"MECH 4250 Critical Design Review"

Fall 2011

Corp_2 – Lunar Excavator

November 10, 2011

Group Members

Anna Holland

Kyle Otte

Cody Salmon

Alex Hollis

Han Cho

Faculty Advisor

Dr. David Beale

Sponsors

Dr. Nels Madsen

Dr. J-M Wersinger

Summary

The purpose of this senior design project is to develop a light, autonomously controlled lunar excavator that can be used to collect at minimum ten kilograms of lunar regolith in ten minutes. The finished lunar excavator will take part in a NASA sponsored competition in May of 2012. The design stage of the project began with looking at the 2011 competition rules, and debating about which designs were the best. . From a decision matrix, hours of research and discussion, and from studying previous competition videos a finalized concept was chosen. Once the new 2012 rules were received, a lot of time was spent in concept generation of a lightweight excavator that could reuse the previously purchased parts. A light-weight design was selected that features four wheels controlled by four motors and one large scoop to dig and deposit regolith into the collection bin. The frame of the excavator is made of fiberglass tubing. Work was immediately started on CAD drawings, Finite Element Analysis, and construction of the newly designed wheel. Also, aluminum axles were cut to the correct lengths and the bucket was constructed.

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1.0 Introduction

NASA's Lunabotics Mining Competition is held once a year to encourage development of innovative lunar excavation concepts that could be used in real world application. The design problem is to design and build a remote controlled or autonomous excavator that can collect and deposit lunar stimulant. The project was assumed to have the same requirements as the 2011 competition. The systems engineering approach, including the use of the Vee Chart and the 11 Systems Engineering Functions, was used to take the lunar excavator design from a list of given requirements and constraints to a finalized concept. The steps taken to reach the final design concept included defining a mission objective, formulating multiple design concepts, and creating a decision matrix. The decision matrix took into effect advantages and disadvantages to each concept along with the probability of failure. From this matrix, hours of research and discussion, and from studying previous competition videos a finalized concept was chosen which included 3 main subsystems: scoop system, drive system, and dump system. Parts were obtained and construction began.

The 2012 Lunabotics Mining Competition Rules were released mid-September of 2011. The new rules incorporated a point system that penalized -10 points per kilogram that the excavator weighs and the maximum height went from 2 m to 1.5 m. A full list of the 2012 rules and point breakdown are shown in Appendix A: 2012 Lunabotics Mining Competition Rules and Rubrics. From these new set of rules and point system, a new, lighter design had to be chosen incorporating already purchased parts into the design. This report details the new design and analysis that was conducted this semester upon receiving the 2012 competition rules.

2.0 Project Management

The lunar excavator senior design project team consists of three instructors, four project managers, and fifteen system engineers. The breakdown of the management structure is shown in Figure 1.

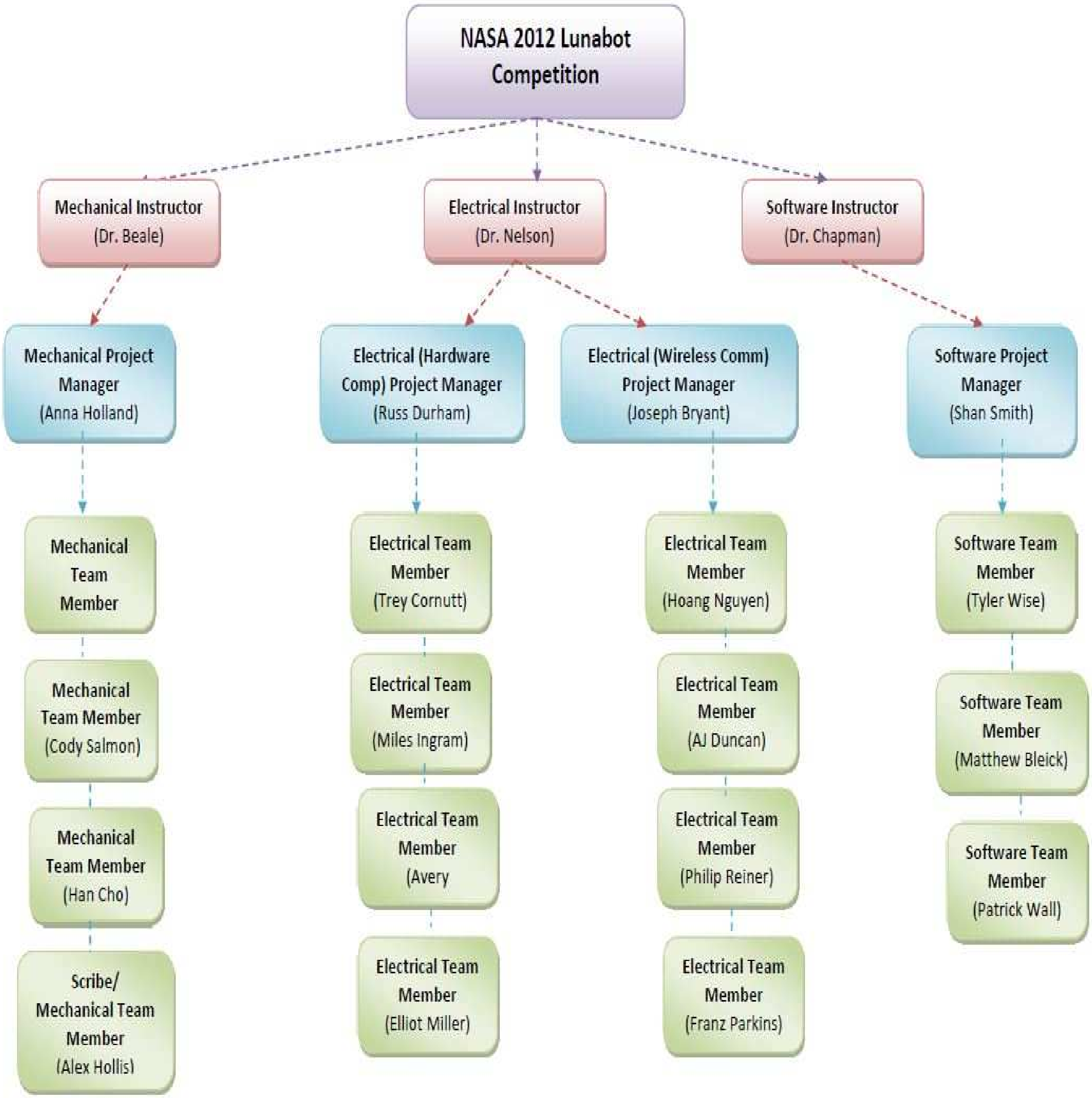


Figure 1: Project Management

The complete work breakdown for fall semester is shown in Figure 2. About 33%, or one month, of the semester was spent procuring parts and beginning construction on the old design. About 67%, or two months, of the semester was spent on redesigning the new excavator (concept generation and creating 3D model), conducting analysis, and construction of one wheel, the bucket, and the axles.

Fall 2011 Work Breakdown		
Week	**Dates**	**Tasks**
1	8/17-8/19	Orders Materials/Parts
2	8/22-8/26	Orders all Materials/Parts - Build Frame
3	8/29-9/2	Machine Wheels/Build Frame
4	9/6-9/9	**RECEIVED NEW RULES**
5	9/12-9/16	Redo MCOD list - Build Drive System for EE and SE groups
6	9/19-9/23	Type up Individual CODs - Redesign Excavator (Concept Gen)
7	9/26-9/30	Concept Generation/Work on new design
8	10/3-10/7	Work on new design and 3D Model
9	10/10-10/14	Complete Design and 3D Model
10	10/17-10/21	Complete CAD Drawings - Cut Axles
11	10/24-10/28	Work on Analysis - Machine Wheel - Build Bucket
12	10/31-11/4	Complete Analysis - Finish Building Bucket - Machine Wheel
13	11/7-11/11	Finish Machining Wheel - **FINAL MINI PRESENTATION**
14	11/14-11/18	Clean up Project Room
15	11/21-11/25	THANKSGIVING BREAK

Figure 2: Fall 2011 Work Breakdown

3.0 Mission Objective

The Mission Objective is to create an autonomous excavator that weighs less than 50 kg, can collect and deposit at least 10 kg of lunar regolith within each of the two 10 minute time periods, and that will win the 2012 Lunabotics Mining Competition. The overall size cannot exceed 0.75 m width x 1.5 m length x .75 m height at the start of the competition and a 1.5 m height throughout the competition. However, the length and width constraints may be exceeded once the competition starts.

4.0 Mission Environment

The mission environment is an Earth representation of the Moon's lunar surface. The testing environment at NASA's Kennedy Space Center will use Black Point-1 (BP-1) which is a replica of lunar regolith. Lunar regolith stimulant is a very fine powder with a particle size between than 60 and 80 micrometers. The regolith has a tendency to cling to everything it touches. The "lunarena" will have two teams competing at one time in parallel areas. The areas will be separated by a wall but the dust the other team kicks up will travel into the other arena. In the pictures of last year's competition the arena appeared to be open to the environment which would allow for humidity to enter the competition area. The lunarena will be 3.88 m wide by 7.38 m long and 1 m deep as shown in Figure 3.

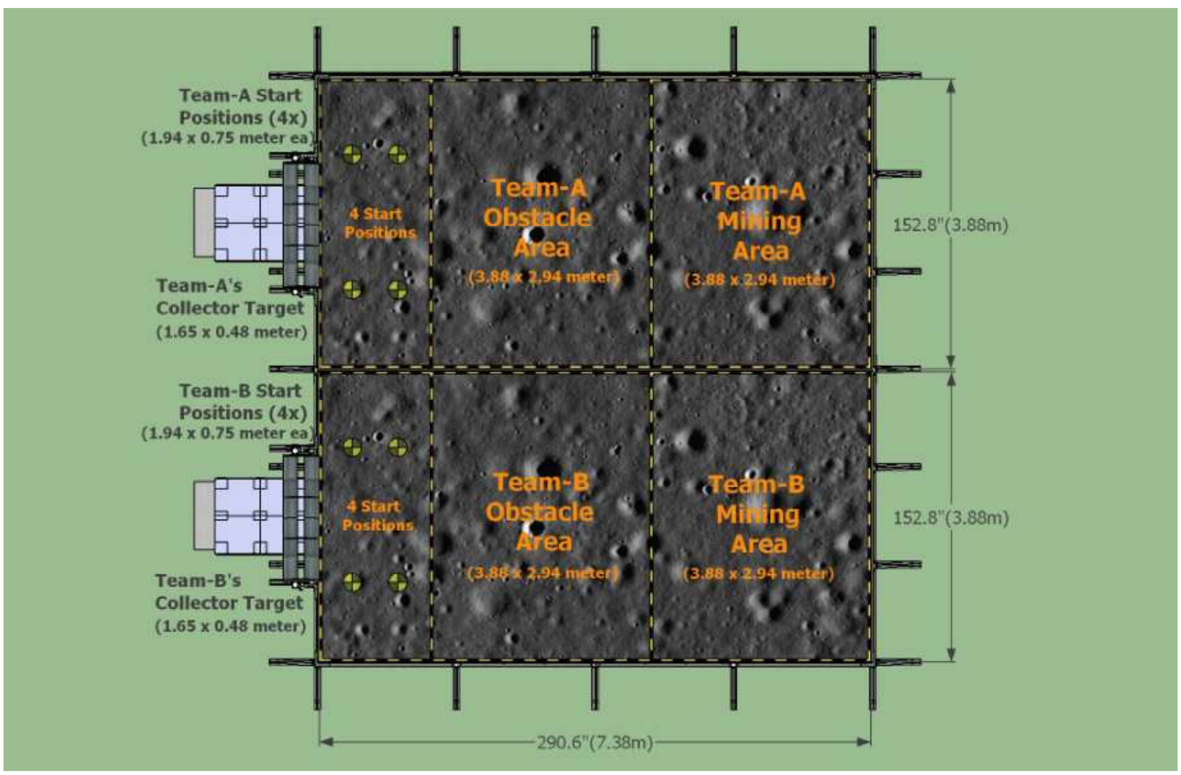


Figure 3 : Lunarena Diagram

The collection bin is 1.65 m wide by .48 m deep by 0.5 m high. There are two craters placed that are no more than 30 cm in depth or width. Three obstacles will be placed in the arena with diameters between 20 and 30 cm and masses between 7 and 10 kg. The dust will be a significant factor since the robot may be operated by cameras and/or sensors that could need a clean lens to work efficiently. The dust could also affect the electronics if they get coated during the competition.

On the actual Moon, the environment is much different from the simulation on earth. The gravity on the Moon is 1.6 m/s^2. Due to the lack of an atmosphere the surface is in a total vacuum with the temperature ranging from 300˚F in the sun to -250˚F in the shade. The surface of the Moon is littered with large craters much larger than the 30 cm craters in the competition. These factors are too difficult to reproduce on Earth and are excluded from the competition environment.

5.0 Architectural Design Development

The systems engineering approach, including the use of the Vee Chart and the 11 Systems Engineering Functions, was used to take the lunar excavator design from a list of given requirements and constraints to a finalized concept. The finalized concept will be discussed in further detail in the following sections of the report breaking the system down into three subsystems: drive subsystem, frame subsystem, and bucket subsystem.

5.1 Subsystem Design Engineering:

The final concept chosen is a 4 wheel, scoop and dump bucket design. Figure 4 shows a screen shot from the 3D Solid Edge assembly of the excavator concept. CAD drawings of the excavator parts are shown in Appendix G.

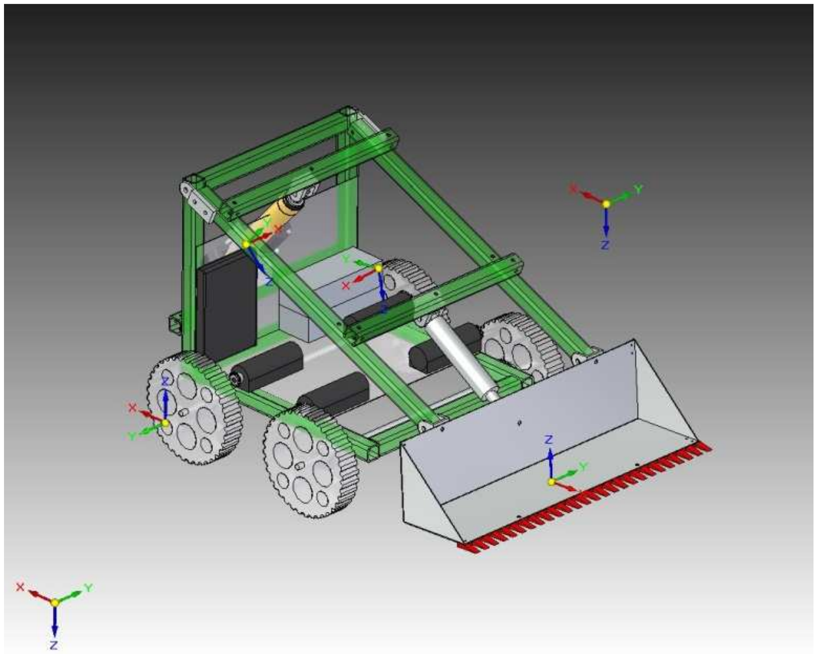


Figure 4 : 3D Model of Final Concept

Concept of operation, details of the work done to date for each subsystem, and the test plan to validate and verify the system are discussed below.

5.1.1 Concept of Operations

The developed lunar excavator must operate precisely in a dusty and dirty environment. The concept of operations is meant to show how the excavator will meet the system requirements. Operations are given in a timeline. Concept of operation will have to be revised by next semester's group once a decision has been made on whether the excavator will operate semi-autonomous or fully autonomous.

Time-ordered sequence of events:

1) Excavator starts in starting position in the lunar arena
2) Excavator is maneuvered around obstacles and drives to the digging area of the lunar arena
3) Bucket is pushed along surface of regolith until it reaches maximum capacity, as shown in Figure 5: Digging Position

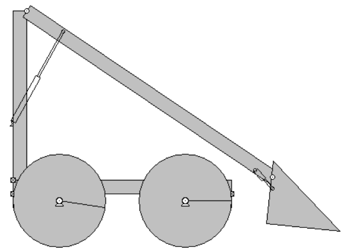


Figure 5: Digging Position

4) Excavator is driven back through obstacles to the collection bin, and the gathered regolith is dumped out as shown in Figure 6: Dumping Position.

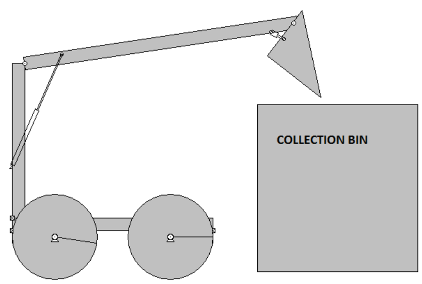


Figure 6: Dumping Position

5) Steps 1-4 are repeated until the 10 minutes are up.

5.1.2 Drive Subsystem

The drive system chosen for the excavator is a four wheel option; each wheel is powered by a motor, as shown previously in Figure 4 : 3D Model of Final Concept. The motor specifications for the current motors are attached in Appendix B: Wheel Motor Specification Sheet.

Finite Element Analysis was performed on the wheels that were developed for the lunar excavator. The analysis was done using SolidEdge software. The wheels are made of ultra-high molecular weight polyethylene, for which SolidEdge contains built-in properties, as shown in

Table 1: UHMWP Properties

Table 1: UHMWP Properties

Modulus of Elasticity	896.318 MPa
Density	913 kg/m^3
Specific Heat	1884 J/kg-C
Yield Strength	19.305 MPa
Poisson's Ratio	0.350

The wheels have an outer diameter of ten in and are two in thick. For the analysis, the 0.5 in center cylinder in the wheels was fixed in all directions. This is the center cylinder that the axle will pass through. 400 N of force was applied to approximately seven degrees of the wheels directly above one of the large holes. This corresponds to about 40 kg resting on 1/48th of the circumference of the wheel. The lunar excavator will weigh approximately 45 kg, and will be capable of hauling about 10 kg. Therefore the total maximum weight will be about 55 kg. Under ideal terrain conditions the weight will be dispersed relatively evenly between all four wheels. This means that our analysis is a worst case scenario in which the excavator is balancing on one wheel with a full bucket. Even under such unrealistic conditions, the total deflection at the end of the wheel is only 0.0765 mm. The maximum Von Misses stress is about 1.17 MPa, as shown in Figure 7. The maximum stress in the Z-direction (up and down) is about 0.283 MPa, and the yield strength of ultra-high molecular weight polyethylene is 19.5 MPa. Therefore, the factor of safety for the wheels is about 16.7.

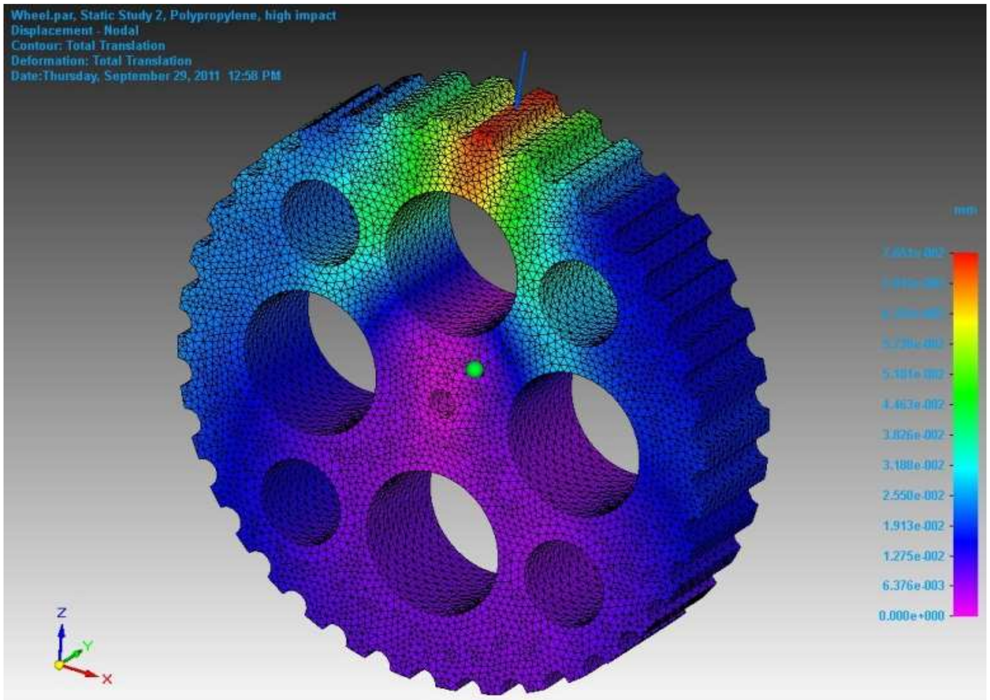


Figure 7: Wheel F.E.A.

The construction of one wheel was completed this semester as shown in Figure 8. The wheel was machined and fabricated in the Design and Manufacturing Lab.

Figure 8: Machined Wheel

5.1.3 Frame Subsystem

The frame of the excavator will be similar to the previous year's frame design. The fiberglass square tubing will be used for the frame material. The spec sheet for the fiberglass tubing is shown in Appendix E: Fiber Glass Tubing. The fiberglass material is lighter than aluminum, and the material has been proven through testing to be strong enough to handle the loads exerted on the excavator. A central box of tubing with plastic paneling will be used to house the electronics. All of the other subsystems will extend from the central frame shown in Figure 9: Frame SubsystemFigure 9.

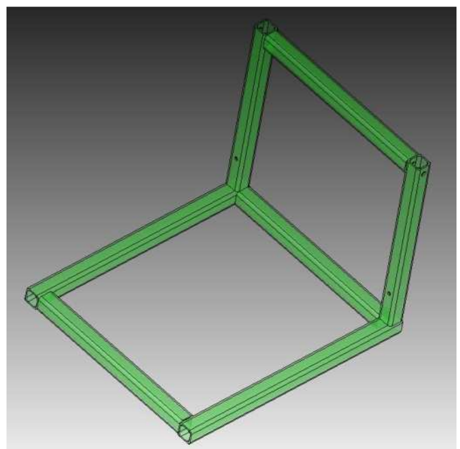


Figure 9: Frame Subsystem

Finite Element Analysis was performed on the bottom frame section of the fiberglass tubing that is to be used for the lunar excavator. The analysis was done using SolidEdge software, and a tetrahedral mesh was used. The tubing is 1-1/2" x 1-1/2" with a wall thickness of approximately 1/8". The piece tested in the simulation is 30-5/8" long, which corresponds to the length of the bottom tube of the excavator. The tubing was ordered from McMaster-Carr and the specification sheet states that the modulus of elasticity ranges from 2.8-5.5 x 10^6 psi. When the two numbers are averaged, the modulus of elasticity is approximately 4.15 x 10^6 psi, or 28,613 MPa. A new material was created in SolidEdge using 28,613 MPa as the modulus of elasticity, and the other material properties were input into SolidEdge using the same averaging system. The properties are listed in

Table 2: Fiberglass Properties

Table 2: Fiberglass Properties

Modulus of Elasticity	28.613 GPa
Density	1190.25 kg/m^3
Yield Strength	162 MPa
Poisson's Ratio	.33

For the analysis, the two ends of the tubing were fixed in all directions. 500 N of force was applied in the center of the tubing, pushing down. This corresponds to about 50 kg resting in the center of the tubing. The lunar excavator will weigh approximately 45 kg, and will be capable of hauling about 10 kg. Therefore the total maximum weight will be about 55 kg. Under ideal terrain conditions the weight will be dispersed relatively evenly between both axles. This means that our analysis is a worst case scenario in which the excavator has broken, or an axle has come off of the excavator. Even under such unrealistic conditions, the total deflection in the middle of the tubing is only 0.267 mm, as shown in Figure 10: 3 Point Bend Test. The maximum stress along the grain of the fiberglass (in the Y-direction) is about 1.084 MPa. The tubing was modeled as a linear elastic isotropic material. The yield strength of the fiberglass tubing is 162 MPa. Therefore the factor of safety for the tubing is about 148. After performing this analysis, we deemed that using wood within the fiberglass tubing is not necessary.

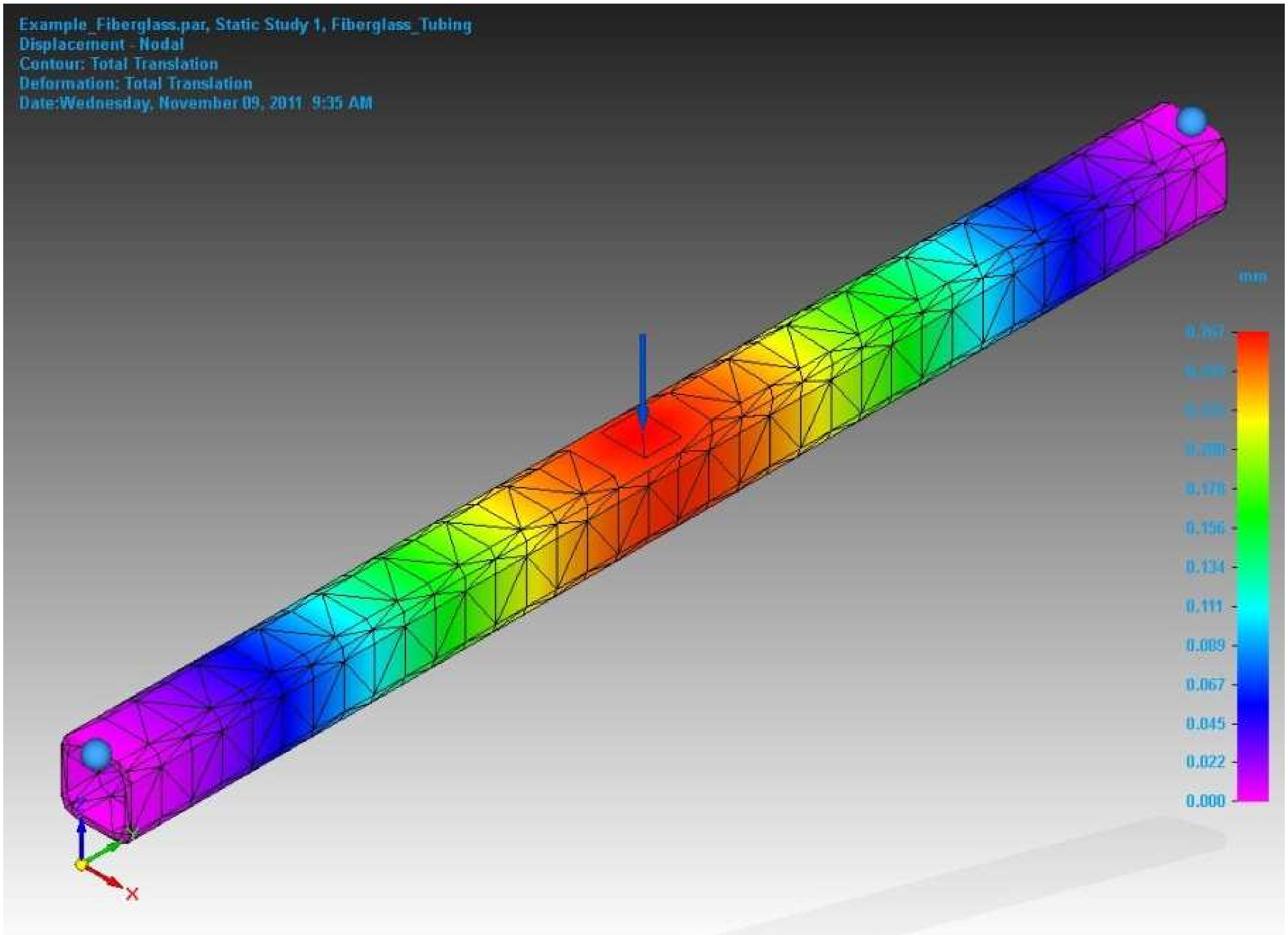


Figure 10: 3 Point Bend Test

5.1.4 Scoop Subsystem

The scoop system chosen for the excavator utilizes an arm and one actuator to operate a bucket as shown in Figure 11.

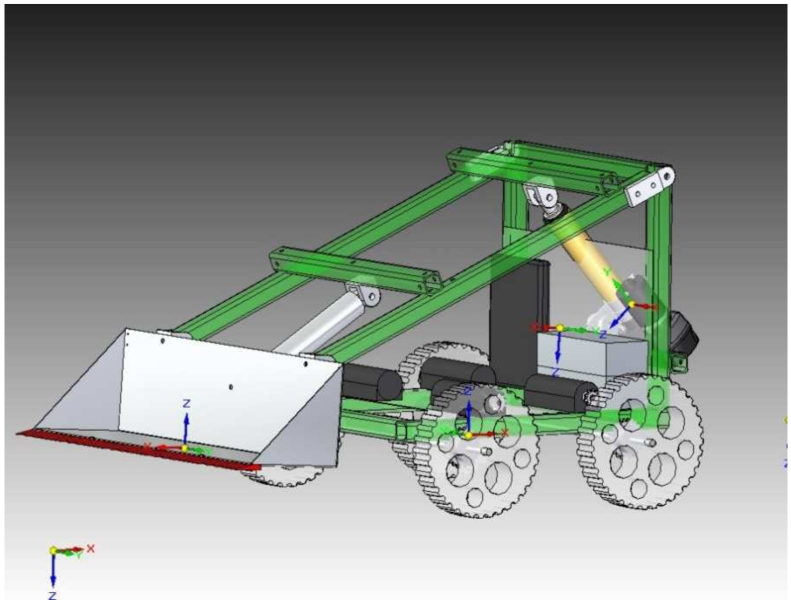


Figure 11 : Scoop Subsystem

After watching many competition videos, a conclusion was drawn that one large bucket system could remove the greatest amount of regolith for a given time period. After calculating the maximum volume of regolith the bucket could hold and using an average density of one g/cm^3, the maximum weight the bucket and arm would need to support is fifteen kilograms. Finite element analysis was used while applying uniform pressure equal to having a full load proved that the bucket and arm could handle the maximum stress. The excavator bucket differs from the previous year's design in the way that the current bucket will be smooth on all interior surfaces allowing regolith to slide in and out with a minimum dumping angle.

Bucket analysis of preformed using Solid Edge, Working Model, and manual calculations. The goal of the analysis was to determine the mass of regolith collected in a single scoop and analyze the bucket arms if they are strong enough to carry the load. Brackets will be tested to find the correct number and strength to with stand the force of lifting a full load.

Knowing the density of lunar regolith and the volume of the bucket the total mass of one scoop can be derived. The volume of the bucket measured about 18000 cm^3 which when multiplied by the density of regolith comes out to be approximately 18 kg of regolith per scoop. In reality the bucket cannot be filled completely and the regolith may be less dense than the 1 gm/cm^3 so an estimation of 10 to 15 kg per scoop was made. Finite element modeling was used to quickly test various configurations of hinges, arms, and weights.

FEM testing was performed using the simulation solver in Solid Edge. In the first test the bucket was initially pinned at the top 2 hinges with a 15 kg load in the bucket. A force of 3000 N was applied to the bracket where the actuator will mount. The goal of the test was to estimate whether the hinges would be strong enough to support the lifting bucket. The analysis showed a maximum stress of 328 MPa which was centered holes in the hinges. The yield strength of the 6061-T6 aluminum is 276 MPa which indicates there will be yielding, but it was determined that this is just a surface point contact stress that does not represent the true stress. Deflection was negligible during this test. The test results with locations of loading are shown in Figure 12.

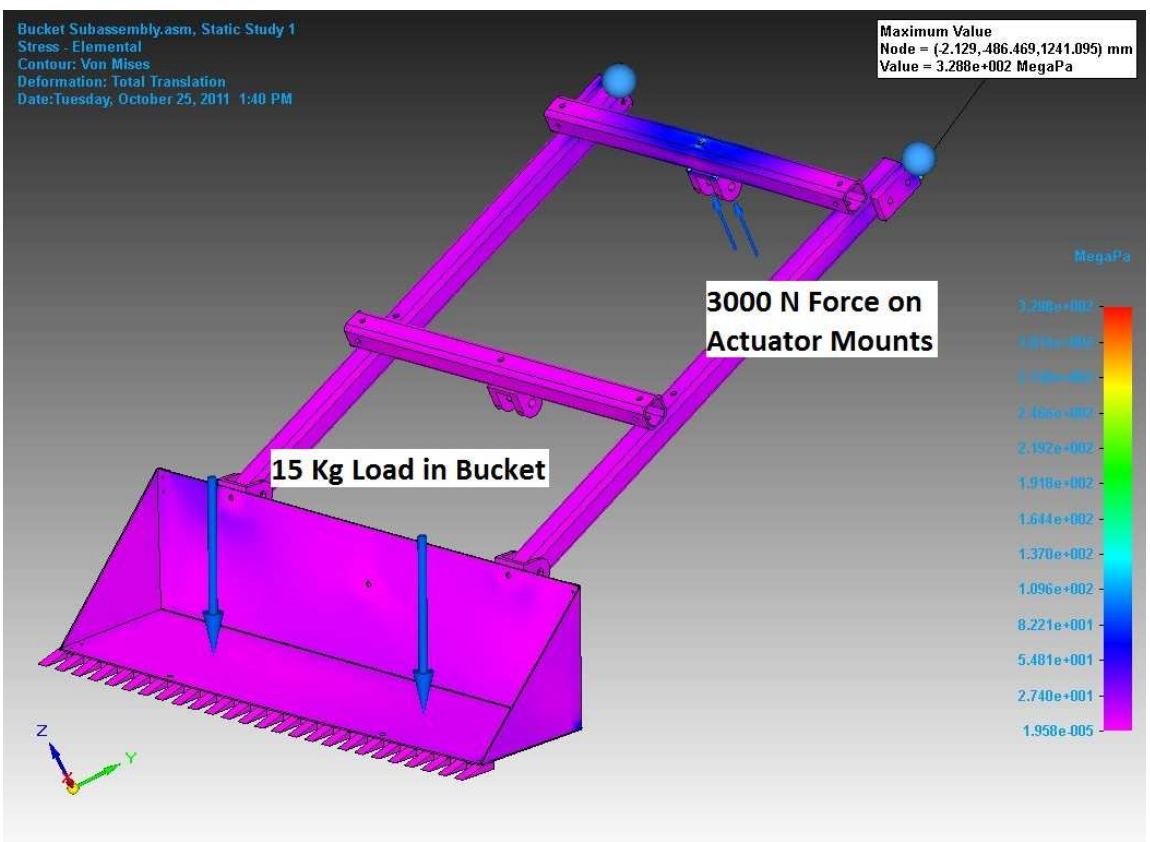


Figure 12: Bucket Stress Test

Working Model was used to determine the minimum amount of force required to lift the bucket at full load. Through trial and error the location along with the strength of the actuators was found. Each actuator tested had different compressed lengths and strokes, so individual testing were required for each actuator. Figure 13 shows the final large bucket actuator design along with forces.

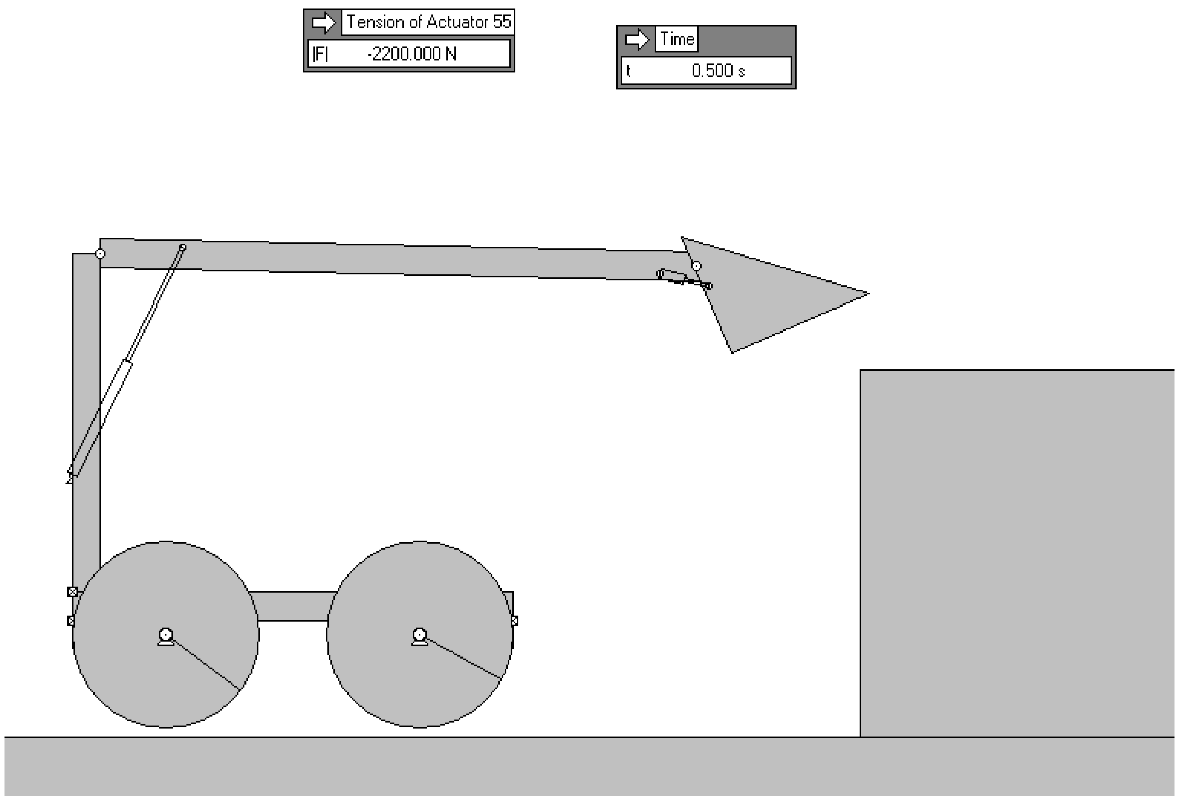


Figure 13: Front Bucket Simulation

The minimum required force to move a 15 kg bucket is about 2200 N when the actuator is placed in the optimal position.

One actuator was chosen to lift the bucket. The actuator chosen is a Nook Industries CCHD-8532. It is rated for 28 mm/s at full load so the time from digging to dumping should take about 3.6 seconds. The actuator's lifting capacity is 3330 N. The locations of the hinges was made as precisely as possible for maximum speed while staying within the limits of the materials strength. The full spec sheet for the large actuator is found in Appendix C: Nook Large Actuator.

The small actuator on the bucket is mainly used to hold the bucket steady and in position when the digging is occurring. The static load for the small actuator is 4459 N which is more than enough to hold back the bucket. The dynamic load of the actuator is 2230 N, which is an ample force to flip back the 15 kg bucket. The actuator is rated for 18 mm/s which will take about 2 seconds to flip the bucket back when dumping. The 2 second time is accounting for the actuator being mounted where the required stroke is only about 1.7 inches. The full spec sheet the small bucket actuator is found in Appendix D: Moteck Linear Actuator.

The construction of the body of the bucket was completed this semester as shown in Figure 14. The bucket was sheared to the correct dimensions, bent, and assembled with rivets in the Design and Manufacturing Lab.

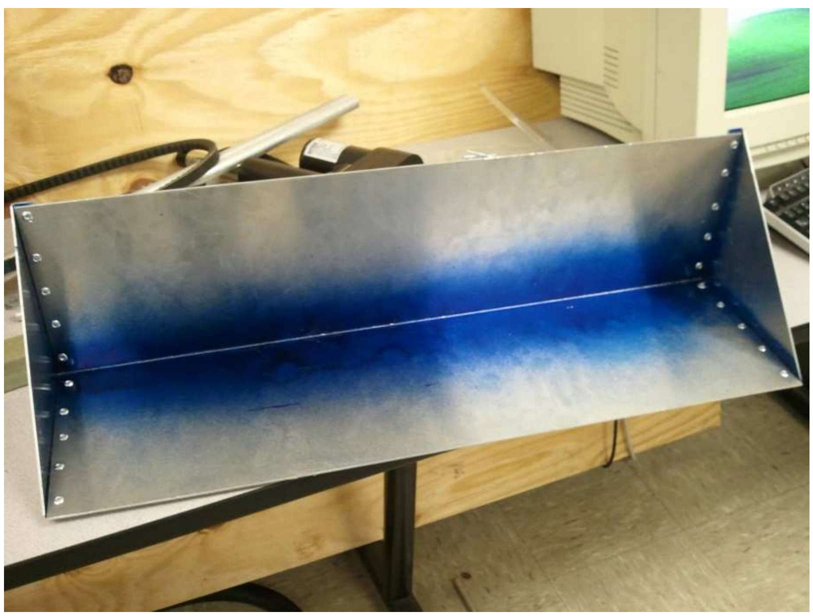


Figure 14: Fabricated Bucket

5.2 Validate and Verify

Through the entire systems engineering process it is important to make sure that the system will meet all requirements once completed. A large part of making sure that the design is on track is validation and verification. Validation for this senior design project should be done using mostly Portland cement mix to represent lunar regolith. One test that was conducted showed the required angle of the bucket in order to dump a load of regolith. The test is shown in Figure 15. A sheet of aluminum representing the bucket bottom was laid flat and covered with the Portland cement and then lifted until all of the cement slid off. The angle of the aluminum was calculated to be about 45°, and therefore the angle of tilt for the bucket needs to meet or exceed this angle. The next group that works on the lunar excavator will need to test all subsystems as they are constructed. It is important that the subsystems be tested before the excavator is completely finished, so that each subsystem can be verified. After each subsystem is verified, the excavator as a whole needs to tested.

Figure 15: Aluminum Angle Test

6.0 CDR Economic Analysis

Table 3: CDR Economic Analysis shows the purchase log for the project to date. The total amount spent to date is $3,844.98. Next semester, a finalized cost breakdown will be created after all of the materials for the excavator are purchased. The total budget for materials and travel for the project is $9000. That leaves $5155.02 left in the budget for remaining materials and travel.

Table 3: CDR Economic Analysis

Pur. #	Date	Vendor	Description	Price/Unit	# Units	Cost	Shipping	Total Cost
1	7/1/11	Copy Cat	Summer Midterm Report Copies	22.35	1	22.35	0	$22.35
2	7/11/11	Home Depot	Bag of Portland Cement Mix	9.85	1	9.85	0	$9.85
3	7/18/11	McMaster-Carr	Fiberglass Tubing 10ft section	45.48	3	136.44	53.79	$190.23
4	7/25/11	Home Depot	Plywood/Pinewood	15.39	1	15.39	0	$15.39
5	7/29/11	Copy Cat	Summer Final Report Copies	15.80	1	15.80	0	$15.80
6	8/18/11	Ridout Plastics	UHMW 10" Dia Rod Cut to Length (4.5")	196.74	6	1180.44	30.78	$1,211.22
7	8/18/11	Nook Industries	Bucket Lift Actuators CC-18 HD/5/001/CA/04/S	517.50	2	1035.00	50.00	$1,085.00
8	8/23/11	Surplus Center	Bucket Tilt Actuator 4" Stroke ID10-12-20-A-100	99.85	1	99.85	12.85	$112.70
9	8/25/11	Super Droid Robots	Motor IG-52GM-04	139.62	2	279.24	8.90	$288.14
10	8/25/11	McMaster-Carr	DML Tools, Axles, and Bearings	332.31	1	332.31	17.11	$349.42
11	8/25/11	McMaster-Carr	Fiberglass Tubing 5ft section	25.13	1	25.13	12.13	$37.26
12	8/26/11	Southern Tool	Aluminum for Hopper and Bucket	325.00	1	325.00	33.62	$358.62
13	11/1/11	Walmart	Xbox Kinect (for Software Group)	149.00	1	149.00	0	$149.00
						TOTAL	**$3,844.98**	

7.0 Mass Budget Tracking

Tracking resource budgets is necessary for this project to ensure the lightest weight is obtained and the project's weight goal of under 50 kg is met. A rough estimate of the system mass breakdown is shown in Appendix F: Mass Breakdown. The estimated weight at this point in the design process is 44 kg. This mass budget is only an estimate and will be detailed more accurately once the excavator is built further in the design process.

Power budget tracking will be provided by the electrical group. It is assumed at this point that two batteries will be used until the calculations and findings of the electrical group are released.

8.0 Conclusions

For designing the excavator, the mission objective of the NASA's competition is collecting a minimum of 10 kg of regolith in each of the 10 minute attempts. After the new rules were received, the redesign process began. The best design that weighed the least amount while incorporating the previously purchased materials was chosen. A 3D model and fully dimensioned CAD drawings were created, analysis conducted, and fabrication of one wheel, the axles, and the bucket were completed.

Next semester a new mechanical group will be assigned to the project to complete the fabrication and testing of the excavator. Also new electrical and software groups will be assigned to work towards semi and full autonomy.

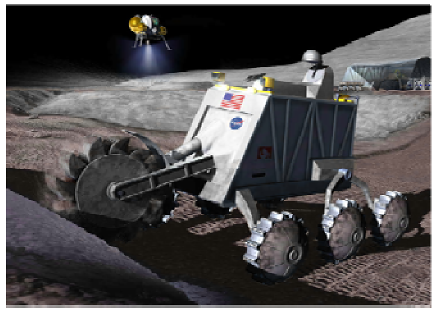
Appendix A: 2012 Lunabotics Mining Competition Rules and Rubrics

NASA's Third Annual Lunabotics Mining Competition

Rules & Rubrics, Revision 2

Kennedy Space Center Visitor Complex

Kennedy Space Center, Florida



Introduction

NASA's Lunabotics Mining Competition is designed to promote the development of interest in space activities and STEM (Science, Technology, Engineering, and Mathematics) fields. The competition uses excavation, a necessary first step towards extracting resources from the regolith and building bases on the moon. The unique physical properties of lunar regolith and the reduced 1/6th gravity, vacuum environment make excavation a difficult technical challenge. Advances in lunar regolith mining have the potential to significantly contribute to our nation's space vision and NASA space exploration operations.

The competition will be conducted by NASA at the Kennedy Space Center Visitor Complex. The teams that can use telerobotic or autonomous operation to excavate lunar regolith simulant, called Black Point-1 or BP-1, and score the most points wins the Joe Kosmo Award for Excellence. The team will receive the Joe Kosmo Award for Excellence trophy, KSC launch invitations, team certificates for each member, a $5,000 team scholarship, and up to $1,000 travel expenses for each team member and one faculty advisor to participate at one of NASA's remote research and technology tests. Awards for other categories include monetary team scholarships, a school trophy or plaque, team and individual certificates, and KSC launch invitations.

Undergraduate and graduate student teams enrolled in a U.S. or international college or university are eligible to enter NASA's Lunabotics Mining Competition. Design teams must include: at least one faculty with a college or university and at least two undergraduate or graduate students. NASA has not set an upper limit on team members. A team should have a sufficient number of members to successfully operate their Lunabot. Teams will compete in up to five major competition categories including: on-site mining, systems engineering paper, outreach project, slide presentation (optional), and team spirit (optional). Additionally, teams can earn bonus points for mined and deposited BP-1 in the competition attempts, having multidisciplinary teams, and collaborating between a majority institution and a U.S. minority serving institution. All documents must be submitted in English.

The Lunabotics Mining Competition is a student competition that will be conducted in a positive, professional way. This is a reminder to be courteous in all your correspondence and all interactions on-site at the competition. Unprofessional behavior or unsportsmanlike conduct will not be tolerated and will be grounds for disqualification. The frequently asked questions (FAQ) document is updated regularly and is considered part of this document. It is the responsibility of the teams to read, understand, and abide by all of NASA's Third Annual Lunabotics Mining Competition Rules and Rubrics, stay updated with new FAQs, communicate with NASA's representatives, and complete all surveys. These rules and rubrics are subject to future updates by NASA at its sole discretion.

For more information, visit NASA's Lunabotics Mining Competition on the Web at www.nasa.gov/Lunabotics; on Facebook at www.facebook.com/Lunabotics; on YouTube at http://www.youtube.com/user/Lunabotics; and follow Lunabotics on Twitter at http://twitter.com/#!/Lunabotics.

Lunabotics On-Site Mining Category

This year the scoring for the Mining Category will not be based primarily on the amount of material excavated in the allowed time but instead will require teams to consider a number of design and operation factors such as dust tolerance and projection, communications, vehicle mass, energy/power required, and level of autonomy. Each team must compete on-site at the Kennedy Space Center Visitor Complex, Florida in the United States of America on May 21-26, 2012. A minimum amount of 10 kg of BP-1 must be mined and deposited during each of two competition attempts according to the rules to qualify to win in this category. In the case of a tie, the teams will compete in a tie-breaking competition attempt. The judges' decisions are final in all disputes. The teams with the first, second, and third most LunaPoints averaged from both attempts will receive team plaques, individual team certificates, KSC launch invitations, $3,000, $2,000, and $1,000 scholarships and 30, 25, and 20 points toward the Joe Kosmo Award for Excellence, respectively. Teams not winning first, second, or third place in the mining category can earn one bonus point for each kilogram of BP-1 mined and deposited up to a maximum average of ten points toward the Joe Kosmo Award for Excellence. The most innovative and lunar like design will receive the Judges' Innovation Award at the discretion of the mining judges.

1) Teams must arrive at the Lunabotics Mining Competition Check-In Tent in Parking Lot 4 of the Kennedy Space Center Visitor Complex no later than 12:00 p.m. (noon) on Tuesday, May 22, 2012.

Game Play Rules

2) Teams will be required to perform two official competition attempts using BP-1 in the LunArena provided by NASA. NASA will fill the LunArena with compacted BP-1 that matches as closely as possible to lunar regolith. NASA will randomly place three obstacles and create two craters on each side of the LunArena. Each competition attempt will occur with two teams competing at the same time, one on each side of the LunArena. After each competition attempt, the obstacles will be removed, the BP-1 will be returned to a compacted state, if necessary, and the obstacles and craters will be returned to the LunArena. The order of teams for the competition attempts will be chosen at NASA's discretion. See Diagrams 1 and 2.

3) In each of the two official competition attempts, the teams will score cumulative LunaPoints. See Table 1 for the Mining Category Scoring Example. The teams' ranking LunaPoints will be the average of their two competition attempts.

   A) Each team will be awarded 1000 LunaPoints after passing the safety inspection and communications check.

   B) During each competition attempt, the team will earn 2 LunaPoints for each kilogram in excess of 10 kg of BP-1 deposited in the LunaBin. (For example, 110 kg of BP-1 mined will earn 200 points.)

   C) During each competition attempt, the team will lose 1 LunaPoint for each 50 kilobits/second (kb/sec) of average data used throughout each competition attempt. A minimum of 10 kg of BP-1 must be mined and deposited in the LunaBin during each competition attempt or the team will lose 100 LunaPoints, which is the maximum number of LunaPoints for this rule. (For example, 5000 kb/sec will lose 100 points.)

   D) During each competition attempt, the team will lose 10 LunaPoints for each kilogram of total Lunabot mass. (For example, a Lunabot that weighs 80 kg will lose 800 LunaPoints.)

   E) During each competition attempt, the team will earn 100 LunaPoints if the amount of energy consumed by the Lunabot during the competition attempt is reported to the judges after each attempt. The amount of energy consumed will not be used for scoring; a team must only provide a legitimate method of measuring the energy consumed and be able to explain the method to the judges.

   F) During each competition attempt, the judges will award the team 0 to 200 LunaPoints for regolith dust tolerant design features on the Lunabot and regolith dust free operation. If the Lunabot has exposed mechanisms where dust could accumulate during a lunar mission and degrade the performance or lifetime of the mechanisms, then fewer points will be awarded in this category. If the Lunabot raises a substantial amount of airborne dust or projects it due to its operations, then fewer points will be awarded. Ideally, the Lunabot will operate in a clean manner without dust projection, and all mechanisms and moving parts will be protected from dust intrusion. The Lunabot will not be penalized for airborne dust while dumping into the LunaBin. All decisions by the judges regarding dust tolerance and dust projection are final.

G) During each competition attempt, the team will earn 250 LunaPoints if the Lunabot is able to drive autonomously (no teleoperation), through the obstacle area only. The Lunabot may be teleoperated in the mining area and LunaBin/starting area. A minimum of 10 kg of BP-1 must be mined and deposited in the LunaBin during each competition attempt to receive these LunaPoints. The points for autonomy through the obstacle area and full autonomy are mutually exclusive.

H) During each competition attempt, the team will earn 500 LunaPoints if full autonomy is achieved and a minimum of 10 kg of BP-1 is mined and deposited in the LunaBin. No teleoperation is allowed to achieve full autonomy status. The points for autonomy through the obstacle area and full autonomy are mutually exclusive.

Mining Category Elements	Specific Points	Actual	Units	LunaPoints
Pass Inspections				1000
Regolith over 10 kg	+2/kg	110	kg	+200
Average Bandwidth	-1/50kb/sec	5000	kb/sec	-100
Lunabot Mass	-10/kg	80	kg	-800
Report Energy Consumed	+100	1	1= Achieved 0= Not Achieved	+100
Dust Tolerant Design & Dust Free Operation	0 to +200	150	Judges' Decision	+150
Autonomy through Obstacles	+250	0	1= Achieved 0= Not Achieved	0
Full Autonomy	+500	500	1= Achieved 0= Not Achieved	+500
Total				1050

Table 1: Mining Category Scoring Example

4) All excavated mass deposited in the LunaBin during each official competition attempt will be weighed after the completion of each competition attempt.

5) The Lunabot will be placed in the randomly selected starting positions. See Diagrams 1 and 2.

6) A team's Lunabot will only excavate BP-1 located in that team's respective mining area at the opposite end of the LunArena from the team's starting area. The team's starting direction will be randomly selected immediately before the competition attempt.

7) The Lunabot is required to move across the obstacle area to the mining area and then move back to the LunaBin to deposit the BP-1 into the LunaBin. See Diagrams 1 and 2.

8) Each team is responsible for placement and removal of their Lunabot onto the BP-1 surface. There must be one person per 23 kg of mass of the Lunabot, requiring four people to carry the maximum allowed mass. Assistance will be provided if needed.

9) Each team is allotted a maximum of 10 minutes to place the Lunabot in its designated starting position within the LunArena and 5 minutes to remove the Lunabot from the LunArena after the 10-minute competition attempt has concluded.

10) The Lunabot operates during the 10-minute time limit of each competition attempt. The competition attempts for both teams in the LunArena will begin and end at the same time.

11) The Lunabot will end operation immediately when the power-off command is sent, as instructed by the competition judges.

12) The Lunabot cannot be anchored to the BP-1 surface prior to the beginning of each competition attempt.

13) The Lunabot will be inspected during the practice days and right before each competition attempt. Teams will be permitted to repair or otherwise modify their Lunabots anytime the LunaPits are open.

Field Rules

14) At the start of each competition attempt, the Lunabot may not occupy any location outside the defined starting position.

15) The LunaBin top edge will be placed so that it is adjacent to the side walls of the LunArena without a gap and the height will be approximately 0.5 meter from the top of the BP-1 surface directly below it. The LunaBin top opening will be 1.65 meters long and .48 meters wide. See Diagrams 1 – 3. A target may be attached to the LunaBin for navigation purposes only. This navigational aid must be attached during the setup time and removed afterwards during the removal time period. The mass of the navigational aid is included in the maximum Lunabot mass limit of 80.0 kg and must be self-powered.

16) There will be three obstacles placed on top of the compressed BP-1 surface within the obstacle area before each competition attempt is made. The placement of the obstacles will be randomly selected before the start of the competition. Each obstacle will have a diameter of approximately 20 to 30 cm and an approximate mass of 7 to 10 kg. There will be two craters of varying depth and width, being no wider or deeper than 30 cm. No obstacles will be intentionally buried in the BP-1 by NASA, however, BP-1 includes naturally occurring rocks.

17) The Lunabot must operate within the LunArena: it is not permitted to pass beyond the confines of the outside wall of the LunArena and the LunaBin during each competition attempt. The BP-1 must be mined in the mining area and deposited in the LunaBin. A team that excavates any BP-1 from the starting or obstacle areas will be disqualified. The BP-1 must be carried from the mining area to the LunaBin by any means and be deposited in the LunaBin in its raw state. A secondary container like a bag or box may not be deposited inside the LunaBin. Depositing a container in the LunaBin will result in disqualification of the team. The Lunabot can separate intentionally, if desired, but all parts of the Lunabot must be under the team's control at all times. Any ramming of the wall may result in a safety disqualification at the discretion of the judges. Touching or having a switch sensor springwire that may brush on a wall as a collision avoidance sensor is allowed.

18) The Lunabot must not use the wall as support or push/scoop BP-1 up against the wall to accumulate BP-1. If the Lunabot exposes the LunArena bottom due to excavation, touching the bottom is permitted, but contact with the LunArena bottom or walls cannot be used at any time as a required support to the Lunabot. Teams should be prepared for airborne dust raised by either team during each competition attempt.

Technical Rules

19) During each competition attempt, the Lunabot is limited to autonomous and telerobotic operations only. No physical access to the Lunabot will be allowed during each competition attempt. In addition, telerobotic operators are only allowed to use data and video originating from the Lunabot and the NASA video monitors. Visual and auditory isolation of the telerobotic operators from the Lunabot in the Mission Control Center is required during each competition attempt. Telerobotic operators will be able to observe the LunArena through overhead cameras in the LunArena through monitors that will be provided by NASA in the Mission Control Center. These color monitors should be used for situational awareness only. No other outside communication via cell phones, radios, other team members, etc. is allowed in the Mission Control Center once each competition attempt begins.

20) The Lunabot mass is limited to a maximum of 80.0 kg. Subsystems on the Lunabot used to transmit commands/data and video to the telerobotic operators are counted toward the 80.0 kg mass limit. Equipment not on the Lunabot used to receive data from and send commands to the Lunabot for telerobotic operations is excluded from the 80.0 kg mass limit.

21) The Lunabot must provide its own onboard power. No facility power will be provided to the Lunabot. There are no power limitations except that the Lunabot must be self-powered and included in the maximum Lunabot mass limit of 80.0 kg.

22) The Lunabot must be equipped with an easily accessible red emergency stop button (kill switch) of minimum diameter five cm on the surface of the Lunabot requiring no steps to access. The emergency stop button must stop the Lunabot's motion and disable all power to the Lunabot with one push motion on the button. It must be

highly reliable and instantaneous. For these reasons an unmodified "Commercial Off-The-Shelf" (COTS) red button is required. A closed control signal to a mechanical relay is allowed as long as it stays open to disable the Lunabot. The reason for this rule is to completely safe the Lunabot in the event of a fire or other mishap. The button should disconnect the batteries from all controllers (high current, forklift type button) and it should isolate the batteries from the rest of the active sub-systems as well.

23) The communications rules used for telerobotic operations follow:

A. LUNABOT WIRELESS LINK

1. Each team will provide the wireless link (access point, bridge, or wireless device) to their Lunabot, which means that each team will bring the Wi-Fi equipment/router and set their own IP addresses.
   a. NASA will provide an elevated network drop (Female RJ-45 Ethernet jack) in the LunArena that extends to the Mission Control Center, where NASA will provide a network switch for the teams to plug in their laptops.
      i. The network drop in the LunArena will be elevated high enough above the edge of the regolith bed wall to provide adequate radiofrequency visibility of the LunArena.
      ii. A shelf will be setup next to the network drop and located 4 to 6 feet off the ground and will be no more than 50 feet from the Lunabot. This shelf is where teams will place their Wireless Access Point (WAP) to communicate with their Lunabot. The distance from the LunArena to the Mission Control Center will be around 150 – 200 feet.
      iii. The WAP shelves for side A and side B of the LunArena will be no closer than 25' from each other to prevent electromagnetic interference (EMI) between the units.
   b. NASA will provide a standard 110VAC outlet by the network drop. Both will be no more than 2 feet from the shelf.
   c. During setup time before the match starts the teams will be responsible for setting up their access point.
2. The teams must use the USA IEEE 802.11 b/g standard for their wireless connection (WAP and rover client). Teams cannot use multiple channels for data transmission. Encryption is not required but it is highly encouraged to prevent unexpected problems with team links.
   a. During a match, one team will operate on channel 1 and the other team will operate on channel 11.
   b. The channel assignments will be made upon team check-in with the LunaPit crew chief.
3. Each team will be assigned an SSID that they must use for their wireless equipment.
   a. SSID will be "Team_##"
   b. Teams will broadcast their SSID
4. Bandwidth constraints:
   a. Teams will be awarded the Efficient Use of Communications Power Award for using the least amount of average bandwidth during the timed and NASA monitored portion of the competition. Teams must collect the minimum 10 kg of BP-1 to qualify for this award.
   b. The communications link is required to have an <u>average</u> bandwidth of no more than 5 megabits per second. There will not be a <u>peak</u> bandwidth limit.

B. RF & COMMUNICATIONS APPROVAL

1. Each team must demonstrate to the communication judges that their Lunabot and access point is operating only on their assigned channel. Each team will have approximately 15 minutes at the communication judge's station.
2. To successfully pass the communications judge's station a team must be able to command their Lunabot (by driving a short distance) from their Lunabot driving/control laptop through their wireless access point. The judges will verify this and use the appropriate monitoring tools to verify that the teams are operating only on their assigned channel.
3. If a team cannot demonstrate the above tasks in the allotted time, the team will be disqualified from the competition.
4. Each team will receive an assigned time from the LunaPit crew chief, on a first come, first serve basis, on Monday, May 21, 2012 or Tuesday, May 22, 2012 to show the communication judges their compliance with the rules.
5. The NASA communications technical experts will be available to help teams make sure that they are ready for the communication judge's station on Monday, May 21, 2012 or Tuesday, May 22, 2012.

6. Once the team arrives at the communication judge's station, the team can no longer receive assistance from the NASA communications technical experts.
7. If a team is on the wrong channel during their competition attempts, the team will be required to power down and be disqualified.

C. WIRELESS DEVICE OPERATION IN THE PITS

1. Teams will not be allowed to power up their transmitters on any frequency in the Lunapits during the practice matches or competition attempts. All teams must have a hard-wired connection for testing in the Lunapits.
2. There will be designated times for teams to power up their transmitters when there are no practice matches underway.

24) The Lunabot must be contained within 1.5 m length x 0.75 m width x 0.75 m height. The Lunabot may deploy or expand beyond the 1.5 m x 0.75 m footprint after the start of each competition attempt, but may not exceed a 1.5 meter height. The Lunabot may not pass beyond the confines of the outside wall of the LunArena and the LunaBin during each competition attempt to avoid potential interference with the surrounding tent. The team must declare the orientation of length and width to the inspection judge. Because of actual lunar hardware requirements, no ramps of any kind will be provided or allowed. An arrow on the reference point must mark the forward direction of the Lunabot in the starting position configuration. The judges will use this reference point and arrow to orient the Lunabot in the randomly selected direction and position. A multiple robot system is allowed but the total mass and starting dimensions of the whole system must comply with the volumetric dimensions given in this rule.

25) To ensure that the Lunabot is usable for an actual lunar mission, the Lunabot cannot employ any fundamental physical processes (e.g., suction or water cooling in the open lunar environment), gases, fluids or consumables that would not work in the lunar environment. For example, any dust removal from a lens or sensor must employ a physical process that would be suitable for the lunar surface. Teams may use processes that require an Earth-like environment (e.g., oxygen, water) only if the system using the processes is designed to work in a lunar environment and if such resources used by the Lunabot are included in the mass of the Lunabot. Pneumatic mining systems are allowed only if the gas is supplied by the Lunabot itself.

26) Components (i.e. electronic and mechanical) are not required to be space qualified for the lunar vacuum, electromagnetic, and thermal environments. Since budgets are limited, the competition rules are intended to require Lunabots to show lunar plausible system functionality but the components do not have to be traceable to a space qualified component version. Examples of allowable components are: Sealed Lead-Acid (SLA) or Nickel Metal Hydride (NiMH) batteries; composite materials; rubber or plastic parts; actively fan cooled electronics; motors with brushes; and proximity detectors and/or Hall Effect sensors, but proceed at your own risk since the BP-1 is very dusty. Teams may use honeycomb structures as long as they are strong enough to be safe. Teams may not use rubber pneumatic tires; air/foam filled tires; ultra sonic proximity sensors; or hydraulics because NASA does not anticipate the use of these on a lunar mission.

27) The Lunabot may not use any process that causes the physical or chemical properties of the BP-1 to be changed or otherwise endangers the uniformity between competition attempts.

28) The Lunabot may not penetrate the BP-1 surface with more force than the weight of the Lunabot before the start of each competition attempt.

29) No ordnance, projectile, far-reaching mechanism (adhering to Rule 24), etc. may be used. The Lunabot must move on the BP-1 surface.

30) No team can intentionally harm another team's Lunabot. This includes radio jamming, denial of service to network, BP-1 manipulation, ramming, flipping, pinning, conveyance of current, or other forms of damage as decided upon by the judges. Immediate disqualification will result if judges deem any maneuvers by a team as being offensive in nature. Erratic behavior or loss of control of the Lunabot as determined by the judges will be cause for immediate disqualification. A judge may disable the Lunabot by pushing the <u>red</u> emergency stop button at any time.

31) Teams must electronically submit documentation containing a description of their Lunabot, its operation, potential safety hazards, a diagram, and basic parts list by April 30, 2012 at 12:00 p.m. (noon) eastern time in the United States.

32) Teams must electronically submit video documentation containing no less than 30 seconds but no more than 5 minutes of their Lunabot in operation for at least one full cycle of operation by April 30, 2012 at 12:00 p.m. (noon) eastern time in the United States. One full cycle of operations includes excavation and depositing material. This video documentation is solely for technical evaluation of the Lunabot.

Video Specifications/Formats/Containers: .avi, .mpg, .mpeg, .ogg, .mp4, .mkv, .m2t, .mov; Codecs: MPEG-1, MPEG-2, MPEG-4 (including AVC/h.264), ogg theora; Minimum frame rate: 24 fps; Minimum resolution: 320 x 240 pixels

Shipping

33) Teams may ship their Lunabots to arrive no earlier than May 14, 2012. The Lunabots will be held in a safe, unairconditioned area and be placed in the team's LunaPit by Monday, May 21, 2012. The shipping address is:

Kennedy Space Center Visitor Complex
Lunabotics Mining Competition
Mail Code: DNPS
Kennedy Space Center, FL 32899

34) Return shipping arrangements must be made prior to the competition. All Lunabots must be picked up from the Kennedy Space Center Visitor Complex no later than 5:00 p.m. on Tuesday, May 29, 2012. Any abandoned Lunabots will be discarded after this date.

LunArena Diagrams

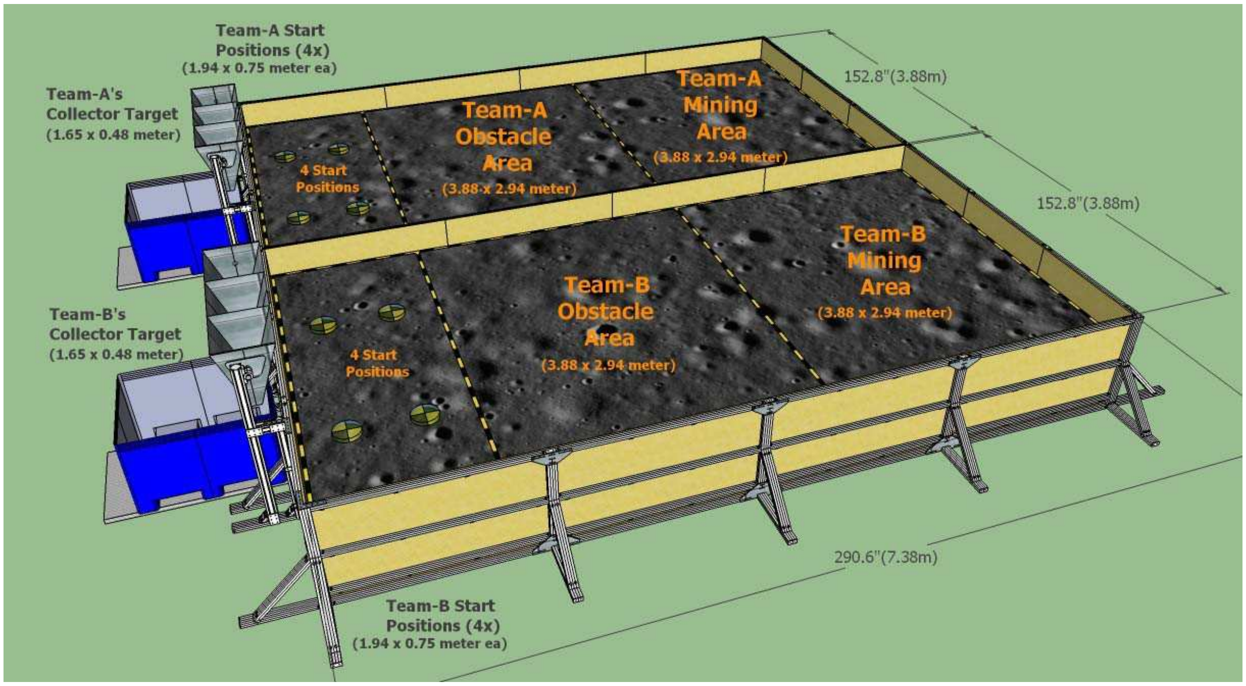


Diagram 1: LunArena (isometric view)

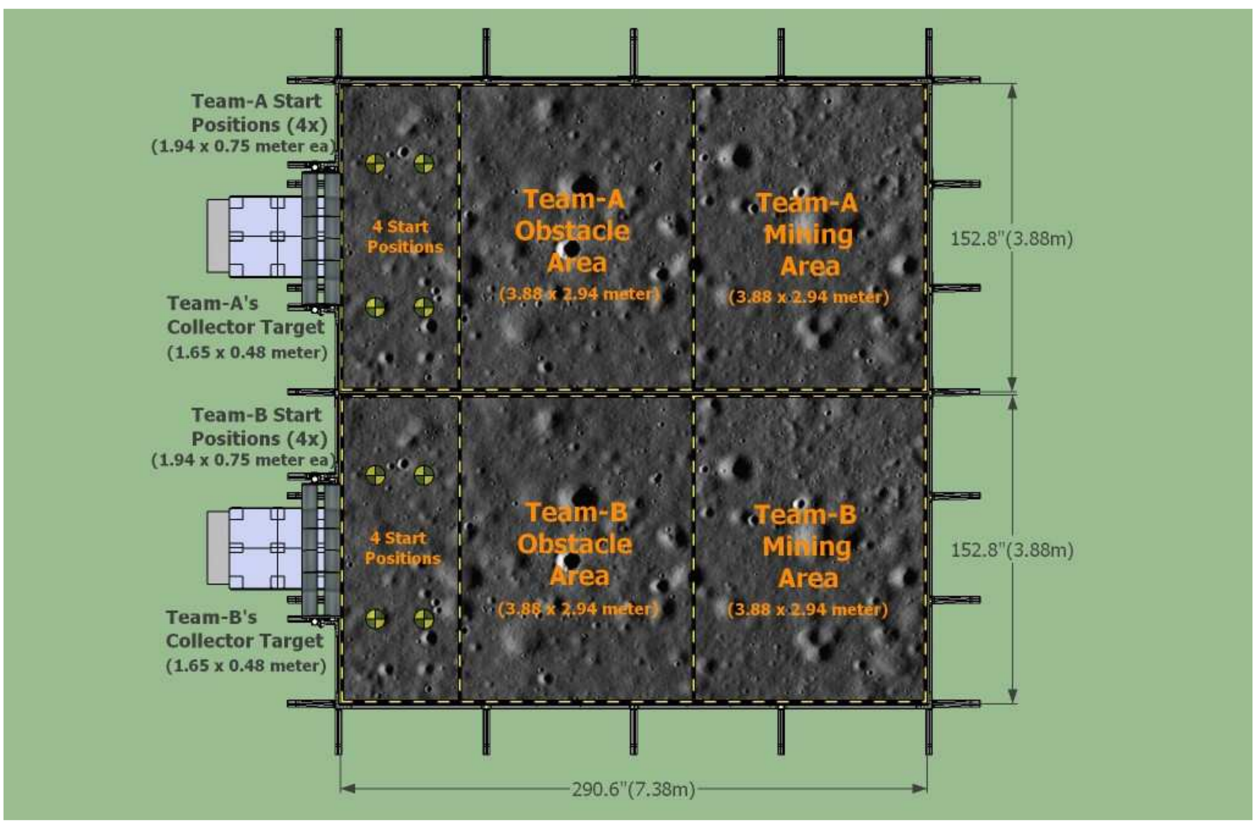


Diagram 2: LunArena (top view)

LunaBin Diagram

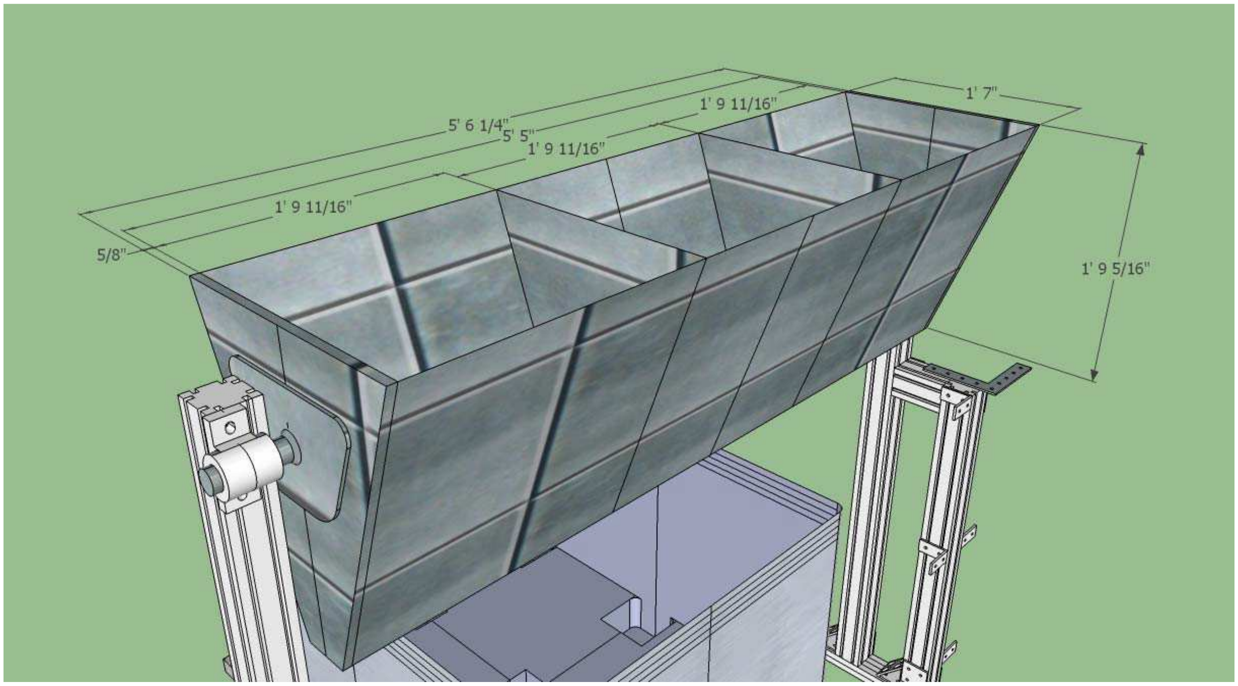


Diagram 3: LunaBin

Appendix B: Wheel Motor Specification Sheet

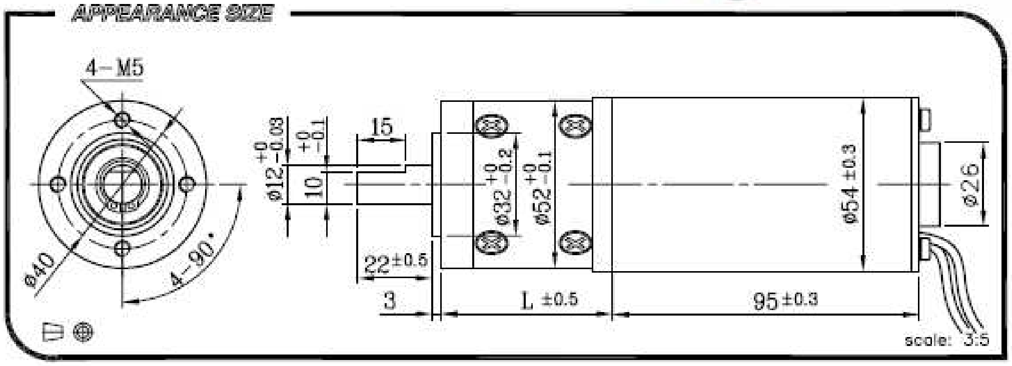
IG-52GM (DC Carbon-brush motors)

03&04 TYPE

REDUCTION RATIO	L	REDUCTION RATIO	L
1/3~1/4	53.0	1/150~1/936	99.5
1/12~1/26	68.5		
1/43~1/113	84.0		

IG-52 GEARHEAD SERIES

APPEARANCE SIZE



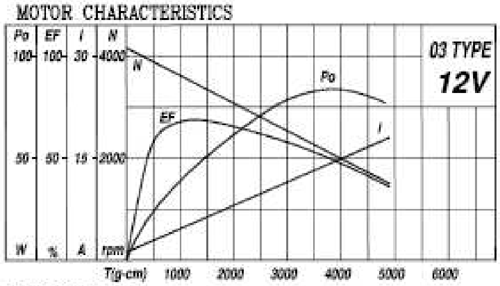
GEARED MOTOR TORQUE/SPEED

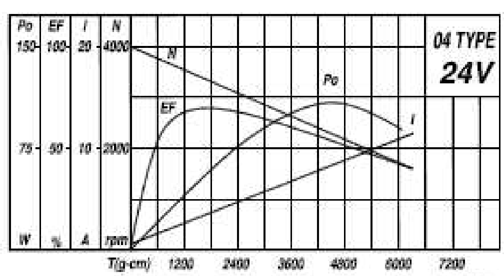
	Reduction ratio	1/3	1/4	1/12	1/15	1/19	1/26	1/43	1/53	1/66	1/81	1/100	1/113	1/150	1/230	1/285	1/353	1/488	1/546	1/676	1/936
12V	Rated torque (Kg-cm)	2.5	3.1	7.7	9.5	11.8	16	23	28	35	44	54	60	67	100	100	100	100	100	100	100
	Rated speed (rpm)	1030	835	295	238	192	139	84	68	55	44	36	32	24	15.5	12.8	10.4	7.6	6.7	5.6	4.0
24V	Rated torque (Kg-cm)	3.6	4.5	11	13.5	17	23	33	41	51	62	78	88	97	100	100	100	100	100	100	100
	Rated speed (rpm)	1000	815	285	230	185	136	82	67	54	44	35	31	23.5	15.6	12.9	10.5	7.7	6.8	5.7	4.1

MOTOR DATTA

Rated volt (V)	Rated torque (g-cm)	Rated speed (rpm)	Rated current (mA)	No load speed (rpm)	No load current (mA)	Rated output (W)	Weight (g)
12	900	3620	≤ 4100	4000	≤ 1200	33.5	920
24	1300	3550	≤ 2850	4000	≤ 700	48.6	920

MOTOR CHARACTERISTICS





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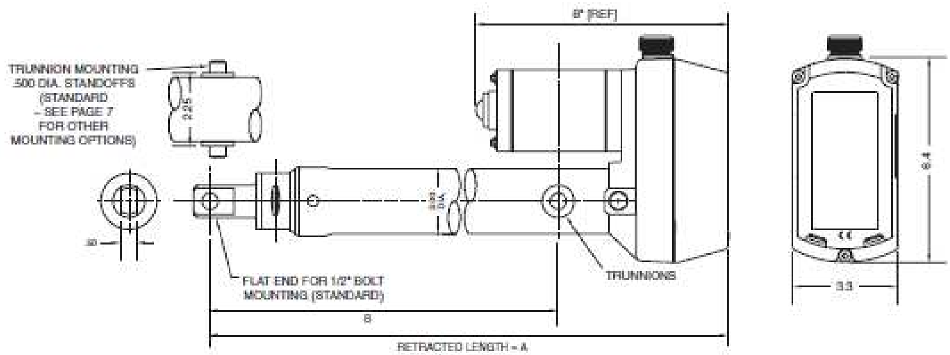
September 2006

Appendix C: Nook Large Actuator

12 AND 24 VDC MODELS

ActionJac CC LINEAR ACTUATORS



12 VDC															
STANDARD UNIT MODEL NUMBER	POTENTIOMETER POSITION SENSOR MODEL NUMBER	HALL EFFECT POSITION SENSOR MODEL NUMBER	LIMIT SWITCH MODEL NUMBER	STROKE		DIMENSIONS				DYNAMIC LOAD		AMP DRAW	TRAVEL RATE	
				(IN)	(MM)	A (IN)	A (MM)	B (IN)	B (MM)	LB	N		IN/SEC	MM/SEC
CCHD-3605	CCHD-1401	CCHD-1335	CCHD-2837	4	102	16.2	412	8.8	224	750	3330	22	1.1	28
CCHD-1187	CCHD-1402	CCHD-1336	CCHD-2838	8	203	20.2	513	12.8	326					
CCHD-3552	CCHD-1403	CCHD-1337	CCHD-2839	12	305	24.2	615	16.8	427					
CCHD-1058	CCHD-1404	CCHD-1338	CCHD-2840	18	457	32.2	818	24.8	631					
CCHD-1188	CCHD-1405	CCHD-1339	CCHD-2841	24	610	38.2	970	30.8	783					
CCHD-1189	CCHD-1406	CCHD-1340	CCHD-2842	36	914	50.2	1275	42.8	1088					
CCHD-4114	CCHD-1407	CCHD-1345	CCHD-2843	4	102	16.2	412	8.8	224	1500	6670	15	0.4	10
CCHD-1190	CCHD-1408	CCHD-1346	CCHD-2844	8	203	20.2	513	12.8	326					
CCHD-4273	CCHD-1409	CCHD-1347	CCHD-2845	12	305	24.2	615	16.8	427					
CCHD-1059	CCHD-1410	CCHD-1348	CCHD-2846	18	457	32.2	818	24.8	631					
CCHD-1191	CCHD-1411	CCHD-1349	CCHD-2847	24	610	38.2	970	30.8	783					
CCHD-1192	CCHD-1412	CCHD-1350	CCHD-2848	36	914	50.2	1275	42.8	1088					

24 VDC															
STANDARD UNIT MODEL NUMBER	POTENTIOMETER POSITION SENSOR MODEL NUMBER	HALL EFFECT POSITION SENSOR MODEL NUMBER	LIMIT SWITCH MODEL NUMBER	STROKE		DIMENSIONS				DYNAMIC LOAD		AMP DRAW	TRAVEL RATE	
				(IN)	(MM)	A (IN)	A (MM)	B (IN)	B (MM)	LB	N		IN/SEC	MM/SEC
CCHD-8532	CCHD-8544	CCHD-8556	CCHD-8568	4	102	16.2	412	8.8	224	750	3330	11	1.1	28
CCHD-8533	CCHD-8545	CCHD-8557	CCHD-8569	8	203	20.2	513	12.8	326					
CCHD-8534	CCHD-8546	CCHD-8558	CCHD-8570	12	305	24.2	615	16.8	427					
CCHD-8535	CCHD-8547	CCHD-8559	CCHD-8571	18	457	32.2	818	24.8	631					
CCHD-8536	CCHD-8548	CCHD-8560	CCHD-8572	24	610	38.2	970	30.8	783					
CCHD-8537	CCHD-8549	CCHD-8561	CCHD-8573	36	914	50.2	1275	42.8	1088					
CCHD-8538	CCHD-8550	CCHD-8562	CCHD-8574	4	102	16.2	412	8.8	224	1500	6670	8	0.4	10
CCHD-8539	CCHD-8551	CCHD-8563	CCHD-8575	8	203	20.2	513	12.8	326					
CCHD-8540	CCHD-8552	CCHD-8564	CCHD-8576	12	305	24.2	615	16.8	427					
CCHD-8541	CCHD-8553	CCHD-8565	CCHD-8577	18	457	32.2	818	24.8	631					
CCHD-8542	CCHD-8554	CCHD-8566	CCHD-8578	24	610	38.2	970	30.8	783					
CCHD-8543	CCHD-8555	CCHD-8567	CCHD-8579	36	914	50.2	1275	42.8	1088					

The specifications and data in this publication are believed to be accurate and reliable. However, it is the responsibility of the product user to determine the suitability of Nook Industries products for a specific application. While defective products will be replaced without charge if promptly returned, no liability is assumed beyond such replacement.

Appendix D: Moteck Linear Actuator

Products Index

- Industrial Actuator
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  - ID11B
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  - ID12B
  - ID13A
  - ID13B
  - LD2
  - LD2Q
  - LD3
  - LD3Q
  - LS3
  - LD6
  - TB
  - BJ plus
  - MN+
  - TD+
  - HV+
  - IA5A
  - IA5B
  - LA5
  - LA8
- Furniture Series
  - FD
  - FD21
  - FD70
  - GD60
  - PD23
  - PD62
  - PD63
  - PD64
  - BD60
  - BD61
  - BDN60
  - BDF60
  - TW32/42

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LINEAR ACTUATOR

ID10 ACME series

FEATURE:

- **Max Load: 3500N**
- **Motor Voltage: 12/24V DC**
- **Max. Speed Range: 8~34 mm/sec**
- **Standard Stroke: 102/153/203/305/457/610mm**
- **Stainless steel extension tube**
- **Powder metallurgy gears**
- **Overload Clutch Protection**
- **No back driving**
- **Working temperature: -25℃ to +65℃**
- **Duty cycle: 25%**
- **Gear ratio: 10:1, 20:1, 40:1**
- **Protection: IP54**

TW40/TW60
TW41/TW61
Medical Actuator
MD50
MD51
MD60
MD7
MD80
MD81
MD100
Control & Accessory
Control Box
CONTROL BOX
CB4M
CB4P
CBP1
MK16
Handsets and Remote Kits
HANDSETS
TI
TX
FOOT SWITCH
Accessories
Accessories
RV / Solar Motorization
RV
LJ
Motor Gear
SC
SC-M
SC-Y
CJ
Solar
STC1
H360
Gate Opener System
GOS
SW200
SW230
SW280
SW300
SW430
SW570
SL350
ROBOBOX50

Option:

- **Optional or Customized Front/Rear Mounting Bracket**
- **Potentiometer**
- **Adjustable limit switches**
- **Manual Drive by Hand Crank**
- **Protection: IP65**

Specification:	
Model	ID10 ACME
Input	12 / 24VDC
Max. Load	3500N
Max. Speed	34 mm/sec
Stroke Length	102, 153, 203, 305, 457, 610 mm
Gear Ratio	10:1, 20:1, 40:1
Duty Cycle	25%
Environment	-25℃ ~ 65℃

SHIPPING INFORMATION:

Model	PCS/Carton	G.W./Carton	Meas./Carton	PCS/20FT	PCS/40FT

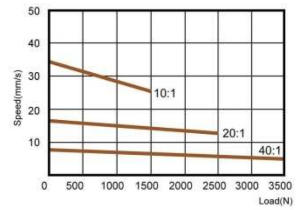
Model No. Designations

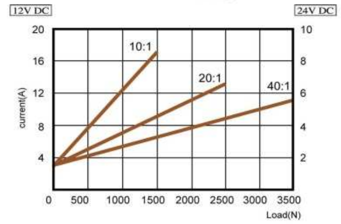
ID10-	24-	20-	A-	102-	LT.POT.MD.C1....
	Voltage 12-12V DC 24-24V DC	Gear Ratio 10-10:1 20-20:1 40-40:1	B:Ball Screw A:ACME	Stroke 102mm 153mm 203mm 305mm 457mm 610mm	LT:Limit Switch POT:Potentiometer MD:Manual Drive IP65

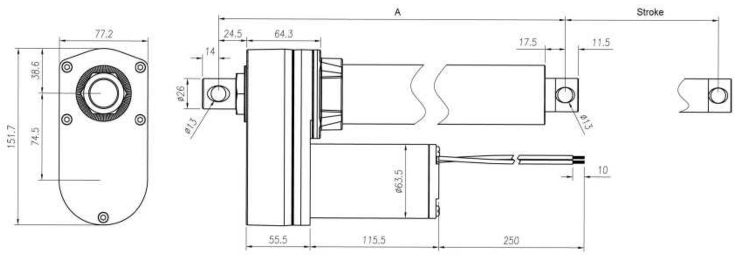
Stroke	102	153	203	305	457	610	
A	262	313	364	465	668	821	

Speed vs Load   **Current vs Load**

Gate Control Box
Solar Control Box
PHOTOCELLS
KEYPAD
ADDITIONAL ANTENNA
Solar Battery Box
Warning Light
Remote Control
ADDITIONAL RECEIVER
GARDEN LAMP CONTROL
TVRO Satellite-Actuator Positioner
MN
TD
HV
DiSEqC Mount
H180 / H360
HSE-12
DS-12
PM-12
EZ2000
EZ2200
V-BOXII
MP828
MP838(V-BOX)
MP880
GP580
EW101 / EW201
GAAPS
Motor Gearbox & TV
Motor GearBox
TV Industry







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Appendix E: Fiber Glass Tubing

Ap

More About Hard Fiber, Fiberglass, and Garolite

Tensile Strength — The maximum pulling force a material can withstand without breaking. It is usually measured in pounds per square inch (psi). A larger number indicates a stronger material.

Impact Strength — The ability of a material to withstand shock loading. Determined by the notched Izod test, which measures the effect on a material when it is suddenly impacted by a swinging pendulum. A larger number signifies greater impact resistance.

Flexural Modulus of Elasticity — The stiffness of a material. The higher the number, the stiffer the material; the lower the number, the more flexible it is.

Short-Term Dielectric Strength — The maximum voltage a material can withstand without rupture, measured as volts per millimeter of thickness. This is an indication of how effective the material is as an electrical insulator. A higher value signifies a better insulator.

Coefficient of Thermal Expansion — The amount a material increases in volume as the temperature rises. A smaller coefficient is an indicator of less thermal expansion.

Warning: Mechanical properties are not guaranteed and are intended only as a basis for comparison. Data is not for design purposes.

Material	Nominal Density, lbs./cu. in.	Tensile Strength, psi	Impact Strength, lbs./in.	Compressive Strength, psi	Flexural Strength, psi	Modulus of Elasticity, psi	Dielectric Strength, volts/mil.■	Coefficient of Thermal Expansion, in./°F	Thermal Conductivity BTU/hr.×sq. ft.	Water Absorption, %
Hard Fiber	0.043	9,000-21,000	1.8-2.5	35,000	16,000-29,000	$8\text{-}12 \times 10^5$	200-215	1.1×10^5	0.168	63-66
Fiberglass (FRP)	0.062-0.072	7,000-40,000	4-40	15,000-65,000	10,000-30,000	$2.8\text{-}5.5 \times 10^6$	200	$3.3\text{-}4.4 \times 10^6$	4	0.45
Fiberglass (GP03)	0.067	10,000-12,000	8.2-12	32,000-32,800	23,200-31,000	1.2×10^6	400-600	1.11×10^5	1.9	0.2
Garolite XX	0.05	8,000-23,900	0.35-1.3	15,000-35,000	14,000-29,000	Not rated	350-700	Not rated	Not rated	0.57-1.3
Garolite LE	0.048-0.051	6,000-15,300	0.8-1.3	22,600-36,000	15,400-19,700	Not rated	140-625	Not rated	Not rated	0.47-1.9
Garolite CE	0.05	6,000-15,100	Not rated	18,000-37,000	15,000-27,100	Not rated	120-550	Not rated	Not rated	1.6
Garolite G-9	0.074	39,000	5.5-7	23,900-70,000	55,000-60,400	1.7×10^6	370-450	Not rated	Not rated	0.5-0.6
Garolite G-10	0.069	15,000	Not rated	25,000	Not rated	Not rated	250-300	Not rated	Not rated	0.09-0.013
Garolite G-10/FR4	0.069	38,000-50,000	5.5-12	35,000-66,000	45,000-60,000	$2.2\text{-}3.3 \times 10^3$	400-800	Not rated	Not rated	0.10-0.25
Garolite G-11	0.069	37,000-58,600	Not rated	32,900-63,000	59,600-76,700	Not rated	521-900	Not rated	Not rated	0.15-0.20
Garolite G-7	0.068	18,000-27,700	Not rated	8,625-45,000	20,900-25,800	Not rated	400-465	Not rated	Not rated	0.6-0.12
Graphite-Impregnated Garolite	0.05	7,000	1.08	26,000	13,000	6.2×10^5	Not rated	Not rated	Not rated	0.7-2.05

■ 1 mil=0.001"

This data is intended only as a basis for comparison. It is given without obligation or liability. No warranty of fitness for a particular purpose or application is made.

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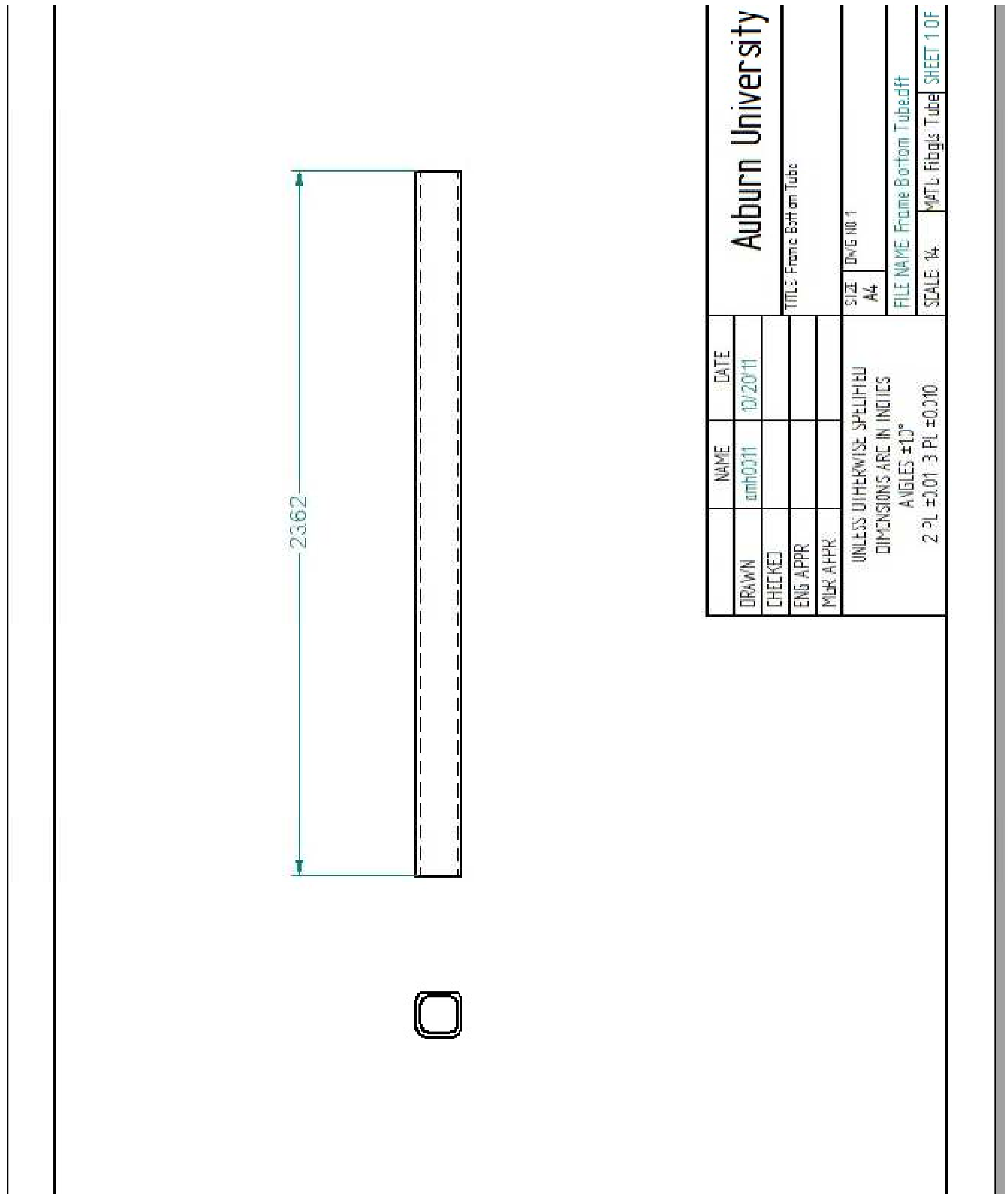
Page 1 of 2

Document 8549KAC

	Lifting Actuator	4.00	1	4.0

	Tilting Actuator	3.64	1	3.6
	Mechanical Arms	1.65	1	1.6
Drive System	Wheel	1.44	4	5.8
	Motor	0.92	4	3.7
	Axles	0.77	2	1.5
Frame	Tubing	2.11	1	2.1
	Plastic Sheeting	1.50	1	1.5
	Xbox Kinect	1.40	1	1.4
	Electrical Circuit System	0.50	1	0.5
	Batteries	4.50	2	9.0
	Netbook	1.50	1	1.5
Miscellaneous	Cameras	0.10	3	0.3
	Miscellaneous Fasteners	2.50	1	2.5
Total Mass (kg)				**44**

Appendix G: C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2 PL ±0.01 3 PL ±0.010
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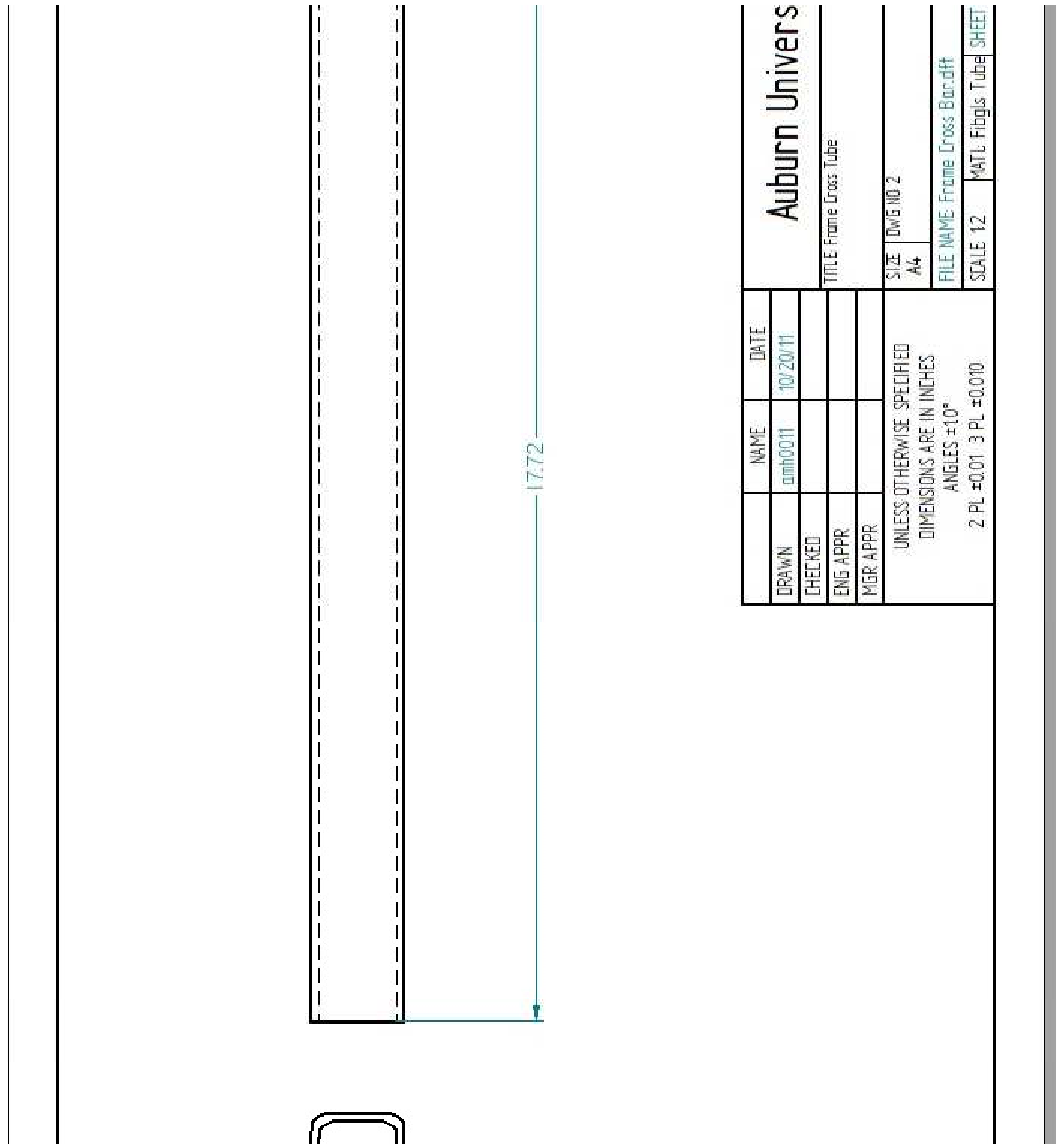
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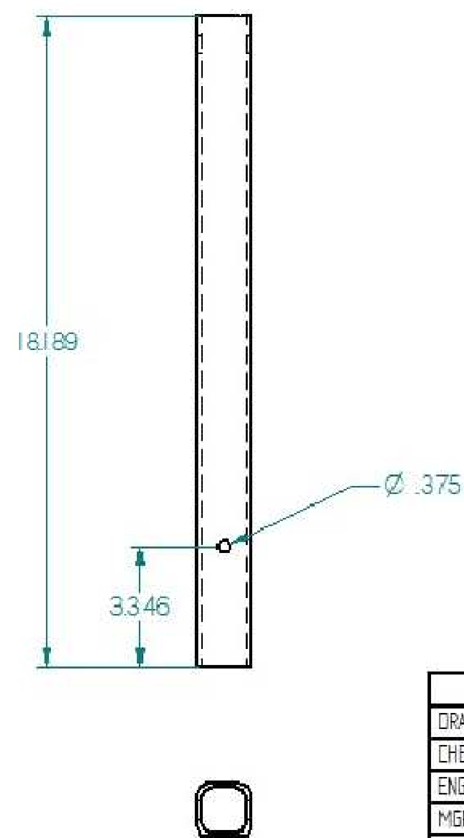
2 PL ±0.01 3 PL ±0.010



NOTE: HOLE DIMENSION FOR ACTUATOR MOUNT SHOWN IS AN ESTIMATE. EXACT HOLE DIMENSIONS WILL BE ACQUIRED DURING ASSEMBLY OF FRAME / EXCAVAOR.

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CHECKED		
ENG APPR		
MGR APPR		

UNLESS OTHERWISE SPECIFIED
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ANGLES ±1.0°
2 PL ±0.01 3 PL ±0.010

Auburn Univers

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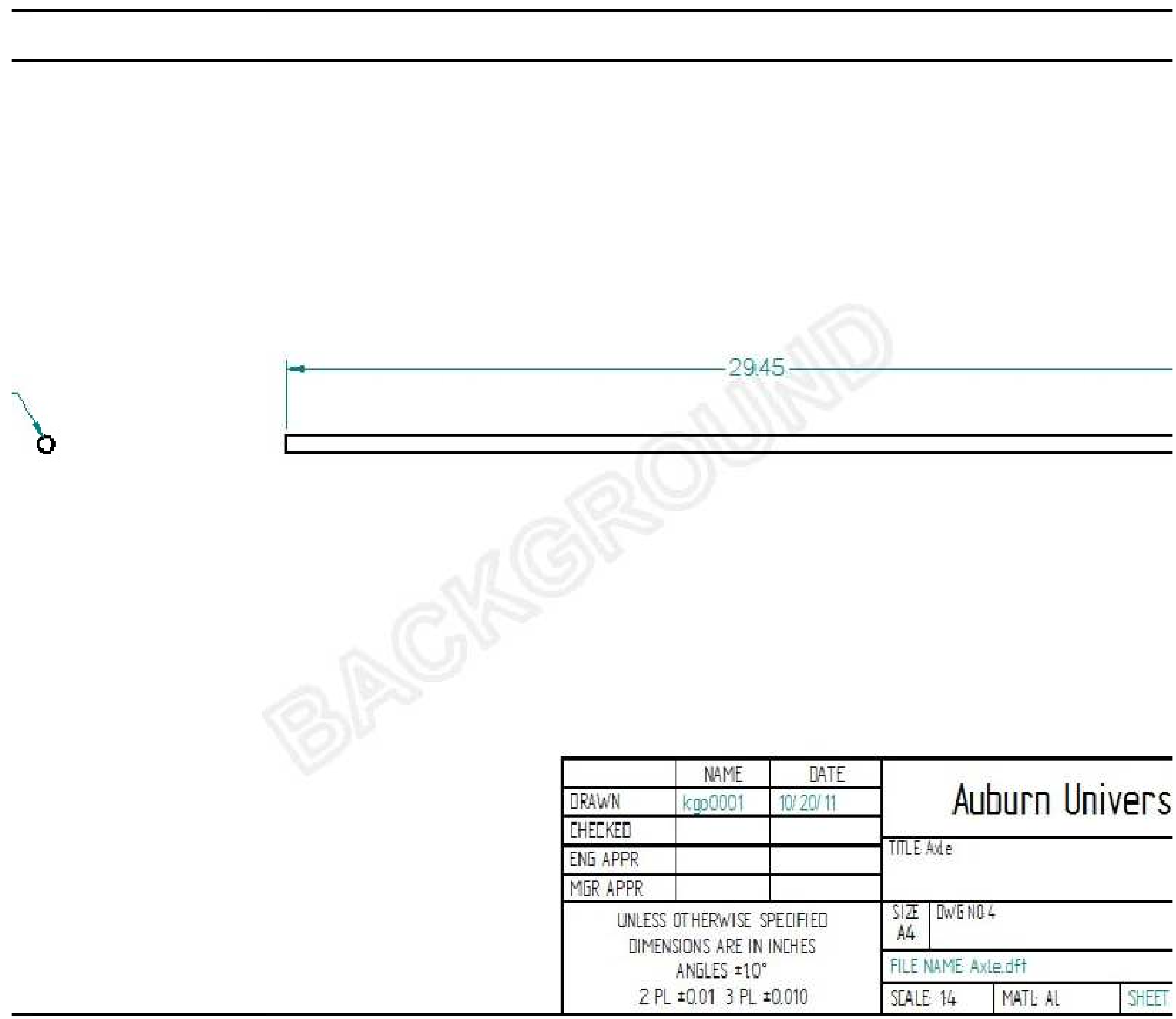
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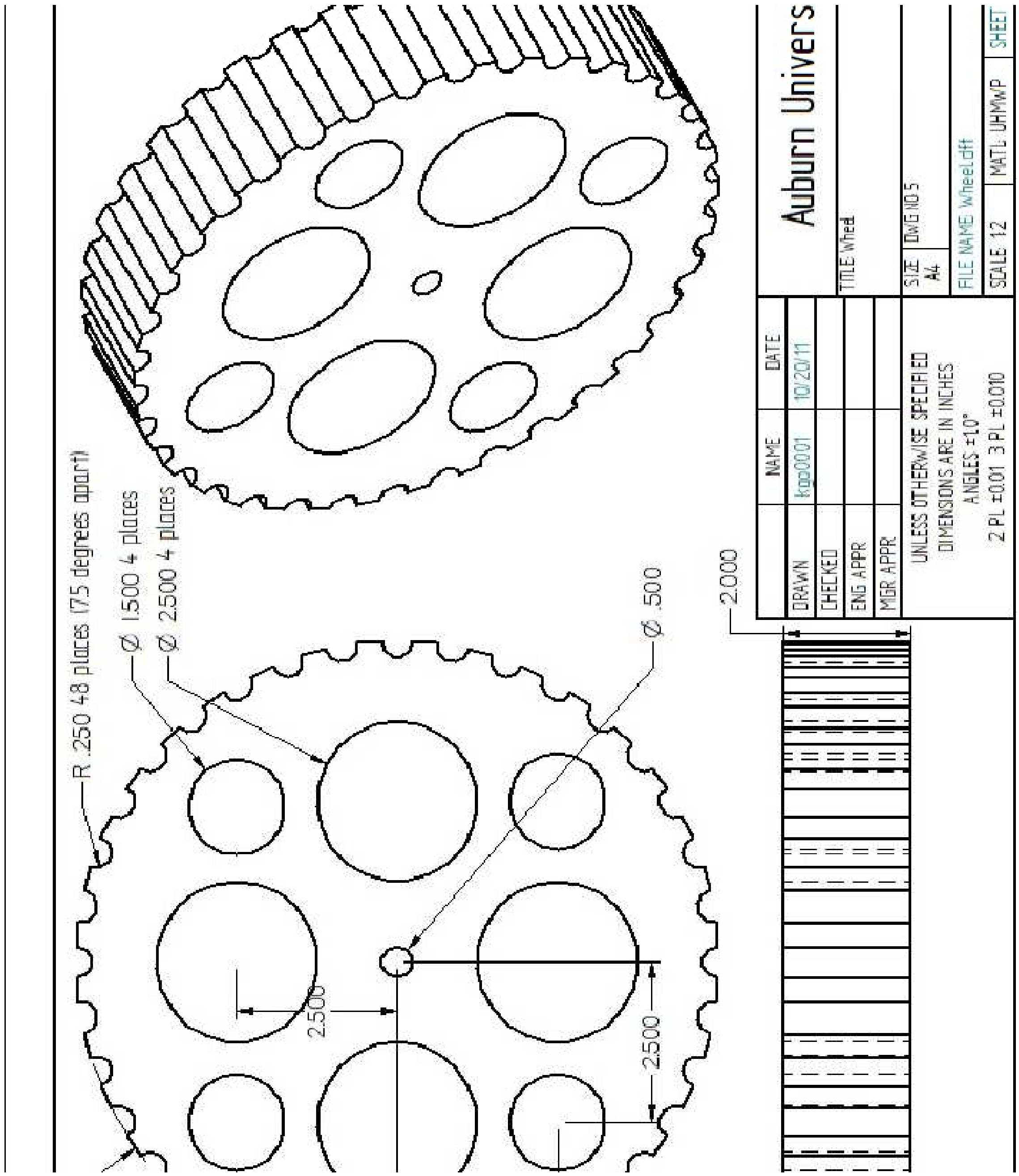
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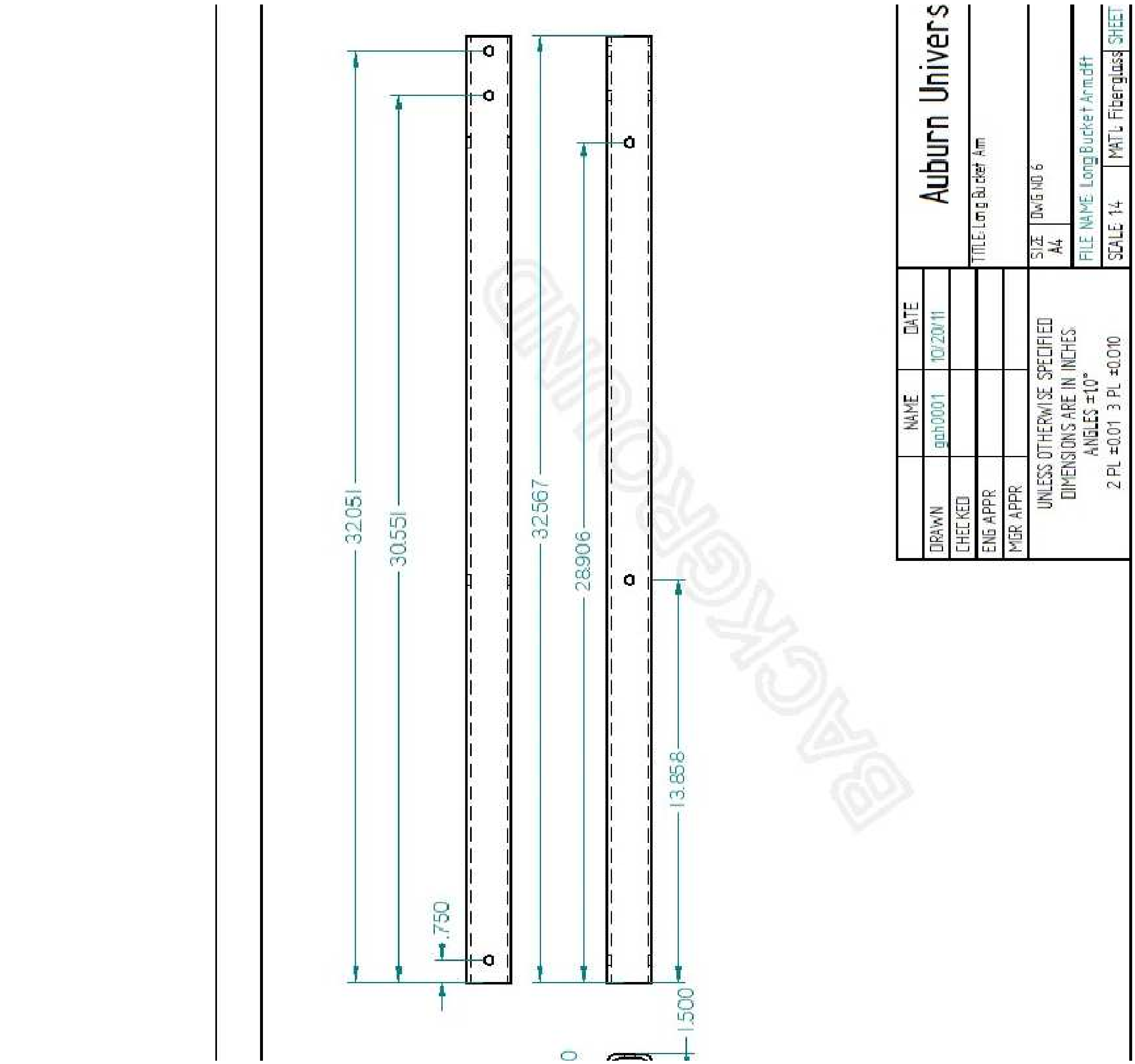
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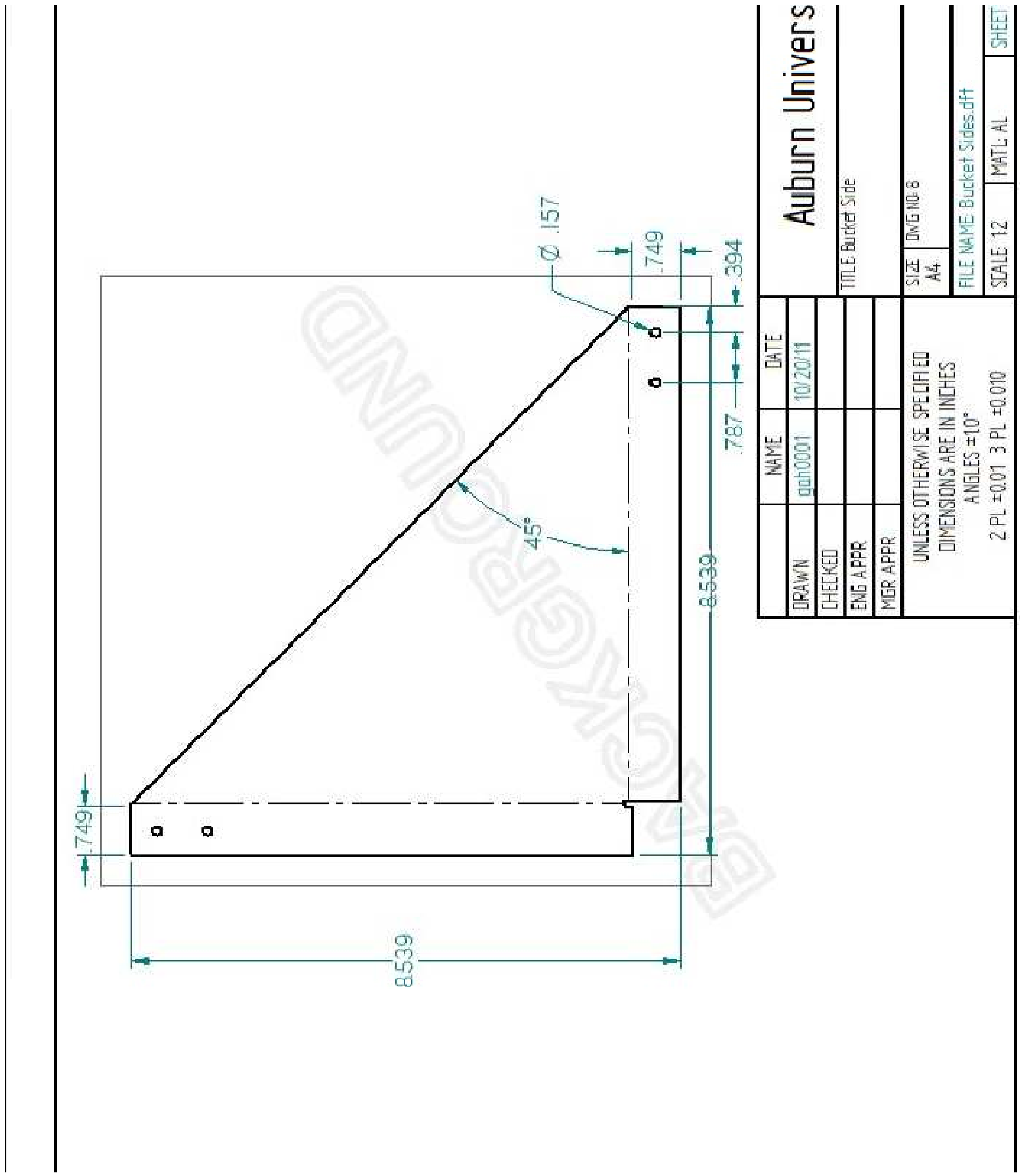
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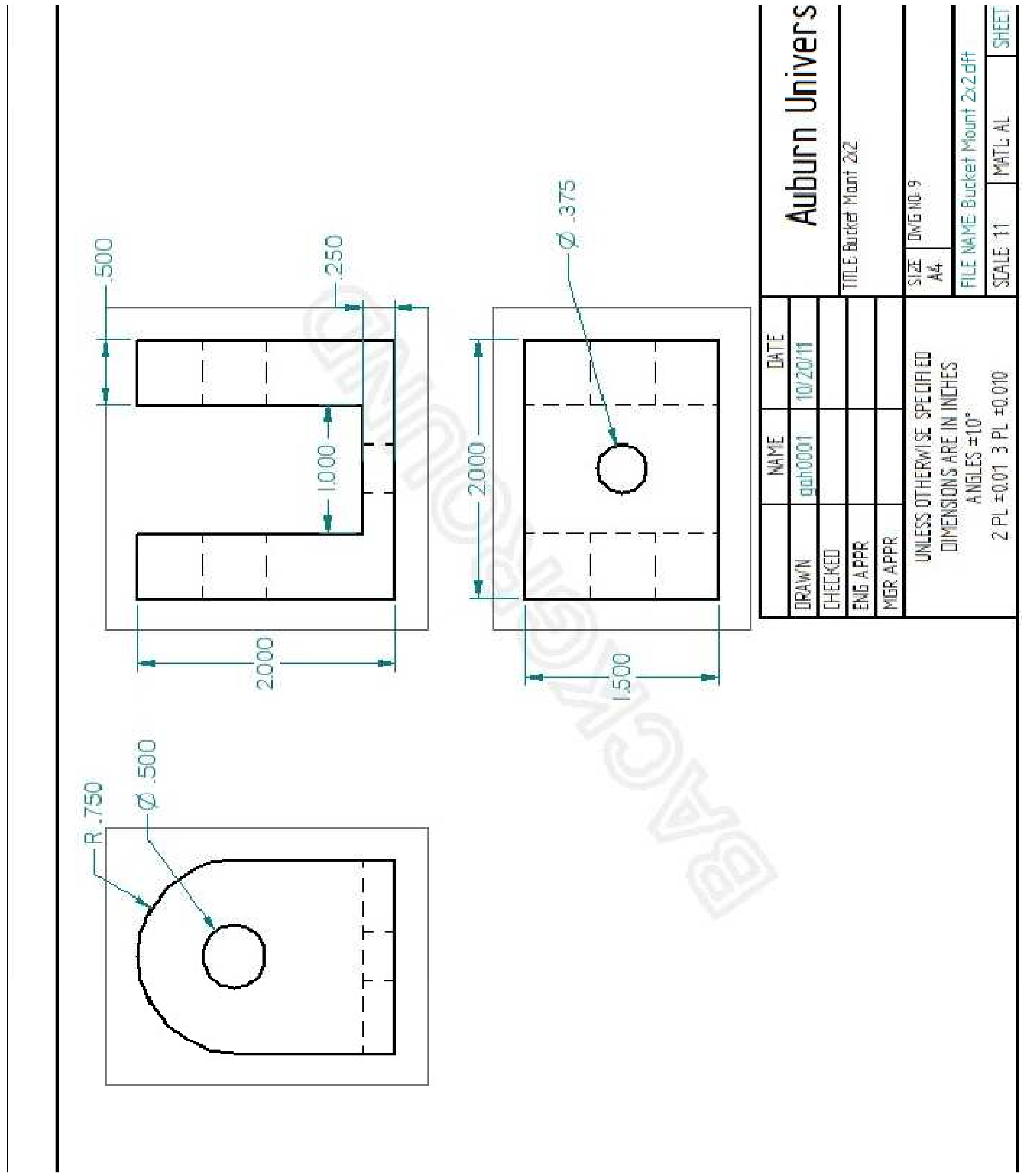

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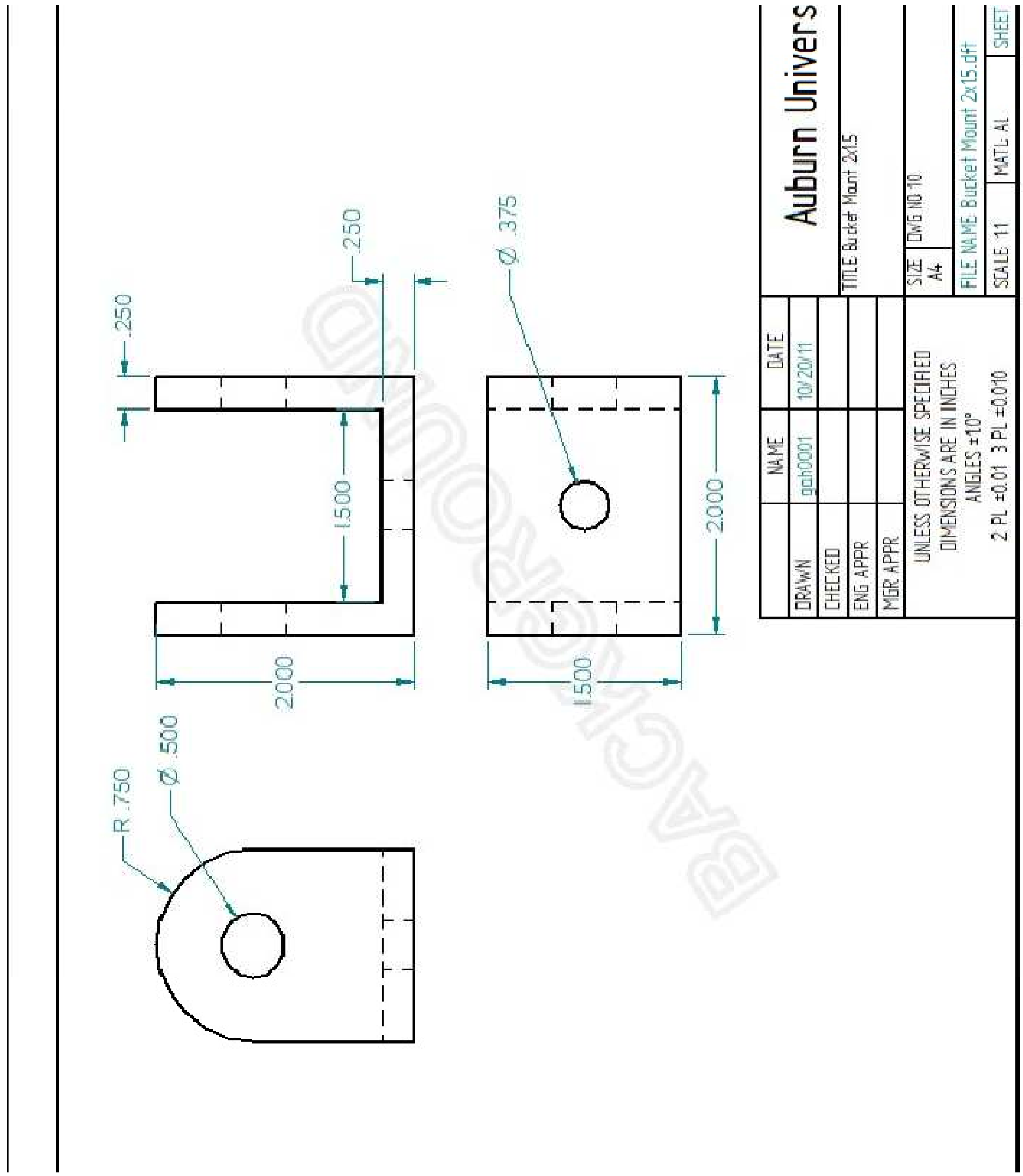
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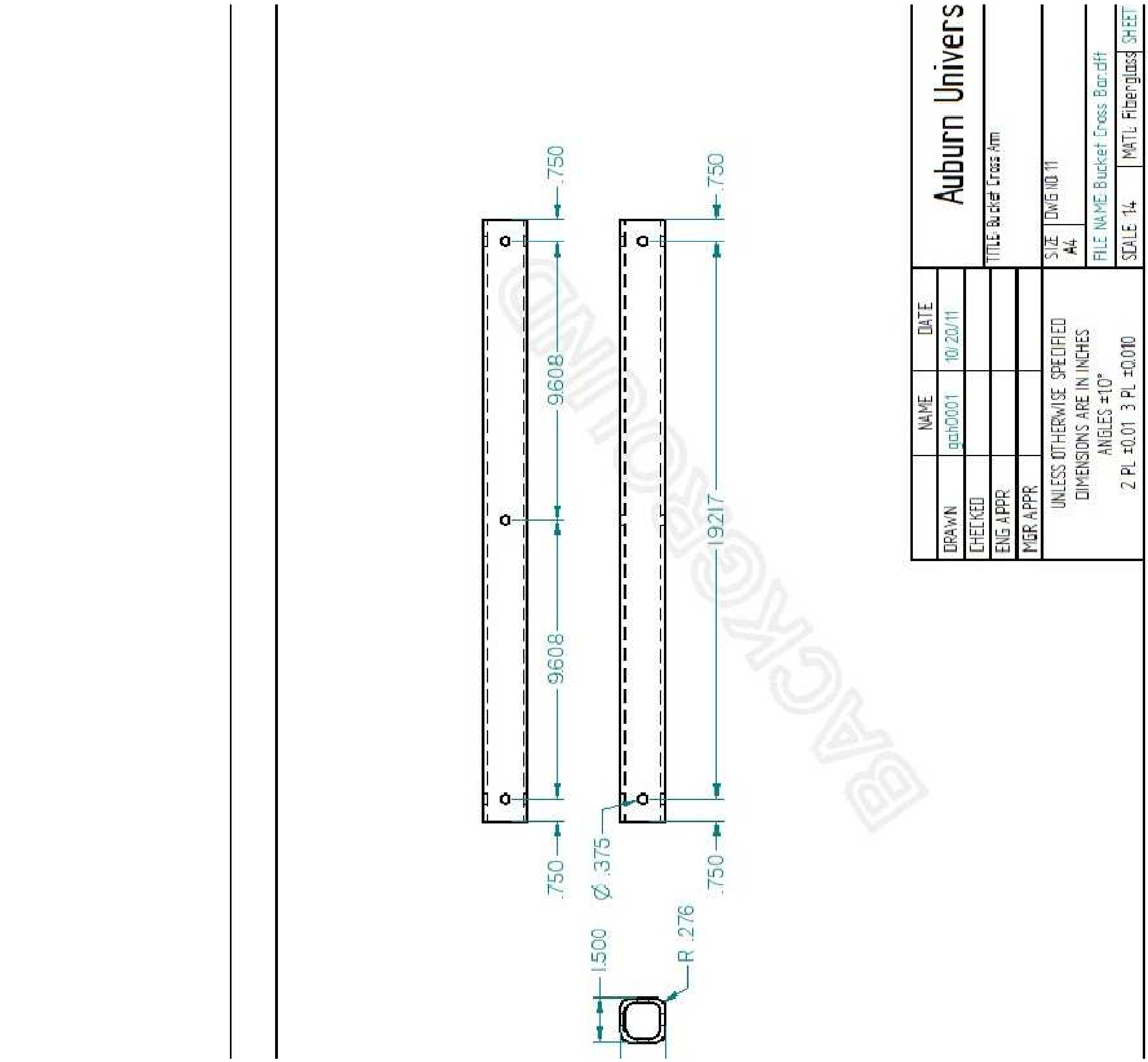

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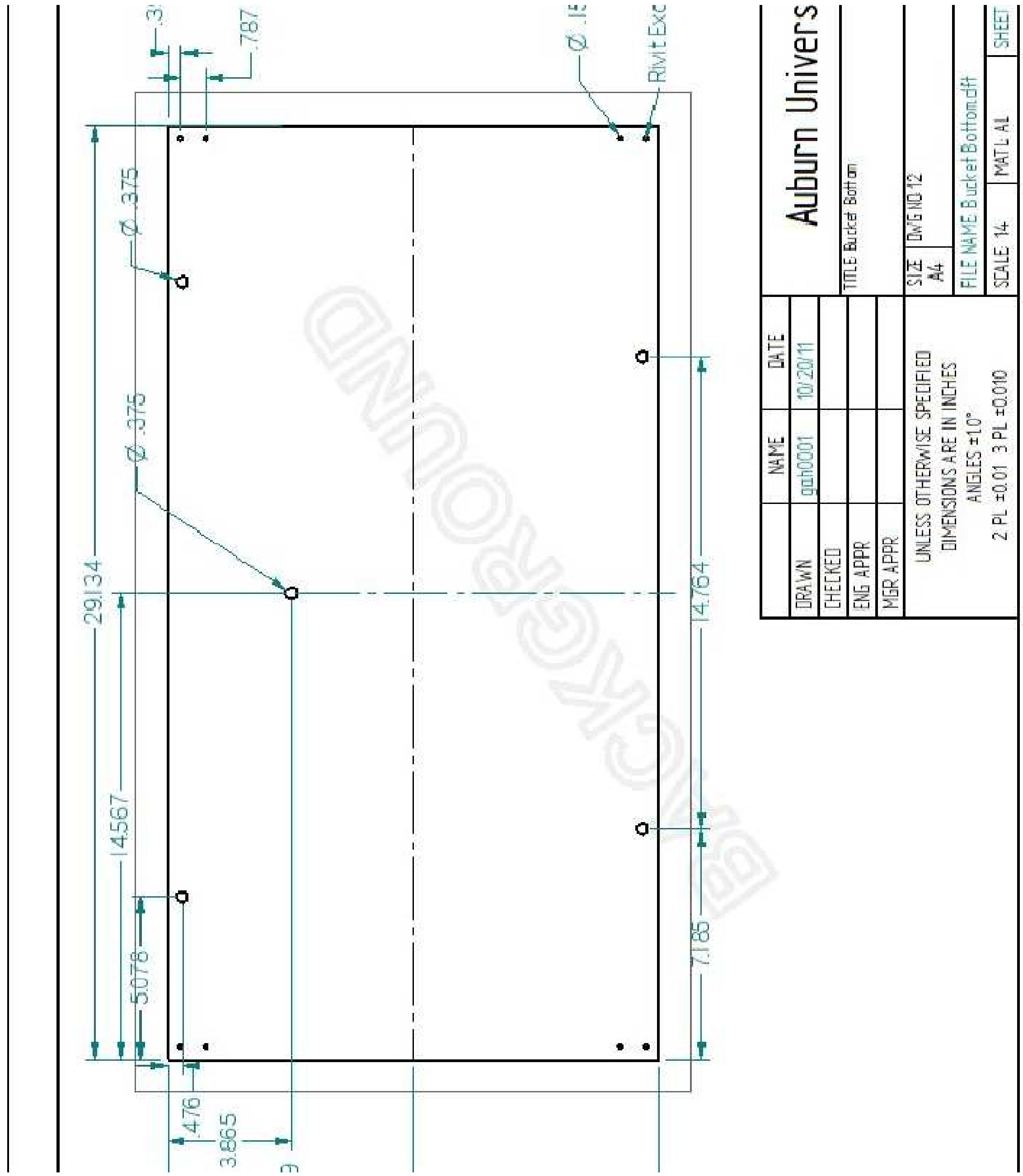
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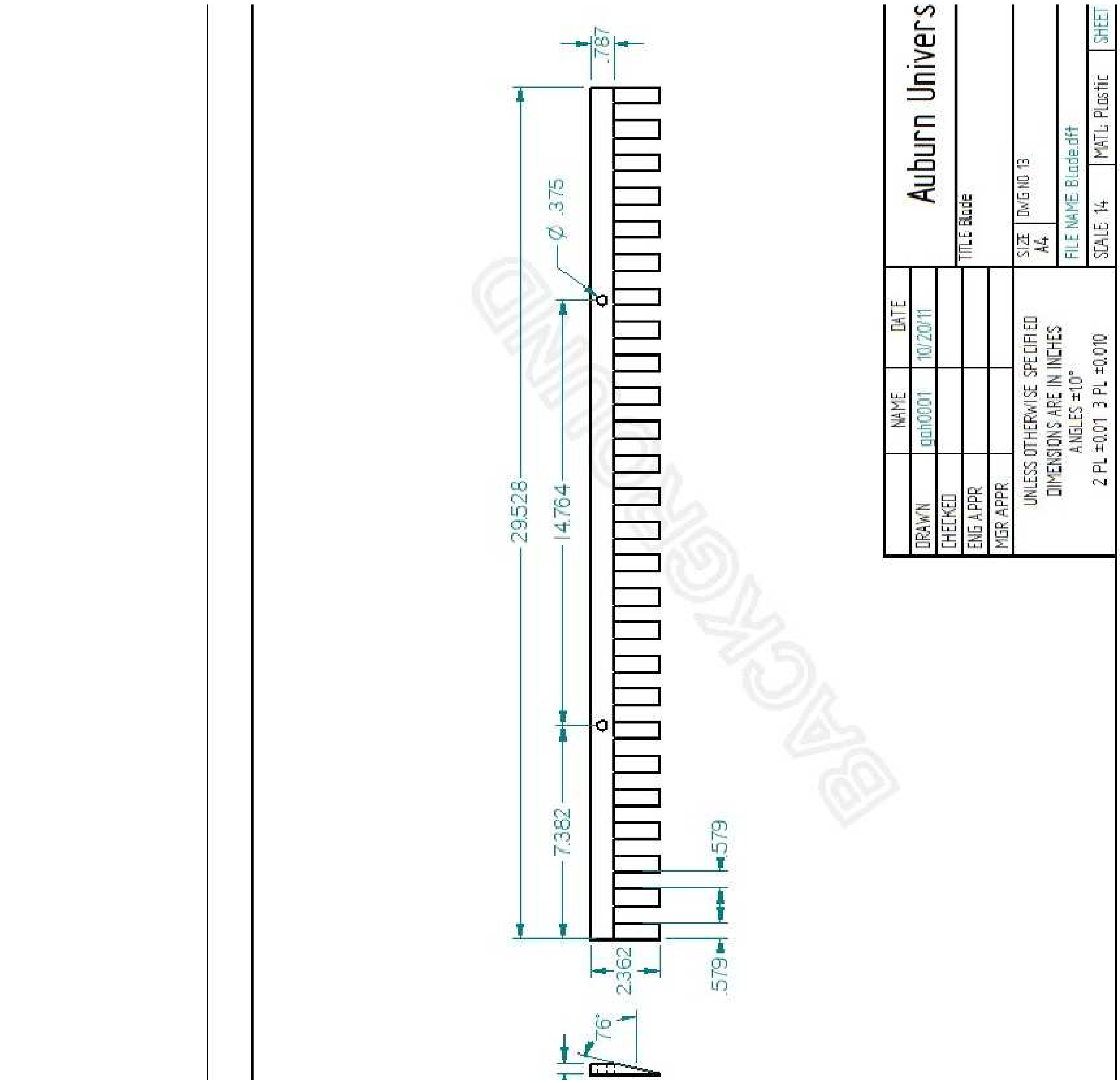
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