UAV Catapult

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Team: Launch Time

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Statement of Disclaimer

Abstract

This document outlines the Senior Design Project proposed by Dr. Aaron Drake that was assigned to a team of Mechanical Engineering students at California Polytechnic State University, San Luis Obispo. The purpose of this project was to design, build, test, and finalize a launching system for two small, fixed wing, unmanned aerial vehicles (UAVs) owned by Dr. Drake and Cal Poly. The goal was to create a system that was both portable and reliable to use, only requiring a two-person team to use effectively in the field. The most important design requirements were determined to be the launch speed, assembly time, and storage size. Multiple propulsion methods were explored, with a pneumatic piston cylinder chosen for the preliminary design. A side clamping carriage design was selected due to the shape of the UAVs being launched. A structural prototype of the UAV carriage was constructed, and the final design was developed as a result of data obtained from the prototype. Following the creation of our final design, a manufacturing plan and design verification plan were produced to bring the concept to fruition. With these plans in place, parts were ordered, and construction began. This document will describe the background research done, the objectives of the project, the preliminary and final design, the manufacturing and testing process, difficulties and obstacles faced, our final results, and what can be improved upon in the future.

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1 Introduction

LaunchTime UAV consisted of four senior Mechanical Engineering students at California Polytechnic State University (Cal Poly) in San Luis Obispo, California: Ben Lacasse, David Garcia, Cearns, and Sean Huxley. We accepted the design challenge as presented by sponsor Dr. Aaron Drake of the Cal Poly Aerospace Department. LaunchTime UAV was advised by Professor Sarah T. Harding of the Mechanical Engineering Department at Cal Poly.

The goal of this project was to create a launch mechanism suitable for two different Aerospace Department UAVs that could be operated by a single user. The device had to be portable with a set up time of under 20 minutes and be capable of remote activation. The launcher was also required to hold the UAV in place while the propeller was running.

The initial steps of the project included extensive background research, defining our project scope, and drafting a project management plan. This background research includes information from team meetings with Dr. Drake, reviewing existing products, and describing relevant technical documents. This document also outlines the specific quantitative needs of the sponsor and considerations that had to be taken while designing.

After defining the scope of work, this document was updated to include a preliminary design, then reviewed by Dr. Aaron Drake. The process leading up to the preliminary design as well as the concept prototype, CAD model, and risks/concerns are described in detail.

A structural prototype was built, and adjustments were made to the final design. Following this, a project management plan was presented to outline the following weeks up until the Senior Project Design Expo, and Dr. Drake's personal use of the launcher.

Manufacturing was completed according to the project management plan, with assembly being nearly complete by the expo date, and testing was planned for the future.

2 Background

In the first three weeks after selecting the project, our team identified three different avenues warranting research: potential customer needs, similar existing products, and pertinent technical documents. During this period, the team also met with Dr. Drake on two occasions to discuss the details of the project. In these meetings, the goals for the project as well as initial observations on the two UAVs were documented. We also spent time researching the existing products on the market. Many existing UAV launchers were analyzed in order to inspire ideas for our own launcher. Most of the existing products were primarily developed to launch larger and heavier UAVs and are therefore overdesigned for our purposes. Additionally, we conducted research on existing patents associated with UAV launch systems and regulations.

2.1 Customer Needs

After receiving the initial project description, we met with Dr. Drake in the Cal Poly UAV lab for introductions and to discuss the project in greater detail. We observed the two UAVs in question: the Altavian Nova™, and the AeroVironment Puma™, shown in Figure 1.

Figure 1. Altavian Nova™, F7200 AT™ (left) and RQ20B Puma AE™ (right) fuselages

The Puma™ has a lower thrust to weight ratio and was the primary driving force behind the need for a UAV launcher. The UAV team has been hand launching the drones which had proven to be an unreliable method, with only a 50% success rate for the Puma™. The Nova™ did not fare much better; thus, an automated launching system would help to avoid damage and save time and effort in both launching the UAVs as well as training people to perform the hand launch method.

Next, we asked preliminary questions about how the UAVs should be launched from such a device. Students were taught to throw the UAVs parallel to the ground in order to maximize speed prior to attaining lift. The UAV launcher would most likely involve a track system that should be angled upwards at roughly 10 degrees. The launch system would be able to accelerate the UAVs at higher speeds than hand launching is capable of, so there would be no need to maintain a zero-degree launch angle. It was unclear what the optimal launch angle would be, so an adjustable angle was desirable.

The Nova™ requires between 15 m/s and 21 m/s for a successful launch while the Puma™ only needs between 13 m/s and 20 m/s. This difference indicated the need for adjustable speed so that the launcher could be calibrated to achieve an optimal launch speed for each aircraft. The other difference between the two UAVs was the body shape.

The Nova™ has a fuselage with a large taper towards the rear while the Puma™ has more of a uniform profile. The shape of the UAV was important because the UAVs could possibly be pushed by a carriage contoured to the body. Dr. Drake did not wish to make any alterations to the UAVs, such as an external pin, if possible. Pushing the UAVs would involve a significant amount of force, so each UAV needed a good way to disperse this force. It was noted that the Nova™ has a large indent in the back for the battery and thus it was ok to push the Nova™ using the battery.

The next design limitation discussed involved the portability of the device. Dr. Drake wished to travel with both UAVs in addition to the launcher using his 2016 Chevy Colorado short bed. Both UAVs have a carrying case that limited the acceptable storage space the device could occupy. The hand launch process typically involved two members: one person launched the plane while the other operated the controls. The entire system had to be easy to assemble and operate by a single individual, allowing one person to both launch and control the drone simultaneously.

2.2 Existing Products

A major part of our background research included an analysis of existing UAV launchers on the market. We analyzed these products to choose an effective method of launch, comparing the advantages and disadvantages of each. Most of these launchers were designed for UAVs that are much larger, heavier, and that required higher launch velocities than our own. Five existing products were researched and evaluated for their unique launching methods. The launcher characteristics are listed in Table 1 to compare the similarities and differences to the needs of our own launcher. It is important to note that these products were chosen because they all contain several of our basic design requirements: portability, remote triggering, no external power source, and the ability to abort a launch.

Table 1: Existing Product Details

Product	Energy Method	Max Launch Velocity (m/s)	Max Plane Weight (kg)	Launch Angle (degrees)	Total Weight (kg)	Track Length (m)	Carriage Type	Set Up Time (Minutes)
Eli™ (Vaher)	Pneumatic	25	40	11	56	5	Claw on rollers	5
UAV Factory™ (Key Features)	Pneumatic	24	35	11	110	3.95	Claw on rollers	10
Seacorp™ (Inflator-Based UAV Launchers)	Airbag	NL	5.9	30-60	1.36	0.4	No carriage	5
Skywalker™ (UUUSTORE Wholesale RC Store)	Elastic Bands	NL	5	30	NL	2.5	Push wings	<5
Senior Project (Miller, Valoria, Warnock, Coutlee)	Elastic Bands	52.3	55	10-30	28.12	2.28	Custom fitting to body	<10

NL – Not Listed

It is useful to analyze these launchers in depth for potential scaling applications. Two of the products, launchers from Eli Pneumatic™ and UAV Lab™, as seen in Figure 2, make use of compressed air to power a piston which pulls the aircraft along a track until it is released at the end. Compressed air appears to be the preferred method for propelling larger UAVs. This method presents a safety hazard due to the addition of pressurized components, but it also provides an easy way to disarm the device using a pressure release valve. We also would need a power source for the compressor (both of the examined launchers use small compact batteries). Both devices also use a carriage system to hold the UAV, with wheels that roll along a foldable track. The carriages have four arms extending upwards which hold a drone in place during launch as seen in Figure 2.

Both designs also have collapsible legs to allow for easy and compact storage. (Vaher) (Key Features)

Figure 2. Eli Pneumatic Catapult™ (Vaher) and UAV Lab™ Carriage (Key Features)

A more unique launcher we found was an airbag powered system made by Sea Corp™. This company has a family of launchers which use commercial off-the-shelf automotive airbag inflators. The perks of this type of launcher are its lightweight design, quick deployment time, and high potential launch force for heavier payloads. The largest drawback is that the UAV must conform to a long tube that the airbag is in. The technology behind the launch mechanism is worth investigating and could be applicable to our own design. (Inflator-Based UAV Launchers)

Figure 3. SeaCorp™ Inflator Based Launcher (Inflator-Based UAV Launchers)

There are also smaller UAV launchers that use the stored energy in elastic bands to pull a UAV along a track. One such product on the market is the Skywalker X8™ catapult (Figure 4). This launcher is designed for smaller UAVs, up to 5 kg, similar to our Puma™ and Nova™. A carriage is attached to an elastic cord that is stretched out when the carriage is pulled back. Things worth noting about this design are the short track length, easy set up, and unique carriage. The carriage on this product has arms that extend upwards and behind the wings to push the UAV along the track. The Skywalker X8™ catapult proves that elastic bands provide an extremely light weight solution to propelling a small UAV, with the caveat that safety is a large concern when storing that much energy and must be taken into consideration. (UUUSTORE Wholesale RC Store)

Figure 4. Skywalker X8™ Catapult (UUUSTORE Wholesale RC Store)

One of the most insightful systems we researched was a past senior project conducted by a team named Rocket Power in 2014. This team was sponsored by Aerojet Rocketdyne with the goal of launching a 55-pound UAV at 52.3 ft/s. This design also utilized elastic energy to launch the UAV. This project was very useful as research due to the team's extensive report on their device. The final design used six surgical bungees to propel the UAV along a track (Figure 5). (Miller, Valoria, Warnock, Coutlee)

Figure 5. 2014 Senior Project (Miller, Valoria, Warnock, Coutlee)

Rocket Power conducted their own analysis on different propulsion methods before choosing elastic bands. Our own analysis will be critical in our design choices. Although the team failed to get their UAV airborne, we can learn from their mistakes to improve upon our own design.

2.3 Technical Literature

Below is a list of patents related to UAV launching devices, as well as a few technical literature resources. The patents list devices built for UAVs that range in size from small toy sized to larger military and ship-based applications and utilize many different energy storage solutions. Of particular note is the patent for the electronic launcher, which describes the functions, drawbacks, and solutions of the more typical pneumatic systems. Other solutions are less practical and may never be produced, but still provide insight into previous work on the subject.

1. Electric unmanned aerial vehicle launcher, Tully, et al. U.S. Patent 9783322B2 describes an electric motor driven tape that causes movement of a shuttle along a launcher rail. This system is designed for UAVs weighing up to 30 pounds. The inclusion of an electric motor would greatly increase the complexity of the control system, the programming and building of which would be outside of our abilities.
2. Rapid unmanned aerial vehicle launcher (UAV) system, Been U.S. Patent 9994335B1 describes an elastically powered launcher with a shuttle that traverses over a rail. A powered winch retracts the carriage, elongating the elastic unit. This patent is similar to the previous senior project, but we avoided their design as it would lead to a large moment on the rail system.
3. Miniature aircraft catapult, Young, et al. U.S. Patent 6626399B2 describes a foot release bungee powered rail system to launch small aircraft. This patent details the rail, retracting, and foot operated pin-release trigger system. This system is good for small RC airplanes, but the release mechanism did not fulfill our sponsor's need of being at least 20m distance away during launch.
4. System for shipboard launch and recovery of unmanned aerial vehicle (UAV) aircraft and method therefor, Urnes, U.S. Patent 8028952B2 describes an arm rotating around a pole used to elevate and release an aircraft in a confined space. This patent includes a releasable mount for the UAV, which releases when the aircraft has enough altitude and rotational velocity to sustain flight. This patent did not seem reasonable or producible, but instead served as an interesting thought experiment. We had no way of producing a launcher with this scale nor a way to safely test it.
5. Unmanned aerial vehicle management, Speasl, et al. U.S. Patent pending 20160364989A1 is an application for a side loading box containing a treadmill style runway for launching and landing UAVs. A novel idea, this patent would require quite a large box to get our UAV up to the necessary launch speed, as we would be limited by the friction of the UAV on the treadmill surface.

The ASME Standards journal article "Aerospace Hydraulic and Pneumatic Specifications, Standards, Recommended Practices, and Information Reports" lists the ASME standards for pneumatic systems, which were useful when we decided to use pneumatics to power our launcher. As the system would be reasonably high pressure, we needed to make sure that all components were rated and tested to at least that pressure, and that any added components would meet these guidelines and standards.

"Optimization of Dynamic Characteristics of a Ground Catapult for Minimizing the Guide's Length." (Sereda) is a journal article that describes the use of pneumatics for launching an aircraft, including the staging of fluid delivery to optimize force and acceleration on the airframe. We looked into what was available to us to optimize fluid delivery, especially since a large restriction on our design was how and where we could apply force to the UAV, and how large that force could be.

3 Objectives:

Dr. Drake needed a way to launch two different UAVs from the ground while simultaneously operating them. However, the existing launch method only had a success rate of 50% and required two people. The new method would have to allow one operator to be self-sufficient in quickly deploying and launching a UAV while also controlling it.

3.1 Boundary Diagram

Figure 6 contains a Boundary Diagram (BD) which was used to give a visual representation of the scope of the project. The dotted line encloses the things that we were directly responsible for managing and/or creating. Anything in contact with the boundary line would have to be considered for the design; everything else would be outside the scope of our design.

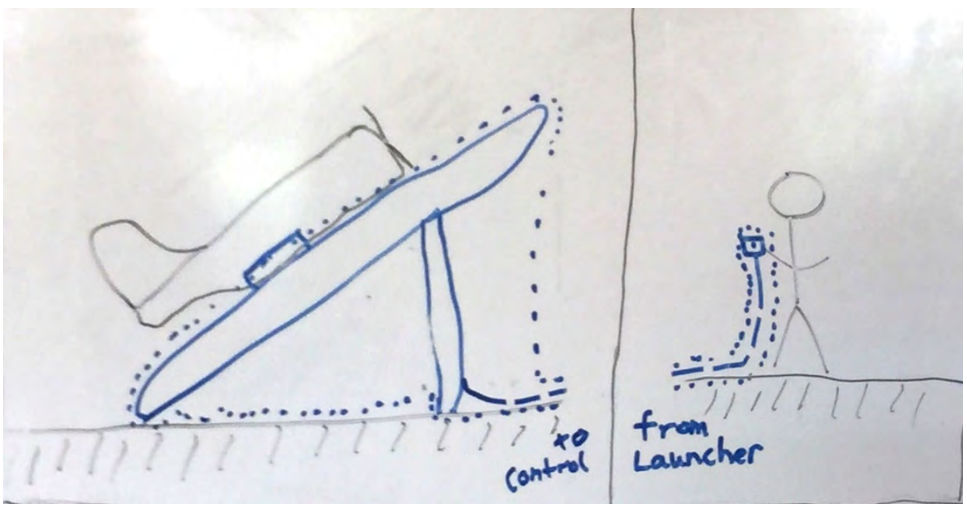


Figure 6. Boundary Diagram for UAV Launcher

As is shown in the diagram, this project would encompass the entirety of the launching system. The support and angle adjustments had to be accounted for, as well as the method for attaching the plane to the launching system and the overall dimensions of the UAV. The controls and the person flying the UAV are outside the BD because we had no control of the plane after its launch.

3.2 Design Considerations

In order to accurately determine the necessary considerations for the project, the team met with our sponsor to designate his “needs” and “wants”. These factors were then given measurable engineering specifications that are testable in order to confirm that we have successfully met the needs of our sponsor. Our sponsor’s needs and wants for the launching system were

- **Portable:** The overall design must be transported repeatedly in and out of the field as launches are performed.
- **Reliable:** The system must successfully launch the UAVs at a higher rate than the current manual method.
- **Easy Use:** The system must be simple enough to set up and operate so that there is no extended period of training new personal to use it.
- **Setup Time:** The system may not take an extremely long time to be both set up or taken down and stored for transportation.
- **Revved Engine:** The system needs to hold onto the UAV as the engines are revved in order to perform calibration and system diagnostics.
- **One Person Operation:** Our sponsor wanted the system to be able to successfully operate with only one person participating in the set up and launching of the UAV.
- **No External Power:** Since the UAVs are launched in the field, there are no external power sources and as such they need to be powered either internally or without electricity.
- **Safety:** The launcher would be used by both staff and students of Cal Poly, and as such will need to meet basic safety standards in order to be useable by either party.
- **Multiple UAVs:** The launch system needs to handle and operate with two different models of UAVs

We were not given a maximum value for our budget when we met with Dr. Drake. He did, however, place a few limitations on what we could and could not purchase. If costs exceeded $1000 at any point, we were to contact him before making a purchase, and if any individual part exceeded $200, then we were to contact him regarding its necessity and to explore alternatives. Regardless, our goal was to build the project within a budget of $1500.

3.3 Quality Function Deployment

In order to determine if we were correctly meeting the specifications given to us by Dr. Drake, we conducted the Quality Function Deployment (QFD) process. By performing QFD, we were able to take the data and information we had compiled through our interviews and background research and assign weights and quantifiable goals to them. These goals could then be used to guide our engineering design process. Needs of the customer that have no measurable values besides a pass or fail test were still considered in the QFD, however there was no need to create a design specification for those needs. Once testing of the product began, the QFD was used to help determine both what types of needs were met and in what direction the design would need to move in order to correctly account for the remaining needs. The results of our QFD are in Appendix A for reference. By using the QFD we found that it was difficult to categorize most of the design considerations for this project into tangible technical specifications. Many of the specifications that were found would need only a simple pass or fail test in order to be approved and were thus not included in the QFD. However, we did find that most of the “important” specifications required a quantitative goal in order to be considered a success.

3.4 Engineering Specifications and Risk Assessment

Table 2 lists the engineering specifications that needed to be met during our tests. The parameters in Table 2 have an inherent risk of failure associated with them and are marked as either High (H), Medium (M), or Low (L) risk. In order to confirm whether they would pass their tests, they would need to be checked for compliance through either Testing (T), Analysis (A), or Inspection (I). The three most important and challenging specifications to meet were the size requirement, the number of pinch points on the launcher, and the success rate of aborting a launch prior to takeoff.

Table 2. Engineering Specifications

Spec #	Parameter description	Target value	Tolerance	Risk	Compliance
1	Assembly Time	20 minutes	MAX	L	T
2	Max Load	8.1kg	MAX	L	T,A
3	Carriage Size	12-21 cm	±2 cm	L	I
4	Minimal Pinch Points	0 pinch points	MAX	H	I,A
5	Success Rate for Launch Abortion	100%	MIN	H	T,A
6	Fit in Truck	33X155cm	MAX	H	T
7	Time to Abort Launch	90 sec	MAX	M	T
8	Range of Launch Speed	10-25m/s	+ 2m/s	M	T
9	Launch Angle Range	0-15 degrees	MAX	L	T,I
10	Resistive Force Prior to Launch	10 N	MIN	L	T,A
11	Number of Consecutive Launches	5 Launches	MAX	M	T,A
12	Reset Time	10 minutes	MAX	L	T,A

The specifications are defined as

1. **Assembly Time:** The amount of time taken to unload the launcher and set it up. This would be tested by averaging the amount of time it takes to go from fully stored to operational.
2. **Max Load:** The largest payload that the system could bring to speed safely. This would be tested through a series of deadweight launches; in which a large weight would be placed within the launcher and the final speed of the weight as it leaves the launcher would be recorded.
3. **Carriage Size:** The overall width of the carriage system that would secure the UAV prior to launch. This would be tested through a simple measurement of the dimensions.

4. **Minimal Pinch Points:** Safety measure to prevent places where extremities can be smashed or cut during operation. Would need to pass a visual and possible tactical test to be deemed a success.
5. **Success Rate for Launch Abortion:** Success Rate for aborted launches prior to take off. This would be tested by repeatedly aborting the launch of the system until it could successfully abort 10 times in a row without a misfire.
6. **Fit in Truck:** Volumetric test to ensure that the launcher could fit in the truck with the other UAV equipment. Testing for this would be done through various configurations of the supplies within the truck until everything was safely stored and did not provide any hindrance to the driver.
7. **Time to Abort Launch:** Overall time taken to safely release the energy stored within the launcher in the event of an aborted launch. This would be tested by repeatedly aborting the launch while averaging the time it takes to do so across several trials.
8. **Range of Launch Speed:** The different speeds the launcher would be required to output. This would be tested by placing the maximum load required into the launcher, and then launching at the desired speeds while measuring the results.
9. **Launch Angle Range:** The range of angles that the launcher would have to successfully perform under. This would be tested by launching the UAV at incremental angles in order to determine if it is still stable
10. **Resistive Force Prior to Launch:** The force holding the carriage in place as the engines are primed. This would be tested by attempting to rev the engines before the launcher is released and would be considered successful if the UAV did not move from its initial position or adversely affect the launcher in any way.
11. **Number of Consecutive Launches:** Largest number of consecutive launches that would be performed before needing to replace or recharge components. This would be tested by performing as many launches with dead weight in rapid succession as possible until the batteries were no longer charged. The process would then be repeated with the results averaged.
12. **Reset Time:** The amount of time needed in order to prepare another launch. This would be tested by recording the amount of time between the last launch to the start of the next launch.

If any of these specifications failed, then the design would be reconsidered in order to provide a higher chance of success.

4 Concept Design

Many different aspects were involved in creating our preliminary design. Numerous concepts were conceived, combined, and discarded to create a design that meets our specifications. This was done by placing the best designs for each function in a Pugh matrix and creating several different combinations of concepts from them, resulting in a functional overall design. This process will be expanded upon below.

4.1 Design Process

In order to accurately meet all the specifications listed in the objectives section, multiple ideation sessions were held. We conducted brainstorming exercises in order to create a list of functions and processes that would be important to accomplishing our objectives. By using the Pugh matrices found in Appendix C, we were able to narrow down the list of viable concepts by comparing different ideas and seeing how well they addressed our needs. These concepts were then placed within a morphological matrix, which can be found in Appendix D, allowing us to derive several new designs from them. Many of these ideas, while novel, were not viable for a variety of reasons, including: unrealistic expectations of feasibility, not meeting specifications, or difficulty of manufacturing.

4.2 Design Concepts

From our ideation process, several design concepts were generated. Some of these concepts are shown in Figure 7- Figure 11.

A trackless, pneumatic piston powered design supported by a tripod stand with a carriage designed to grip the UAVs from the side is shown in Figure 8. The side clamping design solves the issue of finding suitable attach points for UAVs to connect to the carriage.

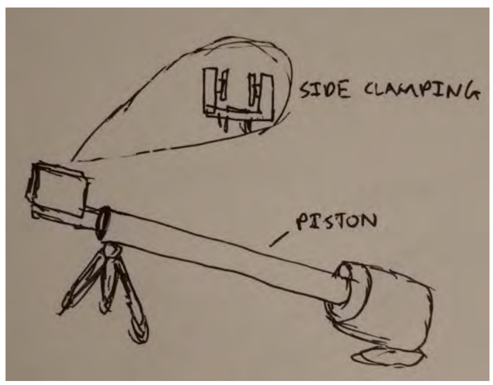


Figure 7. Design Concept 1

A bungie powered design supported by a tripod that pulls a contoured mold along a track is shown in Figure 8. The molds would be custom fit for each UAV. Bungies would be unsafe to use, as releasing the stored kinetic energy in them would be difficult in case of an aborted launch. Building a custom contour fitted mold for each UAV also seemed more difficult than is desirable.

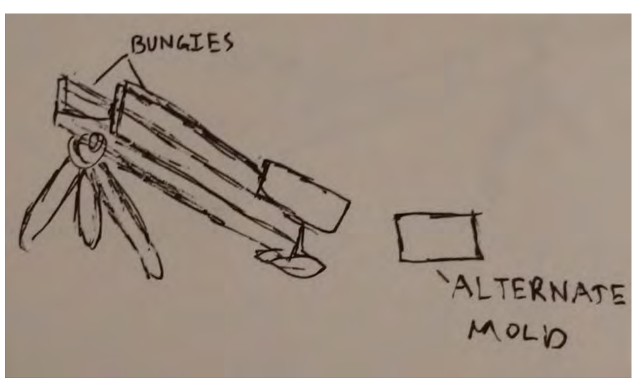


Figure 8. Design Concept 2

A twin spring powered design, using sliding rails to move a carriage that has pinned hooks that attach to points on the UAV with a two-legged stand is shown in Figure 9. Pins would have to be inserted into the UAVs for the hooks to attach to. Many commercial UAV launchers are designed for use with specific UAVs that have mounting pins already built into them. Dr. Drake's UAVs do not have these pins, and calculations would have to be done to determine where pins could be inserted safely. Dr. Drake has expressed that he wishes to avoid going through this process.

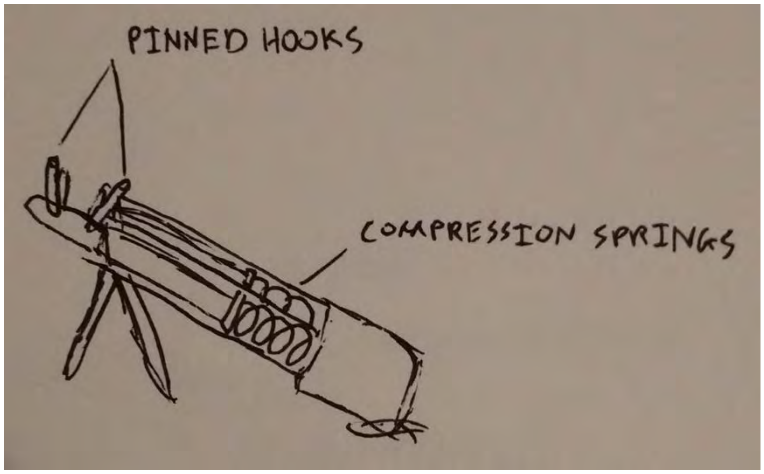


Figure 9. Design Concept 3

A trackless, pneumatic piston powered design, with a two-legged stand and pinned hook carriage system is shown in Figure 10. However, the two-legged stand is more prone to tipping or sliding.

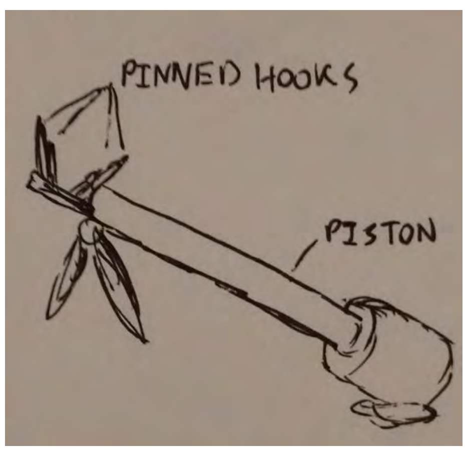


Figure 10. Design Concept 4

A spring powered design which pushes the carriage directly along a track supported by a t-shaped leg is shown in Figure 11. The carriage applies force to the rear of the UAVs. Unfortunately, there is no practical way to apply such a force to the rear of the UAVs due to their shape. A custom mold would need to be created and attached to transfer energy from the spring to the UAV. Also, the stand is more prone to sliding or rolling out from under the track.

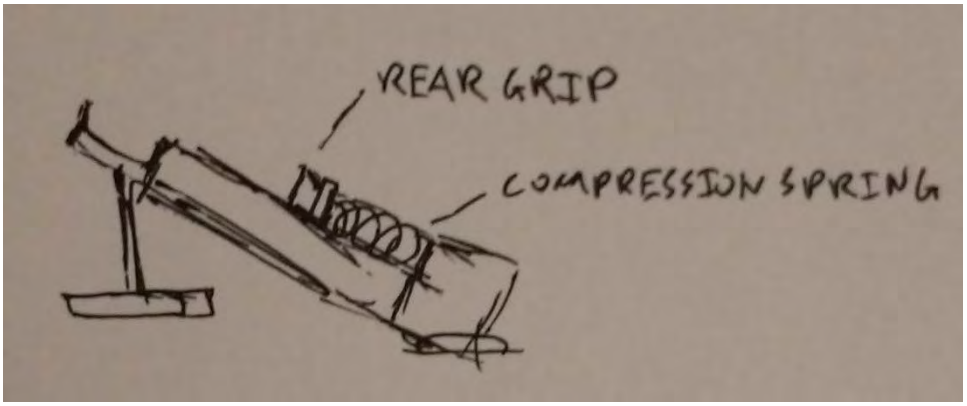


Figure 11. Design Concept 5

4.3 Selected Concept

In order to determine which design would be most viable, the designs resulting from the morphological matrix were placed within the weighted decision matrix in Appendix E. This matrix compared the designs based on how well they met the criteria found within the QFD, with each criterion being weighted based on importance. By adding the weighted values of each need together, total scores could be compared, and a final design could be selected.

The final concept would use three pneumatic pistons with a 50-inch stroke (Figure 12). Three pistons would be used instead of one in order to achieve sufficient launch velocity and this will be explained further in section 4.5. The pistons would be supported in the rear by a two-legged base and supported beneath the end of the cylinders by an adjustable tripod. Junctions made of aluminum would be needed to hold the three cylinders together: one at the base of the cylinders and one at the end of the cylinders. A third junction would be needed to connect the ends of the three pistons. Junctions would be milled and be attached loosely to allow the pistons to move at slightly differing speeds. At the bottom of each junction would be an adapter for either the tripod at the front, or the two-legged base at the back. This would allow the launcher to be disassembled and stored compactly.

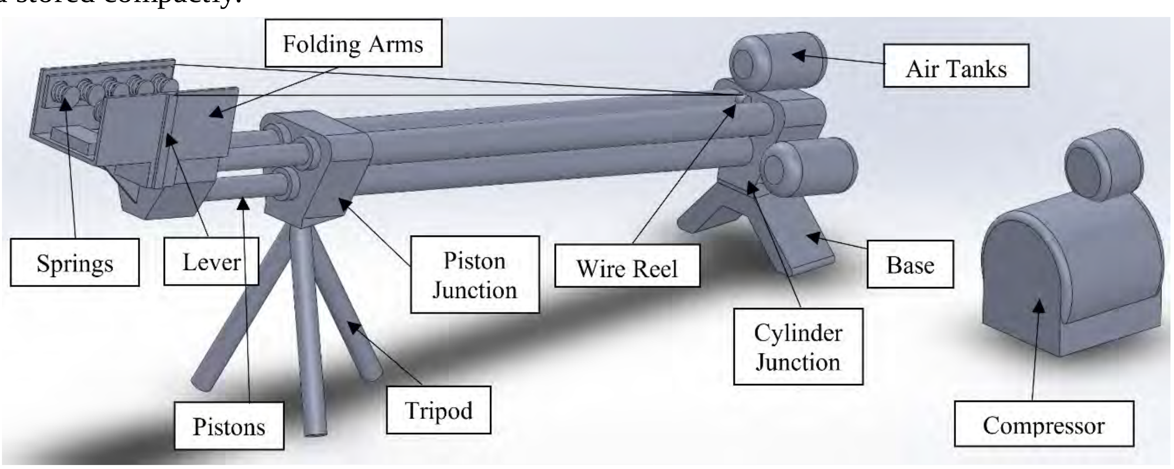


Figure 12. Concept Model

Mounted around the rear junction would be air tanks used to store the compressed air for the pistons. Each air tank would be connected to a compressor and could be charged and stored until the user is ready for launch. Between each air tank and its respective piston would be a solenoid valve that could be remotely triggered by the user. Each tank will also have an air release valve in case the user needs to abort the launch, which could also be controlled remotely. Not pictured in Figure 12 are the lines for compressed air between the compressor, air tank, and cylinder.

4.4 Carriage Prototype

After choosing a final concept to pursue, the next step was to prototype. Due to the magnitude of the project and time constraints, we had to limit ourselves to just one component to prototype. We chose the carriage due to the difficulty of the design and level of uncertainty in its capabilities. The carriage consisted of a base for the UAV to rest on, as well as two arms hinged to the base (Figure 13). Each arm had a row of compression springs along the top to apply pressure to the fuselage from both sides. The arms were then held in a locked position by a lever pinned to each arm. The top of the lever applied pressure to the arm while the bottom had a reaction force from the base. These levers could rotate to lock or release the arms when desired. The carriage would have to be triggered to open before the pistons are at their full stroke length. The tops of the levers were attached to a string which ran down the length of the track and was attached to a reel on the cylinder junction at the base. The length of string was set slightly shorter than the stroke of the piston, so the levers were pulled back just before reaching the end of the stroke. Once the levers were pulled down, the arms would be free to pop open and away from the UAV.

Figure 13. Carriage Prototype

This carriage concept would be suitable for either UAV due to the adaptive nature of the carriage arms. The base of the carriage would also have custom platforms for each UAV to sit on.

The platforms would be contoured to the specific UAV body and could be interchanged easily by sliding them into a slot. The Nova™ would have an additional platform that can push it from the back of its battery pack. The Puma™ could have a platform that supports the landing pads. The custom platforms would need to be tested and studied further.

The base and arms of the carriage would most likely be made of aluminum and manufactured using a mill. The carriage base would be welded to the junction at the end of the pistons to ensure a secure connection. Carriage weight would be a large concern because the UAV needs to achieve a minimum speed. Material would be removed from the carriage whenever possible during the detailed design to minimize the weight.

Other mechanisms of release were explored, but the lever method was chosen for prototyping due to ease of construction. This prototype was a proof of concept and more iterations were needed to improve the design. An issue with this concept was the difficulty of pulling the levers back. The force of friction on the levers was strong, especially when stiffer springs were used. We also prototyped a carriage with the walls held together by two arms which were connected by a pin. However, the problem with this design was the tight tolerance needed to make the pin move smoothly, thus we abandoned this design. The next step was to test other mechanisms of locking and releasing the arms.

The next point of uncertainty with this design was the force from the springs on the fuselage. The force of friction would have to be enough to hold the UAV in place during launch, which would require a very large normal force on the fuselage. This force could be spread over the length of the fuselage to decrease the stress, but we would have to make sure the stress was not so high as to damage the UAV. Another option was to use leaf springs which may distribute the force more evenly. The normal force required could be reduced by increasing the coefficient of friction on the spring ends. Each spring would have an end cap made of rubber in order to increase the coefficient of friction.

Most of the development time was spent on the carriage, which meant further development was needed for the pneumatic pistons and structural support. The pistons would need to be tested at a smaller scale to verify they could achieve the launch velocity we expect. Also, the tripod and base would have to be tested to ensure the system was stable during a launch.

4.5 Initial Calculations

Knowing the required launch speed and limited by the maximum length of a custom-built piston, 50 inches, the required acceleration was found to be about 10g (see Appendix F for calculations). From this acceleration and the weight of the UAVs, the required force was calculated to be about 180 lbf. From this force, a total volumetric flow rate at a given pressure can be calculated. It was found that at the maximum operating pressure of 120 psi, there was too much restriction of flow due to the ¼” National Pipe Tapered thread (NPT) inlet of a single piston of the required dimensions to produce sufficient launch force. Because the fixed orifice size would dictate a need to reduce volumetric flow rate, it was decided that the best course of action was to split the force between multiple pistons, each requiring less flow and therefore less pressure. The requirement of having multiple pistons would create the issue of uneven actuation, leading to binding of the pistons, but this would be addressed in the future.

4.6 Risks and Challenges

After creating the preliminary design, some potential concerns were raised. We planned on addressing these issues early in the design process so that they would not become greater problems later on. These issues were:

1. A suitable mounting mechanism to hold the UAV in the carriage would be one of the most challenging tasks. While the Nova™ has a flat space on the rear that can function as an attach point, the Puma™ is only slightly contoured from the body to the tail. This would leave very little actual space to attach our launcher to, hence the need for a sideways clamping mechanism. It would have to be seen whether we would be able to generate enough frictional resistance using this method to secure our payloads.

2. Sufficient flow rate from the air tanks to the pistons would be critical, so methods of reducing spacing and ensuring minimal amounts of pressure loss were critical. One solution may have been to mount the tanks in-line with the back of the pistons with the solenoid in-between, leading to no tubing in the critical flow path.

3. A design with multiple pistons may have led to binding due to uneven actuation of the cylinder rods. The compliance of pneumatic cylinders would need to be investigated, and if binding was found to be an issue, a flexible mounting method would have to be developed.

4. If the weight and momentum of the carriage and piston when fully extended were too great, the whole launcher will tip over. We would need to investigate if tipping would be an issue with the current design, and if so, how we can avoid it. One idea to fix this was reducing weight at the carriage end and increasing weight at the base, while another was offsetting the carriage from the ends of the pistons so that the center of mass stayed within the two supports.

Our chosen design also had to be examined from a safety-focused perspective. A design hazard checklist is included in Appendix G which addressed some of these concerns.

5 Final Design

After many revisions were made to the design mentioned earlier, we decided to switch to a single piston design, after confirming that a custom-built component could satisfy our design specifications, while removing the problem of potential binding. A wire rope is now attached to the end of the piston, connecting it to the carriage. The carriage travels along two linear motion shafts on either side of the piston-cylinder (See Figure 17). Once fired, the cable attached to the end of the piston pulls the carriage along the track. The carriage then hits a spreader placed at the end of the track, releasing the UAV with enough speed to successfully achieve lift. Two compression spring are mounted to the end of the track as well as two shock absorbers to slow the carriage down, which also prevent the piston from hitting the end of the cylinder.

5.1 Carriage

The final carriage design consists of a base made from an aluminum rectangular tube, two sliding panels, and a rear support. Each side panel is mounted on two steel axles which allows lateral motion, so the system can adjust for the width of each UAV. A spring is attached to the base of each panel to keep the panels compressed on both sides. The angled tip of each side panel fits into a 3D printed receiver (Figure 15) attached to the sides of the UAV with double sided VHB tape. The tips are also designed to resist thrust while sitting on the track prior to launch. A magnet attached to the underside of the carriage keeps the UAV stationary during launch because it is stuck to the steel backplate. The carriage has four linear roller bearings beneath the rectangular tube which slide along the track system.

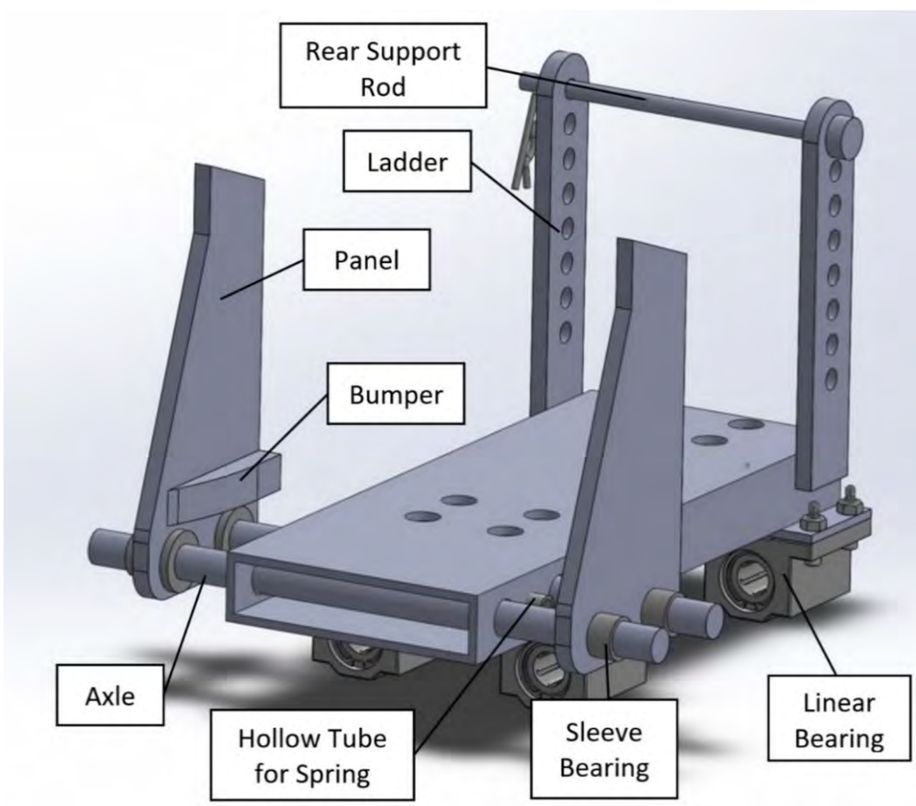


Figure 14. Labeled Carriage

Ideally, the carriage would push the UAV from both the front and the back supports, but due to the tapered contour of the Nova's, fuselage near its center of gravity (CG), it was necessary to use an adjustable support bar for the rear support. The CG is important because the carriage must support the UAV on all sides of it to ensure the UAV is balanced. The back of the Nova™, is a smaller width than the Puma™ just behind the CG, but the support rod fits both UAVs because the rear of both UAVs simply rest on the rod. The back-support panels, or ladders, allow the height of the support rod to be adjusted via multiple holes positioned for a range of heights. This system allows the carriage to not only support the Puma™ and Nova™ but accommodate UAVs that Dr. Drake may obtain in the future.

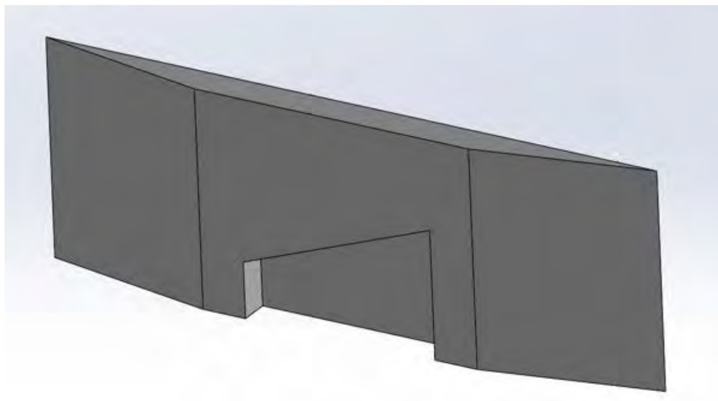


Figure 15. Receiver

A thin receiver attaches to either side of the UAV with double sided, 4910 VHB. The side panels sit inside the indent and transfer force to the UAV. The receivers are 3D printed due to its unique shape and to reduce weight. Dr. Drake has recommended using VHB tape, because it can be removed if need be. The skin of the UAV is the weakest point in this attachment. To ensure that the UAV is not damaged, the surface area of the receiver in contact with the UAV is made large enough to ensure a sufficient distribution of force. Dr. Drake has limited the receiver thickness to 3/8 inch so that they do not affect the aerodynamics of the UAVs. The current design thickness is 1/4 inch. This thickness strikes a balance between a large surface area to withstand the launch force, while maintaining an aerodynamic profile.

In order to release the UAV at the end of the track, each side panel has a bumper on the inner surface. The end of the track has a spreader (Figure 16) which wedges apart the panels when the carriage runs into it. The spreader and bumper widths are set so that the panels spread just wide enough for the UAV receivers to detach from the carriage. Two spreaders are needed, one for each UAV, due to the differing widths of the Puma™ (4.5 inches) and Nova™, (6.5 inches) at the CG. Each spreader can be interchanged easily via the removal of two bolts.

During travel down the track, the side panels must be held tight to the sides of the UAV. A spring with hooked ends runs through the rectangular tube and attaches to both side panels. The side panels have a 3D printed hook for each spring to latch onto.

The cable pulling the carriage is looped to itself using a swage and the loop is place around a ¼ inch diameter bolt that goes through the front end of the carriage. A 3D printed holder is used to hold a small neodymium magnet (Figure 16) on the underside of the carriage. This magnet is placed at the rear so that it comes into contact with the rear plate. The magnet is rated up to 20 pounds which can successfully resist the pull of the UAV's motor.

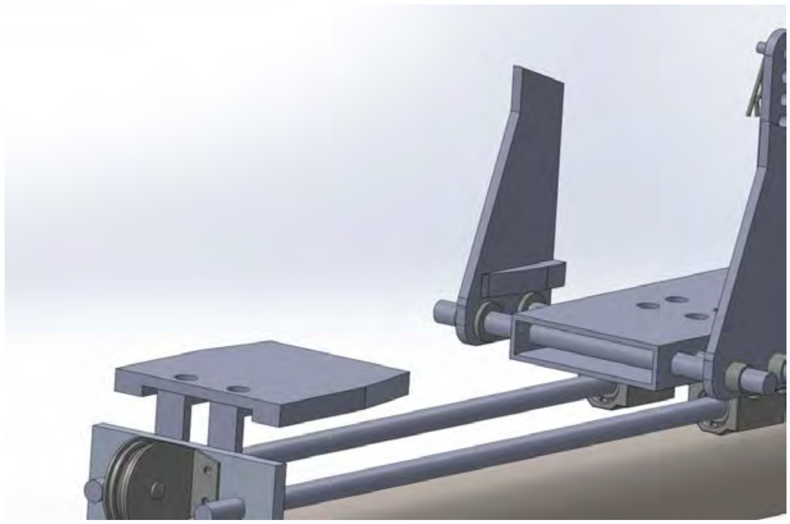


Figure 16. Spreader

Each component of the carriage has undergone stress calculations and materials have been chosen based off the results. The side panels are made of aluminum and are a quarter inch thick. This thickness allows the entire receiver on the UAV to be filled while reducing any deflection in the side panels. Finite element analysis was performed on the panels using the maximum loading, resulting in a factor of safety of 6. These results can be seen in Appendix H.

The points on the carriage with the highest stress concentrations are located at the panel axles. The force on the panel requires a large reaction force from each axle. The force at the end of each axle cause a large moment at the point of connection to the rectangular tube. Hand calculations for this analysis can be found in Appendix I. The stresses are nearly 50,000 psi which is why steel was chosen for these components.

The bumpers, rectangular tube, and spreader are all aluminum. Aluminum was chosen for these parts to reduce the weight of the carriage as well as the overall carrying weight of the entire system.

5.2 Frame and Piston

The frame of the launcher is composed of a front and back plate that support the piston cylinder and two linear motion shafts, with two legs attached to each plate via quick-disconnect pins (Figure 17).

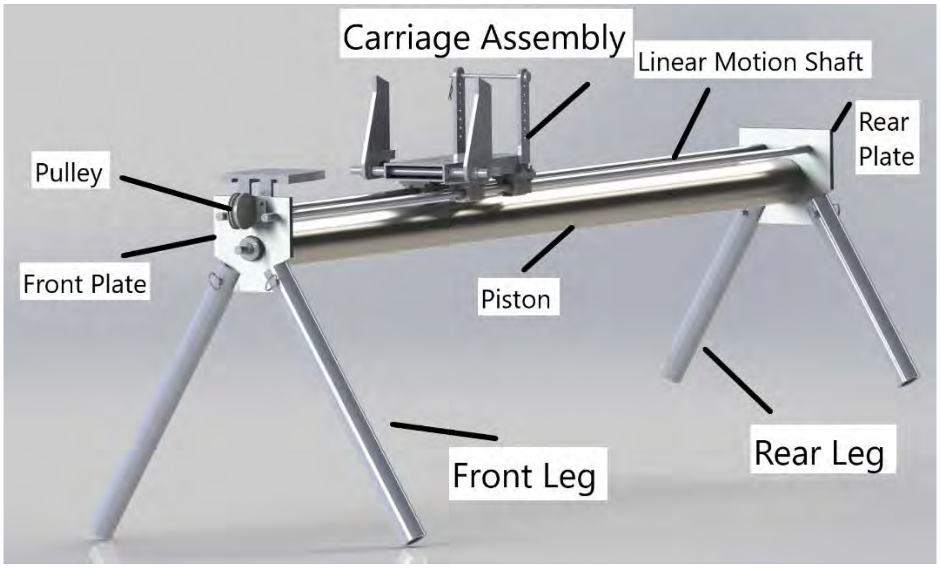


Figure 17. Labelled launcher components

The front and back plates are 3/8" steel, having two clearance holes for the threaded ends of the linear motion shafts to go through. Each rod is secured with two nuts on either side of the plate. The front plate has a clearance hole for the piston to pass through and is secured in place using a nut over the end of the cylinder. A pulley is also mounted on the front plate so that the wire rope can be directed from the end of the piston shaft, over the front plate, and along the frame to the front of the carriage assembly. The same bolts for attaching the pulley are also used to attach the L brackets holding the spreader in place. The bottom bolts for this assemble also secure the shock absorbers.

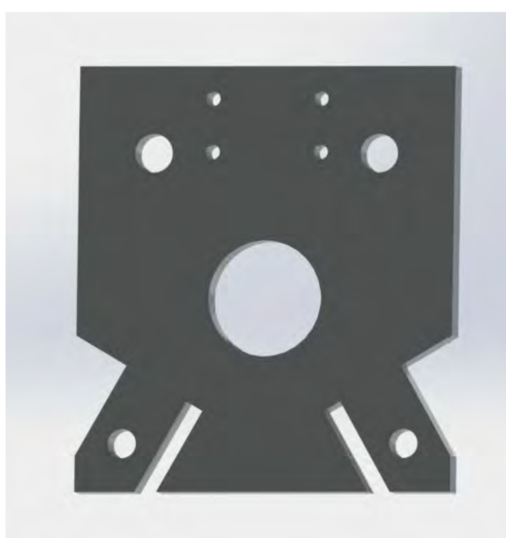


Figure 18. Front Plate

Slots are cut into the front and back plates, creating a tab with the same width as the inside of the leg tubes (Figure 18). A hole is drilled into the tab aligned with a matching hole in the leg, allowing for a quick release pin to secure the leg in place. The moment created by forces on the launcher and the leg are distributed along the edges of this tab, as well as the edge along the top of the tube and through the pin. FEA was performed to model the stress on the front plate generated by a launch, and the factor of safety was determined to be 3.

Running parallel with the piston are two steel linear motion shafts. These shafts are precision ground to a diameter tolerance of -0.001" to -0.0005" and a straightness tolerance of 0.002" per ft. and are case hardened, meaning that they allow the linear motion bearing to slide without binding. The deflection of these shafts with the full weight of the UAV and carriage was modelled using FEA and found to be 0.07”, meaning that at maximum deflection, the bottom of the linear motion bearings do not contact the piston body with a clearance of 0.51”.

The piston is custom ordered from Bimba Pneumatics, based on their Original Line piston. The stroke length is extended to 60” from a catalog maximum of 50” so that the acceleration on the UAV can be reduced from around 9 G’s to 7.5 G’s. This also reduces the required air flow rate from 1268 SCFM to 1067 SCFM. The port on the rear is 1” NPT, originally 1/8” NPT to allow for a higher air flow rate and reduced pressure loss through the orifice (See Appendix J for piston air flow calculations). The seal in the piston for the return action has been removed, as retracting the piston pneumatically is not necessary, and holes have been drilled into the end of the piston body to allow more air to vent and reduce resistance to extension.

5.3 Pneumatic and Electrical Systems

The pneumatic system consists of a tire bead-setting air tank with a 2” fitting, and three ¼” fittings. A 2” to 1” pipe reducer attaches to the 2” fitting leading to a high-pressure hose. This hose meets with a solenoid valve with then connects to the piston with a nipple. The first ¼” NPT fitting is broken out using a tee fitting to attach the filling hose to the compressor and compressor relay. The second ¼” fitting is also broken out with a tee fitting which connects to the safety relief valve, and the solenoid for manual tank release. The pressure gage is attached to the third fitting. The compressor is a 12V automotive compressor.

The electrical system uses 18V DeWalt batteries supplied by the UAV team, which are run through a 12V voltage reducer and then wired into a pressure relay and fuse to regulate the pressure of the pneumatic system. The wiring diagram is shown in Appendix Q. Each electrical component at the air tank is connected via spade plugs so it can be easily detached for transportation. A control box with a 50-foot extension cable houses a switch to activate the compressor relay system, a switch to open the pneumatic dump valve, and a switch and button linked in series to prevent accidental launch, to activate the larger launch solenoid.

The user pressurizes the tank until the relay turns off the compressor at 145 psi. At this point, the user may launch the UAV using the controller, or abort the launch if need be using the dump solenoid. Following launch, air continues to flow through holes at the end of the cylinder until the launch button is released by the user. The tank can be emptied using the dump valve. Once the tank is nearly empty, the carriage slides back to its return position with the piston.

5.4 Safety, Maintenance, and Repair

There are numerous safety risks associated with the UAV launcher. Besides those already mentioned in section 4.6 and Appendix G, the area in front of the launcher must be kept clear whenever it is being operated. Operators should stand no less than 10 ft. away from the launcher while it is prepped for launch. The two-stage switch for launch is a safety measure to prevent accidental misfiring from occurring, and the piston release valve exists in case a launch must be aborted for any reason. Also included on the air tank is a pressure relief valve which does not allow over pressurization of the system. It is extremely important to use the correct spreader respective to its UAV. The Nova™, uses the wider spreader while the Puma™ uses the narrower spreader. Failure to use the correct spreader may result in an impact with the carriage and failure to release the UAV. It is also crucial to ensure the spreader is completely straight. If the bolts on the L bracket become loose, the spreader may not be straight, and the carriage side panel may collide during launch.

Regarding maintenance, the side panel axles should be lubricated to reduce stiction while spreading. The linear bearing shafts should be cleaned and checked for debris to ensure the carriage can slide cleanly along them. The most likely component to fail in the carriage is the spring holding the side panels together. This can easily be replaced by removing the side panels and exchanging the spring for a new one. Should the linear motion bearings wear so that movement is unacceptable, replacements can be purchased from McMaster-Carr and installed in the bearing holders.

The steel rods used for the track should be wiped clean prior to each use to decrease friction and prevent bearing damage. The shock absorbers used to stop the carriage may experience wear after extensive use. Replacement shock absorbers can be purchased from McMaster-Carr.

DeWalt batteries should be charged fully before each use to ensure full pressurization. Cables should be inspected for damage prior to launch and the solenoids should be tested before pressurization each time.

5.5 Cost Analysis

The most expensive component of the final design was the custom piston with a price of $439. Following the piston, the air compressor and linear bearing shafts were $172.66 and $107.52 respectively. The bulk of the cost was from raw materials. Most individual components are inexpensive, but collectively bring the total cost up to $2072. Thus, the final cost of the project exceeded the original rough budget of $2000 but this was done with approval of Dr. Drake. A full list of material purchases can be found in Appendix L.

6 Manufacturing

This section outlines the steps required that were required to manufacture and assemble the individual pieces of the UAV launcher. The overall system can be broken down into four subsystems, the Carriage, Piston Frame, Pneumatic, and Electrical assemblies.

6.1 Carriage Assembly

The carriage used to carry the UAV during the launch was constructed from mostly stock parts with a few additional manufactured components. The major individual components manufactured for the carriage were

- Body
  - Square Aluminum tubing, bought from McMaster-Carr
- Ladder and Side Panels
  - Aluminum stock plate, bought from McMaster-Carr
- Side Panel Axles
  - Steel stock, bought from McMaster-Carr
- Metal Bumper
  - Aluminum stock, bought from McMaster-Carr
- Ladder Pin
  - Aluminum round stock, bought from McMaster-Carr

The different machines needed to manufacture the components were

- Water Jet Cutter
- Metal Chop Saw
- TIG Welder
- Mill

The body of the carriage was cut from square tubing on a metal chop saw. After the dimensions were confirmed, holes were drilled into the tubing using a mill. To create the side panels and ladder support, aluminum stock was waterjet-cut to its specifications. Linear sleeve bearings were then press fit into the side panels. The laddered section was originally supposed to be TIG welded to the back section of the rectangular tube, but due to time constraints, the ladders were bolted to the carriage. After further consideration, spacers were added in between the ladders and carriage to provide extra clearance for the Nova™, due to its larger width. Once that was completed, the side panel axles were cut to size using a metal chop saw, inserted through the rectangular tube, and affixed with epoxy. The linear bearings within the side panels were placed over the side panel axles and secured using a spring. Linear roller bearings were placed under the carriage and attached using screws, nuts, and washers bought from McMaster-Carr. The ladder pin was cut from aluminum stock on a metal chop saw and a hole was drilled through one end using a mill. This was used to secure the end of the ladder using a cotter pin purchased from McMaster-Carr.

The cable which pulls the carriage was looped around a bolt within the carriage. This bolt was placed vertically in the center at the front of the carriage. The cable was wrapped around the bolt and secured to itself using a cable clamp. The front of the carriage was cut ¼ of an inch shorter in order to provide extra clearance before the end of the track.

In order to stop the carriage, two springs were placed over the linear axles at the end of the track. The carriage hits these springs immediately after releasing the UAV and the springs compress one inch before hitting two shock absorbers. The shock absorbers were bolted to the front plate and can dissipate most of the energy from the carriage into heat.

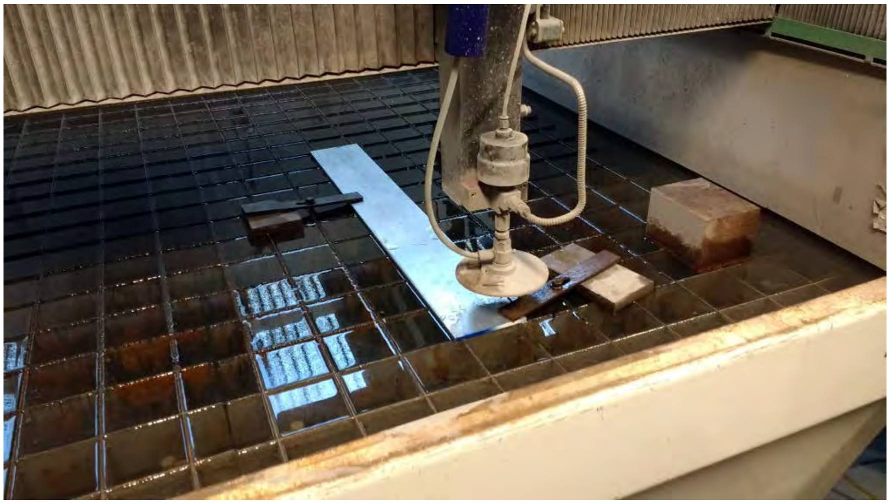


Figure 19. Water-jetting carriage components

Figure 20. Cut carriage components

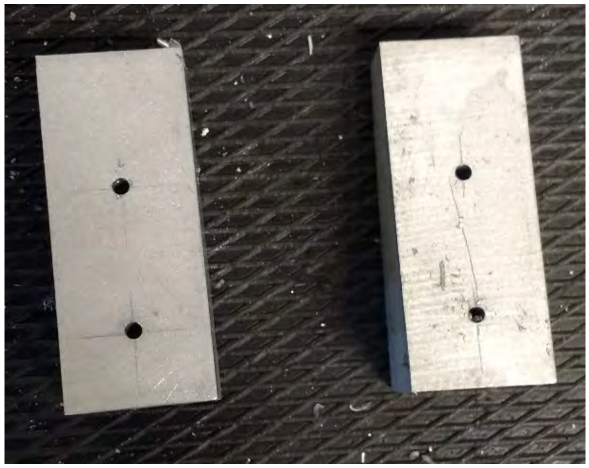


Figure 21. Tapped separator wedges for carriage

6.2 Frame Assembly

The Frame Assembly both elevates the piston to the desired height and creates a track for the carriage to rest upon and traverse. The major individual components manufactured for the frame were

- Frame Front Legs
  - Aluminum Stock tubing, bought from McMaster-Carr
- Frame Back Legs
  - Aluminum Stock tubing, bought from McMaster-Carr
- Frame Front Plate
  - Stainless Steel plate stock, bought from McMaster-Carr
- Frame Back Plate
  - Stainless Steel stock, bought from McMaster-Carr
- Spreader
  - Aluminum plate stock, bought from McMaster-Carr
- Linear Bearing Shaft
  - Steel linear motion shafts, bought from McMaster-Carr
- L Bracket
  - L plate, bought from McMaster-Carr

The different machines needed to manufacture the components were

- Water Jet Cutter
- Metal Chop Saw
- Mill
- Taps and Dies
- Oxy-Acetylene Torch

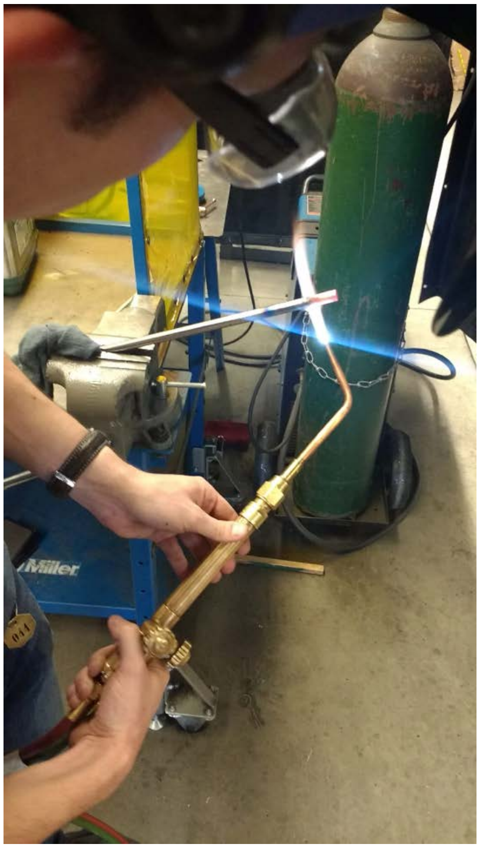
The front and back plates of the frame were cut using a waterjet cutter. An issue arose scheduling time in the Industrial Technology department’s water-jet cutter, as the ME and IME machines were not in operation. This led to a backlog when every department at the school wanted to use their machine. Because of this, a team member needed to wait outside their door for a few hours before shop hours to ensure that we would get some time on the machine.

After they were cut, the two top holes were threaded using a tap. The linear bearing shafts were then cut using a metal chop saw. Because the shafts were hardened, it was not possible to thread the shafts as they were. The ends of the hardened steel were heated with an Oxy-Acetylene torch to 1500-1600°F to anneal the metal, allowed to cool and then threaded on both sides with a die. Cutting the threads on the shafts proved to be very difficult, requiring a large handle and a very specific technique, eventually leading to overheating and breaking an unhardened die. Between broken drill bits and dies, there was much swapping and waiting between the hangar and Mustang 60 to find unbroken and sufficient quality tools to be able to work with steel.

After tapping the holes in the plates and fitting the rods, it was determined that the holes were not tapped straight and would not allow the rods to be parallel to each other. To fix this, the holes were drilled out to a 17/32” clearance diameter and the threads on the rods were further extended to allow them to be fastened on both sides of the plate with nuts.

Holes were drilled in the L bracket using a mill. The spreader was also cut using a waterjet cutter, and two different models were made, each for a specific UAV. Next, the front and back legs were cut separately using a metal chop saw and a single hole was drilled through the end of each of the legs. Unfortunately, due to tolerance issues, these holes ended up being insufficient to allow for proper clearance in attaching the legs to the mounting holes. These holes had to be enlarged and a side of each leg had to be grinded down in order to properly mount the legs.

The front and back plates were then screwed onto the corresponding sides of the piston, and the linear bearing shaft was screwed into the plates. The L bracket was attached to the front plate using bolts, nuts and washers from McMaster-Carr, with the spreader attached to the L bracket in the same fashion. The pulley was fixed to the front plate as well using the same method. Finally, the legs were attached to the corresponding plates using a release pin. Due to the leg holes being made larger than originally chosen, the pins are not completely fixed when the legs are attached. Though it is impossible for them to fall out, causing the legs to detach, they are a bit loose.




Figures 22 and 23. Pseudo-annealing and cutting threads on linear motion shafts

6.3 Pneumatic Assembly

The Pneumatic Assembly is used to propel the carriage and UAV once the launch is initiated. The system is made entirely from stock parts, with the major components being purchased.

- Air Tank
  - 10-gallon air tank, bought from Amazon
- 1'' solenoid valve
  - 1-inch solenoid valve, bought from Amazon
- Air compressor
  - 12V automotive compressor, bought from Amazon
- Pressure release valve
  - Pressure release valve rated at 145 psi, included with air tank
- Pipe diameter reducer
  - 2-inch to 1-inch pipe reducer, bought from McMaster-Carr
- Flexible tubing
  - 1.5-inch flexible tubing, bought from McMaster-Carr
- Piston Cylinder

- 60-inch stroke, 2.5-inch bore, 1-inch inlet piston cylinder, custom ordered from Bimba

The compressor was first attached to the air tank along with the pressure release valve at the appropriate inlet/outlet ports. The flexible tubing was then connected to the solenoid valve, which was attached to the air tank. The other end of the flexible tubing was attached to the pipe diameter reducer, which feeds into the piston cylinder. After assembly, some leakage was detected, requiring the components to be further tightened.

The piston quote was obtained in early February, and the piston was ordered the following week, with an expected delivery date between early and late April. The company made assurances that every effort would be made for an early April delivery, but unfortunately there were multiple uncommunicated and unexplained delays. Because of this, the piston did not arrive in time for the Senior Project Expo and was never added to the assembly.

To finish the product from that point, the most important step was to receive the piston. Once it arrived, the linear bearing shafts were cut and rethreaded to match the length of the piston. Then, the wire rope needed to be attached to the end of the piston and run over the pulley. A clearance issue was identified for the attachment point at the carriage when the launcher was fully extended, as the swage on the wire rope was at the wrong angle to fit between the two L brackets.

6.4 Electrical Assembly

The Electrical Assembly is used to power the entire system as well as receive input from the user. The system is made mostly from stock parts, with the major components being

- DeWalt battery
    - 18V DeWalt battery, supplied by Dr. Drake
- DC-DC Voltage Converter
    - 24V to 13.8V DC voltage reducer purchased from Amazon
- Connective wiring
    - Connective wiring for all the electrical components, received from Aero department
- Voltage adapter
    - 18V DeWalt battery adapter, purchased from eBay
- Toggle switches
    - 2 toggle switches, purchased from McMaster-Carr
- Spring loaded toggle switch
    - Spring loaded toggle switch, purchased from McMaster-Carr
- Push button
    - Spring loaded push button, purchased from McMaster-Carr
- Switch Case
    - Switch Case, 3D printed

The DeWalt battery was first connected to the voltage adapter, with the appropriate port available for the compressor. The voltage adapter and compressor were then soldered to the connective wiring, which in turn leads to the controller. The controller switches were placed in their respective positions, and the spring-loaded toggle switch and push button were wired in series in order to provide a safety countermeasure. The switch was also connected to the solenoid valve on the tank for the safety release.

Figure 24. 3D printed launcher panel with switches installed

7 Design Verification Plan

The performance of our design would be tested once the confirmation prototype is completed. Each of our specifications had to be met for the prototype to be considered a success.

Maximum Pressure: After assembling the pneumatic side of the launcher, the system could be tested at its maximum operating pressure to ensure that there were no leaks, and no component failed. The system consisted of two solenoid valves, a safety release valve, and a pressure gage, all connected to the ten-gallon tank. For safety concerns, the system was hydro tested using a hand pump provided by the Cal Poly Mechanical Engineering department. The test was conducted outside Building 13 on the Cal Poly campus.

First, the tank was filled with water from a hose until it over flowed and then the main solenoid valve was closed. One of the ports on the tank was connected to a hand pump, as seen in Figure 25. Water was pumped into the tank as the pressure was monitored. We immediately noted that some water was slowly dribbling out of one of the ports on the tank. When the pressure first reached about 100 psi, the tank creaked, but this was the only time this occurred. The tank was slowly pressurized to about 135 psi, when the safety release valve opened. It should also be noted that once pumped up to 135 psi, the tank pressure dropped back down to about 100 psi fairly quickly, meaning that there were some air leaks to be addressed. All of these measurements have an uncertainty of ±1 psi due to the resolution of the pressure gage.

Figure 25. Hydro-testing pressure vessel and fittings

The test concluded that the system can be safely pressurized to an operating pressure of 135 psi which is when the safety release valve opened. The test also revealed that there were some minor leaks, which were resolved by tightening each joint. The next step is to tighten the joints and connect the compressor to ensure the compressor can successfully pressurize the tank.

Assembly Time: The final assembly was fully assembled by 2 members of the team. Over the course of 5 separate assemblies, it was found that the average time to assemble the launcher was 12 minutes, which was considered a success. The next step going forward is to have both Dr. Drake and his students, as well as other untrained individuals attempt to assemble the launcher using only the operator’s manual as their guide.

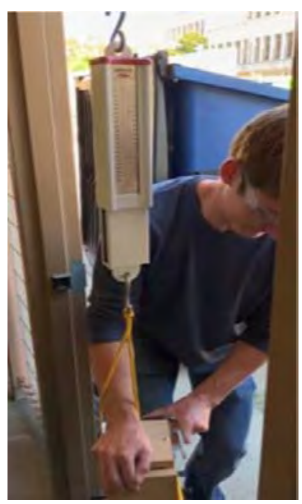


Figure 26. Strength testing the Carriage

Max Load: In order to fully test the max load of the launcher, the piston would be fired with weights in the carriage to simulate the UAV, and the final speed would be recorded. However, since the piston was never assembled, we had to settle for testing by applying loads directly to the carriage. By attaching weights from the carriage and hanging the carriage on the connecting point to the wire rope, the expected force was simulated, as seen in Figure 26. The carriage was able to easily withstand up to 180 lbs. of force, which was considered a success.

Carriage Size: In order to test the capabilities of the carriage sizing, a mock UAV was made from wood and weights, and was constructed with similar dimensions to the Puma™. By attaching the inset tabs along the sides, the mock UAV was then placed in the carriage, to ensure that the mock UAV would be able to fit within the space provided. The mock UAV was successfully sized, and the carriage was able to accommodate the UAV while remaining stable.

Minimal Pinch Points: Once the launcher was fully assembled, the system was examined for any potential pinch points for the operator. This was done by first visually inspecting the launcher for any points in which the operator may be in danger of being pinched or crushed. Since the operator would be standing away from the launcher at a safe distance during its use, the presence of pinch points on the launcher itself is negligible, and thus passed the test.

These were the only tests we were able to complete in the given time frame due to the fact that the piston arrived so much later than expected. The following is a list of possible tests that would need to be conducted in order to completely verify the use and safety of the launcher. These tests will be done once the project has been handed off to the sponsor.

Launch Abortion: This test is important to ensure that the launcher can be successfully and safely disarmed from its prelaunch state if a launch procedure must be aborted. The system will be prepared for launch and disarmed in a series of 10 tests. If even one of these launches cannot be safely disarmed, or misfires, then the prototype is a failure, and additional safeguards will need to be implemented. We expect this test to be a success, with little chance for failure. The predicted mode of failure is an electrical wiring failure, which can easily be fixed in order to remedy the problem.

Size/Fit Test: This is a simple check to ensure that the final design will properly fit in Dr. Drake's method of transportation. An area of 33 cm by 155 cm has been set aside for the storage and transport of the launcher in its stored configuration. The prototype will be measured in its stored state to ensure that this size requirement is met. This test is a high-risk test, as the entire purpose of the project was to ensure that the device would be portable to the sponsor. However, we predict that the launcher will pass, and be safely stored within the space provided, or with a partial amount sticking out of the back of the truck.

Time to Abort Launch: During the multiple tests for successful launch abortion, the time it takes from the start of the disarming process until the process is finished will be measured. While having a reliable disarming method is important for safety, the speed in which the process can be completed is just as important, with a goal of under 90 seconds. Each abort procedure must meet this time limit to be successful. We predict that the test may not pass this goal. With such a large tank and small solenoid, the volume of air that must be released to equalize the pressure is incredibly high. However, this specification is self-imposed, and is not required for the successful use of the safety release of the air.

Launch Speed Adjustability: The catapult will be loaded with a UAV dummy weight and fired at multiple speeds while being recorded with a high-speed camera. The piston will be fired at a range of speeds by adjusting the airflow. A relation between the piston and launch speed will be determined from the data. The range of speeds should span 10-25 m/s to be considered acceptable. We predict that the launcher will not be able to pass this test as well. Being able to accurately measure and adjust the pressure is difficult given the orientation of the compressor, air tank, pressure gauge, and pressure release. Also, all of the force calculations for the travel of the piston and carriage are done under the assumption that the surface is frictionless, which it is not. Because of this, we believe that the carriage will not be able to reach the upper end of the range of speed desired, but will be able to safely launch in the lower end.

Resistive Force of Carriage Pre-Launch: A simple test, the actual UAVs will be placed in the carriage and prepared for launch. The UAVs will then be throttled up to their maximum speeds while on the carriage. The goal is for the UAVs to remain fixed in place on the carriage at the bottom of the launcher. If after 10 trials the UAVs are found to be stationary, this test will be considered successful. We predict that this test will be successful based on the strength of the magnets that we are using in order to secure the carriage to the back plate of the launcher. If the test proves unsuccessful, then the magnets can be switched to stronger magnets, or the method of holding the carriage in place could be modified as well.

Consecutive Launch Capability: The launcher will be loaded with dummy weight and fired in quick succession using one full tank of air. The number of successful launches will be recorded. Ideally, 5 successful launches in a row is desired, though 3 should be considered sufficient for success. We predict that the launcher will not be able to pass this test, as the predicted time necessary for pressurizing the air three times exceeds the amount of time the battery could power the system. To counter this, simply have more charged batteries on site to switch out between launches.

Rapid Launch Capability: The time in between launches should be minimal. Two launches with dummy weights will be performed as quickly as possible, with the time between the launches being measured and averaged over 10 trials. The goal is for the time between launches to be kept under 10 minutes for this to meet design specifications. We predict that the launcher will be unable to meet this specification as well. Since the volume of the tank is so large, the amount of time required to fully pressurize it to the correct pressure is comparatively large as well. With the current tank only having a 33% duty cycle, it can only run for about 20 minutes an hour, making a 10-minute launch reset time difficult to achieve.

8 Project Management

Since this was a long-term project, it was important to layout a timeline for the completion of tasks and key milestones to ensure that our goals were met on schedule. Starting with the Fall term, we completed background research on similar launcher designs and used QFD to determine what important design criteria must be met according to the sponsor’s needs. From this, we began our ideation process to find design solutions that meet those needs. After multiple concept iterations, a final concept design was selected, and a concept prototype was created of one of the design’s components. Following this, a structural prototype was constructed, and the design finalized. Manufacturing and testing began following the Critical Design Review, which was presented to the sponsor. Once the sponsor’s approval was obtained, the project moved into the final construction and assembly phases. Spring term was mostly dedicated to this process, including troubleshooting while giving enough time to address potential issues that arose. The completely assembled device was to be tested for safety and success, with changes being made accordingly. The final product was to be shown at the Senior Design Expo along with the Final Design Review (FDR) and poster detailing the project for attendees. Afterwards, the system was to be delivered to the sponsor in proper working condition, ready for his personal use.

Table 3. Key Deliverable Timetable

Deliverable	Description	Deadline
Scope of Work	Outline of project goals and restrictions	10/19/2018
Preliminary Design Review	Review of initial design choices	11/16/2018
Critical Design Review	Detailed analysis of performance and costs	2/08/2019
Manufacturing & Test Review	Part manufacturing and scheduled testing	3/14/2019
Hardware/Safety Demo	Live demo of final design with safety check	4/25/2019
Final Design Review	Finished product and report, expo preparation	5/31/2019

A Gantt chart is available in Appendix B for a visual representation of our projected timeline with specific dates and details.

Unfortunately, the supplier for the piston, the most important part of the launcher, was unable to meet the deadline they specified in early February for a delivery window in April. Because of this, we did not receive the piston in time for FDR and Senior Design Expo and could not present a complete design or complete testing results. Had the piston arrived on time, the timeline should have been sufficient to complete all the required tasks. As a result, for future projects, we would set aside more time to allow for supplier delays, and in this case, an alternative supplier or propulsion design.

9 Conclusion

The UAV catapult project proposed by Dr. Drake is presented in this document as well as the preliminary and final design by team LaunchTime. The goal was to design and construct a UAV launcher to replace the unreliable method of hand launching currently in use. We conducted research to choose a preliminary design and refined it over time with many different forms of analysis to obtain our final design. We created project management, manufacturing, and design verification plans in order to develop a launcher capable of launching two of Dr. Drake's UAVs by the end of May. Following this, a structural prototype was built to verify the final design and after successfully doing so, we began the construction phase of the final product.

The frame of the launcher was constructed during this period, through the assembly of a combination of purchased and manufactured parts. Preliminary testing of the frame was completed. Alongside this, the pneumatics system was assembled and tested for leaks, with minor adjustments made in accordance with the test results. The electronics system was also assembled at this time, with the wiring for the controller to the pneumatics system being tested for faults. All electrical systems functioned as expected. Unfortunately, at a later time, the dump solenoid stopped functioning for unknown reasons. The wiring was checked with a different solenoid and this solenoid worked as expected, leading us to the belief that the dump solenoid itself is what failed.

However, the piston, a major component of our design, arrived on 5/30/2019, the day before the Cal Poly project exposition. This meant that final assembly could not be performed before this point. This also meant that there were many performance-based design verification tests which we could not perform. Subsequently, we were unable to confirm whether our design meets the necessary specifications for launching the UAVs. We did mostly finish assembling our design in the days following the expo, but testing was unable to be completed before the conclusion of the project time. In hindsight, our project's scope may have been too broad to be properly addressed in the senior project time span.

Part of the reason this project ran over deadlines was that this project was very manufacturing intensive, and in the little time we had to manufacture after the piston arrived, the time spent in the shop was extremely inefficient. When arriving at the shop, it was not uncommon to wait nearly an hour to check in because it was already at capacity, then spend a majority of the time in the shop waiting. At the tool shed, tools frequently would be broken or incorrect, which meant going back to stand in line again each time. Other times, other groups would have checked out the tools needed, and we would have to wait for them to be returned. It was not uncommon to spend two hours at the shop for a 15-minute job to be finished. Also, if a job needed to be completed, a specific shop would have to be used. For example, if a hole needed to be drilled, Mustang 60's 17/32" drill bit was chipped so the Hangar would need to be used. If a shaft needed threads cut, the die in the Hangar was needed to start threads because their handle was bigger but the die in Mustang 60 was needed because it did not have as many broken teeth. Each trip also meant waiting till the next day since the shops open on alternating days.

At the project's end, we had completed about 90% of the manufacturing and assembly we originally planned for. This is not an insignificant amount of progress when taking into account the delays faced from waiting for major parts to arrive. While our physical progress was respectable, very little of our planned testing was able to be completed, at around a third. Thus, we have very little in the way of useful data to analyze the effectiveness of our final design.

Next Steps

For the launcher to satisfy all the goals we laid out in the beginning, a few modifications will need to be made.

1. A new method of attaching the wire rope to the carriage is needed. The current swage fitting contacts the two L-brackets as the carriage reaches the front plate and binds the motion. Alternatively, the L-brackets need to be spread further apart to provide enough clearance for the wire rope.
2. The spreader needs to be extended further down the track, probably by remaking longer L-brackets, or by making the spreader itself longer. Currently, the carriage stops against the bumpers just short of fully opening. It is possible that this will be sufficient for a successful launch, but this has not been confirmed via testing.
3. The side panels on the carriage do not always spread apart symmetrically when loading the UAV. The side panels must be equally spaced or else one of the side panel bumpers will collide with the spreader at the end of the track. A solution to this issue is to create

spacers (specific to the Puma™ or Nova™,) that can be placed on the side panel axels. This will ensure the side panels are equidistant from the carriage base. A simple solution is to 3d print two semicircle spaces that can be snapped on to the axels quickly.

4. The holes used to attach the legs to the front and back plate had to be drilled larger than our specified diameter, due to interference with the corresponding holes on the plates. As a result, the legs are not as secure as our design dictates, with a noticeable amount of movement possible. The easiest fix to this would be to drill new holes in the legs by flipping them upside down and using the undrilled bottom end as the new top end. Filing down one side of the legs will still be necessary to properly fit in the base plate grooves.
5. The dump solenoid failed during testing and no longer actuates. A new solenoid will need to be purchased. The specs are not critical for this solenoid; it must only be 12VDC and ¼” NPT.
6. A flat plate should be added to the front of the carriage where it contacts the bumpers. Currently, the thin wall of the carriage is the only part contacting the bumper and the small amount of surface area may lead to damage to the bumper.
7. The safety release valve that came with the air tank was designed to release the pressure at 145 psi. After hydro testing the system, we found that the release valve opens at 135 psi. This presents a problem because the relay for the compressor will not shut off. A 150-psi pressure release valve should be purchased and implemented. Before operating, the system should be hydro tested again, as it has never experienced this level of pressure.

Once these are completed, the firing capability of the launcher will need to be tested. Using the provided dummy-UAV, the launcher should be repeatedly fired with the pressure slowly increasing each time, being careful to note any impact inside the piston. It is crucial to make sure that an external method is used to stop the piston as it is not designed to stop itself.

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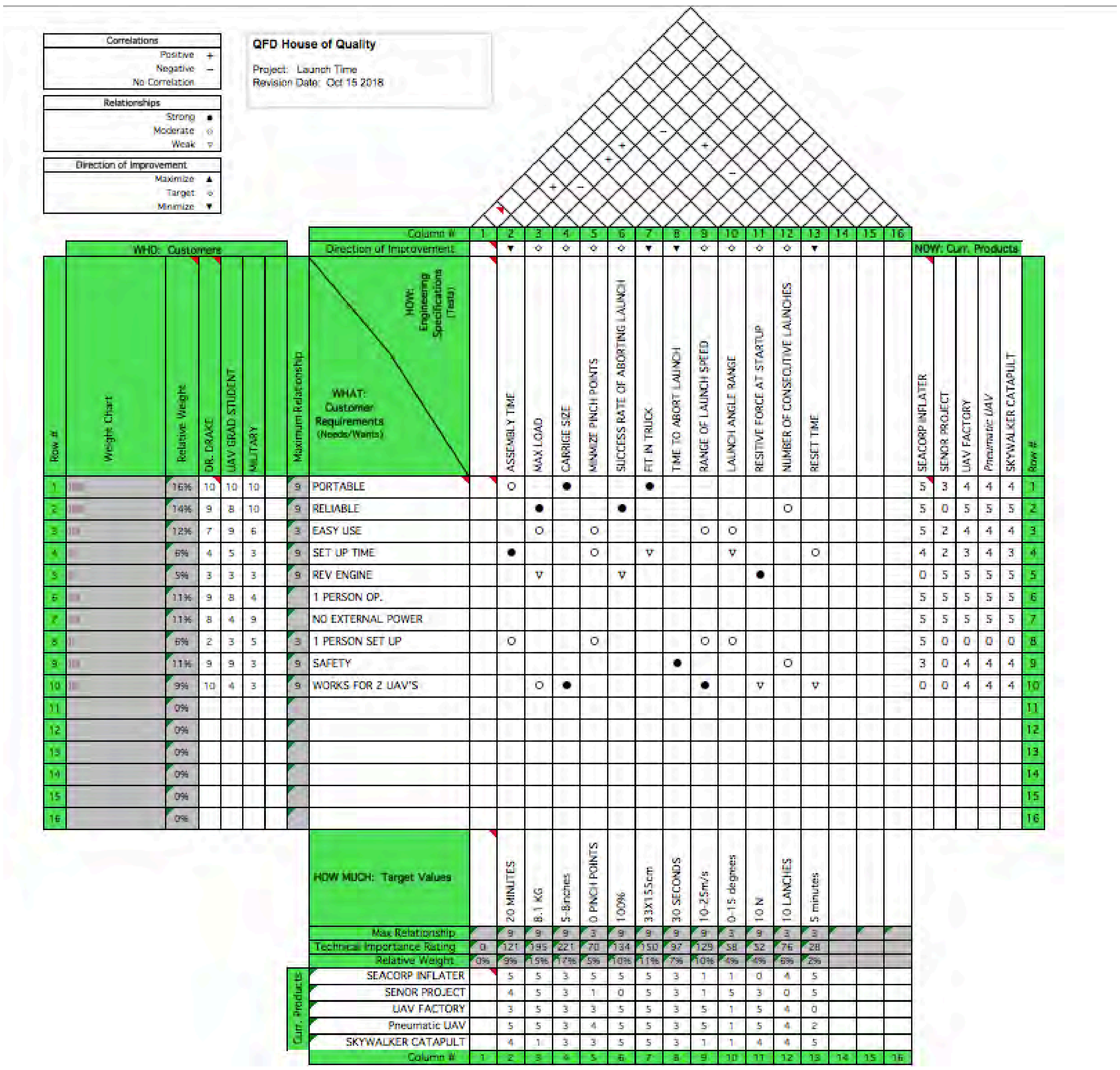
Appendices

Appendix A - QFD House of Quality



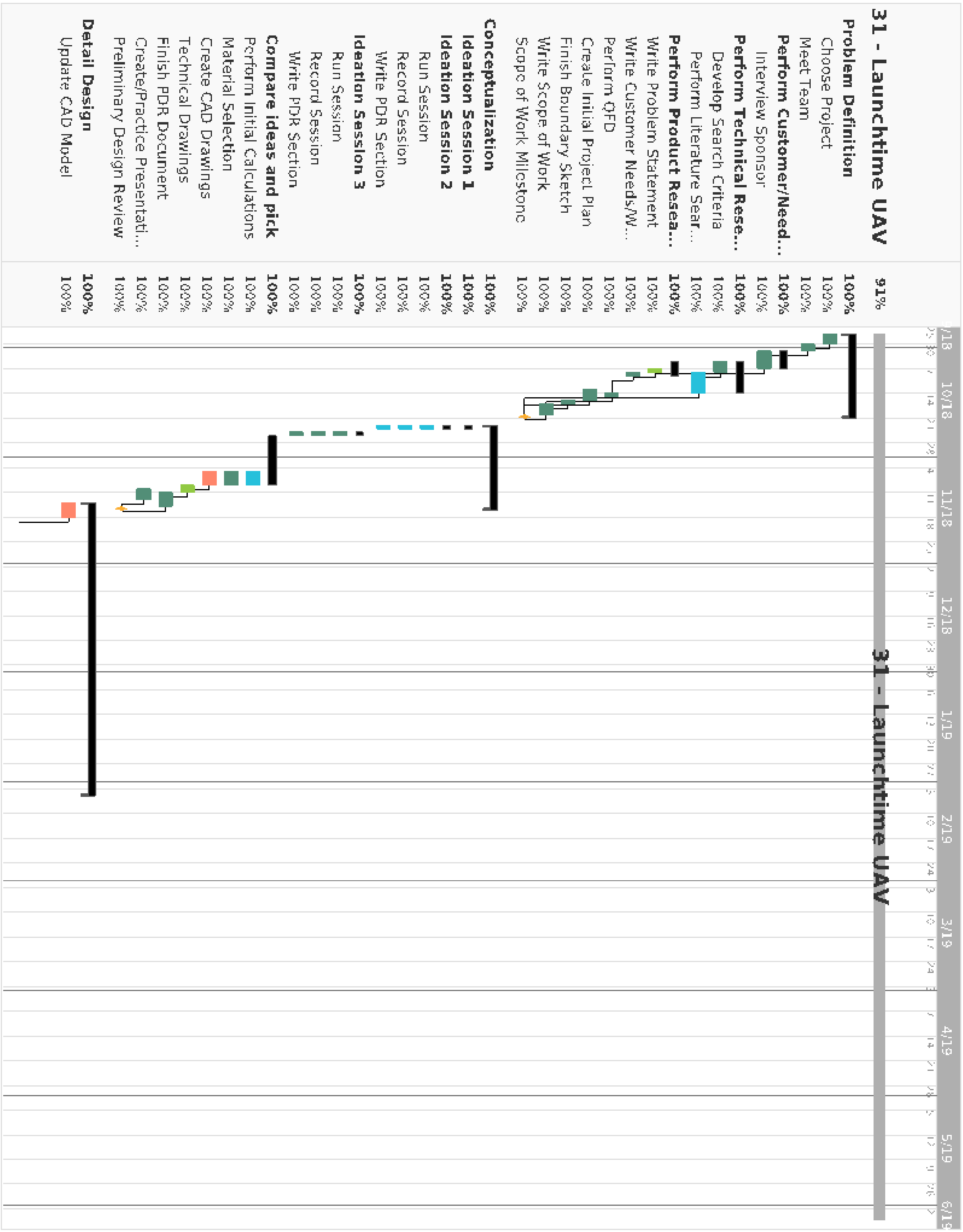
WHO: Customers / WHAT: Customer Requirements (Needs/Wants) / HOW: Engineering Specifications (Tests)

Row #	Relative Weight	DR. DRAKE	UAV GRAD STUDENT	MILITARY	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants)
1	16%	10	10	10	9	PORTABLE
2	14%	9	8	10	9	RELIABLE
3	12%	7	9	6	3	EASY USE
4	6%	4	5	3	9	SET UP TIME
5	5%	3	3	3	9	REV ENGINE
6	11%	9	8	4		1 PERSON OP.
7	11%	8	4	9		NO EXTERNAL POWER
8	6%	2	3	5	3	1 PERSON SET UP
9	11%	9	9	3	9	SAFETY
10	9%	10	4	3	9	WORKS FOR 2 UAV'S
11	0%					
12	0%					
13	0%					
14	0%					
15	0%					
16	0%					

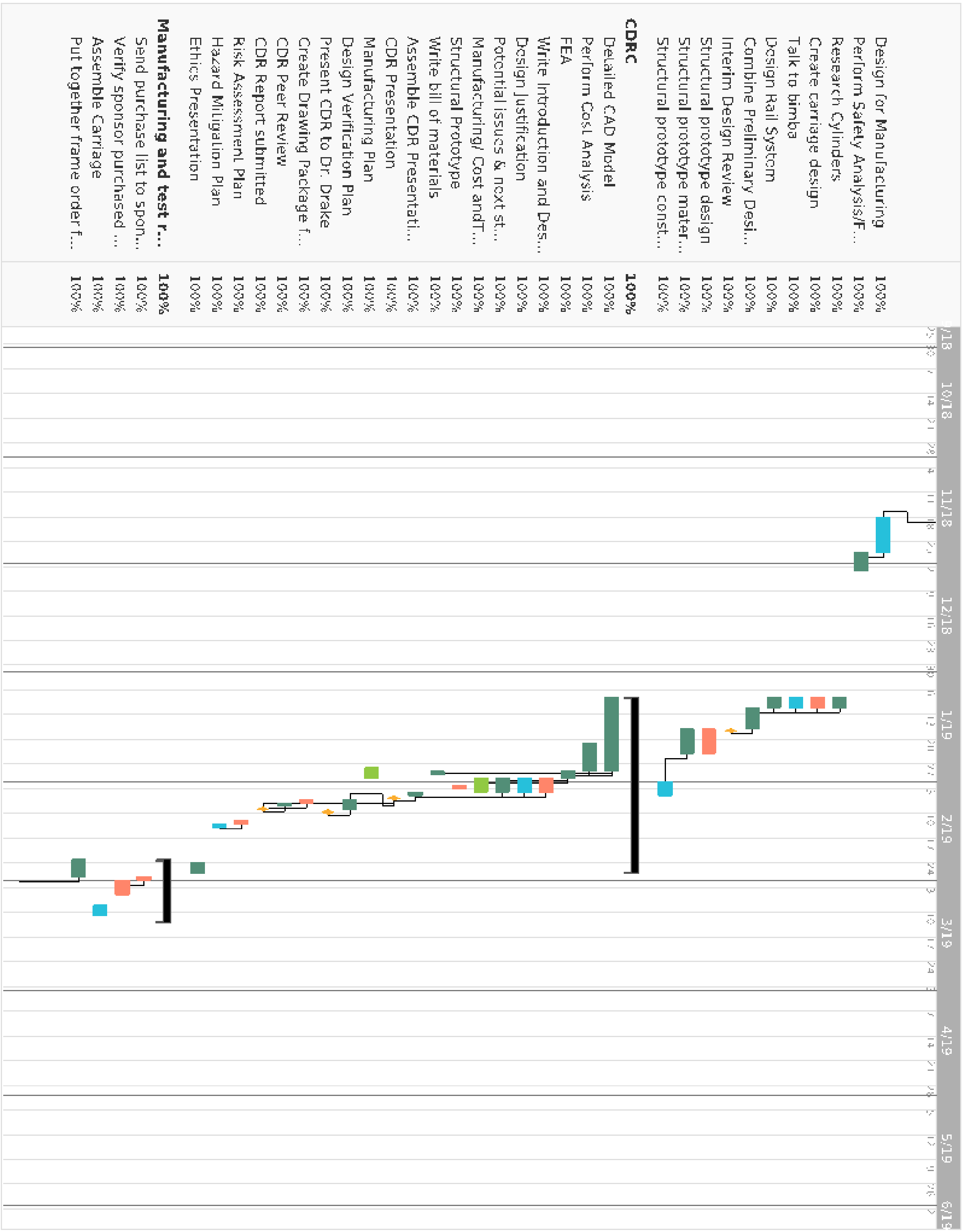
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	SEACORP INFLATER	SENOR PROJECT	UAV FACTORY	Pneumatic UAV	SKYWALKER CATAPULT	Row #
Direction of Improvement		▼	◇	◇	◇	◇	▼	▼	◇	◇	◇	◇	▼				NOW: Curr. Products					
HOW: Engineering Specifications (Tests)		ASSEMBLY TIME	MAX LOAD	CARRIGE SIZE	MINMIZE PINCH POINTS	SUCCESS RATE OF ABORTING LAUNCH	FIT IN TRUCK	TIME TO ABORT LAUNCH	RANGE OF LAUNCH SPEED	LAUNCH ANGLE RANGE	RESITIVE FORCE AT STARTUP	NUMBER OF CONSECUTIVE LAUNCHES	RESET TIME									
PORTABLE		○		●			●										5	3	4	4	4	1
RELIABLE			●			●						○					5	0	5	5	5	2
EASY USE			○		○				○	○							5	2	4	4	4	3
SET UP TIME		●			○		▽			▽			○				4	2	3	4	3	4
REV ENGINE			▽			▽					●						0	5	5	5	5	5
1 PERSON OP.																	5	5	5	5	5	6
NO EXTERNAL POWER																	5	5	5	5	5	7
1 PERSON SET UP		○			○				○	○							5	0	0	0	0	8
SAFETY								●				○					3	0	4	4	4	9
WORKS FOR 2 UAV'S			○	●					●		▽		▽				0	0	4	4	4	10
																						11
																						12
																						13
																						14
																						15
																						16

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HOW MUCH: Target Values		20 MINUTES	8.1 KG	5-8nches	0 PINCH POINTS	100%	33X15.5cm	30 SECONDS	10-25m/s	0-15 degrees	10 N	10 LANCHES	5 minutes			
Max Relationship		9	9	9	3	9	9	9	9	3	9	3	3			
Technical Importance Rating	0	121	195	221	70	134	150	97	129	58	52	76	28			
Relative Weight	0%	9%	15%	17%	5%	10%	11%	7%	10%	4%	4%	6%	2%			
Curr. Products: SEACORP INFLATER		5	5	3	5	5	5	3	1	1	0	4	5			
SENOR PROJECT		4	5	3	1	0	5	3	1	5	3	0	5			
UAV FACTORY		3	5	3	3	5	5	3	5	1	5	4	0			
Pneumatic UAV		5	5	3	4	5	5	3	5	1	5	4	2			
SKYWALKER CATAPULT		4	1	3	3	5	5	3	1	1	4	4	5			
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

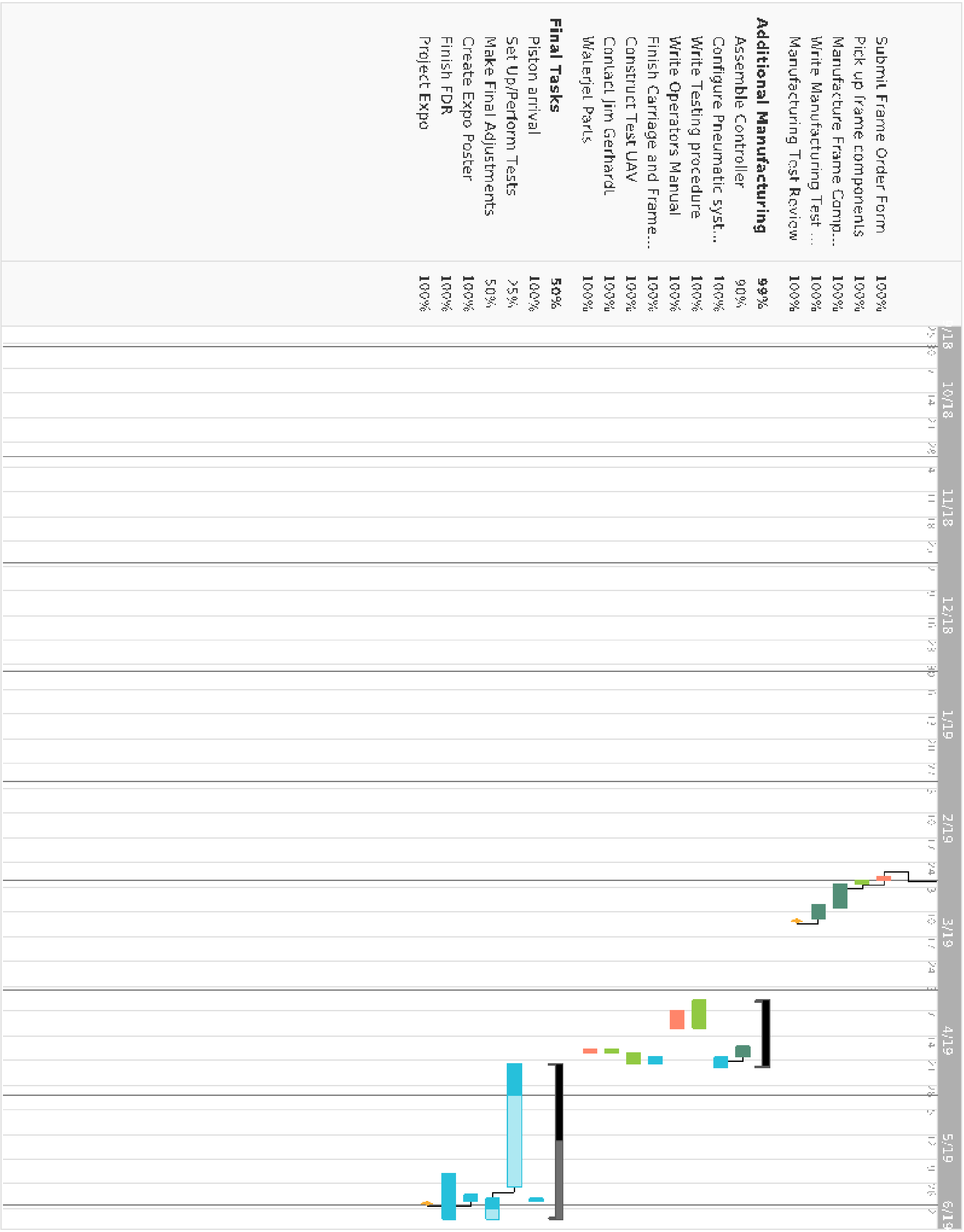
Appendix B - Gantt Chart 9/25/18 – 11/18/18



Appendix B - Gantt Chart 11/18/18 – 3/10/19



Appendix B - Gantt Chart 3/10/19 – 6/7/19



Appendix C - Pugh Matrices

Pugh Matrix - Track System

	Weight	Rectangular Tube with Wheels (2014 Senior Project and UAV LAB)	"I" Channel with Wheels Inside	Two Tube Slider	Two Tube Roller	Piston (No Track)
Stability	2	0	1	1	1	-1
Strength	3	0	1	1	0	1
Friction	3	0	0	-1	0	1
Manufacturability	2	0	0	1	-1	1
Lifetime	1	0	0	-1	0	-1
Collapsibility	1	0	0	1	1	-1
Total		**0**	**5**	**4**	**1**	**4**

Pugh Matrix – Track Support

Track support						Weights
	single pole	a frame	Ladder System	t frame	Tripod	
Portablility	s	s	-	-	s	3
cost	s	-	-	-	-	1
manufacturable	s	s	-	s	s	4
assembly time	s	s	s	s	s	2
resistive force	s	+	s	+	+	3
stability	s	+	s	+	+	4
Adjustable Angle	s	+	-	s	+	2
Result	0	8	-10	3	8	

Pugh Matrix - Carriage

Criteria	Weight	UAV Factory	AVA	H.H Tech	ElevonX	Rear Holding	Side Clamp
Stability	5		-	-	S	-	S
Resistance	4		-	S	+	-	-
Size	3		S	+	-	-	S
Complexity	2		+	+	-	+	+
Durability	1		S	S	S	S	S
Manufacturability	4		+	-	S	+	+

Pugh Matrix - Propulsion

	Piston Pneumatic	Tube (pneumatic)	Bungee	Electric Motor	Spring
Size	D	+	+	+	+
Weight	A	+	+	−	+
Repeatability	T	S	−	S	−
Durability	U	−	−	−	−
Safety	M	−	−	−	−
Cost	☆	S	+	−	+
Power	☆	S	S	−	S
Energy Req.	★	S	+	−	+
Time Commitment / Resource	★	−	S	−	S
Σ +		2	4	1	4
Σ −		3	3	7	3

Appendix D - Morph Matrix

	Concepts		
Sub function	1	2	3
Frame	A Frame	Tripod	T Frame
Track	"I" channel	Two Tube Slider	No Track Piston
Power	Spring	3Pneumatic Pistons	Bungie
Carriage	Pin Hook	Rear Grip+Mold	Side Clamp

Appendix E - Weighted Decision Matrix

Criteria	Weighting		Option 1		Option 2		Option 3		Option 4		Option 5	
			Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Portable	5		4	20	4	20	2	10	4	20	3	15
Reliable	4		4	16	3	12	4	16	4	16	4	16
Easy Use	3		5	15	4	12	3	9	5	15	3	9
Set Up Time	2		3	6	4	8	4	8	3	6	4	8
Rev engine restriction	4		4	16	4	16	3	12	3	12	2	8
1 Person set up	1		5	5	3	3	4	4	5	5	4	4
Safely abort launch	5		5	25	2	10	1	5	5	25	1	5
Works for two UAV's	4		4	16	5	20	2	8	2	8	2	8
		Total Values:		119		101		72		107		73

Option 1	A no track, pneumatic piston cylinder powered launcher that is supported by a tripod and has a carriage that is held in place using a side clamp.
Option 2	An I channel, powered by a set of bungie cords that is supported by a tripod with two different models for a carriage, one with a rear grip molded and another with a Side clamp
Option 3	A two tube slider, powered by springs withing the tubes, supported by an A frame with a Pin hook grip on the carriage
Option 4	A No track, pneumatic piston cylinder powered launcher, that is supported by an A frame and has a Pin hook carriage
Option 5	an I channel, spring powered launcher with a T frame support and a rear grip carriage

Appendix F - Excel calculation file

Piston Bore [in]	1.25		
Piston Area [in^2]	1.23		
Piston Pressure [psi]	27.7		
Piston Force [lbf]	34.0		
UAV Weight [lbm]	4.5		
UAV Acceleration [g]	7.55		
Piston Length [in]	50		
Piston Volume [ft^3]	0.426		
Piston Time [s]	0.185		
Piston Flow Rate [cfm]	138.13		
	ft/s	m/s	mph
Final Velocity	45.02	15.01	30.66

Piston Bore [in]	1.25		
Piston Area [in^2]	=PI()*(B1/2)^2		
Piston Pressure [psi]	27.7		
Piston Force [lbf]	=B2*B3		
UAV Weight [lbm]	=18/4		
UAV Acceleration [g]	=(B4/B5)		
Piston Length [in]	50		
Piston Volume [ft^3]	=(B2/12)*(B7/12)		
Piston Time [s]	=SQRT(2*(B7/12)/(B6*32.2))		
Piston Flow Rate [cfm]	=(B8/B9)*60		
	ft/s	m/s	mph
Final Velocity	=B6*32.2*B9	=B12/3	=B12*0.681

Appendix G - Safety Design Hazard Checklist

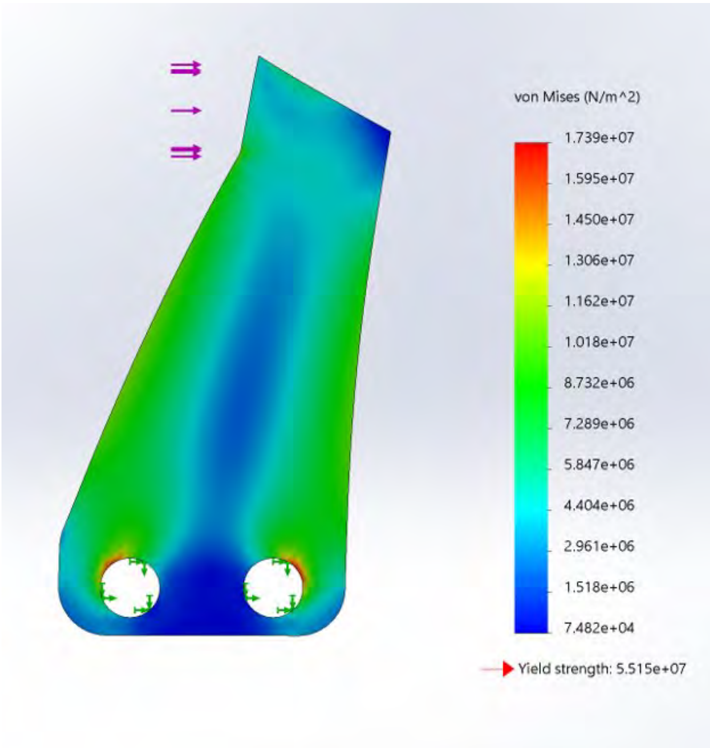
Description of Hazard	Y/N	Planned Corrective Action	Planned Date	Actual Date
1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?	Y	The motion of the drone carriage may create a pinch point between itself and its guide, which will be covered to prevent potential injury	3/25/19	TBD
2. Can any part of the design undergo high accelerations/decelerations?	Y	The carriage will undergo high acceleration as part of the design. A minimum safety distance will be set for the operator to prevent injury	N/A	N/A
3. Will the system have any large moving masses or large forces?	Y	Large forces will be present in the piston used to generate kinetic energy. A cover will be used to prevent operator injury	N/A	N/A
4. Will the system produce a projectile?	Y	By the project's nature, the drone will be launched out of the catapult. The device should not be used if people are in front of its trajectory.	N/A	N/A
5. Would it be possible for the system to fall under gravity creating injury?	Y	The device will stand on legs to provide the desired launch angle. If it were to tip over, it would present a safety risk. The legs will be secured to the ground to prevent tipping.	2/28/19	TBD

6. Will a user be exposed to overhanging weights as part of the design?	N	N/A	N/A	N/A
7. Will the system have any sharp edges?	N	N/A	N/A	N/A
8. Will any part of the electrical systems not be grounded?	N	N/A	N/A	N/A
9. Will there be any large batteries or electrical voltage in the system above 40 V?	N	N/A	N/A	N/A
10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?	Y	High pressure air in compressor. A pressure relief device will be used to prevent over pressurization	3/25/19	5/23/19
11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system? N	N	N/A	N/A	N/A
12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?	N	N/A	N/A	N/A
13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?	N	N/A	N/A	N/A
14. Can the system generate high levels of noise?	N	N/A	N/A	N/A
15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc.?	Y	The device may be used in foggy, humid, hot, or cold weather, so must be able to withstand such	4/30/19	TBD

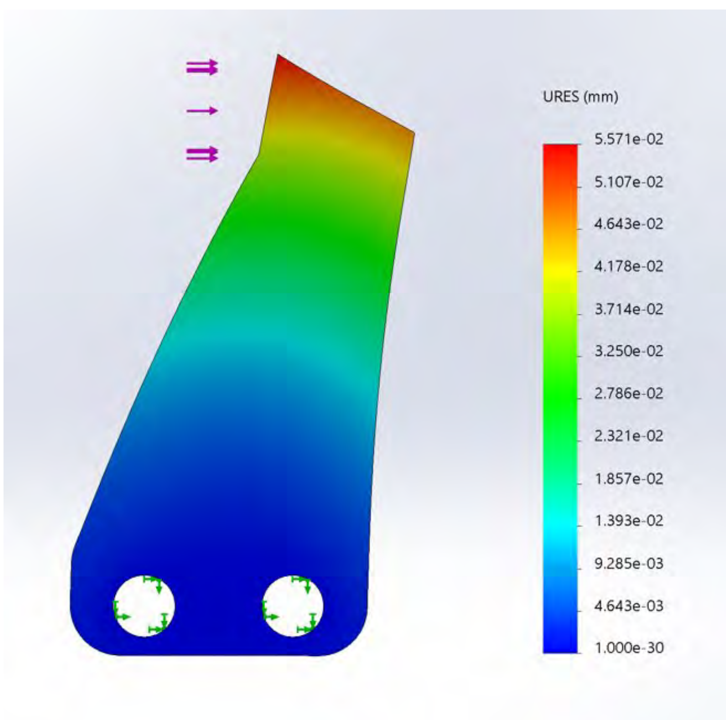
		environmental conditions.		
16. Is it possible for the system to be used in an unsafe manner?	Y	The device could be used to launch objects other than the intended drones. Users must be instructed to only use the catapult to launch the intended items.	4/30/19	5/25/19

Appendix H – Panel FEA

Stress in Panel at Twice the Maximum Load

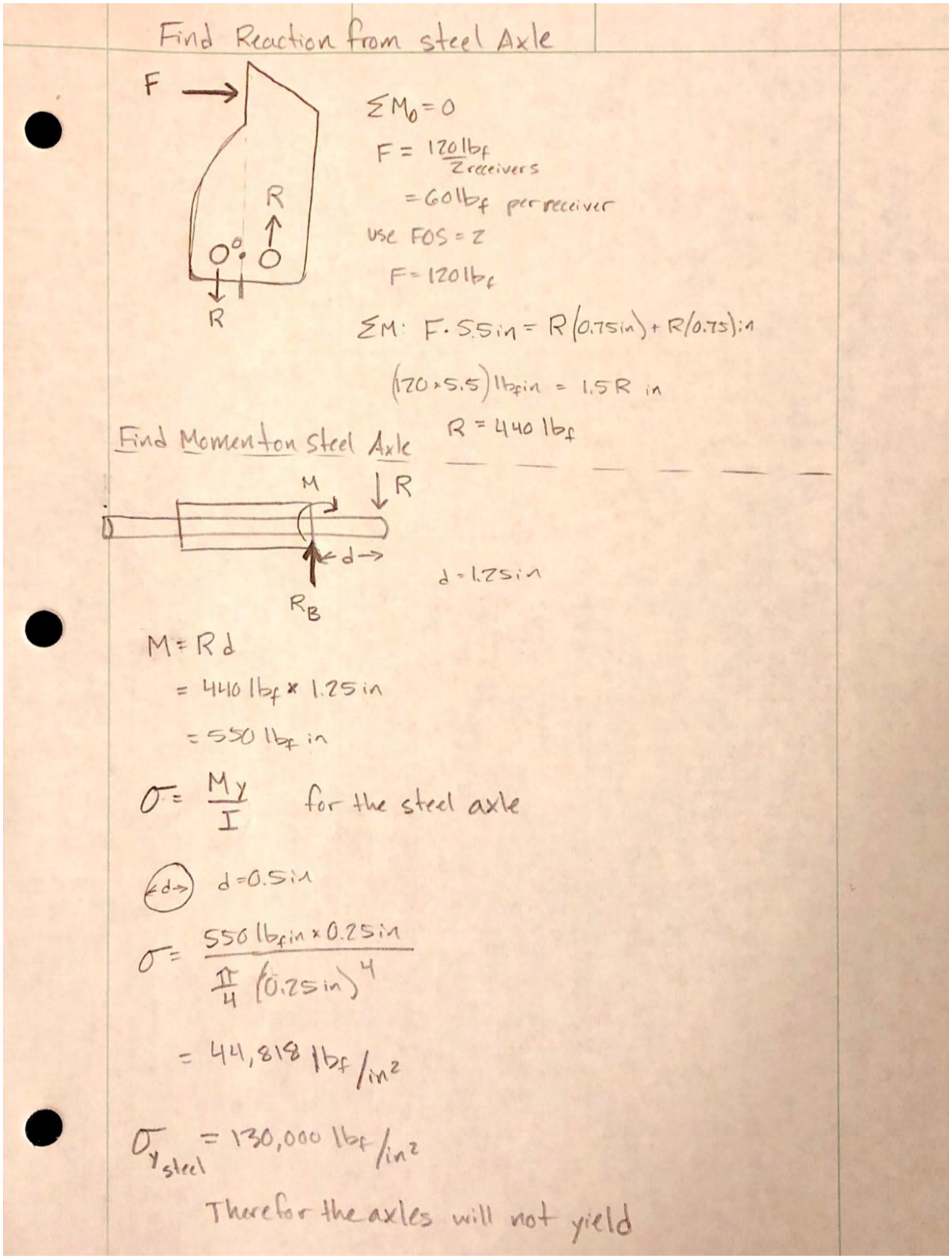


Strain in Panel at Twice the Maximum Load



Appendix I – Carriage Axle Hand Calculations

Hand Calculations for Stress in the Carriage Lateral Axles



Find Reaction from steel Axle

$\Sigma M_0 = 0$

$F = \frac{120\,lb_f}{2\,receivers}$

$= 60\,lb_f$ per receiver

use FOS = 2

$F = 120\,lb_f$

$\Sigma M: F \cdot 5.5in = R(0.75in) + R(0.75)in$

$(120 \times 5.5)\,lb_f in = 1.5R\ in$

$R = 440\,lb_f$

Find Moment on steel Axle

$d = 1.25in$

$M = Rd$

$= 440\,lb_f * 1.25in$

$= 550\,lb_f\,in$

$\sigma = \frac{My}{I}$ for the steel axle

$d = 0.5in$

$\sigma = \frac{550\,lb_f in \times 0.25in}{\frac{\pi}{4}(0.25in)^4}$

$= 44{,}818\,lb_f/in^2$

$\sigma_{y_{steel}} = 130{,}000\,lb_f/in^2$

Therefor the axles will not yield

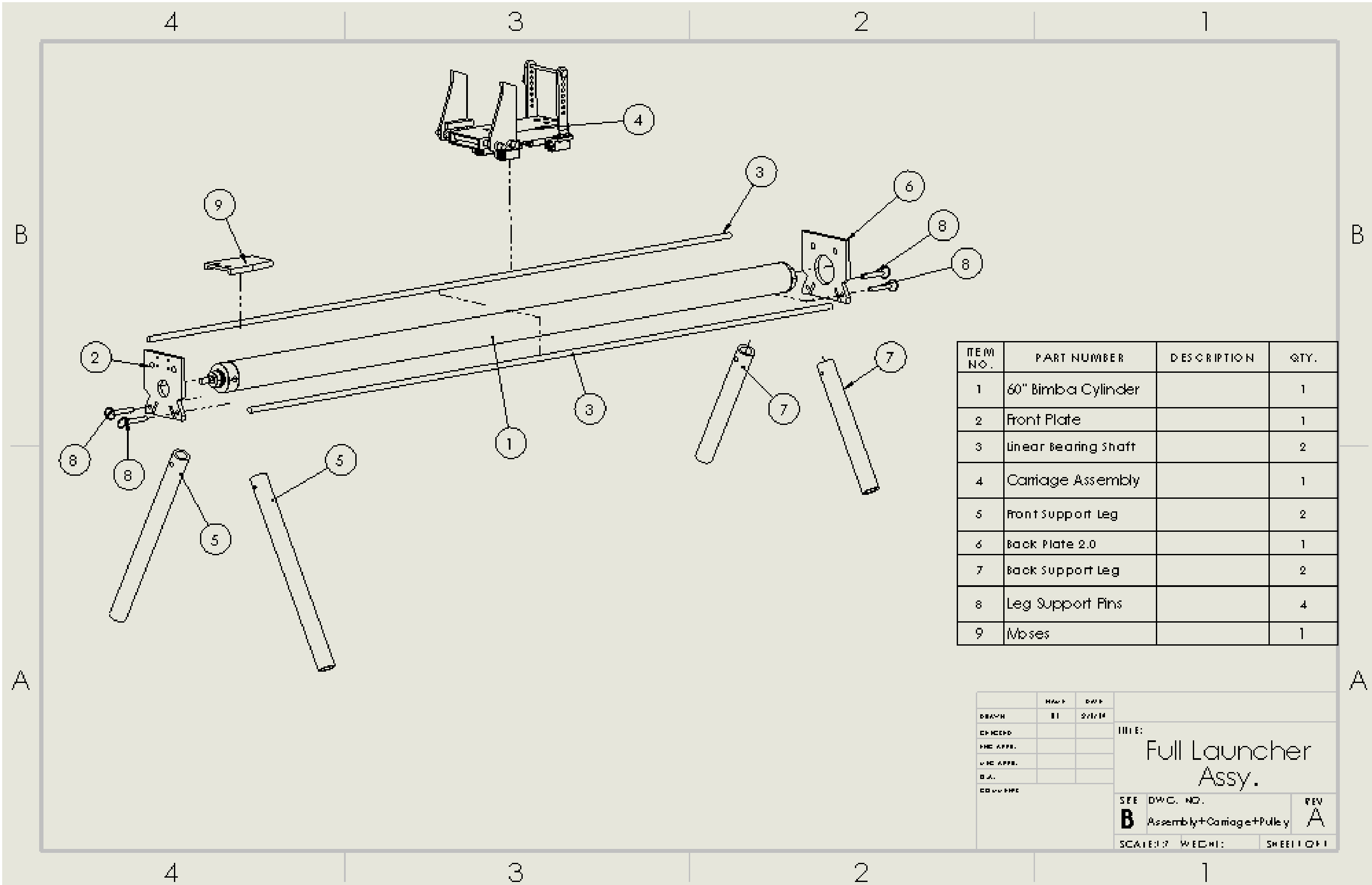
Appendix J – Piston Air Flow Spreadsheet

428 Calcs.xlsx spreadsheet

Piston Bore [in]	2.5		
Piston Area [in^2]	4.91		
Piston Pressure [psi]	27		
Piston Force [lbf]	132.5		
UAV Weight [lbm]	18		
UAV Acceleration [g]	7.36		
Piston Length [in]	60		
Piston Volume [ft^3]	2.045		
Piston Time [s]	0.205	scfm	
Piston Flow Rate [cfm]	597.54	1097.526086	
	ft/s	m/s	mph
Final Velocity	48.69	14.85	33.16

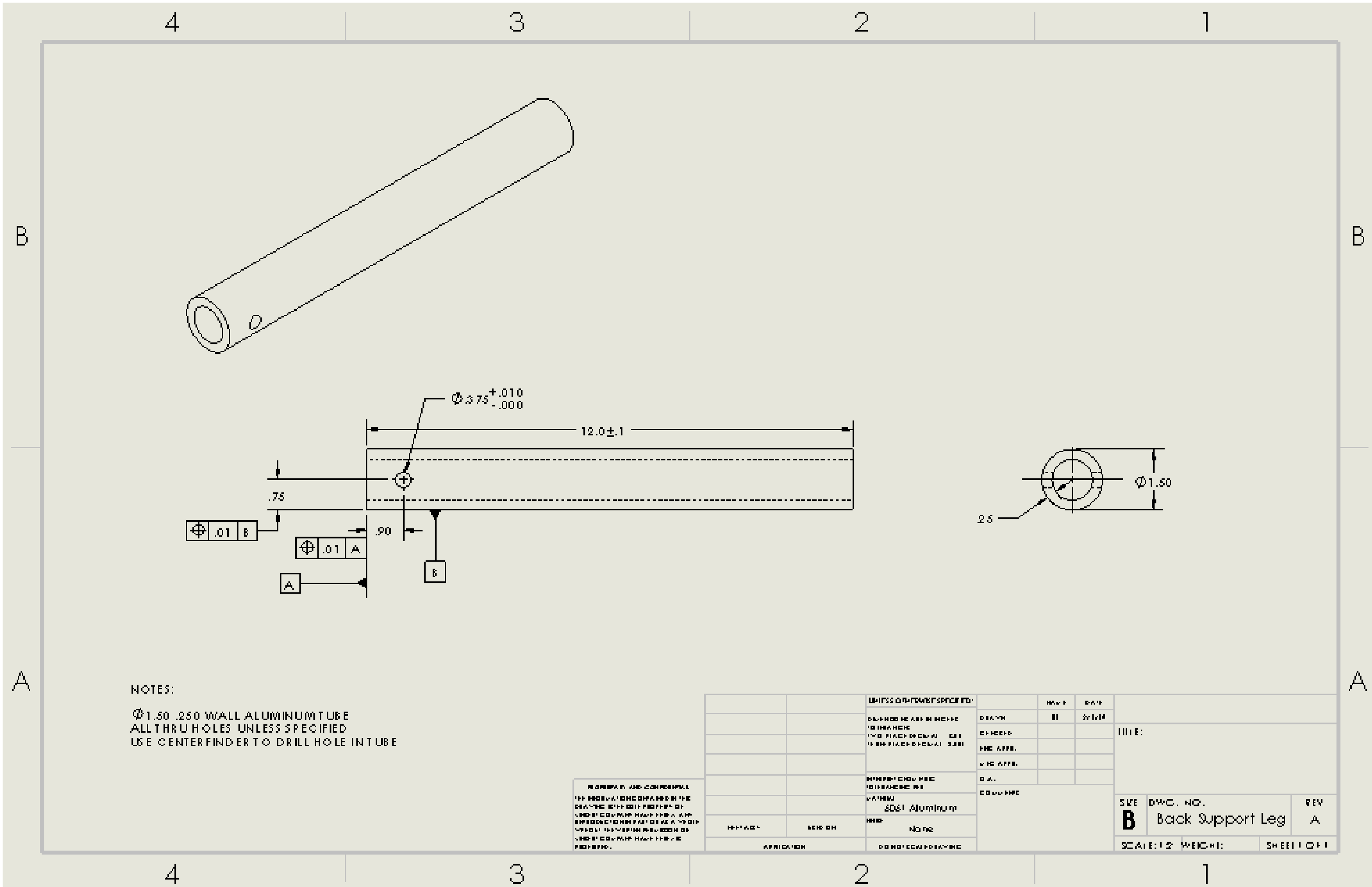
Appendix K – Detailed Drawings

Exploded View of Launcher

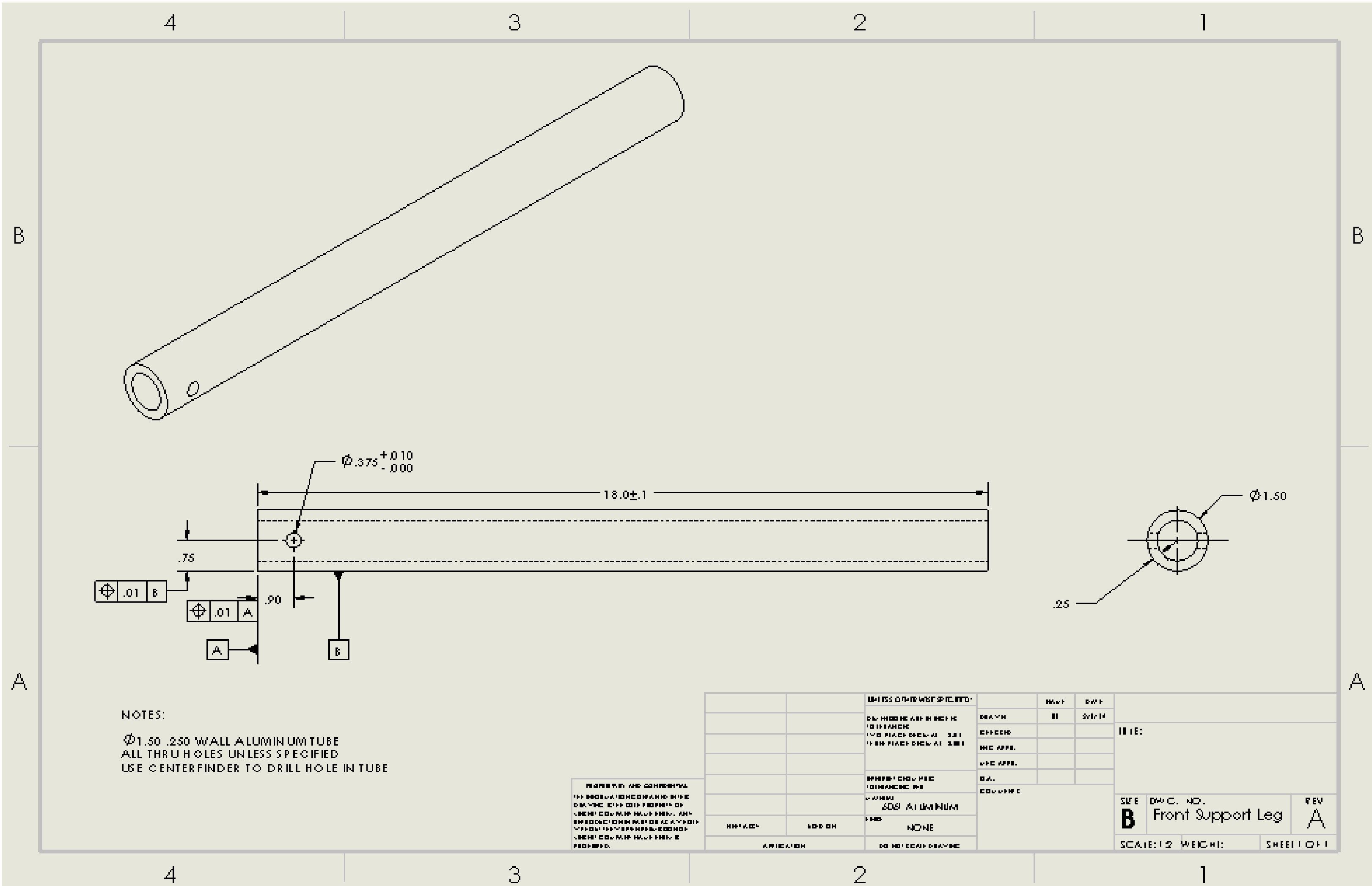


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	60" Bimba Cylinder		1
2	Front Plate		1
3	Linear Bearing Shaft		2
4	Carriage Assembly		1
5	Front Support Leg		2
6	Back Plate 2.0		1
7	Back Support Leg		2
8	Leg Support Pins		4
9	Moses		1

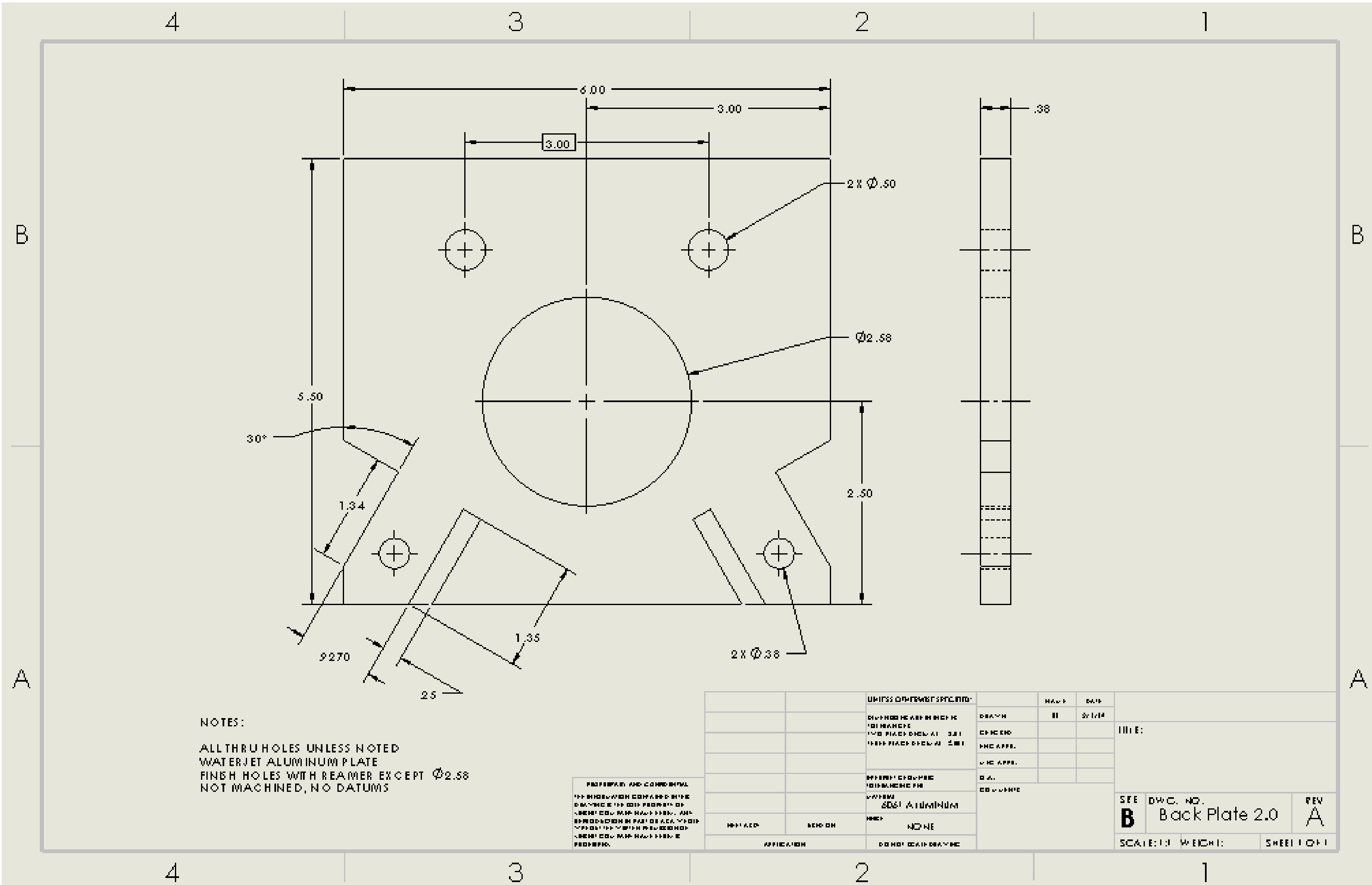
Back Support Leg



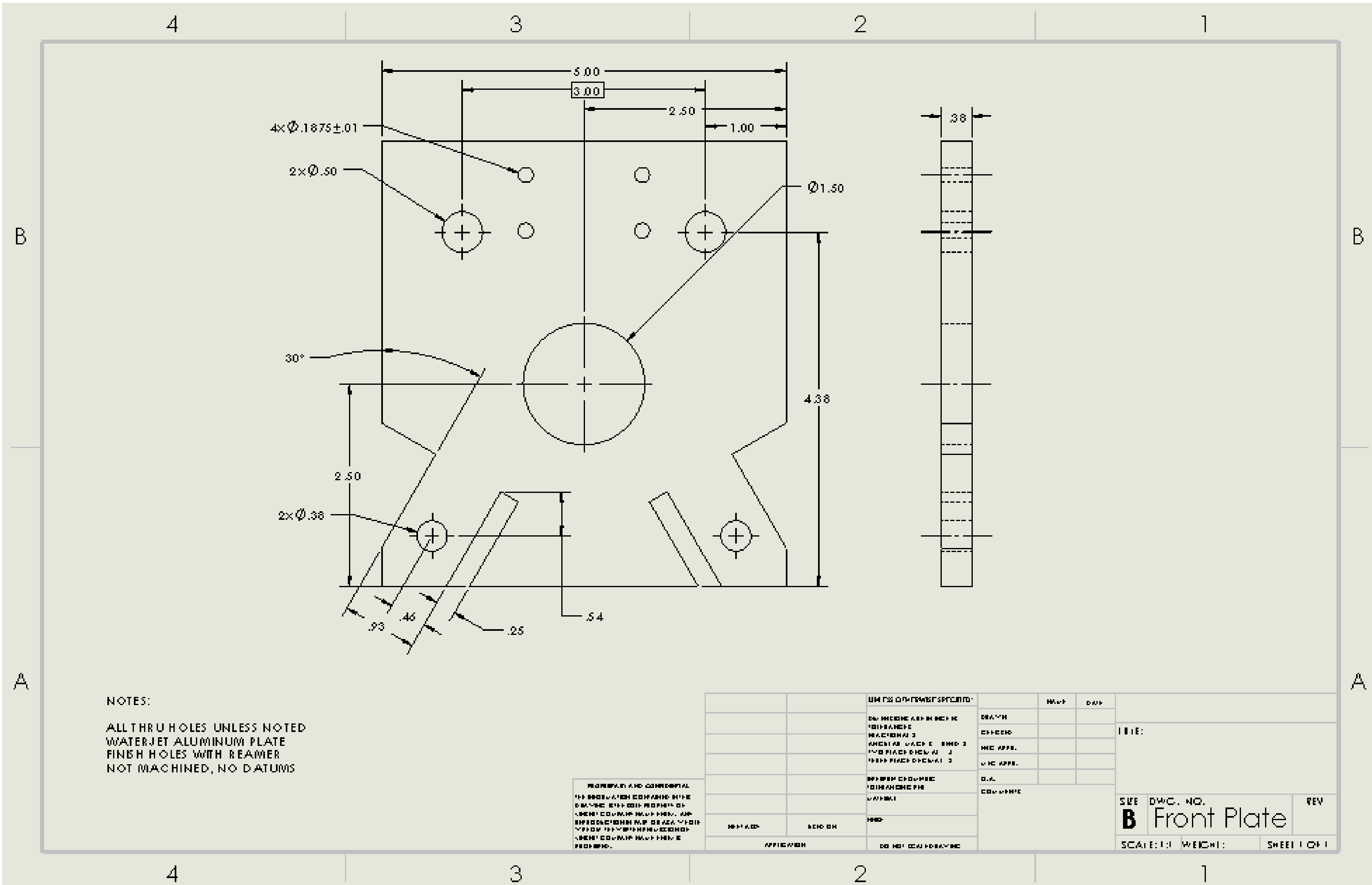
Front Support Leg



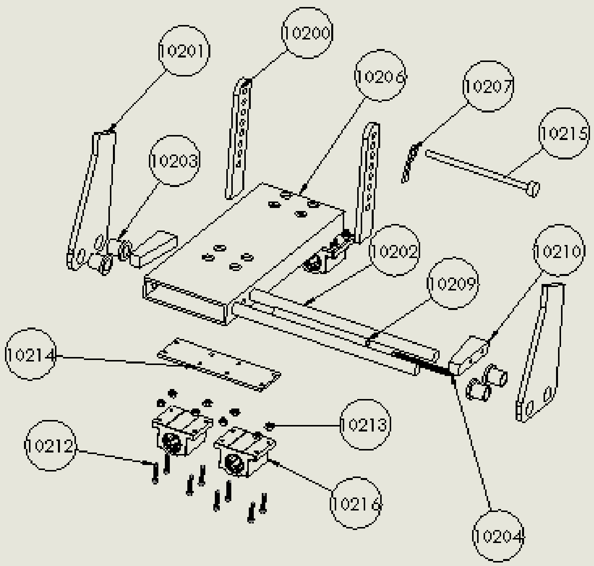
Frame Back Plate



Frame Front Plate



Carriage Exploded View



BOM CARRIAGE			
ITEM NO.	PART NUMBER	Material	QTY.
10206	Rectangular Tube	Aluminum	1
10201	Penguin	Aluminum	2
10202	Axle	High Strength Stainless Steel	2
10200	Ladder	Aluminum	2
10210	Bumper	Aluminum	2
10216	Linear Bearing	Aluminum/ Steel	4
10203	Flanged Bearing	Bronze	4
10209	Aluminum Tube	Aluminum	1
10204	Spring	Stainless Steel	1
10215	Rear Support Rod	Stainless Steel	1
10207	Cotter Pin	Stainless Steel	1
10214	Mounting Plate	Aluminum	2
10212	Bearing Mount Screw	Stainless Steel	16
10213	Bearing Mount Nut	Stainless Steel	16

NOTES:

LADDERS WELDED TO RECTANGULAR TUBE

FLANGED BEARINGS PRESS FIT TO PENGUINS

BUMPERS WELDED TO PENGUINS

AXLES AND ALUMINUM TUBE ARE PRESS FIT INTO A DELRIN INSERT

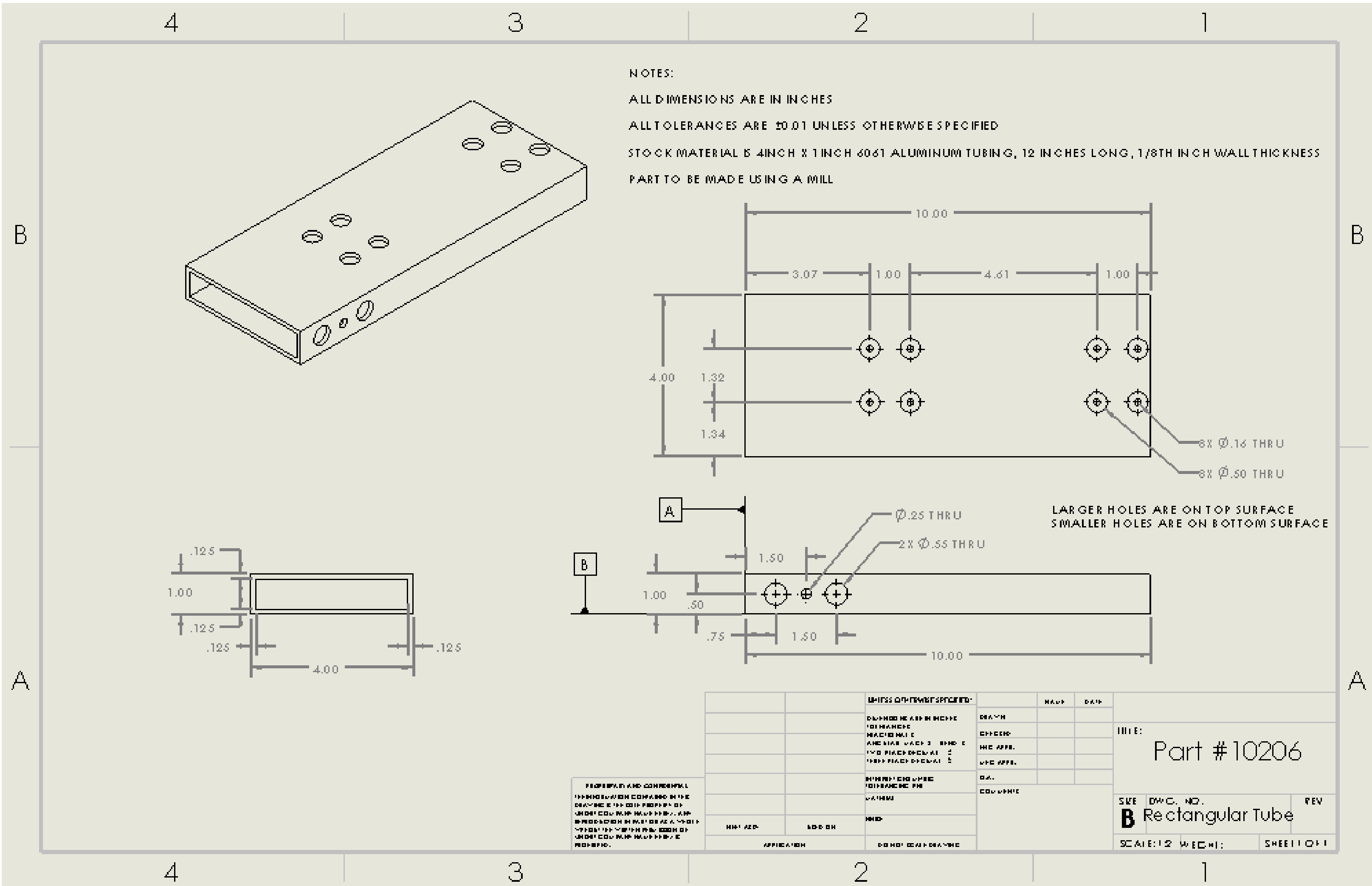
MOUTNING PLATE WELDED TO RECTANGULAR TUBE

TITLE: Carriage

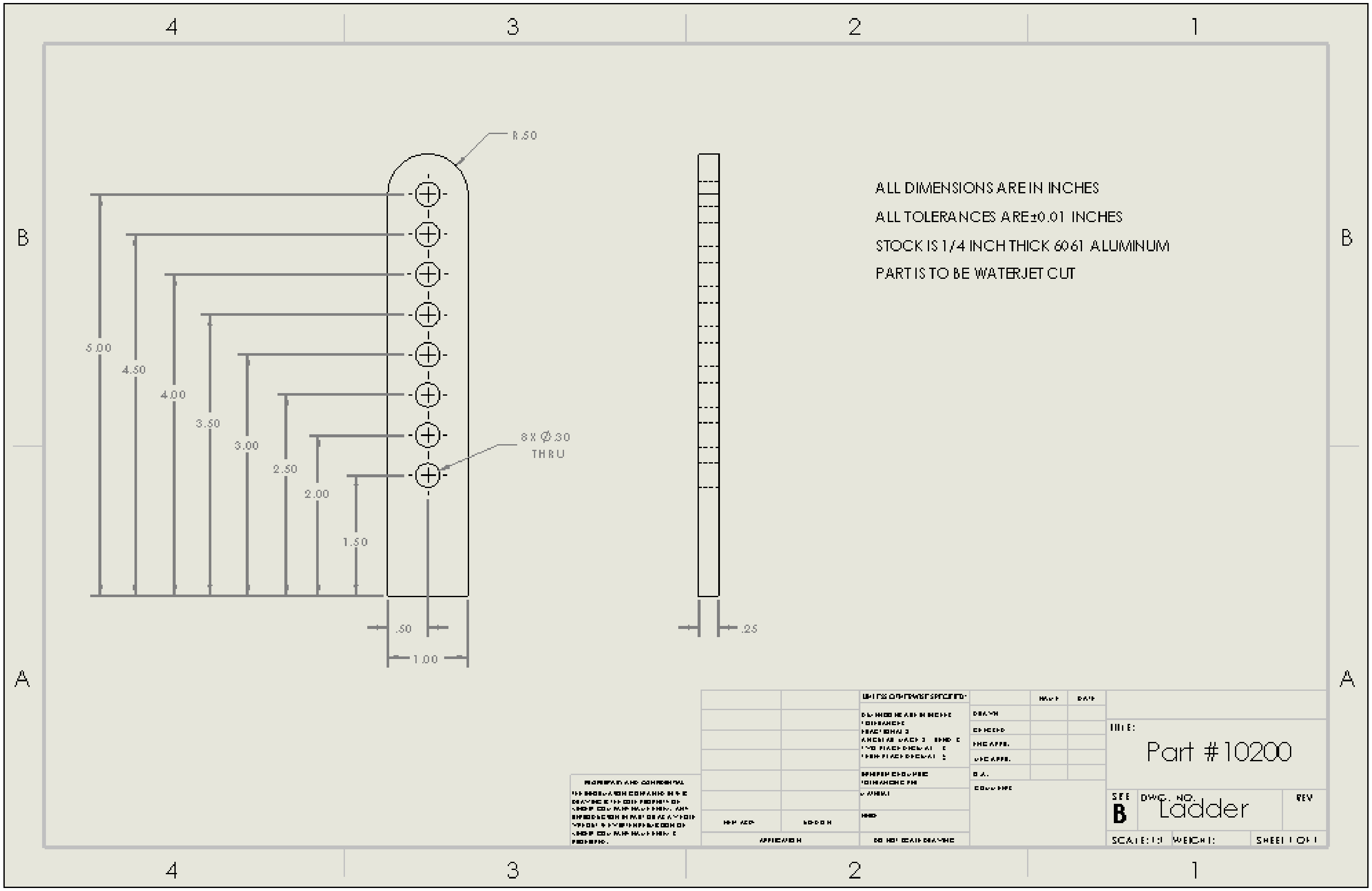
SIZE B | DWG. NO. | REV

SCALE: 1:8 | WEIGHT: | SHEET 1 OF 1

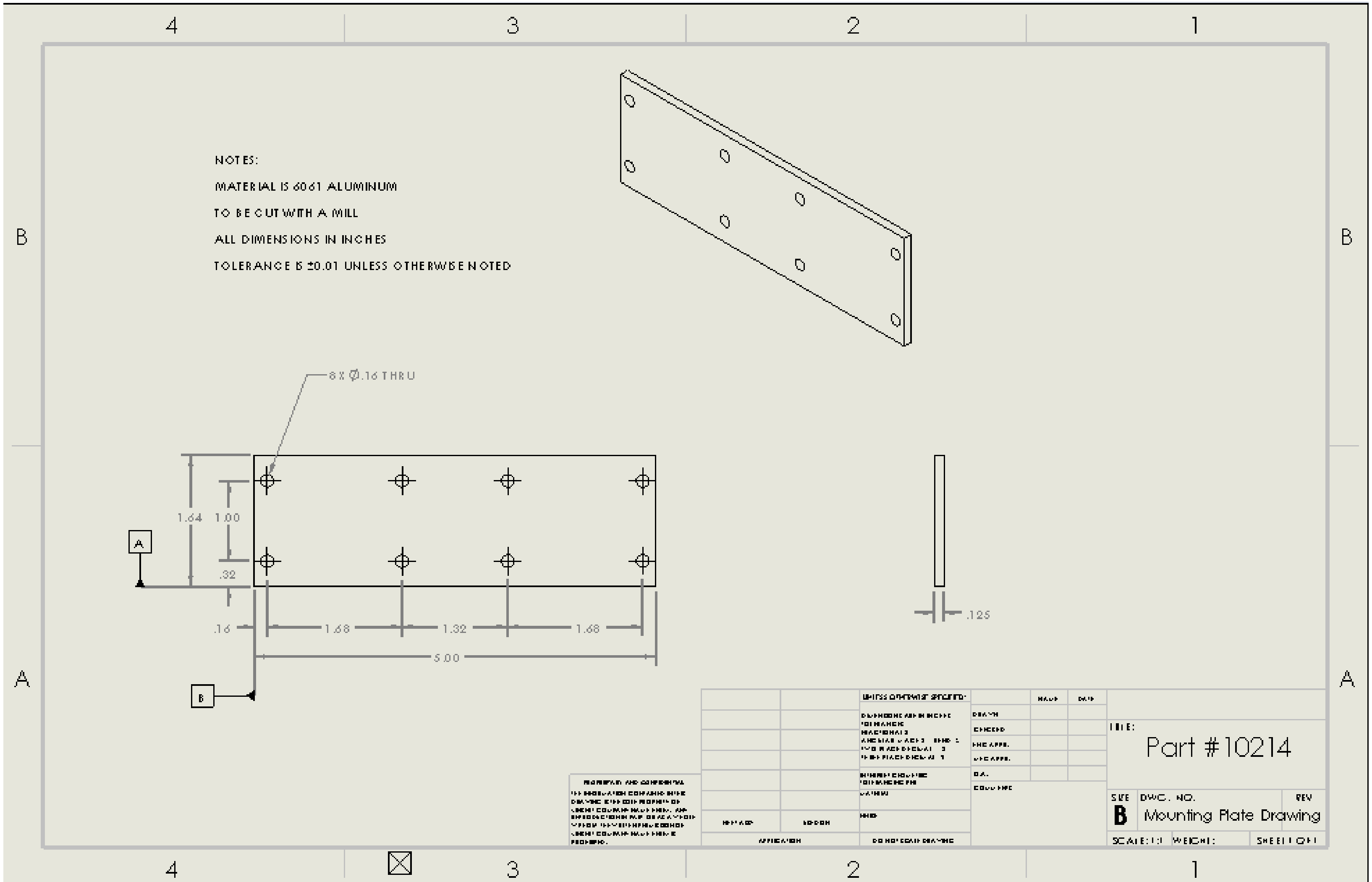
Rectangular Tube (Carriage Base)



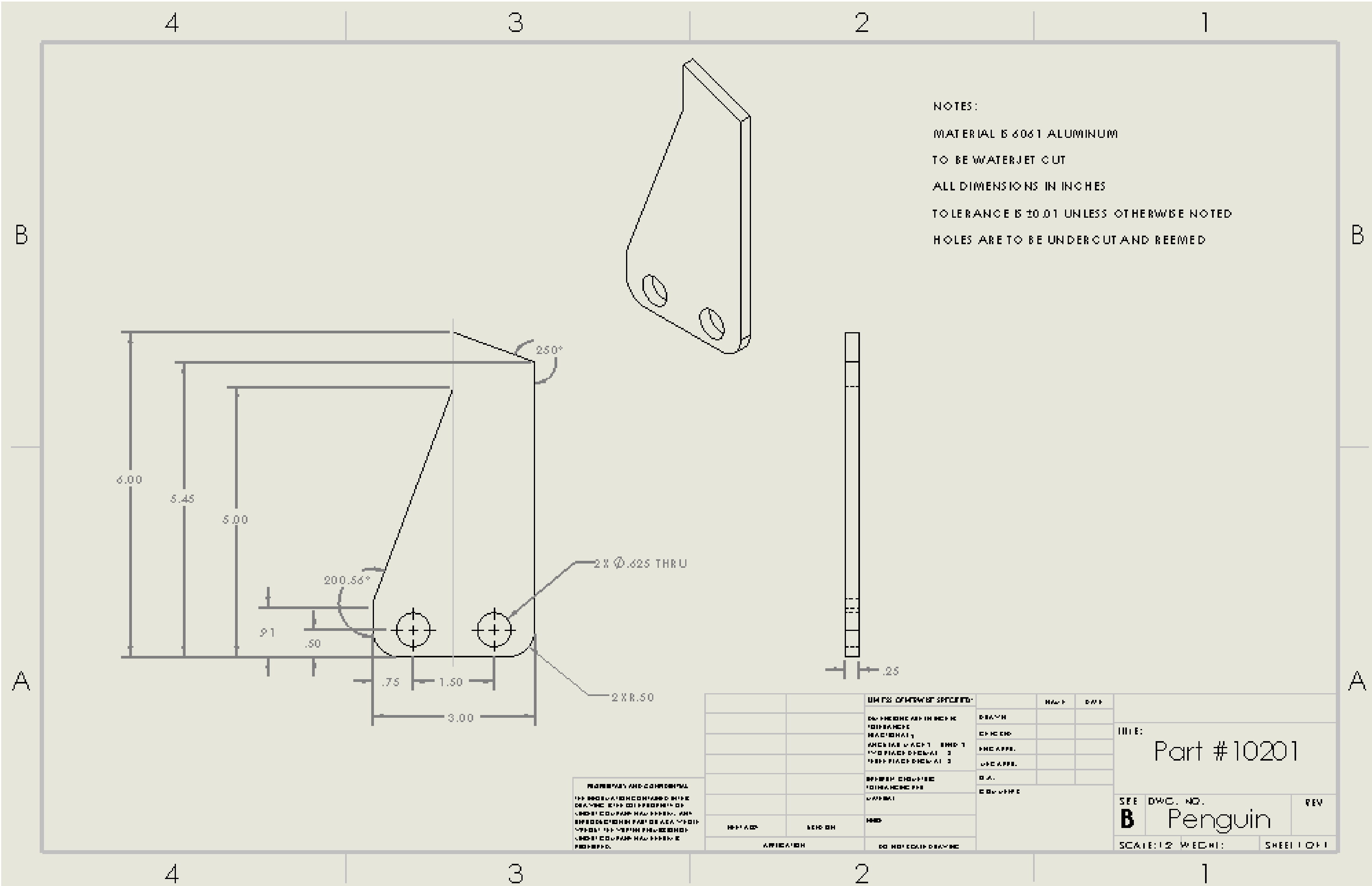
Ladder (Carriage Rear Support)



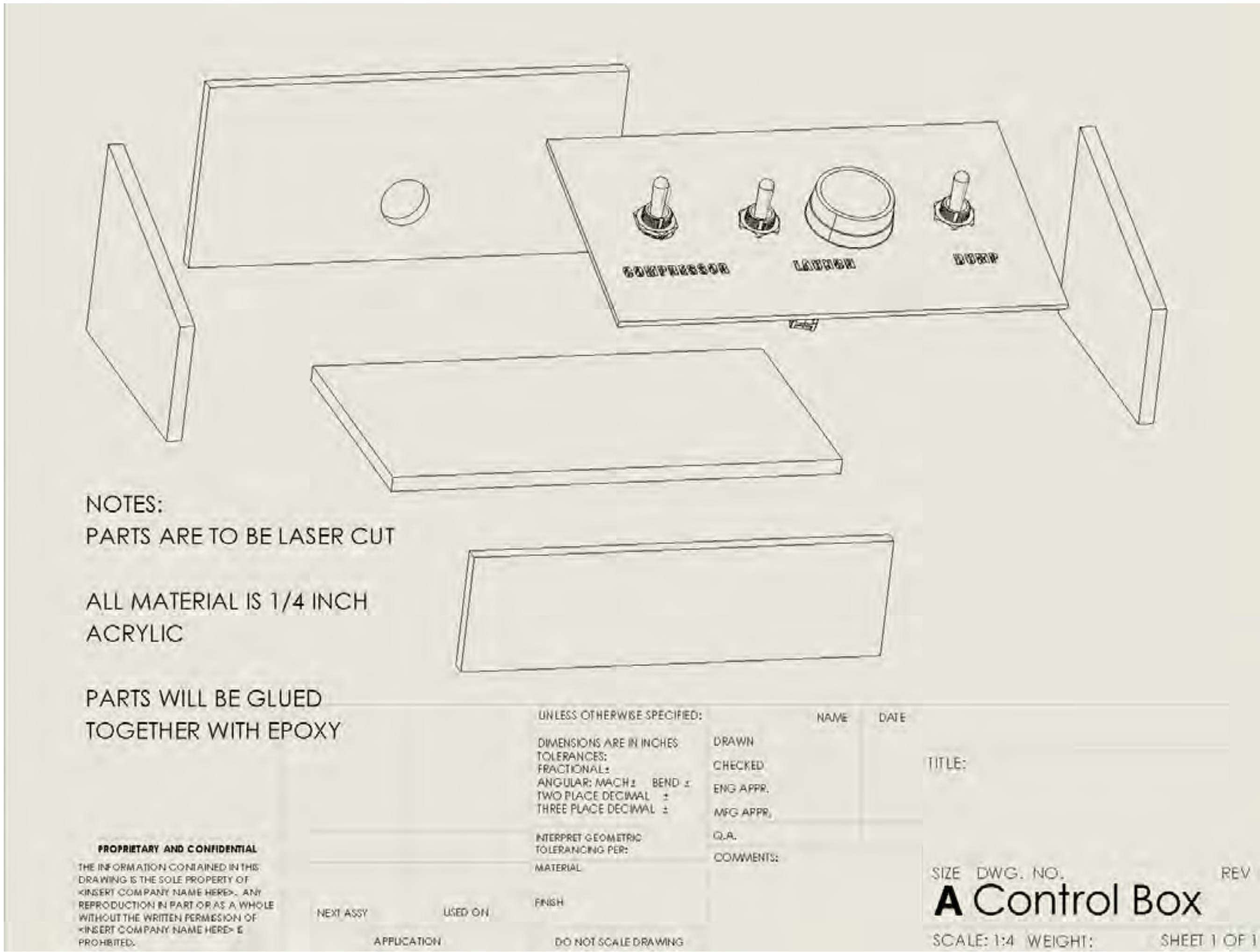
Bearing Mount Plate



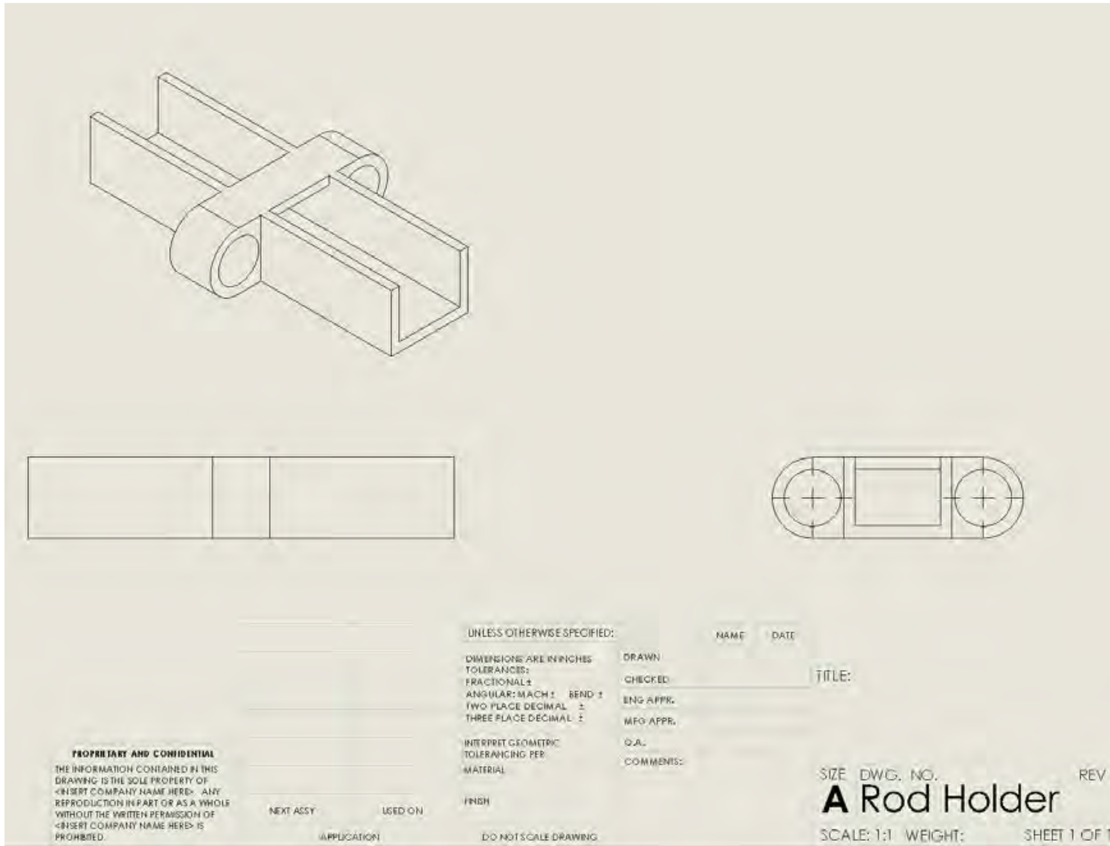
Penguin (Front UAV Support)



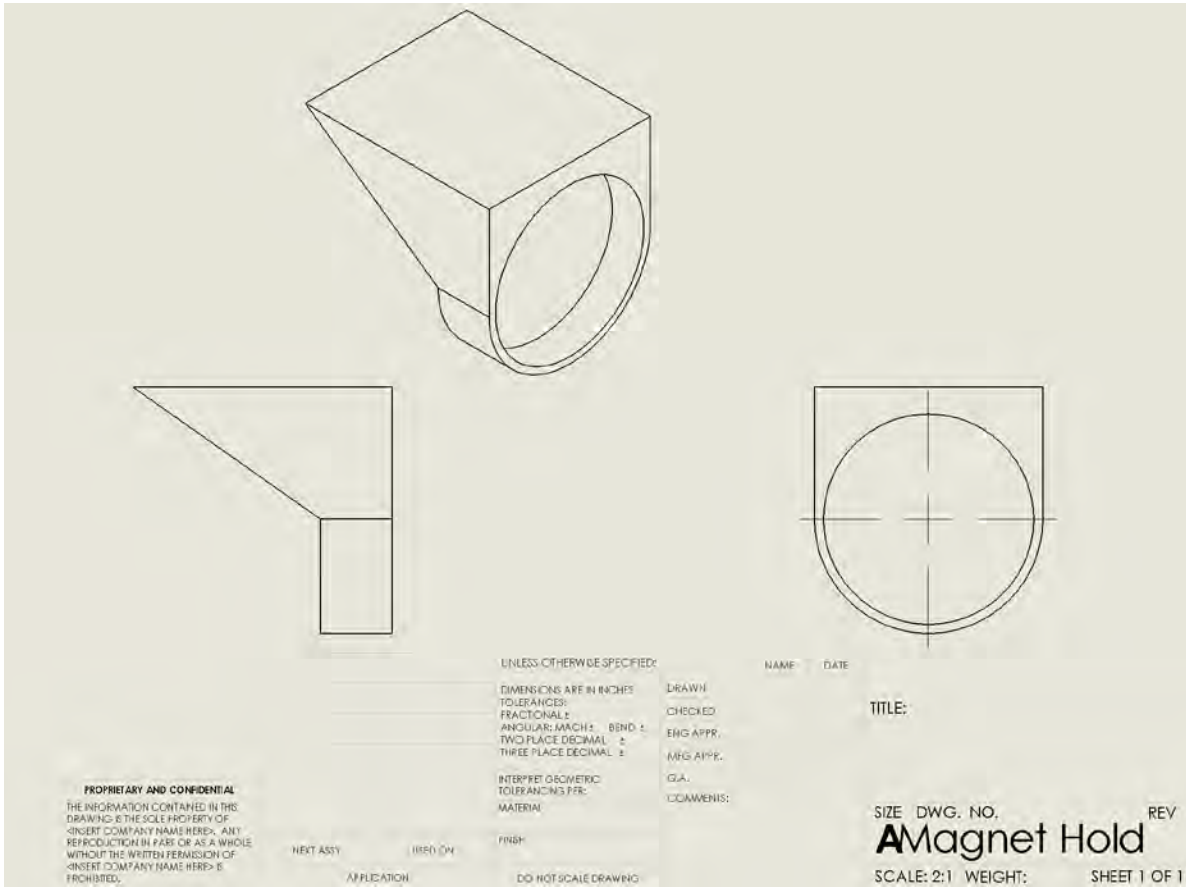
Control Box Assembly (Laser Cut Acrylic)



Rod Holder Inside Carriage (3D Printed)



Magnet Holder Under Carriage (3D Printed)



Appendix L – Bill of Materials

Item	Cost/Unit	Units	Total Cost	Vendor	Vedor Part Number	Associated Part	Method of Purchase	Date Purchased	Date Delivered
				ORDER 1					
Fasteners	0.11	2	0.22	Miner's Ace Hardware	NA	Carriage Prototype	Reimbursement	12/3/2018	12/3/2018
Fasteners	0.14	2	0.28	Miner's Ace Hardware	NA	Carriage Prototype	Reimbursement	12/3/2018	12/3/2018
Fasteners	1.29	2	2.58	Miner's Ace Hardware	NA	Carriage Prototype	Reimbursement	12/3/2018	12/3/2018
Spray Paint	4.59	1	4.59	Miner's Ace Hardware	NA	Carriage Prototype	Reimbursement	12/3/2018	12/3/2018
Dowel	1.39	1	1.39	Miner's Ace Hardware	NA	Carriage Prototype	Reimbursement	12/3/2018	12/3/2018
Hinge	3.99	1	3.99	Miner's Ace Hardware	NA	Carriage Prototype	Reimbursement	12/3/2018	12/3/2018
Fasteners	1.29	4	5.16	Miner's Ace Hardware	NA	Carriage Prototype	Reimbursement	12/3/2018	12/3/2018
Fasteners	1.99	4	7.96	Miner's Ace Hardware	NA	Carriage Prototype	Reimbursement	12/3/2018	12/3/2018
Fasteners	0.95	6	5.70	Miner's Ace Hardware	NA	Carriage Prototype	Reimbursement	12/3/2018	12/3/2018
Dowel	2.59	1	2.59	Miner's Ace Hardware	NA	Carriage Prototype	Reimbursement	12/3/2018	12/3/2018
Aluminum Plate	32.23	1	32.23	McMaster-Carr	8975K432	Carriage	Reimbursement	1/16/2019	1/21/2019
Flanged Bearings	0.80	4	3.20	McMaster-Carr	2938T13	Carriage	Reimbursement	1/16/2019	1/21/2019
Tax + Shipping (estimated)			22.39						
ORDER 1 TOTAL			**92.28**						
				ORDER 2					
Steel rod (1/2 inch)	11.84	1	11.84	McMaster-Carr	6628K29	Carriage	Aero Department	1/28/2019	2/1/2019
Rectangular Tube	13.17	1	13.70	McMaster-Carr	88875K21	Carriage	Aero Department	1/28/2019	2/1/2019
Spring	4.29	1	4.29	McMaster-Carr	9433K33	Carriage	Aero Department	1/28/2019	2/1/2019
Aluminum Tube	10.50	1	10.50	McMaster-Carr	89965k22	Carriage	Aero Department	1/28/2019	2/1/2019
Aluminum Block	19.15	1	19.15	McMaster-Carr	8975k237	Carriage	Aero Department	1/28/2019	2/1/2019
Tax + Shipping (estimated)			37.00						
ORDER 2 TOTAL			**96.48**						
				ORDER 3					
Rectangular Tube	13.70	1	13.70	McMaster-Carr	88875K21	Carriage	Reimbursement	2/14/2019	2/19/2019
Flanged Bearings	0.80	8	6.40	McMaster-Carr	2938T13	Carriage	Reimbursement	2/14/2019	2/19/2019
Wood Board	9.99	1	9.99	Miner's Ace Hardware	NA	Carriage Prototype	Reimbursement	2/14/2019	2/19/2019
Fasteners	1.19	1	1.19	Miner's Ace Hardware	NA	Carriage	Reimbursement	2/14/2019	2/19/2019
Aluminum Tube	2.99	1	2.99	Miner's Ace Hardware	NA	Carriage	Reimbursement	2/14/2019	2/19/2019
Tax + Shipping (estimated)			17.5						
ORDER 3 TOTAL			**51.77**						

Item	Cost/Unit	Units	Total Cost	Vendor	Vedor Part Number	Associated Part	Method of Purchase	Date Purchased	Date Delivered
				ORDER 4					
Bimba Pneumatic Piston	438.90	1	438.9	BRENNER FIEDLER & ASSOCIATES, INC	Custom Part	Piston	Aero Department	2/15/2019	5/30/2019
Linear Bearing	53.76	4	215.04	McMaster-Carr	9338t1	Carriage	Aero Department	2/15/2019	2/21/2019
Steel Rod	45.15	2	90.3	McMaster-Carr	6061k93	Track	Aero Department	2/15/2019	2/21/2019
Spring	4.77	1	4.77	McMaster-Carr	9433k46	Carriage	Aero Department	2/15/2019	2/21/2019
Delrin Block	25.97	1	25.97	McMaster-Carr	8573k126	Carriage	Aero Department	2/15/2019	2/21/2019
Screws	3.07	1	3.07	McMaster-Carr	92185a151	Carriage	Aero Department	2/15/2019	2/21/2019
Locknut	4.43	1	4.43	McMaster-Carr	91831a007	Carriage	Aero Department	2/15/2019	2/21/2019
Tax + Shipping (estimated)			30.00						
ORDER 4 TOTAL			**812.48**						
				ORDER 5					
18-8 Stainless Steel Ring-Grip Quick-Release Pin	2.66	4	10.64	McMaster-Carr	98404A376	Base	Aero Department	2/28/2019	3/8/19
Comie Air Tire Bead Seater Blaster Tool Seating Infl	78.99	1	76.99	Amazon	B016Q3K7V6	Pneumatics	Aero Department	2/28/2019	3/8/19
2" to 1" Reducer	10.18	1	10.18	McMaster-Carr	44605K625	Pneumatics	Aero Department	2/28/2019	3/8/19
1" pipe nipple	1.89	2	3.78	McMaster-Carr	44615K416	Pneumatics	Aero Department	2/28/2019	3/8/19
VIAIR Relay	27.25	1	27.25	Amazon	B000FQ793A	Pneumatics	Aero Department	2/28/2019	3/8/19
VIAIR 400C Compressor	183.64	1	183.64	Amazon	B000FQ78TU	Pneumatics	Aero Department	2/28/2019	3/8/19
1" Solenoid Valve	32.99	1	32.99	Amazon	B010LT2D3Q	Pneumatics	Aero Department	2/28/2019	3/8/19
1/4" Solenoid	11.99	1	10.99	Amazon	B010LT30HE	Pneumatics	Aero Department	2/28/2019	3/8/19
1/4" Tee	4.32	1	4.32	McMaster-Carr	44605K152	Pneumatics	Aero Department	2/28/2019	3/8/19
1/4 Nipple	1.31	3	3.93	McMaster-Carr	44615K412	Pneumatics	Aero Department	2/28/2019	3/8/19
Toggle Switch	4.74	2	9.48	Mcmaster-Carr	7343K184	Electrical	Aero Department	2/28/2019	3/8/19
Push Switch	15.17	1	15.17	Mcmaster-Carr	6749K101	Electrical	Aero Department	2/28/2019	3/8/19
Milwaukee Battery Adapter	16.50	1	16.50	eBay	142929996486	Electrical	Aero Department	2/28/2019	3/8/19
Aluminum Tube 6ft	95.43	1	95.43	McMaster-Carr	9056K27	Base	Aero Department	2/28/2019	3/8/19
Aluminum Bar	53.74	1	53.74	Mcmaster-Carr		Base	Aero Department	2/28/2019	3/8/19
Tax + Shipping (estimated)			22.14						
ORDER 5 TOTAL			**577.17**						

Item	Cost/Unit	Units	Total Cost	Vendor	Vedor Part Number	Associated Part	Method of Purchase	Date Purchased	Date Delivered
				ORDER 6					
Aluminum Block (12 x 8 x 1/2)	36.86	1	36.86	McMaster-Carr	8975k222	Spreader	Aero Department		4/2/2019
1/4" Steel Wire	1.69	10	16.90	McMaster-Carr	3440T56	Track	Aero Department		4/2/2019
SS 304 Sheet 6x12x3/8	50.80	1	50.80	McMaster-Carr	8983k222	Frame	Aero Department		4/2/2019
Compression Sleeve	10.22	1	10.22	McMaster-Carr	3898T18	Frame	Aero Department		4/2/2019
Pulley	17.63	1	17.63	McMaster-Carr	3087T41	Frame	Aero Department		4/2/2019
L Channel	17.20	1	17.20	McMaster-Carr	8982K37	Frame	Aero Department		4/2/2019
Tax + Shipping (estimated)			21.29						
ORDER 6 TOTAL			**170.90**						
				Order 7					
Toggle Switch (spring loaded)	8.20	1	8.20	McMaster-Carr	7343k763	Controller	Aero Department		4/16/2019
Air Hose (3ft)	20.43	1	20.43	McMaster-Carr	5304k47	Pneumatics	Aero Department		4/16/2019
1.5 inch barbed hose fitting	4.95	2	9.90	McMaster-Carr	5363k55	Pneumatics	Aero Department		4/16/2019
1.5 to 1 reducer	10.99	1	10.99	McMaster-Carr	44605k325	Pneumatics	Aero Department		4/16/2019
Aluminum Tube	3.66	1	3.66	McMaster-Carr	6546k51	Carriage	Aero Department		4/16/2019
Rubber Bumper	18.60	2	37.20	McMaster-Carr	9677k13	Frame	Aero Department		4/16/2019
Spring	9.68	1	9.68	McMaster-Carr	1986k151	Frame	Aero Department		4/16/2019
Tax + Shipping (estimated)			40.00						
ORDER 7 TOTAL			**140.06**						
				Order 8					
Wire	31.95	1	31.95	Amazon	B01MU6ITN7	Controller	Aero Department		May
Pressure Gauge	9.64	1	9.64	Amazon	B006K2RIY8	Pneumatics	Aero Department		May
Voltage Reducer	25.99	1	25.99	Amazon	B07NZNLRLT	Controller	Aero Department		May
Pulley	7.38	1	7.38	McMaster-Carr	3099t34	Frame			May
Bike Pump Adapter	5.96	1	5.96	Amazon	B001PLI4BA	Frame			
3/16 wire rope	14.90	1	14.90	McMaster-Carr	3440t55	Frame			May
Tax + Shipping (estimated)			35.00						
ORDER 8 TOTAL			130.82						
				Order 9					
Fastenal Nuts and Miscilaneous	21.01	1	21.01	Fastenal	NA	Frame	Reimbursment	5/30/2019	
Spade Connectors	9.26	1	9.26	Home Depot	NA	Electrical	Reimbursment	5/26/2019	
Tax + Shipping			0.00						
ORDER 9 TOTAL			**30.27**						

TOTAL SPENT $2,071.96

Appendix M – Specification Sheets

Axle

McMASTER-CARR

Easy-to-Machine 1144 Carbon Steel Rod

Ultra-Strength, 1/2" Diameter

$11.77 Each
6628K29

Material	1144 Carbon Steel
Cross Section Shape	Round
Construction	Solid
Appearance	Plain
Diameter	1/2"
Diameter Tolerance	-0.005" to 0"
Tolerance Rating	Undersized
Yield Strength	125,000 psi
Fabrication	Cold Worked
Temper Rating	Hardened
Hardness	Rockwell C30
Hardness Rating	Hard
Heat Treatable	Yes
Maximum Hardness after Heat Treatment	Not Rated
Temperature Range	Not Rated
Straightness Tolerance	Not Rated
Density	0.28 lbs./cu. in.
Surface Resistivity	17 microhm-cm @ 68° F
Thermal Conductivity	350 Btu/hr. × in./sq. ft./°F @ 212° F
Coefficient of Thermal Expansion	7.4×10^{-6}
Elongation	6.5%
Material Composition	
Iron	97.50-98.01%
Carbon	0.40-0.48%
Manganese	1.35-1.65%
Phosphorus	0.04% Max.
Sulfur	0.24-0.33%

Length Tolerance	-3" to 3"
Length	3 ft.
RoHS	Not Compliant

Containing more carbon and manganese than 1117, 1144 carbon steel offers higher yield strength and hardness, even without further heat treatment. Use it to fabricate parts that require stress resistance. Also known as Fatigueproof, these rods have enhanced strength and resistance to breaking from repeated impact compared to High-Strength Easy-to-Machine 1144 Carbon Steel Rods.

Aluminum Plate for Carriage Panels and Ladders

6061 Aluminum

1/4" Thick x 5" Wide

Length, ft.
✓ 3

Each

ADD TO ORDER

Delivers tomorrow
$32.23 Each
8975K432

1 each ordered on January 27
0127JCEARNS.

(Web) System of Measurement	Inch
Material	6061 Aluminum
Cross Section Shape	Rectangle
Construction	Solid
Thickness	1/4"
Thickness Tolerance	-0.012" to 0.012"
Tolerance Rating	Standard
Width	5"
Width Tolerance	-0.034" to 0.034"
Yield Strength	35,000 psi
Fabrication	Heat Treated
Temper	T6511
Temper Rating	Hardened
Hardness	Brinell 95
Hardness Rating	Soft
Heat Treatable	Yes
Appearance	Plain
Temperature Range	-320° to 300° F
Specifications Met	ASTM B221

Straightness Tolerance	Not Rated
Magnetic Properties	Nonmagnetic
Density	0.1 lbs./cu. in.
Surface Resistivity	25 Ohm-Cir Mil/ft
Melting Point Temperature	1080° F
Modulus of Elasticity	10.0 ksi × 10^3
Thermal Conductivity	1,160 Btu/hr. × in./sq. ft./°F @ 75° F
Elongation	12.5%
Material Composition	
Aluminum	95.1-98.2%
Chromium	0.4-0.8%
Copper	0.05-0.4%
Iron	0-0.7%
Magnesium	0.8-1.2%
Manganese	0-0.15%
Nickel	0-0.05%
Silicon	0.4-0.8%
Titanium	0-0.15%
Zinc	0-0.25%
Zirconium	0-0.25%
Other	0.15%
Length Tolerance	-1" to 1"
Length	3 ft.
RoHS	Not Compliant

Often fabricated into vehicle parts, pipe fittings, and containers, 6061 is stronger and offers better corrosion resistance than MIC6 and 2011. It's also nonmagnetic, heat treatable, and resists stress cracking.

Bronze Sleeve Bearing

High-Load Oil-Embedded SAE 863 Bronze Sleeve Bearing

Flanged, for 1/2" Shaft Diameter and 5/8" Housing ID, 3/4" Long

Each

ADD TO ORDER

Delivers tomorrow
$0.80 Each
2938T13

8 each ordered on February 3
0203JCEARNS.

Bearing Type	Plain
Plain Bearing Type	Flanged
For Load Direction	Combined Radial and Thrust
Material	SAE 863 Bronze
For Shaft Diameter	1/2"
ID	0.501"
ID Tolerance	0" to 0.001"
For Housing ID	5/8"
OD	0.627"
OD Tolerance	0" to 0.001"
Length	3/4"
Length Tolerance	-0.01" to 0.01"
Flange OD	7/8"
Flange Thickness	1/8"
Dynamic Radial Load Capacity	830 lbs. @ 120 rpm
Dynamic Thrust Load Capacity	510 lbs. @ 120 rpm
Lubrication	Lubricated
Lubrication Method	Embedded
Lubricant	ISO 460 Oil
For Shaft Type	Round

Shaft Mount Type	Slip Fit
Temperature Range	-15° to 300° F
RoHS	Compliant

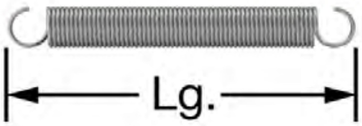
Increased iron content makes these bearings stronger and more resistant to shock loads than standard oil-embedded bearings; however they operate at lower speeds. Startup friction causes them to release a thin layer of oil on the bearing's surface. Color is silver because of the iron.

Note: Dynamic load capacity is the maximum load a bearing can withstand at a given shaft speed. If your application's load and speed requirements are below the values listed, the bearing will work.

Carriage Internal Spring

302 Stainless Steel Extension Springs with Hook Ends

2" Long, 0.25" OD, 0.026" Wire Diameter



Packs of 3

ADD TO ORDER

Delivers tomorrow
$4.77 per pack of 3
9433K46

Spring Type	Extension
System of Measurement	Inch
Length	2"
OD	0.25"
Wire Diameter	0.026"
Extended Length @ Maximum Load	4.66"
Load, lbs.	
Min.	0.35
Maximum	2.67
Rate	0.87 lbs./in.
Material	302 Stainless Steel
End Type	Hook
OD Tolerance	-0.008" to 0.008"
Min. Load Tolerance	-0.05 to 0.05 lbs.
Rate Tolerance	-0.09 lbs./in. to 0.09 lbs./in.
RoHS	Compliant

Made of stainless steel, these springs are more corrosion resistant than steel springs. They're also easier to extend than steel springs. As you stretch an extension spring, it gets harder to pull. Minimum load is the amount of force required to start to extend the spring. Maximum load is the amount of force required to fully extend the spring. Rate is the amount of force required for every inch of extension.

Architectural 6063 Aluminum Rectangular Tube

1/8" Wall Thickness, 1" High x 4" Width

Length, ft.
✓ 1

Each

ADD TO ORDER

Delivers tomorrow
$13.70 Each
88875K21

1 each ordered on February 3
0203JCEARNS.

Material	6063 Aluminum
Cross Section Shape	Rectangle
Corner Shape	
Inside	Square
Outside	Square
Construction	Hollow
Appearance	Plain
Wall Thickness	1/8"
Wall Thickness Tolerance	-0.015" to 0.015"
Tolerance Rating	Standard
Outside	
Height	1"
Width	4"
Inside	
Height	3/4"
Width	3 3/4"
Yield Strength	16,000 psi
Fabrication	Heat Treated
Temper	T52
Temper Rating	Hardened

Temper Rating	Hardened
Hardness	Brinell 60
Hardness Rating	Soft
Heat Treatable	Yes
Temperature Range	-320° to 212° F
Specifications Met	ASTM B221
Straightness Tolerance	Not Rated
Magnetic Properties	Nonmagnetic
Density	0.1 lbs./cu. in.
Surface Resistivity	20 Ohm-Cir Mil/ft
Melting Point Temperature	1110° F
Modulus of Elasticity	10.0 ksi × 10^3
Thermal Conductivity	1,420 Btu/hr. × in./sq. ft./°F @ 77° F
Elongation	11%
Material Composition	
Aluminum	97.5-99.35%
Chromium	0-0.1%
Copper	0-0.1%
Iron	0-0.35%
Magnesium	0.45-0.9%
Manganese	0-0.1%
Silicon	0.2-0.6%
Titanium	0-0.1%
Zinc	0-0.1%
Other	0-0.15%
Length Tolerance	-1/2" to 1/2"
Length	1 ft.
RoHS	Compliant

Commonly used outdoors as architectural trim, railings, and door frames, 6063 aluminum has better machinability than 3003. It is nonmagnetic and heat treatable.

Aluminum Block for Carriage Bumpers

6061 Aluminum

1" Thick x 2" Wide

Length, ft.
1/2
1
2
3
6

Each

ADD TO ORDER

8975K237

(Web) System of Measurement	Inch
Material	6061 Aluminum
Cross Section Shape	Rectangle
Construction	Solid
Thickness	1"
Thickness Tolerance	-0.012" to 0.012"
Tolerance Rating	Standard
Width	2"
Width Tolerance	-0.034" to 0.034"
Yield Strength	35,000 psi
Fabrication	Heat Treated
Temper	T6511
Temper Rating	Hardened
Hardness	Brinell 95
Hardness Rating	Soft
Heat Treatable	Yes
Appearance	Plain
Temperature Range	-320° to 300° F
Specifications Met	ASTM B221
Straightness Tolerance	Not Rated
Magnetic Properties	Nonmagnetic
Density	0.1 lbs./cu. in.
Surface Resistivity	25 Ohm-Cir Mil/ft
Melting Point Temperature	1080° F

Modulus of Elasticity	10.0 ksi × 10^3
Thermal Conductivity	1,160 Btu/hr. × in./sq. ft./°F @ 75° F
Elongation	12.5%
Material Composition	
Aluminum	95.1-98.2%
Chromium	0.4-0.8%
Copper	0.05-0.4%
Iron	0-0.7%
Magnesium	0.8-1.2%
Manganese	0-0.15%
Nickel	0-0.05%
Silicon	0.4-0.8%
Titanium	0-0.15%
Zinc	0-0.25%
Zirconium	0-0.25%
Other	0.15%
Length Tolerance	-1" to 1"
RoHS	Not Compliant

Often fabricated into vehicle parts, pipe fittings, and containers, 6061 is stronger and offers better corrosion resistance than MIC6 and 2011. It's also nonmagnetic, heat treatable, and resists stress cracking.

Socket Head Screw for Bearing Mount

Super-Corrosion-Resistant 316 Stainless Steel Socket Head Screw

6-32 Thread Size, 3/4" Long

Packs of 25

ADD TO ORDER

Delivers Wednesday
$3.07 per pack of 25
92185A151

1 pack added to your order February 12.

Head Type	Socket
Socket Head Profile	Standard
Drive Style	Hex
System of Measurement	Inch
Thread Direction	Right Hand
Thread Size	6-32
Screw Size Decimal Equivalent	0.138"
Thread Type	UNC
Thread Fit	Class 3A
Length	3/4"
Threading	Fully Threaded
Thread Spacing	Coarse
Head	
Diameter	0.226"
Height	0.138"
Drive Size	7/64"
Material	316 Stainless Steel
Tensile Strength	70,000 psi
Hardness	Rockwell B70
RoHS	Compliant

T

These screws are corrosion resistant in wet environments, nonmagnetic, and electrically conductive. Length is measured from under the head.

Coarse threads are the industry standard; choose these screws if you don't know the pitch or threads per inch.

Locknut for Bearing Mounting

18-8 Stainless Steel Nylon-Insert Locknut

6-32 Thread Size

Packs of 100

ADD TO ORDER

Delivers tomorrow
$4.43 per pack of 100
91831A007

1 pack added to your order
February 12.

Material	18-8 Stainless Steel
Thread Size	6-32
Thread Type	UNC
Thread Spacing	Coarse
Thread Fit	Class 2B
Thread Direction	Right Hand
Width	5/16"
Height	11/64"
Insert Maximum Temperature	220° F
Drive Style	External Hex
Nut Type	Locknut
Hex Nut Profile	Standard
Locking Type	Nylon Insert
System of Measurement	Inch
RoHS	Compliant

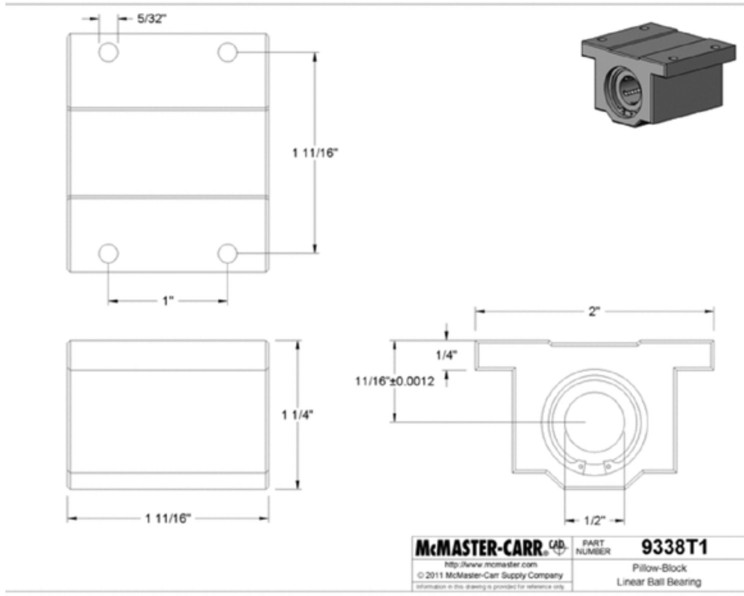
These locknuts have good chemical resistance and may be mildly magnetic. The nylon insert grips the bolt to resist loosening without damaging threads. They're reusable, but their holding power lessens with each use.

Linear Bearing

Linear Bearing Component	Bearing in Housing
For Shaft Type	Round
Bearing Type	Ball
Alignment Style	Self Aligning
Misalignment Capability	1°
Housing Type	Base Mount
With End Seals	Yes
For Shaft Diameter	1/2"
ID	0.500"
ID Tolerance	Not Rated
Overall	
Length	1 11/16"
Width	2"
Height	1 1/4"
Center Height	11/16"
Center Height Tolerance	-0.001" to 0.001"
Base Thickness	1/4"
Material	
Bearing	Acetal
Housing	6061 Aluminum
Ball	Steel
Load Capacity, lbs.	
Dynamic	230
Static	290
Lubrication	Required
Replaceable Insert Bearing	Yes
Temperature Range	-4° to 176° F
For Shaft Material	Stainless Steel, Steel
For Min. Shaft Hardness	
Steel	Rockwell C50
Stainless Steel	Rockwell C50
Mounting Holes	
Number of	4
Diameter	5/32"
Center-to-Center, Length	1"
Center-to-Center	1.688" width
RoHS	Compliant

Bearings are for use with round end-supported shafts. All have end seals to keep lubricant in and dirt out.

Self-aligning bearings compensate for shaft misalignment.


5/32"
1 11/16"
1"
2"
1/4"
11/16"±0.0012
1 1/4"
1 11/16"
1/2"
McMASTER-CARR
PART NUMBER
9338T1
http://www.mcmaster.com
© 2011 McMaster-Carr Supply Company
Pillow-Block
Linear Ball Bearing

Quick Release Pin

18-8 Stainless Steel Ring-Grip Quick-Release Pin

3/8" Diameter, 1-5/8" Usable Length

Each

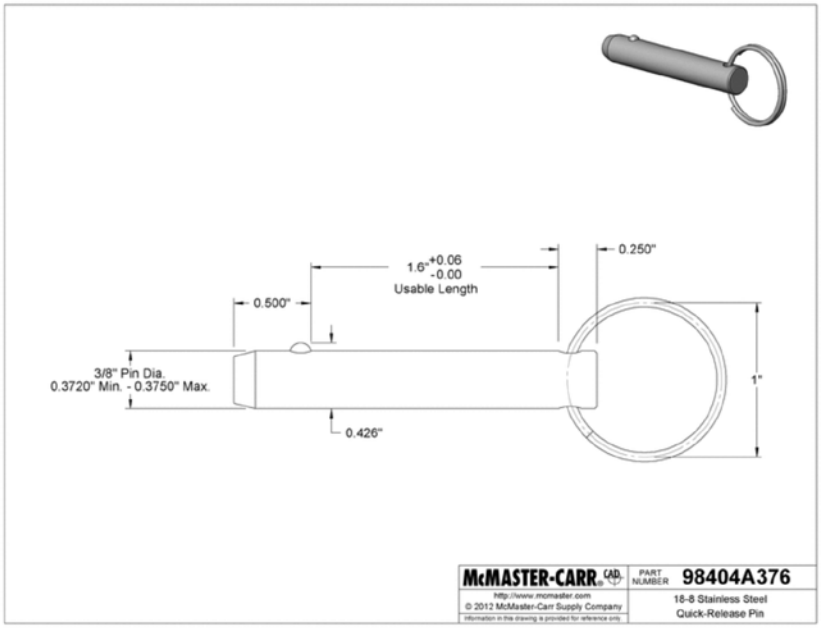
ADD TO ORDER

In stock
$2.66 Each
98404A376

Pin Type	Quick Release
End Type	Spring-Loaded Ball
Head Type	Ring
Shaft Type	Plain
End Shape	Chamfered
System of Measurement	Inch
Material	18-8 Stainless Steel
Usable Length	1 5/8"
Diameter	3/8"
Diameter Tolerance	-0.003" to 0"
Diameter at Extended Ball Height	0.426"
Min. Hardness	Rockwell B85
Breaking Strength	11,000 lbs.
Number of Retaining Balls	1
Ball Material	316 Stainless Steel
Spring Material	316 Stainless Steel
Handle Material	316 Stainless Steel
Lock Type	Nonlocking
Passivation	Not Passivated
RoHS	Compliant

The smooth ring handle on these pins won't catch on parts. A spring-loaded, nonlocking retaining ball pops out to hold pins in place. The hole should be as close to the diameter as possible, but not larger than the diameter at extended ball height. The ends are chamfered for easy insertion. Breaking strength is measured as single shear, which is the force required to break the pin into two pieces. Also known as faspins.

18-8 stainless steel pins offer a balance of strength and corrosion resistance. They may be mildly magnetic.



0.250"
1.6" +0.06 -0.00
Usable Length
0.500"
3/8" Pin Dia.
0.3720" Min. - 0.3750" Max.
1"
0.426"
McMASTER-CARR
PART NUMBER 98404A376
http://www.mcmaster.com
© 2012 McMaster-Carr Supply Company
Information in this drawing is provided for reference only
18-8 Stainless Steel
Quick-Release Pin

Air Tank

Specifications

- Weight:41.3lbs
- Package Dimensions:25.6in(L)x15.75in(W)x15in(H)
- Material: #235 steel
- Color: Yellow
- Weight: 23.5 Lbs
- Maximum Pressure: 145 PSI (1 MPa)

Specifications

- Thickness: 3 MM
- Capacity: 10 Gallons
- Work on tire up to 24.5in
- Operating Pressure: 87-116 PSI (0.6-0.8 Mpa)
- ATV Tire: 40 PSI
- Lawn Tractor Tre: 40-50 PSI (2.7-3.4 bar) \ Tractor Tire: 100-120(6.8-8.2 bar)
- Large Tractor Tire: 120 PSI (8.2 bar)
- Car Tire: 50-60 PSI (3.4-4.1 bar)
- Truck Tire: 100-130 PSI (6.8-8.2 bar)
- 4 × 4 Tire: 6—80 PSI (4.1-4 bar)

1-inch pipe nipple

Standard-Wall Steel Pipe Nipple

Fully Threaded, 1 NPT

Each

ADD TO ORDER

In stock
$1.89 Each
44615K416

1 each added to your order
April 9.

For Use With	Air, Natural Gas, Oil, Steam, Water
Shape	Straight
Type	Pipe
Schedule	40
Threading	Fully Threaded
Connection Type	Pipe
Connection Style	Threaded
Thread Type	NPT
Gender	Male
Pipe Size	1
Length	1 1/2"
OD	1 5/16"
ID	1.049"
Wall Thickness	0.133"
Construction	Welded
Material	Black-Coated Steel
For Fitting	
Class	125, 150
Material	Iron, Steel
For Flange Material	Iron, Steel
Specifications Met	ANSI/ASME B1.20.1, ASTM A53, ASTM A733
RoHS	Not Compliant

Also known as Schedule 40, this pipe is designed for low-pressure applications. Use in noncorrosive applications.

Welded pipe has a weld bead on the inside.

Fully threaded pipe is also known as a close nipple; it is threaded on each end to the center.

Pressure Relay

VIAIR 90111 Pressure Switch with Relay

by VIAIR

56 customer reviews

| 12 answered questions

Price: $27.25 ✓prime FREE One-Day

Get $70 off instantly: Pay $0.00 upon approval for the Amazon Prime Rewards Visa Card. No annual fee.

Note: Available at a lower price from other sellers, potentially without free Prime shipping.

- Pressure Switch with 40 amp Relay
- For 12 volt systems
- Pressure range 110 PSI On and 145 PSI Off
- Pressure sensor connects via 1/8" NPT M Port
- Please consult manufacturer's website for wiring diagram

› See more product details

Compare with similar items

Used & new (30) from $21.99 ✓prime

Report incorrect product information.

Compressor

Technical Details

Brand	VIAIR
Model	40040
Item Weight	9.7 pounds
Product Dimensions	11.8 x 9 x 7 inches
California residents	Click here for Proposition 65 warning
Item model number	40040
Exterior	Painted
Manufacturer Part Number	40040
OEM Part Number	40040
Folding	No
Special Features	Amp Draw: 26 amps, Compressor: Heavy Duty, Dimensions: Viair 40040 Dimensions., Duty Cycle: 33 percent, Max PSI: 150, Note: Uses replacement direct mount air filter assembly 92623. Uses replacement remote mount air filter assembly 92622., Performance Data: Viair 40040 Performance and Tire Fill Rate data.
Voltage	12 volts

1-inch Solenoid Valve

Product description

Size Name: **Brass - 1 Inch**

Specifications:
1.Suitable Media:Air Water Oil .
2.Operation Mode:Normally Closed (Opens when powered)
3.Plunger Tip:NBR
4.Working Pressure:0-1.0Mpa
5.Fluid Temperature: -5-80 Degrees Celsius / 23F to 176F
6.Operating Viscosity: Under 20CST
7.Valve Type:Direct Acting, Wet Armature. Semi-Direct lift valve. Suitable for gravity feed.
8.Installation: Fluid direction should be as the arrow shows .
9.Versatile, small, responsive, light and durable.
10. One year warranty. Contact leoling0420@hotmail.com

Product Description:
1).1"ports, brass body, Viton seal, 12volt DC, for air, water, or oil
2).BACOENG normally closed (N/C) electric solenoid valve is constructed with a durable brass body, two-way inlet and outlet ports with 1 inch female threaded (NPT) connections, and heat and oil resistant Viton gasket.
3).The coil uses alternating current and energizes at 12 volts DC; voltage range + or - 10%. 18 Watt power rating.
4).Semi-direct lift valve operates from 0 PSI to a maximum pressure of 145 PSI (0 MPa to 1.0 MPa). Operational pressure range for water: 0 to 101 PSI; for oil: 0 to 72 PSI; for air or gases: 0 to 101 PSI.
5).Operational temperature range is 23 to 176 degrees Fahrenheit; -5 to +80 degrees Celsius. Suitable for outdoor use; not for use underwater.

Application:
1).Suitable for use with hot or cold water, gases, air, very low viscosity fluids (< 20 cst), oils and hydrocarbons, e.g., gasoline, kerosene, or diesel fuel.
2).Customers chose this general purpose valve for: do-it-yourself projects, moderate temperature applications, harsh chemicals, flow control for irrigation systems, reverse osmosis systems or to control flow of propane gas. This solenoid valve serves as an excellent propane regulator.

Package Includes:
1 x Electric Solenoid Valve
1 x User Manual

¼ Inch Solenoid Valve

Product description

Size Name: **1/4" Brass**

Specifications:
1.Suitable Media:Air Water Oil .
2.Operation Mode:Normally Closed (Opens when powered)
3.Plunger Tip:NBR
4.Working Pressure:0-1.0Mpa
5.Fluid Temperature: -5-80 Degrees Celsius / 23F to 176F
6.Operating Viscosity: Under 20CST
7.Valve Type:Direct Acting, Wet Armature. Semi-Direct lift valve. Suitable for gravity feed.
8.Installation: Fluid direction should be as the arrow shows .
9.Versatile, small, responsive, light and durable.
10. One year warranty. Contact leoling0420@hotmail.com

Product Description:
1).1/4"ports, brass body, Viton seal, 12volt DC, for air, water, or oil
2).BACOENG normally closed (N/C) electric solenoid valve is constructed with a durable brass body, two-way inlet and outlet ports with 1/4 inch female threaded (NPT) connections, and heat and oil resistant Viton gasket.
3).The coil uses alternating current and energizes at 12 volts DC; voltage range + or - 10%. 18 Watt power rating.
4).Semi-direct lift valve operates from 0 PSI to a maximum pressure of 145 PSI (0 MPa to 1.0 MPa). Operational pressure range for water: 0 to 101 PSI; for oil: 0 to 72 PSI; for air or gases: 0 to 101 PSI.
5).Operational temperature range is 23 to 176 degrees Fahrenheit; -5 to +80 degrees Celsius. Suitable for outdoor use; not for use underwater.

Application:
1).Suitable for use with hot or cold water, gases, air, very low viscosity fluids (< 20 cst), oils and hydrocarbons, e.g., gasoline, kerosene, or diesel fuel.
2).Customers chose this general purpose valve for: do-it-yourself projects, moderate temperature applications, harsh chemicals, flow control for irrigation systems, reverse osmosis systems or to control flow of propane gas. This solenoid valve serves as an excellent propane regulator.

Package Includes:
1 x Electric Solenoid Valve
1 x User Manual

¼ Inch Tee

Low-Pressure Pipe Fitting

Iron, Tee Connector, 1/4 NPT Female

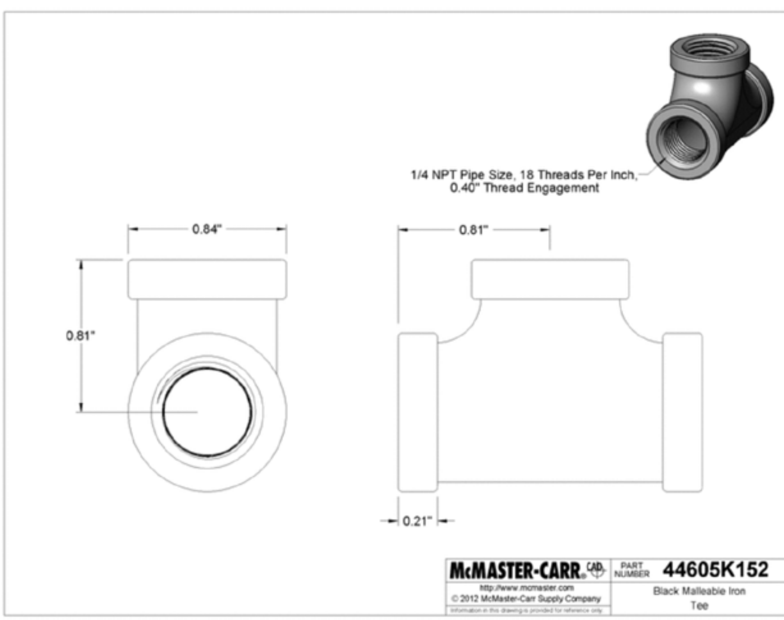
Each

ADD TO ORDER

In stock
$4.32 Each
44605K152

For Use With	Air, Natural Gas, Oil, Steam, Water
Shape	Tee
Type	Connector
Class	150
Connection Type	Pipe
Connection Style	Threaded
Connection	NPT Female
Pipe Size	1/4
Maximum Pressure	150 psi @ 72° F
Maximum Steam Pressure	150 psi @ 350° F
Material	Black-Coated Iron
For Pipe	
Schedule	40
Material	Steel
For Flange Material	Iron, Steel
Specifications Met	ANSI/ASME B1.20.1, ANSI/ASME B16.3, UL Listed
RoHS	Compliant

Use these fittings for low-pressure applications in noncorrosive environments.



¼-Inch Pipe Nipple

Standard-Wall Steel Pipe Nipple

Fully Threaded, 1/4 NPT

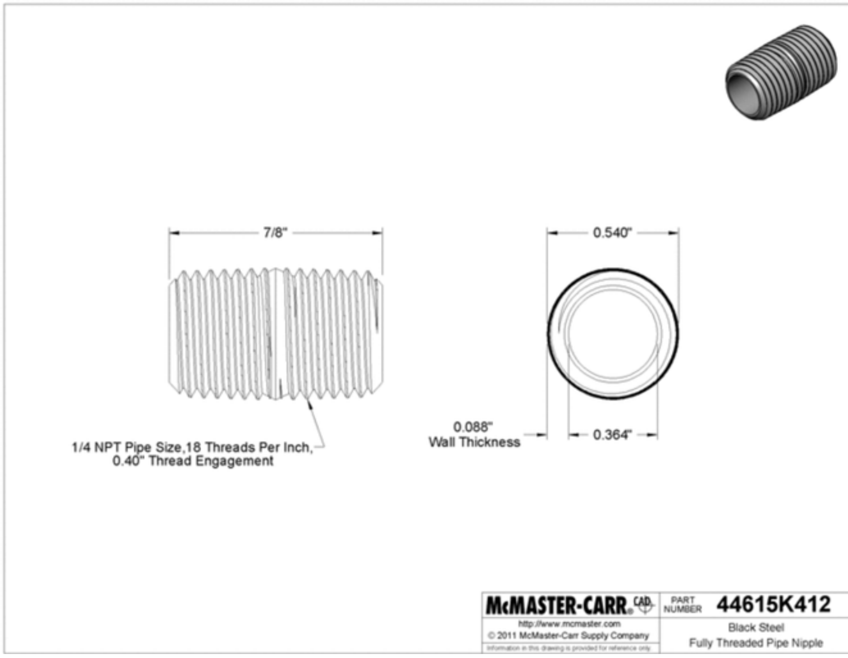
Each	In stock $1.31 Each 44615K412
ADD TO ORDER	

For Use With	Air, Natural Gas, Oil, Steam, Water
Shape	Straight
Type	Pipe
Schedule	40
Threading	Fully Threaded
Connection Type	Pipe
Connection Style	Threaded
Thread Type	NPT
Gender	Male
Pipe Size	1/4
Length	7/8"
OD	35/64"
ID	0.364"
Wall Thickness	0.088"
Construction	Welded
Material	Black-Coated Steel
For Fitting	
Class	125, 150
Material	Iron, Steel
For Flange Material	Iron, Steel
Specifications Met	ANSI/ASME B1.20.1, ASTM A53, ASTM A733
RoHS	Not Compliant

Also known as Schedule 40, this pipe is designed for low-pressure applications. Use in noncorrosive applications.

Welded pipe has a weld bead on the inside.

Fully threaded pipe is also known as a close nipple; it is threaded on each end to the center.


7/8"
0.540"
1/4 NPT Pipe Size,18 Threads Per Inch,
0.40" Thread Engagement
0.088"
Wall Thickness
0.364"
McMASTER-CARR
CAD
PART NUMBER
44615K412
http://www.mcmaster.com
© 2011 McMaster-Carr Supply Company
Information in this drawing is provided for reference only
Black Steel
Fully Threaded Pipe Nipple

Toggle Switch

2 Position, Round, Maintained, 2 Terminal, SPST-NO, 6A

Wire Connection Type
- Quick-Disconnect Terminals
- Screw Terminals
- Solder Lugs

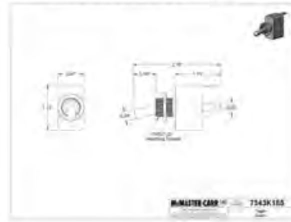
Each

ADD TO ORDER

$4.74 Each
7343K184

Switch Type	Manual
Actuator Style	Toggle
Toggle Style	Rounded
Illumination	Not Illuminated
Number of Positions	2
Number of Circuits Controlled	1
Switch Starting Position	1 Off (Normally Open)
Switch Action	Stays Switched (Maintained)
Number of Terminals	2
Industry Designation	SPST-NO
Position Designation	On-Off
Switching Current @ Voltage	6 A @ 125 V AC/28 V DC
Maximum Voltage	28V DC 250V AC
Mounting Location	Panel
For Panel Cutout Diameter	1/2"
For Maximum Panel Thickness	0.13"
Toggle	
Depth	0.56"
Diameter	0.24"
Mounting Thread	
Size	15/32"-32
Type	UNS
Mounting Hardware Included	Yes
Specifications Met	UL Recognized, CSA Certified
RoHS	Not Compliant

Wire Connection Type: Quick-Disconnect Terminals



Wire Connection Type: Screw Terminals

Wire Connection Type: Solder Lugs

Push Switch

Plastic 22 mm Panel-Mount Switch

Flush Push-Button, Push Reset, 1-3/16" Diameter, SPST-NO

Switch Type	Manual
Mounting Location	Panel
For Panel Cutout Diameter	22 mm
For Panel Cutout Diameter	7/8"
Actuator Style	Push Button
Push-Button Style	Flush
Push-Button Shape	Round
Actuator Material	Plastic
Actuator Base Material	Plastic
Illumination	Not Illuminated
With Cover	Without Cover
Number of Circuits Controlled	1
Switch Starting Position	1 Off (Normally Open)
Switch Action	Springs Back (Momentary)
Reset Type	Push
Number of Terminals	2
Industry Designation	SPST-NO
Switching Current @ Voltage	6 A @ 120 V AC, 2.5 A @ 24 V DC
Maximum Voltage	600V AC 600V DC
Diameter	1 3/16"
For Maximum Panel Thickness	1/4"
Depth Behind Panel	1 13/16"
For Maximum Number of Contact Blocks	6
Wire Connection Type	Screw Terminals
Terminal Numbering	3-4
Environment	Corrosive, Oily, Washdown
Environmental Rating	NEMA 4X, NEMA 13, IP66
Specifications Met	UL Listed, CSA Certified, CE Marked
Related Products	SPST-NO Contact Blocks SPST-NC Contact Blocks

Switches are rated NEMA 4X, 13, and IP66 for protection from corrosion, washdowns, and oil/coolant spraying. Use legend plates (not included) to label switches.

Actuator Color: Gray

Actuator Color: Red

Actuator Color: Orange

DeWalt Battery Adapter

Seller assumes all responsibility for this listing.

Last updated on May 26, 2019 07:05:58 PDT View all revisions

Item specifics

Condition:	Open box: A new, unused item with absolutely no signs of wear. The item may be missing the original packaging, or in the original packaging but not sealed. The item may be a factory second or a new, unused item with defects. See the seller's listing for full details and description of any imperfections. See all condition definitions	Bundle Listing:	Yes
Type:	battery adapter	Model:	NA
MPN:	TF2	Country/Region of Manufacture:	United States
Battery Voltage:	20V	Battery Type:	Lithium-Ion (Li-Ion)
Brand:	Terrafirma	UPC:	Does not apply

Includes 1black battery adapter (c2).

This battery adapter/cover has been tested to work with DeWALT 20V Max Li-ion batteries. Including models: DCB184, DCB204, and DCB205

Adapter has 10 inches of 12 gauge wire installed; ready for high power applications.

Recommended to use M4 mounting screws.

- Do not use this adapter to charge your battery
- Do not short circuit battery or draw more than 20amps continuous
- Disconnect the battery before it reaches 15volts, (prolongs battery life)
- Do not leave battery charged at 100% for long periods of time, recommended to store battery at 70% charge (prolongs battery life)
- Do not leave battery outdoors (especially in hot climates)

Aluminum Tube for Legs

Multipurpose 6061 Aluminum Round Tube

1/4" Wall Thickness, 1-1/2" OD

Length, ft.
1/2
1
2
3
6

Material	6061 Aluminum
Shape	Round Tube
Shape Type	Round Tubes
Wall Thickness	1/4"
Wall Thickness Tolerance	-0.025" to 0.025"
Tolerance Rating	Standard
OD	1 1/2"
OD Tolerance	-0.035" to 0.035"
ID	1"
ID Tolerance	Not Rated
Yield Strength	35,000 psi
Fabrication	Extruded
Temper	T6511
Heat Treatment	Hardened
Hardness	Brinell 95
Hardness Rating	Soft
Heat Treatable	Yes
Appearance	Plain
Temperature Range	-320° to 300° F
Specifications Met	ASTM B241
Aluminum Performance Properties	Corrosion Resistant, Easy to Machine, Easy to Weld
Straightness Tolerance	0.020" per ft.
Elongation	12.5%
Material Composition	
Aluminum	95.1-98.2%
Chromium	0.4-0.8%
Copper	0.05-0.4%
Iron	0-0.7%
Magnesium	0.8-1.2%
Manganese	0-0.15%
Nickel	0-0.05%
Silicon	0.4-0.8%
Titanium	0-0.15%
Zinc	0-0.25%
Zirconium	0-0.25%
Other	0.15%
Warning Message	Physical and mechanical properties are not guaranteed. They are intended only as a basis for comparison and not for design purposes.
RoHS	Compliant

The most widely used aluminum, 6061 is fabricated into everything from pipe fittings and containers to automotive and aerospace parts. It is strong and corrosion resistant, plus it's easy to machine and weld.

Spreader

Multipurpose 6061 Aluminum

1/2" Thick x 8" Wide

Material	6061 Aluminum
Shape	Sheet and Bar
Thickness	1/2"
Thickness Tolerance	-0.009" to 0.009"
Tolerance Rating	Standard
Width	8"
Width Tolerance Range	-0.084" to 0.084"
Length Tolerance	-1" to 1"
Yield Strength	35,000 psi
Fabrication	Extruded
Temper	T6511
Heat Treatment	Hardened
Hardness	Brinell 95
Hardness Rating	Soft
Heat Treatable	Yes
Appearance	Plain
Temperature Range	-320° to 300° F
Specifications Met	ASTM B221
Aluminum Performance Properties	Corrosion Resistant, Easy to Machine, Easy to Weld
Flatness Tolerance	Not Rated
Straightness Tolerance	Not Rated
Elongation	12.5%
Material Composition	
Aluminum	95.1-98.2%
Chromium	0.4-0.8%
Copper	0.05-0.4%
Iron	0-0.7%
Magnesium	0.8-1.2%
Manganese	0-0.15%
Nickel	0-0.05%
Silicon	0.4-0.8%
Titanium	0-0.15%
Zinc	0-0.25%
Zirconium	0-0.25%
Other	0.15%
Warning Message	Physical and mechanical properties are not guaranteed. They are intended only as a basis for comparison and not for design purposes.
RoHS	Not Compliant

The most widely used aluminum, 6061 is fabricated into everything from pipe fittings and containers to automotive and aerospace parts. It is strong and corrosion resistant, plus it's easy to machine and weld.

Stainless Steel for Front/Back Plates

304 Stainless Steel Sheet

6" x 12", 3/8" Thick

Material	304 Stainless Steel
Cross Section Shape	Rectangle
Construction	Solid
Appearance	Plain
Thickness	3/8"
Thickness Tolerance	-0.055" to 0.055"
Tolerance Rating	Standard
Width	6"
Width Tolerance	-1/8" to 1/8"
Length	12"
Length Tolerance	-1/8" to 1/8"
Yield Strength	30,000 psi
Fabrication	Hot Rolled
Hardness	Rockwell B80 (Medium)
Temper Rating	Softened (Annealed)
Heat Treatable	No
Min. Temperature	Not Rated
Maximum Temperature	1500° F
Specifications Met	ASTM A240
Flatness Tolerance	Not Rated
Density	0.29 lbs./cu. in.
Surface Resistivity	469 ohm-cir. mil/ft.
Melting Point Temperature	2400° F
Modulus of Elasticity	28 ksi × 10^3
Thermal Conductivity	100 Btu/hr. × in./sq. ft./°F @ 212° F
Elongation	50%
Material Composition	
Iron	53.48-74.5%
Carbon	0-0.08%
Chromium	17.5-24%
Cobalt	0-0.29%
Copper	0-1%
Manganese	0-2%
Molybdenum	0-2.5%
Nickel	8-15%
Nitrogen	0-0.1%
Phosphorus	0-0.2%
Silicon	0-1%
Sulfur	0-0.35%
Warning Message	Physical and mechanical properties are not guarante They are intended only as a basis for comparison and for design purposes.
RoHS	Compliant

Compression Sleeve for Steel Cable

Wire Rope Compression Sleeve - for Lifting

for Steel Rope, Zinc-Plated Copper, for 3/16" Rope Diameter

Packs of 10

ADD TO ORDER

In stock
$12.42 per pack of 10
3898T16

Fitting Type	Compression Sleeve
Application	For Lifting
Material	Zinc-Plated Copper
For Wire Rope Material	Steel
For Wire Rope	
Diameter	3/16"
Construction	6 × 19 IWRC 7 × 7 Strand Core 7 × 19 IWRC 7 × 19 Strand Core
Attachment Type	Loop
Sleeve Length	15/16"
Required Installation Tool	Compression Tool
Required Number of Compressions	4
Capacity	100% of the Rope's Capacity
Specifications Met	ASME B30.9, MS-51844
RoHS	Compliant
Related Product	Compression Tools

Install with a compression tool to create a strong, permanent loop. Compression sleeves are also known as ferrules, crimps, swaging, and splicing sleeves. They're compatible with Nicopress compression tools.

Zinc-plated copper sleeves are more corrosion resistant than tin-plated copper.

Warning: Fittings must match rope diameter and be installed correctly to obtain maximum holding power. Test all assemblies for required strength before use. Do not use with coated rope unless the coating is removed.

Aluminum L Chanel for Spreader Support

Multipurpose 6061 Aluminum 90 Degree Angle

with Round Edge, 1/4" Thickness, 2.5" High x 2.5" Wide Outside

Length, ft.
✓ 1

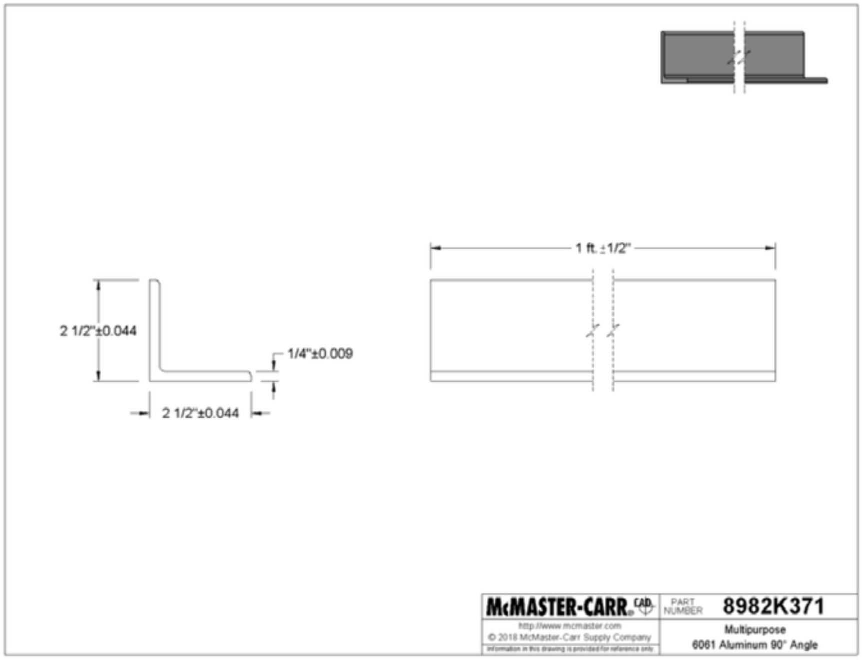
Each

ADD TO ORDER

In stock
$17.20 Each
8982K37

Shape	90° Angle
Shape Type	90° Angles
Wall Thickness	1/4"
Wall Thickness Tolerance	-0.009" to 0.009"
Tolerance Rating	Standard
Outside	
Height	2 1/2"
Height Tolerance	-0.044" to 0.044"
Width	2 1/2"
Width Tolerance	-0.044" to 0.044"
Inside	
Height	2 1/4"
Width	2 1/4"
Length Tolerance	-1/2" to 1/2"
Yield Strength	35,000 psi
Fabrication	Extruded
Temper	T6
Heat Treatment	Hardened
Hardness	Brinell 80 (Soft)
Heat Treatable	Yes
Appearance	Plain
Temperature Range	-320° to 300° F
Specifications Met	ASTM B221
Aluminum Performance Properties	Corrosion Resistant, Easy to Machine, Easy to Weld
Corner Shape	
Outside	Square
Inside	Round
Leg Edge Shape	Round
Elongation	12.5%
Material Composition	
Aluminum	95.1-98.2%
Chromium	0.4-0.8%
Copper	0.05-0.4%
Iron	0-0.7%
Magnesium	0.8-1.2%
Manganese	0-0.15%
Nickel	0-0.05%
Silicon	0.4-0.8%
Titanium	0-0.15%
Zinc	0-0.25%
Zirconium	0-0.25%
Other	0.15%
Warning Message	Physical and mechanical properties are not guaranteed. They are intended only as a basis for comparison and not for design purposes.
Straightness Tolerance	Not Rated
Length	1 ft.
RoHS	Not Compliant

The most widely used aluminum, 6061 is fabricated into everything from pipe fittings and containers to automotive and aerospace parts. It is strong and corrosion resistant, plus it's easy to machine and weld.


1 ft. ±1/2"
2 1/2"±0.044
1/4"±0.009
2 1/2"±0.044
McMASTER-CARR
CAD
PART NUMBER
8982K371
http://www.mcmaster.com
© 2018 McMaster-Carr Supply Company
Information in this drawing is provided for reference only
Multipurpose
6061 Aluminum 90° Angle

Spring Loaded Toggle Switch

Toggle Switch

2 Position, Round, Momentary, 2 Terminals, SPST-NO, 10A

Wire Connection Type
- Quick-Disconnect Terminals
- Screw Terminals

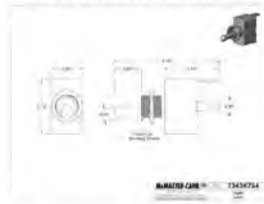
Each

ADD TO ORDER

$8.20 Each
7343K763

Switch Type	Manual
Actuator Style	Toggle
Toggle Style	Rounded
Illumination	Not Illuminated
Number of Positions	2
Number of Circuits Controlled	1
Switch Starting Position	1 Off (Normally Open)
Switch Action	Springs Back (Momentary)
Number of Terminals	2
Industry Designation	SPST-NO
Position Designation	Off-(On)
Switching Current @ Voltage	10 A @ 125 V AC/28 V DC
Maximum Voltage	28V DC 250V AC
Mounting Location	Panel
For Panel Cutout Diameter	1/2"
For Maximum Panel Thickness	0.13"
Toggle	
Depth	0.56"
Diameter	0.24"
Mounting Thread	
Size	15/32"-32
Type	UNS
Mounting Hardware Included	Yes
Specifications Met	UL Recognized, CSA Certified
RoHS	Not Compliant

Wire Connection Type: Quick-Disconnect Terminals



Wire Connection Type: Screw Terminals

Air Hose

1-1/2" ID, 2" OD, 200 PSI, Black

Ft.

ADD TO ORDER

In stock
1-99 Ft. $6.81
100 or more $5.45
5304K47

3 ft. added to your order April 9.

For Use With	Air
Temperature Range	-40° to 200° F
Connection Type	Hose
Hose Connection Type	Without Fittings
Compatible Hose Fittings	Barbed
ID	1 1/2"
OD	2"
Bend Radius	10 1/2"
Clarity	Opaque
Maximum Pressure	200 psi @ 72° F
For Use Outdoors	Yes
Material	EPDM Rubber
Cover Material	EPDM Rubber
Interior Texture	Smooth
Internal Reinforcement	Yarn
Maximum Continuous Length	100 ft.
Color	Black

Hose is made of EPDM rubber, which is the most common material for air applications.

Hose to Tank Fitting

Easy-Fit Barbed Hose Fitting

1-1/2" Hose ID, Steel Hex Body, 1-1/2 NPT End

Each

ADD TO ORDER

In stock
$4.95 Each
5363K55

2 each added to your order
April 9.

For Hose ID	1 1/2"
Pipe Size	1 1/2
Connections	Hex Body Barbed Male Hose Connection with Threaded NPT Male Pipe Connection
Maximum Pressure	125 psi @ 72° F
Temperature Range	-20° to 200° F
Maximum Vacuum	26" of Hg @ 72° F
Material	Steel
For Hose Type	Reinforced Rubber
For Clamp Type	Low-Profile Band Clamps, T-Bolt Clamps, Worm-Drive Hose Clamps
Specifications Met	ANSI/ASME B1.20.1, ASTM A53
For Use With	Air, Water
Shape	Straight
Type	Adapter
RoHS	Compliant

Low-profile barbs and a longer first barb allow for a smoother installation than with other barbed hose fittings.

Also known as hose nipples, they connect hose to threaded pipe.

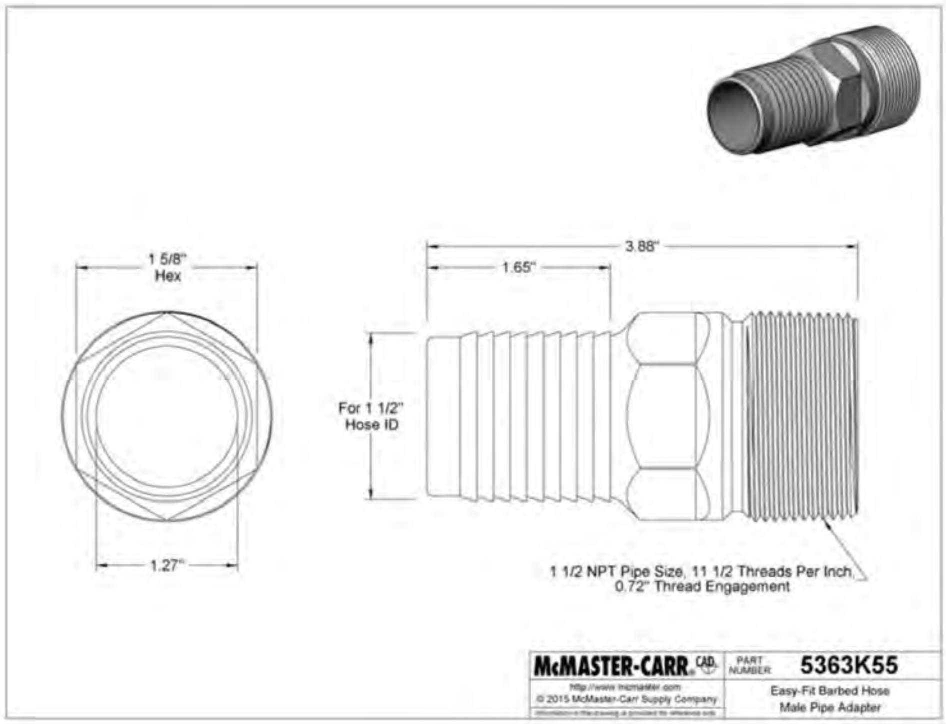
Easy-Fit Barbed Hose Fitting

1-1/2" Hose ID, Steel Hex Body, 1-1/2 NPT End

RoHS Compliant

Low-profile barbs and a longer first barb allow for a smoother installation than with other barbed hose fittings.

Also known as hose nipples, they connect hose to threaded pipe.



1.5 to 1 Inch Reducer

Low-Pressure Pipe Fitting

Iron, Straight Reducer, 1-1/2 x 1 NPT Female

Each

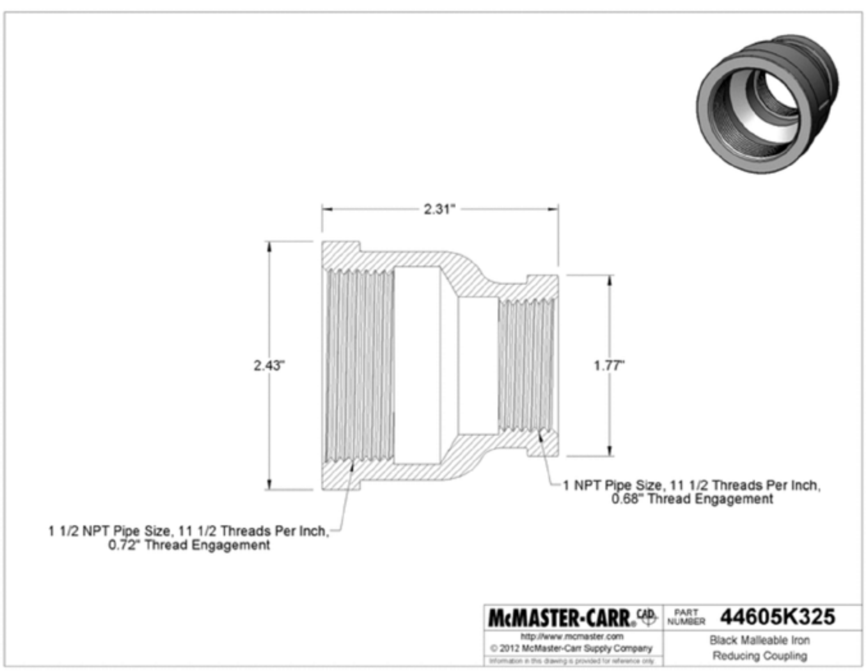
ADD TO ORDER

In stock
$10.99 Each
44605K325

1 each added to your order April 9.

For Use With	Air, Natural Gas, Oil, Steam, Water
Shape	Straight
Type	Reducer
Class	150
Connection Type	Pipe
Connection Style	Threaded
Connection	NPT Female
Pipe Size	
(A)	1 1/2
(B)	1
Length	2 5/16"
Maximum Pressure	150 psi @ 72° F
Maximum Steam Pressure	150 psi @ 350° F
Material	Black-Coated Iron
For Pipe	
Schedule	40
Material	Steel
For Flange Material	Iron, Steel
Specifications Met	ANSI/ASME B1.20.1, ANSI/ASME B16.3, UL Listed
RoHS	Compliant

Use these fittings for low-pressure applications in noncorrosive environments.



Aluminum Tube for Carriage Rear Support Spacer

Multipurpose 6061 Aluminum Rectangular Tube

1/16" Wall Thickness, 1/2" High x 1" Wide

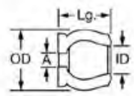
Length, ft.
1
2
3
6

Material	6061 Aluminum
Shape	Rectangular Tube
Wall Thickness	1/16"
Wall Thickness Tolerance	-0.007" to 0.007"
Tolerance Rating	Standard
Outside	
Height	1/2"
Height Tolerance	-0.085" to 0.085"
Width	1"
Width Tolerance	-0.085" to 0.085"
Inside	
Height	3/8"
Width	7/8"
Length Tolerance	-1/4" to 1/4"
Yield Strength	35,000 psi
Fabrication	Extruded
Temper	T6
Heat Treatment	Hardened
Hardness	Brinell 80 (Soft)
Heat Treatable	Yes
Appearance	Plain
Temperature Range	-320° to 300° F
Specifications Met	ASTM B221
Aluminum Performance Properties	Corrosion Resistant, Easy to Machine, Easy to Weld
Corner Shape	
Outside	Round
Inside	Square
Elongation	12.5%
Material Composition	
Aluminum	95.97-97.36%
Chromium	0.04-0.35%
Copper	0.15-0.41%
Iron	0.7%
Magnesium	0.8-1.2%
Manganese	0.15%
Silicon	0.4-0.8%
Titanium	0.15%
Zinc	0.25%
Other	0.15%
Warning Message	Physical and mechanical properties are not guaranteed. They are intended only as a basis for comparison and not for design purposes.
Straightness Tolerance	Not Rated
RoHS	Compliant

Compression Impact Absorber

Ultra-High-Load Fastener-Mount Compression Spring

1.188" Long



Each

ADD TO ORDER

In stock
$18.60 Each
9677K13

Spring Type	Compression
Length	1.188"
OD	1.31"
ID	0.66"
Base Diameter	1.16"
Compressed Length @ Maximum Load	0.67"
Compressed OD @ Maximum Load	1.7"
Maximum Load	1,600 lbs.
Energy Capacity	400 in.-lbs.
Mounting Hole Diameter (A)	0.31"
Mounting Fasteners Included	No
Material	Polyester/Rubber Blend
Color	Black
Hardness	Durometer 55D
Temperature Range	-40° to 120° F
RoHS	Compliant

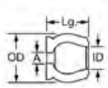
For the heaviest loads, these springs have more than double the load capacity of High-Load Fastener-Mount Compression Springs. Secure by inserting a fastener through the hole at the base. Springs are a polyester/rubber blend that is wear, oil, and fuel resistant.

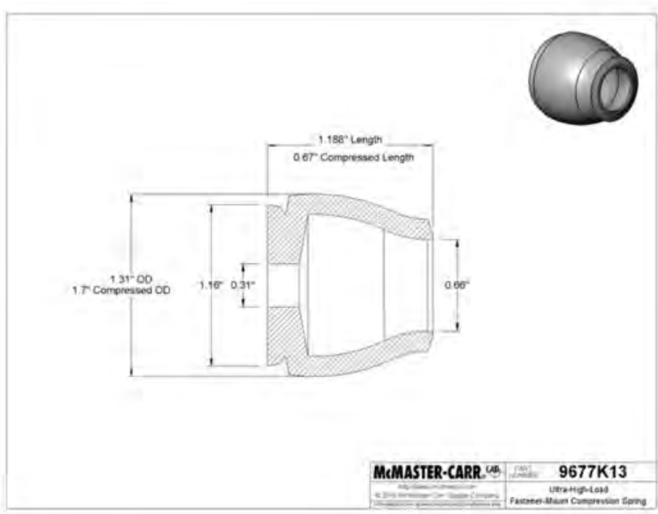
Energy is calculated in one of two ways. For an object that is dropped, energy equals the weight of the item multiplied by distance dropped. For an object moving horizontally, energy equals half of the mass of the item multiplied by velocity squared (1/2 mv^2).

Ultra-High-Load Fastener-Mount Compression Spring

1.188" Long

Energy is calculated in one of two ways. For an object that is dropped, energy equals the weight of the item multiplied by distance dropped. For an object moving horizontally, energy equals half of the mass of the item multiplied by velocity squared (1/2 mv^2).

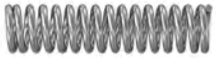




Compression Spring

302 Stainless Steel Corrosion-Resistant Compression Springs

4" Long, 0.938" OD, 0.642" ID



Packs of 3

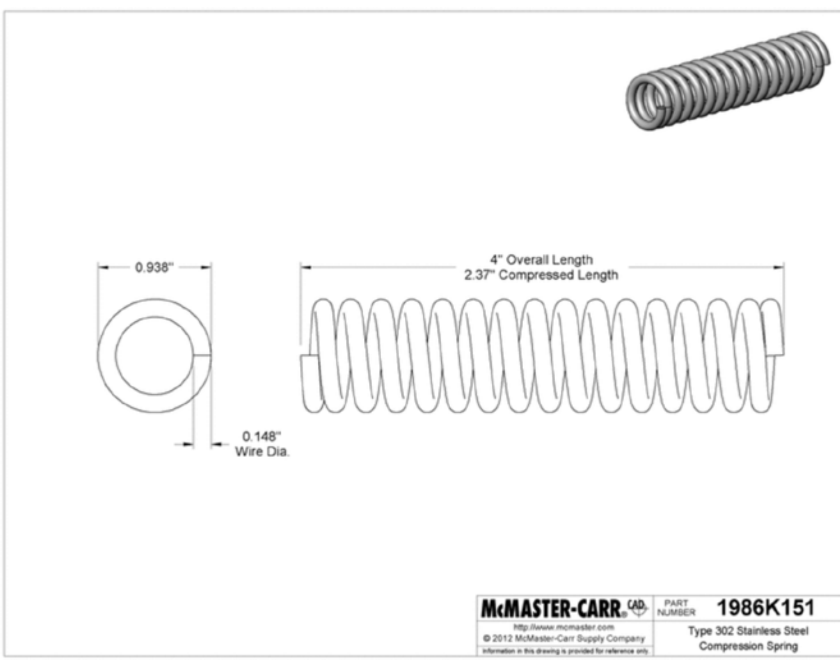
ADD TO ORDER

In stock
$9.68 per pack of 3
1986K151

Spring Type	Compression
System of Measurement	Inch
Length	4"
OD	0.938"
ID	0.642"
Wire Diameter	0.148"
Compressed Length @ Maximum Load	2.37"
Maximum Load	153 lbs.
Rate	93.75 lbs./in.
Material	302 Stainless Steel
End Type	Closed
Rate Tolerance	Not Rated
OD Tolerance	Not Rated
RoHS	Compliant

These springs are more corrosion resistant than standard compression springs. They're also easier to compress than standard compression springs. As you squeeze a compression spring, it pushes back to return to its original length. Rate is the amount of force required for every inch of compression. The higher the rate, the harder it is to compress the spring.

302 stainless steel springs have good corrosion resistance.



Speaker Cable Wire

Roll over image to zoom in

250ft 16AWG 4 Conductors (16/4) CL2 Rated Loud Speaker Cable Wire, Pull Box (For In-Wall Installation) (16AWG / 4 Conductors, 250ft)

by Cables Direct Online

141 customer reviews | 24 answered questions

List Price: ~~$55.95~~

Price: $31.95 prime

You Save: $24.00 (43%)

Thank you for being a Prime member. Get $70 off instantly: Pay $0.00 upon approval for the Amazon Prime Rewards Visa Card. No annual fee.

Free Amazon product support included

Item Shape: **16AWG / 4 Conductors**

12AWG / 2 Conductors | 16AWG / 2 Conductors | 18AWG / 2 Conductors | 14AWG / 2 Conductors | 14AWG / 4 Conductors | **16AWG / 4 Conductors** | 18AWG / 4 Conductors

Length: **250ft**

50ft | 100ft | **250ft** | 500ft

- CCA (COPPER CLAD ALUMINUM) – CCA wire offers the same signal frequency and reliability in terms of corrosion resistance to copper wire. The advantage of the CCA speaker wire is lighter and more flexible than copper wire. The cost of CCA vs Oxygen free copper is much lower and you can enjoy the same functions and reliability as copper wire without paying the extra cost for the installation.
- Tough, yet flexible white insulated jacket is market with a stripe on one side for polarity and is marked with FT count for easy installation.
- The 65 Strands 0.16mm conductors provide exceptional performance, sound quality for professional speaker and audio connections
- 16/4 cable rated CL2 for in-wall use, complies with fire safety for use inside the walls of residential class buildings
- Pull-Out Box with multiconductor cable reduces need to pull multiple wires for easy installation

Pressure Gage

Roll over image to zoom in

DuraChoice 2" Dial Utility Pressure Gauge for Air Compressor Water Oil Gas, 1/4" NPT Center Back Mount, Black Steel Case, 0-200 PSI

by DuraChoice

66 customer reviews | 7 answered questions

Price: $9.74 + $4.64 shipping

Note: Not eligible for Amazon Prime.

Item Package Quantity: **1**

1 2 5 10 20 50 100

Size:

200PSI

- Professional quality & durability
- Black steel case, Copper alloy dry internal parts
- 1/4" back mount connection
- broad applications - water, oil, air and more

Product Specifications

UPC	783583822756
EAN	0783583822756
Item Weight	4.8 ounces
Model Number	PA204B-200
Size	200PSI
UNSPSC Code	25170000

Product description

Item Package Quantity: **1** | Size: **200PSI**

Dial Size: 2" Dial Size (Crimped Casing)

Accuracy: +/- 4/3/4%

Scale: Dual Scale - PSI / Bar

Movement: Copper Alloy

Bourdon Tube: Copper Alloy

Window: Glass

Case: Steel case for protection in harsh environments

Connection: Copper Alloy Center Back Mount; 1/4" NPT (for 2" dial)

Normal Ambient Temp.: -4F to +140F (-20C to +60C)

Product details

Item Package Quantity: **1** | Size: **200PSI**

Item Weight: 4.8 ounces

Shipping Weight: 4 ounces (View shipping rates and policies)

ASIN: B006K2RIY8

California residents: Click here for Proposition 65 warning.

Item model number: PA204B-200

Average Customer Review: 66 customer reviews

Amazon Best Sellers Rank: #284,357 in Industrial & Scientific (See Top 100 in Industrial & Scientific)
#762 in Industrial Pressure Gauges

Would you like to **tell us about a lower price**?

Voltage Reducer

Product description

Wiring: INPUT+ to BAT+, INPUT- to BAT-, OUTPUT+ to LOAD+, OUTPUT- to LOAD-
Reminder: Never reverse the polarity. Use the enough big cable to avoid the voltage drop. Never connect to solar panel or wind turbine. Never charge the battery.

Efficiency: 95%
Input Voltage:DC 24V (18-36V)
Output Voltage: DC 13.8V
Output Current: 30A
Ripple: 130mVp
Line Regulation: ±0.2%
Load Regulation: ±0.2%
Voltage Accuracy: ±1.5%
Enclosures: IP67
Dimension: 74*74*32
mm Net Weight: 0.32kg
Case Operating Temperature: -40~85°C

Warranty: 1 year
MTBF: 100,000 hours
Application:
24V DC battery of vehicles as input power to 12VDC appliances as output load.
Questions
How to choose the correct current for loads?
For example, if the max current of your load device is 10A, then choose 10A/0.8=12.5A at least for resistive loads according to international standard.
If the load device is motor or compressor, then you may choose 10A/0.5=20A according to real testing result since the motor and compressor starting current may be 2-3 times than nominal current.

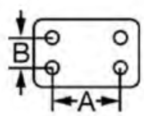
Pulley

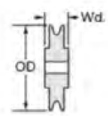
Pulley for Wire Rope-for Lifting

Mounted, for 3/16" Diameter, 2" OD

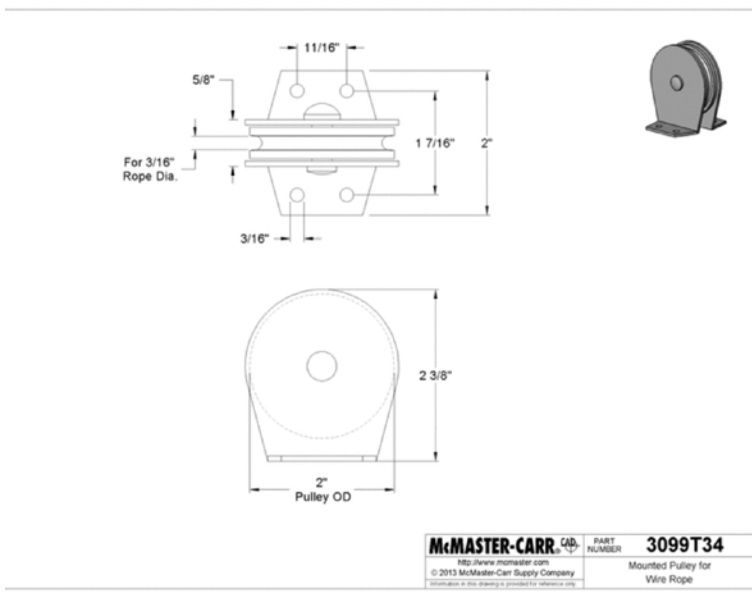
Each — ADD TO ORDER

In stock
$7.38 Each
3099T34



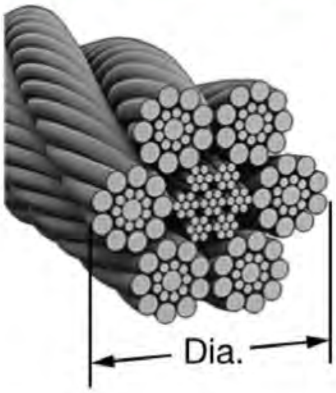


Style	1
Application	For Lifting
For Use With	Wire Rope
Pulley Type	Mounted
For Rope Diameter	3/16"
Capacity	600 lbs.
Number of Grooves	1
Insertion Style	Feed Through
OD	2"
Width	5/8"
Overall Length	2"
Overall Height	2 3/8"
Material	Steel
Housing Material	Steel
Mounting Hole	
Number of	4
Diameter	3/16"
Center-to-Center (A)	1 7/16"
Center-to-Center (B)	11/16"
Specifications Met	ASME B30.26
RoHS	Compliant



Wire Rope

for Lifting, Unfinished Steel, 6 x 19, 3/16" Diameter



Length, ft.	Each
10	
25	ADD TO ORDER
50	
100	In stock
300	$1.49 per ft.
	3440T55

Application	For Lifting
Attachment Type	Without Fittings
Diameter	3/16"
Capacity	750 lbs.
Recommended Pulley/Drum Diameter	6 3/8"
Material	Unfinished Steel
Wire Rope Coating	Uncoated
Construction	6 x 19
Flexibility	Extra Flexible
Core Type	IWRC
Lubrication	Lubricated
Preformed	Yes
Specifications Met	ASTM A1023
RoHS	Compliant

This wire rope provides a good balance of abrasion resistance and flexibility. Individual wire strands are preformed to maintain their shape and prevent rope from unraveling when cut. Rope is lubricated to reduce wear.

Warning: Never use to lift people or items over people.

Appendix N – Risk Assessment

designsafe Report

Application:	UAV Launcher	Analyst Name(s):	Jordan Cearns, Ben Lacasse, Sean Huxley, David Garcia
Description:	Safety precautions for all hazards involving testing, setup and launch	Company:	California Polytechnic State University
Product Identifier:		Facility Location:	San Luis Obispo, CA
Assessment Type:	Detailed		
Limits:			
Sources:			
Risk Scoring System:	ANSI B11.0 (TR3) Two Factor		

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-1	operator Launching	mechanical : crushing Human Interferance	Catastrophic Unlikely	Medium	No standing area	Catastrophic Remote	Low	On-going [Daily] Operator
1-1-2	operator Launching	mechanical : cutting / severing Cable Snapping	Catastrophic Remote	Low	No standing area	Catastrophic Remote	Low	On-going [Daily] Operator
1-1-3	operator Launching	mechanical : unexpected start Valve Failure	Serious Unlikely	Medium	Inspection	Serious Remote	Low	On-going [Daily] Operator
1-1-4	operator Launching	mechanical : break up during operation Structural Failure	Catastrophic Unlikely	Medium	Inspection	Catastrophic Remote	Low	On-going [Daily] Operator
1-1-5	operator Launching	mechanical : machine instability Frame Tipping	Serious Unlikely	Medium	Weighted feet	Serious Remote	Low	Action Item [2/28/2019] Jody
1-1-6	operator Launching	mechanical : impact Bystanders	Catastrophic Unlikely	Medium	No standing area	Catastrophic Remote	Low	On-going [Daily] Operator
1-1-7	operator Launching	electrical / electronic : shorts / arcing / sparking Damaged Insulation	Serious Remote	Low	Inspection	Serious Remote	Low	On-going [Daily] Operator

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-8	operator Launching	electrical / electronic : water / wet locations Weather	Moderate Unlikely	Low	weatherproofing	Minor Unlikely	Negligible	Action Item [4/25/2019] Ben
1-1-9	operator Launching	electrical / electronic : unexpected start up / motion Controller Failure	Serious Unlikely	Medium	two stage starter	Serious Remote	Low	Complete [2/14/2019] Ben
1-1-10	operator Launching	electrical / electronic : power supply interruption Battery Failure	Moderate Unlikely	Low	check battery	Moderate Remote	Negligible	On-going [Daily] Operator
1-1-11	operator Launching	fluid / pressure : pneumatics rupture Overpressurization	Catastrophic Unlikely	Medium	pressure release valve	Catastrophic Remote	Low	Complete [2/14/2019] Ben
1-2-1	operator Setup/Clean up	mechanical : crushing Dropped Equipment	Moderate Unlikely	Low	PPE, shoes	Moderate Remote	Negligible	On-going [Daily] Operator
1-2-2	operator Setup/Clean up	mechanical : cutting / severing Sharp Edges	Moderate Likely	Medium	PPE, gloves	Moderate Remote	Negligible	On-going [Daily] Operator
1-2-3	operator Setup/Clean up	electrical / electronic : energized equipment / live parts Connecting Battery	Moderate Remote	Negligible	PPE, grounding	Moderate Remote	Negligible	On-going [Daily] Operator
1-2-4	operator Setup/Clean up	slips / trips / falls : trip Tripping over Equipment	Moderate Remote	Negligible	Inspection	Moderate Remote	Negligible	In-process Operator
1-2-5	operator Setup/Clean up	material handling : excessive weight Picking up Equipment	Moderate Likely	Medium	weight reduction	Moderate Unlikely	Low	In-process David

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-3-1	operator Troubleshooting	mechanical : pinch point UAV impact	Catastrophic Unlikely	Medium	warning labels	Catastrophic Remote	Low	Action Item [5/1/2019] Sean
1-3-2	operator Troubleshooting	electrical / electronic : improper wiring Controller Failure	Moderate Remote	Negligible	PPE, gloves	Moderate Remote	Negligible	On-going [Daily] Operator
1-3-3	operator Troubleshooting	fluid / pressure : high pressure air Leakage	Serious Remote	Low	inspection	Serious Remote	Low	On-going [Daily] Operator
2-1-1	passer by / non-user walk near machinery	mechanical : impact Hit by UAV	Catastrophic Likely	High	no standing area	Catastrophic Remote	Low	On-going [Daily] Operator
2-1-2	passer by / non-user walk near machinery	fluid / pressure : pneumatics rupture Hit by Part	Catastrophic Unlikely	Medium	inspection	Catastrophic Remote	Low	On-going [Daily] Operator
3-1-1	Builders Launching	mechanical : crushing Human Interferance	Catastrophic Unlikely	Medium	No standing area	Catastrophic Remote	Low	On-going [Daily] All members
3-1-2	Builders Launching	mechanical : unexpected start Valve Failure	Serious Unlikely	Medium	Inspection	Serious Remote	Low	On-going [Daily] All members
3-1-3	Builders Launching	mechanical : break up during operation Structural Failure	Catastrophic Unlikely	Medium	Inspection	Catastrophic Remote	Low	On-going [Daily] All members
3-1-4	Builders Launching	mechanical : machine instability Frame Failure	Serious Unlikely	Medium	Weighted feet	Serious Remote	Low	Action Item [2/28/2019] Jody

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
3-1-5	Builders Launching	mechanical : impact Bystanders	Catastrophic Unlikely	Medium	No standing area	Catastrophic Remote	Low	On-going [Daily] All members
3-1-6	Builders Launching	electrical / electronic : shorts / arcing / sparking Damaged Insulation	Serious Remote	Low	Inspection	Serious Remote	Low	On-going [Daily] All members
3-1-7	Builders Launching	electrical / electronic : water / wet locations Weather	Moderate Unlikely	Low	Weatherproofing	Moderate Unlikely	Low	Action Item [4/25/2019] Ben
3-1-8	Builders Launching	electrical / electronic : unexpected start up / motion Controller Failure	Serious Unlikely	Medium	Two stage starter	Serious Remote	Low	Complete [2/14/2019] Ben
3-1-9	Builders Launching	electrical / electronic : power supply interruption Battery Failure	Moderate Unlikely	Low	Inspection	Moderate Remote	Negligible	On-going [Daily] All members
3-1-10	Builders Launching	fluid / pressure : pneumatics rupture Overpressurization	Catastrophic Unlikely	Medium	Pressure release valve	Catastrophic Remote	Low	Complete [2/14/2019] Ben
3-2-1	Builders Setup/Cleanup	mechanical : crushing Dropped Equipment	Moderate Unlikely	Low	PPE, shoes	Moderate Unlikely	Low	On-going [Daily] All members
3-2-2	Builders Setup/Cleanup	mechanical : cutting / severing Sharp Edges	Serious Unlikely	Medium	PPE, gloves	Serious Remote	Low	On-going [Daily] All members
3-2-3	Builders Setup/Cleanup	electrical / electronic : energized equipment / live parts Connecting Battery	Serious Remote	Low	PPE, gloves	Serious Remote	Low	On-going [Daily] All members

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
3-2-4	Builders Setup/Cleanup	slips / trips / falls : trip Tripping over Equipment	Minor Unlikely	Negligible	Inspection	Minor Unlikely	Negligible	On-going [Daily] All members
3-2-5	Builders Setup/Cleanup	material handling : excessive weight Picking up Equipment	Catastrophic Unlikely	Medium	Weight reduction	Catastrophic Remote	Low	In-process David
3-3-1	Builders Testing	mechanical : crushing Human Interferance	Catastrophic Likely	High	follow safety procedures	Catastrophic Remote	Low	On-going [Daily] All members
3-3-2	Builders Testing	mechanical : cutting / severing Sharp Edges	Moderate Likely	Medium	PPE, gloves	Moderate Remote	Negligible	On-going [Daily] All members
3-3-3	Builders Testing	mechanical : pinch point Assembly	Serious Likely	High	PPE, gloves	Serious Remote	Low	On-going [Daily] All members
3-3-4	Builders Testing	electrical / electronic : shorts / arcing / sparking Wiring	Serious Unlikely	Medium	PPE, gloves	Serious Remote	Low	On-going [Daily] All members
3-3-5	Builders Testing	electrical / electronic : improper wiring Controller Failure	Moderate Unlikely	Low	ground equipment	Moderate Remote	Negligible	On-going [Daily] All members
3-3-6	Builders Testing	ergonomics / human factors : repetition Fatigue	Minor Likely	Low	take breaks	Minor Unlikely	Negligible	Action Item All members
3-3-7	Builders Testing	fluid / pressure : fluid leakage / ejection Pneumatic System	Catastrophic Unlikely	Medium	inspection	Catastrophic Remote	Low	Action Item All members

Appendix O – DVP&R

Senior Project DVP&R

Date:	Team: Launch Time	Sponsor: Dr. Drake	Description of System:	DVP&R Engineer:

		TEST PLAN								TEST REPORT			
Item No	Specification	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES Quantity	SAMPLES Type	TIMING Start date	TIMING Finish date	TEST RESULTS Test Result	TEST RESULTS Quantity Pass	TEST RESULTS Quantity Fail	NOTES
1	Assembly Time	Time total time to assemble launcher from start to finish.	Total time to build is less than 20 minutes	Sean	FP	5	SYS	6/5/2019	6/5/2019	12 minutes Average	5	0	Amount of time required slowly was reduced as we determined which parts could be left together when transporting the launcher
2	Max Load	Load the maximum expected weight into the frame and ensure that the system does not fail.	System does not fail when there is a load applied	David	FP	5	SUB	5/28/2019	5/28/2019	Carriage withstood 185lbs	5	0	Carriage was able to withstand the repeated loading of 185lbs. The test was originally designed to test the entire project, but was changed at the last minute due to delays with the piston
3	Carriage Size	Carriage size will not exceed the given tolearances from the specification sheet	Carriage will be within 12-21cm in length	Jody	SP	1	C	2/5/2019	2/5/2019	Carriage length 28cm	0	1	Carriage was larger than originally planned. However, this was not a priority goal and we will still continue to work on the rest of they systems instead of resdesigning the carriage.
4	Minimal Pinch Points	All components of the system will be moved carefully and slowly to detect if there are any pinch points for the user while operating the launcher safely.	Zero pinch points for the user while the launcher is in use	David	FP	5	SYS	5/30/2019	5/30/2019	0 pinch points for user	5	0	No pinch points for user as long as they are the reccomended distance away from the launcher.
5	Succes Rate for Launch Abortion	Successfully decompress the air inside the tank and abort a launch without damage to the system or UAV	100% success rate of the launch cancelation system	Ben	FP	10	SUB	TBD	TBD				
6	Fit in truck	Launcher will be dismanteled and stored in the bed of Dr. Drakes truck	Launcher Fits within the bed of the truck	Jody	FP	1	SYS	TBD	TBD				
7	Time to Abort Launch	Time the total time to abort a launch by emptying the air tank	Launcher is completely inert after 90 seconds	Sean	FP	10	SYS	TBD	TBD				
8	Range of Launch Speed	Launcher will be fired at a variety of different air pressures in order to vary the launch speed, and will be measured using a high speed camera	Launcher will be able to launch the UAV at a range of speeds from 10-	Ben	FP	30	SYS	TBD	TBD				
9	Resistive Force Prior to Launch	Launcher will be set up and UAV will run its engines while on the launcher, in order to detect any movement from the carriage	Carriage will not move while motors are supplying up to 10 N of force	Jody	FP	5	SYS	TBD	TBD				
10	Number of Consecutive Launches	Launcher will be constructed and fired consecutively until unable to safely fire	Launcher will be able to launch the UAV a total of 5 times before becoming	Sean	FP	3	SYS	TBD	TBD				
11	Reset Time	Time the total time required to reset the launcher and prepare it for another launch	Launcher will be operable again after at most 10 minutes	David	FP	5	SYS	TBD	TBD				

Appendix P – Operator's Manual

Operator's Manual

Warning: This device is intended for use with only an AeroVironment RQ-20 Puma™ or Altavian Nova F7200™ UAV (Unmanned Aerial Vehicle). It is not recommended to use this device with other UAVs. Follow these instructions and designated maintenance procedures to prevent injury or damage to the launcher.

Parts List: 4x legs, launcher frame, 2x spreaders, carriage, air tank with compressor, controller, DeWalt battery

Setup

After arriving at the chosen launch site, the user will need to unload all equipment from the bed of the truck. One person will need to handle the piston track assembly while another carries the air tank. While the track assembly can be carried with little effort, the air tank is heavy and must be lifted carefully. The piston track assembly must be handled carefully because the carriage is mounted on the track and can slide freely if not secured to the magnets. The air tank must also be handled carefully and must be placed on stable ground to prevent tipping; there are multiple attachments at the ports that could be damaged if impacted. All pieces of equipment should be unloaded and laid out at the launch site. It is important that the chosen launch site is a flat area clear of obstructions and at least 10 feet by 10 feet in size.

Assembly

First, the user should attach all four legs to the front and back plate of the track assembly (Figure 1). The two front legs are distinguishable by their longer length. One side of the leg is flattened to slide into the slot on the plate (Figure 2).

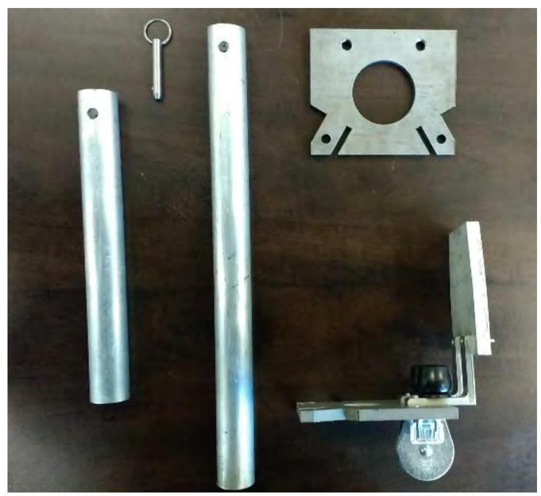


Figure 6. Front and back leg, front and back plate, quick release pins.

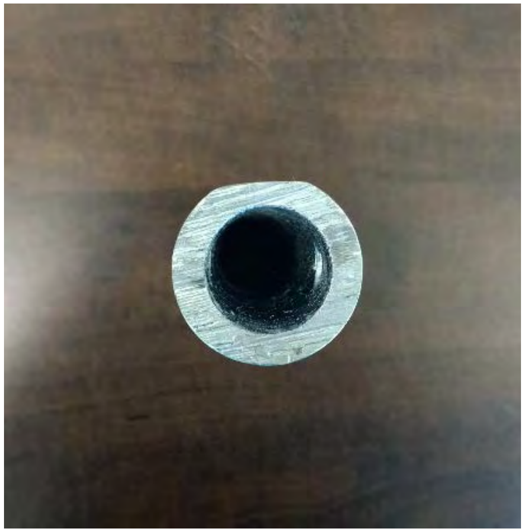


Figure 2. Flattened edge of leg.

First make sure that the flattened side of the leg is facing the groove in the plate. The leg can then be attached by simply sliding the hollow leg over the rectangular notch on the front plate (Figure 3).

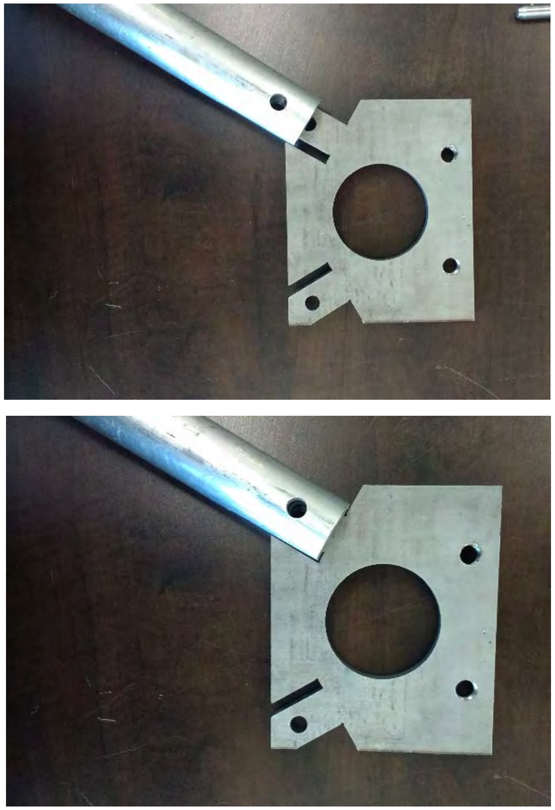


Figure 3. Sliding rear leg on rear plate.

Align the hole on the leg with the hole on the plate and slide the quick release pin through, ensuring that the pin is locked in place. (Figure 4)

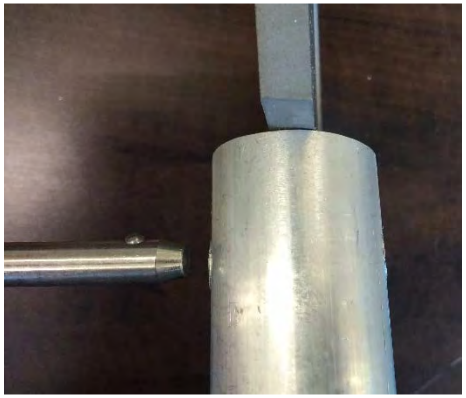


Figure 4. Inserting quick release pin.

Repeat the process for each of the four legs. Once the track system is assembled, if more stability is needed during launch, place a sandbag at the foot of each leg.

Figure 5. Fully attached front leg to front plate.

Next, make sure the air tank is upright and the safety release valve on the air tank is not pointed towards any other equipment (Figure 6). Check that the compressor is secured to the tank tightly. Check that all tee connectors are secured tightly to the tank and components.

Figure 6. Air system assembly

Next, take the group of wires coming from the control box, and identify each wire by its label. The control box has three wires with spade connectors that will need to be connected: the compressor power signal, dump solenoid positive, and launch solenoid positive. Each wire's corresponding wire near the air tank will be labeled as such.

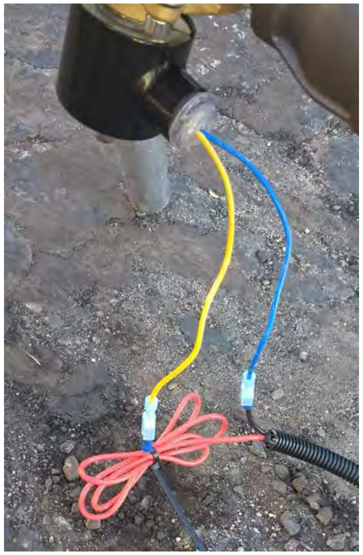


Figure 7. Launch solenoid wires

Figure 8. Battery unit connection

Now connect the air tank to the piston via the provided hose. Ensure that both ends are tightly secured tightening the hose clamps attached.

Verification

Once all connections have been checked, place all switches in the off position (Figure 9). Now, plug in the battery and test both solenoid valves to check that they open and close accordingly. You will be able to hear the solenoids “click” when turned on or off. Next, check that the main tank valve (large green handle) is open. With both solenoids closed, briefly turn on the compressor to check that it works. Release this air by opening the release valve. Before beginning launch procedures, double check that both solenoid valves are closed.

Figure 9. Control panel

Next, the track system should be tested. Wipe the linear steel rods with a clean rag to clear any debris from the surface. Slide the carriage up and down the rods to make sure the bearings roll smoothly. Connect the designated spreader to the two L brackets at the end of the track using two bolts (Figure 5). Run the carriage into the end of the track to check that the side panels separate. Bring the carriage to the start of the track and make sure the cable is inside the groove of the pulley.

Before placing the UAV in the carriage, adjust the rear support rod to an appropriate height. This can be adjusted later but must be close prior to inserting the UAV. Have one person spread the carriage side panels apart while another person places the UAV onto the carriage by aligning the slots in the receivers on the UAV with the carriage walls. Double check that the spreader at the end of the track is meant for the desired UAV. Make sure the carriage is slid to the back of the track and the magnets are in contact. There should be resistance to sliding when the magnets are engaged.

Launch

Enable the compressor using the toggle switch on the controller. Turn off the compressor when the pneumatic system reaches the desired pressure. **Note:** The relay was designed to stop the compressor when pressure reached 145psi, but the safety release valve releases the pressure at 135 psi. The user should either watch the pressure gage until the desired pressure is reached, then turn off the compressor, or, the user can wait until the pressure release valve opens, knowing that the pressure is 135 psi. (A pressure release valve that opens at 150 psi should be purchased and implemented. Then the user can wait at a safe distance until the relay turns off the compressor automatically). At this point, clear the area around the launcher and move at least 40 feet away from the launcher to a safe position. When ready to launch, **hold** the launch toggle switch up and **press and hold** the red launch button. After the UAV has launched, release the launch button.

To release all air pressure in the system, toggle on the dump valve switch and keep toggled until the whole system has been drained.

Take Down

Begin by checking for any remaining air in the tank; discharge if necessary. Disconnect the battery to depower the system. Disconnect the air tank from the piston. Remove the launcher's legs. Begin with the back legs as they are shorter; this will keep the launcher more stable while you remove the front legs. Remove the quick release pins from a single leg at a time, then remove the respective leg from the back/front plate. Disconnect the labeled spade connectors and wind the excess controller wire into a spool for easy transportation. Have at least one person carry the track assembly while another person carries the air tank and transfer the system into the truck bed.

Maintenance

The linear motion shafts on the launcher frame should be kept oiled and dry to prevent surface tarnish or rusting.

The two axels in the carriage should be kept oiled and dry to prevent surface tarnish or rusting.

Batteries should be fully charged between uses so the compressor can fully pressurize the tank.

Visually inspect the shock absorbers at the end of the track to make sure there are no cracks or deformations.

Check that the spring inside the carriage is still stiff by pulling apart the side panels.

Periodically check the air tank for signs of leaking air. A replacement tank may be required if any are found.

Storage

The launcher frame, piston, air tank, and electrical components should be stored in a cool, dry environment to prevent rusting and corrosion of the metals. All air should be released from the system prior to storage, and no batteries should be left connected.

Safety

In order to minimize the risk of injury or damage to the launcher, the following safety concerns should be noted and avoided.

- Do not stand or place objects directly in front of the launcher for approximately 60 ft., as the UAV and/or piston shaft may collide with the person or object before it has a chance to maneuver.
- Do not operate the machinery if the wiring appears to be worn or the insulation has been removed, as this may cause a short and either electrocute someone or cause the launcher to activate prematurely and without warning.
- Always make sure that the air tank is completely drained before transporting it. Any compressed air left in the tank could cause it to rupture if the tank is impacted.
- Do not leave the air tank fully pressurized for extended periods of time. Doing so could cause leakage in the connections.

Troubleshooting

The following is a list of possible problems that may arise from operating the launcher, along with suggestions to resolve the underlying issues.

Pressure is dropping before the launch	Pressurize the air tank to 60psi and place soapy water at each connection for the fittings. If any bubbles are formed, there is a leak and the part may need to be tightened, re-taped, or replaced as needed
Launcher is unstable prior to launch	Ensure that the launcher is on level ground. If the ground does not provide enough friction to prevent movement of the launcher during the launch, place sandbags or weights at the ends of the legs.
Electronics are not functioning	Ensure that the battery is fully charged and fully plugged into the adapter. If so, then examine the connections between the battery and the inoperable component, and solder or replace any connections that are faulty. If the electronics still do not respond, use a multimeter to determine if the part itself is no longer operable. If so, replacement for the adapters or electrical components should be ordered and installed
Piston is not reaching correct speed	Ensure that the pressure in the air tank is set correctly before launching the piston. Also examine the bearing shafts and remove any debris that may be providing excess friction.

Appendix Q – Wiring Diagram