SAE Small Vehicle Lifts

by

Augustus G. Holz

Nathan K. Harry

Tobias W. Shirts

Mechanical Engineering Department

California Polytechnic State University

San Luis Obispo

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Statement of Disclaimer

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ABSTRACT

The SAE vehicle teams need an easy way to access the undersides of their vehicles to facilitate maintenance and servicing. The purpose of this project was to provide a solution that could lift the vehicles effectively and safely from above so that the underside of the vehicles can be accessed, as well as elevating the vehicles to an ergonomic working height. Design specifications were determined based off each vehicle's requirements in addition to what the team intends to do with their suspended vehicle. After several concept iterations, the team decided to purchase an engine hoist and replace the hydraulic cylinder with a fixed tube and construct a custom transmission thereby turning the engine hoist into a crane mechanism that can be operated easily without concerns of reliability. The team constructed a total of three lifts, each with different specifications, for the Baja, Formula, and F2000 cars. Material testing was done to verify that the unknown material of the purchased lifts was strong enough to support the loading, as well as final load testing by lifting a vehicle to its designed height.

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INTRODUCTION

Over the past four years, we have noticed the constant problem of lifting heavy objects in the shop. Not only does lifting heavy objects prove to be troublesome and demanding, it frequently proves to also be unsafe. The SAE teams employ methods of lifting and supporting custom-built vehicles that are often questionable at best. Both the shop supervisor, George Leone, and the club advisor, John Fabijanic, have expressed concern on numerous occasions about the team's methods. These "methods" usually consist of getting 1-5 members to lift the vehicle while others slide precarious homemade blocks or sawhorses underneath the cars. Our project removes the need for the physical lifting of the cars and allows for a much safer work environment while also increasing the quality of life for the teams as they work on and under their cars. Our goal was to design and build a portable lift that meets the needs of the following groups of people:

· SAE Baja

· SAE Formula (Electric and Combustion)

· John Fabijanic

This lift also functions as a means of supporting the SAE Baja car at an elevated position, and removing the engine and batteries from both the F200 and the FSAE cars.

REQUIREMENTS

To determine what each group of users would want from this project, we started by interviewing each of the potential users of this product. The Cal Poly SAE Baja team wanted a device from which they can raise and lower the car to/from a resting position where they have free access to the underside of the vehicle (roughly 18" from the ground). This requirement comes from the troublesome process of removing components fixed to the bottom of the car such as the skid-plates and engine mounting bolts. The ability to work on the vehicle while it is held above ground was deemed necessary as opposed to a device that simply raised the vehicle onto stands, because resting the vehicle on stands is the source of many of the accessibility issues that they currently face.

The Cal Poly Formula SAE team had similar requirements, except they only required the front end of their car to be suspended while working on the vehicle. The ability to raise and lower the car from stands is required with the added option to support half the car with a stand, and the other with the lift. This translated into lifting the vehicle about 36" off the ground.

It was critical to both SAE teams that the lift can be transported to and from competition, and thus must be able to operate without external power, and in a variety of environments including dirt, mud, and rain.

As another potential user of this device, John Fabijanic requested that the lift could raise and lower an F2000 series racecar (weighing in at approximately 1200 lb_f) on and off stands so that access to important components could be facilitated. This also translates into about 36" of vertical travel from the floor. The alternative use of this lift for this user is removing the engine from the vehicle. As the engine is lighter and the vertical travel requirements are less, we designed for the worst case (lifting the entire car).

Through their responses, we established a Quality Function Deployment (QFD) matrix that weighted the needs of each sponsor (found in Appendix A). The list of requirements for this project came directly from this matrix.

The requirements are summarized along with their dimensional restrictions in Table 1. below. Each of these requirements was considered throughout the design process, in the sense that the best choice for any one challenge was the one that best aligned with these requirements.

Table 1. Quantitative lift requirements derived from our goals and customer requests.

Requirements	Units	Value	Qualifier
Number of Parts	#	150	max
Time to Assemble	Min.	30	max
Maintenance Intervals	Weeks	52	min
Steps to Operate	Steps	3	max
Disassembled Footprint	Ft^2	10	max
Operators Req'd	#	1	(to make it work)
Weight	lbs_f	400	max
Operational Speed	in/s	4	max
Access Percentage	%	75	min
Designed Component Life	cycles	$1x10^6$	min
Cost	$	1000	max
Time to Clean	Min.	60	max
Operating Angle	degrees	5	min
Vertical Travel	in	36	min
Throat	in	48	min
Lift Capacity	lbs_f	1200	min

MANAGEMENT PLAN

Having worked together constantly for the last several years, we had a good idea of what would be required to make this team function smoothly. Nathan, being the most CNC capable of us, was responsible for final Design for Manufacturing (DFM) application, and would lead the CNC manufacturing charge. Gus, the most welding capable of us, was responsible for the welding on the project, as well as taking the role of "Project Lead" and doing his best to keep us on track. Toby was responsible for the organization of the documentation of the project, as well as the liaison to the teams, and performing the manufacturing that was neither CNC nor welding (i.e. drilling and tapping holes). During our manufacturing season, we realized that his was not an effective division of labor. Instead, we each approached tasks as they came up, with no formal division of manual labor. Luckily, all three of us were competent enough in the various manufacturing methods that this style worked smoothly for us.

BACKGROUND

Our first step with research was to look for any ANSI standards pertaining to our project. We hoped to find some sort of guidance/rules for car lifts that could assist our design process. In this initial search, we were directed towards ANSI/ALI ALCTV:2011 the American National Standard for Automotive Lifts- Safety Requirements for Construction, Testing, and Validation. This standard proved to be exactly what we were looking for, and was very useful throughout our design process. It details a wide variety of specifications, including factors of safety for load bearing members, loading cases for components, and a list of other applicable standards. Using this list we were able to find a number of other standards we have since procured, and we are in the process of determining their usefulness. The relevant standards included ANSI/ASA B29.8-1954 (Leaf Chains), UL201-2005 (Garage Equipment), MIL-STD-1472F(DODDC Human Engineering) and ANSI/ASSE Z244.1-2003 (Control of Hazardous Energy, Lockout/Tagout and Alternative Methods). After obtaining the primary standard, we contacted the Mechanical Engineering Department Safety Officer (Jim Gerhardt) and arranged a meeting with him. After briefly discussing our project and our desire to design a safe system, Jim was able to provide us with his input. Our discussion with him can be summarized with three main points:

- Standards are optional. If you choose to follow one, that's great, but he certainly won't require it.

- Design the system with safety in mind. Consider pinch points, tripping hazards, etc. early on to alleviate any issues before they arise.

- Complete a full Risk Analysis on the system. (A risk analysis assessment can be found in Appendix D)

With these points in mind, we were given full permission to proceed with the project as planned. When researching existing products, we found that the clear majority of automotive lifts are inherently different from our project requirements.

Figure 1. Automotive lifts currently used in industry.

State of the Art

Many of them are permanently mounted, lift the car from below, and consume a large amount of energy and space, all of which conflict with our project goals. This research served to solidify our conception of the design as an overhead gantry/crane type lift.

Research into Commercially available overhead lifts yielded variants on the same theme. There are many kinds of lift-from-below styles available, but the only types of overhead lift we could find were A-frame style lifts and engine hoists.

Figure 2. An A-Frame style lift, ubiquitous, but expensive. This model is made by Northern Tool and costs $439.99 without any method of lifting a load.

Commercially available A-Frames range from $400-$3200 and include various power sources to accomplish lifting a load from above with a single connective point. Our project requirements included a system that can operate without electrical power in a variety of terrains and quickly enough to allow a single operator to use it effectively without feeling the need to modify the lift to operate faster. The engine hoist option was attractive, and we realized that while hydraulics are impractical and ultimately unsafe for our purposes, it would provide an ideal platform for a mechanical lifting mechanism to be refit. Further research led us to the model from Tractor Supply Company that we decided to use for our lift.

Figure 3. "Big Red" The $229.99 engine hoist that was the platform of our lifts.

PRELIMINARY DESIGN

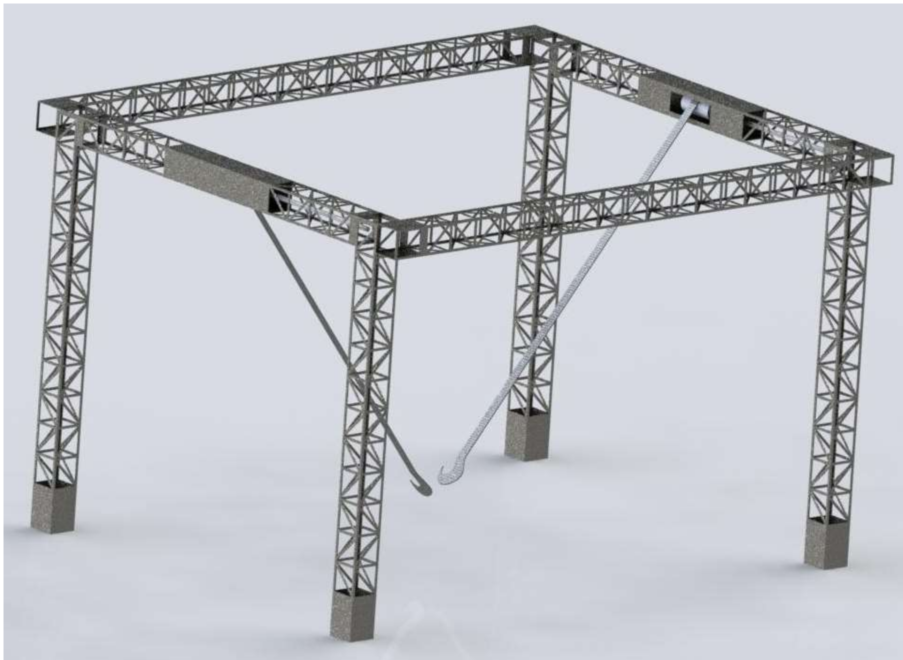


Figure 4. Render of our preliminary design including a four-post lift and two lifting straps.

Our preliminary design layout consisted of a four-post lift with spools (or drums) in the front and rear to lift the vehicles via standard flat tow ropes. The spools were aligned to lift the vehicle vertically. There was one lift point in both front and rear attached to a flexible triangular chain brace that functions as a balance bar to provide additional stability while lifting the vehicles. The four legs were not to be identical, with one of the rears being a slightly larger pillar to house the vertical power transmission and the drive gears. Power was to be transmitted laterally with a chain and sprocket linkage suspended from the lateral member.

The input was to be a handwheel to drive the worm in either direction with a manual ratcheting lock to provide an additional safety mechanism. Final geometries were to be determined by a detailed force analysis and structural design with the assistance of the SCE Steel Bridge team and SAP2000 software, but the overall superstructure is represented by the CAD layout shown above. The entire structure would have been constructed with the aid of the SCE Steel Bridge team's expertise in structural stiffness, naturally driving our design decisions toward a steel-based weldment. Our driveline relied on a worm gear, which would would have been cut by one of our Baja contacts in the Los Angeles area or purchased from an available retailer.

This design was reviewed and found wanting in many aspects. Our requirements call for a light, easy-to-use and maneuverable lift that we are capable of manufacturing three of in a 14-week period. This design met none of those criteria and was eventually scrapped for a much simpler version. Refer to Table 2. below for an analysis of which criteria the preliminary design met.

Table 2. Quantitative design requirements checked against the preliminary design of the lifts.

Requirement	Units	Target	Actual	Pass/Fail
Number of Parts	#	150	41	Pass
Time to Assemble	Min.	30	15	Fail
Steps to Operate	Steps	3	4	Fail
Disassembled Footprint	ft^2	10	8	Pass
Operators Req'd	#	1	1	Fail
Weight	lbs_f	400	157	Fail
Operational Speed	in/s	4	0.85	Pass
Cost	$	1000	571	Fail
Time to Clean	Min.	60	30	Fail
Lift Capacity	lbs_f	1200	1200	Pass

Preliminary Design Efforts

When working on the preliminary design, we focused first on the interfaces with each car. Next, we focused on the lifting mechanism itself. After that came the overall structure, and smaller details.

All in all, this process did not work very well. Without a solid idea of how the lift was shaped, it was impossible to design a drivetrain. And ultimately, the interface with the car should have been far simpler than we were making it. All of this culminated in the overcomplicated design we produced at PDR, and a lot of time wasted on fixing the issues that came along with it. Below is a summary of that initial design, annotated with fallacies and corrective actions we've taken since then.

Number of Legs

Our first decision was that the design should be four legged, since it would be very stable and ultimately very safe. The issue with this is that the design would be very heavy and expensive, and much more difficult to move around than a single post lift. Also, the drivetrain would have been needlessly complicated to span the long overhead lengths and thus much more likely to fail.

Lift Cables

We preeminently made the decision to use some sort of flexible cable to lift the vehicles. The idea was that a cable can be wound and stored when not in use and with our comparatively small loads, a cable can be sized adequately with relative ease. In our decision-making process, we included Wire Rope, Roller Chain, Link Chain, and Fabric Tow Straps. Our initial assessment criterion was working load limit, to meet the safety requirement of a minimum safety factor of 5 from the Automotive Lift Institute standard. Because of how small our actual working load is on an automotive scale, all the above options proved feasible, and generally within a reasonable price range as well. As far as other parameters are concerned, such as weight, ease of use, and cost, fabric tow straps were very clearly the best choice. This is one of several ideas we have retained since PDR. Fabric tow straps have by far the highest strength to weight ratio of the previously listed options, as well as being inexpensive, easy to work with, and easy to maintain.

"Sawhorses"

Ideally, the teams would be able to work on and around their cars when they are lifted. Integrated locking points would make this possible, though after our initial testing it was apparent that only the Baja car was geometrically capable of interfacing with the frame in this way. The aerodynamic wings of the FSAE car severely limited our options in attempting to support the vehicle. Without any input from the Formula team, we decided our product would be used to lift the Formula cars only, and not to support them while in the raised position. If the team so chooses, they can continue to use one or two sawhorses to support their cars. Alternatively, this was easy for the Baja car. The front tow hitch protruded away from the vehicle and was an obvious choice for an attachment point to secure the vehicle. The F2000 car does not need a locking mechanism, as Professor Fabijanic has expressed his lack of need for the ability to work on the car while it is solely supported by the lift.

Drum Roller Vs. Winches Vs. Pulleys

This choice governed how the power was to be transmitted from the operator, through the frame, and to the vehicle mounts. Several ideas had been proposed including a drum roller, winches, and a pulley linkage. The drum roller idea takes inspiration from existing power winches commonly seen on vehicles and overhead cranes. Winches from the four corners of the lift were also considered although this would dramatically complicate the driveline across the lengths of the lift. Pulleys were also considered but were decided against due to the excess rope/wire length that must be stored when the lift is up and while storing the lift. We decided a simple drum that attached to a shaft would be a functional option, and continued to use the idea in our final design. It would keep the tow strap properly aligned and safely contained within our gearbox, with minimal exposure to potential snags or pinch points.

Support Point Requirements and Secure Attachments

It had been tentatively decided that the support points (mount points to the vehicle) would have to accept a range of vehicles (from the Baja car to an F2000 car) as well as be configurable enough to be used for a wide variety of shop objects, without requiring excess effort on the part of the operator. This was mentioned briefly in the "Sawhorses" section. Ideally, we would like to design a fail-shut quick-lock mechanism that securely clamps to tubing and could therefore be used on any of the three vehicles. These would be used while the vehicle is being raised or lowered, and then the "sawhorse" feature would take over and lock onto the vehicle. This design point eventually became obsolete with the decision to use a tow strap as the lifting element and the final decisions made in the "sawhorses" section. The tow strap can easily loop through the roll hoops of any of the three vehicles, and the Baja lift is the only one that required any sort of secure attachment to the lift. We decided to accomplish this by having a pinned connection between the lift body and the tow hitch of the car. The pinned connection allowed for a quick, secure method of locking the Baja car in place.

Locking Mechanism

Our decision on the lifting mechanism was to be self-locking (using worm gears), and have some alternate locking mechanism (ratchet lock), to prevent the weight from falling under load. When raising the vehicle, the ratchet was "disengaged." When lowering the vehicle, the ratchet was in the "locked" position. Therefore, when lowering the vehicle, one hand was used to hold the disengage for the ratchet mechanism, and the other hand was used to turn the crank that runs the worm gear. This was one of the few initial designs that stayed constant throughout the process. The self-locking worm gear would allow for the high ratio needed to lift the vehicles, and would be a safe mechanism on its own. With the addition of a ratchet as a failsafe, the lift was safe to work under and around without fear of the load falling unexpectedly.

Upright Power Transmission

Transferring power from the operator to a junction point where it can be split and sent to either end of the lift is a subject that has created several design alternatives. Some options included chain and sprocket sets, clockwork-type linkages, and worm meshes. This design point was eventually thrown out, as it was a product of our issues with the four-legged design. There was no need to build a gearbox that transferred power vertically if the gearbox and the drum for the strap were located at the same place, at chest height. The initial design was over complicated and unnecessary.

Lateral Power Transmission

Another decision that had to be made was whether to link the lifting mechanisms connected to the front and rear of the car. Linking the two would have required significantly more hardware and power transmission components spanning the length of the device. On the other hand, having the lift mechanism operated from one point, would have allowed the vehicle to be raised (possibly not lowered) by a single person, greatly increasing usability by two of our three target groups. This design point had the same issues as the previous one: it was unnecessary. With the move away from the four-legged design there was no need for a complicated drivetrain.

FINAL DESIGN

The process we used to narrow down our design options was threefold: Initially, we identified those design options that would prevent any one of our requirements from being adequately met. The most important considerations here were whether the lift could be operated by one person, if it could be disassembled, and if we were capable of manufacturing it onsite with our limited budget. The design decisions in the previous section, in conjunction with the Proof of Concept testing, led us to our final design, which was the most closely aligned with the project requirements.

Table 3. Cost Analysis of the various proposed lift configurations.

	Four leg, 1 lift point	Four leg, 2 lift point	A frame, 1 lift point	A frame, 2 lift point	Engine hoist/crane
Initial cost	$0	$0	$1,000	$1,000	$230
Frame cost	$1,100	$900	$200	$200	$200
Drivetrain cost	$150	$400	$150	$400	$160
Total	**$1,250**	**$1,300**	**$1,350**	**$1,600**	**$590**

Table 3. (above) shows the cost analysis we completed to determine what the basic configuration of our lift would be. Based on our $1000 budget, the engine hoist/crane option was chosen as the basic configuration. After researching engine hoists and their availability, we found the best option was a Big Red Engine Hoist that could be purchased in town from Tractor Supply Co. This was the most inexpensive of the hoists we found, but it also had the highest load capacity and was large enough to fit all three cars without being too heavy. It was also by far the easiest to acquire.

PROOF OF CONCEPT TESTING

To verify our design, we had to verify the geometry of an engine hoist would be compatible with the geometry of the vehicles. We were fortunate to be in possession of an engine hoist that was slightly larger than the one we specified for use as our base.

Our testing of the geometry of the lift was a simple Pass/Fail. This data helped us determine the geometry of our final designs, which included some “buffer” for not-yet-designed changes to all three of our market vehicles over the years.

Figure 5. Lifting the Baja car by the roll hoop to allow the team to work at waist height on critical components of the car. Note the lack of significant clearance between the tow hitch and the hydraulic cylinder. We've removed the cylinder in our design, but replaced it with a geometrically identical support beam, which will lock onto the tow hitch of the car and hold it in place.

Figure 6. Lifting the Formula E-car with the hoist. It was particularly well balanced, though settled just off level. There were no significant problems lifting this car with the hoist.

Figure 7. Lifting the Formula C-car with the hoist. It was dramatically off level, but was easily adjustable.

As part of our design process, we included a test that verified the qualitative feel of the desired ergonomic specifications by attaching a torque wrench to the handle of a Bridgeport knee mill that matched roughly with the positioning we wanted for our wheel. Our data indicated that the required operating torque was on the order of 6 ft.*lb_f. Because that knee handle operates a worm drive to lift a large steel table, we were confident it was an adequate analogy to our project, and finding the torque required to match the US MILSPEC value of <35 lb_f applied at the handle radius of 10”, we were satisfied with our choice of standard. After comparing the geometry of the three cars with the lift, it was obvious that we would need to design separate configurations for each of the vehicles. The Baja car was considerably taller than the other two, and due to its 10-inch ride height it didn’t need to be lifted as far to be at a comfortable working height. Also, the Baja car had a longer “throat” (distance between the engine hoist column and the lifting point) than the other two cars. With this in mind, we designed one geometric configuration for the Baja car and a second geometric configuration for both the Formula and the F2000 car. Both configurations can be seen in Figure 8. below.

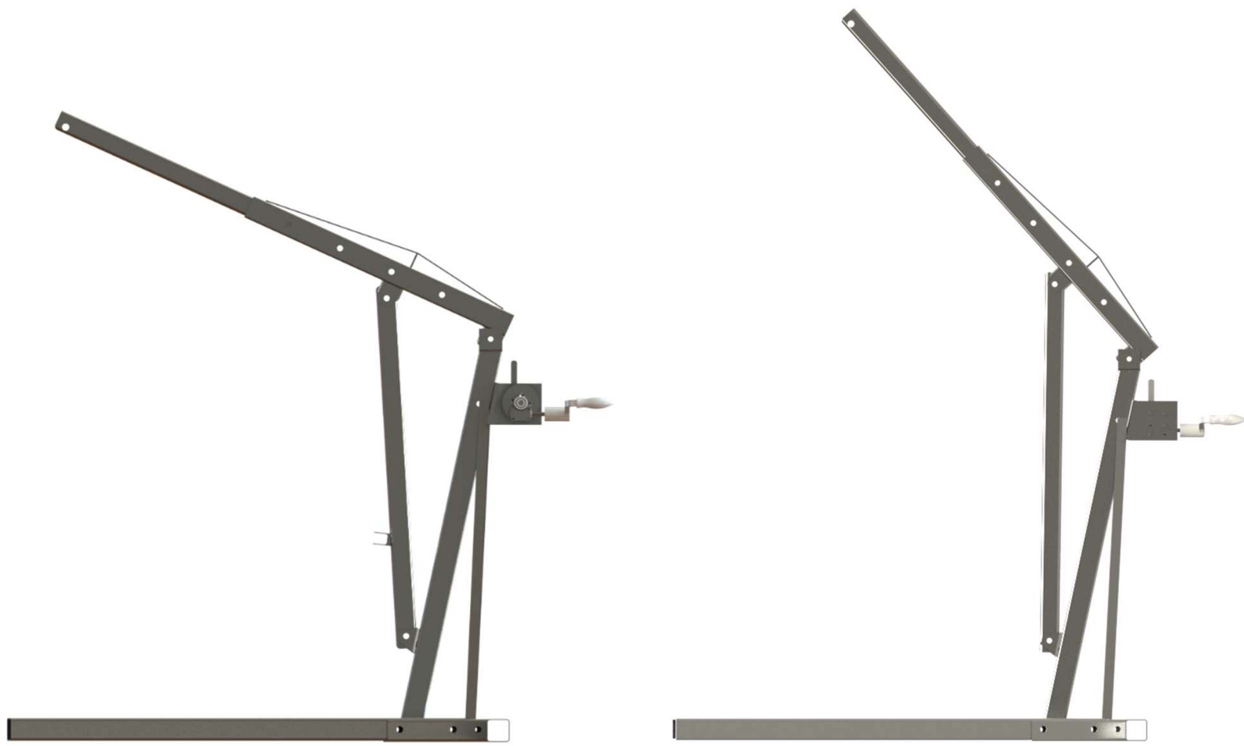


Figure 8. (Left) Render of the Baja configuration of the lift, with a longer "throat" and a lower overall height. (Right) Render of the Formula and F2000 configuration of the lift, with a shorter "throat" and a higher overall lifting point.

The engine hoists were not used "as purchased," but were modified to fit our specific purpose. The first of these modifications was to replace the hydraulic cylinder with a piece of tubing; fixing the overall height of the lifting point. Instead of raising the entire arm of the hoist to lift the vehicle, the drivetrain makes the lift act more like a crane, with a fixed arm position. This ensured the vehicle didn't follow an arced path as it was lifted, and allowed for a much simpler drivetrain. The drivetrain will be discussed in greater detail later in the report.

DETAILED DESIGN

To ensure the tubing replacing the cylinder was strong enough, it was analyzed using the Euler buckling method. Because it is a two-force member, it is held in pure compression and thus has a failure mode of buckling. A picture of the calculation can be found in Appendix E. Using a standard, inexpensive round tubing size of 1.5" x .150", the calculation yielded a factor of safety of 86 for the Baja configuration and 34 for the F2000 configuration. Although this is well in the realm of "overbuilt" we decided to proceed with it, since it doesn't add much weight and it was the least expensive tubing available to us.

Next came the modifications needed to provide the necessary "throat" for the Baja car. Due to the geometry of the lift, we were required to add 9.6 inches to the length of the arm. This increased the bending moment on the lift, and thus made us concerned with the strength of the member. Considering the lift was made of an unknown material, we first had to do testing of material used in the lift's construction so that we could determine its yield strength. We first took a sample of the steel used in the lift (an easily replaceable, non-structural tab) and did a hardness test on it. Results for this test indicated that the material was fairly strong (around 100-110 ksi yield). In order to be sure of this, we decided to also do a tensile test of the material. The tab was cut into two identical tensile test samples. The samples were tested using the Instron in the MATE Department's mechanical testing laboratory. The results from this test can be found in Appendix G. Ultimately, it turned out the material the lift was made of had a yield strength of about 40 ksi.

Given this information, we proceeded to execute some simple bending calculations (documented in Appendix H). We found that the Baja lift arm had a factor of safety of 2.74. This calculation inspired us to inspect the same issue on the F2000 configuration. The result was a factor of safety of 0.85. Obviously, we had to reevaluate the design a bit. The most straightforward approach was to replace the arm of this lift with a stronger tube. It was simple enough to find a tube with the same dimensions made of 1018 steel (yield strength of 53,700 psi) and a slightly thicker wall thickness. With this stronger arm, the factor of safety jumped up to 1.51, so we decided to use it. The purchase totaled $190 and was only necessary for the F2000 lift as the other two cars (being significantly lighter) did not require the extra strength. With the structural integrity of the lifts no longer in question, we proceeded to flesh out the drivetrain design.

Table 4. Decision matrix for drivetrain configuration

		Datum		Option 1		Option 2		Option 3		Option 4		Option 5	
	Weight	Spur gears		Worm gear		Spur gears + chain close		Worm gear + chain close		Spur gears + chain up high		Worm gear + chain up high	
No. of Parts	0.18	0	0	1	0.18	0	0.00	0	0.00	0	0.00	0	0.00
Maintainance	0.12	0	0	0	0.00	1	0.12	1	0.12	-1	-0.12	-1	-0.12
Weight	0.15	0	0	1	0.15	1	0.15	1	0.15	-1	-0.15	-1	-0.15
Cost	0.09	0	0	0	0.00	1	0.09	0	0.00	-1	-0.09	-1	-0.09
Time to clean	0.07	0	0	0	0.00	0	0.00	0	0.00	-1	-0.07	-1	-0.07
Manufacturability	0.07	0	0	-1	-0.07	0	0.00	-1	-0.07	0	0.00	0	0.00
Self-Locking	0.22	0	0	1	0.22	0	0.00	1	0.22	0	0.00	1	0.22
Safety guards	0.10	0	0	0	0.00	0	0.00	0	0.00	-1	-0.10	-1	-0.10
Total:	1		0		0.47		0.35		0.41		-0.53		-0.31

The above table shows the decision matrix for the overall drivetrain configuration. Options 2 & 3 use the word 'close,' meaning the chain is located between the input handle and the transmission. Options 4 & 5 use 'up high' to describe the chain location relative to the input. Based off our weightings, Options 1 & 3 proved to be the best choices. Calculating the ratio required to lift such a load was done using a spreadsheet we generated (see Figure 10.). Using the data we gathered from the military standards as a starting point, we determined that a ratio of about 20:1 for our transmission would be satisfactory for the necessary loading. This required a load of approximately 11.25 lb_f at the end of the 10" handle, which was well within the recommended values put forth by the military standards. Because a 20:1 ratio is easily attainable in purchased components, we chose to move ahead with Option 1 and use only a worm mesh for providing our reduction.

Variable	Unit	Value
BASIC PARAMETERS		
Vehicle Weight	lbs	1200
Drive Drum Diam (appx)	in	3
Handle Diam	in	20
Human Input Speed	rev/s	2
	rpm	120
Torque at Drum	in-lbs	1800
	ft-lbs	150
MAX SPEED CASE		
Max speed	in/s	4
Ratio needed to achieve max speed	rpm/rpm	0.212207
1/Ratio	rpm/rpm	4.712389
Torque at handle due to above	in-lbs	381.9719
	ft-lbs	31.83099
Force at handle end	lbs	38.19719
Time to lift 36 inches	s	9
USER INPUT RATIO		
Ratio to Test	rpm/rpm	0.05
Worm efficiency	%	80
1/Ratio	rpm/rpm	20
Torque at handle due to above	in-lbs	90
	ft-lbs	7.5
Force at handle end	lbs	11.25
Car speed	in/s	0.942478
Time to lift 36 inches	s	38.19719

Figure 9. The ratio calculator used to determine user input loads as a function of drivetrain ratio.

Once the gear ratio was determined, we needed to determine if the gears we sourced from McMaster would be appropriate for our purposes. Using a gear calculator spreadsheet (see Figure 10.), we calculated a factor of safety that was acceptable for our purposes.

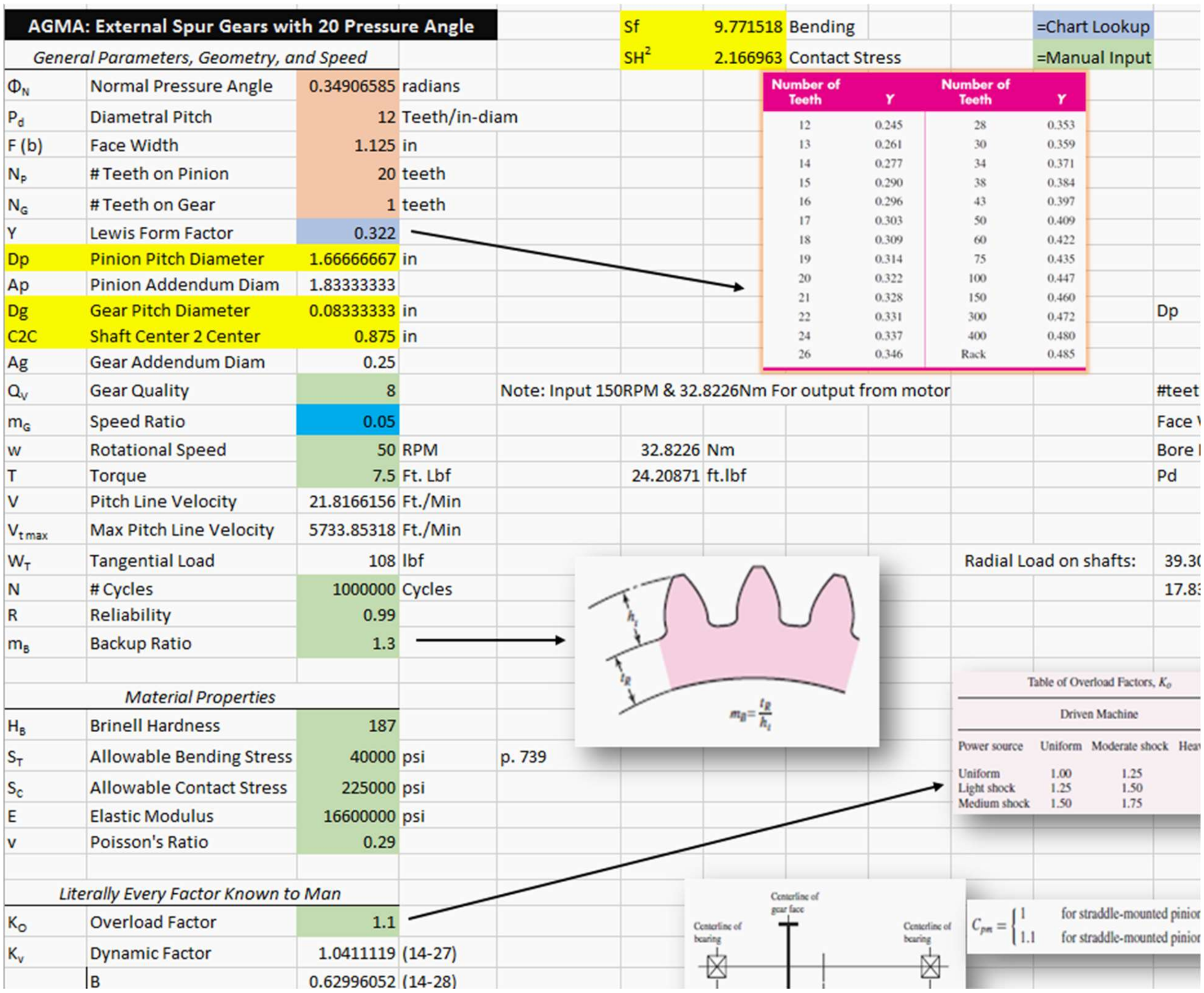


Figure 10. A portion of the spreadsheet used to calculate gear tooth factor of safety and life. Using the torque provided by the largest vehicle weight and the human input speed, we concluded that our worm gear (the failure point of the gear mesh) has a factor of safety of 9.0. This was deemed acceptable for our purposes.

Table 5. A condensed summary of the critical Safety Factors in the design.

Component	Load	F.S.
Ram Support - Baja	1,931 lb_f	86
Ram Support - F2000	4,944 lb_f	34
Drivetrain - Worst case (F2000)	1,800 in*lb_f	9
Arm - Baja	25,868 psi	2.7
Arm - F2000	47,095 psi	1.5
Worm Drive Bearings	96 lb_f	2.6

Table 5. above refers to the worst-case loads for each of the critical load path components of the lift. The safety factors presented can be split into two categories: Structural and Driveline. The structural components of the lift include the Ram Support, and the Arm. Those are the points of the lift that we modified, requiring us to evaluate the structural integrity of the system as it pertained to our new design within the operational parameters of the Lift. Our driveline design was entirely a new addition, and so includes both an overall worst-case safety factor, and a specific factor of safety for the Worm Drive Bearings, because the available options were expensive, and we felt the need to justify using a more affordable bearing. The lowest Safety Factor we see is the Lifting Arm for the F2000 model lift. At 1.5, it should be sufficient under all standard loading conditions. It is also worth mentioning that the lifts include a reinforcing steel strap designed to resist the bending moment applied by the lifting action. Due to the complexity of the reinforcing device and our lack of experience with Finite Element Analysis methods, we omitted it from our calculations, leaving our calculations even more conservative than reality.

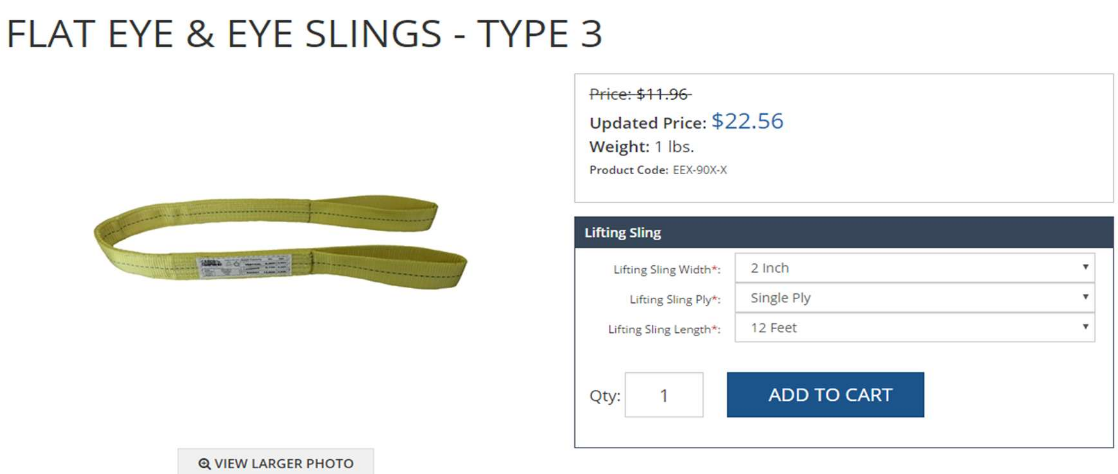


Figure 11. Specifications for the lifting strap chosen for the design of the lifts.

Figure 11. shows the lifting strap that was chosen for our design. This particular strap was chosen based on its low cost and variability in length. Straps are sold in 1 ft. increments in a variety of widths and types. We chose a flat eye type so that the strap would wind nicely around the drive drum. With a 2" strap width, and single ply thickness, the strap was rated to 3200 lb_f. This gave us a factor of safety of 2.7 for our worst-case scenario. It is also worth noting that each strap length may end up being slightly different (by a foot or two) based on what vehicle it is intending to lift, as the Formula cars and the Baja cars had very different hoist geometries and lifting distances. The strap passed up through the roof of the transmission box and in through the rear of the ram where it traveled through the center of the arm, then straight down to the vehicle. The strap changed direction by sliding on rollers that were placed at the front and rear end of the ram and arm. This keeps the strap away from any of the sharp edges located along the edges of the tubes. Altogether, this allowed us to use the hoist as a crane, meaning the car travels linearly upward because the arm of the hoist is never moving.

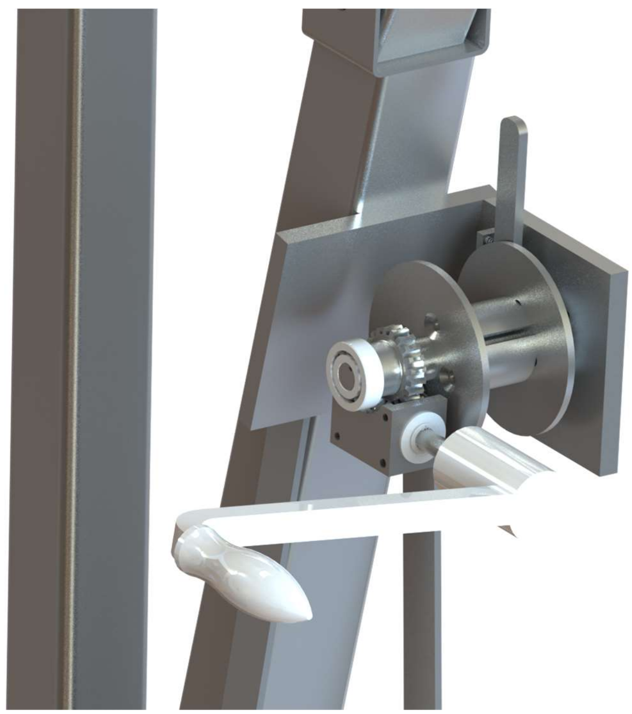


Figure 12. Render of the transmission attached to a lift frame, with some components suppressed for clarity.

Figure 13. Exploded render of the transmission, again with some components suppressed for clarity.

Figures 12 and 13 show views of our final transmission design (note: several components and fasteners have been suppressed for clarity).

Product Realization

Our manufacturing was still limited by the resource constraints of any other senior project, but we have the distinct advantage of having designed our parts within our combined skillsets. We did not need external resources past the facilities and equipment available to us on campus, nor did we need to expend our budget paying for shop time, tech time, or CNC work. The fact that we manufactured parts for other projects in addition to our own was considered, and we adjusted our estimated overall timeline to account for that. In addition, we are well aware of the adage "Triple your manufacturing time."

Listed in the table below are our estimated manufacturing times and a brief summary of the necessary equipment required to accomplish the tasks. It is also worth noting that the freshmen members of the Baja team are always looking for fun jobs to do, and we were not opposed to passing them a simple mill or lathe part to reduce our workload and offer them a valuable learning opportunity. We didn't end up taking advantage of the free labor of the teams, instead opting to use more CNC machines to speed up the process.

Table 6. A summary of our manufacturing plan, including time estimates and material sources.

Part	Method	Time (Per Lift)	Difficulty/ Tolerance	Material
Wheel mounting plates	Mill	1 hr.	Easy / Coarse	Existing Lift
Column Support	Drill Press	1 hr.	Easy / Coarse	4130 Sq. tube
Worm block	CNC Mill	3 hrs.	Hard / Fine	1018 Steel Block
Drive Drum	Lathe	6 hrs.	Medium / Medium	1018 Steel Round
Drum Shaft	Lathe/Mill	2 hrs.	Easy / Fine	5/8" Dia. Steel
Ratchet Gear	Waterjet	.1 hrs.	Easy / Coarse	3/8" Steel Plate
Ratchet Pawl	Waterjet	.1 hrs.	Easy / Coarse	3/8" Steel Plate
Cover Plates	Laser cutter	.25 hrs.	Easy / Medium	Polycarb. Sheet
Gearbox Plates	Mill/Weld	9 hrs.	Hard / Fine	Steel Plate
Worm Shaft	Lathe/Mill	2 hrs.	Easy / Fine	1/2" Dia. Steel
Worm Spacers	Lathe	.25 hrs.	Easy / Fine	5/8" Steel Tube
Strap Rollers	Lathe	1 hr.	Easy/ Fine	Plastic
Handle	Lathe/Weld	2 hrs.	Hard / Fine	Various Steel
Drum Shaft Spacers	Lathe	.1 hrs.	Easy / Fine	3/4" Steel Tube

A flowchart of our manufacturing process can be found in Appendix F. As the critical path, it was important that the gearbox be completed in a timely manner. Unfortunately, this proved to be the primary setback in our manufacturing schedule, and resulted in delays finishing the lifts.

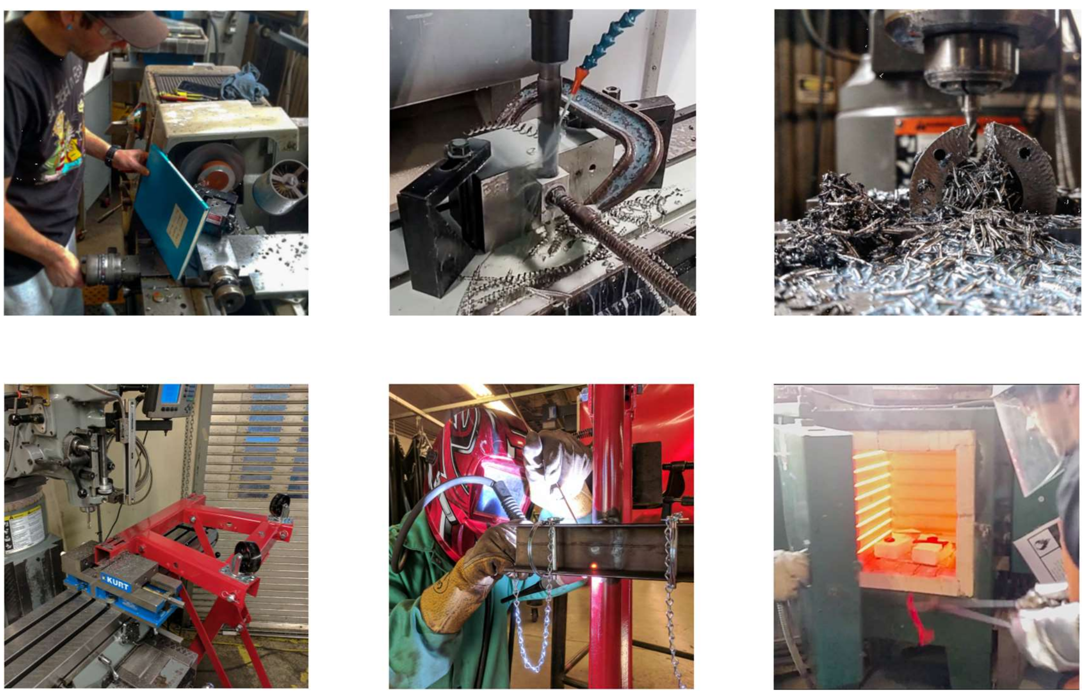


Figure 14. Clockwise, From Left: Gus turns the first Drive Drum Plate, while keeping his senior project notebook close at hand, Nathan uses the TM-1 in the Hangar with some creative fixturing to drill the initial hole for the worm bearing bores, Toby mills the two halves of the drum bodies apart, Toby modifies the original slot pattern to fit larger casters for the Baja lift, Gus welds Baja's locking hitch plate onto the upright support of the lift, Gus removes a ratchet from the oven in the Hangar to water quench it for surface hardness.

We employed a large variety of manufacturing methods to produce our parts, relying heavily on welding to join the thick side plates, CNC milling and turning to machine the transmission components, and manual milling and turning for quick adjustments and final fit up. We also employed the heat-treating oven in the hangar to harden our ratchet and pawl. Whenever we could, we used carbide tooling to improve our cycle time and surface finish, sometimes that meant using a broken or re-sharpened cutter that increased our production at little to no cost to us. This let us make deep, fast cuts and remove a lot of material quickly. We did our best to source material for free or from scrap piles, to keep our project cost within our minimalist budget, and that often led to stock sizes that were not perfectly ideal, and a good amount of time spent preparing stock. Detailed information on the manufacturing of our parts is included in the design drawing packet attached to this report in Appendix B

In addition to our mechanical design manufacturing, we were required to make this device safe to use for the average engineering student. To accomplish this, we decided to shroud the transmission's top and bottom with plastic to prevent unwanted entry by curious finger or errant hardware.

If another group of students is to manufacture either replacement parts or an entirely new lift, it is our recommendation that they employ the same methodology we did. By manufacturing as many of our parts as we could with the CNC machines, and relying heavily on blind tapped holes located with pins to assemble subcomponents, we reduced the variability in our parts dramatically, and allowed ourselves relatively large manufacturing tolerances in non-critical areas as a result. This sped up the process and allowed our team of three to effectively manufacture parts independent of each other, only requiring input when subassemblies were completed.

A useful design change would be to account for the thicknesses of weld beads from the outset and ensure that the various mounting holes won't be either too close to a weld bead, or in an area rendered inaccessible for drilling after it is welded, It would also be worth considering expanding the packaging slightly. Our transmission is tightly and efficiently packaged, which is nice aesthetically, and easy to shield from prying fingers, but difficult to assemble given the tight packaging and small parts such as keys.

DESIGN VERIFICATION

Figure 15. Full system test with the 2015 Baja car.

Aside from the testing we did before CDR to determine the necessary lifting points and allowable torque loads, our validation and verification testing plan was simple. We would have liked to test a lift to failure and observe what the actual weak point of the system was, but due to budgetary and time constraints, we weren't able to manufacture an entire transmission to test on the bench. In lieu of that, we planned to test the completed lift under a working load, and observe the reaction of the system to ensure that it was still within proper operational parameters. Our test went as planned: we could lift the prescribed load for the Baja lift and the integrity of the system was obvious. Our locking method for the Baja lift did also function appropriately, and we were satisfied with how effectively it supported the vehicle.

We noticed that due to the larger casters, the Baja lift is unstable in its folded (storage) configuration. Spacer plates were added to the casters to ensure the lift sat flatter on the ground. Tipping was no longer an issue after this adjustment.

Table 7. Verification of design requirements

Requirement	Units	Target	Actual	Pass/Fail
Number of Parts	#	150	41	Pass
Time to Assemble	Min.	30	15	Pass
Steps to Operate	Steps	3	4	Fail
Disassembled Footprint	ft^2	10	8	Pass
Operators Req'd	#	1	1	Pass
Weight	lbs_f	400	157	Pass
Operational Speed	in/s	4	0.85	Pass
Cost	$	1000	571	Pass
Time to Clean	Min.	60	30	Pass
Lift Capacity	lbs_f	1200	1200	Pass

Maintenance and Repair

Our maintenance plan is largely unknown to us at this time, but we recommend following the manufacturer's instructions regarding the lifting strap, and only using it until it shows signs of wear or visible damage, then replacing it. In addition, many of the locking fasteners we utilized are single-use only, and should be replaced every time they are removed, as well as the keys on the shafts.

The gear mesh requires no oil, but a yearly inspection for wear is advisable. The gears are both stock parts and can be replaced from McMaster-Carr if necessary.

Safety Concerns

Safety concerns with this project are summarized in Appendix D, in our Hazard Identification Checklist. No moving parts should be handled while the lift is operating. To this end we have enclosed the transmission itself in a polycarbonate box that has been slotted to allow the belt to exit the transmission. Operators should not attempt to adjust the strap while the lift is moving, rather they should stop lifting, adjust the strap, and then continue lifting. The rollers inside the overhead arm are pinch points, and should be avoided. During the lifting operation, the operator should ensure that the ratcheting mechanism is working smoothly, and that there are no people or objects beneath the car as it lifts. When the lift is fully up, the vehicle should not be considered "stable" and should be clamped and/or supported by other means before it is worked on. In the case of driveline failure, the ratchet will stop the lifted load from falling, but should not be relied on as a perfect failsafe. Do not allow anyone or anything below the lift while it is operating. In the event of a failure of the ratchet and pawl mechanism, the drive worm is designed (and tested) to be self-locking, and will support the load. This also should not be considered a perfect failsafe. An instruction manual has been prepared, and both the Baja and the Formula team have been instructed in the proper use of the lifts.

CONCLUSIONS AND RECOMMENDATIONS

Our primary conclusion is that the lifts function adequately and meet the design requirements.

Operation is simple enough for a single person, and they performed adequately in our testing to lift and lower their designed loads. Our additional conclusions are:

- Testing of long term use is needed to determine maintenance intervals and long term part wear/ replacement requirements.
- Each team should design a way to more easily move the lift around both in the deployed and the stored configuration. Each lift would benefit from some sort of handle, as we had to remove the stock handles to attach the drivelines, and the absence is notable.
- Additional lifting attachments should be designed to enhance the versatility of the lift to interface more directly with the individual vehicles or with other equipment.
- We have provided a "User's Guide" to operation, in the form of a single half-sheet of heavily laminated paper attached directly to the lifts.

Were a future group of either SAE members or Senior Project students or a Senior project group to continue our work on this project, one goal we had at the beginning was not met with our final design -- the Formula cars have no means of being directly supported by the lift. We did not determine an effective means of overcoming the "Sawhorses" problem, thus, the Formula team still needs to support the car when it is in the elevated position.

APPENDICES

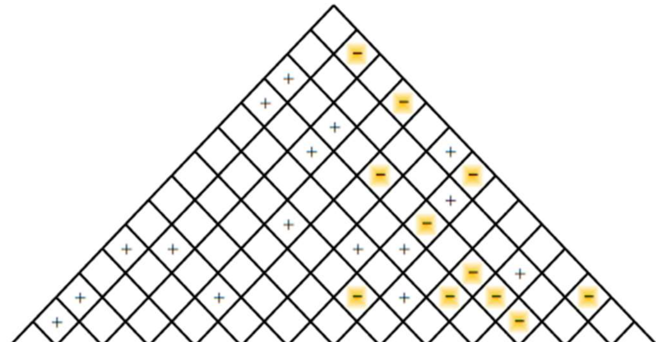
APPENDIX A

QFD

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

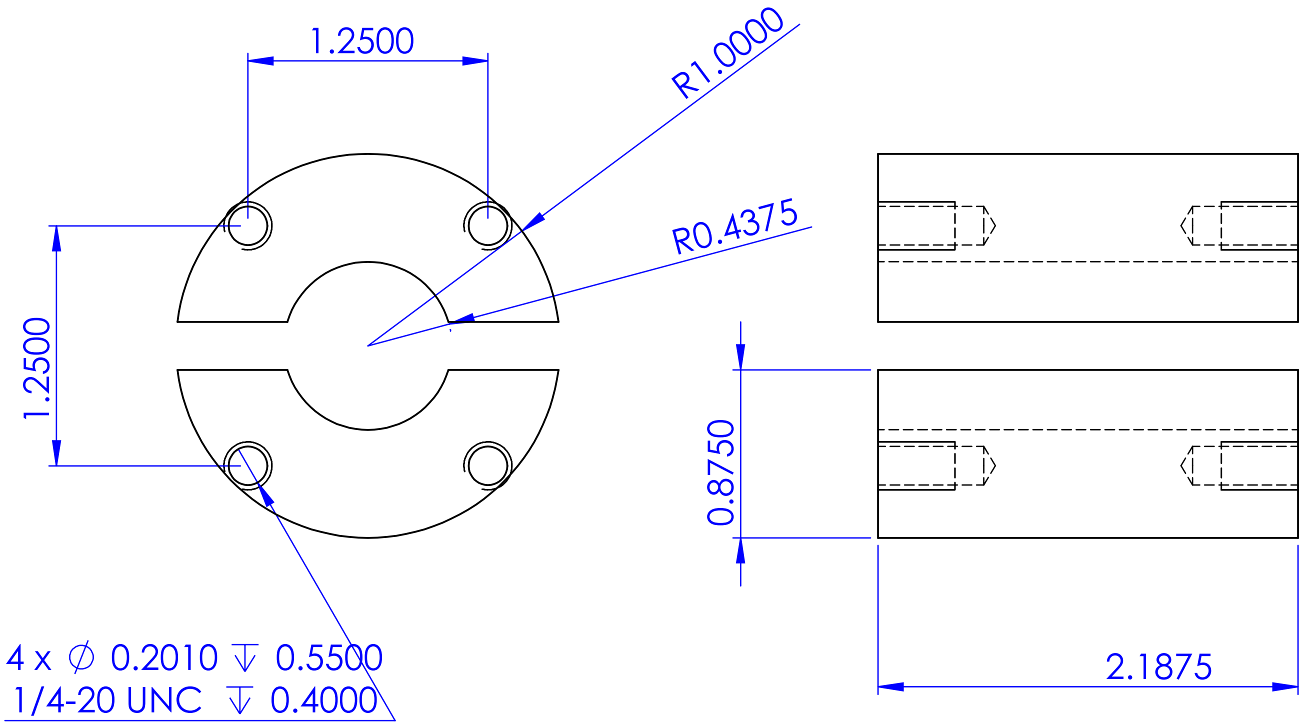
Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

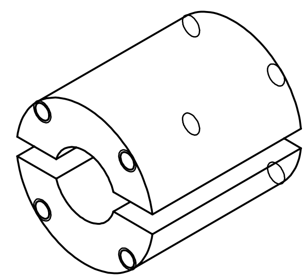


Row #	Weight Chart	Relative Weight	Shop Users	Club Users	Manufacturing	Design	Maximum Relationship	Column #	1	2	3	4	5	6	9	10	11	12	13	14	15	16
								Direction of Improvement	▼	▼	◇	▼	▼	◇	◇	◇	▲	▲	▲	▼	▼	◇
	WHO: Customers							WHAT: Customer Requirements (explicit & implicit) / HOW: Engineering Specifications	# of Parts	TTA [min.]	Maintenance Int. [weeks]	Steps to Operate [#]	Disassembled Volume [ft^3]	Operators req'd [#]	Weight [lbs.f]	Assembled Area [ft^2]	Operational Speed [in/s]	Access Area [ft^3]	Designed Component Life [# Cycles]	Cost [USD]	Time to Clean [min]	Maximum dy Between As-Of-Yet-und
1		10%	5	9	8	6	9	Easy to Assemble/Disassemble	●				▽		●	▽						○
2		5%	1	8	4	2	9	Easy to Maintain/Repair		▽	●								●		○	
3		6%	3	7	2	7	9	Easy to Transport	▽				●		○							
4		9%	9	6	3	8	9	Easy to Operate				●		○				○				
5		7%	6	8	2	5	9	Fast to Assemble/Disassemble	○	●			▽								▽	○
6		3%	2	2	0	6	9	Few People to Operate				○		●				○				
7		4%	0	4	5	3	9	Light Weight	○				▽		●				▽	○		
8		7%	6	2	3	7	9	Small Footprint					○			●						●
9		8%	8	9	1	7	9	Fast Operation				●		▽			●					
10		10%	9	9	2	8	9	Easy to Access Lifted Object						▽				●			▽	
11		9%	1	7	9	7	9	Long Lifespan			●								●	○		
12		8%	3	7	9	3	9	Low Cost	●		○				○				●	●		
13		6%	7	5	2	2	9	Easy to Clean	○		▽							▽			●	
14		6%	0	8	3	8	9	Usable on Uneven Ground								○						●
								HOW MUCH: Target	150	30 Min	52 Weeks	3 steps	840 ft^3	2 operators	2000 lbf	4 in/sec	15ft^3	2 yr	$1,500	1 hr	12 in	>= 1 F2000 racecar
								Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9
								Technical Importance Rating	226.2	70.15	156.4	170.4	98.88	75.76	175.8	88.78	76.43	131	205.1	114.9	85.12	167.8
								Relative Weight	12%	4%	8%	9%	5%	4%	10%	5%	4%	7%	11%	6%	5%	9%
								Weight Chart														

APPENDIX B

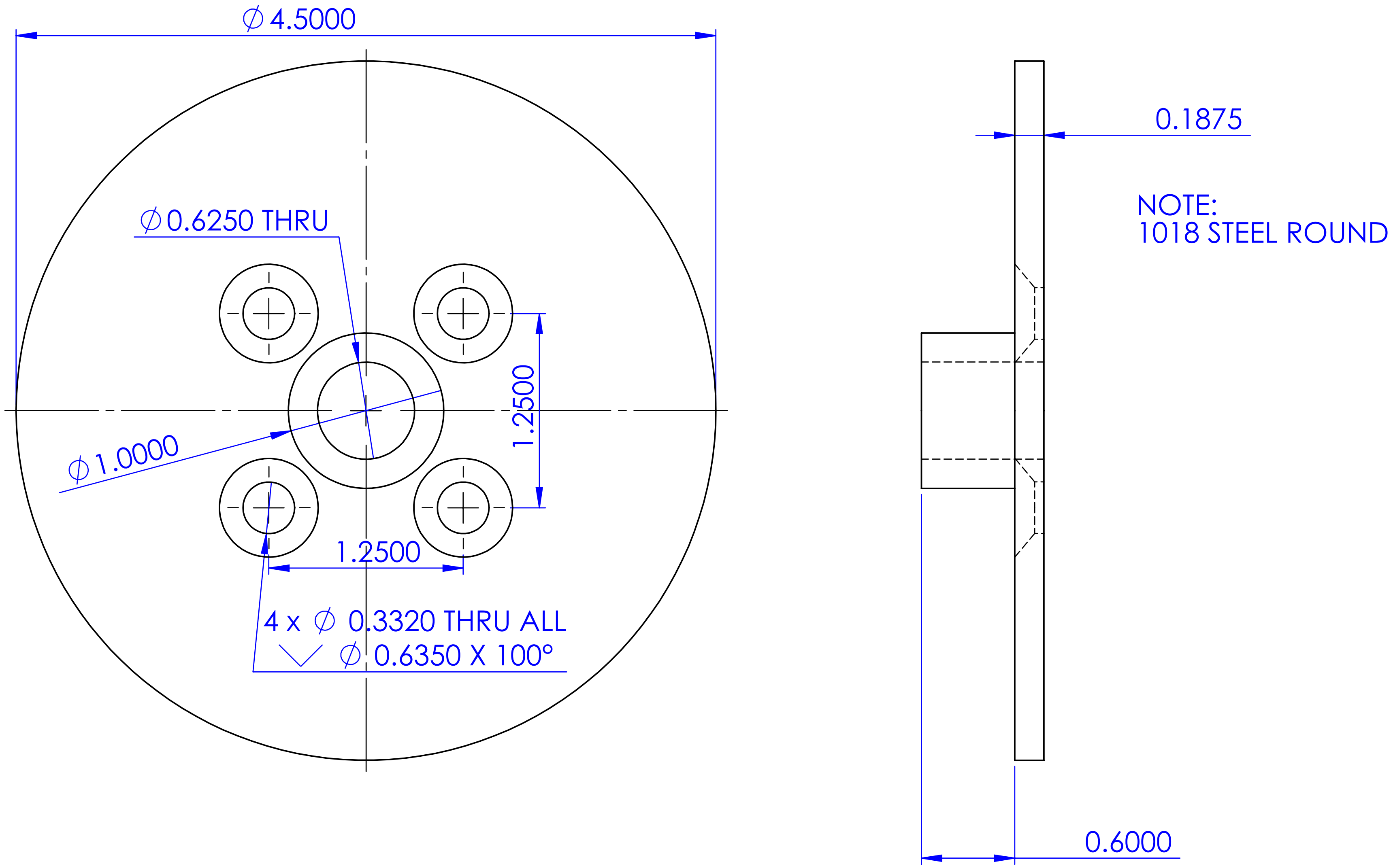
PART AND ASSEMBLY DRAWINGS



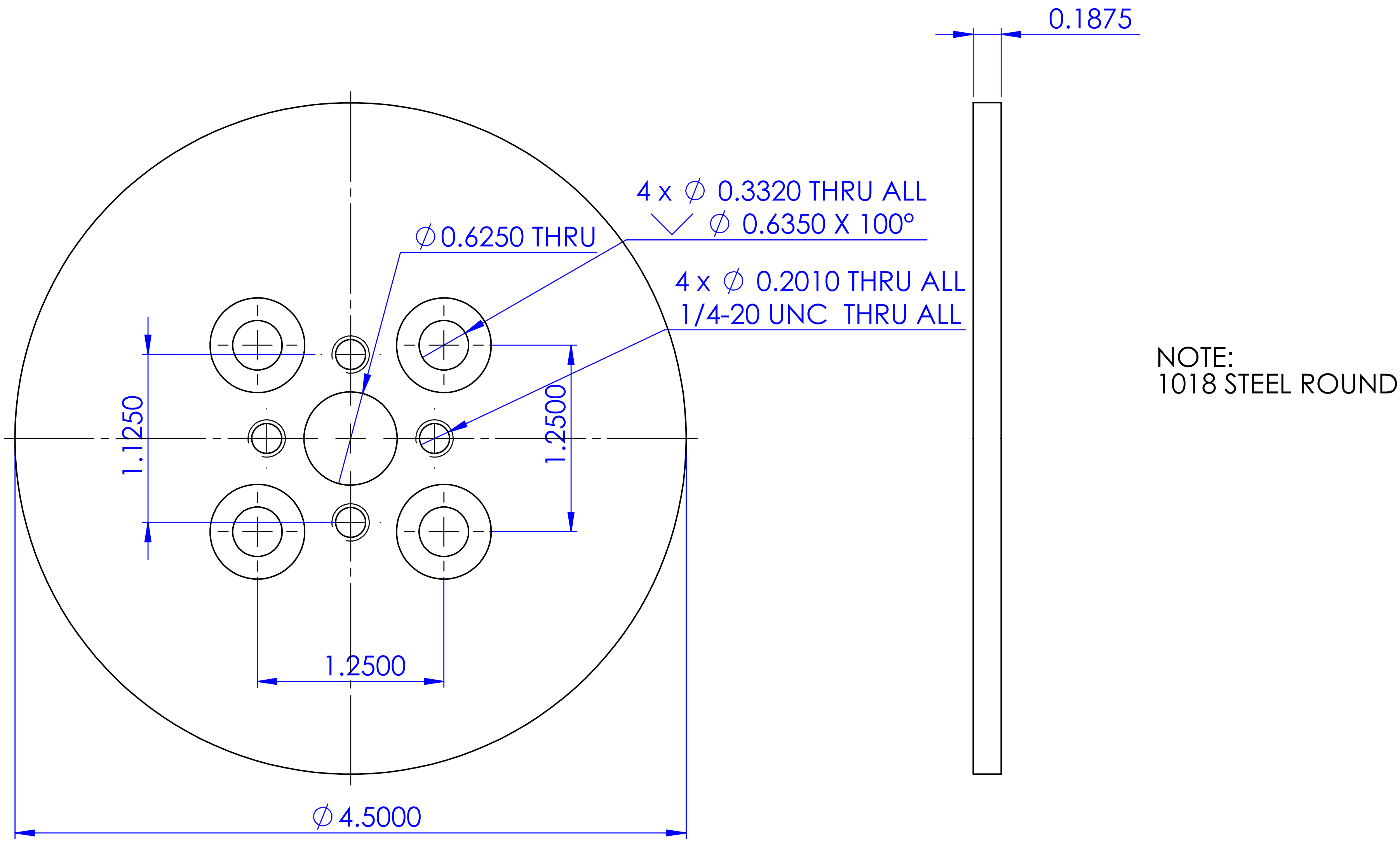


NOTE:
MACHINE AS SINGLE COMPONENT
THEN PART AND FACE
1018 STEEL

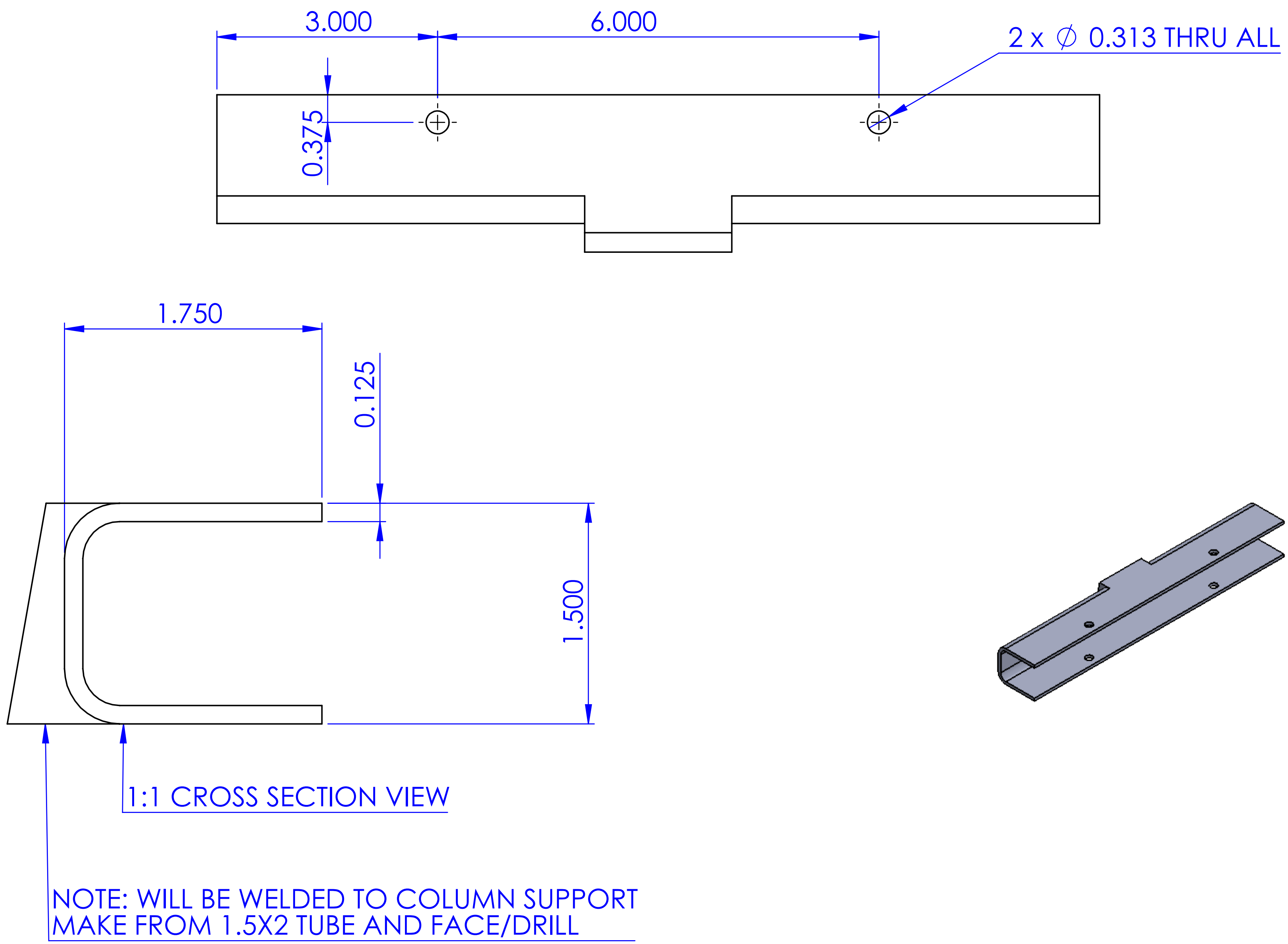
Cal Poly Mechanical Engineering	GANTRY LIFT	Assignment #	Title: DRIVE DRUM		Drwn. By: N. HARRY
ME 429 - FALL 2016	Dwg. #:	Nxt Asb:	Date: 10/27/16	Scale: 1:1	Chkd. By: ME STAFF



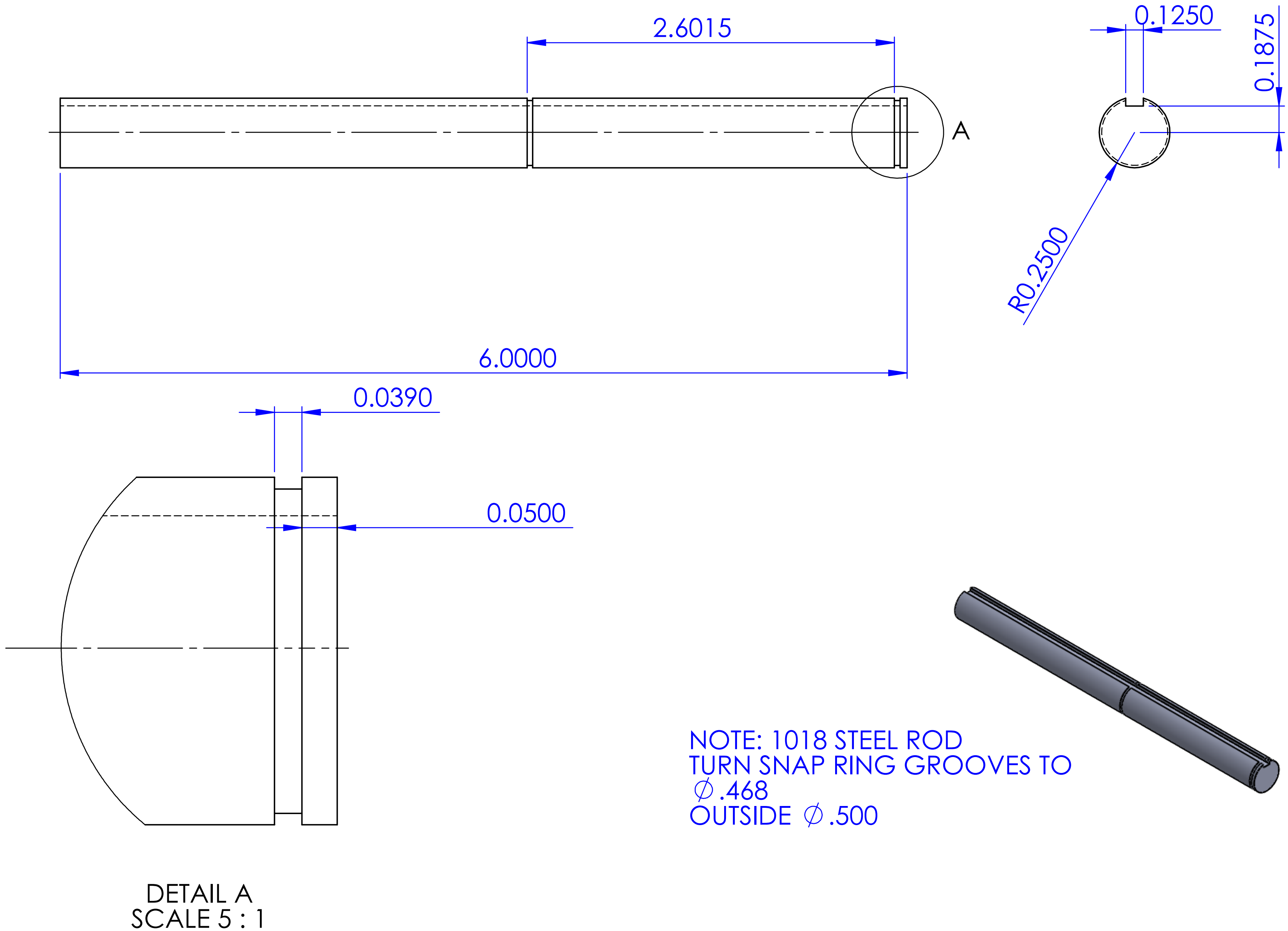
Cal Poly Mechanical Engineering	GANTRY LIFT	Assignment #	Title: DRIVE PLATE		Drwn. By: N. HARRY
ME 429 - FALL 2016	Dwg. #:	Nxt Asb:	Date: 10/24/16	Scale: 1:1	Chkd. By: ME STAFF



Cal Poly Mechanical Engineering ME 429 - FALL 2016	GANTRY LIFT	Assignment #	Title: DRIVEN PLATE		Drwn. By: N. HARRY
	Dwg. #:	Nxt Asb:	Date: 10/24/16	Scale: 1:1	Chkd. By: ME STAFF

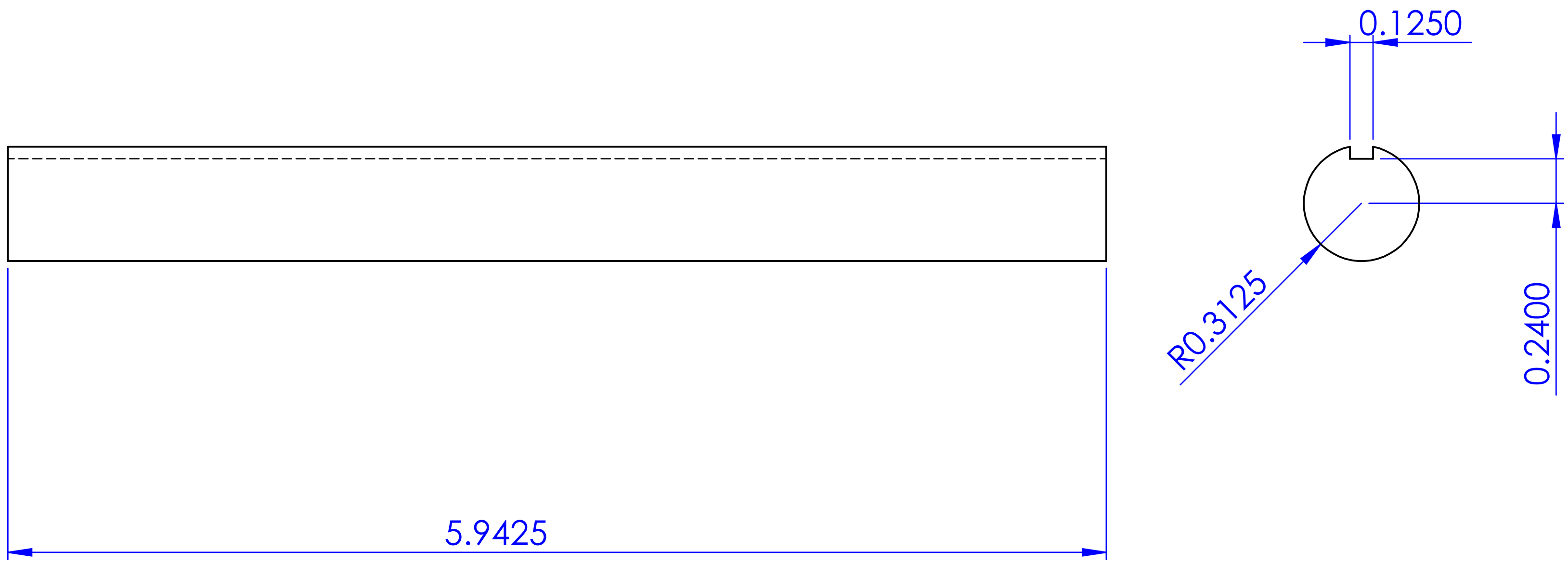


Cal Poly Mechanical Engineering ME 429 - FALL 2016	GANTRY LIFT	Assignment #	Title: HITCH LOCK	Drwn. By: N. HARRY
	Dwg. #:	Nxt Asb:	Date: 10/27/16 — Scale: 1:2	Chkd. By: ME STAFF

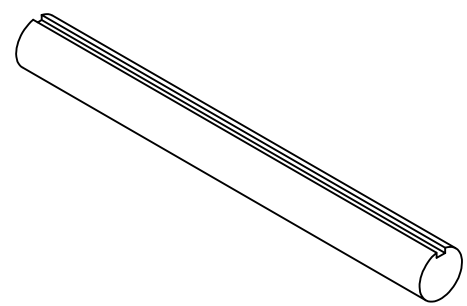


NOTE: 1018 STEEL ROD
TURN SNAP RING GROOVES TO
∅ .468
OUTSIDE ∅ .500

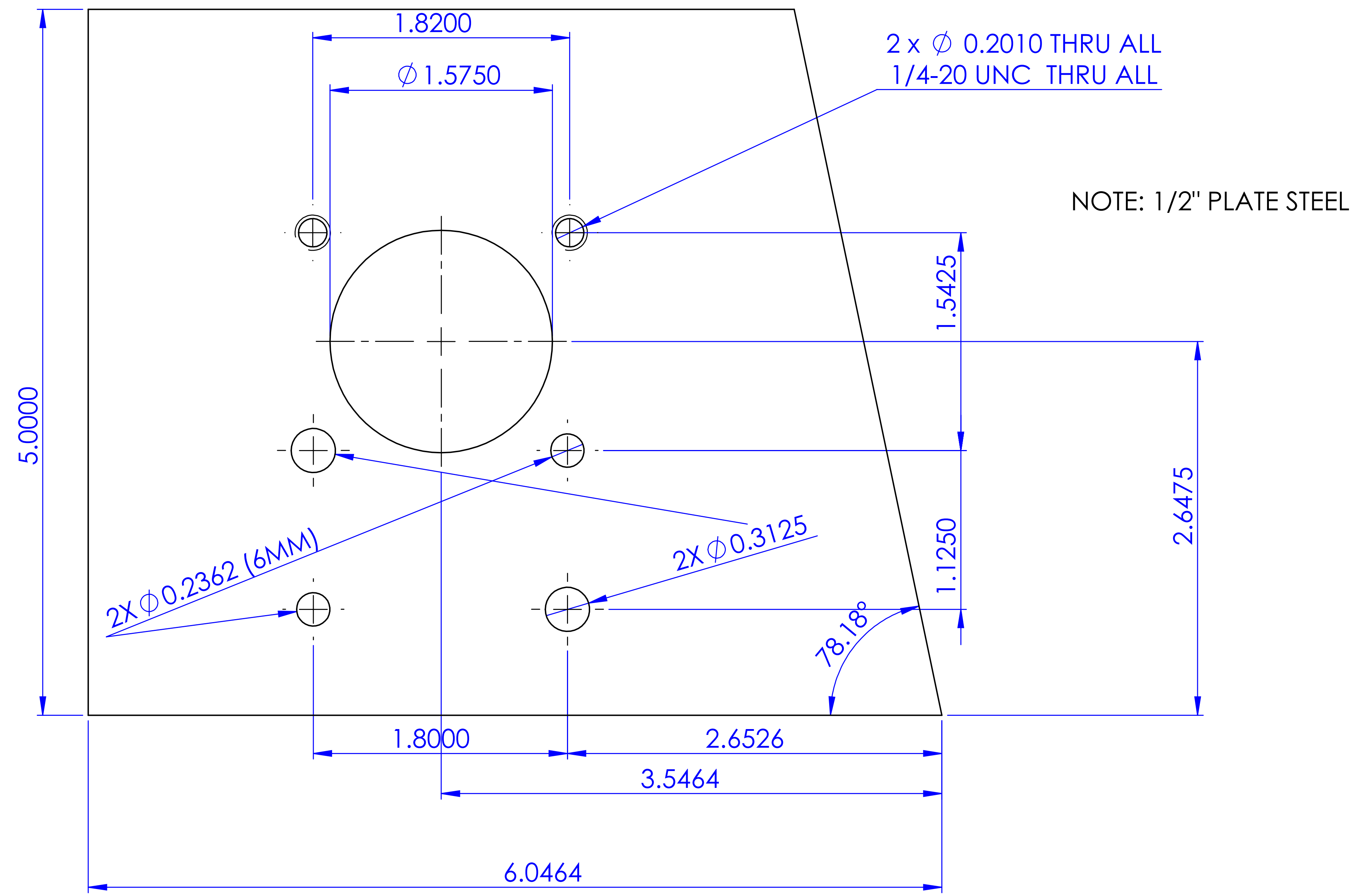
Cal Poly Mechanical Engineering	GANTRY LIFT	Assignment #	Title: INPUT SHAFT		Drwn. By: N. HARRY
ME 429 - FALL 2016	Dwg. #:	Nxt Asb:	Date: 10/27/16	Scale:1:1	Chkd. By: ME STAFF



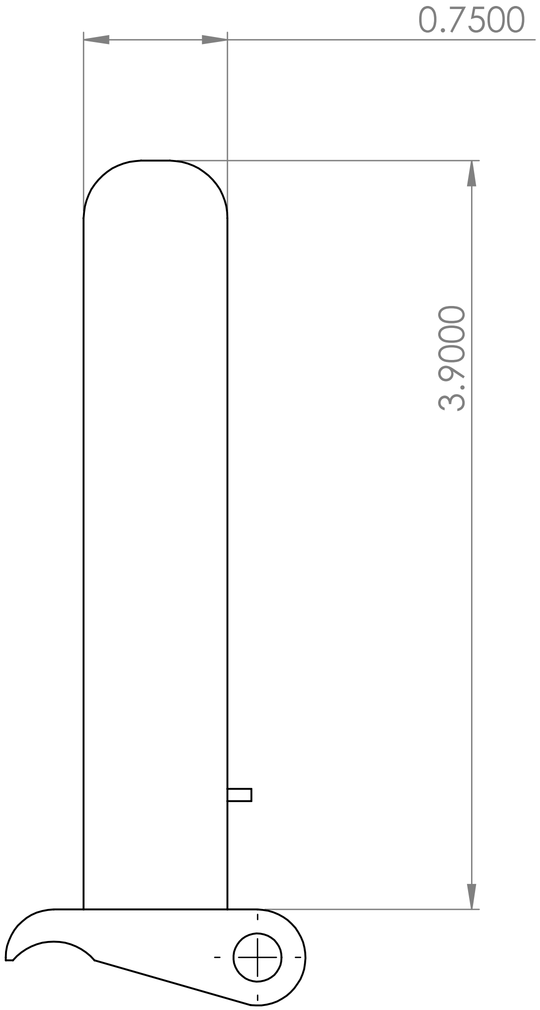
NOTE:
OUTER DIAM .625
1018 STEEL ROUND



Cal Poly Mechanical Engineering	GANTRY LIFT	Assignment #	Title: OUTPUT SHAFT		Drwn. By: N. HARRY
ME 429 - FALL 2016	Dwg. #:	Nxt Asb:	Date: 10/27/16	Scale: 1:1	Chkd. By: ME STAFF

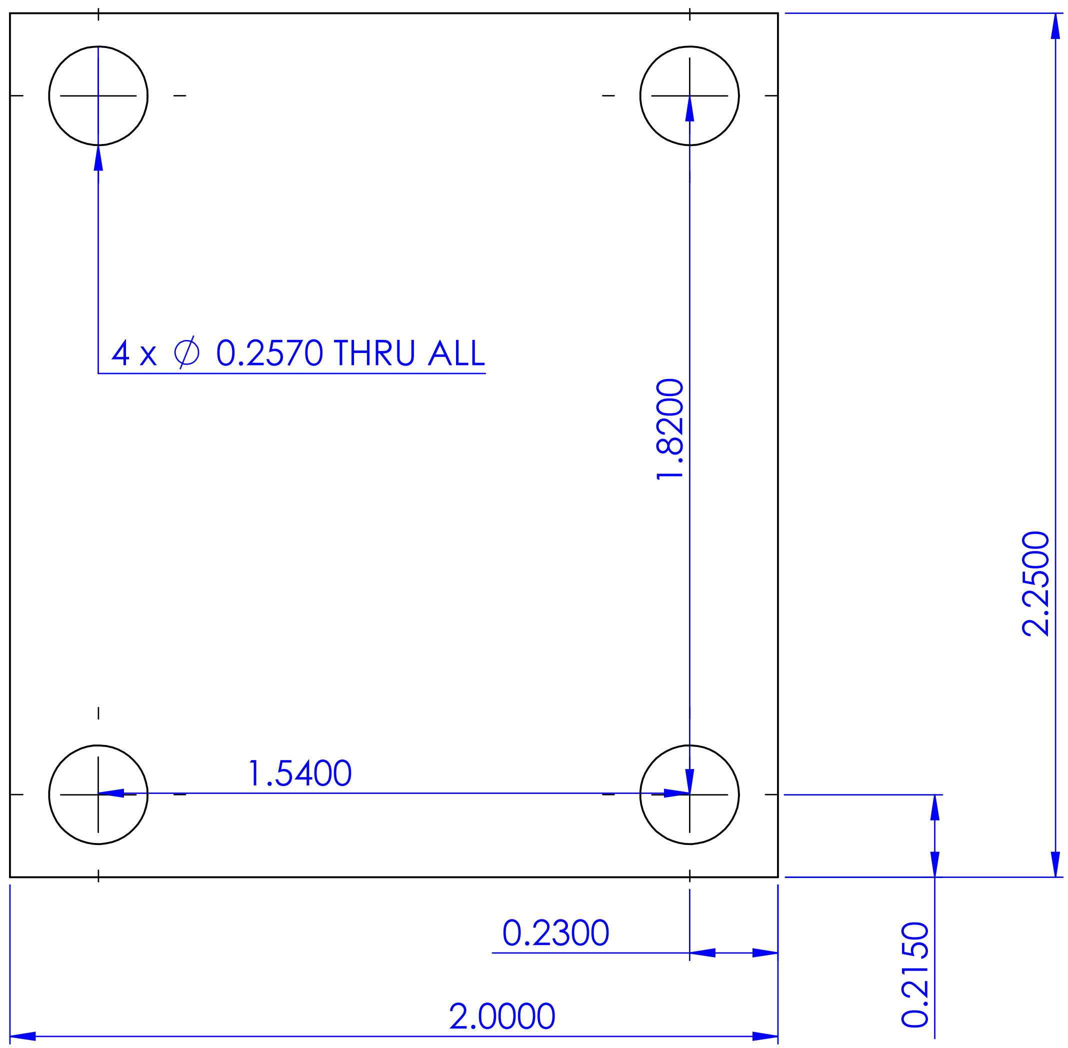


Cal Poly Mechanical Engineering	GANTRY LIFT	Assignment #	Title: PORT SIDE CASEPLATE		Drwn. By: N. HARRY
ME 429 - FALL 2016	Dwg. #:	Nxt Asb:	Date: 10/24/16	Scale: 1:1	Chkd. By: ME STAFF



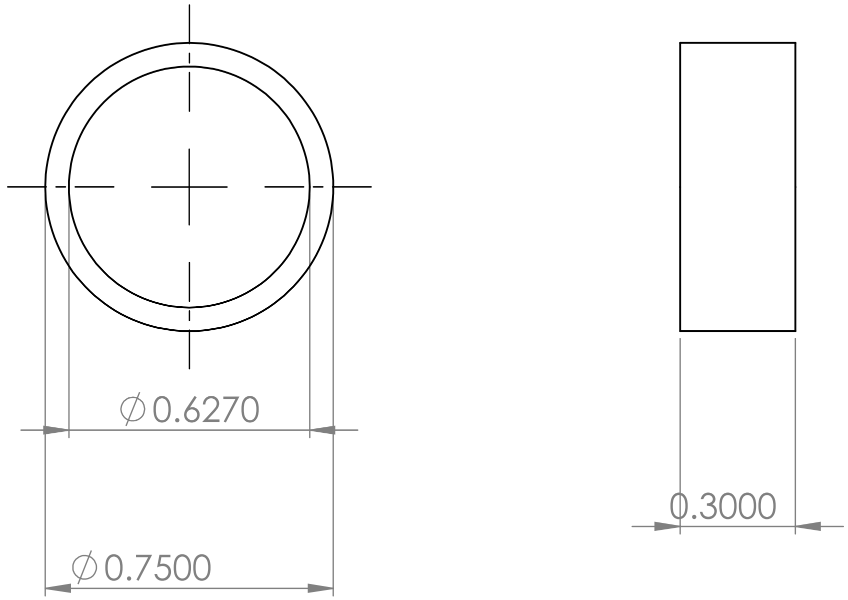
NOTE: PURCHASE PAWL
WELD HANDLE OF NECESSARY DIMENSIONS
ADD STANDOFF FOR RETURN SPRING

Cal Poly Mechanical Engineering ME 429 - FALL 2016	GANTRY LIFT	Assignment #	Title: RATCHET		Drwn. By: N. HARRY
	Dwg. #:	Nxt Asb:	Date: 10/27/16	Scale:1:1	Chkd. By: ME STAFF



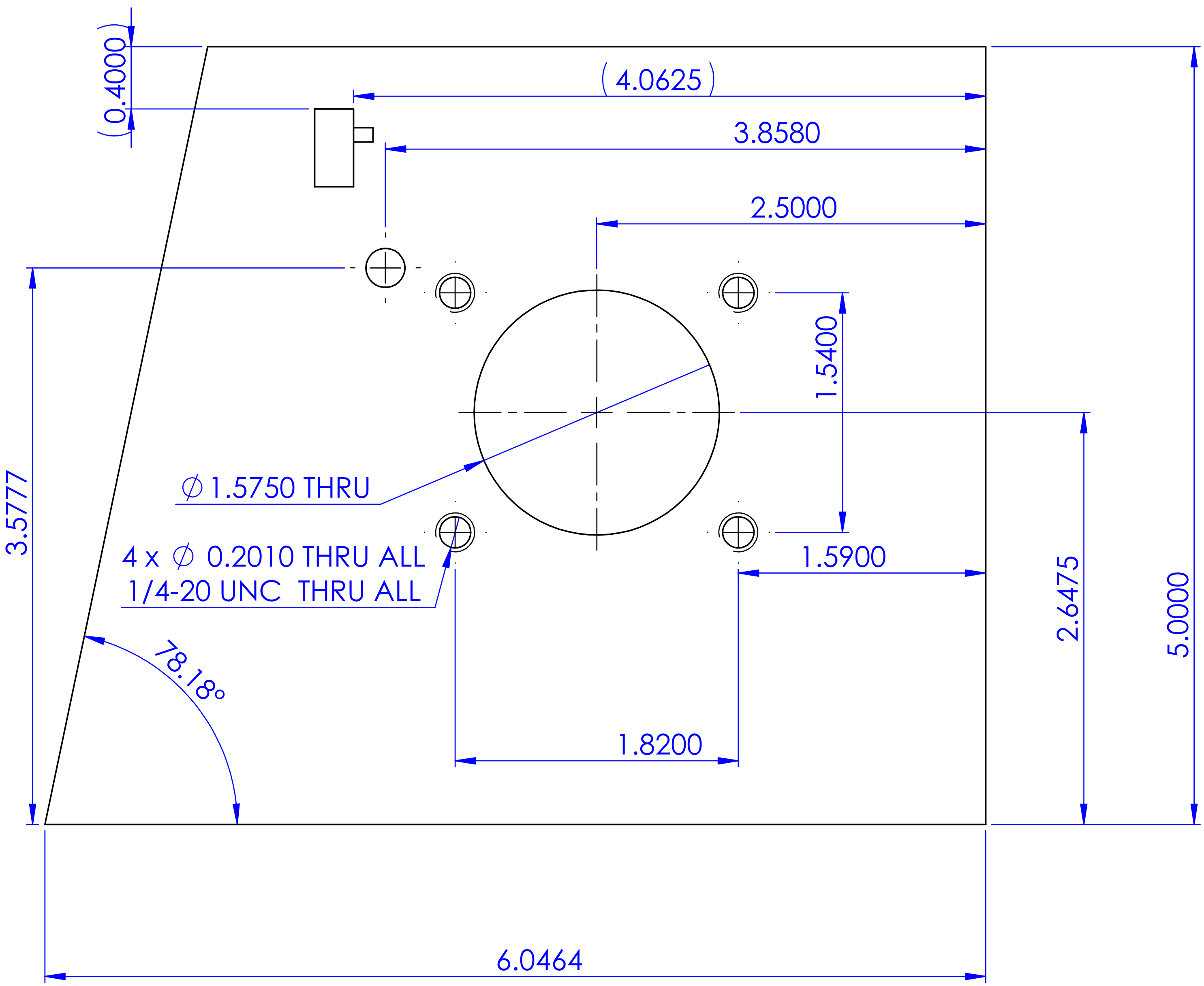
NOTE: .06 SHEET STEEL

Cal Poly Mechanical Engineering ME 429 - FALL 2016	GANTRY LIFT	Assignment #	Title: SHAFT CAP PLATE	Drwn. By: N. HARRY
	Dwg. #:	Nxt Asb:	Date: 10/24/16 / Scale: 2:1	Chkd. By: ME STAFF



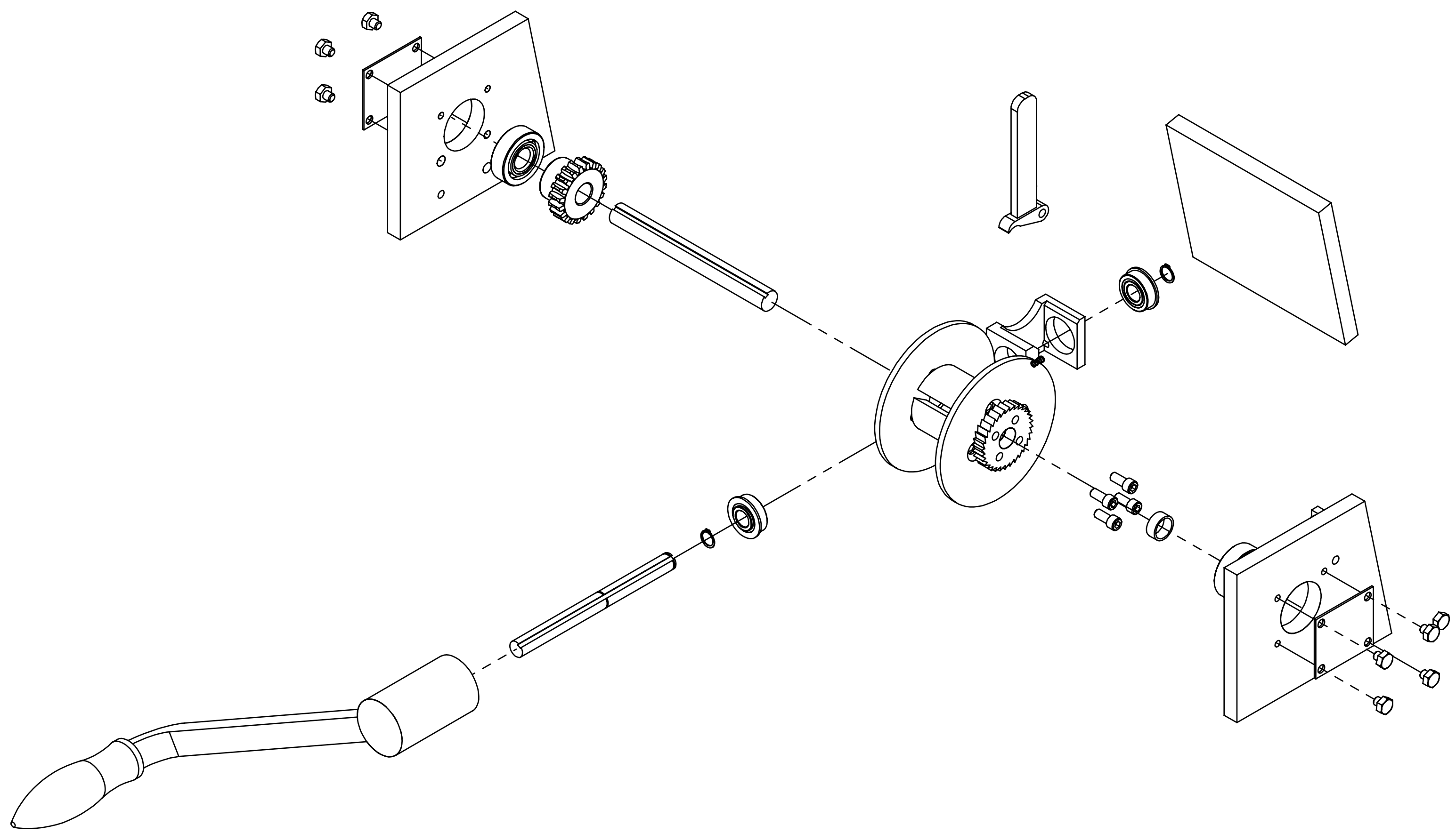
NOTE:
MATERIAL 1018 STEEL

Cal Poly Mechanical Engineering	GANTRY LIFT	Assignment #	Title: OUTPUT SHAFT SPACER		Drwn. By: N. HARRY
ME 429 - FALL 2016	Dwg. #:	Nxt Asb:	Date:10/27/16	Scale: 2:1	Chkd. By: ME STAFF



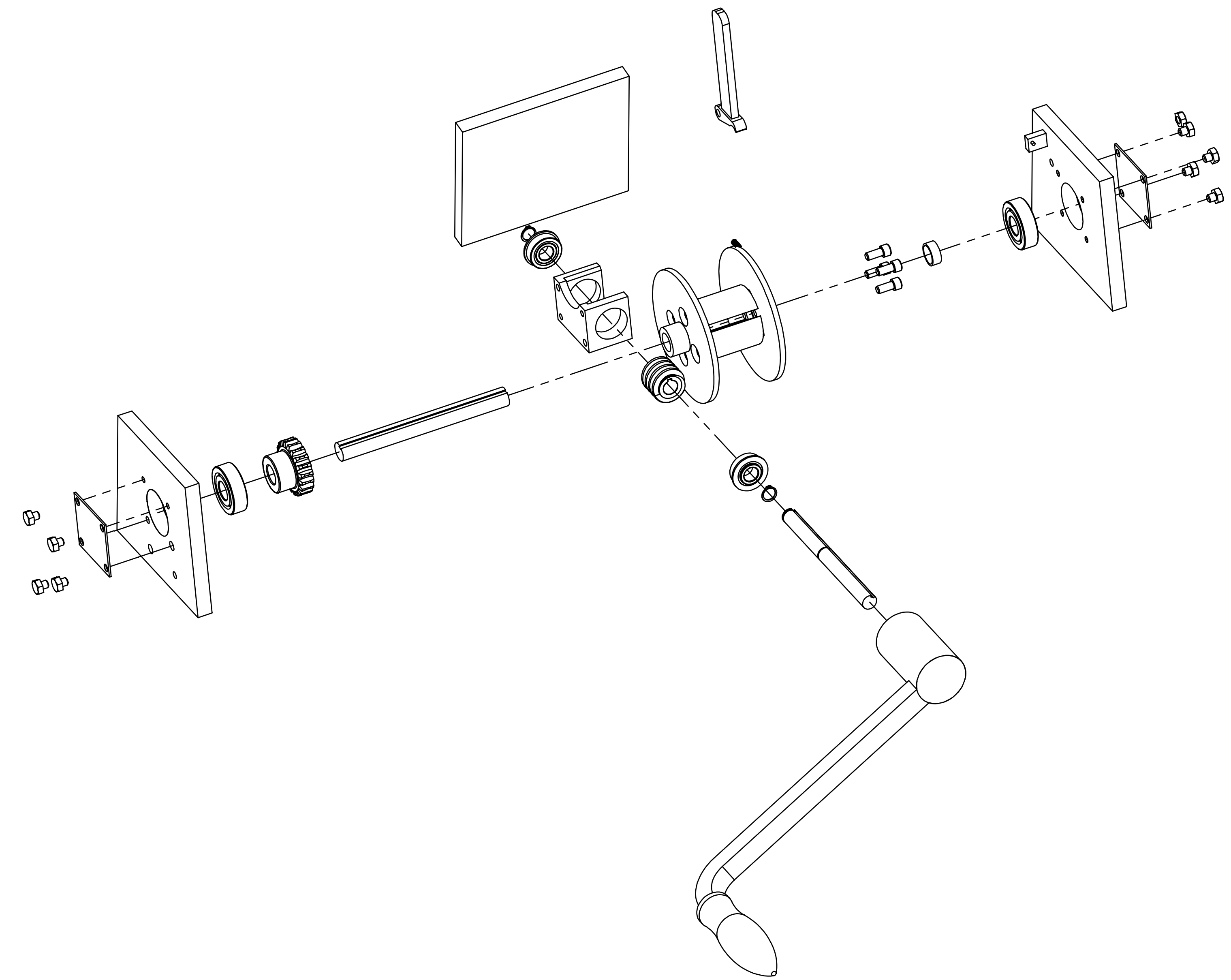
NOTE: 1/2" PLATE STEEL
WELD RATCHET MOUNT
BLOCK TO FIT

Cal Poly Mechanical Engineering	GANTRY LIFT	Assignment #	Title: STARBOARD MOUNT PLATE		Drwn. By: N. HARRY
ME 429 - FALL 2016	Dwg. #:	Nxt Asb:	Date:10/24/16	Scale: 1:1	Chkd. By: ME STAFF

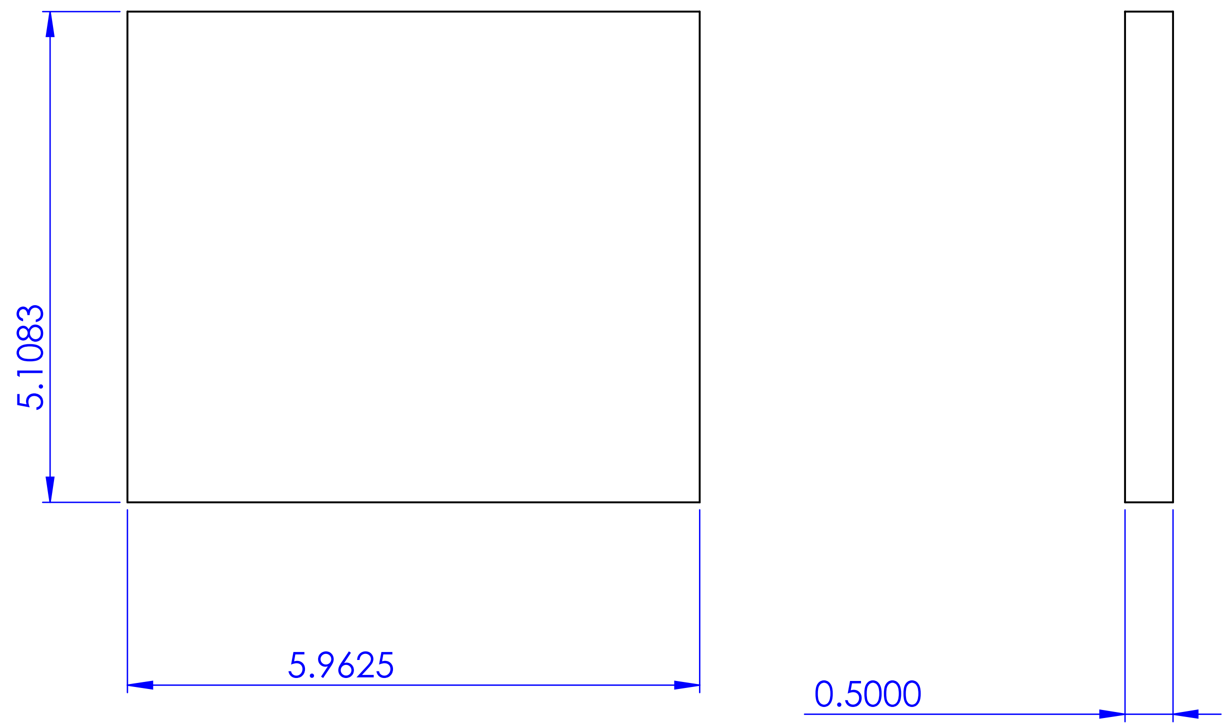


SOLIDWORKS Educational Product. For Instructional Use Only

Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: TRANSMISSION EXPLODED	Drwn. By: N. HARRY
ME 429 -FALL 2016	Dwg. #:	Nxt Asb:	Date: 10/27/16 / Scale: 1:5	Chkd. By: ME STAFF

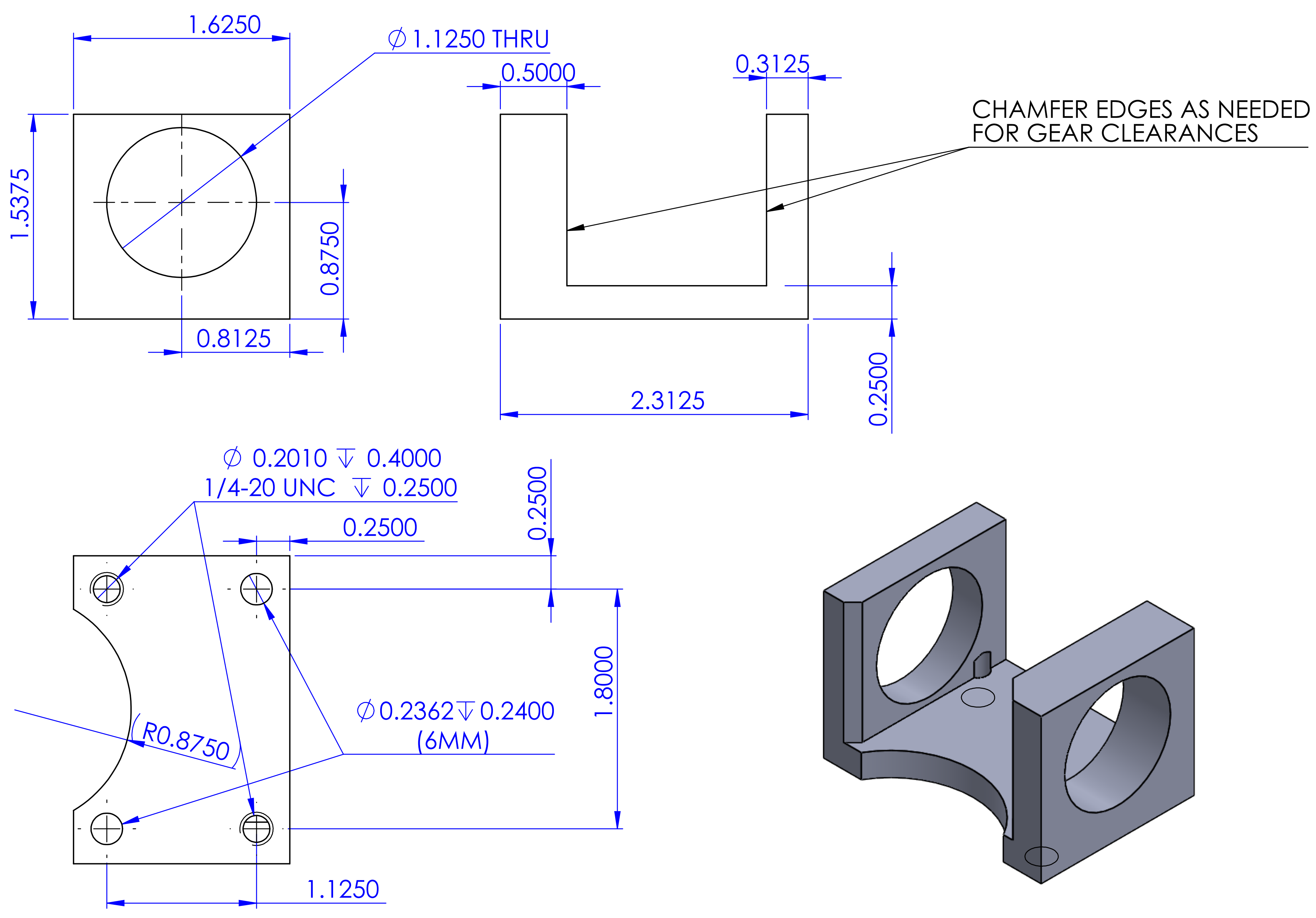


Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: TRANSMISSION EXPLODED		Drwn. By: N. HARRY
ME 429 -FALL 2016	Dwg. #:	Nxt Asb:	Date:10/27/16	Scale: 1:5	Chkd. By: ME STAFF



NOTE:
1018 STEEL PLATE

Cal Poly Mechanical Engineering	GANTRY LIFT	Assignment #	Title: TRANSMISSION MOUNT PLATE		Drwn. By: N. HARRY
ME 429 - FALL 2016	Dwg. #:	Nxt Asb:	Date: 10/27/16	Scale: 1:2	Chkd. By: ME STAFF



Cal Poly Mechanical Engineering	GANTRY LIFT	Assignment #	Title: WORM MOUNT BLOCK		Drwn. By: N. HARRY
ME 429 - FALL 2016	Dwg. #:	Nxt Asb:	Date: 10/24/16	Scale: 1:1	Chkd. By: ME STAFF

APPENDIX C

BILL OF MATERIALS

ITEM DESC	SOURCE	WEB LINK	QTY	PRICE/UNIT	PRICE/ITEM
Locking Bracket Pins	ACE hardware	http://www.acehardware.com/product/index.jsp?produ	2	$ 4.59	$ 9.18
Drive Drum	Manufactured (Donated)	N/A	1	$ -	$ -
Drive Drum Plate	Manufactured (Donated)	N/A	1	$ -	$ -
Driven Drum Plate	Manufactured (Donated)	N/A	1	$ -	$ -
Drum Shaft	Manufactured (Donated)	N/A	1	$ -	$ -
Gear Spacer	Manufactured (Donated)	N/A	2	$ -	$ -
Input Shaft	Manufactured (Donated)	N/A	1	$ -	$ -
Port side Plate	Manufactured (Donated)	N/A	1	$ -	$ -
Roller Drums	Manufactured (Donated)	N/A	2	$ -	$ -
Shaft End Cap	Manufactured (Donated)	N/A	1	$ -	$ -
Starboard side plate	Manufactured (Donated)	N/A	1	$ -	$ -
Steel Crank Handle	Manufactured (Donated)	N/A	1		$ -
Transmission Mounting Plate	Manufactured (Donated)	N/A	1	$ -	$ -
Worm Mounting Block	Manufactured (Donated)	N/A	1	$ -	$ -
1/2 ID flanged bearing	McMaster-Carr	#6384k361	2	$ 11.27	$ 22.54
5/8 ID bearing	McMaster-Carr	http://www.mcmaster.com/#2780t22/=14qakyo	2	$ 17.52	$ 35.04
Flanged bushing	McMaster-Carr	https://www.mcmaster.com/#6338k425/=14sfbwx	4	$ 1.28	$ 5.12
Low Profile Wheels (F2000 and FSAE)	McMaster-Carr	https://www.mcmaster.com/#9936t62/=14sf3y9	2	$ 39.58	$ 79.16
Off-Road Wheels (Baja)	McMaster-Carr	https://www.mcmaster.com/#2319t32/=14sf3ce	2	$ 12.63	$ 25.26
Ratchet Pawl	Manufactured (Donated)	https://www.mcmaster.com/#6283k32/=14sfzks	1	-	-
Ratcheting Gear	Manufactured (Donated)	https://www.mcmaster.com/#6283k23/=14sfzfw	1	-	-
Steel Compression Spring	McMaster-Carr	https://www.mcmaster.com/#9657k264/=14sg0dk	1	$ 6.52	$ 6.52
Steel snap ring	McMaster-Carr	https://www.mcmaster.com/#97633a230/=14sfzzd	1	$ 12.45	$ 12.45
WORM 12 PITCH	McMaster-Carr	http://www.mcmaster.com/#57545k527/=14qc7su	1	$ 30.36	$ 30.36
Worm Gear 12 pitch	McMaster-Carr	http://www.mcmaster.com/#57545k513/=14q7cwl	1	$ 64.26	$ 64.26
Locking Bracket tube	SpeedyMetals	http://www.speedymetals.com/pc-4691-8224-2-12-x-	1	$ 6.46	$ 6.46
Ram Support tube	SpeedyMetals	http://www.speedymetals.com/pc-4785-8251-2-12-s	1	$ 22.62	$ 22.62
Engine Hoist	Tractor Supply Co.	http://www.tractorsupply.com/tsc/product/big-red-2-t	1	$ 229.99	$ 229.99
Nylon Webbing 12' Loop-Loop	US Cargo Supply		1	$ 22.29	$ 22.29
				TOTAL	$ 571.25

APPENDIX D

HAZARD IDENTIFICAITON CHECKLIST

ME428/429/430 Senior Design Project 2015-2016

SENIOR PROJECT CRITICAL DESIGN HAZARD IDENTIFICATION CHECKLIST

Team: Harry Shots-Hole Bearbeitung Advisor: J. Fabijanic

Y	N	
X	☐	Do any parts of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points adequately guarded?
☐	X	Does any part of the design undergo high accelerations/decelerations that are exposed to the user?
X	☐	Does the system have any large moving masses or large forces that can contact the user?
☐	X	Does the system produce a projectile?
X	☐	Can the system to fall under gravity creating injury?
X	☐	Is the user exposed to overhanging weights as part of the design?
☐	X	Does the system have any sharp edges exposed?
☐	X	Are there any ungrounded electrical systems in the design?
☐	X	Are there any large capacity batteries or is there electrical voltage in the system above 40 V either AC or DC?
☐	X	Is there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids when the system is either on or off?
☐	X	Are there any explosive or flammable liquids, gases, dust, or fuel in the system?
☐	X	Is the user of the design required to exert any abnormal effort and/or assume an abnormal physical posture during the use of the design?
☐	X	Are there any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	X	Will the system generate high levels of noise?
☐	X	Will the product be subjected to extreme environmental conditions such as fog humidity, cold, high temperatures ,etc. that could create an unsafe condition?
☐	X	Is it easy to use the system unsafely?
X	☐	Are there any other potential hazards not listed above? If yes, please explain on the back of this checklist.

For any "Y" responses, add a complete description on the reverse side. DO NOT fill in the corrective actions or dates until you meet with the mechanical and electrical technicians.

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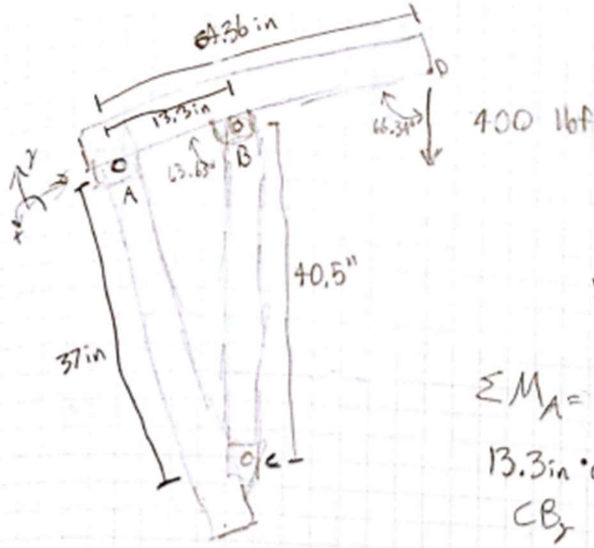
Description of Hazard	Corrective Actions to Be Taken	Planned Completion Date	Actual Completion Date
LARGE SUSPENDED WEIGHT IN FORM OF VEHICLE	POSITIVE - RETENTION CLAMPS AND UNDERSIDE SUPPORT STRUCTURE		
ROTATING/MOVING/SHEARING PARTS USED TO PHYSICALLY LIFT THE VEHICLES	Parts encased in covers that restrict access to moving parts.		
Pinch points (between lift and car, components of lift itself)	Lift will have covers/guards to cover pinch points. Lifting mechanism forces user to be away from lift/car interface.		
Swinging hazard from vehicle after lifted.	Inherent stabilization from vehicle attachment point. Secondary locking mechanism keeps car stable once lifted.		
Assembly dangers including falling parts, crushing possibility, and pinch points.	Design to assemble on ground, complete instruction manual listing proper assembly procedure.		
Rapid descent of lifted vehicle	Self-locking high reduction in drive line, User is forced to be away from vehicle when lowering		
Assembled incorrectly, causing uneven lifting	Parts only fit together in the correct way. Procedure will be well-documented in manual		

APPENDIX E

F.S. ANALYSIS OF COLUMN SUPPORTS



For Baja

$$\Sigma M_A = 0$$

$$13.3\text{in} \cdot CB_y - 64.36\text{in} \cdot 400 \sin(66.34) = 0$$

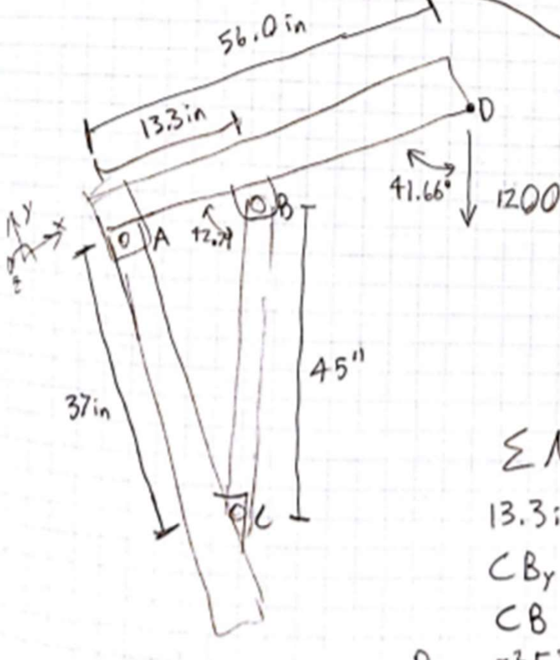
$$CB_y = 1772.94 \text{ lbf}$$

$$CB = 1931.39 \text{ lbf}$$

$$P_{cr} = \frac{\pi^2 E I}{Le^2} = \frac{\pi^2 (29 \cdot 10^6 \text{ psi})(.95215 \text{in}^4)}{(40.5\text{in})^2}$$

$$P_{cr} = 166147.22 \text{ lbf}$$

S.F. = 86.0



For Fab/Formula

$$\Sigma M_A = 0$$

$$13.3\text{in} \cdot CB_y - 56.0 \text{ in} \cdot 1200 \sin(41.66^\circ) = 0$$

$$CB_y = 3358.53 \text{ lbf}$$

$$CB = 4944.00 \text{ lbf}$$

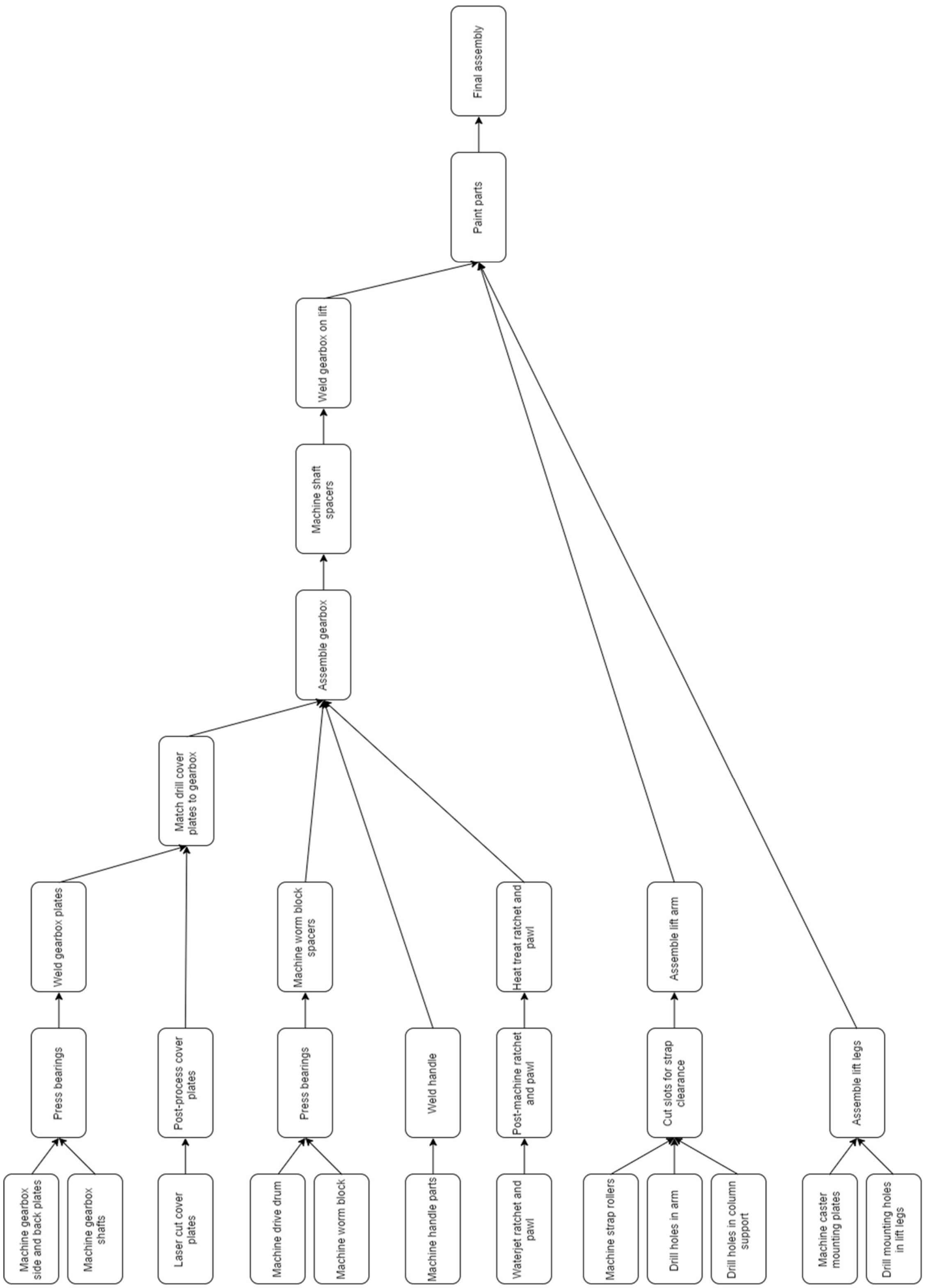
$$P_{cr} = \pi^2 E I = \frac{\pi^2 (29 \cdot 10^6 \text{ psi})(.95215 \text{ in}^4)}{(40.5 \text{ in})^2}$$

$$P_{cr} = 132040.05$$

S.F. = 33.6

APPENDIX F

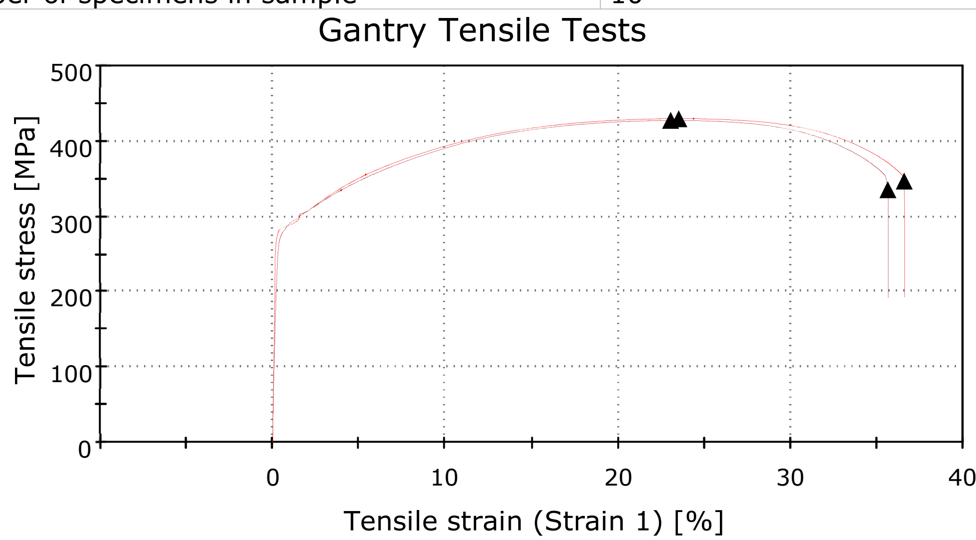
MANUFACTURNING FLOWCHART



APPENDIX G

MATERIAL INSTRON TESTING

Company	Super Duper Multi National Conglomerates R Us
Laboratory Name	Central Laboratories
Operator ID	Mary
Rate 1	3.00000 mm/min
Humidity (%)	50.00000
Temperature (deg C)	18.00
Number of specimens in sample	10



	Specimen label	Modulus (Automatic Young's) [GPa]	Yield Stress (0.2% Offset) [MPa]	Maximum Load [kN]	Tensile Stress [MPa]
1	Sample 1	174.26	282.0	19.06	429.7
2	Sample 2	131.57	268.5	18.16	427.3

	% Elong [%]
1	36.53
2	35.58

APPENDIX H

BENDING CALCULATIONS

Datum / Date:

Recalculating Bending Stresses
given $\sigma_y = 40{,}000$ psi derived from
Instron Testing on 2/10/17

Baja Lift:

$\sigma = \frac{My}{I} = 25867.5$ psi (see previous)

$F.S. = \frac{40{,}000 \text{ psi}}{25867.5 \text{ psi}} = 1.546$

now w/ 4mm wall = 2.74

Formula/Fab Lift:

$\sigma = \frac{My}{I} = 47094.8$ psi (see previous)

Fab $F.S. = \frac{40{,}000 \text{ psi}}{47094.8 \text{ psi}} = 0.849$

$\sigma = \frac{My}{I} = \frac{(14191)(1.181)}{(1.1278)} = 14860$ psi

Formula $F.S. = \frac{40000}{14860} = 2.7$

4 mm wall or 5 mm wall?

4mm: $I_4 = 1.1278$ F.S. = 1.51

5mm: $I_5 = 1.3430$ F.S. = 1.79

given: $\sigma_y = 53700$