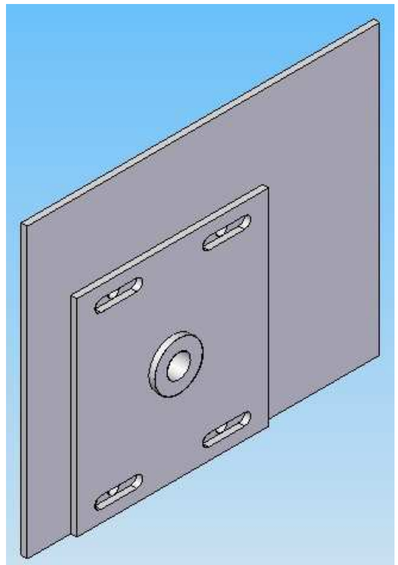


Figure 5.3.30 Tensioning Assembly Front View

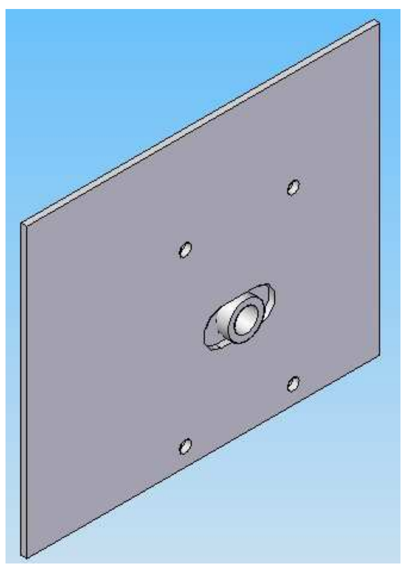


Figure 5.3.31 Tensioning Assembly Rear View

The front wheels will be attached to the tensioning assemblies using a 0.5" shaft made from unhardened steel. Unhardened steel is being used so that the shaft can be secured to the wheel using a set screw. The unhardened steel will allow us to insert a notches in the shaft to accommodate the set screws if needed as unhardened is easier to machine than hardened steel. The lengths of the shafts will be chosen after receiving the needed specifications to machine the wheels. The following assembly shows what the front of the Navigation subsystem when fully assembled will look like.

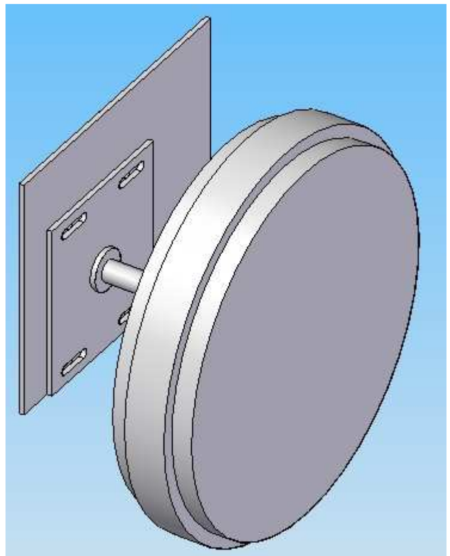


Figure 5.3.32 Tensioning Assembly With Wheel

As shown previously in the report, the treads have already been modeled according to the specifications from the manufacturer. These treads have not arrived yet and therefore have not had the dimensions properly verified at this point. Regardless, the following image shows the entire drive train and how it will assemble with the excavators frame.

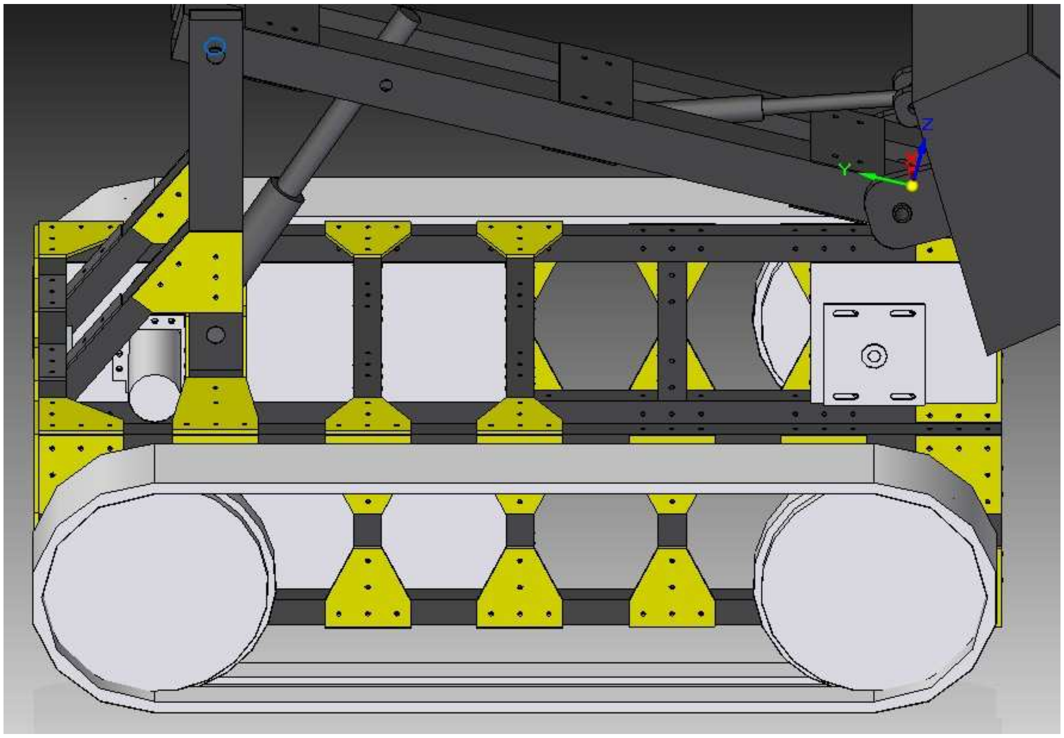


Figure 5.3.33 3D Subsystem Mounted to Frame

Manufacturing Navigation Subsystem Parts

At this point in the design of the Navigation subsystem, the items that need to be completed in order to fully design and assemble the subsystem are dependent upon parts already ordered (treads and associated wheel drawings). Once these drawings and parts are received, the subsytem's concept will be finalized and move into the manufacturing and assembly phase.

To design the subsystem to be as simple as possible, minimal parts are to be manufactured. The following parts require no manufacturing and machining:

- Motors
- Treads
- Sleeve Bearings
- Shafts
- Fasteners

As previously discussed, the wheels will be manufactured once the drawings containing the specifications of the wheels to match the timing of the treads are received. The motor housing, as discussed, will either be made of sheet metal or a composite. The shafts will require, if any work, only to be cut to size. The tensioning assembly will only require to be cut to size and cutouts to be made to house the bearings and fasteners to assemble the system.

5.3.6 Conclusion

At this point, the preliminary design and concept of the Navigation subsystem has been chosen. The first process in the design of the subsystem was to choose some feasible options that could be used to propel the excavator, and from these choices narrow them down to the best option for the application at hand. After this design was chosen (tracks system), the next step was to decide on the necessary parts that would be procured for the system and those that would be machined and manufactured. Key to this process was to verify through computer modeling that each part was sized correctly to fit within the next component of the subsystem. This process has been showing throughout the write up with the use of images taken from the computer modeling software (Solid Edge) showing the parts mating with one another and the drafts displaying the associated dimensions of the parts that will need to be manufactured. Another key step in the process of the Navigation subsystem was to choose a motor that could move the excavator without any problems. Calculations accompanying this process have been showing to verify that the chosen motor will in fact move the excavator and achieve the desired functions that the subsystem is to perform. The subsystem team is currently waiting on some parts and information to come from the respective manufacturer in order to move to the next step of the design process. Once these parts and information is received, the wheels will be able to be manufactured, extra parts needed chosen, and all the parts within the system fully verified to be compatible with each other.

5.4 Power System

The previous power system used to power the lunar excavator used a single 12V battery to power the system's many power requirements. The 12V battery pack was chosen because the maximum voltage in the system was 12V. The designers of the previous lunar excavator cleverly wired the electrical components to utilize the 12V battery and meet the requirements given in the problem statement. Given the current problem statement, requirements and constraints of the design, a new power source would be needed to effectively power the system. The new power system would not only need to power the same electrical components as the previous one but also an extra actuator and two motors. A similar decision making process was taken in order to decide on the type of battery to use in the power system.

The first constraint that was observed was the maximum voltage that the system could occupy, which was 40V. In order not to exceed the maximum voltage, every electrical component could not exceed 40V. Another constraint was also placed on the power system. This constraint was a limit placed on the current that could flow through the circuit. The Cooper Bussman BK/AGC- 15 fuse would enforce this limitation on the current. This fuse only allows 15A to follow through the circuit before the circuit is broken to prevent overheating and potential fire hazards. The limitation on the current also dictates which electrical components can be used in the design of the lunar excavator. Given these main requirements and constraints of the power system, electrical components were chosen to perform the desired operations in order to accomplish the project mission statement.

The first component chosen was the motor(s) that will be used to propel the lunar excavator. The Lunar Excavator will use a track system that operates using two 24V motors. The peak current that each motor consumes is 2750 mA. The next component that was chosen was the actuator(s) that will be mainly responsible for lifting and dumping of the regolith. The actuator(s) both use 12V and consumes 1750mA each. The other components were mainly modeled after the previous excavator's model, as most of the electrical components will remain roughly the same. In the figure below, a chart of the preliminary power distribution is shown.

Table 5.4.1 Power Consumption

Component	Voltage Required (V)	Current Consumed (mA)	Power Consumption (W)
Motors (2)	24	2750(2)	132
Cisco WVC2300 Wireless-G Business Internet Video Camera	12	1000	12

Actuators(2)	12	1750(2)	42
120mm Auxiliary Fan	12	.250	3
PIC Controller	5	100	0.5
Wireless bridge	5	1600	8
WiPort	3.3	400	1.3
Total Hardware (Idle, Connected to ground station)	12	750	9
Sonar Sensor	5V	2	0.01
Camera Board	5V	100	0.5
Siren Speed Controller	12V	100	1.2
Tank Mixer	?	?	?
Total Hardware (Max Load)	24	13052.25	312.254

Now that an estimation of the electrical requirements has been obtained, a power source can be chosen to meet the needs of the excavator. The power source that is chosen should be able to meet the needs of the electrical components and function for at least the required thirty minutes of the competition. The three main types of power sources were considered when determining the best type of battery pack for the system. These three types are lead-acid, NiMH, Li-Ion. Each battery pack has both positive and negative aspects about them. Some of the positive attributes of both NiMH and Li-Ion are they have a long battery life, small, and lightweight. The main negative attribute of these battery packs are the safety issues concerned with each battery pack. Lead-acid batteries are considered safe, but the life expectancy and the weight are a major concern. The decision matrix below shows the decision analysis used when determining the battery pack used.

Table 5.4.2 Battery Decision Matrix

Battery Type Decision Matrix			
	Li-Ion	NiMH	Lead Acid
Battery Life	5	4	2
Weight	5	4	1
Cost	2	3	5
Safety	2	3	5
Size	5	4	2
Total	19	18	15
Average	3.8	3.6	3

Based on the decision matrix, Li-Ion seems to be the best choice given the parameters of the problem statement. Li-Ion combines a small, lightweight battery pack with a very long battery life. This is essential because the lunar excavator has an 80kg weight requirement. After the decision to choose Li-Ion as the source of power for the excavator, the battery life needed to be estimated.

In order to estimate the life expectancy of the battery pack, the preliminary power distribution chart was use. The maximum current consumed in the power system is 13000mA (13A). This current thus gives a maximum of 312W of power consumed in the system. The diagram below shows a schematic of the preliminary electrical circuitry.

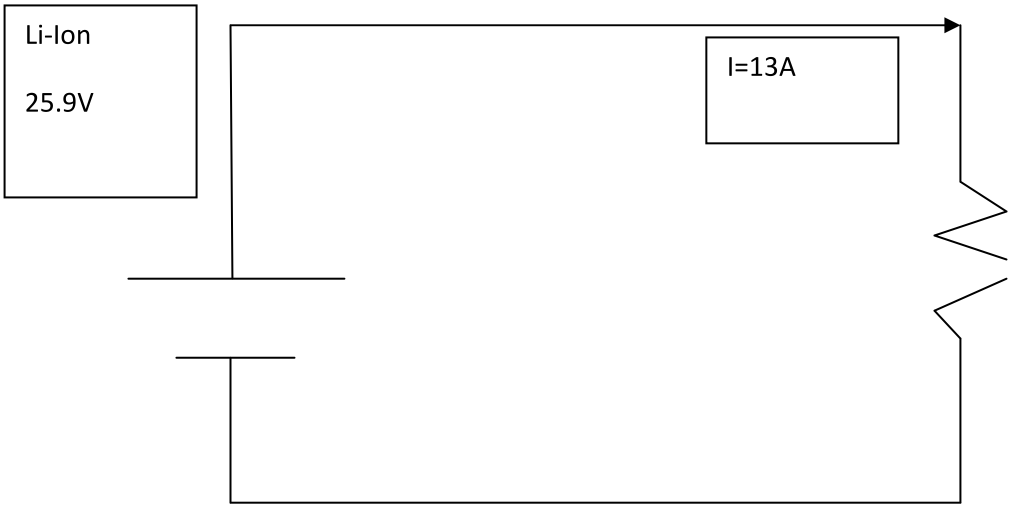


Figure 5.4.1 Preliminary Power Schematic

The Li-Ion battery pack must have a Wh rating above 156Wh. 156Wh would give the system approximately 30 minutes of run time. The battery pack must provide above 156Wh because you cannot fully discharge Li-Ion batteries. Once the battery pack is fully discharged it cannot be recharged. Hence a 25.9V Polymer Li-Ion battery pack with 543.9 Wh was chosen. Li-Ion battery packs do not come in 24V packs but rather in 25.9V packs. This particular pack was chosen because it would give the system an estimated run time of 96 minutes. The battery pack is also installed in a water proof/ fire retardant aluminum enclosure. The battery pack only weighs 3.75 kg and takes up 0.00253m^3 of space. The battery pack costs $669.95.

After careful consideration of the operation of the complete excavator frame, we noticed that the frame was extremely light. The weight of the frame was estimated to be between 20-25kg. The extreme lightweight nature of the frame posed several key concerns. One of these concerns was whether the frame would be heavy enough to provide the amount of traction needed by the treads. Another key concern was whether the frame would tip over when lifting the regolith. One way to address these problems was to add weight to the frame. This weight not only needed to be added to the frame but also positioned in a certain manner as to keep the lunar excavator from tipping over. We decided that the use of a lead acid battery would increase the weight of the frame. By placing this weight at the rear of the frame would allow us to increase the amount of regolith that the excavator could lift without tipping over. The lead acid battery chosen was a 12V 26Ah lead acid battery. The power system will require two of these batteries wired in series, to provide enough power for the motors. Each battery costs $59.95 each. This reduction in price decreases the overall budget by $549.95. The battery is shown pictured below.

Figure 5.4.2 12v Lead Acid Battery

Since the total voltage in the circuit is 24V and most of the components in the circuit do not require 24V, voltage regulators will be implemented to limit the voltage to these components. A total of 6-12V regulators will be used to limit the voltage to each of the six 12V components. A total of 4-5V regulators will be implemented to limit the voltage to the each of the 5V components. One 3.3V regulator will be implemented to regulate the voltage of the WiPort. Below is a schematic drawing of the power system.

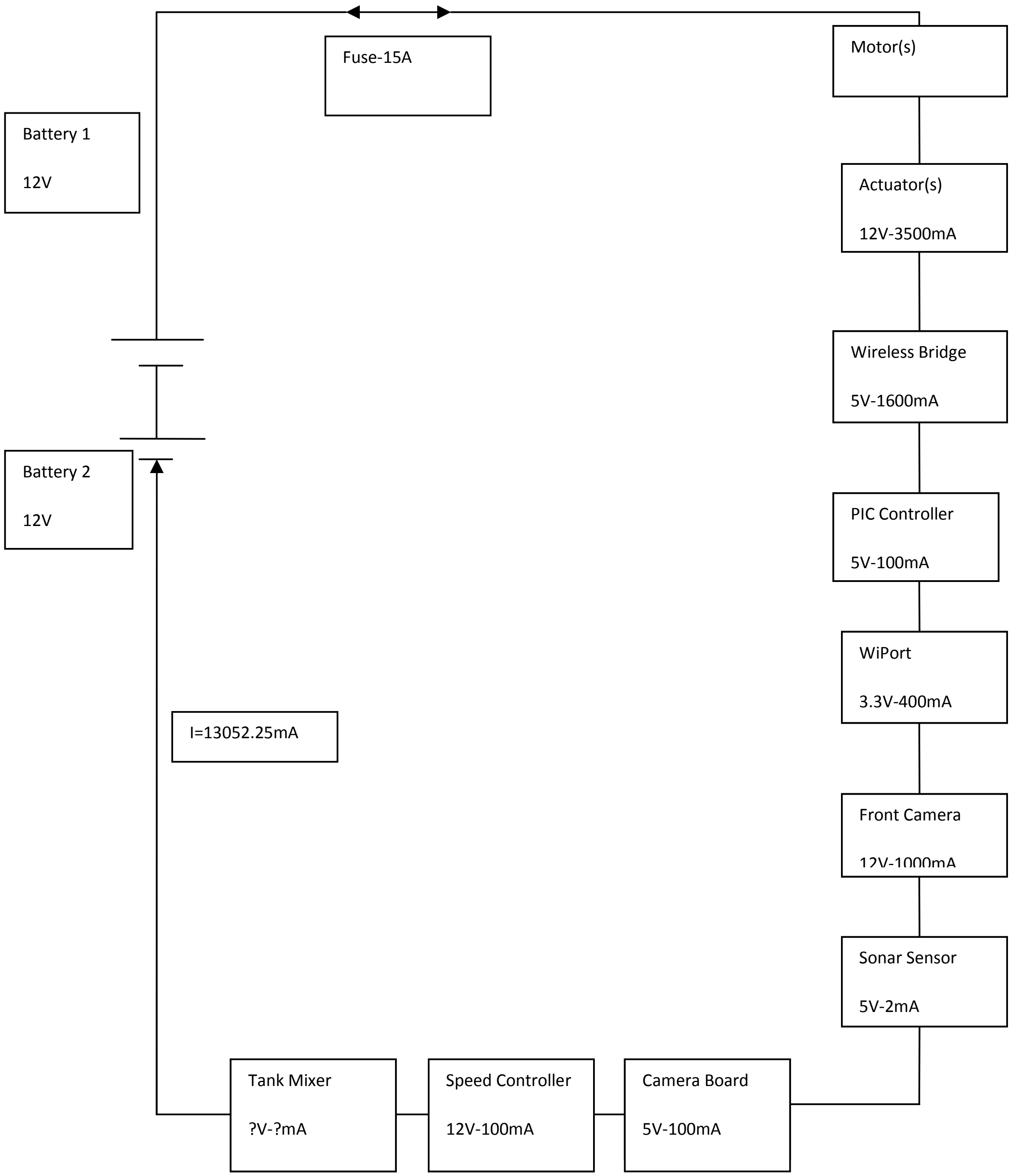


Figure 5.4.3 Power Schematic

Once all the voltage and amperage requirements for the complete system were known the new battery life was calculated. The calculation below shows how the battery life was estimated.

$$Battery\ Life = \frac{Battery\ Current\ Rating}{Current\ Rating}$$

$$Battery\ Life = \frac{52Ah}{13.05225A}$$

$$Battery\ Life = 3.98hrs$$

In the figure below, the batteries are shown mounted on the rear of the excavator frame.

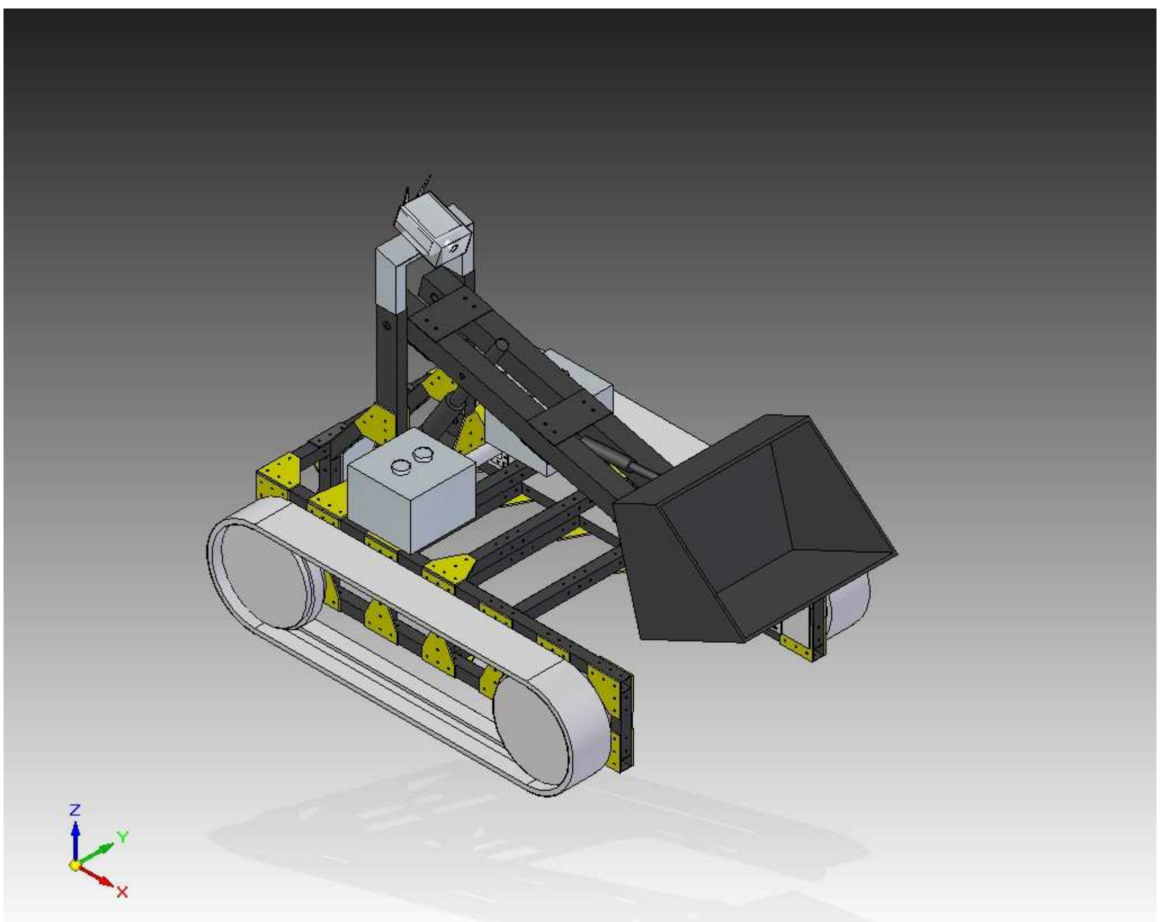


Figure 5.4.4 Visual of Camera Location

5.5 Camera System (Dale Braxton)

The selection of the camera system began with the evaluation of the previous excavator's camera system. The previous excavator used the NetCam XL 3MP camera with a pan and tilt system. This camera is a 2048x1536 (3.1 Megapixel) maximum resolution camera. The optimum resolution of this camera is 1024x768 and has a max frame rate of 30 FPS. The cost of this camera system is $1099, not including the pan and tilt system. The NetCam XL 3MP is also capable of 225 FPS at reduced resolutions. One of the most important things about this camera is that it can be viewed from any computer in the world. The NetCam XL 3MP is able to accomplish this because it is an IP-addressable device. The viewing of live images and videos are available over your LAN network. The camera also can be secured using password protection. The NetCam XL 3MP provides several other benefits as well, such as, it does not require a dedicated PC in order to operate, quality images, dynamic NDS support, browser-based, can be programmed to upload images to your web server based on a schedule you set, two serial ports, bandwidth-adjustable, and an internal clock that can synchronize itself over the Internet or you can set the time manually via a web browser. The pan and tilt system was implemented to give the camera the ability to view images all around the lunar excavator. Even though this camera has an adjustable bandwidth, the minimum bandwidth required by the camera exceeds the bandwidth allowed by the competition. This is one of the various reasons that a new camera system needed to be implemented.

Two of the alternatives that were considered when trying to decide which camera would be used in the new camera system were a Pan-Tilt USB Camera with IP Web Server and USB Camera with IP Web Server (4 Camera Configuration). The cameras were considerably less expensive than the previous camera. Some of the benefits of the Pan-Tilt USB Camera with IP Web Server are it supports remote surveillance by Internet Explorer, remote control of picture angles, motion detection, video record, color CMOS VGA sensor with 350,000 pixels, JPEG compression, up to 30 FPS (typically 12-22 FPS), USB interface, focus distance of 5cm to infinity with a manually adjustable focus lens, auto control for white balance, exposure, color/brightness, pans 320° and tilts 60°. The net weight of this system is 450 grams. Some of the benefits of the USB Camera with IP Web Server (4 Camera Configuration) are night view features, 320 x 240 and 160 x 120 resolution, browser support, video recording, JAVA support, PC and MAC compatible, FTP uploads images, 1MB Flash Memory, 8MB Dynamic Memory, Power input at 5.3VDC 1A Max, 10/100Mbps Fast Ethernet connection, Built-in 2 USB ports for 2 cameras and a net weight of 155 grams. It also only takes up 0.0000829m^3 of space. Although these camera systems boast many positive attributes they also have limitations. These limitations include the resolution of the cameras are not as high as the NetCam XL 3MP, the ability of the Pan-Tilt USB Camera with IP Web Server to only pan 320°, which would not give it the ability to view objects from all angles, and the complexity of the 4-camera system of the USB Camera with IP Web Server. Given both the benefits and limitations of the previous camera system and the new alternatives we must choose which system to use. The decision matrix below illustrates the main tool used to determine which camera system that should be used.

Table 5.5.1 Camera Decision Matrix

Camera System Decision Matrix			
	NetCam XL	Pan & Tilt USB Camera	USB Camera
Weight	3	4	5
Price	1	5	4
FPS	5	4	3
Pan & Tilt	0	4	0
Security	5	4	4
IP - Addressable	5	4	4
Resolution	5	2	2
Dimensions	3	4	5
Total	27	31	27
Average	3.375	3.875	3.375

Based on the decision matrix above the Pan & Tilt USB Camera was chosen. The Pan and Tilt USB Camera only costs $128.40.

After we re-evaluated the performance of the excavator, we realized that camera system with the pan and tilt function was not necessary. By eliminating the pan and tilt function, the overall system would require less control and consume less power. With this decision being made, the pan and tilt camera system was eliminated, and two stationary cameras were implemented. The cameras chosen was the Cisco WVC2300 Wireless-G Business Internet Video Camera and

CMUCam2+ Robot Camera. The Cisco WVC2300 Wireless-G Business Internet Video Camera, pictured below, will be implemented on top of the tower that houses the arms for the digger.

Figure 5.5.1 Cisco Wireless Transmitting Camera

The second camera, the CMUCam2+ Robot Camera, pictured below, is mounted on the rear of the excavator frame.

Figure 5.5.2 CMUCam2+ Robot Camera

Some of the most attractive features of the CiscoWVC2300 camera are its adjustable bandwidth, protocols that it supported, frame rate, and its wireless capabilities. The technical specifications of the Cisco WVC2300 are found on the Cisco website. The figure below is a picture of the camera system mounted on the excavator frame.

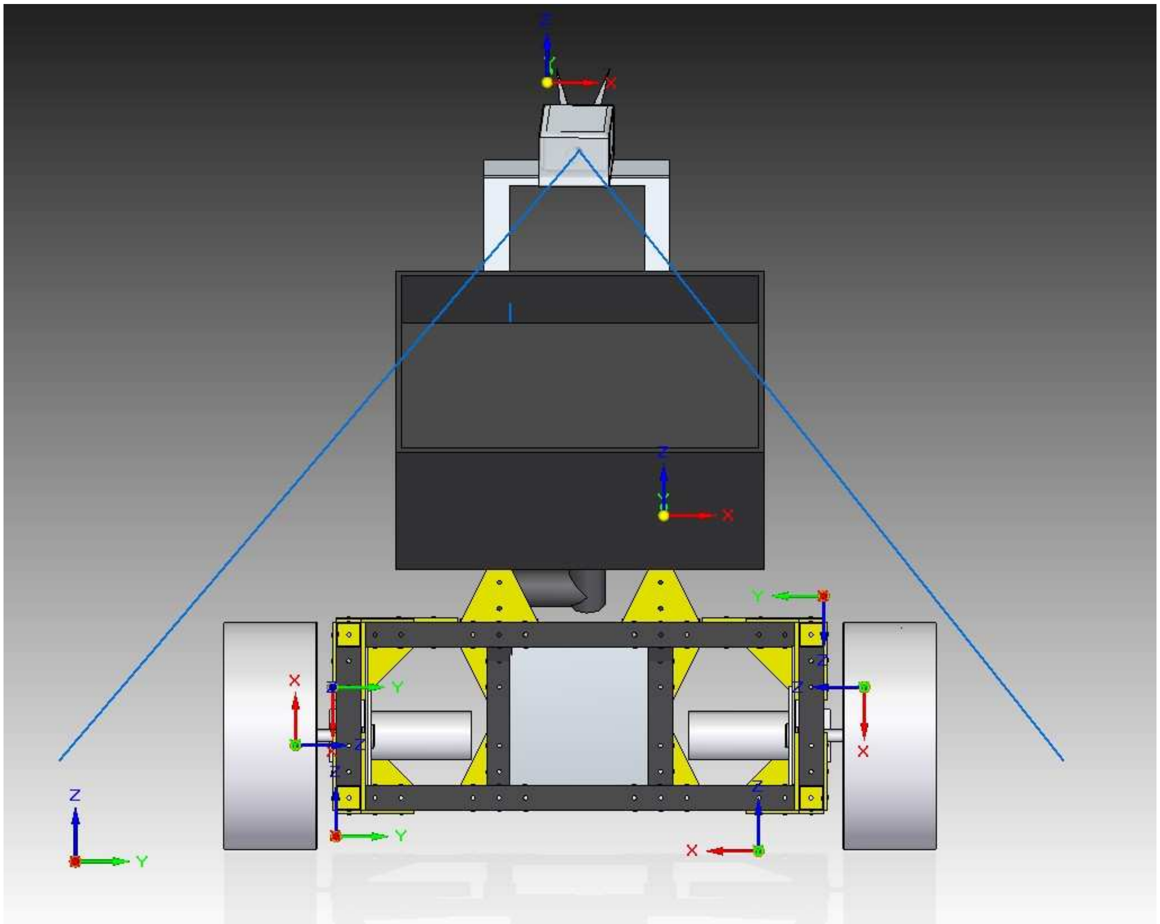


Figure 5.5.3 Viewing Angle of Primary Camera

The camera is mounted on the frame at a 30° angle to view the driving and digging motion of the actuator. The 60° lens view of the camera allows the user to view far enough ahead and around the actuator to be operated safely and efficiently. The camera is also mounted on a frame that is five inches above the arms of the digger. This five inch high mount gives the arms enough clearance to rotate and reach the desired height of 0.7m to dump the regolith. The rear camera is a CMUCam2+ Robot Camera. It is mounted on a circuit board that is then mounted on the rear of the frame. It also has a 60° lens view. The figure below displays the rear view of excavator.

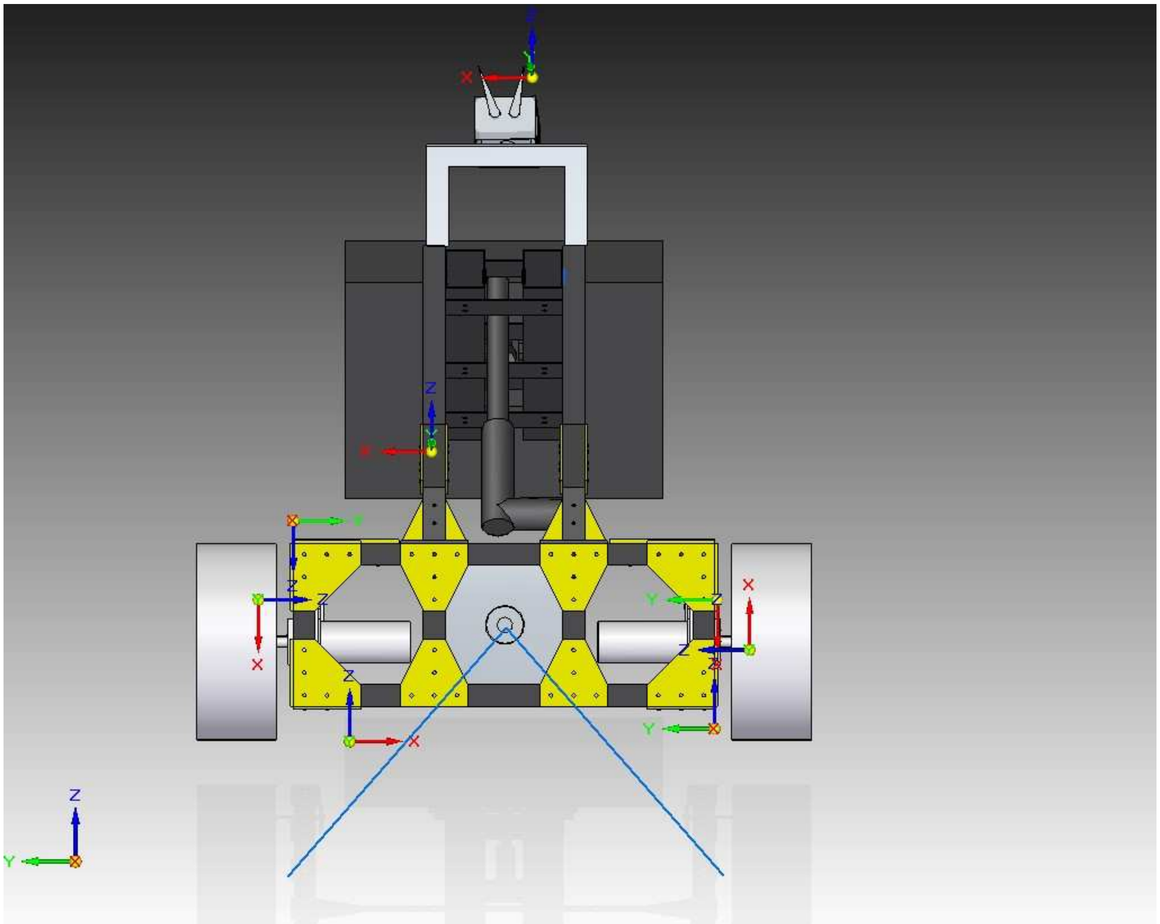


Figure 5.5.4 Viewing Angle of Secondary Camera

By using this two-camera stationary system, we reduced the power consumed by the system and amount of components that needed to be controlled without limiting the range of view of the excavator.

5.6 Excavator Frame Subsystem

5.6.1 Feasible Alternatives:

During initial brainstorming, the frame of the past Lunar Excavator was reviewed to find if it met the weight and size requirements for the project. The old frame exceeded the requirements in both size and weight and therefore a new frame would have to be designed. Also, the new Excavator is required to raise and dump material at a height of .5 meters. The old frame was not built to perform this task.

When designing the new frame, it was determined early on that a “U” shaped frame would be best suited for our needs. The use of a shovel and digger arm was known to be an essential design feature to meet the necessary requirements. A “U” shaped frame would allow enough area for the digger arm and shovel to be placed within the frame and not exceed the maximum vehicle length (51inches = 1.3m).

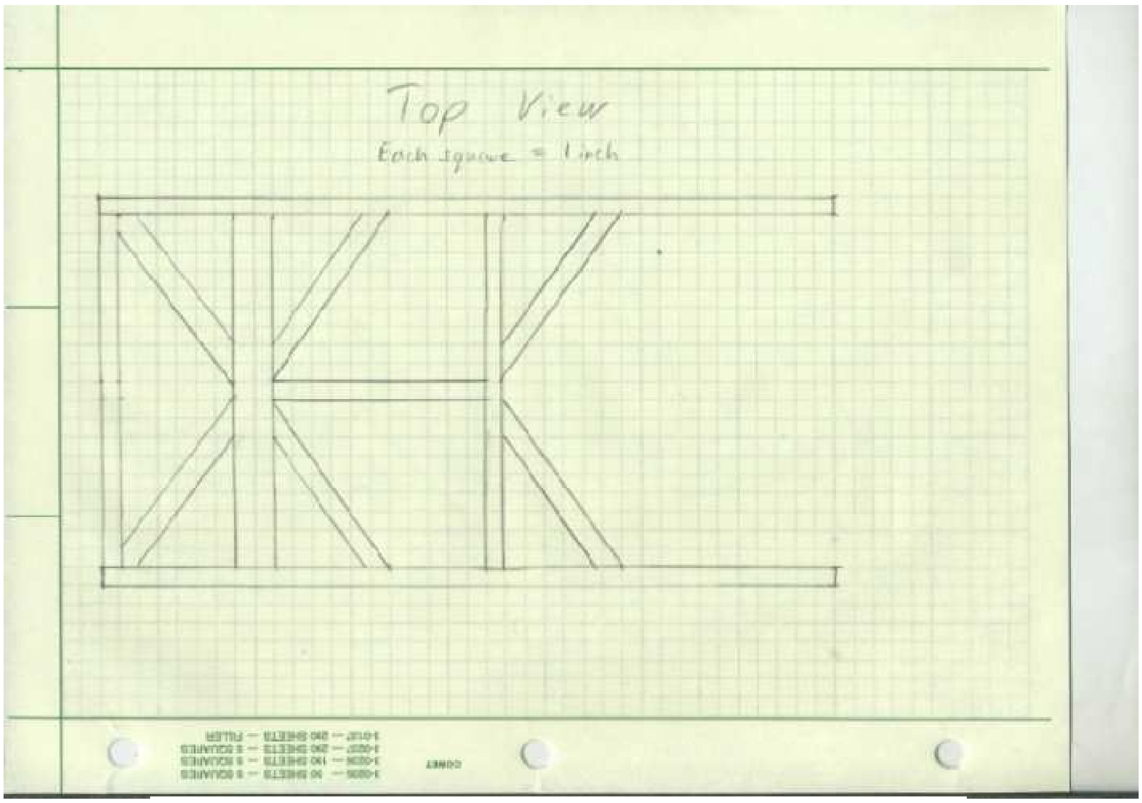


Figure 5.6.1 Frame Conceptual Design Top View

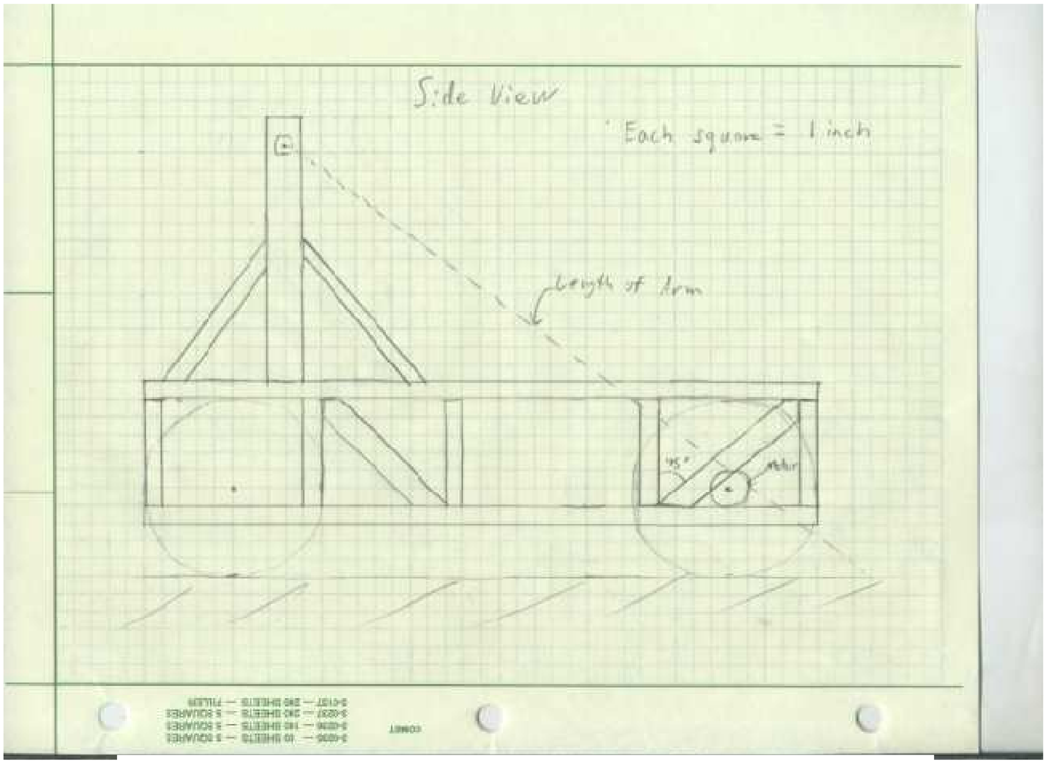


Figure 5.6.2 Frame Conceptual Design Side View

5.6.2 Frame Material Details:

Carbon Fiber Tubing

The frame will be constructed out of square carbon fiber tubing. This will help meet the weight requirement as well as provide a very strong frame. The carbon fiber that has been selected has a tensile strength of 640 kpsi and a modulus of elasticity of 34 Mpsi (Tube Specifications in Appendix). Tubing designs range from 6 inches long to 38 inches long including 1 inch square tubing and 2 inch by 1 inch rectangular tubing. The square tubing will be fastened together using garolite gussets along with the use of Epoxy adhesive, rivets, and screws (Epoxy, rivet, and screw Specifications in Appendix). Each tube contains 3/16 diameter holes for rivets and screws (Manufacturing Drawings of tubes are in Appendix).

Gussets

There are 4 different gusset designs and all are manufactured from garolite. Garolite was choosen due to its weight and strength properties comparable to carbon fiber. However, garolite was also choosen due to its low cost compared to carbon fiber which was the original material choice.

The "Tee" design is used to support 1 inch square tubes in a "T" formation. The "Tee2" design is used to support a 1 inch square tube with a 2X1 inch rectangular tube. The "Angle" design supports a 1 inch square tube at an angle of 129° to a 2X1 rectangular tube. Finally, the "Angle2" design supports a 1 inch square tube to another 1 inch square tube at a 129° angle. All designs include five 3/16 diameter holes. This was choosen to provide adequate contact and support between tubes (Manufacturing Drawings of gussets are in Appendix).

5.6.3 Frame Design Analysis:

The main focus when analizing the frame was of the stress that accumiladed in the support structure of the digger arm while collecting and transporting material. ANSYS Workbench analysis software was used to model and simulate forces acting on specifically the frame support structure of the digger system.

First, a cantelever beam with a 100 lb force was modeled and simulated in the software. When using the ANSYS software, a meshing of the model was produced and then used to calculate results from acting forces (see figure below).

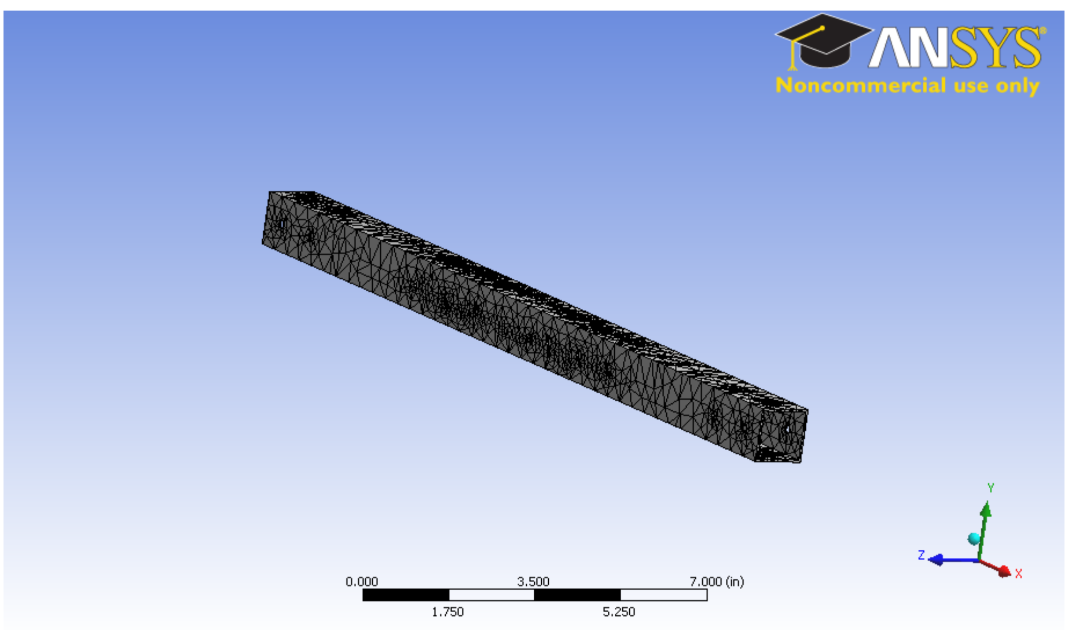


Figure 5.6.3 Mesh of Beam

A figure of the shear stress was then created to show how the stress in the beam maximized and minimized throughout the model (see figure below).

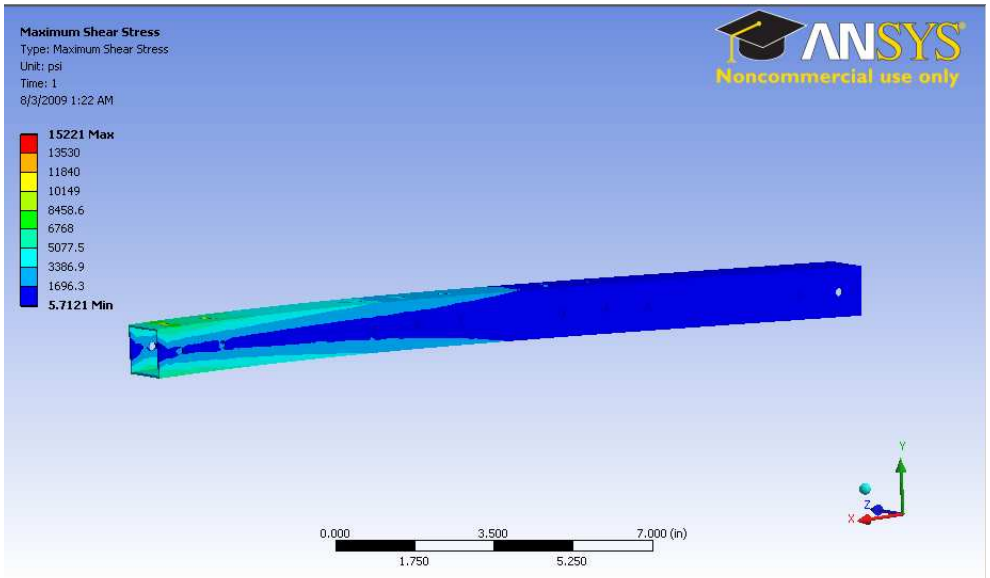


Figure 5.6.4 Shear Stress Diagram of Beam

When analizing the support structure, a 100 lb force was applied to each structure in a perpindicular direction to create a maximum amount of stress in the supports and base beam while the ends of the base beam were locked as fixed supports (see figure below). The magnitude of the forces applied were choosen to well exceed real world forces in order to create a simulation of results that would surpass any outcome that would be encountered during operation. This enabled the support structure to be designed to best withstand forces acting on it.

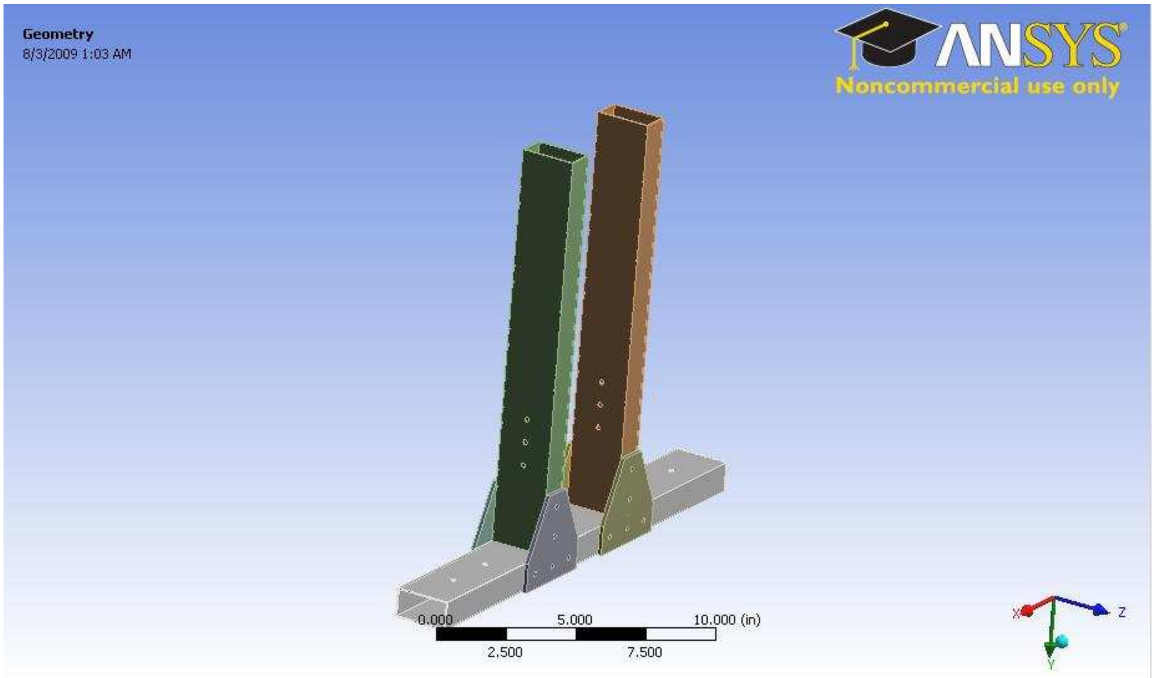


Figure 5.6.5 First Support Structure Design

The first design of the support structure was comprised of two towers that would interface with the digger arm subsystem as shown in the figure above. Then a meshing of the model was created followed by a shear stress diagram (see figures below).

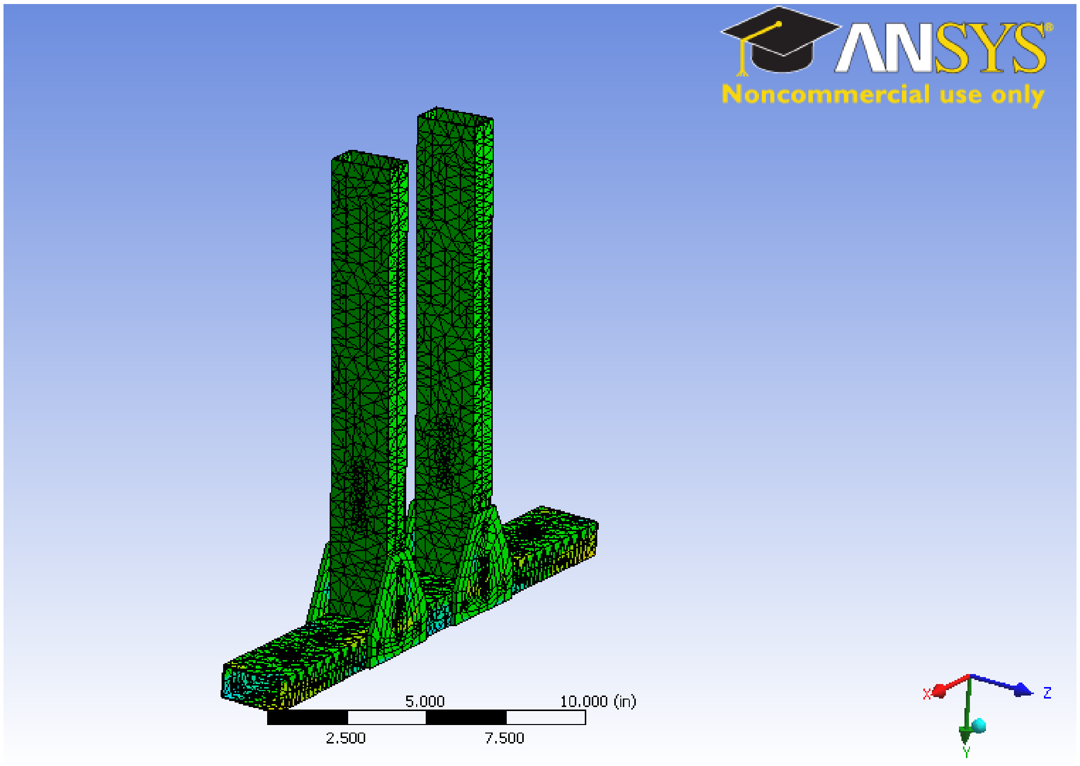


Figure 5.6.6 Mesh of First Design

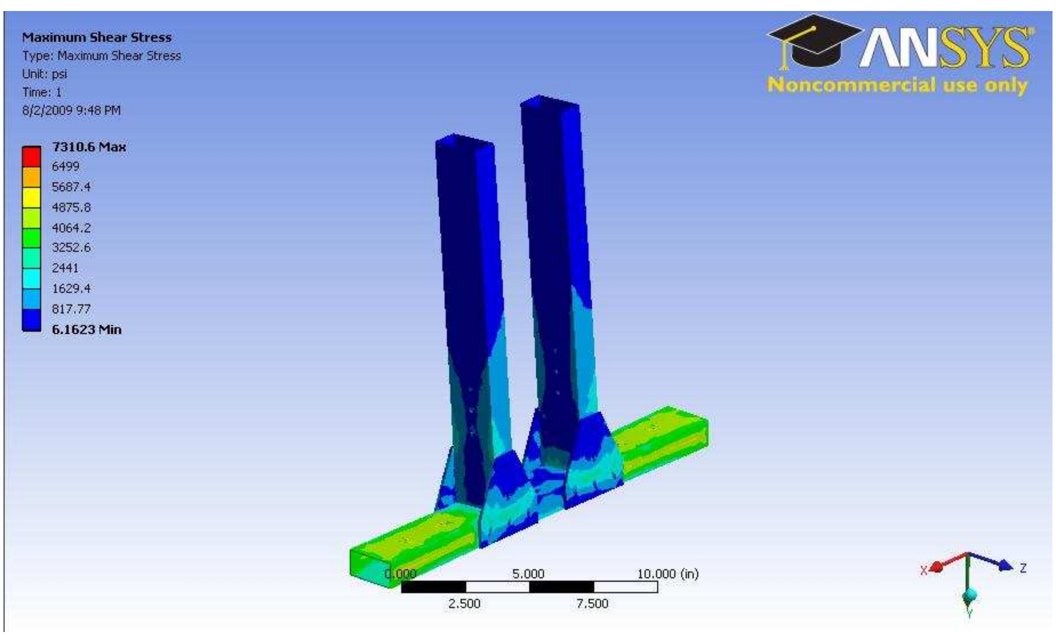


Figure 5.6.7 Shear Stress Diagram of First Design

The green and yellow regions indicate a higher level of stress while the blue regions display lower stresses. A maximum of 7310 psi of stress was calculated on the model with most of this stress concentrated in the base beam. It was desirable to deacrease this stress and direct some of the force away for the base beam and into the rear of the frame to more effeciantly balance the weight when digging and transporting material. A second support design was created with angled supports attached to the towers and simulated the same as the previous experiments (see figure below).

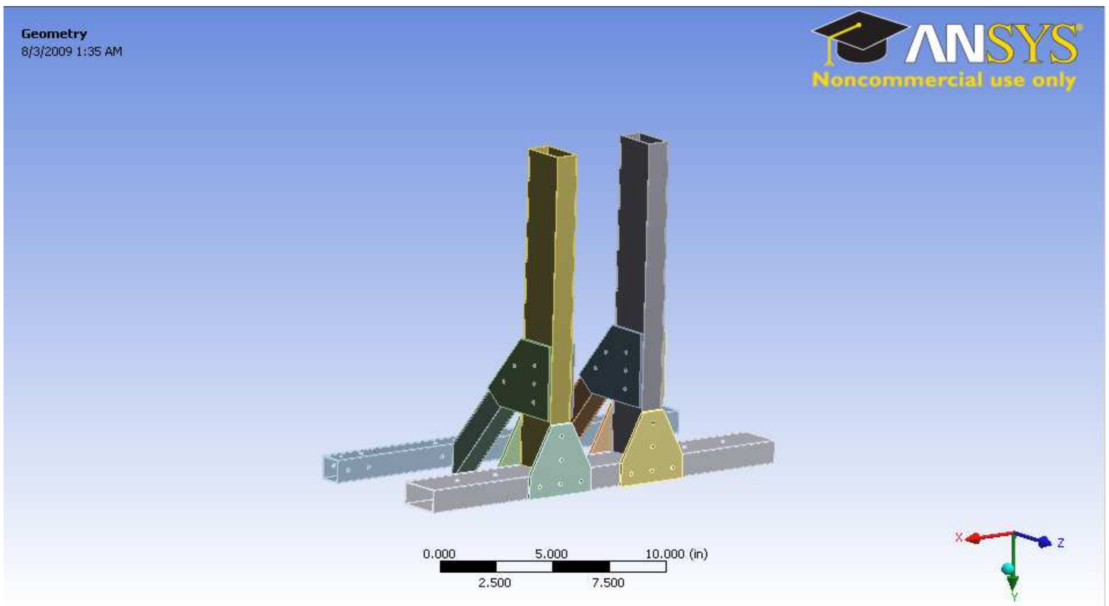


Figure 5.6.8 Second Design of Support Structure

The resulting mesh and shear stress diagrams were created (see figures below).

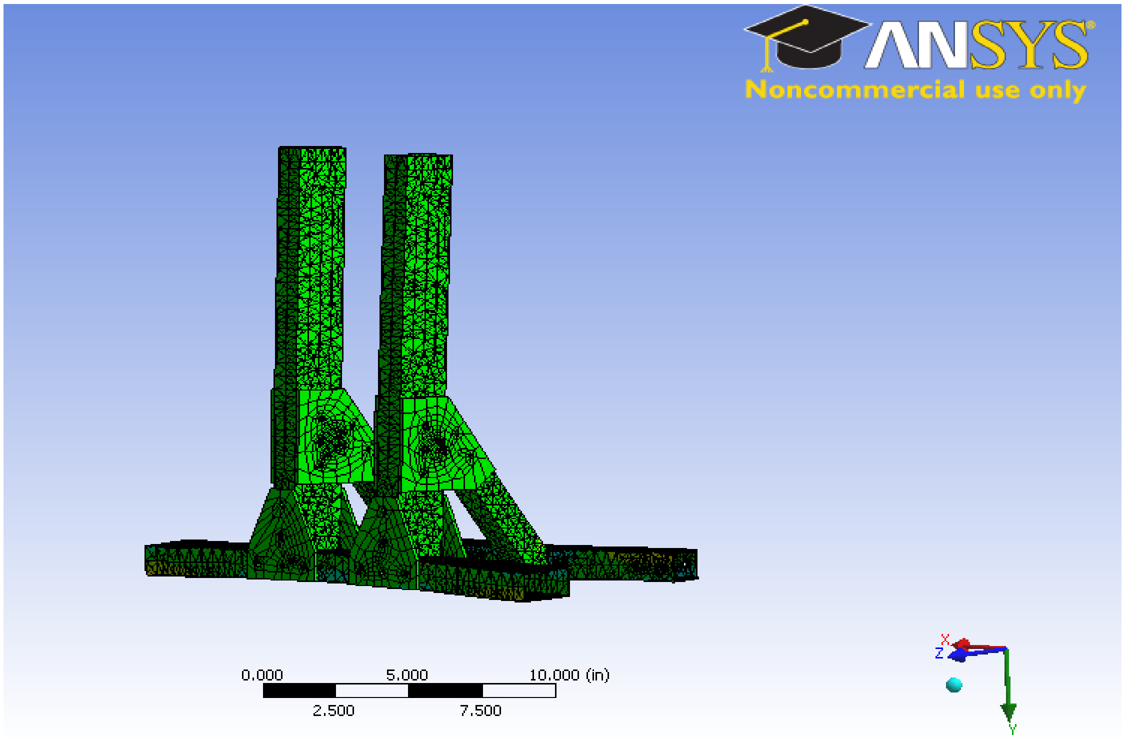


Figure 5.6.9 Mesh of Second Design

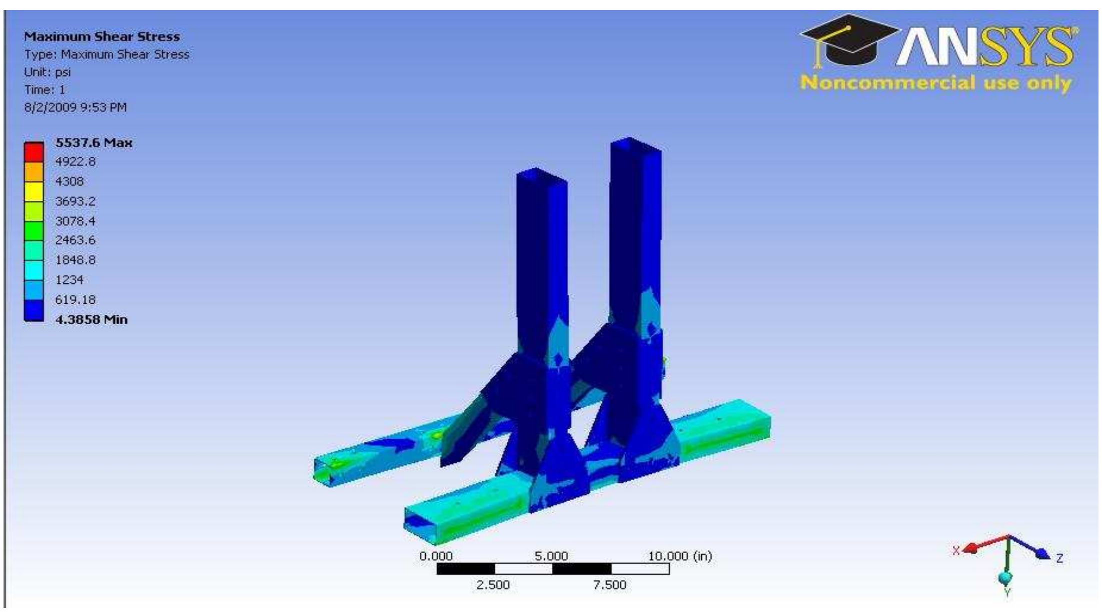


Figure 5.6.10 Shear Stress Diagram of Second Design

From the second design, the maximum shear stress was decreased to 5537 psi and the stress in the base beam was distributed to the added support bar which would be at the rear of the frame. A complete ANSYS Workbench data report of this second design will be added to the appendix of this report.

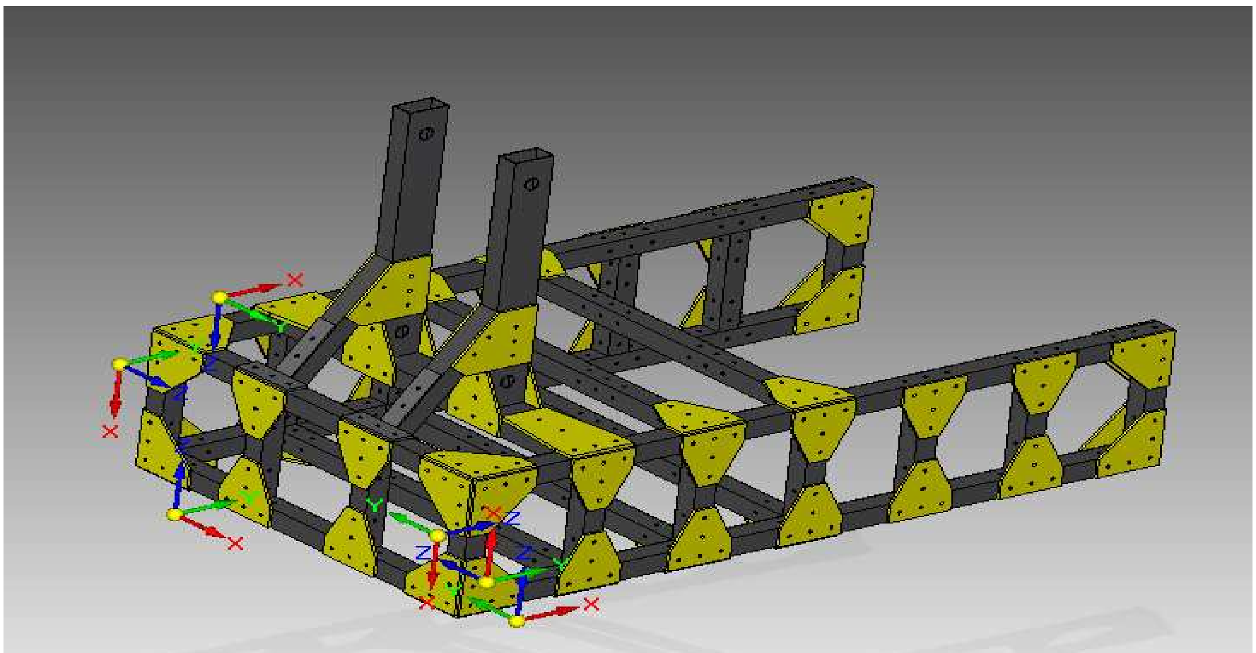


Figure 5.6.11 Final Design of Frame

The above figure shows the assembled frame complete with tubing and gussets. The original “U” shaped design was refined to add more support and strength. The support structure for the digger arm is shown here with the angle supports distributing load to the rear of the frame. The overall dimmensions of the frame are 38 inches long, 21 inches wide, and 23 inches tall.

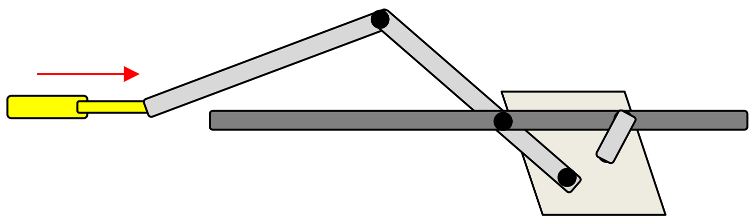
5.7 The Digger System

5.7.1 Digger design requirements

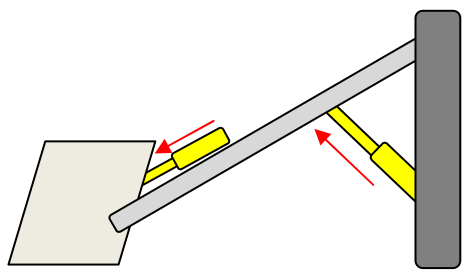
1. Ability to raise the bucket above an elevation of 0.7 meters
2. The system length should be no longer than 1m
3. High bucket capacity

4. Light weight design
5. Minimal power usage
6. A simple, yet efficient, design which is easy to build (for ex. Less number of parts)

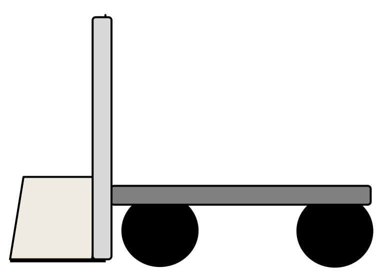
Figure 5.7.1 Digger Selection



Single actuator Four bar mechanism



Dual actuator mechanism



Forklift type mechanism

Table 5.7.1 Digger Material

Alternative / **Goals**	Single actuator(4 bar)	Dual Actuator	Forklift type
Raise 0.5 meters	2	9	8
Less than 1m long	1	8	9
High capacity	8	8	8
Light weight design	6	8	6
Minimum power usage	9	7	8
Simple design	6	9	6
Totals	32	49	45

The selection of a light weight, yet strong, material was a highly crucial decision; Just as important as selecting the operating mechanism. After conducting research on different types of materials, the use of composites was deemed to be the most suitable for our application. This narrowed our options to mainly three types of composites:

- Carbon fiber
- Fiberglass
- Kevlar

The materials listed above were evaluated based on the following criteria

- Strength
- Weight
- Cost
- Temperature resistance

We concluded that carbon fiber would be the best option since it has higher tensile strength and temperature resistance than Kevlar and Fiberglass. It is also more readily available (in the form of square tubes etc.) than Kevlar. However the cost of carbon fiber is slightly higher than the rest.

5.7.2 Final Design for the digger

After careful and systematic evaluation of different alternatives we were able to design a light weight, strong and simple digger system that has the ability to raise a fairly high capacity of Lunar Regolith to an elevation above 0.5 meters.

This design comprises of a single arm made out of two parallel carbon fiber square tubes (each 2x2in) which is attached to a bucket which is made from the same material. These tubes are attached to each other using carbon fiber gussets. The system will use two actuators; one controlling the bucket angle and the other controlling the arm.

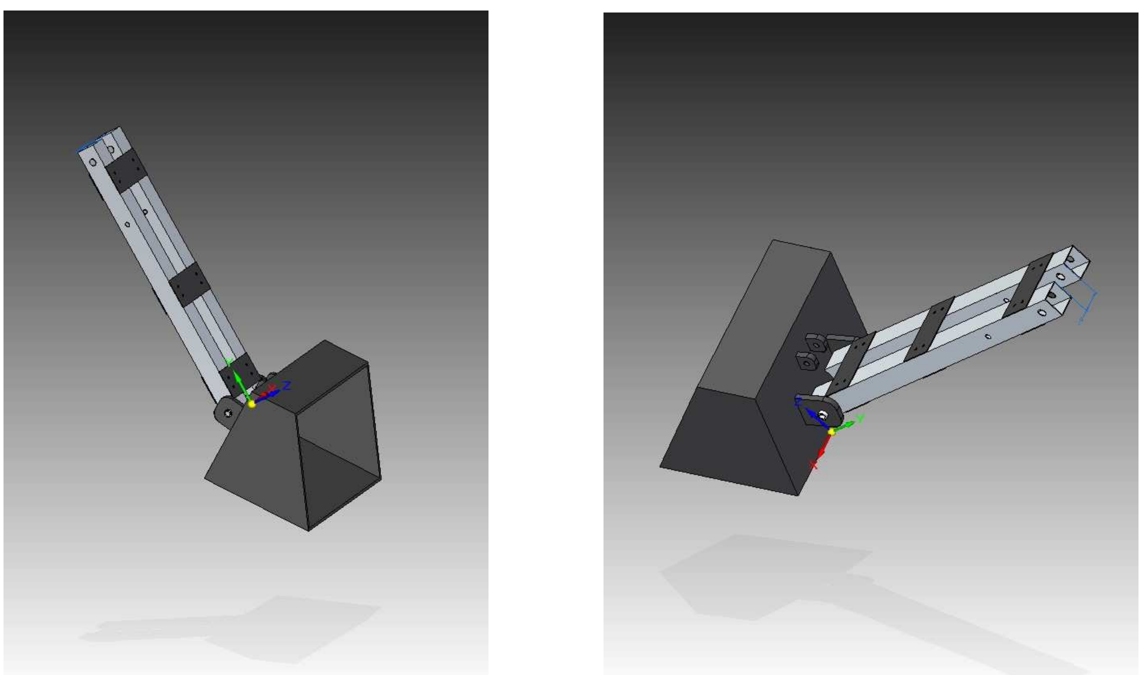


Figure 5.7.2 and Figure 5.7.3: The digger system which include a bucket held by two 2x2in tubes (actuators not shown)

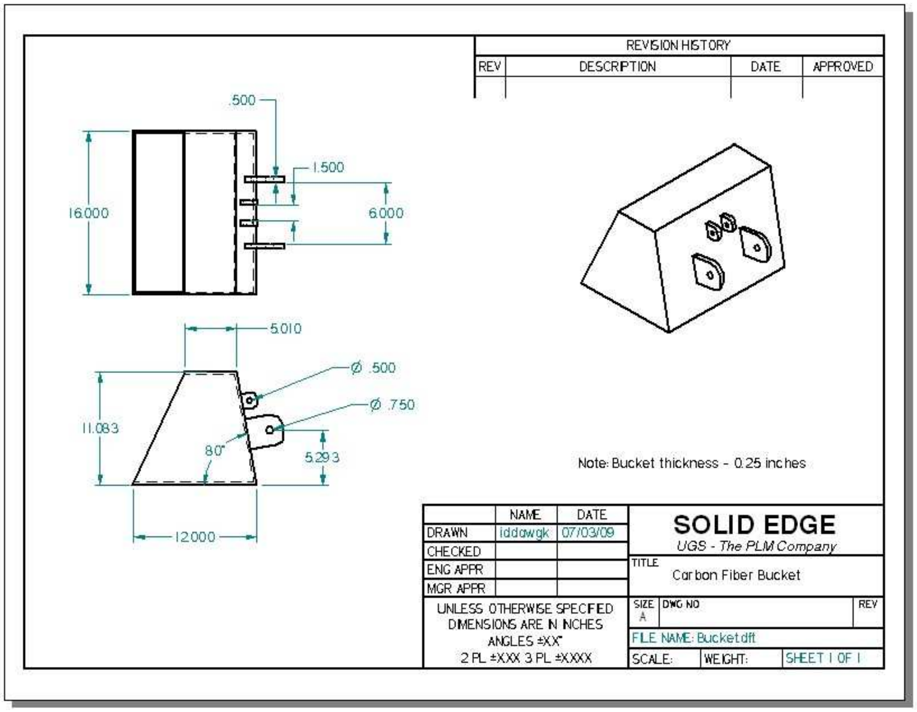


Figure 5.7.4 Bucket Draft dimensions

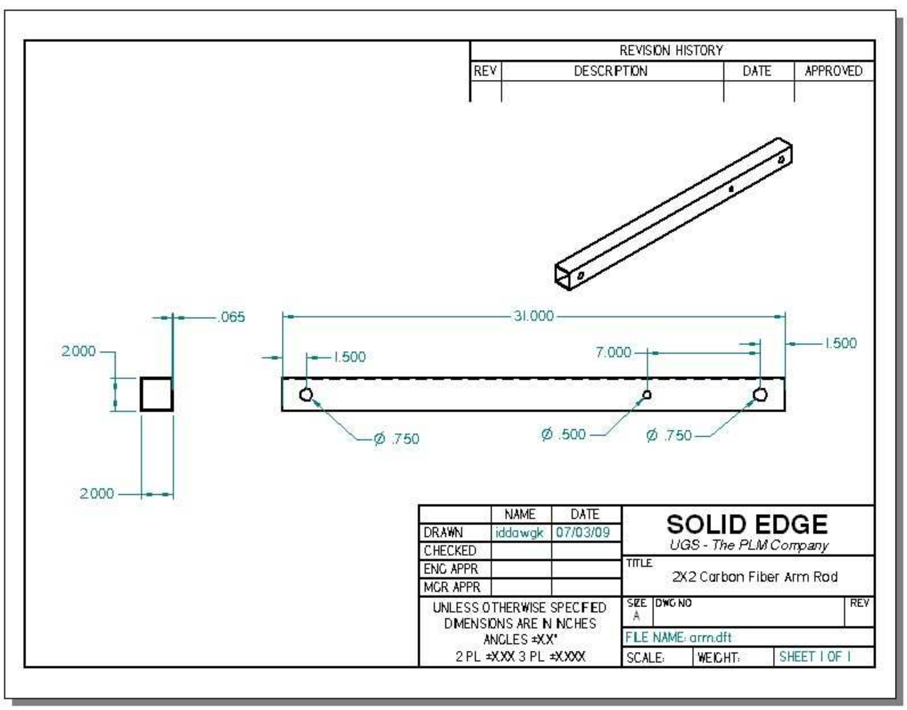


Figure 5.7.5 Carbon Fiber Tubing dimensions

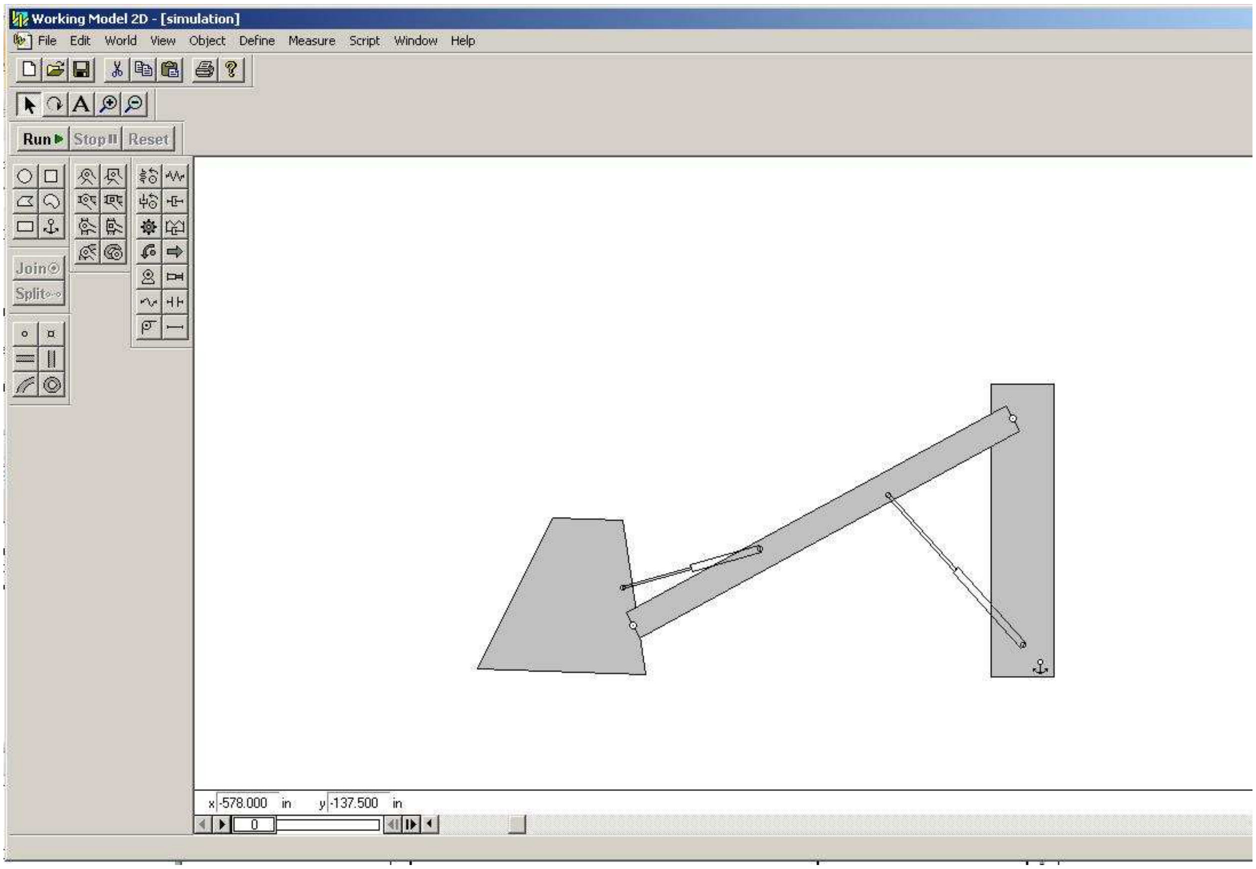


Figure 5.7.6 Working Model design

5.7.3 Digger system force analysis

Forces acting on the digger system were analyzed with the aid of hand calculations and Matlab scripts. The forces which were the main focus of this analysis are the actuator force and the forces at the main hinge. The following diagrams and graphs illustrate the results obtained through this analysis. Detailed hand calculations and Matlab scripts can be found in the Appendix.

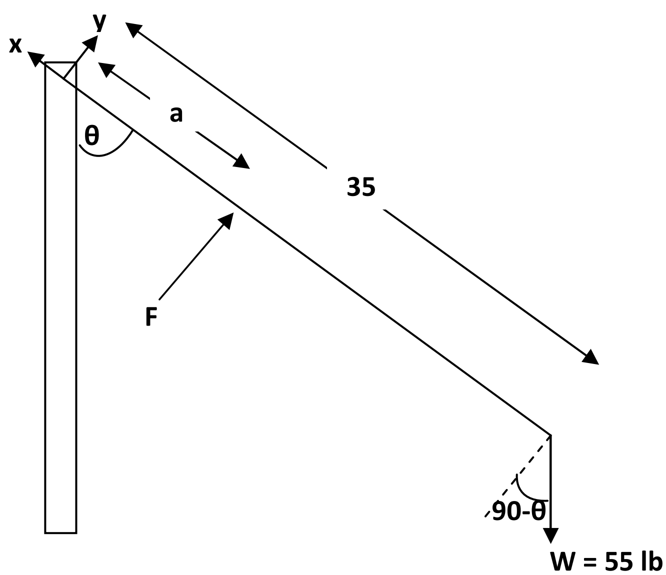


Figure 5.7.7: Free body diagram of digger

W= Weight of loaded bucket ≈ 55lb

F= Actuator Force

Θ= Arm angle

Starting position: θ=50 degrees

Carrying position: θ=70 degrees

Dumping position: θ=100 degrees

Analysis results:

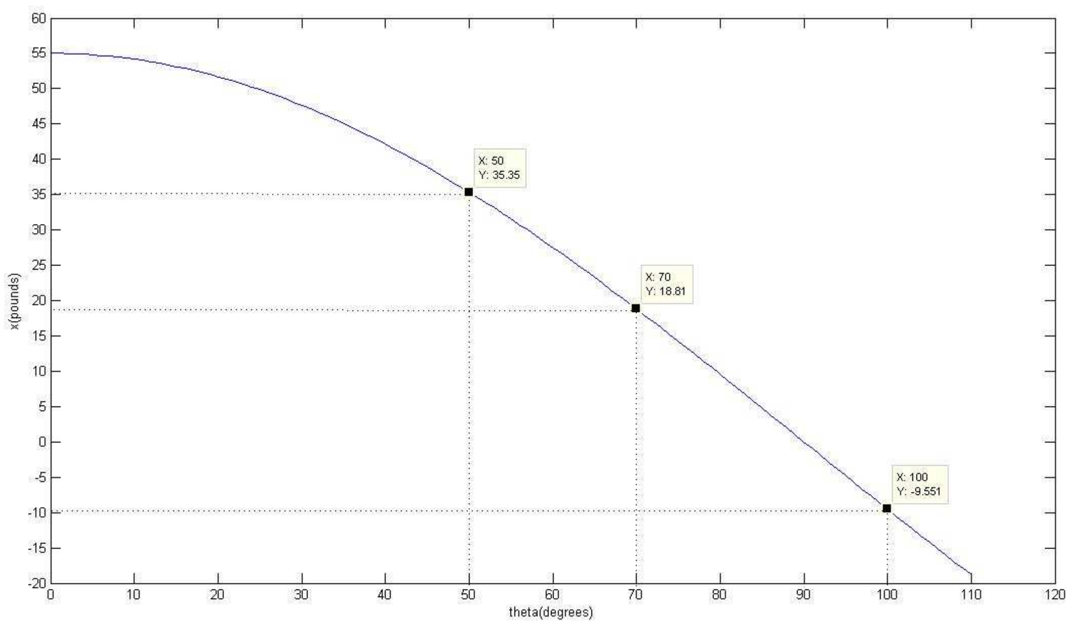


Figure 5.7.8: graph of x vs theta (for a=7in)

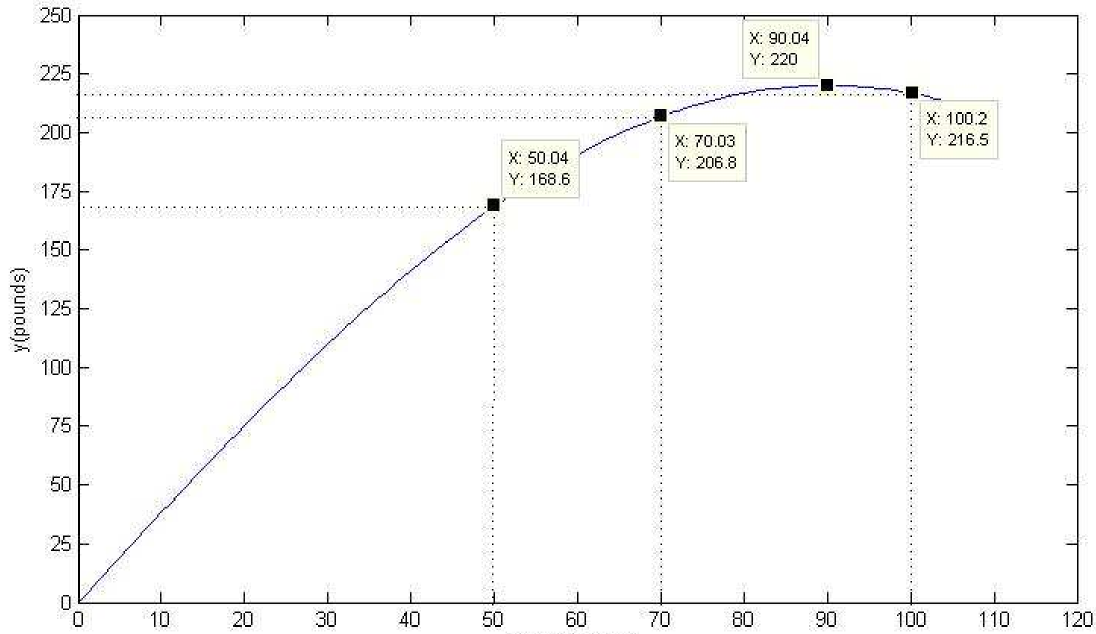


Figure 5.7.9: graph of y vs theta (for a=7in)

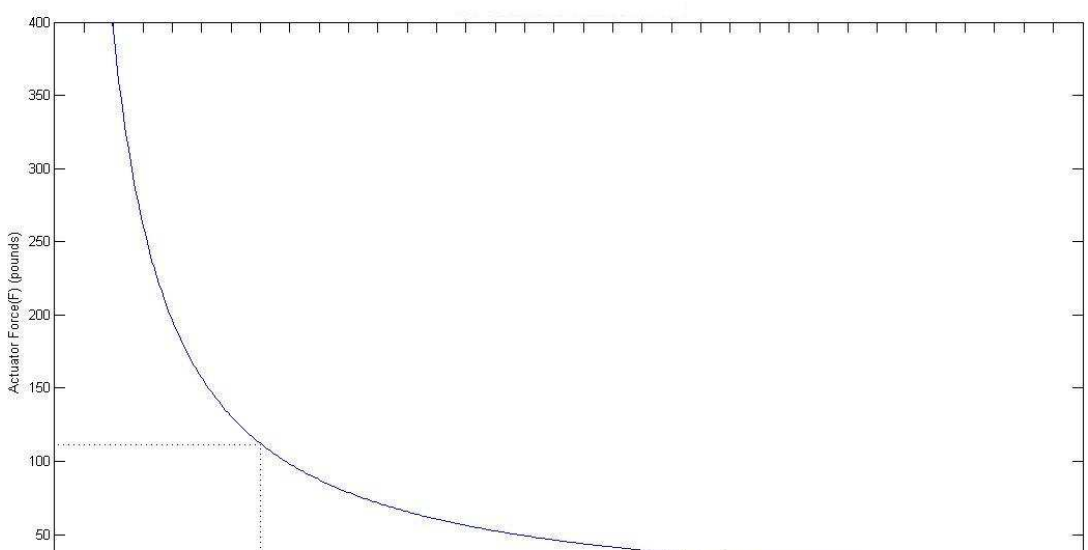


Figure 5.7.10: graph of actuator force (F) vs a

5.7.4 Actuator Selection

There will be two linear actuators controlling the digger subsystem. One large actuator will be controlling the lowering and rising movements of the main arm and another small actuator will control the bucket angle (for digging and dumping). These actuators will be connected to the frame through pin joints allowing them to have two degrees of freedom. The diagram shown illustrates the positioning of these two actuators on the arm.

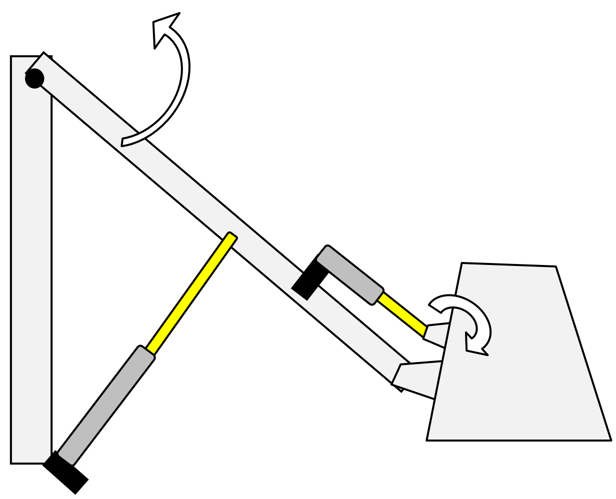


Figure 5.7.11 actuator layout

Selected actuators:

1. Arm actuator (large): We decided to use the existing actuator in our old excavator as the one that controls the arm movement. By doing so we were able to save money and also prevent wastage. The specifications of that actuator are listed below
   - Northern Industrial Linear Actuator
   - Input voltage 12 Volt
   - Stroke 11 13/16 in
   - 8mm per second travel speed

- Center-to-center closed pin distance is 17 5/16in. (440mm)
- 1350-lb. maximum load capacity

2. Bucket actuator (small): The actuator controlling the bucket angle will be the same type and the same manufacturer as the larger one but will have a smaller stroke.
   - Northern Industrial Linear Actuator
   - Input voltage 12 Volt
   - Stroke 3 15/16 in
   - 8mm per second travel speed
   - Center-to-center closed pin distance is 9 7/16in. (240mm)
   - 1350-lb. maximum load capacity
   - Measures 10 5/8in.L x 9in.H
   - Cost $139.00

Figure 5.7.12 Northern tools actuator

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5.8 Controls subsystem

The electronics system was going to be left up to the Electrical Engineering students to setup when they come in the fall, but it was determined that would be too late to get to work on the controls. There is a larger learning curve to produce this as a group of Mechanical Engineering students.

The basic controls have been selected with a brief understanding of the components. Shown below is the schematic for the components selected to date. The lines running in and out of the processor are not in the correct pin diagram right now.

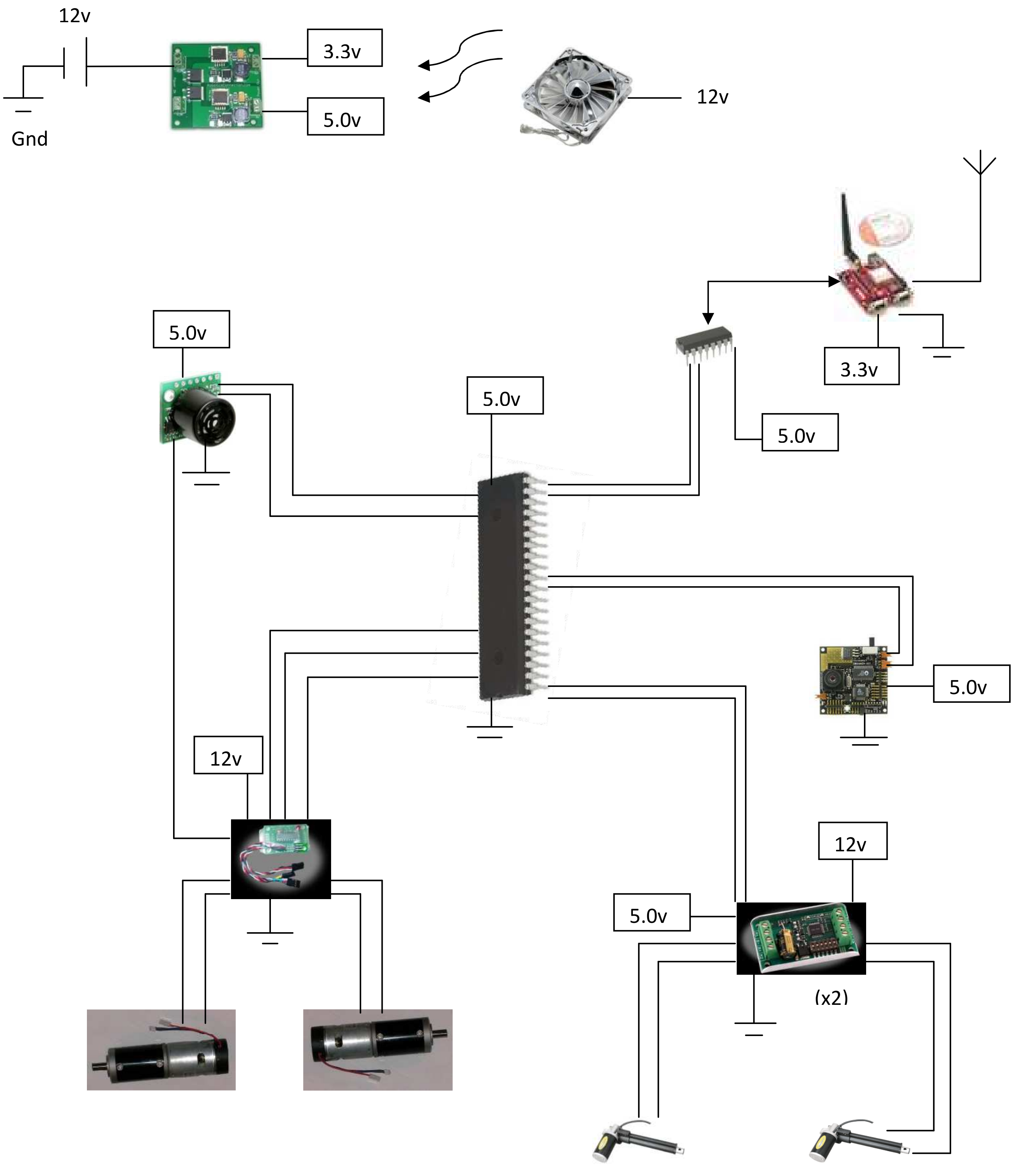


Figure 5.8.1 Electrical Schematic

5.7.1 Microcontroller

The processor is the Microchip PIC18LF4682 I/P 8-bit microcontroller. There will be two DC motors to power backwards and forward independently so the processor will send signals to the IMX-1 tank tread mixer. This motor control will allow the control of both electric motors with on input joystick. Two linear actuators will be controlled each separately by a SyRen 10A motor controller bridge. This processor will be able to communicate through the Lantronix WiPort to ground station controls with a RS232 line driver/receiver. Further analysis and assistance from the EE department is needed to proceed.

5.7.2 Ground Station

The ground station will be operated with a Network adapter that limits bandwidth and implements a delay on the signal. The signals that come into the computer will be distinguished with Java code and video data program is yet to be determined. A handheld game controller will be used to input the operator's commands back to the vehicle.

6.0 Lunar Environment

The design presented is intended to operate on the moon. The conditions are extreme heat or cold (300˚F to -250˚F) in little to no atmosphere. No pressure or liquid cleaning devices can be used on the design. The gravity is at 5.637 ft/s^2. The friction coefficients for rolling and static conditions on the lunar regolith are approximately 0.18 and 0.3, respectively. The regolith is a very dusty, light powder/dirt. It is critical that this does not permeate into our system or electronics.

7.0 Resource Budgeting

Resources such as Power, Mass, and Money were all very important to keep up with in designing the separate subsystems. One document had to keep all of it together so that we did not exceed requirements.

Table 7.1.1 Bill of Materials

Item	Part #	Qty	Description	Cost/per	Cost	Mfg. Source
1	WVC2300	1	Cisco Wireless-G Video Camera	$359.99	$359.99	Cisco.com
2	125012	1	12 V, 11 13/16 stroke linear Actuator	$159.99	$159.99	Northerntool.com
3	LA-12v26ah	2	12v Lead acid battery	$59.95	$119.90	batteryspace.com
4	125011	1	12 V, 7 7/8 stroke linear actuator	$149.99	$149.99	Northerntool.com
5	N/A	2	Sleeve Bearings	$0.80	$1.60	McMaster-carr
6	TD05200	1	4 in. Wide Tread set (2)	$580.63	$580.63	SuperDroidRobots.com
7	TD036290	2	IG52-02 24VDC 290 RPM Gear Motor w/ encoder	$127.80	$255.60	SuperDroidRobots.com
8	N/A	4	1 inch square carbon fiber tubing 96"	$325.00	$1,300.00	dragonplate.com
9	N/A	3	2 inch square carbon fiber tubing 24"	$150.00	$450.00	drgaonplate.com
10	N/A	1	1 inch by 2 inch C.F. rectangular tube 48"	$180.00	$180.00	dragonplate.com
11	9910T22	1	24"X24"Plate(1/8")G-10 Garolite	$55.86	$55.86	McMaster-carr
12	9910T21	1	12"X12"Plate(1/8")G-10 Garolite	$16.90	$16.90	McMaster-carr
13	97526A404	3	Blind Aluminum Rivets (100pk)	$7.14	$21.42	McMaster-carr
14	#2216	1	"Scotch-Weld" Epoxy Adhesive 26.7 fl. oz	$119.00	$119.00	drgaonplate.com
15	6659A21	1	Blind Rivet Installation Tool	$25.18	$25.18	McMaster-carr
16	N/A	1	1/4" x 3/4" fasteners	$1.00	$1.00	N/A
17	N/A	1	1/2"x18" Shaft	$25.08	$25.08	McMaster-carr
18	N/A		Aluminum Sheet		$0.00	N/A
19	DVREG	1	Dual 5v +3.3v Switching Voltage Regulator	$74.95	$74.95	Roboticsconnection
20	SK 3720Q1	1	CMUCam2+ robot camera	$169.96	$169.96	Roboticsconnection
21	EZ3LV	1	Maxbotix Maxsonar-EZ3 Sensor	$24.95	$24.95	Roboticsconnection
22	130898	1	Aerocool Turbine 1000 silver 120mm Fan	$14.99	$14.99	xoxide.com
23	RL-IMX1	1	IMX-1 Invertable RC tank mixer	$39.95	$39.95	Robotcombat.com
24	0-SYREN10	2	SyRen 10A Regenerative Motor Driver	$49.99	$99.98	Robotcombat.com
25	17M0994	2	PIC18LF4682-I/P 8-bit Microcontroller	$8.35	$16.70	Microchip.com
26	N/A	1	Lantronix WiPort Eval kit	$299.99	$299.99	Lantronix.com
27	MAX232ECN	2	TXInst. RS-232 Line Driver/Reciever	$0.86	$1.72	Mouser electronics
					$0.00	
				Total Cost	$4,565.33	

Table 7.1.2 Mass of Materials

Item	Part #	Qty	Description	Mass/per	Mass	Mfg. Source
1	WVC2300	1	Cisco Wireless-G Video Camera	520	520	Cisco.com
2	125012	1	12 V, 11 13/16 stroke linear Actuator	3175	3175	Northerntool.com
3	LA-12v26ah	2	12v Lead acid battery	8800	17600	batteryspace.com
4	125011	1	12 V, 7 7/8 stroke linear actuator	3175	3175	Northerntool.com
5	N/A	2	Sleeve Bearings	250	500	McMaster-carr
6	TD05200	1	4 in. Wide Tread set (2)	6000	6000	SuperDroidRobots.com
7	TD036290	2	IG52-02 24VDC 290 RPM Gear Motor w/ encoder	1140	2280	SuperDroidRobots.com
8	N/A	4	1 inch square carbon fiber tubing 96"	360	1440	dragonplate.com
9	N/A	3	2 inch square carbon fiber tubing 24"	236	708	drgaonplate.com
10	N/A	1	1 inch by 2 inch C.F. rectangular tube 48"	254	254	dragonplate.com
11	9910T22	1	24"X24"Plate(1/8")G-10 Garolite	2206	2206	McMaster-carr
12	9910T21	1	12"X12"Plate(1/8")G-10 Garolite	552	552	McMaster-carr
13	97526A404	3	Blind Aluminum Rivets (100pk)	0.25	0.75	McMaster-carr
14	#2216	1	"Scotch-Weld" Epoxy Adhesive 26.7 fl. oz	85	85	drgaonplate.com
15	6659A21	1	Blind Rivet Installation Tool	0	0	McMaster-carr
16	N/A	1	1/4" x 3/4" fasteners	200	200	N/A
17	N/A	1	1/2"x18" Shaft	750	750	McMaster-carr
18	N/A	1	Aluminum Sheet	1000	1000	N/A
19	DVREG	1	Dual 5v +3.3v Switching Voltage Regulator	20	20	Roboticsconnection
20	SK 3720Q1	1	CMUCam2+ robot camera	5	5	Roboticsconnection
21	EZ3LV	1	Maxbotix Maxsonar-EZ3 Sensor	4.3	4.3	Roboticsconnection
22	130898	1	Aerocool Turbine 1000 silver 120mm Fan	135	135	xoxide.com
23	RL-IMX1	1	IMX-1 Invertable RC tank mixer	25	25	Robotcombat.com
24	0-SYREN10	2	SyRen 10A Regenerative Motor Driver	26	52	Robotcombat.com
25	17M0994	2	PIC18LF4682-I/P 8-bit Microcontroller	5	10	Microchip.com
26	N/A	1	Lantronix WiPort Eval kit	500	500	Lantronix.com
27	MAX232ECN	2	TXInst. RS-232 Line Driver/Reciever	5	10	Mouser electronics
					0	
				Total Mass	41207.05	

8.0 System Design Analysis

An entire concept was needed to evaluate whether or not the system could in fact operate each function, because some subsystems were dependent on others. An analysis of the forces on the concept body was done.

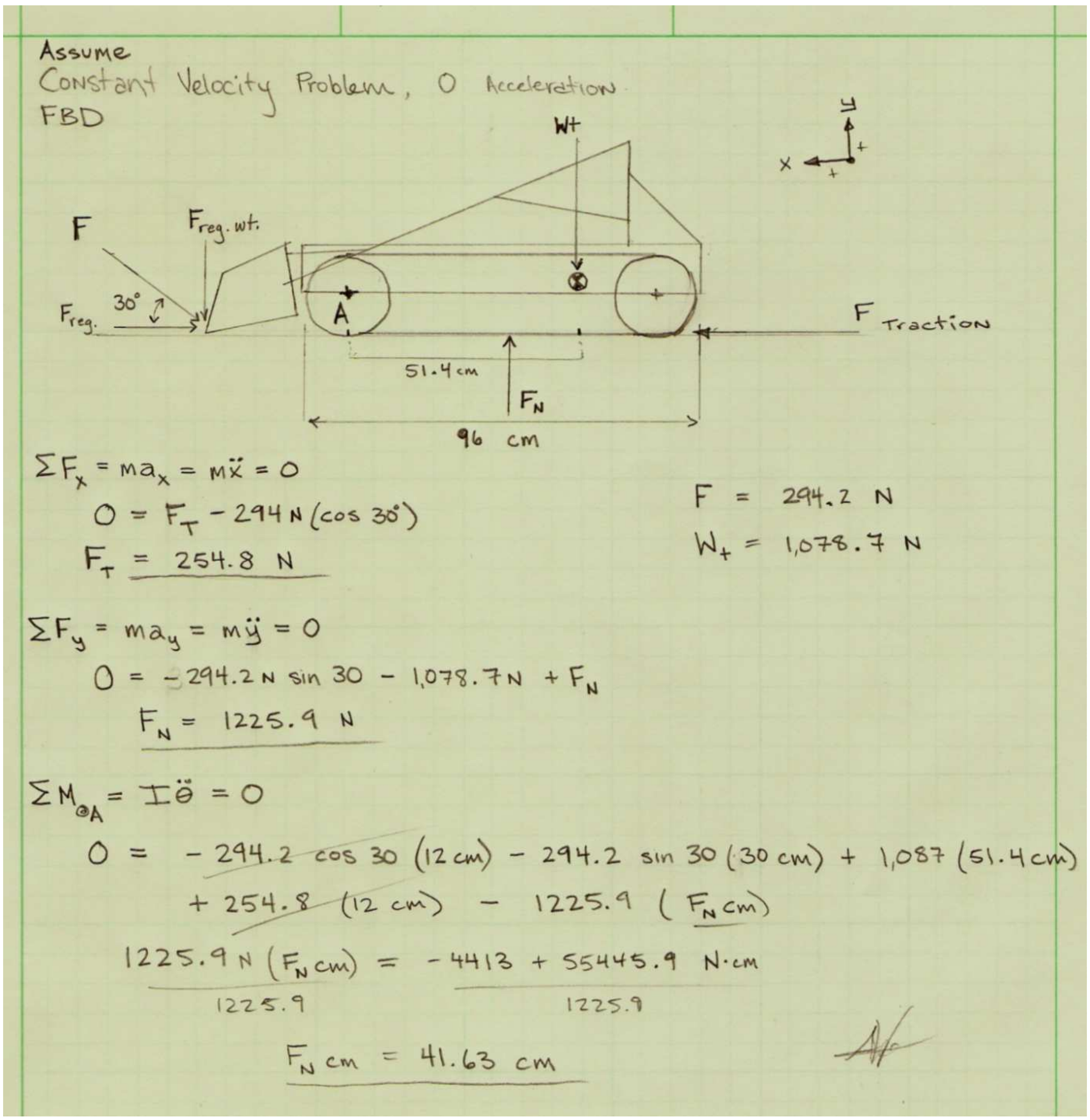


Figure 8.1.1 FBD of Concept Body

A small code was written up in Matlab to vary the values and yield the different results. With large differences in weight of the excavator and soil dug up it is still shown that the force on the vehicle will not cause it to lose traction or tip. The change in position of normal force in the positive y-axis was from 21cm to 36 cm from the front wheels. While the Digger arm is in an upright position there should not be much resistance compared to digging force.

```
%Lunar Excavator System Calc
%clear all
%clc

global F Wt Ft Fn Thta Fx Wtx Fnx

Thta=60/180*pi
F=490.33 %N
Wt=490.33 %N
Fx=13 %cm
Wtx=51 %cm

Ft=F*(cos(Thta))
Fn=F*(sin(Thta))+Wt

Fnx=((-(F*(sin(Thta)))*(Fx))+(Wt*Wtx))/(Fn)
```

The next step is getting a model to test with to analyze actual data from digging. Obtaining the actual weight and conditions of the Excavator will be included for the system calculation then. The bucket and system can only be calculated in theory until then.

8.1 Concept Assembly

After the parts were assembled in Solid Edge CAD drawings the total system was put together. Major dimensions are indicated on the draft of the system. Each of the parts included are dimensioned in the report and fit together accordingly to match this assembly.

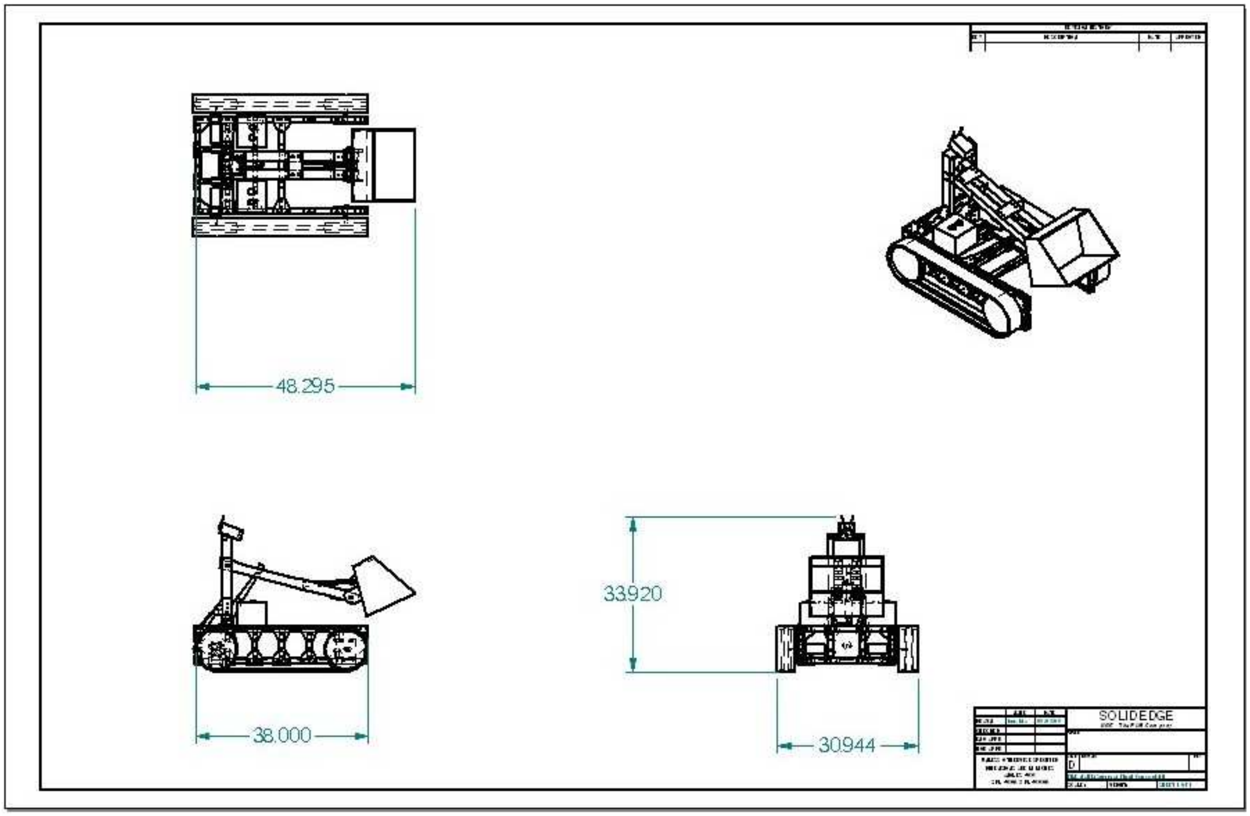


Figure 8.1.2 Isometric view of the Excavator

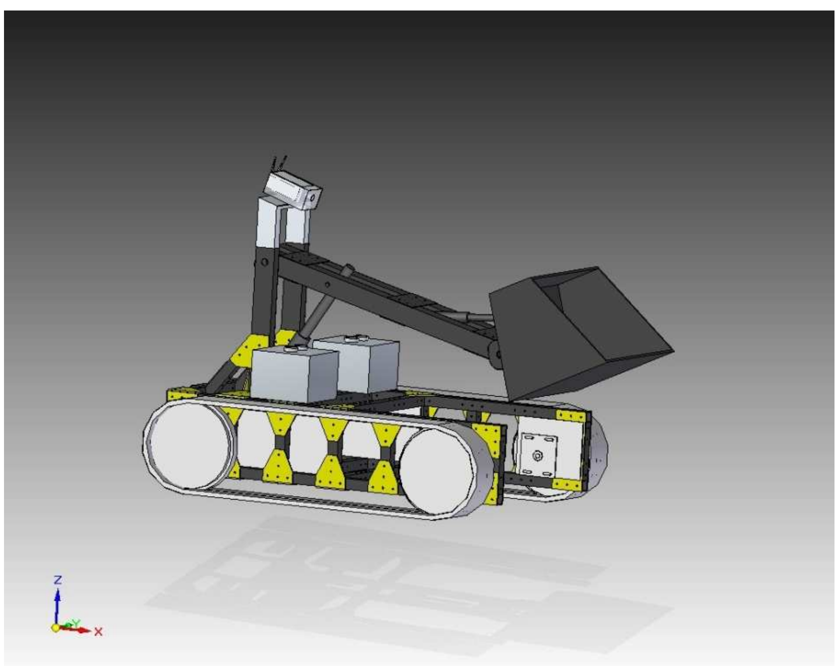


Figure 8.1.3 the 3D Concept of the System Design

8.2 Concept of Operations

The Lunar excavator will be entered into a regolith collecting competition. Here is described how it will perform.

The Vehicle will start in a cell within the “sand box” which is adjacent to the collector bin. It will be turned on and the team will be seated at the ground station out of view of the robot’s operation. From the ground station video will be received from the robot. The team will then control the robot through user input transmitted to the on board system. They will drive the robot and drop and dig small layers of regolith, then return to the start cell to deposit regolith into the collector. This will be repeated until they fill the collector to a weight of 150 kilograms or when time has reached 30 mins.

8.3 Risk Management

There has not been much analysis on the entire system to determine failure modes that could occur. Risks that have been considered start with loss of connection with the robot. If there is a loss of wireless connectivity with the robot, data from the robot will not be recieved and it will lose input from the ground station. The Excavator will cease to function. It is very important that this is considered while selecting a wireless transmitter. Also It has been brought up that there is some danger involved with machining the material that is used, G-10 Garolite. The MSDS was found for the material and show that it will produce a dust that is easy to breathe in, but is not anymore harmful than other dust particles in the air.

9.0 Project Management

9.1 Time Management

Item	Task	Resource Names	June 7 - 13	June 14 - 20	June 21 - 27	June 28 - July 4	July 5 - 11	July 12 - 18	July 19 - 25	July 26 - Aug. 1
1	Brainstorming	All								
2	Concept Generation	All								
3	Concept Design	All								
4	Verification analysis	All								
5	Excavator Subsystem	Givantha								
5.1	Concept Selection									
5.2	Materials/parts Selection									
5.3	CAD Drawings/ Verification									
6	Navigation Subsystem	Ryan								
6.1	Concept Selection									
6.2	Materials/parts Selection									
6.3	CAD Drawings/ Verification									
7	Frame Subsystem	Harrison								
7.1	Concept Selection									
7.2	Materials/parts Selection									
7.3	CAD Drawings/ Verification									
8	Camera Subsystem	Dale								
8.1	Concept Selection									
8.2	Materials/parts Selection									
8.3	CAD Drawings/ Verification									
9	Power Subsystem	Dale								
9.1	Concept Selection									
9.2	Materials/parts Selection									
9.3	CAD Drawings/ Verification									
10	Control Subsystem	Allan								
10.1	Concept Selection									
10.2	Materials/parts Selection									
10.3	Schematics/ Verification									
11	Systems Engineering	Allan								
12	Project Engineering	Allan								

Table 9.1.1 Work Breakdown Structure

When all the tasks were divided between subsystems, goals had to be set and at a reasonable pace to accomplish a prototype required time. A timeline was made to guide and track where time had been devoted and where it needed to be spent

10.0 Conclusion

In conclusion, the lunar excavator utilizes a simple design to accomplish the design objects. The verification of the lunar excavator's design has proved that not only does the excavator meet the competition standards but it surpasses the requirements of the competition. The mass of the excavator is a little more than half the maximum weight requirement. It is also able to safely lift regolith 0.7m, rather than the 0.5m required. Now that the designed has been verified and finalized, the fabrication of the lunar excavator is next. The materials needed for the fabrication of the excavator will be verified once again, and then ordered. Upon arrival of the materials, the frame and treads will be assembled. Next the bucket will be created and implemented on the frame. Then the camera system will be integrated. Finally the excavator's controls will be connected. After the system is completely finished, it will be tested.

Appendix I

008 rpm Stall Torque	425	425	425	425	425	425	425	425
103 rpm Stall Torque	300	300	300	300	300	300	300	300

Calculations 1

m (kg)	10	20	30	40	50	60	70	80
(1/4)*m (kg)	2.5	5	7.5	10	12.5	15	17.5	20
F1 = 0.9*(1/4)*m	2.25	4.5	6.75	9	11.25	13.5	15.75	18
T = F1*r	25.5465	51.093	76.6395	102.186	127.7325	153.279	178.8255	204.372
F2 = 0.3*(1/4)*m	0.75	1.5	2.25	3	3.75	4.5	5.25	6
T = F2*r	8.5155	17.031	25.5465	34.062	42.5775	51.093	59.6085	68.124
F3 = 0.5*(1/4)*m	1.25	2.5	3.75	5	6.25	7.5	8.75	10
T = F3*r	14.1925	28.385	42.5775	56.77	70.9625	85.155	99.3475	113.54

Calculations 2

m (kg)	10	20	30	40	50	60	70	80
(2/5)*m (kg)	4	8	12	16	20	24	28	32
F1 = 0.9*(2/5)*m	3.6	7.2	10.8	14.4	18	21.6	25.2	28.8
T = F1*r	40.8744	81.7488	122.6232	163.4976	204.372	245.2464	286.1208	326.9952
F2 = 0.3*(2/5)*m	1.2	2.4	3.6	4.8	6	7.2	8.4	9.6
T = F2*r	13.6248	27.2496	40.8744	54.4992	68.124	81.7488	95.3736	108.9984
F3 = 0.5*(2/5)*m	2	4	6	8	10	12	14	16
T = F3*r	22.708	45.416	68.124	90.832	113.54	136.248	158.956	181.664

Appendix II

Carbon Fiber Rectangular Tube

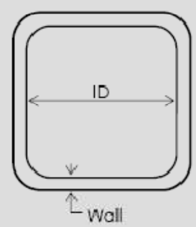
Comprised of carbon fiber braid and Unidirectional Fabrics our rectangular tube is ideal for building light weight frames and structures such as trusses. Engineered to be much stronger under torsional and side loading than pultruded tubing and significantly lighter. Designed so that the unidirectional layers are captured in a sandwich structure, eliminating longitudinal cracking and splitting.

STANDARD SIZES

SIZES	WALL THICKNESS	WEIGHT (lbs/ft)
¾" x ¾" (0.790 x 0.790 ± 0.010) ID	0.050" (± 0.015)	0.07
1" x 1" (1.032 x 1.032 ± 0.010) ID	0.050" (± 0.015)	0.10
1" x 2" (0.990 x 1.980 ± 0.010) ID	0.050" (± 0.015)	0.14
2" x 2" (1.970 x 1.970 ± 0.030) ID	0.065" (± 0.015)	0.26

Lengths: 96", 72", 48", 24" (-0, +.25)
(96" may be up to 98")

Finish: Textured, wet, shiny finish



Additional Options

- Custom Sizes
- Custom Lengths
- Custom Wall Thickness
- CNC Machining
- Design and Engineering Services

TECHNICAL SPECIFICATIONS

Properties of Braid Fiber
Tensile Strength: 640 ksi
Modulus of Elasticity: 34 Msi

Properties of UNI Fiber
Tensile Strength: 640 ksi
Modulus of Elasticity: 34 Msi

Resin
Epoxy resin that accounts for approximately 50% of the composition

$W_f \approx 50\%$

Lay Up Schedule
± 45° bi-axial CF braid
0° uni-directional CF
± 45° bi-axial CF braid

$[\pm 45/\bar{0}]_s$

DragonPlate.com · 321 Route 5 West · Elbridge, New York 13060 · ph. 315-252-2559 · fax 315-252-0502 · service@dragonplate.com

Appendix III

Scotch-Weld™
Epoxy Adhesives
2216 B/A Gray • 2216 B/A Tan NS • 2216 B/A Translucent

Typical Adhesive Performance Characteristics

A. Typical Shear Properties on Etched Aluminum
ASTM D 1002
Cure: 2 hours @ 150 ± 5°F (66°C ± 2°C), 2 psi pressure

	Overlap Shear (psi)		
Test Temperature	**2216 B/A Gray Adhesive**	**2216 B/A Tan NS Adhesive**	**2216 B/A Trans. Adhesive**
-423°F (-253°C)	2440	—	—
-320°F (-196°C)	2740	—	—
-100°F (-73°C)	3000	—	—
-67°F (-53°C)	3000	2000	3000
75°F (24°C)	3200	2500	1700
180°F (82°C)	400	400	140

Test Temperature	Shear Modulus (Torsion Pendulum Method)
-148°F (-100°C)	398,000 psi (2745 MPa)
-76°F (-60°C)	318,855 psi (2199 MPa)
-40°F (-40°C)	282,315 psi (1947 MPa)
32°F (0°C)	218,805 psi (1500 MPa)
75°F (24°C)	49,580 psi (342 MPa)

B. Typical T-Peel Strength
ASTM D 1876

	T-Peel Strength (piw) @ 75°F (24°C)		
Test Temperature	**2216 B/A Gray Adhesive**	**2216 B/A Tan NS Adhesive**	**2216 B/A Trans. Adhesive**
75°F (24°C)	25	25	25

Scotch-Weld™

Epoxy Adhesives

2216 B/A Gray • 2216 B/A Tan NS • 2216 B/A Translucent

Typical Adhesive Performance Characteristics *(continued)*

C. Overlap Shear Strength After Environmental Aging-Etched Aluminum

		Overlap Shear (psi) 75°F (24°C)		
Environment	**Time**	**2216 B/A Gray Adhesive**	**2216 B/A Tan NS Adhesive**	**2216 B/A Trans. Adhesive**
100% Relative Humidity @120°F (49°C)	14 days 30 days 90 days	2950 psi 1985 psi 1505 psi	3400 psi 2650 psi	1390 psi
*Salt Spray @75°F (24°C)	14 days 30 days 60 days	2300 psi 500 psi 300 psi	3900 psi 3300 psi	1260 psi
Tap Water @75°F (24°C)	14 days 30 days 90 days	3120 psi 2942 psi 2075 psi	3250 psi 2700 psi	1950 psi
Air @160°F (71°C)	35 days	4650 psi	4425 psi	
Air @300°F (149°C)	40 days	4930 psi	4450 psi	3500 psi
Anti-icing Fluid @75°F (24°C)	7 days	3300 psi	3050 psi	2500 psi
Hydraulic Oil @75°F (24°C)	30 days	2500 psi	3500 psi	2500 psi
JP-4 Fuel	30 days	2500 psi	2750 psi	2500 psi
Hydrocarbon Fluid	7 days	3300 psi	3100 psi	3000 psi

*Substrate corrosion resulted in adhesive failure.

D. Heat Aging of 2216 B/A Gray
(Cured for 7 days @ 75°F [24°C])

Overlap Shear (psi)	Time aged @ 300°F (149°C)			
Test Temperature	**0 days**	**12 days**	**40 days**	**51 days**
-67°F (-53°C)	2200	3310	3120	2860
75°F (24°C)	3100	5150	4930	4740
180°F (82°C)	500	1000	760	1120
350°F (177°C)	420	440	560	—

Scotch-Weld™

Epoxy Adhesives

2216 B/A Gray • 2216 B/A Tan NS • 2216 B/A Translucent

Typical Adhesive Performance Characteristics *(continued)*

E. Overlap Shear Strength on Abraded Metals, Plastics, and Rubbers.

Overlap shear strengths were measured on 1" x 1/2" overlap specimens. These bonds were made individually using 1" by 4" pieces of substrate (Tested per ASTM D 1002).

The thickness of the substrates were: cold rolled, galvanized and stainless steel – 0.056-0.062", copper – 0.032", brass – 0.036", rubbers – 0.125", plastics – 0.125". All surfaces were prepared by solvent wiping/abrading/ solvent wiping.

The jaw separation rate used for testing was 0.1 in/min for metals, 2 in/min for plastics, and 20 in/min for rubbers.

	Overlap Shear (psi) @75°F (24°C)	
Substrate	**2216 B/A Gray Adhesive**	**2216 B/A Tan NS Adhesive**
Aluminum/Aluminum	1850	2350
Cold Rolled Steel/Cold Rolled Steel	1700	3100
Stainless Steel/Stainless Steel	1900	
Galvanized Steel/Galvanized Steel	1800	
Copper/Copper	1050	
Brass/Brass	850	
Styrene Butadiene Rubber/Steel	200*	
Neoprene Rubber/Steel	220*	
ABS/ABS Plastic	990*	1140*
PVC/PVC, Rigid	940*	
Polycarbonate/Polycarbonate	1170*	1730*
Acrylic/Acrylic	1100*	1110*
Fiber Reinforced Polyester/ Reinforced Polyester	1660*	1650*
Polyphenylene Oxide/PPO	610	610
PC/ABS Alloy / PC/ABS Alloy	1290	1290

*The substrate failed during the test.

Storage and Shelf Life

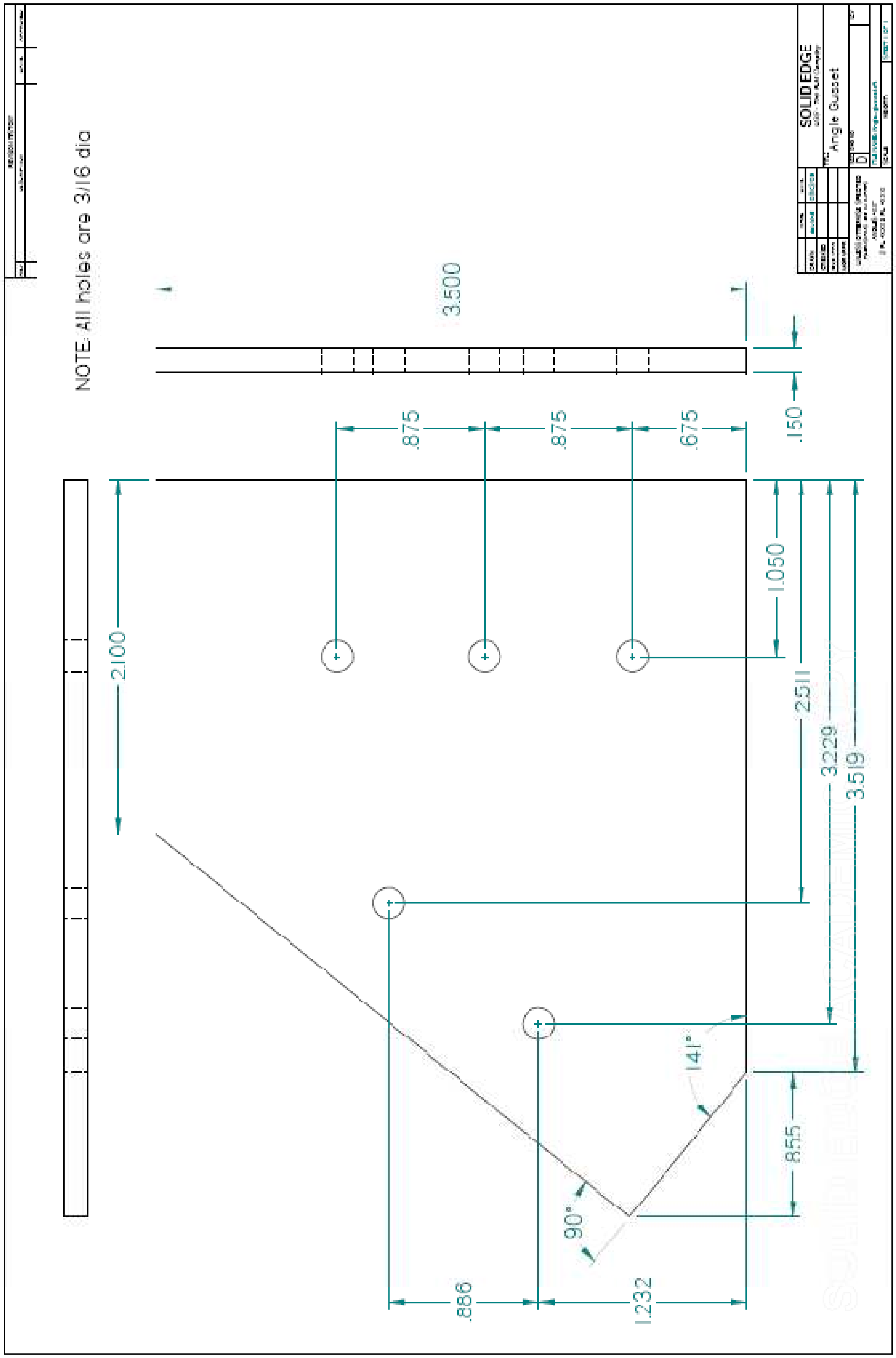
Storage: Store products at 60-80°F (16-27°C) for maximum storage life.

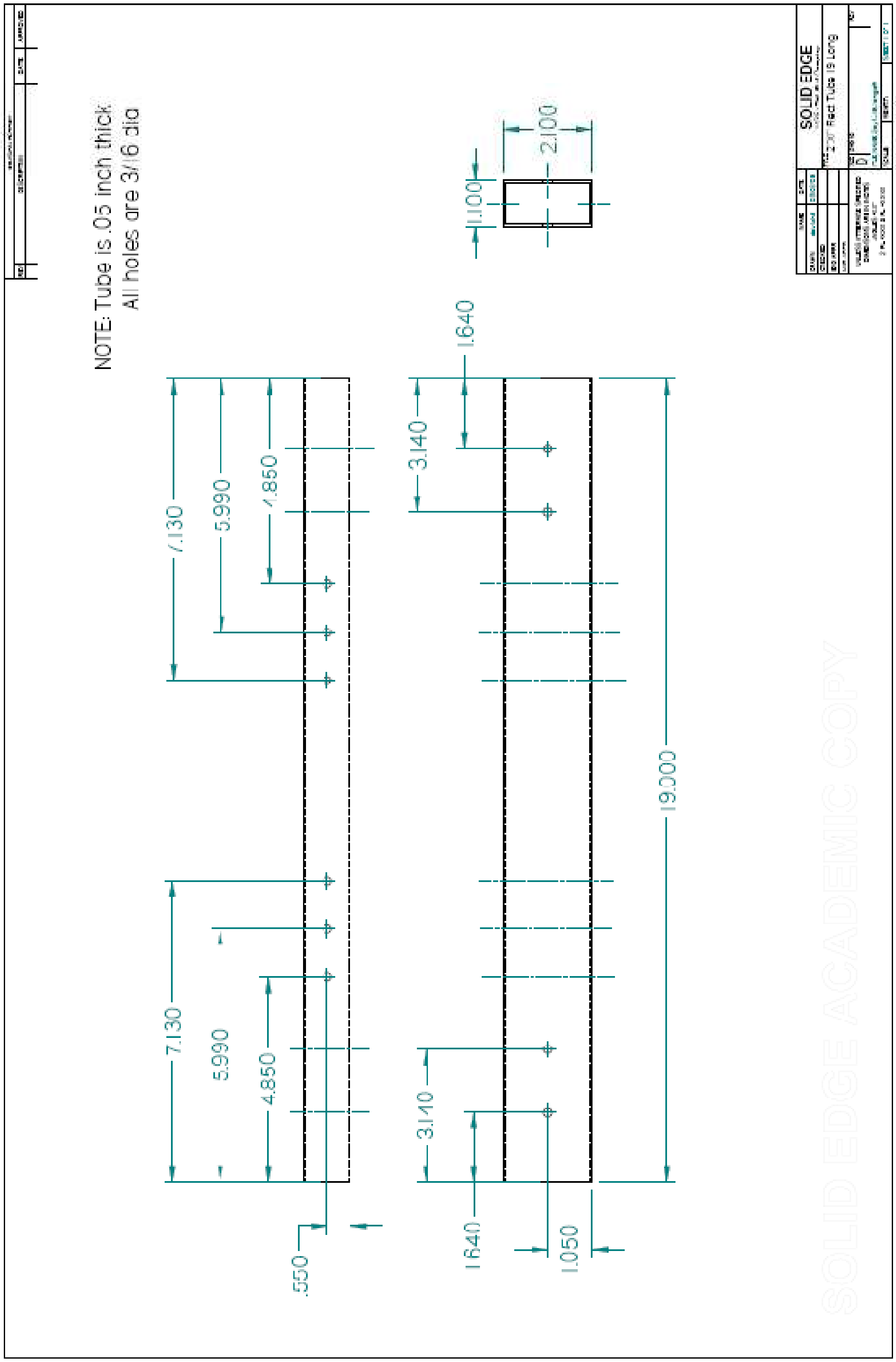
Shelf Life: When stored at the recommended temperatures in the original, unopened containers, the 3M Standard shelf life is two years from date of shipment from 3M.

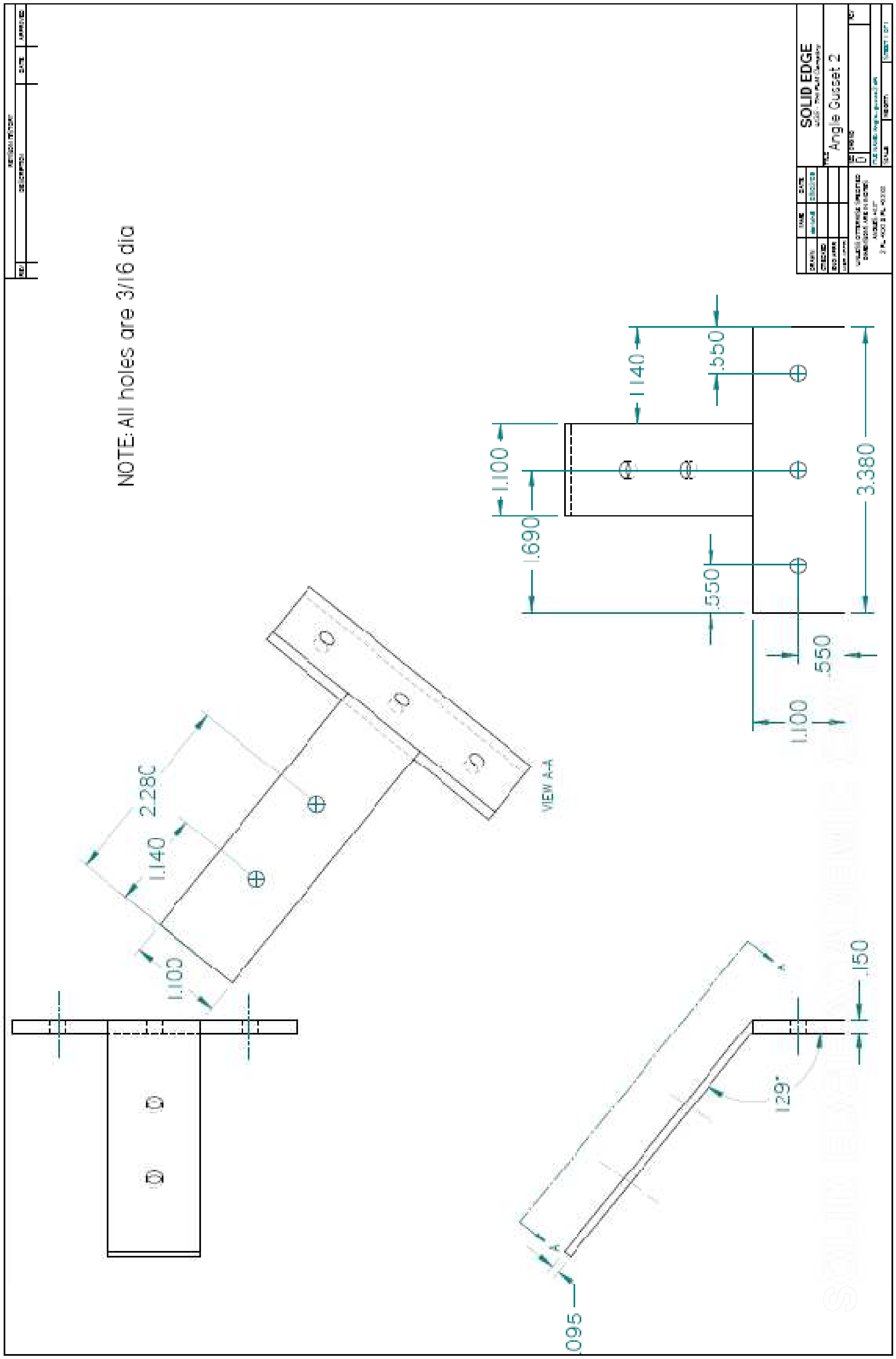
Note

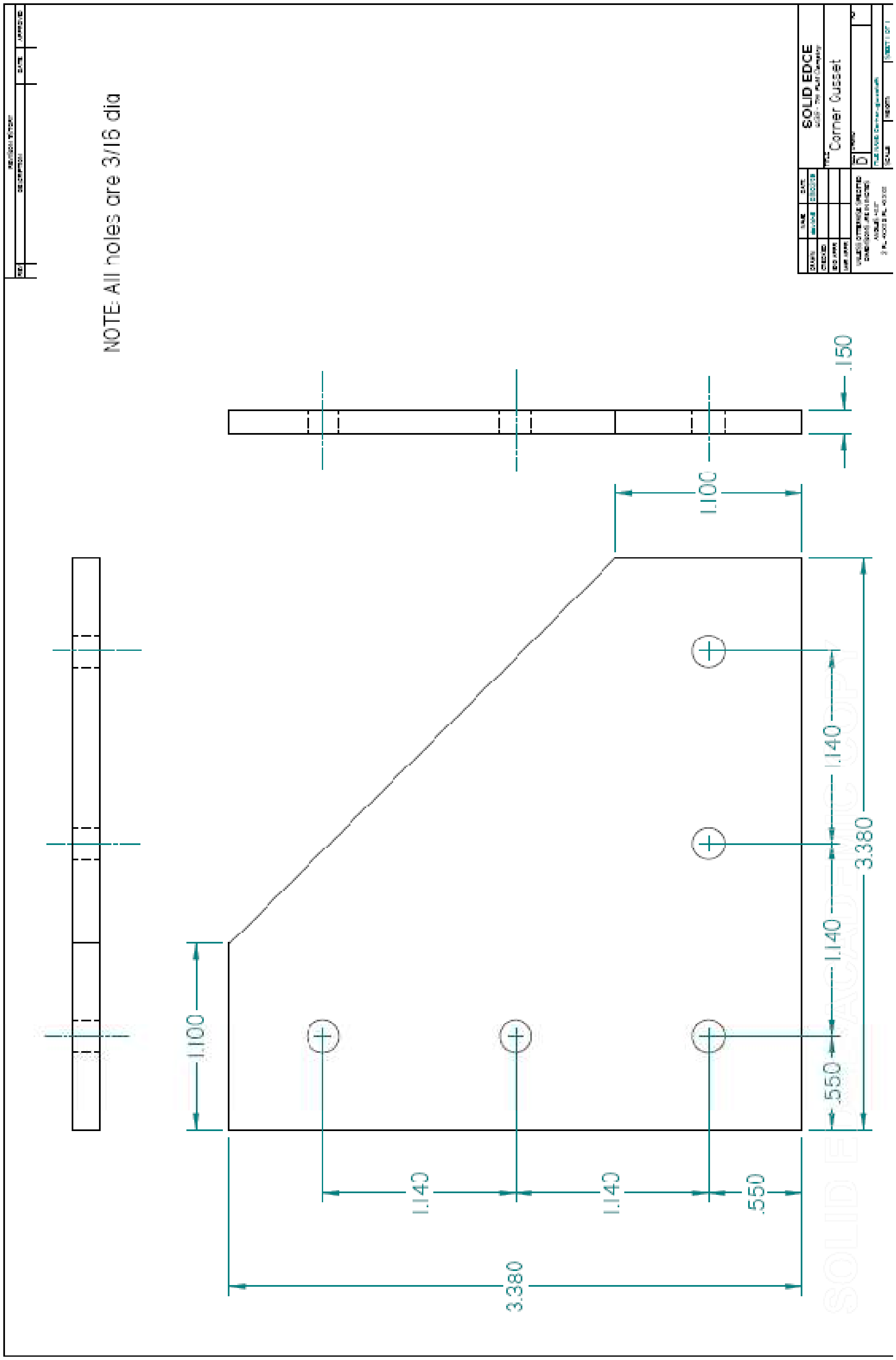
2216 B/A is identical to 3M™ Scotch-Weld™ Epoxy Adhesive EC-2216 B/A in chemical composition. EC-2216 B/A has been labeled, packaged, tested, and certified for aircraft and aerospace applications. 2216 B/A may be used for aircraft and aerospace applications if proper Certificates of Test have been issued and material meets all aircraft manufacturer's specification requirements.

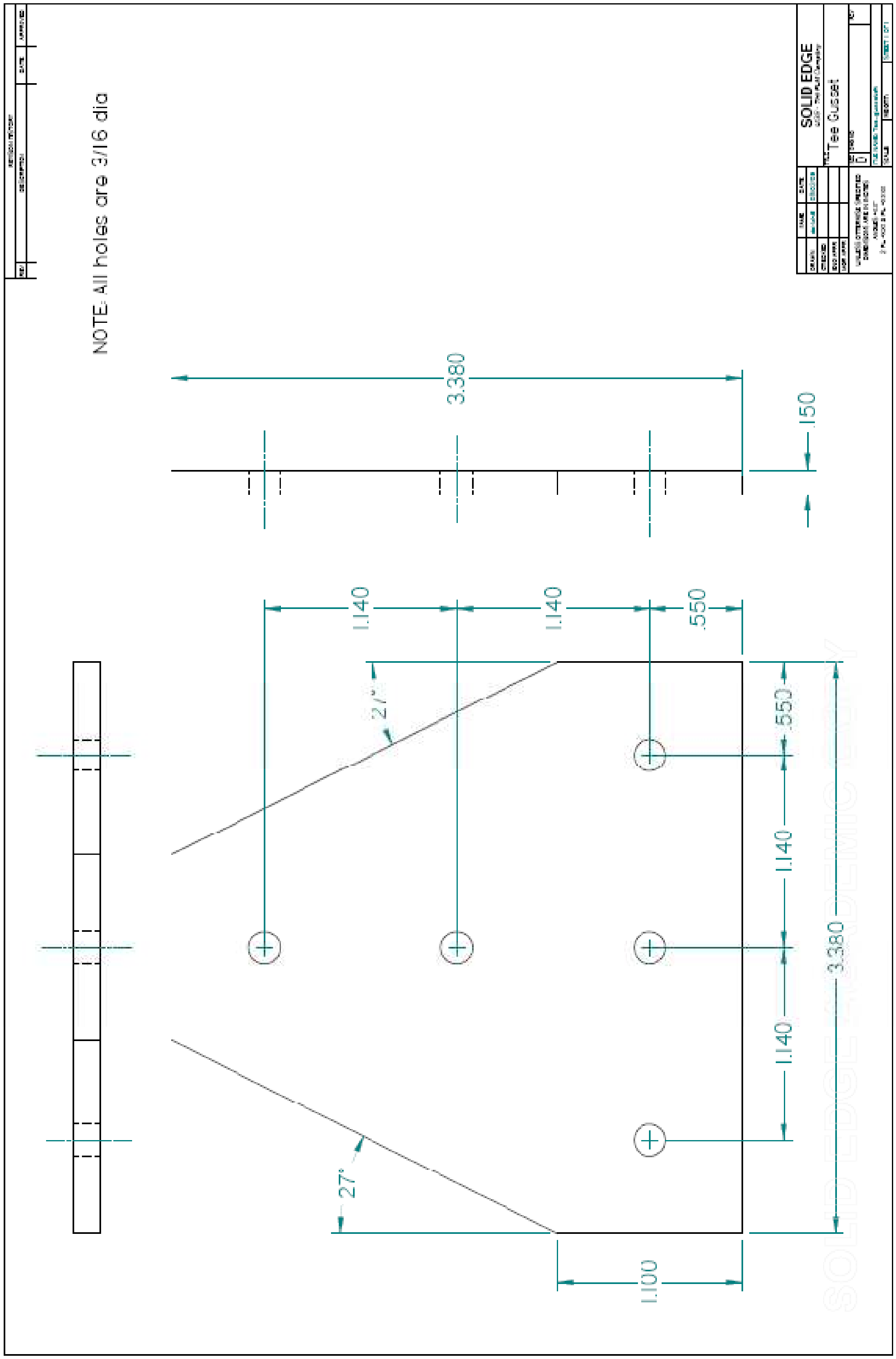
Appendix IV

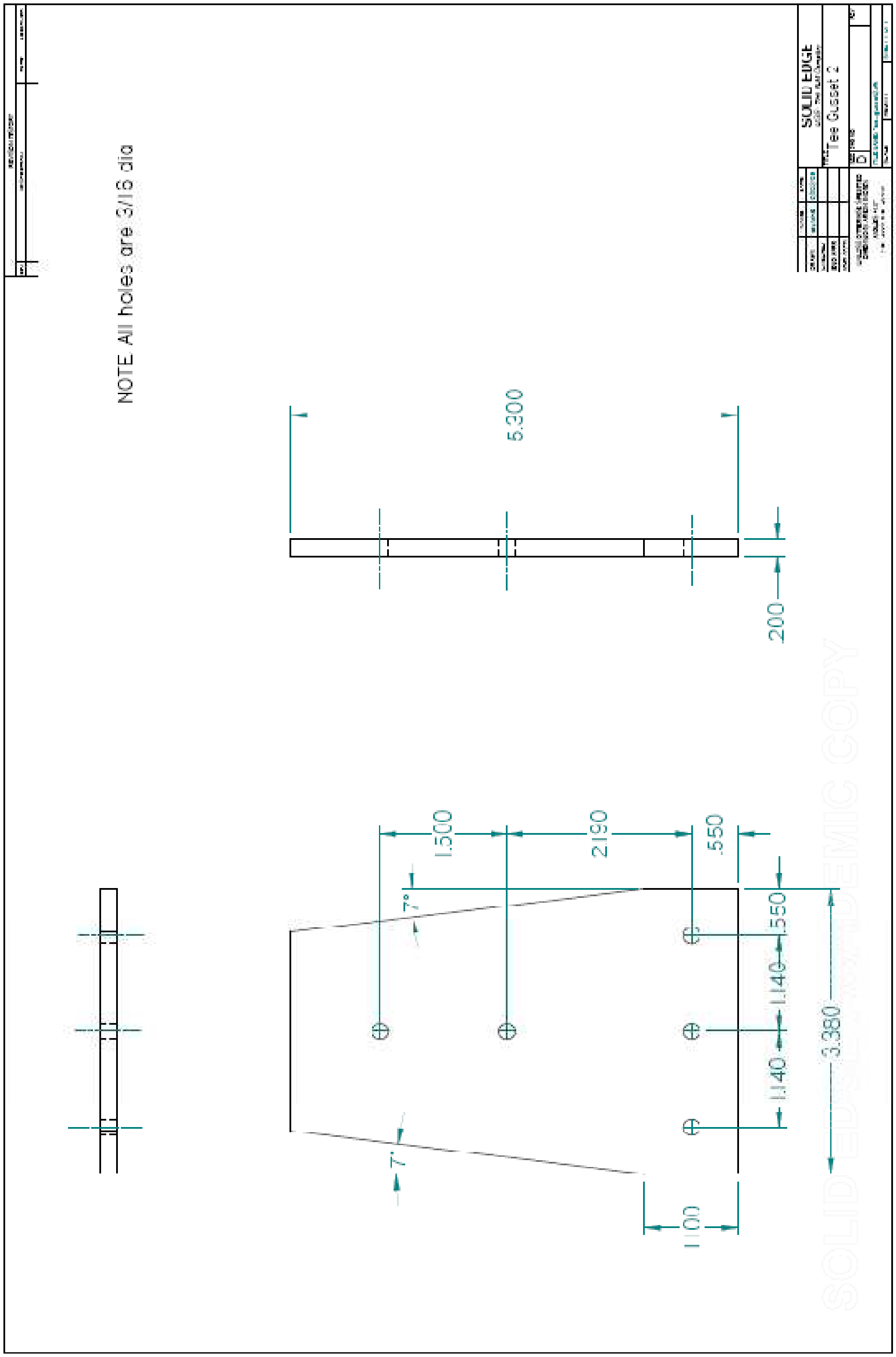

NOTE: All holes are 3/16 dia
3.500
.875
.875
.675
.150
2.100
1.050
2.511
3.229
3.519
141°
90°
.855
.886
1.232
SOLID EDGE
Angle Gusset

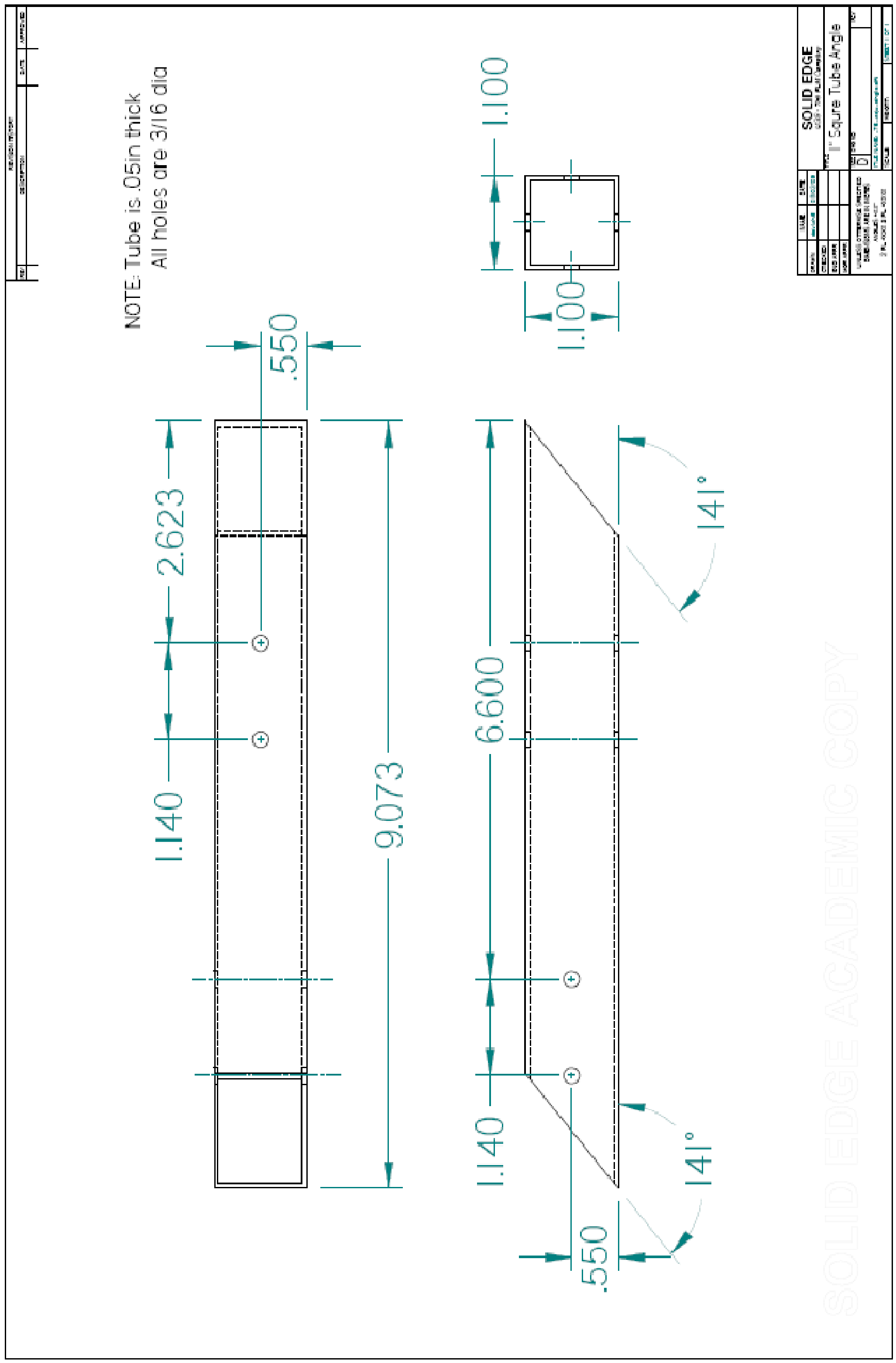

NOTE: Tube is .05 inch thick
All holes are 3/16 dia
7.130
5.990
4.850
3.140
1.640
19.000
.550
1.050
1.100
2.100
SOLID EDGE
SOLID EDGE ACADEMIC COPY

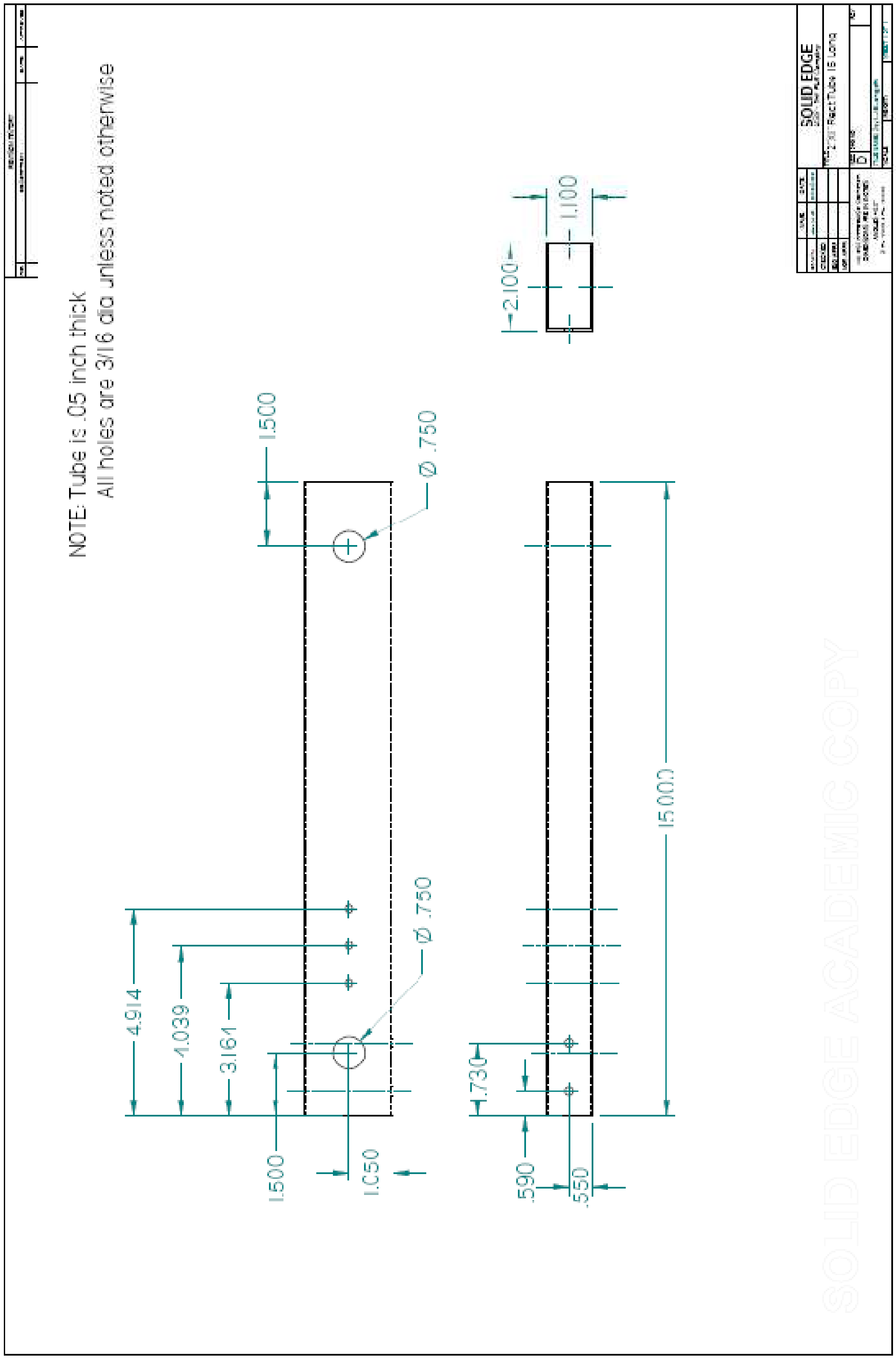

NOTE: All holes are 3/16 dia
SOLID EDGE
Angle Gusset 2
VIEW A-A
2.280
1.140
1.100
1.690
.550
3.380
.150
129°
.095


NOTE: All holes are 3/16 dia
SOLID EDGE
Corner Gusset
3.380
1.140
1.140
.550
1.100
.150

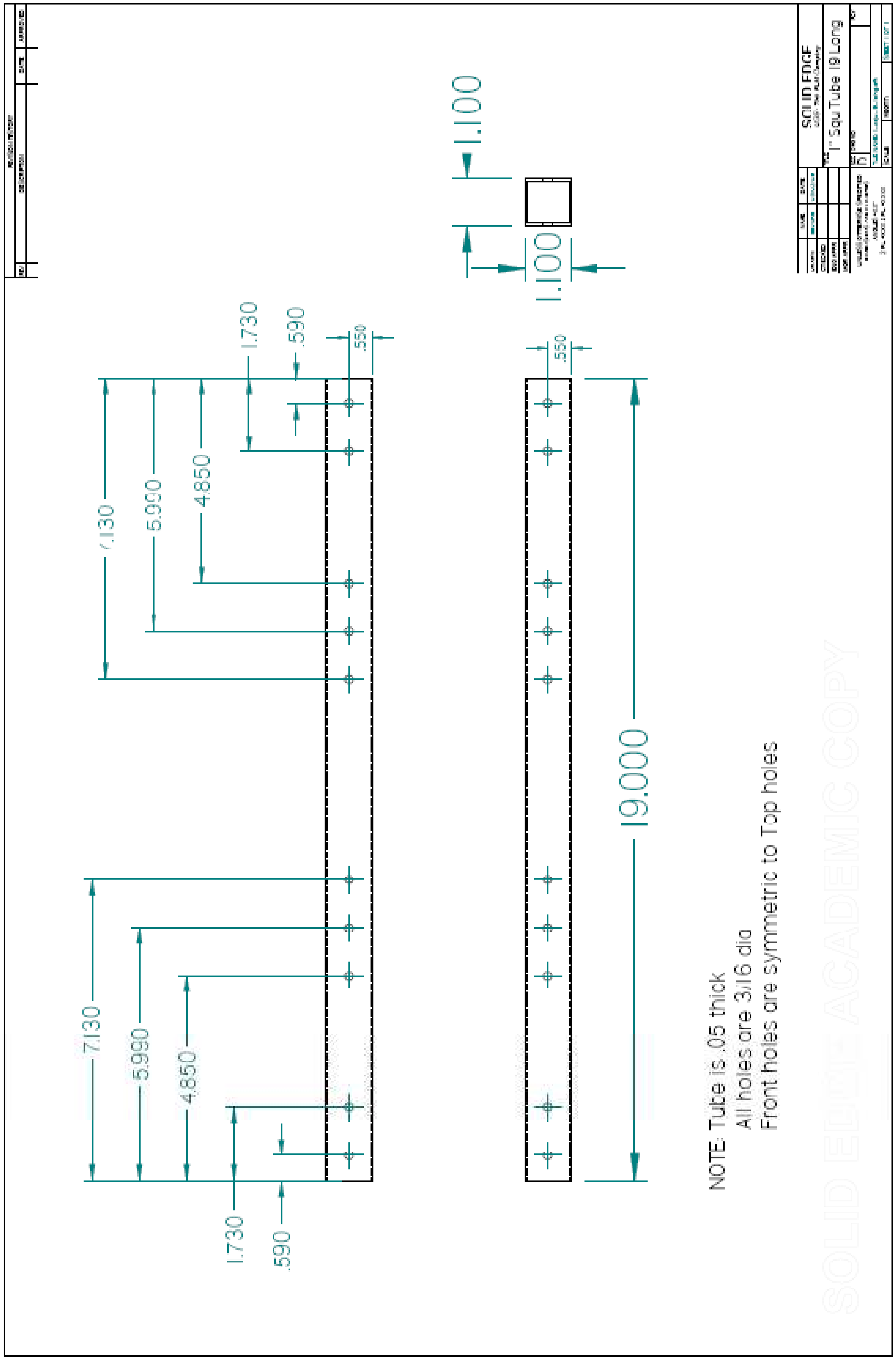

NOTE: All holes are 3/16 dia
SOLID EDGE
Tee Gusset
3.380
.150
1.140
1.140
.550
27°
27°
.550
1.140
1.140
3.380
1.100

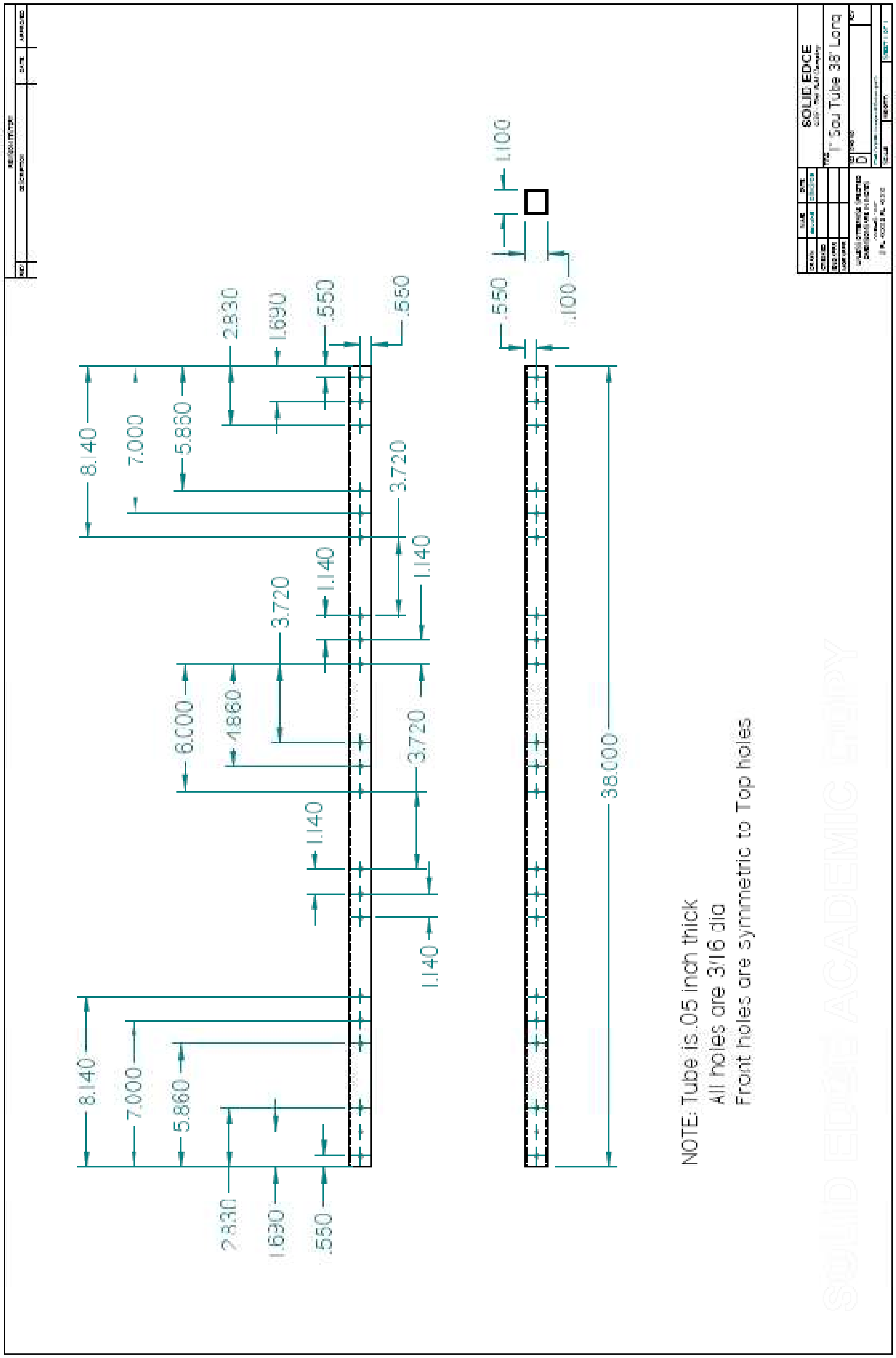

NOTE All holes are 3/16 dia
5.300
.200
1.500
2.190
.550
7°
7°
.550
1.140
1.140
3.380
1.100
SOLID EDGE
Tee Gusset 2
SOLID EDGE ACADEMIC COPY

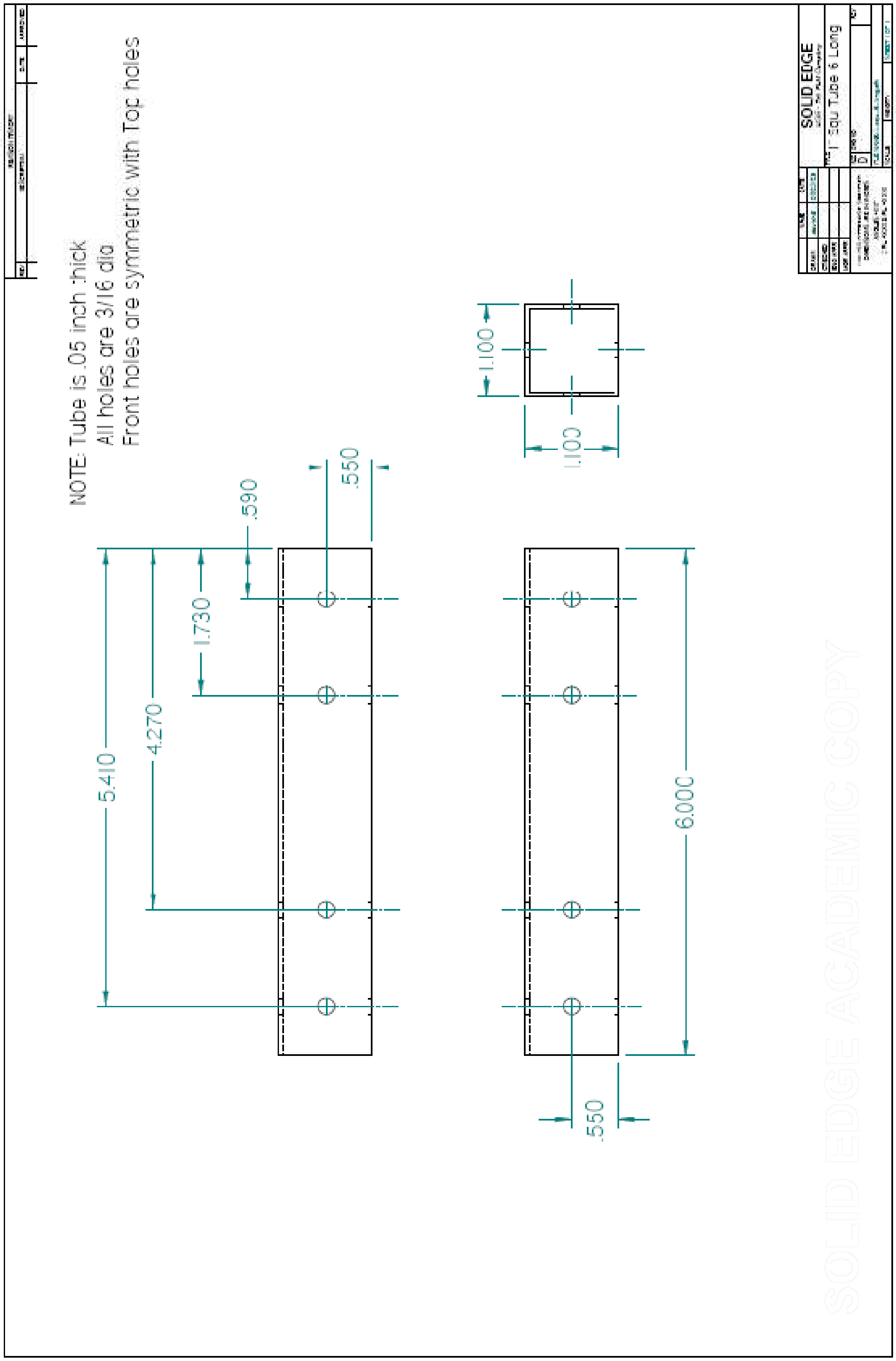

NOTE: Tube is .05in thick
All holes are 3/16 dia
.550
2.623
1.140
9.073
1.100
1.100
6.600
1.140
141°
141°
.550
SOLID EDGE
1" Squre Tube Angle
SOLID EDGE ACADEMIC COPY

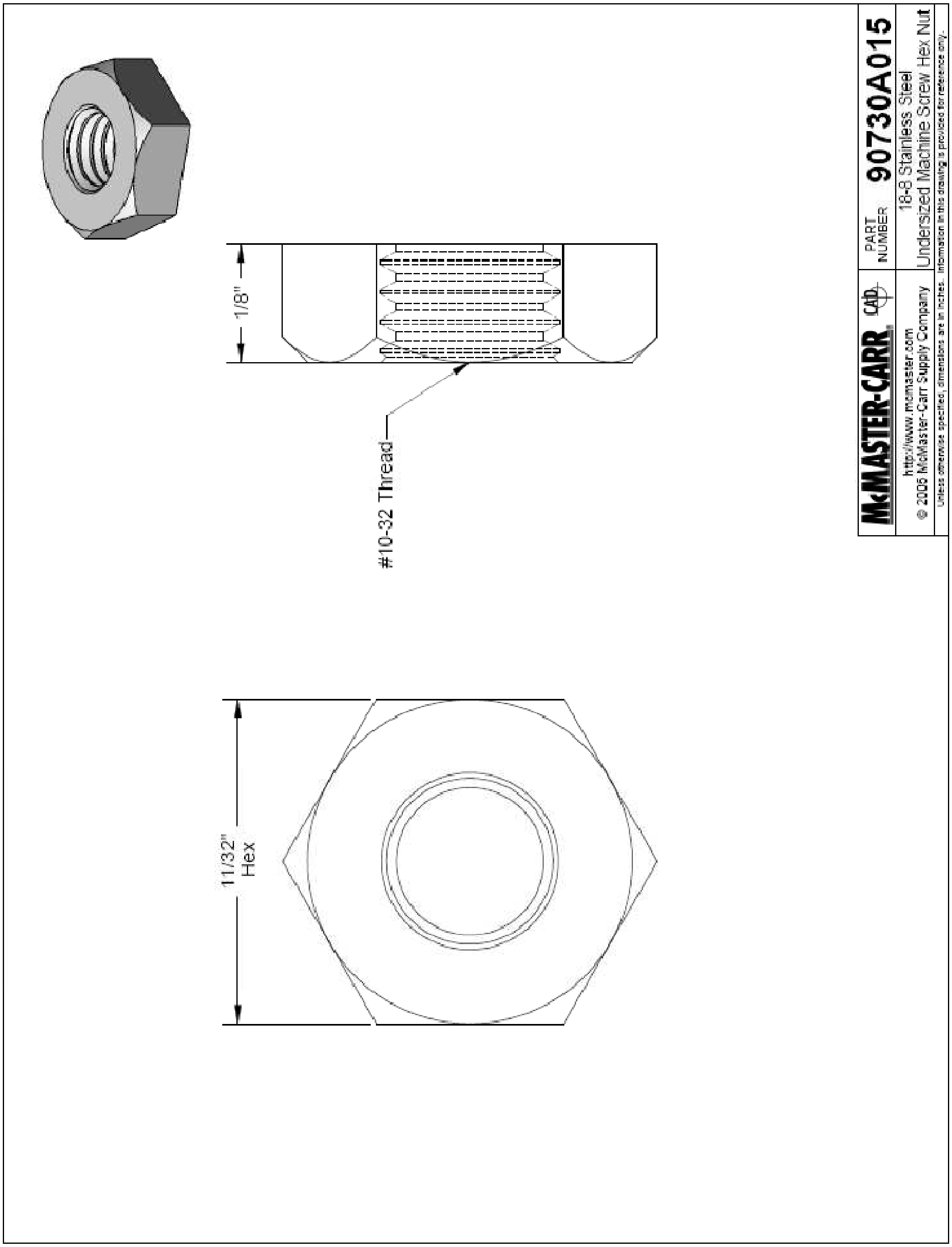


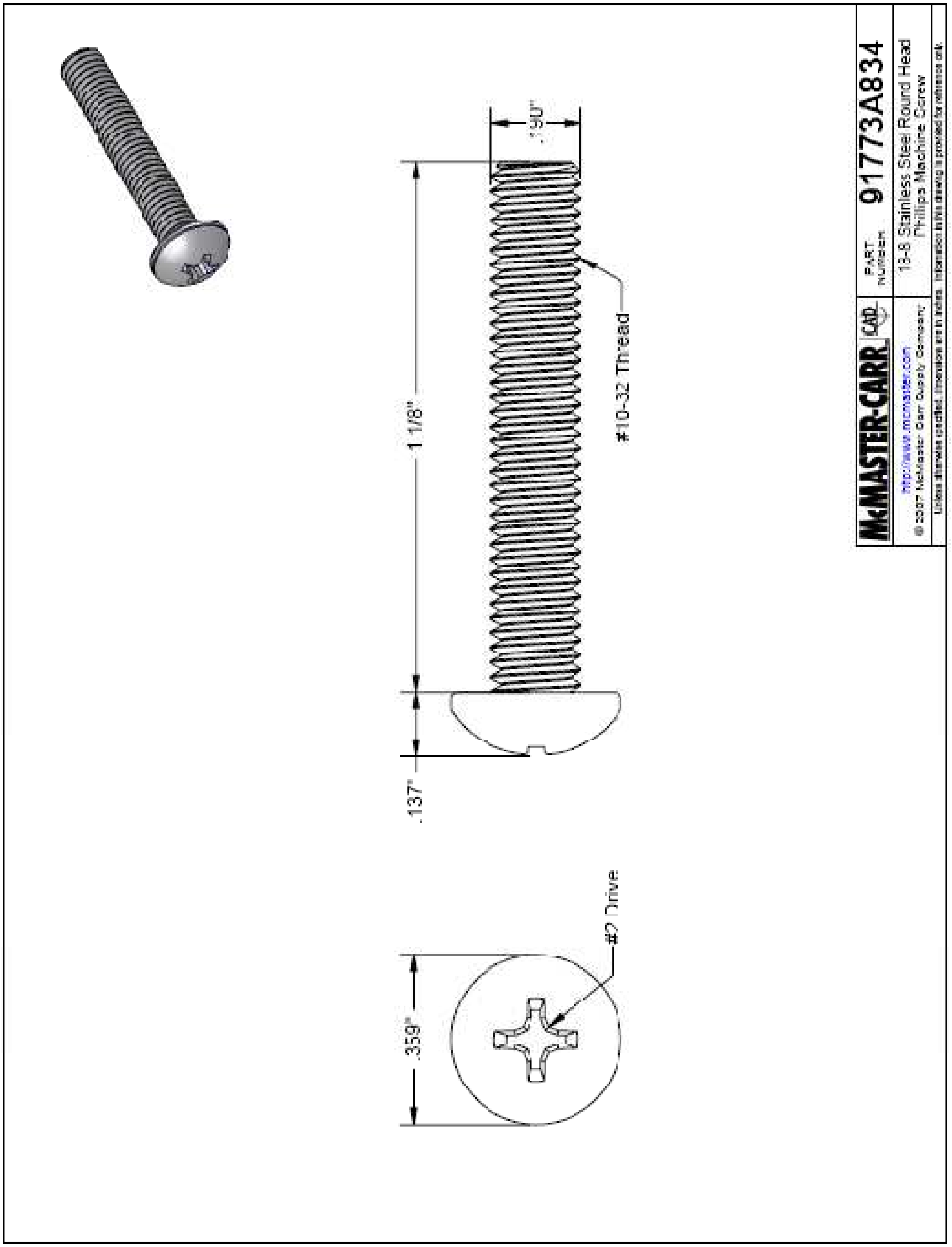
NOTE: Tube is .05 inch thick
All holes are 3/16 dia unless noted otherwise
1.500
Ø .750
4.914
4.039
3.164
1.500
1.050
Ø .750
2.100
1.100
15.000
.730
.590
.550
SOLID EDGE
SOLID EDGE ACADEMIC COPY


1.100
1.100
.550
.550
1.730
.590
7.130
5.990
4.850
19.000
7.130
5.990
4.850
1.730
.590
NOTE: Tube is .05 thick
All holes are 3/16 dia
Front holes are symmetric to Top holes
SOLID EDGE
1" Squ Tube 19 Long
SOLID EDGE ACADEMIC COPY


NOTE: Tube is .05 inch thick
All holes are 3/16 dia
Front holes are symmetric to Top holes
SOLID EDGE
1" Squ Tube 38" Long
38.000


NOTE: Tube is .05 inch thick
All holes are 3/16 dia
Front holes are symmetric with Top holes
.590
1.730
4.270
5.410
.550
1.100
1.100
6.000
.550
SOLID EDGE
1" Squ Tube 6 Long
SOLID EDGE ACADEMIC COPY


1/8"
#10-32 Thread
11/32"
Hex
McMASTER-CARR
CAD
PART NUMBER
90730A015
http://www.mcmaster.com
© 2006 McMaster-Carr Supply Company
18-8 Stainless Steel
Undersized Machine Screw Hex Nut
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.

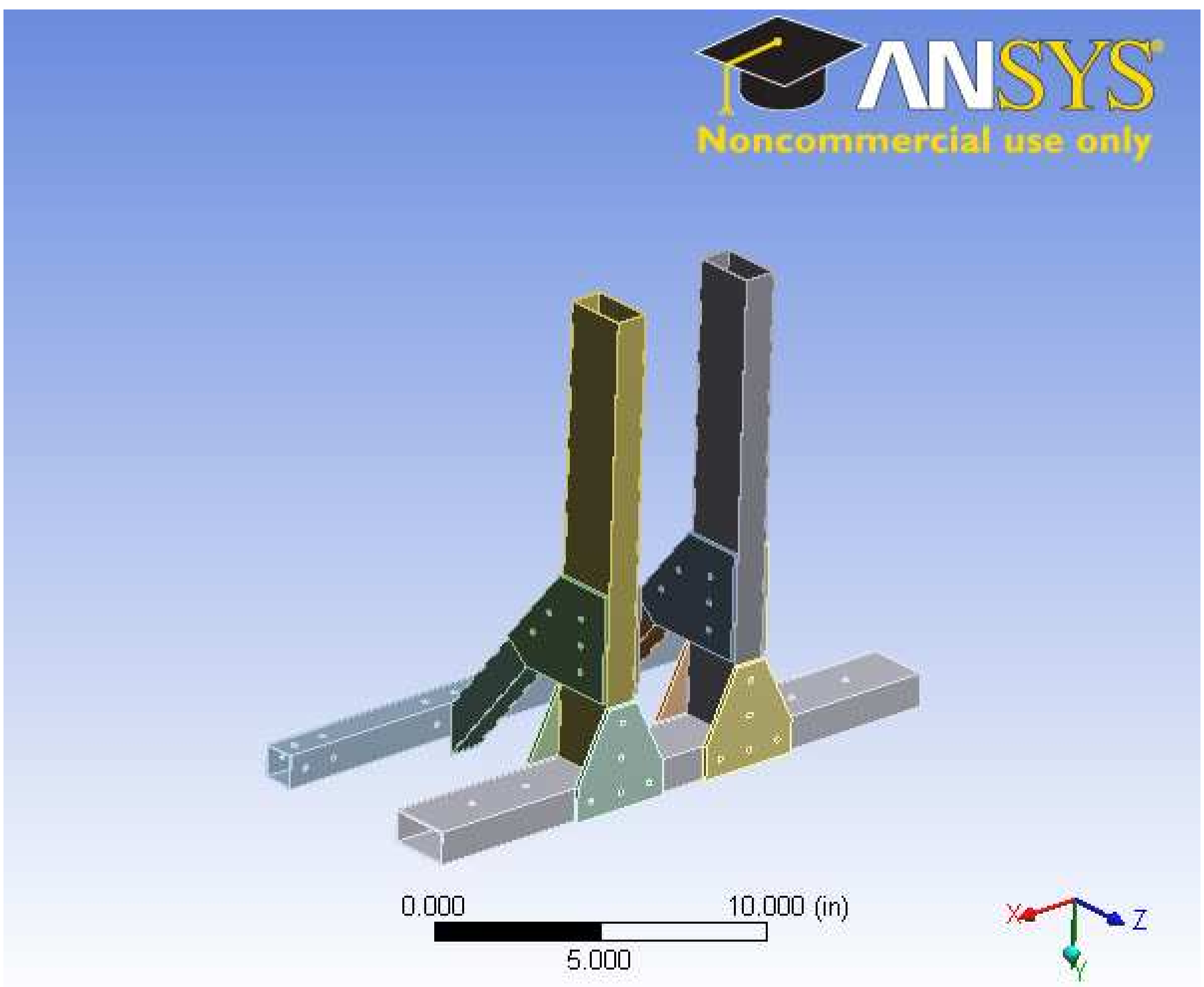


.190"
1 1/8"
#10-32 Thread
.137"
.359"
#2 Drive
McMASTER-CARR
CAD
PART NUMBER
91773A834
http://www.mcmaster.com
© 2007 McMaster-Carr Supply Company
18-8 Stainless Steel Round Head Phillips Machine Screw
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.

Appendix V

Project

First Saved	Thursday, July 30, 2009
Last Saved	Thursday, July 30, 2009
Product Version	11.0 Release



Contents

Units

TABLE 1

Unit System	U.S. Customary (in, lbm, lbf, ℉, s, V, A)
Angle	Degrees
Rotational Velocity	rad/s

Model

Geometry

TABLE 2
Model > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	Unnamed.agdb
Type	DesignModeler
Length Unit	Inches
Element Control	Program Controlled
Display Style	Part Color

Bounding Box	
Length X	19. in
Length Y	16.754 in
Length Z	8.2052 in
Properties	
Volume	34.52 in³
Mass	2.2438 lbm
Statistics	
Bodies	14
Active Bodies	14
Nodes	67516
Elements	27450
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	Yes
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No
Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes

Do Smart Update	No
Attach File Via Temp File	No
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 3
Model > Geometry > Parts

Object Name	*Solid*	*Solid*	*Solid*	*Solid*	*Solid*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Material	Carbon Fiber				
Stiffness Behavior	Flexible				
Nonlinear Material Effects	Yes				
Bounding Box					
Length X	19. in	3.38 in			
Length Y	1.1 in	3.38 in			
Length Z	1.1 in	0.15 in			
Properties					
Volume	3.9348 in³	1.3031 in³			
Mass	0.25576 lbm	8.47e-002 lbm			
Centroid X	6.4627 in	9.0127 in	3.9127 in	9.0127 in	3.9127 in
Centroid Y	0.55644 in	-0.31896 in			

Centroid Z	-3.508 in	1.8222 in		4.0722 in	
Moment of Inertia Ip1	9.4537e-002 lbm·in²	6.9353e-002 lbm·in²			
Moment of Inertia Ip2	7.7341 lbm·in²	6.0188e-002 lbm·in²			
Moment of Inertia Ip3	7.7341 lbm·in²	0.12922 lbm·in²			
Statistics					
Nodes	16106	1338	1342	1197	1158
Elements	7565	175	172	152	145

TABLE 4
Model > Geometry > Parts

Object Name	*Solid*	*Solid*	*Solid*	*Solid*	*Solid*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Material	Carbon Fiber				
Stiffness Behavior	Flexible				
Nonlinear Material Effects	Yes				
Bounding Box					
Length X	19. in	0.15 in			
Length Y	1.1 in	3.5 in			
Length Z	2.1 in	4.3737 in			
Properties					
Volume	5.8624 in³	1.7523 in³			
Mass	0.38106 lbm	0.1139 lbm			

Centroid X	6.4627 in	3.2877 in	8.3877 in	4.5377 in	9.6377 in
Centroid Y	0.55 in	-4.0568 in			
Centroid Z	2.9472 in	2.244 in			
Moment of Inertia Ip1	0.3056 lbm·in²	0.23913 lbm·in²			
Moment of Inertia Ip2	11.704 lbm·in²	0.15365 lbm·in²			
Moment of Inertia Ip3	11.562 lbm·in²	8.5914e-002 lbm·in²			
Statistics					
Nodes	11625	1904	2105	2180	
Elements	5526	253	281	291	

TABLE 5
Model > Geometry > Parts

Object Name	*Solid*	*Solid*	*Solid*	*Solid*
State	Meshed			
Graphics Properties				
Visible	Yes			
Transparency	1			
Definition				
Suppressed	No			
Material	Carbon Fiber			
Stiffness Behavior	Flexible			
Nonlinear Material Effects	Yes			
Bounding Box				
Length X	1.1 in			
Length Y	7.7436 in		15. in	
Length Z	4.8552 in		2.1 in	
Properties				

Volume	1.6146 in³		4.6362 in³	
Mass	0.10495 lbm		0.30135 lbm	
Centroid X	3.9127 in	9.0127 in		3.9127 in
Centroid Y	-2.1105 in		-7.5136 in	
Centroid Z	-0.536 in		2.9472 in	
Moment of Inertia Ip1	0.56853 lbm·in²		5.8234 lbm·in²	
Moment of Inertia Ip2	3.765e-002 lbm·in²		0.24178 lbm·in²	
Moment of Inertia Ip3	0.56948 lbm·in²		5.7105 lbm·in²	
Statistics				
Nodes	3863	4003	9237	9278
Elements	1817	1882	4440	4460

Connections

TABLE 6
Model > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	6.6569e-002 in
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Same Body Grouping	Yes

Revolute Joints	Yes
Fixed Joints	Yes
Transparency	
Enabled	Yes

TABLE 7
Model > Connections > Contact Regions

Object Name	*Contact Region*	*Contact Region 2*	*Contact Region 3*	*Contact Region 4*	*Contact Region 5*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	1 Face				
Target	1 Face				
Contact Bodies	Solid				
Target Bodies	Solid				
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Thermal Conductance	Program Controlled				
Pinball Region	Program Controlled				

TABLE 8
Model > Connections > Contact Regions

Object Name	*Contact Region 6*	*Contact Region 7*	*Contact Region 8*	*Contact Region 9*	*Contact Region 10*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	1 Face				
Target	1 Face				
Contact Bodies	Solid				
Target Bodies	Solid				
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Thermal Conductance	Program Controlled				
Pinball Region	Program Controlled				

TABLE 9
Model > Connections > Contact Regions

Object Name	*Contact Region 11*	*Contact Region 12*	*Contact Region 13*	*Contact Region 14*	*Contact Region 15*
State	Fully Defined				

Scope	
Scoping Method	Geometry Selection
Contact	1 Face
Target	1 Face
Contact Bodies	Solid
Target Bodies	Solid
Definition	
Type	Bonded
Scope Mode	Automatic
Behavior	Symmetric
Suppressed	No
Advanced	
Formulation	Pure Penalty
Normal Stiffness	Program Controlled
Update Stiffness	Never
Thermal Conductance	Program Controlled
Pinball Region	Program Controlled

TABLE 10
Model > Connections > Contact Regions

Object Name	*Contact Region 16*	*Contact Region 17*	*Contact Region 18*	*Contact Region 19*	*Contact Region 20*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	1 Face				
Target	1 Face				

Contact Bodies	Solid
Target Bodies	Solid
Definition	
Type	Bonded
Scope Mode	Automatic
Behavior	Symmetric
Suppressed	No
Advanced	
Formulation	Pure Penalty
Normal Stiffness	Program Controlled
Update Stiffness	Never
Thermal Conductance	Program Controlled
Pinball Region	Program Controlled

TABLE 11
Model > Connections > Contact Regions

Object Name	*Contact Region 21*	*Contact Region 22*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Contact	1 Face	
Target	1 Face	
Contact Bodies	Solid	
Target Bodies	Solid	
Definition		
Type	Bonded	

Scope Mode	Automatic
Behavior	Symmetric
Suppressed	No
Advanced	
Formulation	Pure Penalty
Normal Stiffness	Program Controlled
Update Stiffness	Never
Thermal Conductance	Program Controlled
Pinball Region	Program Controlled

Mesh

TABLE 12
Model > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Advanced	
Relevance Center	Coarse
Element Size	Default
Shape Checking	Standard Mechanical
Solid Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Initial Size Seed	Active Assembly
Smoothing	Low
Transition	Fast

Statistics	
Nodes	67516
Elements	27450

Static Structural

TABLE 13
Model > Analysis

Object Name	*Static Structural*
State	Fully Defined
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Options	
Reference Temp	71.6 °F

TABLE 14
Model > Static Structural > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off

Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	G:\Davis_SolidEdge\Frame2\Tower_ANSYS_2 Simulation Files\Static Structural (2)\
Future Analysis	None
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No

TABLE 15
Model > Static Structural > Loads

Object Name	*Fixed Support*	*Fixed Support 2*	*Fixed Support 3*	*Fixed Support 4*	*Force*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Geometry	1 Face				
Definition					

Type	Fixed Support	Force
Suppressed	No	
Define By		Vector
Magnitude		100. lbf (ramped)
Direction		Defined

FIGURE 1
Model > Static Structural > Force

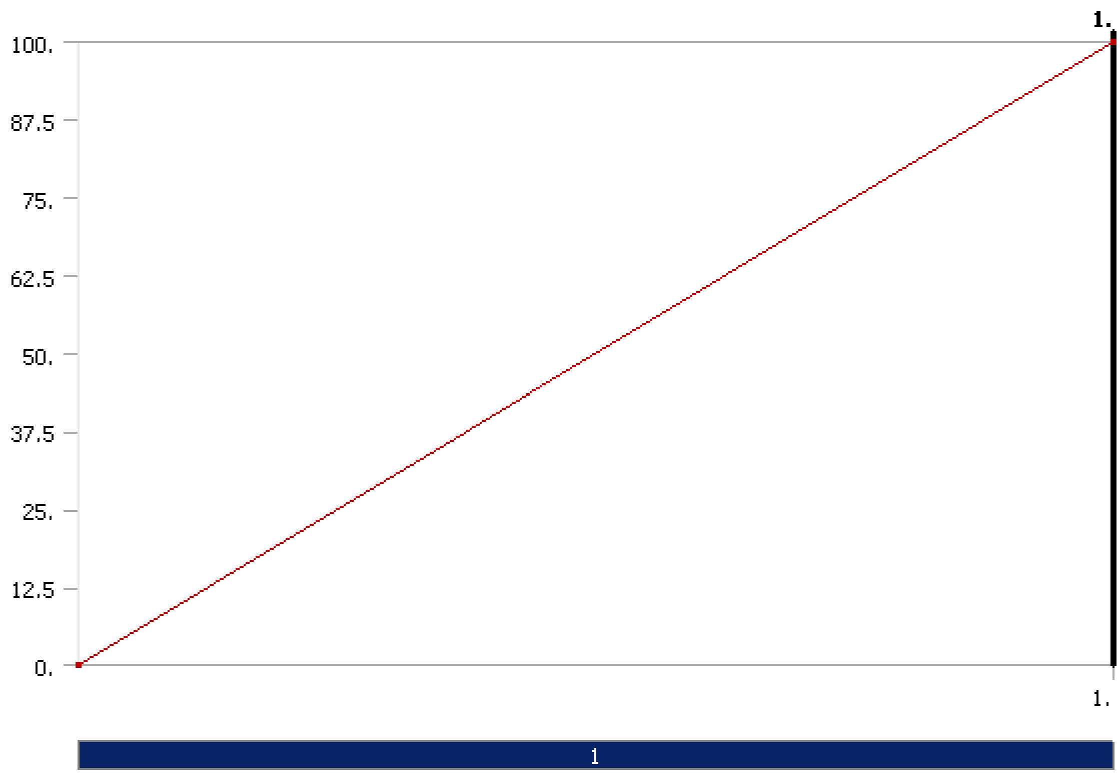
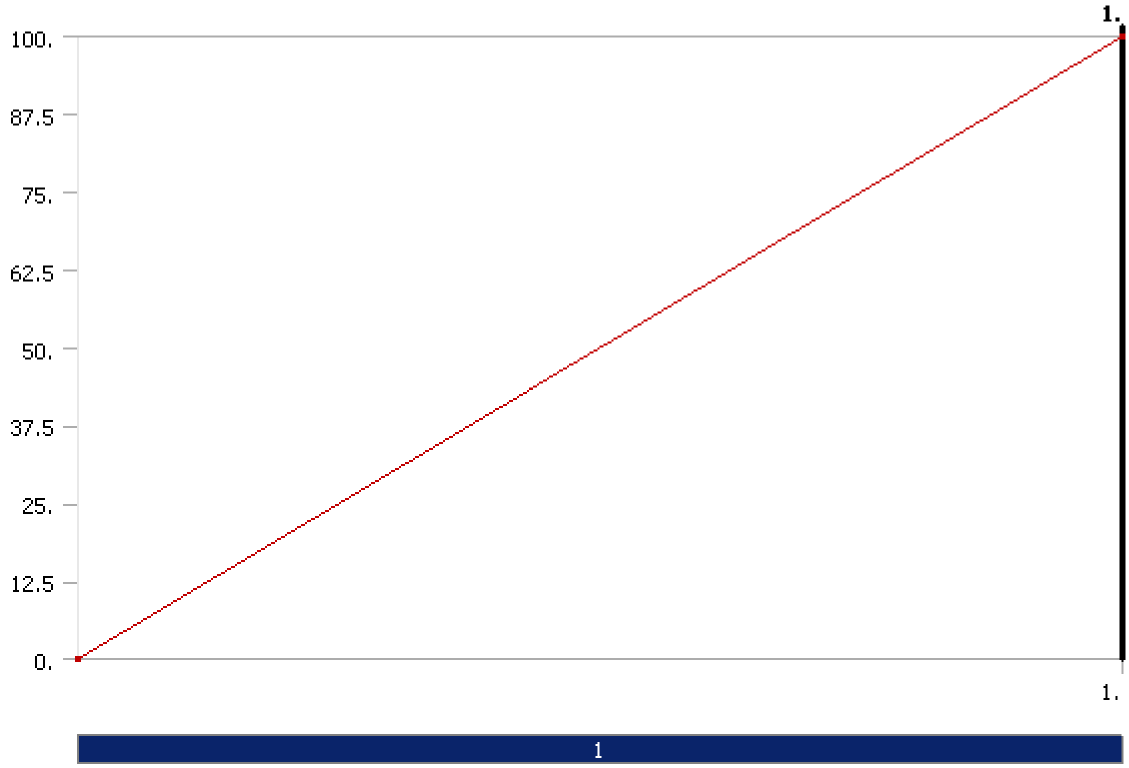


TABLE 16
Model > Static Structural > Loads

Object Name	*Force 2*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Face

Definition	
Define By	Vector
Type	Force
Magnitude	100. lbf (ramped)
Direction	Defined
Suppressed	No

FIGURE 2
Model > Static Structural > Force 2



Solution

TABLE 17
Model > Static Structural > Solution

Object Name	*Solution*
State	Solved
Adaptive Mesh Refinement	

Max Refinement Loops	1.
Refinement Depth	2.

TABLE 18
Model > Static Structural > Solution > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

TABLE 19
Model > Static Structural > Solution > Results

Object Name	*Total Deformation*	*Directional Deformation*	*Maximum Shear Elastic Strain*	*Normal Elastic Strain*	*Maximum Shear Stress*
State	Solved				
Scope					
Geometry	1 Face	All Bodies			
Definition					
Type	Total Deformation	Directional Deformation	Maximum Shear Elastic Strain	Normal Elastic Strain	Maximum Shear Stress
Display Time	End Time				
Orientation		X Axis		X Axis	
Results					
Minimum	2.5957e-003 in	-1.7269e-003 in	3.5086e-007 in/in	-3.2003e-004 in/in	4.3858 psi
Maximum	1.7272e-002 in	1.7205e-003 in	4.43e-004 in/in	3.204e-004 in/in	5537.6 psi

Minimum Occurs On		Solid
Maximum Occurs On		Solid
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

TABLE 20
Model > Static Structural > Solution > Results

Object Name	*Normal Stress*
State	Solved
Scope	
Geometry	All Bodies
Definition	
Type	Normal Stress
Orientation	X Axis
Display Time	End Time
Results	
Minimum	-11185 psi
Maximum	11254 psi
Minimum Occurs On	Solid
Maximum Occurs On	Solid
Information	
Time	1. s

Load Step	1
Substep	1
Iteration Number	1

Material Data

Carbon Fiber

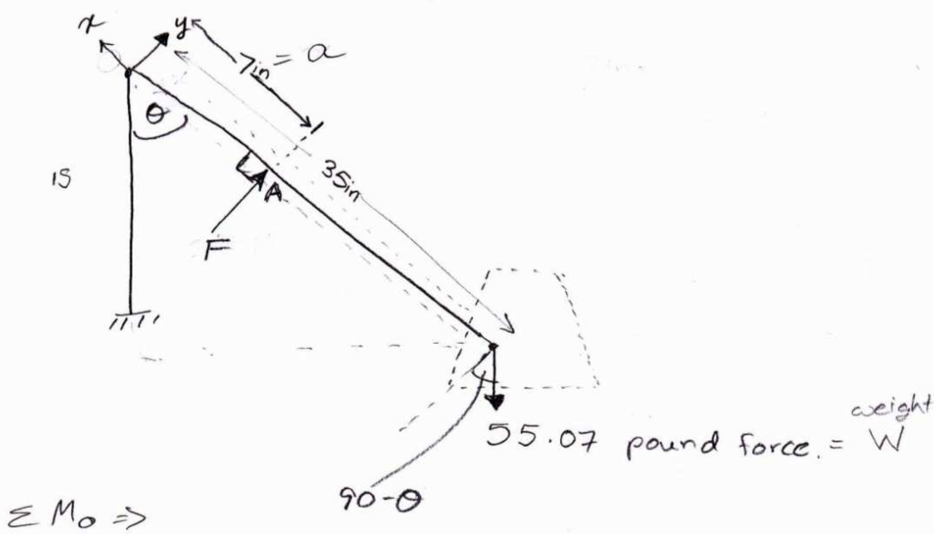
TABLE 21
Carbon Fiber > Constants

Structural	
Young's Modulus	3.4e+007 psi
Poisson's Ratio	0.36
Density	6.5e-002 lbm/in³
Thermal Expansion	5.2222e-006 1/°F
Tensile Yield Strength	1.3489e+005 psi
Compressive Yield Strength	1.3489e+005 psi
Tensile Ultimate Strength	6.4e+005 psi
Compressive Ultimate Strength	0. psi

Appendix VI

Untitled

j



$\Sigma M_O \Rightarrow$

$$a \times F = W\cos(90-\theta) \times 35$$

$$F = \frac{W\cos(90-\theta) \times 35}{a} \quad \text{—— (1)}$$

* note: W & a are known.

$\Sigma F_y \Rightarrow$

$$y + F = W\cos(90-\theta)$$

$$y = W\cos(90-\theta) - F \quad \text{—— (2)}$$

OR

$\Sigma M_A \Rightarrow$

$$a \times y = (35-a) \times W\cos(90-\theta)$$

$$y = \frac{(35-a) \times W\cos(90-\theta)}{a} \quad \text{—— (3)}$$

$$x = W\sin(90-\theta) \quad \text{—— (4)}$$

Starting position = $\theta = 50°$

Carrying Position = $\theta = 70°$

Dumping Position $\theta = 100°$

Page 1

Appendix VII

Force Analysis Matlab Code

```
%Givantha Iddawela
%Nasa - Corp 2
%Digger force analysis
clear all
clc
w=55; %bucket weight in pounds
a=7; %distance to actuator in inches
syms x y F b
theta=0:110;

y=((35-a)*w*cosd(90-theta))/a;
x=w*sind(90-theta);
F= w*cos(90-70)*35/b;

%plot(theta,y)
%xlabel('theta(degrees)')
%ylabel('y(pounds)')



% plot(theta,x)
% xlabel('theta(degrees)')
% ylabel('x(pounds)')

ezplot(F,[0,35])
xlabel('Distance(b) from hinge (inches)')
ylabel('Actuator Force(F) (pounds)')
```

Appendix VIII

VIEW MORE/LARGER IMAGES
SHARE CUSTOMER IMAGES

Northern Industrial Linear Actuator — 12 Volt, 11 13/16in. stroke

Item# 125012

Only $159.99

Perfect for raising and lowering lawn and garden tractor and ATV attachments, along with hoods, trunks, tonneau covers, tailgates, truck cover and more! CE/UL-approved motor.

Overall Rating ★★★★☆ **4.3** / **5**

SPECS

KEY PRODUCT SPECS

Load Capacity (lbs.)	1,350

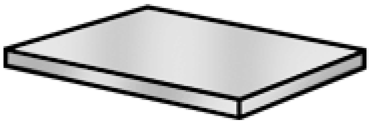
ADDITIONAL SPECS

- 8mm per second travel speed
- Center-to-center closed pin distance is 17 5/16in. (440mm)

Appendix IX

Plastics

This product matches all of your selections.



Part Number: 9910T17 — $38.45 Each

Material	Garolite
Garolite Material	Grade G-10 Garolite
Backing	Plain Back
Shape	Sheets, Bars, Strips, and Cubes
Sheets, Bars, Strips, and Cubes Type	Rectangular Sheet
Thickness	1/16"
Thickness Tolerance	±.0008"
Length	36"
Length Tolerance	±1"
Width	24"
Width Tolerance	±1"
Flatness Tolerance	Not Rated
Opaque	Yellow-Green
Operating Temperature Range	Up to +285° F
Tensile Strength	Excellent
Impact Strength	Excellent
Tolerance	Standard
Hardness	Rockwell M: 110
Specifications Met	Military Specifications (MIL)
MIL Specification	MIL-I-24768

Appendix X

Dual 5V + 3.3V Switching Voltage Regulator

View larger image

We developed this dual 5V and 3.3V Switching Voltage Regulator board to provide efficient power for many accessories. Unlike inefficient linear voltage regulators (which dissipate power via heat), this switching regulator is battery friendly!

This device has 2 power input terminals. They are dioed-or'd together, so that only the highest voltage is powering the device. In this configuration a device can be powered by somehting like a 9.6V battery, and when the battery gets low, a 12V AC/DC adpater can be attached, so that the battery can be unplugged and charged without interupting the devices under power.

This device has 2 output terminals. They are rated at 2.5A each, and can be ordered as two 5V outputs, two 3.3V outputs, or a 5V and a 3.3V output on the same board. You must specify the configuration you desire below.

These are NOT isolated from each other because they share a common ground.

Please note that due to the customization of this product, it could require 3 additional days for order processing.

FYI: Switching regulators typically operate at 85% efficiency, whereas linear regulators typically operate at 40% efficiency.

Appendix XI

CMUCam2+ Robot Camera

View larger image

The latest version of the CMUcam2. Acroname and CMU have partnered together to develop the next wave in low cost image processing.

The logic chips and OV6620 camera module are mounted on a single board. It comes assembled, reducing the time required to add vision to your robotics projects.

The CMUcam2+ consists of a SX52 microcontroller interfaced with a 0V6620 Omnivision CMOS camera that allows high-level data to be extracted from the camera's streaming video. Its primary function is to track and monitor highly contrasting color regions.

It can also detect motion, provide color statistics, and transmit image information to a computer for additional processing. We currently ship the camera with version 1.01 of the firmware.

Appendix XII

Maxbotix MaxSonar-EZ3 Sonar Sensor

View larger image

The MaxSonar®-EZ3™ is one of the easiest to use ultrasonic range finders available.

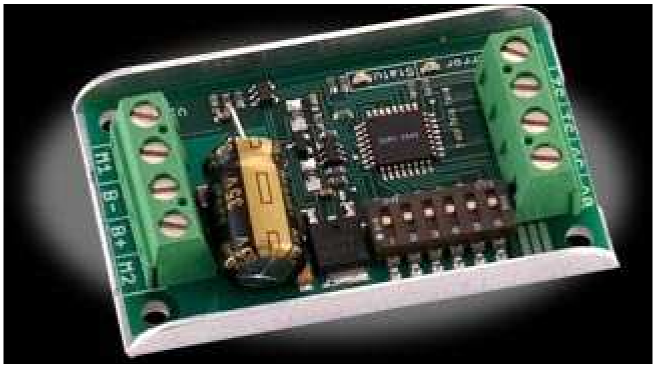
The MaxSonar®-EZ3™ offers very short to long-range detection and ranging, in an incredibly small package, with ultra low power consumption. The MaxSonar®-EZ3™ detects objects from 0-inches, even objects pressing against the front sensor face, to 254-inches (6.45 meters), and provides sonar range information from 6-inches to 254 inches, with 1-inch resolution. Objects between 0-inches and 6-inches range as 6-inches.

Traditional dual-sensor piezoelectric ultrasonic range-finders have many subtle peculiarities. These include the inability to detect very close objects, a central up-close blind spot between the transducers, and very wide-angle beams (some more than 90 degrees!). In addition, if a piezoelectric sensor has a narrow beam, it will, in general, have much shorter detection zones, especially for small objects.

The MaxSonar®-EZ3™ overcomes these problems and more by utilizing a single 42KHz ultrasonic transducer coupled with a continuously variable high gain amplifier. The MaxSonar®-EZ3™ is half the size of competing sensors, while the 2mA nominal current draw is the lowest of any range sensor.

The MaxSonar®-EZ3™ is very easy to use. It has holes for easy mounting, and provides the range directly, using three user interfaces. The pulse width output is similar to other low cost ultrasonic range finders. The analog voltage output provides 10mV per inch output and always holds the latest range reading. In addition, after each range event the digital output sends asynchronous serial data in an RS232 format, except voltages are 0-5V.

Appendix XIII



SyRen 10A Regenerative Motor Driver
rt# 0-SYREN10

$49.99

QTY 1

Stock Status: In Stock

No reviews yet.

The SyRen motor driver is one of the most versatile, efficient and easy to use motor drivers on the market. It is suitable for medium powered robots - up to 30lbs in combat or 100lbs for general purpose robotics.

Out of the box, the SyRen 10 can supply a single DC brushed motor with up to 10A continuously. Peak currents of 15A are achievable for a few seconds.

Overcurrent and thermal protection means you'll never have to worry about killing the driver with accidental stalls or by hooking up too big a motor.

With just one SyRen driver you can control a motor with: analog voltage, radio control, serial and packetized serial. You can build many different robots of increasing complexity for years to come with a SyRen. Owning two SyRens allows you to build differential drive (tank style) robots because they can work in tandem with built in mixing.

The operating mode is set with the onboard DIP switches so there are no jumpers to lose. The SyRen features screw terminal connectors - making it possible for you to build a robot without even soldering.

SyRen is the first synchronous regenerative motor driver in its class. The regenerative topology means that your batteries get recharged whenever you command your robot to slow down or reverse. SyRen also allows you to make very fast stops and reverses - giving your robot a quick and nimble edge.

SyRen has a built in 5V BEC that can provide power to a microcontroller or R/C receiver. The lithium cutoff mode allows SyRen to operate safely with lithium ion and lithium polymer battery packs - the highest energy density batteries available.

SyRen's transistors are switched at ultrasonic speeds (32kHz), meaning no one will be able to hear your robot ninja army approaching.

Specifications

Voltage range	6-24V input nominal, 30V max
Current handling	10A continuous, 15A peak
Size	1.4" x 2.25" x 0.55"
Weight	0.9 oz (26g)
Input types	Analog (i.e. potentiometer), R/C input (radio receiver-no input cable included), or serial (RS-232)
Number of channels	1
Synchronous regenerative drive	yes
Ultra-sonic switching frequency	yes
Thermal and overcurrent protection	yes
Lithium protection mode	Yes

Appendix XIV

IMX-1 Invertable RC Tank Mixer

Part# RL-IMX1

(average customer rating)

$39.95

QTY 1

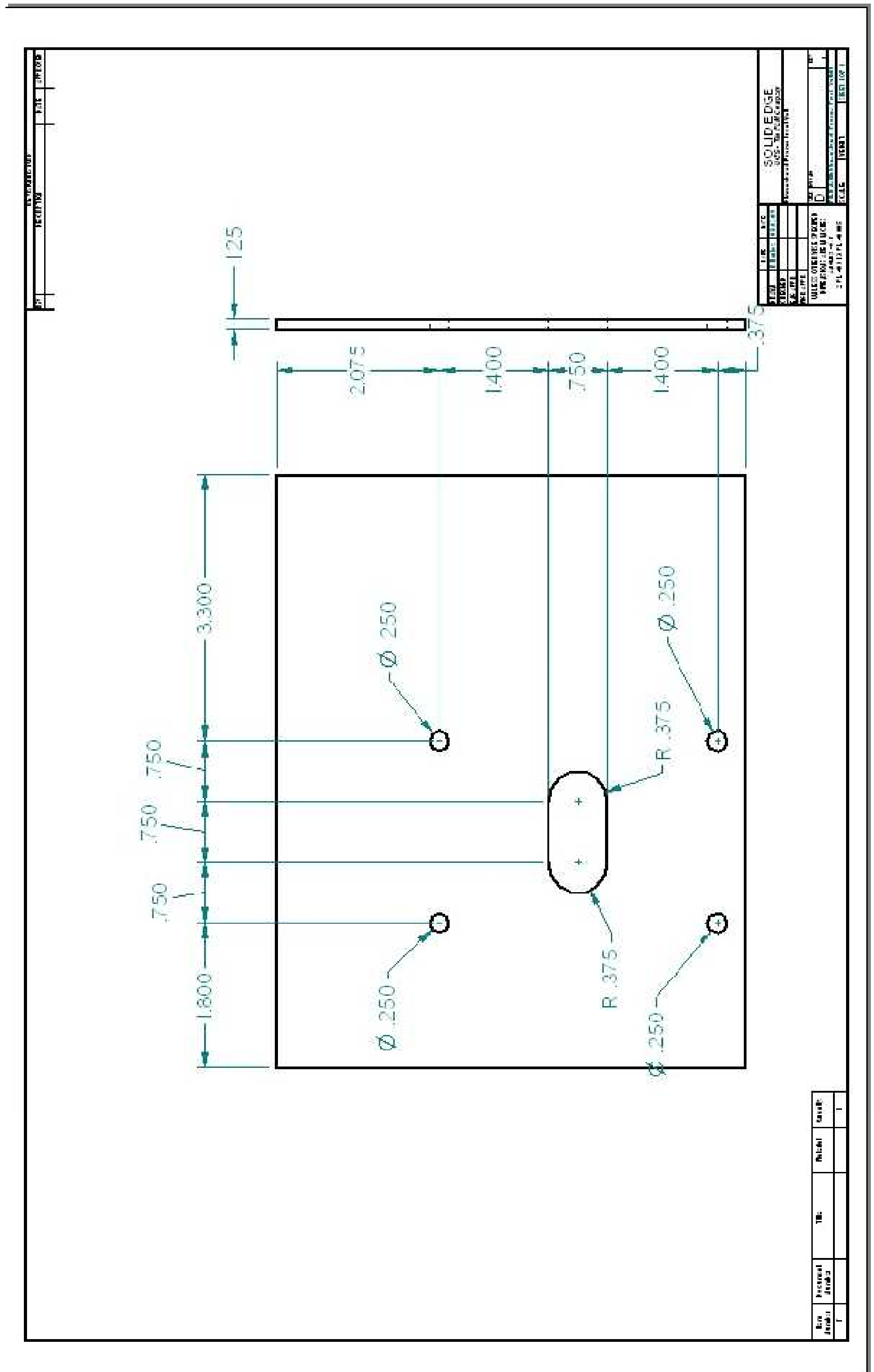
Stock Status: In Stock

This RC mixer from RobotLogic is specifically designed to allow driving a tank steering robot with a single control stick. An invert feature controlled by an RC channel allows driving the robot inverted. Even non-invertable robots can benefit from the invert feature because inverted controls will allow the robot to be easily driven backwards, leading with the rear.

Selectable pass-through mode allows using a tank mixer built in to a speed controller, such an a Vantec, but still retaining the invert feature.

IMX-1 features include:
* Use a third RC channel to invert your forward-backward Y channel
* Failsafe on signal loss
* Tank mixing algorithm designed to give improved robot control over standard Elevon mixing
* Selectable tank mixing or pass-through behavior
* No need for line boosters when used with IFI speed controllers
* An LED provides feedback for proper operation
* Length: 1.9" Width: 1.25" Height: slightly taller than a servo connector
* Remote LED option allows you to mount the LED to the outside of your bot.

Appendix XV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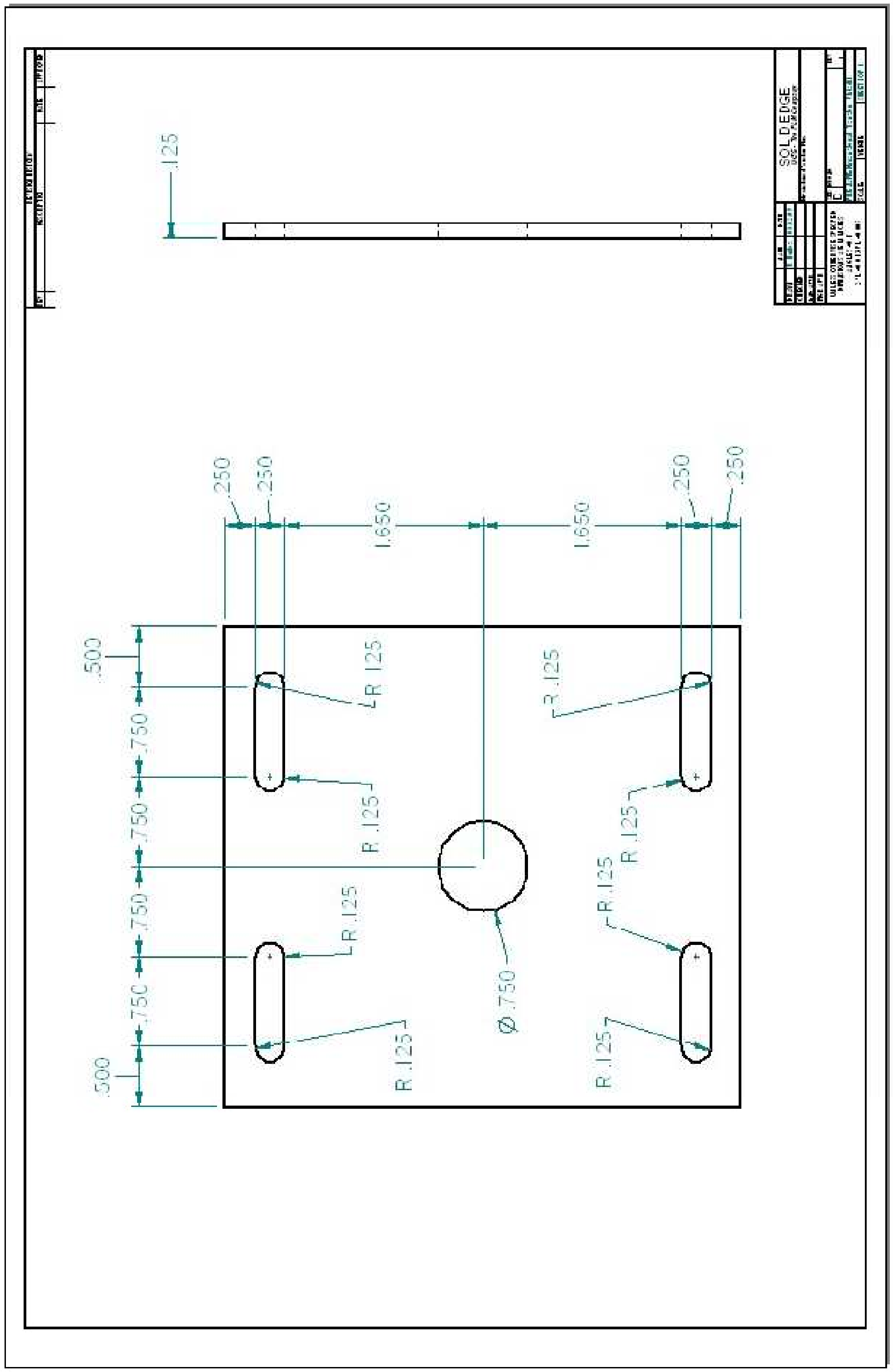
R .375
R .375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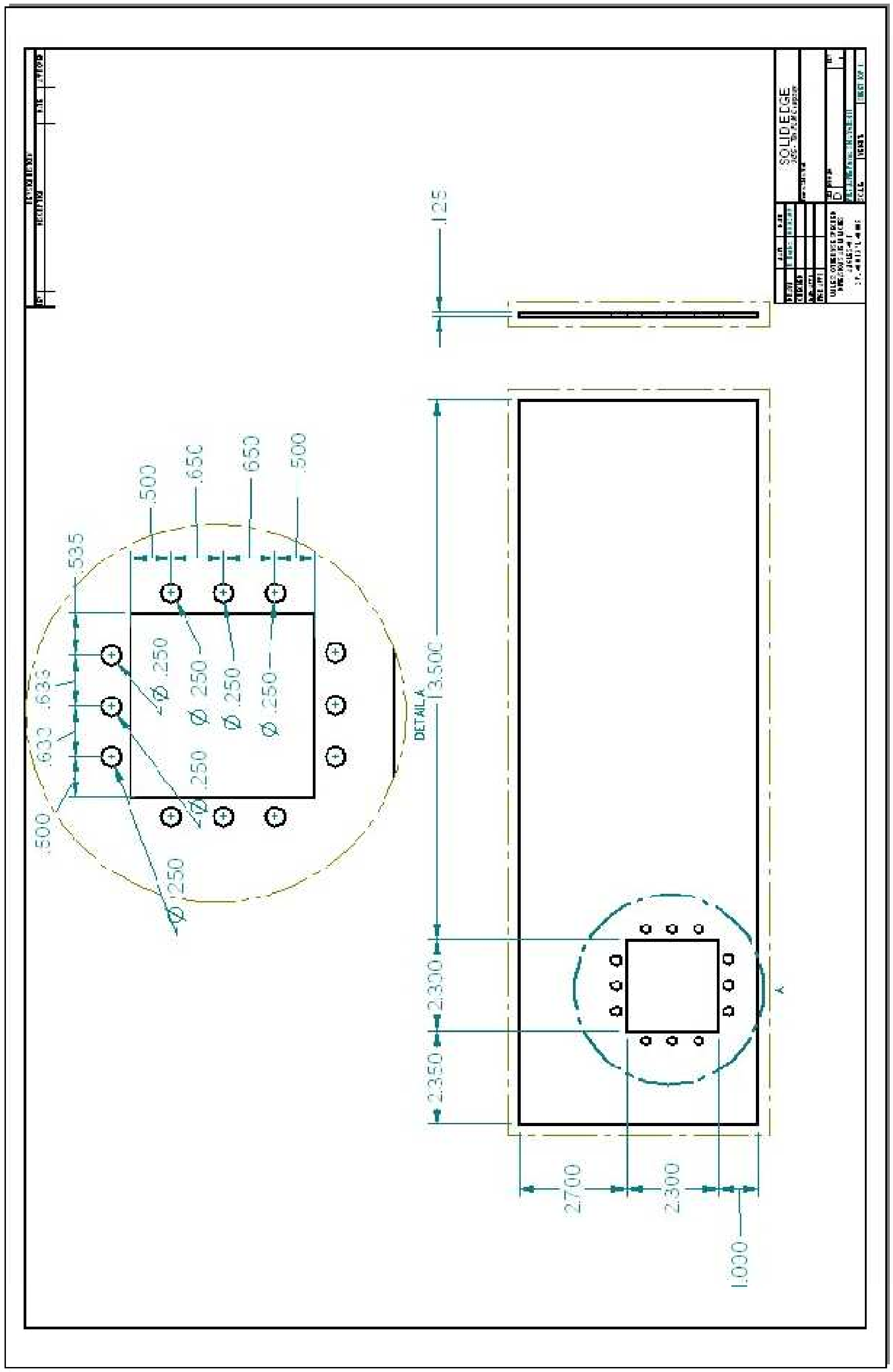
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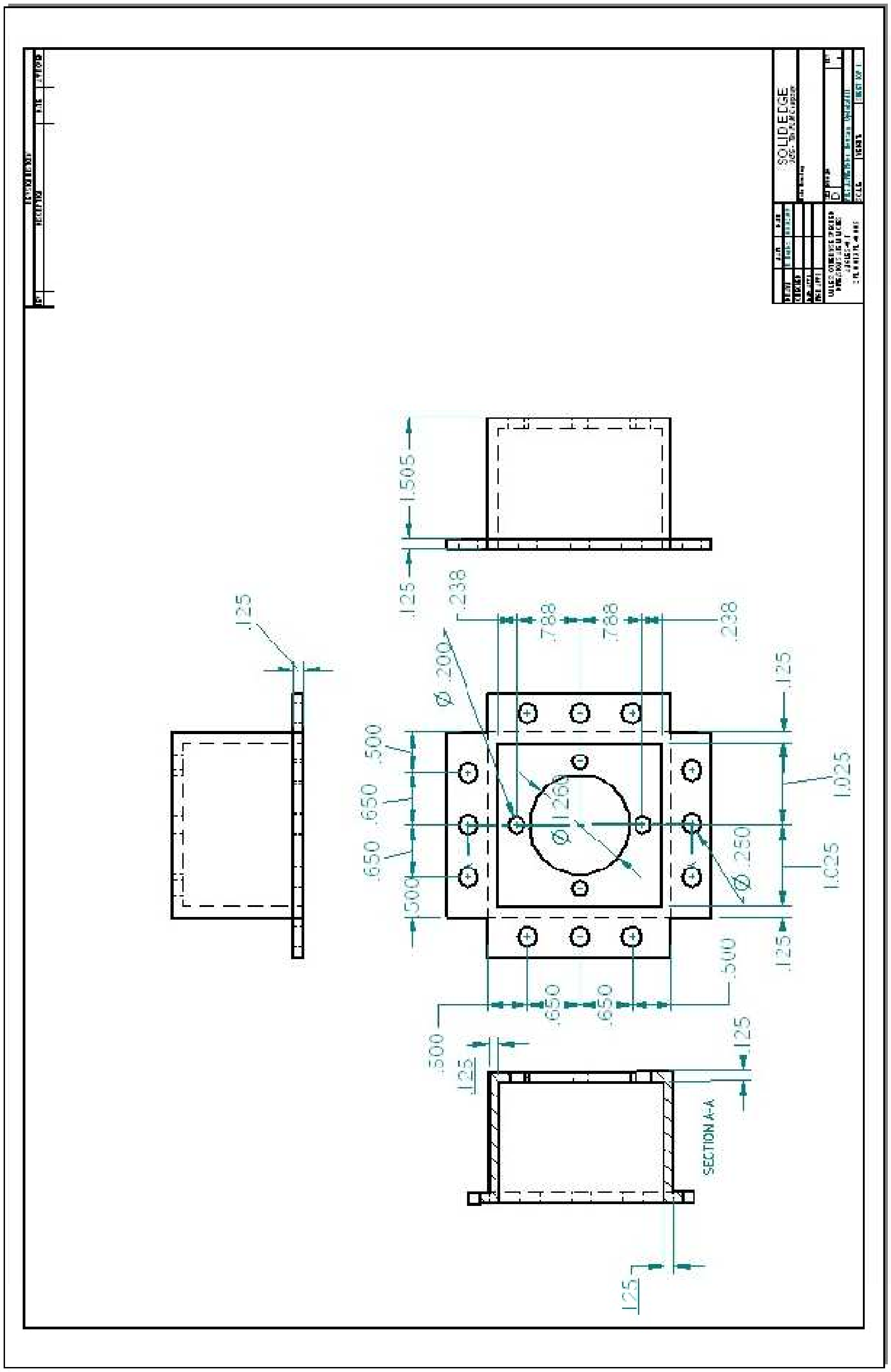
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Appendix XVI

You Know It's Right... When It's Accurate
PLASTICS, INC

8667K SERIES

Accurate Plastics, Inc.
18 Morris Place
Yonkers, New York 10705-1929
Phone (914) 476-0700
Fax (914) 476-0527

MATERIAL SAFETY DATA SHEET

PRODUCT NAME:	**Acculam™ Epoxyglas (NEMA Grades G10, G11, FR4, FR5)**

SECTION 1 — **NAME & HAZARD SUMMARY**

MANUFACTURER'S NAME:	Accurate Plastics, Inc.
ADDRESS:	18 Morris Place Yonkers, New York 10705-1929
EMERGENCY PHONE NUMBER:	914-476-0700
DATE PREPARED:	11/30/01

SECTION 2 — **HAZARDOUS INGREDIENTS / IDENTITY INFORMATION**

No OSHA Hazardous Ingredients
Hazardous Mixtures of other Liquids, Solids or Gases %
NOT APPLICABLE

TLV	ACGIH

Ingredients not precisely identified are proprietary or non hazardous. All ingredients appear on the EPA TSCA Inventory. Values are not product specifications.
gt = greater than, lt = less than, ca = approximately

Hazard summary (as defined by OSHA Communications Standard, 29 CFR 1910.1200) :

PHYSICAL HAZARDS:	If material is sawed or machined, dust can be a hazard.
HEALTH HAZARDS:	Dust inhalation (TLV)
PRODUCT DESCRIPTION:	Product is composed of a thermoplastic polymer modified epoxy resin and E glass cloth. It may contain halogenated organic compounds as a flame retardant, i.e. tetrabromobisphenol A derivatives.

SECTION 3 — **PHYSICAL DATA**

MELTING POINT:	Not determined
BOILING POINT :	Not applicable
VAPOR PRESSURE (mmhg at 20° C) :	Not applicable
VAPOR DENSITY (air = 1) :	Not applicable
SOLUBILITY IN WATER :	Insoluble
PH :	Not applicable
SPECIFIC GRAVITY (H2O=0) (typical) :	1.6
% VOLATILE BY WEIGHT :	< 0.05%
APPEARANCE AND ODOR :	Odorless solid

MATERIAL SAFETY DATA SHEET (continued) **Acculam™ Epoxyglas (NEMA Grades G10, G11, FR4, FR5)**

SECTION 4	**FIRE AND EXPLOSION HAZARD DATA**

FLASH POINT (AND METHOD) : Not applicable
AUTO IGNITION TEMPERATURE : Not applicable
FLAMMABLE LIMITS (STP) : Not applicable
EXTINGUISHING MEDIA : Water, foam, carbon dioxide
SPECIAL FIRE FIGHTING PROTECTIVE EQUIPMENT :
Self-contained breathing apparatus with full face piece and protective clothing.
UNUSUAL FIRE AND EXPLOSION HAZARDS:
Dust from dry fabrication may be explosive if mixed with air in critical proportions in the presence of ignition source.

SECTION 5	**REACTIVITY DATA**
STABILITY :	Stable under normal conditions. (Avoid heating above 450° F.)
INCOMPATIBILITY (MATERIALS TO AVOID) :	Exposure to strong acids or bases will cause surface damage.
HAZARDOUS DECOMPOSITION PRODUCTS :	Combustion products : Small quantities of HCN, CO, CO_2, approximately same as wood
HAZARDOUS POLYMERIZATION :	Will not occur. (Avoid heating above 450° F.)

SECTION 6	**HEALTH HAZARD ASSESSMENT**
GENERAL :	The health hazard assessment is based on an evaluation of the chemical composition together with information from a search of the scientific literature and other commercial sources.
INGESTION :	None
EYE CONTACT :	No irritation is likely to develop following contact with human eyes.
SKIN CONTACT :	No irritation is likely to develop following contact with human skin.
SKIN ABSORPTION :	This product will probably not be absorbed through human skin.
INHALATION :	May occur when sawing or machining.
OTHER EFFECTS OF OVEREXPOSURE :	Dust can cause irritation to the eyes, nose, throat, and lungs. Prolonged inhalation of dust can produce lung disease.
FIRST AID PROCEDURES :	Remove to fresh air.
SKIN :	Wash material off the skin with plenty of soap and water. If redness, itching, or a burning sensation develops, get medical attention. For thermal burns, cool quickly with water and get medical attention Do not peel off solidified material.

EYES : Immediately flush with plenty of water. After initial flushing, remove any contact lenses and continue flushing for at least 15 minutes. If redness, itching, or a burning sensation develops, have eyes examined and treated by medical personnel.

INGESTION : Give one or two glasses of water to drink. If gastrointestinal symptoms develop, consult medical personnel. (Never give anything by mouth to an unconscious person.)

NOTE TO PHYSICIAN : Prolonged eye irritation may occur from pieces of debris sticking to the eyeball or eyelids.

SECTION 7 PRECAUTIONS FOR SAFE HANDLING AND USE

STEPS TO BE TAKEN IN CASE MATERIAL IS SPILLED: None - solid material
DISPOSAL METHOD : Must comply with federal, state and local laws.
CONTAINER DISPOSAL : Puncture or otherwise destroy packaging material before disposal

SECTION 8 CONTROL MEASURES

TLV® OR SUGGESTED CONTROL VALUE :
No TLV is assigned to this mixture. Minimize exposure to dust that may be generated from processing operations such as sawing or machining, in accordance with good hygiene practice.
API recommends that particle concentration be controlled to within the TLV level of 10mg / m3 or nuisance particles. The OSHA PEL for nuisance particles is 15 mg /m3.
VENTILATION :
Remove decomposition fumes with local exhaust if overheating occurs during processing (above 150°C).
RESPIRATORY PROTECTION (SPECIFY TYPE) :
If needed, use MSHA-NIOSH approved respirator for dusts, mists, and fumes whose TLV is greater than 0.05 mg/m3.
PROTECTIVE CLOTHING :
Use work gloves to avoid cuts from sharp edges. Protect from thermal effects when handling heated material.
EYE PROTECTION :
Safety glasses with side shields.
OTHER PROTECTIVE EQUIPMENT :
Eyewash station in work area.

SECTION 9 SPECIAL PRECAUTIONS OR OTHER COMMENTS

Use dust collection for sawing or machining.