Lightweight UAV Launcher
Senior Project for Aerojet-Rocketdyne

Final Report
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Team Rocket Power

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Executive Summary

This report discusses the design, construction, and testing of a lightweight, portable UAV launcher. There is a current need for a small team of soldiers to launch a US Marine Tier II UAV in a remote location without transport. Research was conducted into existing UAV launcher designs and the pros and cons of each were recorded. This research served as a basis for concept generation during the initial design development stage. It was required that the design weigh less than 110 lbs, occupy a smaller volume than 48” x 24” x 18” in its collapsed state, be portable by a single soldier, able to be operated by two soldiers, and launch a 55 lb UAV at 52.3 ft/s. In this report is the detailed analysis and design of the first prototype of such a launcher. The launcher operates using a set of six elastic surgical tubing members and an electric winch and features a collapsible frame made of lightweight aluminum 6061-T6. The launcher succeeded in reaching an exit velocity of 53.7 ft/s, set-up and tear-down times under 5 minutes, weight of 62 lbs, a collapsed volume measuring 43” X 14.5” X 14”, and the need for only a single operator.

Introduction

Team Rocket Power is a team composed of Ben Miller, Corinne Warnock, Christian Valoria, and Jake Coutlee, four senior mechanical engineering students at California Polytechnic State University (Cal Poly) in San Luis Obispo, California who have accepted the design challenge as presented by the project correspondent Kent Wong of Aerojet Rocketdyne, Sacramento California. Team Rocket Power will also be under the advisement of Professor Sarah T. Harding of the mechanical engineering department at Cal Poly.

The goal of this project is to design, build, and test a lightweight and portable Unmanned Aerial Vehicle (UAV) launcher for Aerojet Rocketdyne. The launcher must be able to be carried by a single soldier, operated by a maximum of two, and be able to launch a 55 lb UAV with the right velocity and launch characteristics such that it can generate lift and take flight. The launcher must also be reusable and reloadable within a single mission. This project will support Aerojet Rocketdyne in their pursuit of entrance into the UAV market and the US marines who need such a launcher.

In this report is everything one needs to know about the current launchers on the market, including their strengths and pitfalls, the development of the design, including the initial and revised concepts, the analysis used to design all components, the materials purchased, the manufacturing and test results, the assembly instructions, and future recommendations.

Background

There is a current need for a soldier on the ground to be able to launch an aerial vehicle in remote areas with limited clear space using a simple, lightweight launch assister. Currently, smaller, hand-held UAVs are used in these situations. However, these don't provide the payload capacity of larger UAVs. Furthermore, the launchers with the ability to handle the increased weight aren't mobile or compact enough to transport and launch in remote areas. UAVs large enough to carry extra payloads, but also light enough to for a soldier to carry usually range from 40-55 lbs. The current launchers available to launch these heavier payloads often must be attached to the back of Humvees and other vehicles, which severely limits suitable launch sites. A launcher which can be carried by a soldier and transported on foot would effectively eliminate this problem all together and greatly increase the range and effectiveness of these UAVs in modern warfare. A typical soldier can be expected to carry up to 150 lbs in the field, however keeping that weight down to allow the soldier to carry other essential gear should be a priority. There are only a

Figure 1. Scan Eagle mounted on SuperWedge (Top) SuperWedge being prepared for operation (Bottom)

few portable UAV launchers on the market today, of which only a small number are light and compact enough for a soldier to carry.

The current standard for the UAVs and associated launchers of this size is the Scan Eagle. This UAV weighs 44 lbs. with a 10.2 foot wingspan [6]. The Scan Eagle is launched by the SuperWedge launcher, the scale of which can be seen above in Figure 1.

This particular launcher uses pneumatics to assist with the launch and must be towed for transportation. Some advantages include rigidity and ease of transportation with use of a vehicle. Disadvantages include: bulkiness, heaviness, difficulty to use in remote areas, and requirement of more than a single soldier on foot to transport.

While this launcher seems to be the standard for the launching of UAVs the size of the Scan Eagle, it is limited in two very key ways. First, it is very heavy. Second, the launcher is fairly large and lacks the ability to collapse when being transported; the SuperWedge measures 16' x 3' x 12' [9]. While the launcher can be moved around on wheels, it would be extremely difficult for this to be done by a single soldier, in a remote area, on possibly rugged terrain. Another design has been developed to try and mitigate these problems.

The UAVSI Lightweight Launcher is at the forefront of the lightweight UAV launcher technology. The model is lightweight, simple to operate, and has a small footprint. This launcher weighs 20.0 kg, or 44 lbs, making it much lighter than the other UAV launchers on the market. The propulsion system is pneumatically powered and operates within a wide range of temperatures (-25 to +60 degrees C). Its overall length is 2.1 meters, or 6.89 feet and is freestanding, making it very versatile [1]. Its free standing and lightweight frame allows it to operate in a variety of environments. The launcher can be seen in Figure 2 below.

Figure 2. UTSL Mini Launcher

The only drawback found with this particular launcher is that it isn't collapsible. The launcher must be transported at its operating length of 6.89 feet. While it is light weight, the overall length makes it more difficult for a single individual to carry. This is the key area in which this particular design could be improved. However, overall, this launcher is the lightest and most portable of those on the market that are able to launch UAVs in the 40-55 lb range. While the SuperWedge and UTSL Mini Launcher were found to be the top launchers on the market for launching a 40-55 lb UAV, more research was conducted to determine what other launcher designs, specifically patents, exist.

As part of any design project, a patent search is one of the most important areas of research that needs to be done. The patent search for this project was conducted through the United States Patent Office's online database and Google Patents. One particular patent involved a very creative way of launching a UAV within the UAV weight class of this project. It provides an apparatus for launching a UAV, comprised of a mortar launcher, a means of mounting for mounting a UAV on said mortar launcher; a cap comprised of a mating surface suitable for mating with the head of a mortar round; wherein the cap is connected with a bungee rope to an unmanned air vehicle [3]. Although this design is very creative and suitable for combat situations, this being a school project, the methods described in this patent reach beyond the possibility of any methods which can be proposed for this project Thus no possible conflict will arise for this particular patent.

A similar patent was found wherein a mass with an attached tether is launched there by towing the UAV to launch speed [2]. Various UAV launch tubes have also been patented, however, these launchers are designed for UAVs with collapsible wings and of a smaller weight class [4]. These too will not conflict with the scope of this project. Another patent was found which comprises of a magazine used to store the UAV and a robotic arm to assist in the launching and recovery operation [5]. It is currently presumed that this too will not conflict as a more mechanical (as opposed to robotic) approach will be undertaken for this project. Additionally, a recovery system is not part of this project. Another patent involves the launching of an unmanned projectile includes pre-packaging a barrel with a projectile, a pusher cup, and a gas generator [2]. The gas generator generates gas to propel the projectile out of the barrel. Even though keeping clear of these restrictions shouldn't be a problem, they will be considered throughout the design process.

Upon making the design decision to implement natural latex surgical tubing as the launching mechanism, more research was done to validate this new design for the weight capacity of this project. The Orbiter Launcher [13], by Aeronautics, utilizes a series of elastic bungees. The largest Orbiter UAV is 28 kg, 62 lbs, which proves the ability of bungees to launch the UAV envisioned for this project. Because the Orbiter Launcher utilizes elastic bungees, it is a far simpler design than the other designs mentioned. This design is simple to manufacture, straightforward to operate, and is extremely lightweight. One drawback with this design is that the frame of the launcher is not collapsible. The launcher can be seen in Figure 3.

Figure 3: Orbiter Launcher

Objectives

The primary objective is to create a UAV launch system that can effectively assist in the launch of a US Marine Tier II UAV. The envisioned system is operable by two people and can be easily transported by a single person. The optimal system should be repeatable and not utilize expendables. Because there is not a UAV available to the team to test launch, in order to verify the operational success of the launcher it will be required that it is able to launch a 55 lb deadweight with a modified launch speed; see calculations in Appendix A.

Requirements

To ensure that the design meets the needs of Aerojet Rocketdyne a Quality Function Deployment (QFD) chart, or "House of Quality" was created. Using the QFD, refer to Appendix B, the needs of Aerojet Rocketdyne were converted to respective engineering specifications, which were confirmed by Mr. Wong. Existing UAV launchers were compared to these specifications, as well as Aerojet's requirements, to further benchmark the competition. The team hopes to create a lightweight launch assist system that is competitive with other systems in the market.

Table 1. Aerojet UAV launcher requirements and compliance matrix

Customer Requirement	Weighted Priority	Engineering Specification
Assist UAV Launching	5	Launch 55 lb deadweight at 52.3 ft/s
Portable by a single person	5	< 48" x 24" x 18" (or equivalent volume)
Operated by two people (Max.)	4	No more than 2 simultaneous human inputs required
Safe to Operate	4	Will include operational instructions Will include safety to prevent accidental firing
Lightweight	3	Weight < 110 lbs.
Structural Integrity	2	Apply Factor of Safety of 1.25 to structural loads
Ease of (dis)assembly	1	Set up/Take down time of 10 min

This model helped develop engineering requirements corresponding to requirements specified by the customer. These requirements were then given a weight factor to help compare the importance of each and help provide further direction for design conceptualization. Priority was assigned on a scale of 1-5 with 5 being the highest priority and 1 being the lowest priority. Then, existing products were rated and compared against these weighted requirements. This scoring system provides insight on which existing design satisfies the customer's requirements most and provides a benchmark for the team to beat. The comparison of existing designs also brings light to the successes and pitfalls of certain designs. Discerning useful and not so useful design components will help when conceptualizing the final design.

The customer and engineering requirements and their corresponding weights can be seen in Table 1. The engineering requirements and their weights were determined through discussion with Mr. Wong and the rest of the team. The first customer requirement states that the launcher needs to be lightweight. When discussing how to quantify this, it was determined that this specification is based on the ability of a single person (soldier) to carry the launcher for an extended period of time. The "weight less than 110 lbs" engineering specification is based on the upper end of what weight a typical soldier could be expected to carry in combat. When researching this particular statistic, there was some significant discrepancy in the range of weight a soldiers carries [8]. After discussing with Mr. Wong, the max weight of 110 lbs, or 50 kg, was agreed upon.

The "assist in launching of a UAV" was the next customer requirement to be specified and quantified. Since Aerojet cannot provide an existing UAV launch system (for the weight range specified) and this information is not readily available, it was determined that the launcher should provide 60% of the power needed for the UAV to achieve flight. This specification will be difficult to test as there will be no UAV to test launch with. To create a specification that can be tested, the modified speed at which a 55 lb dead weight must be launch was calculated. This was done assuming the required launch speed of 67.5 ft/s (discerned from the 40 knot launch specification provided by Mr. Wong), a distance to launch of 8 feet, and the aforementioned 60% percent of the power. These calculations can be seen in Appendix A. The modified launch speed was determined to be 52.3 ft/sec. This allows this engineering specification to be tested without actually having to launch a UAV. Note also that this is a rough estimation; if the track length increases or decreases, the average force and acceleration will decrease or increase, respectively. During the design phase, the track length will most likely change. To account for this, a spreadsheet will be made to recalculate the new force and acceleration needed as a function of track length.

Next, it was discussed, that simply because the launcher is lightweight does not mean that it would be easily carried and portable by a single person; the length of the launcher could still make it awkward or non-ergonomic to carry. It was decided that the launcher should be collapsible into a 48" x 24" x 18" cube. This volume is larger than a backpack, but still a reasonable size for a person to carry.

Then, the team looked at how the launcher was to be operated and it was specified that it should not require more than two individuals to operate. To quantify, it was specified that the launcher will not require more than two simultaneous human inputs.

Assembly and disassembly of the launcher was quantified next. The requirement for the launcher is that it must be easy to set up and tear down. To quantify this, the team looked at one of the existing lightweight launchers on the market, the UTSL Mini Launcher. They specify a setup time of 10 minutes. The team agreed that this is a reasonable setup time.

The team then addressed the integrity of the design. It was desired that the launcher be robust and tough enough to handle abuse and exposure to the elements. After discussing with Mr. Wong, it was determined that a factor of safety of 1.25 would be applied to all structural loads to ensure the structural integrity of the design.

Last, but not least, safety had to be addressed. The team chose to quantify this by requiring operation instructions and a safety to prevent the launcher from firing accidentally. Safety will also be later addressed in the design considerations.

After generating engineering specifications for Aerojet Rocketdyne's customer requirements, the team proceeded to evaluate them in the QFD model. First, a weight was assigned to each customer requirement; a 5 being of most importance and a 1 being the least. After these rankings were assigned, the correlation between the customer requirements and engineering requirements were analyzed and entered into the QFD. From these rankings and correlations, the team was able to determine the target requirement score and benchmark current UAV launchers.

The team ranked the "assist in UAV launching" and "portable by a single person" as the most important and assigned them a value of 5. These were ranked highest based on customer importance. As the main goal of this project is to create a portable UAV launcher, everything else falls secondary to that. The operational requirement of no more than two individuals was also ranked as a 4 based on specification by Mr. Wong. Although the "safe to operate" requirement was ranked as a 4, it should be noted that the team does not view safety as a less important requirement, but rather, less influential in driving the overall design. Safety will be considered no matter what design is conceptualized. Next, the weight restriction was ranked as a 3. It was found that this requirement was less driving since it is a maximum, allowing for numerous overall weights to be possible. Below this, the team placed structural integrity at a 2. This is due to the requirement serving as more of a guideline and basic specification than a design driver.

Lastly, the team ranked ease of assembly and disassembly with a 1. This is ranked low for two reasons. First, this specification is a maximum and not a specific timed result. Second, the ability for the design to satisfy all of the aforementioned requirements is more important than the designs ability to be assembled and disassembled in a certain amount of time. Using the results and weightings from the QFD, the team evaluated the three best products currently on the market which would serve the specified purpose. These products provide a benchmark with which to rate the team's design.

The Vigilant Launcher scored highest with 297, which is higher than the target design score. This is due to the launcher exceeding the requirements that weren't valued as highly. The Vigilant Launcher is lightweight, operated by one person, safe to operate, easy to assemble, and adequately assists in the launching of a UAV. It satisfies all but one key engineering and customer requirement: portable by one person. The launcher is not collapsible and does not fit in the specified volume. The Penguin B Launcher placed the second highest score. Like the Vigilant, this launcher also failed to fit in the specified volume. Additionally, the Penguin B far exceeds the weight limit. The last launcher compared was the SuperWedge. This launcher, which is the type of launcher this project aims at replacing, scored lowest due to its large size and weight. This scoring system provides a measurable goal. Using the model as a guide through the design phase, it can be ensured that the team will develop a device that will satisfy Aerojet Rocketdyne as a customer.

Additional Design Considerations

In addition to the above engineering requirements, the following design considerations will be taken into account during the projects conceptual design phase. Although these design considerations aren't specific "must do" requirements, the considerations should be integrated into the design if possible. A design adhering to these considerations will greatly increase said design's marketability. These design considerations are as follows:

The launcher should produce minimal expendables. For an application in which the launcher is transported by a single person in a possibly remote area, it would be advantageous for the launcher to require little to no expendable components. A launch requiring expendable components would require the individual to carry extra weight for the launcher and would limit the number of launches per trip or mission. Utilizing minimal expendables also eliminated the need for cleanup after launch, which lowers breakdown time and leaves no trace of the launch site.

The launcher should be reusable. This directly relates to the idea that the launcher should utilize minimal expendables. It should not be limited by a mechanism which would produce expendables. The launcher should be able to make multiple launches per mission. A limited-use launcher could paralyze a mission and put the involved soldiers in danger.

The launcher should be robust. In addition to the launching mechanism being reusable, the overall construction should be robust. It needs to be strong enough to both withstand the forces created during launch and to provide ample support for the UAV during launch. The launcher should also be capable of enduring non-launch situations, such as repetitive uneven loading at the carrying points from the user running, the impact from a fall, and multiple setups and breakdowns.

The launcher should be quiet. Users will be in relatively close proximity to the launcher during operation. Having a quieter launcher would prevent the users from sustaining hearing damage. A quieter launcher would also be very advantageous in a stealth situation.

The launcher should be fairly impervious to the weather. The launcher should be able to operate in a range of temperature, humidity, and weather conditions. A simple way to specify this would be to say: the launcher must be able to operate in any environmental condition that a UAV can. This consideration will factor heavily into the material selection.

The launcher should be safe. The final design consideration to discuss is safety. This is an extremely important consideration for any design and the team plans to take it seriously. Each component of the design will be analyzed extensively and every precaution will be taken to ensure that no one would be injured in the operation of the launcher. As mentioned in the QFD, operational instructions will be developed and a safety will be implemented into the design. Safety will constantly be considered and integrated into the design throughout the entire process outlined in the next section.

Design Development

In order to determine the best solution to the design challenge of creating a lightweight, collapsible, UAV Launcher as presented by Aerojet Rocketdyne, a long and extensive process of ideation, comparative analysis, and design synthesis was undertaken. The design challenge was broken down into basic "action" characteristics. These basic characteristics became design categories, or subsystems of the overall design. Then different ideas of how each characteristic could be achieved were generated. From these, research was done to determine availability and feasibility of each idea. After determining feasible ideas for each category, Pugh matrices were constructed. This allowed for a number of solutions to be compared before constructing entire systems to be compared. After analyzing the Pugh matrices, entire systems were constructed and compared in a decision matrix; see Appendix C for the decision matrix and system sketches. After analysis and research of each design was conducted, it was determined that the design utilizing the gas tension spring as the launch mechanism is the best solution.

Ideation

To begin the ideation process, the team used a technique presented by Professor Sarah Harding that involved generating a multitude of verbs that could be used to describe the design requirements. The verb generation was focused on three key requirements: the ability for the launcher to launch a 55 lb UAV, store the necessary energy needed to launch the UAV, and be collapsible. After a number of verbs were generated, they were separated into their corresponding design requirements. This formed the basis for ideation of possible solutions for each subsystem: launch mechanism, energy storing mechanism, and the frame. Research was done to find existing mechanisms that could accomplish the verbs associated with these subsystems. Subsystem design solutions were then created and compared in Pugh matrices.

Comparative Analysis

Solutions for the three subsystems, launch mechanism, energy storing mechanism, frame, and track were compared based a number of criteria specific to each subsystem. The criteria was generated based on customer requirements as well as additional considerations deemed important for each subsystem. The solutions were placed in Pugh matrices and compared relative to a selected datum.

Launching Mechanism

The launching mechanism Pugh matrix below was developed to compare a number of different components that could be used in the assisted launching of a UAV. These were compared based on seven different criteria: size, weight, consistency, durability, number required for equivalent energy output, cost, and safety.

Pugh matrix comparing launch mechanisms for lightweight UAV launcher

Criteria	Compression Spring	Extension Springs	Torsion Spring	Leaf Spring	Tension Gas Spring	Pneumatic Piston	Bungee	Friction Wheels	Fly Wheel/Clutch System	Magnets	Chemicals
1	S	S	+	S	+	D	+	+	+	S	S
2	S	S	+	+	+		+	S	S	+	+
3	-	S	S	S	S	A	-	-	S	-	-
4	S	+	+	+	S		-	S	S	-	-
5	S	-	-	S	S	T	S	-	S	-	-
6	+	+	+	+	S		+	-	-	+	+
7	S	S	S	S	+	U	+	-	-	-	-
∑+	1	2	3	3	3		4	1	1	2	2
∑-	1	1	1	0	0	M	2	4	2	4	4
∑S	5	4	2	4	4		1	2	4	1	1

Criteria:

1. Size
2. Weight
3. Consistency
4. Durability
5. Number required for equivalent energy output
6. Cost
7. Safety

Figure 4. Launching Mechanism Pugh Matrix

Size, weight, durability, number required, and safety were specified based on the customer requirements. Size is related to the mechanism's ability to be collapsible. Weight is related to the lightweight requirement. Durability corresponds to structural integrity, but also considers the fact that device will be exposed to a number of environmental conditions and will likely be abused. Number required for equivalent energy output has to do with weight and collapsibility, but is also related to efficiency and reliability. The more parts required to launch the UAV increases the likelihood of a less efficient, less reliable system. Safety simply considers the action of each mechanism. Consistency and cost are simply additional considerations that were found important with respect to the use of each mechanism in the overall design. Consistency is a must; the UAV must launch every time with very little variance in launch speed. Cost is not as important, but still a consideration when on a budget.

To analyze the mechanisms relative to each other, a pneumatic piston was chosen as the datum for launch components since it is most commonly used in lightweight UAV launchers. The gas spring ranked highest of the possible launch components. This was due to the gas spring's light weight, consistency, and durability. The bungee ranked second due to its weight, collapsibility, and cost. However, it should be noted that the bungee ranks poorly in consistency and durability. This is due to the fact that most elastic materials will stretch and wear out after multiple uses. Even if the bungee does not break, the force that is applied to the UAV may lessen on subsequent launches. This is why springs ranked fairly well because - while they are less versatile and heavier than bungees - they are far more consistent and durable. It should be noted that it is likely that springs, bungees, or the gas spring would be coupled with levers or pulleys to help create more mechanical advantage. A friction driver and flywheel/clutch system are less safe as there is less control in their energy release. Chemicals and magnets performed poorly in a number of criteria and would not make a good choice for this application. Lastly, it should be noted that the datum, the pneumatic piston, would not be suitable for this application because of the need for a compressor. This would add to the overall weight and require additional power.

Energy Storing Mechanism

The Energy Storing Pugh matrix below was developed to compare the possible ways of "charging" the UAV launcher. Through preliminary calculations, it was determined that it is unfeasible for a person to charge the launch mechanism without the help of mechanical advantage or a machine. These mechanisms were compared based on six different criteria: weight, size, ease of use, ability to "charge" launching mechanism, minimal expendables, and safety.

Pugh matrix comparing energy storing mechanisms for a lightweight UAV launcher.

		Winches				Linear Actuators		
		Hand Crank	Electric	Hydraulic	Ratchet Puller	Electric	Hydraulic	Pneumatic
		1	2	3	4	5	6	7
Lightweight	1	+	D	-	+	-	-	-
Compact	2	+	A	-	-	-	-	-
Ease of Use	3	-	T	s	-	s	s	s
Ability to "charge"	4	-	U	s	-	+	+	+
Minimal expendables	5	+	M	-	+	s	-	-
Safe to use	6	-		s	-	s	-	-
	Σ+	3	0	0	2	1	1	1
	Σ-	3	0	3	4	3	4	4
	Σs	0	0	3	0	2	1	1

Figure 5. Energy Storing Mechanism Pugh Matrix

Charging ability was chosen to ensure the utility of the energy storing mechanism and all other criteria were chosen to directly correspond with the customer requirements. The ability to charge the launching mechanism correlates to customer requirement that the UAV Launcher would effectively assist in the launch of a UAV; the energy storing mechanism must create enough force to “charge” or “load” the launching mechanism.

The concepts for energy storage fell into three different categories: winches, linear actuators, and the ratchet puller. The winch category included the hand crank, electric, and hydraulic winches, whereas the linear actuator category included electric, hydraulic, and pneumatic actuators. All of the concepts were compared against the electric winch as the datum.

The electric winch was the best suited energy storage device for the requirements of the UAV launcher. Because the weight criteria is one of the more critical concerns, both the hydraulic winch and hydraulic actuator ranked below the electric winch. The hydraulic energy storage devices require hydraulic fluid as well as a pump which greatly increases system weight. The linear actuators (electric, pneumatic, hydraulic) require a large cylinder. To “charge” the launch mechanism, the stroke of the cylinder must extend the length of the ramp and the large size of these cylinders coupled with their inability to collapse to a reasonable size put the linear actuators below the datum. Both the hand crank and ratchet puller were promising concepts due to the utilization of human power and their compactness; however, require more effort therefore they ranked lower in ease of use and charging ability. Also, the operator would ideally be able to operate the launcher from a safe distance; whereas the ratchet puller and hand crank would require the operator to be close to the system.

Frame

The frame Pugh matrix below was developed to compare the different possible ways the frame could provide the structural needs of the launcher and yet still collapse down to a portable state. These were compared based on six different criteria: weight, portability by a single person, meet volume constraint (48” x 24” x 18”), ease of assembly, structural integrity, and ease of manufacture.

Pugh matrix for comparing a collapsible frame for a lightweight UAV launcher.

	Collapsing Mechanisms				
	Attach/Detach	Solid	Ladder/Hinge	Telescoping Rail	Tent Tube
A	D	+	S	S	S
B		-	S	S	S
C	A	-	-	+	S
D		+	+	+	+
E	T	S	-	-	-
F		-	-	-	-
Σ+	U	2	1	2	1
Σ-		3	3	2	2
Σ0	M	1	2	2	3

KEY:
- A Lightweight
- B Portable by a single person
- C Fit in 48"x24"x18" box
- D Ease of Assembly/Disassembly
- E Structural Integrity
- F Ease of Manufacture

Figure 6. Frame Pugh Matrix

Through this Pugh matrix, various designs were compared to an attachable/detachable frame. It was found that a frame which is able to attach and detach is better suited for this application than one that folds or telescopes. Structural integrity is the most important factor, as the frame must withstand the high dynamic impact load from the carriage as well as the forces from the gas spring or any pulleys that may be implemented. For this, it was found that an attachable system would be far better suited to handle the loads present during launch. The ability for different packaging arrangements gives a detachable frame many options for its collapsed portable state, which will be beneficial down the road when packaging the launcher in its backpack-like form. The manufacturability of the attachable parts is much better than a hinge or a telescoping rod. Although a frame which detaches/attaches will have a longer set-up and take-down time, the time difference between them is hypothesized to be fairly small, where both designs satisfy the time requirement. Thus, the longer setup time isn't enough to outweigh the other benefits seen with an attachable/ detachable frame.

Track

It was determined that a fourth Pugh matrix (shown below) was necessary to determine which track would be best fitted to the team's ramp idea. Several different shapes were considered. Each fell into one of three categories: simple geometric shape, complex geometric shape, and double shapes. Each track was judged on six criteria: manufacturability (or availability), wear pattern, mated bearing availability, ability to constrain carriage, ease of breakdown, and stability.

Pugh matrix for comparing tracks of different shapes for a lightweight UAV launcher.

	Single Shape					Single Geometry				Double Shape	
	Round	Square	Rectangle	Oval	Triangle	D-Profile	T-Shape	I-Shape	**Rail**	Round	Triangle
A	+	+	+	-	-	0	0	0	**D**	+	+
B	+	-	-	0	-	0	-	-		+	-
C	0	+	+	-	+	0	+	+	**A**	0	+
D	-	+	+	0	+	0	+	+		+	+
E	+	+	+	-	+	+	0	0	**T**	+	+
F	-	-	-	-	0	-	0	0		-	-
Σ+	3	4	4	0	3	1	2	2	**U**	4	4
Σ-	2	2	2	4	2	1	1	1		1	2
Σ0	1	0	0	2	1	4	3	3	**M**	1	0

KEY:

- A Manufacturability or availability: how easy is it to obtain this type of track?
- B Wear pattern: how evenly does this particular shape load? (We don't want our track to have obvious weak spots.)
- C Mated bearing availability: are bearings, wheels, or other bearing surfaces readily available for this track?
- D Constrains carraige: does the track keep the carraige steady and upright?
- E Ease of breakdown: how easy is it to take this track apart and put it back together quickly?
- F Stability: how stable is the track itself (i.e. does it flex under loading)?

NOTES:

Each of these concepts includes both internal and external applications. Either the track itself or the carraige interface could be shaped in this way. Ratings apply the same way in both cases.
It is assumed that the tracks would end up being approximately the same weight after sizing and installation.

Figure 7. Track Pugh Matrix

Many different track shapes were considered in the Pugh matrix in Appendix B and preliminary bending deflection calculations were performed. In terms of bending strength, the rectangular and I-shape tracks deflected the least, followed closely by the circular track. However, the circular track performed best in all other categories as outlined above. Most importantly, circular railings performed better than the datum in the ease of breakdown category, which is the most challenging part of the railing design. Its only relative weaknesses were in bending and in carriage stability (i.e. holding the carriage stable and level during launch). Both of these issues were remediated by using two circular railings instead of one, as seen in the conceptual design drawings.

Overall Conceptual Design

After analyzing the above Pugh matrices, each of the best components from the energy storing, frame, and railing subsystems were used in combination with the top-ranking launching mechanisms to create the overall design concepts. The top four designs utilize the following launching mechanisms: a tension gas spring, an extension spring (possibly multiple), a bungee, and torsional springs connected by linkages to form a frog leg configuration. All of these choices are configured in similar ways as illustrated by the sketches in Appendix C.

In order to compare the concepts, their performance in important design categories was evaluated. Each category was given a weight factor based on their relative importance. Lightweight was ranked highest due to it being a preferable customer requirement. Safety was ranked next highest due to the mechanism being human operated. One or two soldiers will be required to assembly and operate the launcher, making it very important for its operation to be safe. Its ability to collapse was ranked third highest due to the need for the entire launcher to fit in a specified volume so that it can be carried easily. The system's structural integrity was ranked 4th highest due to it not being a main customer requirement. While it was not a directly specified customer requirement, it is still a very important attribute of any mechanical system. The need for the launcher to be easy to assemble/disassemble was not a direct requirement; however, a launcher which has a quick setup and takedown time would be beneficial for the user of the device. Also, we feel it is important to meet both the customer's (Aerojet Rocketdyne) and the user's (US Marine) needs. Ranked last is durability. Although the optimal design would have a high durability due to the varying and possibly harsh environments in which the launcher will operate, we found the relative importance of this aspect of the design compared to the aforementioned aspects to be lower.

In the initial design selection, the tension gas spring concept scored highest according to our design matrix. It outranked all other design concepts. This was due the tension gas spring design's simplicity in operation and ability to be portable. The tension gas spring can be removed easily and reattached with ease. This differs from the frog leg design which is more difficult to (dis)assemble. While the tension spring design is nearly identical to the tension gas spring design. Tension springs are heavier than tension gas springs, making the tension gas spring a lighter choice. It is important to note that while the bungee design scored exceptionally well, it is not as durable as the rest of the designs. This is due to the fact that bungees wear out much quicker than gas springs or mechanical springs. However, bungees are cheaper, easier to replace, and more compact. The detailed results of this decision matrix can be seen in the Appendix C.

Conceptual Design

The initial top-scoring design will incorporate the subsystem components of a tension gas spring, electric winch, detachable frame, and a double rectangular track; a computer model of this design can be seen below in Figures 8 and 9 (this early concept design was later changed).

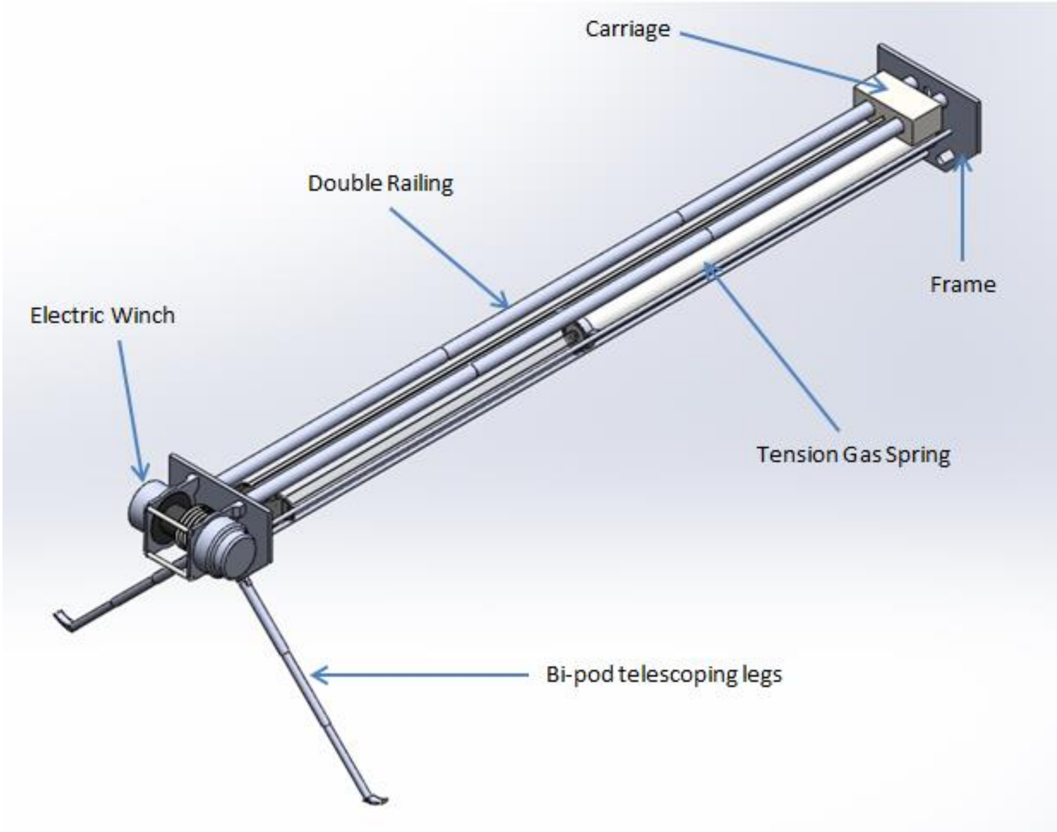


Figure 8. ISO view of initial concept design utilizing tension gas spring as launch mechanism

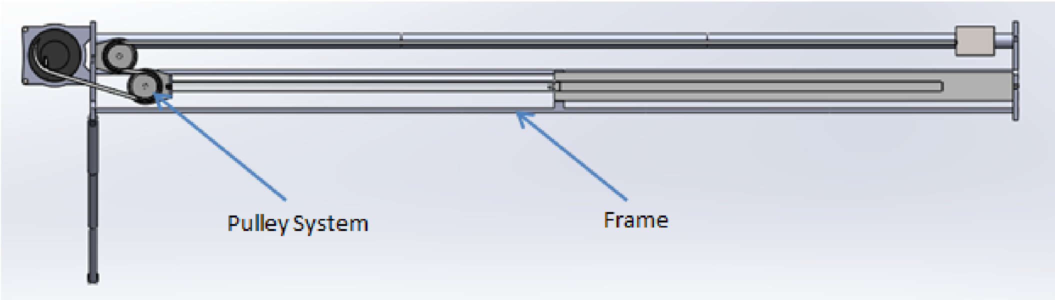


Figure 9. Side view of initial concept design

This design is simple, lightweight, and powerful. When assembled, the system will form a linear track, supported by a frame, with the tension gas spring lying underneath the track and the electric winch at the base, or back, of the frame. Bipod arms that will be spring-activated and extendable will support the front of the railing and provide a launch angle of 10 degrees. A dampening stop will be part of the top, or front, piece of the system. A cable and series of pulleys will connect the tension gas spring to the carriage. The pulleys will be configured in a way that force from the actuation of the tension ring acts in a linear fashion over the length (or majority of the length) of the railing.

To prepare the system for launch, the carriage will be locked in place at the base of the railing, and the electric winch will be used to pull in the slack of the cable and extend the gas spring. Once the gas spring is fully extended, the winch will stop and lock in place. The carriage will then be released using a simple trigger, allowing the tension gas spring to compress, pulling the cable with it, and propelling the carriage up the railing. The carriage will then collide with the damper, causing an abrupt stop that will propel the payload forward, launching it.

In a later iteration of design selection, it was determined in conjunction with Aerojet that the lack in durability of the bungees relative to the other concepts was far outweighed by the benefits seen in cost, replace-ability, compactness, and weight. Due to this reprioritization, bungees were chosen as the replacement to the initial gas spring concept for the launching mechanism and were integrated into our final design.

Final Design

After discussing the initial conceptual design with Aerojet Rocketdyne, it was determined that an alternative method of launch was to be investigated. Aerojet Rocketdyne expressed a desire for the research and development of a bungee launch mechanism. This propulsion method was determined to be simpler than the tension gas spring and pulley mechanism as described in the previous section. Aerojet Rocketdyne did not feel that the durability and consistency characteristics of the tension gas spring were as important as the lightweight and compact characteristics of bungees.

The revised top-scoring design was that utilizing elastic bungees as the launching mechanism, a SolidWorks model of this design can be found in Appendix F. This design is simple, lightweight, and powerful. This design will incorporate the subsystem components of a series of elastic bungees (launch mechanism), a winch (winch mechanism, and a collapsible carriage and frame. When assembled, the system will form a linear track, supported by an adjustable tripod at the front and self-securing stand at the back. Three elastic bungees are attached on either side of track, connecting the carriage with an anchor point on the underside of the linear track. There is a winch at the base, or back, of the frame that is used to pull the carriage back to desired distance (7.5 feet for the 55 lb payload) from the stops at the front of the track. The winch attaches to the carriage via a quick release clip that is released by pulling on a long string attached to the clip.

When fully assembled, the launcher is a little over 9 feet in length and has possible launch angles varying from 10 to 30 degrees due to the telescoping tripod. The launcher, including all of its components, had a total weight of 62 lbs and can be collapsed into a volume measuring 43” X 14.5” X 14” (with the electric winch). It would require a slightly longer volume (45”) for the manual winch.

Figure 10. Final Launcher Design assembly with 55lb deadweight payload

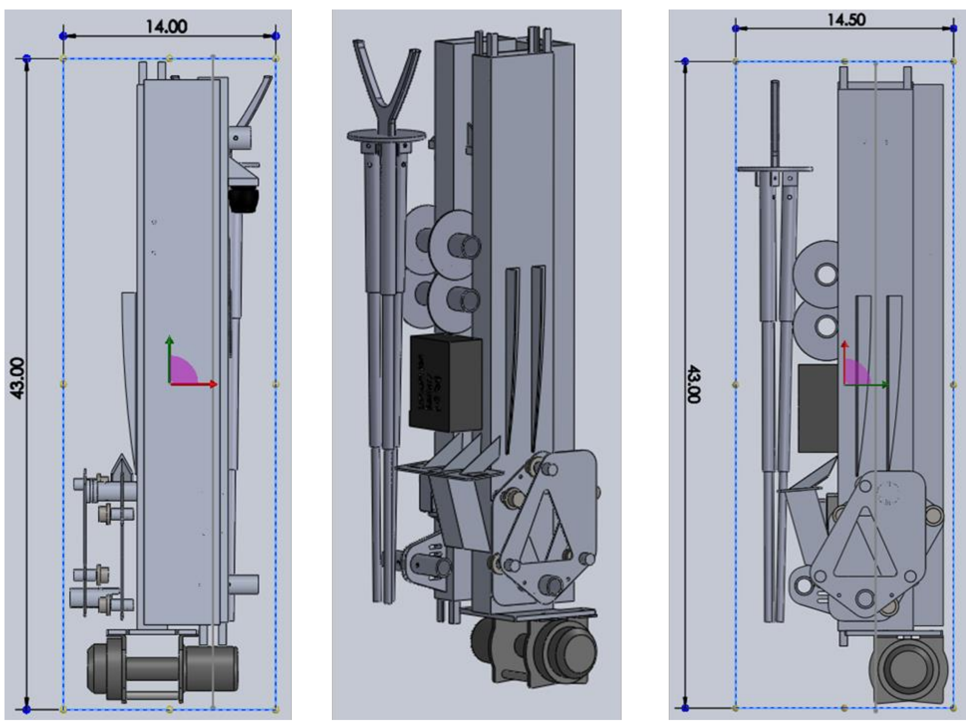


Figure 11. Collapsed view of Final Launcher Design

In the following sections the details of the design, supporting analysis, assembly instructions, and manufacturing details will be discussed.

Details

In discussing the details of the design, the launcher will be broken up into four major components (this will be done for the analysis as well). The four major components to be discussed are: the launch mechanism, winch mechanism, carriage, and structure. While the overall operation has been discussed above, the details of the parts and functionality of each major component will now be discussed in further detail.

As described above, the launch mechanism will be a set of six surgical tubing pieces, bungees that have loops at both ends. The best configuration for these loops were determined through testing, but a number of different crimping methods were explored and tested. Examples of these crimping devices are illustrated below.

Figure 12. Example of three different crimping options

From end to end, the optimal total length of each bungee is 5 feet, with a 22 inch inner crimp-to-crimp distance. The 22 inch crimp-to-crimp distance is the portion of the bungee where the vast majority of the deflection takes place. The extra length outside of this 22 inch section accounts for the crimping surface area and allows the total formed length (from loop to loop) to be long enough for a small pre-load during launcher assembly. The bungees each have a 1” outer diameter, and 3/8” wall thickness.

Second, the additional components and details of the manual and electric winch will be described. Both an electric winch and a hand-operated winch have been sourced: from Warn and Gilmore-Kramer, respectively. For prototyping purposes, an electric winch will be used so its components will be discussed in greater detail. The components of the electric winch include the winch, cable, battery, contactor box, and rocker switch. Weight reduction will be discussed as well. Furthermore, the electric winch specified here did not perform as specified by manufacturer; for more information see testing section of this report.

Next, the unique geometry and components involved in the carriage configuration will be explained. The carriage frame is made entirely from aluminum. The ⅛ inch thick plate that makes up the sides of the carriage is cut into a diamond shape with an oblong protrusion at the front. This protrusion exists to provide a perpendicular surface for the impact of the carriage with the rubber compression springs upon launch. The diamond shape was utilized to help limit material used and therefore reduces the weight of the carriage. At the top of the side plate there is female sleeve constructed from aluminum tubing. At the edge of this aluminum tubing mating notches were cut for each side of the carriage. An outer collar is used to further assist in the mating alignment of the two sides of the carriage. The six wheels on the carriage are cam followers that have an outer diameter flange. This flange keeps the carriage centered on the track. The wheels screw into tapped holes with locking HeliCoil®. Lastly, a solid aluminum rod is slid through the aluminum tubing at the top of the carriage and secured with two quick release pins. A picture of the carriage assembly is illustrated below:

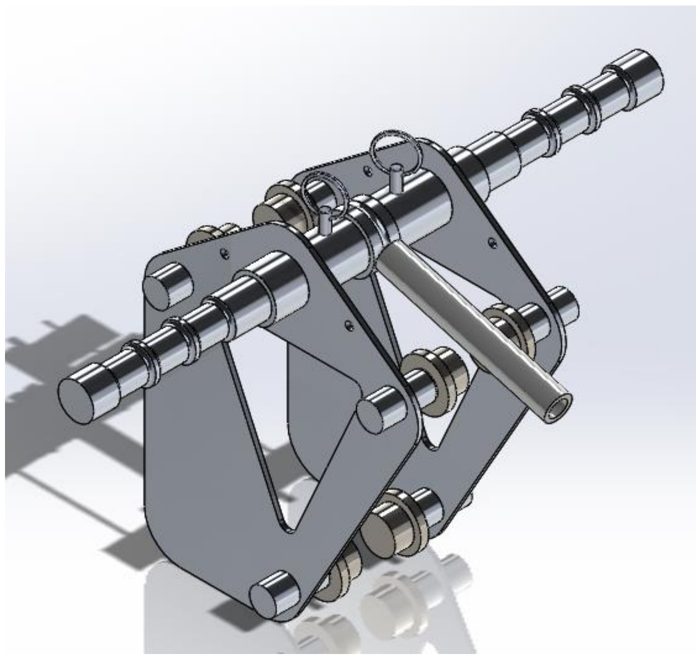


Figure 13. The Carriage in its assembled form

Lastly, the structure is the most complex of the major components and consists of the most parts. For this reason, extensive discussion will be needed to explain its details and functionality. The track is made up of 5” X 2” X ⅛” wall aluminum rectangular tubing that has been split into three 36 inch modular pieces. Each end piece of the track is fitted with four pieces of 0.5” X 0.5” X 1/16” wall angle aluminum, aligned in each corner, and half of an R5 SouthCo draw latch (see Appendix J) on either side of the rectangular tubing. The middle track has the mating halves of the draw latches fitted at its ends. The angle aluminum aligns the rectangular tubing when assembling and the latches secure them in place.

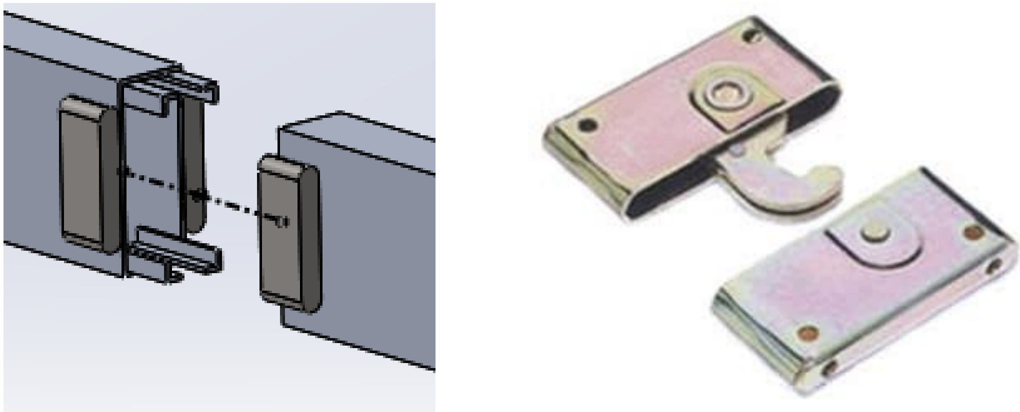


Figure 14. Track connection and SouthCo draw latch

From here, the lower and upper track modules have more complex configurations. The lower track has additional features such as the stand and the winch. The stand is one weldment that consists of a piece 2” X 2” X ⅛” wall aluminum square tubing with ⅛” thick plate welded to the bottom of it. On the bottom of this plate are angled cuts of angle aluminum. These weldment pieces, that resemble spikes or claws, are designed to dig into the ground and continue to do so even as the payload is being launched.

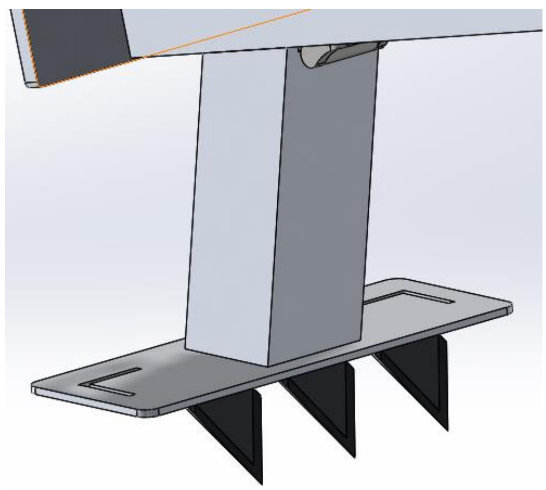


Figure 15. Stand with friction hinge

Slots have also been cut in the plate to allow for the option of pounding in stakes to further secure the launcher. The stand weldment is attached to the rectangular tubing using a friction hinge (Appendix H). This hinge will hold the weldment at any desired angle it is moved to (this is mainly for packing purposes).

The winch is mounted at the bottom or back of this track to 5/16 inch aluminum plate that has been welded to the rectangular tubing. This is where the winch is anchored in place.

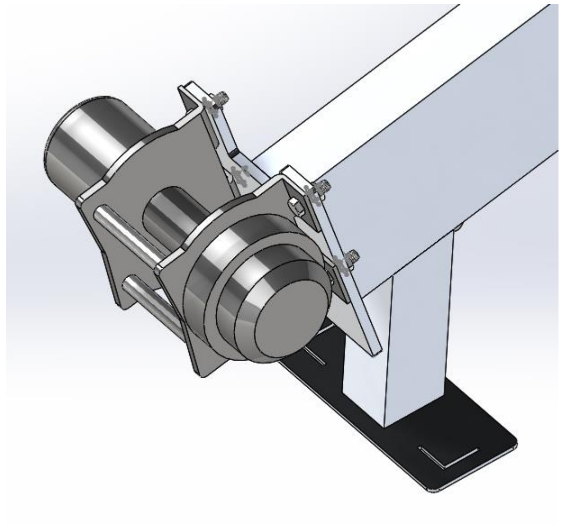


Figure 16. Electric winch attached to lower track

The upper track contains a few additional features. Most of the bungee connections and interactions with the launcher occur at this module. On the underside of the track is a weldment that holds an aluminum rod with notches in place. This is the lower connection point for the bungees. From this point, the bungees will be placed up and around the rollers at the front of the track. The rollers are made of machined Delrin® and are mounted to a hollow aluminum tube that is fixed to the track with quick release pins. The rollers are retained on the shaft with an e-ring that is clipped onto the aluminum tubing. Each roller has machined flanges to retain the bungees in place. Last to be discussed with the upper track are the rubber compression springs. These high strength rubber springs are mounted directly to the weldments protruding from the track using ½ inch nuts and bolts.

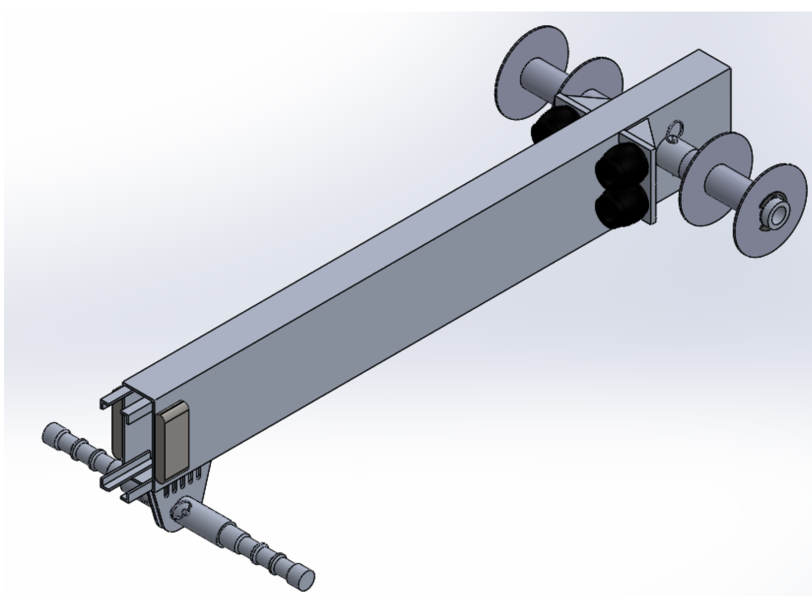


Figure 17. Upper track assembly

The last component of the structure to be discussed is the tripod. This part will simply be purchased from BOGgear and integrated into the design. Each of the tripod's legs are individually adjustable; this increases the versatility of the launcher. By having individually adjusted legs, the tripod can be set up on very uneven surfaces and still achieve the desired launch angle of the UAV. As a whole, the tripod height is adjustable from 22 inches and 68 inches. The interface between the tripod and the upper track is by use of a simple bolt and wing nut for fast assembly. A picture of the selected tripod is shown below in Figure 18.

Figure 18. BOGgear tripod

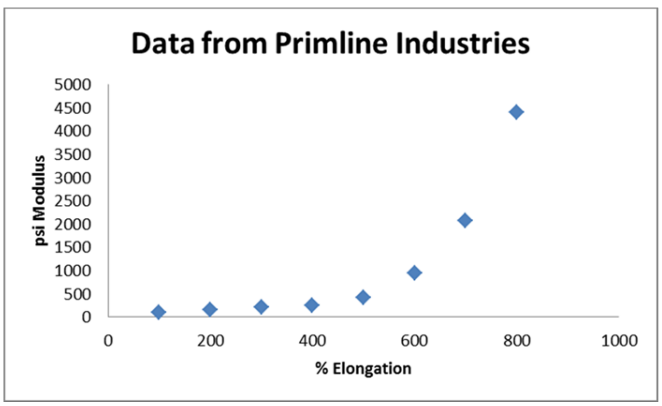
All in all, the new launcher design has a number of details and components. There are a number of outsourced components and unique geometries and configurations that have been integrated together to accomplish the overall goals of the design. However, it is these components and configurations that allow for the design to be compact when disassembled, reassemble in a simple, quick, and direct manner, maintain structural integrity, and launch a 55 lb payload.

Analysis

In order to analyze the design, the launcher was broken up into four major components: the launching mechanism, winch mechanism, carriage, and structure. Each component was analyzed for performance and structural integrity. This confirmed the functionality of each component and ensured that areas of the design experiencing high stress/impact will not fail.

Launch Mechanism

The launching mechanism is the component of the design that when released, will provide all the energy to the carriage/UAV system. As discussed in the final design section of this report natural rubber latex surgical tubing, or elastic bungees, will be used as the launching mechanism. The first step in sizing the bungees was to determine the UAV launch speed. As this project is a proof of concept, a UAV will not be available for testing purposes; because of this, a deadweight of equal weight will be perched atop the carriage during the testing phase. The UAV launch speed envisioned by Aerojet Rockeydyne is 40 knots (67.5 ft/sec) with the UAV's own propulsion system supplying 40% of the total power. Because the deadweight lacks its own propulsion system, a modified test launch speed was calculated based on the launcher providing 60% of the power over the track length. This modified test launch speed was calculated to be 52.3 ft/sec. Due to the high number of possible track length configurations, an energy approach was taken to select the bungee size and configuration. From the modified test speed and the UAV and carriage weight, the total kinetic energy at launch was calculated and found to be 2762 lbf-ft. With a safety factor of 1.25, the target stored energy in the launching mechanism was calculated to be 3453 lbf-ft; the minimum amount of energy the bungee configuration needs to supply. Using the empirical data for psi modulus of obtained from Primeline Industries [14], left graph of Figure 19, Force vs. deflection curves were plotted for a multitude of bungee sizes. However, due to the lack of data from Primeline Industries below 100% elongations, a conservative linear extrapolation of the psi modulus (curve in blue of graph on right) was taken from 100% elongation to 0%, also seen in Figure 19.



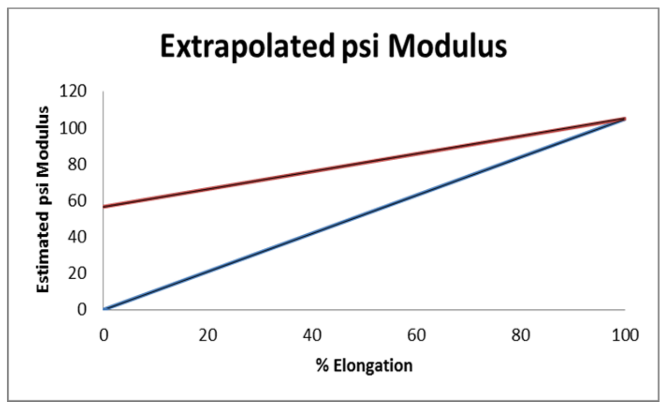


Figure 19. Empirical data of the natural latex surgical tubing from Primeline Industries (left) and extrapolated psi modulus (right). On the figure at the right, the red line corresponds to the actual trend of the data. This however fails for elongations near 0%. The blue line corresponds to the conservative estimate which was used in the analysis and in Figure 20 below.

Combining both graphs of Figure 19, and converting psi modulus to force by multiplying by the cross sectional area, the Force vs. deflection curve was plotted, which when integrated gives the total stored potential energy of a single bungee. This curve for the chosen bungee size can be seen below in Figure 20.

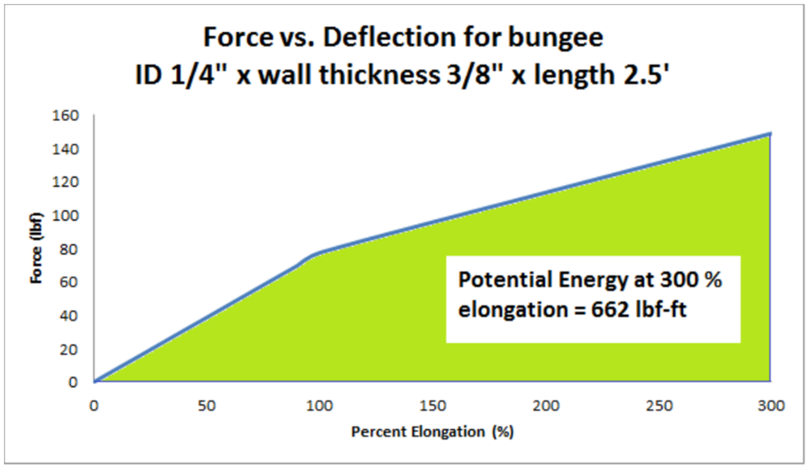


Figure 20. Stored elastic energy in bungee at 300% elongation

Three parallel trade studies were conducted involving bungee inner diameter, wall thickness, and un-stretched length to observe the effect on number of bungees needed, weight per bungee, total weight of bungee configuration, bungee stretched length, maximum winch pulling force, required force input for set up (due to pre-load), and total cost. A summary table of these results can be found in Appendix D, and a more detailed calculation can be found in Appendix A.

Once the bungee size and configuration was determined, the kinetics and kinematics of the carriage-UAV system was plotted, seen in Figures 21 and 22 below. The main takeaways from this analysis was that the maximum load on the carriage is 900 lbs, the maximum acceleration of the carriage is 13.75 g's, the amount of bungee elongation to reach design stored energy is 275% elongation, which leaves close to 6.5 ft of travel of the carriage along the track. This is good, because if for some reason the UAV's weight increases, or the bungee's characteristics are lower than anticipated, there is extra room to obtain more potential energy on the track.

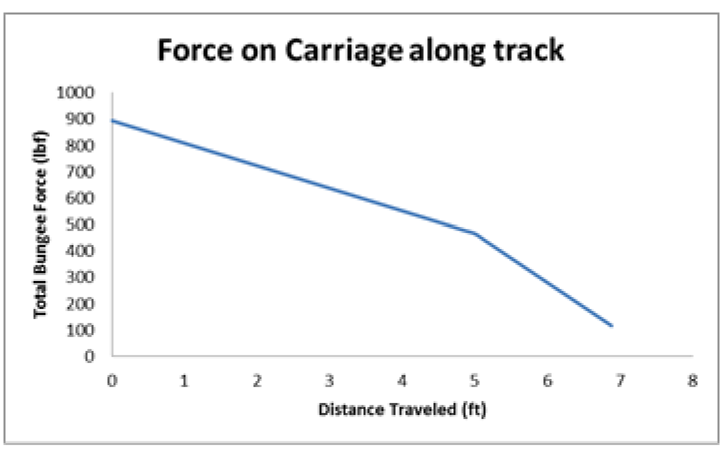


Figure 21. Force vs. Carriage displacement

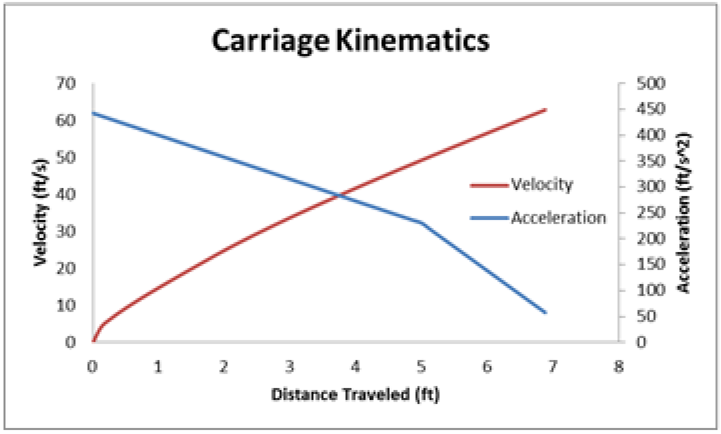


Figure 22. Velocity and Acceleration vs. Carriage displacement

Winch Mechanism

In order to pull back the carriage, significant force must be applied and is maximum at about 900 lbs at the “fully charged” position. Pulling this amount of force is not possible for an individual, so a winching mechanism is employed to utilize mechanical advantage. Both hand-operated and electric winches were considered. Comparing the two types of winches, advantages and disadvantages of each were established. The hand-operated winch was advantageous due to its serviceability; however, it was found that safety and ease of use were concerns. Advantages of the electric winch were its safety, weight, and ease of use; however, the pitfalls for the electric winch were its use of batteries, and its lack of reliability. After presenting the conceptual design with Aerojet Rocketdyne, it was decided that hand-operated winches were desired due to their reliability and serviceability in the field. Though it was established that a hand-operated winch would be ideal for the final product, for prototype purposes an electric winch will be implemented due to safety concerns of Cal Poly and the senior project advisors.

The Warn RT15 electric winch (P/N 78000) was chosen for its 1500 lb pulling capacity and its weight (11.5 lbs) as well the ability to operate the winch from a distance. The primary market for the RT15 winch is for all-terrain vehicles so it has a sealed motor to protect it from debris and it is compact (10.3” L x 4.0” D x 4.6” W) so it can be easily mounted to the ATV bush guard which makes it perfect for the launcher application. The components included with the Warn RT15 winch seen in Figure 23 are fairleads, for angled pulling, a mounting plate, 50 ft of 0.156” diameter aircraft grade wire rope, a contactor box, and a rocker switch and the winch itself. A significant amount of weight can be reduced by removing unnecessary components. Because the winch will be pulling foot forward along the track without large angles, the fairleads can be removed which reduces winch assembly weight by about 2 lbs. The winch will only be pulling a distance of about 10 ft, so 40 ft of aircraft grade rope can be cut which reduces assembly weight by 2 more lbs. Both the contactor box and rocker switch are necessary for winch operation; however, instead of the rocker switch, a remote may be purchased for the prototype in order for the operators to control the launcher from a safe distance. Instead of using the included mounting plate, a 5/16” thick Aluminum 6061-T6 mounting plate will be manufactured and welded to the bottom track for winch mounting. The manual for the winch recommends a 3/16” thick plate;

however after further analysis, it was determined a larger plate would be necessary. The winch will be mounted “foot-forward” on the plate so it will be pulling cable toward its drum from the foot side.

Lithium-Ion Specifications	
Voltage	
Nominal	13.2 V
Maximum	14.7 V
Minimum	10 V
Capacity	4.5Ah
Current	
Maximum	250 A
Maximum Continuous	100 A

Figure 23. Warn RT15 Electric Winch and Lithium-Ion Battery Specifications

In order to power the winch, a 12VDC, 12 A/h battery is recommended. Both sealed lead acid (SLA) and lithium ion batteries were considered for use with the winch. For two comparable batteries SLA and Li-Ion, energy density and specific energy were taken into account. For the Werker 12V, 12Ah battery, Energy density was found to be 0.343 MJ/L and the Specific energy was found to be 0.136 MJ/kg. For the lithium ion battery sourced from Lithium Start, the energy density was calculated at 0.579 MJ/L and the specific energy was 0.342 MJ/kg. This makes the lithium ion battery 1.7 times more energy dense with 2.5 times more specific energy. Because weight and volume are major design concerns, the lithium ion battery proved to be optimal for the system.

Using performance data given for the winch (refer to Winch Spec. sheet), the time to pull back the carriage and UAV was calculated and found to be 54 seconds, where the plot for pull back distance vs. time can be found seen in the figure below. Energy vs. time plots were also created to determine the amount of energy used during each carriage pull back. For each pull-back, the battery uses 0.41 Ah of its capacity. The Li-ion battery has a 4.5 Ah rating, so the battery allows for 10 launches.

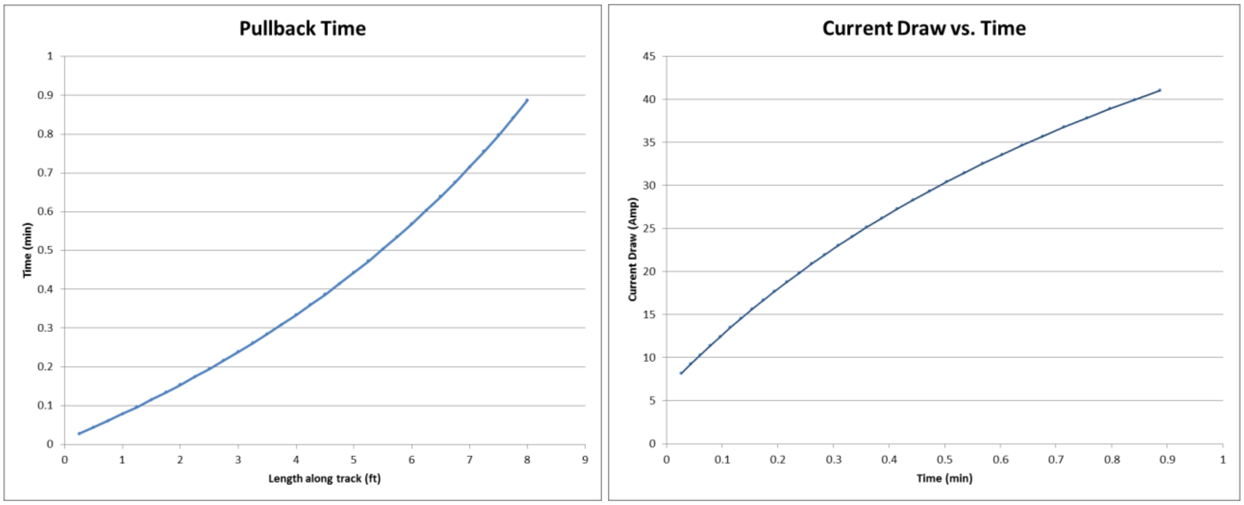


Figure 24. Battery Performance Curves

If a hand-operated winch were implemented into the system rather than an electric winch, the winch, mounting plate, and cable would be the only components in the winch assembly. The weight would increase slightly for the 2000 lb winch from Gilmore-Kramer and the mounting plate would be similar to the electric winch's mounting plate, with a different bolt geometry.

Carriage

The function of the carriage is to transfer load first from the winch to the bungees, then from the bungees to the UAV. The carriage sees significant loading during all parts of launch, from the 900 lb pullback to the total equivalent launch impact of 10,000 lb. The main area of concern in the carriage is the side support plate. This plate is susceptible to bending during pullback and takes the entirety of the impact force. The bungee shaft is another critical element, since it is cantilevered out of the sides of the carriage. All of these elements were verified with FEA.

The pullback loading affects both the bungee shaft and the side supports. The bungee loads were modeled as point forces acting through the center of each bungee groove. Each load was applied at an angle of 2.58° below horizontal and straight forward toward the bungee rollers. The winch load was modeled as a single point force acting through the center of the shaft, acting at an angle of 45° below horizontal. The directions of the forces is important because it takes into account any deflection that the system may have due to a bending moment in the front plane of the bungee shaft. The carriage was constrained at the roller axle holes. The two closest to the winch were pinned while the others were free to move along the track.

The results of the analysis did not predict failure in any structure. The maximum stress in the assembly under pullback occurred at the center of the bungee shaft and at the first machined groove in the shaft, but those stresses did not exceed 16 ksi and 14 ksi, respectively. The maximum deflection of the bungee shaft was 0.048 inches at the very end. The maximum deflection of the side supports was only 0.0005 inches toward the track, which is negligible in terms of achieving launch.

The impact loading case affects primarily the side supports. The force of impact was modeled as a pressure over the area which the bumpers will contact the supports. Each bumper was calculated to experience approximately 2500 lb of equivalent impact force. The carriage was constrained at the wheel stubs in the same way as the pullback case.

Impact does not result in a yielding stress at any point on the sides of the carriage. The absolute maximum stress occurs at the front fillet of the lightening hole (27 ksi). However, the stresses in the remainder of the side support average to about 15 ksi, far below the yielding stress of aluminum. The maximum deflection of 0.01 inches occurs at the very front of the side support where the bumpers connect. This is a negligible amount of in-plane deflection which does not affect the remainder of the structure.

Structure

The overall structure of the launcher has several key locations that experience high stress, both during the winching back of the carriage and the impact felt at launch. The areas experiencing significant amounts of stress during the winching process include the lower bungee connection and the roller shaft at the front of the launcher. The key components in these areas are the shafts. These were analyzed in similar ways: the shaft was split in half (due to symmetry) and treated as a cantilever beam with point loads at each of the locations on which the tension load of the bungees would be acting. For the shaft at the lower bungee connection, this load was simply equal to the tension load when the bungees are fully extended (150 lbs each). This configuration is illustrated in the figure below.

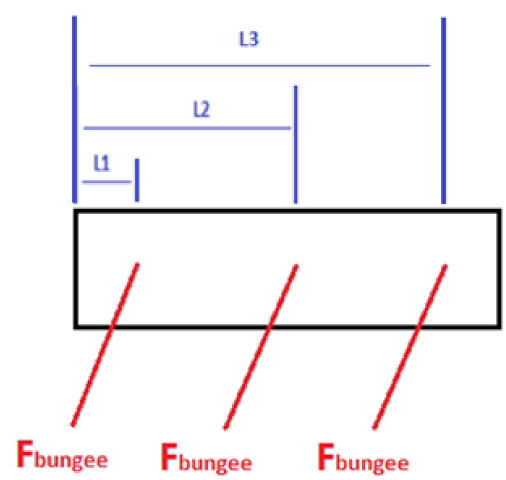


Figure 25. Free Body Diagram of bungee attachment

Assuming the shaft is cantilevered out from center with forces acting as illustrated above, the maximum stress due to bending was calculated and used to size the shaft. To determine the size of the shaft, the factor of safety (F.O.S.) was determined for a number of different diameters. The results are summarized in Table 2 below.

Table 2. Bungee attachment trade study of different types of Aluminum

Material	L1 (in)	L2 (in)	L3 (in)	Moment at Base (lbf-in)	Shear Force at Base (lbf)	O.D. (in)	Wall Thickness (in)	Von-Mises Stress (kpsi)	F.O.S.	Weight (lbs)
6061-O Aluminum	5	6.125	7.25	2738	447	1.750	SOLID	10.74	1.53	1.06
6061-T4 Aluminum	5	6.125	7.25	2738	447	1.375	SOLID	14.29	1.49	0.65
6061-T6 Aluminum	5	6.125	7.25	2738	447	1.000	SOLID	27.91	1.25	0.34
2024-O Aluminum	5	6.125	7.25	2738	447	1.375	SOLID	19.60	1.30	0.67
2024-T3 Aluminum	5	6.125	7.25	2738	447	1.000	SOLID	41.65	1.40	0.35
2024-T351 Aluminum	5	6.125	7.25	2738	447	1.000	SOLID	41.65	1.47	0.35

From these calculations, it was determined that a 1 inch diameter shaft would be needed to maintain a F.O.S of 1.25 as specified by the sponsor. This was also confirmed using finite element analysis (FEA). The detailed results can be seen in Appendix A.

For the shaft supporting the rollers and bungees at the front of the launcher, a similar approach was taken, but the point loads were doubled due to the dual tension loads of the bungees. This configuration is shown to the right.

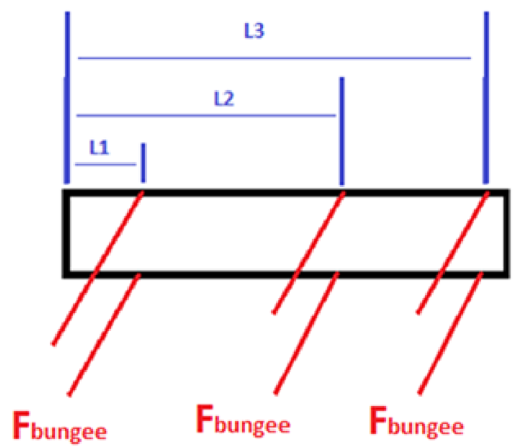


Figure 26. Free Body Diagram of roller

The same calculations performed with the lower shaft were performed with this shaft in order to size it. However, since size is not as much of a constraint in this area on the design, a hollow shaft was investigated. Due to the groove being placed in the shaft for the e-ring mentioned in the overall design section, a ¼ inch wall was selected for the shaft. Keeping the ¼ inch wall a constant and a F.O.S. of 1.25, the minimum outside diameter of the shaft was calculated to be 1.375 inches. A summary of the results is shown below in Table 3.

Table 3. Trade Study of different diameters and wall thicknesses for chosen material 6061-T6 Aluminum

Material	L1 (in)	L2 (in)	L3 (in)	Moment at Base (lbf-in)	Shear Force at Base (lbf)	O.D. (in)	Wall Thickness (in)	Von Mises Stress (kpsi)	F.O.S.	Weight (lbs)
6061-T6 Aluminum	5	6.125	7.25	5476	894	1.75	0.125	22.74	1.54	1.12
6061-T6 Aluminum	5	6.125	7.25	5476	894	1.375	SOLID	21.48	1.63	2.61
6061-T6 Aluminum	5	6.125	7.25	5476	894	1.375	0.25	25.72	1.36	1.55
6061-T6 Aluminum	5	6.125	7.25	5476	894	1.875	0.125	19.54	1.79	1.21
6061-T6 Aluminum	5	6.125	7.25	5476	894	2.00	0.125	16.98	2.06	1.29

After determining necessary shaft sizes, the manner in which they were secured was then analyzed. Since the upper shaft supporting the bungees and the rollers is secured directly with the rectangular tubing (track), it was assumed that this section would not experience significant amounts of stress. This was confirmed using FEA, and also confirmed the shaft OD, and can be seen in Appendix E. However, the connection of the lower shaft was determined to be worth analyzing. The need for the shaft to be cantilevered from the track and for the cantilever to be fairly thin was a cause for concern. Both the resulting shear and bending stresses were calculated for the plates welded to the bottom of the top track module, supporting the lower shaft. A summary of the results can be seen in the table below.

From these calculations, it was determined that the configuration utilizing two ⅛ inch thick plates as shown in the overall design section would be more than sufficient in handling the stress imposed by the bungees. For the detailed results, FEA, and analysis, see Appendix E.

Next, the weldment supporting the rubber compression springs needed to be analyzed. This was identified as a high stress component due to the high load that would be experienced upon impact by the carriage into the compression springs. Due to the complex loading (a distributed load about the base of the compression spring), FEA was used to determine the minimum thickness of the aluminum pieces involved in the weldment. While the resulting load from the impact of the carriage was calculated, the load that the compression springs were rated for was used when analyzing the weldment to create a "worst case scenario." With the load being applied at the contact area between the compression spring and "bumper support plate" (see Appendix E) and the weldment secured at the base of the "bumper support ribs" (see Appendix E) the FEA was performed. By iteration, and keeping the "bumper support ribs" ⅛ inch thick, the minimum allowable thickness of the "bumper support plate" was determined to be 5/16 of an inch. See Appendix E for details.

Each compression spring is rated to absorb 1,400 in-lbs of kinetic energy and is able to provide a peak dynamic force of 3200 lbs, making the four compression springs more than adequate to absorb the impact from the carriage. Calculations for the peak dynamic force and kinetic energy absorption can be found in Appendix A.

Finally, analysis of the stand was performed. Since the actual load due to the impact of the carriage transferred to the stand was difficult to determine, an alternative the load used for analyzing the stand was determined. This load was determined by creating a "worst case scenario" for the stand and the hinge connection it to the track. The maximum shear force the hinge could handle before yielding was calculated and used for the force imposed on the stand. This force was calculated to be 4000 lbs. This is a reasonable "worst case scenario" to assume since, if the load exceeds this and the hinge yields, it will not matter what happens with the stand since the design will already be compromised. Looking at the square tubing of the stand, FEA was performed assuming that the top is fixed and that the reaction force of 4000 lbs occurs at the base. The FEA shows that the square tubing will yield, but only at the rear corners. This would not compromise the functionality of the stand, since its shape is still retained and it will not break. See Appendix E for details.

To size the latches, a static analysis was performed on the fully cocked state of the launcher. When the launcher is in this state the latch sees its highest tensile load, which is how latches are rated. For this calculation, refer to Appendix A.

While the components discussed above were determined to be the critical areas with respect to stress experienced by the structure, a simple FEA was performed on the overall track configuration as a sanity and safety check. This FEA was performed under normal loading conditions as well as the worst case in which all of the bungees on one side of the launcher break at full tension. The results are shown in Appendix E and confirm that the track experiences the least amount of stress and that the structure will maintain its integrity and rigidity.

For verification of this analysis, see the results in the testing section. It should be noted that the above analysis did not perfectly model the actual behavior of the design.

Assembly

As expressed in the Objectives section, one of the major goals of the project was to make the launcher collapsible and easily assembled. This design seeks to meet that goal. By creating a symmetric design, utilizing simple components and configurations, and creating quick connection interfaces this design accomplishes that goal. The larger components will be strapped and fitted together in a manner that the launcher can be carried easily on the back or side. The single tool required for assembly, a 5/16 hex wrench, and other small components will be placed in a bag and secured to the larger components for transportation. For step by step instructions that illustrate how the user will assemble the launcher and prepare it for launch refer to Appendix F.

Manufacturing

The launcher was manufactured using the on-campus resources at the Mechanical Engineering Student Projects Centers (the Aero Hangar and Mustang '60 machine shops) and the BRAE labs. The shops are equipped with a wide variety of tools which we used to manufacture the project. The primary machines used for this project were manual mills and lathes with precise digital readouts (DROs), a water-cooled TIG welder, and an optical plasma cutter, as well as basic machine tools such as drill presses, band saws, and pneumatic sanding and cutting tools. The manufacture of the entire prototype took approximately 360 total man hours to complete.

Track

The track was manufactured first since all of the other launcher components are sized and manufactured relative to the track. The rectangular tubing was already extruded to the correct profile (5” x 2” x 1/8”) so it was only necessary to cut down the stock and machine the pieces to 3 ft each. The ends of each piece were machined down precisely using a mill to ensure that each piece would fit together flat when assembled. With each of the three pieces machined to length, ½” angle aluminum was welded into the inside corners of the middle track piece.

Figure 27. Angle Aluminum Welded to Track.

The leg of the launcher was cut to the proper angle using an aluminum miter saw. The foot was cut out with a bandsaw and the slots for the tie down stakes were machined on the mill. The tripod, originally a rifle shooting support stand, was purchased and later attached to the track.

Bungee Interface

Attaching the bungees to the frame involved machining two bungee retaining shafts, one roller shaft, and the roller assembly which held the bungees in place on the roller. Each shaft required a sleeve for installation and the lower shaft required plates to be machined for attachment to the track.

Each shaft was machined on the manual lathe using non-ferrous carbide tooling to ensure a good surface finish and accurate cut. The bungee retaining shaft grooves were machined by adjusting the rake of the cutting tool. The roller shaft E-ring grooves were machined slightly deeper than specified by the E-ring manufacturers to improve ease of installation. The carriage shaft sleeve was manufactured in two parts for ease of carriage of assembly. The fingers on the shaft were machined using a manual mill and a DRO. Holes were located and drilled in the shaft sleeves using the mill to accept the quick release pins necessary for assembly (see “Assembly Hardware”). The roller assembly consisted of the Delrin® rollers and 1/8” aluminum flanges to keep the bungees on the rollers during pullback and launch. The rollers were machined in two fitted parts on the manual lathe. The aluminum flanges were cut out using a plasma cutter.

With the shafts and sleeves finished, the attachment plates were cut out on the plasma cutter and slots were machined using the manual mill. Then, the lower bungee shaft sleeve was welded to the attachment plates and those were welded in place on the bottom of the track. A hole was bored in the track on the mill to allow for the roller shaft sleeve and that was welded to the track.

Carriage Assembly

The carriage assembly was arguably the most complex part of the manufacturing process. The irregular geometry required the use of all of the machine tools in the shop. The carriage assembly consists of two symmetric halves, each with a 1/8” thick aluminum plate base, half of the interlocking carriage shaft sleeve, and three studs for the stud mounted track rollers.

The plates were cut on the plasma cutter and the holes for the carriage shaft sleeve, studs, and test mount were measured precisely and drilled on the drill press. The studs were machined to length from 0.75” extruded aluminum round using a parting tool on a lathe. They were then welded into the stud holes drilled in the plate. Half of the interlocking carriage shaft was welded to each plate by assembling the carriage bungee shaft in the sleeve and fixturing the entire carriage together in its final assembled shape before welding.

Figure 28. Carriage Assembly Components.

Bumper Assembly

The bumper plates and attachment flanges were cut from 5/16” thick aluminum plate on the bandsaw. Before welding the assembly together, the holes in the bumper plate were drilled on the drill press. The holes were drilled prior to welding because they would have been inaccessible after being welded to the track. Each bumper assembly was first welded together separately, and then each assembly was welded to the side of the track. Since the bumper plates and flanges were so thick, preheating was required in order to achieve full weld penetration.

Winch Assembly

The winch plate which holds the winch in place at the bottom of the track was also cut from 5/16” thick aluminum plate. The shape was rough cut on the plasma cutter and the cutout for the cable was post-machined on the mill to ensure that the surface was smooth so that the cable would not wear on the winch plate surface. The winch was used as a template for marking the holes in the winch plate to ensure that the holes would line up for assembly, and then the holes were drilled using the drill press.

Assembly Hardware

The hardware which holds the launcher together was attached to each part after manufacturing was complete since many of the parts had to be heat treated (see “Manufacturing: Considerations”). All hardware was selected to make assembly as quick an easily as possible and to allow the launcher to break down into components which are easy to pack away.

The main breakdown feature of the launcher is the collapsible track. The track pieces are attached with heavy duty SouthCo latches. These latches were attached to the track with bolts after the track pieces were all heat treated. Bolts were used instead of rivets so that the latches could be replaced if necessary and so that the latches could move together a small amount when closing them to tighten the track pieces together during assembly.

The foot of the launcher was attached to the track using a friction hinge. The friction hinge serves to keep the foot in place when folded down and packed away and also to keep the foot in the folded-out position for assembly. A chain was also added to the foot to keep it in the folded-out position when fully assembled. The chain is meant to help absorb the reactionary force of launch.

The shafts are kept in place using quick release pins which provide a strong attachment when assembled, but disassemble quickly and easily. With holes already drilled in the shaft sleeves from prior manufacturing, matching holes were drilled in each shaft using the mill to accept the quick release pins. Clearance holes were drilled to ensure ease of installation.

The carriage required an interface to attach to the quick release. To achieve this, a short length of wire rope from the winch was crimped into a loop at one end and around a thimble at the other. The loop is large enough to fit over the carriage shaft sleeve and the thimble end is large enough to accept the quick release. The thimble is used to prevent wear from the quick release after multiple launches.

The track rollers for the carriage also had to be installed. The holes for the top two rollers on each carriage plate were drilled and tapped on a mill to locate them properly. Helicoils were installed in each hole so that the steel studs of the track rollers would not wear on the aluminum studs. Then, the track was used to locate the third hole such that the rollers would straddle the track with a slight clearance for ease of assembly. The final holes were then marked, drilled, tapped, and Helicoiled to install the last two track rollers. The holes for the track rollers, which were originally blind holes, had to have an access hole drilled through due to a manufacturer drawing discrepancy. The rollers were advertised as being installed from the front, but in reality they had to be installed from the stud side with an allen key. This slight design modification did not affect the effectiveness of the rollers.

Figure 29. Final Prototype, Ready for Launch.

Considerations

There were a number of factors to consider during the manufacture of the parts. The first and foremost consideration in manufacturing was material. The primary material used for the launcher is 6061-T6 aluminum. Aluminum was chosen for the final design due to its low weight and relatively high strength. 6061-T6 was chosen for the first article prototype due to its high availability and high machinability. The only disadvantage to working with aluminum which was discovered during the manufacturing process was post-processing. Since aluminum is so soft, it clogs grinders quickly and therefore any post-processing or finish work is limited to sanding. This increased manufacturing time on the prototype.

Another factor to consider for machining was manufacturer part tolerance. The shaft sleeves were purchased to achieve a slip fit with the machined shafts, but loose manufacturer tolerancing required that they be bored out on a manual mill to ensure that the shafts would be easy to install. The loose tolerances also caused much of the shaft raw material to have inconsistent diameters which complicated machining. However, these loose tolerances drove down the price of raw material and allowed for a larger testing and emergency budget.

The limitations and setup of the machines available also had to be considered in manufacturing. When using the plasma cutter, the width of the plasma beam had to be taken into account when creating drawings for the optical system to read. The drawing for every part cut out on the plasma cutter was scaled up by 8% in order to allow for the width of the beam and any inaccuracies in the optical reading system. The parts which were plasma cut also required a significant amount of rework.

With all of the machine tools, the setup time to obtain the necessary tooling, square the chuck or vise, and set up the part to be machined took much longer than anticipated and drove up the total manufacturing time. It was also important to consider the way that drawings were dimensioned in terms of manufacturing. Some of the drawings had to be modified in order to make a feature measurable on a machine. While adjusting the dimension references, it was valuable to consider where the machine tool would be cutting and where the cutting surface is defined relative to the reference on each part.

The most important consideration for the launcher prototype were the options and ramifications involved with welding aluminum. Many of the parts on the launcher were welded together in order to decrease the overall number of parts which decreased the overall setup/teardown time, so welding was the most prominent process in the prototype manufacture.

First, the type of welding had to be considered. Aluminum lends itself to AC Tungsten Inert Gas (TIG) welding, which uses a strong electrical arc to excite and melt the material to be welded. However, since aluminum requires very high amperage to melt the material, a robust welder was required. The water-cooled TIG worked well for this application, but with only one in the shop, welding time was limited by machine functionality and availability.

It is also important to consider the filler rod used for welding. For this application, 4043 welding rod was chosen due to its low likelihood of cracking and its superior weldability. 3/32" diameter rod was used for the welds in order to achieve a large weld bead which would be able to withstand the predicted loads on each welded member.

The biggest consideration when welding aluminum is the strength of the Heat Affected Zone (HAZ). Raw 6061-T6 aluminum has a yield strength of approximately 40 ksi. Under ideal conditions, the material in the HAZ created by welding has a yield strength of 24 ksi. In order to restore the strength of the welded material, heat treatment was required. Once manufacturing was complete, all welded parts were sent to Astro Aluminum Heat Treatment in Downey, CA for heat treatment. The facilities at Astro were able to fully heat treat the parts and confirmed that the temper of each part reached T6. Some rework was required after the heat treatment due to the warping of previously drilled holes, but the rework was easily achieved by means of reams in a handheld drill.

Design Verification (Testing)

Testing was separated into two main sections; component based, and performance based. The goal of component based testing was to confirm the manufacturer data and the engineering analysis upon which calculations and component sizing was based. The performance based testing, which was the last phase of testing after all the individual component based testing was completed and verified as consistent with our design assumptions and calculations, aimed to test the launcher's performance in all design requirement categories. The performance testing is where most of the design oversights were realized and the suggestions for future re-design stemmed from. Viewing the behavior of the system with multiple high speed cameras from different angles allowed us to view what was happening to the launcher during pullback, release, acceleration, and launch as much of this action was too fast to see with the naked, unassisted eye.

Component Testing

Component testing overall was a great success; most of the components selected in the design were verified to behave as predicted and did not need to be altered upon implementation on the launcher.

Delrin® Rollers

The Delrin® rollers behaved exactly as expected; upon applying tension to the surgical tubing, the rollers allowed the surgical tubing to roll over the shaft smoothly ensuring the surgical tubing was stretched and thus loaded uniformly and minimizing any possible wear from the surgical tubing rubbing on the sleeve.

Bumpers

To model the impact load experienced by the carriage upon striking the bumper at launch, an average de-acceleration of the carriage must be assumed. This average de-acceleration was calculated by using the following equation: $a = \frac{{V_f}^2 - {V_{launch}}^2}{2*\Delta x}$, where V_f is equal to zero and Δx is equal to the stopping distance of the carriage, or the deflection of the bumper. From this average acceleration, an equivalent impact load can be determined by using Newton's Second Law: $F = ma$. The carriage was sized assuming it would experience a stopping distance of ¼", thus the bumpers were sized to be able to handle the load and provide a deflection of at least ¼". To verify this amount of deflection of the bumpers a custom drop test was designed and manufactured. This drop test consisted of a vertical track of PVC pipe to direct the falling weight at the bumpers, a base to secure the bumper to, and a drop weight. The drop weight and drop height were sized and calculated, respectively, to simulate an equivalent energy impact upon the bumpers. Furthermore, an 1/8" thick blade was attached to the drop weight to mimic the load distribution on the bumper that would actually be present during operation. The original chosen bumpers were sliced in half during this test, as seen in Figure 31 below. This was due to the small surface area of the bumper actually resisting the load, and was a design oversight by the team. New bumpers were quickly ordered, also seen below, that provided contact area over the entirety of the 1/8" blade.

Figure 30. Bumper Types and Behavior

To measure the deflection, floral foam (permanently deformable foam) was attached around the blade, as seen in Figure 31 above. After each test, the deflection of this foam was measured and recorded with the average bumper test deflection of 7/16”. Although this test consistently produced deflections above the target of ¼”, meaning the impact load was below design impact load, the team debated the accuracy of the experiment. This test was expanded upon to further verify the deflection of the bumpers by use of a high speed camera and was performed on the working launcher. By zooming in on the bumpers, the actual deflection was measured as the carriage struck the bumper at full launch speed, and was measured to be 0.68”; significantly greater than the design deflection of 0.25”. Thus the new solid rectangular polyurethane bumpers were verified as they resulted in a decreased impact load to less than half of the design load.

Winch

Winch performance testing was performed to verify the max load the winch could pull, the maximum current draw, and the energy used during and time required for pullback. Unfortunately, the specified Lithium Ion battery was never received; thus a heavier, bulkier lead-acid battery was used in its place for testing purposes. To test these parameters, the winch was connected to a set of 6 bungees (to simulate the launcher). The current draw was then measured with respect to time while the winch stretched the bungees to the required load (measured by a load cell). From this data, the peak current draw and amp-hours required were determined. Because of the extremely high expected current draw, a simple multi-meter could not be used. Instead, a complicated electronic system, designed by a fellow student at Cal Poly, was put in place to make these measurements as follows. It was performed with an Allegro Micro ACS756. The output pin of the ACS756 was run through a simple low-pass RC filter in an attempt to filter out as much motor commutation noise as possible (which occurs at high frequencies, related to motor speed). Then the filtered voltage is measured with the 10 bit ADC of an arduino, and the data is fed back to the computer via serial port. The data can be seen in Figure 32 below.

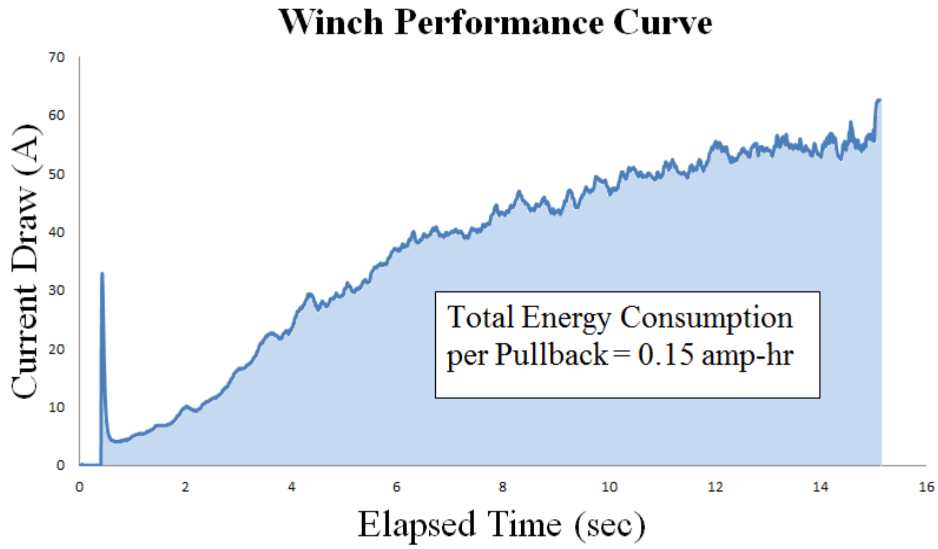


Figure 31. Winch test data; Max current draw = 62 amps, Energy Consumed per pullback = 0.15 amp*hr, Time to pullback = 15 sec

Furthermore, it was found that the maximum pull of the rated 1500 lbs winch was 1000 lbs with no wrapping of the cable and less than 900 lbs during actual testing with actual needed cable wrapping. Wrapping of the winch cable around the spool increases the lever arm radius which increases the effective torque the winch motor sees; thus the maximum pull of the winch is decreases the farther it pulls and the more cable wraps around the spool. This winch did not perform as described by manufacturer and a new winch should be purchased for future design iterations.

Quick Release

The quick release was able to hold desired loads, but unable to release effectively. It took many attempts to detach the carriage from the winch cable before the quick release would actually release. Because of this reason, either a stiffer release cable needs to be implemented with the quick release or a new quick release entirely needs to be selected.

Bungees Crimping Method

Due to difficulty and lack of understanding of how to theoretically model different crimping methods, testing the crimping method for creating the bungee loops was perhaps the most critical test the team performed. The test involved placing bungees with different crimping methods in series with a load cell and the winch. Then pulling with the winch to 300 lbs measured by the load cell, or until crimp or bungee failure. Furthermore, the behavior of the bungee was carefully observed throughout the loading for any detrimental effects. The full testing procedure can be found in Appendix G. During the first phase of testing, each crimp was tagged as either advised for further testing or discontinued. The two main crimping methods advised for secondary testing were hose clamps and bailing wire, for their ability to hold and be lightweight and compact. The main takeaway from the first phase of testing however was that the most dangerous component to the bungee was the bungee itself. Crimping down tightly didn't cause much, if any, damage to the bungee. The main factor in bungee wear, and the eventual failure of the bungee-crimp system was the bungee rubbing on itself as it stretched. The main goal of secondary testing was finding and implementing a barrier to act between bungees and protect it from rubbing on itself. Secondary tests were similar to initial tests in operation but by first wrapping the bungee in a protective layer. The optimal protective layering and crimping method combination was found to be heavy-duty rubber splicing tape and a series of three ¾" hose clamps. The splicing tape was strong enough to withstand the high compressive load from the hose clamps, yet flexible enough to give and bend with the compressing surgical tubing. Furthermore, there seemed to be no wear from the splicing tape rubbing on itself as the bungees were loaded. Unfortunately, after applying this crimping method to all of the bungees it was found that the sun dried out the rubber splicing tape, and cracks were found in the tape. The tape still worked as before, and protected the bungees during performance testing, but not a significant amount of outside testing was performed to ensure rubber splicing tape would hold after significant number of launches or time in the sun. For this reason, it is advised that in future iterations, this aspect of the rubber splicing tape is tested or a different protective layering is devised that can withstand the UV rays from the sun.

Bungees

The most important and pivotal component based testing performed was on the tensile properties of the bungee. Primeline's elasticity data must be verified to ensure the bungees as a suitable launch mechanism and the success of the launcher as whole. This was done using the same experimental set up as the crimp testing with the addition of a string and tape measure to record the displacement of the bungee simultaneously with the tensile load from the load cell. The full testing procedure can be found in Appendix G. This test was repeated 12 times with no degrading effects from the bungee. This can be seen by the minimal statistical uncertainty error bars in Figure 32 (they are there, just too small to see). The actual curve showed is the average of all test trials. It can be seen that the actual force vs. deflection curve closely matches the model, only slightly below up until around 425% elongation. Above this elongation, the model increases parabolically, whereas the actual trend of the data stays linear. This disconnect between the model and experimental data proves why doing these tests is so vital. Overall, the actual data matches very closely with the model, this can all be seen in the Figures 33 and 34.

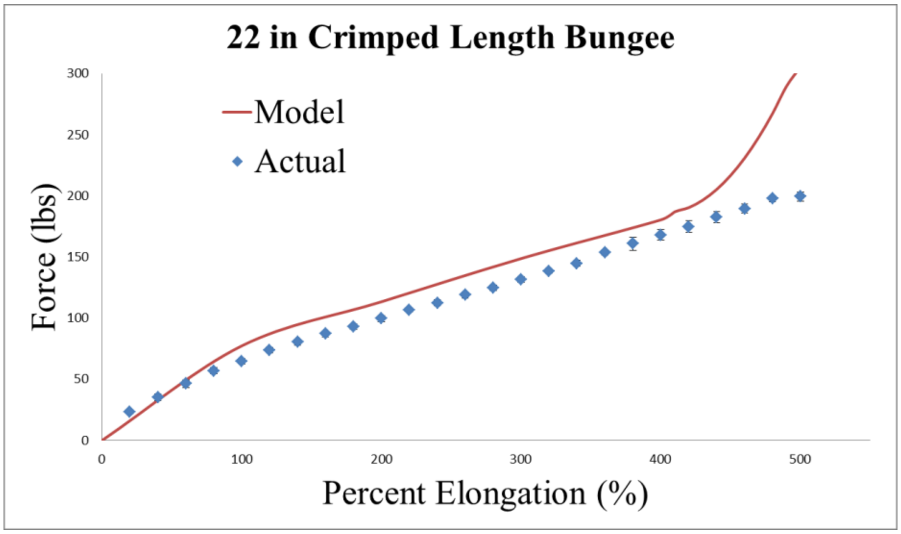


Figure 32. Force output with respect to percent elongation

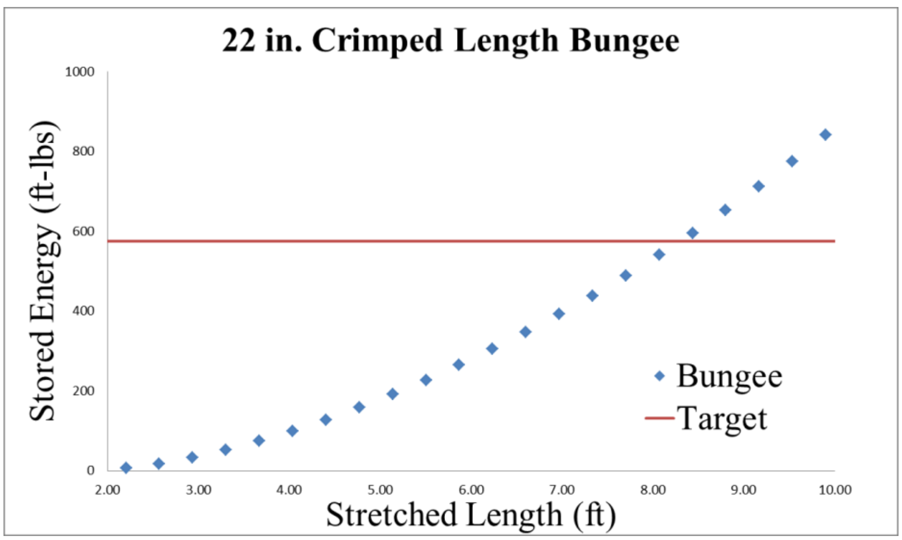


Figure 33. Stored an energy of stretched bungee

Once the bungee tensile properties were verified, the crimp-to-crimp length could be determined to optimize, amount of pullback and travel along the track, as well as the pre-load. The optimal total length of each bungee was found to be 5 ft long, with a 22 in crimp-to-crimp length. The total length of the bungee allowed for the loops to be created so that the pre-load on the bungee is minimal but still existent.

Performance Testing

Set up time/take down time

With some practice, it took five minutes on average to set up the launcher from its portable state. Similarly, take down time was measured to be around 5 minutes; both well below the 10 minute target.

Total weight

The total combined weight of the launcher and all of its components was measured to be 62 lbs, significantly below target weight limit of 110 lbs including the addition of the selected battery.

Collapsed Volume

The collapsed volume was found to 43” x 14.5” x 14” in a conservative measurement. Furthermore, the entirety of the launcher and components were found to fit nicely in a med-large backpacking backpack. The three railing sections stick up above the head and require a rope to tie them together, but this wasn’t found to take away from the user’s mobility when compared to a backpack of the same weight. The backpack’s ergonomics was felt to be similar to that of a backpacking backpack of similar size, proving the portability of the launcher.

Launch Speed

To confirm the launch speed, a high speed camera and a ruler attached to the railing were used. The camera frame was focused on the area just in front of the bumpers and the impact was recorded as seen in Figure 35 below. Full testing procedure can be found in Appendix G.

Figure 34. High speed camera setup

By recording the distance traveled at impact, knowing the number of frames for the distance traveled, and the number of frames per second, the impact velocity of the carriage was determined. This is the exit velocity of the projectile. For a pullback displacement of 70 inches the measured velocity of the carriage – UAV system was 53.7 ft/s. Thus we can see that the launcher was able to get the UAV to the specified launch speed. Once the final velocity of the carriage was determined, with respect to the specified pullback distance, the kinematics along the track of the carriage-UAV system were back-calculated based on the bungee behavior measured from the bungee tensile test. Figure 36 compares the actual kinematics of the carriage-UAV system calculated from this back-calculation to the theoretical model. As seen, the actual behavior closely matches the expected behavior from the model; this verifies the engineering analysis and overall design of the launcher.

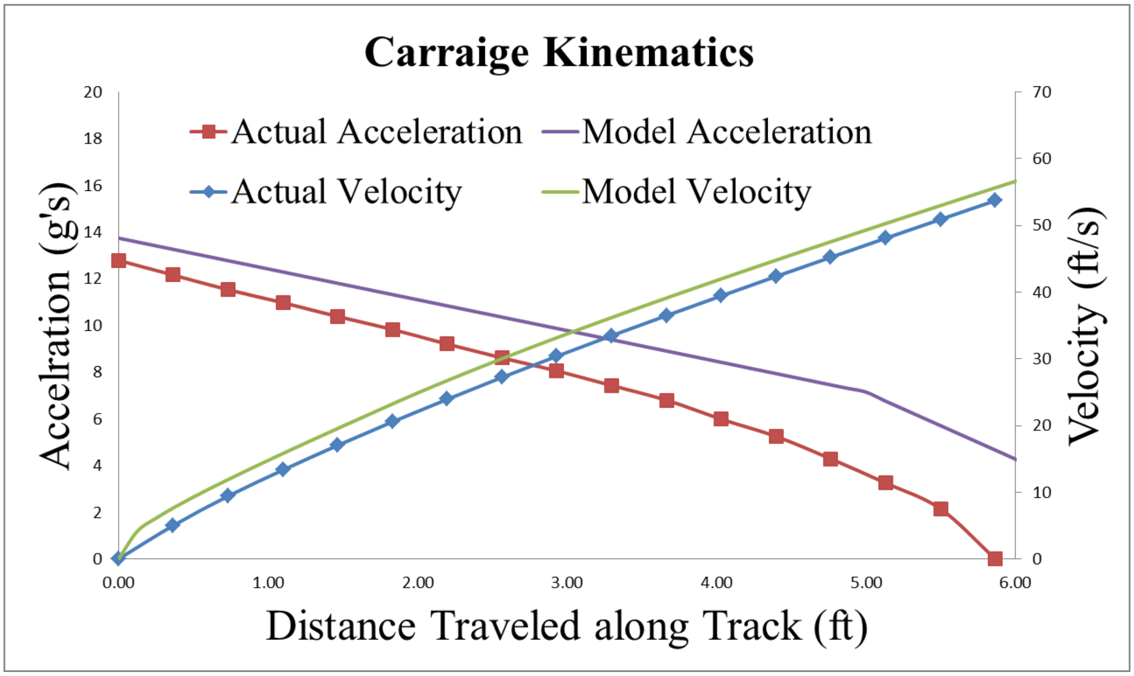


Figure 35. Launch Kinematics Verification

Structural Integrity

Although we were able to meet all the previously stated design requirements, the performance based testing also brought to light a major design flaw in the carriage. During a "dry test" (launch test with no added weight simulating UAV) the carriage was found to flip over the track upon impacting the bumpers. This disappointing flaw in the design is believed to be due to the high center of gravity of the carriage. The center of gravity of the carriage was above impact zone of the bumpers; this caused two main problems which when coupled together allowed the carriage to flip over the track. To help visualize the problem, one can consider the total momentum of a geometrically complex object, such as the carriage, to be traveling in the direction of movement at the center of gravity of that object. Because this momentum was above the impact zone of the bumpers the reactive force from the bumpers created a moment which flipped the carriage over the track. At this point the only counter-balancing force to keep the carriage engaged with the track is the normal force from the bottom rollers. At low impact speeds, the bottom rollers were able to provide enough force to keep the carriage engaged. However, for higher speeds more reminiscent of actual launch velocities the rollers themselves cannot provide this force. The plates of the carriage begin to bend outwards in an attempt to store this energy, much like a spring, but cannot provide enough force and soon the bottom rollers are off the track and the entire carriage flips over the track "head first" in that the bottom rollers traveled up and behind the carriage as it flipped over. In an attempt to solve this problem the team lowered the center of gravity of the carriage by bolting weight to the bottom of the carriage. Additionally, the team stiffened up the plates by bolting on 2" angle iron, effectively implementing an exoskeleton on each carriage plate; this can be visualized by increasing the spring stiffness in the previous analogy. These two modifications helped and the new carriage was able to stay engaged on the track without flipping over for higher launch speeds. Unfortunately, these modifications still weren't enough for launch speeds close to the target launch speed of 52.3 ft/s.

During full pullback test with 55 lb dead weight, another carriage failure mode was realized. This failure mode, similar in nature to the one previously described, occurred as the carriage was traveling along the track before it was able to strike the bumpers. As before, the carriage plates bent outwards allowing the bottom rollers to dis-engage from the track allowing the carriage to flip over the track. This time however, the carriage flipped over "backwards", meaning that the bottom rollers traveled ahead of the carriage as it flipped over. This was seemingly due to the massive weight of the 55 lb dead weight simulating the UAV. This weight increased the center of gravity of the carriage - UAV system above even the bungee shaft (55 lb of the UAV to 10 lbs of the carriage). As soon as the quick release was pulled the 900 lb force of the bungees pulling on the carriage created a moment about the center of gravity, that again, the bottom rollers were alone in containing. The carriage plates bent outwards and once again the carriage flipped over the track, except this time with a 55 lb block of steel in the midst. Even though this flipping began soon after launch, the deadweight had enough forward velocity to keep it flying forward over the launcher in the aimed direction. Viewing these effects with the high speed camera provided great insight to the behavior of the launcher during launch. Carriage design modifications will be discussed in the recommendations section of this report.

One additional slight problem was due to the latches not holding the tracks perfectly straight. During pullback, the latches would give slightly resulting in the adjacent track pieces not being perfectly level with one another. The cause of this was not confirmed as the latches themselves were rated for loads much greater than they experienced during pullback. Either the latches themselves were defected or they weren't installed correctly. It is believed that these latches can still work as the track pieces did still hold together. The latches or their instillation do need to be fixed to ensure smoother carriage travel.

Despite the fact that the carriage must be redesigned, all the above performance tests verify what this project originally set out to do; which is to prove the concept that a transportable, collapsible, launcher can be made to launch a 55 lb UAV. So in that sense, this project and the testing was a success. As with any design however, there must be a significant amount of redesign for this launcher to prove to be repeatable. This will be discussed further in the recommendations section.

Project Management Plan

To successfully and efficiently progress through the design process and create a finished project which meets all design requirements, a management plan was created. The following management plan, which adheres to each of the team members' respective individual strengths, was devised. Instead of a typical management hierarchy, the management plan devised here centers around the concept of a team lead. The whole team will be participating in each of these responsibilities; however, it is the duty of the team lead to ensure the process keeps moving forward at a rate which allows all deadlines to be met. This plays to the unique strength of each team member and will increase overall work efficiency. Below is a list of general roles and their corresponding team leads.

Information Gathering: Ben Miller

- Patent Search
- Design and Component Research
- Lessons Learned from other designs

Progress Documentation: Christian Valoria

- Weekly Updates
- Records - project status, finances, work completed

Report Documentation: Jake Coutlee

- Milestone Documents - ensure completion and quality of report documents

Engineering Analysis: Ben Miller

- Structural Analysis
- Dynamic Analysis

Models and Drawings: Christian Valoria

- Produce solid models (Solidworks)
- Create detailed component and assembly drawings
- Compile B.O.M.

Manufacturing Responsibility: Jake Coutlee

- Ensure manufacturability throughout design process
- Fabrication process - assist in developing fabrication process with design

Prototype Fabrication: Corinne Warnock

- Handle machining, welding, and overall assembly of the final product.
- Evaluate best manufacturing process for each component.

Testing Plan: Corinne Warnock

- Decide which testing methods would best demonstrate the design's fulfillment of the project requirements.
- Compile test data in a meaningful way.
- Determine any improvements that should be made based on test results.

The following timetable of milestones shows the major deadlines scheduled for this project.

Table 4. List of major milestones with corresponding due dates.

Milestone	Date of Completion
Project Proposal	10/24/13
Conceptual Design Report	12/5/13
Conceptual Design Review	12/9/13
Analysis, Drawings, BOM Review, DVP&R	1/7/14
Test Plan Development	1/14/14
Design Report	2/4/14
Critical Design Review	2/6/14
Manufacturing and Test Review	3/4/14
Project Hardware/Assembly Demo	4/28/14
Senior Project Expo	5/29/14
Final Report	6/6/14

As stated in the previous report, the team reported weekly progress to the team's advisor, Professor Sarah Harding, in order to stay on track. A Gantt chart, see Appendix G, was generated to outline tasks completed by June 6th, 2014. This chart is an illustration of amount of time spent on each task and when they were completed.

Recommendations

Lessons Learned

Throughout this entire project, there were many lessons learned by Team Rocket Power. However, there are a few lessons that should be highlighted. The first of these is understanding the lead times of material and component suppliers. For orders placed that are considered typical by the supplier, the stated lead time is usually reliable and accurate. For custom, or non-typical, orders, the stated lead time is less reliable. Since custom orders are not part of the daily operations of the supplier, fulfilling that custom order can encounter problems and setbacks. This can lead to the order being shipped at a later than expected date. This being said, delays in shipping can occur with both typical and custom orders. Delays in shipping should always be accounted for in lead times of ordered material and components.

The next, and possibly most important lesson learned by the team, is to be fully aware of in-house resources. It is extremely important to be aware of in-house manufacturing and testing capabilities.

When creating the manufacturing and test plan, it was assumed that everything could be completed in-house (within the Mechanical Engineering department at Cal Poly). Upon manufacturing and testing, it was discovered that some necessary resources were not available within the Mechanical Engineering department. For manufacturing, this included (but was not limited to): an angle varying band saw, an end mill longer than two inches, frequency varying TIG welder, necessary tapping and installation tool for helicoils, and a heat treatment oven. To compensate for these, a number of actions were taken. For the lack of an angle varying band saw, a jig was constructed so that accurate angle could be cut using a hacksaw. To find a long enough end mill, the team worked with another department with the necessary tooling. Since the TIG welder did not have a varying frequency, the metal needed to be preheated and the welding path was done more slowly. The necessary helicoil tools had to be purchased and the heat treatment process was outsourced. Resources lacking for testing included: an instron with the needed travel distance, a load cell with the necessary load capacity (at least 300 lbs), a custom built current measuring device, and a drop test machine. To adjust for the lack of the needed instron a new apparatus needed to be synthesized. This new apparatus was constructed with the help of another department. The description of this apparatus can be seen in the testing section. The necessary load cell was borrowed from another department. For the drop test, an alternative apparatus was constructed. A description of this apparatus can be seen in the testing section. While these lack of resources were compensated for, they delayed the project and put the team behind schedule.

Lastly, it should be noted that aluminum will warp significantly when welded and heat treated. The team knew this was the case for welding and planned to mitigate the warping by using welding clamps and tools. Unfortunately, this was another resource that was lacking in the Mechanical Engineering machine shops. The welding was performed with what was available, but warping still occurred. Unknown to the team, warping occurred during heat treatment. While straightening was provided by the outsourced company, holes had migrated out of the desired tolerances. These changes required rework for some parts and required more time for manufacturing.

Design Modifications

After performing the final system test, it was determined that a number of necessary design modifications needed to be made. A more rigid carriage and railing interface is needed to keep the carriage from separating from the launcher frame. Lowering the center of gravity of the carriage is important for a more symmetrical impact at the bumpers. An additional bumper positioned to impact higher up on the carriage would also help with this. It was determined that winch selected did not have the necessary pulling strength. A more powerful winch is required. Lastly, an alternative material may be considered.

From the results of the system performance test, it can be seen that the launcher did not perform as expected. The main failure that occurred was the carriage separating from the frame unintentionally, due to the lack of rigidity in the carriage plates. The moment resulting from the bottom wheels contacting the railing forced the carriage plates to deflect apart, allowing the wheels to slide around the rectangular tubing. The separation of the carriage from the frame can be viewed in the sequence of high-speed pictures in Figure 37 below.

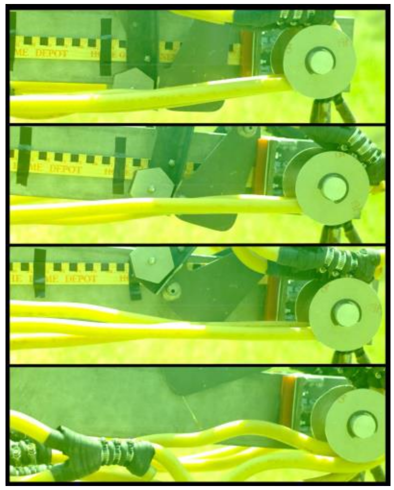


Figure 36. High Speed Camera Snapshots of Carriage Separation

To prevent this deflection from occurring, improved rigidity must be designed into the carriage. For the existing design, making the plates thicker and adding angle aluminum (running vertically up the sides) would improve the carriage's rigidity. It is important that the angle aluminum is welded to the shaft sleeve so that the plates will not deflect at the weld joining the plate and sleeve.

An alternative to the above solution would be to lower the center of gravity of the carriage and add a bumper to the top of the railing. By lowering the center of gravity, the moment deflecting the carriage plates would be reduced. Also adding a bumper to the top of the railing would counteract the moment acting on the carriage due to the acceleration of the center of gravity upon impact. These modifications would make for more symmetrical accelerations along the railing. This will keep the carriage from separating from the frame.

While the above possible solutions are modifications to the existing design, there is an alternative solution that involves modifying much more of the existing design. The main idea behind this solution is fully constraining the carriage to the railing. This means that the carriage would have to break (stress would surpass ultimate strength) to separate from the railing during use. To do this, three main modifications would need to occur. The carriage would need to have wheels that span the width of the railing, connecting the carriage plates on both top and bottom. This would completely constrain the carriage to the railing. This would force the lower bungee connection to be moved to the back of the frame so that the carriage could have the full travel of the railing. Currently, the wheels straddle the plates for the lower bungee connection. By having the wheels span the width of the railing, the carriage would no longer be able to pass this lower connection during launch. Since the lower connection would be much farther from where the bungees would be connected with the carriage, smaller bungees would be needed. Smaller bungees would require less individual force to stretch. This would be needed for the longer stretched distance for assembly. Smaller bungees would mean that more would be needed and an alternative crimping method may need to be explored. This solution would require some redesign, but it would allow for the carriage to be fully constrained, fixing the main problem with the current design.

One problem that was determined during testing was that the winch was not powerful enough. The winch selected for the project was not able to pull the required 900 lb tension load. To fix this, a more powerful winch needs to be selected. An alternative to this solution would be the addition of a pulley to the winch cable. By fixing one end of the cable to the rear of the frame and attaching a pulley to the quick release, the required load for the winch to pull back would be reduced by half. This, however, would add additional complexity to the design and would increase the number of parts.

It should be noted that all of the above modifications have a trade off with weight and size. For some, the result of the trade-off is unknown without a SolidWorks, or even a working model. These solutions, along with the following features, need to be investigated further.

Further Investigations Needed

Due to lack of time and the functional failure of the lightweight UAV launcher prototype, there are some additional features of the design that need to be investigated. During the system performance test there were a couple elements of the prototype that didn't perform as expected. The behavior of the latches and the quick release need to be investigated further to determine whether they need to be modified or replaced. The securing method for the frame needs to be investigated further. Lastly, an alternative material should be considered.

During the system performance test, when the carriage was being winched back, the latches holding the railing together loosened. This should not have occurred since the latches had a rated tensile strength of 2750 lbs. One possible reason for them not working properly is that they were not installed correctly. The latches could have been attached to the railing too far apart. The true reason for their loosening needs to be investigated. Also during the system performance test, when trying to release the carriage from the winch, the quick release did not perform as expected. It did not release the carriage as easily as hoped. One possible reason for this that the string used to pull the quick release was very thin and stretched when being pulled. The quick release may require a more rigid actuation. Further testing of the quick release needs to be performed to determine whether this is the case or if it needs to be replaced.

An important observation from testing was that during launch there is a large reactive force acting on the frame in the opposite direction of the launch. A method for securing the launcher to the ground to prevent any backward motion is an important feature. Possible methods of doing this need to be tested and investigated further. While the design incorporated a couple possible methods of securing the launcher, none of them were able to be tested. This was due to the functional failure of the launcher and inability to perform sequential launches. This will be one of the most important features that needs to be investigated in the future. It presents a unique design challenge in the fact that the UAV being launched could weigh more than the launcher.

Lastly, the material selection for the lightweight UAV launcher may need further consideration. The choice of aluminum for this prototype was based on its lightweight characteristics and student familiarity. The use of carbon fiber or another composite in place of the aluminum should be considered. A materials engineer should be consulted when investigating an alternative material for this application.

Conclusion

The team consisting of Ben Miller, Christian Valoria, Corinne Warnock, and Jake Coutlee accepted the design challenge of creating a lightweight UAV launcher as presented by Aerojet-Rocketdyne. After performing background research, a number of different launchers for the specified size of a 55 lb UAV were found, yet none were both portable and lightweight. From information gathered through background research as well as discussions with Mr. Wong, engineering requirements for the design challenge were developed and agreed upon.

Once the specifications were set and non-quantifiable, desirable characteristics of the launcher were known, the team synthesized a number of possible design solutions. Of those solutions, a conceptual design was chosen that utilized a tension gas spring, in conjunction with a pulley system and a dual-shaft railing. During conceptual design presentation with Aerojet-Rocketdyne some concerns with this design were realized and the launcher was reevaluated. The new design consisted of a detachable rectangular railing and multiple bungees as a simple repeatable launch mechanism.

After presenting the critical design to Aerojet Rocketdyne, the team was given approval to begin procuring material and manufacturing the prototype. The team fabricated the prototype and tested in accordance with the design verification plan. Both individual component and system performance were tested. Among the components tested were: the bungee force output, the bungee crimping method, the current draw and pulling capacity of the winch, and the bumpers. The system performance was tested against the engineering specifications.

Although the carriage disengaged from the railing causing the prototype to fail structurally, the launcher succeeded in reaching an exit velocity of 53.7 ft/s, set-up and tear-down times under 5 minutes, weight of 62 lbs, a collapsed volume measuring 43” X 14.5” X 14”, and the need for only a single operator. As explained in the “Recommendations” section, given more time to make alterations to the design based on the failure mode experienced, the team believes a fully-functioning, successful prototype could have been built. As it stands however, the team has undoubtedly proved possible the concept of a US Marine Tier II UAV launcher that is lightweight, portable, and repeatable in the field.

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Appendix A. Hand Calculations

1. Goal: Find modified launch speed, v_2', to account for launching a dead-weight

Known:

v_2 = $67.5\ ft/sec$

v_1 = $0\ ft/sec$

Find:

v_2'

Assumptions:

- Launcher provides 60% of launching force

Method: Kinetics & Kinematics

$$(v_2)^2 - (v_1)^2 = 2 * a * \Delta x$$

$$a = 285\ ft/sec^2$$

$$F_{tot} = ma$$

$$F_{tot} = 575\ lbf$$

$$F_{launcher} = 0.6 * F_{tot}$$

$$F_{launcher} = 345\ lbf$$

$$F_{launcher} = ma'$$

$$a' = 171\ ft/sec^2$$

$$(v_2')^2 - (v_1)^2 = 2 * a' * \Delta x$$

$$v_2' = 52.3\ ft/sec$$

2. Goal: Find Potential Energy Needed to Launch UAV

Known:

v_2 = 52.3 ft/sec

v_1 = 0 ft/sec

PE_2 = 39 lbf-ft*

W_{1-2} = 0 lbf-ft

Find:

PE_1

* PE_2 is a non-zero number due to the pre-loading of the bungee

Assumptions:

- No Frictional Losses

Method: Conservation of Energy

$$PE_1 + KE_1 + W_{1-2} = PE_2 + KE_2$$

$$KE = \frac{1}{2}mv^2$$

$$PE = \int F dx$$

$$PE_1^{Theory} = 2762\ lbf * ft$$

$$PE_1^{Design} = F.O.S. * PE_1^{Theory}$$

$$PE_1^{Design} = 3453\ lbf * ft$$

3. Goal: Find Potential Energy stored in a single bungee

Known:

$L_{unstretched}$ = $2.5\ ft$

$F\ vs. \Delta x$

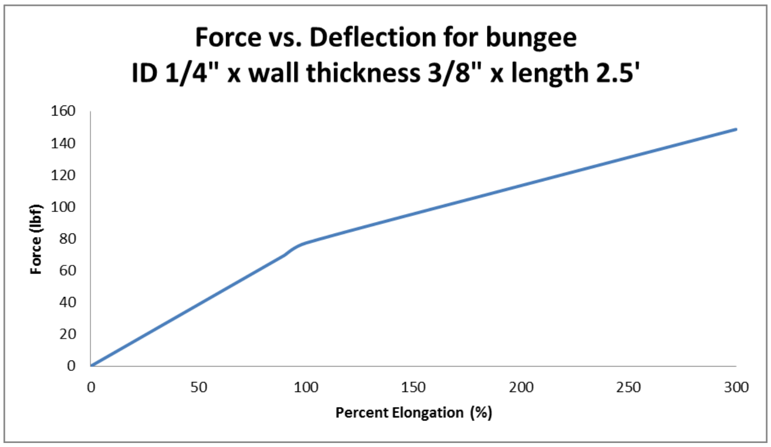
Find:

PE_1

Assumptions:

- Linear extrapolation to zero from 100% elongation

Method: Integration



$$PE = \int F dx$$

$$PE_1 = \frac{1}{2} b * h_{100} + \frac{h_{100} + h_{300}}{2} * b$$

$$PE_1 = \frac{1}{2} * \left(\frac{100}{100} * 2.5\ ft\right) * 77.3\ lbf + \frac{77.3\ lbf + 149\ lbf}{2} * \left(\frac{300 - 100}{100} * 2.5\ ft\right)$$

$$PE_1 = 662\ lbf * ft$$

4. Goal: Find weight of a single bungee

<u>Known:</u>

ρ = $58.0\ lbf/ft^3$

ID = $0.25\ in$

OD = $1\ in$

L = $2.5\ ft$

<u>Find:</u>

Weight

<u>Method:</u>

$$W = \rho * V$$

$$V = \frac{\pi}{4} * (OD^2 - ID^2) * L$$

$$W = 0.74\ lbs$$

5. Goal: Sizing Bungee Attachment OD (solid shaft)

Known:

F_{bungee} = 150 lbf

L_1 = 5 in

L_2 = 6.125 in

L_3 = 7.25 in

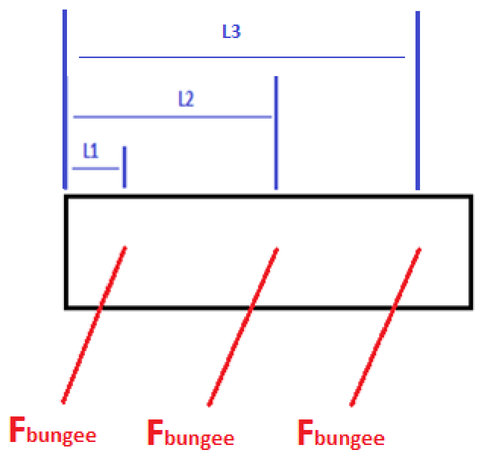
OD = 0.875 in

σ_y = 35 kpsi

Find:

F.O.S.

Method: Static Analysis



$$M_{base} = F_{bungee} * (L_1 + L_2 + L_3)$$

$$V = 3 * F_{bungee}$$

$$I = \frac{\pi}{64} * (OD^4)$$

$$A = \frac{\pi}{4} * (OD^2)$$

$$\sigma = \frac{M * OD}{2 * I} = 5.36\ kpsi$$

$$\tau = \frac{V}{A} = 0.30\ kpsi$$

$$\sigma_{von\ mises} = \sqrt{\sigma^2 + 3 * \tau^2} = 5.39\ kpsi$$

$$F.O.S. = \frac{\sigma_y}{\sigma_{von\ mises}} = 6.49$$

6. Goal: Sizing Roller inner Cylinder

Known:

F_{bungee} = $150\ lbf$

L_1 = $5\ in$

L_2 = $6.125\ in$

L_3 = $7.25\ in$

OD = $1.375\ in$

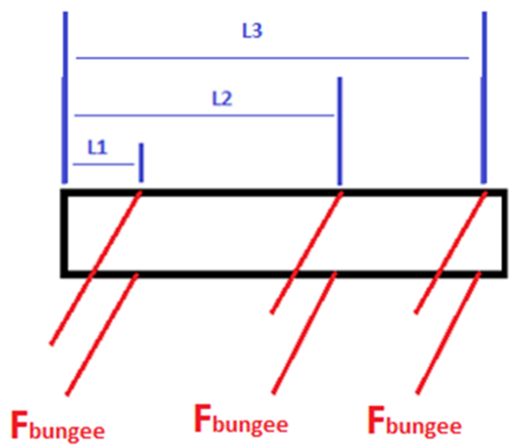
ID = $0.875\ in$

σ_y = 35 kpsi

Method: Static Analysis

Find:

F.O.S.



$$M_{base} = 2 * F_{bungee} * (L_1 + L_2 + L_3)$$

$$V_{base} = 6 * F_{bungee}$$

$$I = \frac{\pi}{64} * (OD^4 - ID^4)$$

$$A = \frac{\pi}{4} * (OD^2 - ID^2)$$

$$\sigma = \frac{M_{base} * OD}{2 * I} = 25.66\ kpsi$$

$$\tau = \frac{V_{base}}{A} = 1.01\ kpsi$$

$$\sigma_{von\ mises} = \sqrt{\sigma^2 + 3 * \tau^2} = 25.72\ kpsi$$

$$F.O.S. = \frac{\sigma_y}{\sigma_{von\ mises}} = 1.36$$

7. Goal: Sizing Track Latches

<u>Known:</u>

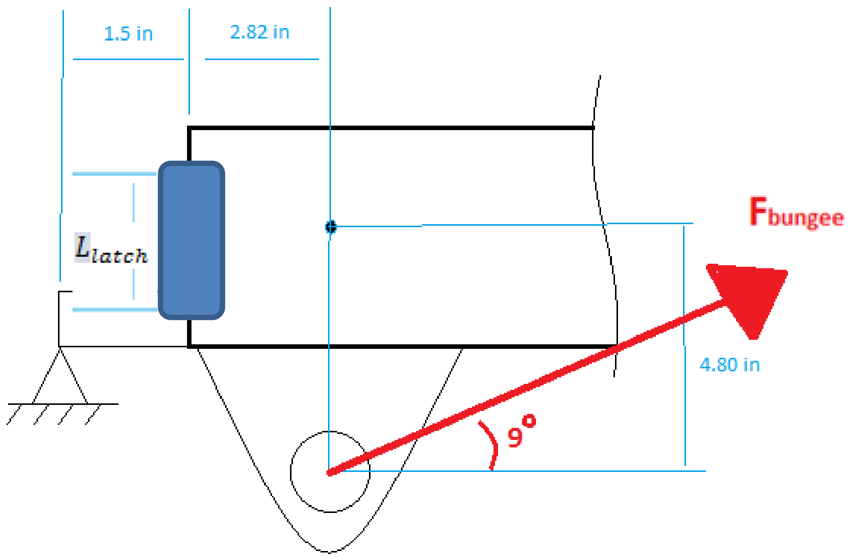
F_{bungee} = $900\ lbf$

L_{latch} = $1.5\ in$

<u>Find:</u>

Tensile Load in Latch, T

<u>Method:</u> Static Analysis



$$M_{latch} = F_{bungee} * \sin(9^{\circ}) * (4.8)$$

$$T_{latch} = \frac{M_{latch}}{1.5}$$

$$T_{latch} = 1400\ lbf$$

8. Goal: Sizing Rubber stops for impact load

Known:

$v_{carriage}$ = 52.3 ft/sec

$\Delta x_{to\ stop}$ = 0.25 in

$m_{UAV+carriage}$ = 60 lbs

Find:

Impact Load, F

K.E. to be absorbed, K.E.

Method: Kinetics

$$V_f^{\ 2} - V_0^{\ 2} = 2a \cdot \Delta x$$

$$a = \frac{V_0^{\ 2}}{2\Delta x} \quad \rightarrow \quad a = \frac{[52.3\, ft/sec]^2}{2(.25\ in) * \frac{1\, ft}{12 in}}$$

$$a = 2038\, ft/sec^2$$

$$F = m * a$$

$$F = \frac{60\ lbs}{32.2\, ft/sec^2} * 2038\, ft/sec^2$$

$$F^{tot} = 10190\ lbs$$

$$F^{per\ stopper} = \frac{10190\ lbs}{4} = 2547\ lbs$$

$$K.E.^{tot} = \frac{1}{2} m v_{carriage}^{\ 2} = 2762\ lbf * ft$$

$$K.E.^{per\ stopper} = \frac{K.E.^{tot}}{4} = 690\ lbf * ft$$

9. Goal: Finding rubber stopper drop test Height

<u>Known:</u>

$K.E._{carriage}$ = $212.4\ lbf * ft$

g = $32.2\ ft/sec^2$

$m_{carriage}$ = 5 lbs

<u>Find:</u>

Drop Height, h

<u>Method:</u>

$$mgh = K.E.$$

$$h = \frac{K.E.}{m * g}$$

$$h = \frac{212.4\ lbf * ft}{\frac{5\ lb}{32.2\ \ ft/sec^2} * 32.2\ \ ft/sec^2}$$

$$h = 3.86\ ft$$

Appendix B. Quality Function Deployment

Customer Requirements	Scale (1-5)	Launch 55 lbs	Weight < 110 lbs	Size ≤ 48"x24"x18"	Set up/Take down time - 10 mins*	Apply Factor of Safety of 1.25 to structural loads	Will include operational instructions Will include safety to prevent accidental firing	No more than 2 simulataneous human inputs req'd	Provides 60% of launch power	Super Wedge (Boeing)	Vigilant Launch System (UAVSI)	Penguin B Launcher
Lightweight	3		●	○						1	5	3
Assist UAV launching	5	●							○	5	5	5
Portable by 1 person	5		●	○						1	2	1
Operated by max. 2 people	4							●		4	5	5
Safe to operate	4					Δ	●			4	4	4
Ease of (dis)assembly	1				●					2	4	3
Structural Integrity	2					●				5	3	4
Targets		45	72	24	9	22	36	36	15		259	
Benchmark #1		45	18	6	18	49	36	36	15	223		
Benchmark #2		45	63	21	36	31	36	45	15		292	
Benchmark #3		45	24	12	27	40	36	45	15			244

● = 9 Strong Correlation

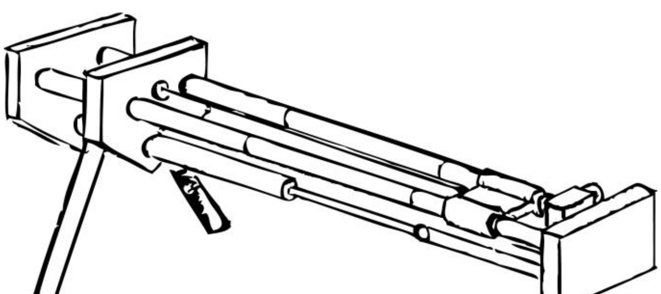
○ = 3 Medium Correlation

Δ = 1 Small Correlation

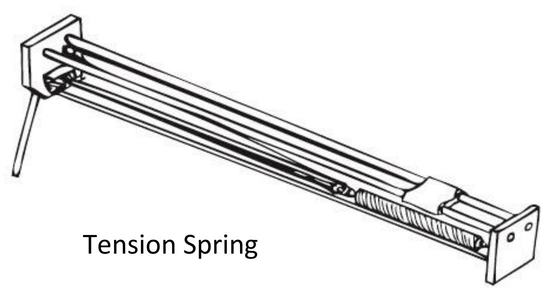
Blank No Correlation

Appendix C. Decision Matrix

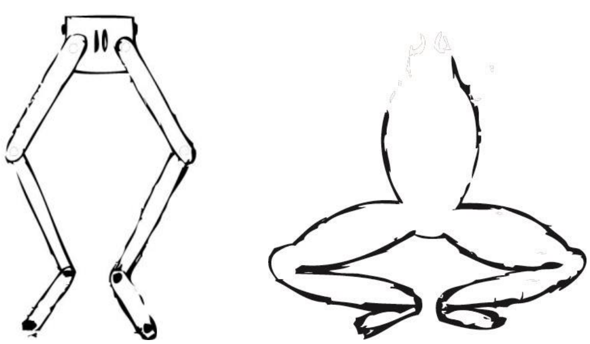
	Weight Factor	Gas Spring	Tension Spring	Frog Legs	Bungee
Lightweight	6	**D**	-1	-1	1
Safe to operate	5		0	-1	-1
Collapsible	4	**A**	1	1	1
Structural Integrity	3		-1	-1	-1
Ease of Assembly	2	**T**	1	1	-1
Durability	1		1	0	-1
∑ 1	--	**U**	7	6	10
∑ -1	--		9	14	11
∑ 0	--	**M**	5	1	0



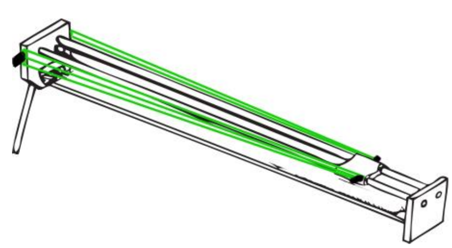
Tension Gas Spring



Tension Spring



Frog Legs



Bungee

Appendix D: Bungee Trade Study

I.D. (in)	Wall Thickness (in)	Unstretched Length (ft)	Weight per Band (lbf)	% Elongation	# Bands needed	Total Bungee Weight (lbf)	Force Input by Soldier to Set up (lbf)	Net Energy at 300 % elongation (lbf-ft)	Total Force at 300 % elongation (lbf)	Cost ($)	Selected
0.25	0.5625	2.50	1.45	300	4	5.79	37.69	5151	1160	34	
0.25	0.50	2.50	1.19	300	4	4.75	30.90	4188	960	34	
0.25	0.375	2.50	0.74	300	6	4.45	19.25	3937	892	51	x
0.25	0.375	2.50	0.38	300	10	3.80	10.00	3529	790	85	

Appendix E: FEA

The following appendix summarizes the results of the FEA analysis performed on the various components of the launcher. The analysis is broken down by:

E.1: Winch mounting plate
E.2: Carriage pullback
E.3: Carriage impact
E.4: Lower bungee connection
E.5: Roller shaft
E.6: Bumper weldment
E.7: Rake connection
E.8: Track
E.9: Bent track

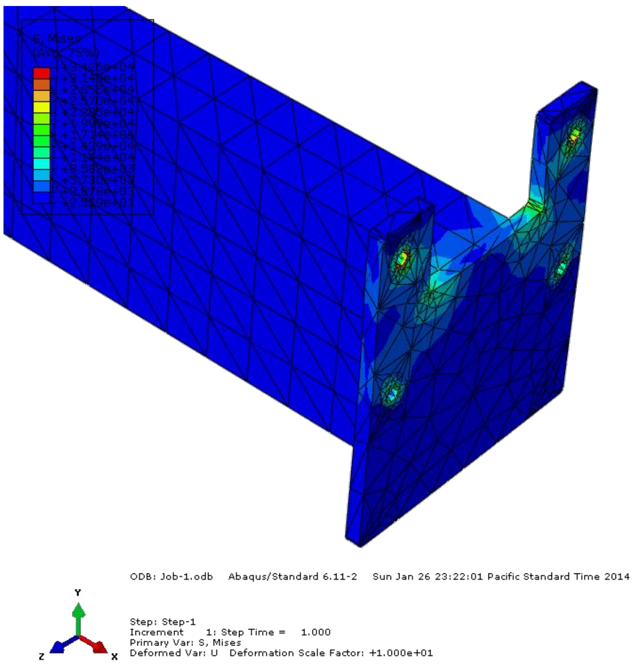
Each analysis includes a detailed description of the forces and boundary conditions applied to the model, images of the analysis, and the maximum stresses and deflections caused by the loads. The directions of the forces and boundary conditions will use the following axis naming convention:

Axis Description	Positive Displacement	Positive Rotation
Along track, from rear (winch) to front (bumper)	U1	R1
Left to right perpendicular to the track	U2	R2
Up and down perpendicular to the track	U3	R3

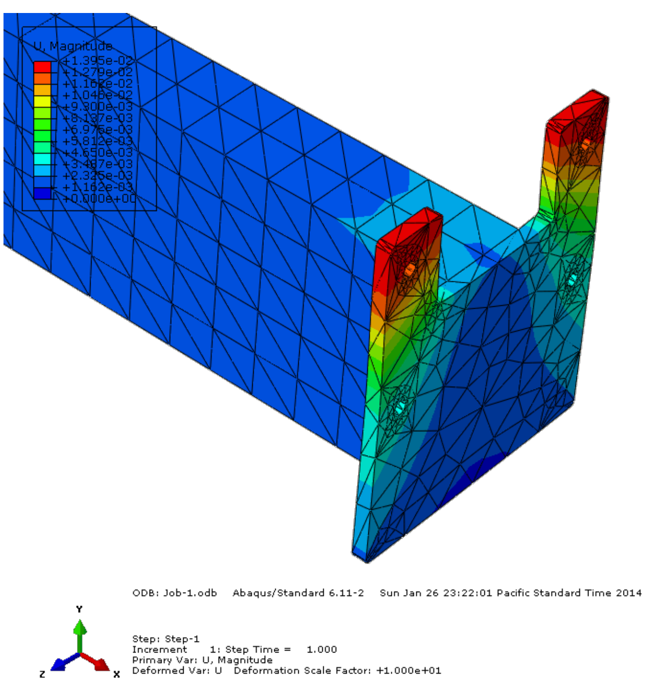
All angles are described in terms of their relation to the axis mentioned. For example, a force in the direction U1, -2.58^{o} is describing a force which is pulling forward, 2.58^{o} below the positive horizontal axis along the track.

E.1: Winch plate

	Type	Location	Direction
Forces	2x 337 lb total pressure	Top winch contact patches	-U1
	2x 118 lb total pressure	Bottom winch contact patches	-U1
Boundary conditions	Encastre	Top winch bolt holes	U1, U2, U3, R1, R2, R3
	U1 displacement only	Bottom winch bolt holes	U2, U3, R1, R2, R3



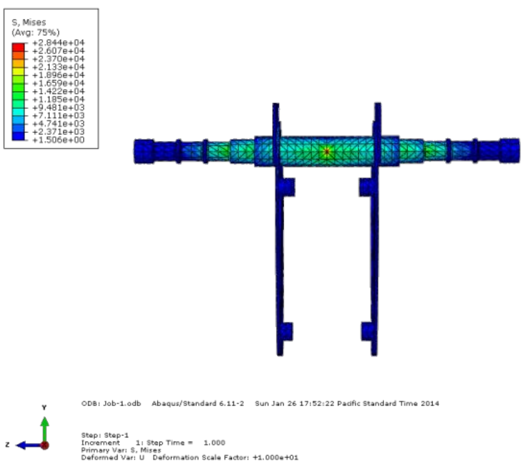
The maximum stress in the winch plate occurs at the corners of the cutouts with a magnitude of 20 ksi. The maximum stress shown on the bolt holes of the model is due to the constraints on the bolt holes and do not appear in the actual model.



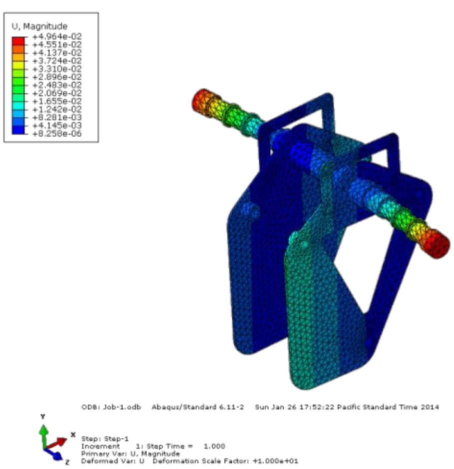
The maximum deflection of the winch plate occurs at the winch plate tabs. The tabs deflect by 0.01 inches under load, which is a reasonable deflection for the amount of load the plate sees.

E.2: Carriage pullback

	Type	Location	Direction
Forces	6x 150 lb concentrated force	6x bungee grooves	U1, -2.58°
	900 lb concentrated force	Center of bungee shaft	-U1,- 45°
Boundary conditions	Pinned constraint	Top rear wheel holes	U1, U2, U3, R1, R3
	Directional constraint	Front and lower wheel holes	U2, U3, R1, R3



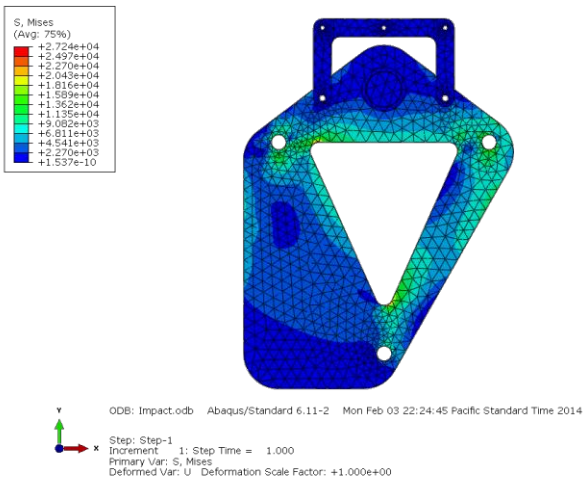
The maximum stress in the carriage occurs at the middle of the bungee sleeve and at the edges of the bungee grooves. The maximum stress in either location does not exceed 17 ksi. The large stress in the center of the shaft is due to the type of force application (concentrated force) applied to that point. In reality, the force would be applied as a pressure over the collar of the bungee shaft, severely decreasing the amount of stress in that area.



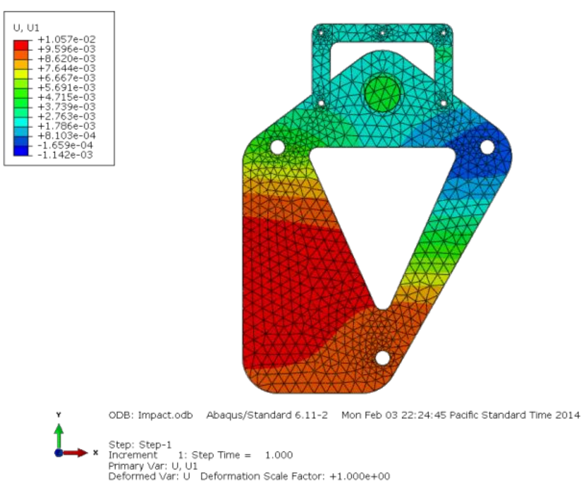
The maximum displacement in the carriage occurs at the ends of the bungee shaft. The ends of the shaft deflect 0.05 inches at the very tips, which is not enough to cause the bungees to slide off. The sides of the carriage deflect inward by 0.005 inches, which is not enough to cause the track roller flanges to clamp onto the track and prevent pullback or launch.

E.3: Carriage impact

	Type	Location	Direction
Forces	4x 2700 lb total pressure	4x bumper contact patches	-U1
Boundary conditions	Pinned constraint	Top rear wheel holes	U1, U2, U3, R1, R3
	Directional constraint	Front and lower wheel holes	U2, U3, R1, R3



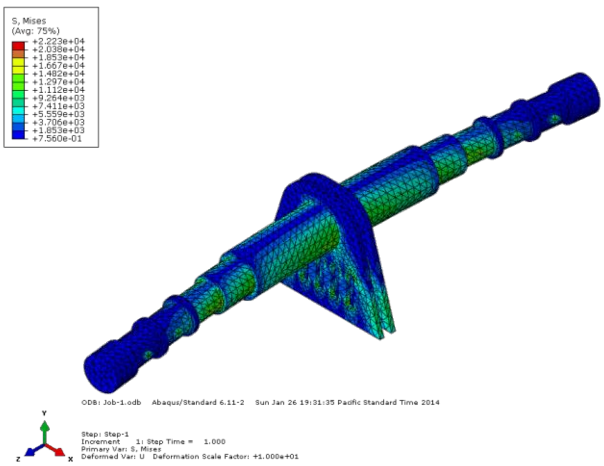
The maximum stress for the winch plate occurs at the top front fillet of the carriage lightening hole. The stress at that fillet is 27.3 ksi, which still does not cause the side support to yield. The remainder of the plate does not exceed 18 ksi.



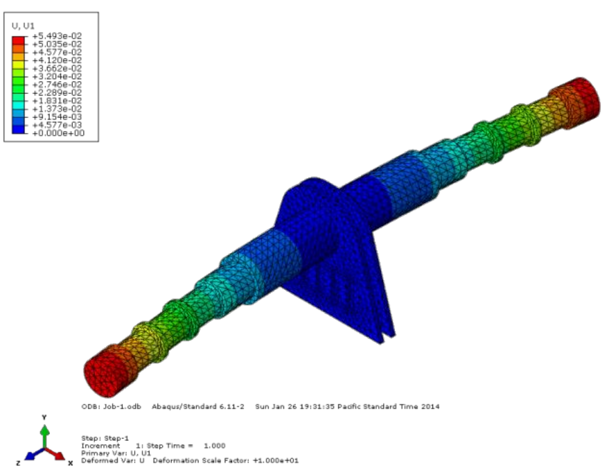
The maximum deflection for the carriage occurs at the bumper point of contact at the front plane. The deflection does not exceed 0.02 inches. Since the loads are in plane, the increased amount of material at the front of the carriage does not allow for significant deflection.

E.4: Lower bungee connection

	Type	Location	Direction
Forces	6x 150 lb concentrated force	6x bungee grooves	U1, 9.15°
Boundary conditions	Encastre	Weld joint between track and lower bungee supports	U1, U2, U3, R1, R2, R3



The maximum stress in the shaft of the lower bungee connection occurs at the center, with a magnitude of 15 ksi. The maximum stress in the plates supporting the shaft is 14 ksi at the front of the plates where they are welded to the track. (Note that this drawing is upside down. The front of the assembly, or the part facing the top of the launcher, is pictured here.)

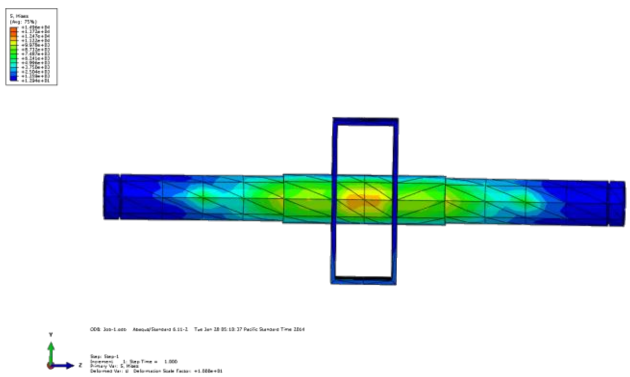


The maximum deflection of the system occurs at the ends of the shaft. The ends deflect 0.055 inches forward due to the forces from the bungees. Similar to the carriage loading case, this does not cause the bungees to slip off of the shaft.

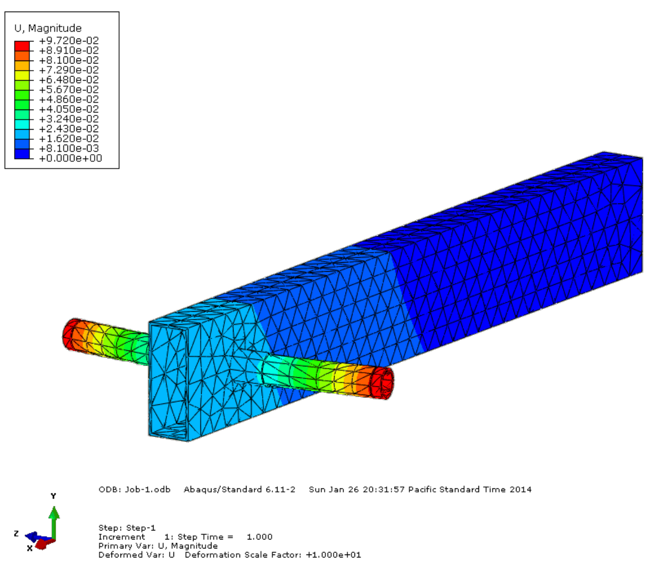
E.5: Roller shaft

	Type	Location	Direction
Forces	2x 150 lb concentrated force	2x middle of roller shaft	-U1, -5.87°
Boundary conditions	Encastre	Rear end of upper track assembly	U1, U2, U3, R1, R2, R3

NOTE: The forces were averaged on the roller shaft in an attempt to eliminate any deflection of the shafts in the R2 direction. Since the shafts will be fitted with rollers, there will be no appreciable moment exerted on the shaft.



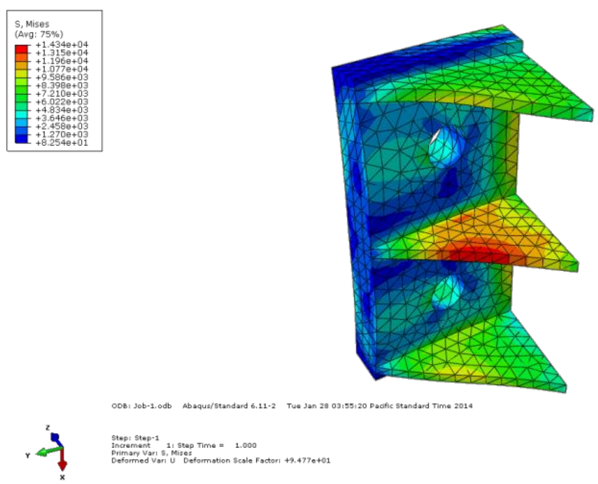
The maximum stress in the bungee roller shaft occurs at the center of the shaft with magnitude 14 ksi.



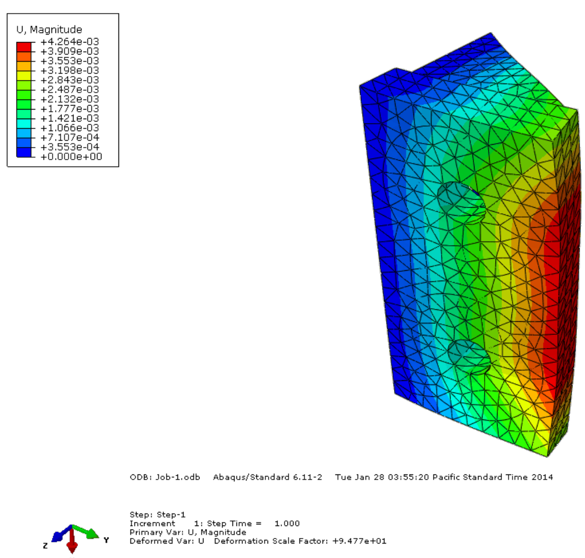
The maximum displacement in the bungee roller shaft occurs at its ends. The ends deflect by 0.1 inches on either side. The increased deflection is due to the fact that this shaft sees twice the load of the other two shafts in this system. This deflection is handled with a flange on the Delrin® bungee roller which prevents the bungees from falling off.

E.6: Bumper weldment

	Type	Location	Direction
Forces	2x 3200 lb total pressure	2x bumper contact patches	U1
Boundary conditions	Encastre	Weld joint between track and ribs and plate of weldment	U1, U2, U3, R1, R2, R3



The maximum stress in the bumper weldment due to the impact load occurs at the center rib of the support structure. This stress does not exceed 14 ksi, which is not enough to yield the aluminum rib.

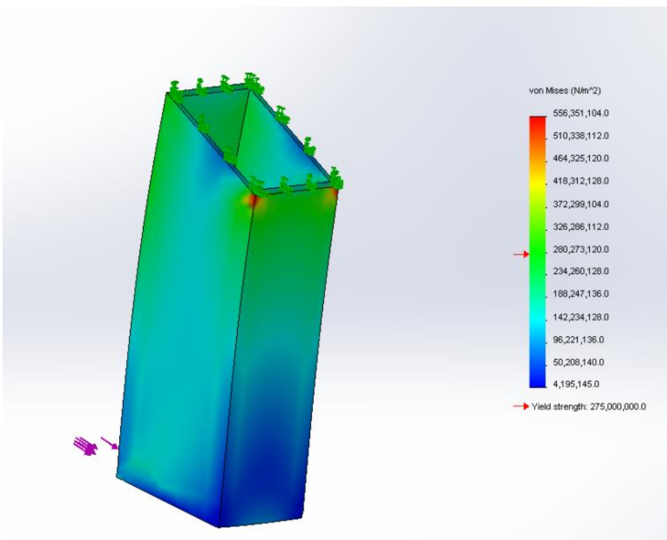


The maximum deflection in the bumper weldment occurs at the outside edge. The deflection at the edge is 0.005 inches.

E.7: Rake Connection

	Type	Location	Direction
Forces	4000 lb edge force	Bottom edge of rake support	U1
Boundary conditions	Encastre	Top edge of the rake support where it attaches to the track	U1, U2, U3, R1, R2, R3

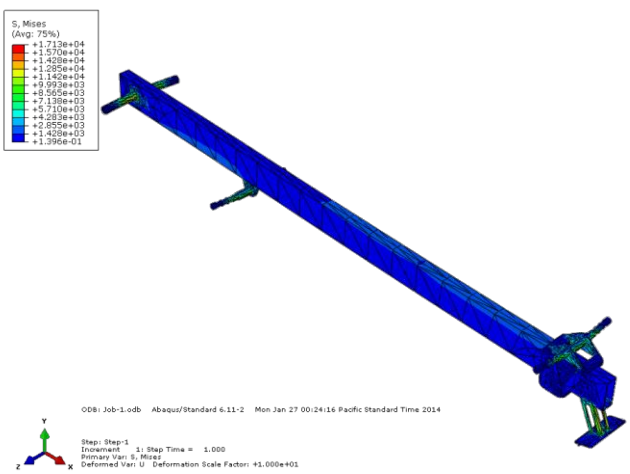
The force applied to the rake system is the maximum force that the hinge can withstand. Therefore, this analysis was conducted to ensure that the replaceable hinge would fail before the rake stand.



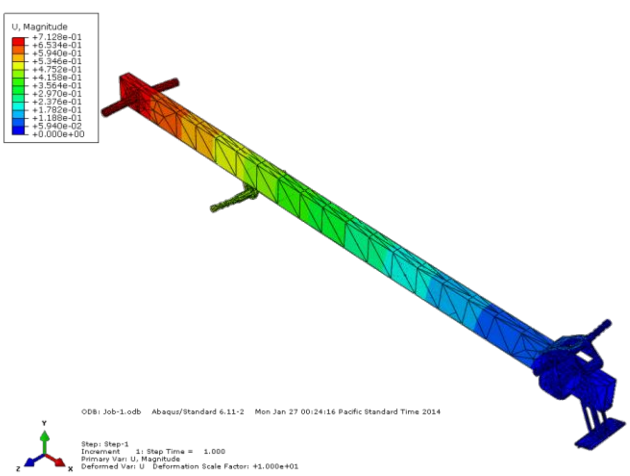
The maximum stress in the rake support is at the top corners of the assembly where it is attached to the frame. The maximum force exceeds the yield strength of the material, but does not exceed the failure point. The average stress in the system is close to the yield point. However, the system is not predicted to break under the loads which the rake is predicted to see.

E.8: Track

	Type	Location	Direction
Forces	900 lb concentrated force	Carriage bungee shaft	-U1, -45^o
	6x 150 lb concentrated force	Carriage bungee grooves	U1, -2.58^o
	6x 150 lb concentrated force	Bungee roller top	-U1, 2.58^o
	6x 150 lb concentrated force	Bungee roller bottom	-U1, -9.15^o
	6x 150 lb concentrated force	Lower bungee connection	U1, 9.15^o
Boundary conditions	Encastre	Bottom of rake plate assembly	U1, U2, U3, R1, R2, R3



The maximum stress that the launcher sees is at the bungee attachment points. The maximum stress in the track is 13 ksi at the bungee roller. This confirms that the area of highest stress occurs at the bungee roller.

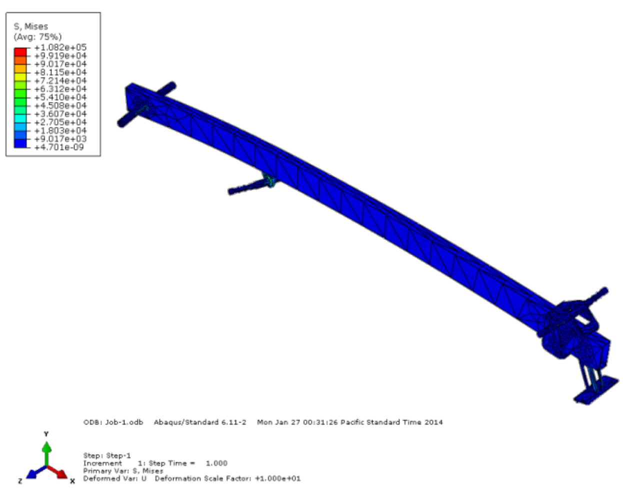


The maximum deflection in the track occurs at the top where a moment is created from the lower bungee connection. This deflection does not exceed 0.7 inches throughout the entire length of the track.

E.9: Bent track

	Type	Location	Direction
Forces	900 lb concentrated force	Carriage bungee shaft	-U1, -45°
	3x 150 lb concentrated force	Carriage bungee grooves	U1, -2.58°
	3x 150 lb concentrated force	Bungee roller top	-U1, 2.58°
	3x 150 lb concentrated force	Bungee roller bottom	-U1, -9.15°
	3x 150 lb concentrated force	Lower bungee connection	U1, 9.15°
Boundary conditions	Encastre	Bottom of rake plate assembly	U1, U2, U3, R1, R2, R3

This analysis was performed to show that the launcher will not fail under the worst case scenario loading of having all of the bungees on one side of the launcher break. This loading case is highly unlikely, but all cases were still considered in the analysis of the overall launcher design.



The maximum stress in the one-sided bungee loading case occurs at the very rear corner of the bungee roller assembly. The material of the track would yield in this scenario, but the material around it would not, causing the roller to deflect but not break. The material of the lower bungee assembly would yield as well, but does not reach the breaking point of 45 ksi.

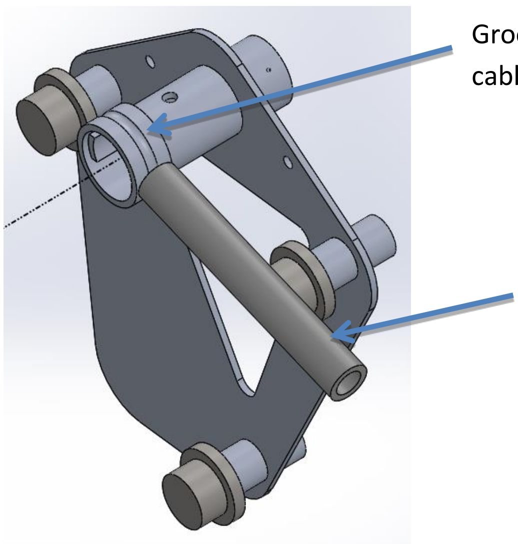
However, this is only a theoretical calculation which may not accurately emulate all of the factors which cause all the bungees on one side to break. Therefore this should not be used as an accurate estimation of catastrophic bungee failure.

Appendix F: Installation Instructions

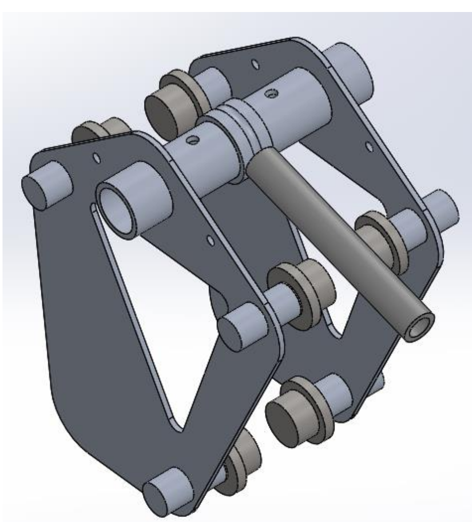
These steps provide an easy to follow road map illustrating the manner in which the launcher can be assembled in the field. They show the simplicity of the design and the ease in which the launcher can be assembled.

Step 1. Place all components in a spread out and organized fashion in front of you.

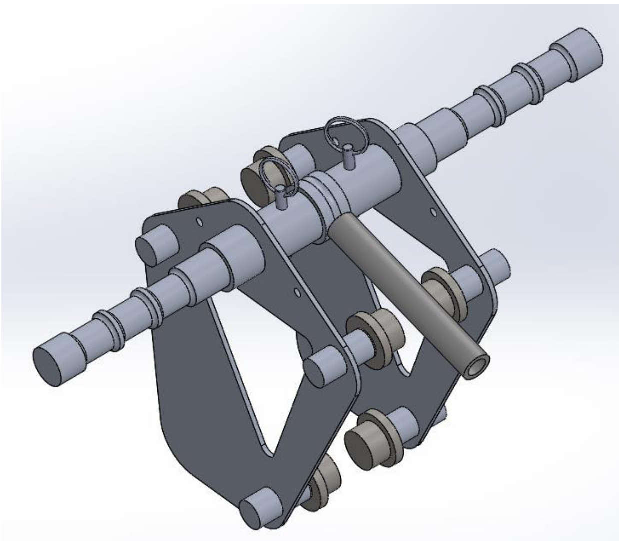
Step 2. Start with the Carriage assembly first. Slide the cable noose over the notched collar on the right side of the carriage assembly. Confirm noose is fairly tight and will not slide off during the rest of assembly.

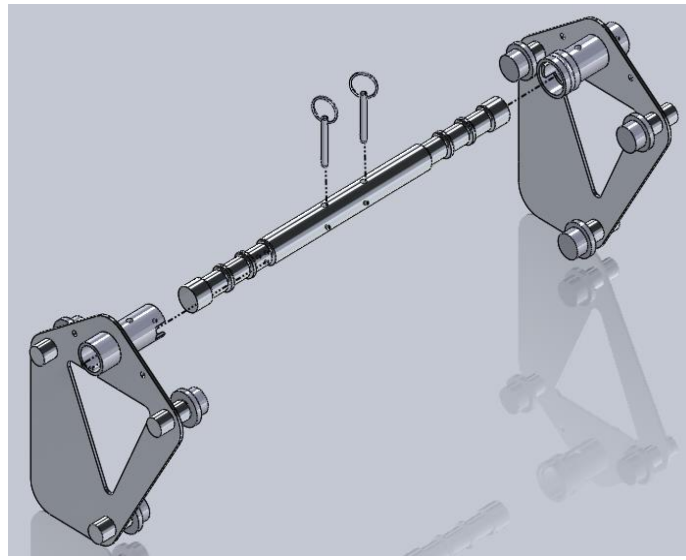


Next, mate the hollow tubing with its corresponding female connection point, aligning wheels on similar axis of rotation.

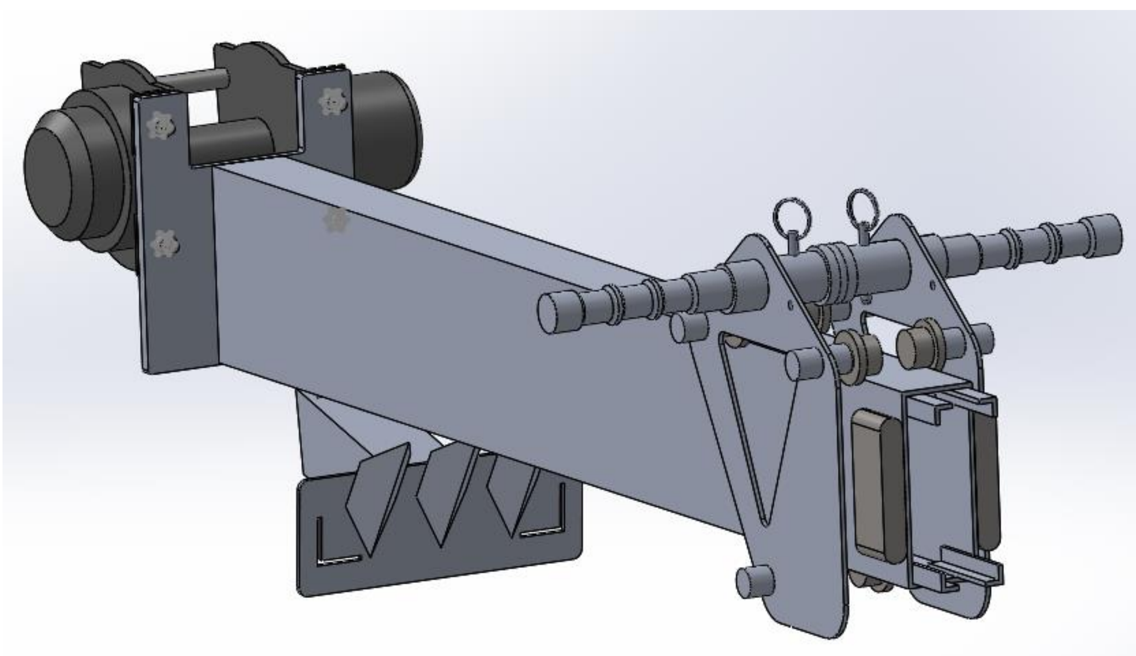


Keeping the two sides of the carriage together, slide the bungee connection shaft through the hollow tubing on the carriage and slip two quick release pins through the holes in the hollow tubing and shaft. This secures the carriage together and completes the assembly.

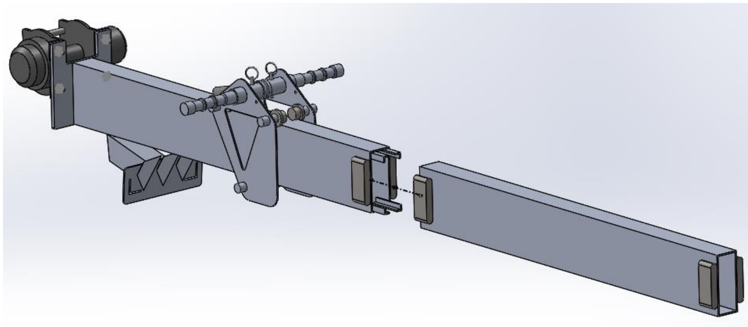


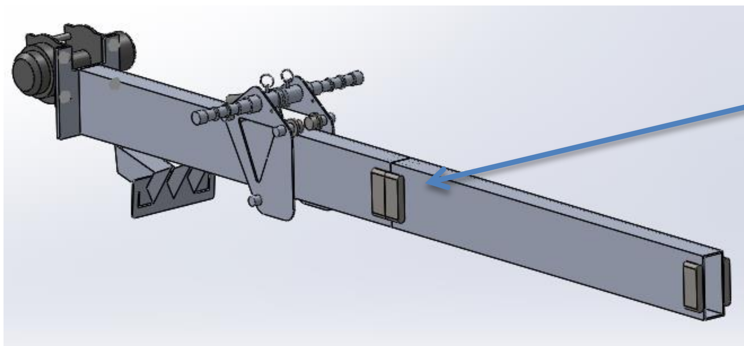


Step 3. Keeping the stand on the lower track folded; slide the carriage over the track, keeping the bungee shaft connection on the opposite side of the track as the stand and the thicker portions of the carriage plates facing away from the winch.

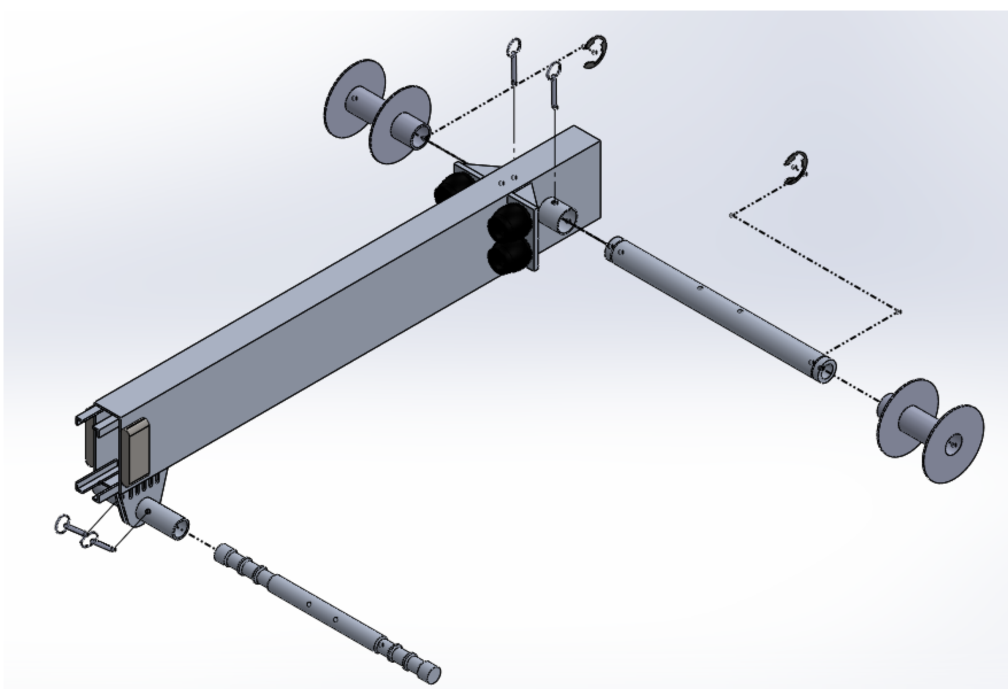


Step 4. Align the middle track with lower track and use the 5/16 hex wrench to tighten the latches, securing the track in place.

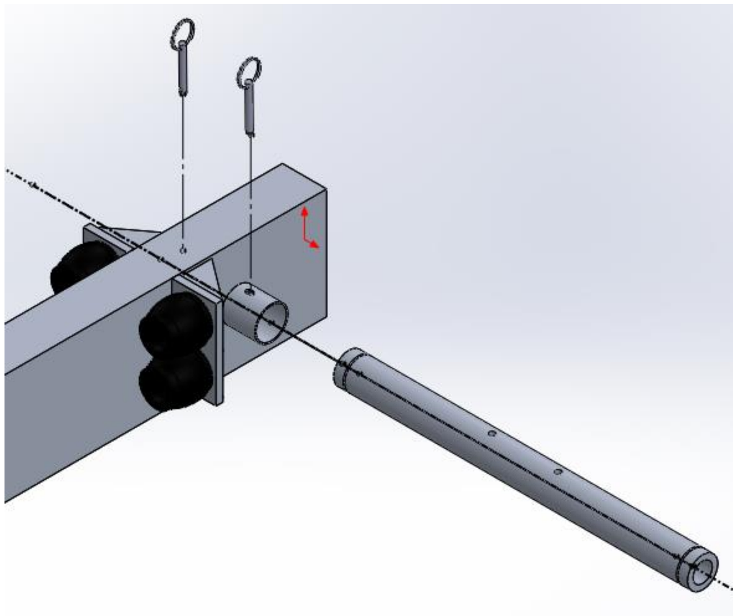




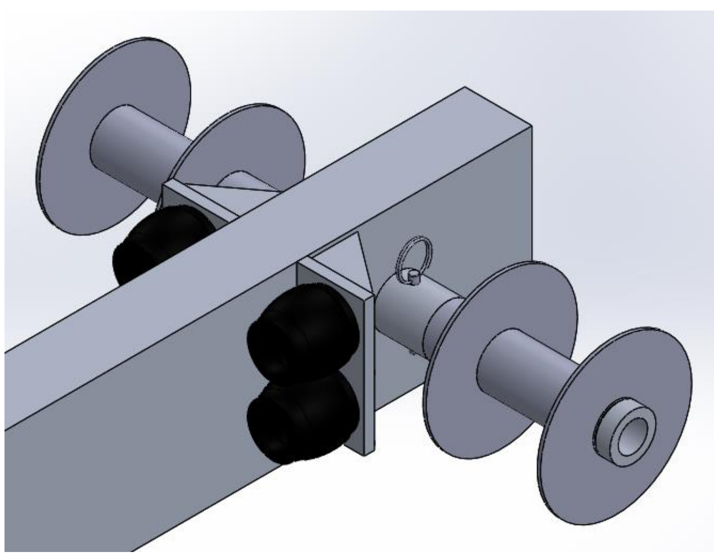
Step 5. Next, assemble the top track configuration. This will take a few steps. First, gather together the top track, the bungee roller shaft, the two rollers, two e-rings, four quick release pins, and the lower bungee connection shaft.



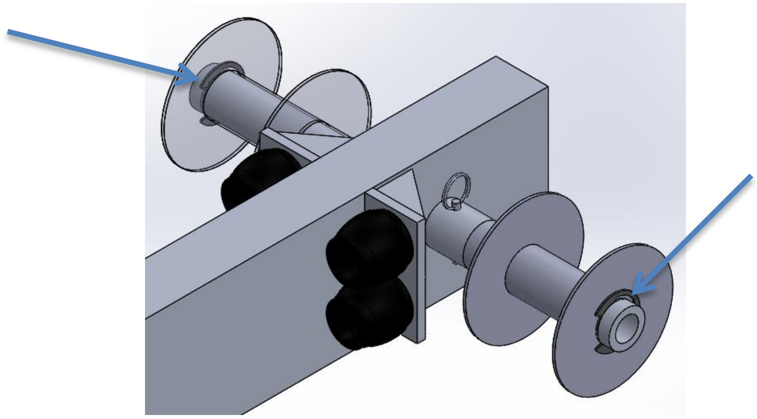
After procuring these parts, start by sliding the bungee roller shaft through its female tube (located behind the rubber compression springs), aligning the through holes, and inserting two quick release pins, securing the shaft in place.



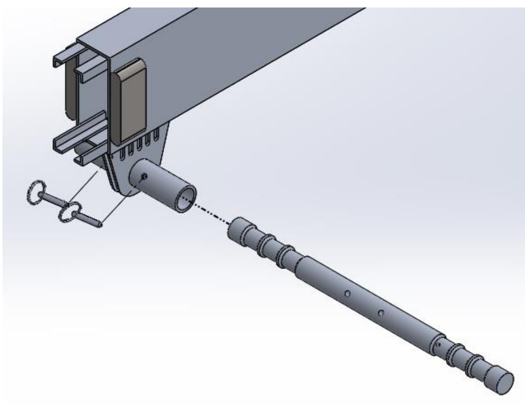
Then, slide both rollers over the roller shaft so that the flat faces of the outer flange are oriented outward and away from the track. The correct orientation is shown below:

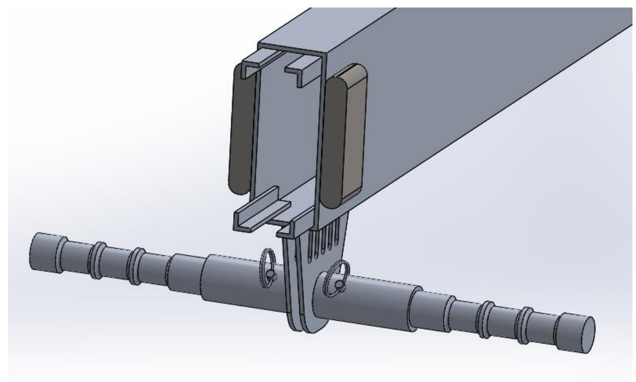


Press both e-rings into the two grooves on the shaft, securing the rollers in place.

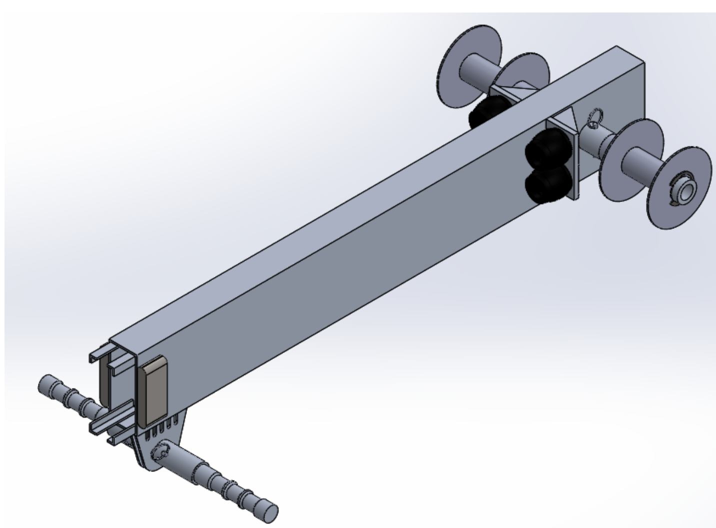


Finally, slide the lower bungee connection through its corresponding female tube. Like the bungee roller shaft, align through holes and secure using two quick release pins.

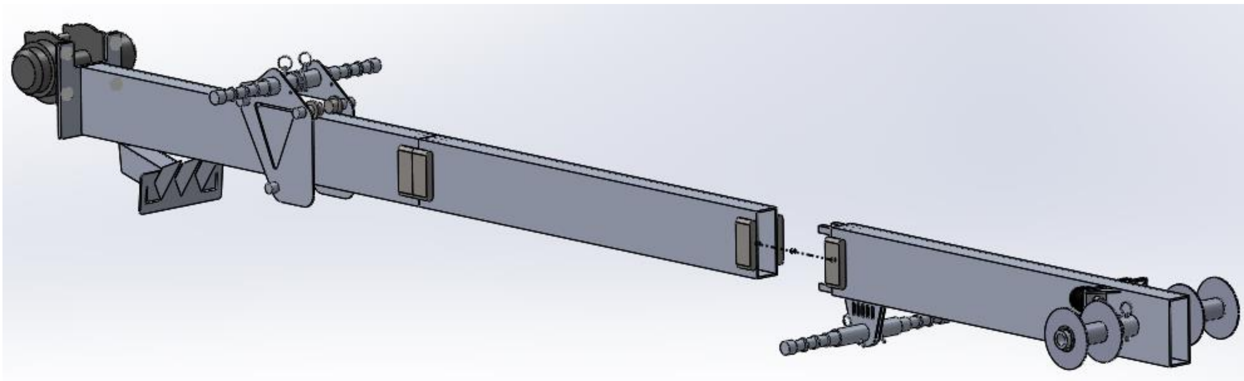


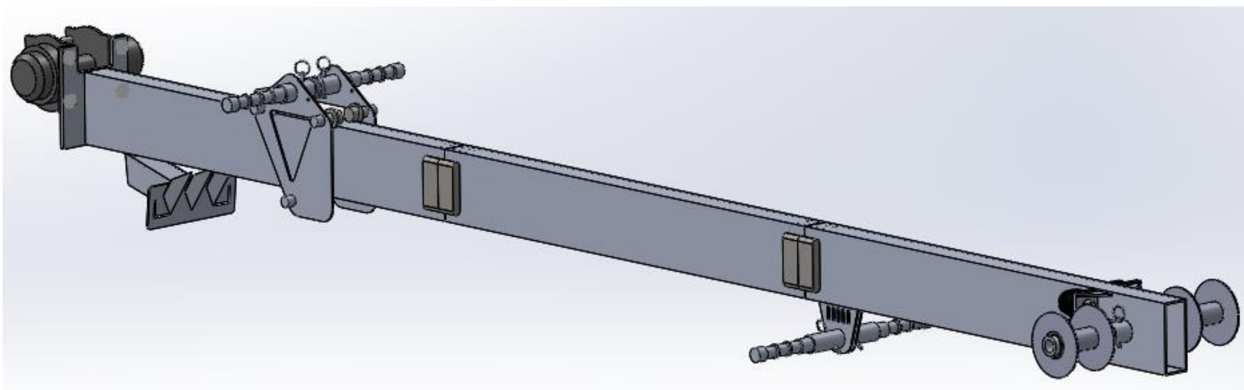


The top track configuration is fully assembled.

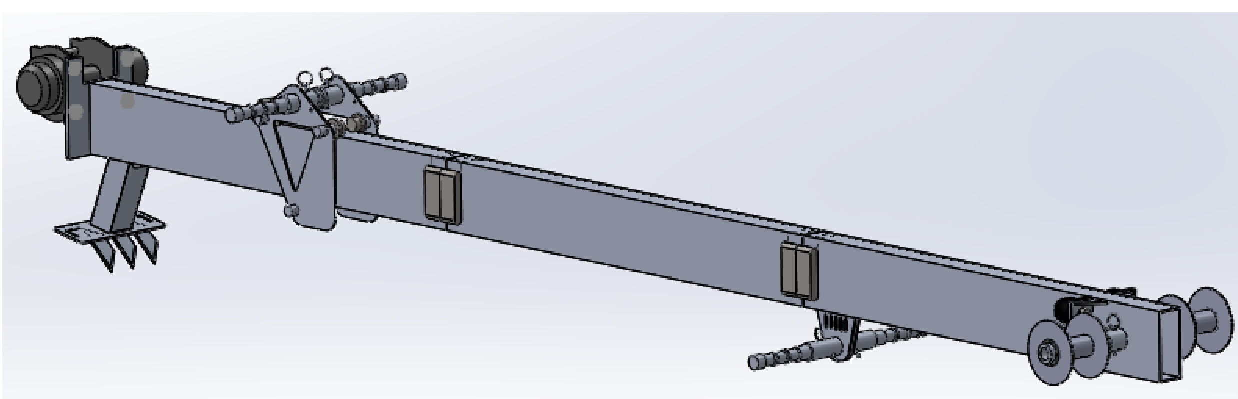


Step 6. Aligning the top track configuration with the middle track so that the lower bungee connection is on the same side as the stand, secure the track in place by tightening the latches using the same 5/16 hex wrench.

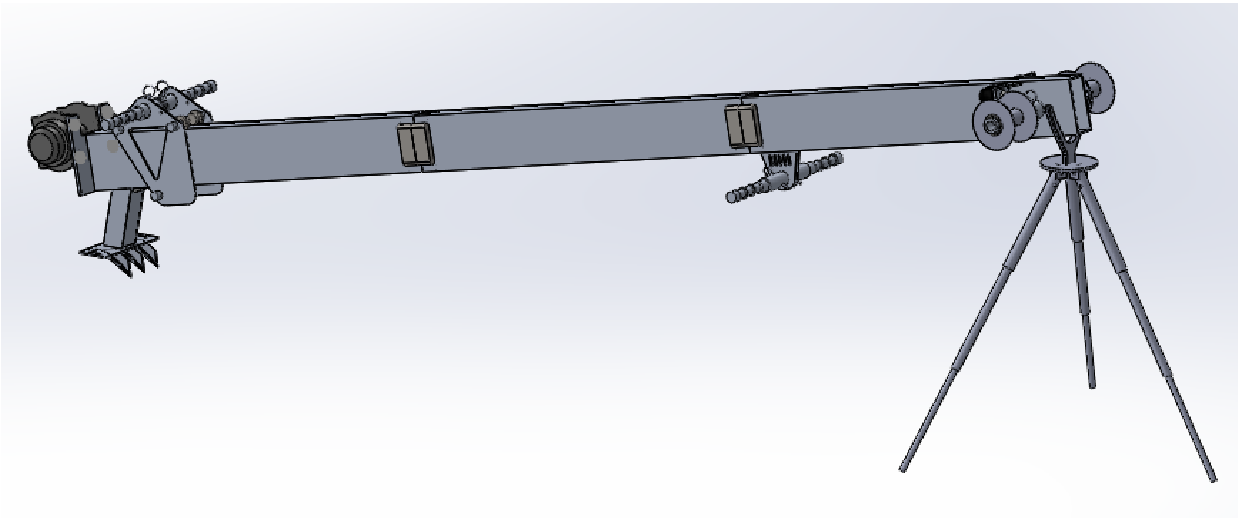




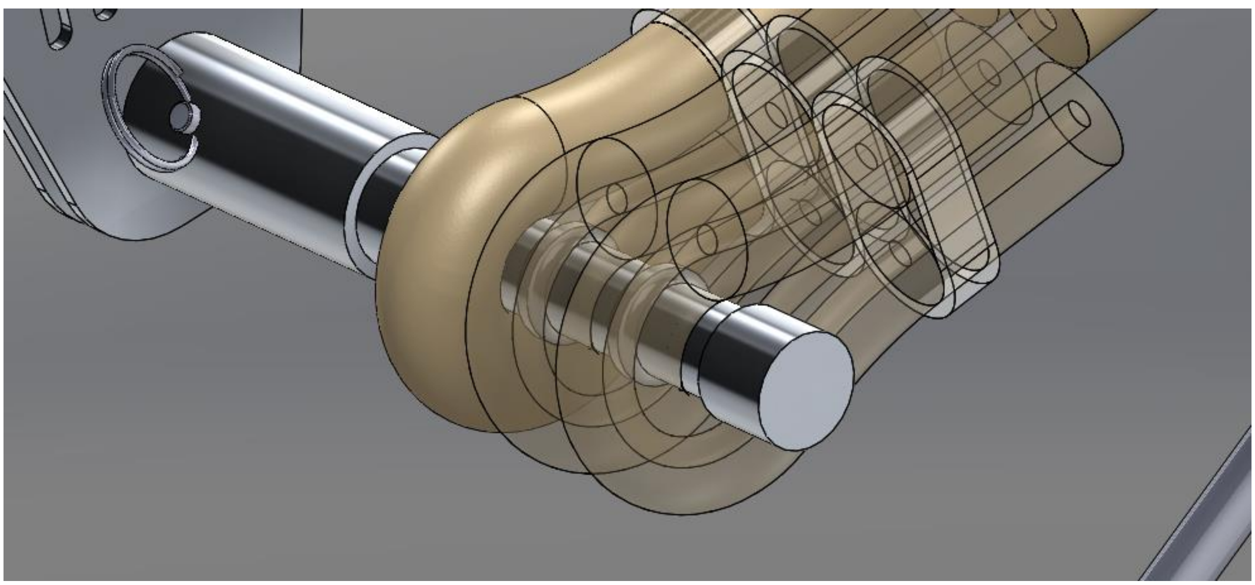
Step 7. Unfold stand and level on ground.



Step 8. Attach tripod to the bottom side of the upper track configuration. Adjust legs to desired height.



Step 9. Procure all 6 bungees. Loop one end of each over the lower bungee connection shaft, aligning each bungee with each notch in the shaft.



Next, starting with the inside bungees and working your way out, pull each over the rollers and loop other end over the bungee connection shaft on the carriage, again aligning each bungee with each groove. When performing this part of the assembly, alternate each side when securing the bungees to the carriage.

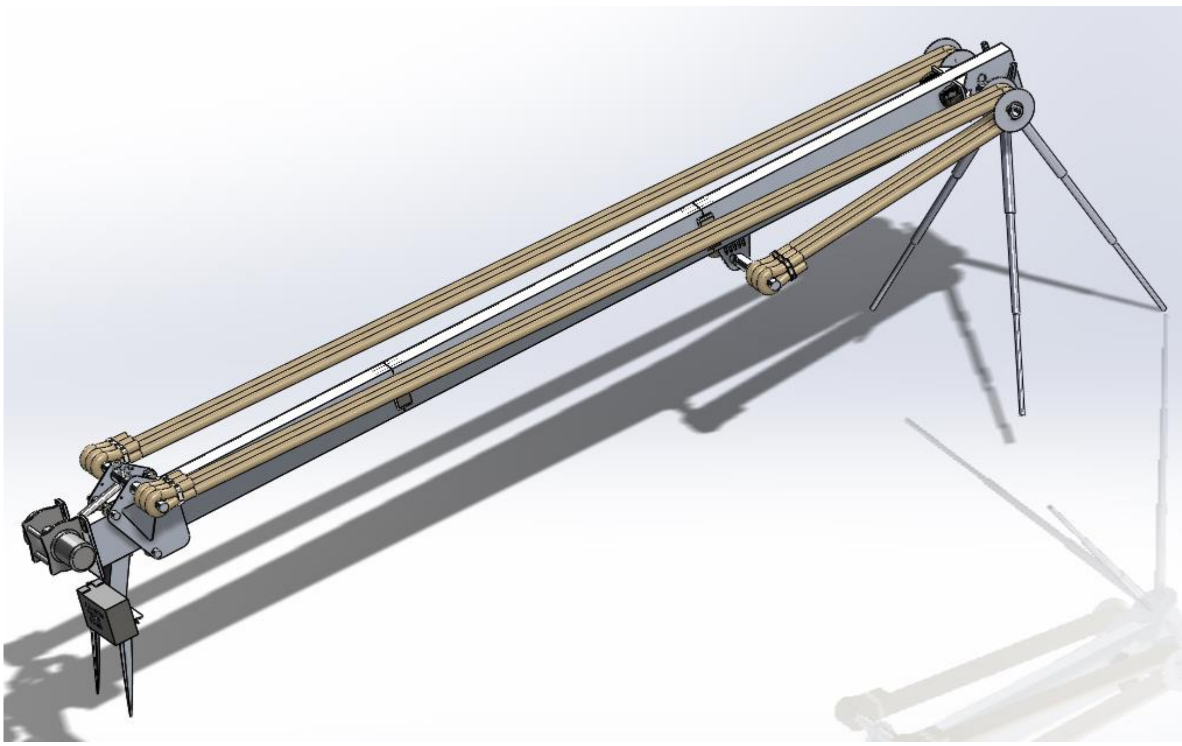
(Step 10 for electric winch only)

Step 10. To prepare the winch for pulling, connect the contactor box wires to the battery terminals and the wires from the winch motor to the contactor box. Retrieve the rocker switch and confirm that it is properly wired to the contactor box.

Step 11. Check that launcher is balanced and at desired launch angle before proceeding. If desired, secure the stand using stakes. Load payload.

Step 12. Unwind the winch so that the quick release clip can be attached to the cable at the rear of the carriage. Attach the cable and ensure that the string attached to the quick release will not catch on anything while the carriage is being winched back.

Step 13. Winch carriage back to desired length. Confirm that launch path is clear. Pull string, releasing the quick release latch, and let her fly!



Appendix G: Testing Procedures

Bumper Compression Test

<u>Objective:</u>

The objective of this experiment is to determine the deflection of a chosen bumper upon impact of a 27.5 lb deadweight dropped from a height of 66.5 inches. This information will be used to confirm the calculations done for the impact of the carriage on the bumpers at the end of the railing of the Lightweight UAV Launcher for the Aerojet Rocketdyne.

<u>Supplies:</u>

- Compression spring test plate assembly
- Impact foam block
- Drop test apparatus

<u>Setup:</u>

- Bolt Bumper to test plate as shown
- Place PVC on plate as shown
- Tape floral foam to deadweight

<u>Schematic:</u>

Procedure:

1. Confirm that the apparatus is as described in the setup.
2. Load the drop test with the 27.5 lb deadweight and raise to 66.5 inches above the surface of the bumper.
3. Release the deadweight.
4. Raise the weight and remove the foam.
5. Measure the distance the foam compressed. Record.
6. Replace the foam and repeat steps 1-5.
7. Repeat steps 1-6 for each bumper sample until results are consistent.

Bungee Crimping Method Test

Objective:

Optimal crimping method suitable for this application

Schematic:

Supplies:

- Shields
- 2 Forklifts
- Winch, remote, battery, and mounting plate
- Bungee samples
- 2 D-clevises
- Crimps
- 10,000 lb limit load cells plus digital read-out
- String and tape measure

Procedure:

1) Position forklifts so that the forks with bolt holes are facing the back of the other forklift. Position forklifts approximately 20 feet apart.
2) Mount load cell to rear of forklift in front of the other forklift.
3) Mount the winch to the forks of the forklift using ¾ " bolt, washer, and nut.
4) Connect all red ends of winch and remote wiring to the positive terminal of the battery. Connect the black wire to the negative terminal.
5) Secure one end of the bungee sample to the load cell using a D-clevis.
6) Secure the other end of the bungee sample to the winch using another D-clevis.
7) Attach one end of the string to a D-clevis and set up pulley device to change the direction of string travel past the winch from parallel to perpendicular to direction of bungee stretch.
8) Set up shields between the testing apparatus and the operators. Make sure that the digital read-out is behind the shields and turned on.
9) Turn the winch remote on by holding both the in and out button down until the light turns green.

10) Making sure that everyone is behind the shields, begin to stretch the bungee.
11) Controlling the motion with the winch remote, pull slowly with the winch
12) Keep note of the load cell output throughout the test.

Bungee Force vs. Elongation Test

Objective:

Measure the Force vs. Elongation characteristics of our bungee from 0-500%

Schematic:




Supplies:

- Shields
- 2 Forklifts
- Winch, remote, battery, and mounting plate
- Bungee samples
- 2 D-clevises
- Crimps
- 10,000 lb limit load cells plus digital read-out
- String and tape measure

Procedure:

1) Position forklifts so that the forks with bolt holes are facing the back of the other forklift. Position forklifts approximately 20 feet apart.
2) Mount load cell to rear of forklift in front of the other forklift.
3) Mount the winch to the forks of the forklift using ¾ " bolt, washer, and nut.
4) Connect all red ends of winch and remote wiring to the positive terminal of the battery. Connect the black wire to the negative terminal.
5) Secure one end of the bungee sample to the load cell using a D-clevis.
6) Secure the other end of the bungee sample to the winch using another D-clevis.
7) Attach one end of the string to a D-clevis and set up pulley device to change the direction of string travel past the winch from parallel to perpendicular to direction of bungee stretch.
8) Set up shields between the testing apparatus and the operators. Make sure that the digital read-out is behind the shields and turned on.
9) Turn the winch remote on by holding both the in and out button down until the light turns green.

10) Making sure that everyone is behind the shields, begin to stretch the bungee.
11) Controlling the motion with the winch remote, pull two inches and stop. Keeping the string taut, pull the winch so that the string moves two inches measured by the tape measure.
12) Record the force output from the load cell and corresponding deflection.
13) Repeat steps 11 and 12 until the load cell reads 200 lbs or the bungee breaks.
14) Record observations throughout each test.
15) Repeat steps 1-14 for each end fixture.

System Performance Test

Objective:

The objective of this experiment is to confirm the lightweight UAV launcher designed by Ben Miller, Christian Valoria, Corinne Warnock, and Jake Coutlee can provide the necessary launch speed of 53.2 ft/s to a 55 pound UAV. This was the requirement as specified by Aerojet Rocketdyne. Since Aerojet has not provided a UAV to launch, a block of steel will be launched in its place.

Schematic:

Supplies:

- Safe Launch Site
- Entire Launcher System plus components
- High Speed Camera
- Sawhorse
- Grid measurement device

Precautions and safety concerns/procedures:

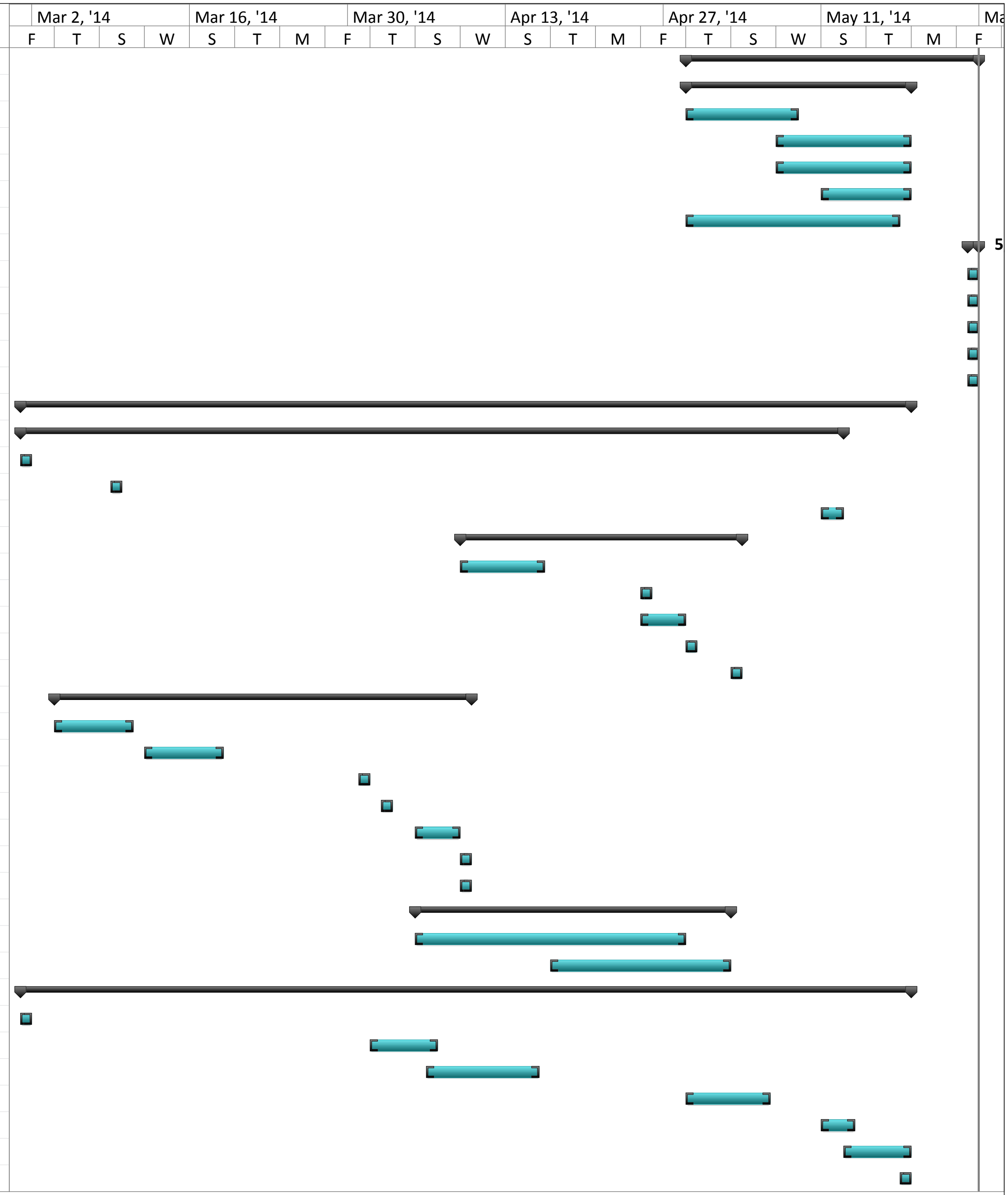
1) Make sure that all persons in the area are behind the concrete wall or sufficient protective shielding. Each bungee will experience 150 lbs of tension. It is important that those in the area are behind protective shielding when the launcher is in operation.
2) The 52 lb deadweight will become an uncontrolled projectile once launched. Make sure that no one is or will be in the projectile path nor within a 50 foot radius of it's predicted impact point (approximately 32 feet from the end of the launcher).
3) In the case that the launcher jams while in operation, meaning that the bungees are in tension but cannot be released using the quick release, a single individual will approach the launcher to address the issue. In this particular case, this individual will be Jake Coutlee. If such an event occurs, he will approach the launcher from the side wearing full leathers, boots, a face shield, and hardhat. This attire will be mainly to protect against piercing of the skin should something go wrong. He will also be carrying a hammer, crowbar, and cable cutters. Once at the launcher, Jake Coutlee will remove the deadweight, attach the quick release to the carriage, and attempt to free the jam without causing any harm to the launcher (while remaining behind the projected launch path). Should any serious injury be inflicted on Jake Coutlee during this process, the other members of the team will immediately call 911 and drive Jake Coutlee's vehicle in

between Jake and the launcher. If there is not enough space for the vehicle, they will push the launcher away from Jake (using the vehicle) or position the vehicles tire on top of the launcher. There is a First Aid kit in the vehicle.

Procedure:

16) Assemble Launcher within safe launch site (concrete trough at sheep unit). Make sure that deadweight is the in correct position and that the drawer slides are fully engaged.
17) Make sure to secure launcher with sand bags so that the frame can't move in the lateral direction.
18) Set up grid measurement device on the side of the track with gradations in front of bumper.
19) Set up the high-speed camera to the side of the launcher making sure to place the barriers between the camera and the launcher.
20) Mount high-speed camera to sawhorse so that in the camera's view is the grid measurement device and the upper rail assembly.
21) Make sure that the string attached to the quick release is long enough to be pulled from behind the concrete wall.
22) Check everything is set up as described (launcher and camera system).
23) Turn on camera and data acquisition program.
24) From behind the concrete wall, use the winch remote to winch the carriage back to "specified pullback point" on launcher.
25) Pull the quick release rope.
26) After dead weight has landed and come to a standstill, and you have verified the launcher is in an unloaded state, you may again go near the launcher.
27) Review camera data and launch distance. From this calculate the launch speed.
28) Based on this launch speed, determine if "specified pull back point" needs to be moved back or forward by comparing to target launch speed.
29) Repeat test until the launch speed has been confirmed at 53.2 ft/s and/or the deadweight is projected 32 feet away from the launcher. This data should be repeatable.

ID	Task Name	Duration	Start
1	**Testing**	**19 days**	**Tue 4/29/14**
2	**Parts**	**14 days**	**Tue 4/29/14**
3	Bumper Deflection	8 days	Tue 4/29/14
4	Winch Current Draw	9 days	Wed 5/7/14
5	Winch Pull Speed	9 days	Wed 5/7/14
6	Bungee Tensile Strength	6 days	Sun 5/11/14
7	Bungee Crimp Failure	14 days	Tue 4/29/14
8	**Performance**	**0 days**	**Sat 5/24/14**
9	Launch Speed	1 day	Sat 5/24/14
10	Launch Distance	1 day	Sat 5/24/14
11	Pullback Time	1 day	Sat 5/24/14
12	Setup Time	1 day	Sat 5/24/14
13	Collapse Time	1 day	Sat 5/24/14
14	**Manufacture**	**56 days**	**Sat 3/1/14**
15	**3 Frame Members**	**52 days**	**Sat 3/1/14**
16	Machine to length	1 day	Sat 3/1/14
17	Weld angle iron	1 day	Sun 3/9/14
18	Attach latches	2 days	Sun 5/11/14
19	**Lower Frame Member**	**18 days**	**Wed 4/9/14**
20	Machine winch plate	5.5 days	Wed 4/9/14
21	Weld winch plate to frame	1 day	Fri 4/25/14
22	Machine stake plate assy (SPA)	2 days	Fri 4/25/14
23	Weld stake plate assy	1 day	Tue 4/29/14
24	Attach SPA to frame	1 day	Sat 5/3/14
25	**Upper Frame Member**	**27 days**	**Tue 3/4/14**
26	Machine roller sleeve	5 days	Tue 3/4/14
27	Machine lower sleeve	5 days	Wed 3/12/14
28	Machine hole for roller sleeve	1 day	Mon 3/31/14
29	Weld sleeve to frame	1 day	Wed 4/2/14
30	Machine lower supports (x2)	3 days	Sat 4/5/14
31	Weld lower support assy (LSA)	1 day	Wed 4/9/14
32	Weld LSA to frame	1 day	Wed 4/9/14
33	**Bungee Shafts**	**20 days**	**Sat 4/5/14**
34	Machine upper/lower shafts (x2)	17 days	Sat 4/5/14
35	Machine roller shaft	12 days	Thu 4/17/14
36	**Carriage Assy**	**56 days**	**Sat 3/1/14**
37	Machine standoffs	1 day	Sat 3/1/14
38	Plasma cut side plates (-holes)	5 days	Tue 4/1/14
39	Machine sleeve halves	8 days	Sun 4/6/14
40	Assemble and weld sleeve halves	5.5 days	Tue 4/29/14
41	Weld standoffs to plates	3 days	Sun 5/11/14
42	Drill and tap roller halves	5 days	Tue 5/13/14
43	Assemble halves	1 day	Sun 5/18/14

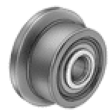


Appendix H: Spec sheets for sourced components

Flange-Guided Track Rollers

Stud Mount with Single Flange (Hex Socket in Stud End)

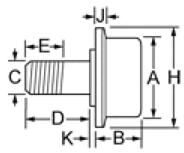
Stud Mount with Double Flange (Hex Socket in Stud End)



Shaft Mount with Single Flange

Flanges keep rollers on their track and are great for applications that require linear alignment. All of these rollers handle high speeds and are rated for both radial load and thrust load. They're lubed for life with seals that retain lubricant and block contaminants. Maximum temperature is 225° F.

Stud Mount with Single Flange



Rollers have a hex socket in the stud end. They also have ball bearings, unless noted. Mounting nut included.

Roller		Stud		Thread		Flange				Static Load Cap., lbs.			
Dia. (A)	Wd. (B)	Dia. (C)	Lg. (D)	Size	Lg. (E)	Dia. (H)	Thick. (J)	(K)	Max rpm @ No Load	Radial	Thrust		Each
Steel													
1"	3/4"	7/16"	1"	7/16"-20	1/2"	1 3/8"	7/32"	1/32"	8,000	230	140	**6318K42**	$44.37

Product Detail

Perma-Lube Thrust-Load-Rated Track Roller, Single Flange, 1" Roller Diameter, 3/4" Roller Width

Each

ADD TO ORDER

In stock

Screw-Lock Helical Inserts

Repair threads to restore parts that would otherwise have to be scrapped. Once installed, the coil expands to permanently anchor the insert. Also known as Heli-Coil inserts. Made from 18-8 stainless steel. Rockwell hardness is C42-C50. Minimum tensile strength is 200,000 psi.

Screw-lock inserts have a locking mechanism that grips your bolt or screw to prevent loosening from vibration. Inch sizes are dyed red for easy identification and meet Mil. Spec. 21209 except 90296A037 and 90296A038.

Plug taps are used to create threads in through holes.

Also Available: Bottoming taps for use in blind holes. Please select 91709A555 and specify internal thread size.

For technical drawings and 3-D models, click on a part number.

Inch

Screw-Lock Inserts					Plug Taps	
Internal Thread	Installed Lg.	Pkg. Qty.		Pkg.		Each
7/16"-20	0.438"	5	**90296A221**	5.81	91709A155	46.40

Product Detail

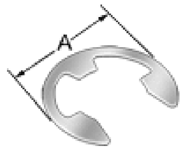
18-8 Stainless Steel Screw-Lock Helical Insert, 7/16"-20 Internal Thread, .438" Long, MS21209

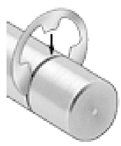
Packs of 5

ADD TO ORDER

In stock

Side-Mount External Retaining Rings (E-Style)





Snap rings into the groove from the side of the shaft. Their three prongs make contact with the shaft and provide a wider shoulder than other external retaining rings for a larger retaining surface. They are magnetic.

Black-finish and **zinc and yellow chromate-plated steel** rings have a minimum Rockwell hardness of C47.

Stainless steel rings are made of Type 15-7 or 17-7 PH stainless steel. Minimum Rockwell hardness is C44.

CAD For technical drawings and 3-D models, click on a part number.

	Fits Groove		Ring Size				
For Shaft Dia.	Dia.	Width	(A)	Thick.	Pkg. Qty.		Pkg.
Black-Finish Steel							
1 3/8"	1.23"	0.068"	1.875"	0.062"	10	**97431A400**	4.53

Product Detail CAD

Side-Mount External Retaining Ring (E-Style), Black-Finish Steel, for 1-3/8" Shaft Diameter

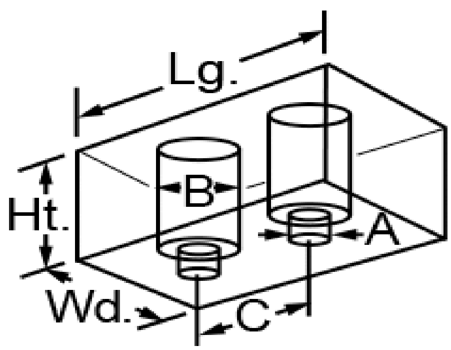
Packs of 10

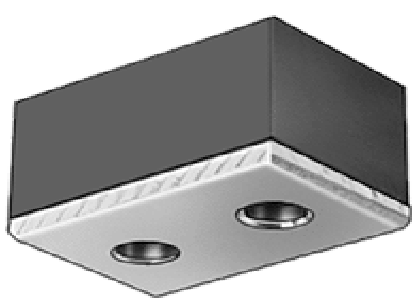
ADD TO ORDER

In stock

Bumper

Polyurethane with Aluminum Plate, 4" Long, 1" Wide





Each

ADD TO ORDER

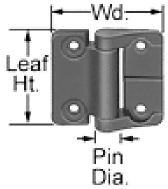
In stock
$23.96 Each
9306K27

Length	4"
Width	1"
Height	3/4"
Hole Diameter (A)	9/32"
Counterbore Diameter (B)	13/32"
Mounting Holes	
Center-to-Center (C)	1"
Number of Holes	2
Additional Specifications	Polyurethane with Aluminum Plate

Often used as stops, these bumpers have a metal plate at the base for added reinforcement. They can be used outdoors; temperature range is –40° to 200° F. Bumpers are hard with an 80A durometer.

Polyurethane bumpers resist abrasion and ozone. Material is nonmarking. Color is red.

Friction Hinges



1

Constant resistance through the full range of motion holds lids, panels, and doors at any angle. Apply force to change the hinge position. The full range of motion is 180°, except Style 2 have a 270° range of motion. All are surface mount, reversible for right- and left-hand doors, and have a nonremoveable pin. **Styles 1** and **2** have four mounting holes, **Style 3** have five holes, and **Style 4** have six holes; screws not included.

Black nylon hinges have a temperature range of 32° to 140° F.

Polished Type 304 stainless steel hinges include a matching plastic cover to conceal mounting screws.

CAD For technical drawings and 3-D models, click on a part number.

Leaf Ht.	Wd.	Leaf Thick.	Pin Dia.	Screw Size	Torque, in.-lbs.		Each
(1) Black-Painted Aluminum—Steel Pin							
1 1/2"	1 9/16"	0.125"	13/32"	No. 8	8	**2190A21**	$23.33

Product Detail CAD

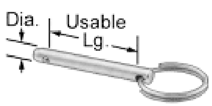
Friction Hinge, Aluminum, 1-1/2" High Leaf, 1-9/16" Width, 8-lb Torque, Black

Each

ADD TO ORDER

In stock

Quick-Release Pins



Without Lanyard

Also known as faspins, these pins have a ring grip. The ball springs inward during installation and pops out to lock the pin in place. The ball and spring are Type 316 stainless steel. The pin diameter equals the hole size. Shaft diameter tolerance is -0.003". Shafts have a minimum Rockwell hardness of B85, except aluminum have a minimum Rockwell hardness of B56. Breaking strength is measured as single shear, which is the force required to break a pin into two pieces.

Type 316 stainless steel pins are the most corrosion resistant. May be mildly magnetic.

18-8 stainless steel pins are more corrosion resistant than zinc-plated pins and may be mildly magnetic. **Pins with lanyard** that have a usable length up to 2.9" have a 6" long lanyard; all others have a 12" long lanyard. All lanyards are nylon coated.

Zinc-plated steel pins have good rust resistance.

Aluminum pins are lightweight, corrosion resistant, and nonmagnetic.

CAD For technical drawings and 3-D models, click on a part number.

Type 316 Stainless Steel without Lanyard

Not rated for breaking strength.

Usable Lg.		Each
3/16" Dia.		
1.5"	**95255A268**	4.01

Product Detail CAD

Each

ADD TO ORDER

In stock

Quick-Release Pin, Type 316 Stainless Steel, 1/4" Diameter, 1.5" Usable Length

Wichard 3 1/4" Quick Release Snap Shackle w/ Large Bail

Item# 2773

Regular price: $119.90

Sale Price : $95.92

Add to cart

Product Description

Wichard 3 1/4" Quick Release Snap Shackle w/ Large Bail

Features

- Weight- 0,119 Lbs
- Length- 3 5/32 inch
- Working load- 1940 Lbs
- Breaking load- 2646 Lbs
- A- 35/64 inch
- B- 3/4 inch

Description

- HR forged (17.4 PH) quick release snap shackle with large bail
- The opening is made by pulling the lanyard
- Perfect to attach several lines (spinnaker shhets...)
- Outstanding working and breaking loads
- Free rotation of the snap shackle thanks to the swivel

Applications

- For spinnaker operations
- Perfect to attach several lines: spinnaker sheets...

Material

- HR stainless steel 17.4 PH


BOGgear
ZOOM
What item is right for you?
Ask our Experts!
BOGgear Camo Legged Devil Tall Tripod
B&H # BOCLD3 ▪ Mfr # CLD-3
In Stock
Free Shipping (USA)
You Pay: $89.00
1
ADD TO CART
ADD TO WISHLIST
Ratings:
7 reviews
write a review
Product Highlights
Switcheroo Shooting System
Universal Shooting Rest, 360° Swivel
Aluminum Legs with Camo Finish
Three-Section Adjustable Legs
All-Terrain Footing System
Rapid Adjust Lever Locks
22-68" Height/0-40° Adjustable Legs

PRIMELINE INDUSTRIES

Natural Rubber Latex Tubing

Specification Sheet

CHEMICAL RESISTANCE:

Strong Alkalies	Fair
Weak Alkalies	Good
Strong Acids	Poor
Weak Acids	Good
Petroleum	Poor

PHYSICAL PROPERTIES:

Tensile Strength (psi) .... 3500 min.
Ultimate Elongation .... 750% min.
Hardness (Shore A) .... 35 ± 5
100% Modulus (psi) .... 125 max.
Specific Gravity .... 0.97 max.

OZONE RESISTANCE: Poor

UV RESISTANCE: Fair

LOW TEMPERATURE FLEX:

Brittle	-67°F
Flexible	0°F

RECOMMENDED STERILIZATION:

Steam Autoclave 30 minutes @15 psi
Ethylene Oxide

PROTEIN IN NATURAL RUBBER:

Less than 50 micrograms/gram. Fifty ug/g is detection limit of ASTM D5712-05.

MAXIMUM RECOMMENDED OPERATING TEMPERATURE: 212°F Intermittent - 158°F Continuous

Primeline's natural rubber latex tubing meets or exceeds the physical properties of Commercial Item Description A-A-52047C Type I Class 1, 2, and 3, Type III, Type IV, and Type V Class 1, 2, and 3 which replaced Federal Specification ZZ-T-831D.

Primeline's amber natural rubber latex tubing is in compliance with USP Biological Classification IV.

Standard Tolerances:

Inside diameter, ± 0.015 inch on sizes up to 3/8 inch, proportionately greater on larger sizes.

Wall thickness, 1/32 inch and 3/64 inch ± 0.007 inch.
1/16 inch and 5/64 inch ± 0.010 inch.
3/32 inch and 1/8 inch ± 0.015 inch.
Wall thickness greater than 1/8 inch are gauged on the outside diameter tolerance.

Primeline offers natural rubber latex tubing in sizes which range from 1/16 inch inside diameter (ID) x 1/32 inch wall to 1 inch ID x 1/4 inch wall.

Primeline Industries supports the world-wide goal to eliminate the use of ozone depleting chemicals. We do not knowingly use a Class I or Class II ozone depleting chemical as identified in the U.S. Clean Air Amendments of 1990 in the manufacturing process of our natural rubber latex tubing.

4083 Embassy Parkway, Akron, Ohio 44333, Tel: 330-668-6555 FAX: 330-668-6510
Visit our website at: http://www.primelineindustries.com
info@primelineindustries.com

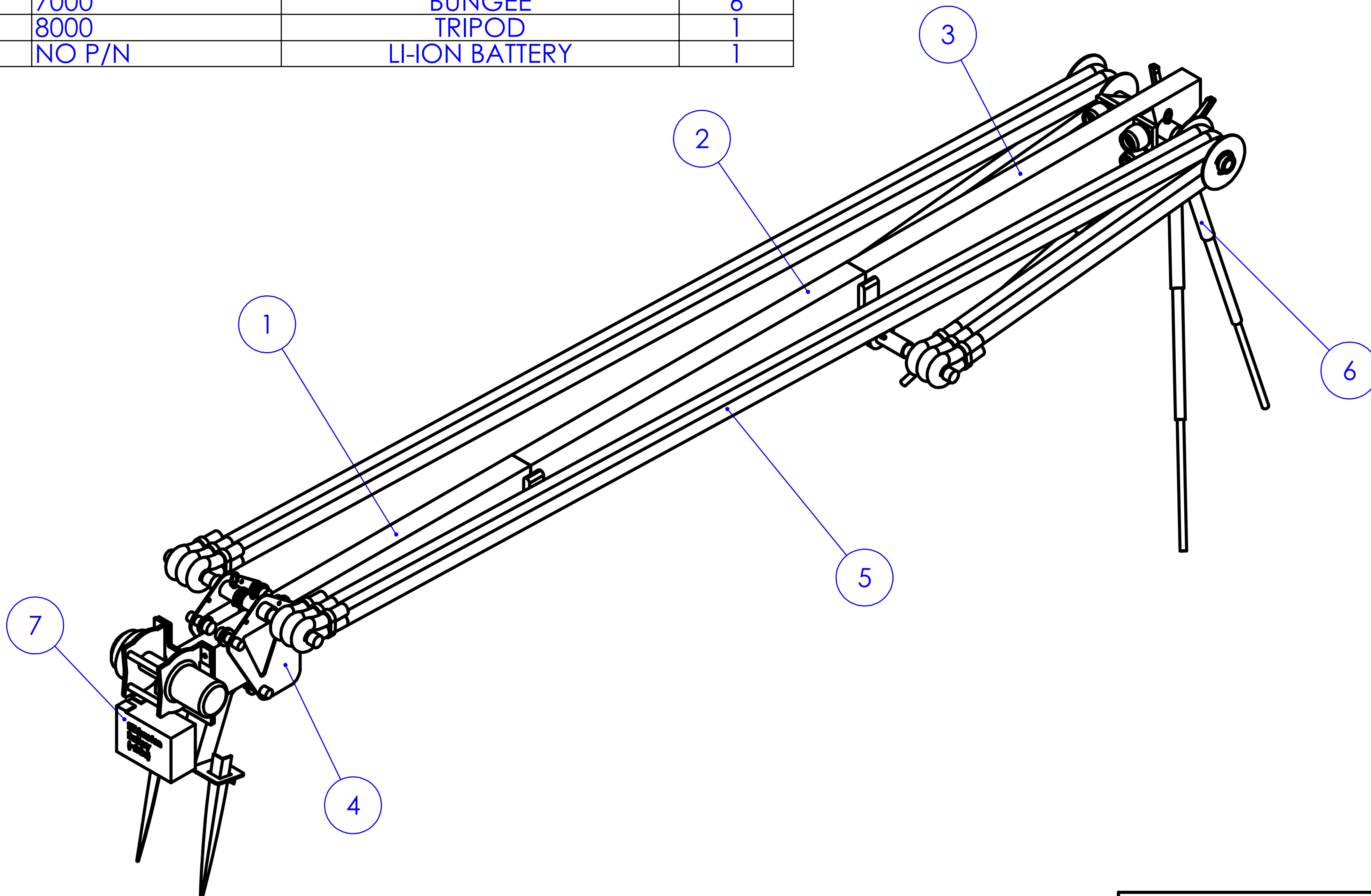
Appendix I: Bill of Materials

BOM	Column1	Column2	Column3	Column4	Column5	Column6
Subassembly	Item	Price, $	Qty (pkg)	Subtotal, $	Source	Material Description/Part No.
Carriage	Track rollers	44.37	6	266.22	McMaster	3618K42
	Track roller helicoils	5.81	5 (2)	5.61	McMaster	90296A221
	Aluminum Rod	18.87	1	18.87	Online Metals	1.25" OD, 36"
	Aluminum Rod	4.74	1	4.74	Online Metals	0.75" OD, 24"
	Aluminum Tubing	27.64	1	27.64	Online Metals	1.5" OD 1.25" ID X 24"
	Al Plate	36.07	1	36.07	Online Metals	12"x36" - 0.125"
	Helicoil Tooling	36.86	1	36.86	Amazon	
			Subassembly Total	396.01		
Front Railing Assembly	Aluminum Tubing	16.24	1	16.24	Online Metals	1.375" OD round rod, 24"
	Aluminum Tubing	16.36	1	16.36	Online Metals	1.5" OD X 1.37" ID
	Delrin for roller	26.30	1	26.30	McMaster	8572K32
	e-ring	10.31	10 (1)	10.31	McMaster	97431A400
	Rubber Bumper	23.96	2	47.92	McMaster	9306K27
	Bumper Bolts	12.28	25 (1)	12.28	McMaster	92865A716
	Bumper Nuts	13.45	100 (1)	13.45	McMaster	90473A223
			Subassembly Total	142.86		
Rear Railing Assembly	Al Plate	41.05	1	41.05	Online Metals	12"X12" - 0.3125
	Lead Acid Battery	97.19	1	97.19	Lithium Start LLC	
	Hinge	23.33	1	23.33	McMaster	2190A21
	Quick Release	95.92	1	95.92	Sound Boatworks	
	Warn RT15 Winch	229.97	1	229.97	Warn	78000
			Subassembly Total	487.46		
Frame	Aluminum RT Tubing	129.60	1	129.60	Metals Depot	T35218
	Aluminum SQ Tubing	22.95	1	22.95	Metals Depot	SQ32
	Angle Aluminum	10.99	1	10.99	Miner's Ace Hardware	
	Fasteners	30.00	1	30.00	Aircraft Spruce	ANX-XX
	Tripod	90.00	1	90.00	B&H	Devil Tall Tripod
	Quick Release Pins (1.5")	4.01	4	16.04	McMaster	95255A268
	Quick Release Pins (2")	4.21	2	8.42		
	Latches	29.62	6	177.72	D.B. Roberts Inc.	R5-0074-07, R5-0079-07
	2.5' bungee	8.53	18	153.45	Primeline Industries	custom
	Heat Treatment	341.00	1	341.00		
	Miscellaneous	100.00	1	100.00	NA	
			Subassembly Total	1080.17		
Test Equipment	Drawer Slides	5.39	1	5.39	Home Depot	
	Angle Iron	16.19	1	16.19		
	Crimping Methods (TOTAL)	137.83	1	137.83		
			Subassembly Total	159.41		
Grand Total, $	2265.91					

Appendix J: Detailed Drawings

Assembly/Part	Drawing Number	PUR Part Number	Checked
Final Assembly (Electric Winch)	1000		CRV
Final Assembly (Manual Winch)	2000		CRV
Carriage Assembly	3000		CRV
Right Carriage Subassembly	3100		CRV
Carriage Right Weldment	3110		CRV
Carriage Plate	3111		CRV
Cam Follower Spacer	3112		CRV
Carriage Male Sleeve	3113		CRV
Carriage Sleeve Collar	3114		CRV
Cam Follower	SPEC SHEET	3618K42	
Quick Release Pin	SPEC SHEET	95255A268	
Helicoil	SPEC SHEET	90296A221	
Left Carriage Subassembly	3200		CRV
Carriage Left Weldment	3210		CRV
Carriage Plate	3111		CRV
Cam Follower Spacer	3112		CRV
Carriage Female Sleeve	3211		CRV
Cam Follower	SPEC SHEET	3618K42	
Quick Release Pin	SPEC SHEET	95255A268	
Helicoil	SPEC SHEET	90296A221	
Carriage Bungee Shaft	3103		CRV
Lower Rail Assembly	4000		CRV
Rail Bottom Leg Weldment	4010		CRV
Mounting Plate	4011		CRV
Rail Corner Alignment	4012		CRV
Rail Lower Leg	4013		CRV
Stake Weldment	4020		CRV
Stake Bottom Plate	4021		CRV
Stake Stand	4022		CRV
Rake Spike	4023		CRV
3/16" Bolts	SPEC SHEET	92865A583	
Winch	SPEC SHEET	RT15 78000	
Li-Ion Battery	SPEC SHEET	NO EXISTING P/N	
3/16" Nyloc Nuts	SPEC SHEET	97149A150	
Latch	SPEC SHEET	R5-0074-07/R5-0079-07	
Hinge	SPEC SHEET	2190A21	
Middle Rail Assembly	5000		CRV
Rail Middle Leg	5001		CRV
Latch	SPEC SHEET	R5-0074-07/R5-0079-07	
Upper Rail Assembly	6000		CRV
Upper Permanent Assembly	6100		CRV
Rail Top Leg Weldment	6010		CRV
Rail Top Leg	6011		CRV
Bungee Bottom Connection Plate	6012		CRV
Bottom Bungee Sleeve	6013		CRV
Rail Corner Alignment	4012		CRV
Upper Weldment Sleeve	4013		CRV
Bumper Support Weldment	6020		CRV
Bumper Support	6021		CRV
Bumper Support Rib	6022		CRV
Bumper Nut	SPEC SHEET	90473A223	
Bumper Bolt	SPEC SHEET	92865A716	
Latch	SPEC SHEET	R5-0074-07/R5-0079-07	
Rubber Bumper	SPEC SHEET	9677K22	
Bottom Bungee Shaft	3103		CRV
Bungee Roller	6023		CRV
E-ring	SPEC SHEET	97431A400	
Quick Release Pin	SPEC SHEET	95255A268	
Upper Bungee Shaft	6004		CRV
Bungee Assembly	7000		CRV
Bungee	SPEC SHEET	CUSTOM	
Crimp Ring	SPEC SHEET	TBD	
Tripod Assembly	N/A		
Tripod	SPEC SHEET	DEVIL TALL TRIPOD	

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	4000	LOWER RAIL ASSEMBLY	1
2	5000	MIDDLE RAIL ASSEMBLY	1
3	6000	UPPER RAIL ASSEMBLY	1
4	3000	CARRIAGE	1
5	7000	BUNGEE	6
6	8000	TRIPOD	1
7	NO P/N	LI-ION BATTERY	1



NOTES:

SCALE: 1:12

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/64
ANGULAR: MACH ± 1° BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

TITLE: **LAUNCHER ASSEMBLY**
Dwg. #: 1000
MATL: N/A

Drwn. By:	CRV	02/03/14
Chkd. By:	CMW	02/04/14

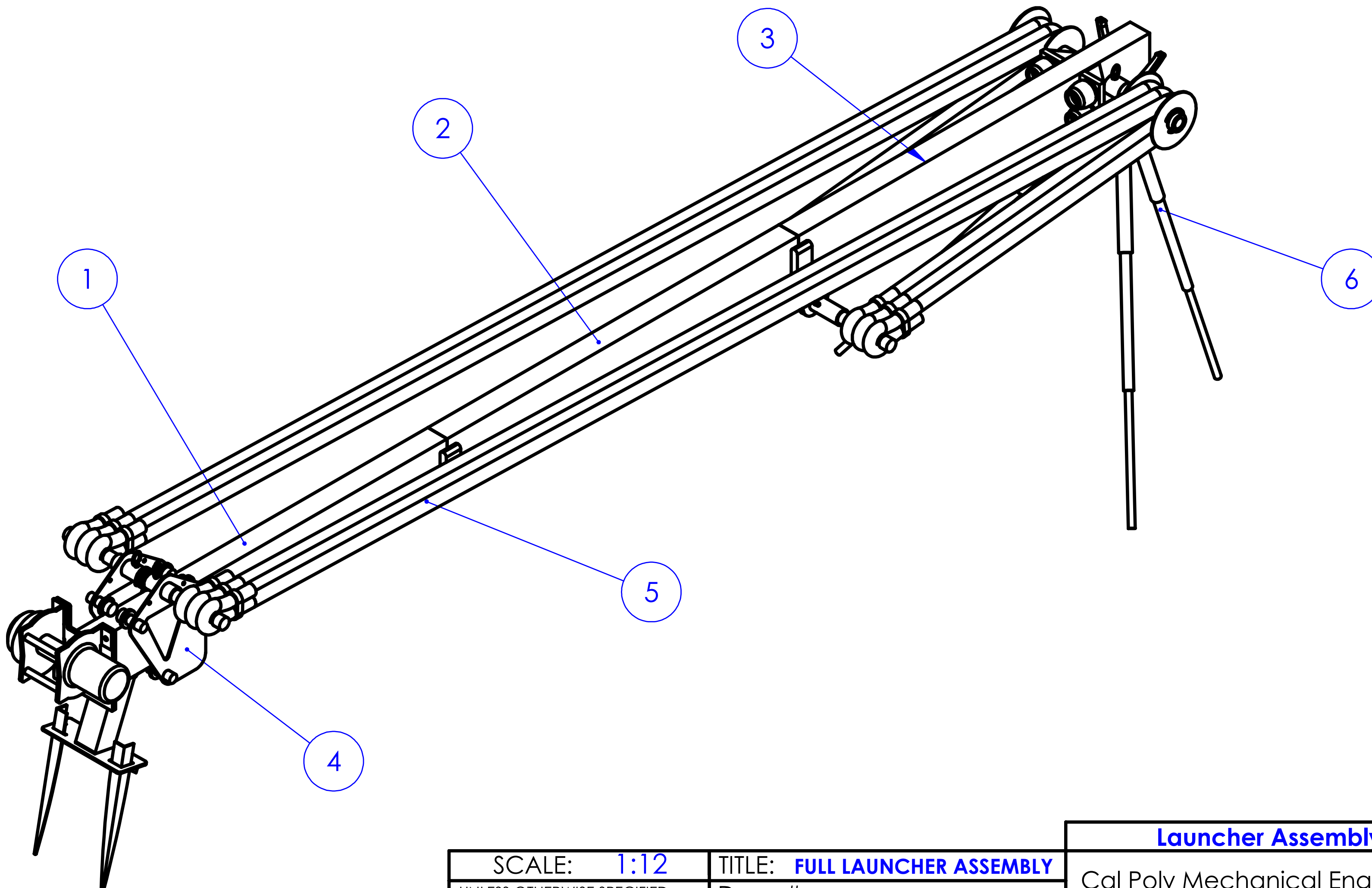
LAUNCHER ASSEMBLY

Cal Poly Mechanical Engineering

Rocket Power

Senior Project for Aerojet-Rocketdyne

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	4000	LOWER RAIL ASSEMBLY	1
2	5000	MIDDLE RAIL ASSEMBLY	1
3	6000	UPPER RAIL ASSEMBLY	1
4	3000	CARRIAGE	1
5	7000	BUNGEE	6
6	8000	TRIPOD	1



NOTES:

SCALE: 1:12	TITLE: **FULL LAUNCHER ASSEMBLY**		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 2000		
	MATL: N/A		
	Drwn. By:	CRV	02/03/14
	Chkd. By:	JOC	02/04/14

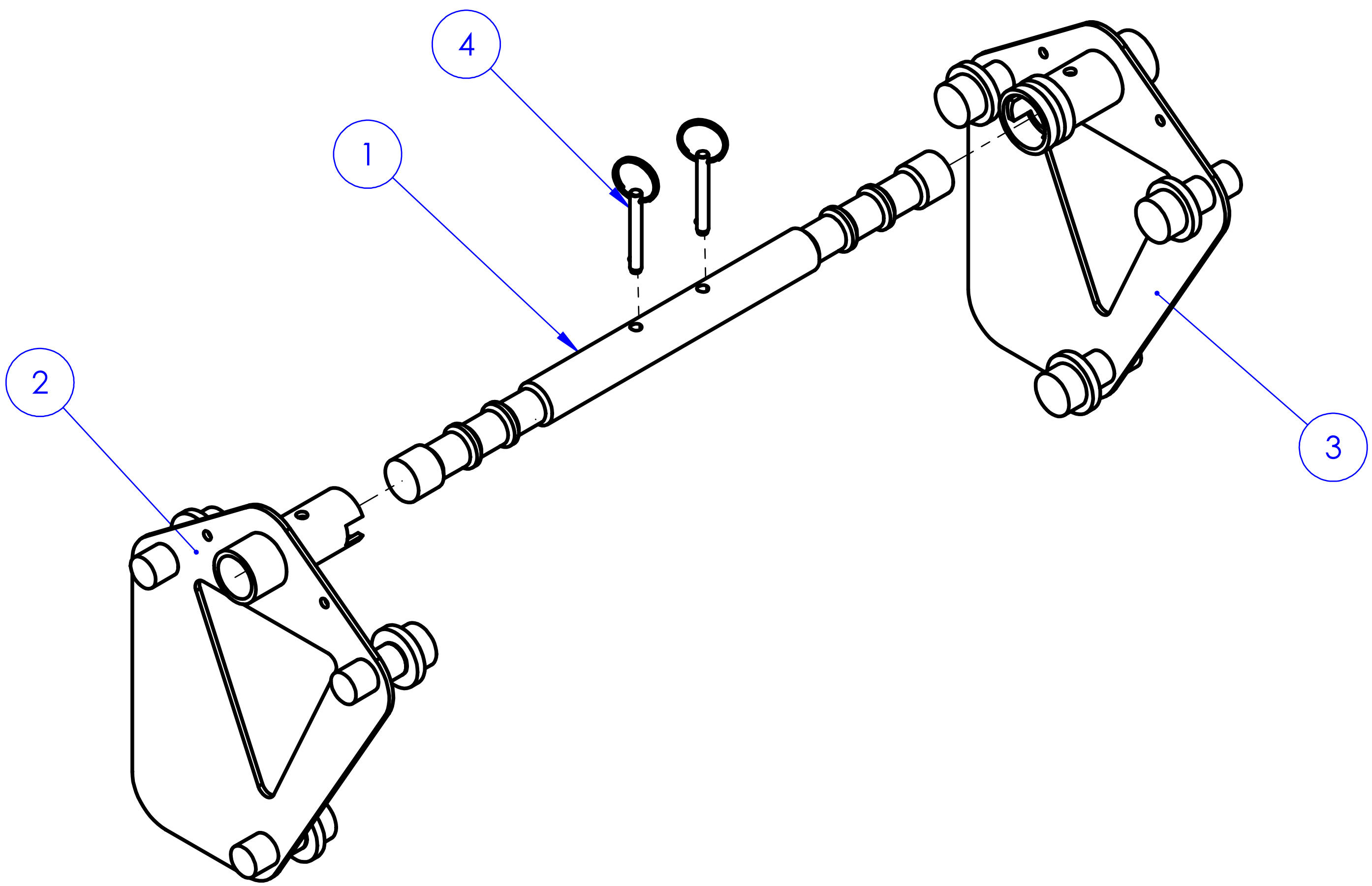
Launcher Assembly

Cal Poly Mechanical Engineering

Rocket Power

Senior Project for Aerojet-Rocketdyne

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3103	CARRIAGE BUNGEE SHAFT	1
2	3210	CARRIAGE LEFT AND WHEELS	1
3	3110	CARRIAGE RIGHT AND WHEELS	1
4	95255A268	QUICK RELEASE PINS	2



NOTES:

SCALE: 1:4	TITLE: **CARRIAGE ASSY.**		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 3000		
	MATL: N/A		
	Drwn. By:	CRV	02/01/14
	Chkd. By:	JOC	02/01/14

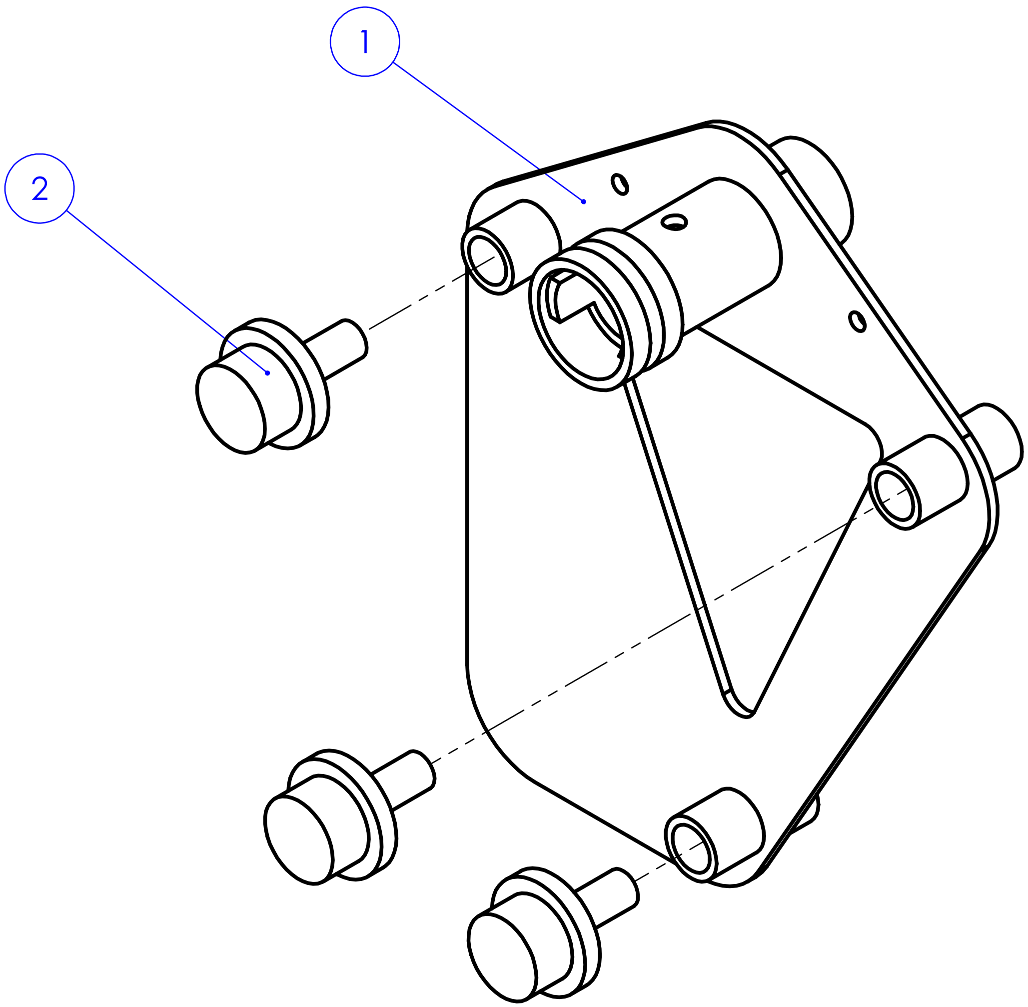
CARRIAGE ASSEMBLY

Cal Poly Mechanical Engineering

Rocket Power

Senior Project for Aerojet-Rocketdyne

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	CARRIAGE SIDE PLATE	CARRIAGE MALE SLEEEVE	1
2	3618K42	CAM FOLLOWER	3
3	90296A221	7/16"-20 HELI-COIL	3



NOTES:

1. ITEM NO. 3 HELICOIL NOT PICTURED IN ASSEMBLY

SCALE: 1:2	TITLE: **RIGHT CARRIAGE SA**		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 3100		
	MATL: N/A		
	Drwn. By:	CRV	02/01/14
	Chkd. By:	JOC	02/01/14

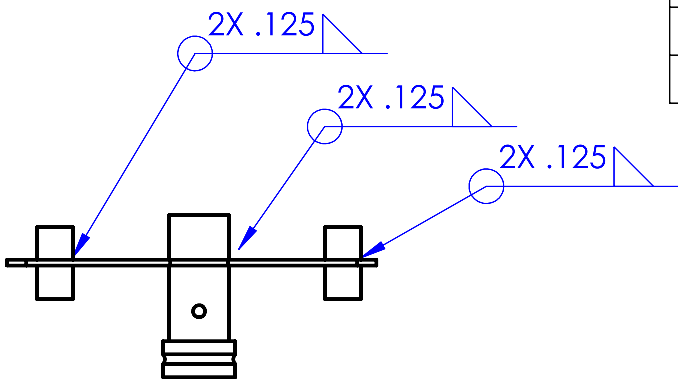
CARRIAGE RIGHT

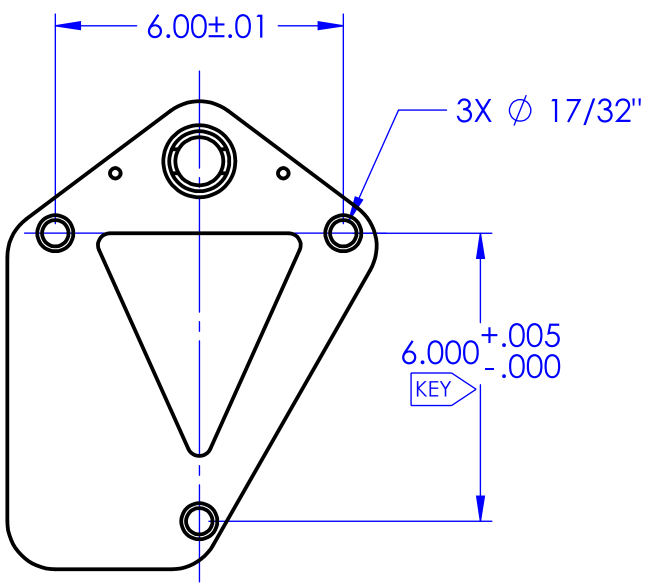
Cal Poly Mechanical Engineering

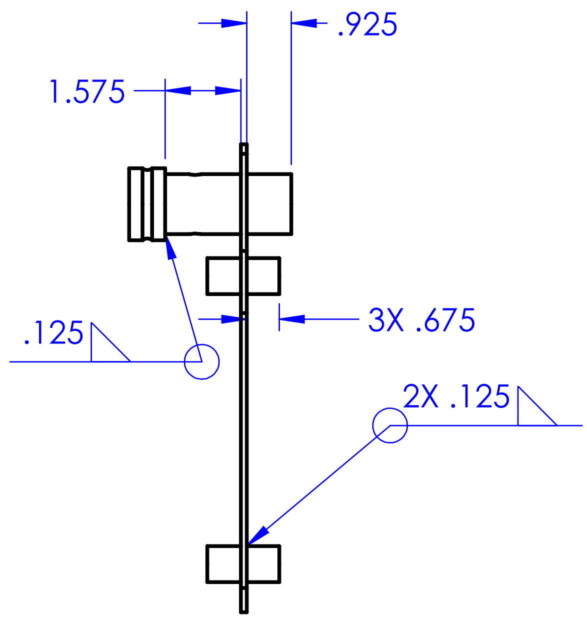
Rocket Power

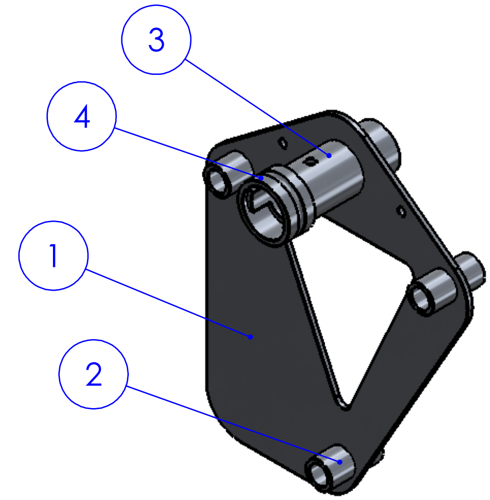
Senior Project for Aerojet-Rocketdyne

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3111	CARRIAGE SIDE PLATE	1
2	3112	CAM FOLLOWER SPACER	3
3	3113	CARRIAGE MALE SLEEEVE	1
4	3114	CARRIAGE SLEEVE COLLAR	1









NOTES:

1. DRILL AND TAP SPACER HOLES AFTER WELDING SPACERS TO PLATE.
2. SPECIAL TOOLING REQIRED FOR TAPPING.

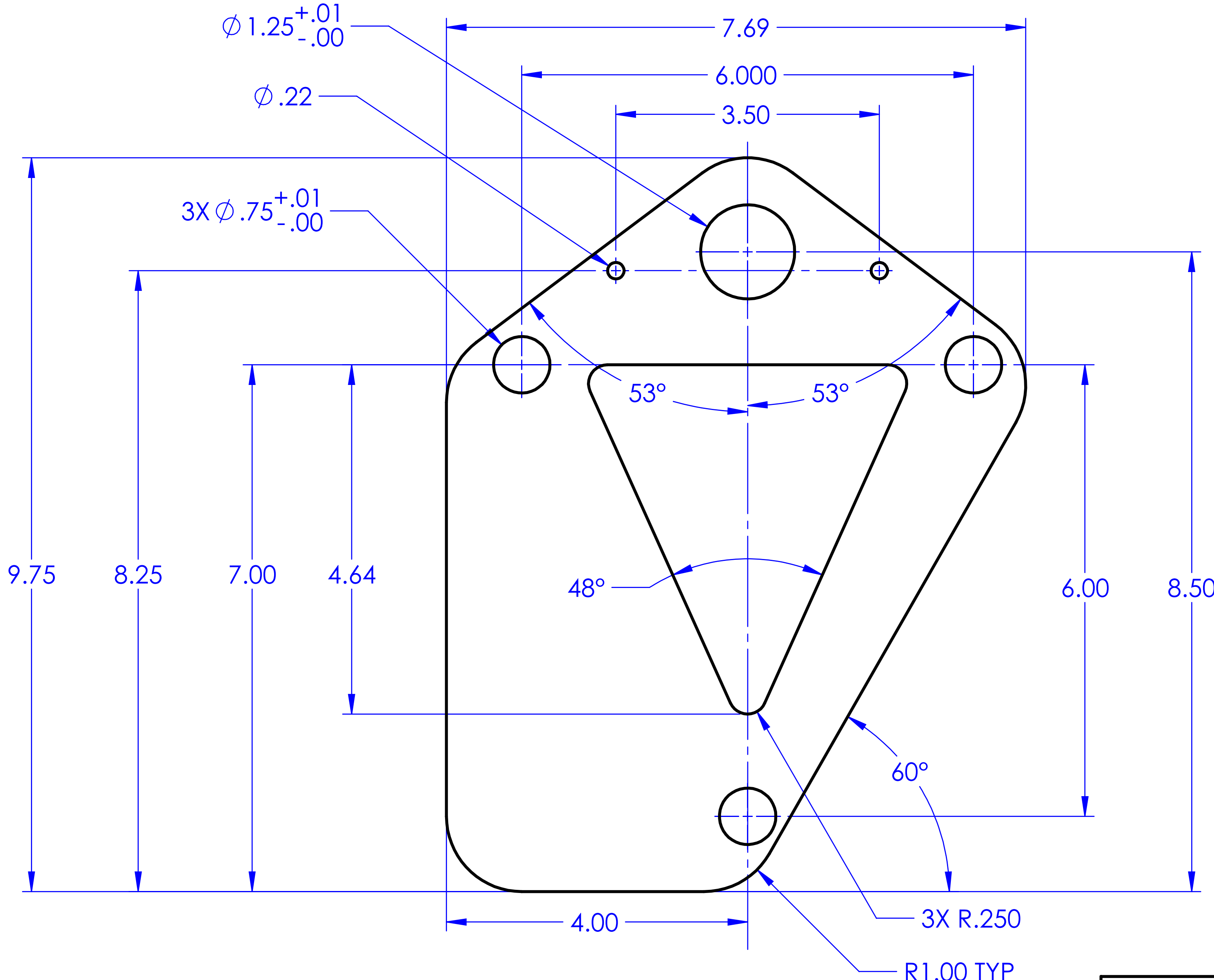
SCALE: 1:4	TITLE: **RIGHT CARRIAGE WELDMENT**		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ±1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 3110		
	MATL: N/A		
	Drwn. By:	CRV	02/01/14
	Chkd. By:	CMK	02/04/14

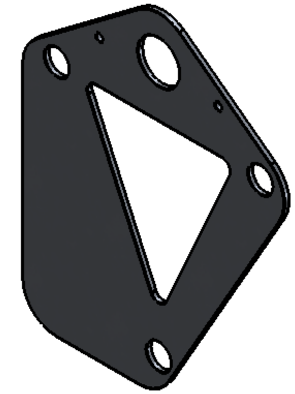
CARRIAGE RIGHT

Cal Poly Mechanical Engineering

Rocket Power

Senior Project for Aerojet-Rocketdyne

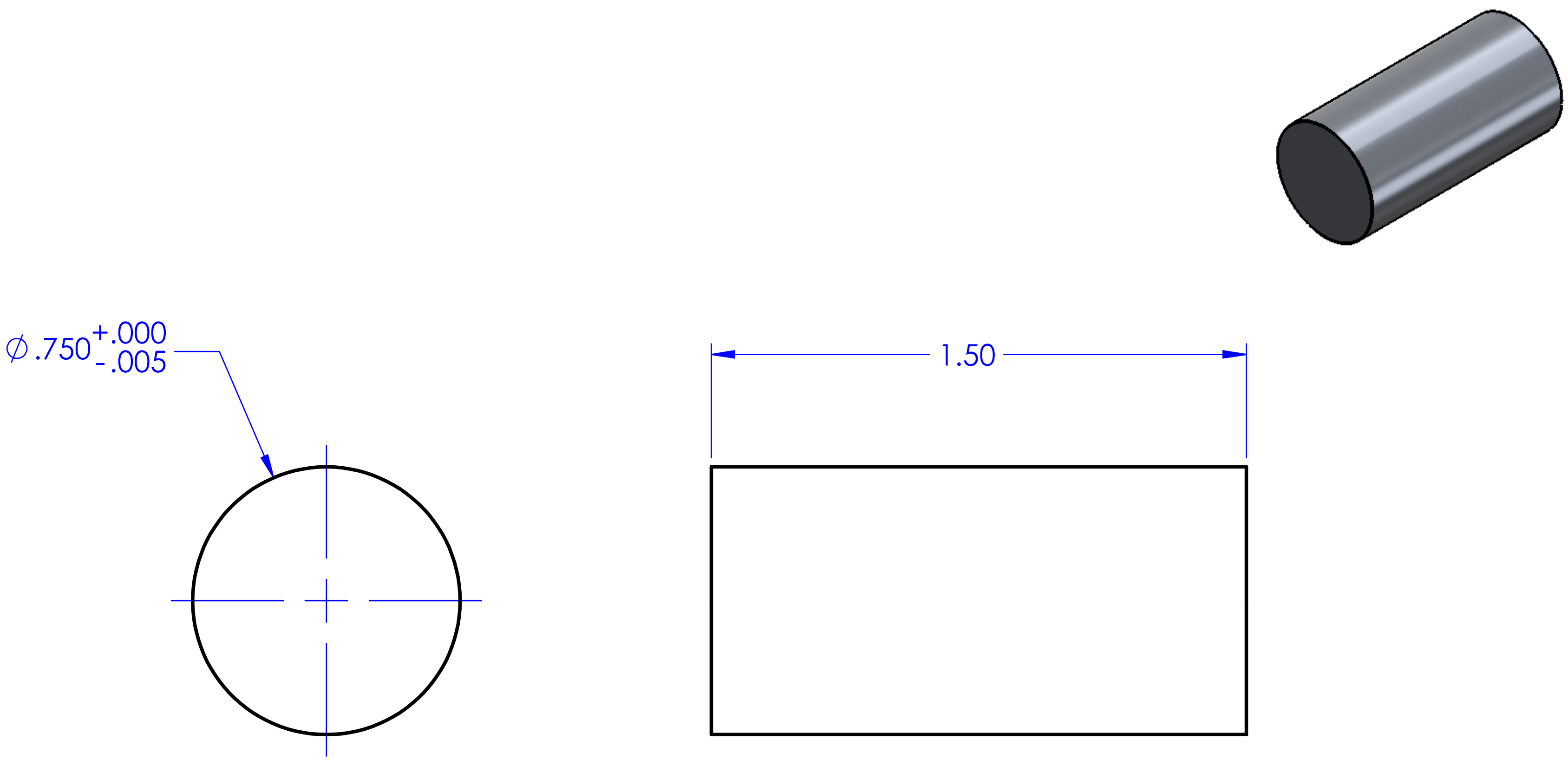




NOTES:

1. ALL HOLES SYMMETRIC ABOUT VERTICAL AXIS.
2. MAKE OUT OF 1/8" THICK ALUM. PLATE.

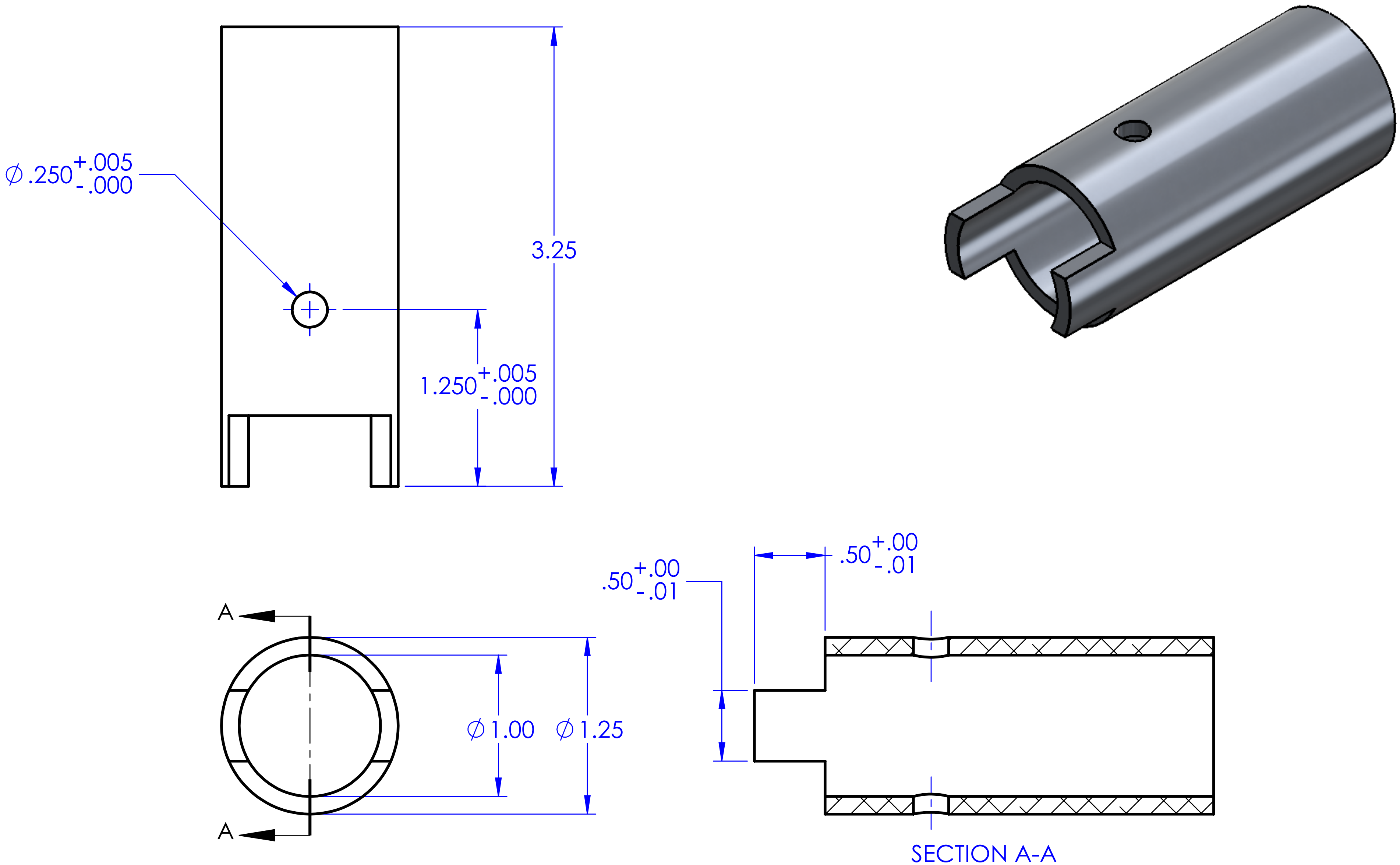
SCALE: 1:2	TITLE: **CARRIAGE PLATE**			**CARRIAGE ASSEMBLY**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 3111			Cal Poly Mechanical Engineering
	MATL: ALUMINUM 6061-T6			Rocket Power
	Drwn. By:	CRV	02/01/14	
	Chkd. By:	JOC	02/01/14	Senior Project for Aerojet-Rocketdyne



NOTES:

1. BREAK SHARP EDGES.

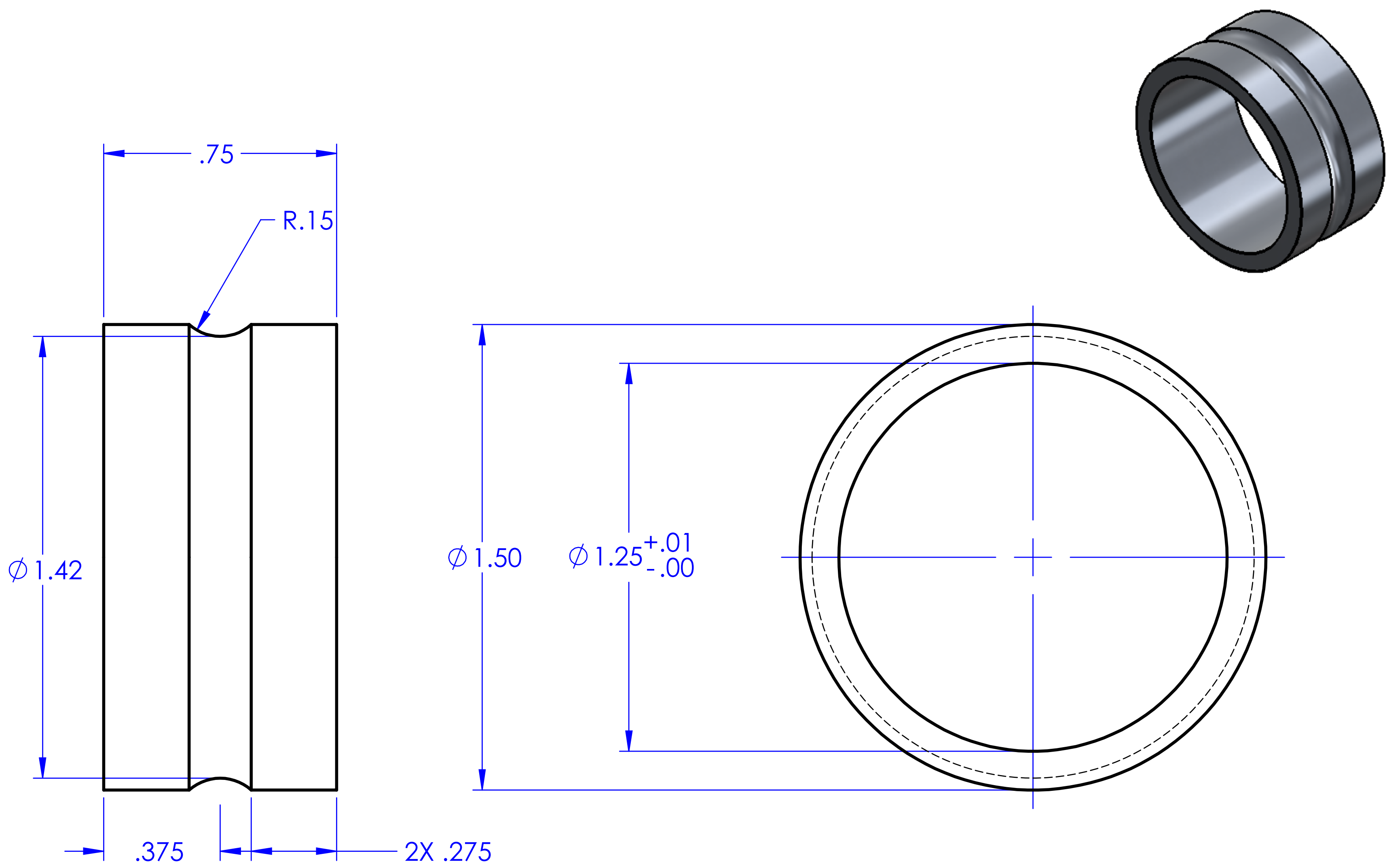
SCALE: 2:1	TITLE: **CAM FOLLOWER SPACER**		**CARRIAGE ASSEMBLY**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 3112		Cal Poly Mechanical Engineering
	MATL: ALUMINUM 6061-T6		Rocket Power
	Drwn. By: CRV	02/01/14	
	Chkd. By: JOC	02/01/14	Senior Project for Aerojet-Rocketdyne



NOTES:

1. BREAK SHARP EDGES.

				CARRIAGE RIGHT
SCALE: 1:1	TITLE: CARRIAGE MALE SLEEVE			Cal Poly Mechanical Engineering Rocket Power
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 3113			
	MATL: ALUMINUM 6061-T6			
	Drwn. By:	CRV	02/03/14	
	Chkd. By:	JOC	02/03/14	Senior Project for Aerojet-Rocketdyne



NOTES:

SCALE: 2:1	TITLE: **CARRIAGE SLEEVE COLLAR**		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 3114		
	MATL: ALUMINUM 6061-T6		
	Drwn. By:	CRV	02/03/14
	Chkd. By:	JOC	02/03/14

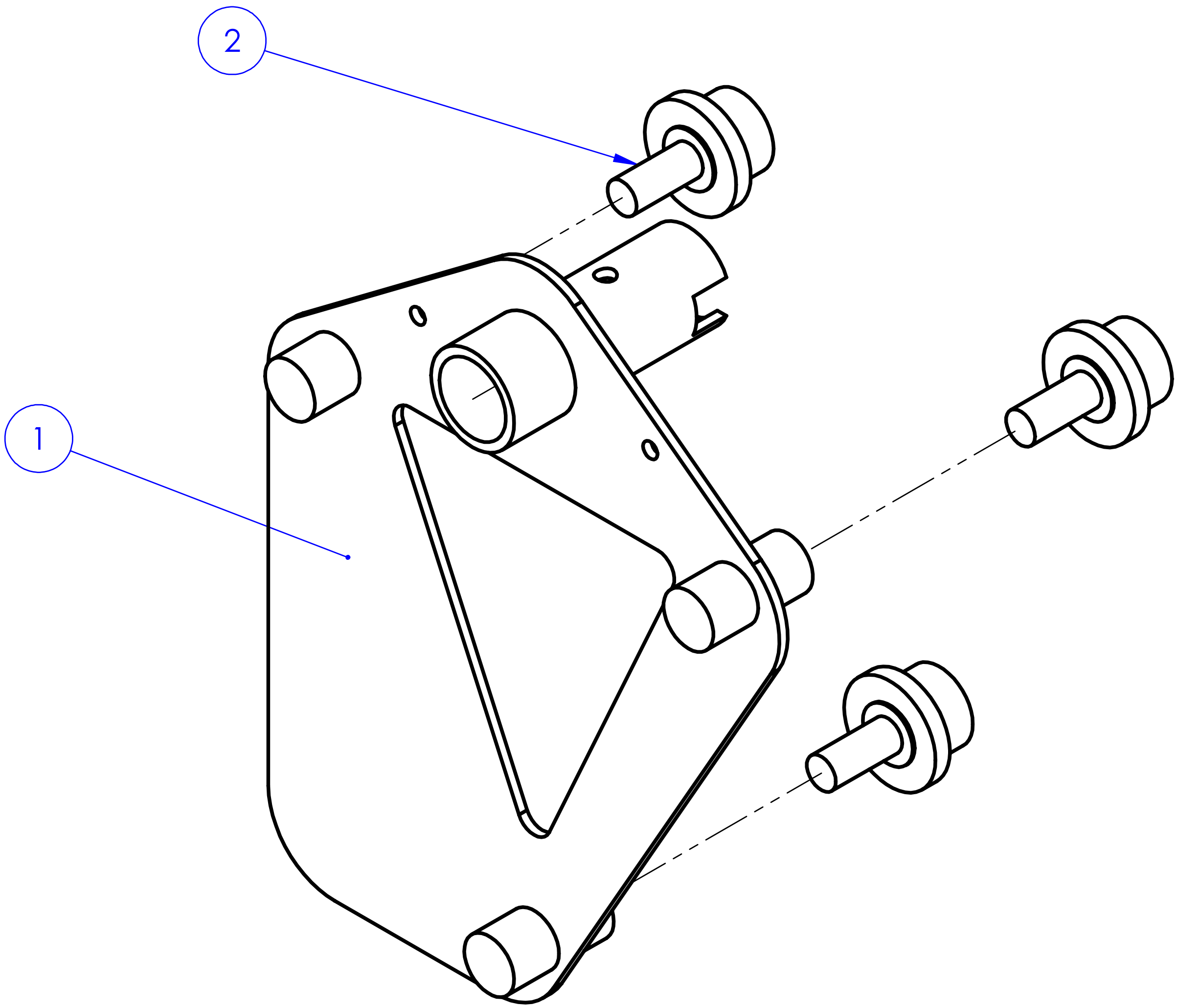
CARRIAGE RIGHT

Cal Poly Mechanical Engineering

Rocket Power

Senior Project for Aerojet-Rocketdyne

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3210	CARRIAGE LEFT PLATE AND SLEEVE WELDMENT	1
2	3618K42	CAM FOLLOWER	3
3	90296A221	7/16"-20 HELICOIL	3



NOTES:

1. ITEM NO. 3 HELICOIL NOT PICTURED IN ASSEMBLY

SCALE: 1:2	TITLE: **LEFT CARRIAGE SA**		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 3200		
	MATL: N/A		
	Drwn. By:	CRV	02/01/14
	Chkd. By:	JOC	02/01/14

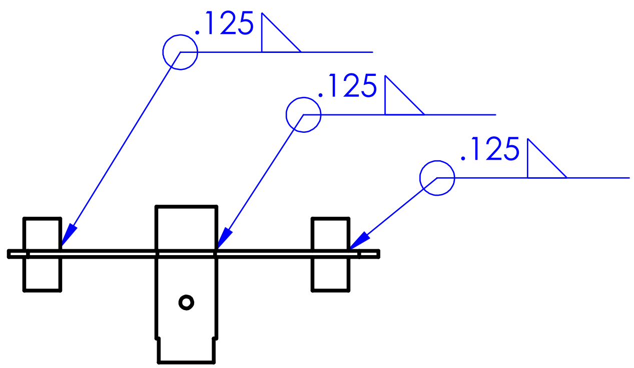
CARRIAGE LEFT

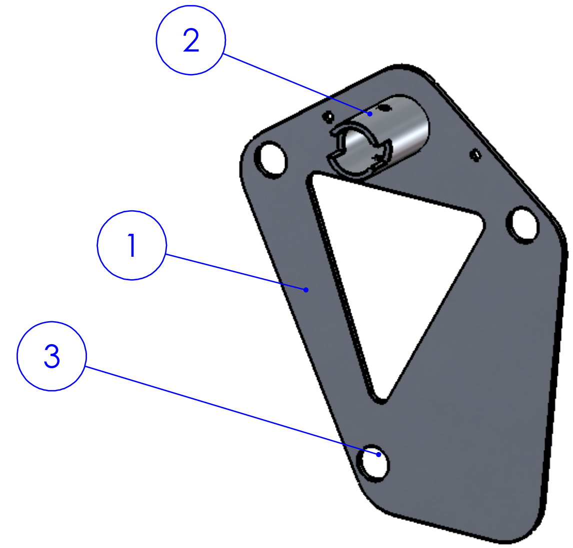
Cal Poly Mechanical Engineering

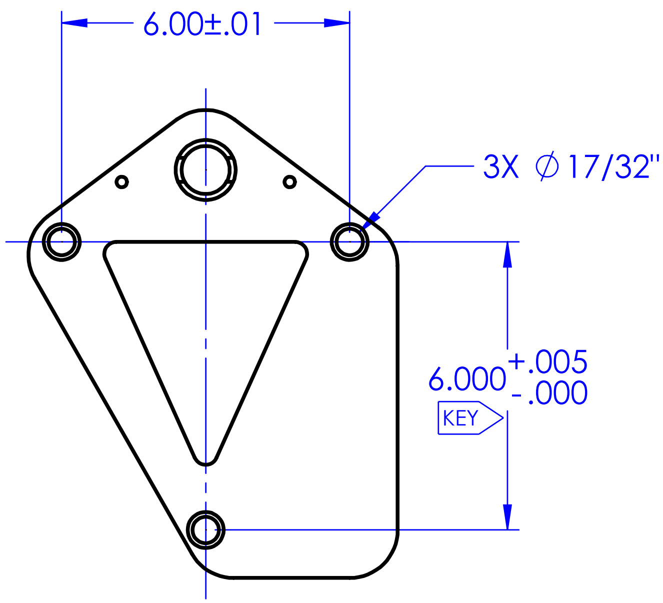
Rocket Power

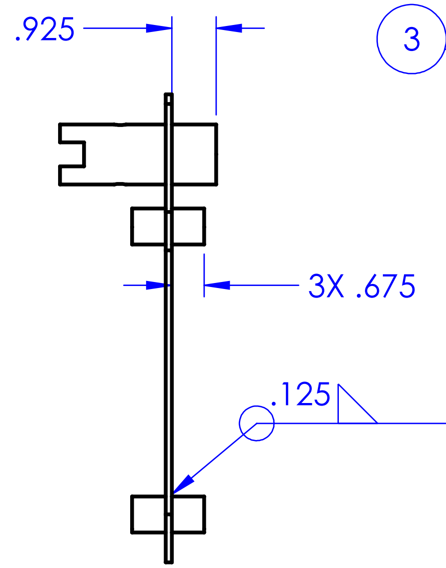
Senior Project for Aerojet-Rocketdyne

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3111	CARRIAGE PLATE	1
2	3211	CARRIAGE FEMALE SLEEVE	1
3	3112	CAM FOLLOWER SPACER	3





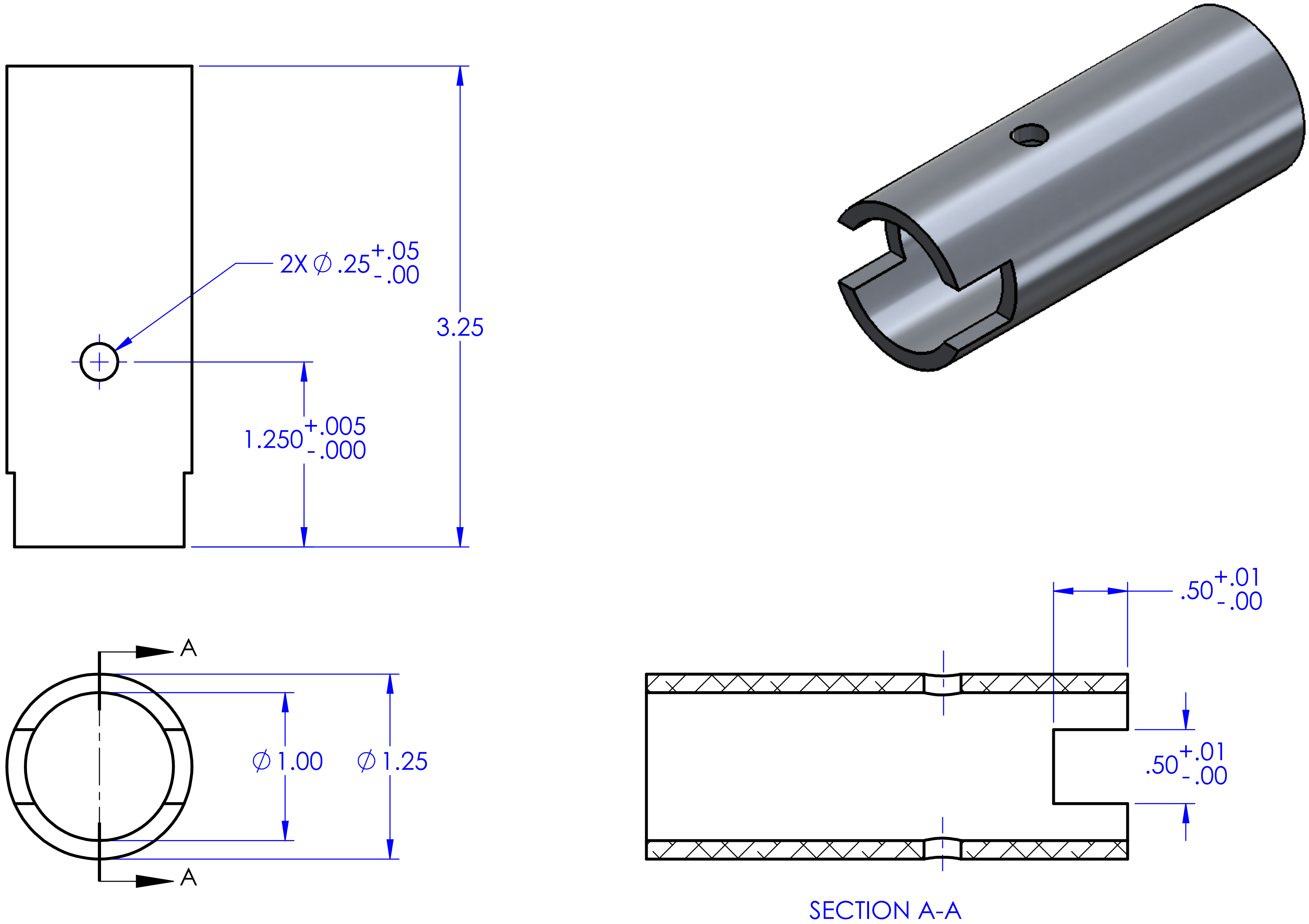




NOTES:

1. DRILL AND TAP SPACER HOLES AFTER WELDING SPACERS TO PLATE.

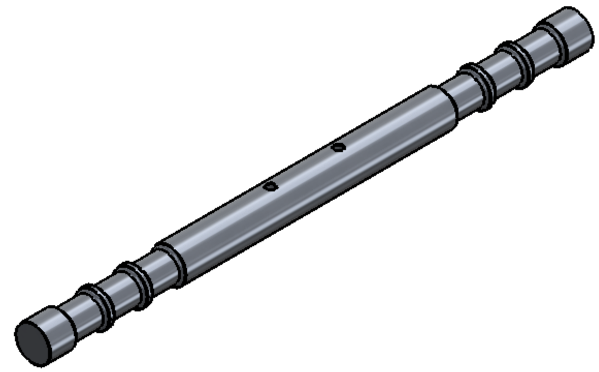
SCALE: 1:4	TITLE: **LEFT CARRIAGE WELDMENT**		**CARRIAGE LEFT**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 3210		Cal Poly Mechanical Engineering
	MATL: N/A		Rocket Power
	Drwn. By: CRV	02/01/14	
	Chkd. By: JOC	02/01/14	Senior Project for Aerojet-Rocketdyne

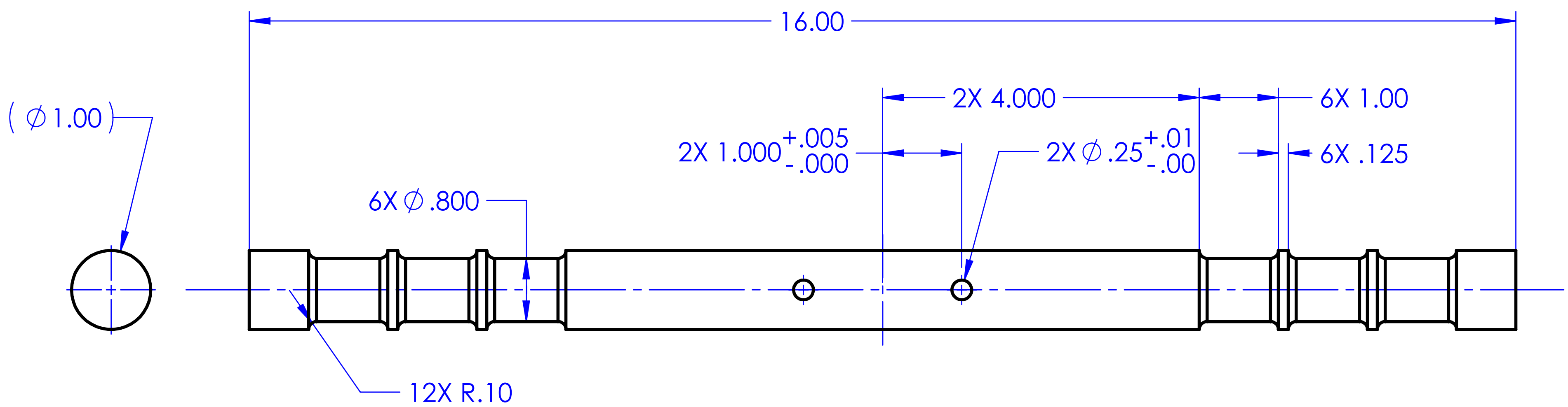


NOTES:

1. BREAK SHARP EDGES.

SCALE: 1:1	TITLE: **CARRIAGE FEMALE SLEEVE**		**CARRIAGE LEFT**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 3211		Cal Poly Mechanical Engineering
	MATL: ALUMINUM 6061-T6		Rocket Power
	Drwn. By: CRV	02/03/14	
	Chkd. By: JOC	02/03/14	Senior Project for Aerojet-Rocketdyne





NOTES:

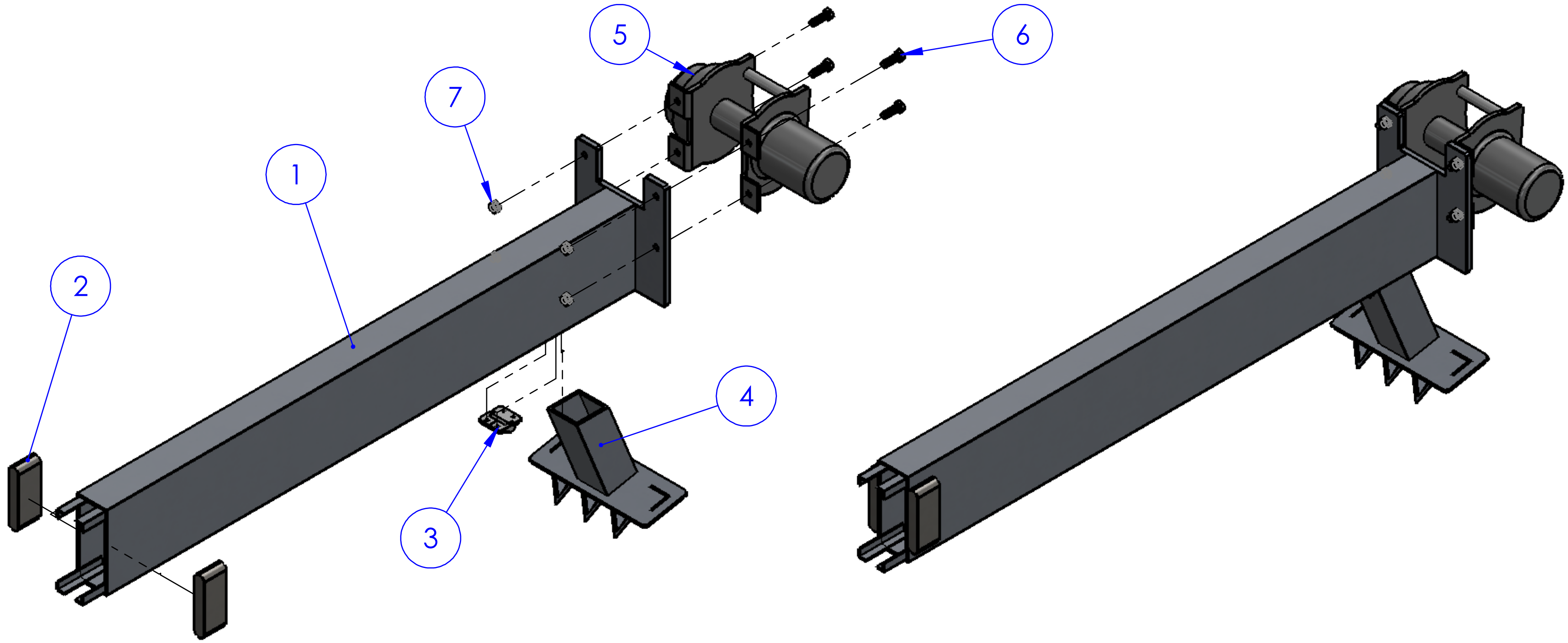
SCALE: 1:2	TITLE: **BOTTOM BUNGEE SHAFT**		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 3103		
	MATL: ALUM. 6061-T6		
	Drwn. By:	CRV	02/01/14
	Chkd. By:	JOC	02/01/14

UPPER RAIL ASSEMBLY/CARRAIGE

Cal Poly Mechanical Engineering

Rocket Power

Senior Project for Aerojet-Rocketdyne

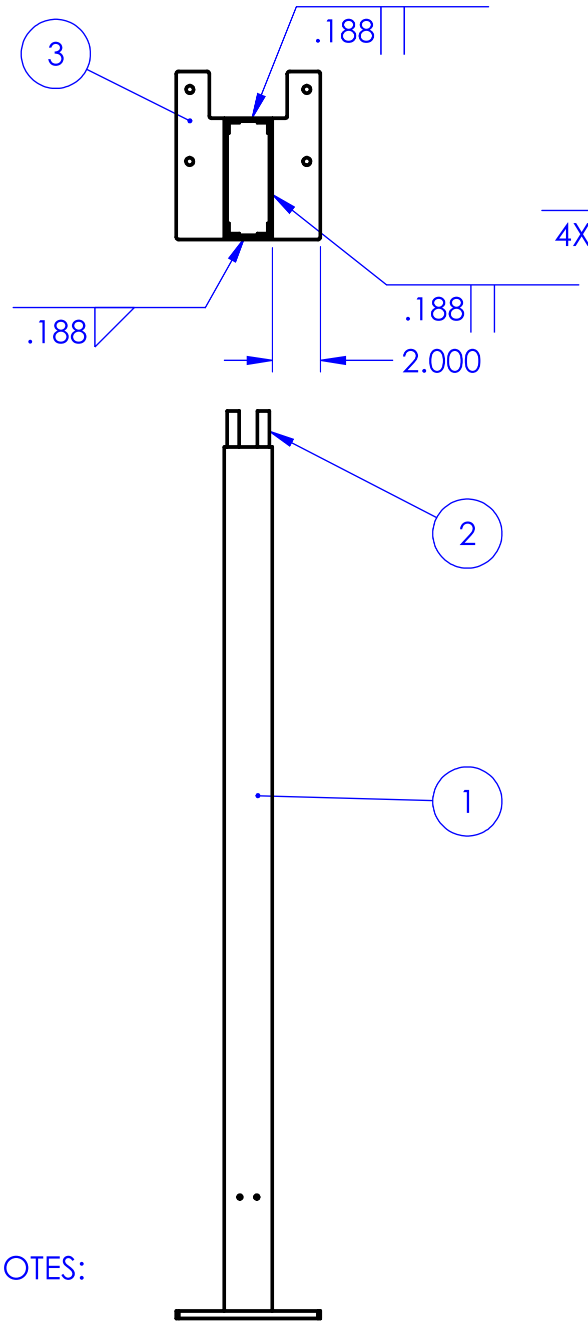


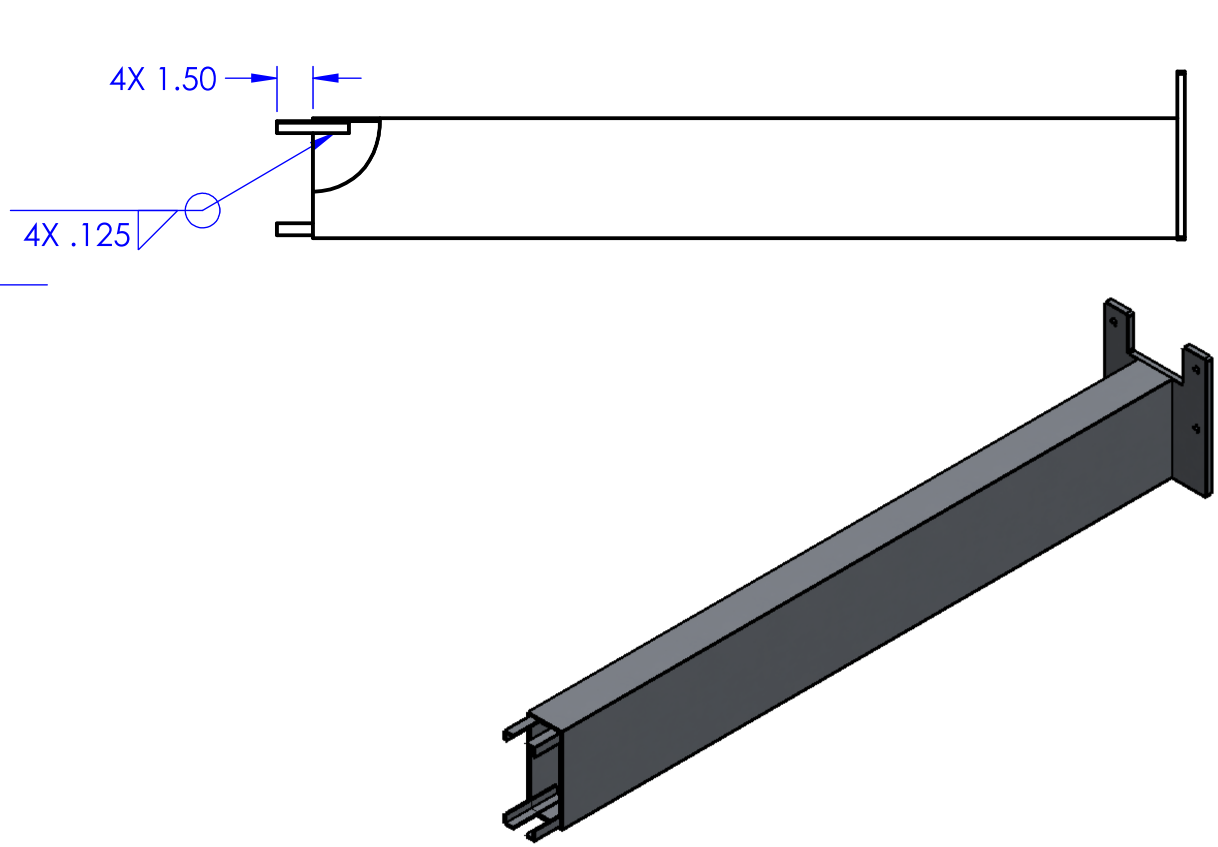
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	4010	RAIL BOTTOM LEG WELDMENT	1
2	R5-0074-07/R5-0079-07	LATCHES	2
3	2190A21	HINGE	1
4	4020	STAKE WELDMENT	1
5	RT1578000	WARN RT15 WINCH	1
6	92865A583	5/16" BOLT	4
7	97149A150	5/16" NYLOC NUT	4

NOTES: RIVET LATCHES TO RAILING USING 1/4" RIVETS

USE 1/8" BOLTS TO FASTEN HINGE TO RAILING AND STAKE WELDMENT

SCALE: 1:12	TITLE: LOWER RAIL ASSEMBLY		LAUNCHER ASSEMBLY
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 4000		Cal Poly Mechanical Engineering
	MATL: SEE BOM		Rocket Power
	Drwn. By: JOC	02/01/14	
	Chkd. By: CRV	02/01/14	Senior Project for Aerojet-Rocketdyne





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	4013	RAIL LOWER LEG	1
2	4012	RAIL CORNER ALIGNMENT	4
3	4011	MOUNTING PLATE	1

NOTES:

LOWER RAIL ASSEMBLY

Cal Poly Mechanical Engineering

Rocket Power

Senior Project for Aerojet-Rocketdyne

SCALE: 1:8

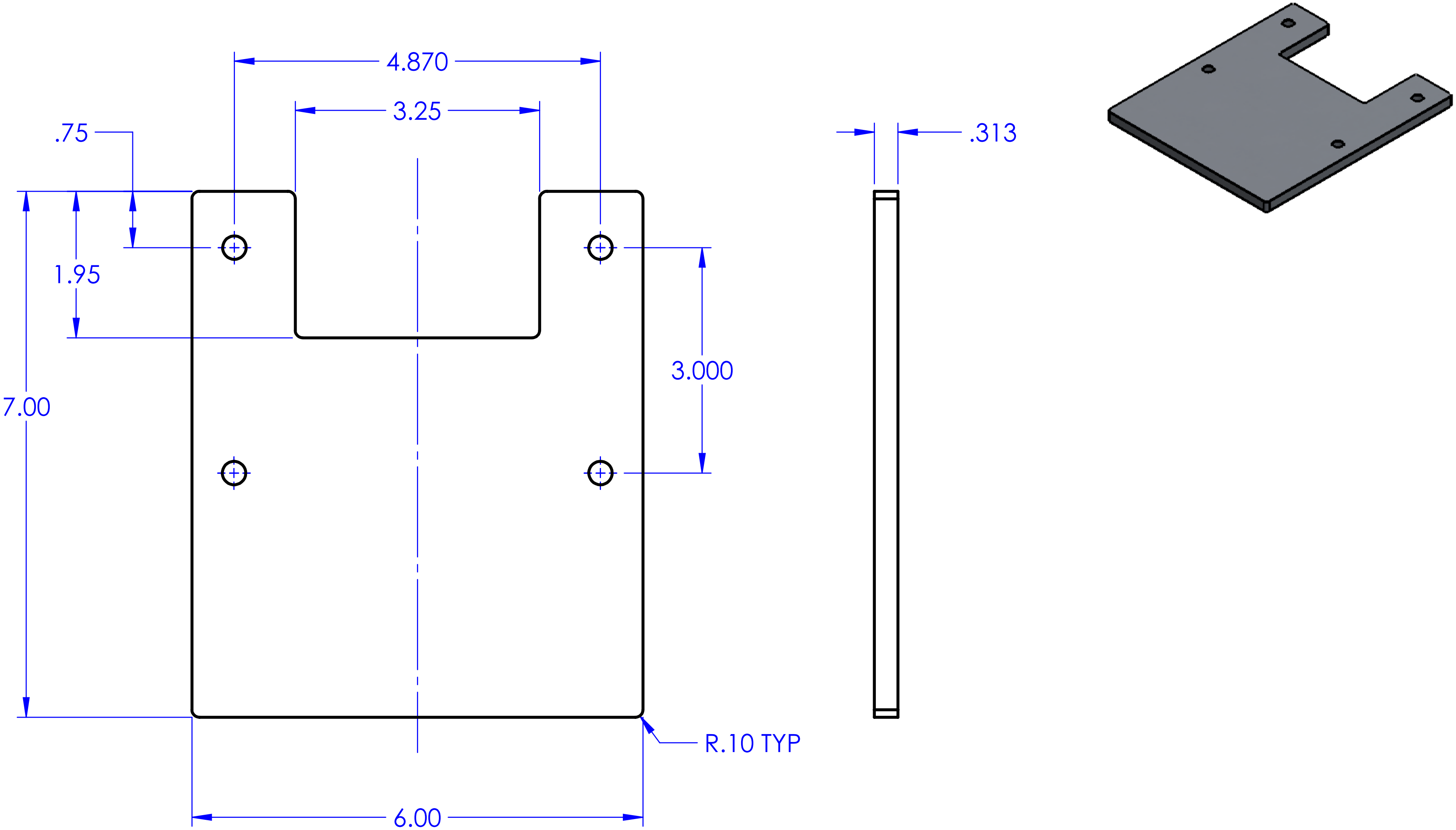
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/64
ANGULAR: MACH ± 1° BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

TITLE: **RAIL BOTTOM LEG WELDMENT**

Dwg. #: 4010

MATL: SEE BOM

Drwn. By:	CRV	02/01/14
Chkd. By:	JOC	02/01/14



NOTES:

SCALE:	1:2
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	

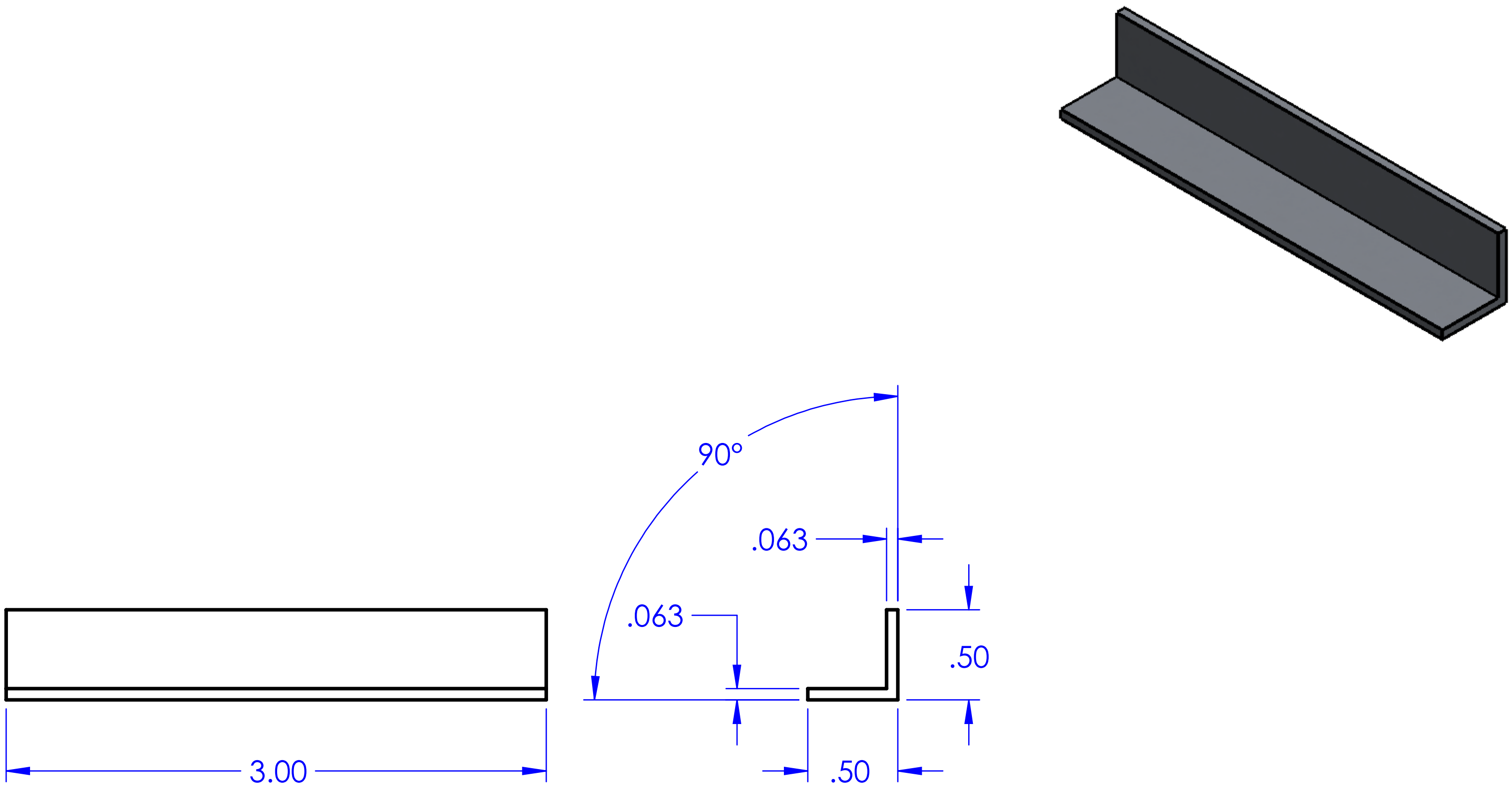
TITLE:	**WINCH MOUNTING PLATE**	
Dwg. #:	4011	
MATL:	ALUMINUM 6061-T6	
Drwn. By:	CRV	02/01/14
Chkd. By:	JOC	02/01/14

RAIL BOTTOM LEG WELDM.

Cal Poly Mechanical Engineering

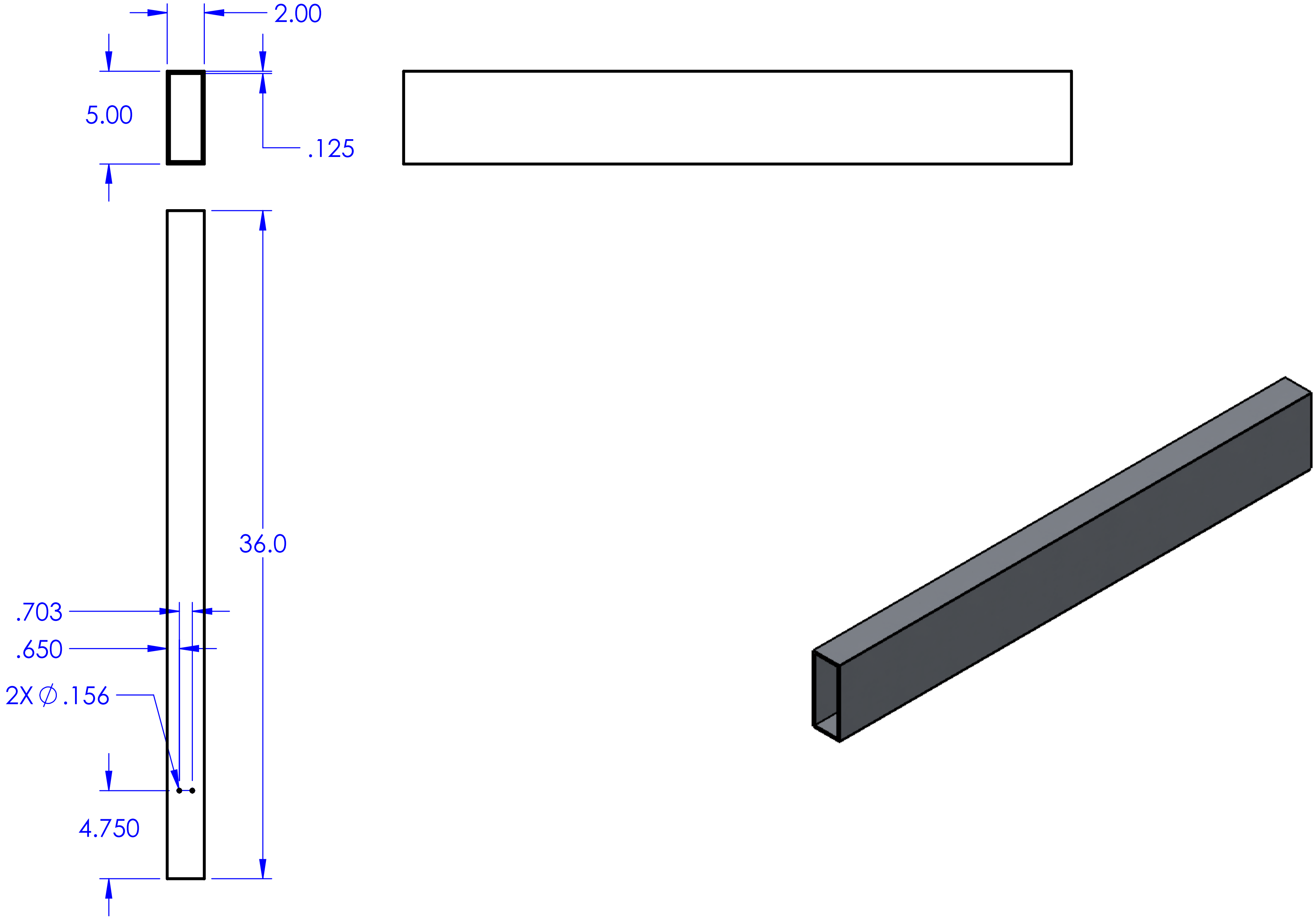
Rocket Power

Senior Project for Aerojet-Rocketdyne



NOTES:

SCALE: 1:1	TITLE: **CORNER ALIGNMENT**		**RAIL BOTTOM LEG WELDMENT**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 4012		Cal Poly Mechanical Engineering
	MATL: ALUM. 6061-T6		Rocket Power
	Drwn. By: JOC	02/01/14	
	Chkd. By: CRV	02/01/14	Senior Project for Aerojet-Rocketdyne



NOTES:

SCALE: 1:8	TITLE: **RAIL LOWER LEG**		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 4013		
	MATL: ALUM. 6061-T6		
	Drwn. By:	JOC	02/01/14
	Chkd. By:	CRV	02/01/14

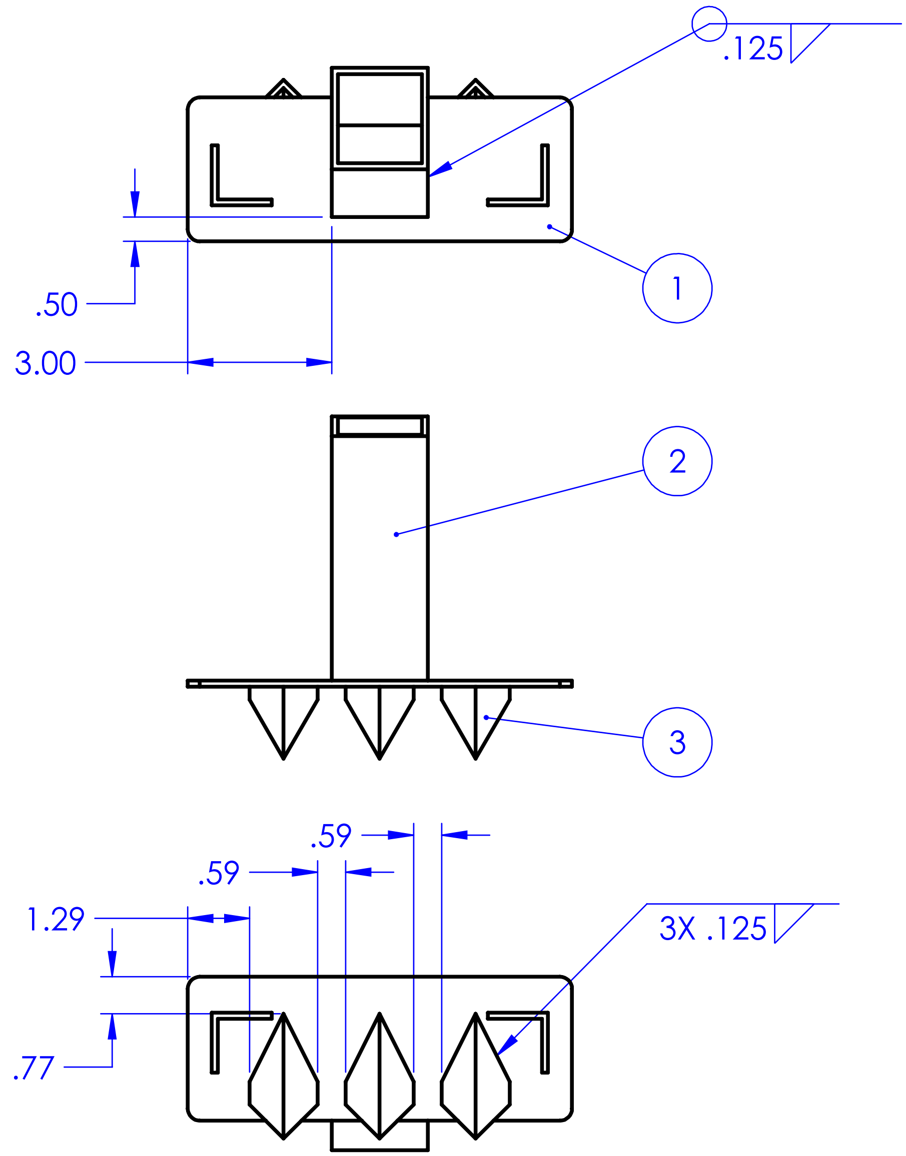
RAIL BOTTOM LEG WELDMENT

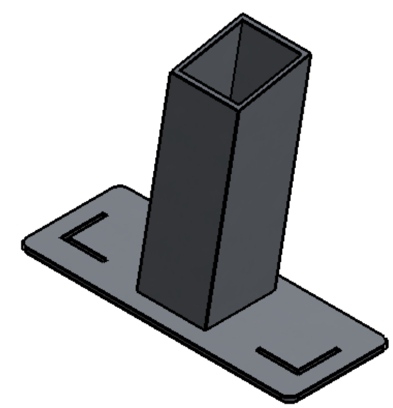
Cal Poly Mechanical Engineering

Rocket Power

Senior Project for Aerojet-Rocketdyne

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	4021	STAKE BOTTOM PLATE	1
2	4022	STAKE STAND	1
3	4023	RAKE SPIKE	3





NOTES:

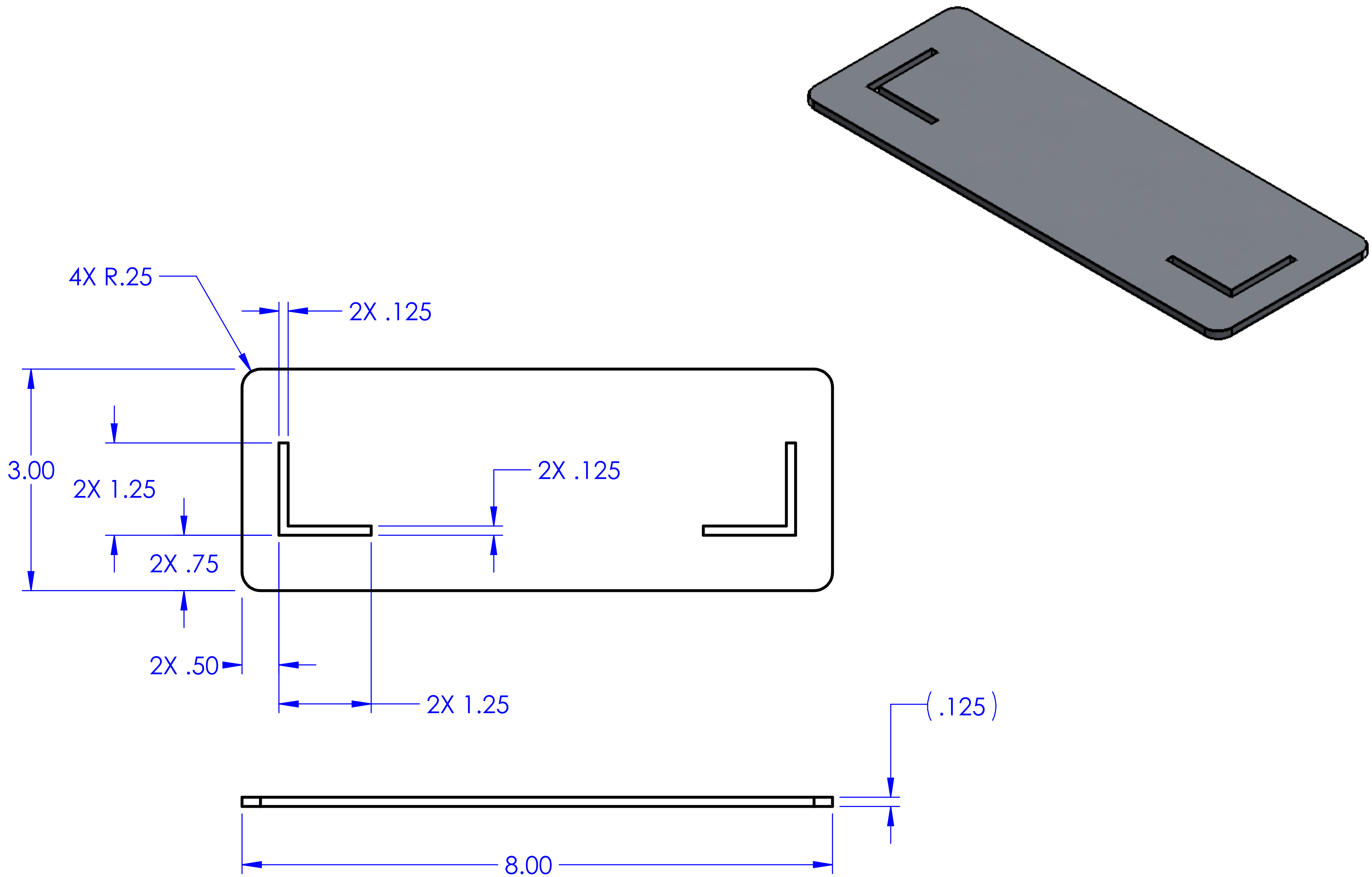
SCALE: 1:4	TITLE: **STAKE WELDMENT**		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 4020		
	MATL: SEE BOM		
	Drwn. By:	JOC	02/01/14
	Chkd. By:	CRV	02/01/14

LOWER RAIL ASSEMBLY

Cal Poly Mechanical Engineering

Rocket Power

Senior Project for Aerojet-Rocketdyne



NOTES:

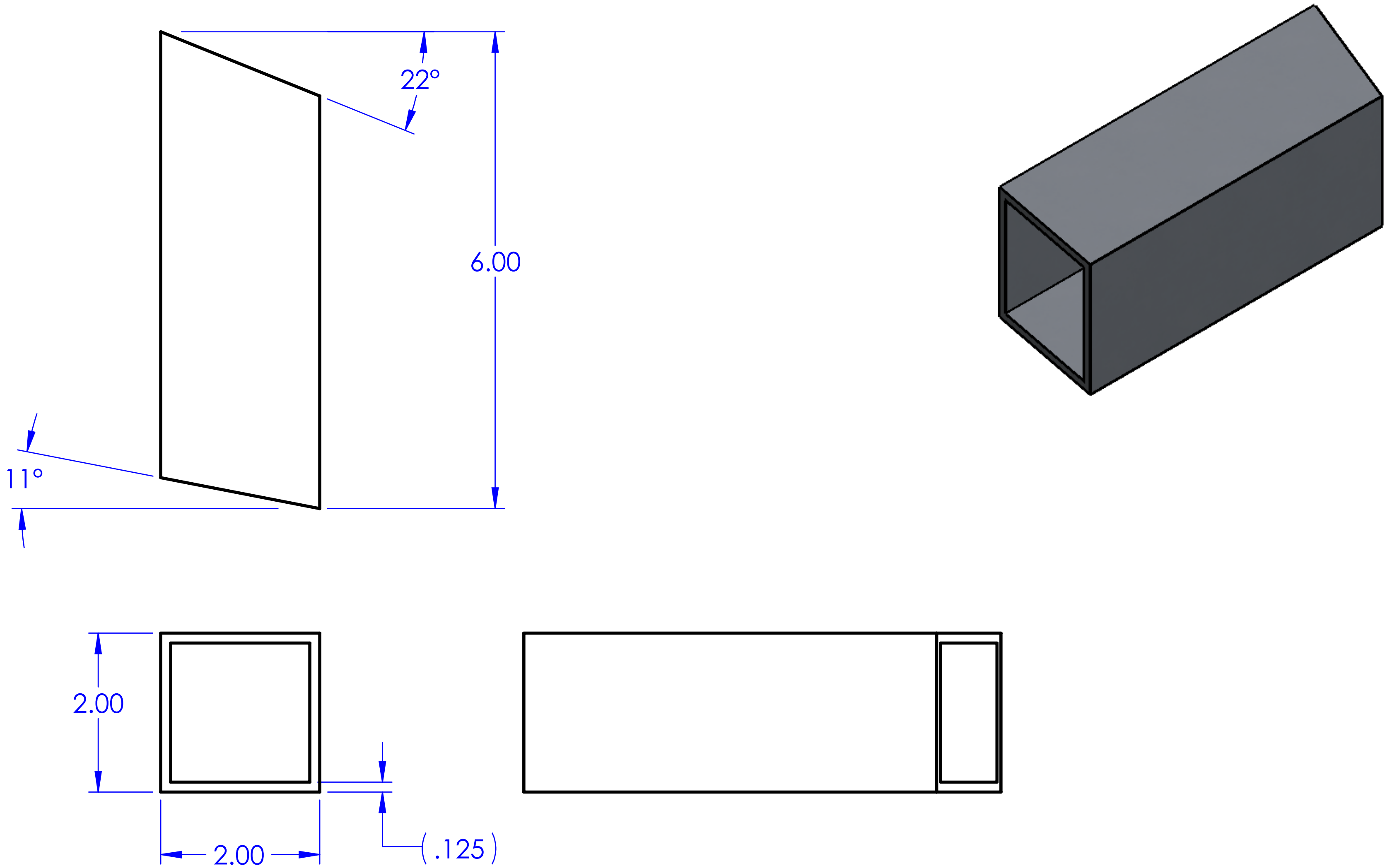
SCALE: 1:2	TITLE: **STAKE BOTTOM PLATE**		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 4021		
	MATL: ALUM. 6061-T6		
	Drwn. By:	CRV	02/01/14
	Chkd. By:	JOC	02/01/14

STAKE WELDMENT

Cal Poly Mechanical Engineering

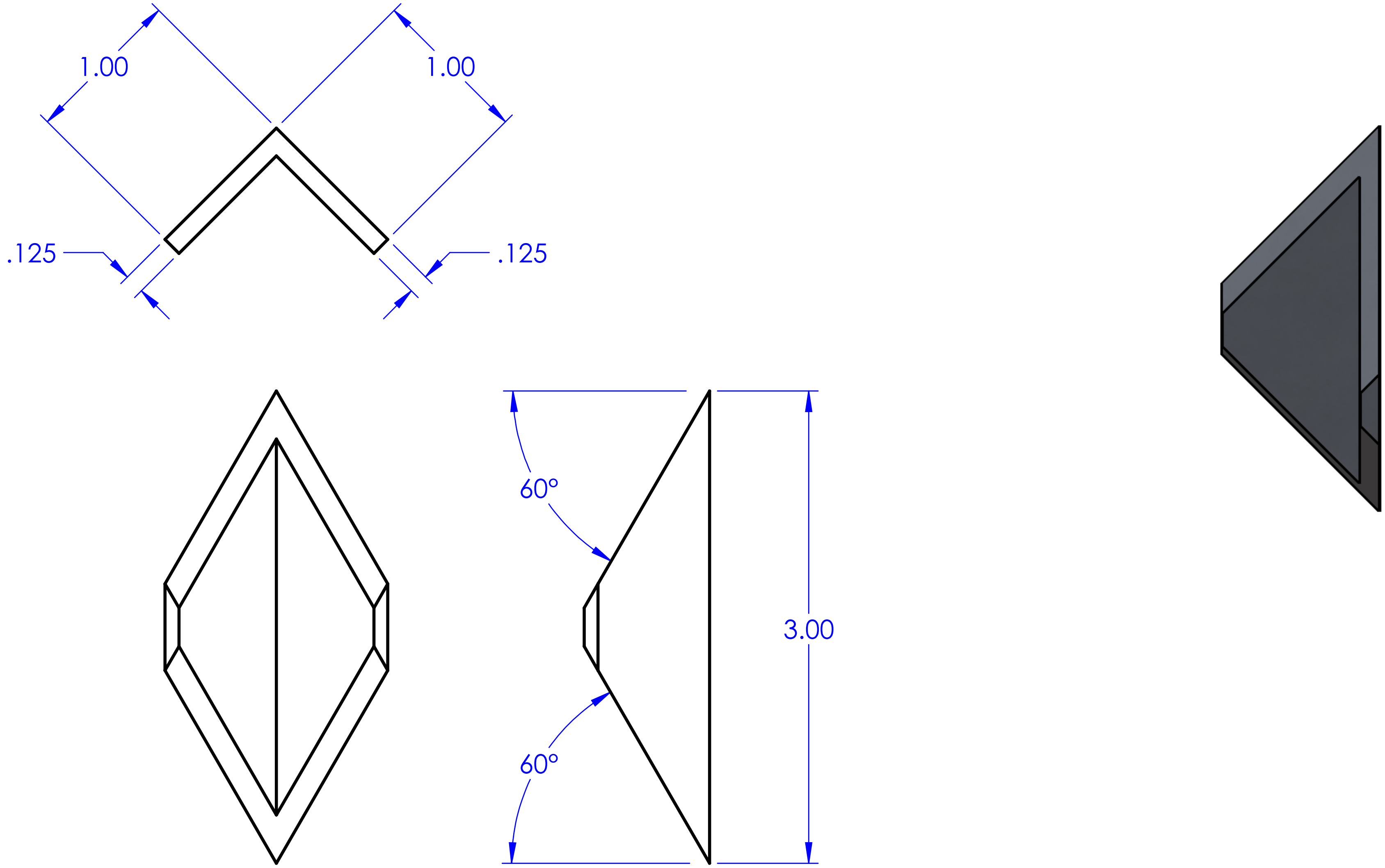
Rocket Power

Senior Project for Aerojet-Rocketdyne



NOTES:

SCALE: 1:2	TITLE: **STAKE STAND**	**STAKE WELDMENT**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 4022 MATL: ALUM. 6061-T6 Drwn. By: JOC 02/01/14 Chkd. By: CRV 02/01/14	Cal Poly Mechanical Engineering Rocket Power Senior Project for Aerojet-Rocketdyne



NOTES:

SCALE: 1:1	TITLE: **RAKE SPIKE**		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 4023		
	MATL: ALUM. 6061-T6		
	Drwn. By:	JOC	02/01/14
	Chkd. By:	CRV	02/01/14

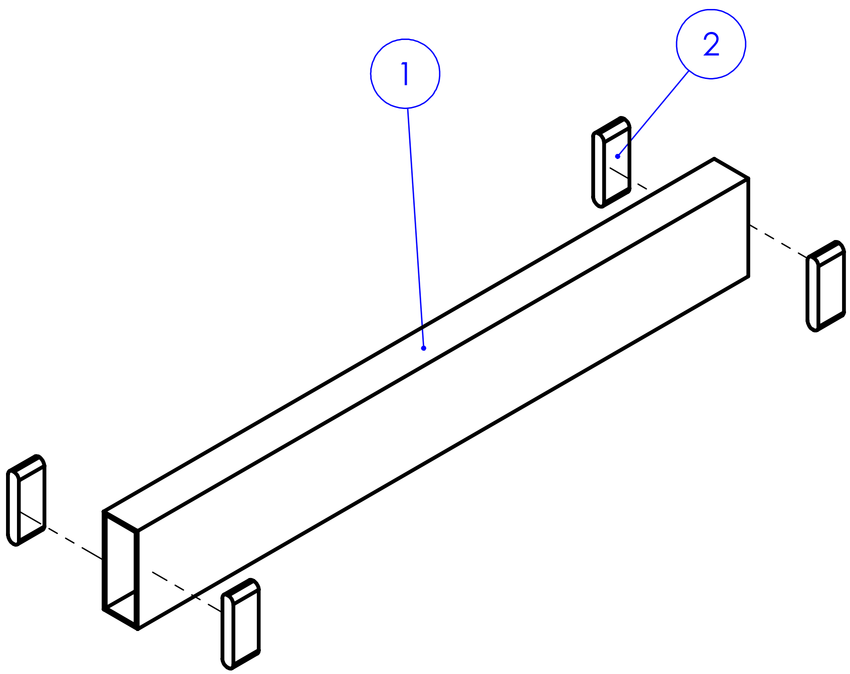
STAKE WELDMENT

Cal Poly Mechanical Engineering

Rocket Power

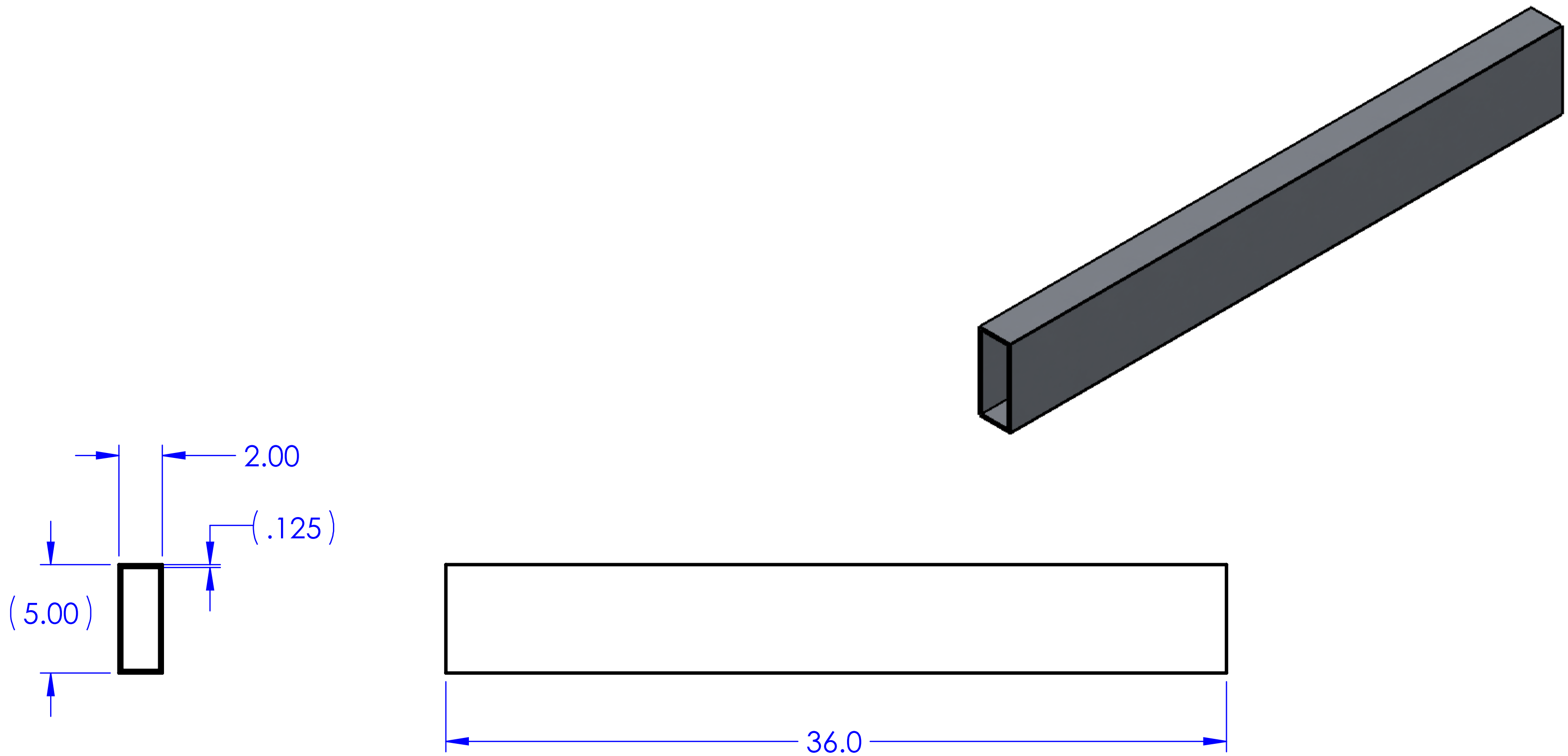
Senior Project for Aerojet-Rocketdyne

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	5001	RAIL MIDDLE LEG	1
2	R5-0074-07/R5-0079-07	LATCH	4



NOTES: RIVET LATCHES TO RAILING USING 1/4" RIVETS

SCALE: 1:8	TITLE: **MIDDLE RAIL ASSEMBLY**		**LAUNCHER ASSEMBLY**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 5000 MATL: SEE BOM		Cal Poly Mechanical Engineering Rocket Power
	Drwn. By: CRV	02/01/14	
	Chkd. By: JOC	02/01/14	Senior Project for Aerojet-Rocketdyne



NOTES:

SCALE: 1:8

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/64
ANGULAR: MACH ± 1° BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

TITLE: **Rail Middle Leg**
Dwg. #: 5001
MATL: ALUM. 6061-T6

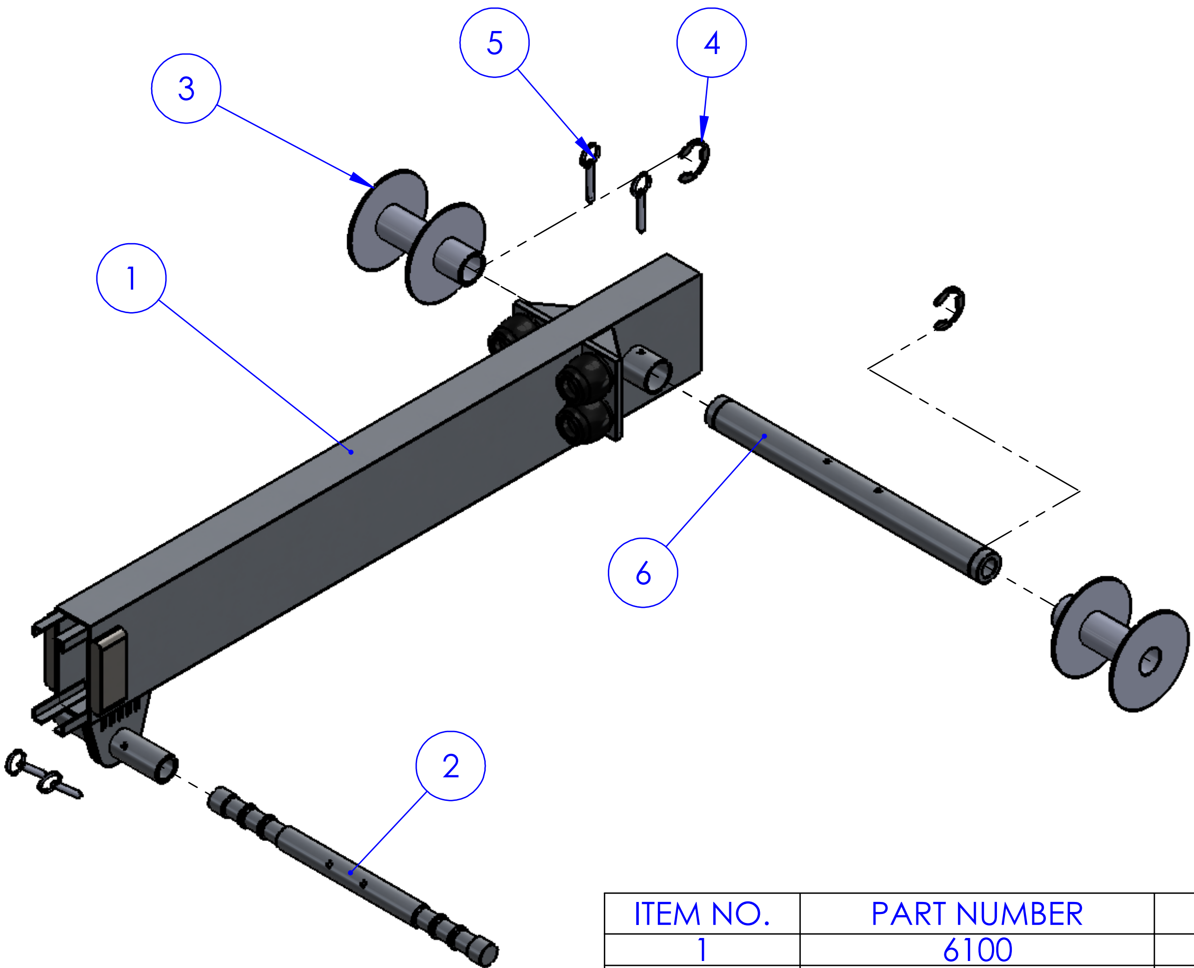
Drwn. By:	JOC	02/01/14
Chkd. By:	CRV	02/01/14

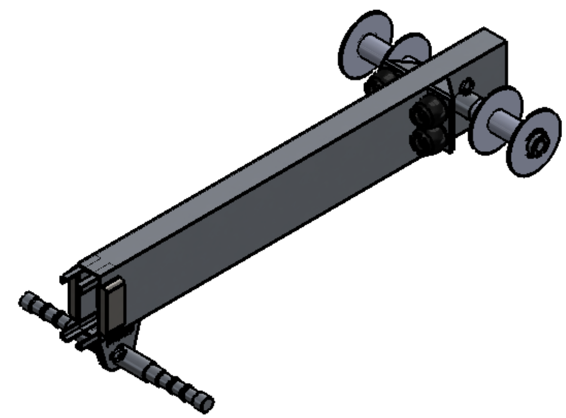
MIDDLE RAIL ASSEMBLY

Cal Poly Mechanical Engineering

Rocket Power

Senior Project for Aerojet-Rocketdyne

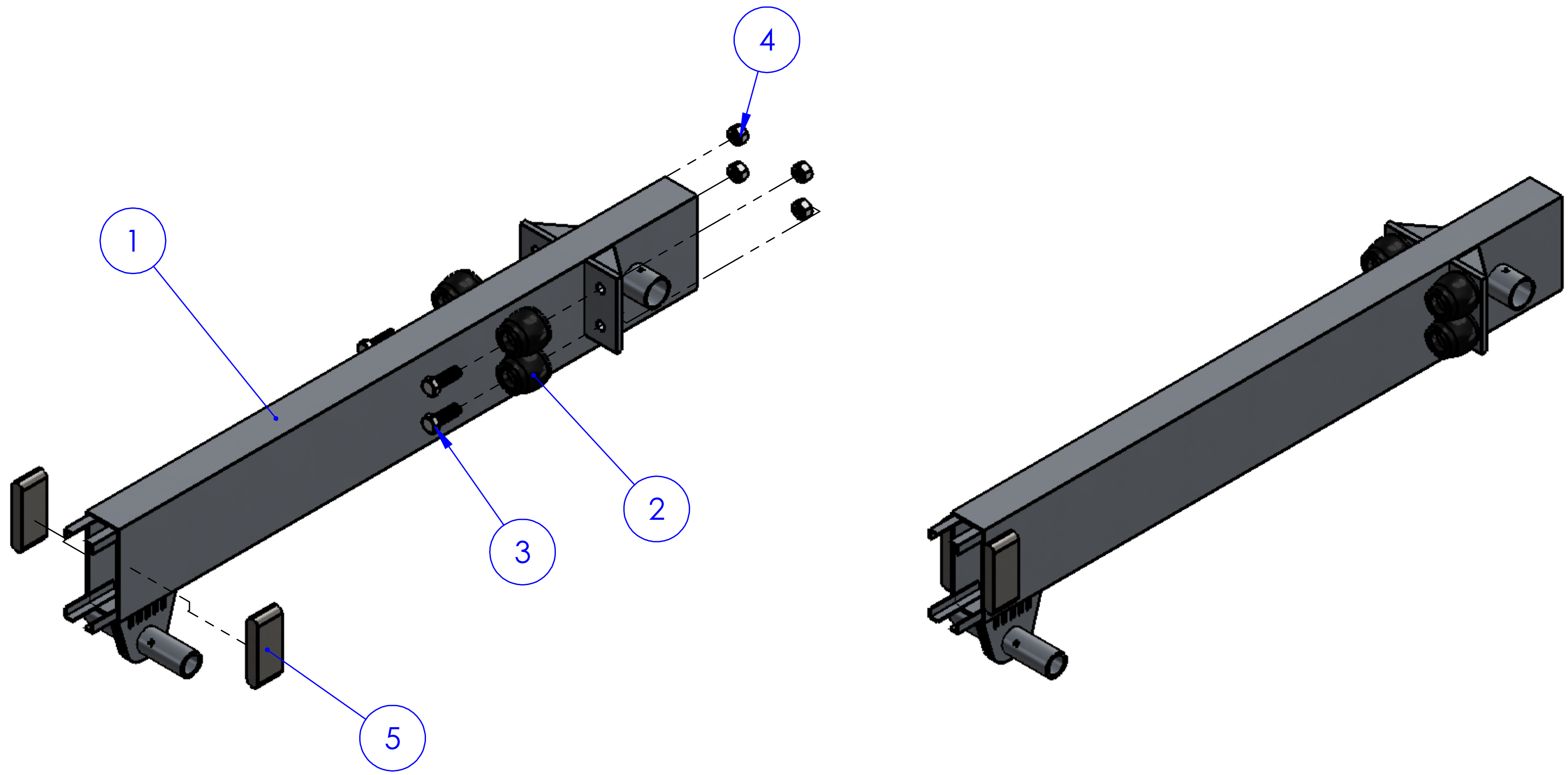




ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	6100	UPPER PERMANENT ASSEMBLY	1
2	3103	BOTTOM BUNGEE SHAFT	1
3	6023	BUNGEE ROLLER	2
4	97431A400	E-RING	2
5	95255A268	QUICK RELEASE PIN	4
6	6004	UPPER BUNGEE SHAFT	1

NOTES:

SCALE: 1:8	TITLE: **UPPER RAIL ASSEMBLY**		**LAUNCHER**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 6000		Cal Poly Mechanical Engineering
	MATL: SEE BOM		Rocket Power
	Drwn. By: JOC	02/01/14	
	Chkd. By: CRV	02/01/14	Senior Project for Aerojet-Rocketdyne



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	6010	RAIL TOP LEG WELDMENT	1
2	9677K22	RUBBER BUMPER	4
3	92865A716	BUMPER BOLT	4
4	90473A223	BUMPER NUT	4
5	R5-0074-07/R5-0079-07	LATCHES	2

NOTES: RIVET LATCHES TO RAILING USING 1/4" RIVETS

UPPER RAIL ASSEMBLY

SCALE: 1:8

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/64
ANGULAR: MACH ± 1° BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

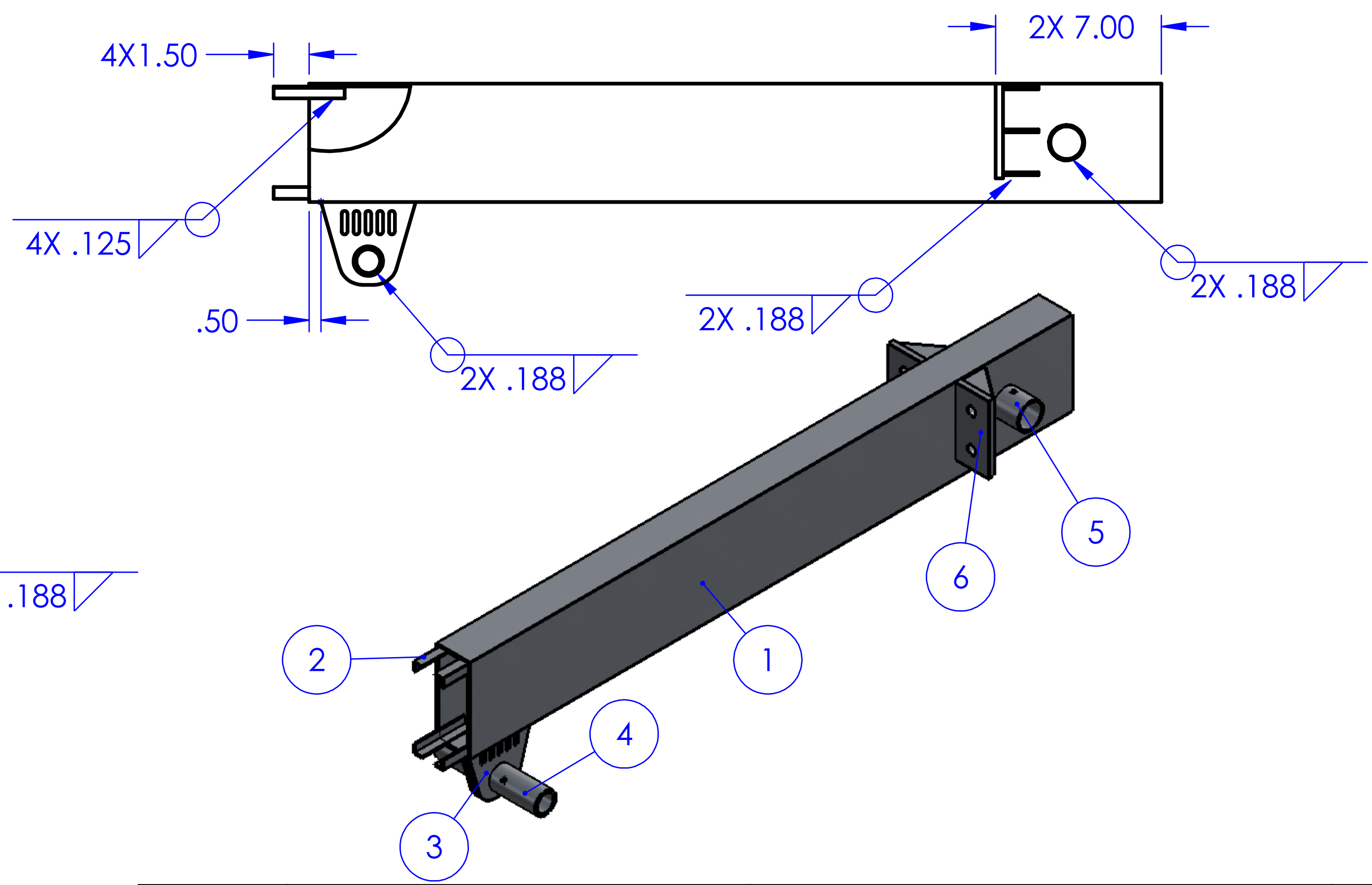
TITLE: **UPPER PERMANENT ASSEMBLY**
Dwg. #: 6100
MATL: SEE BOM

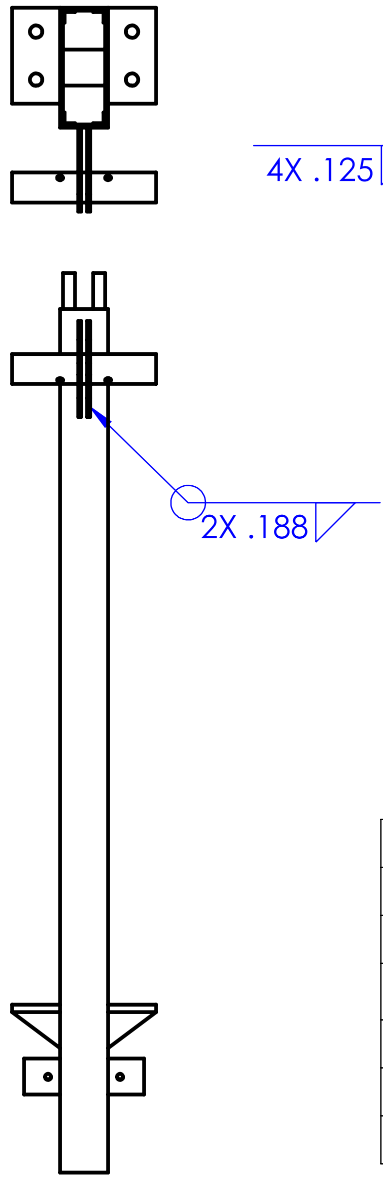
Drwn. By:	CRV	02/01/14
Chkd. By:	JOC	02/01/14

Cal Poly Mechanical Engineering

Rocket Power

Senior Project for Aerojet-Rocketdyne





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	6011	RAIL TOP LEG	1
2	4012	CORNER ALIGNMENT	4
3	6012	BUNGEE BOTTOM CONNECTION PLATE	2
4	6013	BOTTOM BUNGEE SLEEVE	1
5	4013	UPPER WELDMENT SLEEVE	1
6	6020	BUMPER SUPPORT WELDMENT	2

NOTES: FOR POSITIONS NOT SPECIFIED, ASSUME SYMMETRY WITH RESPECT TO THE RECTANGULAR TUBING

UPPER PERMANTENT ASSEMBLY

SCALE: 1:8

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/64
ANGULAR: MACH ± 1° BEND ± 1°
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

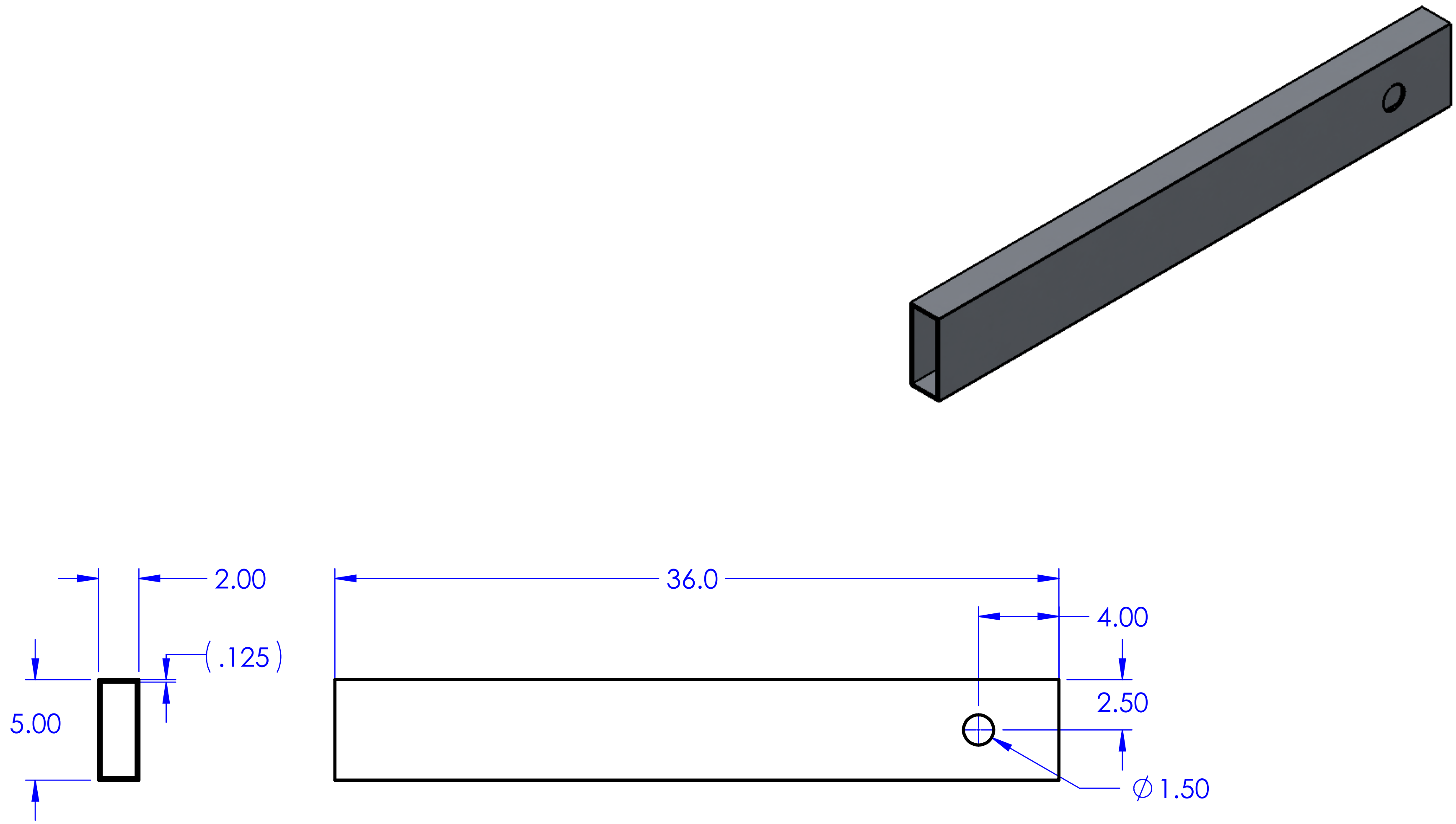
TITLE: **RAIL TOP LEG WELDMENT**
Dwg. #: 6010
MATL: SEE BOM

Drwn. By:	joc	02/01/14
Chkd. By:	CRV	02/01/14

Cal Poly Mechanical Engineering

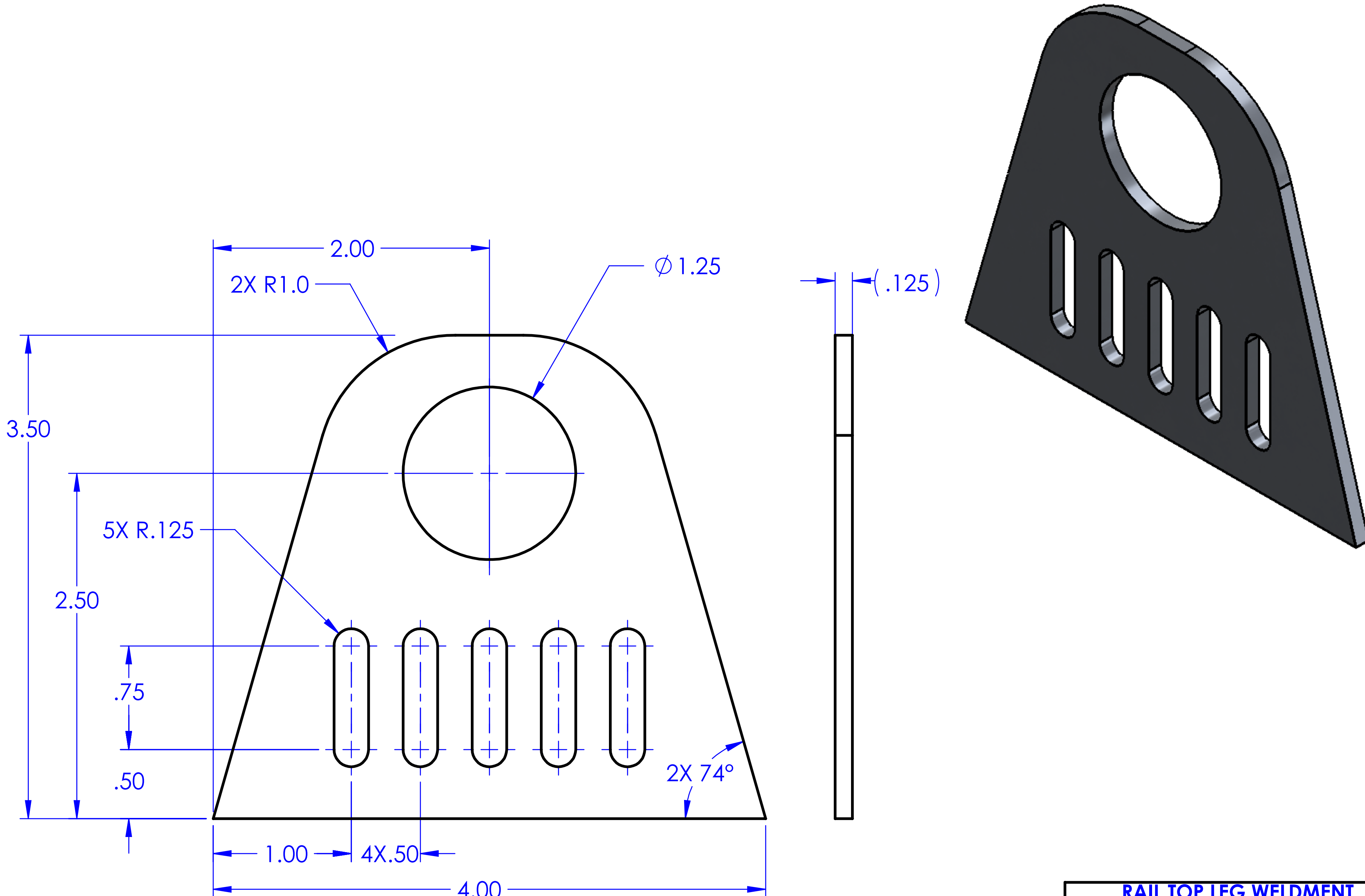
Rocket Power

Senior Project for Aerojet-Rocketdyne



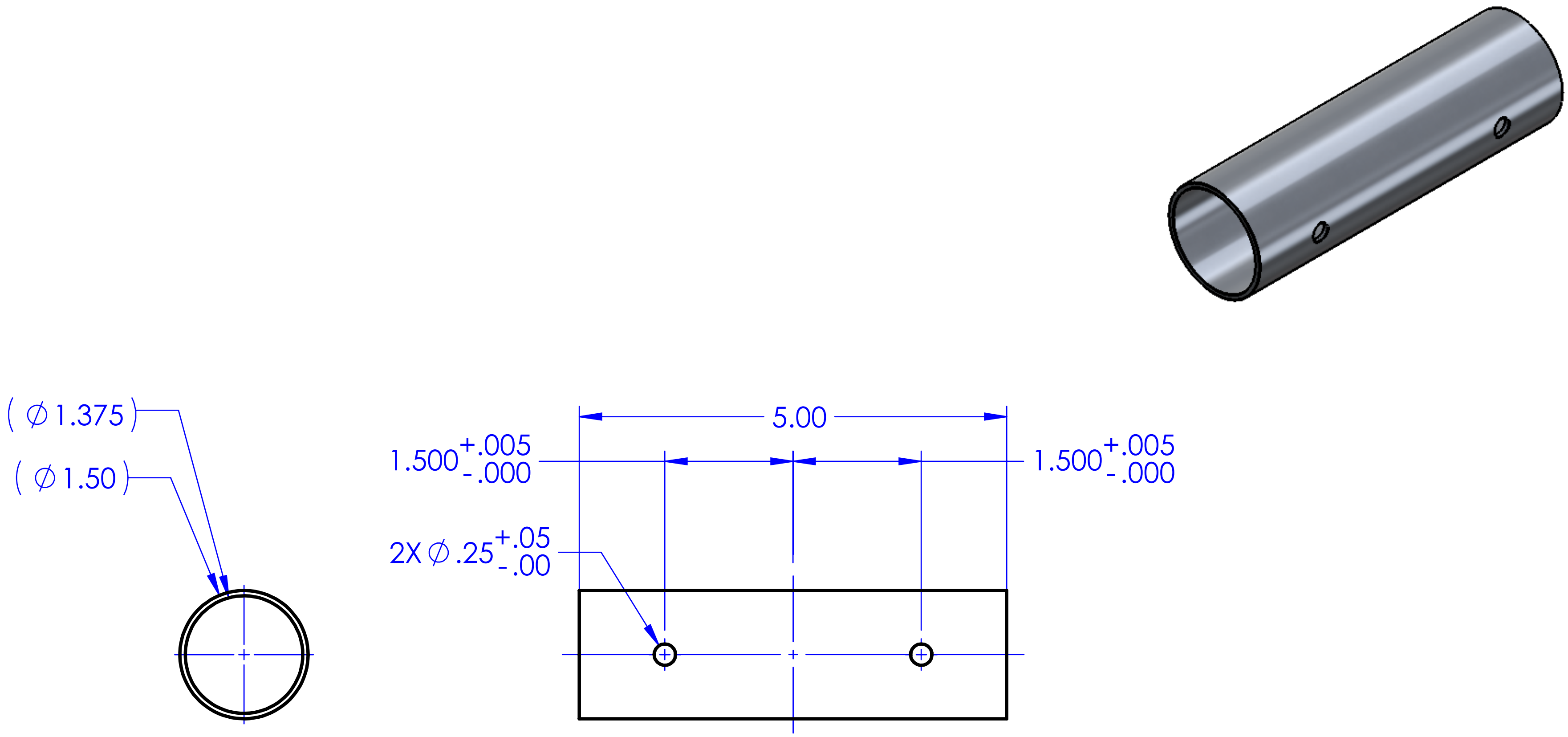
NOTES:

SCALE: 1:8	TITLE: **RAIL TOP LEG**		**UPPER RAIL WELDMENT**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 6011		Cal Poly Mechanical Engineering
	MATL: ALUM. 6061-T6		Rocket Power
	Drwn. By: JOC	02/01/14	
	Chkd. By: CRV	02/01/14	Senior Project for Aerojet-Rocketdyne



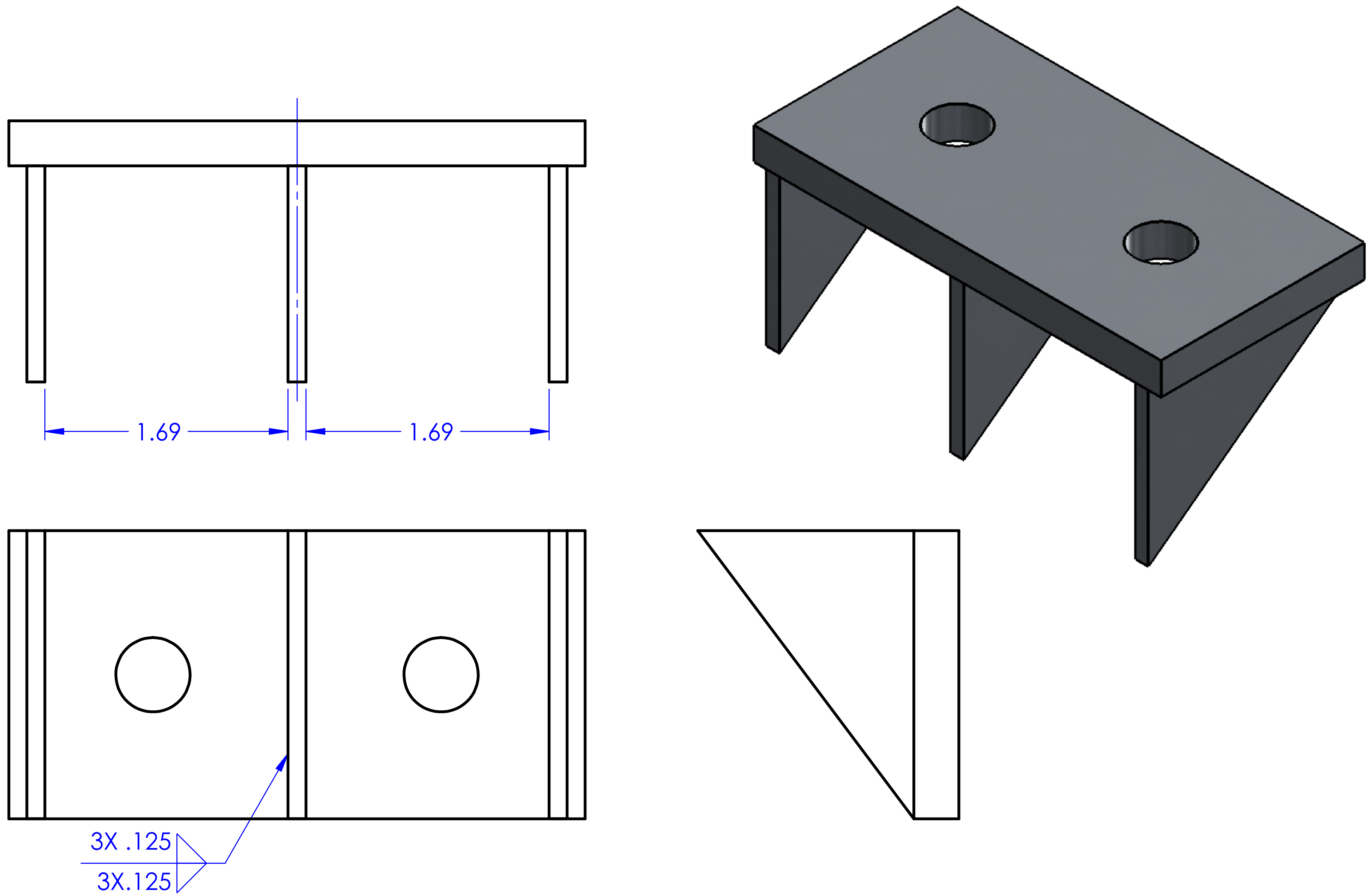
NOTES:

SCALE: 1:1	TITLE: **BUNGEE BOTTOM CONNECTION PLATE**			**RAIL TOP LEG WELDMENT**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 6012			Cal Poly Mechanical Engineering Rocket Power
	MATL: ALUM. 6061-T6			
	Drwn. By:	JOC	02/01/14	
	Chkd. By:	CRV	02/01/14	Senior Project for Aerojet-Rocketdyne



NOTES:

SCALE: 1:2	TITLE: **UPPER WELDMENT SLEEVE**	**RAIL TOP LEG WELDMENT**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 6013 MATL: ALUM. 6061-T6 Drwn. By: JOC 02/01/14 Chkd. By: CRV 02/01/14	Cal Poly Mechanical Engineering Rocket Power Senior Project for Aerojet-Rocketdyne



NOTES:

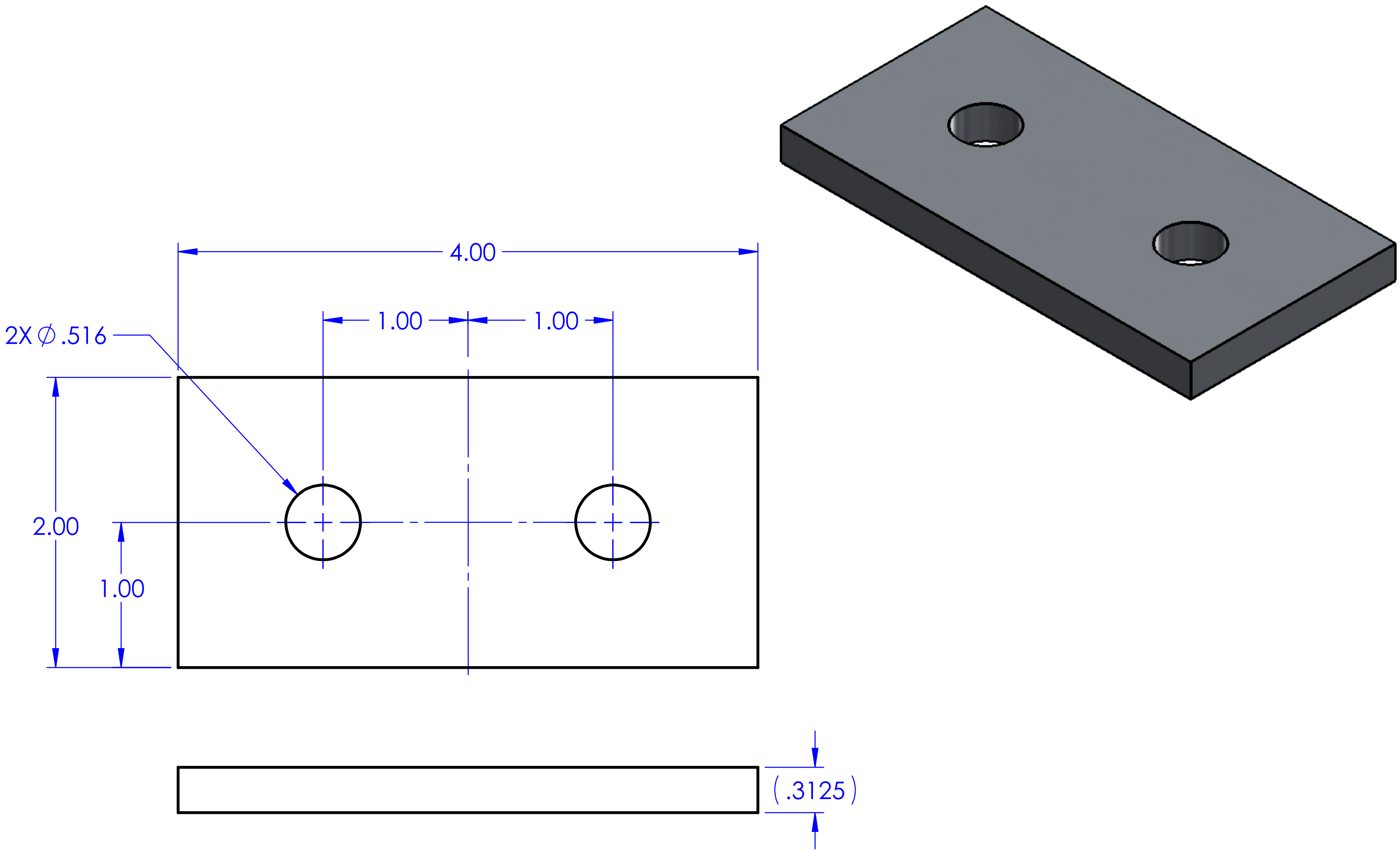
SCALE: 1:1	TITLE: **BUMPER SUPPORT WELDMENT**		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 6020		
	MATL: ALUM. 6061-T6		
	Drwn. By:	JOC	02/01/14
	Chkd. By:	CRV	02/01/14

RAIL TOP LEG WELDMENT

Cal Poly Mechanical Engineering

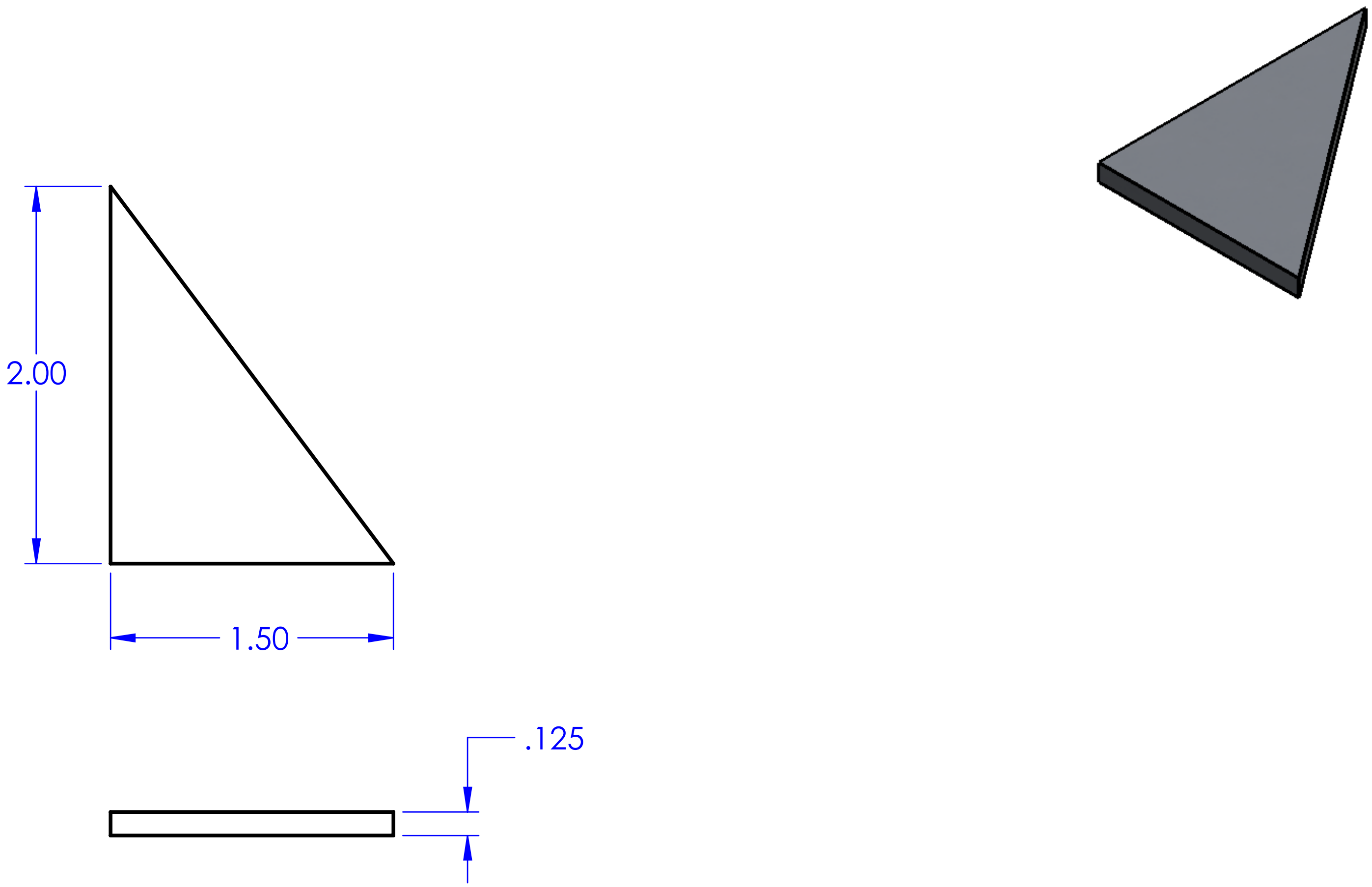
Rocket Power

Senior Project for Aerojet-Rocketdyne



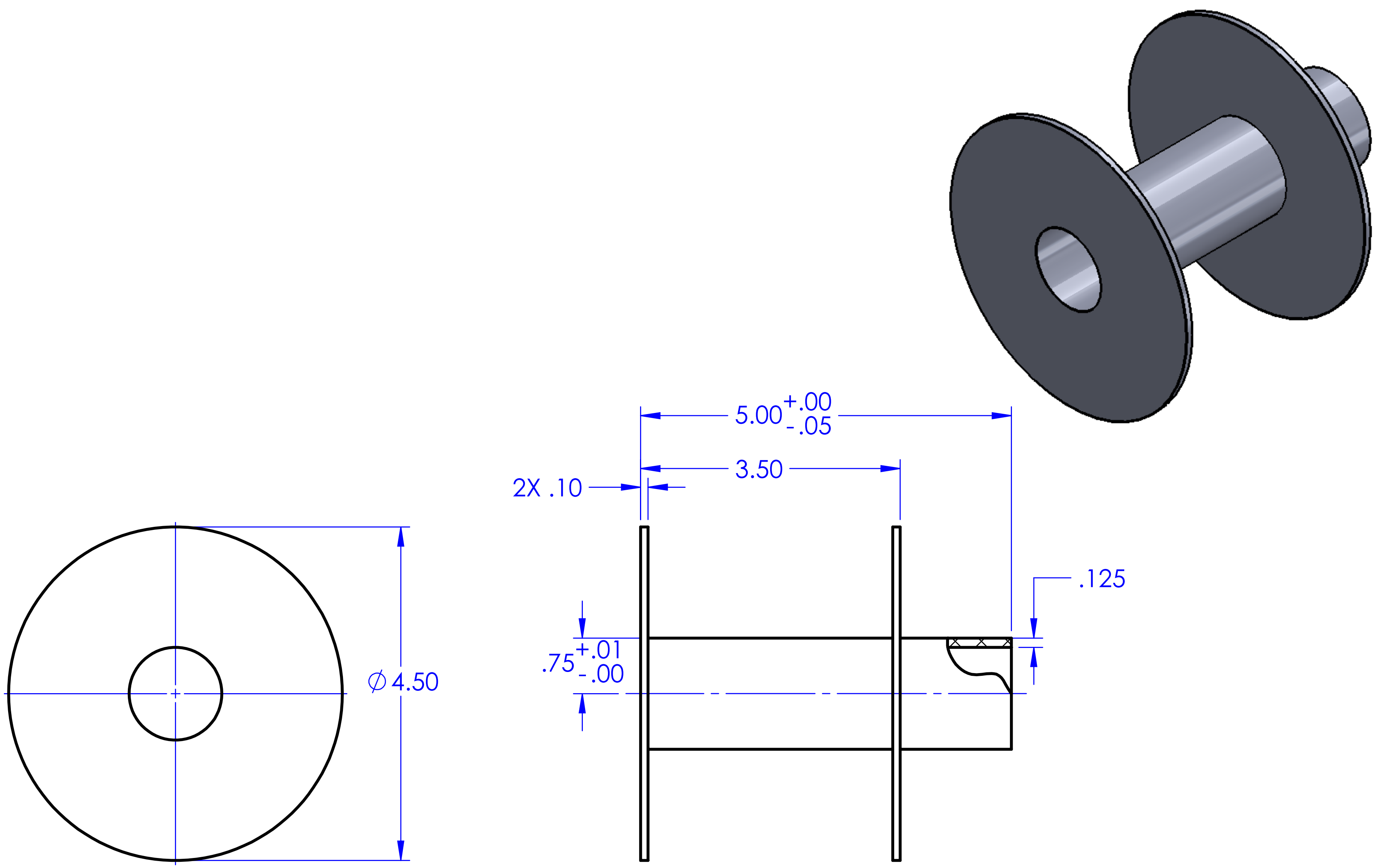
NOTES:

SCALE: 1:1	TITLE: **BUMPER SUPPORT PLATE**			**BUMPER SUPPORT WELDMENT**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 6021			Cal Poly Mechanical Engineering
	MATL: ALUM. 6061-T6			Rocket Power
	Drwn. By:	JOC	02/01/14	
	Chkd. By:	CRV	02/01/14	Senior Project for Aerojet-Rocketdyne



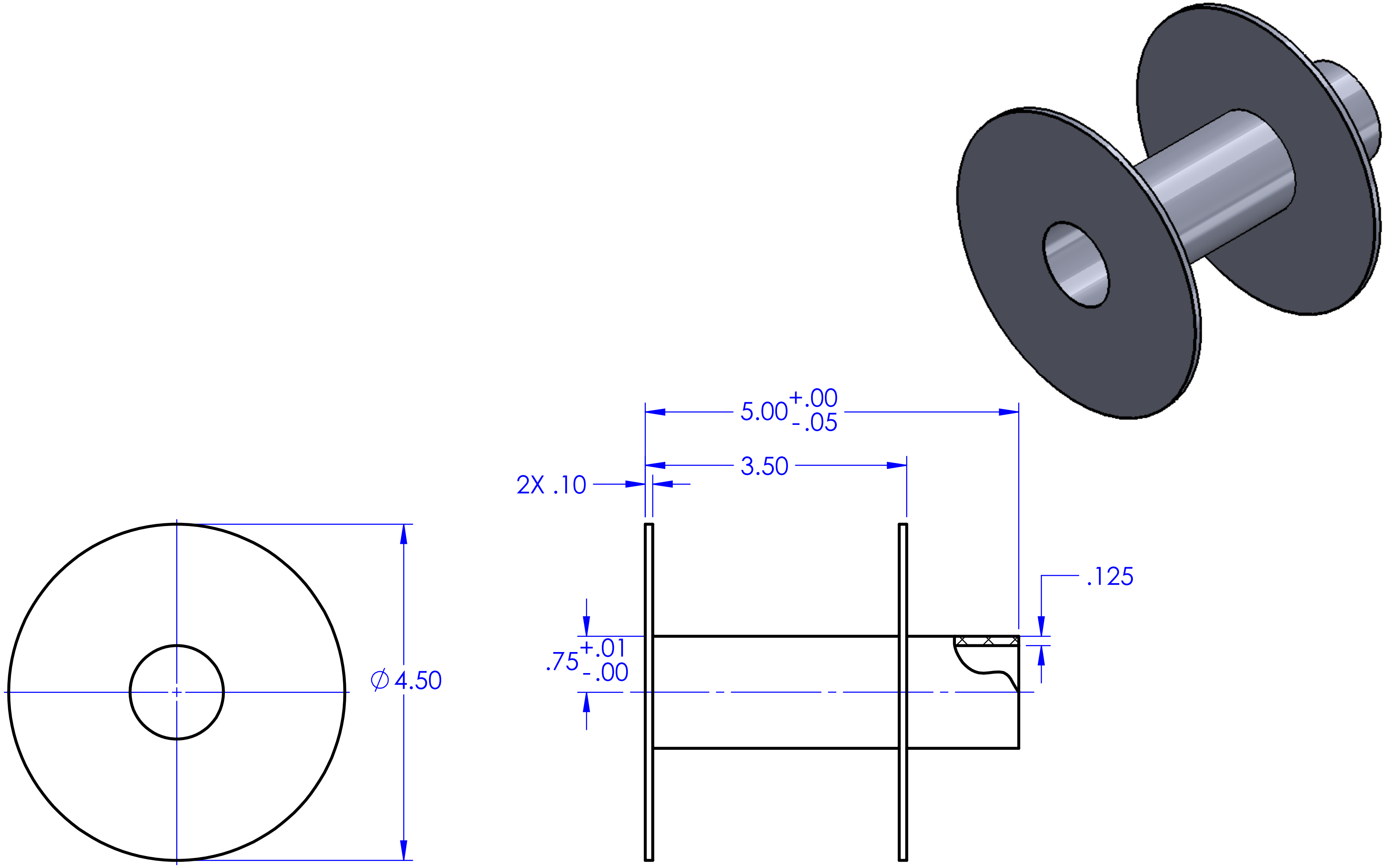
NOTES:

SCALE: 1:1	TITLE: **BUMPER SUPPORT RIB**		**BUMPER SUPPORT WELDMENT**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 6022		Cal Poly Mechanical Engineering
	MATL: ALUM. 6061-T6		Rocket Power
	Drwn. By: JOC	02/01/14	
	Chkd. By: CRV	02/01/14	Senior Project for Aerojet-Rocketdyne



NOTES:

SCALE: 1:2	TITLE: **BUNGEE ROLLER**		**UPPER RAIL ASSEMBLY**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 3102		Cal Poly Mechanical Engineering
	MATL: ALUM. 6061-T6		Rocket Power
	Drwn. By: JOC	02/01/14	
	Chkd. By: CRV	02/01/14	Senior Project for Aerojet-Rocketdyne



NOTES:

SCALE:	1:2
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	

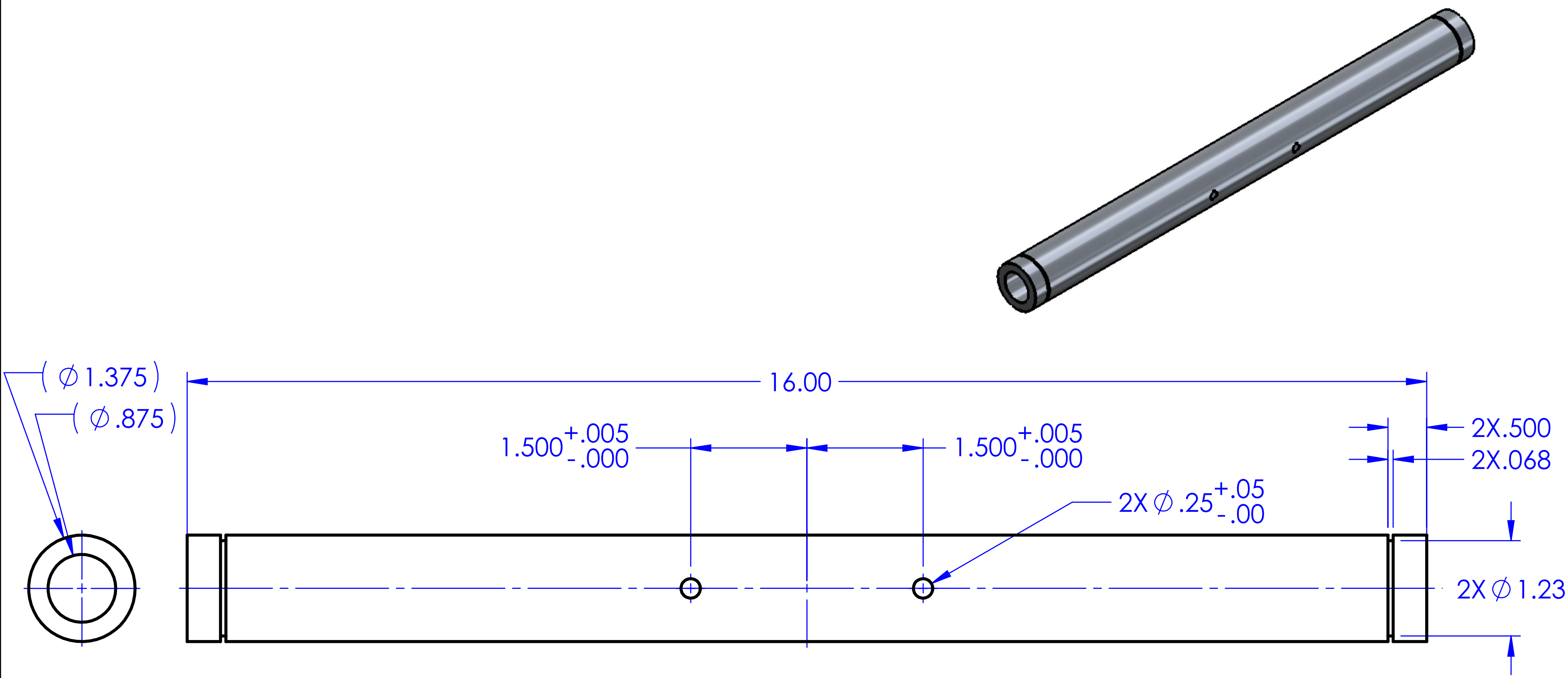
TITLE:	**BUNGEE ROLLER**	
Dwg. #:	3102	
MATL:	ALUM. 6061-T6	
Drwn. By:	JOC	02/01/14
Chkd. By:	CRV	02/01/14

UPPER RAIL ASSEMBLY

Cal Poly Mechanical Engineering

Rocket Power

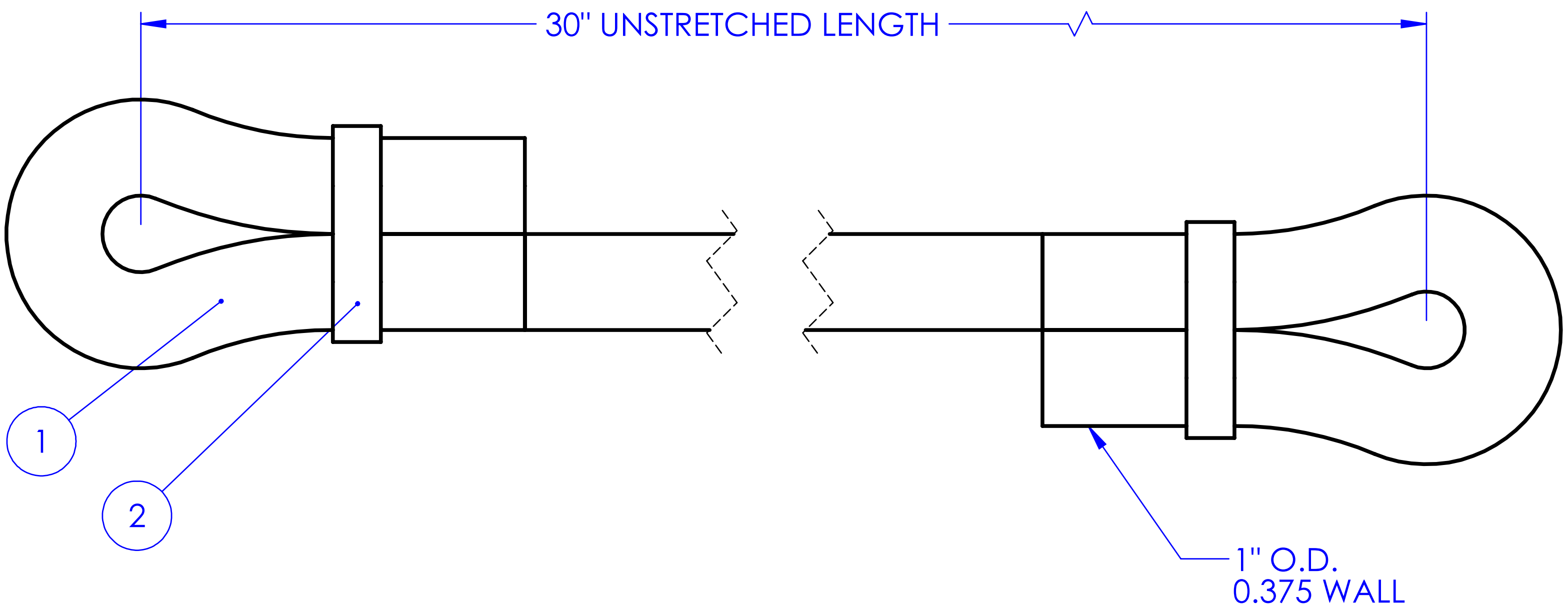
Senior Project for Aerojet-Rocketdyne



NOTES:

SCALE: 1:2	TITLE: **UPPER BUNGEE SHAFT**		**UPPER RAIL ASSEMBLY**
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ±1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 6004		Cal Poly Mechanical Engineering Rocket Power
	MATL: ALUM. 6061-T6		
	Drwn. By: JOC	02/01/14	
	Chkd. By: CRV	02/01/14	Senior Project for Aerojet-Rocketdyne

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	CUSTOM	1" O.D. 0.375 WALL LATEX BUNGEE	1
2	TBD	CRIMP RING	1



NOTES:

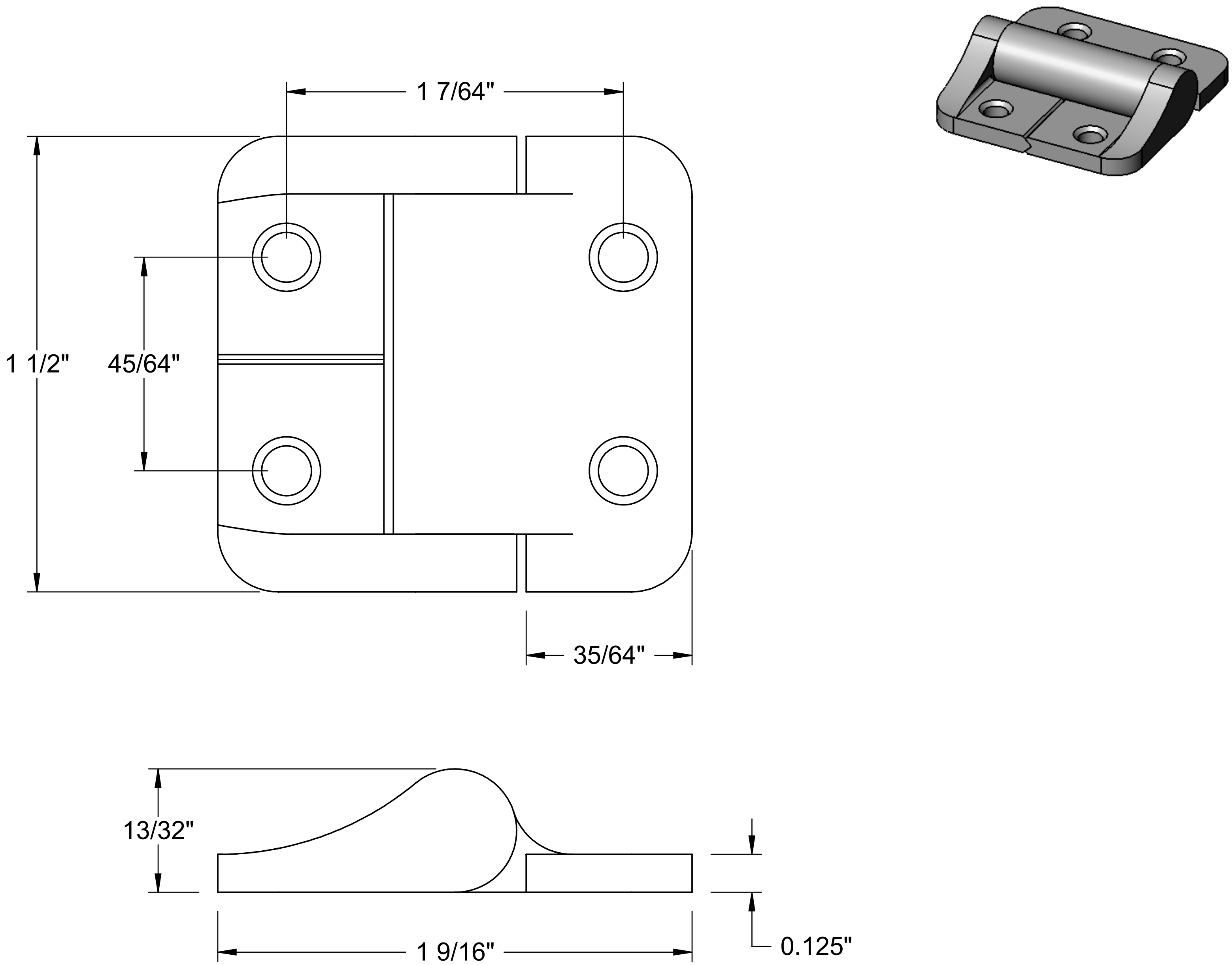
SCALE: N/A	TITLE: **BUNGEE ASSEMBLY**		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 ANGULAR: MACH ± 1° BEND ± 1° TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	Dwg. #: 7000		
	MATL: NATURAL LATEX		
	Drwn. By:	CRV	02/03/14
	Chkd. By:	JOC	02/03/14

BUNGEE ASSEMBLY

Cal Poly Mechanical Engineering

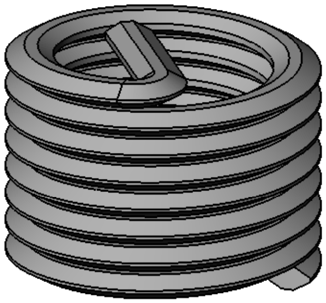
Rocket Power

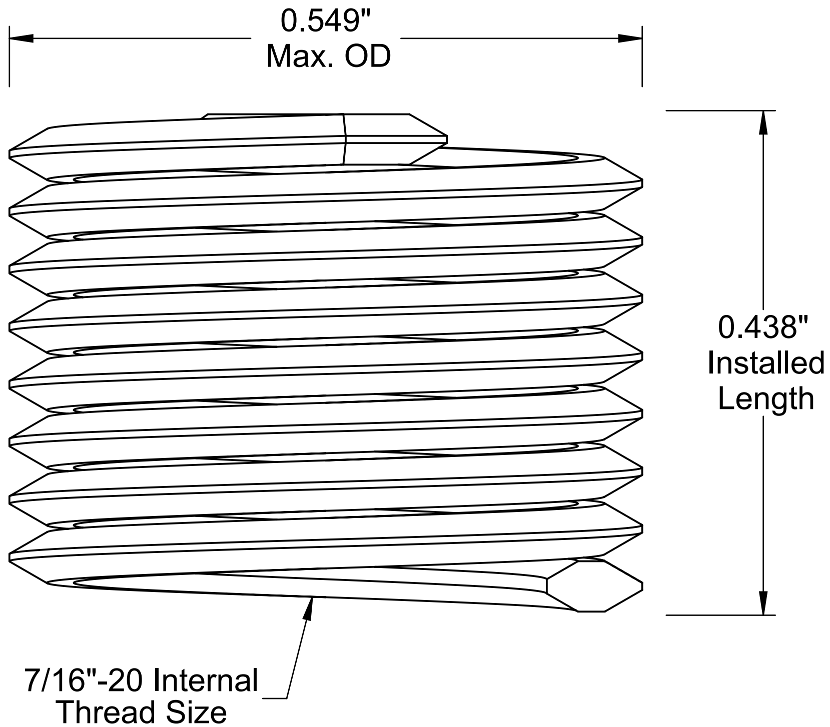
Senior Project for Aerojet-Rocketdyne



Hinge uses #8 screws.

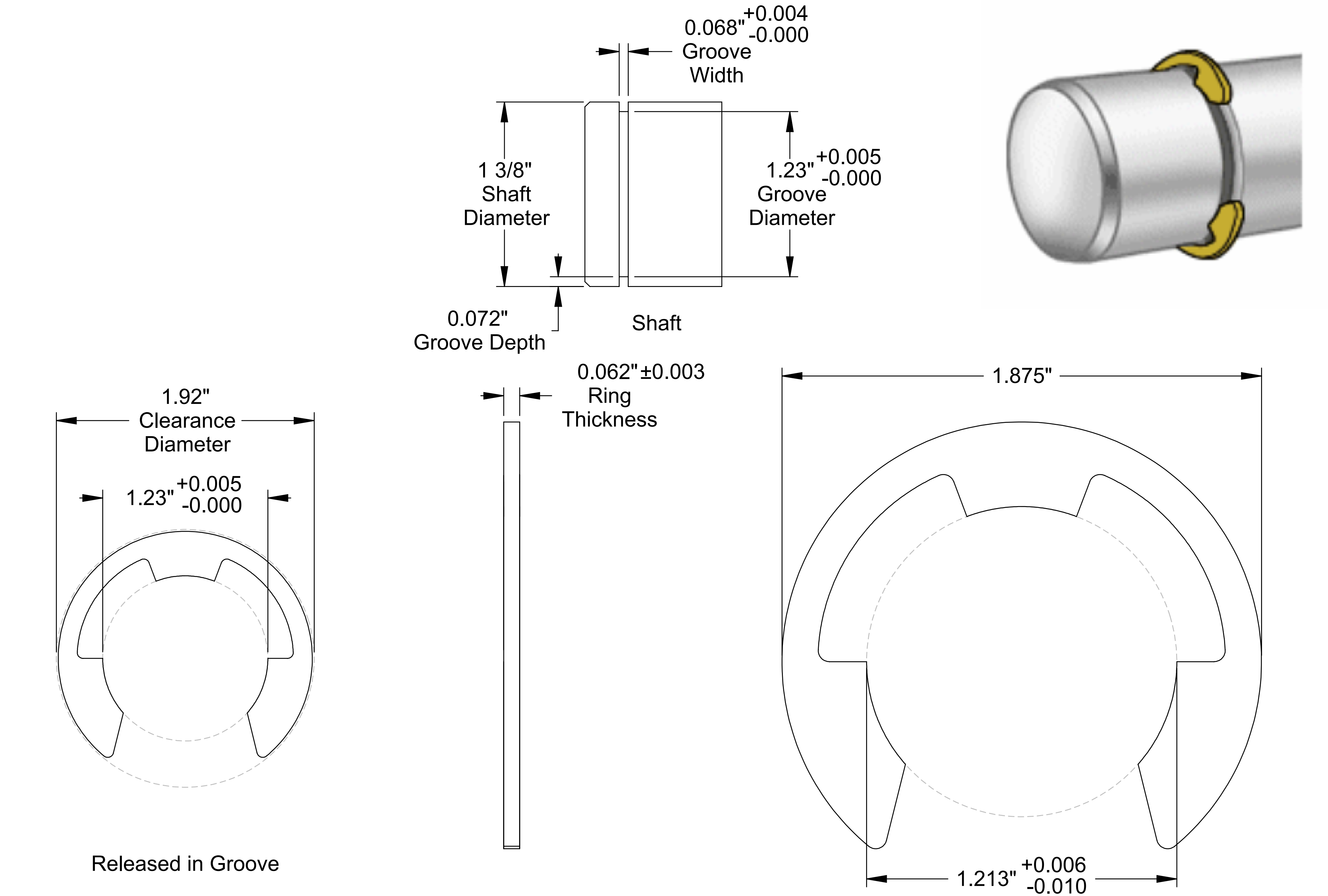
McMASTER-CARR® CAD	PART NUMBER	2190A21
http://www.mcmaster.com Information in this drawing is provided for reference only.	Friction Hinge	





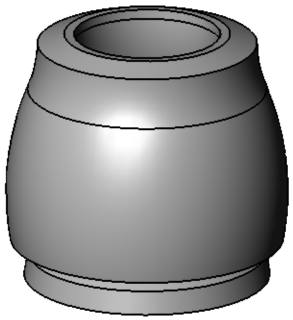
Suggested Drill Bit Size 29/64"
Plug Tap 91709A155 Sold Separately

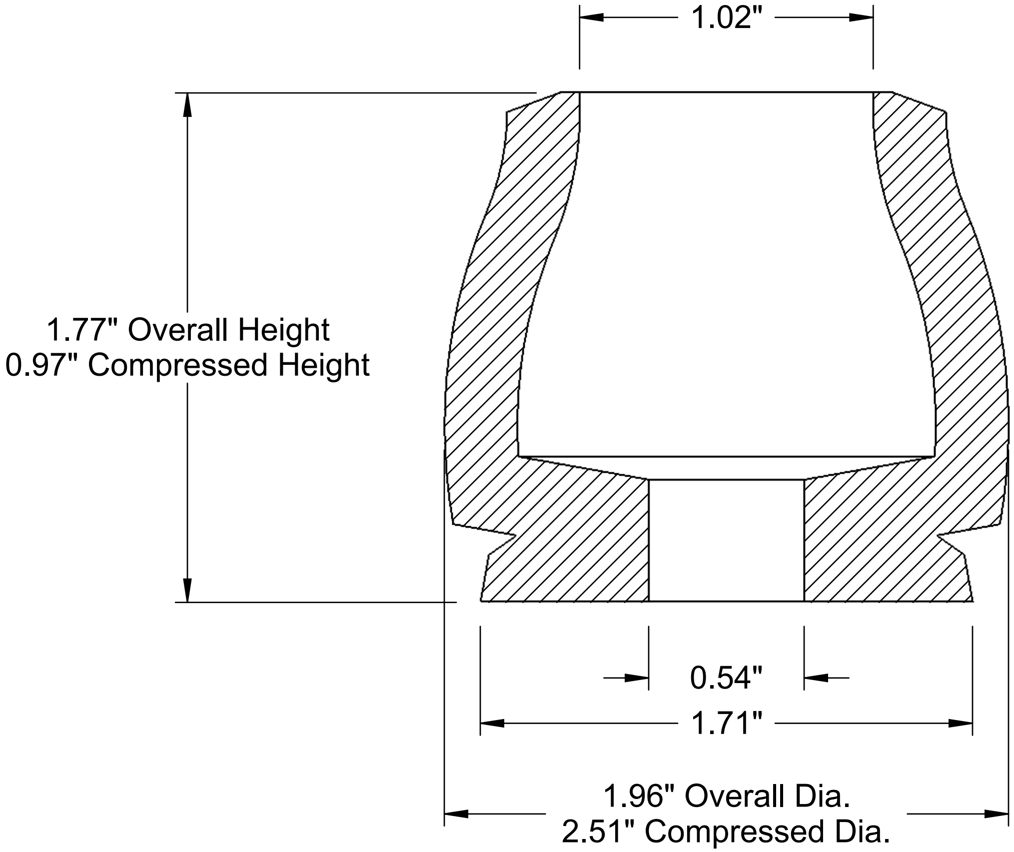
McMASTER-CARR® CAD		PART NUMBER	90296A221
http://www.mcmaster.com © 2012 McMaster-Carr Supply Company Information in this drawing is provided for reference only.		Screw-Lock Helical Insert	



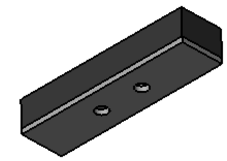
Note: Clearance diameter is the diameter of a housing that can pass freely over the ring.

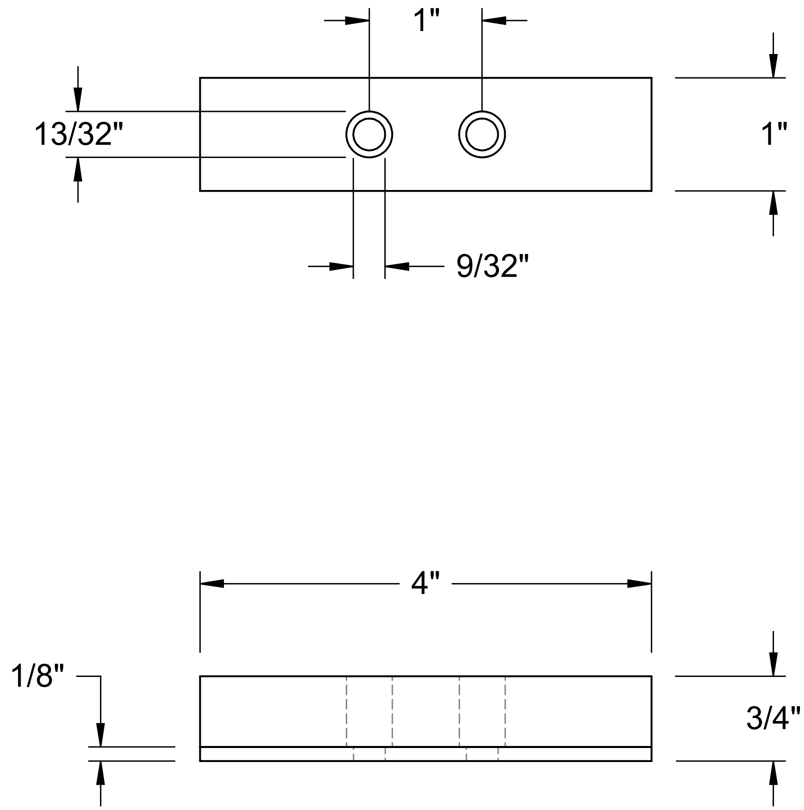
McMASTER-CARR® CAD	PART NUMBER 97431A400
http://www.mcmaster.com © 2011 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Black-Finish Steel Side-Mount External Retaining Ring





McMASTER-CARR® CAD		PART NUMBER	9677K22
http://www.mcmaster.com © 2012 McMaster-Carr Supply Company Information in this drawing is provided for reference only.		Shock-Absorbing Plastic Compression Spring	



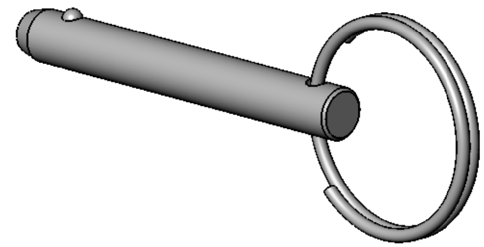


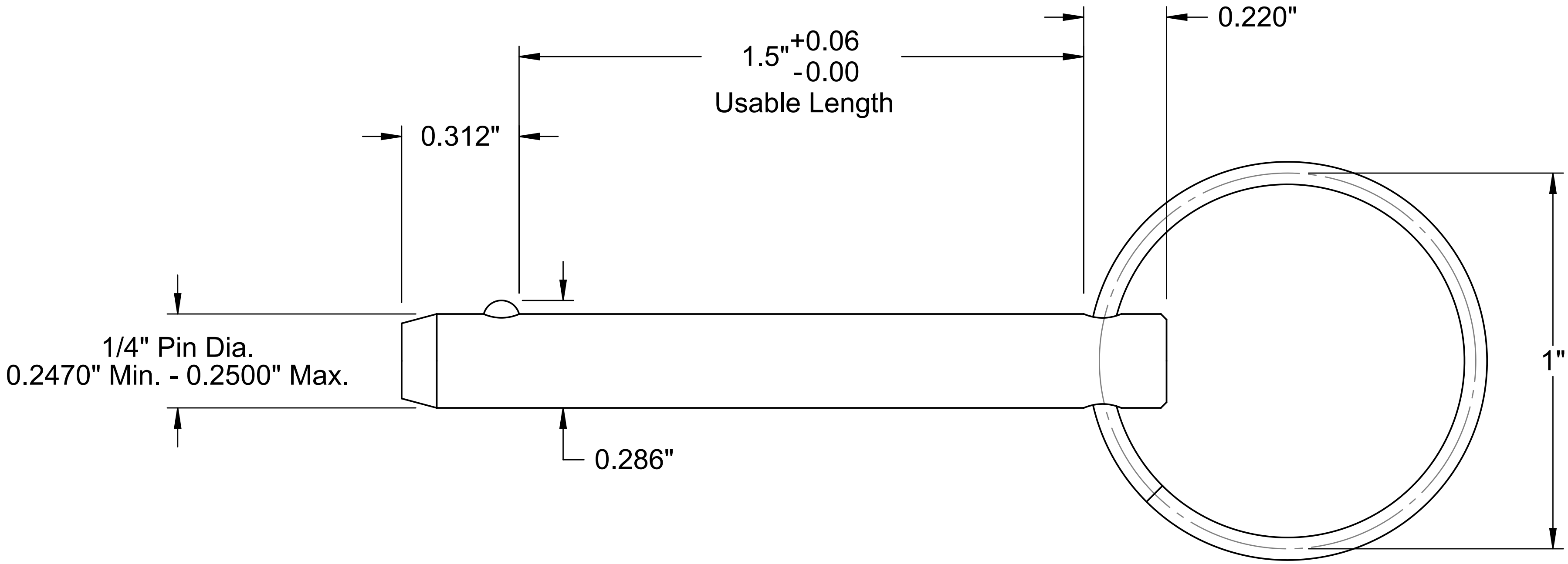
McMASTER-CARR® CAD

PART NUMBER **9306K27**

http://www.mcmaster.com

Heavy Duty Bumper



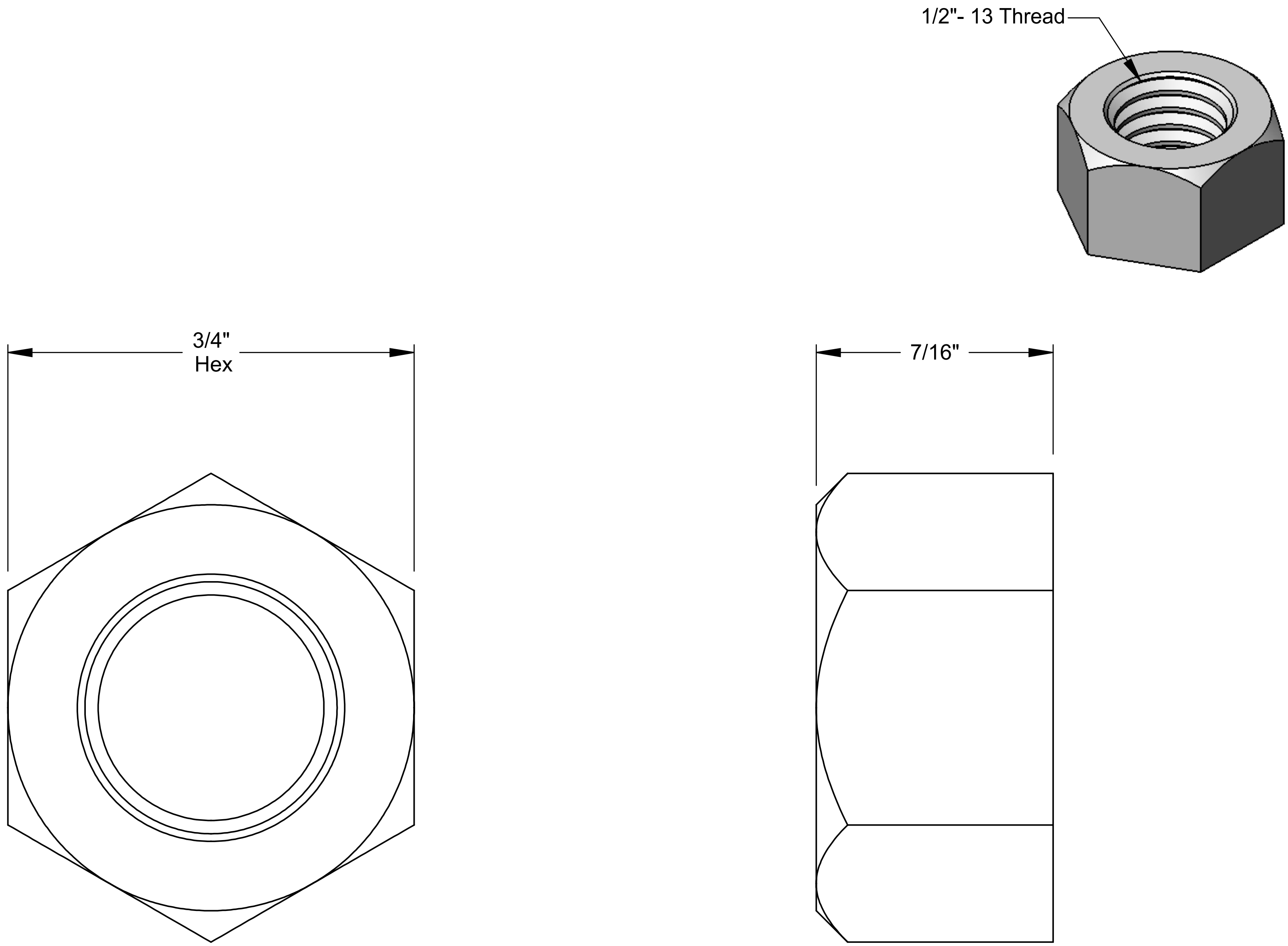


McMASTER-CARR® CAD

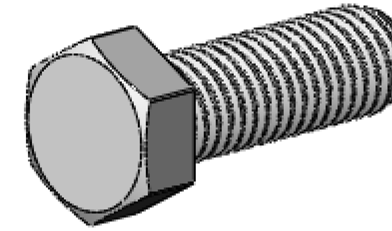
PART NUMBER **95255A268**

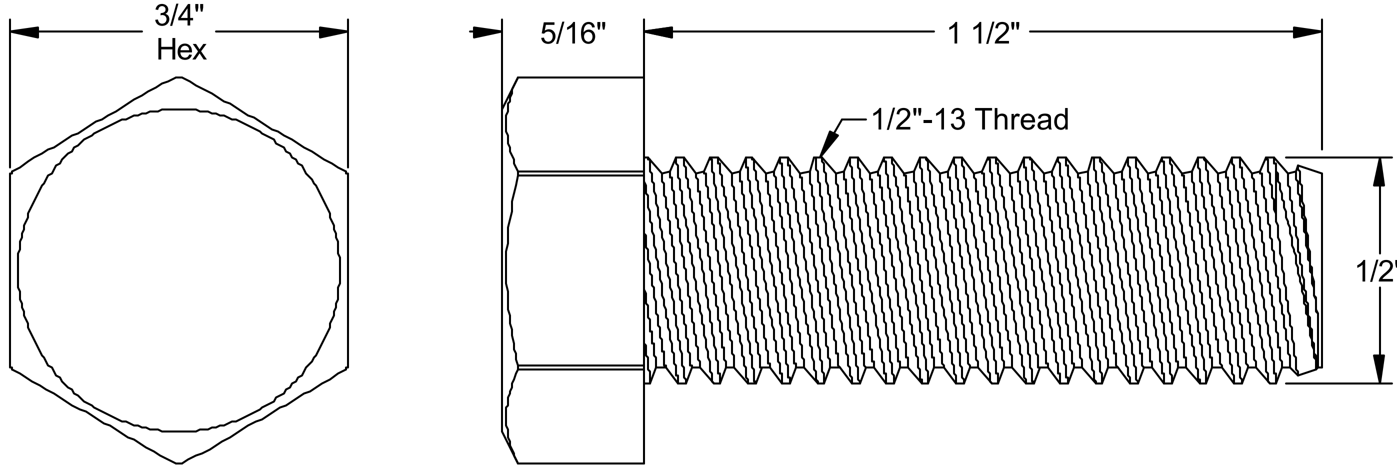
http://www.mcmaster.com

Type 316 Stainless Steel
Quick-Release Pin



McMASTER-CARR® CAD	PART NUMBER	90473A223
http://www.mcmaster.com © 2009 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Zinc Plated Grade 2 Steel Hex Nut	





McMASTER-CARR® CAD	PART NUMBER 92865A716
http://www.mcmaster.com (c) 2004 McMaster-Carr Supply Company	Grade 5 Zinc-Plated Steel Hex Head Cap Screw

Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.

R5 Draw Latch

Concealed · Heavy-duty

- **High tensile load**
- **Consistent pull-up**
- **Concealed installation**

Material and Finish
Steel, zinc plated

Performance Details
Average ultimate tensile load:
11,100 N (2500 lbf)

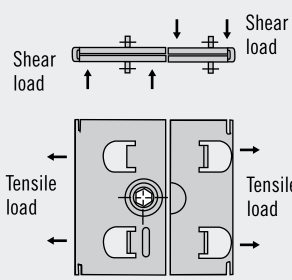
Average ultimate shear load:
76,920 N (17292 lbf)

Installation Notes
Install assembly with Ø 6 (1/4) rivets or M6 (1/4) screws (not supplied)

Accessories
Actuation tool
Part number: 29-0059-02

Hole plugs
Part number:
White: T5-7075-000
Black: T5-7075-028

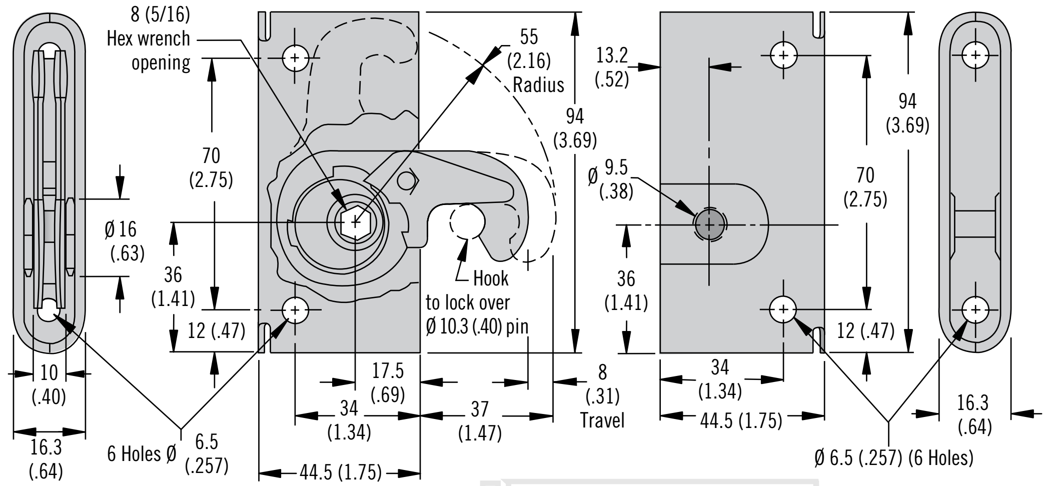
Notes
Operating force
To open: 4 N•m (35 in•lbf)
To close: 4 N•m (35 in•lbf)



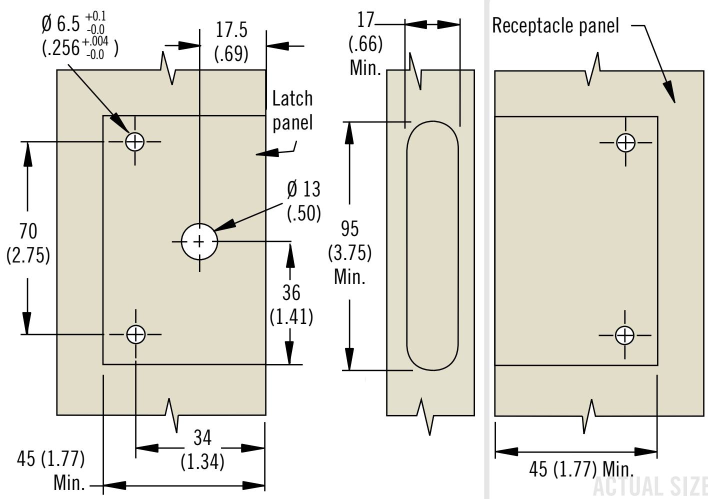
Part Number
See table

Order latch and keeper separately

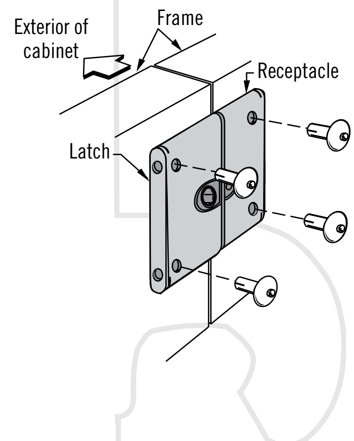
Latch / Receptacle



Recessed Pocket

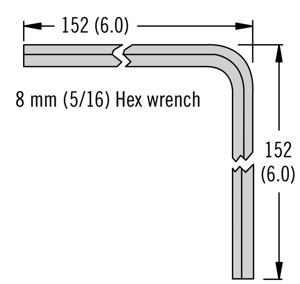


Side Mount

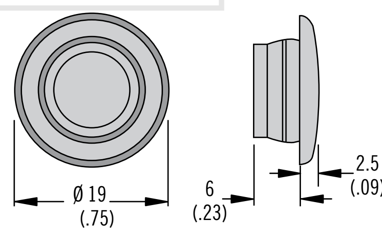


Accessories

Actuation Tool



Hole Plugs
Optional hole plugs to conceal actuator access hole are available for a 13 (.50) diameter hole



Part Number	
Latch	**Receptacle**
R5-0074-07	R5-0079-07

INFO CLIC www.southco.com/R5

Dimensions in millimeters (inch) unless otherwise stated

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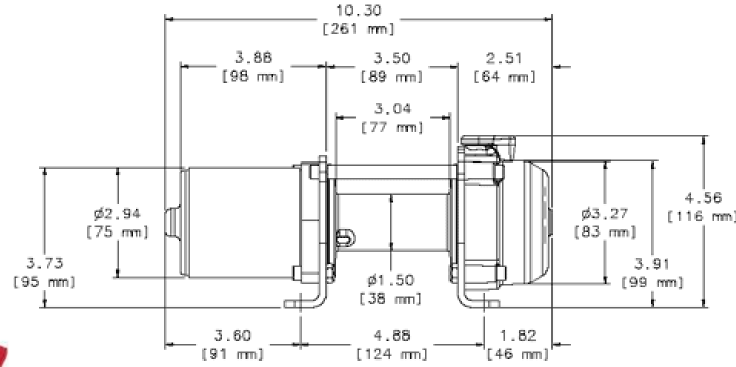

RT 15 SPECS/PART NUMBERS

Part Number: 78000

Capacity: 1500 lbs. (680 kgs)

No-load Linespeed: 15 ft./min. (4.6m/min)

Full-load Linespeed: 5 ft./min. (1.5 m/min)

Series: Rugged Terrain

Sealing: Motor

Geartrain: Metal gears in plastic housing

Rope: 50' Aircraft-grade wire, 5/32" diameter (15m, 4mm)

Control: Sealed handlebar-mounted mini-rocker control

Motor*: 12V DC, 0.4hp permanent magnet, Sealed

Gear Ratio: 103:1

Clutch Control: Flip Tab

Brake: patented disc brake

Drum Diameter/Length: 1.5"/3.0"

Fairlead: Hawse

Recommended Battery*: 12 Amp/hour minimum

Battery Leads: 10 gauge

Duty Cycle: Intermittent

Warranty: Limited Lifetime (valid in USA and Canada only)

Winch Weight: 11.5 lbs (5.2 kgs.)

*Designed for use with 12V DC battery systems only. No other voltage systems recommended:

PERFORMANCE DATA

Line Pull Lbs.(Kgs.)	Line Speed FT./min(M/min.)	Motor Current
0	15 (4.6)	6
500 (227)	11 (3.3)	27
1000 (455)	7 (2.1)	44
1500 (680)	5 (2.1)	65

PULL BY LAYER

Pull by layer layer/Lbs(Kgs.)
1/1500 (680)
2/1320 (599)
3/1162 (527)
4/1020 (463)