FINAL DESIGN REPORT

LUNAR EXCAVATOR

NASA – CORP 1

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1.0 ABSTRACT

The objective of this design project was to design and develop a second generation lunar excavator. The purpose of the excavator is to excavate lunar regolith in order to extract oxygen and other elements that are vital to sustain life in a lunar environment. The three main design challenges that the second generation excavator intends to solve are:

1. The excavator must interface with the KSC interface plate.
2. Design the excavator with materials that are able withstand the lunar environment.
3. Incorporate a vibratory bit in the new design of the excavator.

When designing the new excavator the design specifications and constraints from the first excavator were kept in mind. The excavator mass must be less than 100 kilograms, power consumption must be no more than 100 watts, and must be able to excavate regolith at a rate of 300 kilograms per hour.

The main design issue facing the excavator is the incorporation of the vibratory bit. The purpose of the bit is to break up/loosen the regolith grains, which allows for easier excavation. Initial concepts were composed of a square tube bit with a simple voice coil to provide the forced vibration. However, after further design concepts were developed a square tube bit with a translating shovelhead design was ultimately decided upon.

To begin, the first generation excavator was tested in order to find the main problems or issues that the original excavator was facing. The main issues from the first excavator were the interface height/angle and the inability to scoop or excavate dirt/regolith.

In order to design for the lunar environment, five main areas were researched. They were the lunar environment and thermal conditions, operable materials in the lunar conditions, motors/actuators operable in lunar conditions, and bearings and hardware operable in lunar conditions. From thorough research appropriate components were determined to be applied to feasible concepts that were developed.

Table of Contents

List of Figures

List of Tables

2.0 INTRODUCTION

This project was completed under the purview of Auburn University and NASA – KSC. The supervising faculty member at Auburn University was Dr. David Beale. The sponsor contact was Mr. Rob Mueller, Surface Systems Lead Engineer, Advanced Systems Division.

This report details our efforts to design a "second generation" lunar excavator. NASA is very interested in the prospect of lunar excavation for the future. Not only will this process be for terraforming the lunar surface, but the harvested lunar regolith will be used for the extraction of oxygen from the abundant silicon oxide, aluminum oxide, and titanium oxide that exist in the lunar soil. The proposed design will be attached, via KSC interfacing plate, to a NASA Scout Rover used to explore the lunar surface. Due to the nature and cost of space missions, NASA wants a low cost excavator — low in weight and power requirements — that removes regolith at a rate of 300 kilograms per hour. The design herein utilizes the motion of the rover itself to push a vibrating translational blade. The regolith will be driven up the blade where it falls onto a conveyor that dumps the soil into a storage bin.

3.0 DESIGN SPECIFICATIONS AND CONSTRAINTS

3.1 Design Specifications

The design objective is to design a "second generation" lunar regolith excavator, based upon the platform from the first generation concept.

Based upon testing in the USDA soil bin, propose design modifications at the concepts presentation to improve performance. These modifications should be presented via Solid Edge drawings. The sponsor desired the incorporation of a vibratory bit. The bit should allow for variable frequency, and isolate the bit vibration from the rest of the excavator. Test using a regolith substitute that is expected to have similar characteristics as the lunar regolith. The “first generation” prototype was unable to achieve the low angles to the ground that were desired during testing. Newly design or redesign whatever is necessary in order to achieve the necessary angles, and be mindful that the excavator will need to fit onto the KSC interfacing plate.

Review past NASA literature and other literature regarding design engineering issues that need to be eventually addressed when designing and building lunar machinery. These issues should include mechanical components, heat transfer, material selection, the lunar environment, power systems, motors, etc. It is not necessary for the "second generation" excavator to survive on the moon, but an awareness of these issues should guide the final design.

Sufficiently maintain and develop a Solid Edge drawing database and design documentation system, to facilitate knowledge transfer and sustaining corporate memory.

3.2 Design Constraints

The specific constraints for the second-generation excavator contain the constraints followed by the first generation excavator, as well as new specifications and constraints as stated in the second-generation project description. The constraints to be followed from the first generation excavator mentioned above are as follows:

1. Mass must be less than 100 kilograms, with overall packaging, and mass kept to a minimum to reduce cost and space in transportation to the moon.
2. The maximum power consumption of the excavator must not exceed 100 watts. The excavator will draw DC power from the lunar rover.
3. The excavator should be able to excavate regolith at a rate no less than 300 kilograms per hour. Also, it should be able to excavate regolith to a depth of 30 centimeters from the surface.

The second-generation excavator will dump the regolith in a storage bin attached to the lunar rover, in the same fashion as the first generation excavator. Also, since the rover is a multi-purpose unit on the moon all mating and interfacing between the rover and the excavator was designed to be installed and removed with as much ease as possible. The design issues facing the second generation excavator are as follows:

1. Incorporate an adjustable and vibratory bit into the new design. The vibration must be isolated from the rest of the excavator and should operate at a variable frequency.
2. The excavator should be engineered so as to be fit for the lunar environment. Issues to be addressed are abrasion of regolith, extreme temperature/thermal considerations, and operation in a vacuum, etc.
3. The digging equipment on the excavator must be able to operate for 3 years, with scheduled maintenance on the excavator every year. Also, where appropriate all components should be sealed or have a dust cover to reduce abrasions from the lunar environment.

In order to reduce cost, when the excavator is built for testing on earth, the design will include components that may not be suitable for the lunar environment; however, the lunar appropriate counterpart will be suggested to replace the component for lunar testing.

4.0 CONCEPT PRESENTATION

The second generation excavator is designed to be just that – an updated design based upon the platform of the first generation excavator. The first design step was to solve the issues and underlying problems that the first generation excavator faced.

4.1 Interface

The major problem found with the first generation excavator was the interface height and digging angle. The first generation excavator, once mounted onto the John Deere Gator (earth replacement of the lunar rover used for testing), had an unadjustable conveyor height of approximately 40 inches. This height caused the excavator, when in contact with the ground, to have a steep angle, greatly hindering excavation. When testing the first generation excavator the steep angle caused the bit to dig into the ground rather than "scrape" the dirt into the conveyor. This action of the bit caused a pole-vault-like motion of the excavator and the Gator.

In order to solve this problem an exact rover height of 19 inches was determined, thus setting a datum point to be designed around. Even though a 19 inch datum was used, a vertically adjustable interface was desired. This is achieved by manually removing/inserting pins on a track to hold the conveyor at different heights. The interface-mounting bracket redesign allowed the excavator to be dropped to a reasonable height, which solved the steep angle problem while still maintaining vertical adjustability. The new interface mount still fits all the specifications for the KSC interface plate on the lunar rover. The new interface can be seen in Figure 4.1-1. The old interface is shown in Figure 4.1-2.

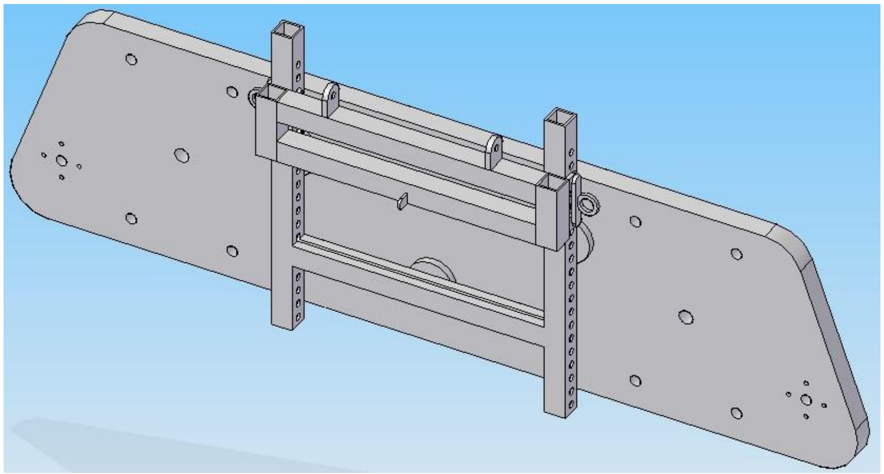

Figure 4.1-1 New Mounting Interface

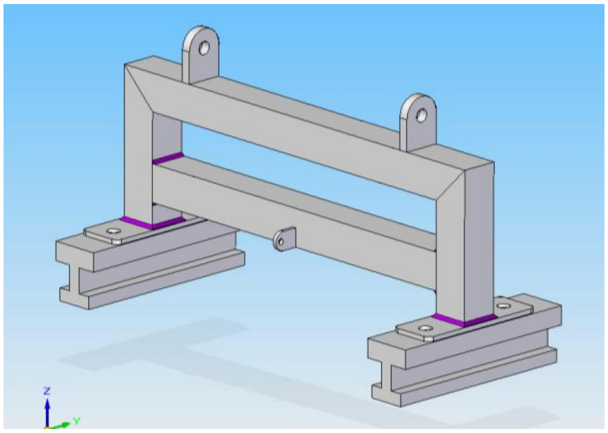

Figure 4.1-2 Old Mounting Interface

4.2 Frame and Support Members

Another problem that needed to be solved from the first generation excavator was that the support member and frame were scraping the ground, adding to the "digging in" effect described above. To solve this problem the support member was moved to the top of the frame. In moving the member to the top it solved two problems that needed to be addressed. First it solved the problem of hitting or dragging on the ground, secondly it provided a mounting point for the bit actuator which will be described later. The support member was designed in such a way to give the front end of the frame the structural support that it needed and also high enough above the conveyor tabs so as not to cause any clearance or collision issues.

As mentioned above the frame hitting the ground also contributed to the inability of the excavator to actually excavate the dirt during testing. Depending upon the angle of the excavator, it may or may not make contact with the ground. When the frame is actually in contact with the ground the sharp points at the end of the frame rails were the cause of the excavator 'digging in' or getting hung up. After research it was discovered that it may not be possible to completely prevent the frame rails from contacting the ground, but in order to alleviate some of the problem the frame rails were causing, the ends have been rounded off and boxed. By rounding off the ends, the frame can glide or skid across the regolith rather than dig into it. Boxing the ends prevents regolith from building up in the frame rails, hopefully prolonging the life of the excavator frame. The proposed idea for the frame is shown in Figure 4.2-1.

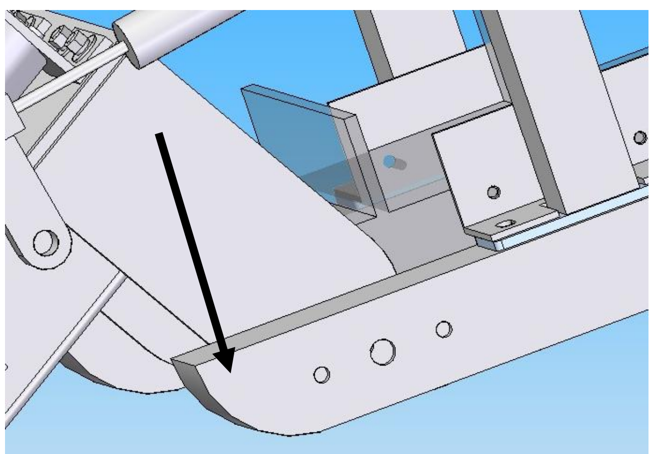

Figure 4.2-1 Frame Support Ends

4.3 Bit Adjustment

For the first generation excavator it was found that the optimum angle for excavation was a fixed 35 degrees. When designing the second generation excavator, the addition of an adjustable angle bit was incorporated into the design. The new design allows the bit to pivot about a common axis. The adjustable bit design, shown in Figure 4.3-1, is comprised of two supports that are attached to the frame which allow bit to pivot. The two supports are also welded in a fixed position to the bit itself. One end of a linkage is then attached (free to pivot) to the side of the bit, and the other is attached to a linear power screw. The power screw is then attached to a cross support above the frame and conveyor. This assembly allows the bit angle to change independently of the frame angle so that when the excavator is in operation, the bit can be adjusted so the angle can remain at 35 degrees (or another angle justified by testing).

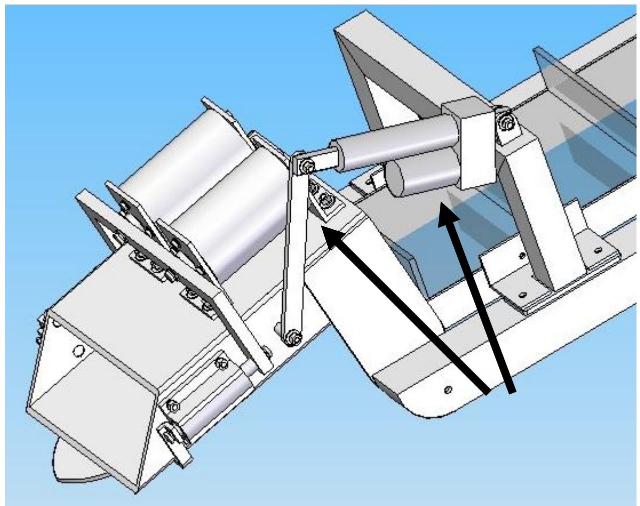

Figure 4.3-1 Bit Adjustability

4.4 Bit Vibration

An important design aspect of the bit is the ability to vibrate to aid in excavation. The initial idea for the bit vibration was to use an offset rotating mass as the vibration source. For this design, the bit would resemble a similar shape to the first generation prototype; however, the bit is now "boxed" or enclosed. With an enclosed bit the vibration source could be mounted in a lateral or transverse direction on the top of the bit. After further development, it was decided upon to use a separate vibrating spade tip. The main body of the bit would continue to remain boxed; however, a shovel type head is mounted on linear bearings on each side of the boxed portion of the bit. Using voice coil linear actuators, the shovelhead portion of the bit translates/vibrates from forward to back. From [3] it was determined the best way to reduce soil cohesion and reduce soil draft force is to vibrate at a frequency of 60 hertz and a force of approximately 165 newtons. The power consumption required to provide the amount of force necessary for our excavation design, is approximately 80 watts for both actuators. By shortening the boxed portion of the bit to an overall length of 11.5 inches (compared to 17.5 inches), it created less distance for the regolith to travel between the ground and the conveyor. The goal of the shortened boxed portion is to have an increased rate and easier excavation of the regolith. The proposed vibratory bit is shown in Figures 4.4-1 through 4.4-5.

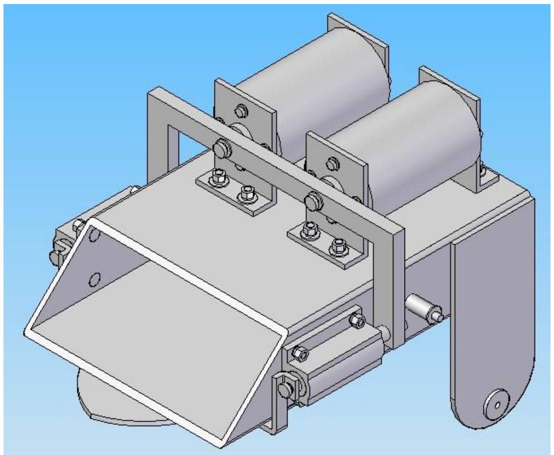

Figure 4.4-1 Vibratory Bit, View 1

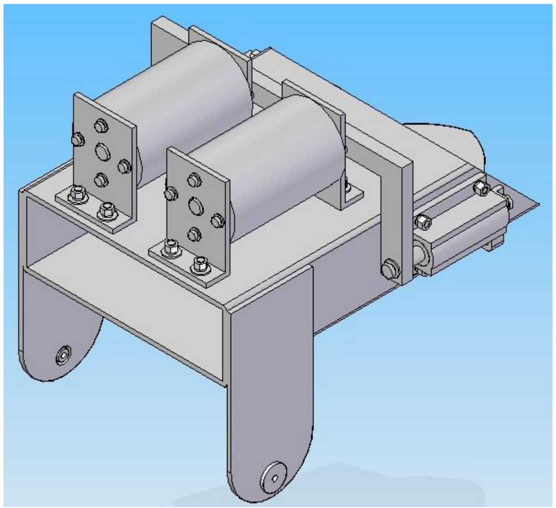

Figure 4.4-2 Vibratory Bit, View 2

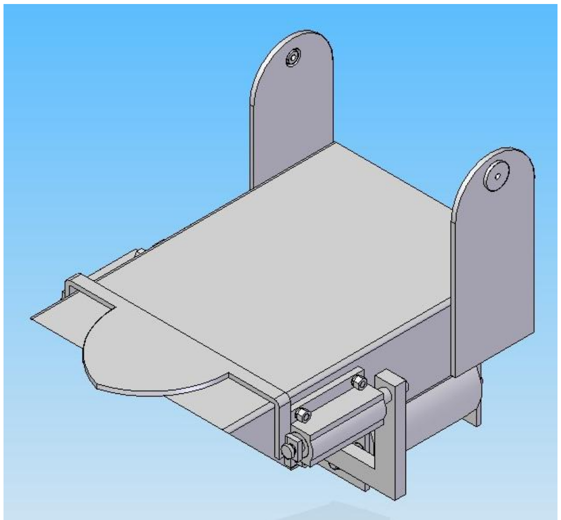

Figure 4.4-3 Vibratory Bit, View 3

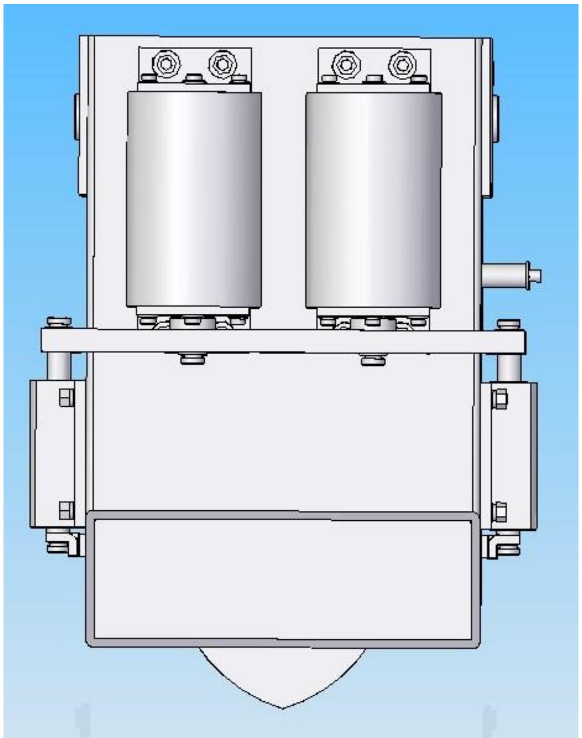

Figure 4.4-4 Vibratory Bit, Top View

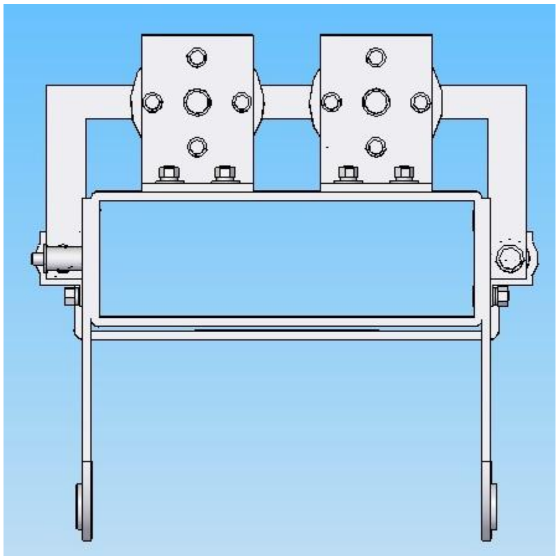

Figure 4.4-5   Vibratory Bit, Back View

4.5 Material Selection

The structural components of the excavator will be made of 1199-O Aluminum. This includes the frame rails, conveyor frame and brackets, and the rover interface mount. 1199-O Aluminum is typically used in frame materials of spacecraft [5]. Aluminum is the most common conventional structural material [8]. Its good strength-to-weight ratio, ready availability, and ease of fabrication make it a good choice. The rubber conveyor belt is going to be a problem at both low and high temperatures, so we propose to use Kapton tape instead. Kapton is used in such applications as outer layering in thermal blankets [8]. It should offer better performance at high temperatures than rubber. The materials for the bit will be made of a 300 series Stainless Steel (most likely 304). Stainless steel is typically used in applications requiring higher strength and/or higher temperature resistance [8]. Stainless is preferred because it is non magnetic, and it eliminates the issue of rust. Also, stainless steel exhibits the toughness needed for the parts most directly exposed to the highly abrasive regolith. Finally, in low temperature applications, stainless steel's low ductile-to-brittle (DBT) temperature becomes important. For the mechanical components, we have chosen AISI 440C Stainless Steel, a material with high wear resistance commonly used in space mechanism bearings [5].

The materials detailed above are the materials intended for the purposes of a space qualified excavator. Comparable substitutes have been chosen for the terrestrial prototype. 6061 Aluminum will replace the 1199-O structural components. It is reasonably the same weight, easy to machine, and readily available. The conveyor belt will remain in its as-received condition (rubber). We will use A-34 Carbon Steel for the tray, 4140 Steel for the spade tip and blade supports, and general steel for nuts, bolts, etc. These steels will replace the 304 Stainless Steel. They are available and comparable in weight and strength (to enough of an extent). The mechanical components will remain AISI 440C Stainless Steel when possible.

4.6 Regolith Removal

A simple idea or concept was desired to detail removal of the lunar regolith from the collecting bin. Since much of our system motion is derived from power screws and linear actuators, we propose to use another to empty the bin.

We will actually use a slightly smaller conveyor than all of all drawings indicate. The frame sizing will remain the same. This will create a small opening at the top of the conveyor through which regolith will fall off the conveyor and into a collection bin. A simplified sketch showing the regolith being conveyed and deposited is shown in Figure 4.6-1. This bin will be slid out of the way of critical components, such as the power screw. Then a linear actuator will push up on one side of the bin, much like the action of a dump truck, spilling the regolith out and moving it closer to its destination. Note that we mention here that when building the lunar device, a shorter conveyor will be used. Throughout the report, we will treat the conveyor as the longer one we currently have. All drawings indicate the longer of the two will be used. The reason for specifying the shorter and drawing/using the longer is that we already have the longer one and will be using it for testing purposes. No special bin collection method will be needed during our testing phase.

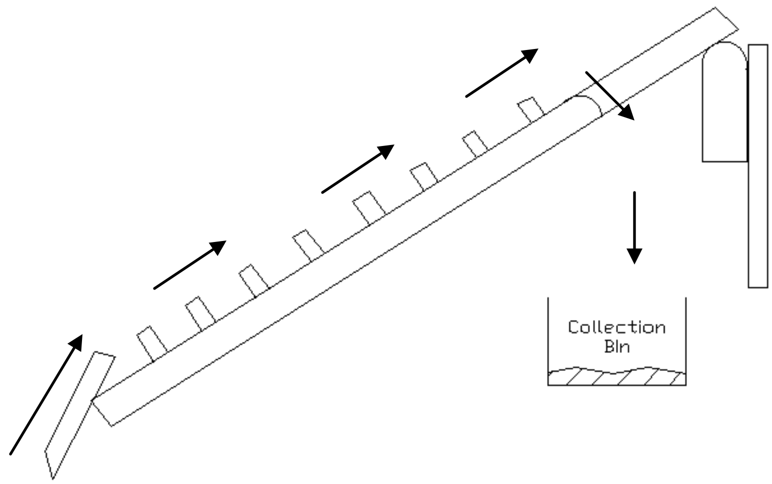

Figure 4.6-1 Sketch of Regolith Collection in Bin from Conveyor

5.0 ENGINEERING ANALYSIS

With regards to the preliminary design specifications and the lunar environment, the current excavator prototype was analyzed and investigated for possible improvements. After analysis it was deemed necessary for several structural alterations to reduce weight, improve clearance, and mount to the KSC interface. The addition of two more linear actuators, one to control bit angle and one to control the mounting height at the interface plate, were added to provide two more degrees of freedom and adjustability. However, the main design change in the current prototype was the incorporation of an adjustable and vibratory bit. Vibratory movement will decrease the draft force of lunar regolith, resulting in reduced impact and reaction forces. [3] concentrates on the reduction of forces while applying vibratory motion in the direction of travel. The experimental data from regolith substitutes states that there is a reduction of draft force of approximately eighty-four percent at a frequency of sixty hertz for JSC-1 and roughly ninety percent reduction at seventy hertz for MLS-1. Using this data and applying it to the current prototype, a conceptual design for a bit with vibratory motion was constructed with voice-coil type linear actuators. These actuators were selected because of their ability to supply high frequency vibration with relatively low inertial forces. They were sized to provide approximately 165 newtons of force with a stroke of approximately three millimeters, similar to the experiment performed in [3]. In the event that the excavator encounters large static forces due to impact with rocks, the mounting point for the linear actuator for angle adjustment also serves as a "bump" stop for the vibrating spade tip. A structural stop mounted on the bit will prevent the voice-coil actuators from being damaged due to an overload of force.

Design changes and concepts were visualized and created through the use of Solid Edge. Proposed concepts for vibration tillage and excavation were acquired from current terrestrial machinery and experimental data collected from technical reports. Space qualified components will be recommended for the lunar excavator; however, components suitable for the earth environment will be selected for use on the prototype for cost savings and testing purposes.

5.1 Bit Calculations

Studies were conducted using the Zeng model [1] to analyze variances due to variable inputs in order to determine ideal conditions concerning the excavation process. Using the Zeng model we were able to determine the horizontal, vertical, and total excavation forces that the blade will possibly encounter during excavation. The equations used in the Zeng model incorporated several characteristics including soil-soil cohesion, passive earth pressure, tool-blade acceleration, and tool-soil friction. Using two variable inputs, rake angle and blade depth, two separate analyses were conducted to analyze their effects upon the excavation process.

The first of these analyses compared the excavation forces to the depth of the blade in the lunar regolith. The results, shown in Figure 5.1-1, were as expected, showing a direct relationship between the depth of the blade and the resulting excavation forces. As the blade approaches the set maximum depth of 15 centimeters (~6 inches), forces around 130 pounds or greater should be expected. However, the depth of excavation will most likely be kept to a maximum depth of about 10 centimeters to avoid abrupt changes in the regolith characteristics. This design constraint comes from the fact that the regolith density increases beyond the first 15 centimeters, as shown in Figure 5.1-2.

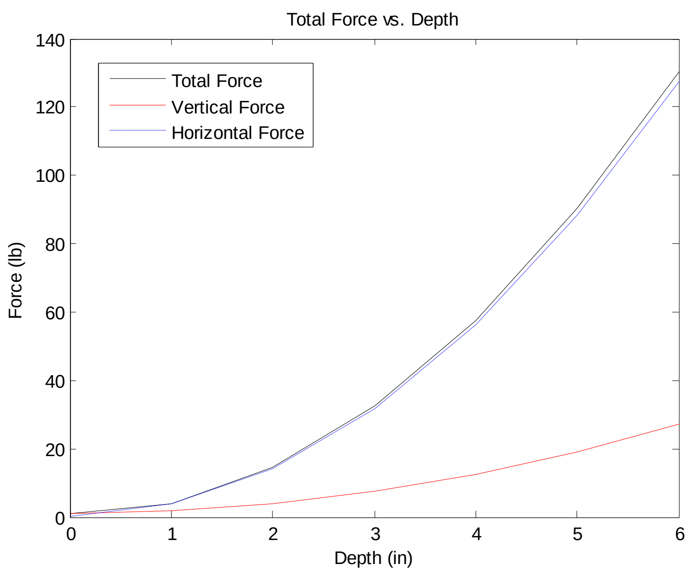

Figure 5.1-1 Total Force as a Function of Depth

Average Bulk Density (g/cm^3)	Depth Range (cm)
1.50 ± 0.05	0 – 15
1.58 ± 0.05	0 – 30
1.74 ± 0.05	30 – 60
1.66 ± 0.05	0 – 60

Figure 5.1-2 Regolith Density Properties

For the second analysis, the rake angle of the blade, relative to the horizontal, was compared to the forces of excavation. The data from this analysis, shown in Figure 5.1-3, resulted in an unexpected relationship between the rake angle and excavation forces. The results also presented an ideal bit angle contrary to that of the angle previously established. These results showed a decrease in force for small angles ($\alpha_c < 40\,\text{deg}$) and, conversely, an increase in force for large angles ($\alpha_c > 60\,\text{deg}$). Thus, an ideal angle range resulted, $40\,\text{deg} > \alpha_c < 60\,\text{deg}$, with excavation forces ranging from 76 to 80 pounds. The new ideal bit angle of 52 degrees creates a minimum force of 76.84 pounds at a constant excavation depth of 10 centimeters.

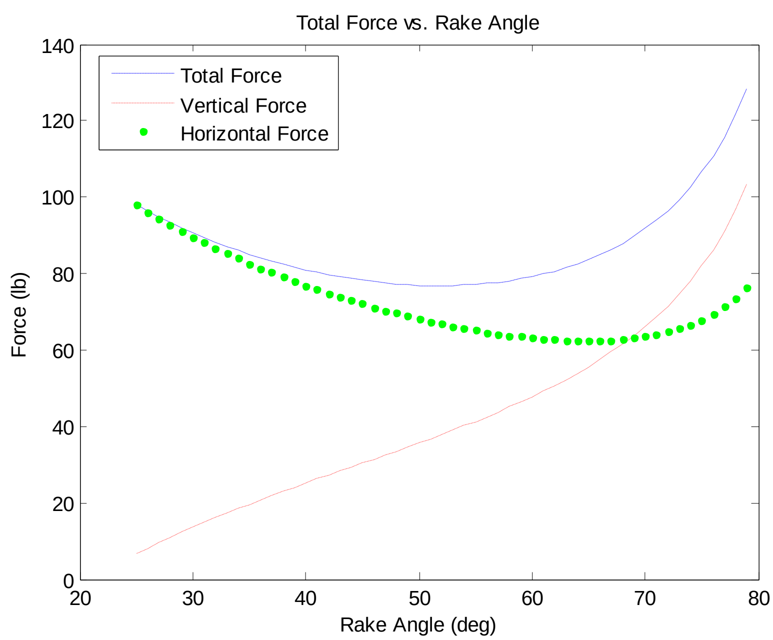

Figure 5.1-3 Total Force as a Function of Rake Angle

Based upon our current results further testing will need to be conducted to help verify our information. It should be noted, however, that due to the uncertainty of several of the regolith properties, the results from the above analyses and any further analyses should be used only as a general estimate of the expected values, as they will surely change in the actual lunar environment. The equations and calculations outlining the method discussed above are detailed in Appendix II with their corresponding graphs. Also in Appendix II are the calculations for determining the rover thrust available.

6.0 ECONOMIC ANALYSIS

A proposed budget and cost for the overall project has not been set by our corporate sponsor, however, an attempt to keep costs as low as possible was constantly considered when designing the second generation excavator. In order for the excavator to operate in the lunar environment, all of its components need to be space qualified. This causes the costs to drastically increase because of the extensive engineering required to fabricate space qualified components. As mentioned earlier, when building a prototype for testing on earth, it will be built with off the shelf non-space rated components to keep actual costs as low as possible. Table 6.0-1 gives a cost analysis for the proposed space qualified materials and parts.

Item #	Component	Quantity	Material	Cost
1	Frame Rail	2	Al-1199	NA
2	Conveyor	1	Kapton	$249.98
3	Conveyor Frame	2	Al-1199	NA
4	Conveyor Bckt.	4	Al-1199	NA
5	Conveyor Motor	1	-	NA
6	Bit	1	304 Stainless	$255.00
7	Voice Coil	2	-	$2,350.00
8	Voice Coil Bkt	4	304 Stainless	$127.50
9	Vibrating Bckt	1	304 Stainless	$221.00
10	Vibrating Pillow Block	2	304 Stainless	$146.20
11	Vibrating Rail	2	304 Stainless	$59.50
12	Bit Actuator	1	-	$1,500.00
13	Shovelhead	1	304 Stainless	$102.00
14	Shovelhead Bkt.	2	304 Stainless	$59.50
15	Frame Actuator	1	-	$25,000.00
16	Bit linkage	1	304 Stainless	$8.50
17	Bit Spacer	2	304 Stainless	$5.10
18	Vibration Isolator	4	-	$3,600.00
19	Interface mount	1	Al-1199	NA
20	Nuts,Bolts, etc.	-	Grade 8	$50.00
21	Bearings, lubricant	-	-	$300.00
			Total	$34,034.28

Table 6.0-1 Cost Analysis for Space Qualified Materials and Parts

For parts and components that are to be used when building the terrestrial prototype, the cost estimate is shown in Table 6.0-2. This will serve as the Bill of Materials for the project.

Item #	Part	Item	Quantity	Material	Part #	Cost	Supplier
1	Frame Rail	2"x2"x6' .188"th- tube	2	6061-AL	6546K14	$146.00	MCC
2	Bit Angle Cross Member	1.5"x1.5"x6' .125" th-tube	3	6061-AL	6546K12	$124.74	MCC
3	Bit angle Mount	-	2	-	-	-	-
4	Cross Member	-	1	-	-	-	-
5	Cross Member Mount	-	2	-	-	-	-
6	Vertical interface Mount	-	2	-	-	-	-
7	Horizontal Interface Mount	-	2	-	-	-	-
8	Weld plate	.25"x1.75"x12" Flat	1	6061-Al	89215K494	$16.22	MCC
9	Voice Coil Mount	3/16 th x 3"x6' Angle Iron	1	Carbon Steel	9017K24	$46.58	MCC
10	Voice Coil U-Bracket	.75"x5"x12" Flat	1	6061-AL	8975K491	$24.59	MCC
11	Spade Tip	.25"x5"x18" Flat	1	4140 Steel	89715K251	$90.85	MCC
12	Blade Supports	.25"x4"x18" Flat	2	4140 Steel	-	-	-
13	Pillow Block	1.5"x3"x12" Flat	1	6061-AL	8975K315	$36.01	MCC
14	Voice Stop/ Acutator Mount	1" dia. 1" length	1	6061-AL	-	-	DML
15	Bit Actuator Link	.5"x1"x4" Flat	1	6161-AL	-	-	DML
16	Vibration Damper/ Isolator	Rubber Gromet	4	Rubber	MR2000238	$8.64	WRS
17	Interface Clevis Pin	.5" dia. 2" ht. Clevis Pin	4	Steel	98306A387	$7.62	MCC
18	Clevis Pin Holder	.25"x.75"x3.5" Flat	2	Steel	-	-	DML
19	Mounting Tabs	.25"x2"x12" Flat	1	6061-AL	6023K281	$18.96	MCC
20	Tray	.125"x20"x24" Flat	1	A-34 Carbon Steel	9720K37	$130.00	STS
21	Voic Coil Actuator-18lb. Force	H2W Voice	2	-	NCM05-28-180-2LB	$3,706.00	H2W
22	Bit Power Screw	4" Linear Actuator	1	-	FA-240-S-12-4"	$109.00	FA
23	Voice Coil Remote	Keyless Entry Remote	1	-	4CH-RC	$65.00	FA
24	Interface Mount	.5"th x3"dia	3	6061-AL	-	-	DML
25	Pillow Block Bolt	1/4"-28x1.5" Plain Screw	10	Steel	91400A862	$9.71	MCC
26	Pillow Block Washer	1/4" Flat Washer	222	Steel	91083A029	$3.39	MCC
27	Pillow Block Lock Washer	1/4" Lock Washer	100	Steel	90073A029	$1.85	MCC
28	Voice Coil Screw	#8-32x.625" Pan Screw	100	Steel	90272A196	$2.96	MCC
29	Voice Coil Washer	# 8-32 Washer	585	Steel	91083A009	$4.59	MCC
30	Voice Coil Lock Washer	# 8-32 Lock Washer	100	Steel	90073A009	$1.25	MCC
31	Pillow Block Bolt	1/4"-28 Hex Nut	100	Steel	95505A611	$2.41	MCC
32	Voice Coil Mount Bolt	1/4"-28x.75" Pan Screw	10	Steel	91400A853	$5.93	MCC
33	Bearing Rod Bolt	1/4"-28x.75" Flat Screw	50	Steel	90273A559	$10.66	MCC
34	Voice Coil Mount Washer	1/4" -.375" OD Flat Washer	100	Steel	90089A310	$7.10	MCC
35	Voice Coil Nut	#8-32 Nut	100	Steel	90760A009	$2.85	MCC
35	Taper Tap	1/4"-28 Taper Tap	1	HS Steel	8332A25	$5.77	MCC
36	Bottoming Tap	1/4"-28 Bottom Tap	1	HS Steel	8332A27	$5.77	MCC
37	Taper Tap	No. 8-32 Taper Tap	1	HS Steel	8330A42	5.44	MCC
38	Bottoming Tap	No. 8-32 Bottom Tap	1	HS Steel	8330A44	5.44	MCC
39	Linear Bearings	7/8" OD 1/2" ID Linear Bearing	4	Steel	XLEC08	$80.00	NOOK
40	Frame Support Bolts	1/2"-13 x 2.5" Bolt- Grade 8	25	Steel	92865A722	$6.86	MCC
41	Frame Support Washer	1/2" ID 1-1/16" OD washer	50	Steel	90126A033	$2.59	MCC
42	Frame Lock Washer	1/2" ID lock washer	100	Steel	91102A770	$6.21	MCC
43	Frame Support Nut	1/2"-13 nut	50	Steel	94846A523	$10.21	MCC
44	Drill for Pillow Block	55/64" Taper Length Drill Bit	1	HHS	29315A193	47.15	MCC
45	Motor Sprocket	1.5"OD .5" ID ANSI -35	2	Steel	6280K332	15.82	MCC
46	Sprocket Chian	ANSI 35 - 2'	1	Steel	6261K292	$5.48	MCc
					Total	$4,758.35	

WRS- Western Rubber Supply
DML-Design and Mfg. Lab
FA-Firgelli Auto
Nook -Nook Industries
STS-Southern Tool Steel

Table 6.0-2 Cost Analysis for Terrestrial Materials and Parts

It is estimated that to machine all of the components will take approximately 50 hours. This estimate is based on the slow feed rate and small cutting depth that should be used when machining steel. When machining the aluminum, it is assumed to be similar to a general purpose aluminum alloy. When machining the metals, the feed rate and tool speed vary depending on what machine is being used (lathe, mill, etc.) and will be calculated using the formulas in [9].

7.0 CONCEPT RECOMMENDATION

We believe there are many advantages in the presented second generation rover design over the first generation design. The first advantage is the lower interface height and angle between the excavator and the ground, as well as height adjustability. This puts less torque and stress on the frame, resulting in the frame being able to withstand higher impact forces. Another advantage of the lower interface height and angle is that it allows the regolith to travel more easily up the bit and onto the conveyor. For the issue when the bottom of the frame rail makes contact with the regolith, rounding the frame rail ends allows the frame to skid over the regolith rather than dig in. Incorporation of a variable angle bit allows the bit angle to be adjusted to the optimum angle of 35 degrees for shearing the regolith at all times. Also, with the variable angle bit adjustment, the bit angle is independent of the frame angle. Adding a vibratory bit to the new excavator reduces the regolith cohesion and increases the percent draft force reduction through vibration contact with the regolith. This decreases the load experienced by the excavator and increases regolith removal rate. Lastly, by including a vibration isolator it ensures structural integrity for the frame by reducing/eliminating the forces caused by the vibrating bit and any impulse reaction forces. Figure 7.0-1 shows an image of the overall concept.

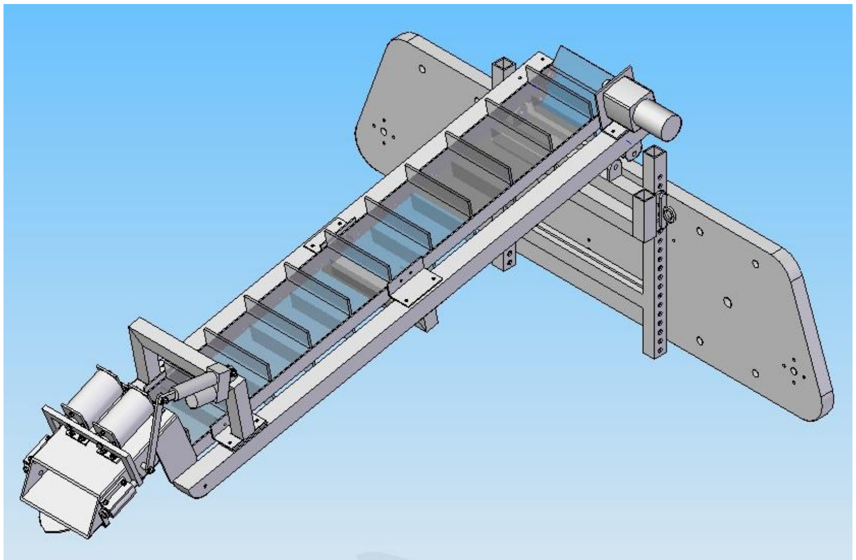

Figure 7.0-1 Overall Concept

Despite the advantages of the second generation excavator, there are also believed to be some disadvantages associated with the new concept. The first disadvantage believed to exist with the second generation excavator is the possibility of the regolith having difficulty traveling up the bit due to the vibration required to reduce the regolith cohesion. Secondly, there exists the problem of dust protection for the vibrating bit and all of the components associated with the bit. Lastly, despite having the electrical components operating independently of each other, it is believed that the excavator will exceed the specified power requirements due to addition of necessary electrical components and the need for these components to be space qualified.

8.0 CONCLUSIONS

Ultimately, the second generation excavator is a further adaptation of the first generation excavator. The design of a second generation excavator is one more step towards the final goal of regolith excavation. Being able to harvest lunar regolith provides essential elements to sustain life in the lunar environment.

The overall development of the second generation excavator intends to solve the shortcomings posed by the first generation excavator. The design criteria and concerns of the first generation excavator that needed to be addressed were also present in the design of the second generation excavator. The second generation excavator was designed to meet all the first generation excavator requirements as well as the new specifications determined and desired in the second generation project statement. As stated before the design specifications the second generation excavator intendeds to solve are:

1. Mass must be less than 100 kilograms, with overall packaging, and mass kept to a minimum to reduce cost and space in transportation to the moon.
2. The initial power consumption rate of the excavator is stated not to exceed 100 watts.
3. The excavator should be able to excavate regolith at a rate, no less than 300 kilograms per hour. Also, it should be able to excavate regolith to a depth of 30 centimeters from the surface.
4. Incorporate an adjustable and vibratory bit into the new design. The vibration must be isolated from the rest of the excavator and should operate at a variable frequency.
5. The excavator should be engineered, so as to be fit for the lunar environment. Issues to be addressed are abrasion of regolith, extreme temperature/thermal considerations, and operation in a vacuum, etc.
6. The digging equipment on the excavator must be able to operate for 3 years, with scheduled maintenance on the excavator every year. Also, where appropriate all

components should be sealed or have a dust cover to reduce abrasions from the lunar environment.

Also, another concern in designing the second generation excavator was to keep overall costs as low as possible, despite the high costs associated with space rated components and materials. While adding new key components necessary to the new design, we still kept within the mass requirement, measuring approximately 85 kilograms. For the linear voice coil actuators to provide the amount of vibratory force needed for excavation in our design, their power consumption will be approximately 80 watts. Including the power consumption for the conveyor motor, the maximum consumption should not exceed 120 watts (allotting 40 watts for the electric motor). Due to the power consumption of the voice coil actuators, the linear actuators used to adjust height and angle can only be used after the voice coils have been stopped. The interfacing height of the first generation excavator need to be lowered and the excavation angle needed to be decreased. The main development of the second generation excavator was the addition of the adjustable and vibratory bit to decrease the reaction force needed to excavate that lunar regolith. In addressing the concerns of the lunar environment, the parts and components selected are believed to reduce the weight of the overall excavator. By using aluminum to comprise the major structural elements compared to steel the overall weight of the excavator is reduced, still keeping a good strength-to-weight ratio. The concept presented in this report is believed to the best solution to the problems that have been set forth by NASA.

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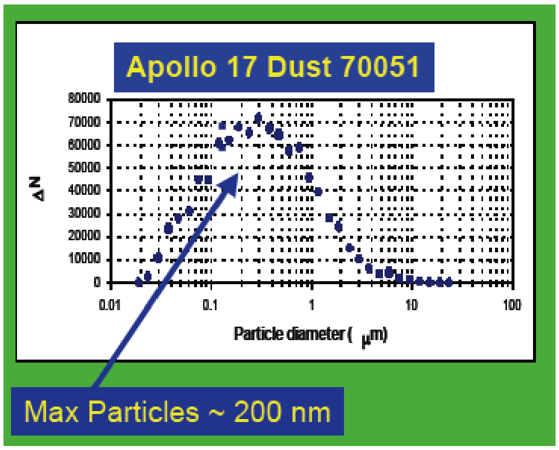
APPENDIX I – LUNAR ENVIRONMENT CHARACTERISTICS

- Regolith particles are very abrasive
- The regolith particle shape is sharp and angular
- Grain size ranges from about 5 microns to 45 microns
- 

*note that this graph is only for dust
- Particles are electrostatic, ranging from 100 volts on the light side to 1000 volts negative on the dark side
- There is no moisture in regolith, which effects the manner in which it clumps together
- Gravity on the moon is 1.62 m/s^2
- Atmospheric pressure ranges between 10-14 atmospheres
- Temperatures can range from -250 degrees to 250 degrees Celsius
- The density of the regolith varies between 1.3 g/cm^3 on the surface to 1.9 g/cm^3 at depths greater than 30 cm
- Radiation in the main source of heat transfer on the moon
- Sources of radiation include cosmic rays, solar flare events and solar winds
- There is no convection on the moon

- The vacuum on the moon varies between 10^{-12} and 10^{-14} torr by day and night respectively
- Surface is covered by many small craters (micro craters)

Lunar Atmosphere

The moon for all intensive purposes can be said to have no atmosphere as well as no measurable magnetic field. Technically speaking though, the moon does have an atmosphere which measures approximately $10^4\, molecules / cm^3\, day$. The gravitational force found on the moon is 1/6 of that found on the Earth and the lunar cycle is approximately 29.5 days. Other characteristics of the lunar environment include its hard vacuum, severe temperature fluctuations, and its susceptibility to solar events and cosmic rays. Its terrain is comprised of several familiar terrestrial features such as craters, ridges, mountains, and plains that were primarily formed by volcanism and high-velocity impacts. Although today there is no longer any volcanic or seismic activity, the lunar surface is still impacted by high velocity micrometeoroids. Averaging in size of about less than on milligram, these micrometeoroids bombard the lunar surface unimpeded by any sort of atmosphere.

Lunar Regolith

The lunar regolith consists of extremely fine and abrasive particles created from billions of years of constant bombardment from solar winds and micrometeoroids. Thinly covering the lunar surface, the regolith ranges in depths from 4-5 meters in the mare areas up to 15 meters in the highland areas. Also as one would expect the deeper one goes, the denser and more cohesive the regolith becomes. The average density of the regolith ranges from $65 \pm 3\%\ (medium - dense)$ to $92 \pm 3\ \%(very\,dense)$. These particles range in size from approximately $45 - 100\ \mu m$ and are said to consist of 4 main components: lithic fragments (pieces of rock), minerals, glasses, and agglutinates (glass plus minerals). Similar to silty sand the lunar regolith has a very low electrical conductivity and dielectric losses. Due to the sharp UV flux, the regolith may become electrostatically charged. This phenomenon presents many problems for the advancement in lunar exploration and excavation. Severe degradation of mechanical and electrical components can result due to dust adhesion in the lunar environment.

Lunar Thermal Properties

Temperatures in the lunar environment fluctuate drastically during the day/night cycle. Temperatures may drop as low as 40 Kelvin during the lunar night and may get as high as 400 Kelvin during the lunar day. The moon’s average albedo is about 0.1 which makes it as absorptive as black paint. This characteristic can cause an object that is partially covered by a shadow while partially covered by sunlight to see both ends of the extreme temperature differences.

Due to the absence of a lunar atmosphere, the lunar surface is susceptible to three main ionizing sources of radiation. These radiation sources consist of large fluxes of low energy solar wind particles, small fluxes of high energy galactic cosmic rays, and infrequent but intense particle fluxes from solar flares. Expressed in units of electron volts (eV) the lunar surface may see radiation energies as low as 1 eV from the solar winds or as high as 10 GeV from the galactic cosmic rays. Concerns that arise from these radiation sources consist of material degradation due to sputtering and dangerous levels of radiation for humans.

Physical Comparison of the Moon and Earth [LSB]

Property	Moon	Earth
Mass	7.353×10^{22} kg	5.976×10^{24} kg
Radius (spherical)	1738 km	6371 km
Surface area	37.9×10^6 km^2	510.1×10^6 km^2 (land = 149.8×10^6 km^2)
Flattening*	0.0005	0.0034
Mean density	3.34 g/cm^3	5.517 g/cm^3
Gravity at equator	1.62 m/sec^2	9.81 m/sec^2
Escape velocity at equator	2.38 km/sec	11.2 km/sec
Sidereal rotation time	27.322 days	23.9345 hr
Inclination of equator/orbit	6°41'	23°28'
Mean surface temperature	107°C day; -153°C night	22°C
Temperature extremes	-233°C(?) to 123°C (Table 3.3)	-89°C to 58°C
Atmosphere	~10^4 molecules/cm^3 day 2×10^5 molecules/cm^3 night	2.5×10^{19} molecules/cm^3 (STP)
Moment of inertia ($1/MR^2$)	0.395	0.3315
Heat flow (average)	~29 mW/m^2	63 mW/m^2
Seismic energy	2×10^{10} (or 10^{14}?) J/yr†	10^{17}-10^{18} J/yr
Magnetic field	0 (small paleofield)	24-56 A/m

APPENDIX II – SOIL AND ROVER FORCE CALCULATIONS

ROVER FORCE CALCULATIONS:

The calculations are to show the translational thrust available to the rover. For the data that could not be obtained for the scout rover, information from the Apollo LRV was substituted.

Bekker Forward thrust equation:

$$H = H_0\left[1 - \frac{\kappa}{S \cdot L}\left(1 - e^{-S \cdot L/\kappa}\right)\right]$$

Ideal drawbar pull:

$$H_0 = nAc + W\tan\phi$$

Table 1: Parameter Set Base: (SI Units) Used for Traction Calculations.

	Values	Units
calculated slippage, *S*	8.301650852	%
scout rover mass, *W*	612	kg
internal friction angle, *Φ*	35	degrees
soil cohesion, *c*	170	N/m^2
calculated wheel contact area, *A*	0.0399718978	m^2
calculated wheel contact length, *L*	0.1884955592	m
number of wheels, *n*	6	
shear deformation slip modulus, *κ*	0.018	m

Substituting:

$$H = \left[6 \cdot 0.03997 \cdot 170 + 612\tan(35)\right] \cdot \left[1 - \frac{0.018}{8.30165 \cdot 0.188496}\left(1 - e^{-8.30165 \cdot 0.188496/0.018}\right)\right]$$

$$H = 463.845N$$

or

$$H = 104.240lb$$

The thrust, *H*, represents the thrust that will be used for blade calculations. *H* is assumed to be the maximal *constant* force that the rover can apply.

SOIL FORCE CALCULATIONS:

Zeng Model

NOMENCLATURE

$\alpha_b = acceleration\ in\ horizontal\ direction\ (ft/s^2)$

$\alpha_v = acceleration\ in\ vertical\ direction\ (ft/s^2)$

$c = soil\ cohesion\ (psi)$

$d = depth\ of\ excavation\ (in.)$

$Fside = side\ friction\ (lbf)$

$Fblade = friction\ on\ the\ blade\ (lbf)$

$g = gravitational\ acceleration\ (ft/s^2)$

$K = Gill's\ cut\ resistance\ index\ (lbf/ft)$

$K_{PE} = dynamic\ passive\ earth\ pressure\ coefficient$

$K_o = earth\ pressure\ coefficient\ at\ rest$

$P_P = passive\ earth\ pressure\ (lbf)$

$q = surface\ surcharge\ (psi)$

$T = total\ excavation\ force\ (lbf)$

$v = tool\ velocity\ (ft/s)$

$W = tool\ length$

$W_b = weight\ of\ excavation\ blade\ (lbf)$

$\alpha_c = inclination\ angle\ of\ the\ blade\ (\deg)$

$\alpha_P = inclination\ angle\ of\ the\ failure\ wedge\ (\deg)$

$\beta = inclination\ angle\ of\ the\ side\ friction\ (\deg)$

$\gamma = unit\ weight\ of\ soil\ (lbf/ft^3)$

$\phi = internal\ friction\ angle\ (\deg)$

$\varphi = inclination\ friction\ angle$

$\sigma_v = vertical\ normal\ stress\ in\ soil\ (psi)$

$\sigma_h = horizontal\ normal\ stress\ in\ soil\ (psi)$

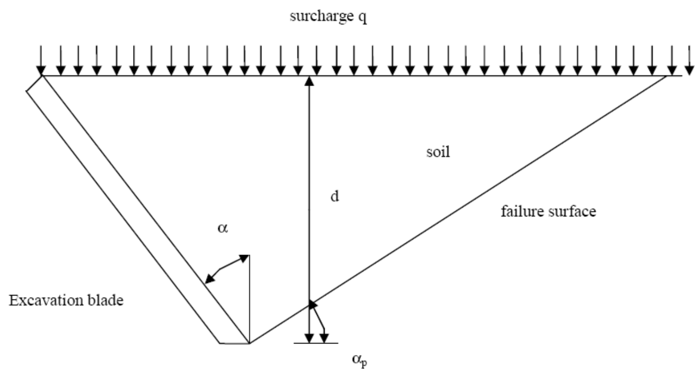


Figure AppII-1 Excavation blade and soil body at failure

Assumptions and Known:

Symbol	*Coding Parameter*	*Units*	*Description*
c	c	psi	$soil\ cohesion\{68:4500\}[Wilkinson, DeGennaro]$
d	d	$in.$	$tool\ depth\{0:5.91in\}$
W_b	W_b	lb	$weight\ of\ blade\{3.0\,lb\}$
g	g	ft/s^2	$lunar\ gravitational\ force\{5.637\ ft/s^2\}$
ϕ	phi	deg	$internal\ soil\ friction\ angle\{35\deg\}$
δ	$delta$	deg	$soil-blade\ friction\ angle\{\frac{2}{3}\phi\}\{McKyes\}$
W	W	$in.$	$blade\ length\{17.5\,in.\}$
v	$vel.$	ft/s	$blade-tool\ velocity\{0:11.81\ ft/s\}$
q	q	psi	$soil\ surcharge\{1\ psi\}$
K_0	$Knot$		$earth\ pressure\ coefficient\ at\ rest\{0.573\}$
γ	$gamma$	lbf/ft^3	$unit\ weight\ of\ soil\{1200:3500\ psi\}$
β	$beta$	deg	$inclination\ angle\ of\ side\ friction\{10\deg\}$
α	$alpha$	deg	$rake\ angle\{5:90\}$
K		lbf/ft	$Gill's\ Cut\ resistance\ Index\{737.56\,lbf/ft\}$
c_a		psi	$soil-tool\ adhesion\{.27985\}$

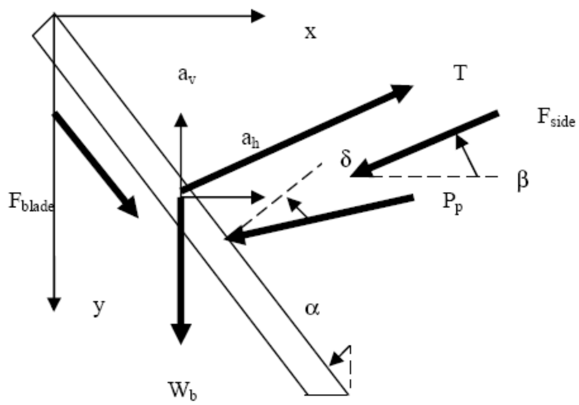


Figure AppII-2 Forces Acting on the Blade

<u>Equations:</u>

The total excavation forces may be calculated using the following equations:

(1) $$T_x = -F_{blade}\sin\alpha_c + P_P\cos(\alpha-\delta) + F_{side}\cos(\beta) + (W_b/g)a_h$$

(2) $$T_Y = F_{blade}\cos\alpha + W_b + P_P\sin(\alpha-\delta) - F_{side}\sin(\beta) + (W_b/g)a_v$$

(3) $$T = \sqrt{T_x^2 + T_Y^2}$$

****Note**:** F_{blade} is neglected because the cohesion component of the friction is small due to the small surface cohesion expected on the moon.

(4) $$P_P = 0.5K_{PE}(1 + a_v/g)\gamma d^2 W + 2cdW\sqrt{K_{PE}} + K_{PE}Wqd$$

(5) $$\varphi = \tan^{-1}[a_h/(g + a_v)]$$

(6) $$K_{PE} = \frac{\cos^2(\phi+\alpha+\varphi)}{\cos(\varphi)\cos^2(\alpha)\cos(\delta-\alpha-\varphi)\{1-\sqrt{[\sin(\delta+\phi)\sin(\phi+\varphi)]}/[\cos(\delta-\alpha-\varphi)\cos(\alpha)]\}^2}$$

(7) $$C_{3E} = \sqrt{\{\tan(\phi+\varphi)[\tan(\phi+\varphi)+\cot(\phi+\alpha+\varphi)][1+\tan(\delta-\varphi-\alpha)\cot(\phi+\alpha+\varphi)]\}}$$

(8) $$C_{4E} = 1 + \{\tan(\delta-\varphi-\alpha)[\tan(\phi-\varphi)+\cot(\phi+\alpha+\varphi)]\}$$

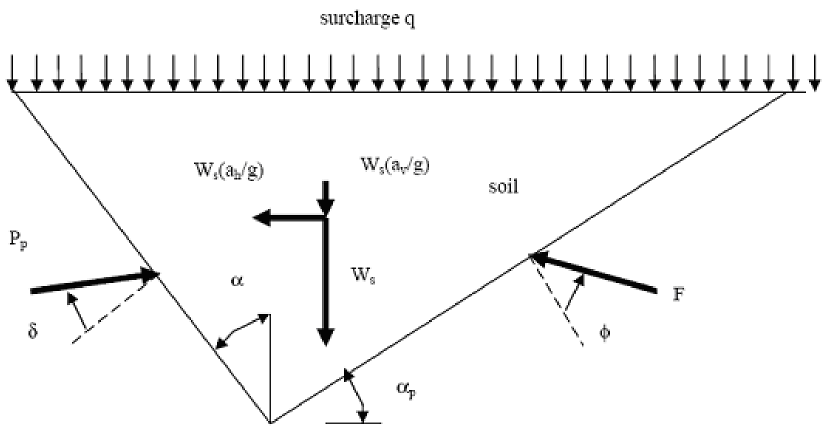


Figure App II-3 Failure Wedge in the soil in front of the blade

(9) $\alpha_p = -\varphi - \phi + \tan^{-1}\{[\tan(\phi - \varphi) + C_{3E}]/C_{4E}\}$

(10) $L_w = d(\tan\alpha + \cot\alpha_p)$

(11) $L(y) = L_w[d - y)/d]$

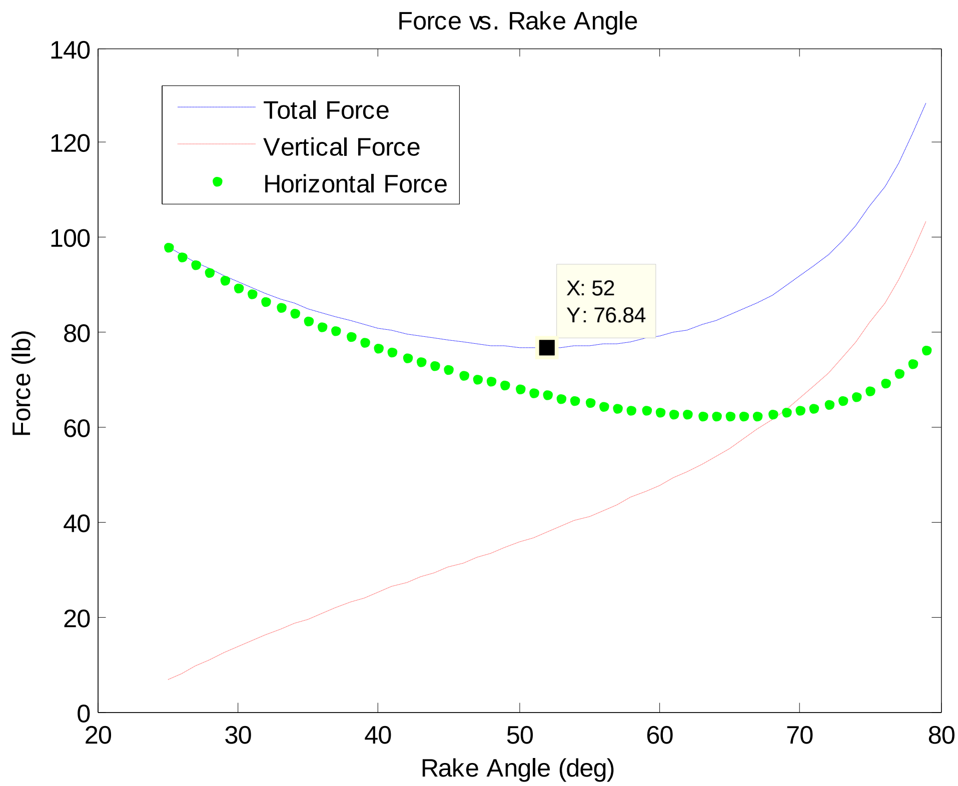
(12) $F_{side} = L_w(cd + K_o qd \tan\phi + K_o \gamma \tan\phi d^2/3)$

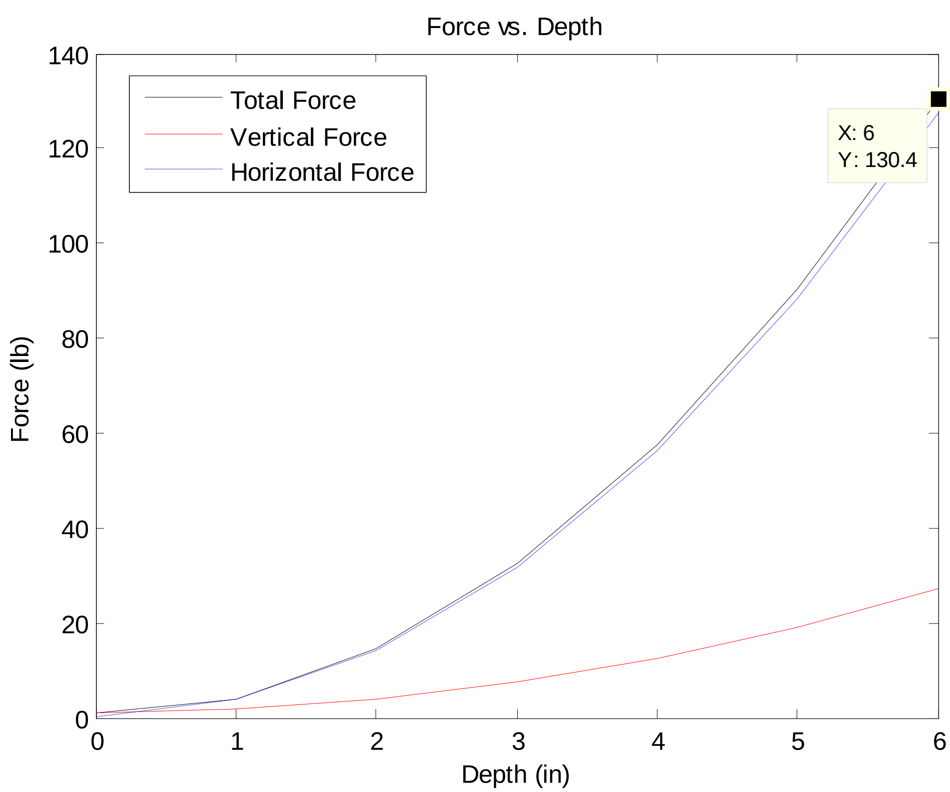
(13) $\delta = (\frac{2}{3}\phi)$

(14) $y = .7083\cos(\alpha)$

****Note**:** It is expected that the depth of the blade shall never exceed half of its its length.

Graphical Results





Gill & Vanden Berg Model

Note that the total force calculated (522.5) is in newtons. This was then converted to pounds (1N = 4.448lb), giving a total force, T, of 117.5 pounds.

$$H = N_o \sin\beta + \delta N_o \cos\beta + K * w$$

$$H^* = H - K*w = \left[g\gamma \frac{\sin(\beta+\rho)}{\sin\rho}\left(l + \frac{d\cos(\beta+\rho)}{2\sin\rho} + \frac{d\sin(\beta+\rho)\tan\beta}{2\sin\rho}\right) + \frac{c}{\sin\rho(\sin\rho+\phi\cos\rho)} + \frac{\gamma v^2\sin\beta}{\sin(\beta+\rho)(\sin\rho+\phi\cos\rho)}\right] \bullet \frac{wd(\sin\beta+\delta\cos\beta)(\sin\rho+\phi\cos\rho)}{\sin(\rho+\beta)(1-\phi\delta)+\cos(\rho+\beta)(\phi-\delta)}$$

$$T = H\csc(\beta+\delta)$$
$$V = H\cot(\beta+\delta)$$

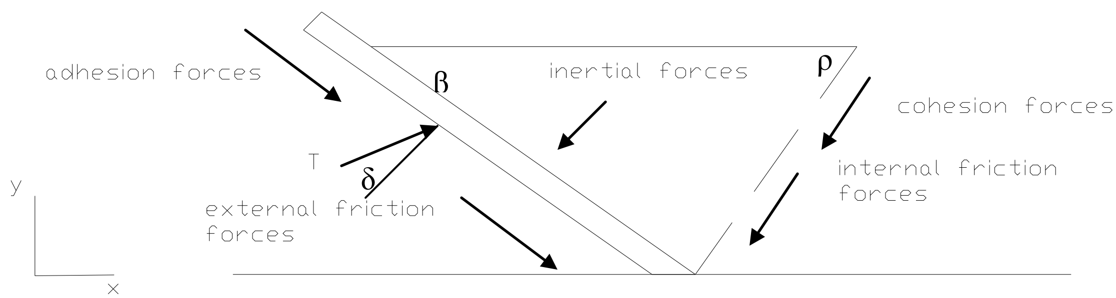


Figure AppII-4 Soil Forces on Bit

VARIABLE	UNITS
$tool\ width, w = 0.4445$	[m]
$tool\ length, l = 0.2032$	[m]
$tool\ depth, d = 0.15$	[m]
$soil\ specific mass, \gamma = 1680$	[kg/m^3]
$rake\ angle, \beta = 35$	[deg]
$shear\ plane\ failure angle, \rho = 55$	[deg]
$internal\ friction angle, \phi = 35$	[deg]
$external\ friction angle, \delta = 10$	[deg]
$cohesion, c = 170$	[N/m^2]
$tool\ speed, v = 0.1$	[m/s]
$lunar\ gravity, g = 1.63$	[m/s^2]
$Gill's\ cut\ resistance\ index, K = 1000$	[N/m]
$horizontal\ force, H$	[N]

$total\ force, T$ [N]
$vertical\ force, V$ [N]

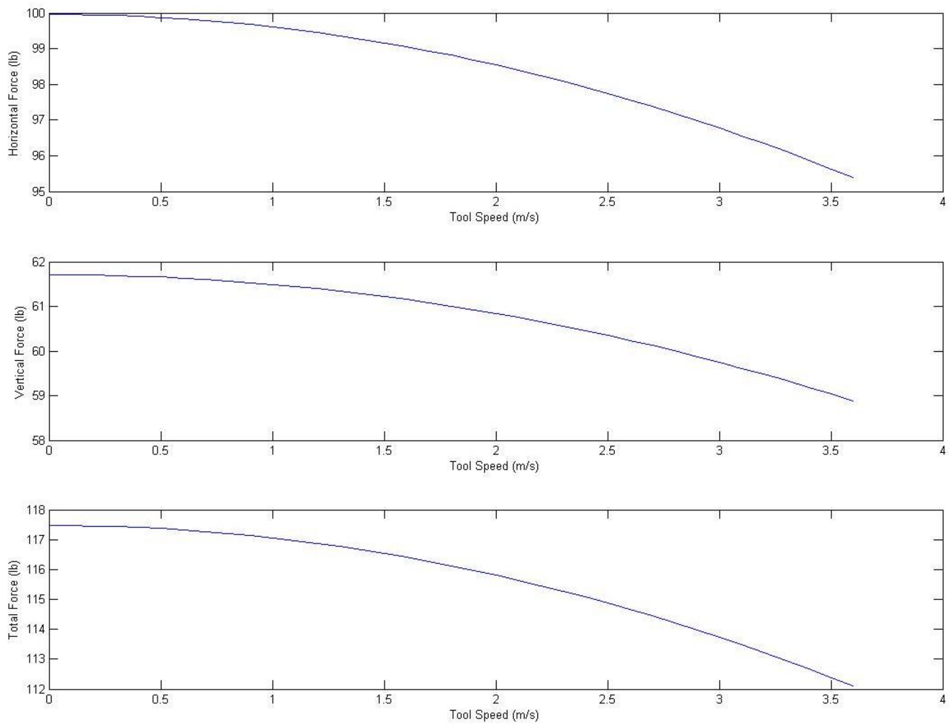


Figure AppII-5 Force versus Tool Speed

APPENDIX III – MAXIMUM IMPACT FORCE

The maximal impact force represents the theoretical maximum dynamic load that the rover can deliver. This force will be used to analyze and size the structural members and would represent the rover traveling at top speed and colliding with an immovable object such as a rock. For these calculations some reasonable assumptions will be made.

Using Kinetic Energy and Equivalent Static Force Equations:

$$\bullet U = \frac{1}{2}Wv^2 \qquad \bullet F_e = \sqrt{2Uk}$$

Combining and substituting, $k = \frac{3EI}{L^3}$:

$$F_e = \sqrt{\frac{3WEIv^2}{L^3}}$$

The velocity, v, is equal to 3.611m/s and was obtained from the Apollo lunar rover's top recorded speed on the moon. The area moment of inertia, I, of the main structural member was calculated to be 1.481 x 10^{-7} m^4, and the modulus of elasticity, E, is known to be 200 GPa.

Substituting variables:

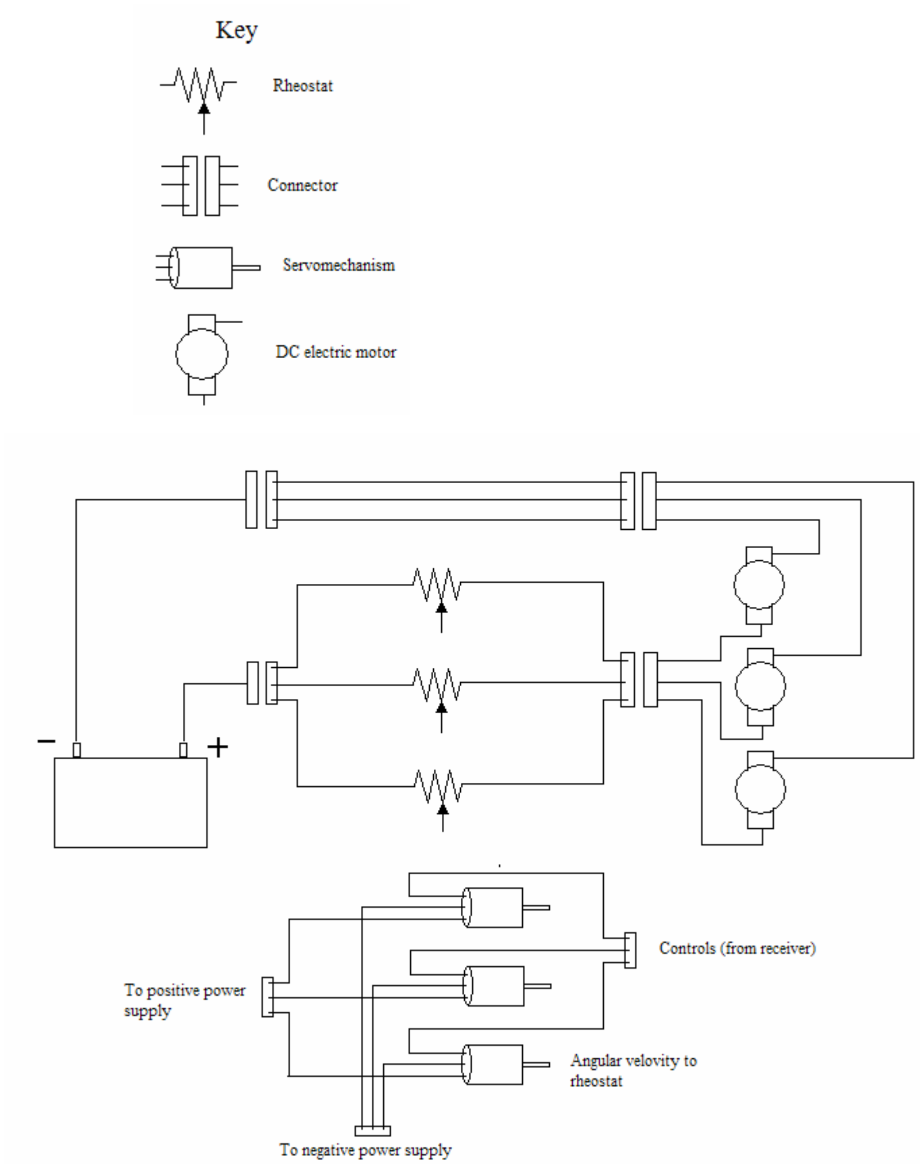
$$F_e = \sqrt{\frac{3 \cdot 612 \cdot 200x10^9 \cdot 1.481x10^{-7} \cdot 3.611^2}{.508^3}}(N)$$

$$F_e = 73{,}555.42N$$

or

$$F_e = 16{,}530.09lb$$

APPENDIX IV – ELECTRONICS SCHEMATIC



APPENDIX V – LINEAR VOICE COIL

H2W Technologies, Inc.
28310-C Ave Crocker • Valencia, CA 91355
E-mail: info@h2wtech.com
Call Toll Free: 888.702.0540
Phone: 661.702-9346 • Fax: 661.702.9348

Innovation in Linear Motion

Product Info:

VOICE COIL APPLICATION SPECIFICATIONS

Frequency of Oscillation: 60 Hz

Force Required per Actuator: 80 N

Mass of Spade Tip: 0.5 Kg

Stroke: 3 mm

Type of Operation: Open Loop

Available Power Source: DC

Operating Info:

Required Electronics:

Because of the very low inductance of the actuator, a DC linear servo amplifier is required to provide power to the **Voice Coil**. A programmable motion controller is required to close the position loop on the system.

Environmental Considerations:

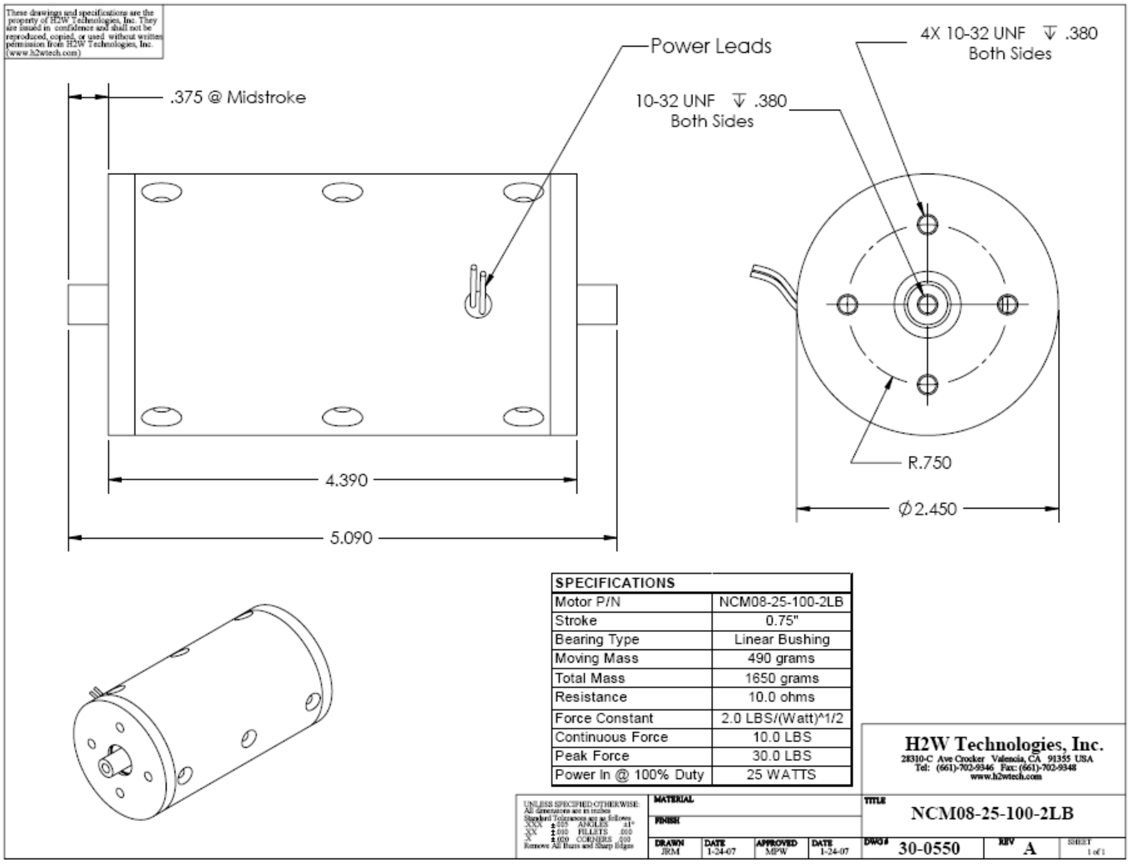
The NC Actuators should not be mounted in an environment that is wet or excessively dirty or in an environment with ambient temperatures (>50ºC).

Mounting:

Mounting holes are provided on the housing, shaft and / or coil assemblies for mounting the actuator to customer supplied base and payload

Maintenance:

No maintenance is required.



SPECIFICATIONS	
Motor P/N	NCM08-25-100-2LB
Stroke	0.75"
Bearing Type	Linear Bushing
Moving Mass	490 grams
Total Mass	1650 grams
Resistance	10.0 ohms
Force Constant	2.0 LBS/(Watt)^1/2
Continuous Force	10.0 LBS
Peak Force	30.0 LBS
Power In @ 100% Duty	25 WATTS

H2W Technologies, Inc. • 28310-C Ave Crocker • Valencia, CA 91355 USA
Phone: (888) 702-0540 or (661)-702-9346 • **Fax:** (661) 702-9348 • **E-Mail:** info@h2wtech.com

Technologies, Inc.

QUOTATION A041608-01

Date: April 16, 2008

Attn: Chris Lambert
Auburn University
lambejc@auburn.edu

Ref: Voice Coil Actuator, Servo Amplifier

Dear Chris:

In regards to the item referenced above, we are pleased to submit the following offer for your consideration:

Item	Part Number	Description	Qty	Price (ea)
1	NCM05-28-180-2LB	Non-Commutated DC Linear Actuator. Moving Magnet Type. 18 lbs Continuous Force, 54 lbs Peak Force @ 10% Duty, 0.5" Travel.	2	**$1,175**
2	H2W16A20AC	PWM Brush-type Servo Amplifier. 8 Amps Continuous, 16 Amps Peak. Can be interfaced with a programmable motion controller, or used as a standalone system with a function generator. 110 VAC input.	2	**$678**

Delivery: 1-2 Weeks. Please refer to standard terms and conditions. **Terms:** Net 30 or credit card, FOB Santa Clarita. **Validity:** Quotation is valid for 30 days

Thank you again for this opportunity. Please feel free to contact H2W Technologies should you need additional information.

Sincerely,

Kristine Gottesman
H2W Technologies, Inc.
krissyg@h2wtech.com
661.702.9346

H2W VOICE COIL ACTUATOR TEST DATA SHEET

Customer:	H2W	Date:	8/11/2005
Customer PO:	305304	H2W SO:	200622
Motor Part Number:	NCM05-28-180-2LB		
Total Weight:	5.5 LBS 2.50 KGS	Hipot @	250V
Moving Weight	0.92 LBS 0.42 KGS	Tested By:	James R. Mitchell

Serial #	Resistance (OHMS)	Current (AMPS)	Inductance (mH)	Power In (WATTS)	Force Output (POUNDS)	Km LBS/(WATT)^0.5
H501	10.25	1.00	4.79	10.25	9.0	2.81
	10.25	2.00	4.79	41.00	18.0	2.81
H502	10.20	1.00	4.74	10.20	9.0	2.82
	10.20	2.00	4.74	40.80	18.0	2.82
H503	10.16	1.00	4.68	10.16	9.0	2.82
	10.16	2.00	4.68	40.64	18.0	2.82
H504	10.23	1.00	4.79	10.23	9.0	2.81
	10.23	2.00	4.79	40.92	18.0	2.81
H505	10.18	1.00	4.79	10.18	9.0	2.82
	10.18	2.00	4.79	40.72	18.0	2.82
H506	10.21	1.00	4.76	10.21	9.0	2.82
	10.21	2.00	4.76	40.84	18.0	2.82
AVG	10.21		4.76			2.82

Ki (Force Output / Amp)	9.00 LBS/AMP 40.00 N/AMP	E / v	1.02 Volts / ips 40.00 Volts / m/sec

APPENDIX VI – LINEAR ACTUATOR (BIT)

PRODUCT INFORMATION

FIRGELLI AUTOMATIONS

Firgelli Automations, 3888 Sound Way, Bellingham, WA 98227 USA

Tel, 604-542-8945
Fax 1 866 226-1649
Email sales@firgelliauto.com
www.FirgelliAuto.com

- Low noise design
- Enhanced corrosion resistance
- Aluminum outer and inner tube
- Zinc alloy housing
- Powder metal gears
- Lubrication for longer life
- Small compact Design
- Low Price

Specifications

Model	**FA-PO-20-12-xx" (High Speed)**	**FA-PO-100-12-xx" (Standard Force)**
Input Voltage	12 VDC	
Load Capacity	20 lbs	100lbs
Static Load	2 x max load capacity	
Stroke Length	2" to 12"	
Speed at No Load	2"/sec (50mm/s)	½"/sec (12mm/sec)
Feedback	10K ohm 3 wires Potentiometer	
Clevis Ends	6.3mm diameter	
Screw	ACME screw	
Gear Ratio	5:1	20:1
Duty Cycle	20%	
Operation Temperature Range	-26ºC~65ºC (-15ºF~150ºF)	
Limit Switch	Built-in (Factory Preset) Not movable	
IP Grade	IP54 (dust and splash proof)	

APPENDIX VII – LINEAR ACTUATOR (FRAME)

PRODUCT INFORMATION

Firgelli Automations, 3888 Sound Way, Bellingham, WA 98226 USA

Tel, 1-360-450-5522
Fax 1 866 226-1649
Email sales@firgelliauto.com
www.FirgelliAuto.com

- Low noise design
- Enhanced corrosion resistance
- Aluminum outer and inner tube
- Zinc alloy housing
- Powder metal gears
- Lubrication for longer life
- Small compact Design
- Low Price

Specifications

Model	**FA-35-S-12-x" (High Speed)**	**ZYJ(s)02 (Standard Speed)**	**FA-150-S-12-x" (Standard Force)**	**FA-240-S-12-x" (High Force)**
Input Voltage	12 VDC			
Load Capacity	35 lbs	57 lbs	150 lbs	200 lbs
Static Load	2300N (522 lbs)			
Stroke Length	1" to 28" (25mm to 711mm)			
Speed at No Load	2"/sec (50mm/s)	1"/sec (25mm/s)	0.4"/sec (10mm/s)	0.3"/sec (7mm/s)
Speed at Full Load	50mm/s	23mm/s	11mm/s	8mm/s
Clevis Ends	6.3mm diameter			
Screw	ACME screw			
Gear Ratio	5:1	10:1	20:1	30:1
Duty Cycle	25%			
Operation Temperature Range	-26ºC~65ºC (-15ºF~150ºF)			
Limit Switch	Built-in (Factory Preset) Not movable			
IP Grade	IP54 (dust and splash proof)			

APPENDIX VIII – ELECTRONIC CONTROL (KEYLESS)

PRODUCT INFORMATION

FIRGELLI AUTOMATIONS

Firgelli Automations, 3888 Sound Way, Bellingham, WA 98226 USA

Tel, 1-360-450-5522
Fax 1 866 226-1649
Email sales@firgelliauto.com
www.FirgelliAuto.com

4 Channel Remote Control Systems

[4CH-RC]

Specifications:

- A 5 amp fuse should be used to protect the remote system
- Radio Frequency 310 MHz, 2 or 4 Channel, ideal for Actuators motors, garage door openers etc. Features: RF (Radio Frequency) 2 Remotes, requires 12vdc Input, not included. Each remote control has 4 buttons, 2 buttons per Actuator.
- These remotes have 2 modes, Sustaining or Momentary. The remotes are also programmable so you can by more remotes if required.

APPENDIX IX – CONVEYOR SYSTEM

Quotation # 141450

Date: 7/8/2007 7:31:55 PM

Driven by Customers...
...Powered by Proven Products

This quote presented for your review:

Alan Freidrich
Auburn University

Auburn , 36830
Phone No: 251-458-7151
Email: friedea@auburnedu.com

Orders accepted by your local representative:

Carolina Fluid Components, LLC.
6020-D Unity Drive
Norcross GA , 30071

Item Number	Description	Qty	Price Ea.	Extended
Conveyor				
1ESBH10-030-ASQ-CAK010	QC 125 Series Cleated Conveyor 10" X 30" with 10 3" Cleats on approx. 6" Centers	1	$1,280.00	$1,280.00
Drive				
M1-S1SE	Standard Duty Side Drive Mounting Package	1	$153.00	$153.00
051-120	Standard Duty Electric GearMotor	1	$330.00	$330.00
Sides/Guides				
125-0215-030	2" Aluminum Extruded High Sides	1	$55.00	$55.00
Support				
0182-33-36-10	Exact Width Aluminum Stand - Infeed	1	$174.00	$174.00
None	No Mount Required - Infeed	0	$0.00	$0.00
0182-33-36-10	Exact Width Aluminum Stand - Discharge	1	$174.00	$174.00
None	No Mount Required - Discharge	0	$0.00	$0.00
125-0235-024	Aluminum Cross Ties	1	$109.00	$109.00
			Quote Total:	**$2,275.00**

Quoted by:

Cale Harbour
Carolina Fluid Components, LLC.
6020-D Unity Drive
Norcross GA , 30071
Cell No: (678) 234-7350
Office No: (770) 682-2882
Email: charbour@cfcsite.com

DRAWINGS & MODELS CAN BE DOWNLOADED AT
http://www.qcindustries.com/cad
THANK YOU FOR CONSIDERING
QC INDUSTRIES

Please Reference Quote Number When Placing Order

Delivery: 15 BUSINESS DAYS A.R.O.
Terms: Net 30 Days
Pending Credit Approval
FOB: Batavia, OH
Quote Valid Until 9/6/2007

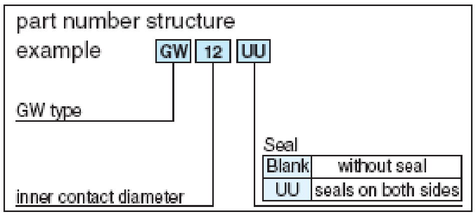
Pricing, specifications, availability and terms may change without notice. Taxes, expediting fees, shipping, handling and any applicable restocking charges are extra, may vary, and are not subject to discounting. QC Industries cannot be responsible for pricing or other errors, omissions, or consequences of use or misuse of this site and its functions and reserves the right to cancel orders arising from such errors. All sales are subject to QC Industries Terms and Conditions of Sale.

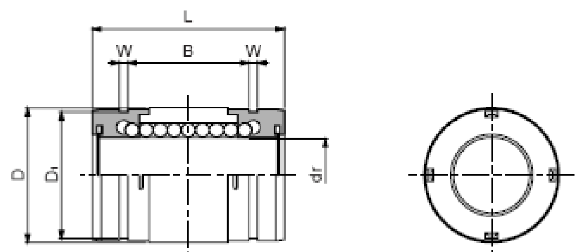
Quote Generated by QC Industries, Conveyor Configurator - ver 2.1.0

APPENDIX X – LINEAR BEARING

GW TYPE

– Single Type –





part number	number of ball circuits	major dimensions								basic load rating		mass
		dr		D		L	B	W	D_1	dynamic	static	
			tolerance		tolerance					C	Co	
		inch	inch	inch	inch	inch	inch	inch	inch	N	N	g
GW 4	4	.2500	0 −.00040	.5000	0/−.00045	.7500	.4329	.0390	.4687	206	265	5.4
GW 6	4	.3750		.6250	0 −.00050	.8750	.5577	.0390	.5880	225	314	7.8
GW 8	4	.5000		.8750		1.2500	.8710	.0459	.8209	510	784	26
GW 10	4	.6250		1.1250		1.5000	.9920	.0559	1.0590	774	1,180	51
GW 12	6	.7500		1.2500	0 −.00065	1.6250	1.0538	.0559	1.1760	862	1,370	72
GW 16	6	1.0000		1.5625		2.2500	1.6187	.0679	1.4687	980	1,570	138
GW 20	6	1.2500	0/−.00050	2.0000	0/−.00075	2.6250	1.8687	.0679	1.8859	1,570	2,740	269

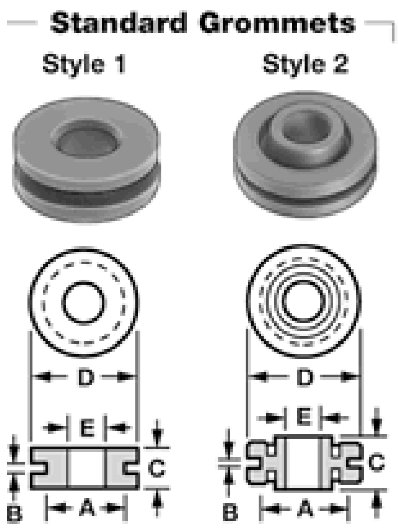
1N≒0.225lbf 1kg≒2.205lbs

Address
41 Orchard Street / Ramsey, NJ 07446
Contact Information
800.981.8190 Toll-Free / 201.236.3886 Tel

APPENDIX XI – VIBRATION ISOLATION

McMASTER-CARR

Vibration-Damping Grommets & Mounts



A	B	C	D	E	PKG. QTY
0.503"	0.070"	0.396"	0.751"	0.277"	25

HIGH DAMP PVC

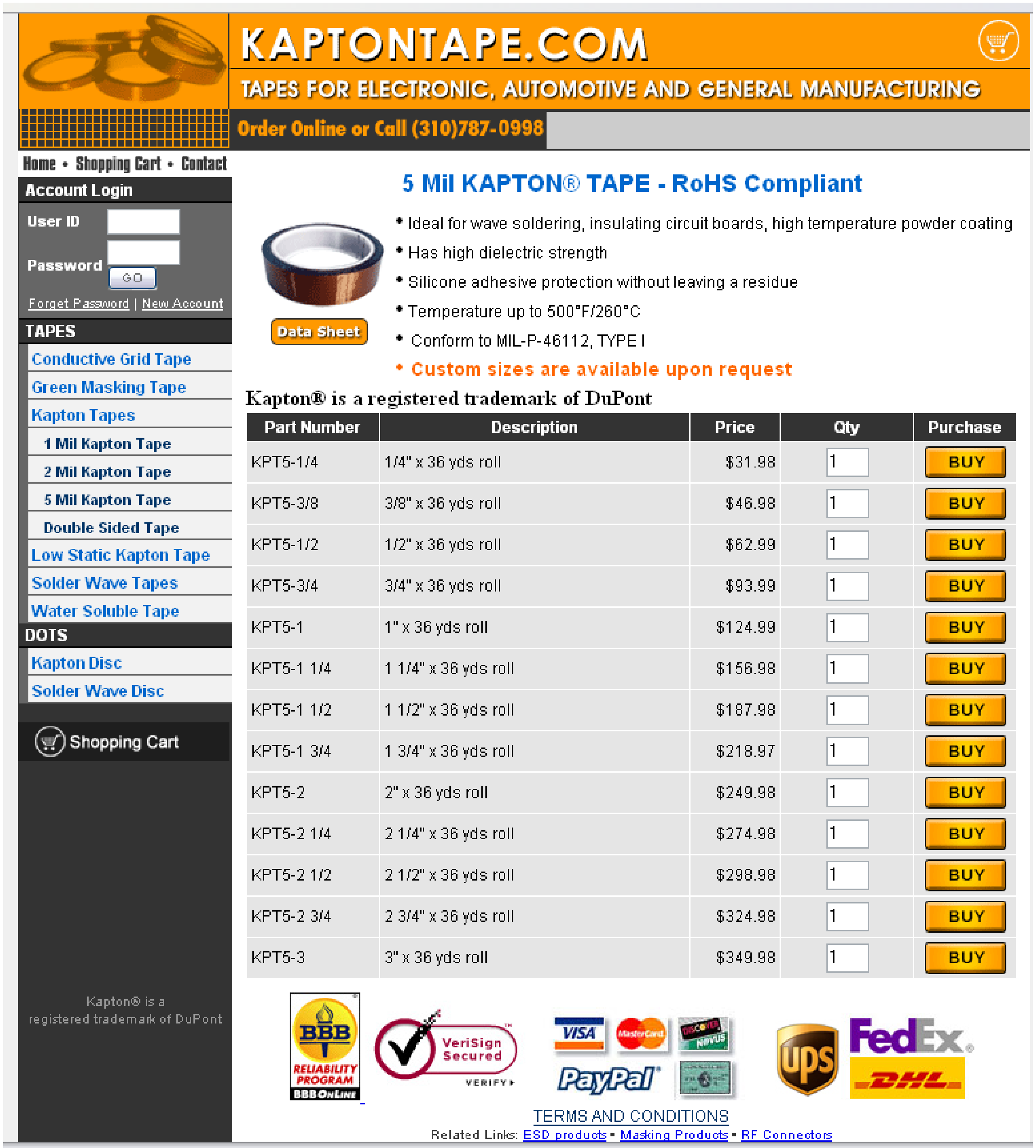
VERTICAL		HORIZONTAL			
LOAD PER MOUNT LBS	DEFLECT @Max Load	LOAD PER MOUNT LBS	DEFLECT @Max Load		per pkg
40	0.033"	1.3	0.021"	9311K129	10.71

LOW DAMP TPR

VERTICAL		HORIZONTAL			
LOAD PER MOUNT LBS	DEFLECT @Max Load	LOAD PER MOUNT LBS	DEFLECT @Max Load		Per pkg.
40	0.041"	1.6	0.022"	9311K9	10.71

E-Mail
atl.sales@mcmaster.com
Sales and Customer Service
(404) 346-7000
(404) 629-6500
Address
6100 Fulton Industrial Blvd. SW
Atlanta, GA 30336-2853

APPENDIX XII – KAPTON TAPE



KAPTONTAPE.COM

TAPES FOR ELECTRONIC, AUTOMOTIVE AND GENERAL MANUFACTURING

Order Online or Call (310)787-0998

Home • Shopping Cart • Contact

Account Login

User ID

Password

GO

Forget Password | New Account

TAPES

- Conductive Grid Tape
- Green Masking Tape
- Kapton Tapes
  - 1 Mil Kapton Tape
  - 2 Mil Kapton Tape
  - 5 Mil Kapton Tape
  - Double Sided Tape
- Low Static Kapton Tape
- Solder Wave Tapes
- Water Soluble Tape

DOTS

- Kapton Disc
- Solder Wave Disc

Shopping Cart

Kapton® is a registered trademark of DuPont

5 Mil KAPTON® TAPE - RoHS Compliant

Data Sheet

- Ideal for wave soldering, insulating circuit boards, high temperature powder coating
- Has high dielectric strength
- Silicone adhesive protection without leaving a residue
- Temperature up to 500°F/260°C
- Conform to MIL-P-46112, TYPE I
- Custom sizes are available upon request

Kapton® is a registered trademark of DuPont

Part Number	Description	Price	Qty	Purchase
KPT5-1/4	1/4" x 36 yds roll	$31.98	1	BUY
KPT5-3/8	3/8" x 36 yds roll	$46.98	1	BUY
KPT5-1/2	1/2" x 36 yds roll	$62.99	1	BUY
KPT5-3/4	3/4" x 36 yds roll	$93.99	1	BUY
KPT5-1	1" x 36 yds roll	$124.99	1	BUY
KPT5-1 1/4	1 1/4" x 36 yds roll	$156.98	1	BUY
KPT5-1 1/2	1 1/2" x 36 yds roll	$187.98	1	BUY
KPT5-1 3/4	1 3/4" x 36 yds roll	$218.97	1	BUY
KPT5-2	2" x 36 yds roll	$249.98	1	BUY
KPT5-2 1/4	2 1/4" x 36 yds roll	$274.98	1	BUY
KPT5-2 1/2	2 1/2" x 36 yds roll	$298.98	1	BUY
KPT5-2 3/4	2 3/4" x 36 yds roll	$324.98	1	BUY
KPT5-3	3" x 36 yds roll	$349.98	1	BUY

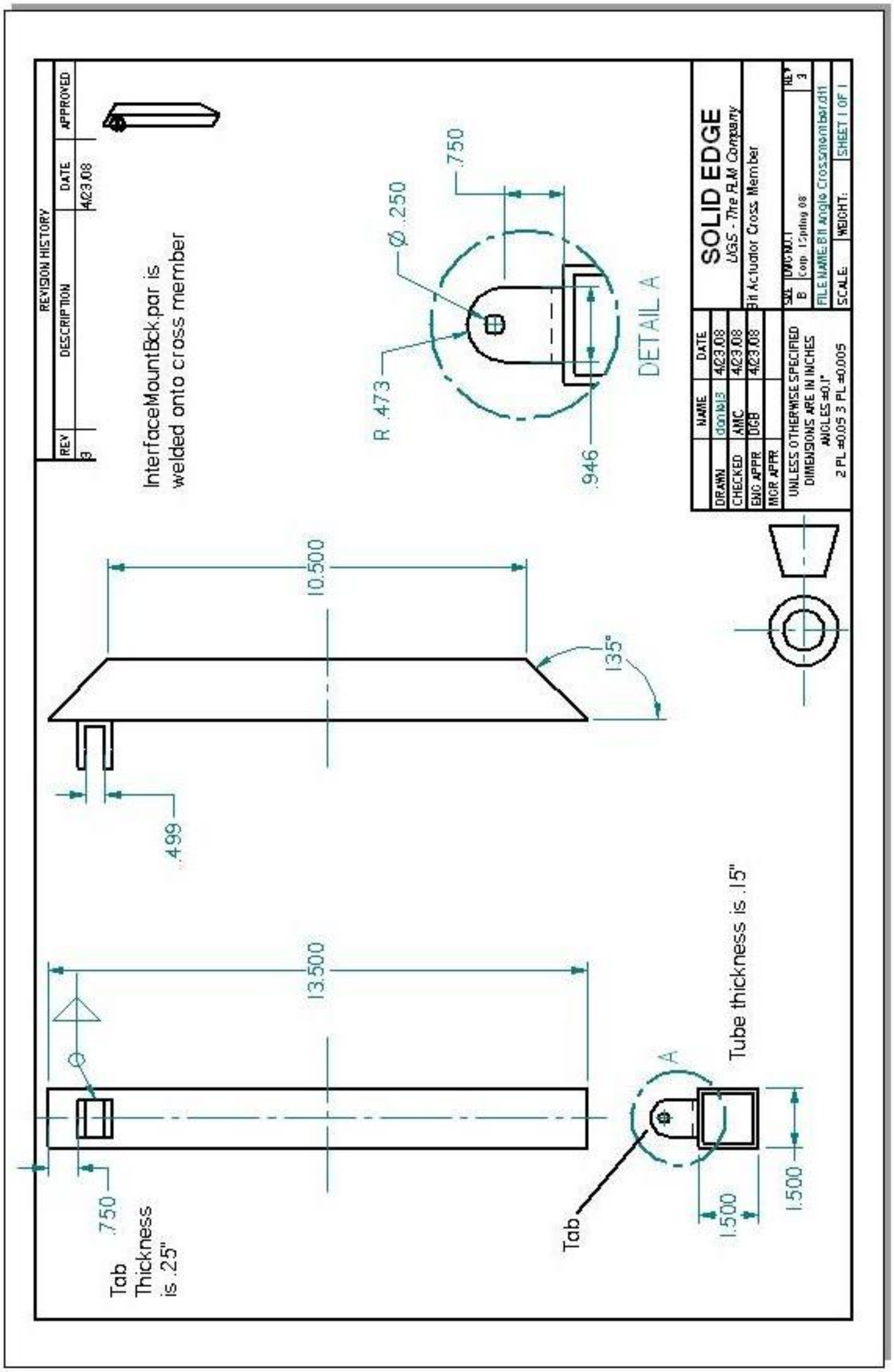
TERMS AND CONDITIONS

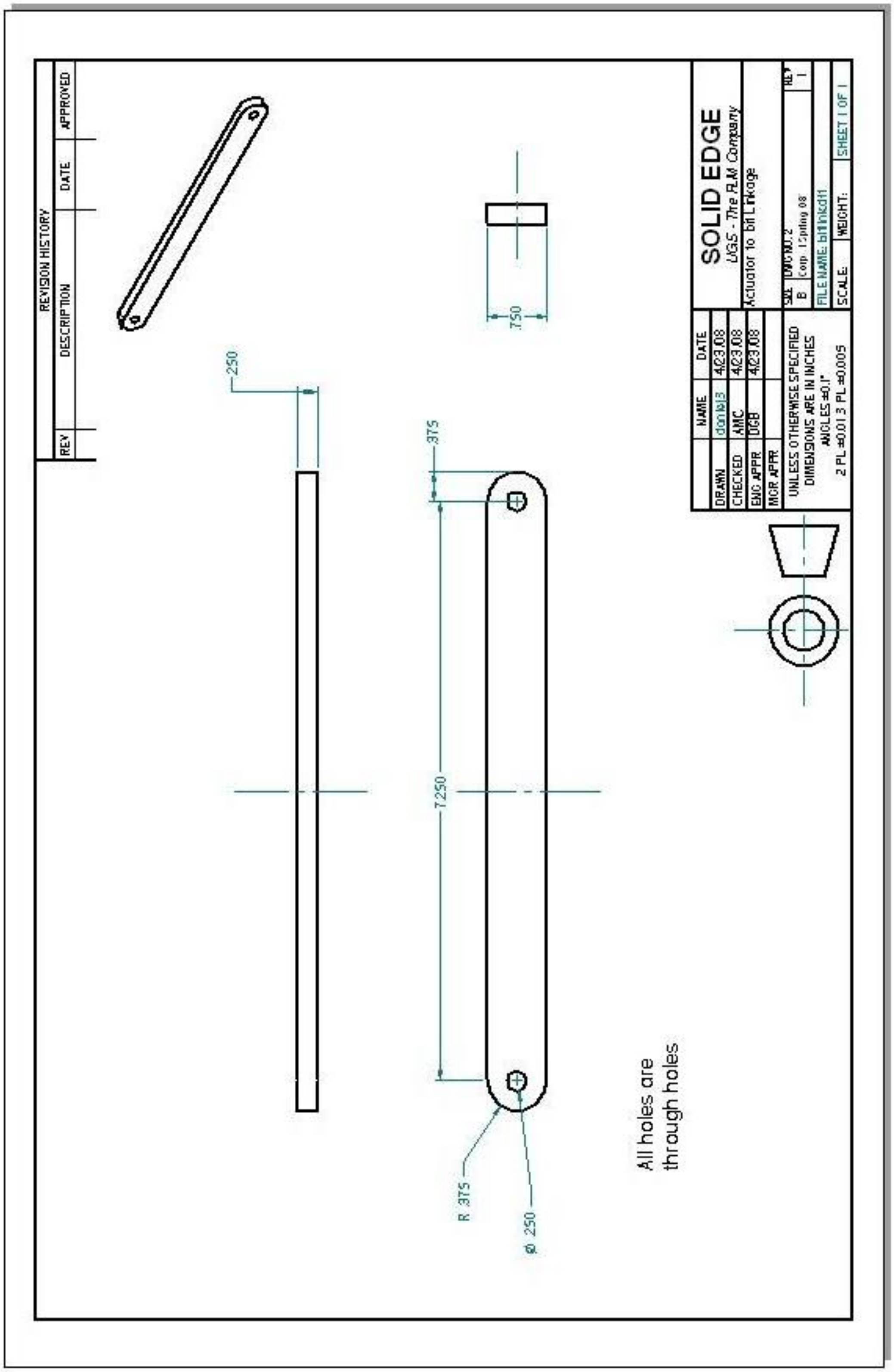
Related Links: ESD products • Masking Products • RF Connectors

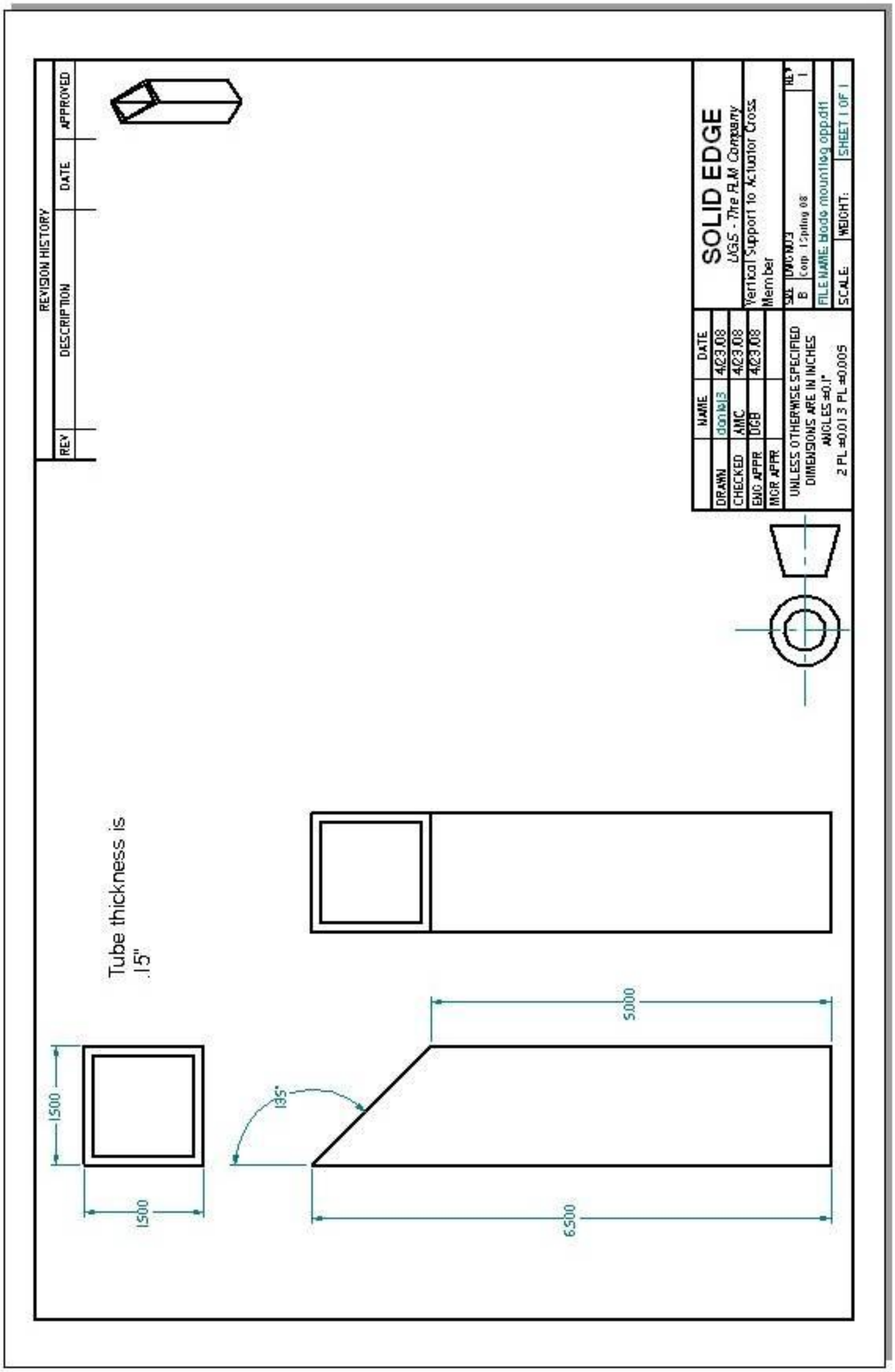
APPENDIX XIII – GANTT CHART (SCHEDULE)

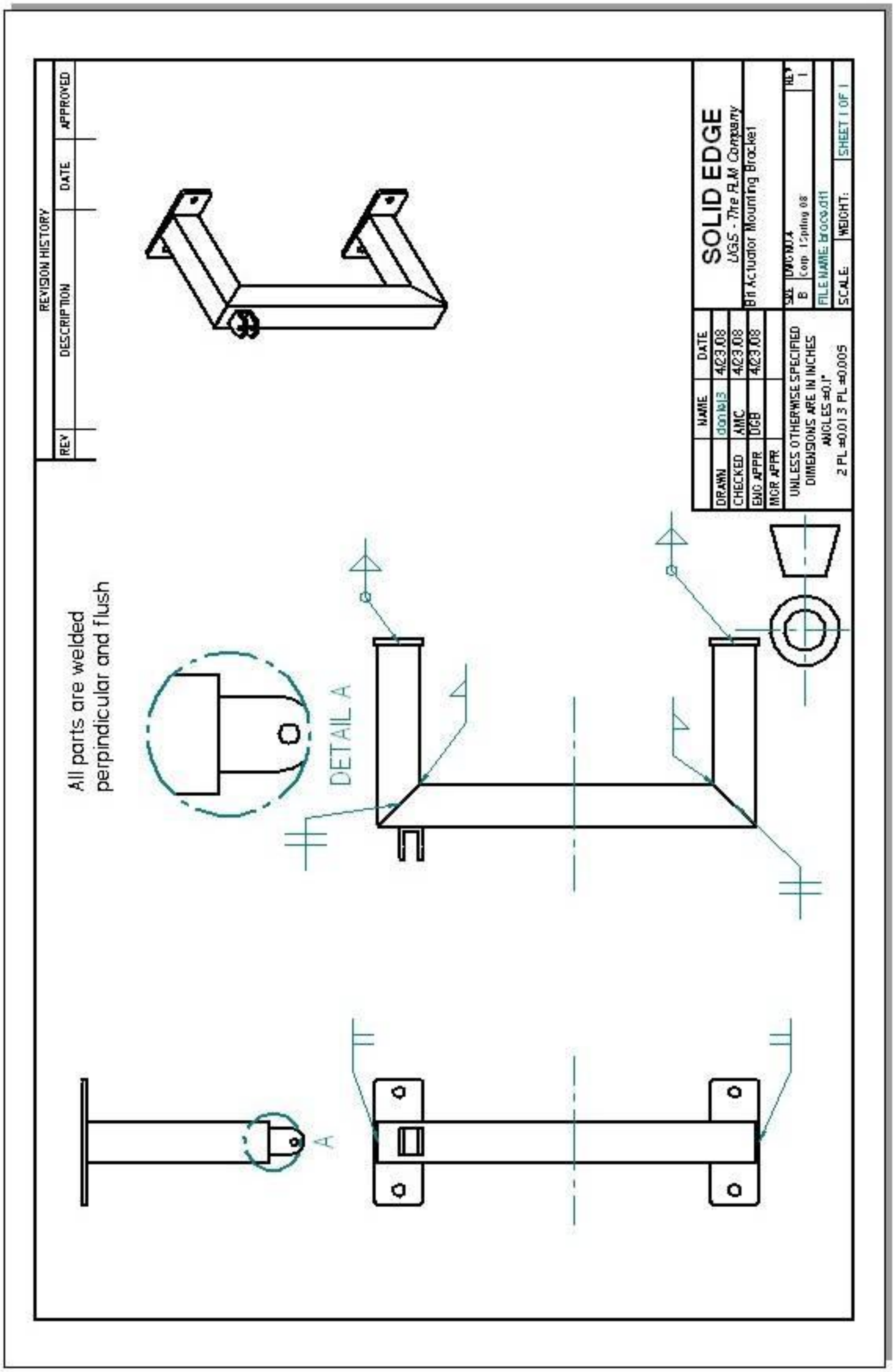
	Milestone	Assigned To	Schedule by Week											
	Associated Major Task		5/19 - 5/25	5/16 - 6/1	6/2 - 6/8	6/9 - 6/15	6/16 - 6/22	6/23 - 6/29	6/30-7/6	7/7 - 7/13	7/14- 7/20	7/21 - 7/27	7/28 - 8/3	8/4-8/13
	Overall Schedule													
	Receiving Parts, Fabrication and Assembly	Group												
	Testing	Group												
	Final Presentation and Delivery	Group												
	Journal	Group												
	Gantt Chart													
	Critical Path													
1	**Frame and Support Brackets**													
1.1	Receive Stock Material for Frame Rails and Support Brackets	Group												
1.2	Cut Members to Correct Dimmensions and Drill Hole	John, Allen												
1.3	Send Frame and Support Members to be Welded Together	Group												
2	**Machine Bit Components**													
2.1	Receive Stock Materials for Vibrational Bit	Group												
2.2.1	Machine Tray and Tray Components	John, Allen												
2.2.2	Send Tray and Tray Components to be Welded Together	Group												
2.3	Machine Voice Coil Mounts	Allen												
2.4	Machine Pillow Blocks	John												
2.5	Machine Vibrating U-Bracket	Allen												
2.6	Machine Linear Bearing Shaft	John												
2.7	Machine Bit Space	John												
2.8	Machine Spade Tip	John,Allen												
3	**Assemble Frame and Conveyor**													
3.1	Assemble Conveyor And conveyor Frame	Taylor, Nathan, Chris												
3.2	Assemble Main Frame and Supports	Taylor, Nathan, Chris												
3.3	Mount to Interface	Taylor, Nathan, Chris												
4	**Assemble Bit Components**													
4.1	Arrival of Voice Coils, Linear	Group												
4.2	Assemble Bit Components	Taylor												
4.2.1	Assemble Linear Bearings and Pillow Block	Chris												
4.2.2	Assemble Voice Coil and Mounts	Nathan												
4.2.3	Mount Pillow Blocks on Bit	John												
4.2.4	Mount Spade Tip and U-Bracket	Allen												
5	**Assemble Bit and Conveyor**	Group												
6	**Excavator Testing and Tuning**	Group												
7	**Midterm Presentation and Report**	Group												
8	**Final Presentation and Report**	Gourp												
8.1	Prepare Final Report and Presentation	Group												
8.2	Deliver Final Report	Group												

APPENDIX XIV – SOLID EDGE DRAWINGS

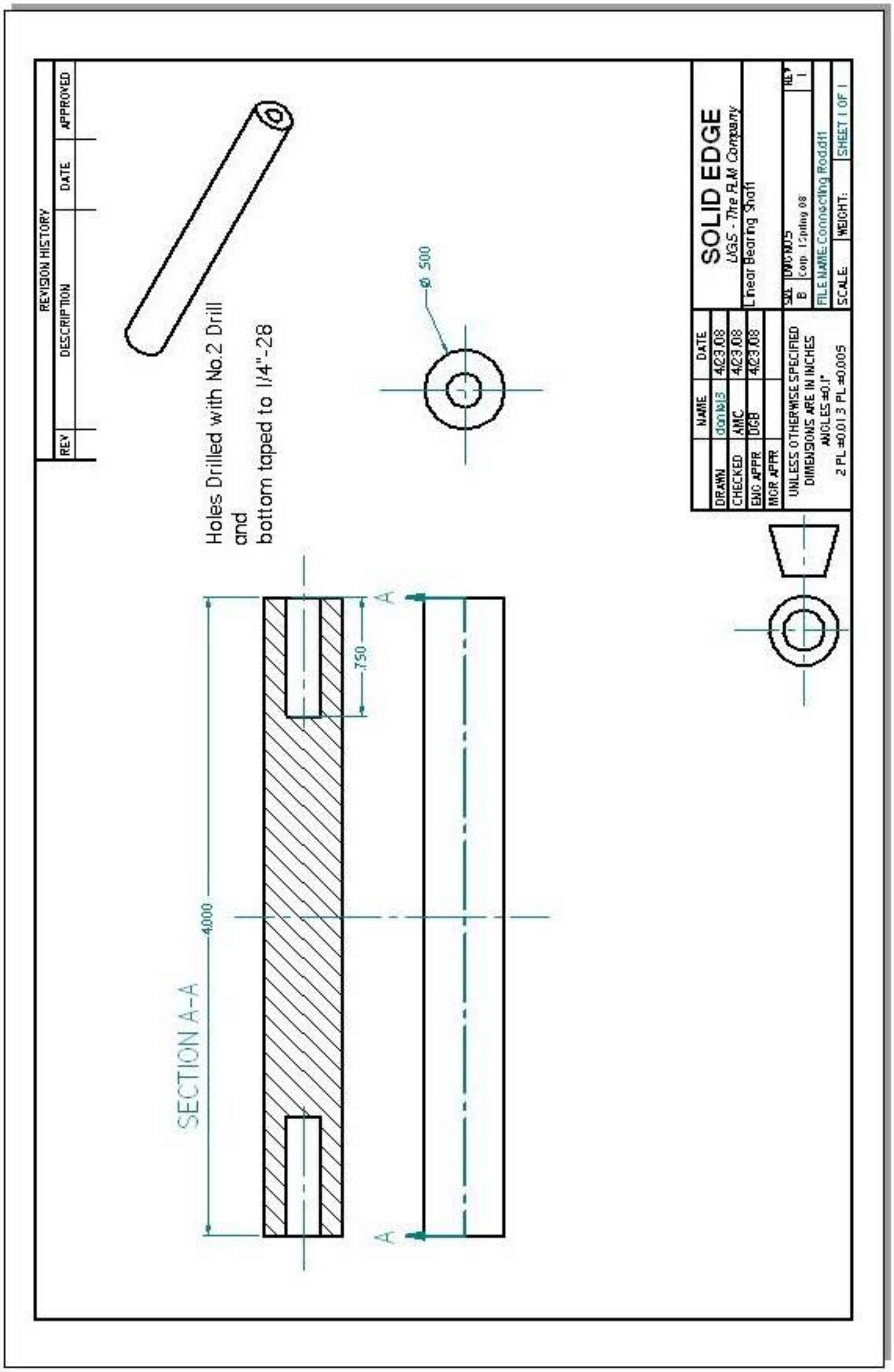

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
3
4/23/08
InterfaceMountBck.par is welded onto cross member
Ø .250
.750
R .473
.946
DETAIL A
10.500
135°
.499
13.500
Tube thickness is .15"
A
Tab Thickness is .25"
.750
Tab
1.500
1.500
SOLID EDGE
UGS - The PLM Company
Bit Actuator Cross Member
NAME
DATE
DRAWN
4/23/08
CHECKED
AMC
4/23/08
ENG APPR
DGB
4/23/08
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.05 3 PL ±0.005
B
SCALE:
WEIGHT:
SHEET 1 OF 1
REV
3


REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
.250
.375
7.250
.750
R .375
ø .250
All holes are through holes
DRAWN
CHECKED
ENG APPR
MGR APPR
NAME
DATE
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
SOLID EDGE
UGS - The PLM Company
SCALE:
WEIGHT:
SHEET 1 OF 1

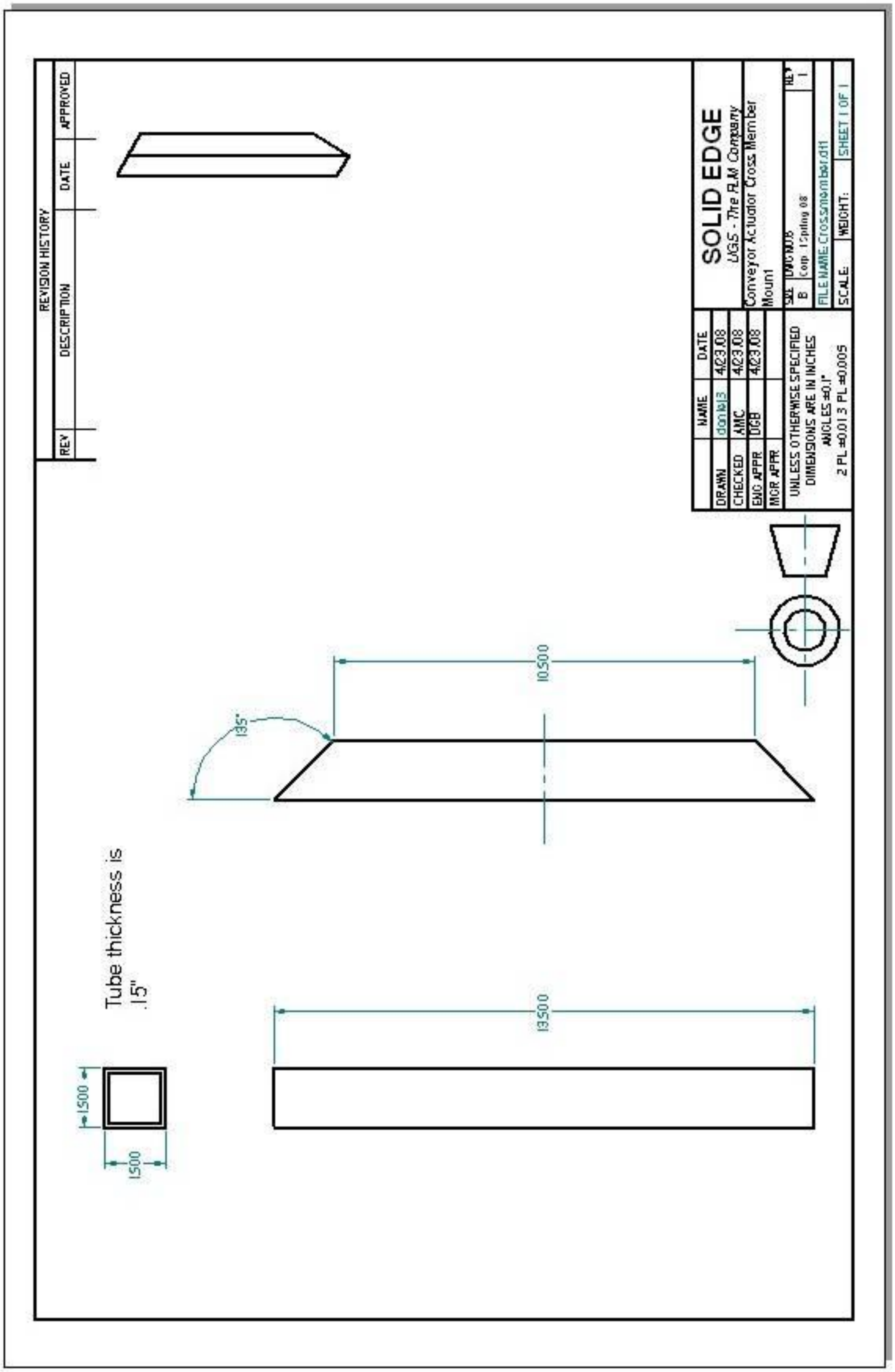

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
Tube thickness is
.15"
1.500
1.500
135°
5.000
6.500
NAME
DATE
DRAWN
CHECKED
ENG APPR
MGR APPR
AMC
4/23/08
DGB
4/23/08
4/23/08
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Vertical Support to Actuator Cross
Member
SIZE
B
SCALE:
WEIGHT:
SHEET 1 OF 1

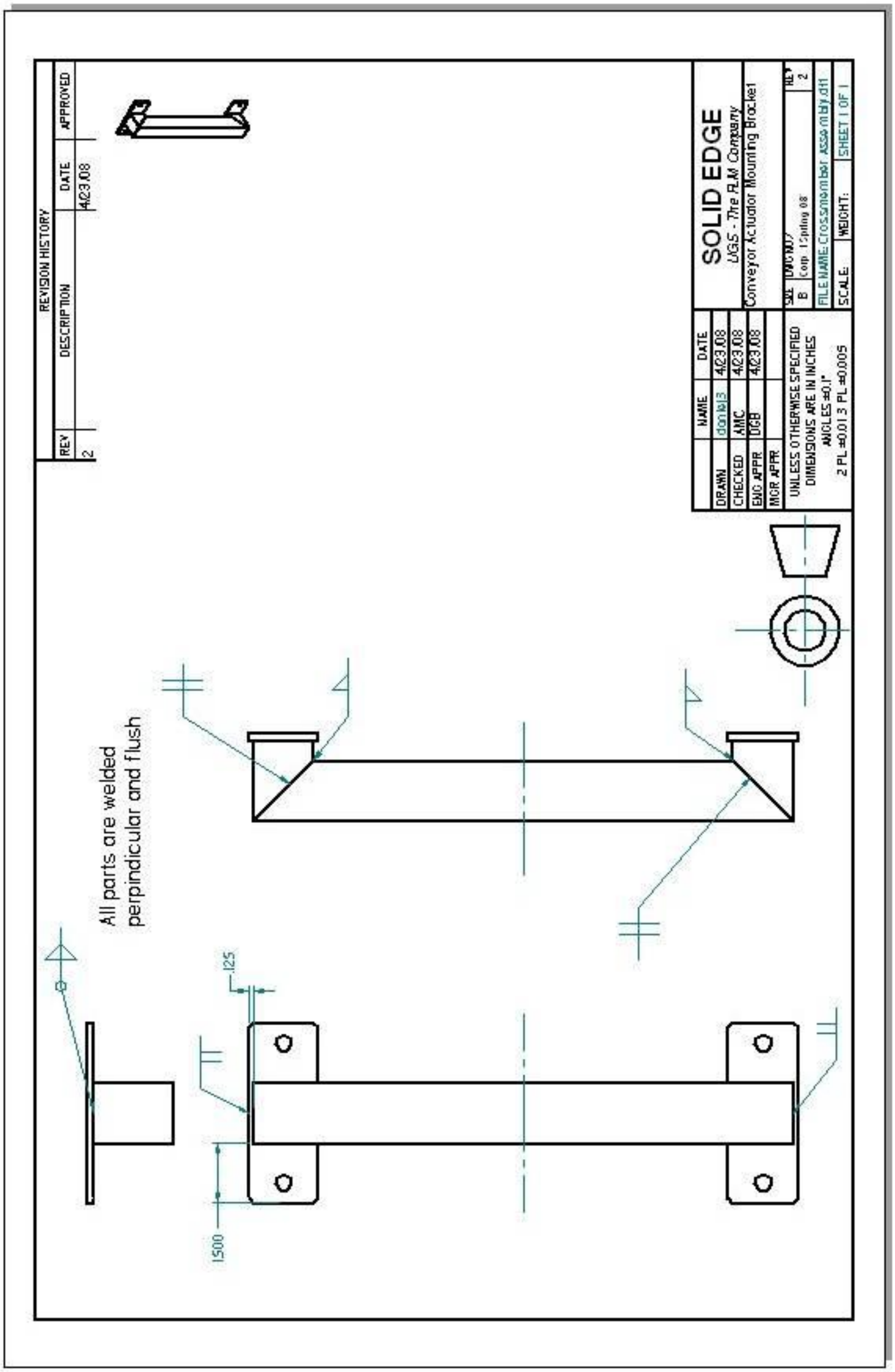


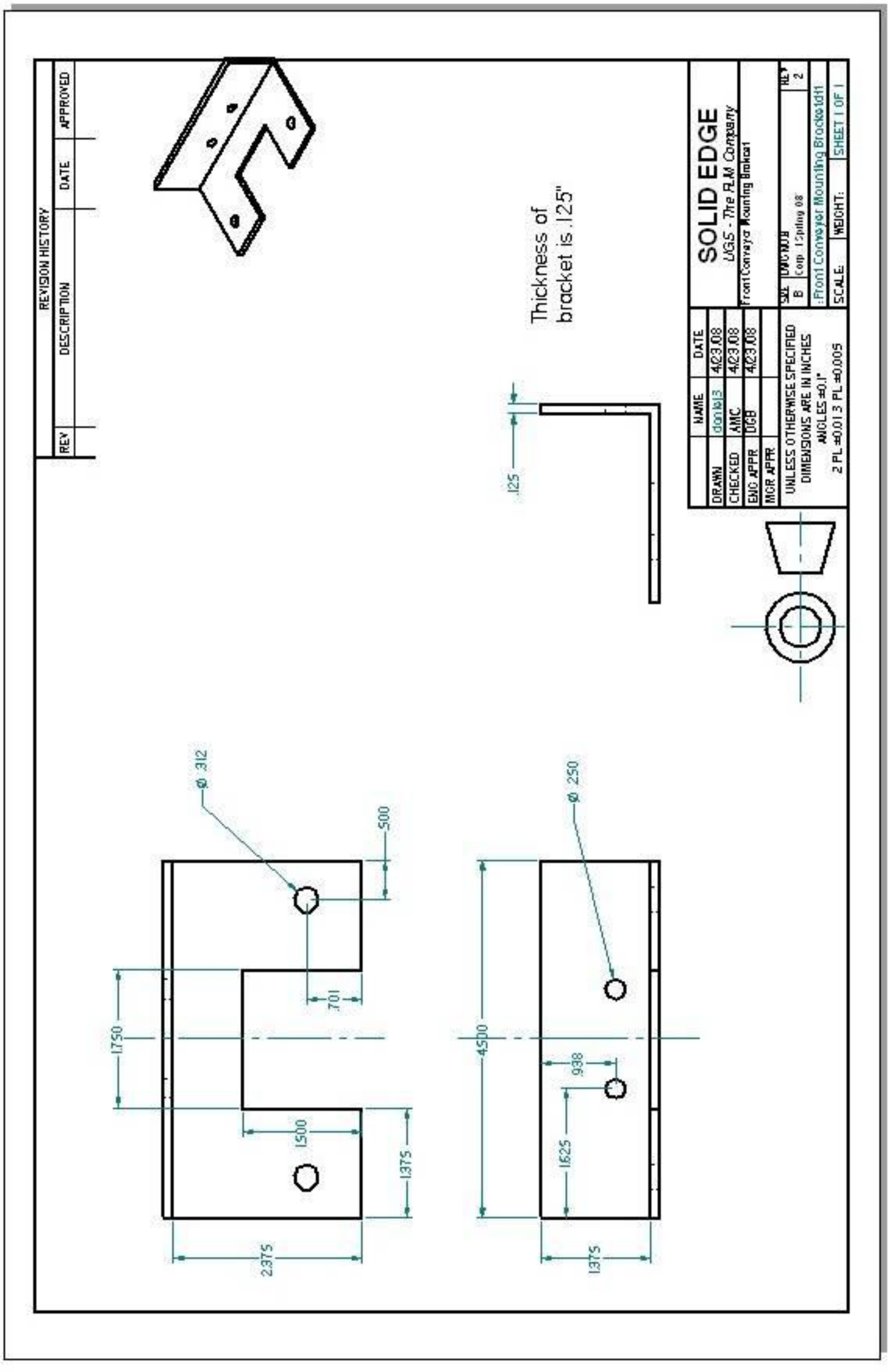
REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
All parts are welded
perpindicular and flush
DETAIL A
A
DRAWN
CHECKED
ENG APPR
MGR APPR
NAME
DATE
danlel3
4/23/08
AMC
4/23/08
DGB
4/23/08
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Actuator Mounting Bracket
SIZE
B
Corp 1 Spring 08
REV
1
FILE NAME: brace.dft
SCALE:
WEIGHT:
SHEET 1 OF 1

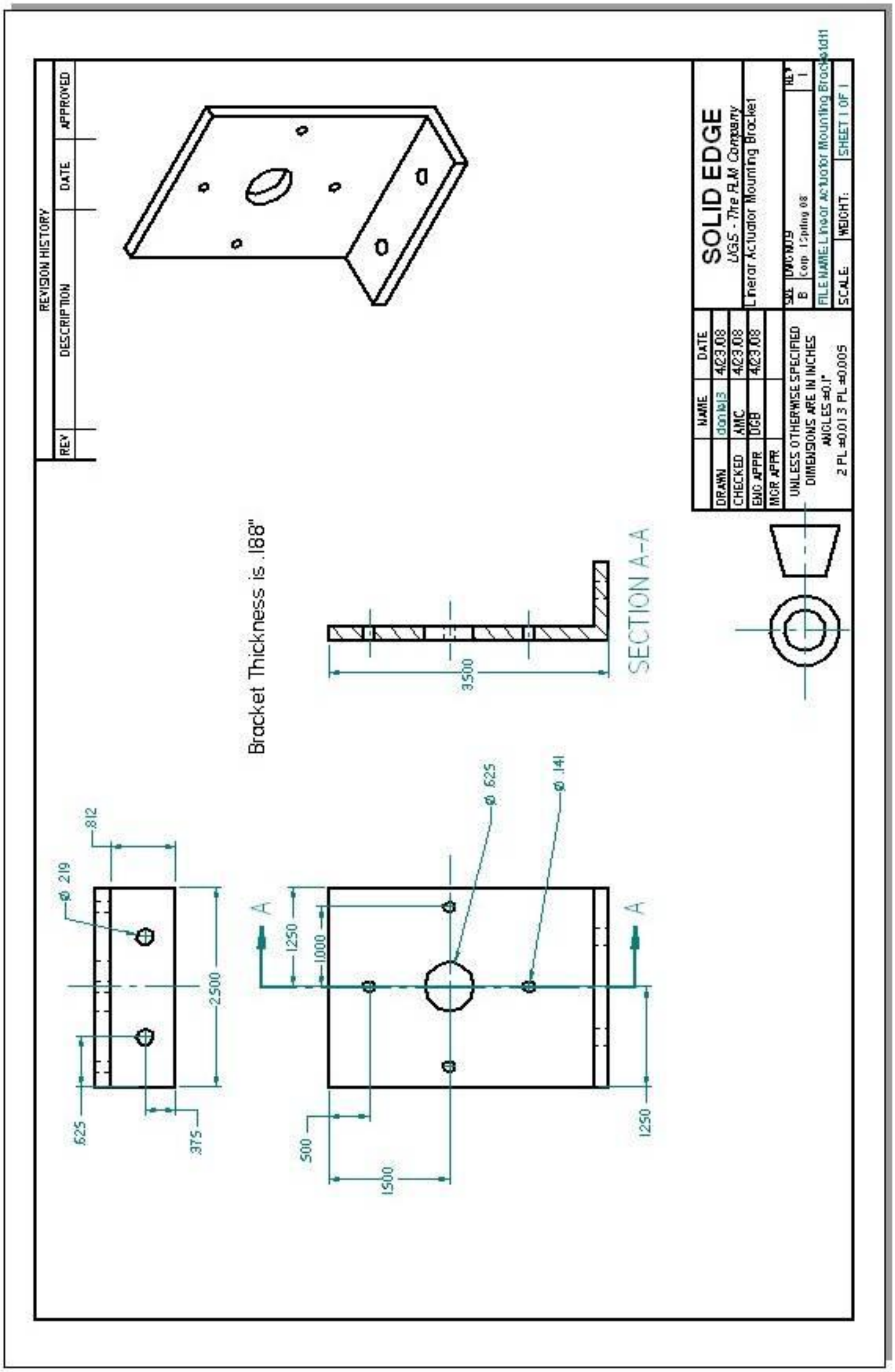


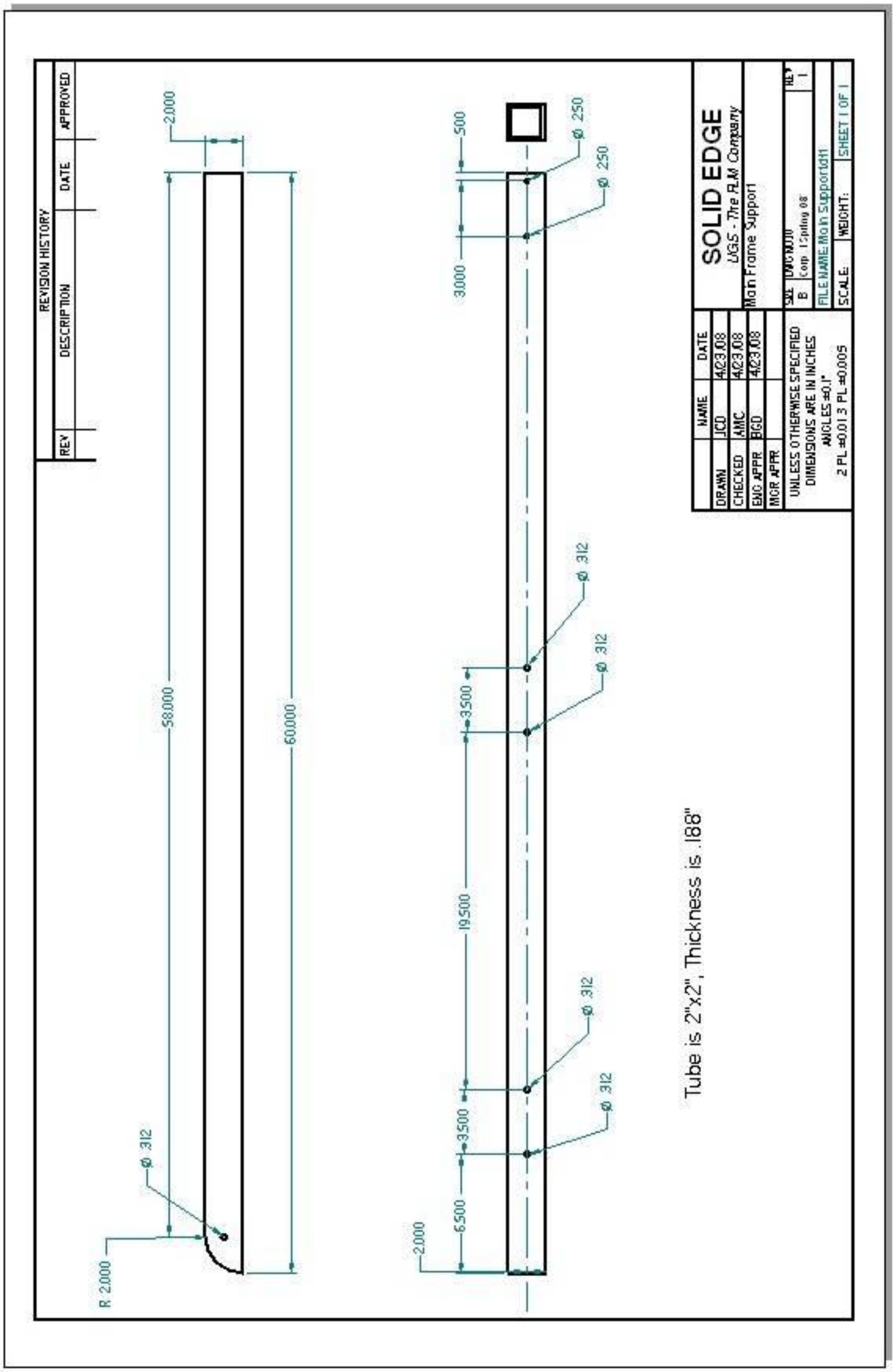
REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
Holes Drilled with No.2 Drill
and
bottom taped to 1/4"-28
Ø .500
SECTION A-A
4.000
.750
A
A
NAME
DATE
DRAWN
danlel3
4/23/08
CHECKED
AMC
4/23/08
ENG APPR
DGB
4/23/08
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Linear Bearing Shaft
SIZE
B
REV
1
FILE NAME: Connecting Rod.dft
SCALE:
WEIGHT:
SHEET 1 OF 1

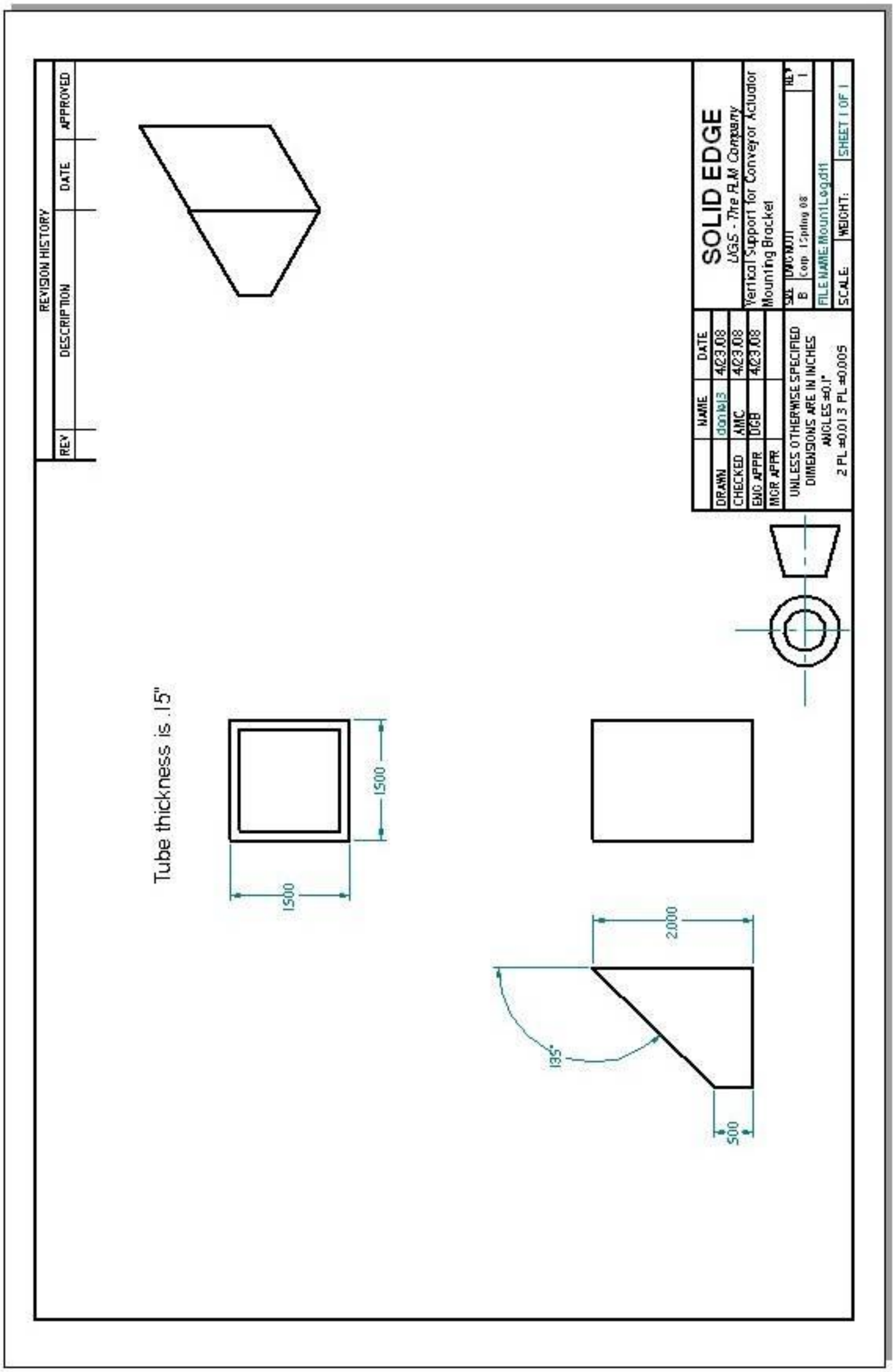

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
Tube thickness is .15"
1.500
1.500
13.500
10.500
135°
DRAWN daniel3 4/23/08
CHECKED AMC 4/23/08
ENG APPR DGB 4/23/08
MGR APPR
NAME
DATE
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Conveyor Actuator Cross Member Mount
SIZE B
REV 1
FILE NAME: Crossmember.dft
SCALE:
WEIGHT:
SHEET 1 OF 1

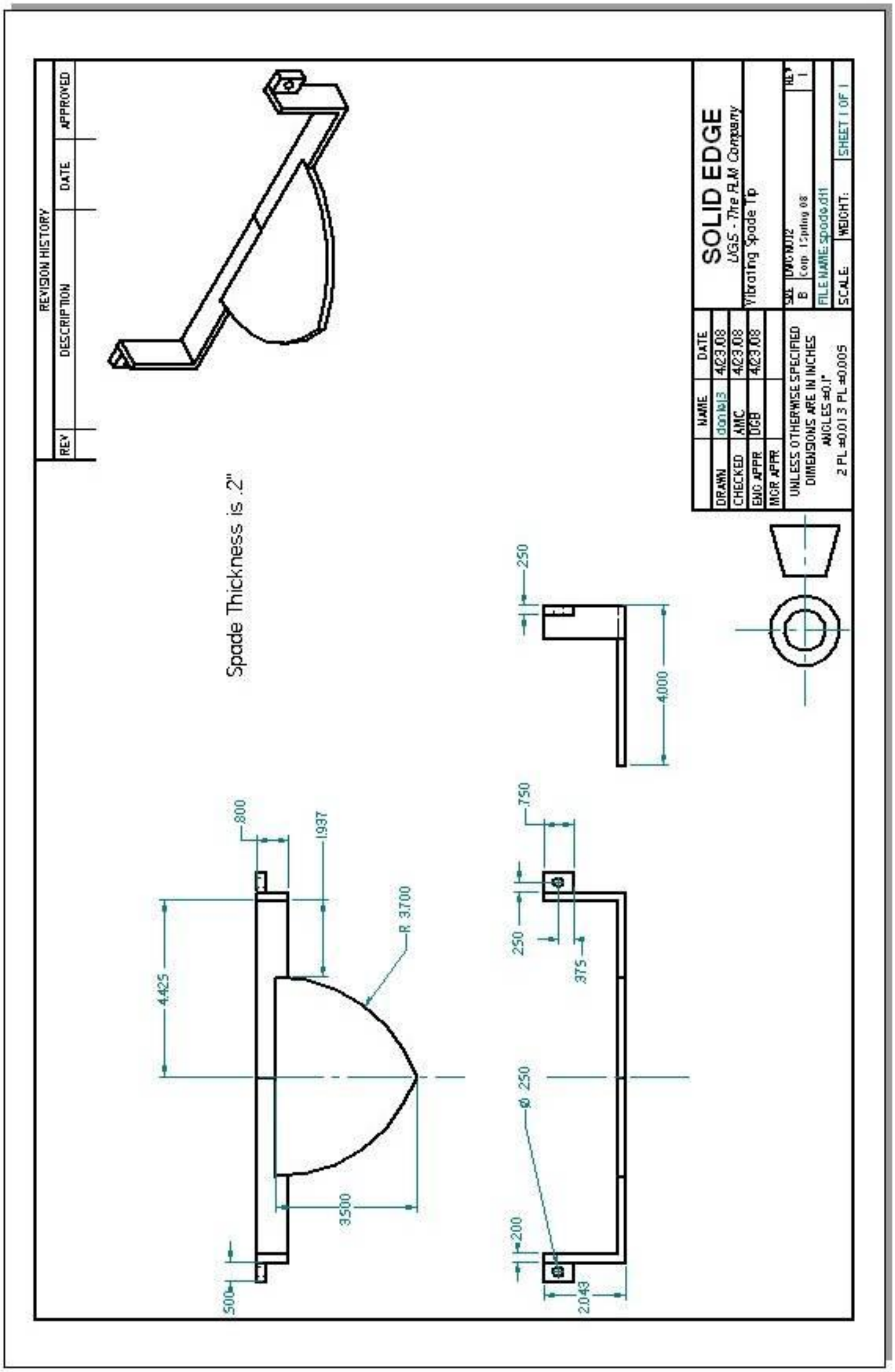

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
2
4/23/08
All parts are welded
perpindicular and flush
.125
1500
NAME
DATE
DRAWN
CHECKED
AMC
4/23/08
ENG APPR
DGB
4/23/08
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
SOLID EDGE
UGS - The PLM Company
Conveyor Actuator Mounting Bracket
B
REV
2
SCALE:
WEIGHT:
SHEET 1 OF 1

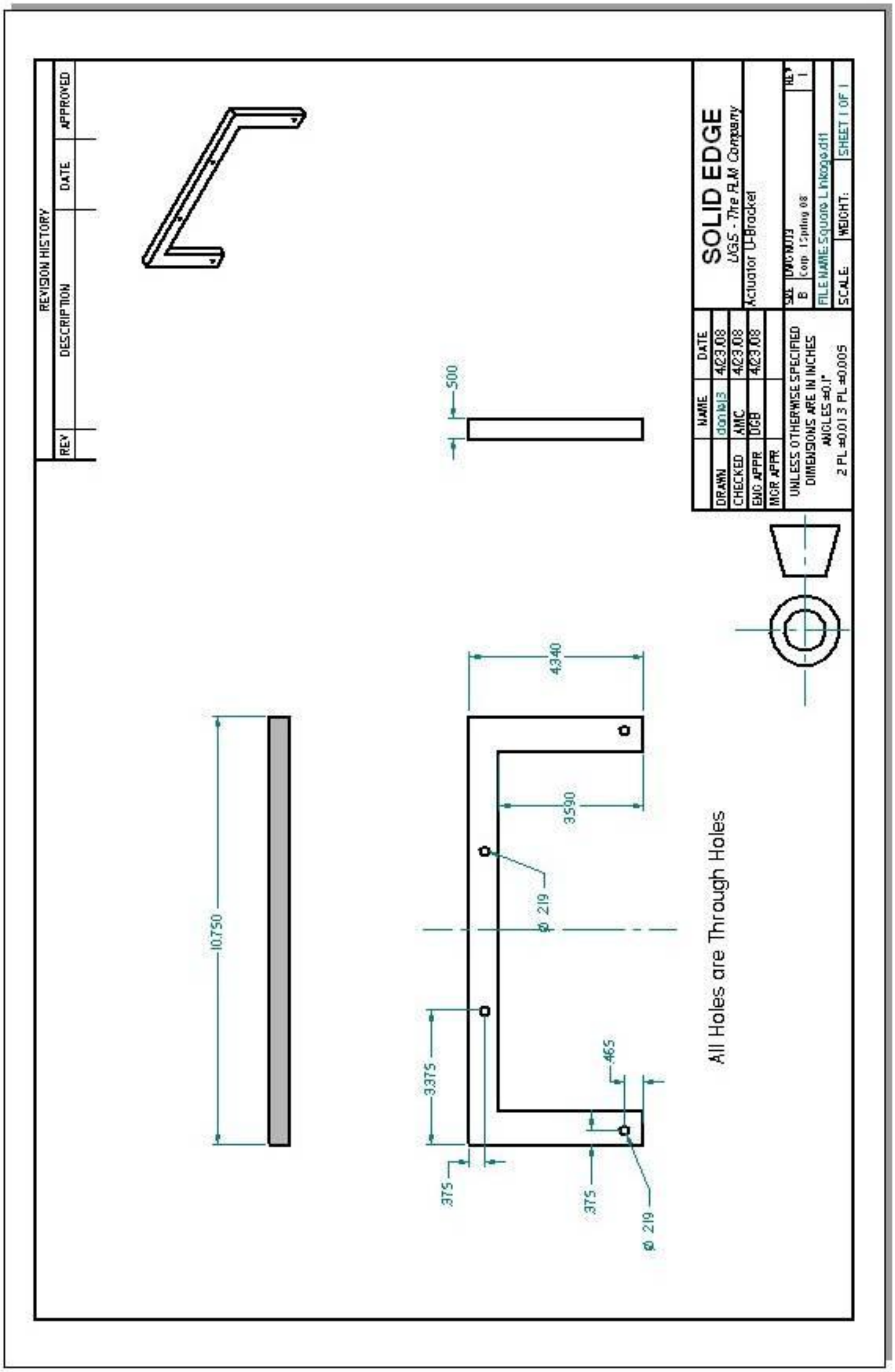

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
Thickness of bracket is .125"
.125
Ø .312
Ø .250
.500
.701
1.750
1.500
1.375
2.375
4.500
.938
1.625
1.375
DRAWN
CHECKED
ENG APPR
MGR APPR
NAME
DATE
4/23/08
4/23/08
4/23/08
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
SIZE
B
REV
2
SCALE:
WEIGHT:
SHEET 1 OF 1

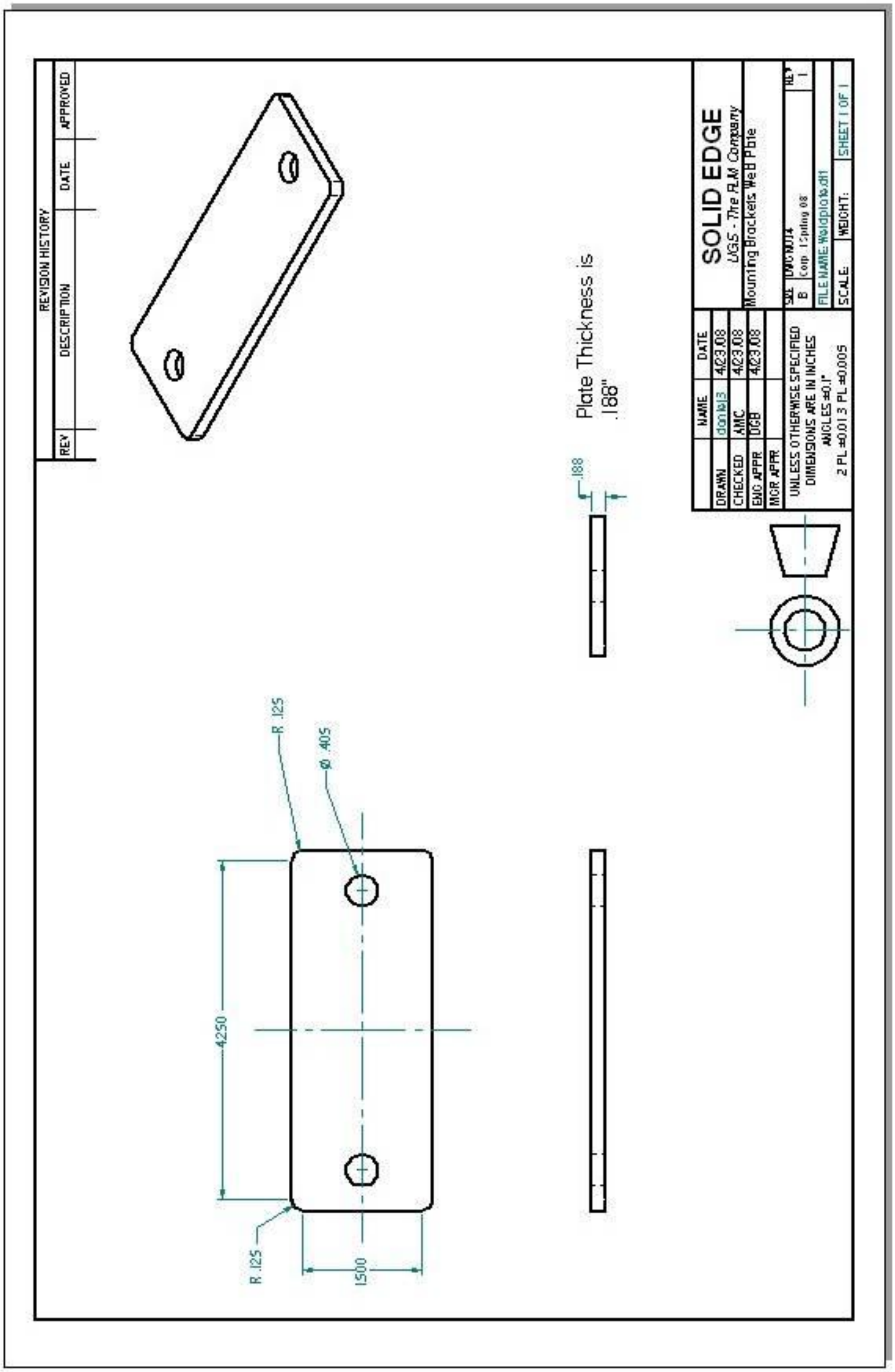

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
Bracket Thickness is .188"
SECTION A-A
A
Ø .219
Ø .625
Ø .141
.812
2.500
3.500
1.250
1.000
.625
.375
.500
1.500
DRAWN
CHECKED
ENG APPR
MGR APPR
NAME
DATE
4/23/08
AMC
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Linear Actuator Mounting Bracket
SIZE
B
REV
1
SCALE:
WEIGHT:
SHEET 1 OF 1


REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
2.000
58.000
60.000
R 2.000
Ø .312
500
3.000
Ø .250
Ø .250
3.500
19.500
3.500
6.500
2.000
Ø .312
Ø .312
Ø .312
Ø .312
Tube is 2"x2", Thickness is .188"
NAME
DATE
DRAWN
JCD
4/23/08
CHECKED
AMC
4/23/08
ENG APPR
BGD
4/23/08
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Main Frame Support
SIZE
B
REV
1
FILE NAME: Main Support.dft
SCALE:
WEIGHT:
SHEET 1 OF 1

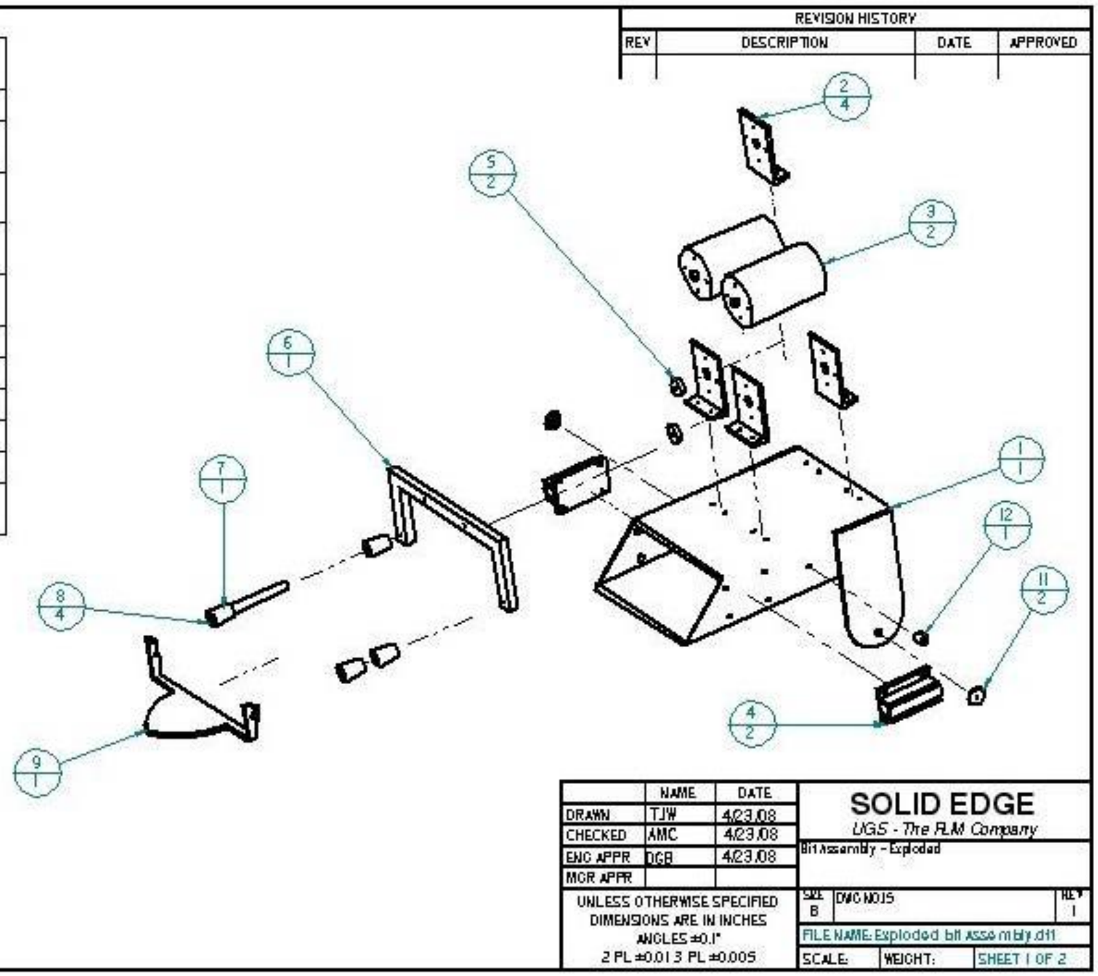

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
Tube thickness is .15"
135°
NAME
DATE
DRAWN
4/23/08
CHECKED
AMC
4/23/08
ENG APPR
DGB
4/23/08
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Vertical Support for Conveyor Actuator
Mounting Bracket
SIZE
DWG NO
B
REV
1
SCALE:
WEIGHT:
SHEET 1 OF 1


REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
Spade Thickness is .2"
4.425
.800
1.937
R 3.700
3.500
.500
.250
.750
.375
Ø .250
.200
2.043
4.000
DRAWN
CHECKED
ENG APPR
MGR APPR
NAME
DATE
AMC
DGB
4/23/08
4/23/08
4/23/08
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Vibrating Spade Tip
SIZE
B
FILE NAME: spade.dft
SCALE:
WEIGHT:
SHEET 1 OF 1
REV
1

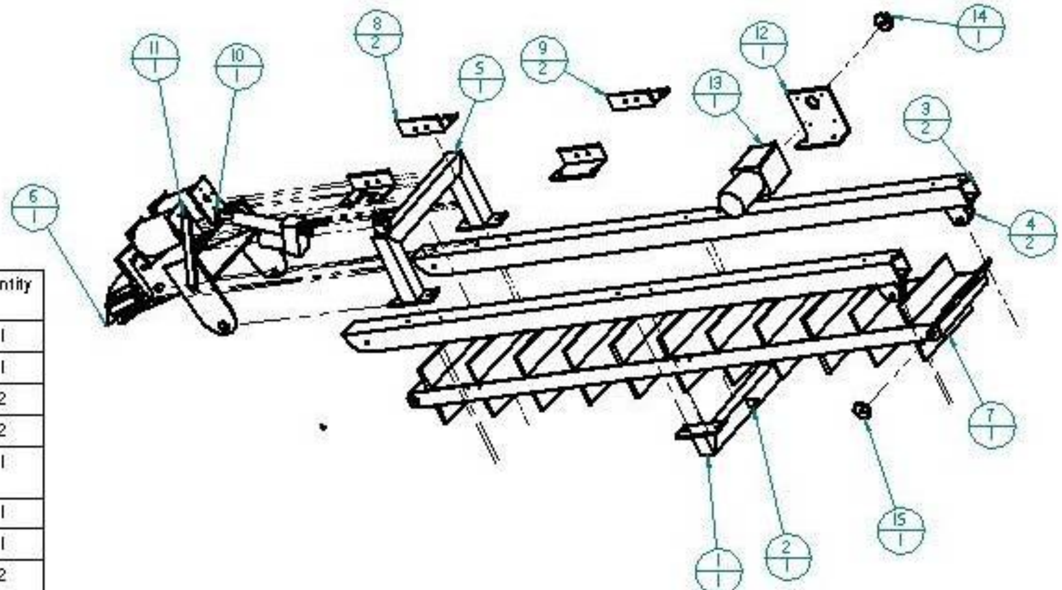

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
.500
4.340
3.590
⌀ .219
10.750
3.375
.465
.375
.375
⌀ .219
All Holes are Through Holes
NAME
DATE
DRAWN
4/23/08
CHECKED
AMC
4/23/08
ENG APPR
DGB
4/23/08
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Actuator U-Bracket
SIZE
B
FILE NAME: Square Linkage.dft
SCALE:
WEIGHT:
SHEET 1 OF 1
REV
1


REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
R .125
Ø .405
4.250
1.500
R .125
.188
Plate Thickness is
.188"
NAME
DATE
DRAWN
4/23/08
CHECKED
AMC
4/23/08
ENG APPR
DGB
4/23/08
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Mounting Brackets Weld Plate
SIZE
B
FILE NAME: Weldplate.dft
SCALE:
WEIGHT:
SHEET 1 OF 1
REV
1

Item Number	Title	Quantity
1	TRAY	1
2	BRACKET, MOUNTING, ACTUATOR	4
3	ACTUATOR, LINEAR VOICE COIL	2
4	PILLOW BLOCK, LINEAR BEARING	2
5	SPACER, ACUATOR, RUBBER	2
6	BRACKET, CONNECTING	1
7	SHAFT, LINEAR BEARING	1
8	BEARING, LINEAR, SEALED	4
9	BLADE TIP	1
11	BUSHING, RUBBER	2
12	SPACER, BIT ADJUSTMENT LINK	1



REVISION HISTORY			
REV	DESCRIPTION	DATE	APPROVED



Item Number	Title	Quantity
1	Crossmember, Bottom	1
2	Tab, Actuator Mount	1
3	Frame Rail	2
4	Conveyer Clevis	2
5	Crossmember, Vibrating Bit Actuator	1
6	Vibrating Bit Assembly	1
7	Conveyer Belt	1
8	Front Conveyor Mounting Bracket	2
9	Rear Conveyor Mounting Bracket	2
10	Bit Actuator	1
11	Actuator Link, Vibrating Bit	1
12	Motor Bracket	1
13	Motor	1
14	Motor Sprocket	1
15	Conveyor Sprocket	1

	NAME	DATE
DRAWN	TJW	4/23/08
CHECKED	AMC	4/23/08
ENG APPR	DGB	4/23/08
MGR APPR		

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±XX°
2 PL ±XXX 3 PL ±XXXX

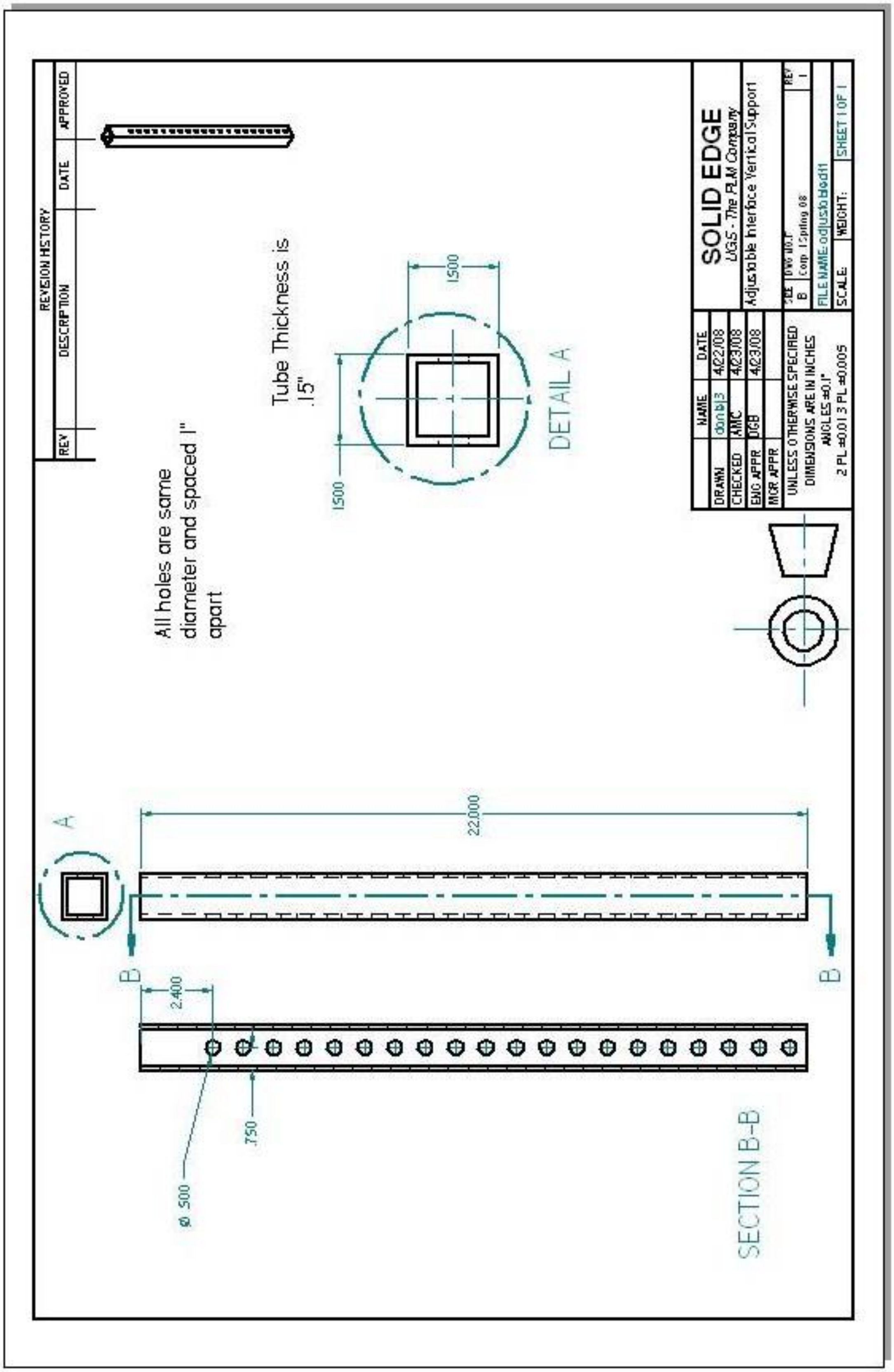
SOLID EDGE
UGS - The PLM Company

TITLE
Frame Assembly-Exploded

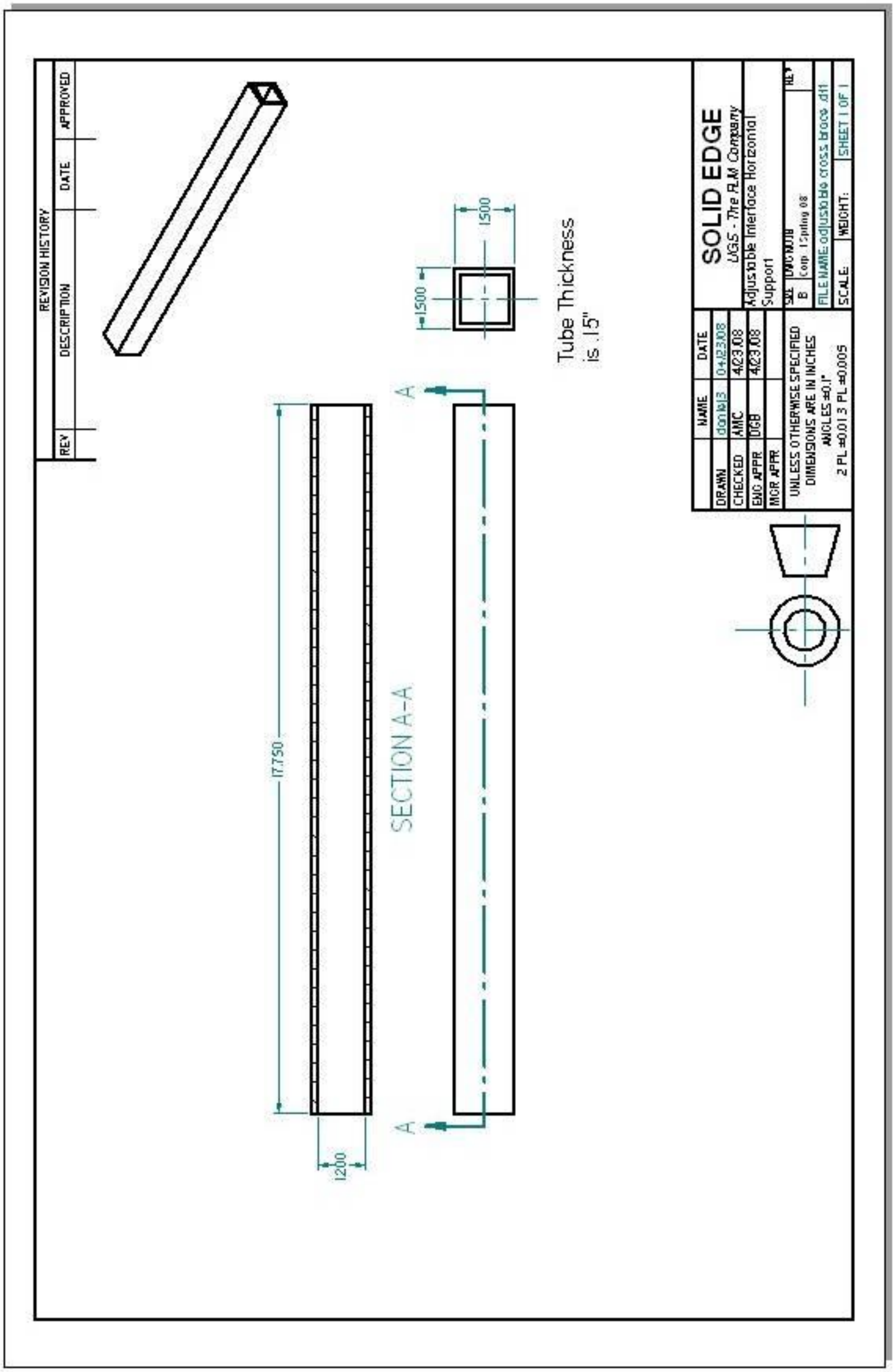
SIZE	DWG NO	REV
B	16	1

FILE NAME: Explode Frame Assembly1.dft

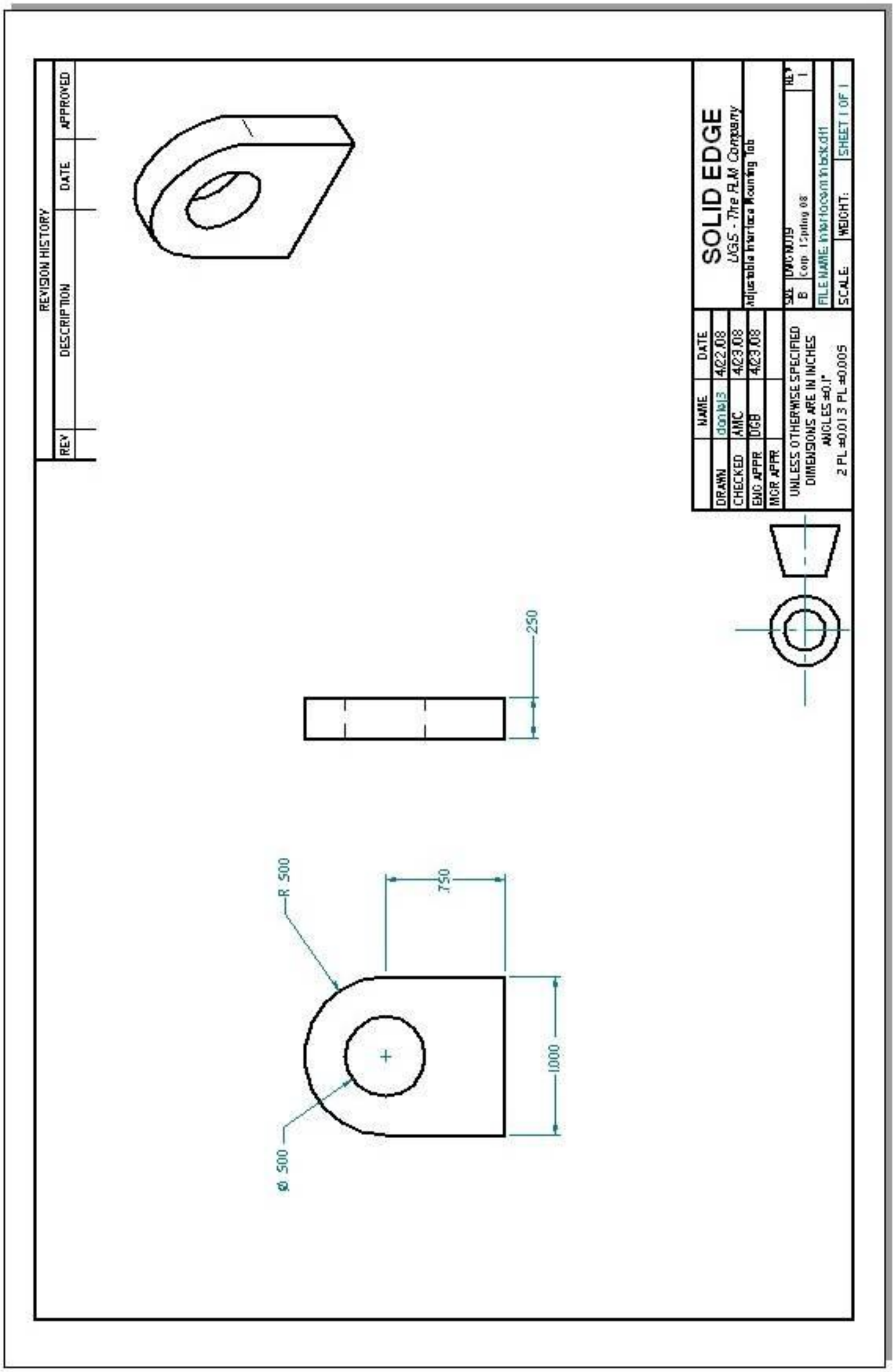
SCALE:	WEIGHT:	SHEET 1 OF 1

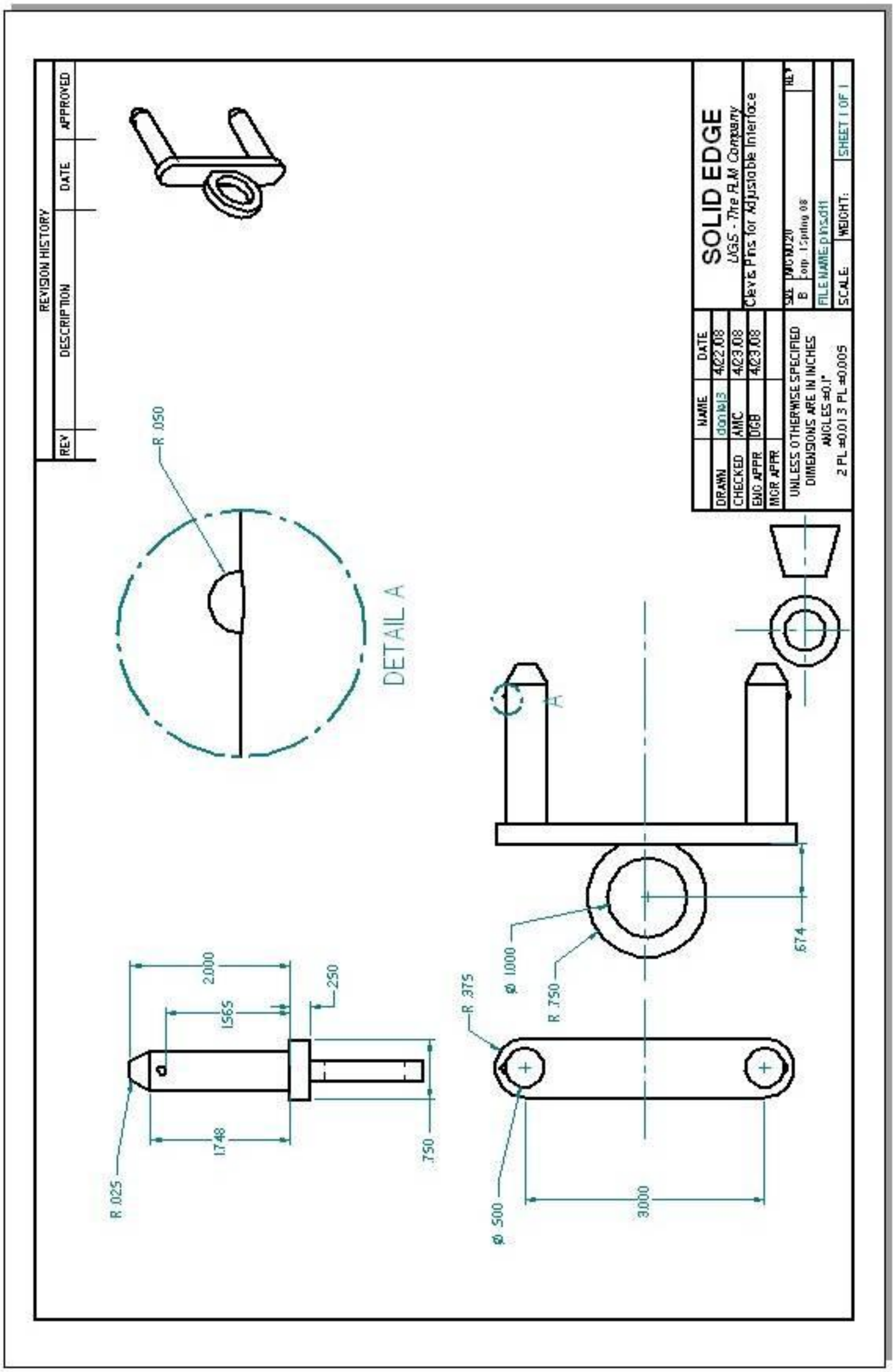


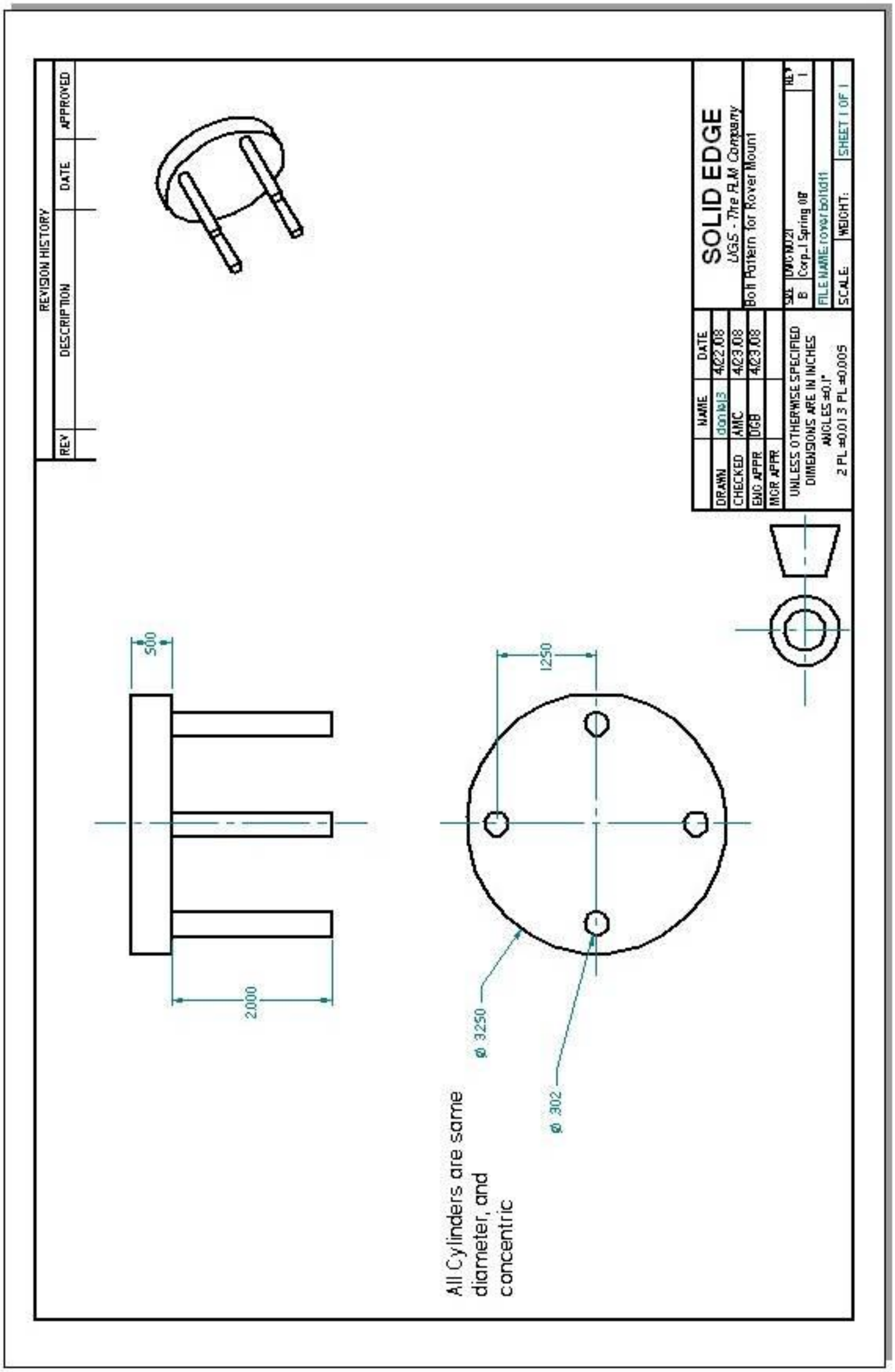
REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
All holes are same diameter and spaced 1" apart
Tube Thickness is .15"
1500
1500
DETAIL A
A
22.000
B
B
2.400
Ø .500
.750
SECTION B-B
SOLID EDGE
UGS - The PLM Company
Adjustable Interface Vertical Support
NAME
DATE
DRAWN
CHECKED
AMC
4/23/08
ENG APPR
DGB
4/23/08
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SCALE:
WEIGHT:
SHEET 1 OF 1
REV
1

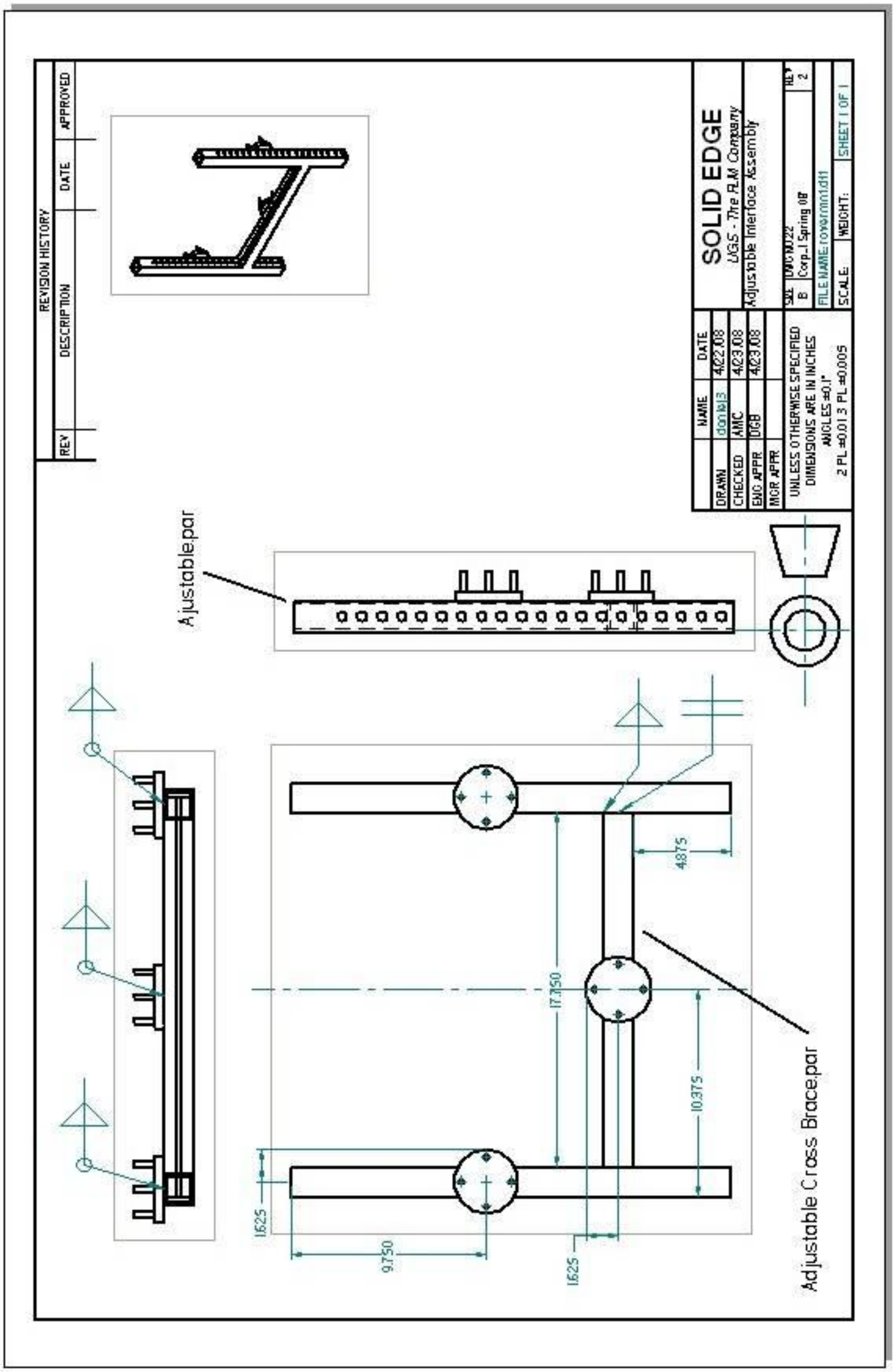


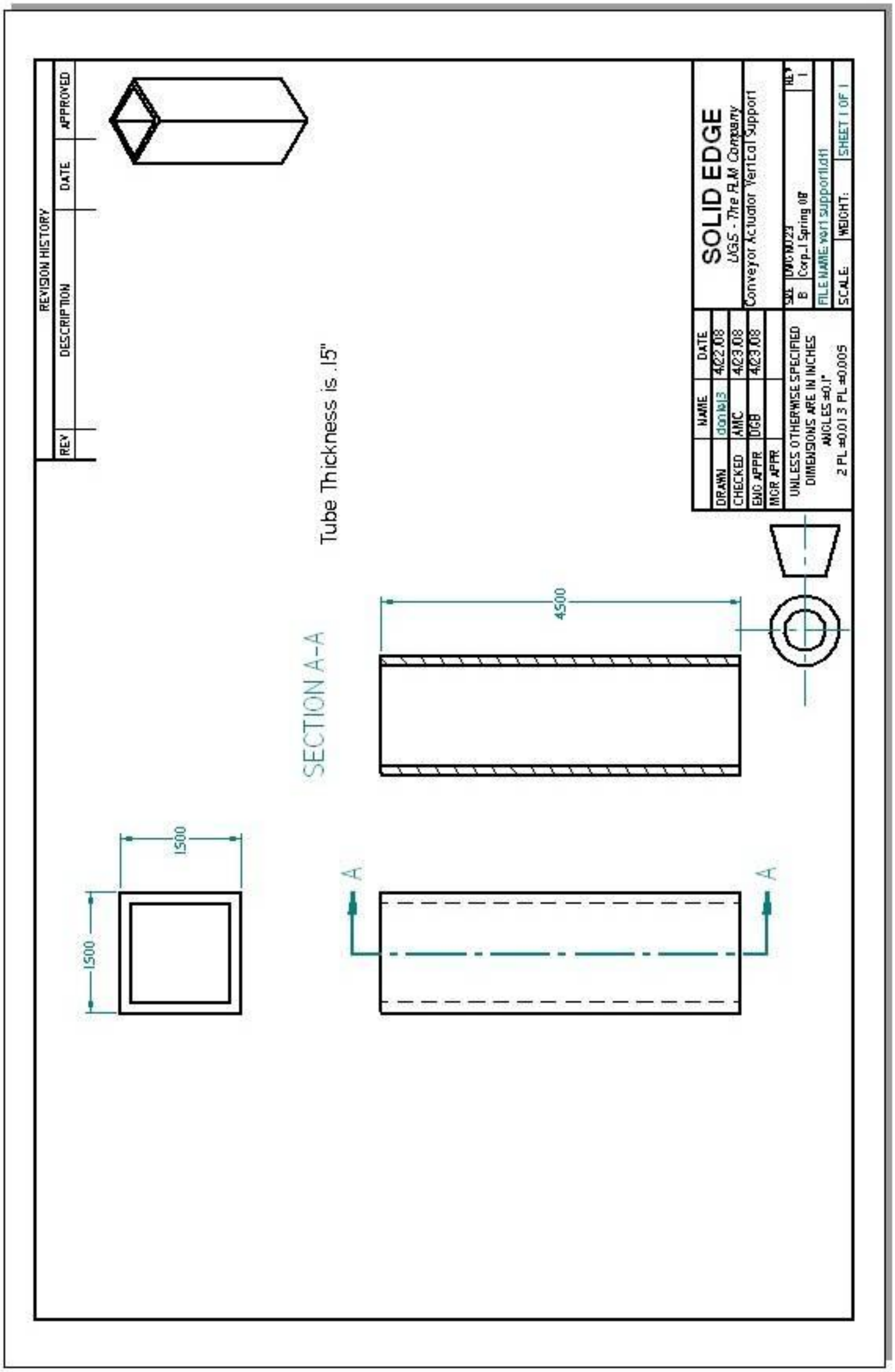
REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
17.750
1200
SECTION A-A
A
A
1500
1500
Tube Thickness is .15"
SOLID EDGE
UGS - The PLM Company
Adjustable Interface Horizontal Support
NAME
DATE
DRAWN
daniels
04/23/08
CHECKED
AMC
4/23/08
ENG APPR
DGB
4/23/08
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SIZE
B
REV
FILE NAME: adjustable cross brace.dft
SCALE:
WEIGHT:
SHEET 1 OF 1

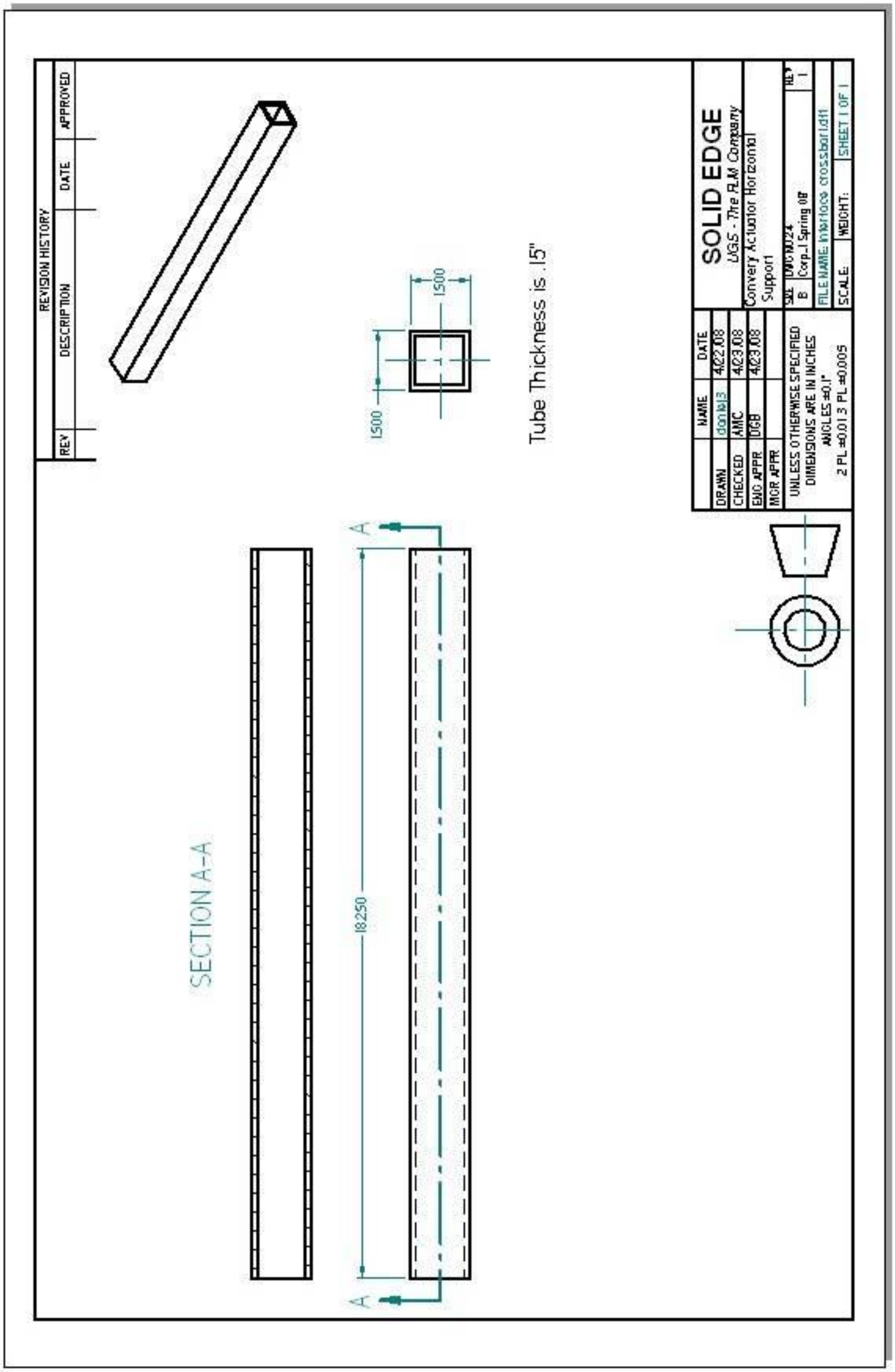

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
R .500
.750
.250
1.000
Ø .500
NAME
DATE
DRAWN
CHECKED
ENG APPR
MGR APPR
AMC
DGB
4/22/08
4/23/08
4/23/08
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
SIZE
B
REV
1
SCALE:
WEIGHT:
SHEET 1 OF 1

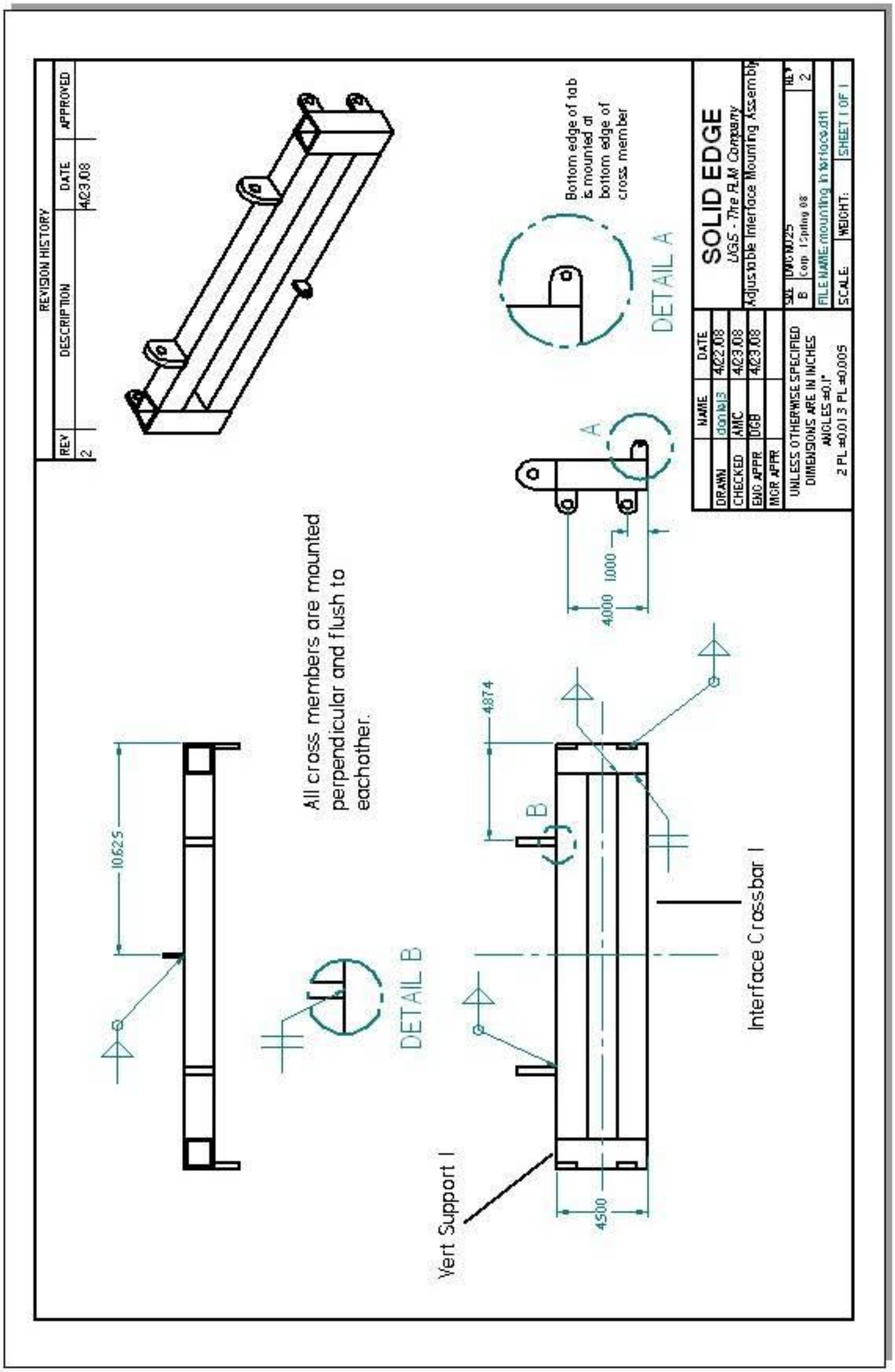

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
R .050
DETAIL A
A
2.000
1.565
.250
1.748
.750
R .025
R .375
ø 1.000
R .750
.674
ø .500
3.000
SOLID EDGE
UGS - The PLM Company
Clevis Pins for Adjustable Interface
NAME
DATE
DRAWN
danielj3
4/22/08
CHECKED
AMC
4/23/08
ENG APPR
DGB
4/23/08
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SIZE
B
REV
FILE NAME: pins.dft
SCALE:
WEIGHT:
SHEET 1 OF 1

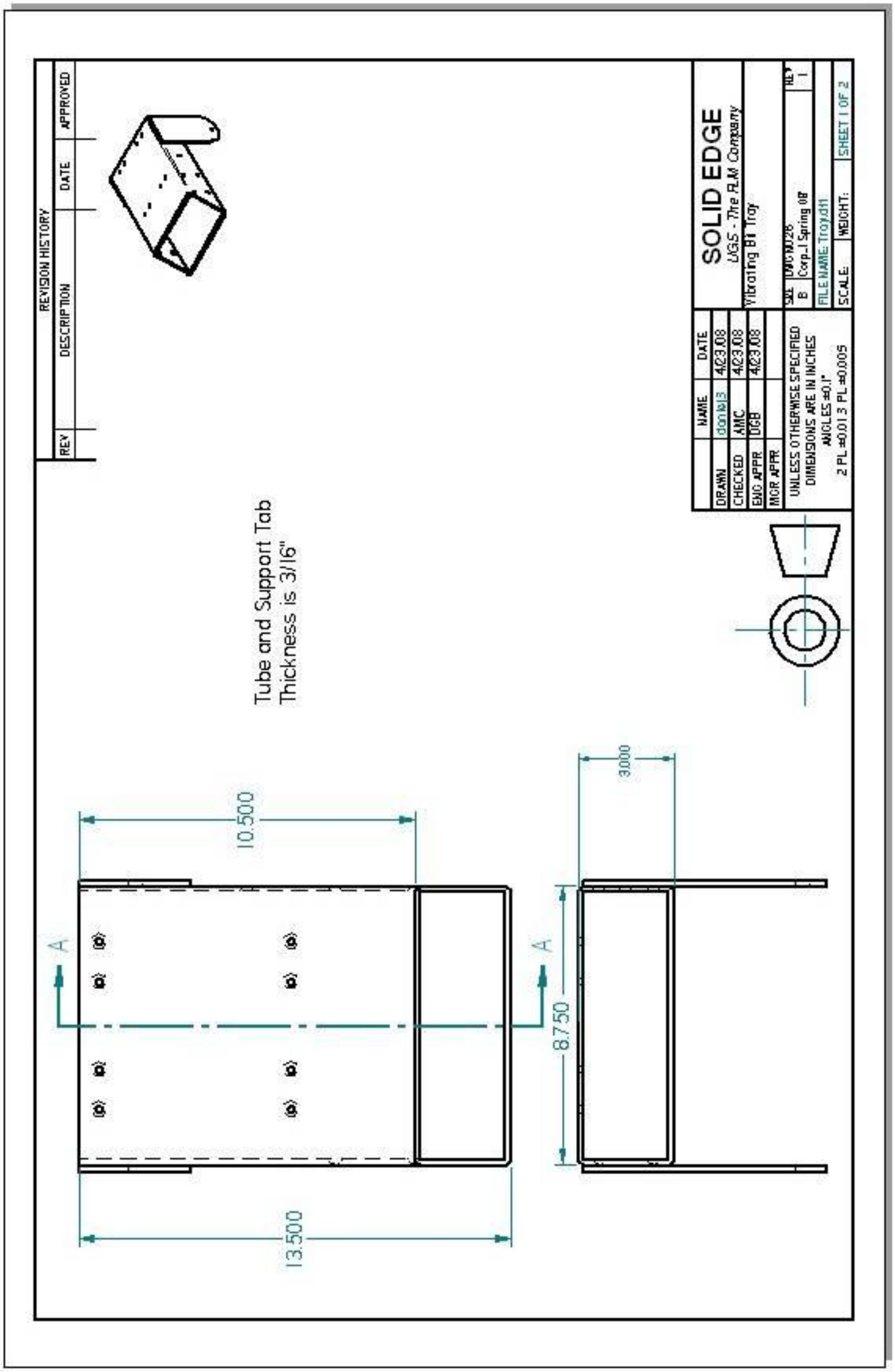

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
.500
1.250
2.000
Ø 3.250
Ø .302
All Cylinders are same diameter, and concentric
NAME
DATE
DRAWN
4/22/08
CHECKED
AMC
4/23/08
ENG APPR
DGB
4/23/08
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Bolt Pattern for Rover Mount
SIZE
B
REV
1
SCALE:
WEIGHT:
SHEET 1 OF 1

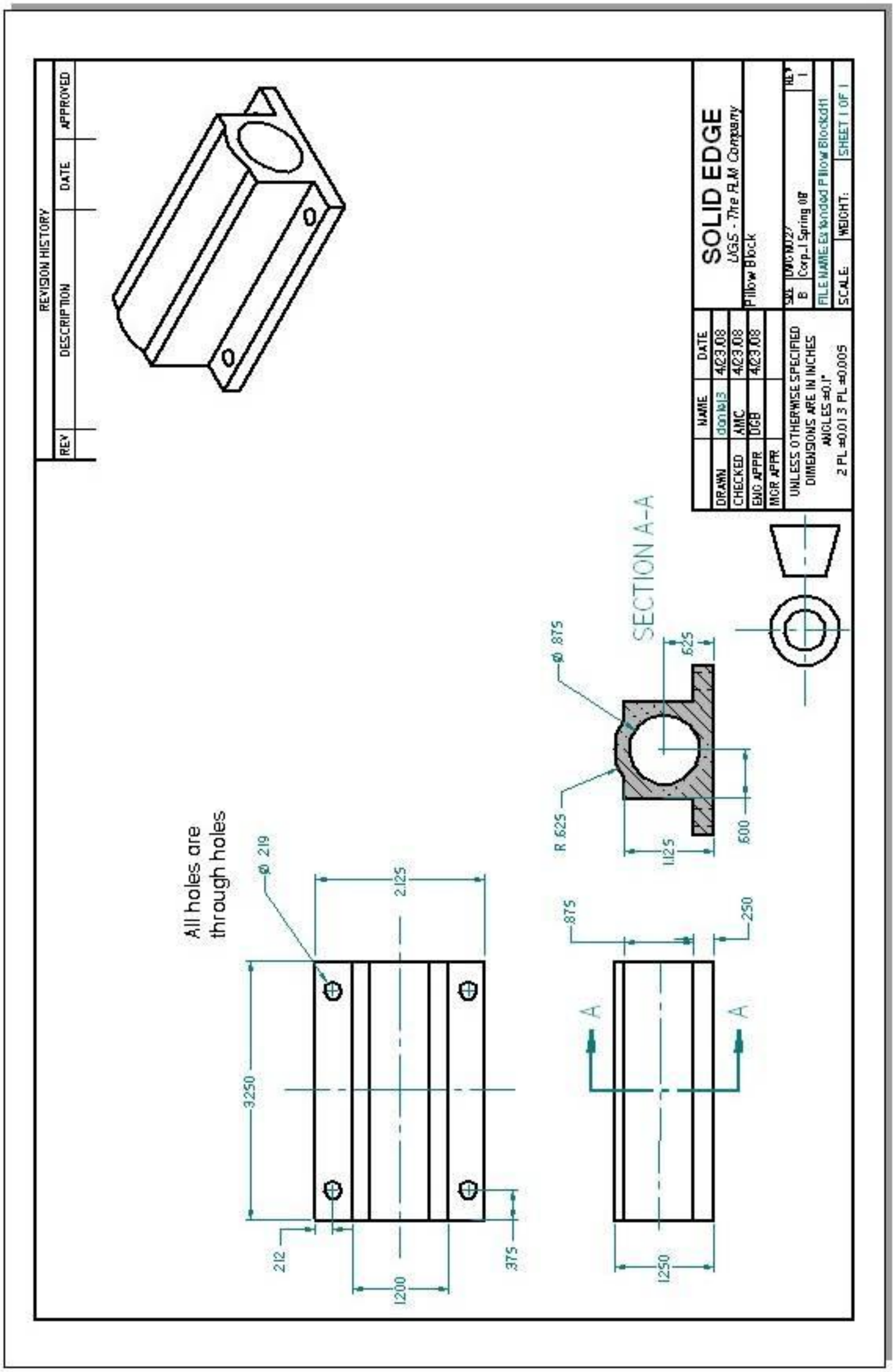

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
Ajustable.par
Adjustable Cross Brace.par
17.750
10.375
4.875
1.625
9.750
1.625
DRAWN
CHECKED
ENG APPR
MGR APPR
NAME
DATE
4/22/08
AMC
4/23/08
DGB
4/23/08
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
SOLID EDGE
UGS - The PLM Company
Adjustable Interface Assembly
SCALE:
WEIGHT:
SHEET 1 OF 1


REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
Tube Thickness is .15"
SECTION A-A
A
A
1.500
1.500
4.500
DRAWN
CHECKED
ENG APPR
MGR APPR
NAME
DATE
AMC
DGB
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
SOLID EDGE
UGS - The PLM Company
Conveyor Actuator Vertical Support
SCALE:
WEIGHT:
SHEET 1 OF 1

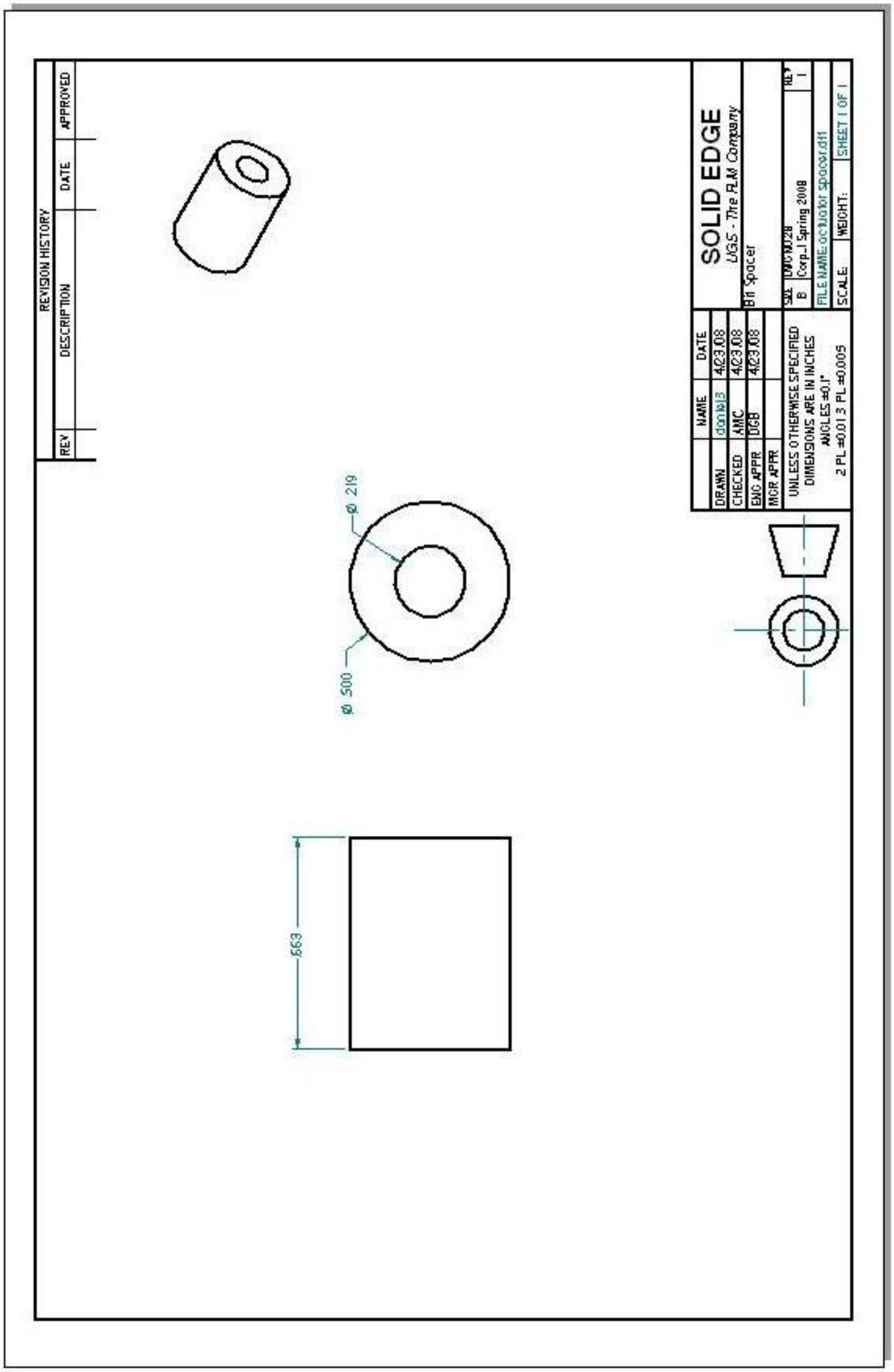

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
1500
1500
Tube Thickness is .15"
SECTION A-A
A
A
18.250
DRAWN
CHECKED
ENG APPR
MGR APPR
NAME
DATE
AMC
DGB
4/23/08
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
SOLID EDGE
Support
FILE NAME:
SCALE:
WEIGHT:
SHEET 1 OF 1

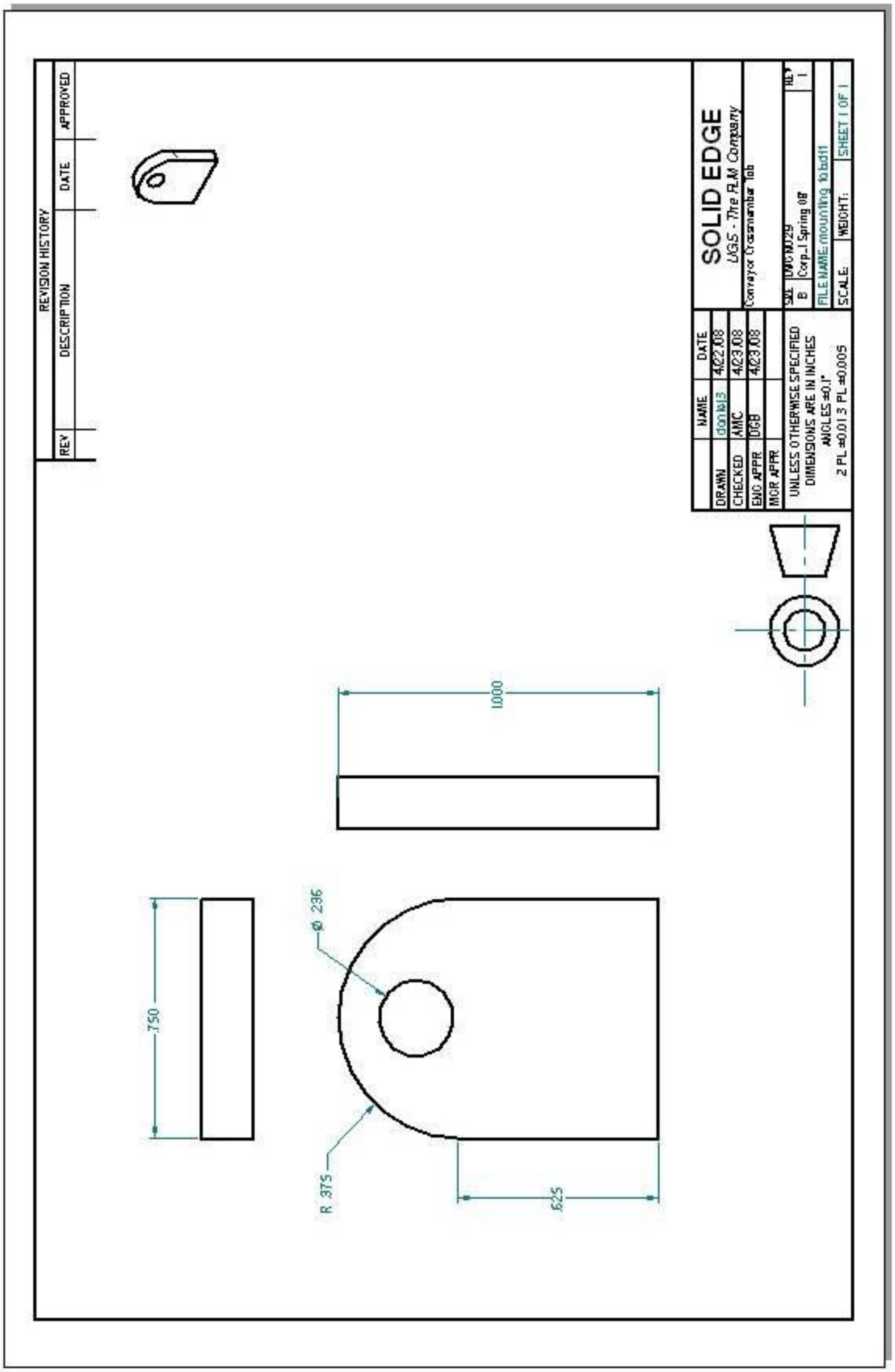

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
2
4/23/08
All cross members are mounted perpendicular and flush to eachother.
Bottom edge of tab is mounted at bottom edge of cross member
DETAIL A
DETAIL B
A
B
10.625
4.874
4.000
1.000
4.500
Vert Support I
Interface Crossbar I
NAME
DATE
DRAWN
CHECKED
ENG APPR
MGR APPR
AMC
DGB
4/22/08
4/23/08
4/23/08
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Adjustable Interface Mounting Assembly
SIZE
B
REV
2
FILE NAME: mounting interface.dft
SCALE:
WEIGHT:
SHEET 1 OF 1

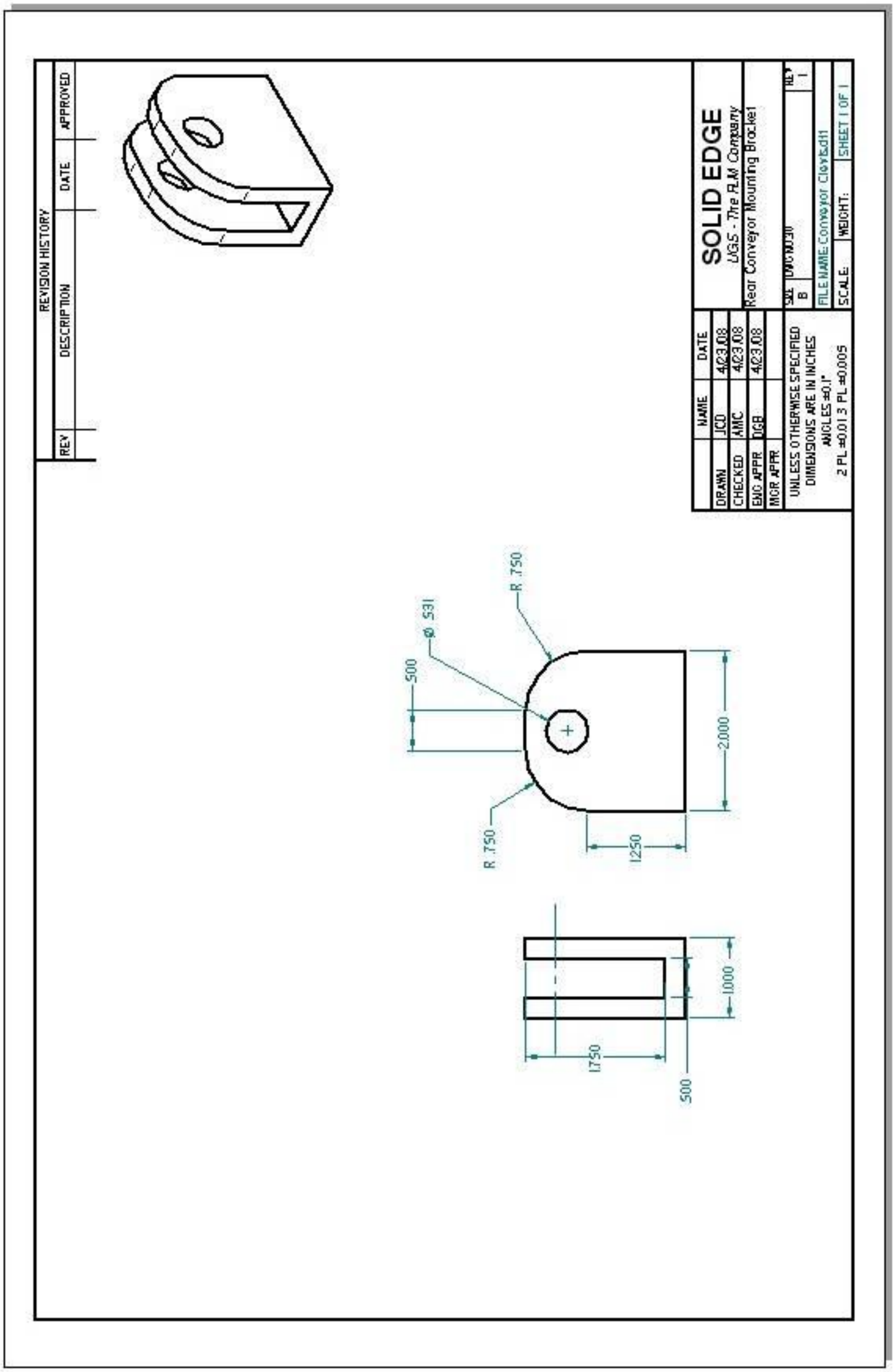

REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
Tube and Support Tab
Thickness is 3/16"
10.500
13.500
8.750
3.000
A
A
DRAWN
CHECKED
ENG APPR
MGR APPR
NAME
DATE
AMC
DGB
4/23/08
4/23/08
4/23/08
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
SOLID EDGE
UGS - The PLM Company
Vibrating Bit Tray
SCALE:
WEIGHT:
SHEET 1 OF 2



REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
All holes are through holes
Ø .219
3.250
2.125
.212
1.200
.375
.875
.250
1.250
A
A
R .625
Ø .875
1.125
.600
.625
SECTION A-A
NAME
DATE
DRAWN
CHECKED
ENG APPR
MGR APPR
AMC
DGB
4/23/08
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Pillow Block
Corp-I Spring 08
SCALE:
WEIGHT:
SHEET 1 OF 1


REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
Ø .219
Ø .500
.663
NAME
DATE
DRAWN daniel3 4/23/08
CHECKED AMC 4/23/08
ENG APPR DGB 4/23/08
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
B11 Spacer
SIZE
B
Corp.I Spring 2008
REV
1
FILE NAME: actuator spacer.dft
SCALE:
WEIGHT:
SHEET 1 OF 1


REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
SOLID EDGE
UGS - The PLM Company
NAME
DATE
DRAWN
CHECKED
ENG APPR
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
SIZE
B
SCALE:
WEIGHT:
SHEET 1 OF 1
REV
1
.750
1.000
.625
R .375
Ø .236


REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
R .750
Ø .531
.500
R .750
2.000
1.250
1.000
1.750
.500
DRAWN JCD 4/23/08
CHECKED AMC 4/23/08
ENG APPR DGB 4/23/08
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.005
SOLID EDGE
UGS - The PLM Company
Rear Conveyor Mounting Bracket1
SIZE B
REV 1
FILE NAME: Conveyor Clevis.dft
SCALE:
WEIGHT:
SHEET 1 OF 1