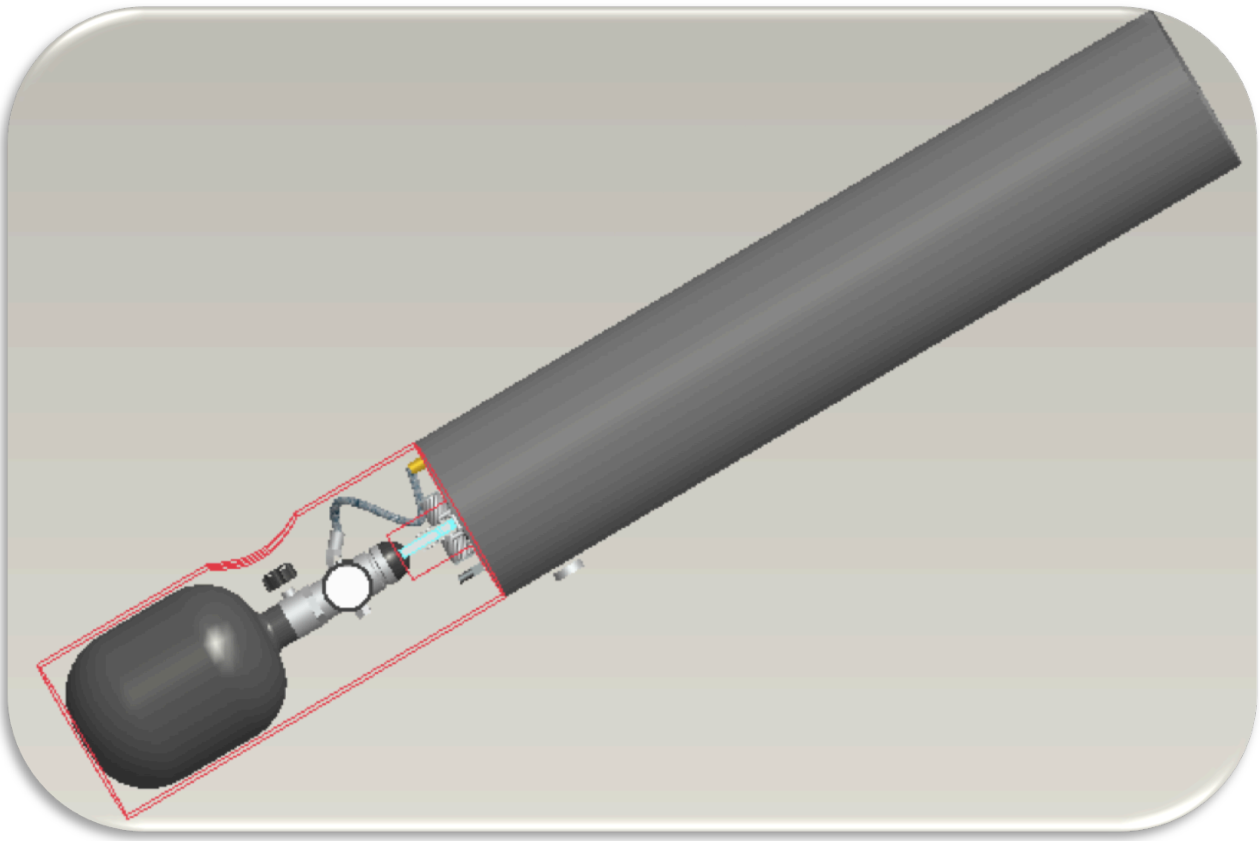
Final Design Report

Compact Pneumatic UAV Launcher
Sponsored By Eglin AFB



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Performed Fall 2008 through Spring 2009
Submitted on April 9th, 2009

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Needs Assessment

The primary objective of this design is to provide a new, safe, efficient, and effective means of propelling an Unmanned Aerial Vehicle (UAV) prototype into flight, which will be provided by Eglin Air Force Base.

Project Scope

Problem Statement

Eglin Air Force Base needs a new safe, efficient, and effective method of launching their current UAV prototype into flight.

Justification

Currently at Eglin AFB, the team's sponsor Jeff Wagener, tests the capabilities of Unmanned Aerial Vehicles. The company equips the UAVs with GPS systems, video cameras, and other electronics to help soldiers in the field. The sizes of the UAVs that Eglin tests range from a foot in length to approximately six feet. Mr. Wagener has informed the team that the UAV that needs to be launched will be eighteen inches long and three and a half pounds. The team took advantage o f the opportunity to visit Eglin to see where the remote controlled UAVs are designed and manufactured in his workshop. During the visit, Mr. Wagner showed the team the current launching methods and set up, in which were all considered severely insufficient. One method consisted of launching a larger UAV with a "launch system" attached to the landing gear. The "launch system" was simply a tank of compressed air that was released through a remote control valve and into the barrel of the launch tube. The materials that were used in this set-up severely limited the performance of the launcher. However, since the UAV was already traveling at a decent speed (by way of a larger UAV), it only needed to be pushed out of the launch tube. It seems fairly wasteful and impractical to have to launch a larger UAV just to test a much smaller UAV prototype. Therefore, the team was contracted to produce an alternative but effective means of launching the UAV from ground level.

Executive Summary

The primary objective of the compact pneumatic UAV launcher design is to provide a new, safe, efficient, and effective means of propelling an Unmanned Aerial Vehicle (UAV) prototype into flight, which will be provided by Eglin Air Force Base. The method must produce an exit velocity of 18.288 m/s (60ft/s) without exceeding 600Gs of acceleration. The design cannot surpass 36 inches in length or 5.5 inches in diameter. Originally, the launcher weight was restricted to 2.5 lbs (fully operational).

During the fall semester, the team decided on a method of propulsion (launcher), which uses pressurized compressed air within a chamber of a launcher. With the use of a quick release pin, all of the energy stored in the system will be released instantaneously, which would then discharge the projectile into flight. The expansion process of the compressed air against a moving lid is the driving force of the system. The expansion was originally modeled as a polytrophic process, isentropic, to be more specific.

A prototype was developed to test the functionality of the fall final design. After testing was completed, the polytrophic expansion was more accurately modeled. The final design was then optimized by using a more effective, and stronger quick release pin and receiver, and would be primarily constructed out of carbon fiber components. With an approved weight and length extension, the team is confident the optimized final design meets all of the customer's expectations.

Project Specifications & Constraints

Objective

The primary objective of the project is to completely design but not necessarily fabricate an effective pneumatic UAV launcher capable of efficiently propelling an UAV into flight for Eglin Air force Base no later than the close of the spring 2009 semester while staying within the following parameters set before us more in particular those listed within the specifications section:

- Minimum exit velocity: 18.288 m/sec
- Instantaneous acceleration must not exceed 600g
- Launcher weight limit: 1.134 kg, including all accessories, stand, etc.
- Launch angle estimated between 30-45 degrees
- No energetic methods or accelerants
- Must be repeatable at minimum of 5X
- Maximum tube dimensions .914m L x .114m W x .114m H square, or .914m x .1397m diameter round (if a tube is used)

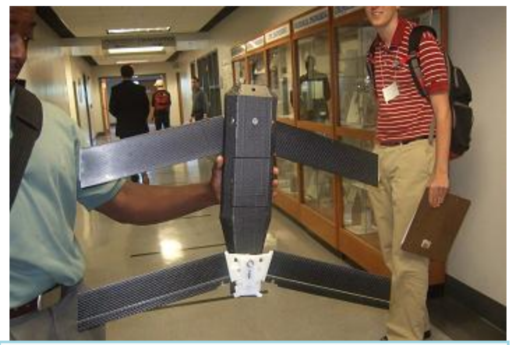

Figure 1 - Actual UAV Prototype provide by EAFB

Constraints

Though the project is open for multiple designs, the design team is limited to several factors that include but are not limited to the following:

- Physical Fabrication skill
- Capital expenditure (1500 ME Dept + EAFB supplementary funds)
- Various fabrication costs
- No energetic methods or accelerants
- Must be repeatable a minimum of 5X

Methodology

Initially, the team will perform sufficient background research and analysis to find the necessary force, stress, strain, and other allowable tolerances to meet the project needs. After a more clear understanding, the team will brainstorm on various effective methods of approach and propulsion techniques. With several ideas in hand, the design team can derive a sufficient analysis that included, but was not limited to a decision matrix, pro/con chart, and several open team discussions.

Further analysis and calculations on the final design selection will be conducted to ensure proper selection. After the team has decided on a final design, they will break the system up into components and perform concept selection in order to select the optimal design. Lastly, the team will construct a prototype manufactured for testing and analysis. If the testing data meets the team and customer's specifications, then a final product will be manufactured and retested with hopes of completion.

Expected Results

The team is expected to design and construct a means of launching an UAV. This will include but is not limited to the following:

- Detailed schedule and plan of approach
- Proper operation manual
- Functional prototype
- A complete and fully functional UAV Launcher that meets or exceed the customer's requirements.

Figure 2 – Current Launcher Used by Others

Background

The Unmanned Aerial Vehicle-

It took an unexpected amount of time to receive any information regarding the project or the UAV itself due to a military clearance that restricted release of any publications. At this time the team has not received any dimensional details, which is really hindering the detailing process. A request has been sent to the sponsor to obtain an operational UAV for final design specifications, prototype building, and help in visualizing how the aircraft needs to exit the tube. Figures 3,4, & 5 show pictures of the un-manned aerial vehicle. At this time, one of the only critical specifications of the aircraft that the team knows is that it weighs 3.5lbs.

Figure 3 – Front view of the UAV (wings retracted)

Figure 4– side view of the UAV (wings retracted)

Figure 5 – Angled view of the UAV (wings at full span)

Launch Methods –

As the project specifications became more clear, research topics were dealt out to members of the team. The research topics included but were not limited to existing UAV launchers, alternative means of propulsion, and lightweight materials. Each team member was given a topic to research and report to others within a period of one week.

It was decided that one critical part of research and product design is making sure that one does not "reinvent the wheel", meaning; are there any existing products out there that satisfy the requirements? UAV's come in all shapes, sizes, and weights, so it is not easy to find information on UAV launchers that are similar to the specifications that were given by the customer. Most of the launchers that were found were much larger in size and heavier in weight. A common way found to launch unmanned aerial vehicles seemed to be on the back of a vehicle, either manually or mechanically. Figure 6 below illustrates a soldier launching a UAV manually out of a moving vehicle; this is the method currently used by the customer.

Figure 6 – Customer's current method of launching

Typically, the larger launchers use a system of cables and/or pneumatics to propel the UAV's into flight. Through much research the group found that No existing launchers launched the UAV via a tube. A few launchers used a separate chamber that pushed a metal rod through a barrel while the rod was attached to the UAV. Upon flight, the rod would be released. Per the customer specifications, nothing should fly out of the launcher except the UAV. The customer's current method of launching the UAV is either by throwing it, a slingshot type of launch system using surgical tubing, or remotely pushing it out of a tube attached to a larger UAV as described in the project scope justification (Page 2). This takes substantial time to setup in the field, which the customer would like to reduce. The research for this topic exposed the fact that there were no existing launch systems that could be used to meet the customer's specifications.

The second topic of research pertains to alternative methods of propulsion. Every concept was considered; no "shooting down" or deterring of ideas was accepted during this stage. However, considering that the UAV needs to be accelerated at an extremely high rate, in a short distance, with minimal weight, there were other means of propulsion that did not make it to concept screening. A trebuchet design could easily be ruled out considering it uses counterweight to launch projectiles. Also, anything with a combustion chamber could not be used since the customer specified not to use energetics or accelerants. After the research time period expired, there were five alternative methods of propulsion that seemed logical enough to give more thought to. These methods included pneumatic force, spring force, electromagnetic force, electric linear actuator, and that of a cable/pulley system similar to a crossbow.

Figure 7 – Electric Linear Actuator

Figure 8 – Pressurized CO_2 canister

Figure 9 – Crossbow/Pulley System

Before screening the ideas, there were reasons for these systems to be considered. After seeing how fast certain projectiles could be accelerated by these systems, the question was asked; can the speed be reached that the customer has set forth without any of the constraints considered? If the answer was "yes" then it became a candidate for concept screening.

The last research topic was lightweight materials. Taking into consideration that there are going to be large forces at work when launching, metal was the first material considered. Some common metals that are widely used are Aluminum and Magnesium. They have densities of 2.70g/cm^3 and 1.738g/cm^3. If the entire system were made out of either of these materials, it would be too large. However, they are fairly strong materials considering how light they are. Because of those large forces, some of the components will have to be made of some type of metal. Aluminum and Magnesium have the characteristics that fit the customer specifications. Also, an alloy of aluminum and Magnesium is not ruled out.

Figure 10 – Aluminum Tubes

Figure 11 – Raw Magnesium Blocks

The new, hot material on the market is carbon fiber. It is lightweight, durable, thin, easily molded, high ultimate tensile strength, low thermal expansion, and the surface can be finished with different kinds of seals. Carbon fiber could be used for the structure of the launcher. It was also found that they make pressure vessels out of carbon fiber. All of the properties of carbon fiber make it very popular in aerospace, civil engineering, military, and motor sports, along with other competition sports.

Figure 12– Unprocessed Carbon Fiber

Figure 13 – Carbon Fiber tubes

Figure 14– BMW's new Carbon Fiber air box

It was difficult to find material specifications on particular plastics and polycarbonates. Using common sense, plastics and polycarbonates could be used for fittings, bushings, and structural parts that have low impact stress. Plastics include rubber, PVC, nylon, and synthetic rubber. Thinking ahead, the rubber can be used to reduce impact of parts or reduce recoil. Rubber can come in many different densities with just as many properties. Hard plastics are the same way; very versatile and common throughout military applications.

Figure 15 – Plastic bottles, rated for 1.207 MPa

Figure 16 – PVC pipes are extremely durable, rated up from 3.447MPa – 17.24 MPa.

Brainstorming

The team held meetings of which the sole purpose was to brainstorm with all of the new information that had been researched. On these nights, it was more of an open forum, to get the “creative juices flowing”. Typical sessions lasted approximately four hours each. There would be an abundance of food and drinks along with Monday night football to create a less formal atmosphere as shown below in figure 17. A whiteboard was used to better convey ideas while other members took notes, made sketches, gave advice, and asked questions. As the team socialized, work was to be done. Each of the propulsion ideas that were found through researched were discussed and worked through in further detail. Lightweight materials were discussed to see how they could be implemented or used in launching the UAV. The team also referenced online sites such asYoutube.com. The team was able to watch videos of functional UAVs being launched. They were considerably larger than the aircraft pictured in Figures 4, 5, and 6. As notes were taken, the team concluded that they would spend time by themselves to come up with different ideas and concepts for the propulsion systems. The main goal of the brainstorming session was to gain a better knowledge basis for the concept screening session that would be happening in the near future; this goal was achieved.

Figure 17 – Team 3 brainstorming

Concept Screening

Table 1 – Method Concept Scoring

Selection Criteria	Concepts					
	Pneumatic	Spring	Electro-magnet	Compound Pulley	Linear Actuator	Manual Launch (Reference)
Repeatable for min. 5 launches	+	+	+	+	+	0
Ease of field assembly	+	0	-	0	+	0
Ease of use	+	0	+	0	+	0
Safety	-	-	-	-	-	0
Maintenance	-	-	-	-	-	0
Durability	+	+	-	+	-	0
Reliability	+	+	+	+	+	0
Feasibility	+	+	-	+	-	0
Sum +'s	6	4	3	4	4	0
Sum -'s	2	2	5	2	4	0
Sum 0's	0	2	0	2	0	8
Net Score	4	2	-2	2	0	0
Rank	1	3	6	2	5	4
Continue?	Yes	Revise	No	Yes	No	No

After the brainstorming phase was completed, the following five conceptual ideas to provide the propulsion for the UAV launcher were developed: pneumatic, spring, electromagnet, compound pulley, and a linear actuator. These five potential designs were then put into a concept screening matrix in an effort to further narrow the scope of possibilities for the final design (Table 1). By using a matrix, each idea was compared against one another as well as against the manual launch method. The criterion that was compared included the device's ability to operate at least five times without being recharged, the ease of field assembly, safety, maintenance, durability, reliability, and feasibility.

The first idea evaluated was pneumatic. It held the overall highest score. The only criteria in which pneumatic scored lower than the benchmark, manual launch method, were safety and maintenance. It received a minus score on safety because the pneumatic designs deal with highly pressurized vessels. It would require maintenance because of valves, fittings, and the high pressure forces exerted on the launcher. However, this design is very feasible for meeting most, if not all, of the product specifications. It would be reliable and probably the easiest to use. Very little field assembly would be required.

The second idea was to have a spring powered means of propulsion. This also received negative scores on safety and maintenance. The spring would have to be very powerful to propel the UAV to 60 ft/s. The spring in compression, as well as the fatigue of repeated use, can create dangerous consequences. The high spring forces exerted on the launcher and the fatigue on the spring require routine maintenance. This design is feasible, but with such a low score it was decided to revise the spring concept to be implemented in other designs. A possible implementation of the spring could be to reduce the impact force of certain parts. It was decided to revise the spring design into a spring powered pneumatic chamber. This operates under the same principles as a spring powered air-soft guns. The spring would compress an air chamber that would propel the UAV out of the tube.

As one might expect, the electromagnet idea scored the lowest. Here the UAV would have been accelerated through a magnetic field, similar to the operation of a rail gun. This idea was very creative, just not feasible. It would have required the most maintenance, and more importantly, the most dangerous. It would have been relatively easy to operate, but the cons far outweigh the benefits. Also, the sponsor has confirmed that the magnetic field would interfere with the GPS and other electronic devises housed inside the UAV.

The compound pulley scored the second highest in the decision matrix. The compound pulley idea would have behaved like a crossbow firing a UAV instead of an arrow. The bow and cable would be under extreme tension, which would require periodic maintenance and safety precautions. It would be similar to the hand or surgical tubing launch in the ease of assembly and the ease of use. It surpasses the benchmark in durability, reliability, and feasibility.

The last idea put through the screening matrix was a linear actuator. Here the linear actuator would convert electrical energy into mechanical energy as it accelerates the UAV through the launch tube. This received a score of zero. Any advantage this idea had was matched equally with a disadvantage. This design was reliable, but not feasible.

Concept Scoring

Table 2 – Functionality Concept Scoring

Criteria	Weighting	Pneumatic	Spring+	Compound Pulley
Min. exit velocity of 60 ft/s	10	10	8	8
Max. Weight of 2.5 lbs	9	7	2	5
600g max. inst. Acceleration	10	9	7	7
repeatable for min. 5 launches	8	6	8	8
Cost	7	5	7	6
Ease of field assembly	7	5	3	4
Ease of use	7	5	3	4
Safety	10	3	4	4
Maintenance	7	5	7	6
Durability	8	4	6	5
Reliability	9	8	8	7
Feasibility	8	7	4	5
Total	100	74	67	69
Weighted Total		74%	67%	69%

Next, the conceptual designs that passed the screening matrix; pneumatic, revised spring, and compound pulley were placed into a concept scoring matrix (Table 2). Here the criteria were weighted proportionally to what the team deemed most important. The minimum exit velocity, maximum instant acceleration, and safety were deemed the most important and given a weighting of ten percent. The components within the UAV would be damaged if the acceleration were to exceed 600Gs. The maximum weight of 2.5 lbs was given a 9 percent weighting, because the sponsor indicated the team might be able to slightly adjust this specification. Reliability was decided to have the same weight of nine percent. The 5 repeatable launches, durability, and feasibility were each given eight percent weightings. The cost, ease of use and assembly, and maintenance were all weighted seven percent each. The cost was deemed an adjustable constraint. After this screening, the conceptual design will be narrowed down to one general concept.

The pneumatic concept was ranked number one once again. It was determined to be the best in meeting the minimum velocity of 60 ft/s, determined to be the lightest, and the most feasible. The pneumatic design would also be the easiest to use and assemble. On another note, the pneumatic design was more prone to exceed the maximum instantaneous acceleration limit of 600Gs than the other designs. This design would most likely cost the most to fabricate and be more difficult to implement five launches considering the stringent weight limit. After extensive consideration, the advantages of the pneumatic design far outweighed the disadvantages.

The revised spring concept still failed to overcome the other ideas. It was determined to be cheaper, more durable, and more reliable than the compound pulley. It also would require the least maintenance of all the designs; unfortunately it proved to be the least feasible for the team.

The compound pulley idea (Appendix A4) just barely outranked the revised spring idea. The compound pulley would be lighter, easier to use, and easier to assemble in the field than the revised spring. The team then performed rough, simplified calculations of the exit velocity a compound pulley crossbow could achieve with the weight restriction. These calculations determined that not even the most modern crossbows on the market could achieve the required exit velocity. To modify such a concept into one that could reach the necessary exit velocity would greatly hinder the weight restraint amongst other things. These calculations can be found in Appendix B. Thus, the pneumatic concept was determined to be the direction the team will be headed into.

Detailed Design

Once the team decided on a general pneumatic design, the team's detailed specifications were considered. There were six major subjects to be covered which included but was not limited to the following:

- Single chamber vs. dual chamber vs. nozzle
- Piston vs. compression chamber
- Valve vs. airtight seal
- External vs. inline reservoir chamber
- Single vs. dual reservoir
- Stand design

The team took a vote on each subject, and if any member disagreed or voted opposite the rest of the team, the matter was discussed in more detail.

The single barrel (Appendix A2) vs. dual barrel (Appendix A1) vs. nozzle (Appendix A3) was the first issue that was addressed, and the single chamber concept was chosen unanimously as the best design. The single barrel design means that the compressed air will be shot out of the same tube the UAV is launched out of. The dual barrel design is one that uses a smaller, subsidiary barrel, where air is forced through the smaller barrel. The smaller barrel has an attachment that moves through both barrels, to propel the UAV. The nozzle design is one that the carriage that holds the UAV is a pressure vessel that uses a converging nozzle to propel itself out of the barrel. By using a single chamber, the team would eliminate the problem of an airtight seal in the smaller chamber, the team's design was simplified and the weight constraint on the design would be easier to achieve.

The pneumatic piston vs. compression chamber was the next issue considered. The team was initially split on the decision, so a table of the pros and cons of both ideas was created in addition to discussion.

Table 3 – Pneumatic Piston vs Compression Chamber

Concepts	Pros	Cons
Pneumatic Piston	Easier to solve the airtight issue; Use less air to propel object	Cuts possible length of propulsion in half; Highstress part due to smaller cross-sectional area; Heavier and more complex due to moving parts
Compression Chamber	Adds possible length to propulsion distance; Easier and less complex	Possibly less efficient at transferring energy; More difficult to make airtight seal

As seen in Table 1, the pneumatic piston was feasible because it transferred the energy kinetically rather than pneumatically, the shape would be easier to create an airtight seal, and it would use less air to provide the same propulsive force. The drawbacks were that the part would be under higher stress, the addition of the subsystem would add weight, and the design would shorten the effective distance to launch. Since the piston, by definition, is up to ½ the length of the reservoir, the maximum piston length would be 0.457 meters. Since the team's overall design is limited to 0.91 meters in transport, this subsystem would leave a maximum of 0.457 meters to propel the UAV to the minimum exit velocity. The team decided that length was a major issue in the design, and in order to use the maximum length specified efficiently, the compression chamber concept was chosen.

The issue of using a valve to release pressure vs. using a physical means of holding the carriage at rest while the charge is being loaded. Once again, the team was split in the decision; so another list of pros and cons was put together to address this issue (Table 4).

Table 4 – Release Valve vs Airtight Seal

Concepts	Pros	Cons
Release Valve	safer in field use	more expensive
	easier in assembly and usage	more complex
	does not require an airtight seal to operate	may require more pressure
		Slight delay in air release/pressure build
Airtight seal	simpler	Much more difficult in design
	releases entire charge immediately	high stress part
		less safe

The release valve subsystem can be described as follows: a valve (yet to be determined) would quickly release a metered amount of air into the compression chamber. This air would pressurize the compression chamber and propel the UAV. There were several distinct advantages with the release valve. This subsystem would be safer in field usage because the air would be stored in the reservoir behind the valve up until the UAV is ejected, rather than being pressurized and potentially dangerous. Also, a valve would be easier than a sealed chamber to remotely actuate. The drawbacks of this subsystem were the increased cost, the added design complexity, and the fact that the rate of pressure increase in the compression chamber would be incumbent to the valve design chosen. The airtight seal subsystem can described as follows: the compression chamber would be pressurized before the UAV is ejected and held back physically with a pin or gate. When the UAV is to be ejected, the pin or gate would be remotely released and allow the built up pressure to eject it. This subsystem has the advantages of simplicity and immediate response. Disadvantages included the fact that it would be more difficult in usage, as it requires pulling a pin or releasing a gate that is under shear stress. Also, it is less safe, since a physical failure of the safety would allow the UAV to eject prematurely. The team decided to continue design with an airtight seal, but the release valve subsystem will be further researched and developed for an alternative when the team builds a prototype.

The next subsystem debated was the location of the air reservoir. An inline reservoir can be described as a sealed, hollow chamber located at the back of the launcher to ease transport. It would be constrained to the same dimensions as the tube. An external reservoir is defined as a conventional air tank strapped to the outside of the tube. Initially, the team was unclear about the customer expectations on the total size of the UAV launcher. After the team spoke with the customer, it became clear that they expect the launcher and all components to fit within the required lengths and diameters.

Next, the team discussed using two air reservoirs vs. one air reservoir. The two-reservoir subsystem would operate as follows: a main reservoir would store air, while a smaller reservoir would store the required pressure of air to launch each time. For example, if a predetermined amount of air at 20 MPa were required per launch, the smaller reservoir would be previously filled to 20 MPa by the larger air reservoir. When the UAV is ejected, the smaller tank could then be refilled to the required pressure via the larger tank. The single air tank would limit the system's repeatability, as the main tank would be emptied after every launch. The decision was made to use two air tanks to provide repeatable results every launch.

Lastly, and of least importance, the team had to design a stand that could withstand the recoil generated by the UAV ejection while remaining stable. The team decided on a machine gun-style bipod on the front and rear of the launcher. There would be notches on the tube to allow for launch height adjustment.

Interim Design Review

After looking back at the way the team approached the design and decision process, the team feels very confident in what they have accomplished. Each step was critical in determining the final design. If one of the steps was to be skipped over, or out of place, the design process would have been much more difficult and ineffective. Teamwork by communication can do wonders for a project, being able to convey ideas and thoughts through words and drawings are essential in the success of a team. There were some ideas that the team has kept on the drawing board in case the final design is unsatisfactory. However, by combining the design subsystems, the team plans to integrate and mesh them into one, single cohesive design that should lead them to a successful end result. The final design will be a single barrel, compression chamber, and internal pressure reservoir, with a rifle stand.

Fall Final Design

Project Scope Update -

After the initial design concept was selected, the team had the opportunity to take a trip to Eglin Air Force Base and meet with the sponsors. The team was able to sit with the customers and refocus on the objectives and project specifications. The customer was able to the team's presentation and concept selection report. The overall response was very positive. They felt that the team was progressing appropriately but emphasized the need to stay on schedule. At that point, there was one change to the initial project specifications. In the final concept, the team had decided on a two-chamber system, which would make it easier to achieve repeatability. After a few quick calculations, the team concluded that it would take a very strong reserve tank to hold the compressed air. The team was aware that there were very strong, small tanks that would suffice and intensely scoured the Internet and stores for the best available option. It turned out that the dimension restraints were not the biggest issue, but the weight of the tank was critical. The lightest tank the team could find was .8182kg. This would be 72% of the initial weight specification of 1.1364kg. A proposal for leniency was written on the weight restriction and was met with much understanding by the team's customer (see Appendix H). Due to the request, the customer granted us an extra three pounds. This would give us a total weight of 2.5kg. All of the other specifications remained the same and are listed below for convenience.

Specifications-

- Minimum exit velocity: 18.288 m/sec
- Instantaneous acceleration must not exceed 600g
- Launcher weight limit: 2.5 kg, including all accessories, stand, etc.
- Launch angle estimated between 30-45 degrees
- No energetic methods or accelerants
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Fall Final Design Components

Overview-

In the final design concept, the team was able to conceptualize the launcher's functionality. A few of the design concepts of the initial design could be reused, but many of the subsystems had yet to be determined. It was decided that the launcher could be broken up into different components. Because the launch system components are supposed to work together, it is obvious that design concepts of certain components influence other component's performance or feasibility. The team chose to explore all possibilities and during concept selection, design with the ability to integrate with other component concepts. This would insure that the team would not choose certain component concepts that will not work well with other concepts.

The first component of the system deals with how the carriage would be released upon the pressure build in the charge chamber. This will be called the Releasing System. The second component is that of the "carriage", which would be the part that attaches to the UAV and carries it down the barrel only to release it at the end of the barrel. This will be referred to as the Carriage Component. The third component of the system is of the charge chamber itself, particularly how to keep it airtight. An airtight seal would insure that the pressure build is sufficient to launch the UAV at the speed required. This will be referred to as the ATS (Air Tight Seal) component. The fourth component is dependent on the Carriage and Releasing System components. It addresses the problem of how to stop the carriage from exiting the barrel of the launch tube without damaging itself or the barrel. The fifth and last component is material/part selection. The reason the team considered this a component was that the materials within or on the launcher will be under high stresses and the length of the charge chamber determines these high stresses. Depending on which Releasing System is chosen, it might give the team more length or width to add to the charge chamber, which would decrease the amount of pressure the charge chamber would have to hold. With less pressure in the charge chamber, it would reduce the stresses on the walls. If the team could reduce the pressure in the charge chamber, it could have an influence on the types of materials the team could use.

After all of the components go through concept generation and selection, the team visions an optimized final design.

1.Carriage Component-

1.1 Component Specifications –

The Carriage is a very important part of the entire launch system. Because the UAV is not a uniform shape, it would be susceptible to rolling inside of the barrel when the compressed air is released through the tube. The concepts for the carriage should address this issue, insuring the UAV does not roll or come out uneven. Also, the wings of the UAV are spring loaded and do not lock into place. This poses a problem if it were to be launched inside the tube without being secured because the wings would be in contact with the sides of the tube. The spring action on the wings could possibly catch on the inside of the barrel and damage the wings of the UAV. Therefore, the design should make sure the wings are secured and undamaged during the launch. The sponsor had an issue with their "carriage" and launcher when they experienced blow by. This should be another focus for concept designs.

1.2 Concept Generation-

Carriage with Styrofoam Insert (Figure 19)-

The carriage in this design would be a thin cylindrical shell with a solid backing. The backing would be thicker than the shell, because most of the forces are acting on the backing directly. These forces include the initial (highest) force and the stopping force. This shell would help minimize the blow by, because the shell would fill up the entire cross-sectional area of the barrel. The pressure will only act on this cross-sectional area during the launch. The quick release pushpin receiver will be mounted to the back this solid backing. The back of the UAV would be flush with the back inside of the carriage. To restrain the wings from scraping along the inside of the barrel two Styrofoam inserts will be placed around the UAV in the front of the carriage. These inserts were called Styrofoam Wing Restrictors in the diagram below. These inserts will hug the wings keeping them in their locked position during the launch. They would then fly out of the barrel with the UAV and then detach from the UAV. If damaged, these Styrofoam inserts would have to be replaced.

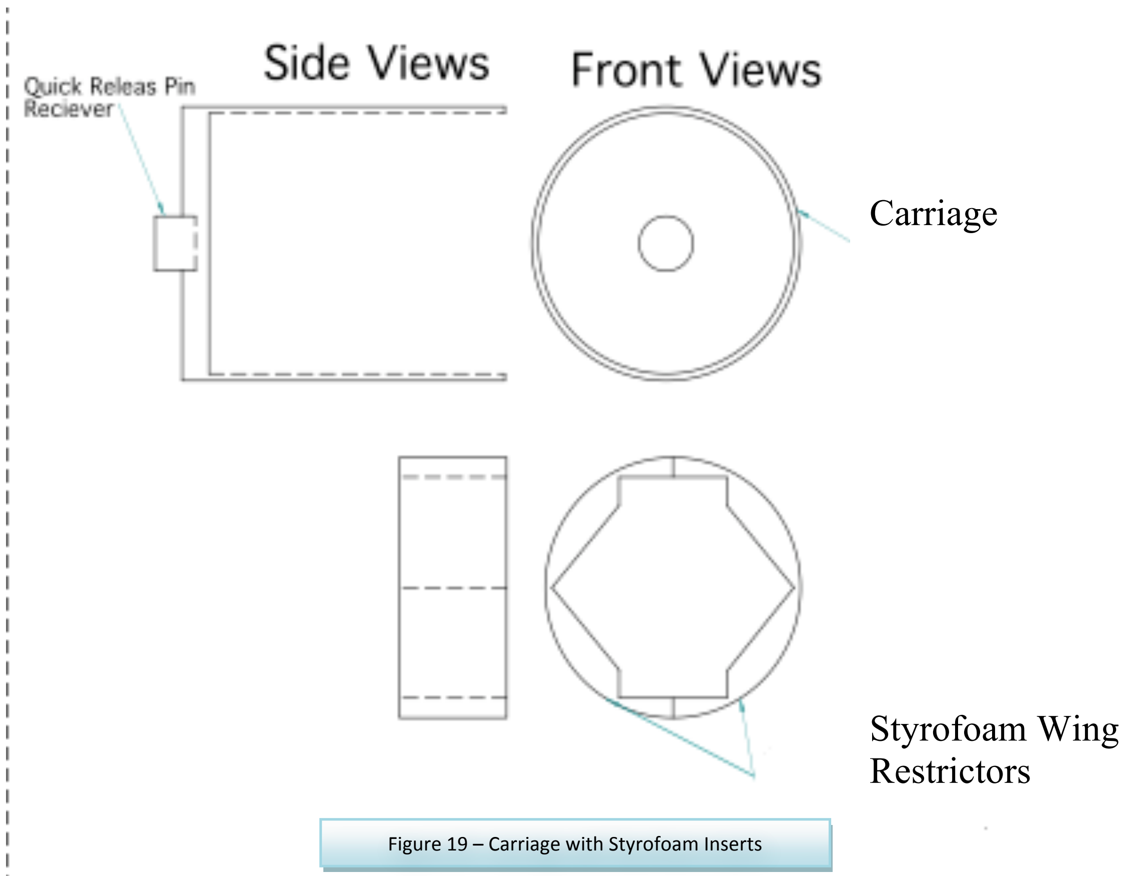


Figure 19 – Carriage with Styrofoam Inserts

Carriage without Insert (Figure 20)**-**

Another design idea for the carriage only has the UAV exiting the barrel during the launch. In this design, there is a solid circular disc backing where the quick release pin would be mounted to the back. . The blow by is minimized using the same principle as the previous design. Two square edged u- brackets would make up the top and bottom of the carriage. These would wrap around the wings to restrict them to their locked position. Attached to the front of the carriage is a hollowed out circular shell that is the same outer dimension as the backing of the carriage. This is to ensure the carriage does not tilt during the launch. A sketch of this design can be seen in the figure below.

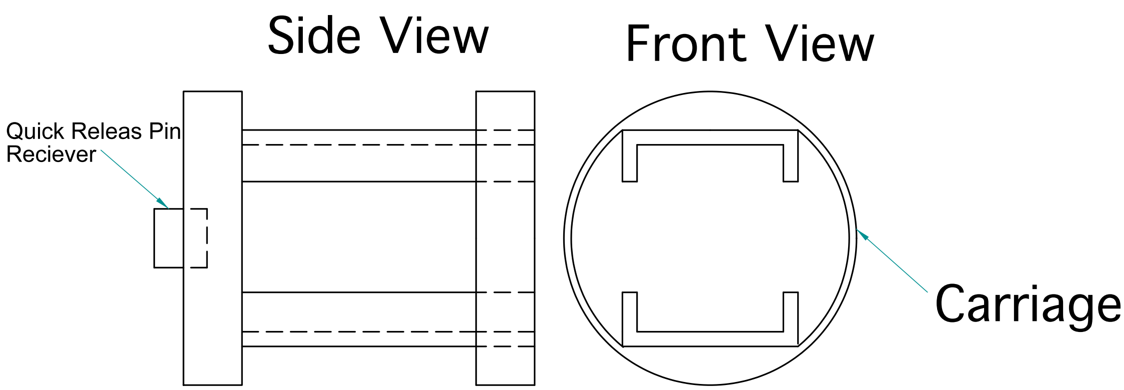


Figure 20 – Carriage without Insert

1.3 Carriage Selection:

The team decided to go with the design that uses Styrofoam inserts. This carriage would minimize blow by slightly better than the other design, because the circular shape spans the entire length of the carriage. Both designs were very similar and satisfy the given requirements, but the Styrofoam inserts allow flexibility in the UAV's configuration. The Styrofoam inserts allow the UAV to be modified in the future without having to redesign the entire carriage. Only the Styrofoam inserts would have to be remolded.

2.Releasing System-

2.1 Component Specifications –

The releasing system is the most intricate part of the design. The system should be able to be activated from a safe distance, reliable, feasible, cost effective, and allow the UAV to reach appropriate speed and acceleration.

2.2 Concept Generation

Tube Shape –

One of the first decisions that had to be decided in each pneumatic design was the geometry of the launch tube. The maximum dimensions for the launch tube were given for square and cylindrical tubes in the project specification. Using these maximum dimensions, the ratios of cross-sectional area to perimeter were calculated. The highest possible ratio was desirable, because it would yield the highest force behind the UAV with least amount of contact with the tube in the form of friction. (Appendix C)

Passive Release –

When considering a valve to act as the releasing system, a potential problem was presented. The compressed air powering the UAV would be choked at the throat of the valve. The pressure behind the valve and the throat area of the valve would then limit the mass flow rate exiting the valve. The UAV would also start to move once the force generated by the mass of compressed air behind the UAV was higher then the weight of the UAV and carriage and the frictional force. To help eliminate these problems, a passive release method would be added between the valve and carriage. A second chamber, called the compression chamber, would also need to be added.

A passive release mechanism, in the sense of this project is one that the user does not have complete control over exactly when the UAV will be launched. The user would, however, initiate the launch process by means of a valve. The valve would open and start to transfer the compressed air from the charge chamber to a compression chamber. Once a certain pressure is reached in the compression chamber, it would create a high enough force to overcome the restraint that the user has put on it to hold it back. This requires the carriage to be pressed against the compression chamber and create an airtight seal that is broken when the restraint is overcome. The entire amount of compressed air from the charge chamber should not be released into the expansion chamber, but be evacuated once the passive release is complete.

Breaking String –

This design implements the use of a string or cord that breaks at a predetermined force. The string would be attached to the back of the carriage as well as the back of the compression chamber. As the pressure builds, the tension in the string increases as a result of the pressure pushing on the carriage. Once the compression chamber would reach its desired pressure, the string would break because of the force generated by this desired pressure. The carriage would then be free to move and begin the launch process. As one can see in figure 21, another string would need to be attached for each launch, because the string breaks during each launch. The team would need to be able to open the back of the launch tube to reattach the string each time because the carriage would prevent access to the back of the launch tube. This adds a bit of complexity to the design that was not expected earlier.

The figure on the next page illustrates the launch process. The string is represented by the blue line in figure 21. The mass of air entering the compression chamber was denoted in red with an arrow showing the direction of flow. Once the desired pressure (P set) was met, the string snaps and the carriage would start to move forward (indicated by the green arrow).

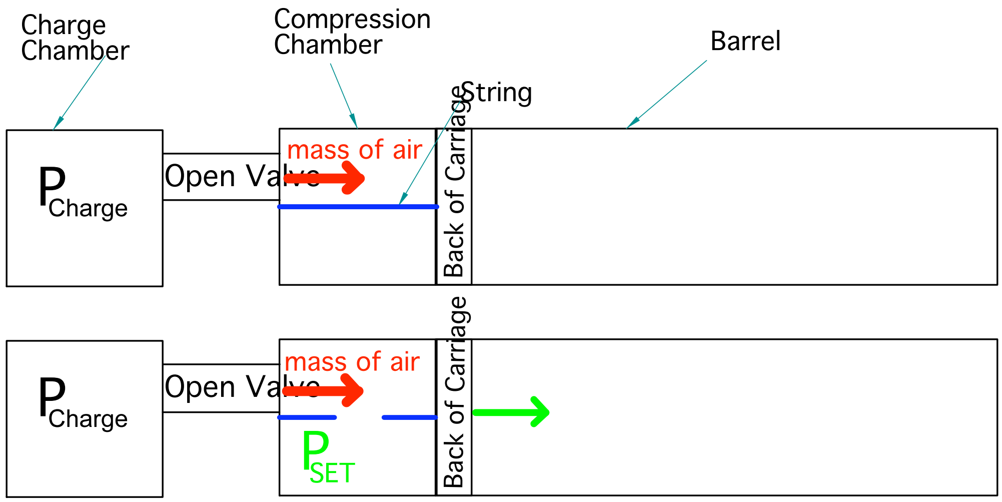


Figure 21 – Breaking String Method

Side Pin –

This design works under the same principles of the string, except that the restraint is put on the front of the carriage. A spring loaded pin, or multiple pins depending on the forces involved, would sit in front of the carriage embedded in the walls of the launch barrel. The pressure would build in the charge tank and the carriage would want to move forward, putting forces on the spring-loaded pins. There are spring-loaded pins that have a wide range of collapsing pressures. Once the pressure has built up to the desired pressure, the forces on the pins will be great enough to overcome the resisting forces and push the pins down into the walls of the barrel. This would then release the UAV so the pressure from the charge chamber would accelerate it through the tube. The advantage of the side pins over the breaking string would be the pins would not need to be replaced after each launch. However, the carriage would need pushed back down the barrel with the same amount of force needed to release the carriage during the launch.

Active Release –

An active release mechanism, in the sense of this project, is one that the user has complete control over when the UAV will be launched. In this design, there is only the reservoir tank and a charge chamber. This concept moves the charge chamber inside the barrel and eliminates the use of an actuated/electronic valve. Since this concept eliminates the need of an actuated valve, it allows the team to make the charge tank larger, which decreases the pressure that the tank will need. Essentially, the user would be able to open a manual valve from the reservoir tank and build the pressure in the charge tank. The back of the carriage will be one side of the charge chamber. Once the desired pressure is reached, the user shuts off the valve to the reservoir and the carriage is actively held in place until the user wants to launch. This concept requires that there be some sort of device that can trigger the launch without the user having to be too close to the launcher. With this addition, the customer won't have to physically touch the launcher in order to launch the UAV.

Cord –

The cord concept is fairly similar to the breaking string in the passive design, except that the cord restrains the carriage and "breaks", in this case, gets released upon the push of a button from a safe distance. The cord would travel on the back of the carriage and be reusable. This design is also similar to the breaking string in the fact that one would need to access the back of the launch tube to reset the cord to be launched again. Pictured below is a simple sketch of the concept. The letter A in the picture represents the connection point between the back of the launch tube. This will be where the release is triggered. The connection between the carriage and the cord is represented by point B. This will be a connection that is not designed to fail. However, after many uses, it might be appropriate to regularly replace the cord, as it might become worn. The carriage itself is represented in Figure 22 as C.

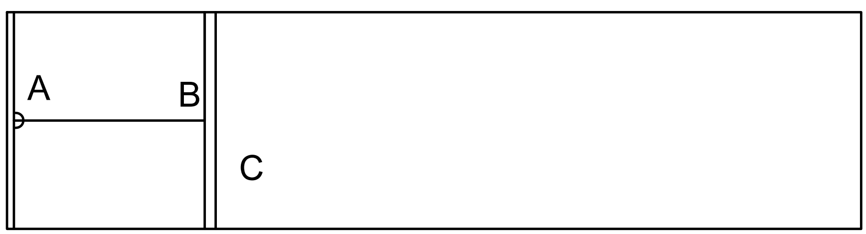


Figure 22 Cord Concept

Push Pin –

The push pin concept implements the use of a spring loaded quick release pin. The button of the pushpin would extrude out of the back of the charge chamber. This is represented by point A in the picture below. The Charge chamber is labeled as point B. The carriage would be locked into the pin via male and female connections; point C. The pressure would build in the charge chamber and create shear stresses on the connection point where the carriage and pin are connected. Since the pin stays attached to the rear of the launch tube, the system will be easily reset by simply loading the UAV into the carriage and pushing it into the tube until the pin connection locks. The carriage is represented in Figure 23 as D.

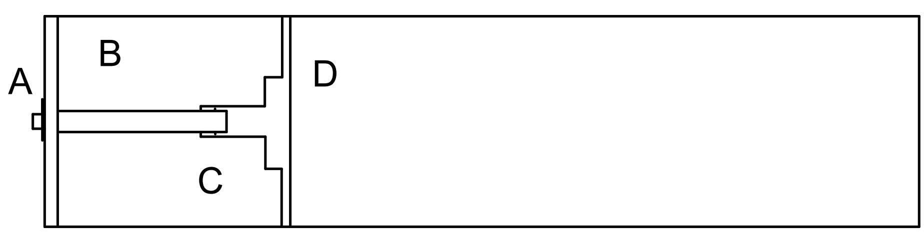


Figure 23 – Push Pin Concept

2.3 Release Method Concept Selection –

All of the concept designs had benefits and as well as downfalls. The team made a concept selection matrix to aid in the decision making process.

Table 5 – Release Method Concept Selection Matrix

	Weight	Cord	Push Pin	String	Side Pin
Reliability	8	6	7	4	4
Feasibility	10	7	9	8	6
Cost	7	5	6	4	5
Weight	8	6	5	7	5
Safety	9	7	8	5	6
Maintenance	7	5	7	7	6
Overall Length	9	8	9	5	6
Ease of use or assembly	8	6	8	7	8
Total	66	50	59	47	46
Weighted Total		75.758	89.394	71.21212	69.69697

The chart pictured above is the concept selection matrix for the releasing system. The team decided on the most important attributes the system should have and determined how the concepts would be rated.

The most reliable designs were the active release designs because the user would always know when the UAV was to be launched. In the passive designs, the user would initiate the launch, but there would be a short delay before the UAV "broke" away from its restraints. The reason the Push Pin design scored higher in this category than the cord design was that the cord was more prone to failure than the pin.

The next attribute, the team decided, was the most important of the eight. Feasibility was decided to be the most important because the more simple and feasible it is, the fewer problems the team will run into in the constructing and testing process. Not every design is perfect, but the Push Pin design scored the highest in this category as well. With all of the other designs, there would have to be a way to open the back of the launch tube in order to reset the releasing system each time. This adds complexity because the team has to have an airtight seal to achieve the most efficient results. All of the designs can be done, but require a lot of intricacies that require a lot more attention compared to the pin idea that is much more straight forward.

As far as cost is concerned, the string design proved to be the most expensive design. The team felt that because it requires a string to be broken, and replaced, each time, it could get costly over the long term. Also, both passive designs incorporate at sprinkler valve that costs upwards of $35 and a way of opening the back of the launch tube, which will add money as well. The side pin design also requires a few spring-loaded pins as opposed to the pushpin that has one big spring. The cord would have to be replaced after it has been worn by repeated usage, so the team decided that the most cost effective design was the Push Pin design.

The only category that the pushpin design did not score the highest on was weight. The pin would be made of a dense metal that is able to withstand a great amount of shear stress. This would cause the weight to increase depending on the metal used. However, it would lose weight due to the fact that a sprinkler valve is not needed in the design. But, compared to the cord, which would be some sort of high-tension cable, it would be considerably heavier. The string design needs a valve to operate, but other than that, the fact that it would be made out of a composite material would make the releasing system very light.

Safety is always a very important concern when designing components. Due to the fact that the active designs give the user the ability to determine exactly when the launch will take place, they are safer. When looking at the active designs, one would compare the cord to the pin. The pin would have a higher factor of safety being as it would be made from metal while the cord is made of composite. If the side pins were to somehow get pushed down at different times, the carriage might get wedged in the tube and would become a high pressure vessel with no way of releasing the pressure or freeing the carriage.

The next category to consider would be maintenance. The term maintenance, in this application, refers to how much would the sponsor have to service the system (i.e. replace parts, clean components, etc.). It has already been established above that the string would have to be replaced each time, but it simply has less parts. The string design, therefore, has less maintenance. Also mentioned above, the cord would need to be periodically replaced due to repeated usage. The springs in all of the side pins in the side pin design would need to be replaced eventually due to normal wear and tear. The string design and the pushpin design scored the best in this category.

Due to certain specifications from the customer, the length of the overall design is restricted to 36 inches. Saving every inch counts and it would be beneficial if length of the releasing system was reduced so that length could be added to the barrel length. Both of the passive release designs require the use of the sprinkler valve before even considering the release system itself. This puts the passive designs at an extreme disadvantage in this category. The Active designs would not have a sprinkler valve but would require a manual valve. This would save anywhere from 2 to 3 inches initially. The cord design calls for a way to open the back of the launch tube to reattach the cord to the release mechanism. This would add a bit of length to the system, but not a drastic amount. The pin does not require the user to open the back of the launch tube to reset, but simply push the carriage's receiver onto the pin connection while the button of the pin is pressed.

The last category to consider was ease of use and ease of assembly in the field. The team would like it to be very simple to operate. Too many intricate steps could prove to be dangerous if one is forgotten or done incorrectly. Ideally, the launcher would be simple to assemble in the field so that the customer could quickly launch the UAV and move to another location. As mentioned above, the passive designs need to be reloaded by opening up the back of the launch tube and the string design in particular needs to be reassembled. The cord design needs to be reloaded and reattached to the releasing mechanism as well. The only design that had a simple reloading process and operation procedures is the pushpin design.

Overall, the pushpin design was the best design choice. It scored an 89% on the desired attributes determined by the design team. The cored was second, followed by the string and then the side pin designs. Since the design team feels that the releasing system is the most important component of the entire launch system, it will be the foundation for the entire launch system. Thus, it will influence the concept designs of the rest of the components.

After calling numerous companies in search of an adequate pin, Jergens provided the team with sufficient information and product specifications. This allowed the team to select an appropriate pin and receiver for connecting the pin to the carriage. The pressure that the carriage will experience just before launch is calculated to be approximately 2430 Newtons. The pin selected would be able to withstand 4893 Newtons of locking element tensile strength. This would give a factor of safety of 2.008. The pin is made from Stainless Steel. Pictured Below.

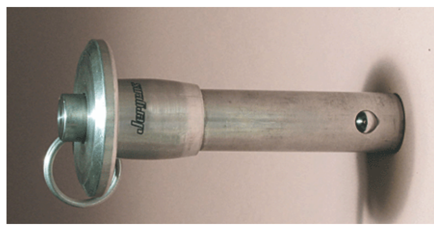


Figure 24 – Push Pin

The pin selected has a push button release mechanism that would need to be pressed in order to release the load it is experiencing (Figure 24). After talking with a Jergens representative, it was determined that the force required to press the release button, even when the pin is loaded with a large force, would be minimal. After some research and discussion, the team chose to use a hydraulic trigger release that would be fastened to the back of the launch tube. It would be placed over or to the side of the push button. The trigger release is a system that contains an incompressible fluid that transfers the force you apply through the system and operates the push button from a safe distance. If the team has to mount the hydraulic trigger release off center, it comes with an "L" shaped bar that can be modified for the proper application.

3.Airtight Seal Component-

3.1 Component Specifications –

Obtaining an airtight seal was one of the most important considerations in this design, without it, more pressure would be needed. This would then affect how much pressure would be needed in the reservoir tank, decreasing the factors of safety and increasing the overall weight. All in all, it is the most efficient way of transferring the potential energy of the stored compressed air to kinetic energy. The team considered a few options: a fixed rubber O-ring near the bottom of the barrel, a moving O-ring on the carriage itself, and a flap that creates an airtight seal.

3.2 Concept Generation –

Moving O-ring-

When the team initially considered launching the UAV with an airtight seal, air blow-by became an issue. Blow-by is when the air escapes the tube by blowing around the object that is in the tube instead of pushing the object out of the tube. In order to prevent blow-by, the idea was brought up to place an o-ring around the carriage (Figure 25). In theory, this o-ring would allow pressure to build behind it initially, as the pressure chamber became charged. When launched, the o-ring would then efficiently limit air blow-by until the UAV was launched. As the idea was developed, critical problems arose. In order to maintain an airtight seal, the o-ring would be held very tightly against the side of the barrel. When the carriage containing the o-ring was released to launch, the o-ring would cause an extreme amount of friction to the inside of the barrel. This would increase the initial launch pressure greatly, which would then require an even greater airtight seal. The idea was fundamentally flawed, so it was disregarded.

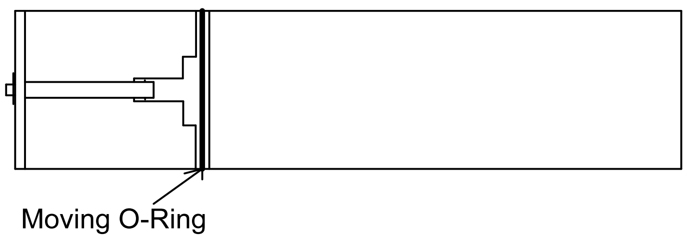


Figure 25 – Moving O-Ring Concept

Flap-

The next idea considered to obtain an airtight seal was a rubber flap-type device. This rubber flap would be fitted around the carriage, with a blade similar to a rubber squeegee. This angled surface would initially rest lightly against the inner surface of the barrel. As pressure built up inside the chamber, the flap would be forced against the sides of the barrel, forming an airtight seal. Finally, when the carriage was released, the initial air pressure forming an airtight seal would loosen, reducing the friction between the carriage and the barrel. This idea was aimed at reducing the friction dilemma in the moving o-ring concept. There were a few issues with this concept also. First, there is a chance that in the initial pressurizing of the pressure chamber, air would simply rush by the flap and never pressurize. Although the friction is reduced with this design, it is still significant as the rubber flap is still forced to rub against the inside of the barrel. Also, a secure method of attaching the rubber flap to the carriage would need to be devised. Due to the complications of this design, the team continued to search.

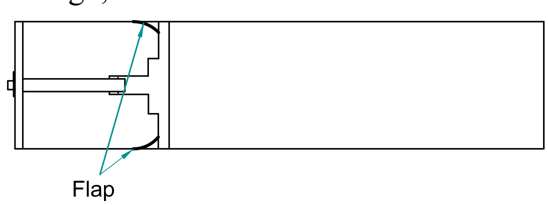


Figure 26 – Flap Concept

Fixed O-Ring-

When considering the nature of an airtight seal at a relatively high pressure, the team realized that by nature, it would be extremely difficult to create a method of maintaining an airtight seal while allowing the object to move. Out of this dilemma, the fixed o-ring concept emerged (Figure 27). A rubber o-ring would sit against a lip inside the pressure chamber. In order to create an airtight seal initially, the bottom of the carriage would be forced backwards against the fixed o-ring. When the carriage is released for launch, the seal is broken, and the carriage is allowed to slide smoothly against the barrel. To prevent excessive blow-by, metal or felt rings will be used to provide enough of a seal to launch successfully.

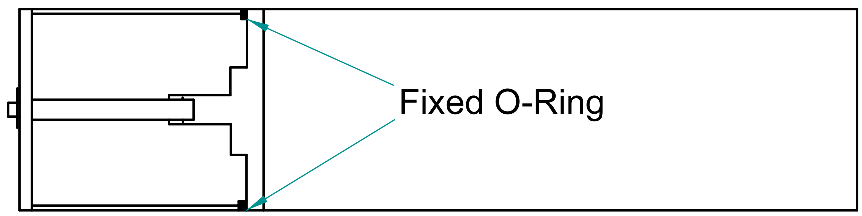


Figure 27 – Fixed O-Ring Concept

3.3 Concept Selection –

The team decided to design for a fixed o-ring that sits on a lip near the bottom of the barrel. The O-ring would be pinched between the carriage and the lip, forming an airtight seal initially. Once the quick-release pin releases the carriage, the pressurized chamber will propel the UAV. The main flaw with this design is that the carriage will allow some air to blow by. With tighter tolerances, the pressure loss will be minimized.

Once the team had decided on the fixed O-ring concept, a product of proper dimensions needed to be found. McMaster-Carr was the resource used in locating this part. The o-ring selected has an outer diameter of 4 7/8 inches and an inner diameter of 4 ¾ inches (Figure 28). Therefore, it had a thickness of 1/16 inch. McMaster offered this size O-ring in different shapes; round, square, or quad. Since the lip is not rounded, but squared, it would be more appropriate to use a square O-ring. A sample is pictured below.

Figure 28 – O-Ring

4.Carriage Recovery System-

4.1 Component Specifications –

The customer had specified that they did not want anything to fly out of the barrel of the launcher except the UAV. Since the team decided that there was a need for a carriage, there is also a need to design a way of stopping the carriage from fully traveling out of the barrel of the launcher. The system has to be extremely safe, because if it were to fail, it would be sending an unexpected projectile out of the tube at a high speed. The design also has to address the fact that the carriage must not be damaged in the process of stopping it.

4.2 Concept Generation –

Tethered Line –

A fairly lightweight, non-elastic, filament will be attached to rear center of the launch carriage as well as the inner, rear center of the launch tube itself using Al clamps. The filament will basically have sufficient slack to allow the carriage to reach its maximum travel distance yet preventing it from exiting the tube itself. There are several pros to this design including a minimum amount of moving parts, a simple, cheap, effective design. One obvious downfall to this design is the severe stresses exerted on the filament itself. If used, the carriage will accelerate from rest to an estimated velocity of 60ft/sec then back to rest over a distance of only nearly 18 inches in an estimated .05sec of travel time. With forces of this nature, an inappropriate filament and poor connection pieces could suffer major damage and may fail over a short period of time. This is why the team must make sure that the filament can withstand the necessary forces. One immediate solution that came to mind when trying to resolve the stress on the filament was to implement a spring that would elongate when force is applied. It was also mentioned that, if an appropriate filament was found that was fairly inexpensive, it could always be replaced when it has reached its life cycle.

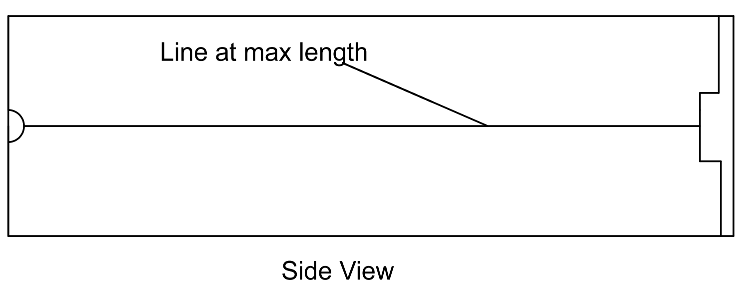


Figure 29 – Tethered Line Concept

Dampening System –

A system of rather lightweight, heavy duty, yet compressible springs will serve as a dampening system to decelerate the launch carriage near the end of the launch tube. The spring system consists of a couple springs in series capable of decelerating the carriage at its furthest distance of travel while dampening of the impact simultaneously.

With this design, the team derived a few pros and cons alike. On a positive note, the springs could theoretically increase the time of impact, therefore decreasing the amount of energy absorbed into the UAV and or carriage upon impact. Even though the impact time is crucial, the most apparent drawback is the effect on available launch distance. Implementing a spring dampening system means that the carriage will not be able to travel a maximum of eighteen inches, meaning less distance to accelerate to the necessary 60ft/sec exit velocity. If the length of the barrel was increased to counteract the length lost to the dampening systems; more important components would have to be compromised.

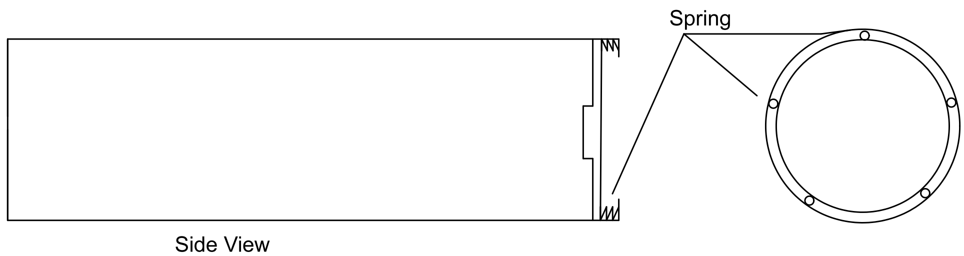


Figure 30 – Dampening System Concept

Rigid Cylinder Lip –

Considerably the most simple design concept of all of the design components; it can be described as a thin, yet durable, piece of material that is placed strategically at the end of the barrel. The lip would be shaped so that the UAV would be the only thing that exits the barrel. This will exert a great deal of force on the carriage system, the lip, and possibly the UAV upon impact. A few ways to decrease the force are to use a carriage of lightweight material, have the impact surface made of a compressible material to absorb the impact, and ensure that the UAV will be deployed on impact each and every time. If the UAV did not come out immediately upon impact, it could possibly suffer damages due to high deceleration. Without such alterations and assumptions, the design is sure to fail and cause severe damage to the launcher.

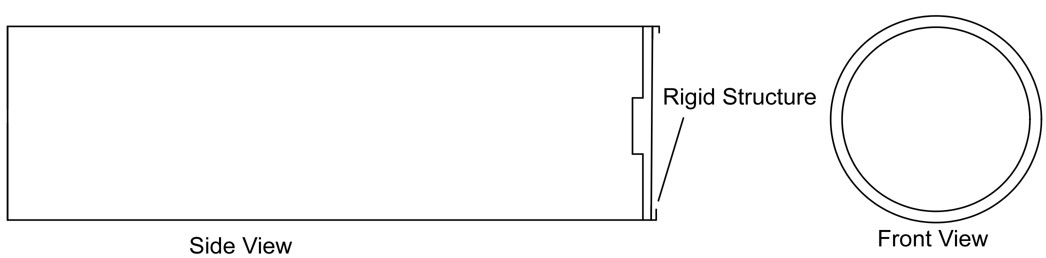


Figure 31 – Rigid Lip Cylinder Concept

4.3 Concept Selection –

Table 6 - Stopping Mechanism Concepts Pros and Cons

Concepts	Pros	Cons
Tethered	Lightweight less moving parts simple and cheap	Part under severe stress
Dampening System	Increases the impact time, and decreases impulse force	Decrease launch distance
Rigid Cylinder Lip	Simple	Severe impulse force on all components high stress design

Due to weight restrictions, the dampening system and the rigid lip cylinder were ruled out (Table 6). The cable was also a more simple design and less costly than the other two designs. The rigid cylinder lip has the potential to inflict damage on both the carriage and itself. Once the team decided to use the cable, one needed to be found that would satisfy all of the requirements.

The team used McMaster-Carr as a reference when selecting the stopping cable. The first specification that the cable must satisfy is the 661 lbs of impulse force (See Appendix C for calculations) that it would experience. There were many different nylon coated wire rope that satisfied the requirement. The thickness of the wire rope was the second most important attribute, seeing as they were all relatively cheap. The wire rope that was 3/16 inches thick and was already certified Mil-Spec was the obvious choice. The breaking force of the wire is 1750 lbs of force.

When the team decided on using a cable/wire to stop the carriage, the problem became fastening the cable to the carriage and back of the charge chamber. As the team researched eyebolts and other ways of connecting the cables to the carriage and tube, wire rope connectors (wire anchors) came to light. These connectors take a free end of wire, insert it into a sleeve, apply a plug and lock it into place (Figure 32). Now, one end is a cable and the other end is threaded so it has the ability to screw it in to the carriage or tube. Concerned with the forces that this connection would be under, McMaster was contacted to ensure it would not break. The team was informed that the connection, when correctly assembled, would be as strong as the wire it was connected to. Pictures below.

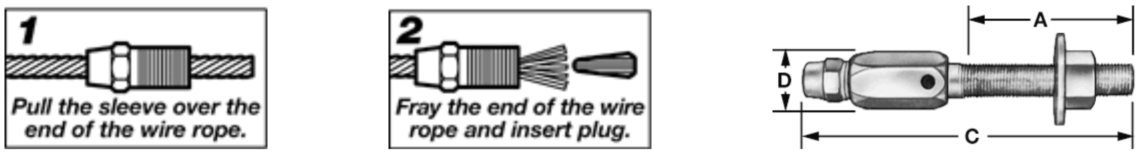


Figure 32 – Wire Anchor for Stopping Mechanism

5.Material/Part Selection -

5.1 Component Specifications –

In order to meet all of the team's project specifications, the team needs to determine which materials are most appropriate for each component of the entire system. The material should be fairly available, cost effective, and provide an appropriate about of safety without sacrificing weight. It should also be able to be machined, cast, or have other accurate means of being constructed.

5.2 Material/Miscellaneous Part Selection –

Reservoir Tank –

The team made a fairly easy decision when choosing how to hold a large amount of compressed air within a small amount of space. After initial research was complete, the team looked deeper into compressed air tanks. The paintball industry has provided consumers with a large selection of compressed air tanks and accessories. The team found the lightest tank that was on the market that met the specified dimensions and pressure ratings. The nitrogen tank is made by Guerrilla Air and weighs in at 1.8lbs.

Washers/Nuts –

Due to the nature of the project, having an airtight seal is essential to achieving maximum efficiency. The pin and the wire connector are going to be breaching the seal of the charge chamber and will need to have an airtight seal to prevent leaks. McMaster-Carr provided the team with many different ways of ensuring an airtight seal. The washers that were chose are specially made for pressure sealing. It consists of a molded Nitrile sealing element mechanically locked into a zinc plated steal washer. They come in many different sizes so that they can be applied to both the pin and the wire connector. The nuts that will be used to decrease the probability of leaks come in similar sizes and also incorporate a rubber and metal combination. It uses an O-ring to seal the hole that the pin or wire connector is threaded through. The team will be working with pressures less than 100 pounds per square inch and the O-ring is rated for 6000 pounds per square inch.

High Pressure Braided Line –

The high pressure braided line was needed to transfer the air from the tank regulator to the charge chamber. It needed to be flexible enough so that it could be bent into a shape that would allow the team to easily select where it would fit onto the back of the charge chamber. It could not be placed directly onto middle of the back of the charge tank due to the fact that the push pin was going to be located in the center. The air, since it would be loaded into the charge chamber slowly, could be loaded off center. The line is rated for 1000 psi, which is more than will be loaded into the reservoir tank.

Protection Rods –

The protection rods were needed to protect the UAV launcher components behind the charge chamber. The protector rods also gave these components support and restrain their movement. Their primary function is to protect the launcher components against the impact force caused by the launch process. The team decided to construct three rods to surround the reservoir tank, regulator, braided lines, and trigger mechanism. The components will be zip tied to the rods to give the user the ability to detach all of the components. The rods will be 3/8" diameter aluminum rods. The team selected aluminum as the material because it will be able to support the weight of the reservoir tank and the other components while remaining relatively light. Also, aluminum has the ability to be welded together, which gives more variability if the team decides to place the rods in alternative places.

Tank Regulator –

Since the team had decided to use a reservoir tank to feed air pressure into a subsidiary tank, there needed to be a way of regulating the pressure that was in the reservoir tank. There were a few options on the market, but virtually none that met the requirements. The regulators that dealt with high tank pressure and could reduce the outgoing pressure to an accurate, workable amount were too heavy or bulky for the application. The pressure regulators that were small, light, did not have the right amount of accuracy when regulating the air pressure. There were two options as far as where to place the regulator; in line with the reservoir tank and tube or at the mouth of the tank. The team, through professional product advice, chose the tank regulator that replaces the existing tank regulator. The particular model chosen has an adjustable range of 0-1000 psi.

Launch Tube Material –

In an effort to reduce the weight of the overall design, carbon fiber was chosen as the material to be used for the launch tube. It has mechanical properties that compare to aluminum, but with two thirds of the weight. Many companies did not have the tools or machines for the dimensions the team was looking for. Because of this, some changes had to be made to the inner and outer diameters of the launch tube. Once these changes were made, a quote was given by Nim-Cor. They specialize in carbon fiber tube fabrication. It was explained to the team that carbon fiber, unless it is molded, cannot be woven onto flat surfaces. Carbon fiber can only be woven onto convex surfaces and would not be able to be woven in a way that it closes the back of the tube. In order to achieve this, an aluminum mold would have to be placed into the tube and bonded with the carbon fiber with a space grade adhesive. This would give the end of the tube a convex shape on which they could weave the carbon fiber. This adds weight and complexity due to the curve of the aluminum where the pin would be inserted. The team opted to mold an aluminum piece with a flat back and adhere it to the inside of the carbon fiber tube. This would mean that there would not be carbon fiber on all surfaces of the tube, but the aluminum backing would give a better working surface and help increase the safety on the charge chamber.

Carriage Material –

The carriage will be under both high impact force and high pressure forces. The weight of the carriage is crucial to the overall weight of the launcher as well, so the less it weighs without sacrificing performance; the better. Also, if the carriage is lighter, less pressure will have to be loaded into the charge chamber. Considering these specifications, a mixture of materials was chosen. The back of the carriage will experience the bulk of the forces, and will be made of aluminum. In order to reduce weight, the aluminum will be bonded to the inside of a carbon fiber tube, similar to the design for the launch tube. Aluminum is a very workable metal and it will be easier to drill and thread the appropriate holes for the pin receiver and threaded wire connectors. With Styrofoam inserts holding the wings in place, the UAV will sit in the carbon fiber tube upon being launched.

Fall Final Design Review

In conclusion, the primary goal was to design a new, safe, effective and efficient system that could repeatedly launch a UAV (provided by Eglin Air Force Base) into flight. This was accomplished by implementing a pneumatic, remotely triggered, launch system with a custom charge chamber as the primary propulsion mechanism. In developing an optimal solution for the launcher design, the team performed sufficient research on current propulsion methods, compressed gas flow and release methods, actuation techniques, and material properties. With quite an extensive understanding of the necessary background and system requirements, the team brainstormed multiple creative ideas to finally generate five feasible conceptual designs. After further analysis, the team chose the most feasible concept and decided to implement multiple features such as a valve and disk backing to optimize the design. Fortunately the team was able to take a trip to Eglin Air Force Base to assess the operating conditions and get a better understanding of the real-time application. After consulting with the customer, the team saw a need to make alterations to the conceptual design and increase the work rate to better meet the customer's need. Since mid November, the team has made drastic progress. After further analysis and consulting with the advisor a few flaws in the initial calculations were found. Those issues have been corrected and the final design mathematically simulates a very powerful system that is well capable of exceeding the customer's expectations.

Table 7 shows the factors of safety certain components of the final design possessed. These safety factors were able to be determined once the dimensions and material selection were finalized. See Appendix C for exact calculations. The factor of safety for the hoop stress in the charge chamber will be even higher because the aluminum charge chamber will be wrapped in aluminum.

Table 7 - Mechanism Factors of Safety

Application	Factors of Safety
Stopping Mechanism Fracture	1.667
Stopping Mechanism Tear Out	4.407
Release Mechanism Tear Out	5.602
Carriage Hoop Stress	50.712+

Figure 32 below represents the net pressure distribution acting on the UAV and carriage during a launch. This is for an exit velocity of 19.812 m/s and a forty-five degree launch angle. The initial pressure acting on the UAV and carriage was .2461 MPa. The pressure acting on UA and carriage at the end of the launch process was 30.02kPa

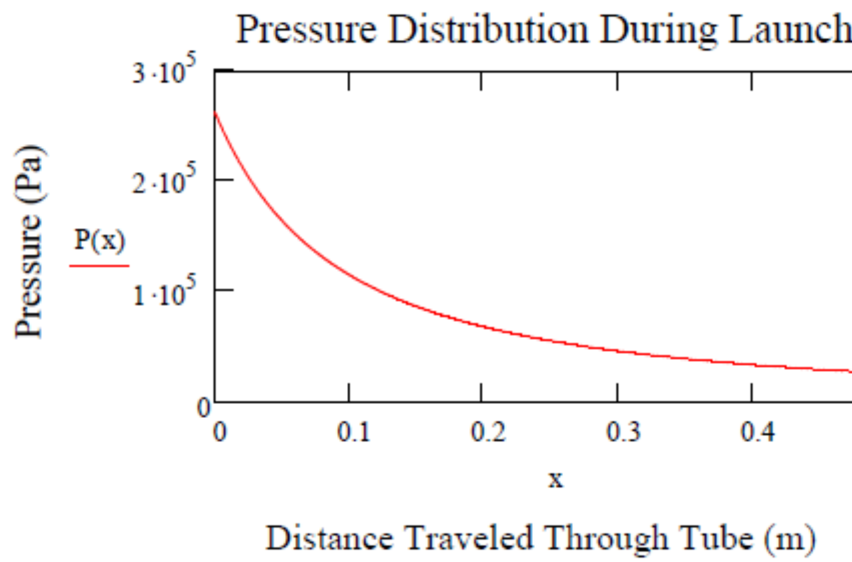


Figure 32 – Pressure Distribution During Launch

Once the pressure was determined, the instantaneous Gs the UAV and carriage experience during the launch process were calculated. This is for an exit velocity of 19.812 m/s, a forty-five degree launch angle, and an initial pressure of .2461 MPa. The instantaneous acceleration ranged from 150.028 down to only 17.099 Gs during the launch. The instantaneous acceleration in which the UAV and carriage will experience has been simulated and the data can be seen below in Figure 33.

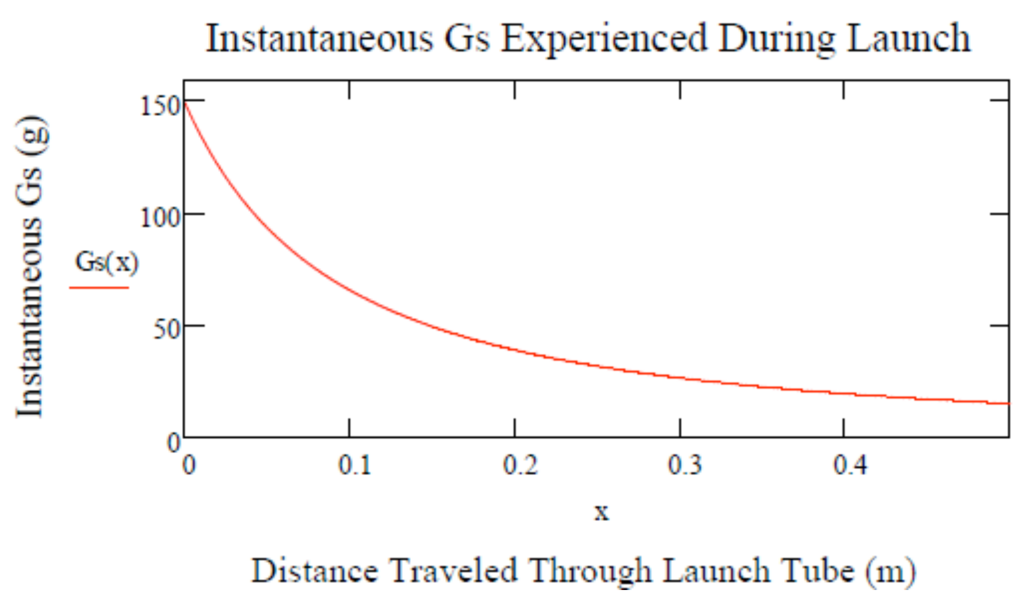


Figure 33 – Instantaneous Gs Experienced During Launch

The figure 34 below shows the exit velocity as a function of the initial pressure the charge chamber was loaded to. The theoretical calculations show that the UAV can reach a velocity of up to 41.431 m/s before experiencing a maximum instantaneous acceleration nearing

600Gs. This would mean that the initial pressure within the charge chamber should be loaded to be 1.0546 MPa.

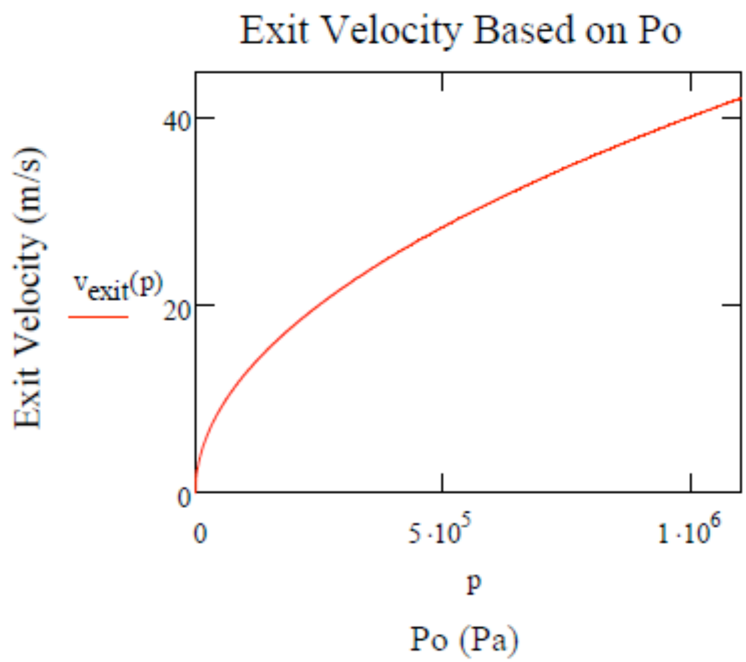


Figure 34 – Exit Velocity Based on Po

At this point, the UAV launcher team has developed a final design that meets over 95% of the customer's requirements. Even though the team put much thought and analysis into meeting each and every design specification, the weight issue was unable to be addressed safely and effectively therefore a requisition for a larger weight restriction has been given and is currently under review by the customer (Appendix H). The original weight constraint was officially discussed between the team and the customer in early September 2008 as both parties realized that the constraint was quite unrealistic. The final design consists of one high pressure, inline system located in the rear of a lightweight launch tube in which the UAV will be located during storage, launch, and/or transport. System specifications, concepts, and material selection were all developed and analyzed for each component to find the most proficient and optimal design possible. As a result of this design, the team is quite sure that Eglin Air Force Base will have much better and efficient prototype testing capabilities. Due to its very sleek style and unmated capabilities, the compact pneumatic UAV launch system will allow ground forces and/or training personnel to be exposed to much less danger and physical stress as he or she is able to transport and effectively deploy a reconnaissance unmanned aerial vehicle into a "hot zone". The team looks forward to having this design used in training and or actual ground force interactions at some time soon.

Spring Update and Introduction

Within the spring semester of 2009, the team will be manufacturing a test prototype based on the final design from fall 2008. The objective of the test prototype will be to confirm the theories and concepts instilled in the design. Once the prototype is capable of being tested the data will be recorded and analyzed. Once testing is complete, the team will have a better understanding of the processes that occur during launch. Hopefully, the test results will confirm the theoretical calculations and assumptions made in the fall. If they do not, there will be an opportunity to adjust the calculations to better predict at what pressures the UAV would achieve target velocity. Based on the new calculations, the team can design an optimized final design that will meet the project specifications. While the funds might not be present to actually manufacture the optimized final design, it will be the next step in the design process. This is clearly understood and has been approved by the customer.

Prototype Design Changes

There are many different reasons for changing designs, some of which include the failure of parts, the availability of certain materials, and to simply improve the design. The changes that have been made to the final design of the UAV launcher are significant, but only improve the overall design.

The first change that was made to the final design was material selection. After contacting John Ritchie, of Nim-Cor, the team came to the conclusion that using a carbon fiber/aluminum tube and carriage would be too costly. Since the team already had plans for the barrel and carriage of the testing prototype to be made out of acrylic, it was decided that this would replace both the carbon fiber/aluminum barrel and carbon fiber carriage. The advantages of using acrylic would be that it is much more inexpensive, the ability to machine parts in the machine shop at the College of Engineering, and it is comparable in weight to the carbon fiber/aluminum tube design.

The second change that was made to the final design hinged on the selection of the acrylic tube as a replacement for the carbon fiber tube. The earlier design for the test prototype included an aluminum disc that plugged one end of the tube, to provide the backing and surface to mount the regulator, stopping mechanism, quick release pin, and Schrader valve. Also, the carriage was to have a similar design, where the aluminum disc provided the backing and closed off one end of the carriage. The aluminum disc was to be held in place using epoxy. Considering we would be pressurizing the tank to somewhere in the range of 60psi and the aluminum disc would have a surface area of approximately 25 square inches; the approximate force on the disc would be 1500lbs. The epoxy would not have been strong enough to withstand that great of a force. The team decided to use one inch thick acrylic to create plugs at the end of the barrel. This design would increase surface area for the chemical bonding agent to work while giving a work-able, flush surface to drill holes where needed.

The next significant design change was to the quick release pin and receiver. After a brief testing period to confirm if the charge chamber would hold a considerable amount of pressure without leaking, it was apparent that a larger pin was needed. During testing, the contact point between the pin and receiver became deformed due to the high amount of stress on the parts. There were only two contact points between the pin and receiver in the original design (Figure 35 & 36). The team contacted a company called Big Sky Precision to manufacture a custom pin that had four points of contact and a larger contact area. The custom pin was also larger in diameter, by an eighth of an inch.

Figure 35 – Contact Points of Quick Release Push Pin

Following the changes mentioned above, the application of silicone II was needed. During pressurization tests, there were small leaks found in many of the connection points at the back of the tube. A significant leak was found at the point where the pin is press fit into the back of the acrylic tube. In order to fix this, a layer of silicone along with a rubber washer was

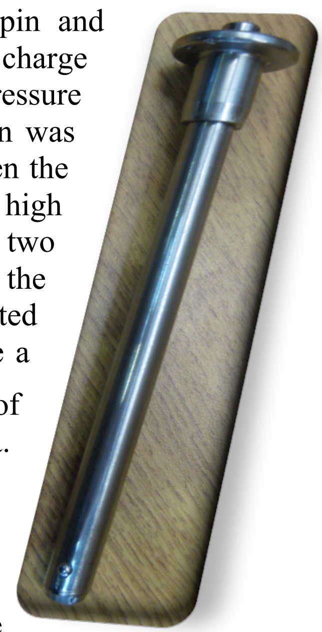


Figure 36 – Quick Release Push Pin

added and allowed to dry over night. This fixed the major leak in the system and testing resumed.

During later testing, the team was again faced with a leaking problem. After a decent amount of wear and tear, the quick release pin, which is hollow, had air leaking through the button. Air was escaping through the bottom of the pin, up through the shaft and out of the space around the button while the pin was in the receiver (Figure 37). There were only two ways that air could get to the openings at the bottom of the pin; through the threads of the receiver and where the shaft of the pin meets the receiver. Teflon tape was used to seal the threads of the receiver so that no air could pass. This quickly reduced the amount of air leaking out of the system. Next, a 5/8" diameter rubber tube was slid over the shaft of the pin. The tube was a 1/8 of an inch thick and slightly longer than the quick release pin. This setup can slightly be seen from the rear view in Figure 36. Once the pin was forced into the receiver, the receiver compressed the tube, creating a seal around the section where the pin enters the receiver.

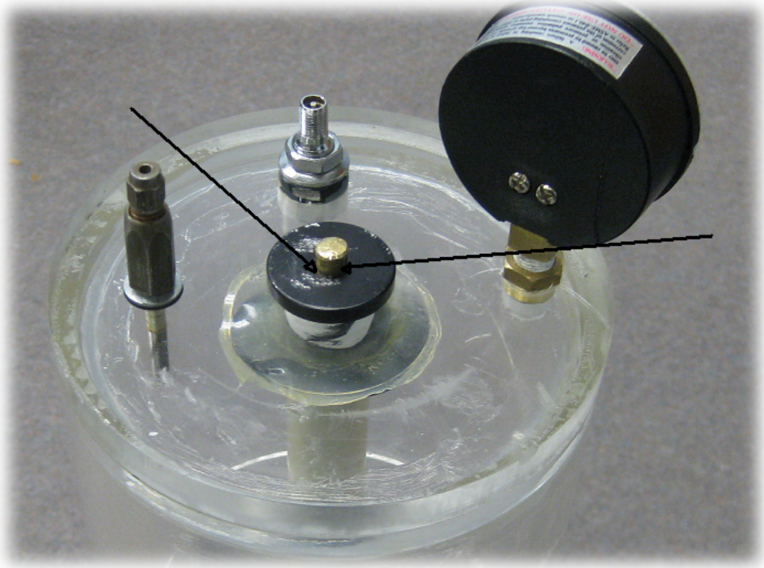


Figure 37 – Rear Angle View of Launcher

Another significant change made to the final design of the UAV launcher was the release mechanism. The earlier design implemented a hydraulic pushbutton that the operator could activate from a safe distance. As testing continued, it was apparent that it would take a great deal of force to trigger the quick release button, due to all of force acting on it. The team used rotational springs on a shaft to create a small spring-loaded, hammer-like, firing mechanism (Figure 38). The hammer mechanism has to be reset manually and is released by pulling a string that is attached to a ring that restrains the hammer in tension. Once the string is pulled, the hammer is released and the rotational springs whip the hammer down onto the button of the quick release pin. This impulse force of the hammer mechanism is great enough to induce a launch at 60psi.

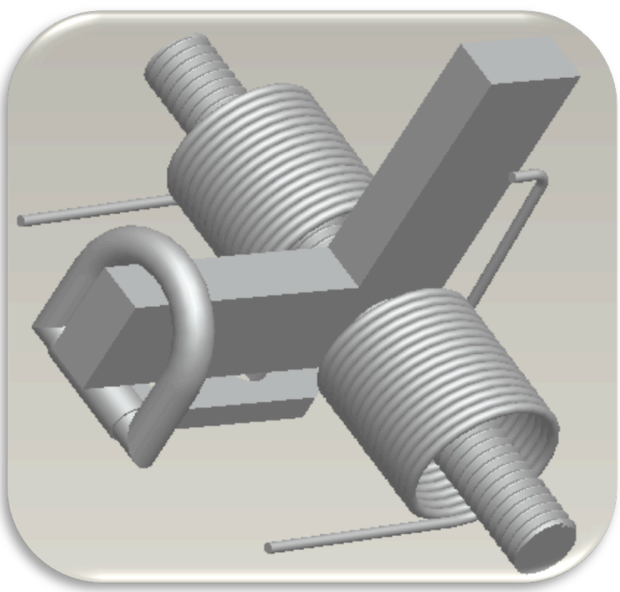


Figure 38 – Firing Mechanism

The last change made to the final design affects the way the air delivery system is protected. In the initial final design, the team had decided on three aluminum rods that would be secured to the back of the tube to encompass the air system and keep it stationary. This was a concern because the air system deals with high-pressure air and any damage to the components can result in system failure or personal injury. The rods were replaced with a new protective design and an acrylic sleeve the same diameter as the launch tube. The tube surrounds the entire air system and the hammer mechanism. There are notches cut out of the tube to enable the user to access all of the components. It was bonded to the back of the launch tube with weld on. The tube protects the fragile components from impact when being dropped or recoil when the UAV is launched.

Prototype Manufacturing

To keep costs as low as possible, the team decided to manufacture the final design themselves. The manufacturing was conducted in the FAMU-FSU College of Engineering's Mechanical Engineering machine shop under the supervision of Mr. Keith Larson. A #8 threaded bar was cut down to three inches long using a chop saw. This bar would be used as the center axis for the trigger mechanism.

Figure 39 – Working in Machine Shop on Sand Belt

The tubes were cut using a hacksaw to cut halfway through the tube, and then finished on the band saw. The cut edge was then sanded down until it was level (Figure 39). The acrylic tubing used for the launch barrel was originally thirty-six inches long, with an inner diameter of five and a half inches and an inner diameter of five inches. The tube was then cut down to twenty-five inches long. The carriage side tubing was cut down to four and a half inches in length. This tubing had an inner diameter of four and a half inches, and an outer diameter of five inches. Tubing that created the inner lip for the launch barrel was cut down to five inches long. The lip tubing had an outer diameter of five inches and an inner diameter of 4.75 inches.

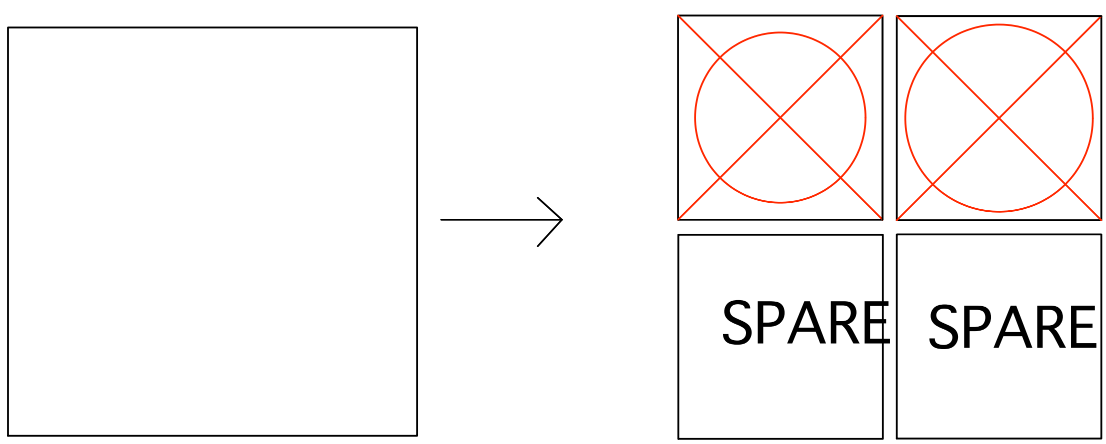


Figure 40– Backing of Carriage and Barrel Manufacture

Figure 40 portrays how the backings of the carriage and launch barrel were created out of a 1'x1'x1" acrylic sheet. First, the sheet was cut into four six-inch square pieces. Diagonal lines were drawn across the corners of two of the squares to find the centers. A compass was used to draw the approximate diameters of each backing from the center. These approximate diameters were five inches for the carriage backing, and five and a half inches for the launch barrel backing. These lines are shown in red in Figure 40. The circles were then roughly cut out of the acrylic squares using a band saw. The circles then had a holes drilled through their centers so they can be fit on a lathe.

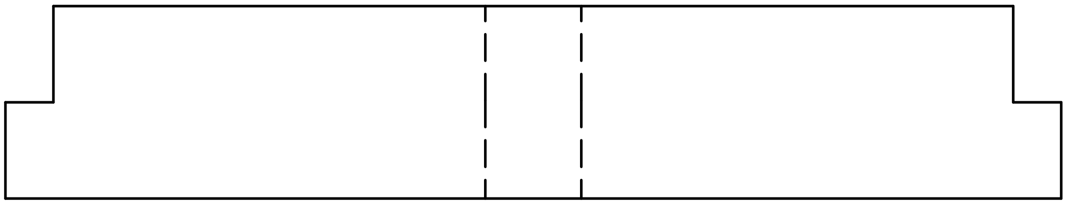


Figure 41 – Side View of End Cap/Backing

Once on the lathe, circular pieces were shaved down to have the exact inner and outer diameter of the respective tube they would be capping within five hundredths of an inch. Figure 41 shows a side view of one of the caps.   The caps were milled down to the inner diameters of their tubes for the first half-inch and were milled down to their outer diameter for the second half inch. The holes that were drilled through each backing were done on a drill press.

A plug for the center hole of the carriage was machined out of a scrap piece of half inch thick acrylic. It was cut roughly using a band saw, and then sanded down to approximately three inches using a belt sander.

Bonding:

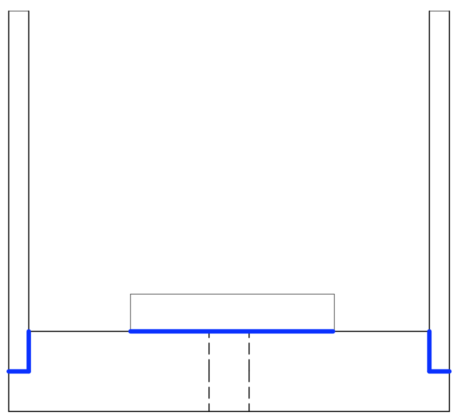


Figure 42 – Weld on Application and Contact

To bond the acrylic tubes to their appropriate backings, weld on was used at all points of contact between the two bonding surfaces. Figure 42 shows a side view of the carriage. It shows in blue where the bonding agent would be applied for the carriage assembly in blue. These areas are between the carriage tube and backing and between the carriage backing and plug. The barrel bonding process would be the same, accept there plug is replaced with an inner lip tube. This can be seen in Figure 43, the side view of the launch barrel.

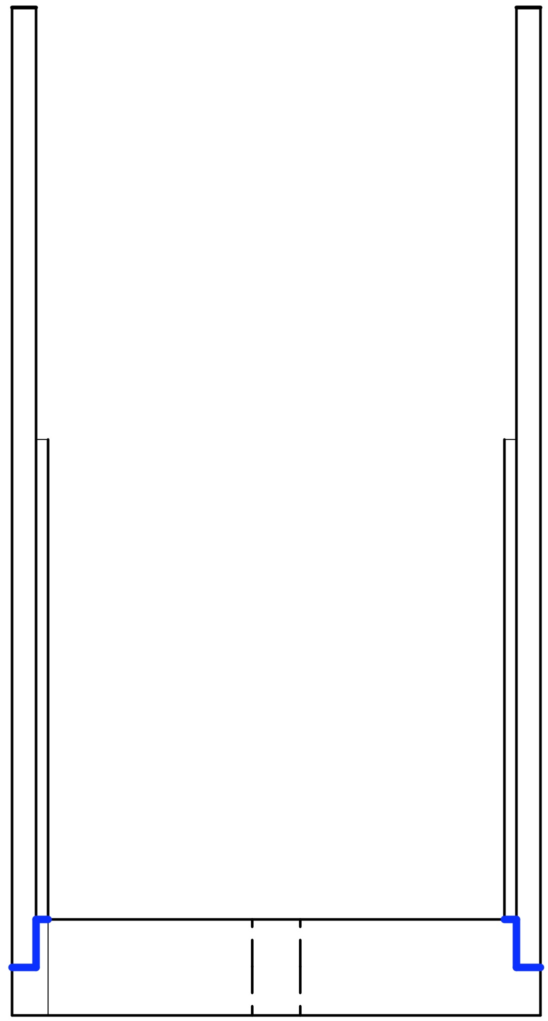


Figure 43 – Side View of Launch Barrel

Prototype Assembly

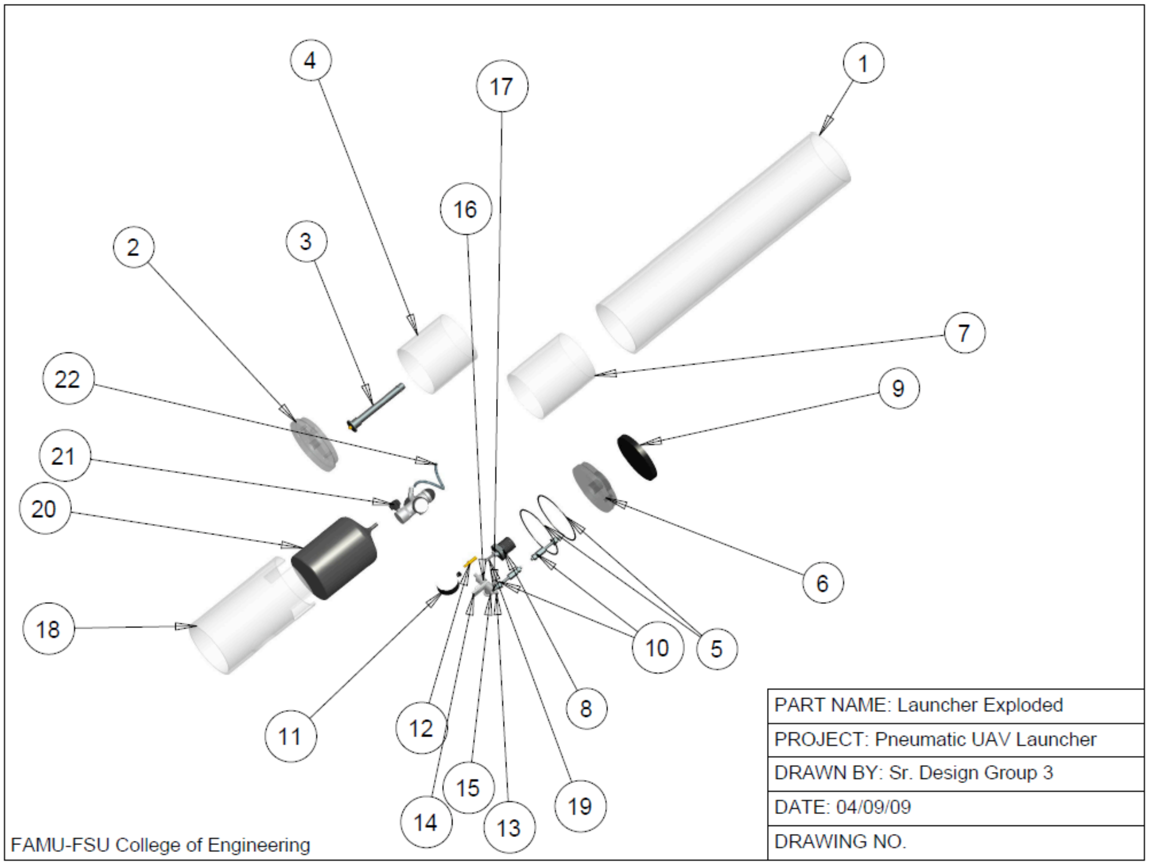


Figure 44 – Exploded View of Prototype

Figure 44 depicts the exploded view of the prototype design, and will be used to describe its assembly. As previously mention in the prototype manufacturing section, the launch barrel (1) was chemically bonded to the barrel backing plate (2) using acrylic bonding. The compression chamber tube (4) was then quickly bonded to the barrel backing plate (2). The quick release pin (3) was then press fit into the center hole of the barrel backing plate (2). The o-rings (5) were placed on top of the compression chamber tube. One of the cable fasteners (10) was screwed into the top of the barrel backing plate (2). The Schrader valve (12) and pressure gauge (11) were then mounted to the bottom of the launch barrel backing (2) with Teflon tape between them.

The carriage backing plate (6) was chemically bonded to the carriage tube (7). The pin receptacle (8) was screwed into the back of the carriage backing plate (6) with Teflon tape. The remaining cable fastener (10) was bolted to the back of the carriage backing plate (6). The carriage assembly was then slid into the launch barrel until the threaded receptacle (8) locked into place with the quick release pin (3). Two neoprene discs (9) were placed inside the carriage (7).

The trigger mechanism was then mounted to the barrel backing. This was done by first mounting the two support brackets (24) to the back of the launch barrel backing (2). The L bracket hammer (14) was then placed in-between the support brackets (24). The trigger rod (13) was then slid through the side holes of the L bracket hammer (14) and support pins (24) The left and right springs (16 and 17) were then slid onto each side of the trigger rod (13). The d-ring was then mounted to the back of the launch barrel backing (2).

After the trigger mechanism was properly installed, the tank support (18) was chemically bonded to the bottom of the launch barrel backing (2). The air supply fitting (19) was screwed into the back of the barrel backing plate (2). The air hose (22) was then screwed into the other end of the air supply fitting (19) and the outbound port of the pressure regulator (21). Finally, the air tank (20) screwed into the pressure regulator (21).

Prototype Cost Analysis

Below is a list of vendors that the group has used to purchase the parts that make up the final prototype for the customer.

McMaster-Carr –
McMaster has provided the team with the bulk of the desired parts for the final product.

Address: 200 Aurora Industrial Pkwy, Aurora, OH 44202-8087
Phone: 330-995-5500

E-Paintball –
This vendor specializes in distributing aftermarket paintball products. Since the team chose to use a carbon fiber paintball tank as a reservoir, the lightest tank on the market was supplied by E-Paintball.

Address: e-Paintball, 811 TX State HW 62, Buna, TX 77612
Phone: 409-994-9818

Sak World Paintball –
Since some of the parts must be compatible with aftermarket paintball supplies, it was easy to find high-pressure lines and a pressure regulator that would fit the application. Sak World is also another aftermarket paintball accessory retailer.

Address: SAK World Paintball Supply and Service, L.L.C., North Andover, MA 01845
Phone: 877-725-9675

Big Sky Precision –
This company manufactures a range of different products mainly for heavy-duty industrial use. The items that the team requires are for heavy lifting. The quick release pin purchased from Big Sky had to be specially made.

Address: Big Sky Precision, PO Box 470, Manhattan, MT 59741
Phone: 888-213-1492

Home Depot-
Home Depot provided the team with instant access to materials. While no purchase orders were used for materials from home depot, a significant amount of hardware was purchased from the local store.

Address: 1490 Capital Cir. NW, Tallahassee
Phone: 850-350-9001

Table 8 – Part/Material Expenses

Part/Material Expenses

Item	Quantity	Vendor	Part Number	Total Price
5"1/2x36"x1/4" acrylic tube	1	McMaster-Carr	8486K588	$109.86
High Pressure reservoir tank	1	E-Paintball.com	100992	$154.95
Tank Regulator	1	Sakworld Paintball	144891330	$99.95
Schrader Valve	1	Advanced Auto Parts	04134-8	$6.96
Quick Release Pin	1	Big Sky Precision	Custom Part	$122.45
Quick Release receiver	1	Big Sky Precision	845104	$29.53
5"x12"x1/4" acrylic tube	1	McMaster-Carr	8486K583	$26.93
12"x12"x1" acrylic sheet	1	McMaster-Carr	8560K321	$43.96
Pressure gauge	1	Home Depot	TC2104	$9.46
5"x12"x1/8" acrylic tube	1	McMaster-Carr	8486K387	$18.28
High Pressure steel braided line	1	Sakworld Paintball	N/A	$10.03
Hammer Trigger Release	1	Home Depot	N/A	$14.54
5/8" ID 1" OD O-Ring	1	Home Depot	M32-L	$0.98
5"x1/8" O-rings	1 pack	McMaster-Carr	4061T27	$14.88
1/8" Cable strong grip end fittings	2	McMaster-Carr	3475T885	$18.69
Cable	1	McMaster-Carr	3459T72	$19.30
Pressure sealing washers	1 pack	Home Depot	M32-N	$2.17
Silicone II sealant	1	Home Depot	GE5003TG	$6.93
1/8" to 1/4" NPT fitting	1	Capital Rubber	S406-4-2	$0.75
5/8" Rubber Tube	1	Machine Shop	N/A	$0.00
Weld on - Acrylic bonding agent	1	Machine Shop	N/A	$0.00
			Total=	$710.60

Table 9 – Shipping Expenses

Shipping Expenses

McMaster Orders				$40.69
Sakworld Paintball Orders				$14.00
Big Sky Precision Orders				$27.98
E-Paintball Orders				$42.50
			Total=	$125.17

Table 10 – Travel Expenses

Travel Expenses

Travel to Eglin AFB for Adewale Adelakun			$170.80
Travel to Eglin AFB for Tim Bartlett			$98.79
		Total=	$269.59

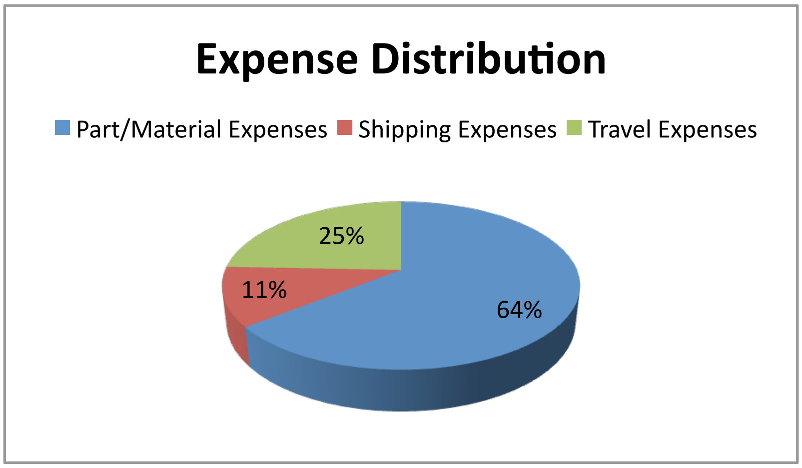


Figure 45 – Expense Distribution

As displayed in Table 8, the total amount for the final product for just the parts and materials amounts to approximately $711. There were a few unexpected expenses that the team incurred that were not included in the last cost analysis. This includes a few parts that were re-ordered due to part failure or inadequacy. Referring to the Design Changes section, the team had to replace the initial Quick Release Pin and Receiver with a custom pin of a larger diameter. This was unexpected, and cost the team an additional $150. Most of the new parts are fairly inexpensive. The team was actually able to get a few items free of charge from the machine shop. All of the manufacturing of the actual launcher was done at the FAMU-FSU College of Engineering machine shop. Therefore, there were no expenses due to labor.

The cost of travel was also a contributing factor to our project expenses as one can see in Tale 10. The team was lucky to have the opportunity to travel to Eglin AFB to meet with the sponsor in October of 2008. The team paid out-of-pocket for the trip, hoping to be reimbursed by the school. The team was reimbursed by the school; through the project account from Eglin AFB. This ended up accounting for around 25% of the total expenses for the project.

The lease influential, but still worthy of mention is the cost incurred due to shipping expenses (Table 9). Normally, this would be included in the Part/Material Expenses, but much of the parts were sent overnight or next day due to complications. As mentioned before, the team experienced part failure and custom part fabrication. In these instances, parts were needed immediately as to not hold up testing and manufacturing processes. Custom part fabrication takes a considerable amount of time as is, therefore, the team opted to ship some parts next day.

Figure 45 illustrates the overall expense distribution and clearly shows the financial impact of each expense pertaining to Tables 8, 9, & 10.

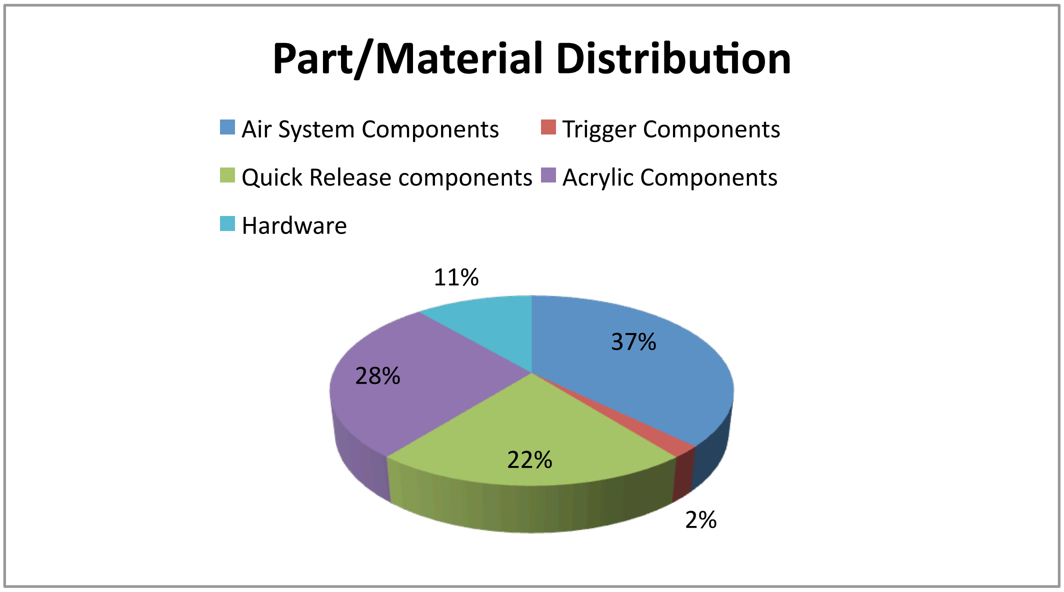


Figure 46– Part /Material Distribution

Using information from Table 8, Figure 46 above was created. This chart shows the breakdown of the parts that were purchased. The Air System Components only consist of three parts, however, the parts are by far the most expensive parts on the entire parts list. The most expensive part being the high pressure air tank.

The next most expensive category of the parts/materials, are the acrylic components. Three different sizes of tube are used in the final design; the launch tube, the carriage tube, and the stationary tube on the inside of the laucnh tube that creates the charge chamber. Also, the acrylic backings for the launch tube and the carriage were made from a slab of 1" thick acrylic. The most expensive acrylic part being the launch tube.

After the acrylic components, the Quick Release components are the next costly category. There are only two parts included in the quick release category, but again, custom parts are fairly expensive. The custom pin is the most expensive quick release part at $122.45.

The hardware is the second inexpensive category at 11%, this would include all of the fittings, the pressure gauge, the stopping mechanism, the o-rings, schrader valve, and pressure washers.

The most inexpensive part of the final design is the hammer mechansim, but with out it, the launcher would not be opperable. The cost is a compliation of parts used to make the hammer mechanism.

Prototype Testing

Initial Tests

The initial testing involved pressurizing the compression chamber to test for an airtight seal. With the initial design, the compression chamber leaked air very quickly at pressures above 20 psi (1.379*10^5 Pa). This was found to be due to air leaking around the inner sleeve of the compression chamber. Air was also being forced around the receiver and back through the quick release pin. (Figure 35, 36, & 47) These led to our initial design modifications. The group decided to put a spacer around the ½" pin and stacked o-rings to create a seal where the pin meets the receiver. Liquid silicone was also utilized to seal around the bottom section of the compression chamber to prevent air from escaping around the sides of the barrel (Figure 47).

These changes allowed pressures to be held steadily to 30 psi (2.065*10^5 Pa), which is approximately 700 lbf (3.114kN) acting on the carriage and pin. At 30 psi, however, the team ran into the first major component failure of the design. (Figure 35, 36, & 47) As shown above, the receiver failed due to elastically deformed under pressure. This is believed to be due to the small and few contact points with the original receiver. There are only two balls, and under high loads, the stress at the contact points exceeded the stress at the yield strength of the receiver. This led to the first major design alterations in which a 5/8" pin and receiver were implemented. The new pin uses 4 larger balls instead of 2, so the contact stress is greatly reduced. To address the air leak around the pin, a large rubber sleeve was placed over the pin. This allowed a better airtight seal that the spacer and o-rings created, and it needs no adjustment after every shot. The rubber sleeve slides back over the balls in the pin after the receiver has been released. This modification reduces the openings within the pin better than the o-ring and spacer modification. These major design changes now allow the pressure chamber to create and hold an airtight seal to pressures upwards of 60 psi (4.167*10^5Pa).

Figure 47 – Pin Receiver

During the initial testing, it became apparent that the pin release button was extremely difficult to press by hand at lower pressures, and impossible to press by hand at launching pressures. This difficulty is caused by the force placed on the balls of the quick release pin. The pin was originally designed to take large tensile loads and release by hand when the tensile load was removed. Since the final design specifies releasing the pin under pressure, a load is placed on the pin. The original triggering mechanism was a simple hydraulic plunger that could simulate pressing by hand from a safe distance. Since the pin could not be pressed by hand, a more forceful triggering mechanism was needed. A spring-loaded hammer approach was then devised, and it is detailed in the design changes section.

Full-scale Testing

Full scale testing began when the silicone sealant placed around the pin and edges of the compression chamber had time to cure. Also, a wooden test rig was created. (Figure 48) 2x2 wood was cut to create a triangle, and wooden blocks were used to create a resting point for the back of the barrel. This rig provided stable launches at 45 degrees, and it provided a surface for the group to test the modified trigger mechanism. When concrete blocks were placed on the test rig, recoil was drastically reduced, and repeatable test results were obtained.

In order to measure the exit velocity of our UAV dummy, the team obtained a radar gun, which functions by measuring the difference between radar pulses leaving the gun and pulses that return. It then displays the highest velocity that was recorded while pulling the trigger. Readings were obtained with the gun, but the results seemed inconsistent. This will be further discussed in the testing results section. The decision was made to verify the testing results using projectile motion equations. In order to calculate the exit velocity at a known angle, the distance that the dummy traveled was measured, and the flight time of the dummy was also timed. This required a tape measure and stopwatch.

Figure 48 – Prototype Test Rig

Since the air tank purchase order had not arrived, an air compressor was used to pressurize the air chamber each time. The full-scale testing was done in 5psi (3.447*10^5 Pa) increments to ensure that repeatable results were recorded. Our maximum pressure limit was set at 60psi, to ensure that the limits of the acrylic tube, quick release pin, and receiver were not exceeded by fatigue or tension. The limit was mainly due to the force rating of the quick release pin. There will always be a slow leak around the o-rings, because the team cannot compress the o-rings with a great enough force to equal the force exerted on the o-rings once the chamber has been pressurized. The testing launches were conducted by over pressurizing the charge chamber by 5psi, and then pulling the trigger mechanism when the pressure dropped to the desired value. So, the greatest pressure the launcher was pressurized to be 65psi (4.482*10^5 Pa).

Test Results

After the testing was completed, the minimum exit velocity was not achieved. At the maximum safe launch pressure, 60psi, the exit velocity was approximately 50ft/s (15.24m/s). After reviewing the theoretical calculations and adding friction, the testing data could not accurately be modeled as a non-reversible polytrophic expansion. The expansion was not an isentropic process. The expansion process could be more accurately modeled by using the testing data to determine the polytrophic exponent. The exponent the team found that best matches our test data is 3. This was a big change compared to the isentropic exponent of 1.4.

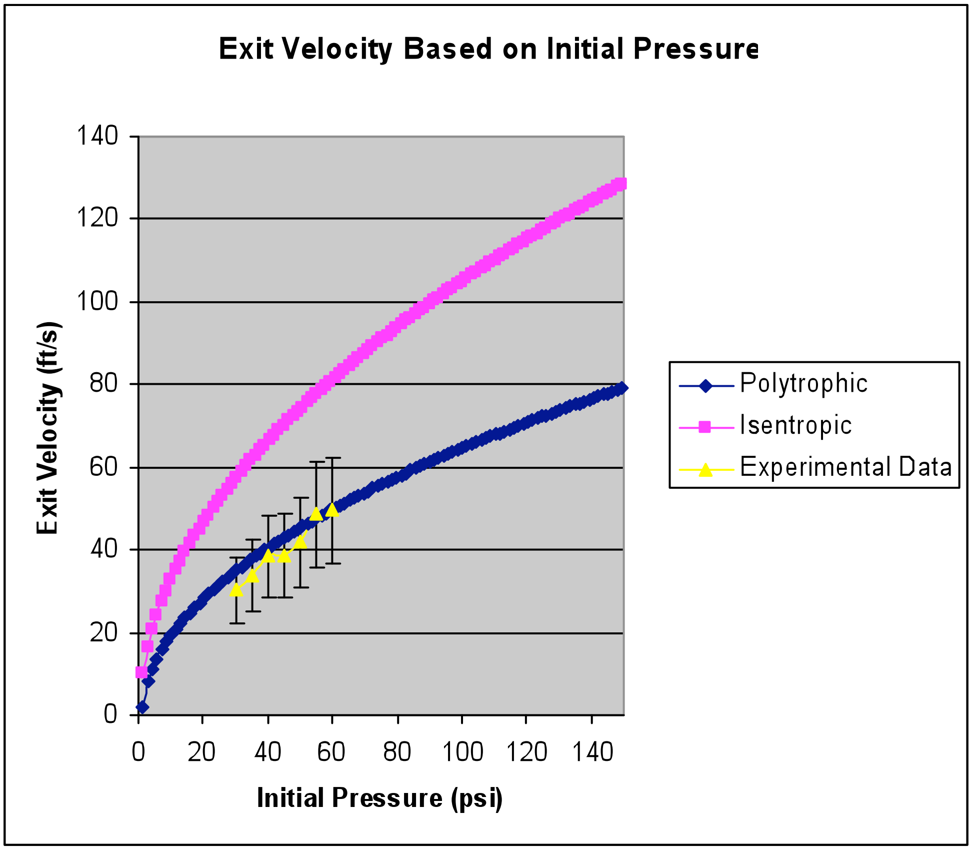


Figure 49– Exit Velocity Based on Initial Pressure

Figure 49 shows a graph of exit velocities based on initial pressures of the charge chamber. The polytrophic and isentropic theoretical modelings were plotted with the experimental data. The error bars were based on the velocity calculations made using time and distance, because those reading were prone to be the most inaccurate. The test data plotted were the average readings based on each recorded pressure. As one can see, the testing data falls within the polytrophic plot fairly well. Based on the polytrophic modeling, the charge chamber would need to be loaded to approximately 85psi (5.861*10^5Pa) to achieve an exit velocity of 60ft/s. To achieve this initial pressure, another quick release pin and receiver would need to be implemented. The pin and receiver should both be rated for at least

However, it is important to note the stopping mechanism was never needed during testing. Before the carriage would come out of the launch barrel, the pressure would equalize with atmospheric conditions. This essentially created a vacuum behind the carriage, thus stopping it from leaving the barrel. The o-rings were not glued together or to the back of the lip of the charge chamber. Any attempts to do so severely weakened the team's ability to get an airtight seal. The stopping mechanism would be difficult to install, and might need to be taken out and reinstalled after each launch. It would only need to be reinstalled if the o-ring fell into the charge chamber. If a new pin and receiver were installed and the initial pressure would be increased, the stopping mechanism would need to be installed.

Acceleration:

Unfortunately, due to time constraints and budgeting the maximum instantaneous acceleration the UAV experiences was unable to be accurately tested. An accelerometer that would be rated up to 600gs would be between 800 and 900 dollars. The cheapest way of making sure the launch process did not exceed 600gs would be to put an electronic device rated to a certain G specification within the launch dummy. For example, the Nintendo Wii remotes are rated to withstand 1000gs. The team recommends to whoever uses the launcher at Eglin Air Force Base mount an electronic component of UAV to the test dummy and launch the dummy a few times. If the electronic component fails, only a piece of the UAV would be damaged instead of the entire UAV.

The figure below shows the theoretical acceleration the UAV would experience as it travels through the barrel. As one might expect, the highest accelerations occur at the beginning of the launch and decrease drastically as it travels the launch barrel. The red line in Figure 50 illustrates the adiabatic plot for an exit velocity of 60ft/s at 85psi. The maximum the Gs experienced by the UAV would be 387gs. This is how much the maximum acceleration would theoretically be, if the quick release pin and receiver were upgraded. The green line shows what maximum acceleration the UAV theoretically experienced during the testing of the current design. Its maximum acceleration was 270gs. This occurred at an initial pressure of 60psi and exit velocity of 50ft/s. The maximum acceleration the team thought the UAV would experience if the process was isentropic would be 147gs. Therefore the instantaneous acceleration should still be well under 600gs.

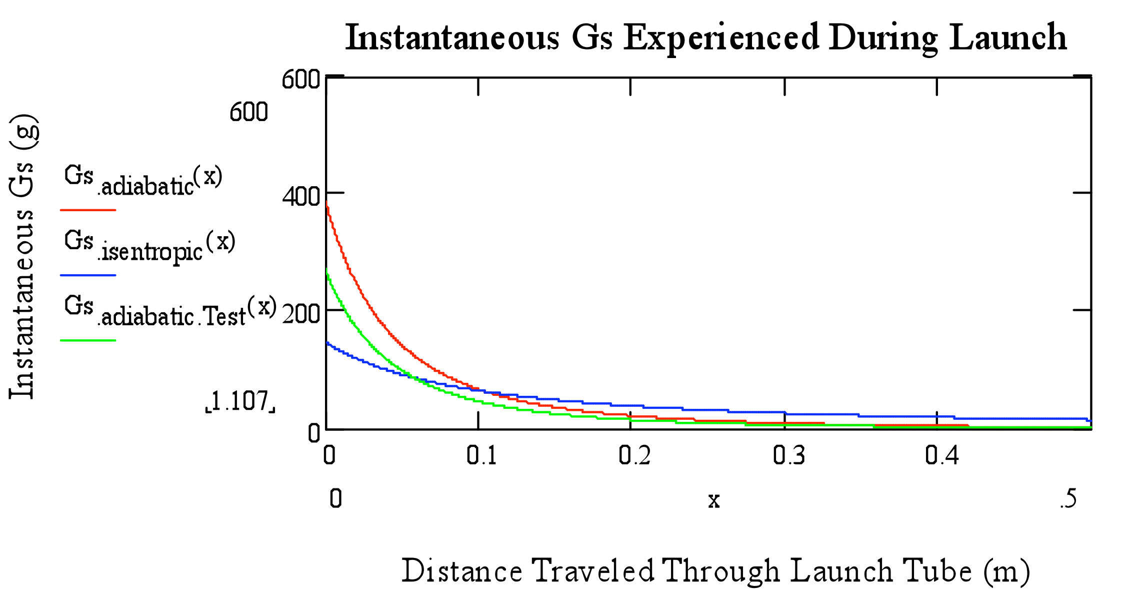


Figure 50 – Instantaneous Gs Experienced During Launch

Optimized Final Design

The primary goal of the project was to design and provide a new, safe, effective and efficient system that could repeatedly launch a UAV (provided by Eglin Air Force Base) into flight. The prototype was not intended to meet the specifications of the sponsor. However, the team had hoped the minimum exit velocity would have been achieved. In order to satisfy the objectives set forth by the sponsor the group came up with an optimized final design.

When planning the prototype, the dimensions and material selection of the launcher were decided based on cost and weight since the theoretical calculations showed that the pressures the team would have to reach in order to achieve target velocity would be fairly low. However, the prototype launcher was not able to meet the minimum exit velocity, mainly due to the fact that it would be unsafe to pressurize the system to the levels thought needed. Referring to the testing section above; the team gathered the appropriate data and was able to model data to better predict at what pressure the UAV would reach the minimum exit velocity of 18.288m/s. This turns out to be around 85psi. With this information, the team set forth to create an optimized final design to meet the project specifications.

The final design proposed in the fall called for the launch tube and carriage to be made of carbon fiber and aluminum. This will be the same for the optimized final design. The quotes that were received for the carbon fiber and aluminum parts amounted to approximately $1000. Also on the fall final design, the custom quick release pin is to be made of stainless steel with a tear out strength of 1500lbs. A better material was available, but would have cost over $300 more. The optimized design would include this quick release pin because it would be able to withstand the 2125lbs of force associated with 85psi. There would be no other changes to the optimized design from the prototype that was built. Everything worked fairly well except for the fact that the charge chamber was unsafe to pressurize over 65psi.

Based on the projected pressure needed to launch the UAV at the target velocity, the thickness of the carbon fiber can be 1/8". The thickness of the carbon fiber will be constant throughout the tube and the carriage. The aluminum used for the barrel backings for both the carriage and launch tube will be a 1/8" of an inch thick as well. The aluminum has to have 2in of contact with the carbon fiber for the bonding agent to have an effective bond. Using the volumes of the parts and the densities of the materials used, the weight was calculated in the Table 11 below.

Table 11 – Prototype Component Information

Component	Weight (lb)	Volume (in^3)	Material	Density (lb/in^3)
Barrel	3.268789	50.2890625	Carbon Fiber	0.065
Carriage	0.497494	7.65375	Carbon fiber	0.065
Backing	1.961273	30.1734375	Aluminum	0.098
Lining of tube	0.592	6.04082031	Aluminum	0.098
Carriage Support	0.55053	5.61765625	Aluminum	0.098
Pin	0.5	-	Stainless Steel	0.289
Receiver	0.3	-	Stainless Steel	0.289
Reservoir Tank	1.8	48	-	-
Regulator	0.8	-	-	-
Hardware	0.5	-	-	-
Total weight	10.77009	-	-	-

The heaviest component of the final design is the launch barrel even though it is made out of carbon fiber. It is also the largest component of the design as well. The protective backing for the air system components is also made of carbon fiber and is the next heavy. Surprisingly, the aluminum for both the tube and the carriage only combined to just over 1lb. The solid steel pin and receiver account for less than a pound. The air delivery system components listed combine to 2.6lbs. The air tank is made of carbon fiber and the regulator is stainless steel. They are very dense parts because they have to stand up to such high pressures. The only other parts to consider are rubber o-rings, the Schrader valve, and the steel braided lines. Together they account for less than .5 lbs. Overall, the total final design would weigh just under 11lbs.

Optimized Final Design Manufacturing

The manufacturing for the final design will, in large part, be outsourced to Nim-Cor, the company that would be making the carbon fiber/aluminum tubes. The process would start by having Nim-Cor fabricate two thin aluminum tubes with one closed end. Holes would be drilled in the flat surface of the closed ends of the tubes. The holes will allow the quick release pin, stopping mechanism, Schrader/blow off valve, and the fitting for the steel braided line to be mounted. The aluminum pieces will fit into the custom sized carbon fiber tubes. A space grade epoxy will be used once the closed end of the aluminum pieces is flush with the end of the carbon fiber tube. Once all of the epoxy has cured, the launch tube and the carriage will then be shipped to the FAMU-FSU College of Engineering.

As the tubes are being manufactured, Big Sky Precision would be manufacturing the new quick release pin and receiver. As mentioned before, the pin and receiver will be made of 4130 Steel. It has been estimated to take nearly 2 weeks to manufacture the custom pin; therefore time must be allotted for shipping. Once the tubes arrive, assembly can begin.

Optimized Final Design Assembly

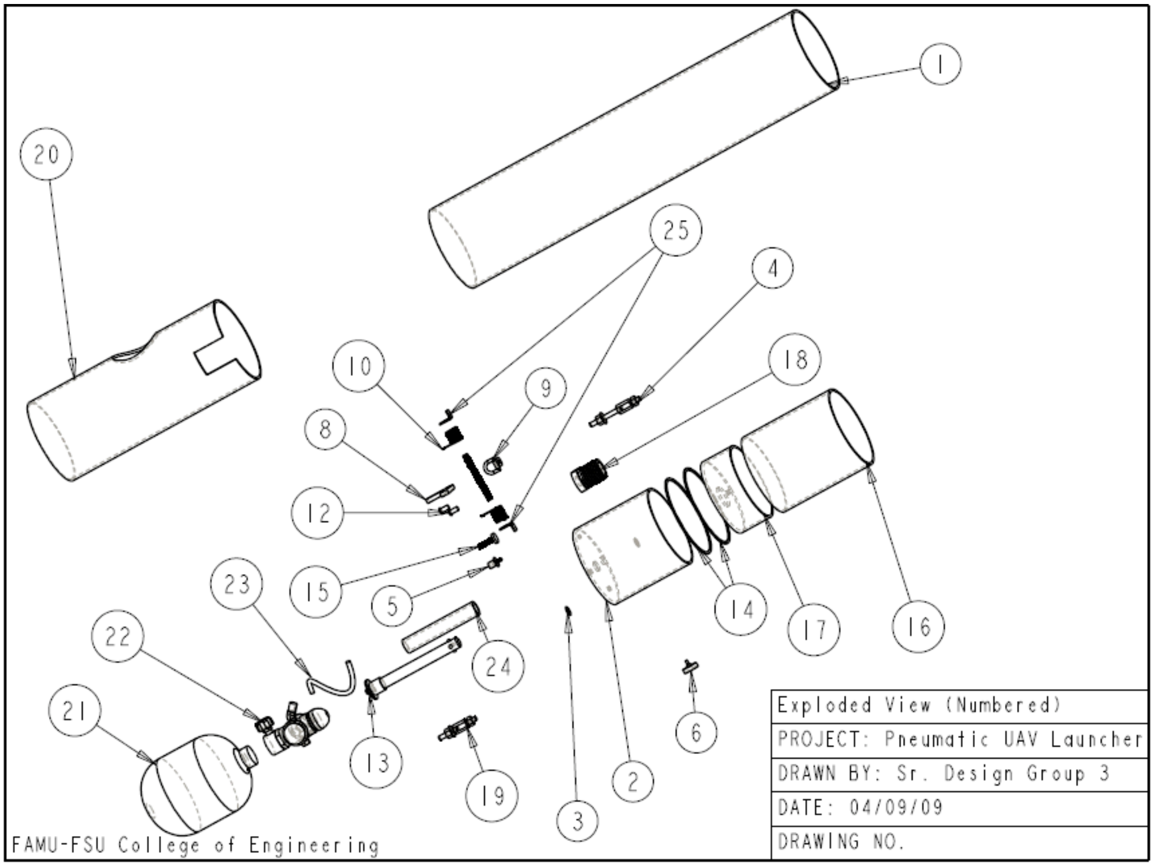


Figure 51 – Exploded View of Final Design

Figure 51 was the exploded view of the optimized final design. As previously mentioned in the manufacturing section, the barrel (1) was bonded to the barrel backing (2) using space grade epoxy. The same process would bond the carriage (16) to the carriage backing (17). Both of these bonding processes would have been done by Nim-Core.

The quick release pin (13) was then press-fit into the center hole of the barrel backing (2). The release pin rubber tube could then be slid over the quick release pin (13). The rubber o-rings (14) were placed on the top lip of the barrel backing (2). The Schrader valve (15) was then bolted down into the appropriate hole in the barrel backing (2). The stopping mechanism cable fastener (4) was then crewed into the top of the barrel backing (2). The mini pressure gauge (6) was screwed into the side of the barrel (1) with Teflon tape in between the threads.

The pin receiver (18) was then crewed into the back of the carriage backing (2) with Teflon tape in between the threads. The remaining cable fastener was then bolted down to the back of the carriage backing (17). The carriage assembly can now be slid down the barrel until the quick release pin (13) mates with the pin receiver (18).

The trigger mechanism was then mounted to the barrel backing. This was done by first mounting the two support brackets (25) to the back of the barrel backing (2) using trigger screws (12). The L bracket hammer (8) was then placed in-between the support brackets (25). The trigger rod (7) was then slid through the side holes of the L bracket hammer (8) and support pins (25) The left and right springs (10 and 11) were then slid onto each side of the trigger rod (7). The d-ring was then mounted to the back of the barrel backing (2).

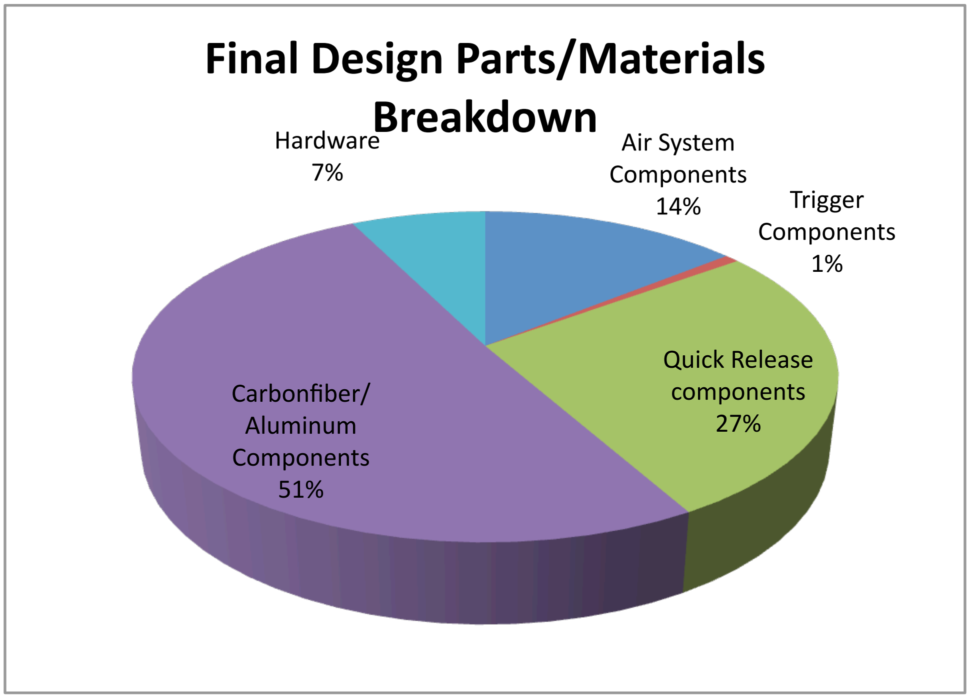
After the trigger mechanism was properly installed, the reservoir support (20) was then bonded using epoxy to the bottom of the barrel backing (2). The air supply valve (5) was screwed into the back of the barrel backing plate (2). The air hose (23) was then screwed into the other end of the air supply valve (5) and the outbound port of the pressure regulator (22). Finally, the reservoir tank (21) screwed into the pressure regulator (22).

Optimized Final Design Cost Analysis

Part/Material Expenses

Item	Quantity	Vendor	Part Number	Total Price
5"1/2x36"x1/8" Carbon fiber/aluminum tube	1	Nim-Cor	Custom Part	$600.00
High Pressure reservoir tank	1	E-Paintball.com	100992	$154.95
Tank Regulator	1	Sakworld Paintball	144891330	$99.95
Schrader Valve	1	Advanced Auto Parts	04134-8	$6.96
Quick Release Pin	1	Big Sky Precision	Custom Part	$423.00
Quick Release receiver	1	Big Sky Precision	Custom Part	$80.00
12"x12"x1/8" aluminum sheet	1	McMaster-Carr	1924T61	$57.78
Pressure gauge	1	Home Depot	TC2104	$9.46
5"x12"x1/8" Carbon fiber/aluminum tube	1	Nim-Cor	Custom Part	$350.00
High Pressure steel braided line	1	Sakworld Paintball	N/A	$10.03
Hammer Trigger Release	1	Home Depot	N/A	$14.54
5/8" ID 1" OD O-Ring	1	Home Depot	M32-L	$0.98
5"x1/8" O-rings	1 pack	McMaster-Carr	4061T27	$14.88
1/8" Cable strong grip end fittings	2	McMaster-Carr	3475T885	$18.69
Cable	1	McMaster-Carr	3459T72	$19.30
Pressure sealing washers	1 pack	Home Depot	M32-N	$2.17
Silicone II sealant	1	Home Depot	GE5003TG	$6.93
1/8" to 1/4" NPT fitting	1	Capital Rubber	s406-4-2	$0.75
5/8" Rubber Tube	1	Machine Shop	N/A	$0.00
			Total=	$1,870.37

The chart above is a list of materials and parts that would be used when constructing the final design. There is much disparity between the price of the testing prototype and the final design. This is mainly due to the addition of high-end materials. The majority of the price increase comes from ordering custom parts made from carbon fiber and aluminum. This, however, is a necessity because it is a lightweight material that will be able to provide the strength needed to hold highly pressurized air. Also, the quick release pin and receiver would be made out of 4130 steel, which costs almost three times as much to manufacture compared to 304 stainless steel. All of the other components remained the same.



Looking at the pie chart above, it is apparent that slightly over half of the cost of the final design is due to the price of the carriage and launch tube. This is expected since these parts are critical to the functionality and specifications of the design. The quick release components are also very critical to the functionality, which is why it is the next expensive category. The hardware, air system components, and trigger components have all seen a reduction in percentage of cost for the respective sections compared to the test prototype. This is due to the fact that the majority of the parts did not change from testing prototype to final design.

Conclusion

In conclusion, the team feels that the primary objective has been accomplished. The primary objective was to provide a safe, effective, and efficient means of propelling a compact UAV into flight. The primary objective was limited by specifications that the team was expected to meet which included but was not limited to; minimum exit velocity of 60ft/s, maximum acceleration of 600Gs, less than 11lbs, no accelerants, and within 36"Lx5"1/2D cylindrical tube.

The team designed a test prototype based on theoretical calculations to test the concepts and functionality of the design. Unfortunately, the prototype was not able to meet the minimum velocity requirement consistently. This shows that the theoretical calculations did not model the test data very well. However, the team was able use the test data along with an equation for polytrophic expansion, to create a better-fit model for the data.

Using the model, a more accurate prediction can be made for the pressure it will take to reach the minimum exit velocity. Using the prediction of 85psi, which correlates to 2250lbs of pressure acting on the quick release pin, the team created a final design that can withstand such forces and pressures. The final design is an iteration of the test prototype created. The main difference between the prototype and the final design is material selection. Since the first theoretical calculations were incorrect, the testing prototype was only designed to handle pressures that do not exceed 65psi. With carbon fiber and aluminum used in the launch tube and carriage, the final design will be more effective. With the test data, and general understanding of the process, it is highly believed that the design is capable of withstanding the target exit velocity.

Unfortunately, the instantaneous accelerations the UAV would experience were unable to be verified during the testing process of the prototype. However, the highest instantaneous Gs the UAV would experience would occur at the very beginning of the launch. This would be where the pressure driven force acting on the UAV would be the absolute highest. Theoretically the maximum Gs experienced would be only 387Gs. As long as the vibrations that occur during the launch do not exceed 213Gs, the launcher meets the maximum acceleration requirement. The team is confident that the vibrations are well under 213Gs.

As mentioned above, the final design was an iteration of the testing prototype and the length dimensions did not change. The only dimensions that were changed were the diameters of the launch tube and carriage. In the prototype, the thickness of the two components was 1/4". Now, because carbon fiber is much stronger, the thickness of the launch tube and carriage are only 1/8". The launcher is still within the required dimensions. The material change also influenced the weight of the UAV launcher. The prototype weighs more than 15lbs, while the final design would weigh approximately 10.77lbs.

Overall, the team feels very confident about the final design and its capabilities. The process was long, but the result shows months of planning and teamwork that led to the completion of a final goal. As explained above, all of the project specifications were addressed and considered in each design iteration. The requirements of the design were met to the best of the team's ability and are considered to have been achieved!

Appendix A

Glossary

ATS – Air Tight Seal, the third component of the final design concept.

Barrel – the section of the launch tube that the carriage travels while being launched.

Blow By – the term blow by refers to air passing by an object that is in an enclosed space. In this case, the object is the carriage. If too much space is left between the carriage and the tube, the air could escape around the carriage and the system would lose power and efficiency.

Carriage – Specifically refers to the component that holds the UAV inside the tube while creating an airtight seal. Since the UAV is not a uniform shape, there is no way to create a tube that fits around the tube with a sufficient airtight seal without having something behind it.

Carriage System – the second component of the final design concept, also see Carriage.

Charge Chamber – refers to the chamber that holds the compressed air required for a single launch.

Compression Chamber – refers to the concept generation for the passive release system. It is a small chamber that experiences pressure build (compressing the air) and puts pressure on the back of the carriage that holds the UAV. Upon reaching a certain pressure, the passive force would overcome a restraining force and allow the carriage to be released and the compression chamber to expand.

Launch Tube – The entire tube enclosure.

Material Selection Component – the fifth component of the final design concept

Releasing System – the first component of the final design concept, concerned with how to release the UAV through the barrel once sufficient pressure has built up in the charge tank.

Reservoir tank – refers to the tank that acts as a pressurized air reservoir that feeds specific amounts of air into the charge tank to be evacuated through the launch tube.

Appendix B

Fall Assumptions -

While performing the theoretical calculations, several assumptions had to be made. The first assumption was to neglect friction. The launch process dealt with such high forces that the effect of friction would be not significant. Every component was also designed to have factors of safety where additional pressure can still be added to compensate for any frictional losses.

The second assumption was how to model the expansion of the compressed air. The expansion process was assumed to be adiabatic, since the entire launch process takes place in under .05 seconds. Any heat loss was assumed to be negligible due to this launch time. The expansion of air can also be modeled as polytrophic. This means the product of the volume raised to an exponent n and the pressure was assumed to remain constant. Due to difficulty calculating what exactly n would be, the expansion process was then modeled as a reversible adiabatic process, or isentropic. This meant n would now be equal to gamma (1.4), the ratio of specific heats of air. The conservation of momentum was then used to relate the initial pressure required for each launch and exit velocity. The exit velocity was modeled to be 19.812 m/s.

The instantaneous Gs experienced by the UAV during the launch process were modeled as the net force behind the carriage divided by the weight of the UAV and carriage. No vibrations were taken into account.

While determining the amount of air the reservoir would need to hold, the process of filling or empting the tank was modeled as an isothermal process. The temperature of the air was assumed to be the ambient temperature of outside air (27^{o}C). The actual temperature of the air will rise as it is compressed, and fall as it is decompressed. However, if long enough time passes in between compression processes, the temperature of the tanks can be assumed to be ambient temperature of the surroundings.

The charge chamber was modeled as being a thin walled pressure vessel to calculate the stresses on the chamber due to its pressure. The charge chamber is open on one end, but the back of the carriage was locked into place crating an airtight seal prior to launch.

While conducting the factors of safety, normally it is the stress upon failure divided by the calculated stress. However, the team decided to make it the yield stress divided by the calculated stress. This will give lower factors of safety. The team's rationality behind this decision was based on the fact that the UAV launcher experiences cyclic loading. Any permanent deformation would influence the next launch and could possibly be very dangerous.

The time the stopping mechanism would take to bring the carriage to a complete stop was unknown. The shorter the time would be, the closer the impulse force would approach infinity. The impulse force was taken to be a magnitude higher than the pressure driven force (due to the isentropic expansion) acting on the back of the carriage at the desired stopping distance.

Appendix C

Fall Calculations

Compound Crossbow Calculations:

Note: These calculations were performed under the assumption that the kinetic energy output of the crossbow remains constant in an effort to determine the exit velocity of a bigger arrow (the uav). This assumption will give a very rough estimate to see if the most expensive crossbow available a www.huntersfriend.com can overcome our project specification of a minimum exit velocity of 60 ft/s. The actual exit velocity will be even smaller.

$1 \cdot \mathrm{lb} = 7000\mathrm{grains}$

$\mathrm{grains} := \frac{1}{7000} \cdot \mathrm{lb}$

$m_{uav} := 3.5\mathrm{lb}$

$m_{uav} = 2.45 \times 10^{4}\,\mathrm{grains}$

$v_{design} := 313\,\frac{\mathrm{ft}}{\mathrm{s}}$

$m_{arrow} := 420\mathrm{grains}$

$KE_{designed} := m_{arrow} \cdot v_{design}{}^{2}$

$KE_{designed} = 247.705\ \mathrm{J}$

$v_{uav} := \sqrt{\frac{KE_{designed}}{m_{uav}}}$

$\boxed{v_{uav} = 40.981\,\frac{\mathrm{ft}}{\mathrm{s}}}$

This crossbow fails to meet our project specification of a minimum exit velocity of 60 ft/s.

References for calculation:

http://www.huntersfriend.com/crossbows/tenpoint-pro-elite-crossbow.htm

http://www.huntersfriend.com/crossbows/crossbow-field-performance-expectations.htm

Pneumatic Calculations:
Deciding Square or Round Tubing:

$Area_{Square} := 4.5in \cdot 4.5in$

$Area_{Square} = 0.013\ m^2$

$Perimeter_{Square} := 4 \cdot 4.5in$

$R_{Square} := \frac{Area_{Square}}{Perimeter_{Square}}$

$\boxed{R_{Square} = 0.029\ m}$

$Area_{Circle} := \frac{\pi \cdot (5.5in)^2}{4}$

$Area_{Circle} = 0.015\ m^2$

$Perimeter_{Circle} := \pi \cdot 5.5in$

$R_{Circle} := \frac{Area_{Circle}}{Perimeter_{Circle}}$

$\boxed{R_{Circle} = 0.035\ m}$

The acceleration needed to achieve the minimum exit velocity:

$v_0 := 0\ \frac{m}{s}$ $\quad v_{exit} := 65\ \frac{ft}{s}$ $\quad x_{exit} := 18in$

$x_{exit} = 0.457\ m$

$v_{exit} = 19.812\ \frac{m}{s}$

$v_{exit}^2 = v_0^2 + 2a \cdot x$

$a := \frac{v_{exit}^2 - v_0^2}{2 \cdot x_{exit}}$ $\quad a = 429.26\ \frac{m}{s^2}$

$V_{exit} = V_0 + a \cdot t$

$t := \left(\frac{v_{exit} - v_0}{a}\right)$ $\quad \boxed{t = 0.046\ s}$

Neglecting Friction:

$\Sigma F = m \cdot a$

$F - W \cdot \sin(\theta) = m \cdot a$

$F = W \cdot \sin(\theta) + m \cdot a$

$m_{uav} := 5 \cdot lb$

$m_{uav} = 2.268\ kg$

Note: The UAV weighs 3.5lbs, but an additional 1.5lbs was allotted for carriage the uav will sit in while being propelled in the barrel of the launch tube.

$F_{prop}(\theta) := m_{uav} \cdot g \cdot \sin(\theta) + m_{uav} \cdot a$

$F_{prop}(30deg) = 984.666\ N$

$F_{prop}(45deg) = 989.272\ N$

$F_{prop}(90deg) = 995.786\ N$

Determining Initial Pressure Required:

Note: The expansion process was modeled as an adiabatic, isentropic process neglecting friction. These calculations were in order to achieve an exit velocity of 65 ft/s. $Area_{Circle}$ denotes the area based on the inside diameter of the barrel.

$$\frac{P}{P_0} = \left(\frac{V_0}{V}\right)^{\gamma} \qquad V_0 = A \cdot x_0$$

$$P = P_0 \cdot \left(\frac{V_0}{V}\right)^{\gamma} \qquad V = A(x_0 + x) \qquad Area_{Circle} := \frac{\pi \cdot (5in)^2}{4}$$

$$P(x) = P_0 \cdot \left(\frac{A \cdot x_0}{A(x_0 + x)}\right)^{\gamma} - \frac{m \cdot g \cdot \sin(45deg)}{A} = P_0 \cdot \left(\frac{x_0}{x + x_0}\right)^{\gamma} - \frac{m \cdot g \cdot \sin(45deg)}{A}$$

$$P(x) = P_0 \cdot x_0^{\gamma} \cdot \left(\frac{1}{x + x_0}\right)^{\gamma} - \frac{m \cdot g \cdot \sin(45deg)}{A} = P_0 \cdot x_0^{\gamma} \cdot (x + x_0)^{-\gamma} - \frac{m \cdot g \cdot \sin(45deg)}{A}$$

$$\int_0^{x_{exit}} \frac{P(x) \cdot A}{m}\, dx = \frac{A}{m} \cdot \int_0^{x_{exit}} P(x)\, dx = \frac{A}{m} \cdot \int_0^{x_{exit}} P_0 \cdot x_0^{\gamma} \cdot (x + x_0)^{-\gamma} - \frac{m \cdot g \cdot \sin(45deg)}{A}\, dx$$

For simplicity the integral will be broken up into two integrals:

$$\int_0^{x_{exit}} \frac{P(x) \cdot A}{m}\, dx = \frac{A}{m} \cdot \int_0^{x_{exit}} P_0 \cdot x_0^{\gamma} \cdot (x + x_0)^{-\gamma}\, dx - \frac{A}{m} \cdot \int_0^{x_{exit}} \frac{m \cdot g \cdot \sin(45deg)}{A}\, dx$$

$$\frac{A}{m} \cdot \int_0^{x_{exit}} \frac{m \cdot g \cdot \sin(45deg)}{A}\, dx = \frac{1}{m} \cdot \int_0^{x_{exit}} m \cdot g \cdot \sin(45deg)\, dx = m \cdot g \cdot \sin(45deg) \cdot x_{exit}$$

$$\frac{A}{m} \cdot \int_0^{x_{exit}} P_0 \cdot x_0^{\gamma} \cdot (x + x_0)^{-\gamma}\, dx = \frac{A \cdot \left(P_0 \cdot x_0^{\gamma}\right)}{m} \cdot \int_0^{x_{exit}} (x + x_0)^{-\gamma}\, dx$$

$$\int_0^{x_{exit}} (x + x_0)^{-\gamma}\, dx = \int u^{-\gamma}\, du = \frac{u^{1-\gamma}}{1-\gamma} = \frac{(x + x_0)^{1-\gamma}}{1-\gamma} \qquad \begin{array}{l} u = x + x_0 \\ du = 1dx \end{array}$$

$$\int_0^{x_{exit}} \frac{P(x) \cdot A}{m}\, dx = \frac{A \cdot \left(P_0 \cdot x_0^{\gamma}\right)}{m} \cdot \frac{(x_{exit} + x_0)^{1-\gamma} - x_0^{1-\gamma}}{1-\gamma} - m \cdot g \cdot \sin(45deg) \cdot x_{exit}$$

$$\int_0^{x_{exit}} \frac{P(x)\cdot A}{m}\,dx = \int_0^{v_{exit}} v\,dv = \int_o^{x_{exit}} a\,dx$$

$$\frac{A\cdot P_0\cdot x_0^{\gamma}}{m}\cdot\left[\frac{(x_{exit}+x_0)^{1-\gamma}-x_0^{1-\gamma}}{1-\gamma}\right] - m_{uav}\cdot g\cdot \sin(45deg)\cdot x_{exit} = \frac{v_{exit}^{2}}{2} = a\cdot x_{exit}$$

$x_e := 18in \quad x_{exit} := \frac{x_e}{m} \quad \gamma := 1.4 \quad x_a := 5in$

$$x_0 := \frac{x_a}{m}$$

$$P_0 = \frac{\frac{m\cdot v_{exit}^{2}}{2} + m_{uav}\cdot g\cdot \sin(45deg)\cdot x_{exit}}{A\cdot x_0^{\gamma}\cdot\left[\frac{(x_{exit}+x_0)^{1-\gamma}-x_0^{1-\gamma}}{1-\gamma}\right]}$$

Note: x_{exit} and x_0 were unitless for the Mathcad to work (raised to an exponent). The m in the denominator of the Po equation is to adjust to make the units work.

$$P_0 := \frac{\frac{m_{uav}\cdot v_{exit}^{2}}{2} + m_{uav}\cdot g\cdot \sin(45deg)\cdot x_e}{Area_{Circle}\cdot x_0^{\gamma}\cdot m\cdot\left[\frac{(x_{exit}+x_0)^{1-\gamma}-x_0^{1-\gamma}}{1-\gamma}\right]} \qquad \boxed{P_0 = 35.699\,psi} \qquad \boxed{P_0 = 2.461\times 10^{5}\ Pa}$$

Recalculating Po based on Pin location and reduction in diameter of charge chamber:

$D_{Charge} := 4.75in$

$D_{Pin} := .5in$

By having the quick release pin in the back of the charge chamber the initial volume will decrease, thus the initial pressure required had to be recalculated.

$$Area_{Charge} := \frac{\pi\cdot\left(D_{Charge}^{2} - D_{Pin}^{2}\right)}{4}$$

$$A_{ratio} := \frac{Area_{Charge}}{Area_{Circle}}$$

$A_{ratio} = 0.892$

$$\frac{P}{P_0} = \left(\frac{V_0}{V}\right)^{\gamma} \qquad V_0 = A\cdot A_{RATIO}\cdot x_0$$

$$P = P_0 \cdot \left(\frac{V_0}{V}\right)^{\gamma} \qquad V = A\left(A_{RATIO} + x\right)$$

$$P(x) = P_0 \cdot \left(\frac{A \cdot A_{ratio} \cdot x_0}{A\left(A_{ratio} x_0 + x\right)}\right)^{\gamma} - \frac{m \cdot g \cdot \sin(45deg)}{A} = P_0 \cdot \left(\frac{A_{ratio} x_0}{x + .892 x_0}\right)^{\gamma} - \frac{m \cdot g \cdot \sin(45deg)}{A}$$

$$P(x) = P_0 \cdot \left(A_{ratio} \cdot x_0\right)^{\gamma} \cdot \left(\frac{1}{x + A_{ratio} x_0}\right)^{\gamma} - \frac{m \cdot g \cdot \sin(45deg)}{A}$$

$$P(x) = P_0 \cdot \left(A_{ratio} \cdot x_0\right)^{\gamma} \cdot \left(x + A_{ratio} x_0\right)^{-\gamma} - \frac{m \cdot g \cdot \sin(45deg)}{A}$$

$$\int_0^{x_{exit}} \frac{P(x) \cdot A}{m} \, dx = \frac{A}{m} \cdot \int_0^{x_{exit}} P(x) \, dx = \frac{A}{m} \cdot \int_0^{x_{exit}} P_0 \cdot \left(A_{ratio} \cdot x_0\right)^{\gamma} \cdot \left(x + A_{ratio} x_0\right)^{-\gamma} - \frac{m \cdot g \cdot \sin(45deg)}{A} \, d$$

For simplicity the integral will be broken up into two integrals:

$$\int_0^{x_{exit}} \frac{P(x) \cdot A}{m} \, dx = \frac{A}{m} \cdot \int_0^{x_{exit}} P_0 \cdot \left(A_{ratio} \cdot x_0\right)^{\gamma} \cdot \left(x + A_{ratio} x_0\right)^{-\gamma} dx - \frac{A}{m} \cdot \int_0^{x_{exit}} \frac{m \cdot g \cdot \sin(45deg)}{A} \, dx$$

$$\frac{A}{m} \cdot \int_0^{x_{exit}} \frac{m \cdot g \cdot \sin(45deg)}{A} \, dx = \frac{1}{m} \cdot \int_0^{x_{exit}} m \cdot g \cdot \sin(45deg) \, dx = m \cdot g \cdot \sin(45deg) \cdot x_{exit}$$

$$\frac{A}{m} \cdot \int_0^{x_{exit}} P_0 \cdot \left(A_{ratio} \cdot x_0\right)^{\gamma} \cdot \left(x + A_{ratio} \cdot x_0\right)^{-\gamma} dx = \frac{A \cdot \left[P_0 \cdot \left(A_{ratio} \cdot x_0\right)^{\gamma}\right]}{m} \cdot \int_0^{x_{exit}} \left(x + A_{ratio} x_0\right)^{-\gamma} dx$$

$$\int_0^{x_{exit}} \left(x + A_{ratio} \cdot x_0\right)^{-\gamma} dx = \int u^{-\gamma} du = \frac{u^{1-\gamma}}{1-\gamma} = \frac{\left(x + A_{ratio} \cdot x_0\right)^{1-\gamma}}{1-\gamma} \qquad \begin{array}{l} u = x + A_{ratio} \cdot x_0 \\ du = 1dx \end{array}$$

$$\int_0^{x_{exit}} \frac{P(x) \cdot A}{m} \, dx = \frac{A \cdot \left[P_0 \cdot \left(A_{ratio} \cdot x_0\right)^{\gamma}\right]}{m} \cdot \frac{\left(x_{exit} + A_{ratio} \cdot x_0\right)^{1-\gamma} - \left(A_{ratio} \cdot x_0\right)^{1-\gamma}}{1-\gamma} - m \cdot g \cdot \sin(45deg) \cdot x_{exit}$$

$$\int_0^{x_{exit}} \frac{P(x) \cdot A}{m} \, dx = \int_0^{v_{exit}} v \, dv = \int_o^{x_{exit}} a \, dx$$

$$\frac{A \cdot P_0 \cdot (A_{ratio} \cdot x_0)^{\gamma}}{m} \cdot \left[\frac{(x_{exit} + A_{ratio} \cdot x_0)^{1-\gamma} - (A_{ratio} \cdot x_0)^{1-\gamma}}{1-\gamma}\right] - m_{uav} \cdot g \cdot \sin(45deg) \cdot x_{exit} = \frac{v_{exit}^{2}}{2} = a \cdot x_e$$

$x_e := 18in$ $\quad x_{exit} := \frac{x_e}{m}$ $\quad x_a := 5in$ $\quad \gamma := 1.4$ $\quad x_0 := \frac{x_a}{m}$

$$P_0 = \frac{\frac{m \cdot v_{exit}^{2}}{2} + m_{uav} \cdot g \cdot \sin(45deg) \cdot x_{exit}}{A \cdot (A_{ratio} \cdot x_0)^{\gamma} \cdot \left[\frac{(x_{exit} + A_{ratio} \cdot x_0)^{1-\gamma} - (A_{ratio} \cdot x_0)^{1-\gamma}}{1-\gamma}\right]}$$

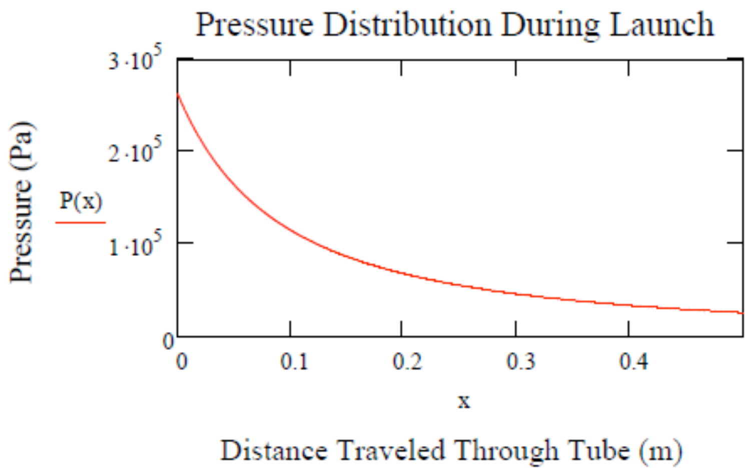
$$P_0 := \frac{\frac{m_{uav} \cdot v_{exit}^{2}}{2} + m_{uav} \cdot g \cdot \sin(45deg) \cdot x_e}{Area_{Circle} \cdot (A_{ratio} \cdot x_0)^{\gamma} \cdot m \cdot \left[\frac{(x_{exit} + A_{ratio} \cdot x_0)^{1-\gamma} - (A_{ratio} \cdot x_0)^{1-\gamma}}{1-\gamma}\right]}$$

$\boxed{P_0 = 2.647 \times 10^{5}\ Pa}$ $\quad \boxed{P_0 = 38.384\ psi}$

$$P(x) := P_0 \cdot x_0^{\gamma} \cdot (x + x_0)^{-\gamma} - \frac{m_{uav} \cdot g \cdot \sin(45deg)}{Area_{Circle}}$$

$\boxed{P(.457) = 3.002 \times 10^{4}\ Pa}$

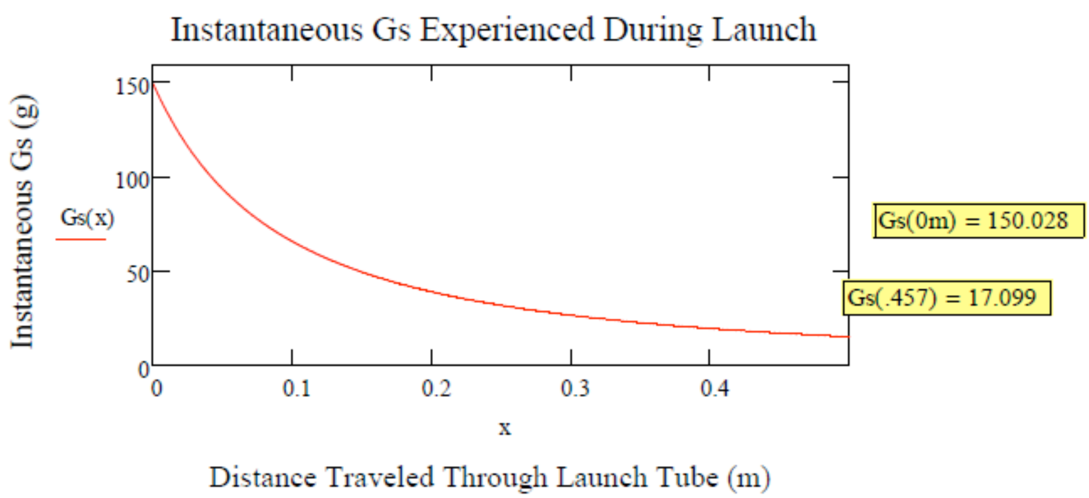
$F_{initial} := P_0 \cdot Area_{Charge}$ $\quad \boxed{F_{initial} = 672.656\ lbf}$ $\quad \boxed{F_{initial} = 672.656\ lbf}$



Instantaneous g experienced by the UAV:

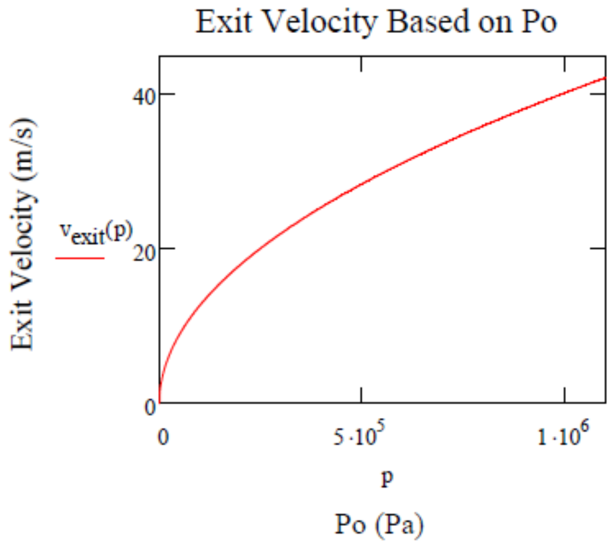
$$Gs(x) := \frac{P(x)\cdot Area_{Circle}}{m_{uav}\cdot g}$$

Note: Still neglecting friction. These calculations are to ac heave an exit velocity of 65ft/s.



Exit Velocity of the UAV based on Po:

$$V_{exit}(p) := \sqrt{\frac{2Area_{Circle}\cdot p\cdot Pa\cdot x_0{}^{\gamma}\cdot m}{m_{uav}}\cdot\left[\frac{(x_{exit}+x_0)^{1-\gamma}-x_0{}^{1-\gamma}}{1-\gamma}\right]}$$



$v_{exit}(10.54683 \cdot 10^5) = 41.341 \frac{m}{s}$

$v_{exit}(10.54683 \cdot 10^5) = 135.633 \frac{ft}{s}$

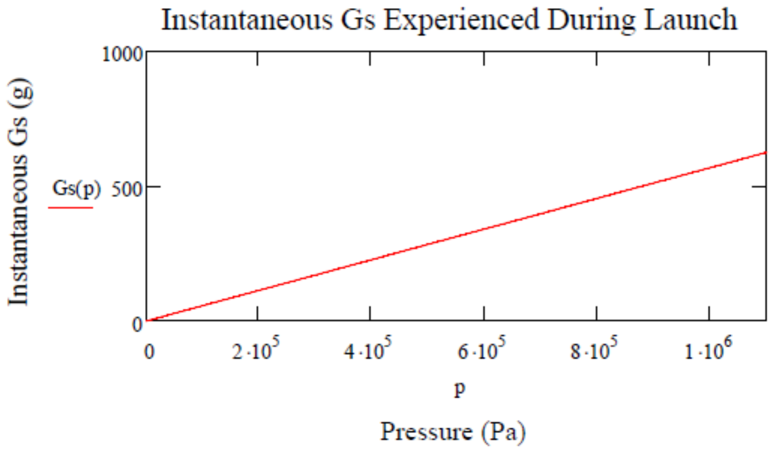
Maximum G Experienced based on Po:

$$Gs(p) := \frac{p \cdot Pa \cdot Area_{Circle} - m_{uav} \cdot g \cdot \sin(45deg)}{m_{uav} \cdot g}$$

$Gs(10.54683 \times 10^5) = 600$

$P_{OMAX} := 10.54683\,10^5 Pa$

$P_{OMAX} = 152.969\,psi$



Tank Pressure Calculations Using Air:

$x_0 := x_a$

$Volume_{Charge} := Area_{Circle} \cdot x_0$

$Volume_{Charge} = 1.609 \times 10^{-3}\, m^3$

$P_{Charge} := P_0$

$P \cdot V = m \cdot R \cdot T$

$T_{AIR} := (27 + 273) \cdot K$

$R_{air} := 287 \frac{J}{kg \cdot K}$

$m_{Charge} := \frac{P_{Charge} \cdot Volume_{Charge}}{R_{air} \cdot T_{AIR}}$

$m_{Charge} = 4.945 \times 10^{-3}\, kg$

The mass requires for ten shots:

$m_{total} := m_{Charge} \cdot 10$

$m_{total} = 0.049\, kg$

$Volume_{Tank} := 48 in^3$

Note: For these calculations the process was modeled as an isothermal process. The actual temperature of the air will rise as it is compressed, and fall as it is decompressed. However, if long enough time passes in between compression processes, the temperature of the tanks can be assumed to be ambient temperature of the surroundings.

$$m_{InitialResevoir} := \frac{P_0 \cdot Volume_{Tank}}{R_{air} \cdot T_{AIR}}$$

$$m_{InitialResevoir} = 2.418 \times 10^{-3}\ kg$$

$$m_{ResevoirTotal} := m_{InitialResevoir} + m_{total}$$

$$P_{ResevoirTotal} := \frac{m_{ResevoirTotal} \cdot R_{air} \cdot T_{AIR}}{Volume_{Tank}}$$

$$m_{ResevoirTotal} = 0.052\,kg$$

$$P_{ResevoirTotal} = 823.464\,psi$$

Stress Calculations:

Stress experienced by cylindrical pressure vessels:

$$\sigma_{1HoopStress} = \frac{P \cdot r}{t}$$

$$\sigma_{2Longitudinal} = \frac{P \cdot r}{2t}$$

Where P is the pressure inside the vessel, r is the inner radius of the vessel, and t is the thickness of the walls of the vessel. For the following calculations the hoop stress of the vessel will only be determined, since its stress is twice the longitudinal stress.

Factors of Safety:

$$FS = \frac{\sigma_{FAIL}}{\sigma_{ALLOW}} = \frac{\sigma_Y}{\sigma_{ALLOW}}$$

For our purposes the pressure vessels will fail when permanent deformation starts to occur.

For the charge chamber:

$P_{max} := P_0$

$r := 2.375in$

$t_1 := .125in$

The maximum pressure that will be loaded into the charge chamber will be P.o.

$$\sigma_{Charge} := \frac{P_{max} \cdot r}{t_1} \qquad \sigma_{Charge} = 729.304\,psi$$

For PVC:

$\sigma_y := 7500psi$

$$F_S := \frac{\sigma_y}{\sigma_{Charge}} \qquad F_S = 10.284$$

For Polycarbonate:

$\sigma_y := 10400psi$

$$F_S := \frac{\sigma_y}{\sigma_{Charge}} \qquad F_S = 14.26$$

For Carbon Fiber:

$\sigma_y := 29010psi$

$$F_S := \frac{\sigma_y}{\sigma_{Charge}} \qquad F_S = 39.778$$

For Magnesium:

$\sigma_y := 22050psi$

$$F_S := \frac{\sigma_y}{\sigma_{Charge}} \qquad F_S = 30.234$$

For Titanium:

$\sigma_y := 39890psi$

$$F_S := \frac{\sigma_y}{\sigma_{Charge}} \qquad F_S = 54.696$$

For Steel:

$\sigma_y := 30020psi$

$$F_S := \frac{\sigma_y}{\sigma_{Charge}} \qquad F_S = 41.163$$

For AL2024:

$\sigma_y := 255MPa$

$$F_S := \frac{\sigma_y}{\sigma_{Charge}} \qquad \boxed{F_S = 50.712}$$

The team decided to go with Aluminum shell for the charge chamber. This chamber will then be wrapped in carbon fiber creating a higher factor of safety, and the launch barrel will be simply the wrapped carbon fiber.

For the pressure tank: Because the carbon fiber tank the group decided to use is rated for 4500psi, no stress analysis was really needed.

Impulse force Calculations:

$I = F \cdot \Delta t = m \cdot \Delta v$

$P(.457) = 3.002 \times 10^4 \text{ Pa}$

$P = \frac{F}{A} \qquad F = P \cdot A$

$F_{end} := P(.457) \cdot Area_{Circle}$

$F_{end} = 380.295 \text{ N}$

$F_{impulse} := 10 \cdot F_{end}$

$\boxed{F_{impulse} = 3.803 \times 10^3 \text{ N}}$ $\boxed{F_{impulse} = 854.936 \text{ lbf}}$

The time for the carriage to come to a stop is not known, so accurately calculating the impulse force would be rather difficult. The impulse force acting on the carriage was assumed to be a magnitude higher than the force acting on the carriage at 18in (.457m). That is, F(impulse) $\simeq 10 {*} F_{end}$.

Fracture Calculations:

For the stopping mechanism:

The fastener used to attach the stopping cable to the carriage and charge chamber were analyzed to make sure they did not fracture while stopping the carriage.

$D_{fastener} := .25\text{in}$

$A_{fastener} := \frac{\pi \cdot D_{fastener}^2}{4}$

$\sigma_{allow} := \frac{F_{impulse}}{A_{fastener}}$

$\sigma_{allow} = 1.742 \times 10^4 \text{ psi}$

$\sigma_{allow} = 1.201 \times 10^8 \text{ Pa}$

$\sigma_Y := 200\text{MPa}$

$FS_{fastener} := \frac{\sigma_Y}{\sigma_{allow}}$

$FS_{fastener} = 1.666$

Tear out Calculations:

For the stopping mechanism:

$D_{washer} := .505in$

$th := .125in$

$A_{TEAROUT} := \pi \cdot D_{washer} \cdot th$

$$\tau_{allowStop} := \frac{F_{impulse}}{A_{TEAROUT}}$$

$\boxed{\tau_{allowStop} = 2.972 \times 10^{7}\ Pa}$

$\boxed{\tau_{allowStop} = 4.311 \times 10^{3}\ psi}$

$\tau_y := 131MPa$ This yield stress calculation, τ_y, is for Al6061-T6 (Hibbeler, 758).

$$FS_{Stop} := \frac{\tau_y}{\tau_{allowStop}}$$

$FS_{Stop} = 4.407$

For the quick release pin:

$D_{bigWasher} := .88in$

$A_{tearout} := \pi \cdot D_{washer} \cdot th$

$$\tau_{allowInitial} := \frac{P_0 \cdot Area_{Charge}}{A_{tearout}}$$

The highest force exerted on the quick release pin will occur when the charge chamber is fill to Po, the pressure required for one launch.

$\tau_{allowInitial} = 2.339 \times 10^{7}\ Pa$

$\tau_{allowInitial} = 3.392 \times 10^{3}\ psi$

$$FS_{Initial} := \frac{\tau_y}{\tau_{allowInitial}}$$

$FS_{Initial} = 5.602$

Spring Calculations:

$$Area_{Circle} := \frac{\pi \cdot (5.5in)^2}{4}$$

Note: The UAV weighs 3.5lbs, but an additional 1.75lbs was allotted for carriage the uav will sit in while being propelled in the barrel of the launch tube.

$$m_{uav} := 5.25 \cdot lb$$

$$m_{uav} = 2.381\ kg$$

Now that testing data has been taken, the launch process can be modeled a more accurate polytrophic process, instead of an isentropic.

$$v_{exit} := 60 \frac{ft}{s}$$

Recalculating Po based on Pin location, friction, and adiabatic process:

$$D_{Charge} := 4.75in \qquad D_{Pin} := \frac{5}{8} in$$

By having the quick release pin in the back of the charge chamber the initial volume will decrease, thus the initial pressure required had to be recalculated.

$$Area_{Charge} := \frac{\pi \cdot \left(D_{Charge}{}^2 - D_{Pin}{}^2\right)}{4}$$

$$A_{ratio} := \frac{Area_{Charge}}{Area_{Circle}}$$

$$A_{ratio} = 0.733$$

Now that acrylic has been selected, the coeficient of friction from acrylic to acrylic is between .45 and .8 (http://www.scribd.com/doc/8637812/Acrylic-Material-Data-from-PARSGLASS). For our purposes the coeficient of friction will be .625.

$$\mu := .625$$

$$\frac{P}{P_0} = \left(\frac{V_0}{V}\right)^n \qquad V_0 = A \cdot A_{RATIO} \cdot x_0$$

$$P = P_0 \cdot \left(\frac{V_0}{V}\right)^n \qquad V = A\left(A_{RATIO} + x\right)$$

$$P(x) = P_0 \cdot \left(\frac{A \cdot A_{ratio} \cdot x_0}{A\left(A_{ratio} x_0 + x\right)}\right)^n - \frac{m \cdot g \cdot \sin(45deg)}{A} - \mu \cdot \frac{m \cdot g \cdot \cos(45deg)}{A}$$

$$P(x) = P_0 \cdot \left(A_{ratio} \cdot x_0\right)^n \cdot \left(\frac{1}{x + A_{ratio} x_0}\right)^n - \frac{m \cdot g \cdot \sin(45deg)}{A} - \mu \cdot \frac{m \cdot g \cdot \cos(45deg)}{A}$$

$$P(x) = P_0 \cdot \left(A_{ratio} \cdot x_0\right)^n \cdot \left(x + A_{ratio} x_0\right)^{-n} - \frac{m \cdot g \cdot \sin(45deg)}{A} - \mu \cdot \frac{m \cdot g \cdot \cos(45deg)}{A}$$

$$\int_0^{x_{exit}} \frac{P(x) \cdot A}{m}\, dx = \frac{A}{m} \cdot \int_0^{x_{exit}} P(x)\, dx$$

$$\int_0^{x_{exit}} \frac{P(x)\cdot A}{m}\,dx = \frac{A}{m}\cdot\int_0^{x_{exit}} P_0\cdot(A_{ratio}\cdot x_0)^{\gamma}\cdot(x + A_{ratio}\cdot x_0)^{-\gamma} - \frac{m\cdot g\cdot \sin(45deg)}{A} - \mu\cdot\frac{m\cdot g\cdot\cos(45deg)}{A}\,dx$$

For simplicity the integral will be broken up into two integrals:

$$\int_0^{x_{exit}} \frac{P(x)\cdot A}{m}\,dx = \frac{A}{m}\cdot\int_0^{x_{exit}} P_0\cdot(A_{ratio}\cdot x_0)^{\gamma}\cdot(x + A_{ratio}\cdot x_0)^{-\gamma}\,dx\ \ldots$$
$$+ -\frac{A}{m}\cdot\left[\int_0^{x_{exit}} \frac{m\cdot g\cdot(\sin(45deg) + \mu\cdot\cos(45deg))}{A}\,dx\right]$$

$$\frac{A}{m}\cdot\left[\int_0^{x_{exit}} \frac{m\cdot g\cdot(\sin(45deg) + \mu\cdot\cos(45deg)}{A}\,dx\right] = g\cdot x_{exit}\cdot(\sin(45deg) + \mu\cdot\cos(45deg)$$

$$\frac{A}{m}\cdot\int_0^{x_{exit}} P_0\cdot(A_{ratio}\cdot x_0)^{n}\cdot(x + A_{ratio}\cdot x_0)^{-n}\,dx = \frac{A\cdot\left[P_0\cdot(A_{ratio}\cdot x_0)^{\gamma}\right]}{m}\cdot\int_0^{x_{exit}} (x + A_{ratio}\cdot x_0)^{-n}\,dx$$

$$\int_0^{x_{exit}} (x + A_{ratio}\cdot x_0)^{-n}\,dx = \int u^{-n}\,du = \frac{u^{1-n}}{1-n} = \frac{(x + A_{ratio}\cdot x_0)^{1-n}}{1-n} \qquad u = x + A_{ratio}\cdot x_0 \qquad du = 1\,dx$$

$$\int_0^{x_{exit}} \frac{P(x)\cdot A}{m}\,dx = \frac{A\cdot\left[P_0\cdot(A_{ratio}\cdot x_0)^{\gamma}\right]}{m}\cdot\frac{(x_{exit} + A_{ratio}\cdot x_0)^{1-n} - (A_{ratio}\cdot x_0)^{1-n}}{1-n} - m\cdot g\cdot\sin(45deg)\cdot x_{exit}$$

$$\int_0^{x_{exit}} \frac{P(x)\cdot A}{m}\,dx = \int_0^{v_{exit}} v\,dv = \int_o^{x_{exit}} a\,dx$$

$$\frac{A\cdot P_0\cdot(A_{ratio}\cdot x_0)^{\gamma}}{m}\cdot\left[\frac{(x_{exit} + A_{ratio}\cdot x_0)^{1-n} - (A_{ratio}\cdot x_0)^{1-n}}{1-n}\right] - g\cdot\left(\begin{array}{l}\sin(45deg)\ \ldots\\ +\mu\cdot\cos(45deg)\end{array}\right)\cdot x_{exit} = \frac{{v_{exit}}^2}{2}$$

$$P_0 = \frac{\dfrac{m\cdot {v_{exit}}^2}{2} + m_{uav}\cdot g\cdot\sin(45deg)\cdot x_{exit} + \mu\cdot m_{uav}\cdot g\cdot x_{exit}\cdot\cos(45deg)}{A\cdot(A_{ratio}\cdot x_0)^{n}\cdot\left[\dfrac{(x_{exit} + A_{ratio}\cdot x_0)^{1-n} - (A_{ratio}\cdot x_0)^{1-n}}{1-n}\right]}$$

$x_e := 18\text{in}$ $\quad x_{exit} := \frac{x_e}{m}$ $\quad x_a := 5\text{in}$ $\quad \boxed{n := 3}$ $\quad \gamma := 1.4$ $\quad x_0 := \frac{x_a}{m}$ $\quad x_a = 0.127\ \text{m}$

$$P_0 := \frac{\frac{m_{uav} \cdot v_{exit}^2}{2} + m_{uav} \cdot g \cdot \sin(45\text{deg}) \cdot x_e + m_{uav} \cdot g \cdot \mu \cdot x_e \cdot \cos(45\text{deg})}{Area_{Circle} \cdot \left(A_{ratio} \cdot x_0\right)^n \cdot m \cdot \left[\frac{\left(x_{exit} + A_{ratio} \cdot x_0\right)^{1-n} - \left(A_{ratio} \cdot x_0\right)^{1-n}}{1-n}\right]}$$

$$P_{0isentropic} := \frac{\frac{m_{uav} \cdot v_{exit}^2}{2} + m_{uav} \cdot g \cdot \sin(45\text{deg}) \cdot x_e + m_{uav} \cdot g \cdot \mu \cdot x_e \cdot \cos(45\text{deg})}{Area_{Circle} \cdot \left(A_{ratio} \cdot x_0\right)^\gamma \cdot m \cdot \left[\frac{\left(x_{exit} + A_{ratio} \cdot x_0\right)^{1-\gamma} - \left(A_{ratio} \cdot x_0\right)^{1-\gamma}}{1-\gamma}\right]}$$

$\boxed{P_{0isentropic} = 2.262 \times 10^5\ \text{Pa}}$ $\quad \boxed{P_{0isentropic} = 32.809\ \text{psi}}$

$\boxed{P_0 = 5.924 \times 10^5\ \text{Pa}}$ $\quad \boxed{P_0 = 85.913\ \text{psi}}$

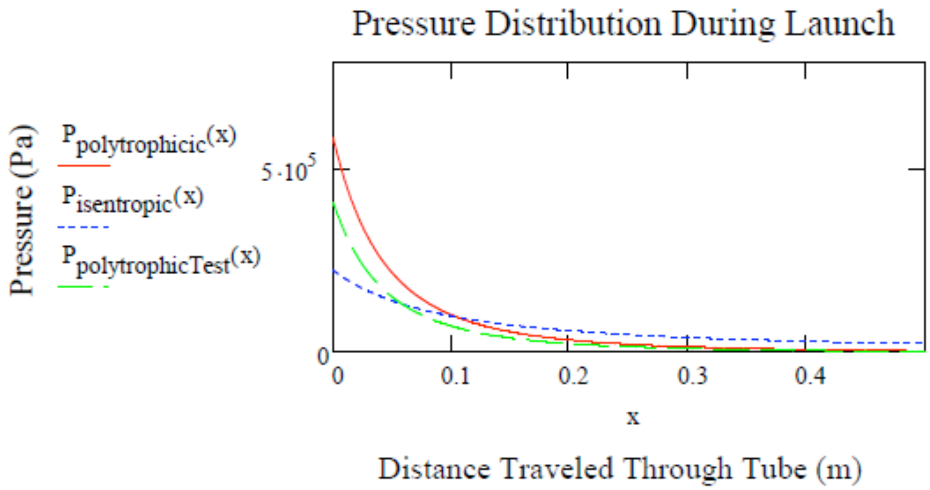
$$P_{polytrophicic}(x) := P_0 \cdot x_0^{\,n} \cdot \left(x + x_0\right)^{-n} - \frac{m_{uav} \cdot g \cdot \sin(45\text{deg}) + \mu \cdot m_{uav} \cdot g \cdot \cos(45\text{deg})}{Area_{Circle}}$$

$$P_{isentropic}(x) := P_{0isentropic} \cdot x_0^{\,\gamma} \cdot \left(x + x_0\right)^{-\gamma} - \frac{m_{uav} \cdot g \cdot \sin(45\text{deg}) + \mu \cdot m_{uav} \cdot g \cdot \cos(45\text{deg})}{Area_{Circle}}$$

$$P_{polytrophicTest}(x) := 60\text{psi} \cdot x_0^{\,n} \cdot \left(x + x_0\right)^{-n} - \frac{m_{uav} \cdot g \cdot \sin(45\text{deg}) + \mu \cdot m_{uav} \cdot g \cdot \cos(45\text{deg})}{Area_{Circle}}$$

$\boxed{P_{polytrophicic}(.457) = 4.341 \times 10^3\ \text{Pa}}$ $\quad \boxed{P_{isentropic}(.457) = 2.497 \times 10^4\ \text{Pa}}$

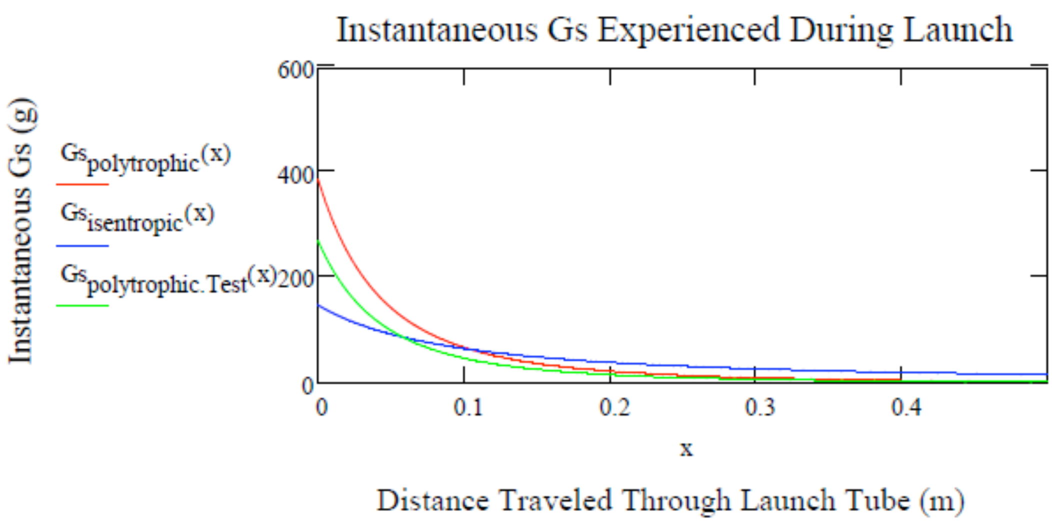
$F_{initial} := P_0 \cdot Area_{Circle}$ $\quad \boxed{F_{initial} = 2.041 \times 10^3\ \text{lbf}}$ $\quad \boxed{F_{initial} = 9.08 \times 10^3\ \text{N}}$



Instantaneous g experienced by the UAV:

$$Gs_{polytrophic}(x) := \frac{P_{polytrophicic}(x)\cdot Area_{Circle}}{m_{uav}\cdot g} \qquad Gs_{isentropic}(x) := \frac{P_{isentropic}(x)\cdot Area_{Circle}}{m_{uav}\cdot g}$$

$$Gs_{polytrophic.Test}(x) := \frac{P_{polytrophicTest}(x)\cdot Area_{Circle}}{m_{uav}\cdot g}$$



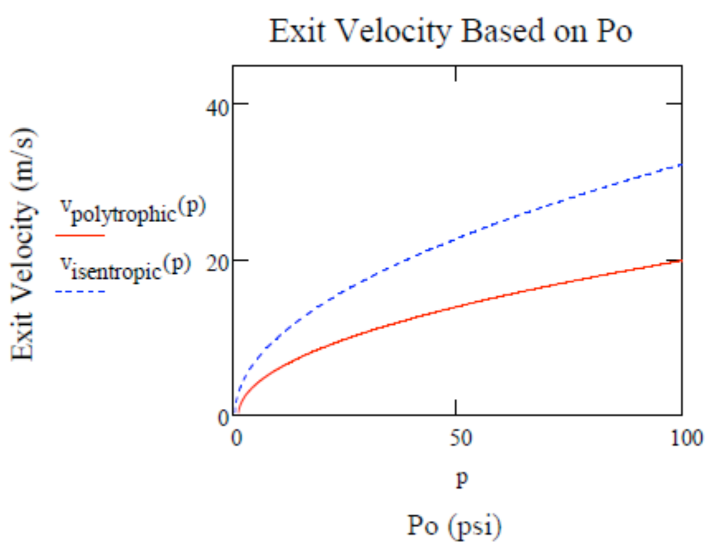
$Gs_{polytrophic}(0) = 387.643$ $\quad Gs_{polytrophic.Test}(0) = 270.374$ $\quad Gs_{isentropic}(0) = 147.324$

$Gs_{polytrophic}(.457) = 2.849$ $\quad Gs_{polytrophic.Test}(.457) = 1.643$ $\quad Gs_{isentropic}(.457) = 16.39$

Exit Velocity of the UAV based on Po:

$$v_{polytrophic}(p) := \sqrt{\frac{2 \cdot p \cdot psi\, Area_{Circle} \cdot (A_{ratio} \cdot x_0)^n \cdot m \cdot \left[\frac{(x_{exit} + A_{ratio} \cdot x_0)^{1-n} - (A_{ratio} \cdot x_0)^{1-n}}{1-n}\right]}{m_{uav}} \cdots + -g \cdot \sin(45deg) \cdot x_e - \mu \cdot g \cdot \cos(45deg) \cdot x_e}$$

$$v_{isentropic}(p) := \sqrt{\frac{2 \cdot p \cdot psi\, Area_{Circle} \cdot (A_{ratio} \cdot x_0)^{1.4} \cdot m \cdot \left[\frac{(x_{exit} + A_{ratio} \cdot x_0)^{1-1.4} - (A_{ratio} \cdot x_0)^{1-1.4}}{1-1.4}\right]}{m_{uav}} \cdots + -g \cdot \sin(45deg) \cdot x_e - \mu \cdot g \cdot \cos(45deg) \cdot x_e}$$



$v_{polytrophic}(7.252) = 4.894 \frac{m}{s}$

$v_{polytrophic}(35) = 26.019\ mph$

$v_{polytrophic}(40) = 27.882\ mph$

$v_{polytrophic}(45) = 29.628\ mph$

$v_{polytrophic}(50) = 31.276\ mph$

$v_{polytrophic}(60) = 34.337\ mph$

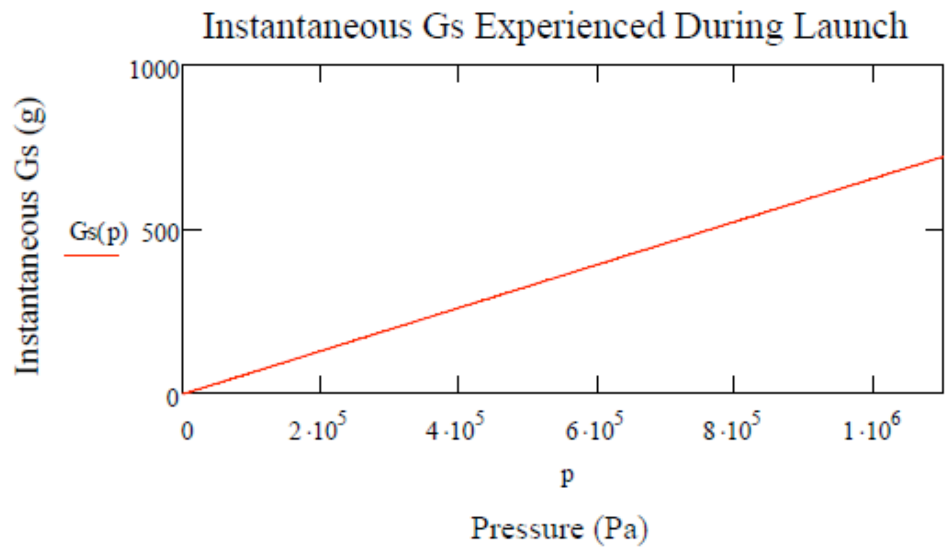
Maximum G Experienced based on Po:

$$Gs(p) := \frac{p \cdot Pa \cdot Area_{Circle} - \left[m_{uav} \cdot g \cdot \sin(45deg) + \mu \cdot (m_{uav} \cdot g \cdot \cos(45deg))\right]}{m_{uav} \cdot g}$$

$Gs(9.15894 \times 10^5) = 600$

$P_{OMAX} := 9.15894\ 10^5 Pa$

$P_{OMAX} = 132.839\ psi$



Projectile Motion Sample calculations:

$$\Delta t := \begin{pmatrix} 2.37 \\ 2.2 \\ 2.4 \\ 2.35 \\ 2.5 \\ 2.1 \end{pmatrix} \cdot s \qquad \Delta x := \begin{pmatrix} 59 \\ 61 \\ 70 \\ 70 \\ 78 \\ 72 \end{pmatrix} \cdot ft$$

$$v_{yf} := 0 \frac{m}{s}$$

$$g = 32.174 \frac{ft}{s^2}$$

$$\theta := 45.92deg$$

<u>Horizontal Velocity Component</u>

$$\Delta x = v_{xi} \cdot \Delta t$$

$$v_{xi} := \frac{\Delta x}{\Delta t}$$

$$v_{xi} = \begin{pmatrix} 24.895 \\ 27.727 \\ 29.167 \\ 29.787 \\ 31.2 \\ 34.286 \end{pmatrix} \frac{ft}{s}$$

<u>Vertical Velocity Component</u>

$$v_y := g \cdot \frac{\Delta t}{2}$$

$$v_y = \begin{pmatrix} 38.126 \\ 35.391 \\ 38.609 \\ 37.805 \\ 40.218 \\ 33.783 \end{pmatrix} \frac{ft}{s}$$

calculated using theoretical height final velocity

$$v_{yf} = v_{yi} - g \cdot \left(g \cdot \frac{\Delta t}{2} \right)$$

$$v_{yi} := g \cdot \frac{\Delta t}{2}$$

$$v_{yi} = \begin{pmatrix} 38.126 \\ 35.391 \\ 38.609 \\ 37.805 \\ 40.218 \\ 33.783 \end{pmatrix} \frac{ft}{s}$$

Total Velocity

$$v_o := \sqrt{v_{xi}^2 + v_{yi}^2}$$

$$v_o = \begin{pmatrix} 45.534 \\ 44.959 \\ 48.387 \\ 48.13 \\ 50.901 \\ 48.133 \end{pmatrix} \frac{ft}{s} \qquad v_o = \begin{pmatrix} 31.046 \\ 30.654 \\ 32.991 \\ 32.816 \\ 34.705 \\ 32.818 \end{pmatrix} mph$$

$$v_{o2} := \sqrt{v_{xi}^2 + v_y^2}$$

$$v_{o2} = \begin{pmatrix} 45.534 \\ 44.959 \\ 48.387 \\ 48.13 \\ 50.901 \\ 48.133 \end{pmatrix} \frac{ft}{s} \qquad v_{o2} = \begin{pmatrix} 31.046 \\ 30.654 \\ 32.991 \\ 32.816 \\ 34.705 \\ 32.818 \end{pmatrix} mph$$

Propagation of error:

$$\frac{\Delta z}{z} = \left[\left(\frac{\Delta t}{t} \right)^2 + \left(\frac{\Delta d}{d} \right)^2 \right]^{.5} \qquad \frac{\Delta z}{z} = \left[.2^2 + \left(\frac{12}{72} \right)^2 \right]^{.5}$$

$$error := \left[.2^2 + \left(\frac{12}{72} \right)^2 \right]^{.5}$$

$$\boxed{error = 0.26}$$

Appendix D

Radar Gun Test Data

Radar Gun Test Data		
Date	Pressure (psi)	Velocity (mph)
4/3/2009	30	26
	30	17
	30	19
	35	21
	35	24
	35	24
	40	27
	40	25
	40	24
	40	29
	45	27
	45	26
	45	26
	50	28
	50	27
4/4/2009	50	26
	55	33
	55	33
	55	32
	60	30
4/7/2009	60	33
	60	34
	60	33

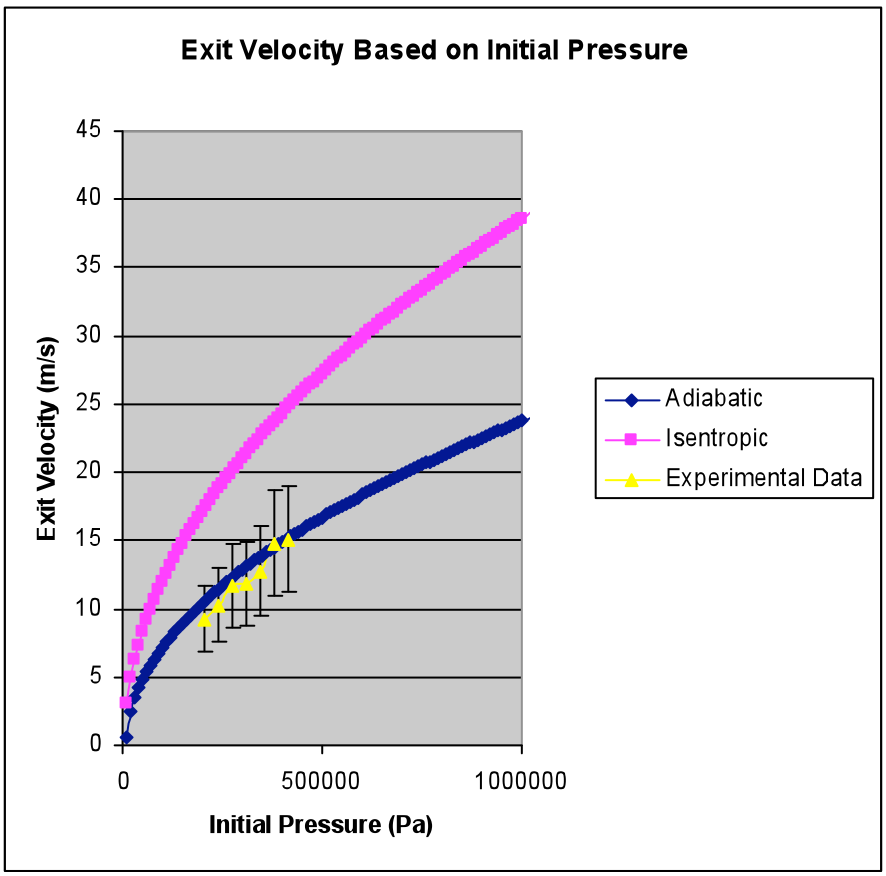
Projectile Motion Calculations

Projectile Motion Calculations						
Date	Pressure (psi)	Distance (ft)	Travel time (s)	Velocity(x) (mph)	Velocity (y) (mph)	Velocity Total (mph)
4/4/2009	50	59	2.37	16.97352827	26.01612943	31.06347779
	50	61	2.2	18.90495364	24.14999356	30.66952006
	55	70	2.4	19.88635833	26.34544752	33.00833005
	55	70	2.35	20.30947234	25.79658403	32.83197244
	55	78	2.5	21.2727216	27.4431745	34.72256487
	60	72	2.1	23.37661714	23.05226658	32.83097963
4/7/2009	60	72.5833333	2.59	19.10757651	28.43112878	34.25534358
	60	73	2.58	19.29174961	28.32135608	34.26763507
	60	73	2.59	19.21726409	28.43112878	34.3166479

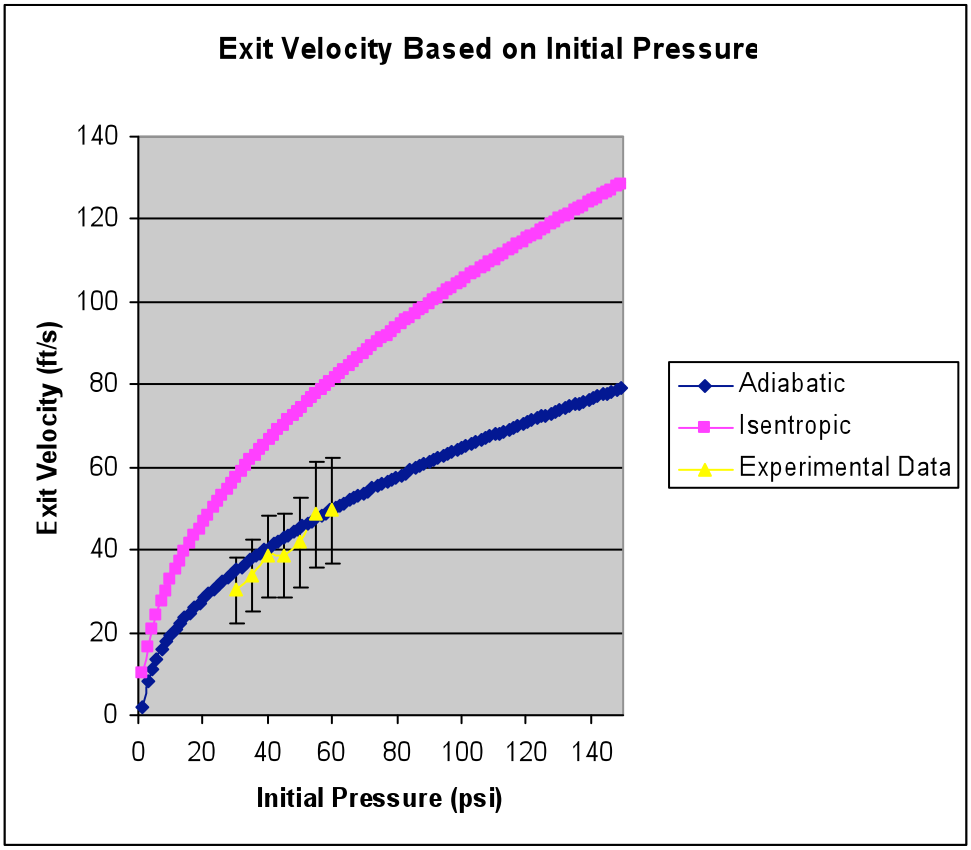
Note: Before the data in blue was collect another air leak was found and corrected. The data in the red was when the test stand broke, so the reading was inaccurate (low).

Averaged Test Data

Averaged Test Data			
Pressure (Pa)	Pressure (Pa)	Average Velocity (m/s)	Average Velocity (ft/s)
30	206839.4926	9.238826667	30.31111116
35	241312.7413	10.28192	33.73333338
40	275785.9901	11.7348	38.50000006
45	310259.2388	11.77205333	38.62222228
50	344732.4876	12.76147187	41.8683461
55	379205.7363	14.79425737	48.53758987
60	413678.9851	15.11290444	49.5830199

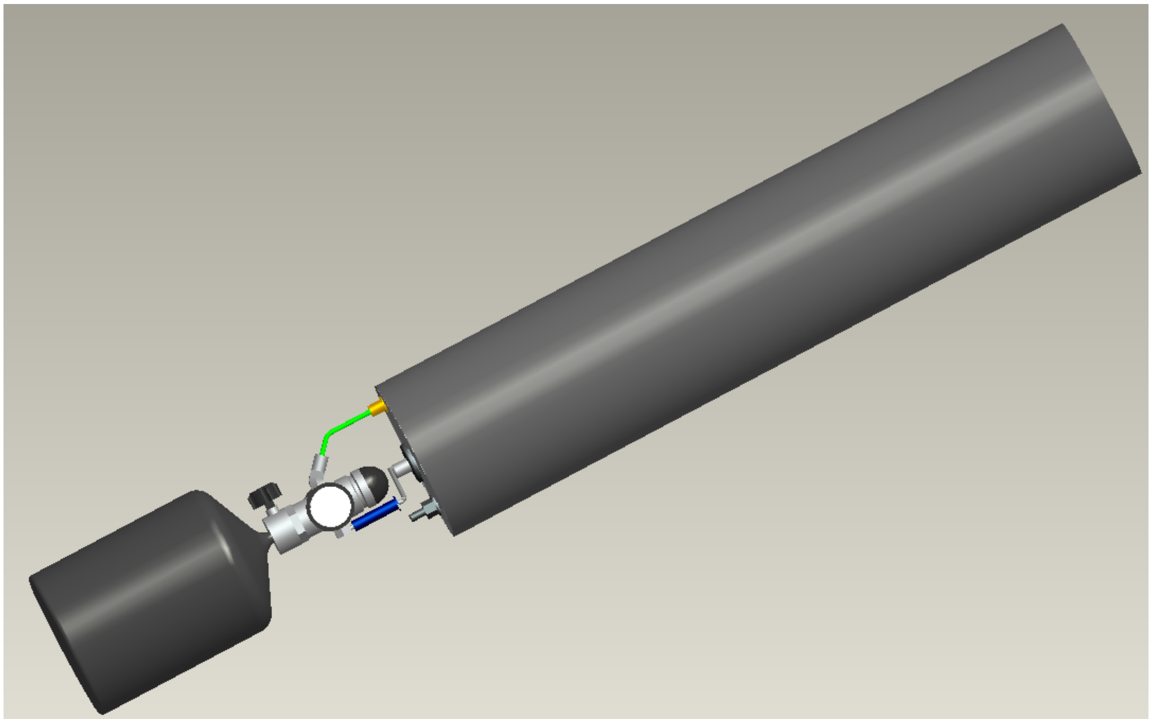


Exit Velocity Based on Initial Pressure

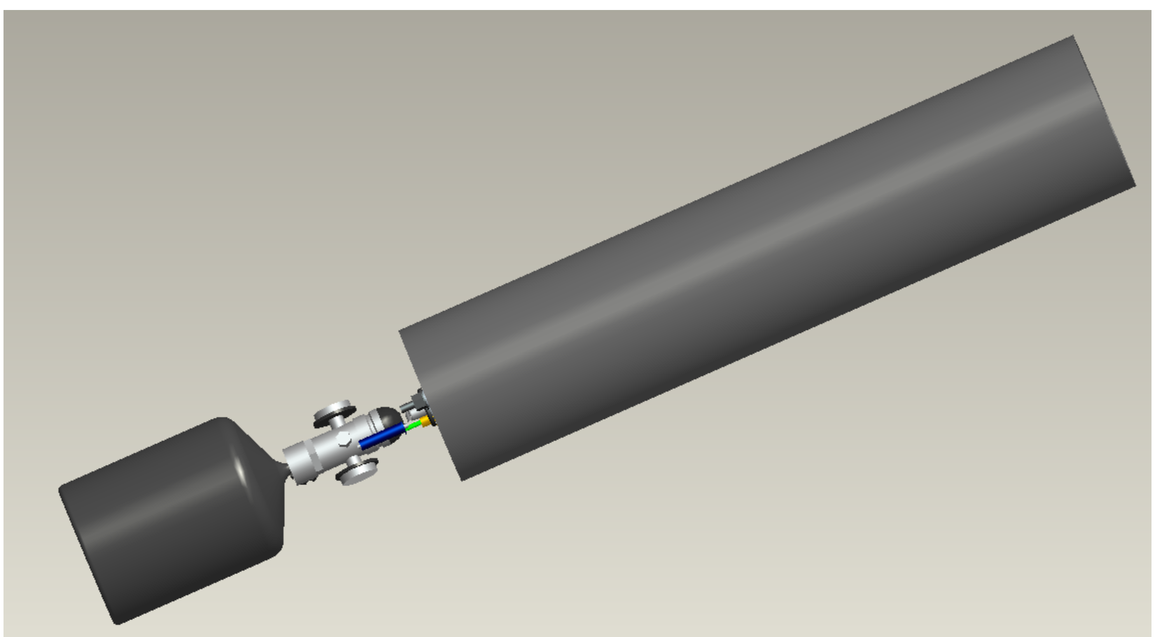


Exit Velocity Based on Initial Pressure

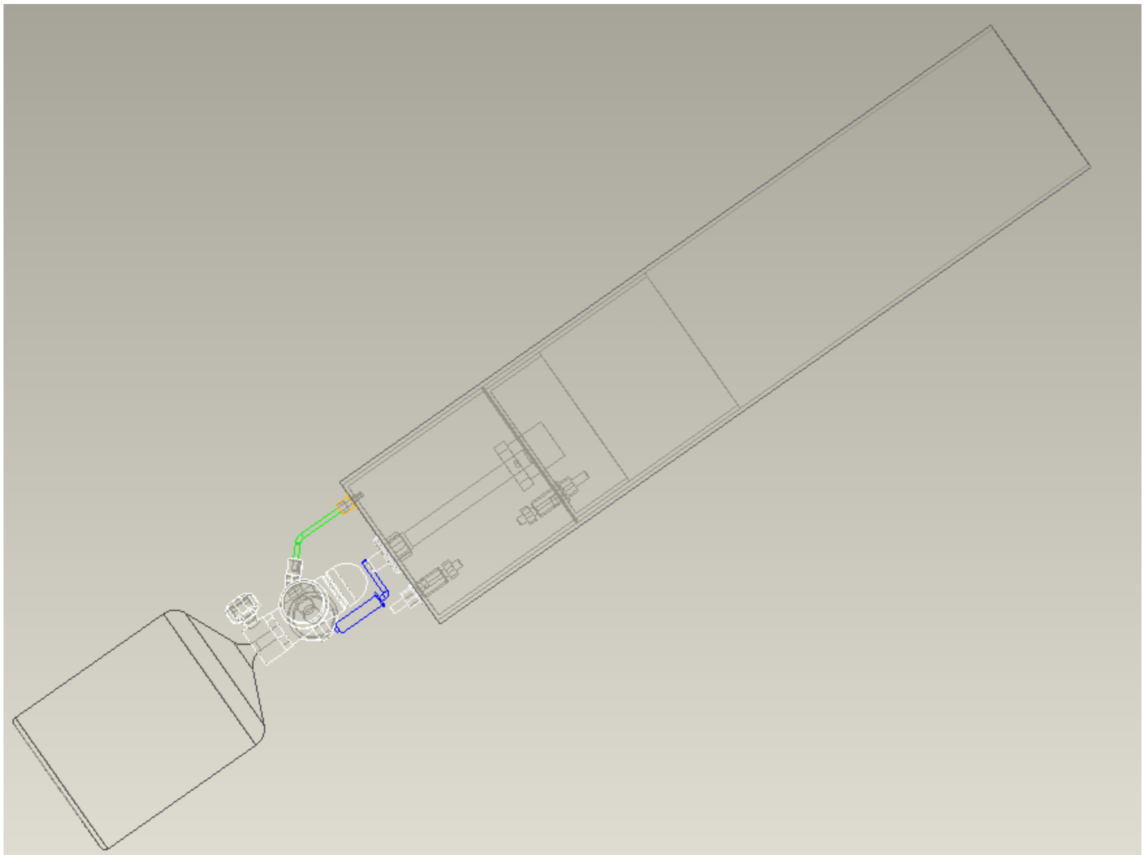
Appendix E
Fall Final Design



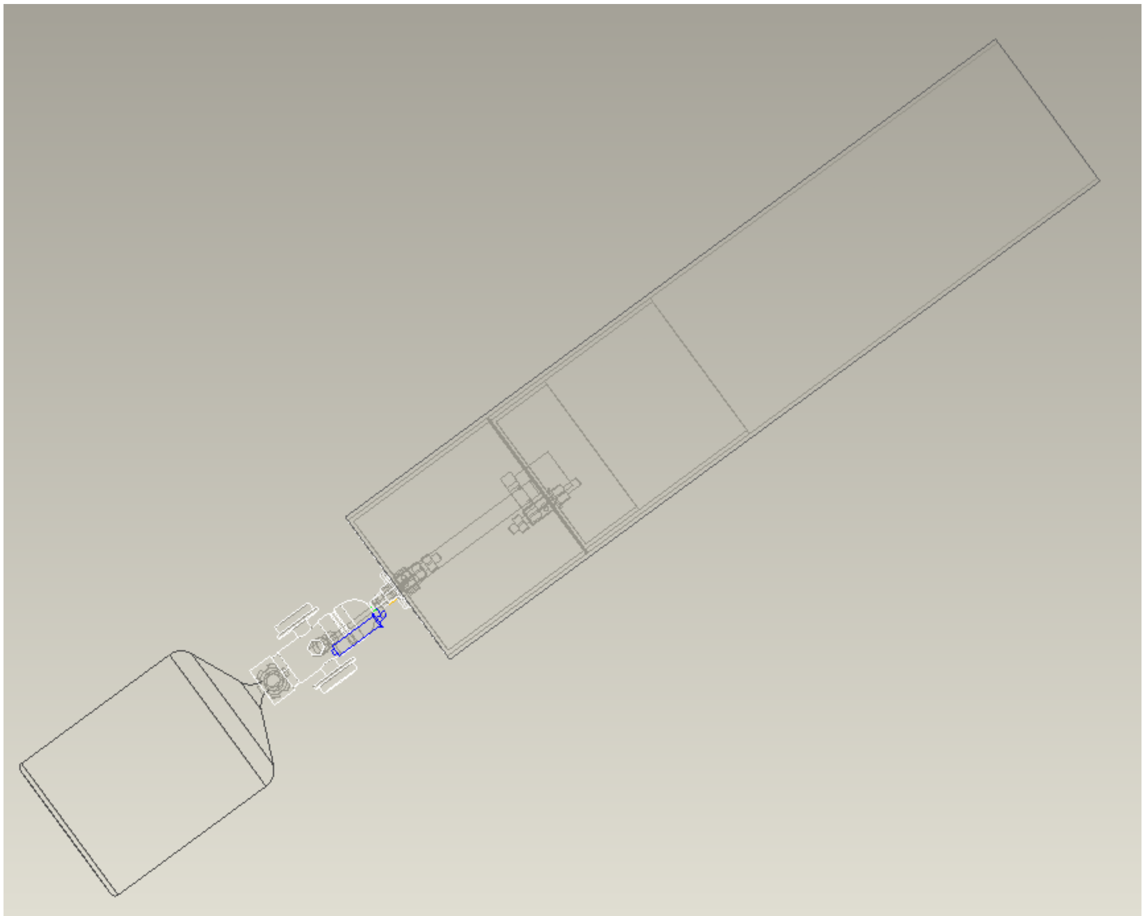
Launch Tube Assembled



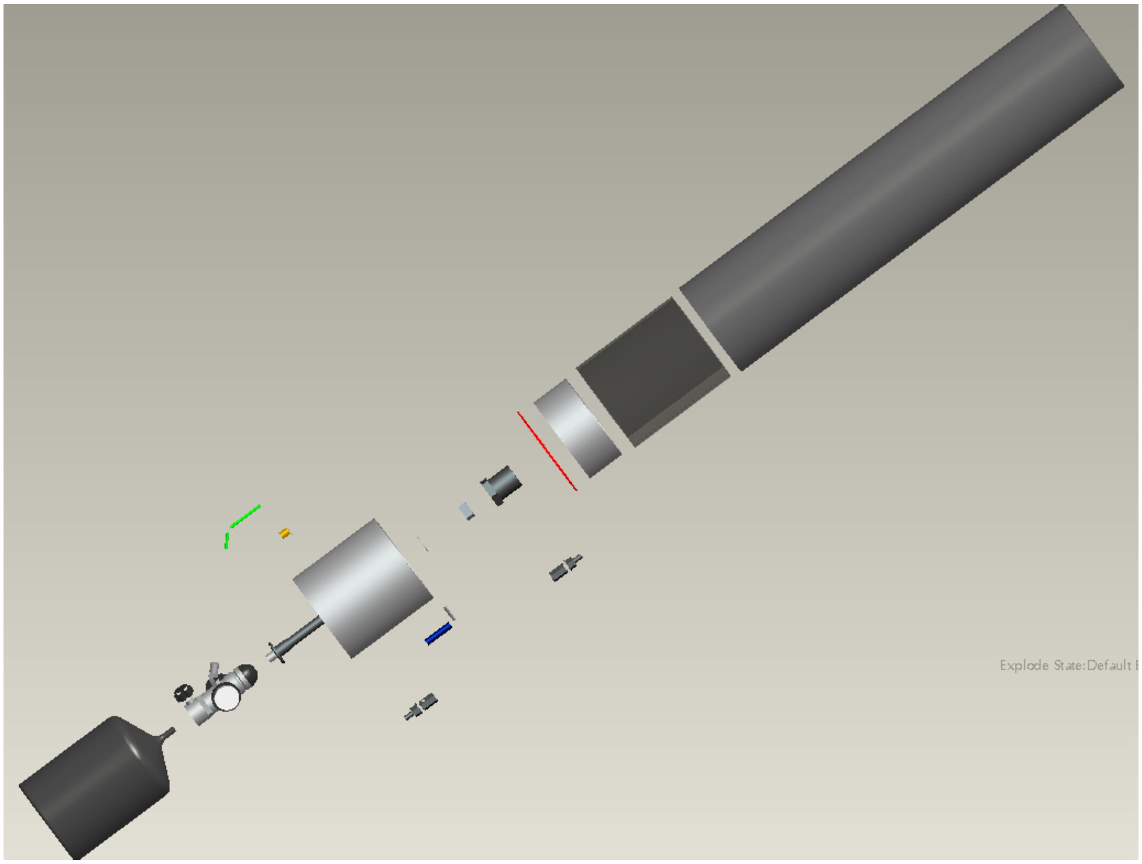
Launch Tube Assembled



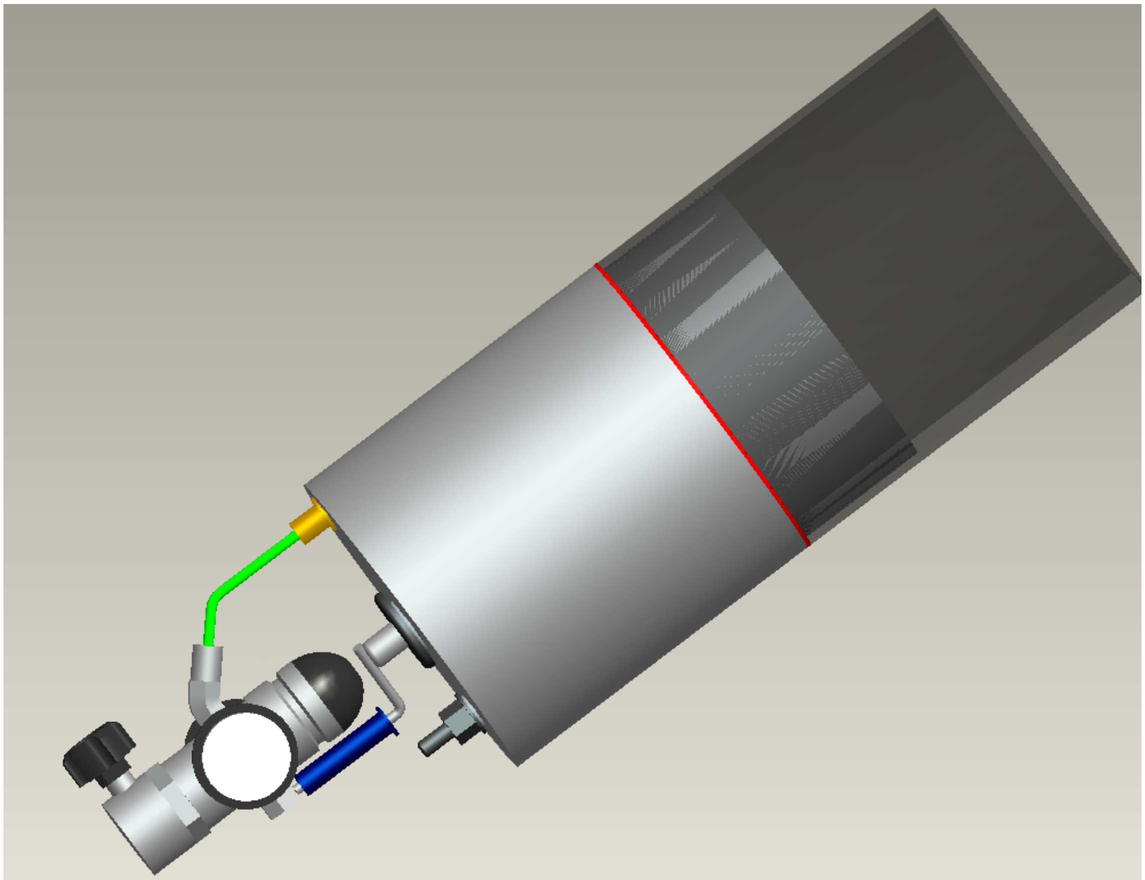
Launch Tube Assembled Clear View



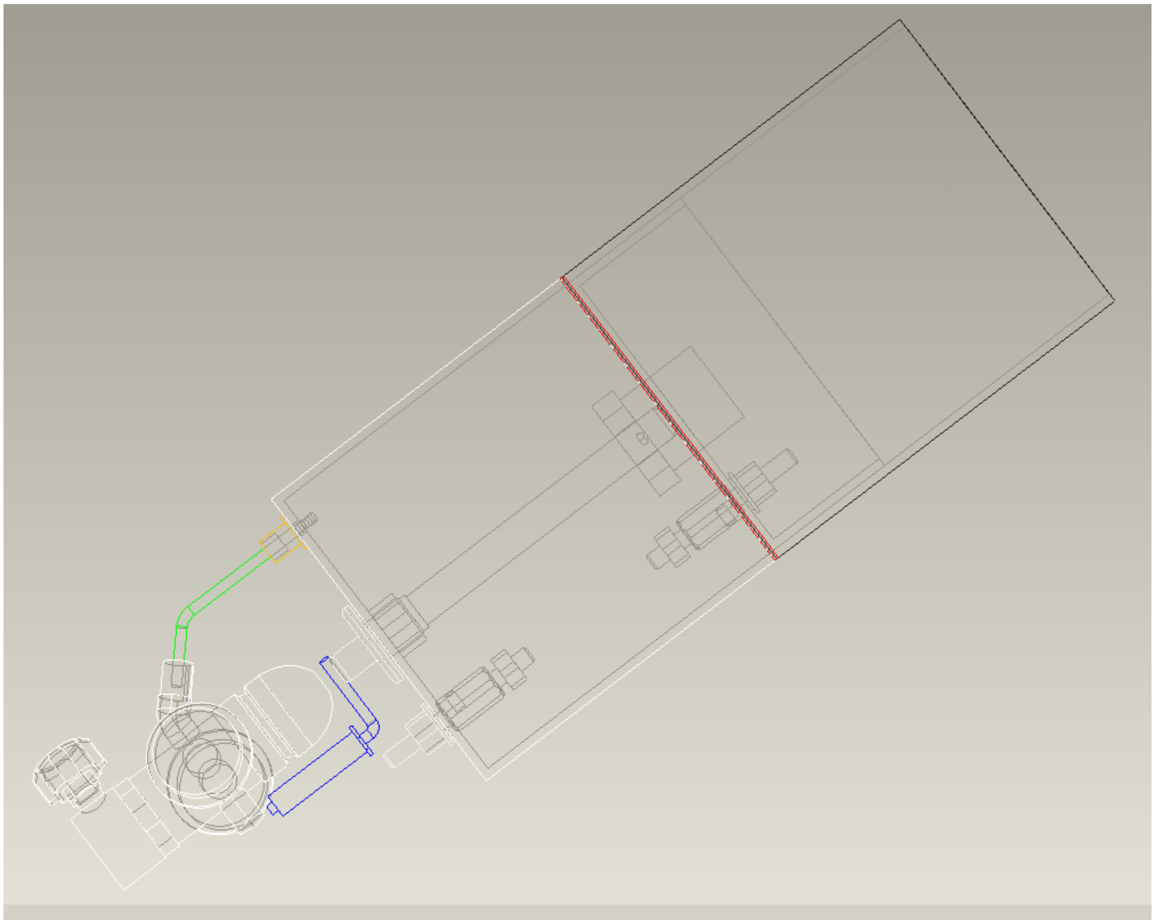
Launch Tube Assembled Clear View



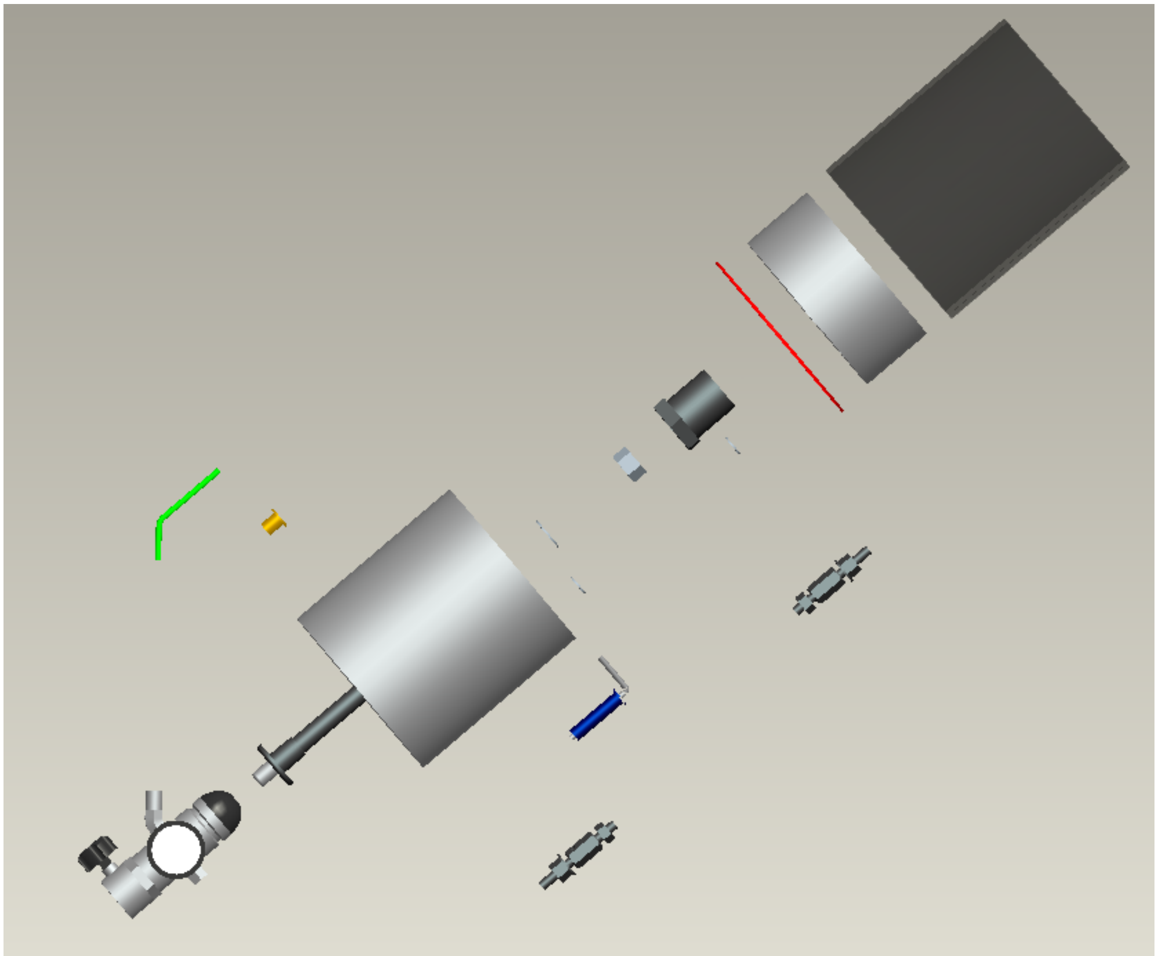
Launch Tube Exploded



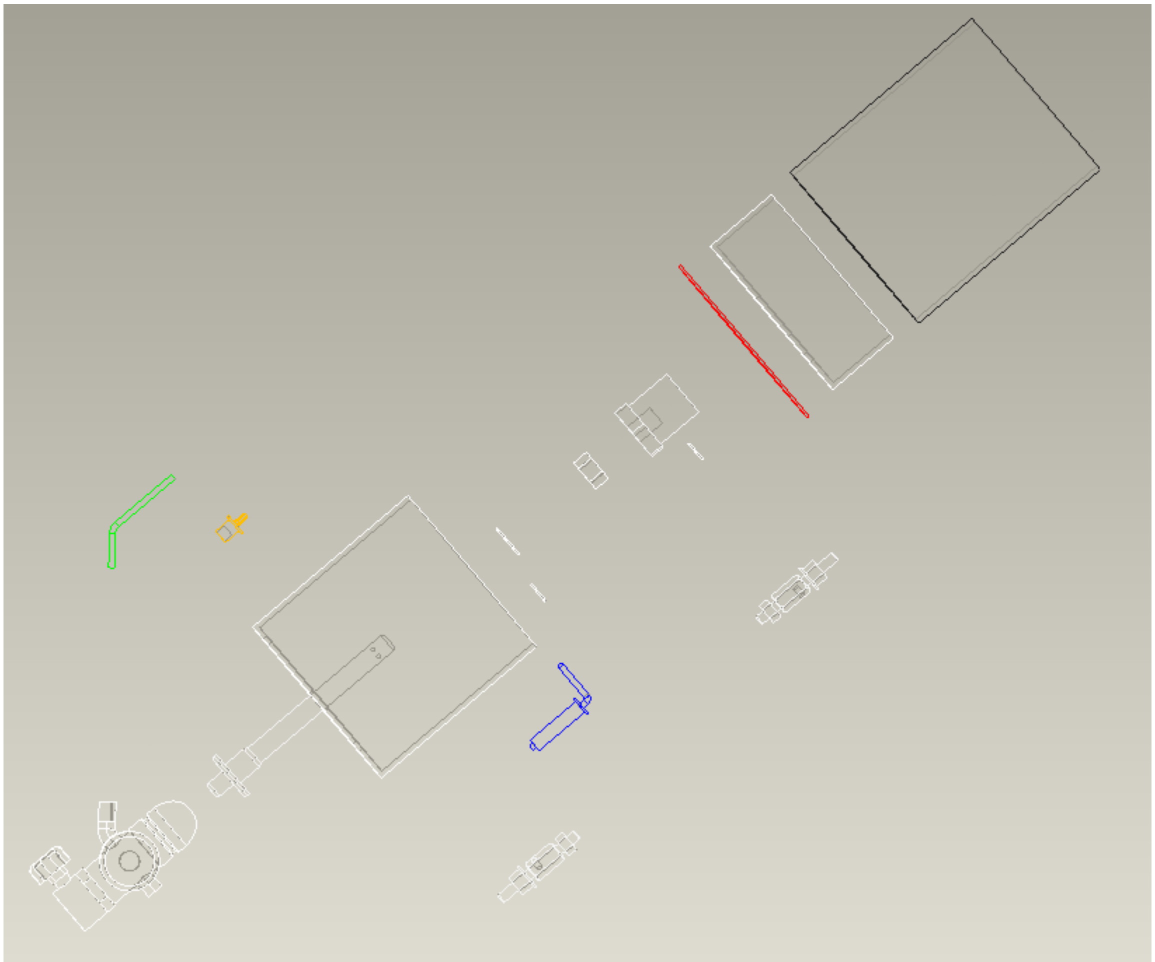
Charge System



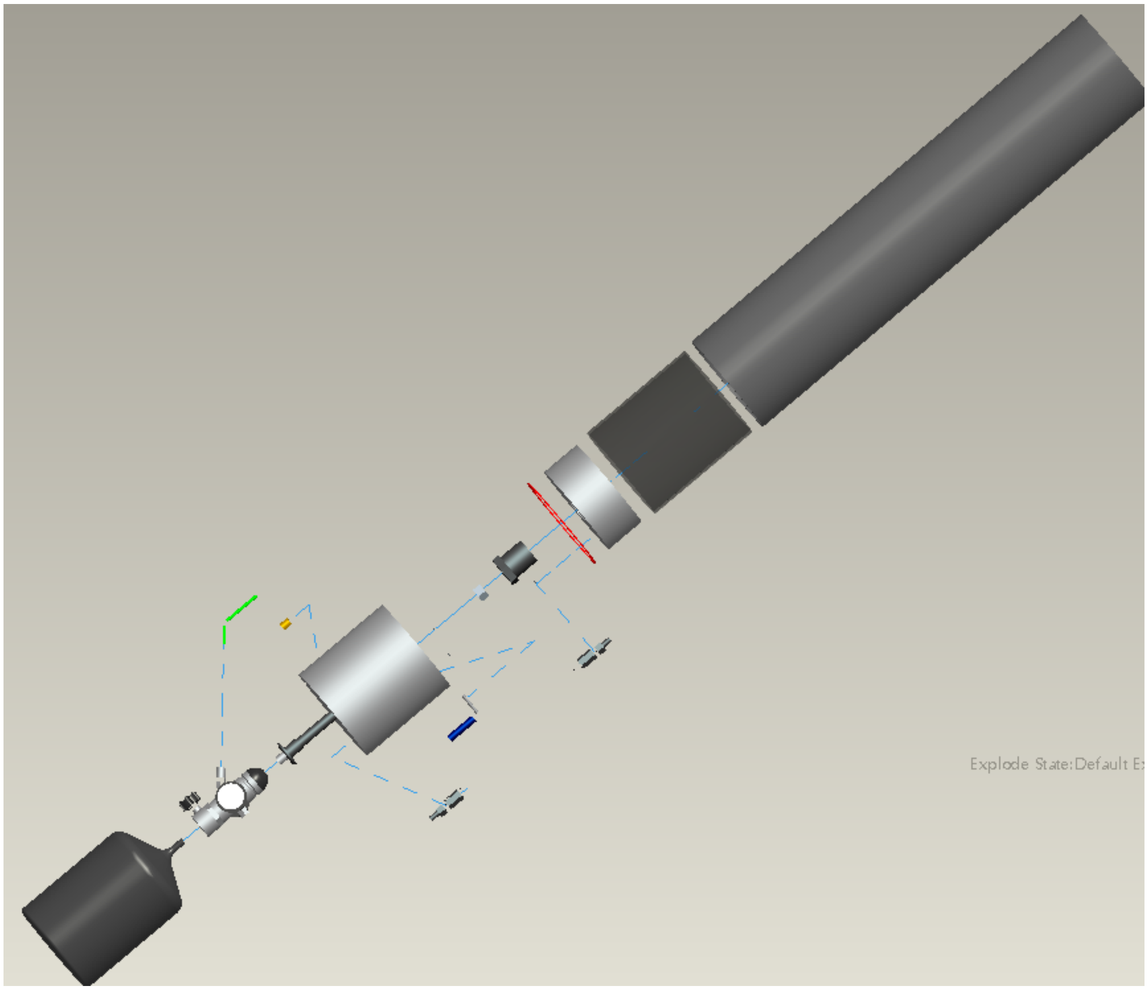
Charge System



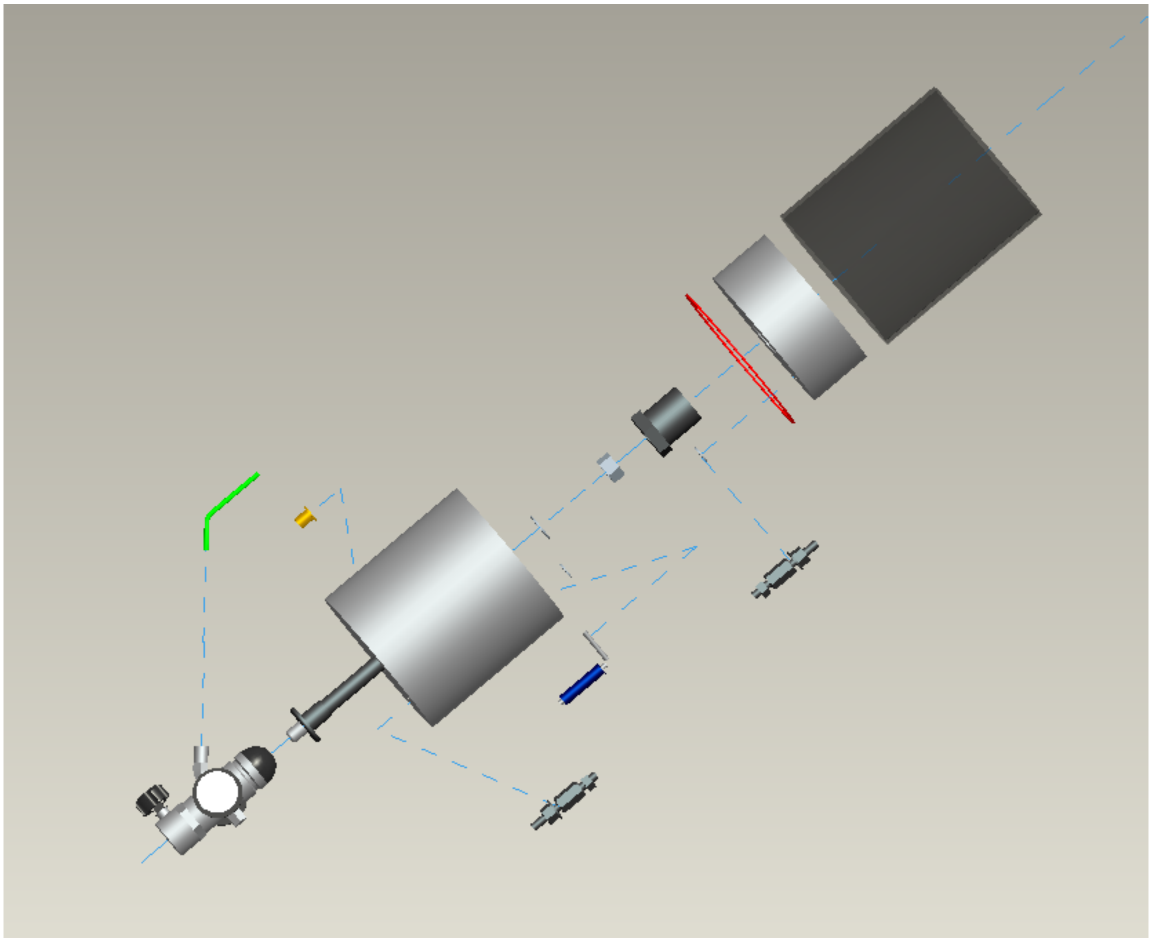
Charge System Exploded View



Charge System Exploded Clear View

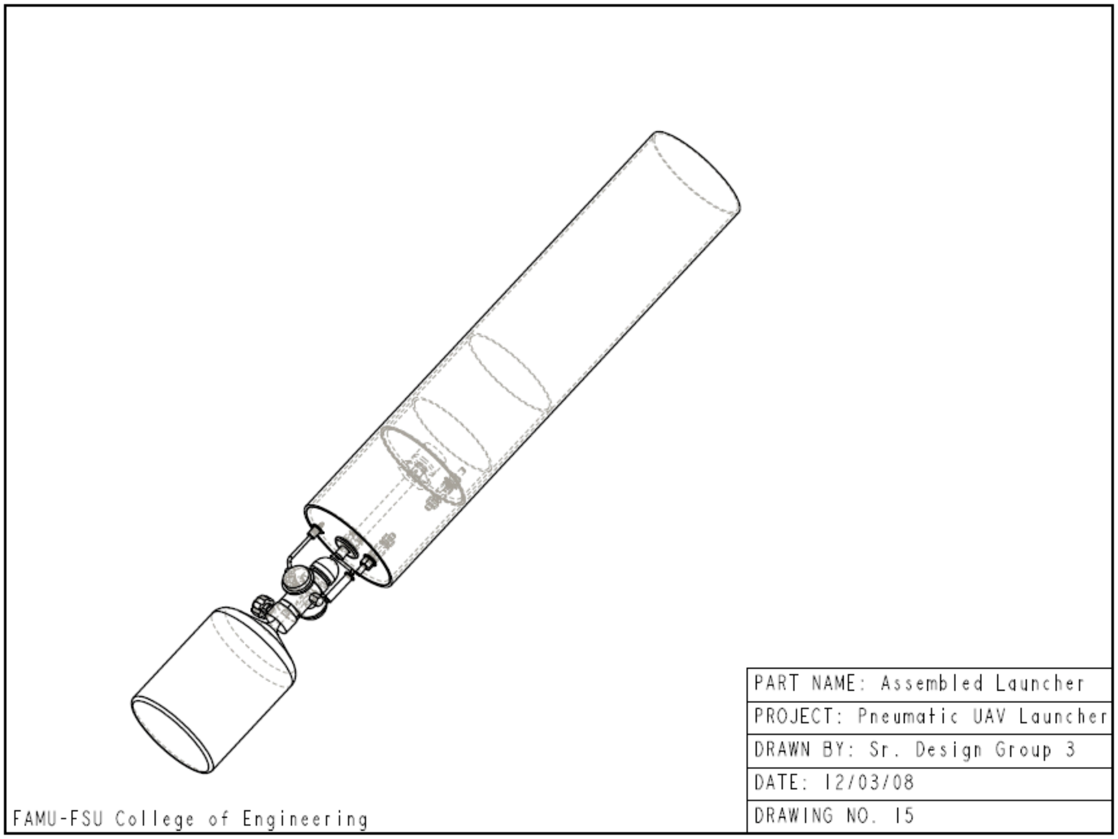


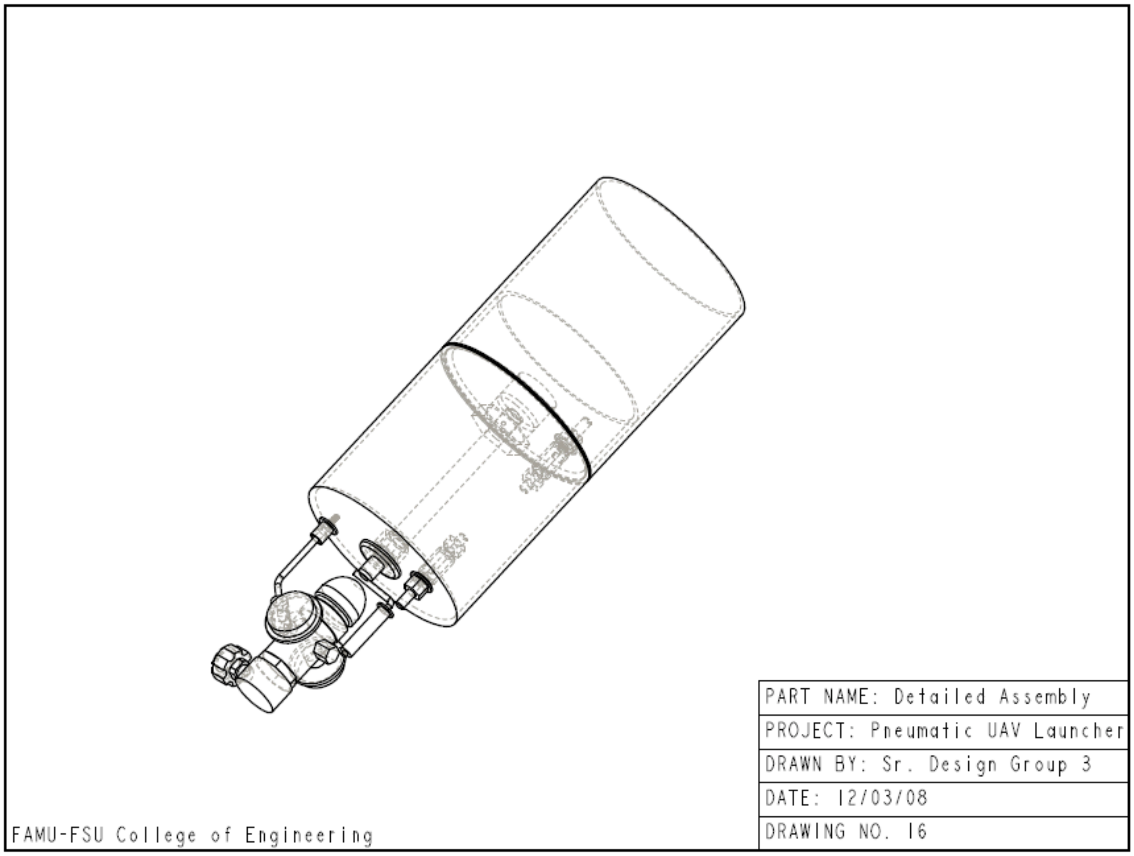
Launch Tube Exploded

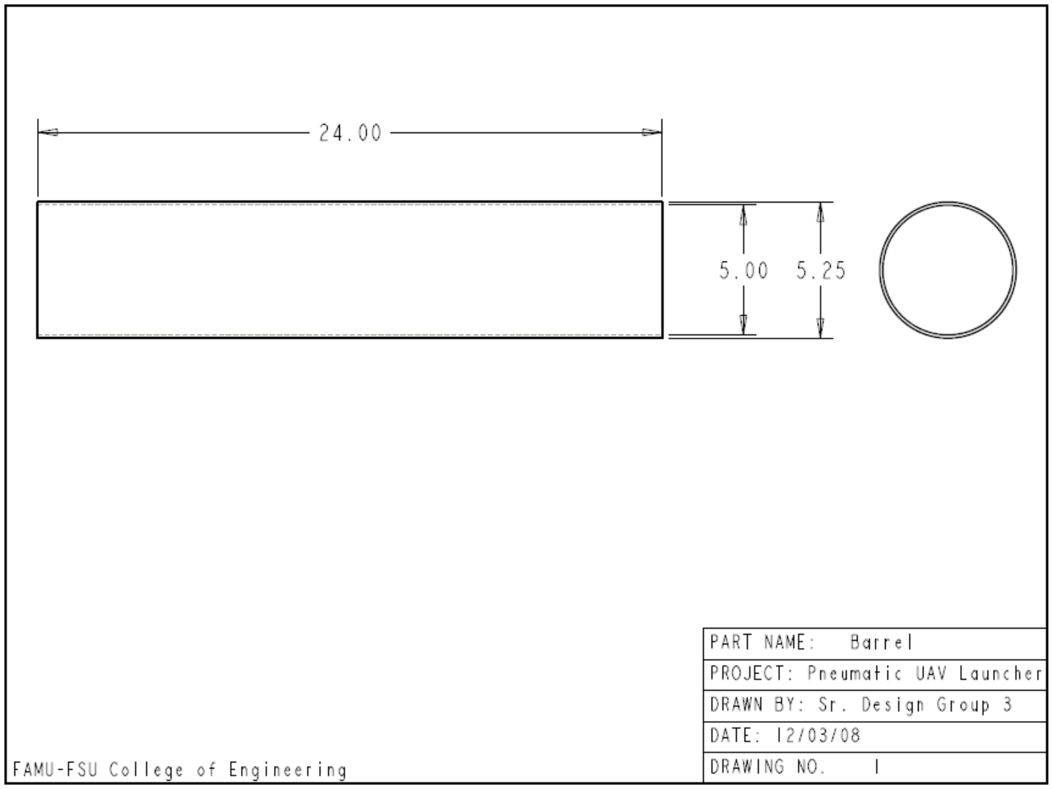


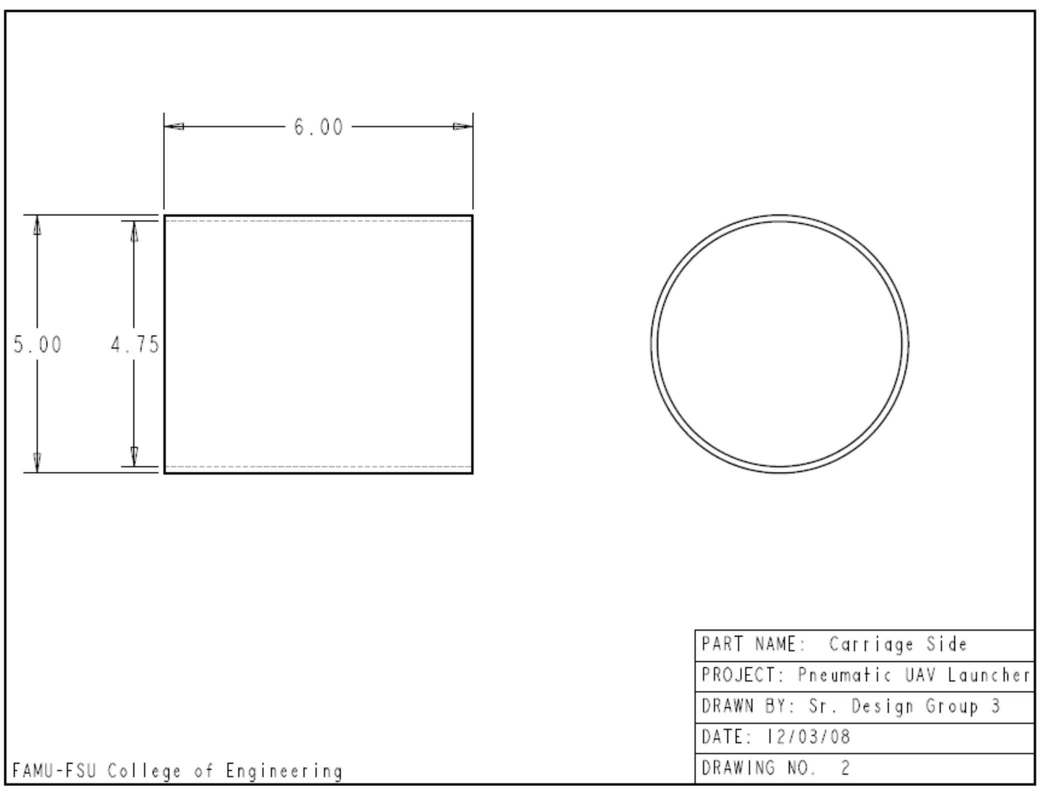
Charge System Exploded

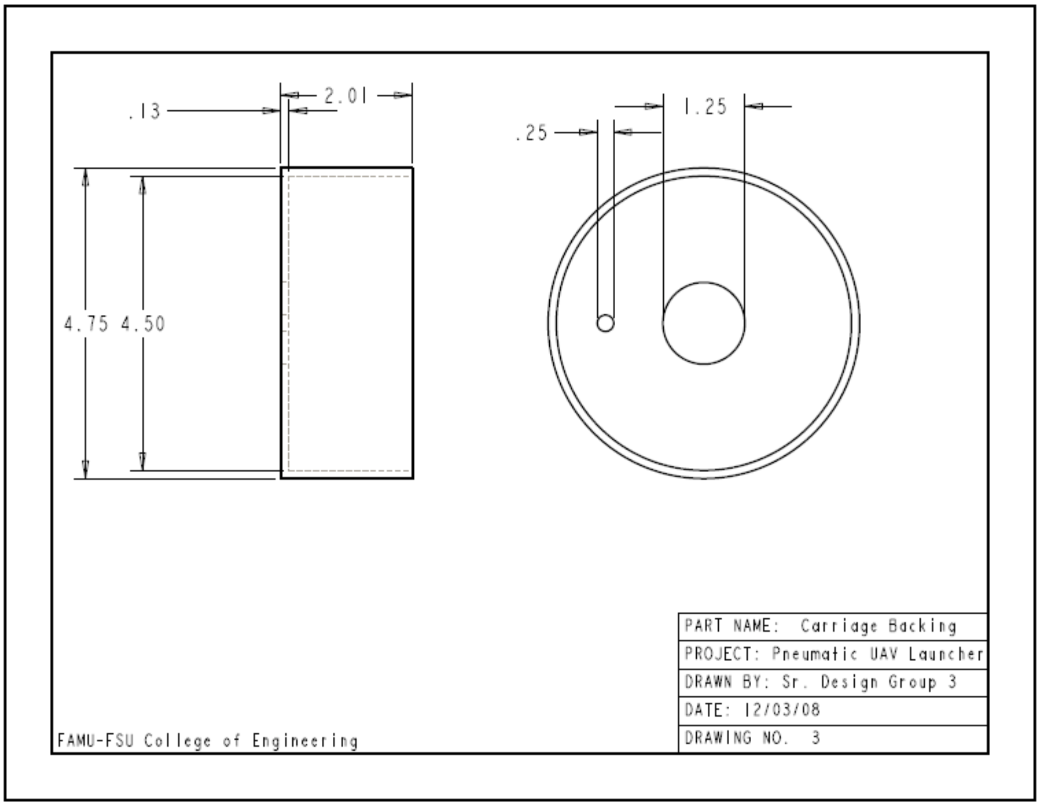
The following are fall final design Pro-E drawings

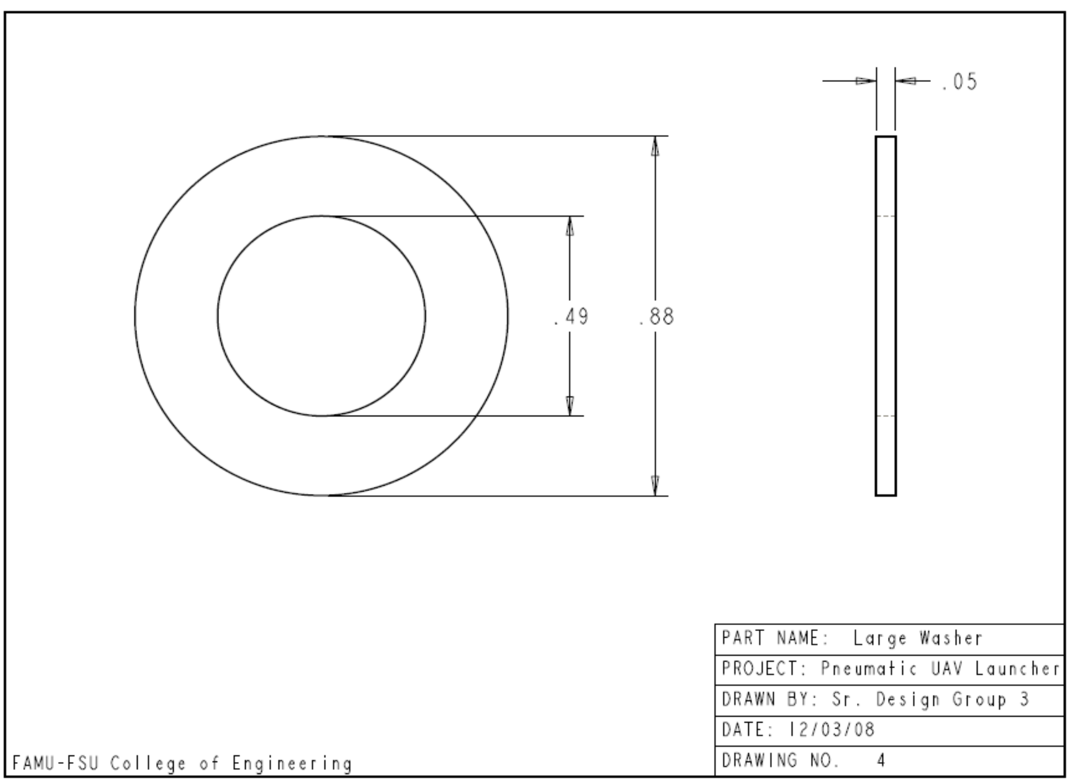


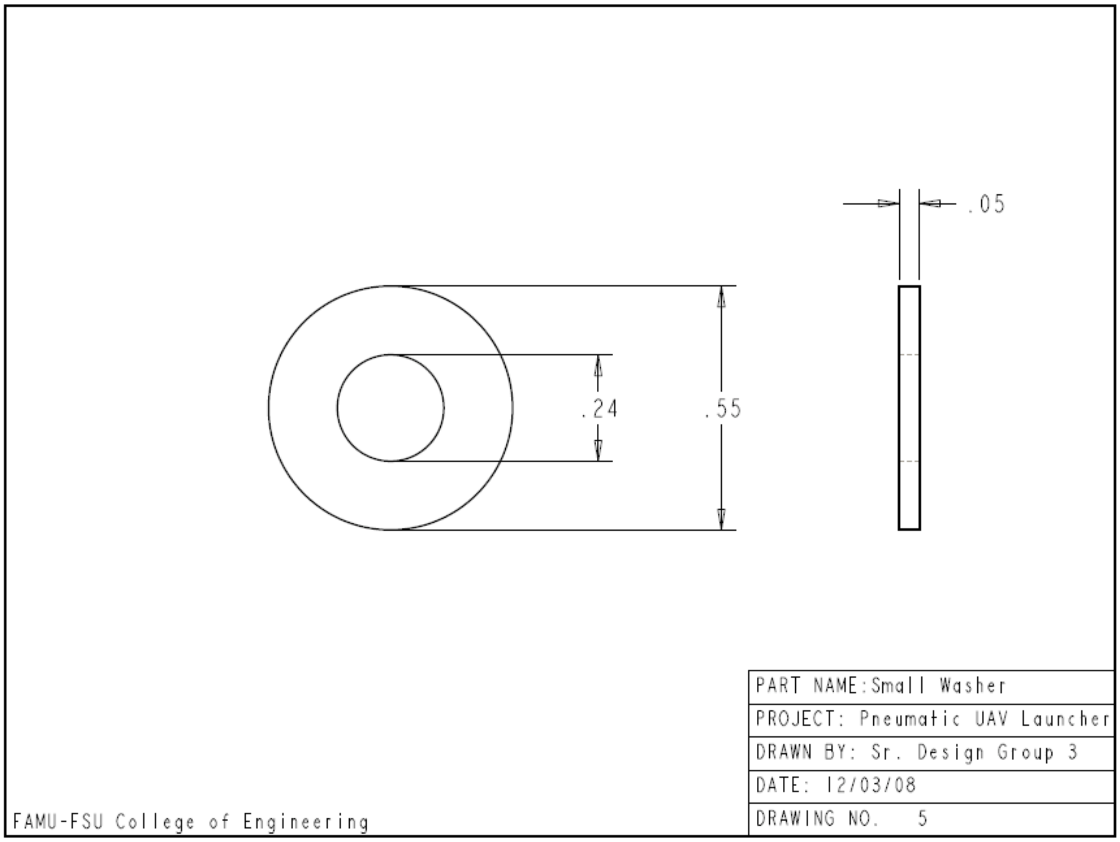

PART NAME: Detailed Assembly
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 16
FAMU-FSU College of Engineering

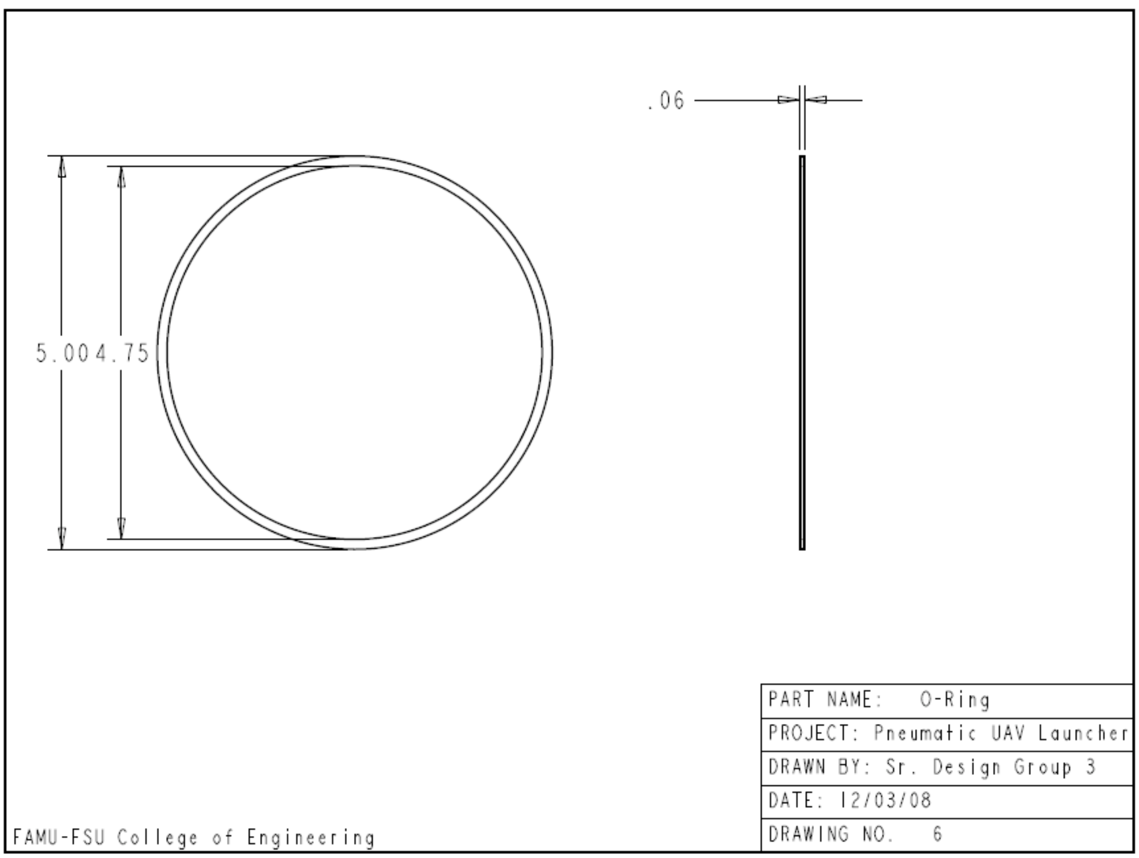

24.00
5.00
5.25
PART NAME: Barrel
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 1
FAMU-FSU College of Engineering

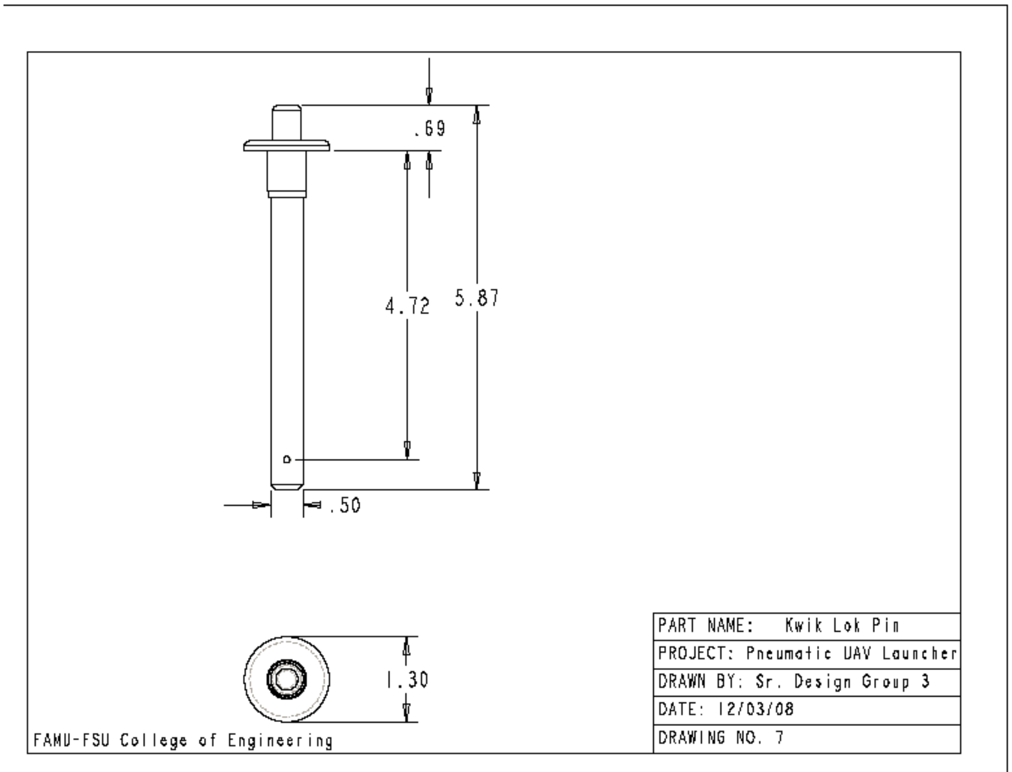

6.00
5.00
4.75
PART NAME: Carriage Side
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 2
FAMU-FSU College of Engineering

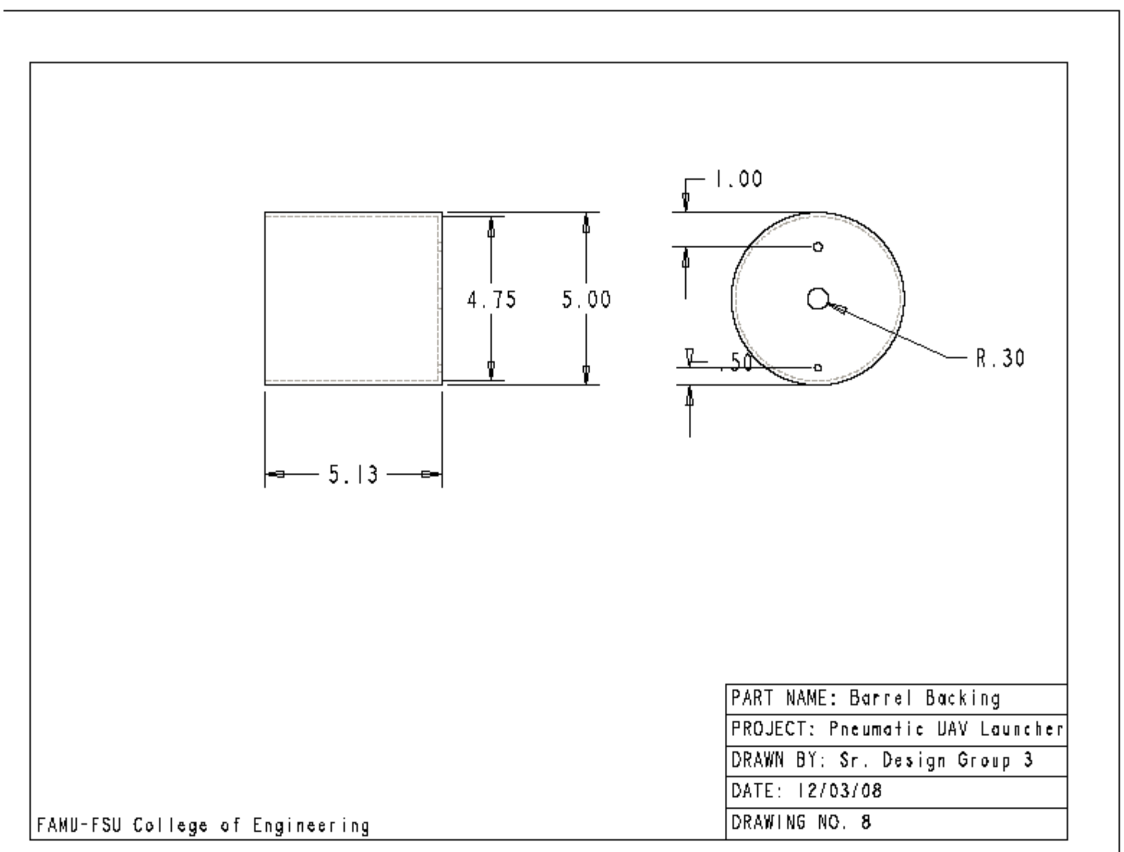

.13
2.01
.25
1.25
4.75 4.50
PART NAME: Carriage Backing
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 3
FAMU-FSU College of Engineering

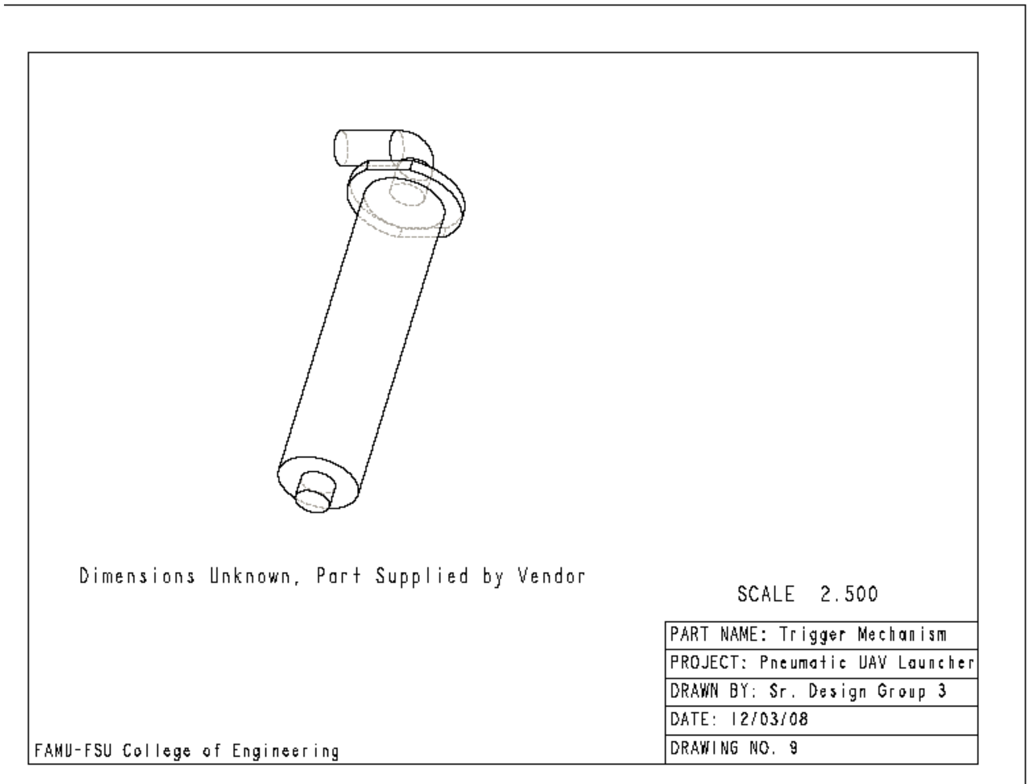

.05
.49
.88
PART NAME: Large Washer
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 4
FAMU-FSU College of Engineering

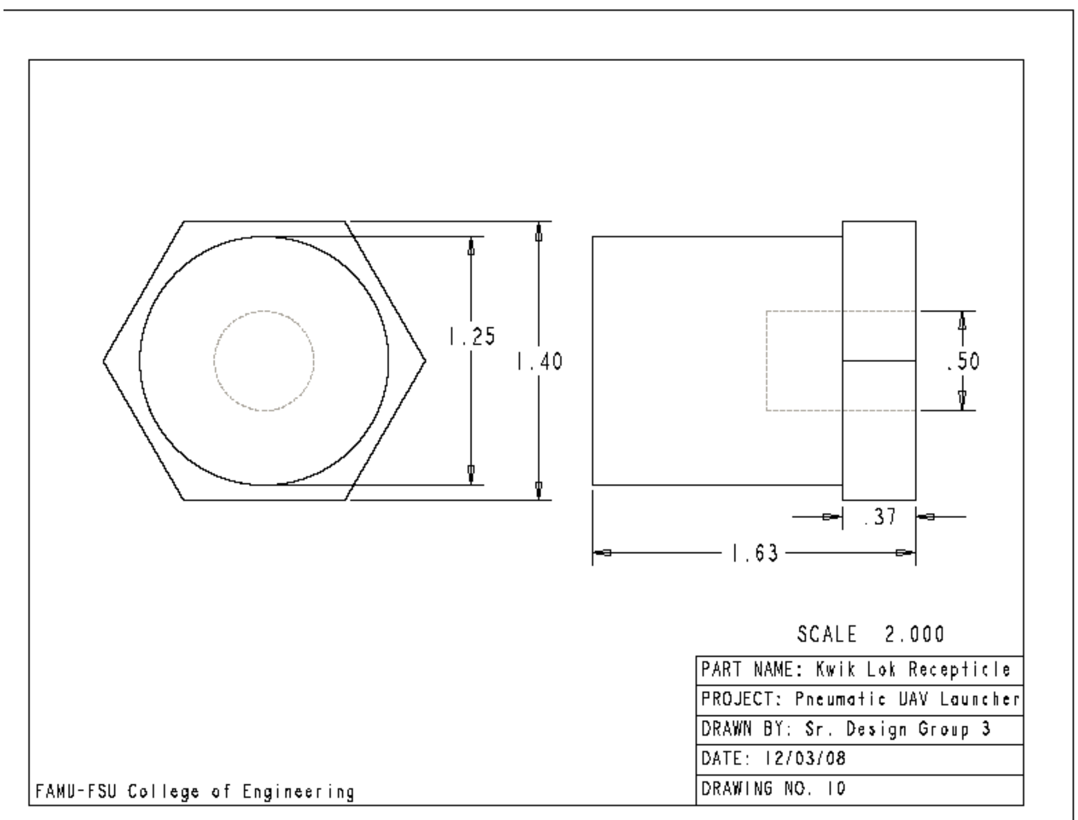

.05
.24
.55
PART NAME:Small Washer
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 5
FAMU-FSU College of Engineering

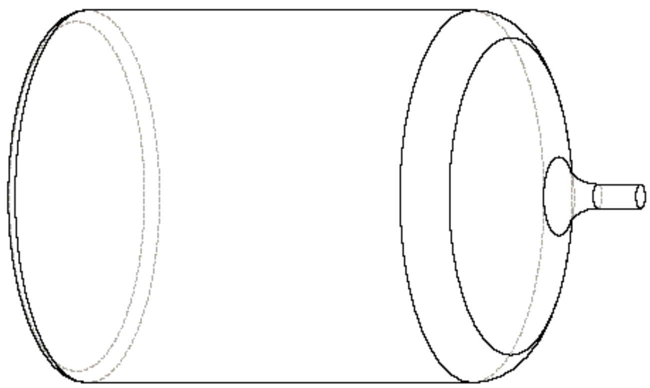

.06
5.00
4.75
PART NAME: O-Ring
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 6
FAMU-FSU College of Engineering


.69
4.72
5.87
.50
1.30
PART NAME: Kwik Lok Pin
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 7
FAMU-FSU College of Engineering


1.00
4.75
5.00
.50
R.30
5.13
PART NAME: Barrel Backing
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 8
FAMU-FSU College of Engineering


Dimensions Unknown, Part Supplied by Vendor
SCALE 2.500
PART NAME: Trigger Mechanism
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 9
FAMU-FSU College of Engineering

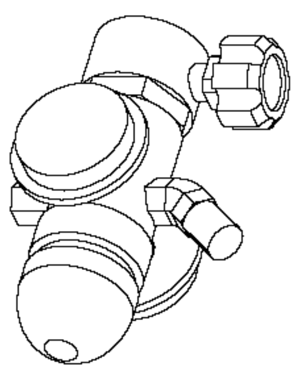

1.25
1.40
.50
.37
1.63
SCALE 2.000
PART NAME: Kwik Lok Recepticle
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 10
FAMU-FSU College of Engineering



SCALE 0.750

Specific Dimensions Unknown, Vendor will supply part

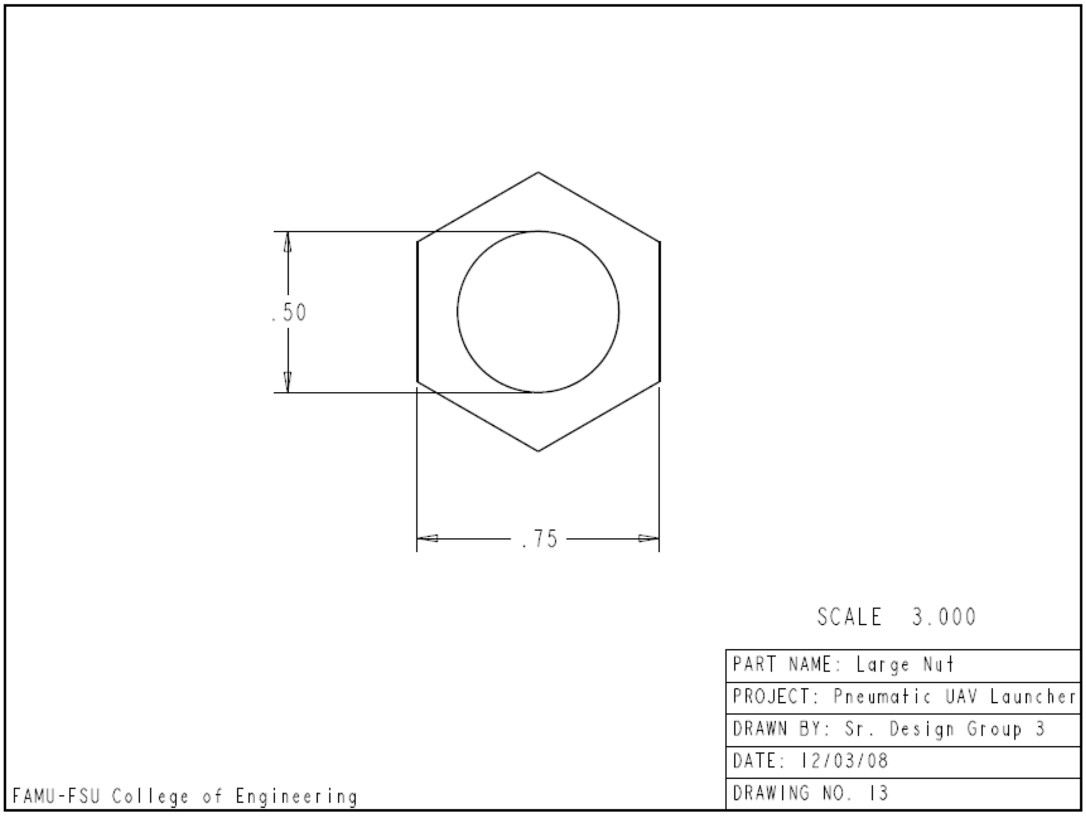
FAMU-FSU College of Engineering	PART NAME: Reservoir Tank
	PROJECT: Pneumatic UAV Launcher
	DRAWN BY: Sr. Design Group 3
	DATE: 12/03/08
	DRAWING NO. 11

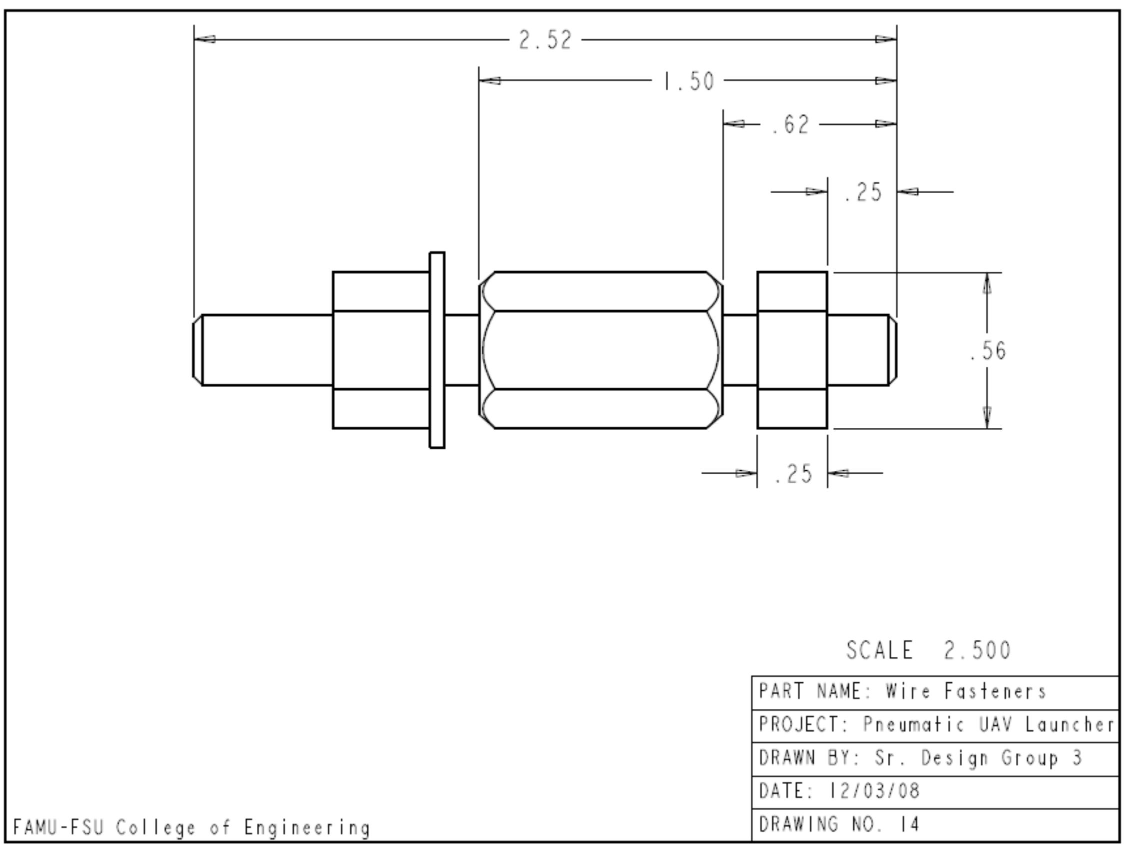


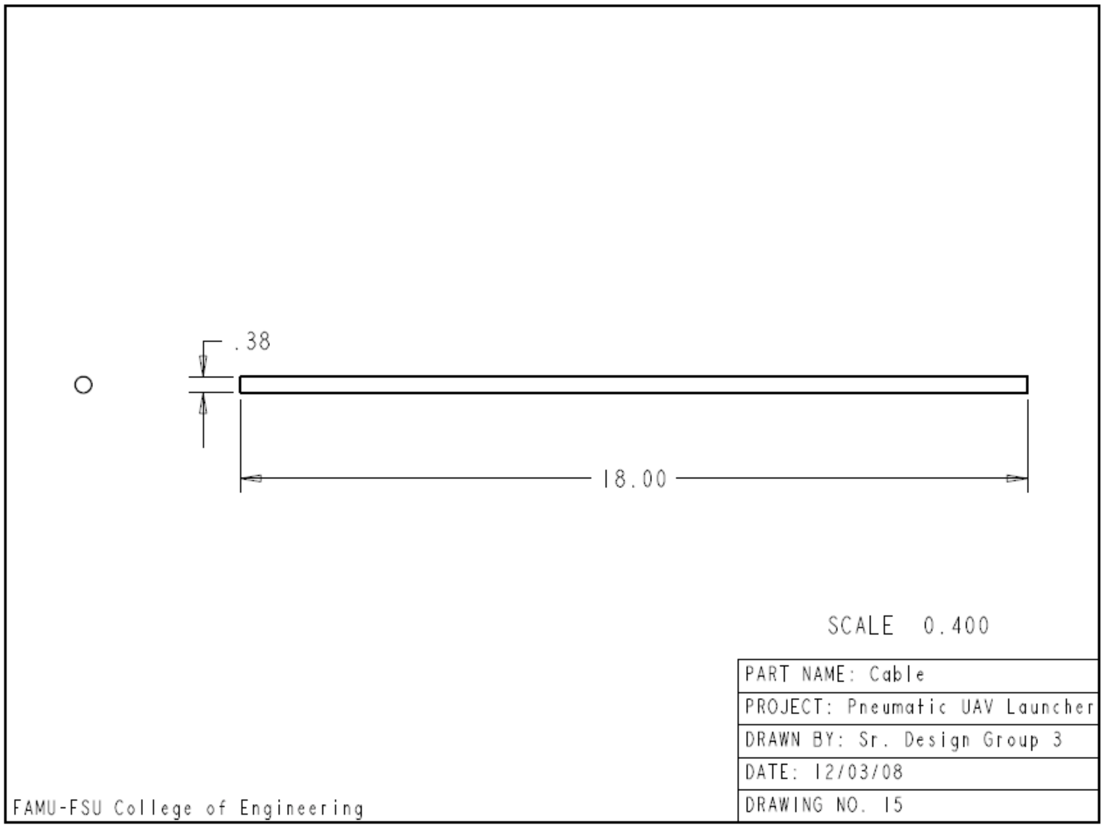
Specific Dimensions are Unknown, Vendor will supply part

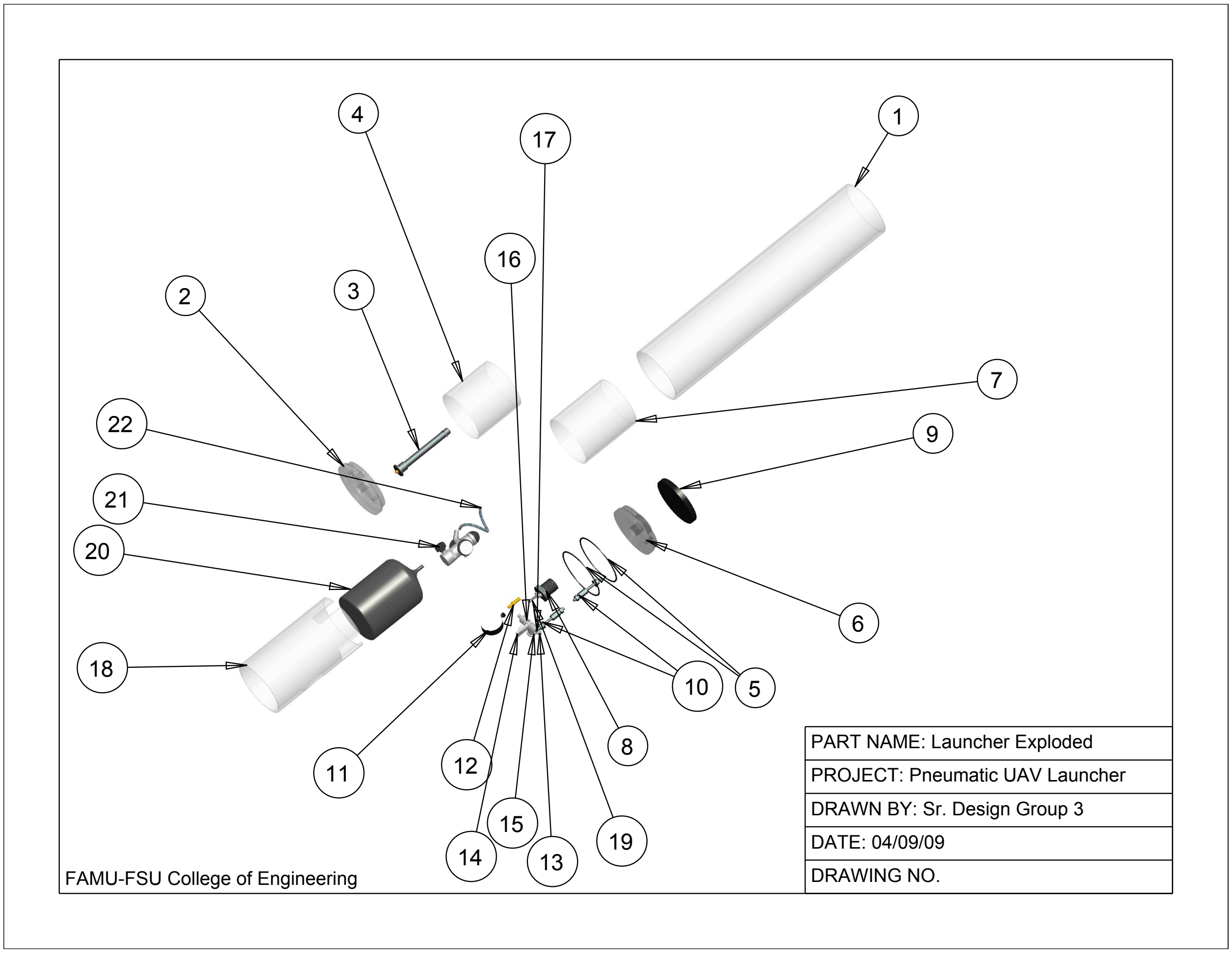
SCALE 1.000

FAMU-FSU College of Engineering	PART NAME: Pressure Regulator
	PROJECT: Pneumatic UAV Launcher
	DRAWN BY: Sr. Design Group 3
	DATE: 12/03/08
	DRAWING NO. 12


.50
.75
SCALE 3.000
PART NAME: Large Nut
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 13
FAMU-FSU College of Engineering


2.52
1.50
.62
.25
.56
.25
SCALE 2.500
PART NAME: Wire Fasteners
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 14
FAMU-FSU College of Engineering

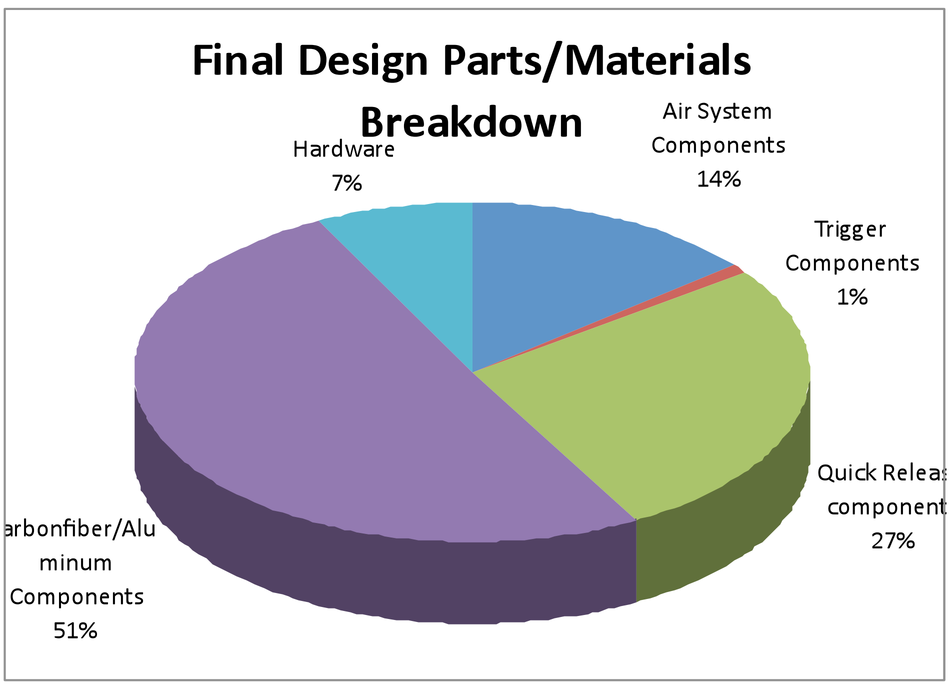

.38
18.00
SCALE 0.400
PART NAME: Cable
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 12/03/08
DRAWING NO. 15
FAMU-FSU College of Engineering


4
17
1
16
2
3
7
22
9
21
20
6
18
10
5
8
11
12
15
19
14
13
PART NAME: Launcher Exploded
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO.
FAMU-FSU College of Engineering

Appendix H

Fall Final Design Cost Analysis

Fall Final Design Cost Analysis						
	Number of Parts	Vendor	Manufacturer	Part Number	Cost	
Resevoir Tank	1	E-Paintball.com	Guerrilla	100992	154.95	
Tank Regulator	1	Sakworld Paint	Sak Paintball	144891330	99.95	
Pin Washers	2	McMaster	McMaster	98783A033	12.32	
Wire Connector Washers	4	McMaster	McMaster	93783A029	7.93	
O-ring	1	McMaster	McMaster	4061T153	14.88	
Launch Tube	1	Nim-Cor	Nim-Cor	Custom	360	
Carriage	1	Nim-Cor	Nim-Cor	Custom	175	
Push Pin	1	Jergens	Jergens	806493	55.3	
Pin Reciever	1	Jergens	Jergens	845103	29.18	
Pipe Sealant	1	Lowe's	Oatey	23535	1.83	
Cable	1	McMaster	McMaster	3459T72	19.3	
Self Sealing Nuts 1/4-28	4	McMaster	McMaster	91339A135	12.84	
Self Sealing Nuts 1/2-20	2	McMaster	McMaster	91339A170	8.52	
Cable Connector	2	McMaster	McMaster	3475T29	83.02	
High pressure line	1	Sakworld Paint	Sak Paintball	N/A	10	
Remote trigger release	1	Cabela's	HySkore	IJ-226084	19.99	
Hose Fittings	1	McMaster	McMaster	53485K71	10.65	
Protection Rods	3	McMaster	McMaster	6516K23	26.22	
				Total:	**1101.88**	



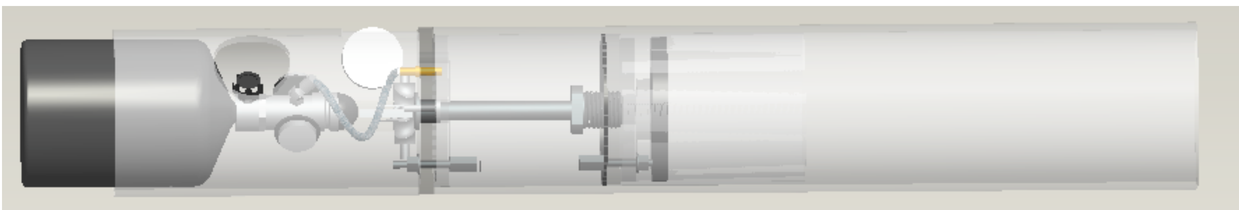
Final Design Parts/Materials Breakdown

Appendix G

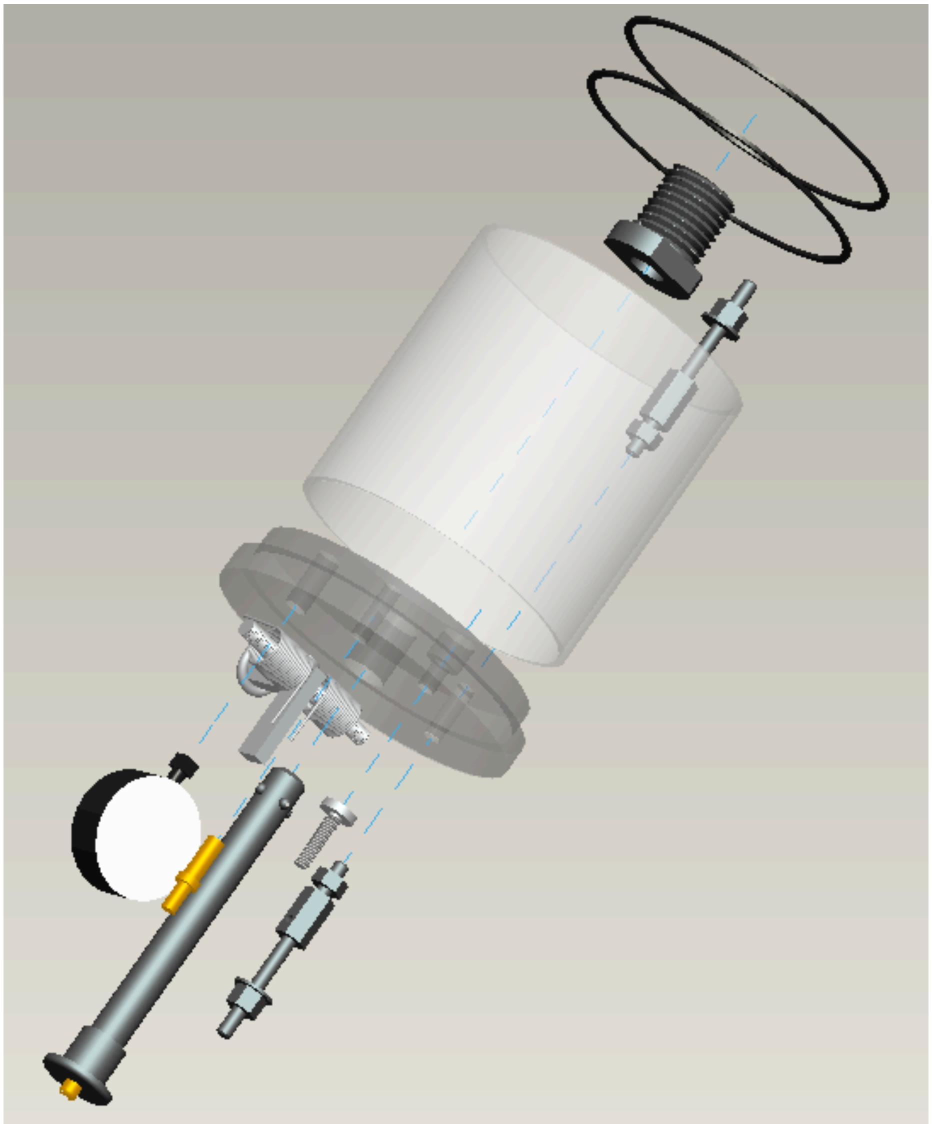
Prototype Pro-E Parts

Prototype Assembly without air supply components.

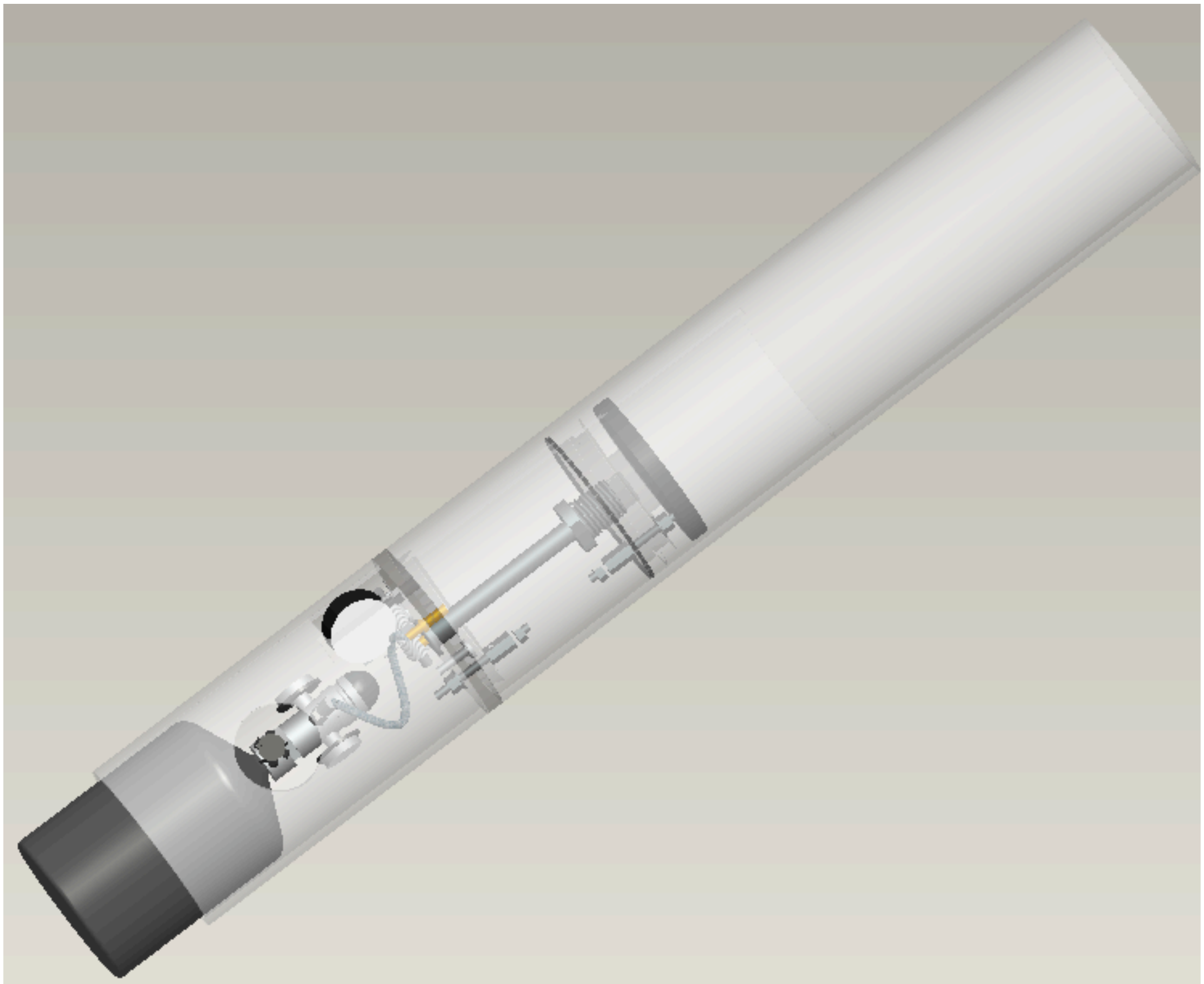
Prototype Exploded View without Air System



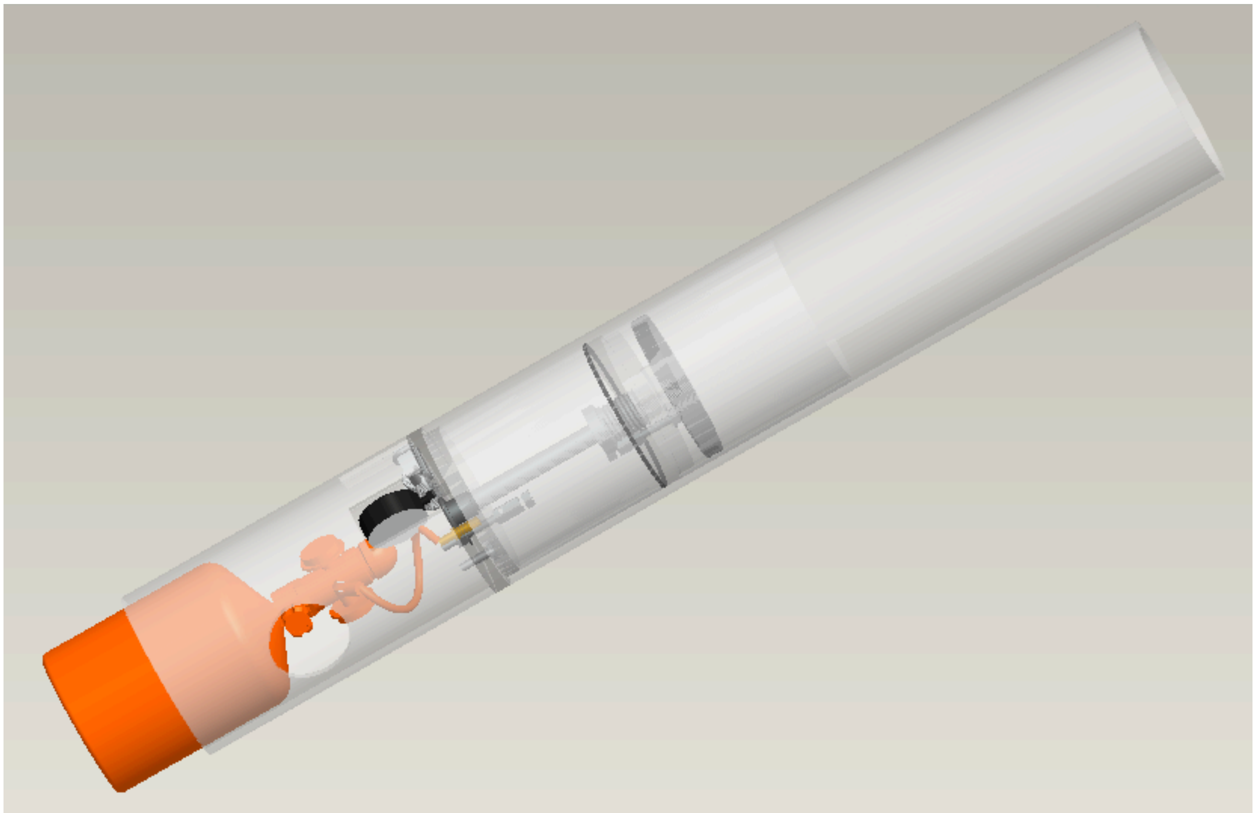
Prototype Assembly with Air System



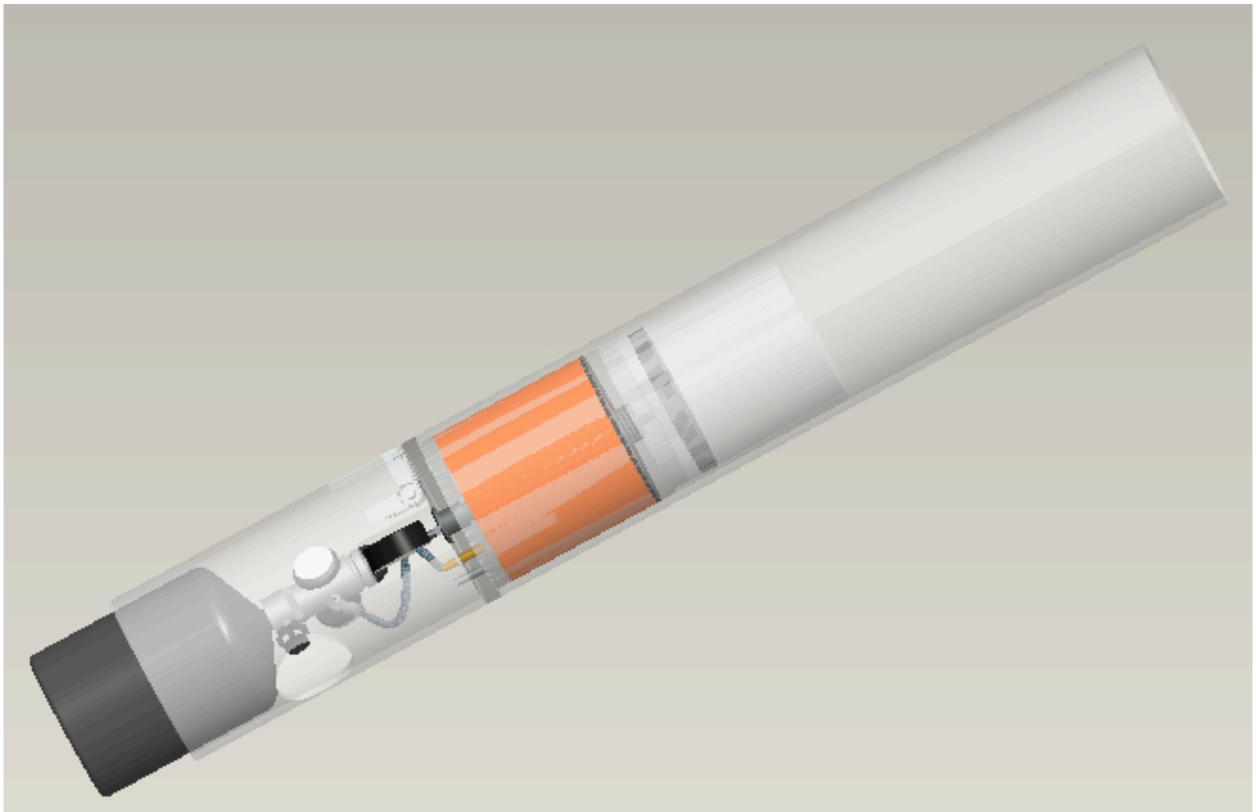
Prototype Charge Chamber Assembly



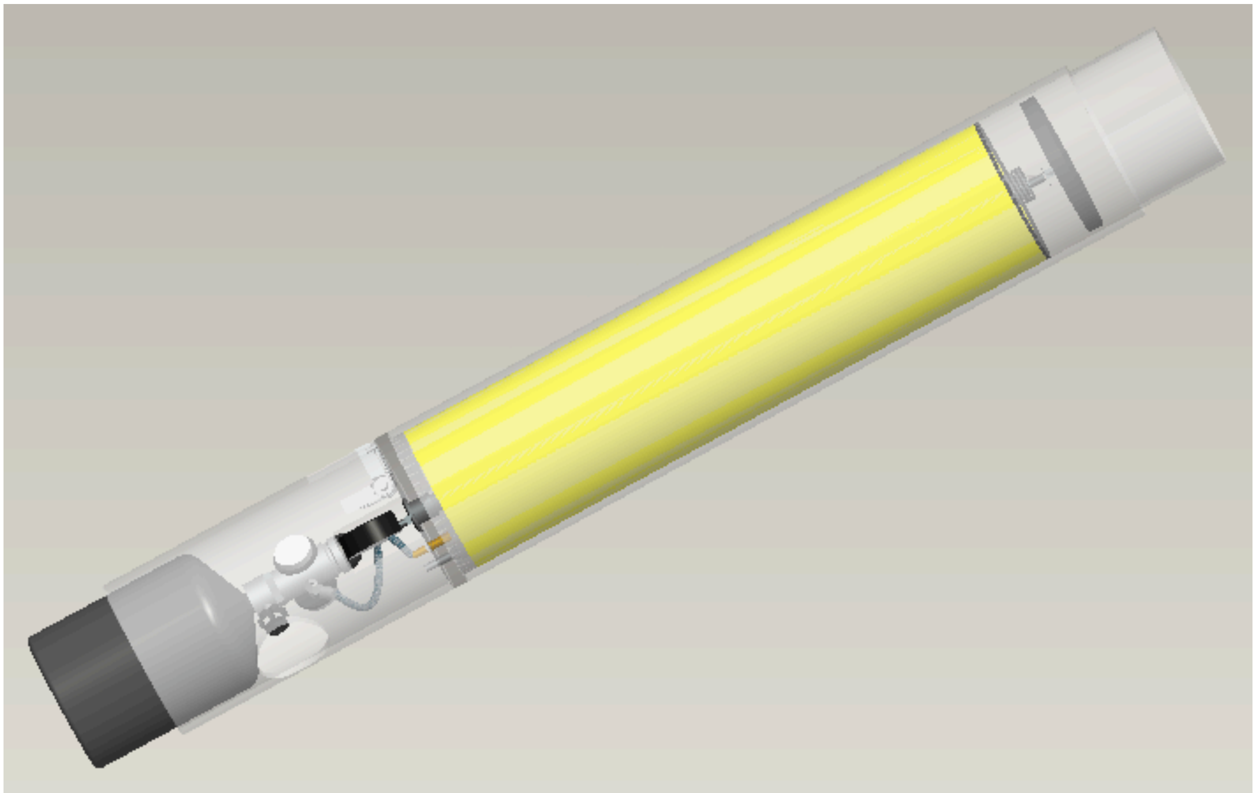
Prototype Assembly with Air System



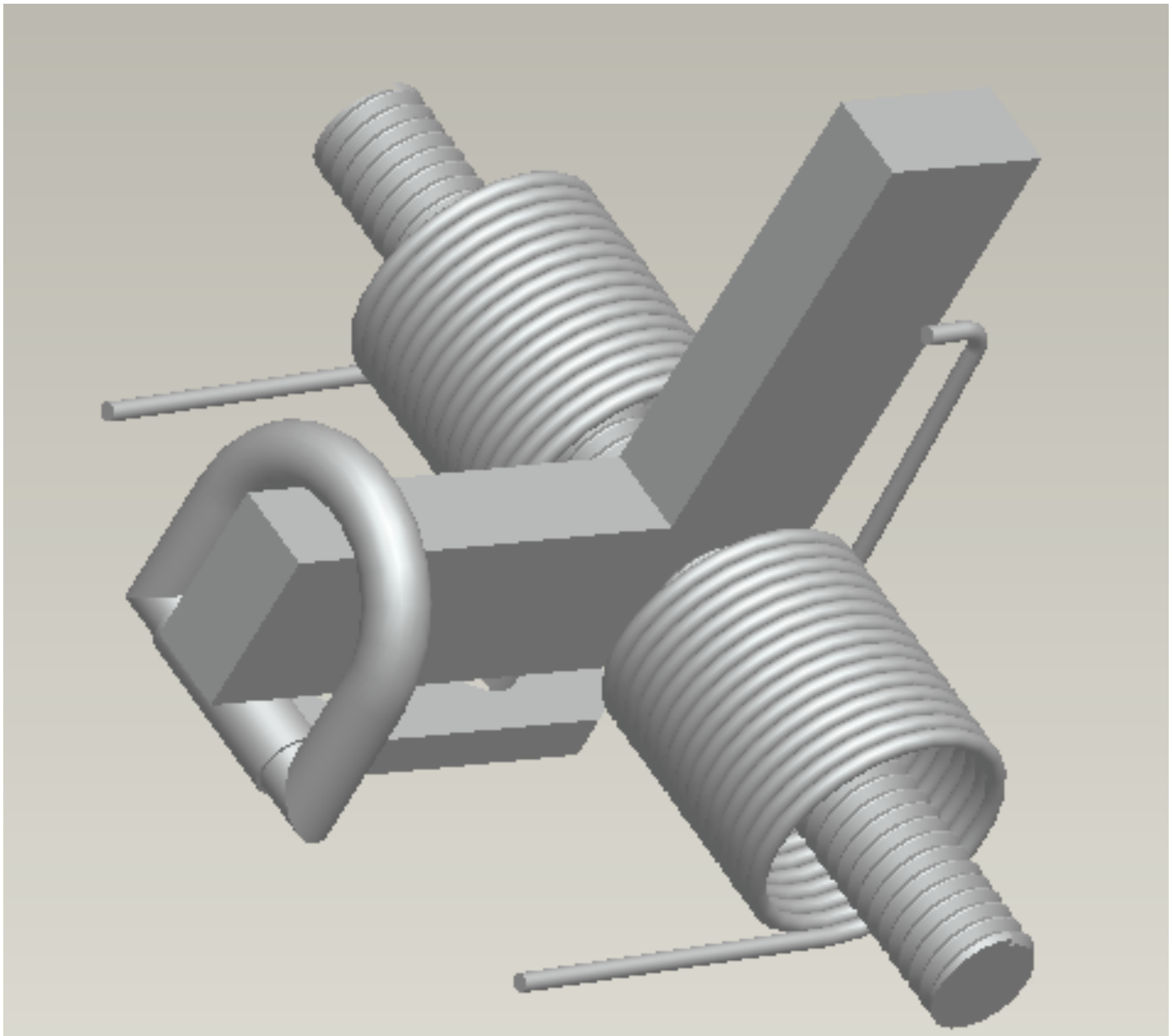
Compressed air in Tank



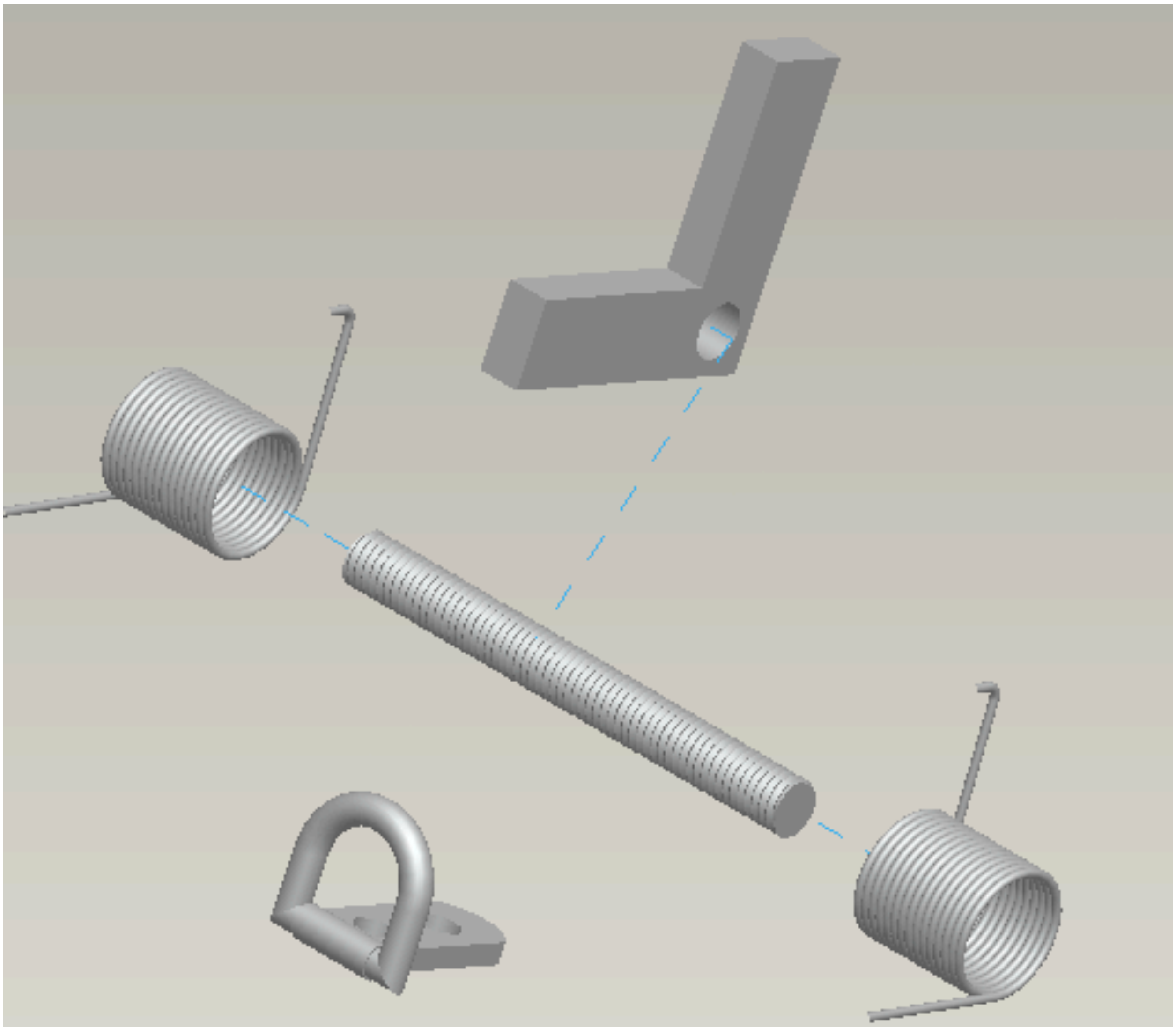
Compressed air in Charge Chamber



Expanded air in Barrel

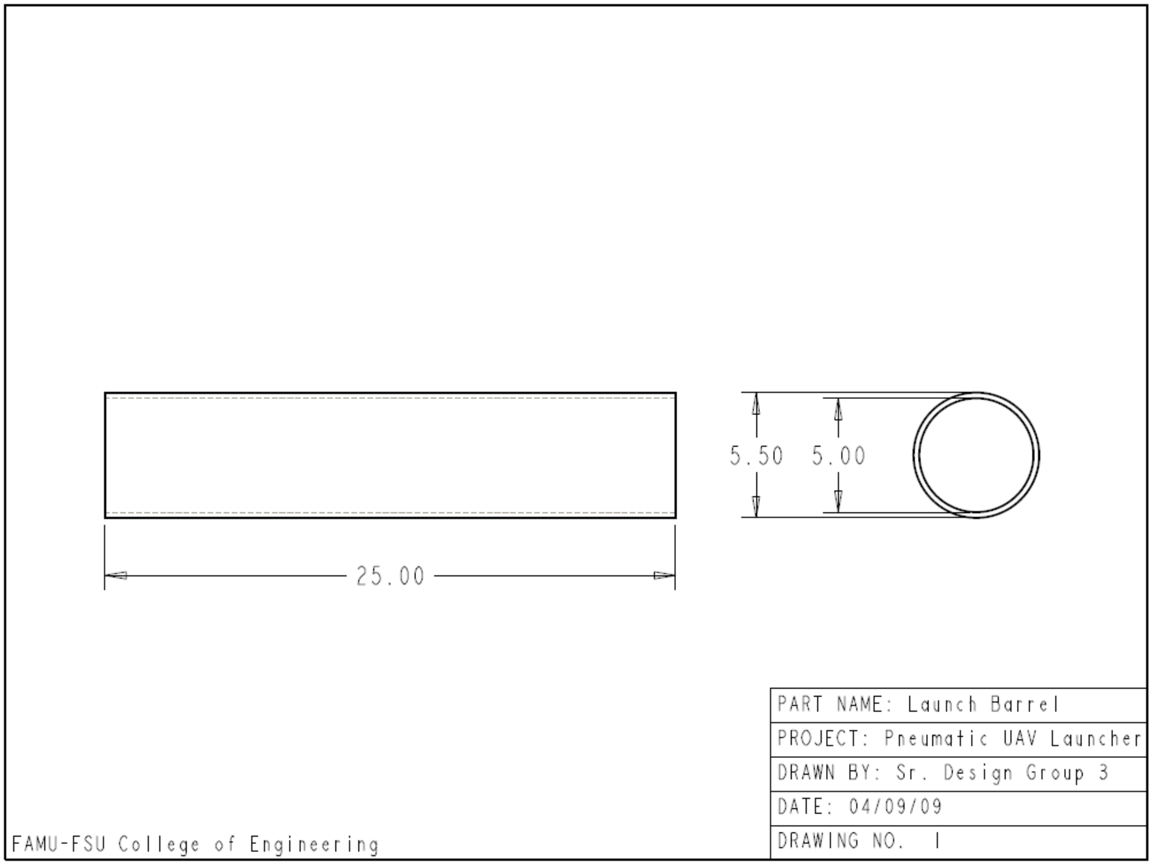


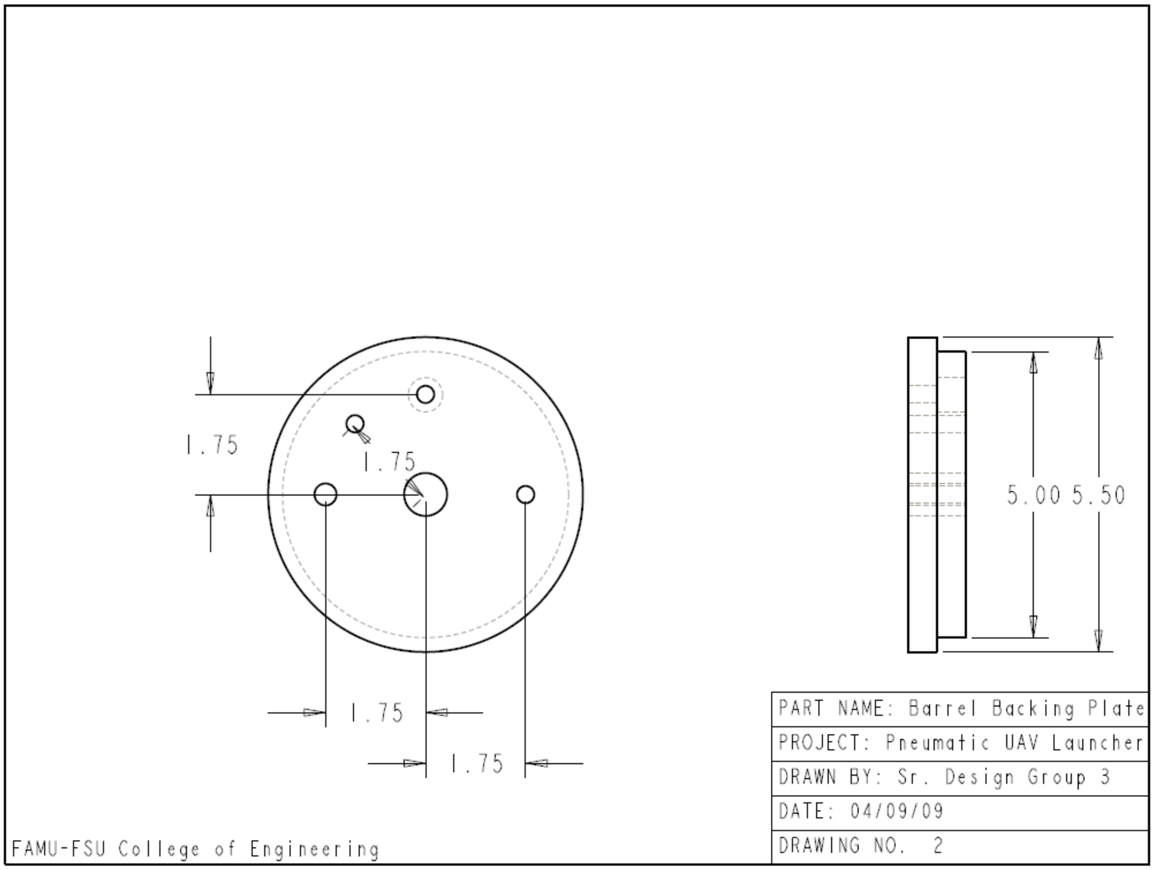
Trigger Mechanism Assembly

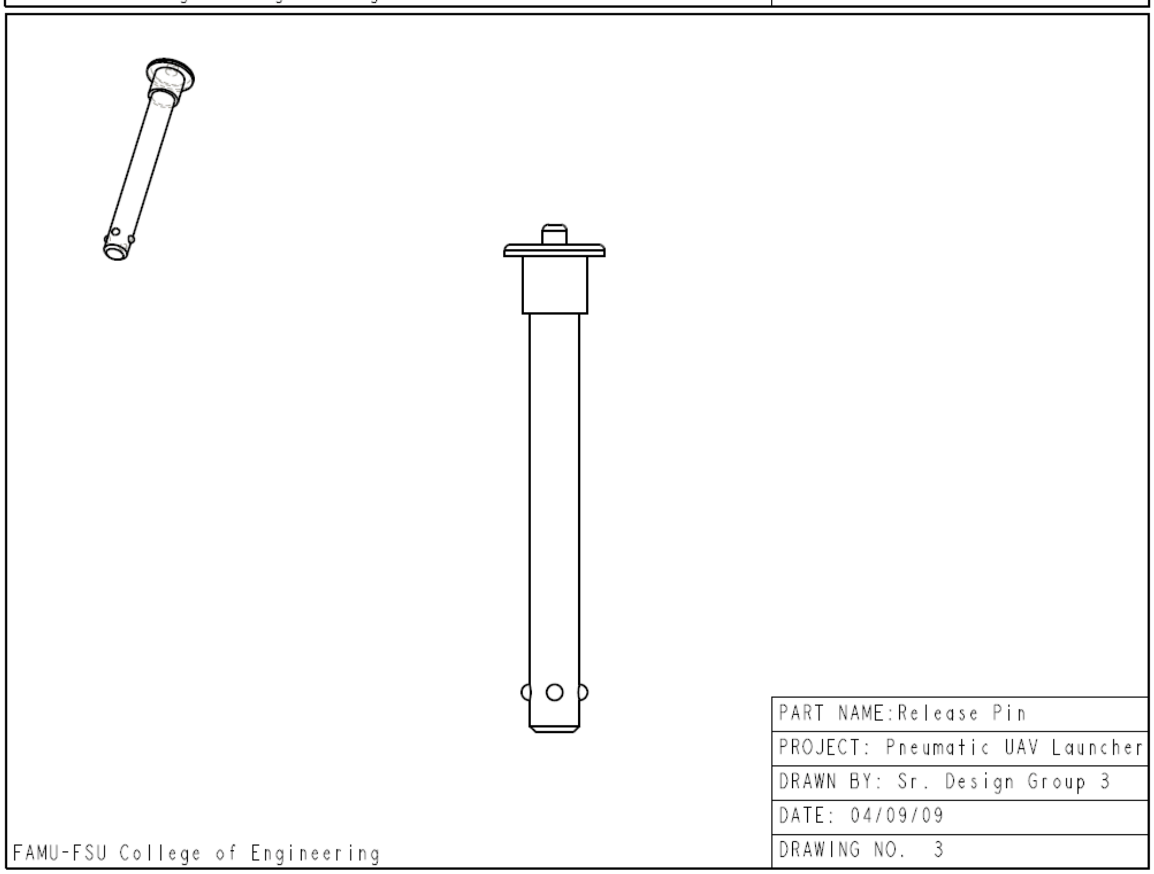


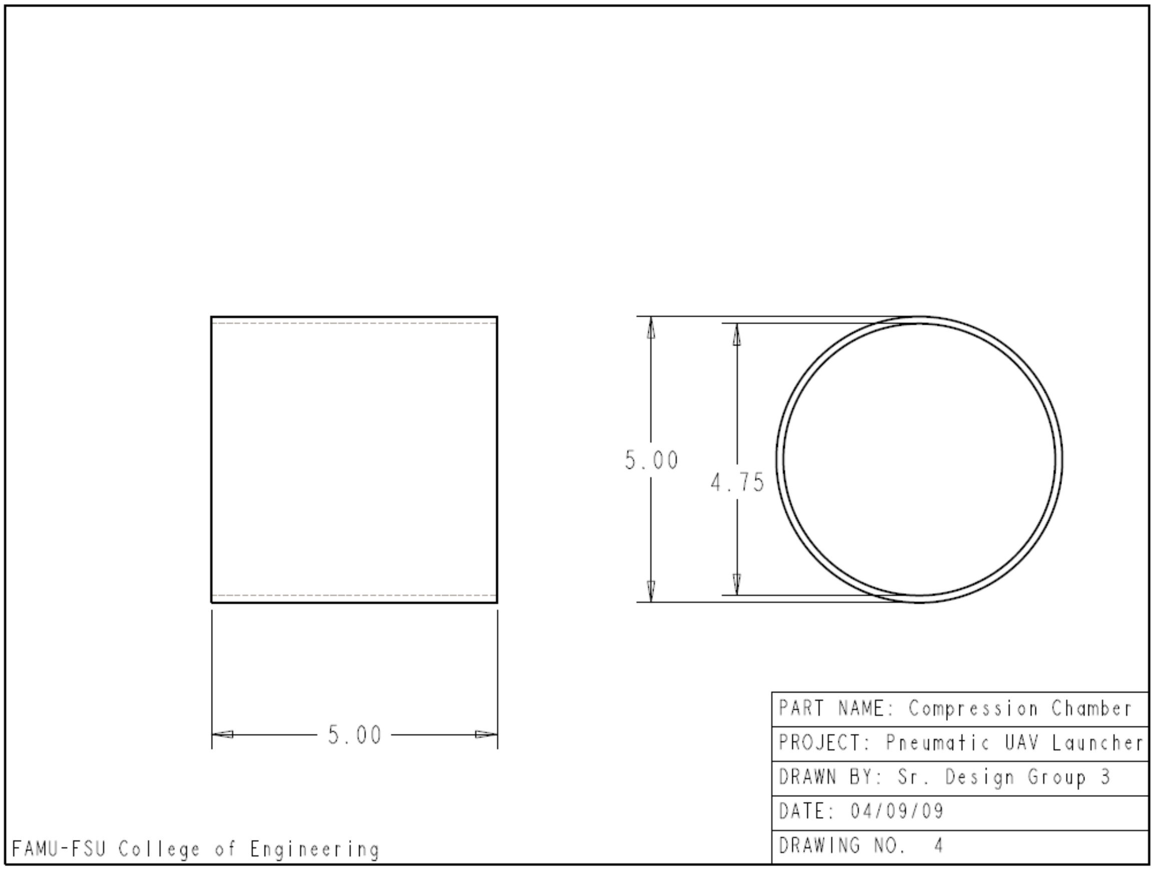
Trigger Mechanism Exploded View

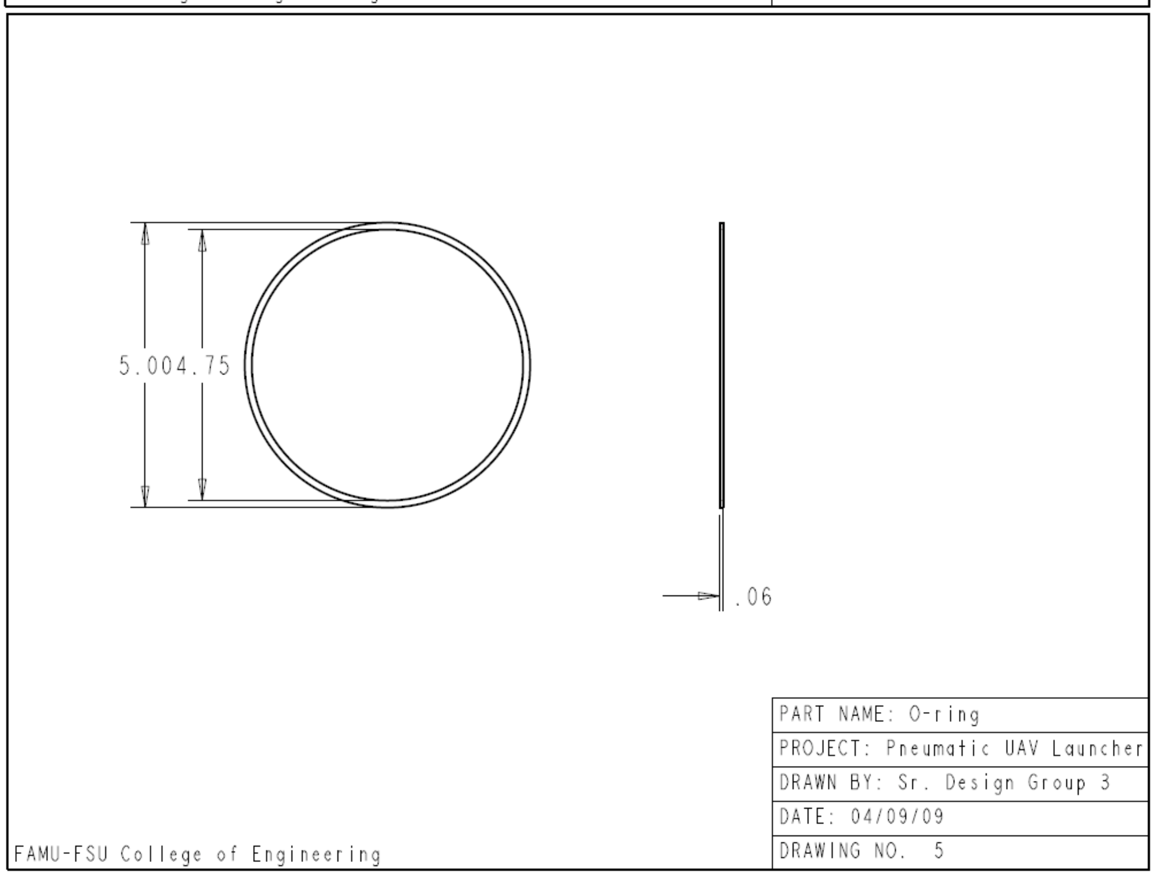
The following diagrams are the Pro-E drawings for the prototype design.

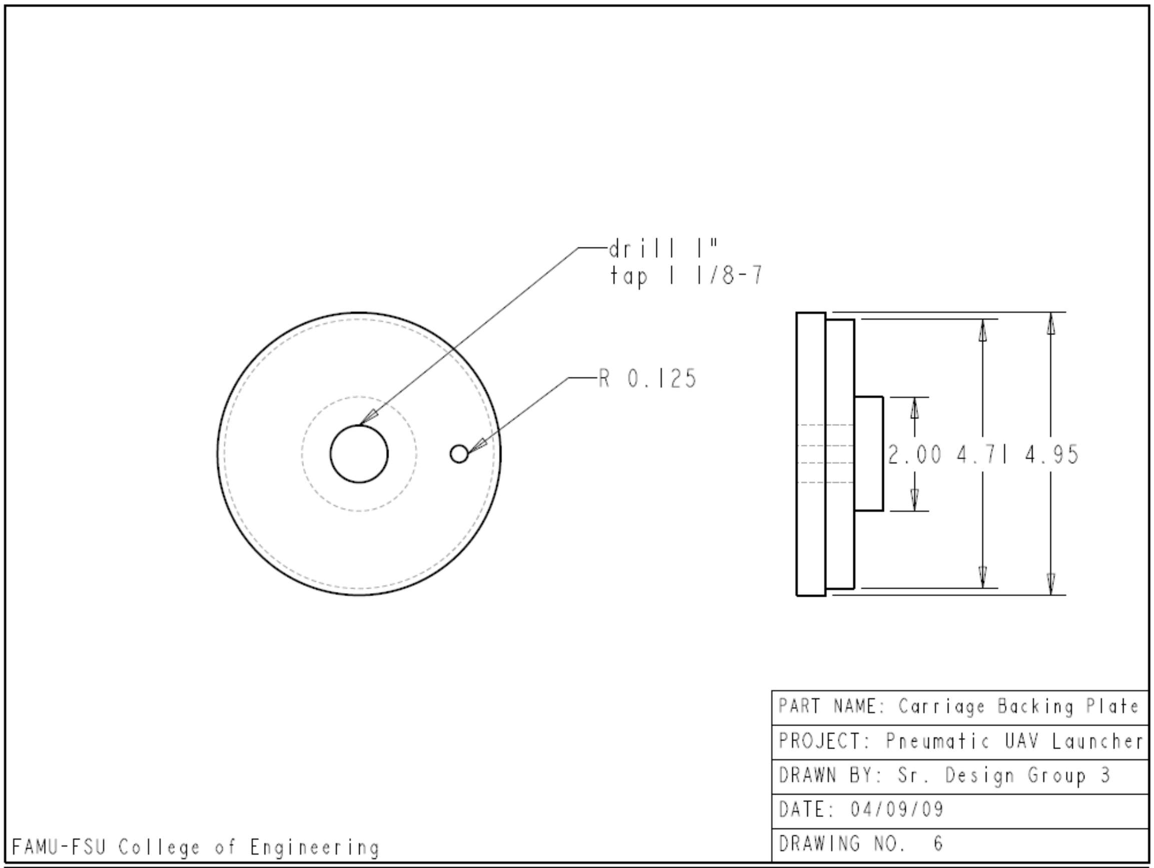


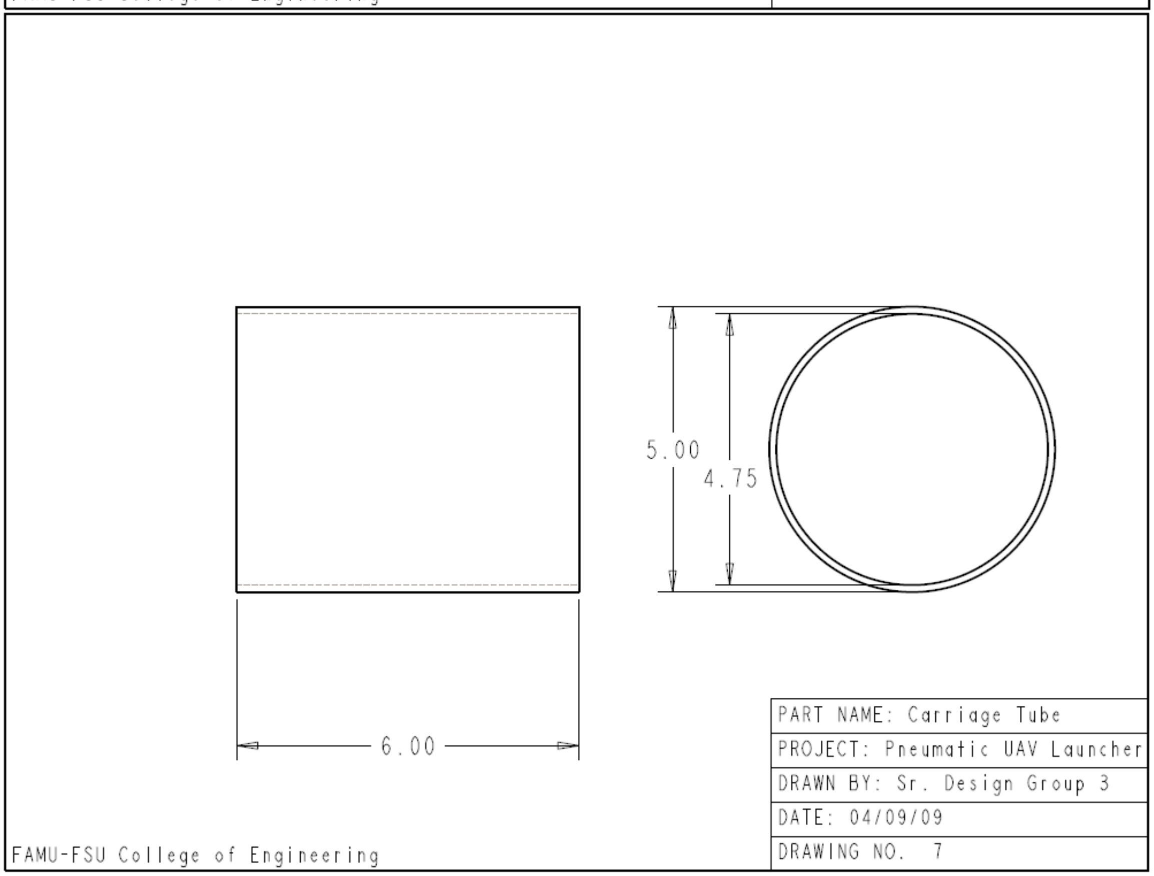

1.75
1.75
1.75
1.75
5.00
5.50
PART NAME: Barrel Backing Plate
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 2
FAMU-FSU College of Engineering

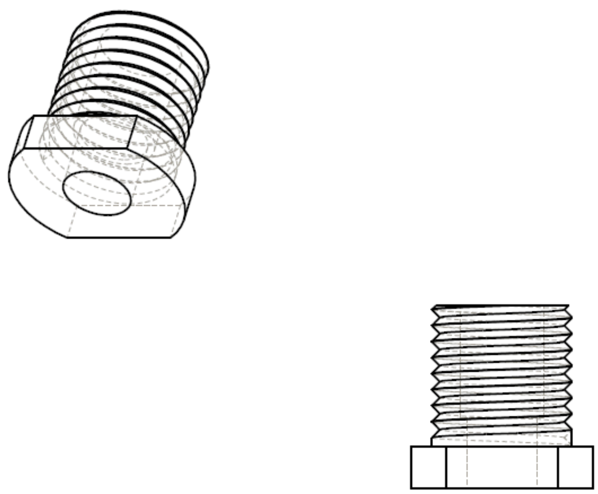

PART NAME:Release Pin
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 3
FAMU-FSU College of Engineering


5.00
4.75
5.00
PART NAME: Compression Chamber
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 4
FAMU-FSU College of Engineering

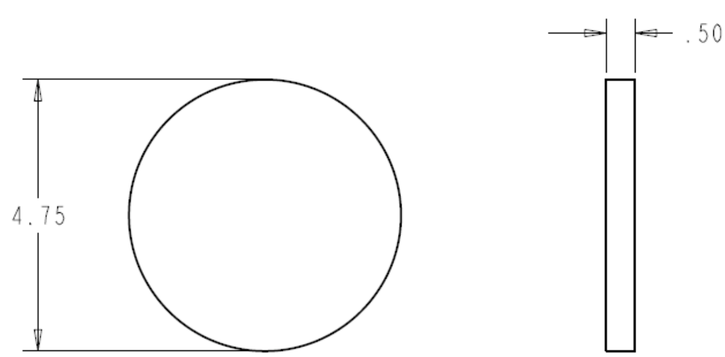

5.004.75
.06
PART NAME: O-ring
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 5
FAMU-FSU College of Engineering


drill 1"
tap 1 1/8-7
R 0.125
2.00
4.71
4.95
PART NAME: Carriage Backing Plate
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 6
FAMU-FSU College of Engineering

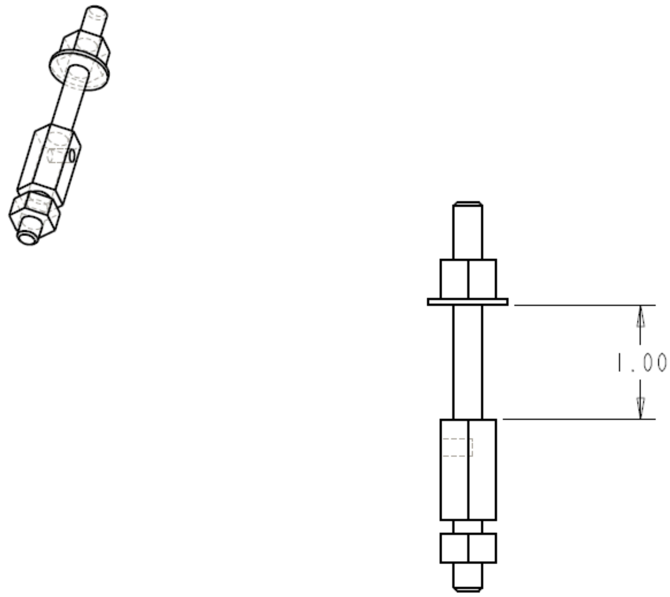

5.00
4.75
6.00
PART NAME: Carriage Tube
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 7
FAMU-FSU College of Engineering



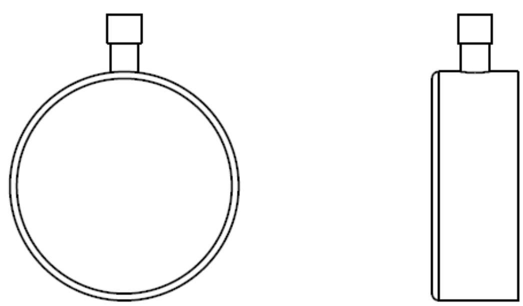
FAMU-FSU College of Engineering	PART NAME: Pin Receptacle
	PROJECT: Pneumatic UAV Launcher
	DRAWN BY: Sr. Design Group 3
	DATE: 04/09/09
	DRAWING NO. 8



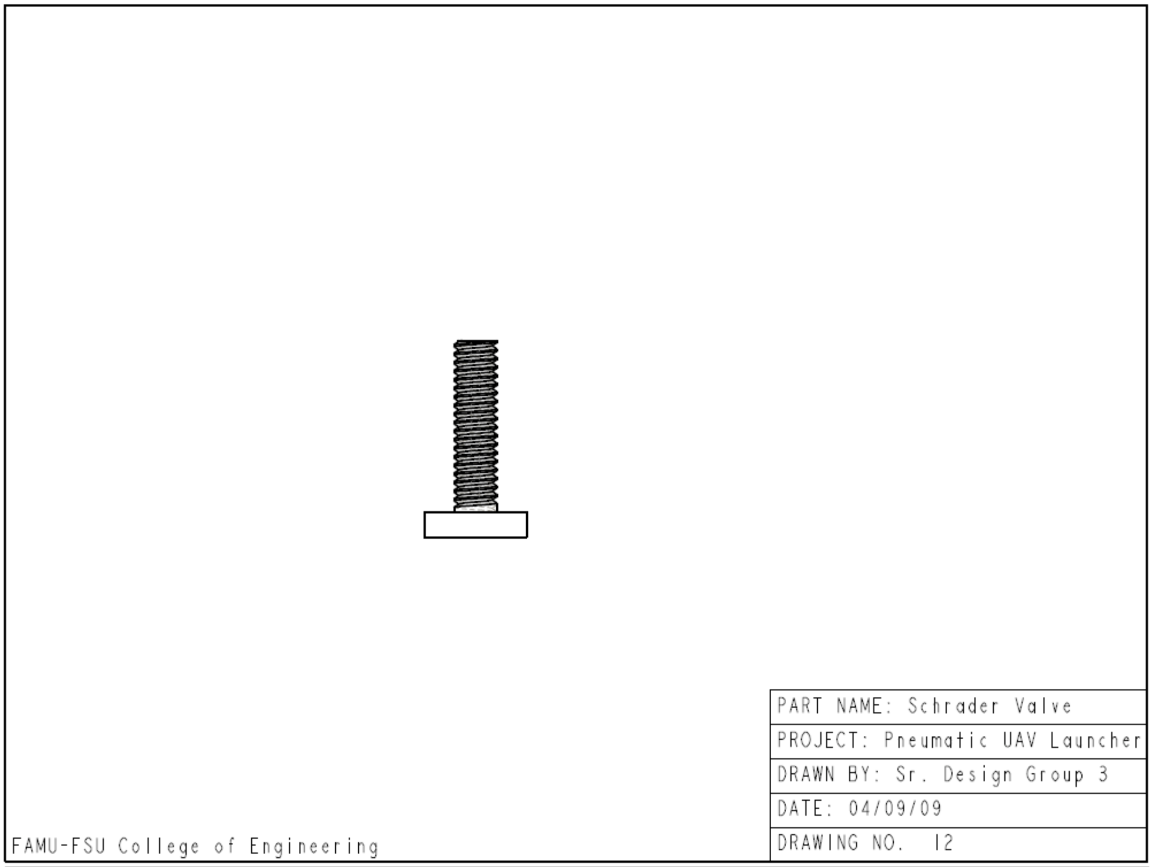
FAMU-FSU College of Engineering	PART NAME: Foam Disc
	PROJECT: Pneumatic UAV Launcher
	DRAWN BY: Sr. Design Group 3
	DATE: 04/09/09
	DRAWING NO. 9

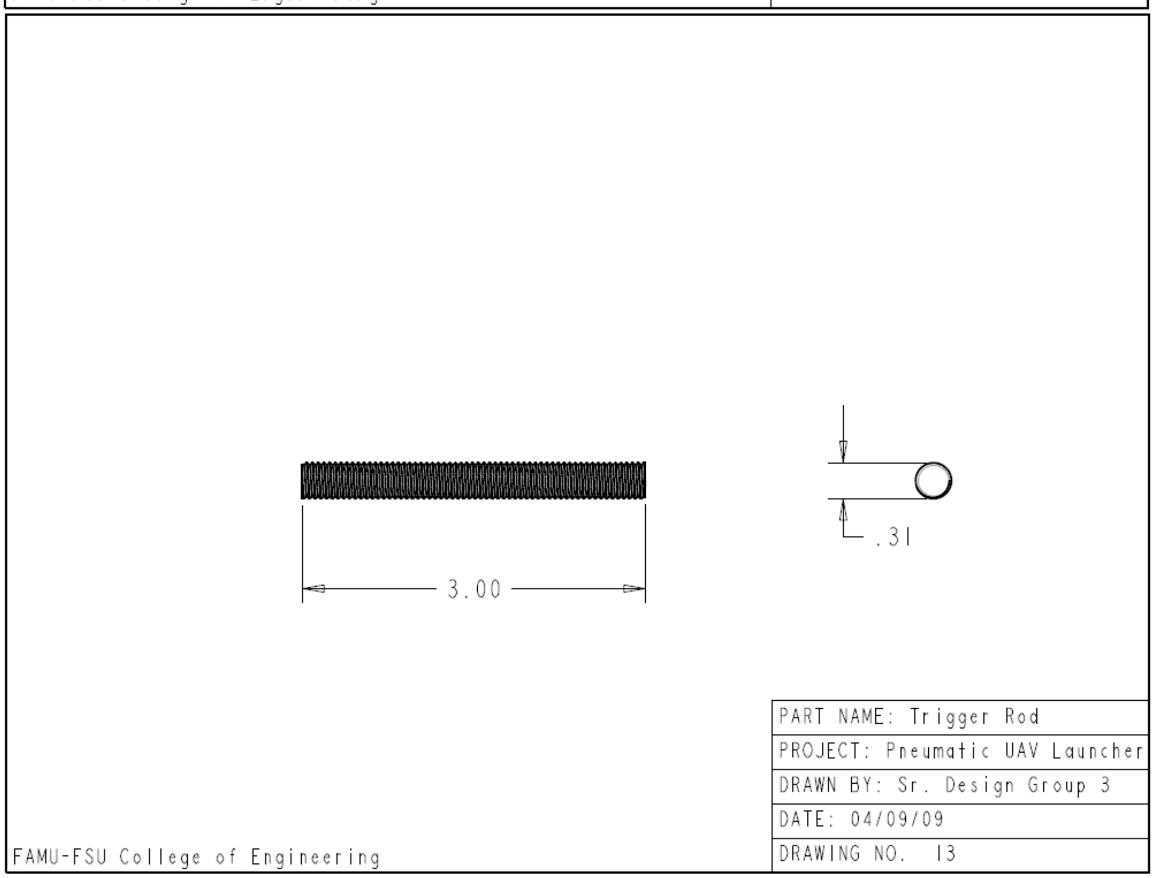


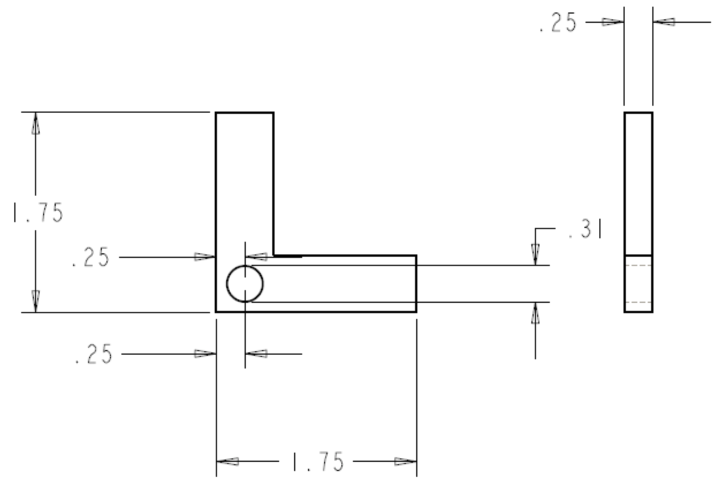
	PART NAME: Cable Fastener
	PROJECT: Pneumatic UAV Launcher
	DRAWN BY: Sr. Design Group 3
	DATE: 04/09/09
FAMU-FSU College of Engineering	DRAWING NO. 10



	PART NAME: Pressure Gauge
	PROJECT: Pneumatic UAV Launcher
	DRAWN BY: Sr. Design Group 3
	DATE: 04/09/09
FAMU-FSU College of Engineering	DRAWING NO. 11

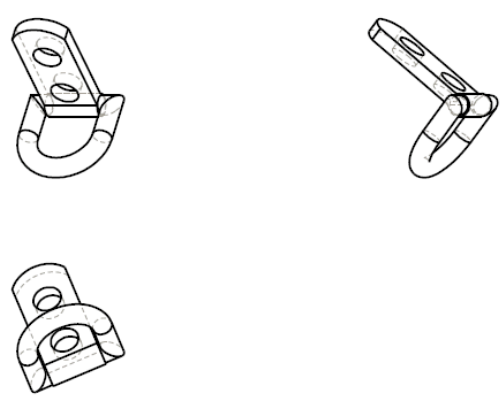

PART NAME: Schrader Valve
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 12
FAMU-FSU College of Engineering


3.00
.31
PART NAME: Trigger Rod
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 13
FAMU-FSU College of Engineering



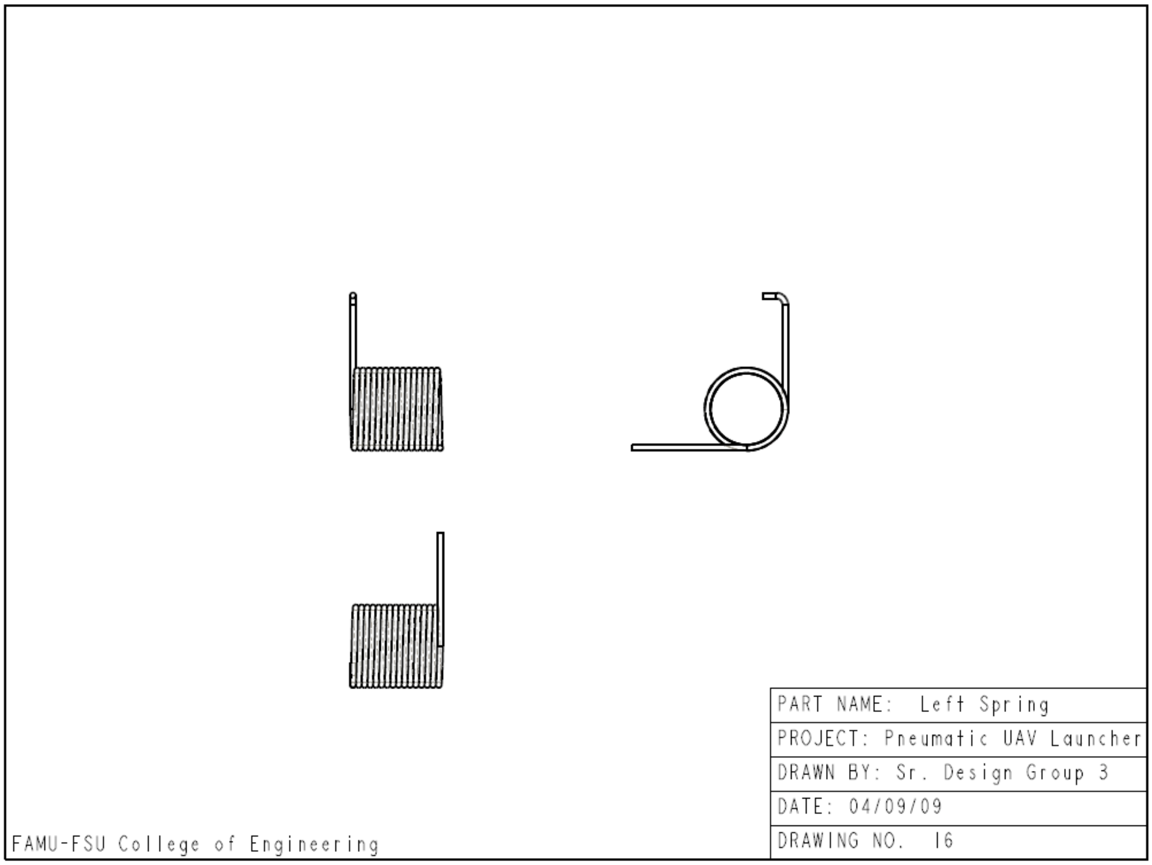
PART NAME: L Bracket Hammer
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 14

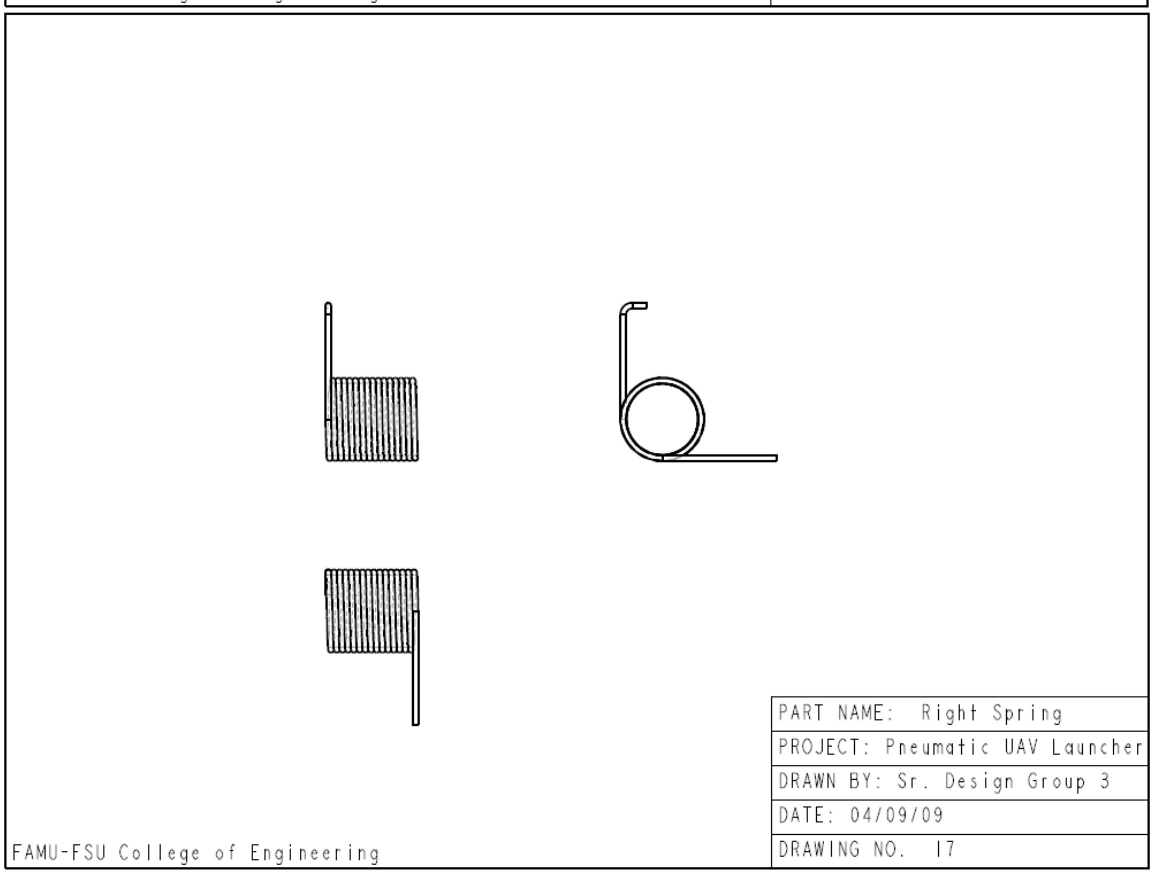
FAMU-FSU College of Engineering

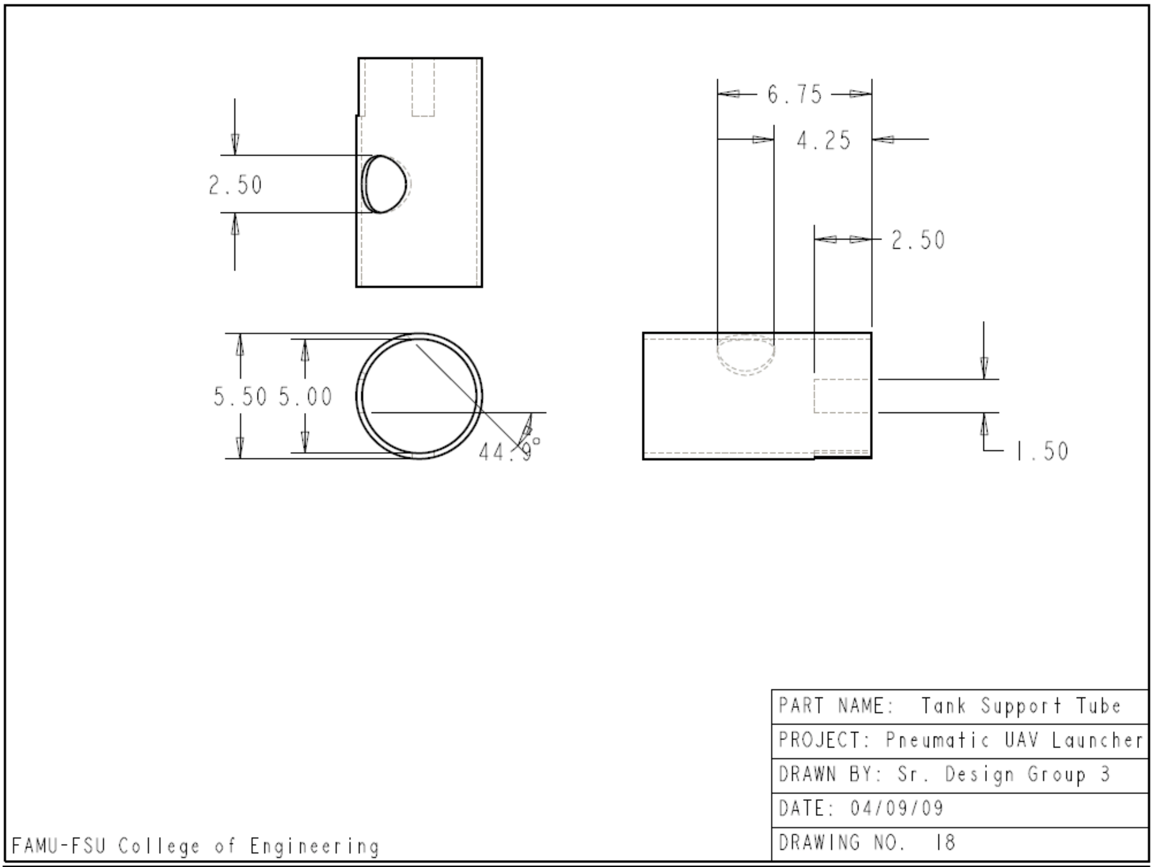


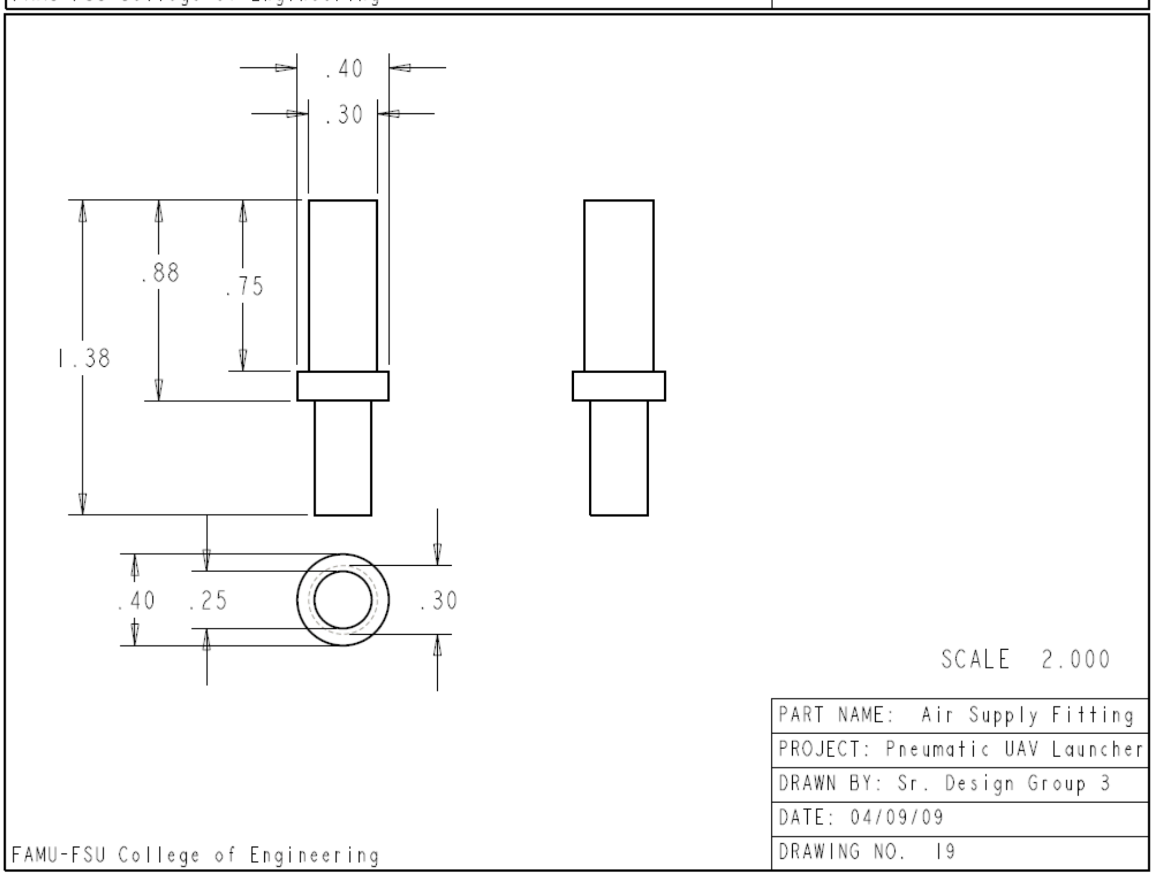
PART NAME: D-Ring Trigger
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 15

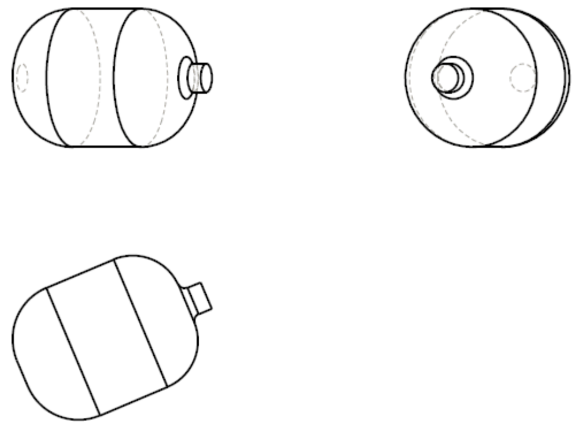
FAMU-FSU College of Engineering


PART NAME: Left Spring
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 16
FAMU-FSU College of Engineering

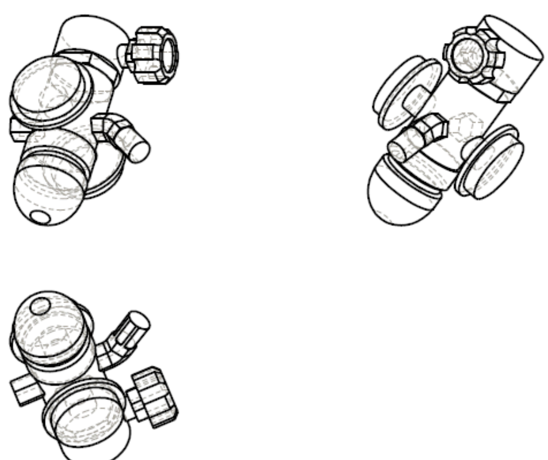

PART NAME: Right Spring
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 17
FAMU-FSU College of Engineering


6.75
4.25
2.50
2.50
5.50
5.00
44.9°
1.50
PART NAME: Tank Support Tube
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 18
FAMU-FSU College of Engineering

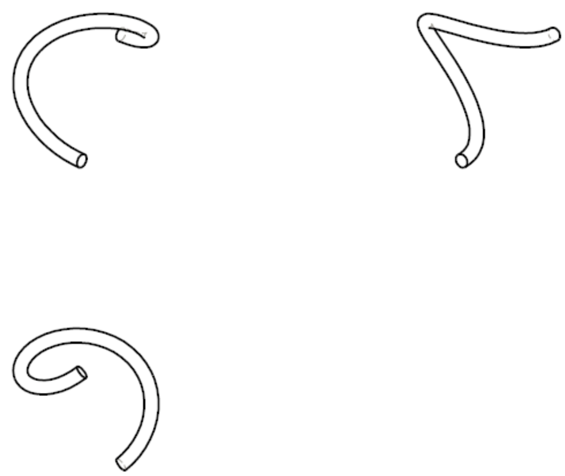

.40
.30
.88
.75
1.38
.40
.25
.30
SCALE 2.000
PART NAME: Air Supply Fitting
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 19
FAMU-FSU College of Engineering



FAMU-FSU College of Engineering	PART NAME: Air Tank
	PROJECT: Pneumatic UAV Launcher
	DRAWN BY: Sr. Design Group 3
	DATE: 04/09/09
	DRAWING NO. 20

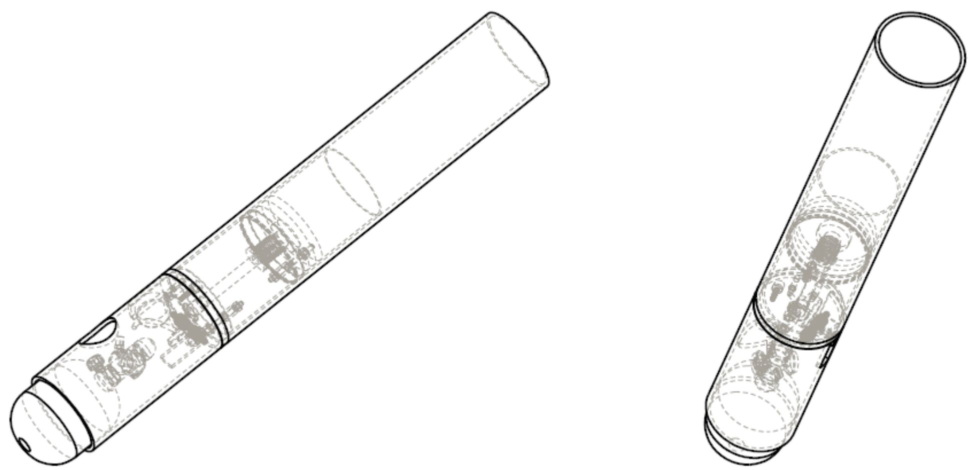


FAMU-FSU College of Engineering	PART NAME: Pressure Regulator
	PROJECT: Pneumatic UAV Launcher
	DRAWN BY: Sr. Design Group 3
	DATE: 04/09/09
	DRAWING NO. 21

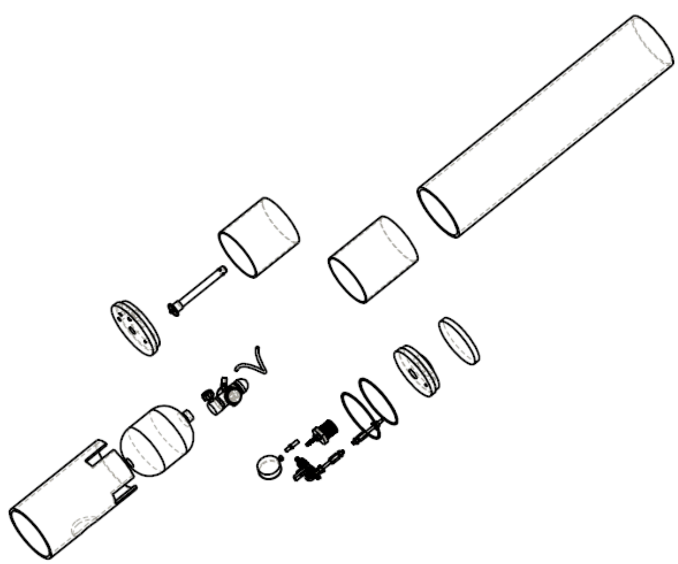


FAMU-FSU College of Engineering	PART NAME: Air Hose
	PROJECT: Pneumatic UAV Launcher
	DRAWN BY: Sr. Design Group 3
	DATE: 04/09/09
	DRAWING NO. 22

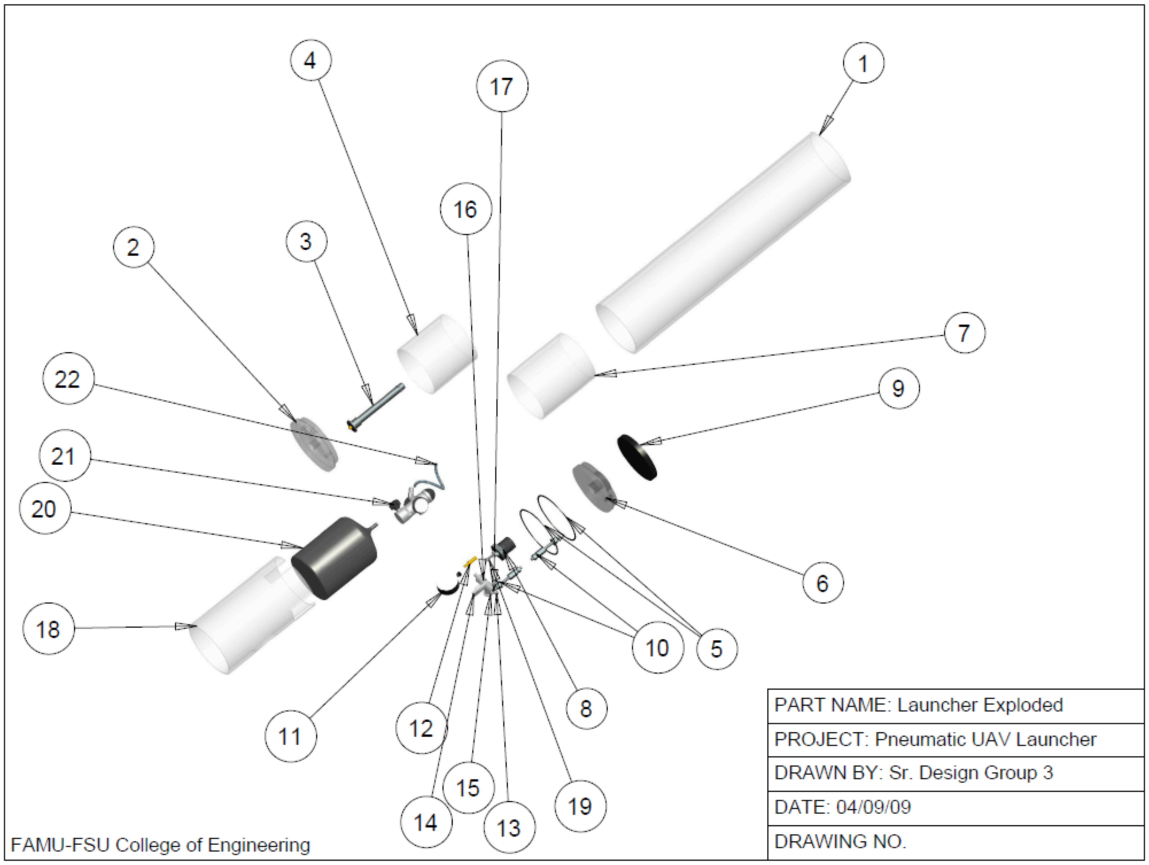
FAMU-FSU College of Engineering	PART NAME: UAV Launcher
	PROJECT: Pneumatic UAV Launcher
	DRAWN BY: Sr. Design Group 3
	DATE: 04/09/09
	DRAWING NO.



FAMU-FSU College of Engineering	PART NAME: UAV Launcher
	PROJECT: Pneumatic UAV Launcher
	DRAWN BY: Sr. Design Group 3
	DATE: 04/09/09
	DRAWING NO. 23



FAMU-FSU College of Engineering	PART NAME: Launcher Exploded
	PROJECT: Pneumatic UAV Launcher
	DRAWN BY: Sr. Design Group 3
	DATE: 04/09/09
	DRAWING NO. 24



Exploded View of Prototype UAV Launcher

Prototype UAV Launcher Parts List

Summary of parts for assembly LAUNCHER_ASSEMBLED:

##	Quantity	Type	Name	Material
1	1	Part	LAUNCH_BARREL	Acrylic
2	1	Part	BARREL_BACKING_PLATE	Acrylic
3	1	Part	RELEASE_PIN	304 SS
4	1	Part	COMPRESSION_CHAMBER_TUBE	Acrylic
5	2	Part	O_RING	Rubber
6	1	Part	CARRIAGE_BACKING_PLATE	Acrylic
7	1	Part	CARRIAGE_	Acrylic
8	1	Part	PIN_RECEPTACLE	304 SS
9	1	Part	FOAM_DISC	Neoprene
10	2	Part	CABLE_FASTENER	Steel
11	1	Part	PRESSURE_GAUGE	Brass/Plastic
12	1	Part	SCHRADER_VALVE	Stainless Steel
13	1	Part	TRIGGER_ROD	Steel
14	1	Part	L_BRACKET_HAMMER	Aluminum
15	1	Part	D_RING_TRIGGER	Aluminum
16	1	Part	LEFT_SPRING	Steel
17	1	Part	RIGHT_SPRING	Steel
18	1	Part	TANK_SUPPORT_TUBE	Acrylic
19	1	Part	AIR_SUPPLY_FITTING	Stainless Steel
20	1	Part	AIR_TANK	Carbon Fiber/Aluminum
21	1	Part	PRESSURE_REG	Stainless Steel
22	1	Part	AIR_HOSE	Stainless Steel

Appendix H

Part/Material Expenses

Part/Material Expenses				
Item	**Quantity**	**Vendor**	**Part Number**	**Total Price**
5"1/2x36"x1/4" acrylic tube	1	McMaster-Carr	8486K588	$109.86
High Pressure reservoir tank	1	E-Paintball.com	100992	$154.95
Tank Regulator	1	Sakworld Paintball	144891330	$99.95
Shrader Valve	1	Advanced Auto Parts	04134-8	$6.96
Quick Release Pin	1	Big Sky Precision	Custom Part	$122.45
Quick Release receiver	1	Big Sky Precision	845104	$29.53
5"x12"x1/4" acrylic tube	1	McMaster-Carr	8486K583	$26.93
12"x12"x1" acrylic sheet	1	McMaster-Carr	8560K321	$43.96
Pressure gauge	1	Home Depot	TC2104	$9.46
5"x12"x1/8" acrylic tube	1	McMaster-Carr	8486K387	$18.28
High Pressure steel braided line	1	Sakworld Paintball	N/A	$10.03
Hammer Trigger Release	1	Home Depot	N/A	$14.54
5/8" ID 1" OD O-Ring	1	Home Depot	M32-L	$0.98
5"x1/8" O-rings	1 pack	McMaster-Carr	4061T27	$14.88
1/8" Cable strong grip end fittings	2	McMaster-Carr	3475T885	$18.69
Cable	1	McMaster-Carr	3459T72	$19.30
Pressure sealing washers	1 pack	Home Depot	M32-N	$2.17
Silicone II sealant	1	Home Depot	GE5003TG	$6.93
1/8" to 1/4" NPT fitting	1	Capital Rubber	s406-4-2	$0.75
5/8" Rubber Tube	1	Machine Shop	N/A	$0.00
Weld on - Acrylic bonding agent	1	Machine Shop	N/A	$0.00
			Total=	$710.60

Parts/Material Distribution

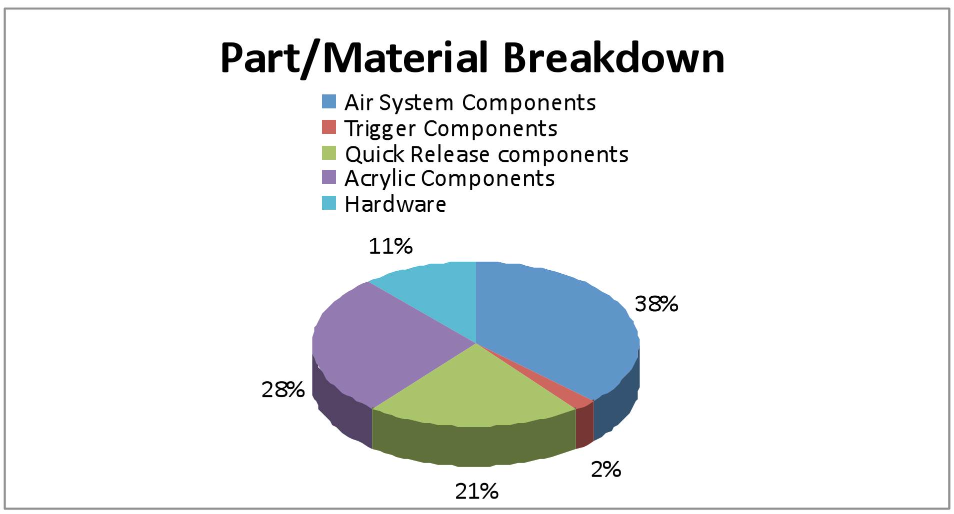
Parts/Material Distribution		
Air System Components		$264.93
Trigger Components		$14.54
Quick Release components		$151.98
Acrylic Components		$199.03
Hardware		$80.12
	Total=	$710.60

Part/Material Expenses

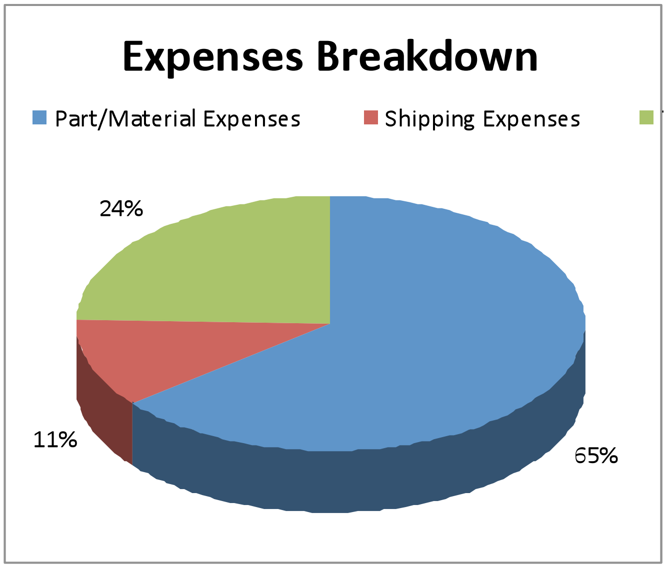
Shipping Expenses				
McMaster Orders				$40.69
Sakworld Paintball Orders				$14.00
Big Sky Precision Orders				$27.98
E-Paintball Orders				$42.50
			Total=	$125.17

Part/Material Expenses

Travel Expenses			
Travel to Eglin AFB for Adewale Adelakun			$170.80
Travel to Eglin AFB for Tim Bartlett			$98.79
		Total=	$269.59



Expense Distribution

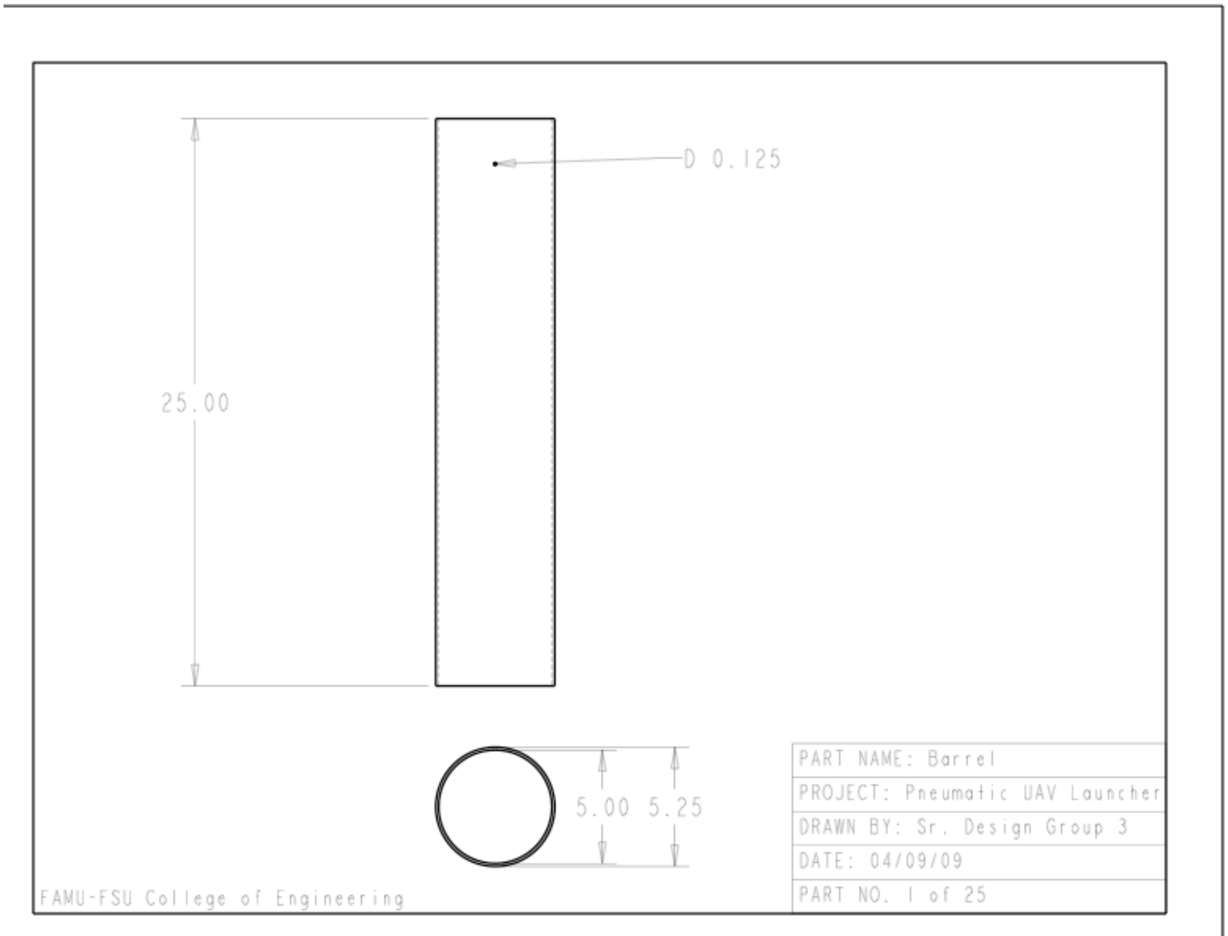


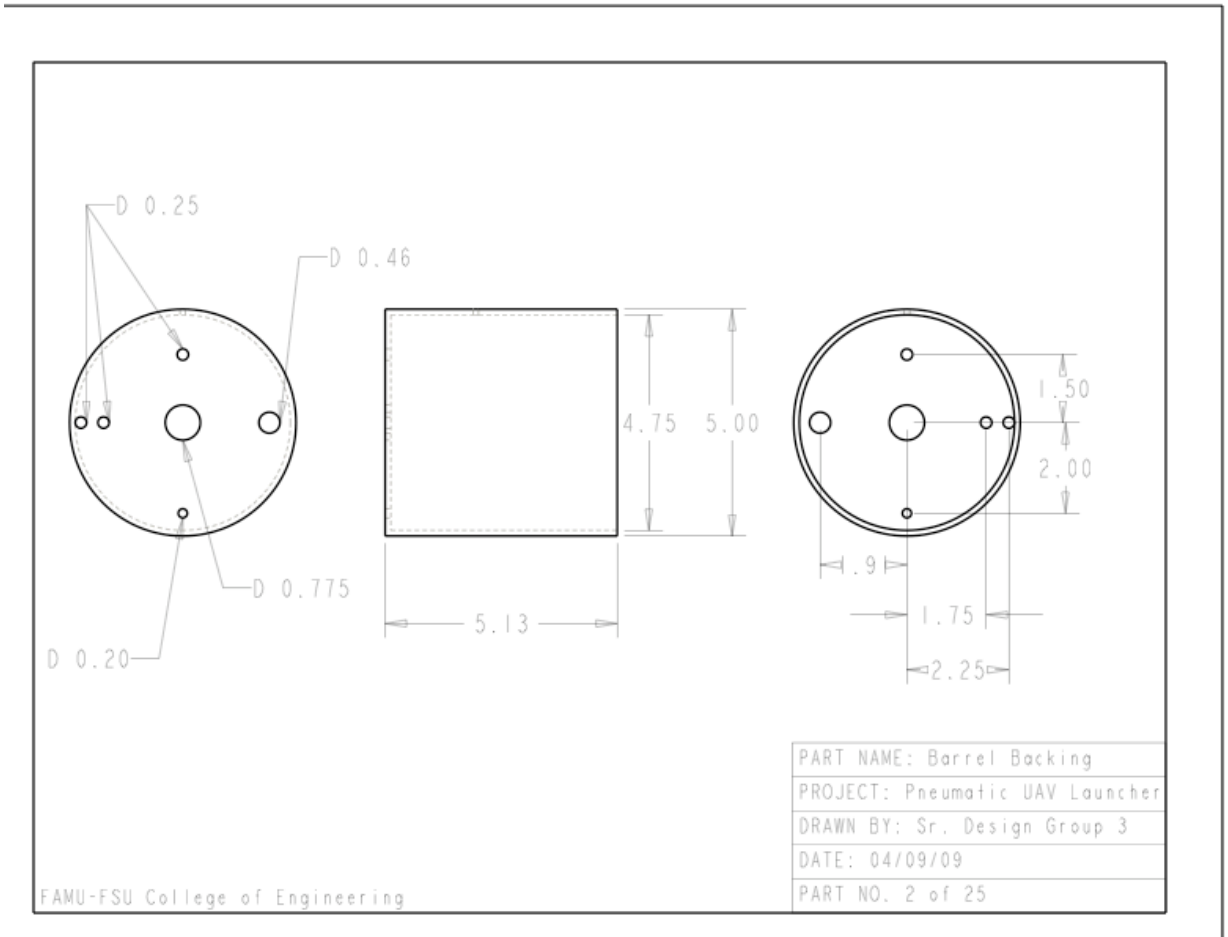
Expense Distribution

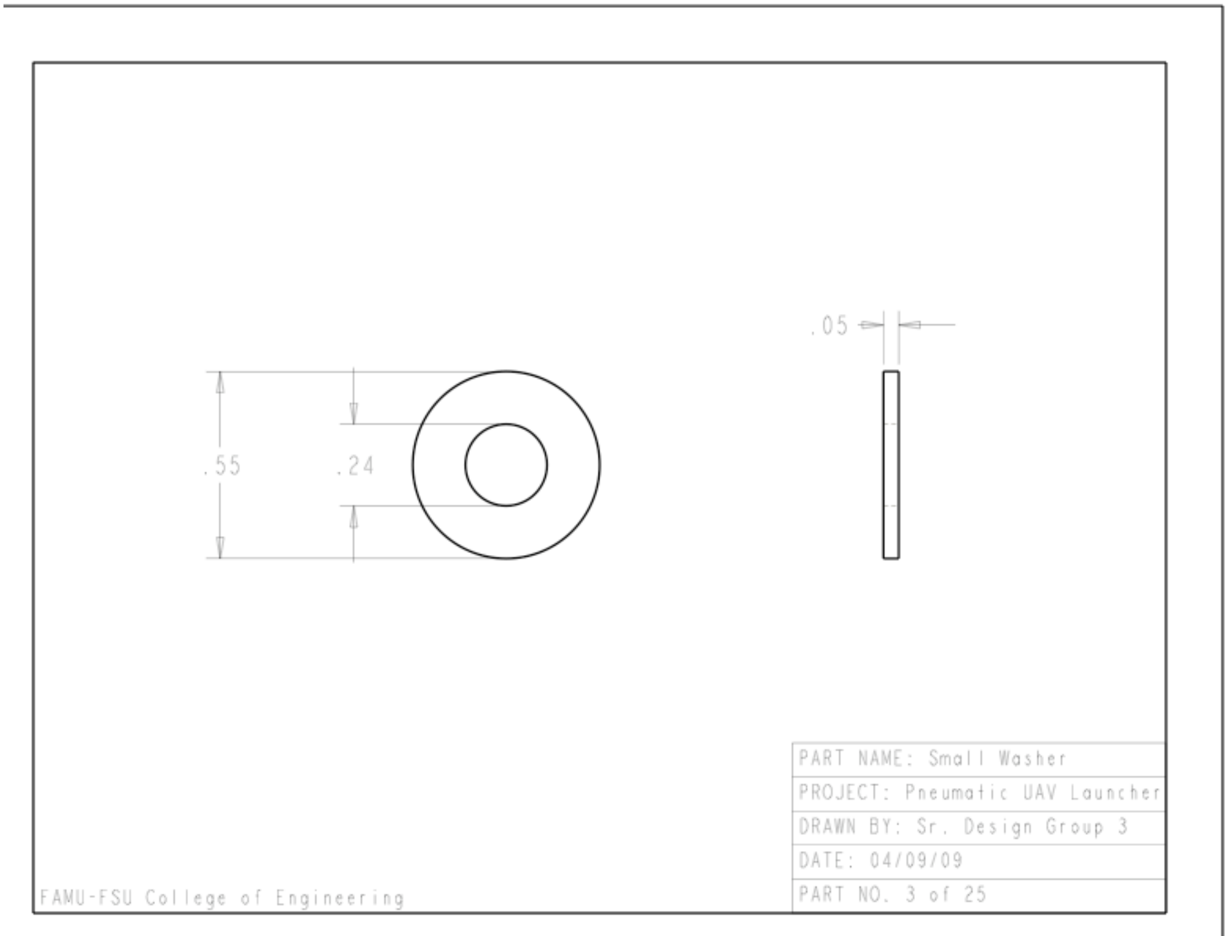
Weight Distribution

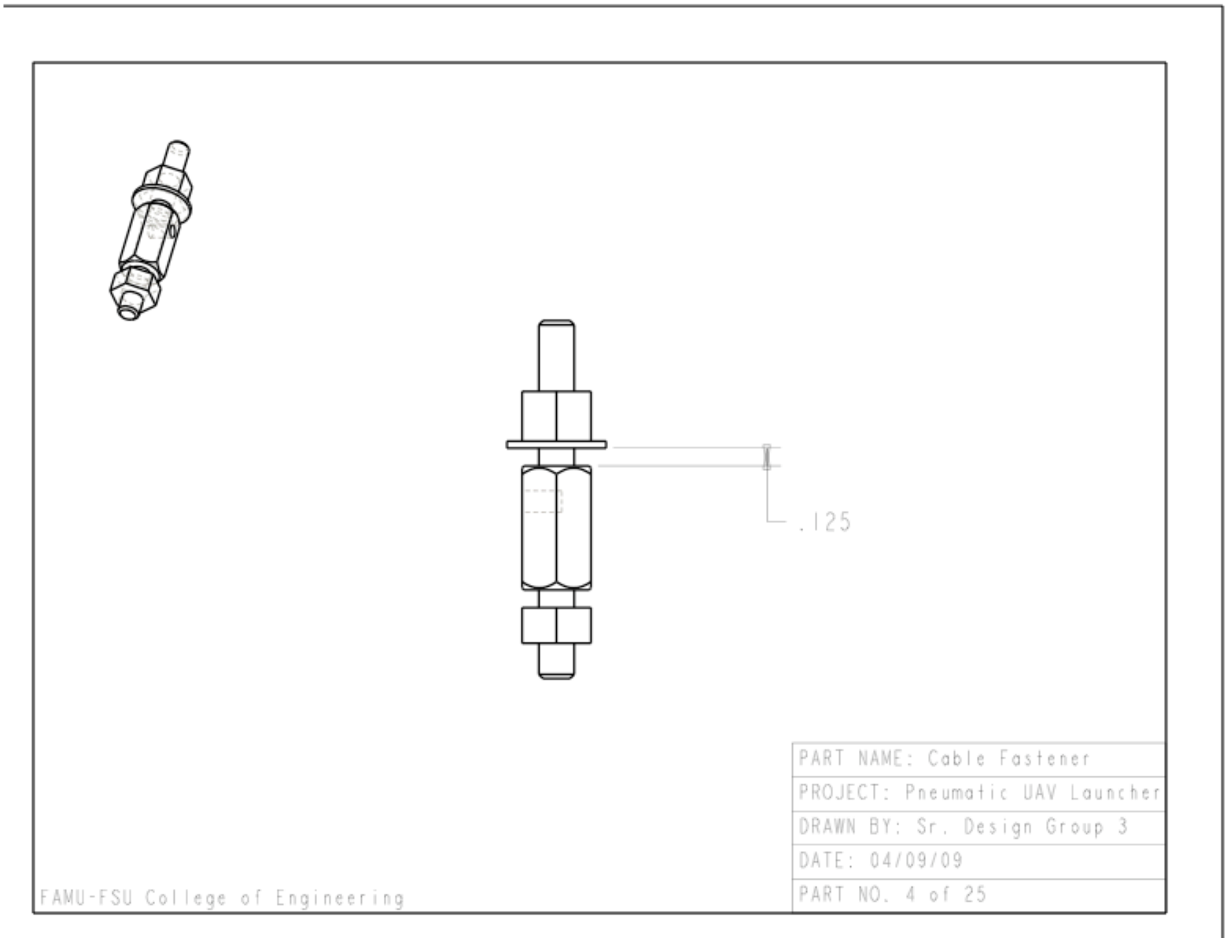
Component	Weight (lb)	Volume (in^3)	Material	Density (lb/in^3)
Barrel	3.268789	50.2890625	Carbon Fiber	0.065
Carriage	0.497494	7.65375	Carbon fiber	0.065
Backing	1.961273	30.1734375	Aluminum	0.098
Lining of tube	0.592	6.04082031	Aluminum	0.098
Carriage Support	0.55053	5.61765625	Aluminum	0.098
Pin	0.5	-	Stainless Steel	0.289
Receiver	0.3	-	Stainless Steel	0.289
Reservoir Tank	1.8	48	-	-
Regulator	0.8	-	-	-
Hardware	0.5	-	-	-
Total weight	10.77009	-	-	-

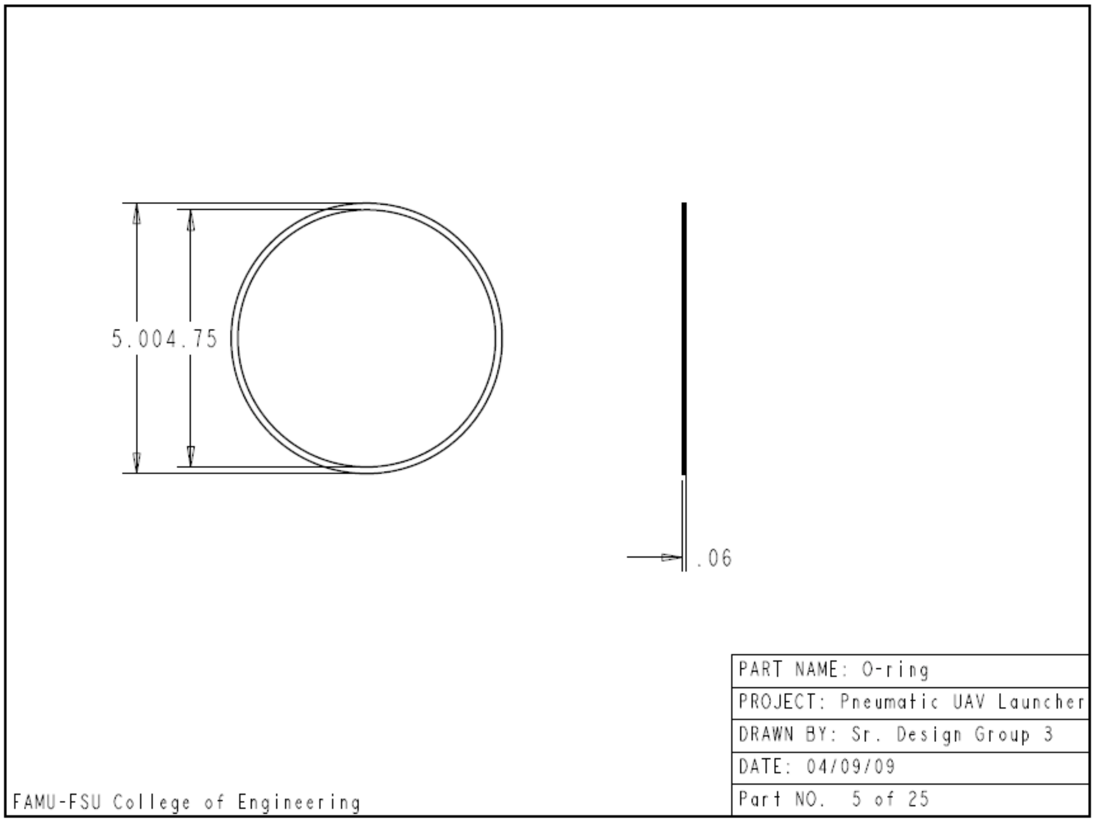
Appendix I
Optimized Final Design Drawings

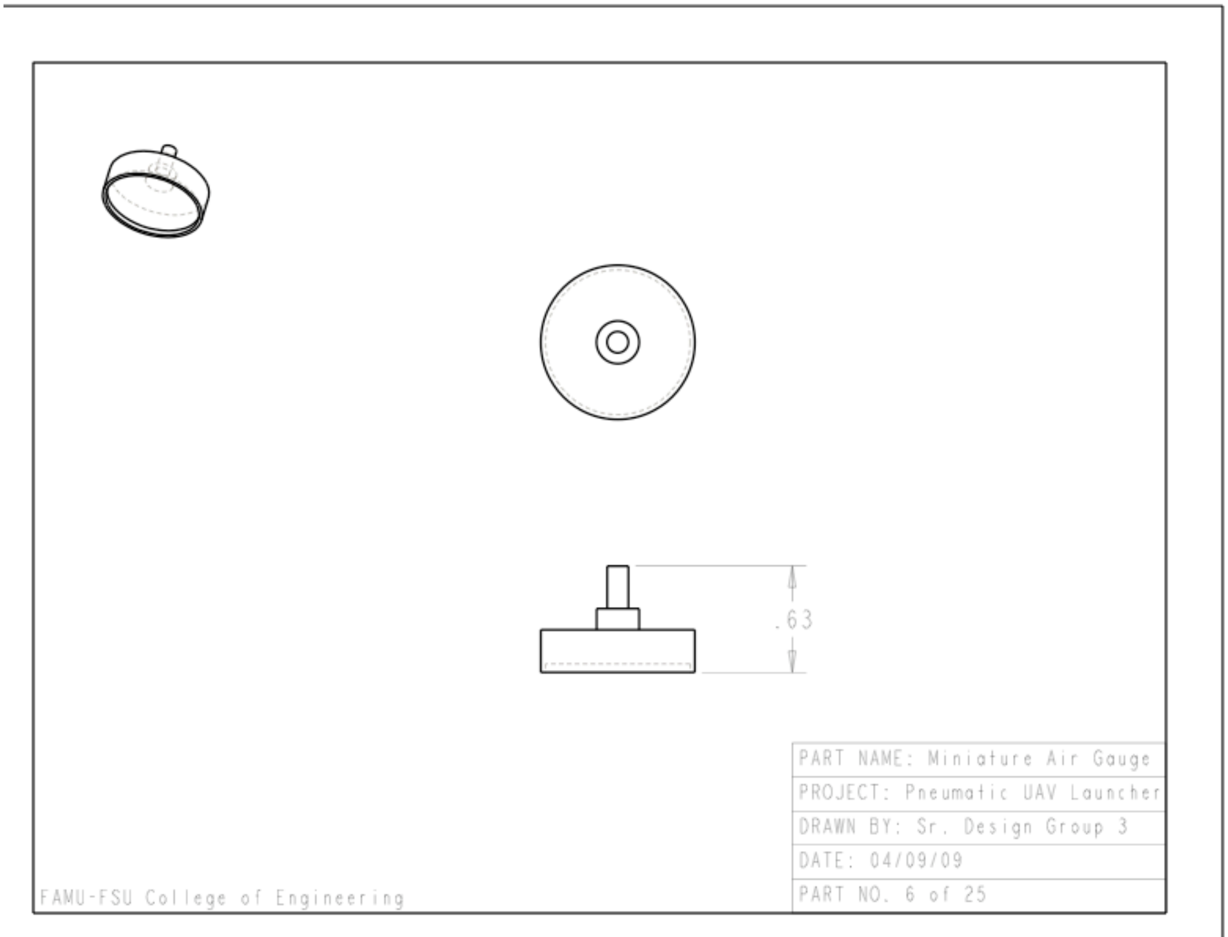


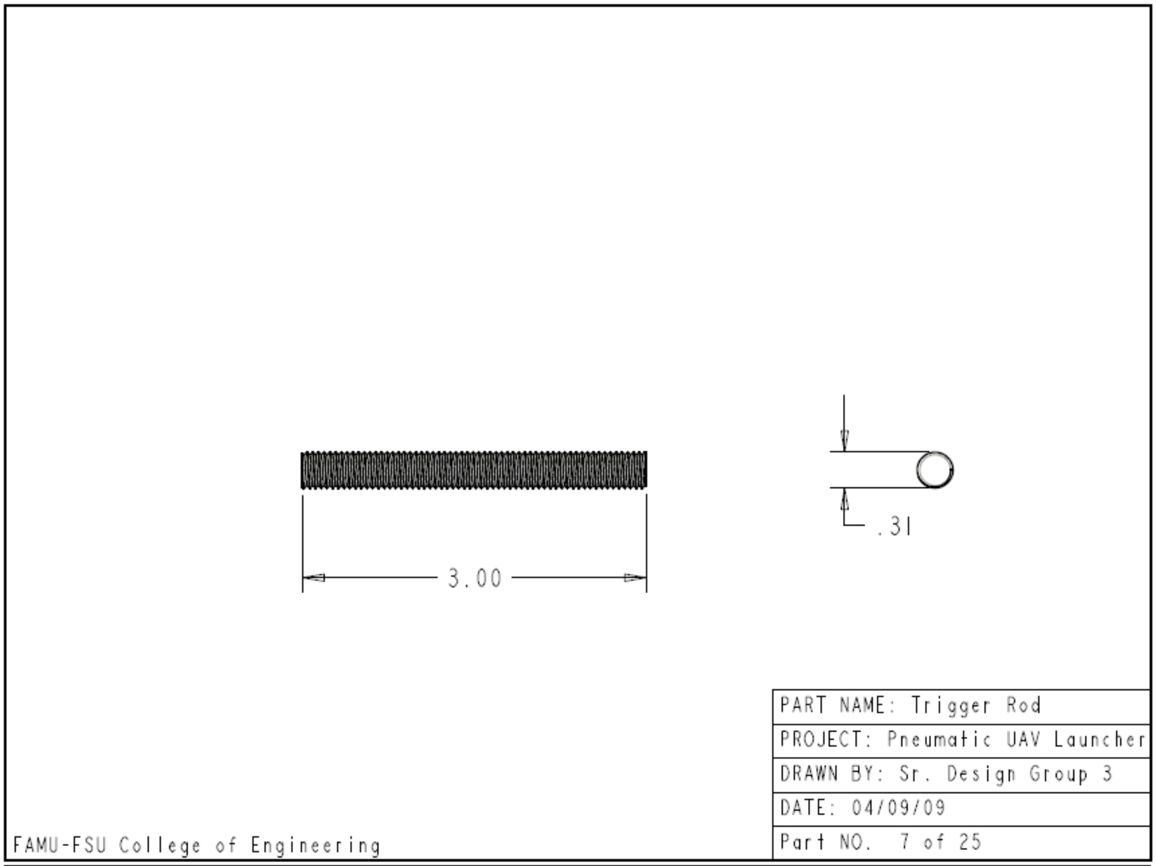

D 0.25
D 0.46
D 0.775
D 0.20
4.75
5.00
5.13
1.50
2.00
.9
1.75
2.25
PART NAME: Barrel Backing
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
PART NO. 2 of 25
FAMU-FSU College of Engineering

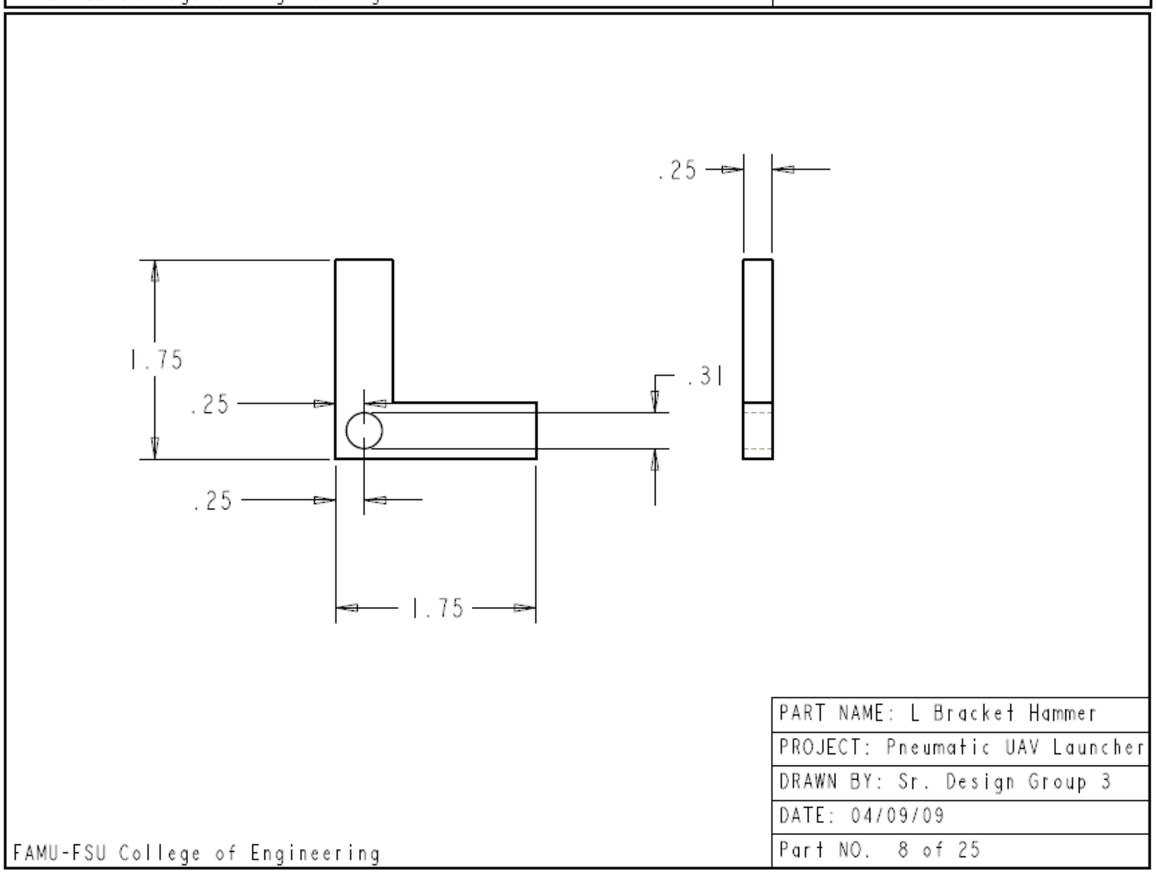

.05
.55
.24
PART NAME: Small Washer
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
PART NO. 3 of 25
FAMU-FSU College of Engineering

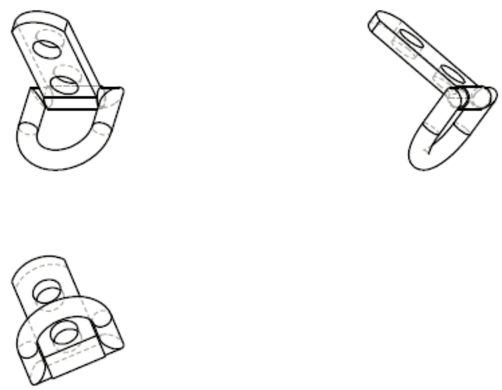

.125
PART NAME: Cable Fastener
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
PART NO. 4 of 25
FAMU-FSU College of Engineering


5.00
4.75
.06
PART NAME: O-ring
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
FAMU-FSU College of Engineering
Part NO. 5 of 25


.63
PART NAME: Miniature Air Gauge
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
PART NO. 6 of 25
FAMU-FSU College of Engineering

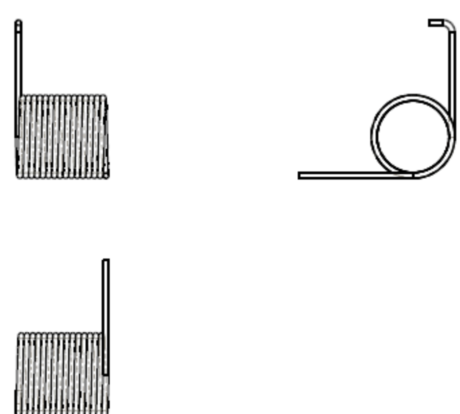

3.00
.31
PART NAME: Trigger Rod
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
Part NO. 7 of 25
FAMU-FSU College of Engineering


.25
1.75
.25
.31
.25
1.75
PART NAME: L Bracket Hammer
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
Part NO. 8 of 25
FAMU-FSU College of Engineering



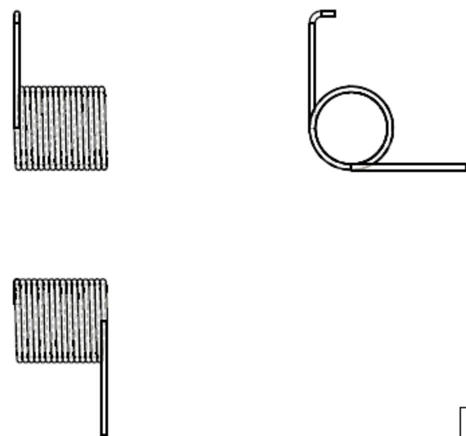
FAMU-FSU College of Engineering

PART NAME: D-Ring Trigger
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
Part NO. 9 Of 25



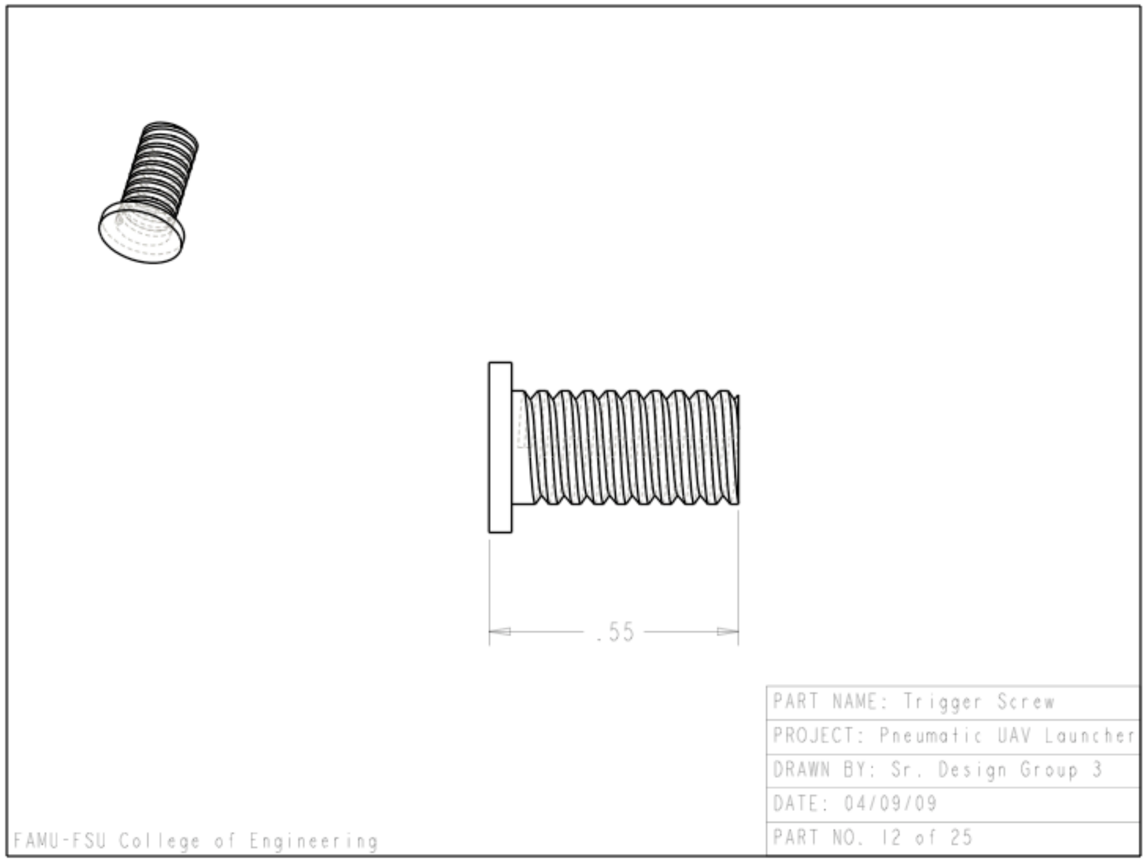
FAMU-FSU College of Engineering

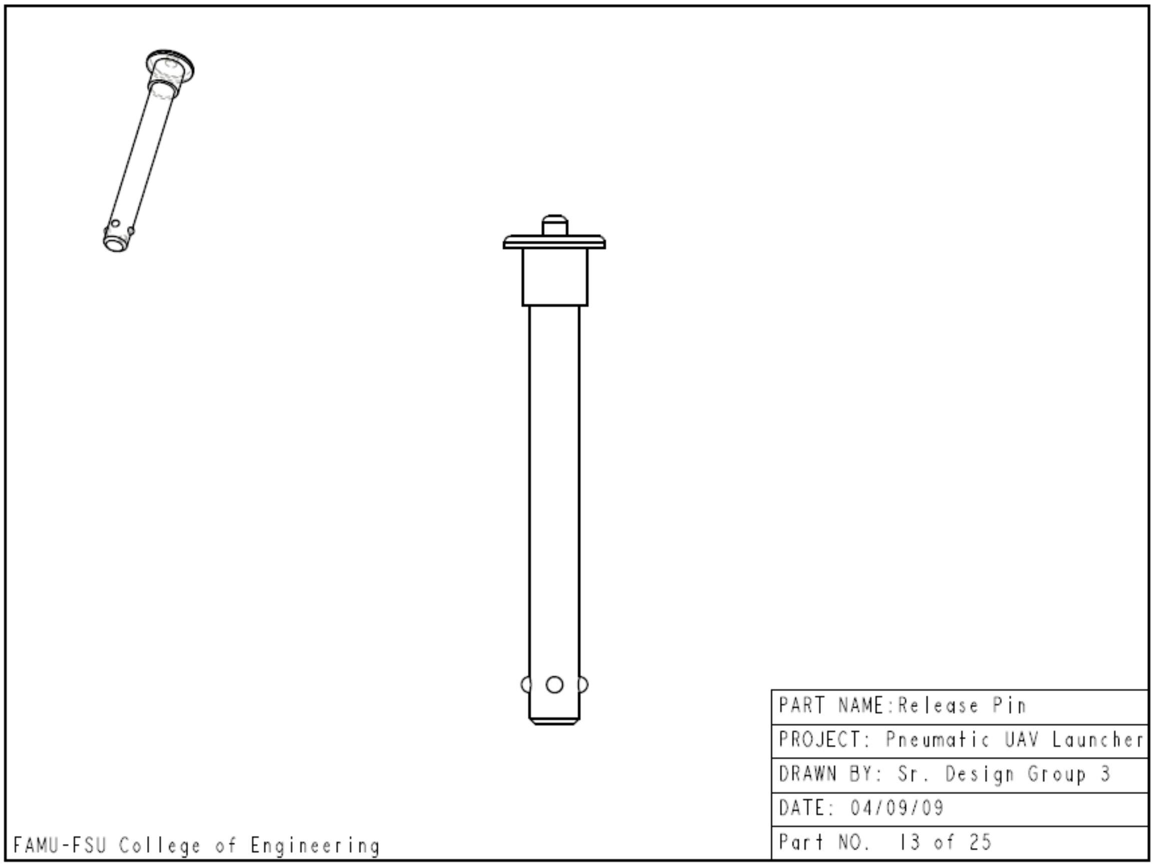
PART NAME: Left Spring
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO. 10 of 25



PART NAME:	Right Spring
PROJECT:	Pneumatic UAV Launcher
DRAWN BY:	Sr. Design Group 3
DATE:	04/09/09
Part NO.	11 of 25

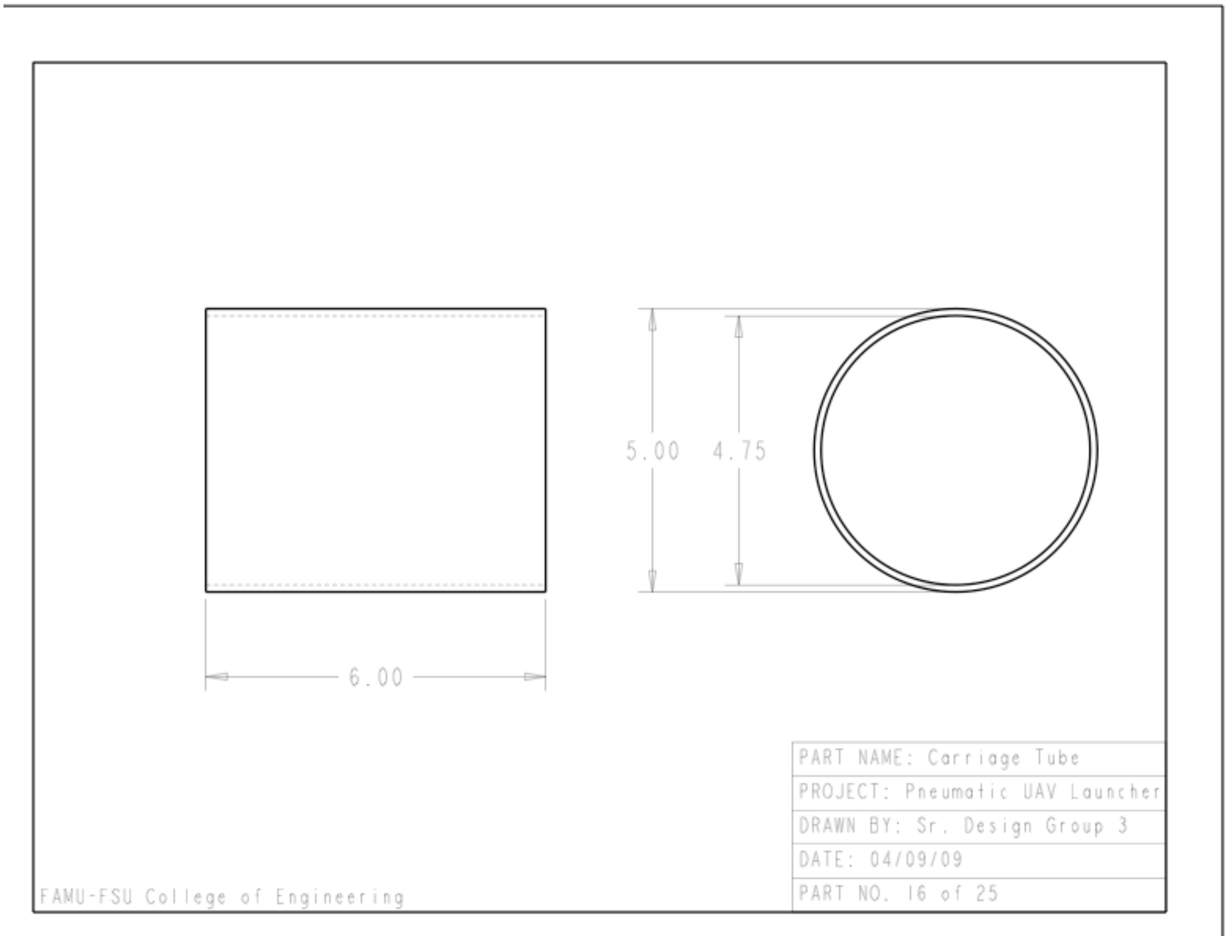
FAMU-FSU College of Engineering

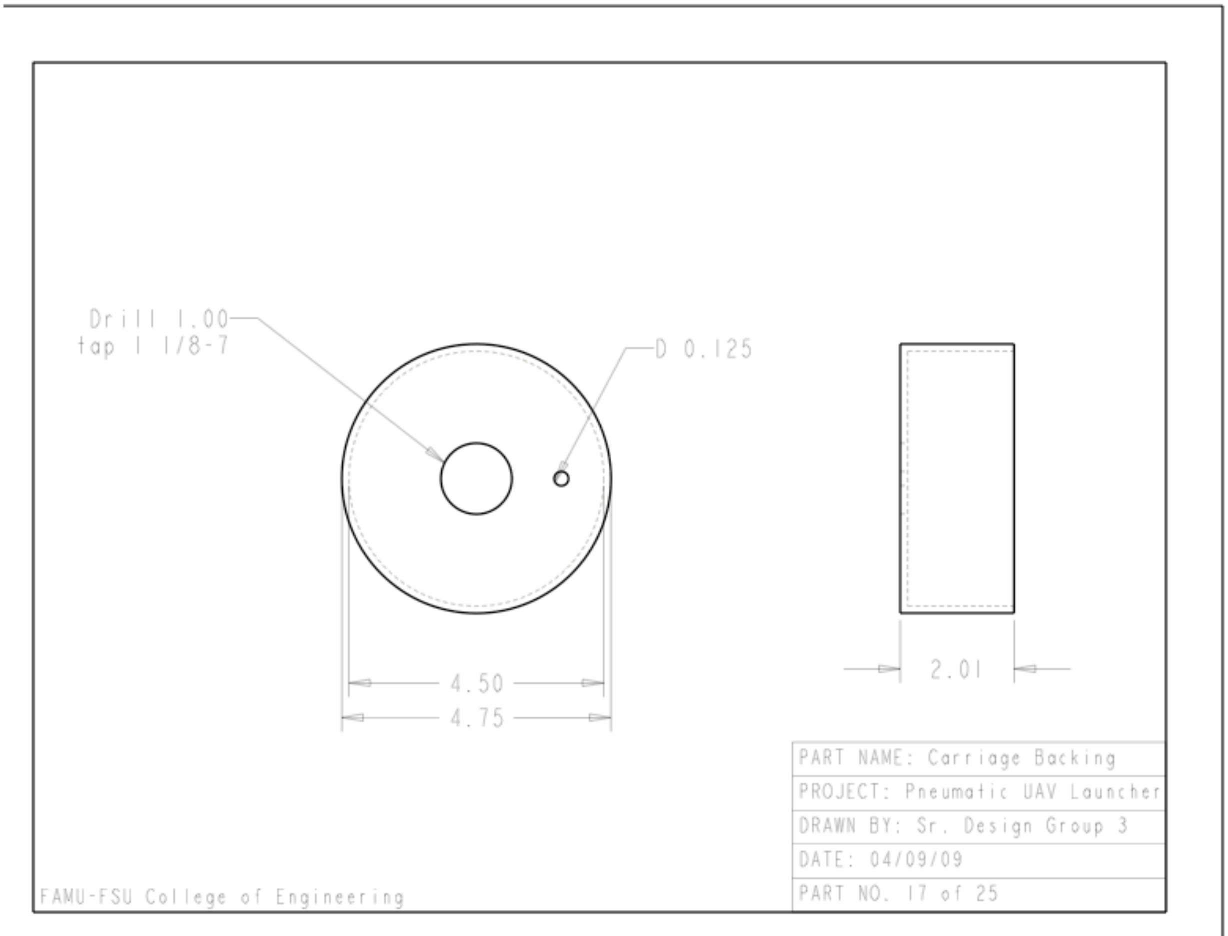

.55
PART NAME: Trigger Screw
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
PART NO. 12 of 25
FAMU-FSU College of Engineering

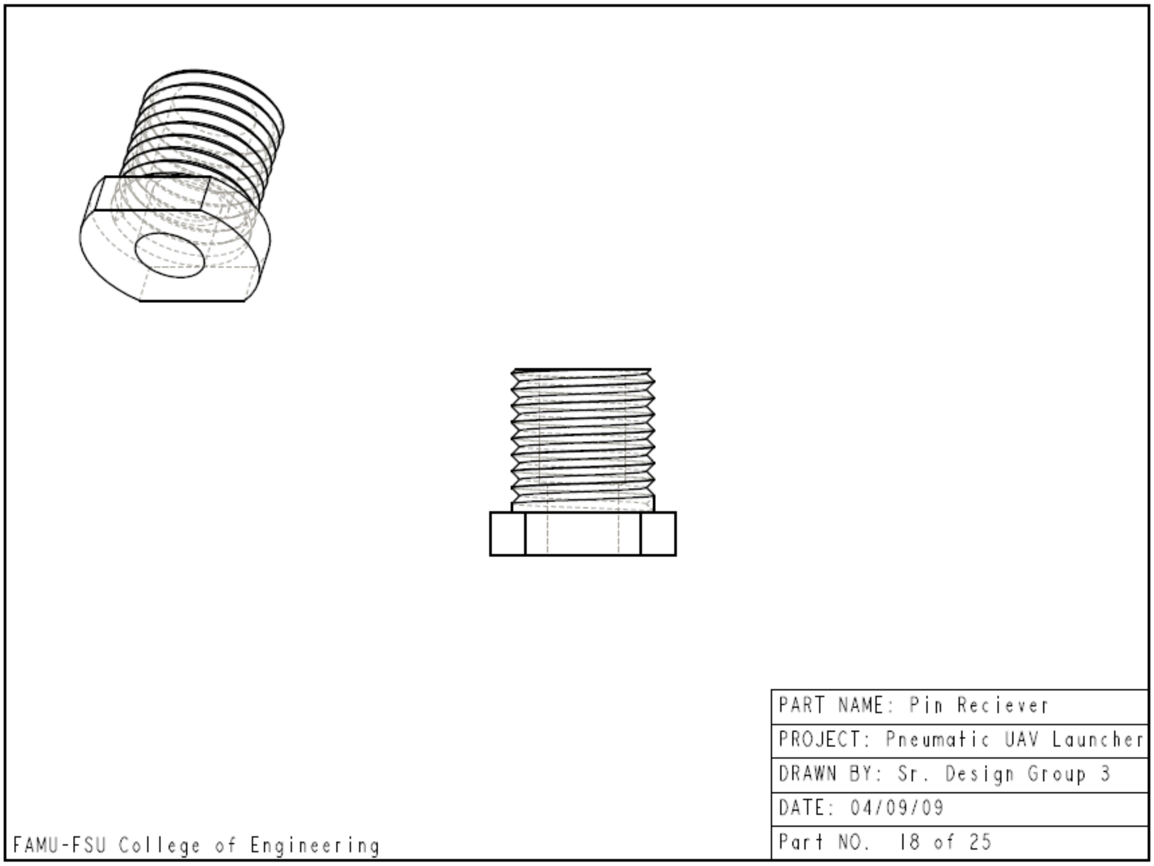

PART NAME:Release Pin
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
Part NO. 13 of 25
FAMU-FSU College of Engineering

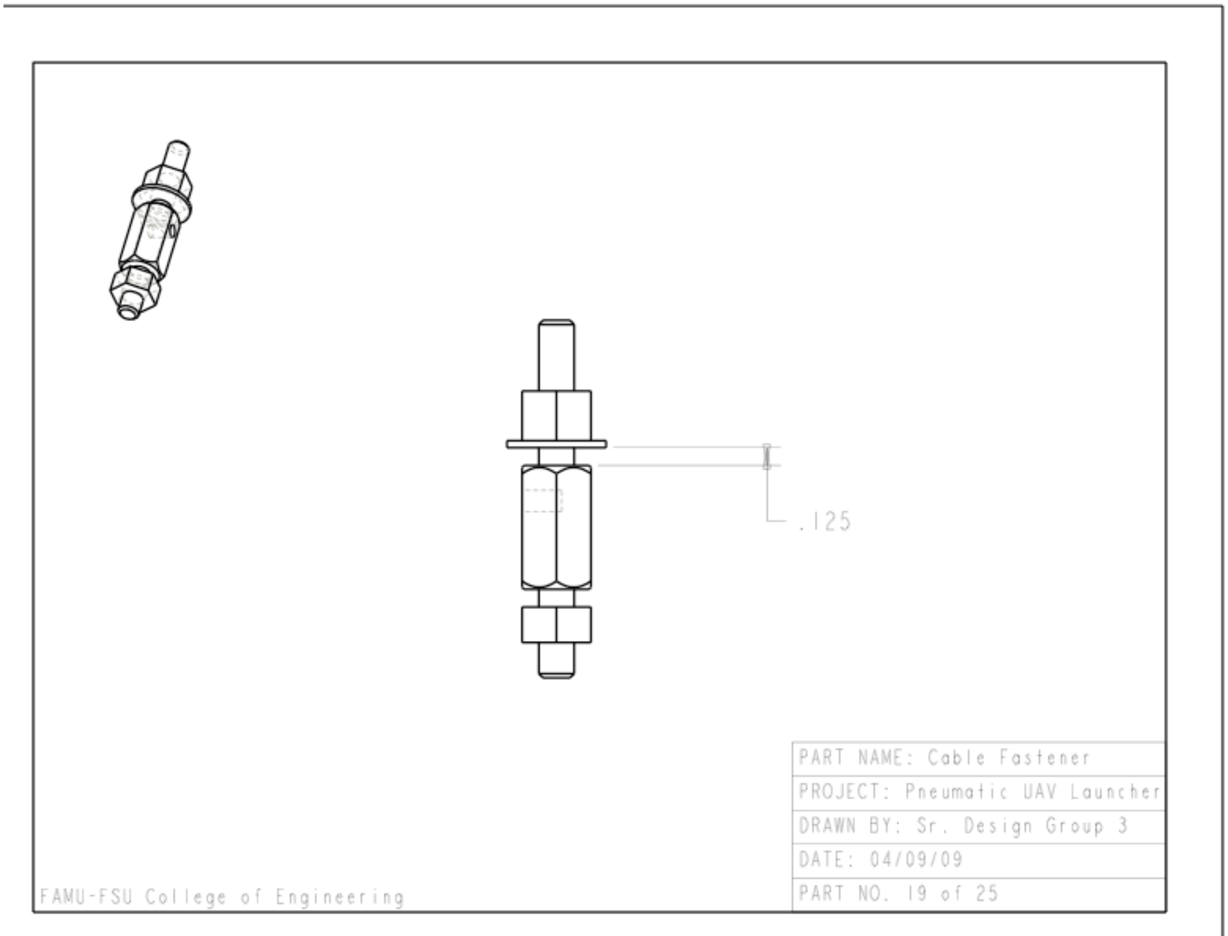
PART NAME: Schrader Valve	
PROJECT: Pneumatic UAV Launcher	
DRAWN BY: Sr. Design Group 3	
DATE: 04/09/09	
Part NO. 15 of 25	

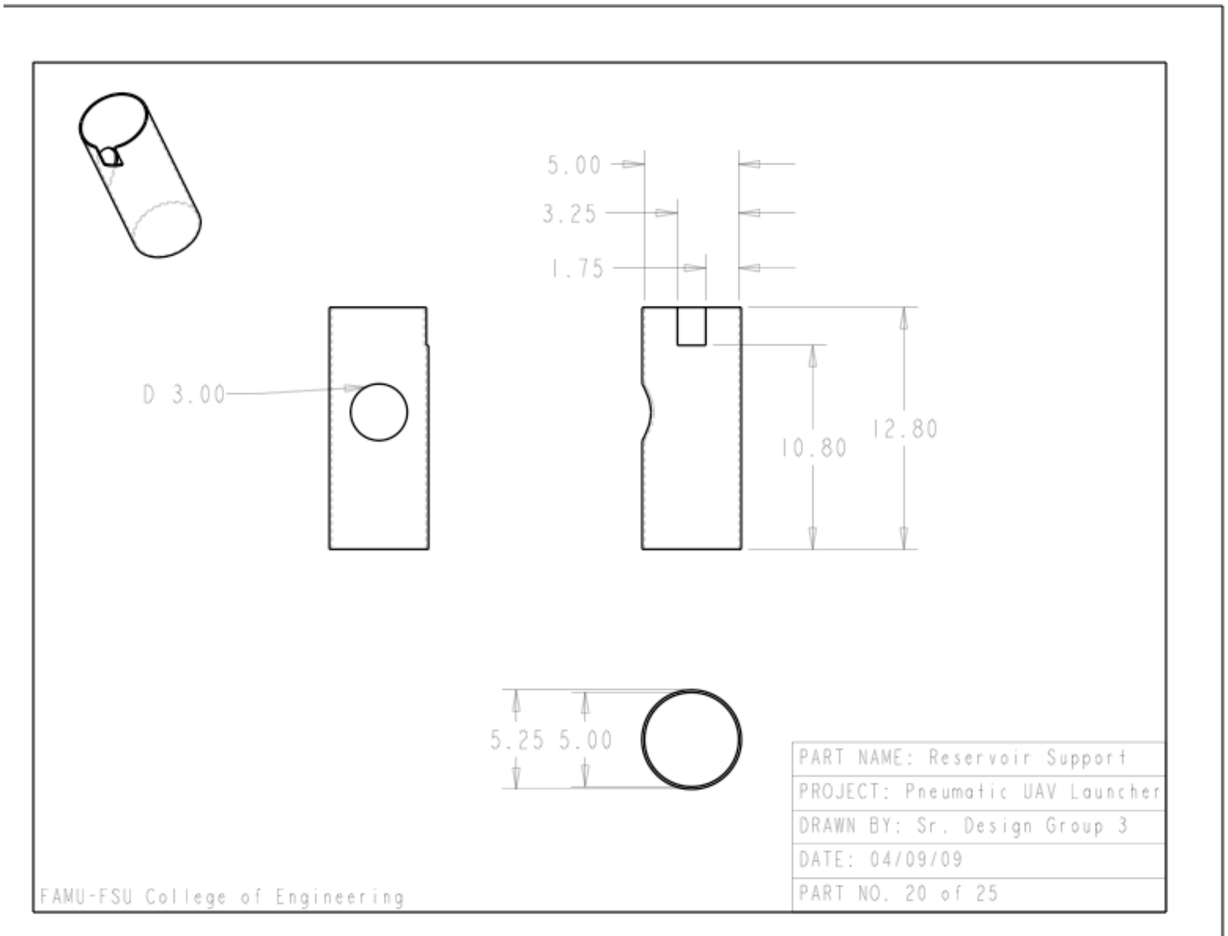
FAMU-FSU College of Engineering

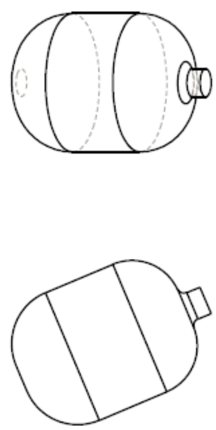

5.00
4.75
6.00
PART NAME: Carriage Tube
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
PART NO. 16 of 25
FAMU-FSU College of Engineering


Drill 1.00
tap 1 1/8-7
D 0.125
4.50
4.75
2.01
PART NAME: Carriage Backing
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
PART NO. 17 of 25
FAMU-FSU College of Engineering


PART NAME: Pin Reciever
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
Part NO. 18 of 25
FAMU-FSU College of Engineering

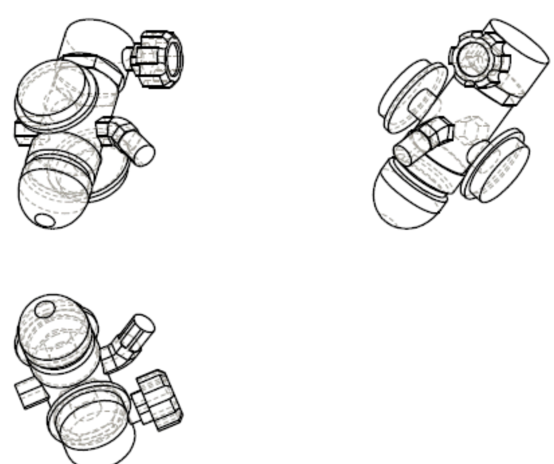

.125
PART NAME: Cable Fastener
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
PART NO. 19 of 25
FAMU-FSU College of Engineering


5.00
3.25
1.75
D 3.00
10.80
12.80
5.25 5.00
PART NAME: Reservoir Support
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
PART NO. 20 of 25
FAMU-FSU College of Engineering



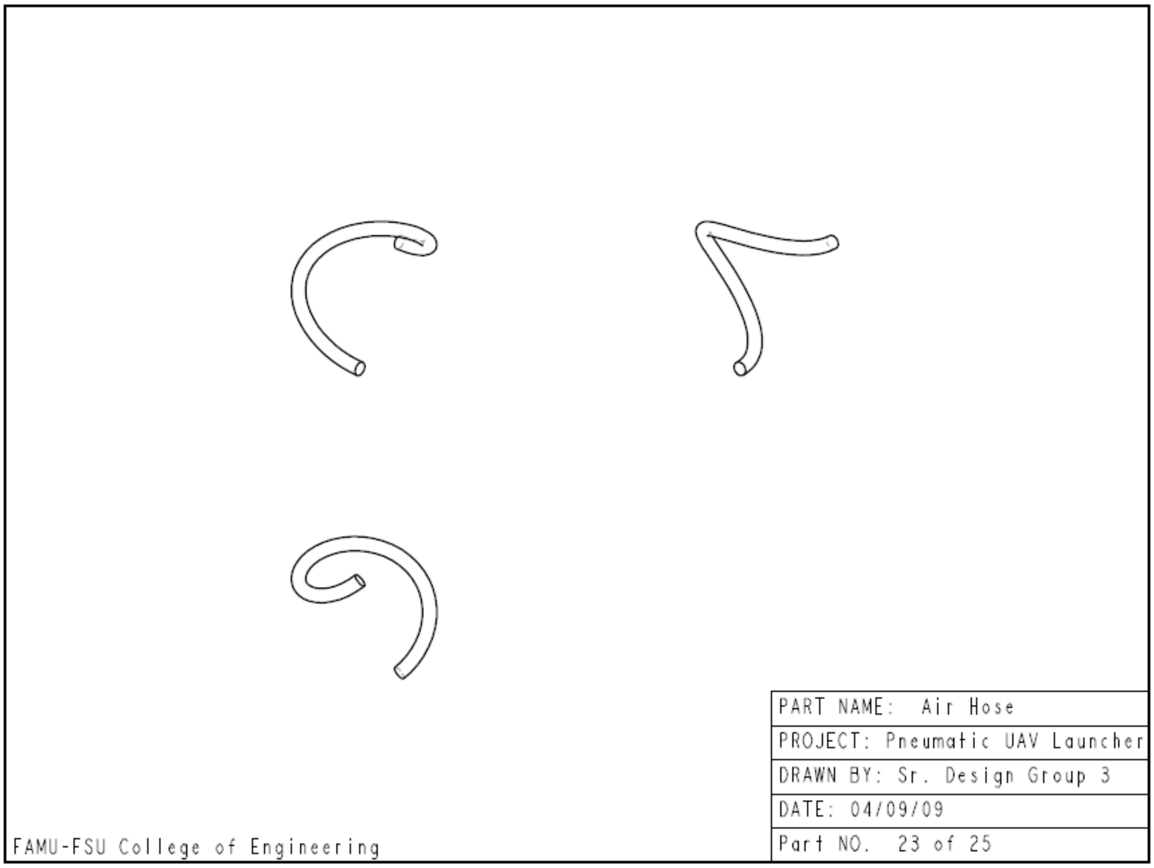
PART NAME:	Resevior Tank
PROJECT:	Pneumatic UAV Launcher
DRAWN BY:	Sr. Design Group 3
DATE:	04/09/09
Part NO.	21 of 25

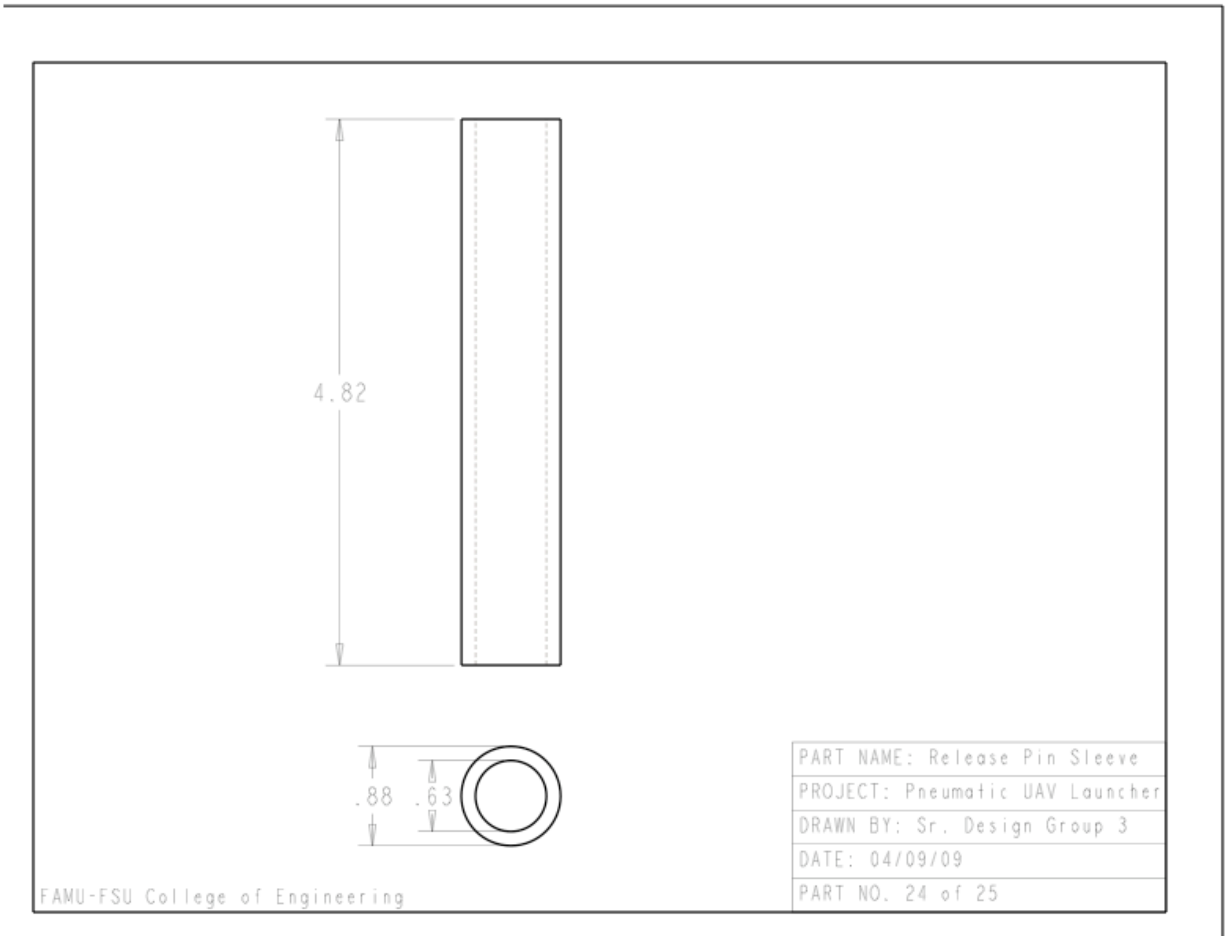
FAMU-FSU College of Engineering

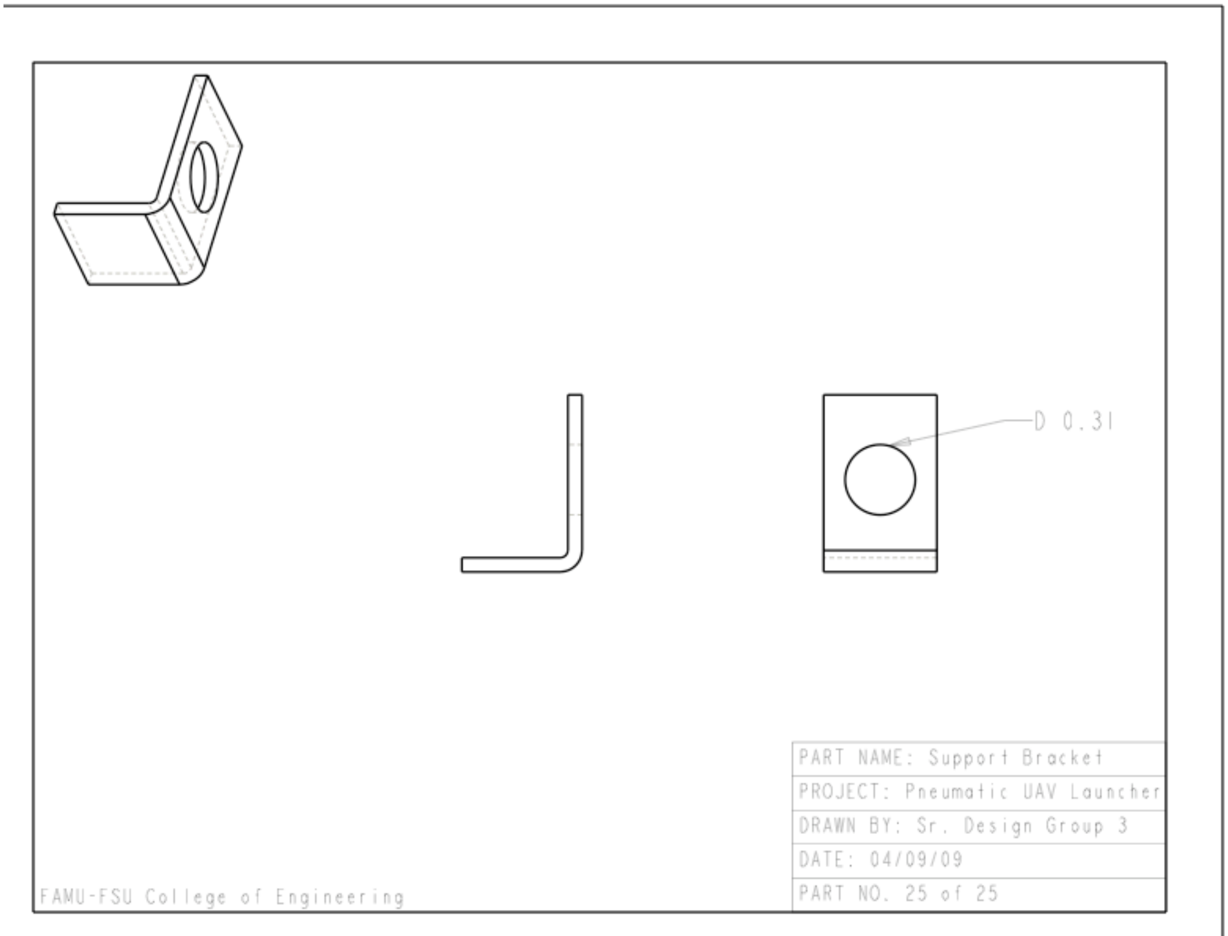


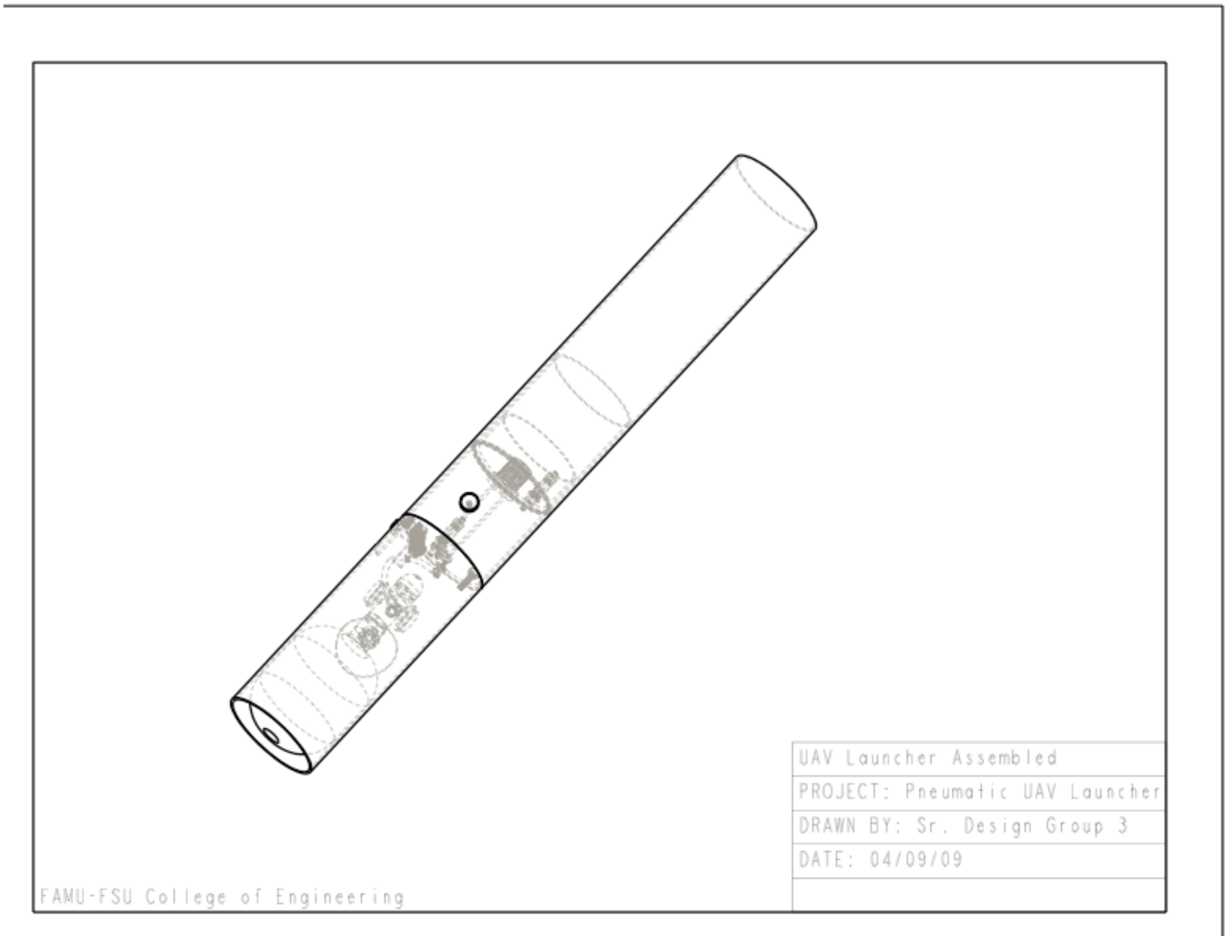
PART NAME:	Pressure Regulator
PROJECT:	Pneumatic UAV Launcher
DRAWN BY:	Sr. Design Group 3
DATE:	04/09/09
Part NO.	22 of 25

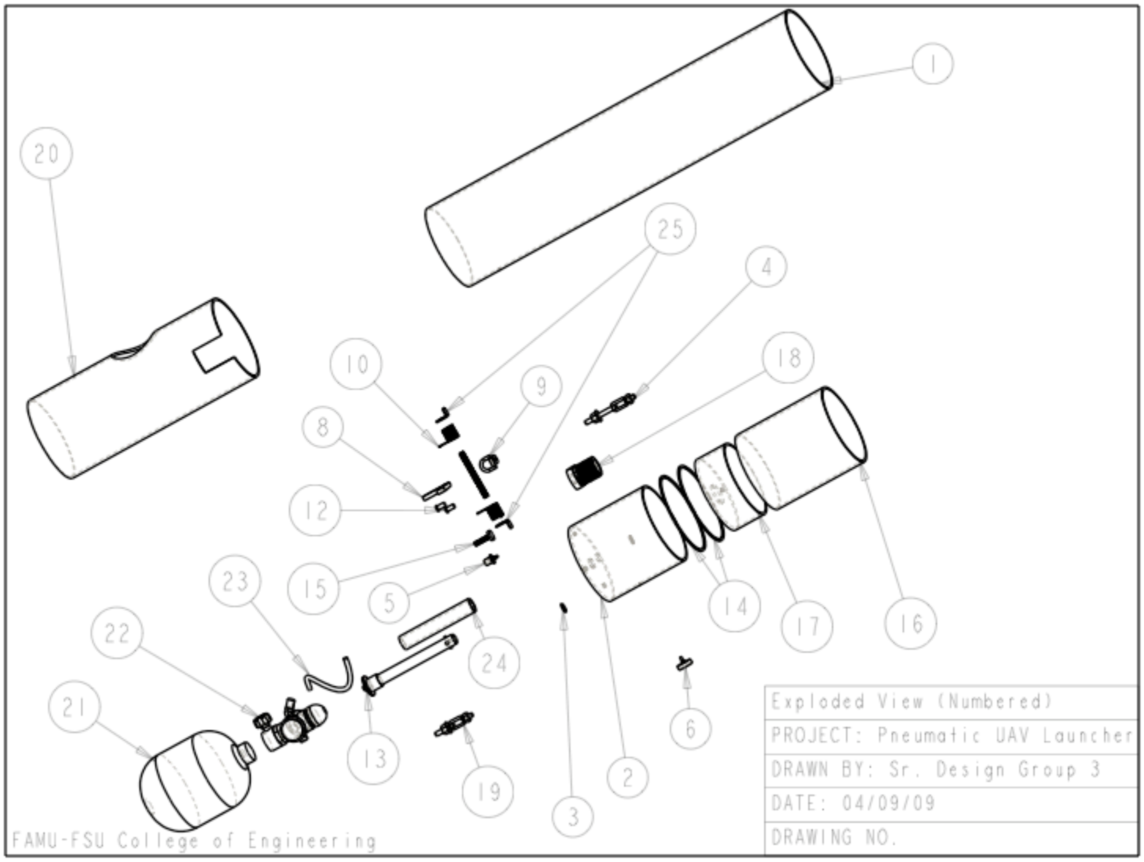
FAMU-FSU College of Engineering

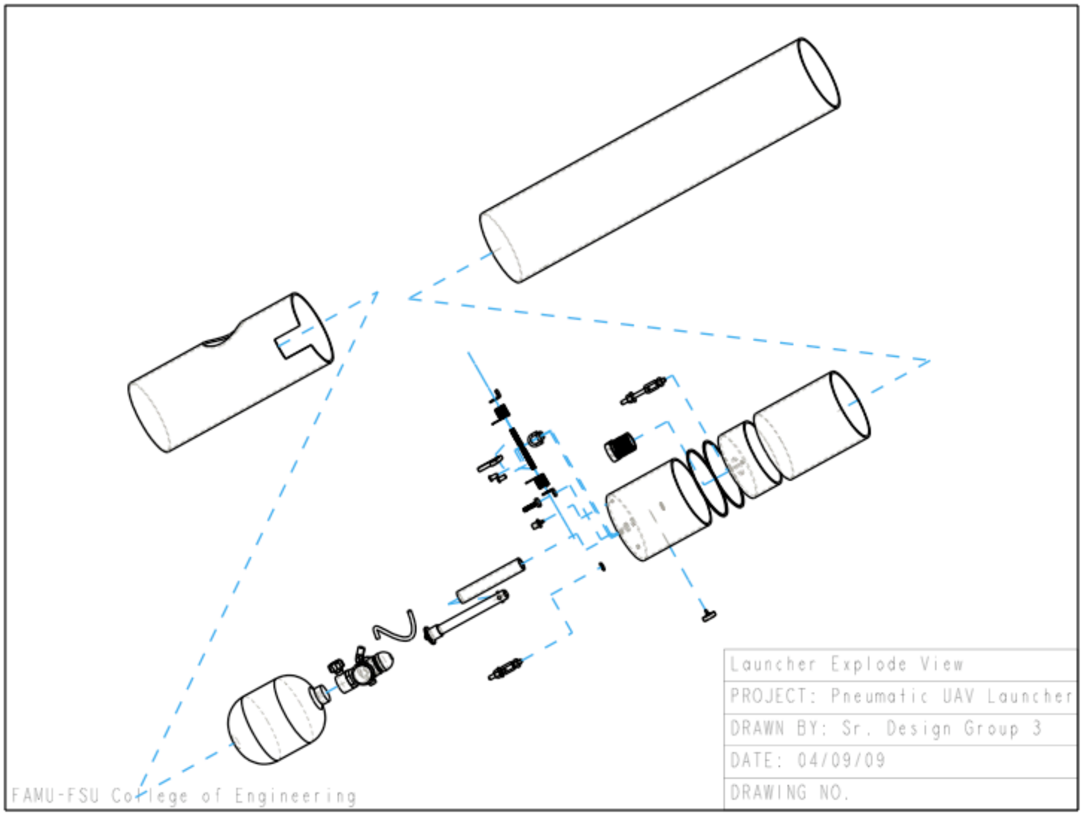

PART NAME: Air Hose
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
Part NO. 23 of 25
FAMU-FSU College of Engineering

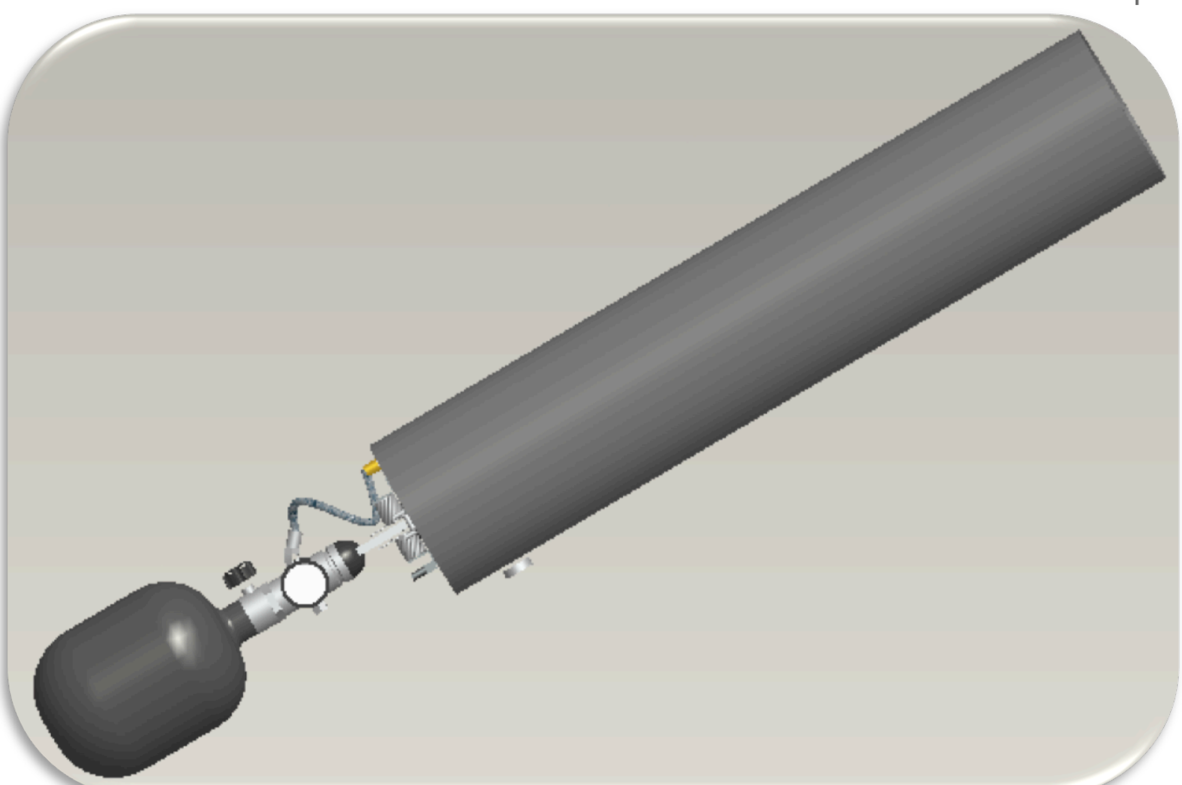

4.82
.88
.63
PART NAME: Release Pin Sleeve
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
PART NO. 24 of 25
FAMU-FSU College of Engineering


D 0.31
PART NAME: Support Bracket
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
PART NO. 25 of 25
FAMU-FSU College of Engineering


UAV Launcher Assembled
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
FAMU-FSU College of Engineering


1
20
25
4
10
9
18
8
12
23
15
5
14
17
16
22
24
21
13
6
19
2
3
Exploded View (Numbered)
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO.
FAMU-FSU College of Engineering


Launcher Explode View
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09
DRAWING NO.
FAMU-FSU College of Engineering



Assembly UAV_LAUNCHER_ASSEMBLY contains:

Number	Quantity	Part	Material
1	1	BARREL	CARBON FIBER
2	1	BARREL BACKING	ALUMINUM
3	2	SMALL WASHER	ALUMINUM
4	1	CABLE FASTENER	STEEL
5	1	AIR SUPPLY VALVE	BRASS
6	1	MINI GAUGE	N/A
7	1	TRIGGER ROD	STEEL
8	1	L BRACKET HAMMER	ALUMINUM
9	1	D-RING TRIGGER	ALUMINUM
10	1	LEFT SPRING	STEEL
11	1	RIGHT SPRING	STEEL
12	2	TRIGGER SCREW	STEEL
13	1	QUICK RELEASE PIN	STEEL
14	2	O-RING	RUBBER
15	1	SCHRADER VALVE	STEEL
16	1	CARRIAGE	CARBON FIBER
17	1	CARRIAGE BACKING	ALUMINUM
18	1	PIN RECEIVER	STEEL
19	1	CABLE FASTENER	STEEL
20	1	RESERVOIR SUPPORT	CARBON FIBER
21	1	RESERVOIR TANK	CARBON FIBER
22	1	PRESSURE REGULATOR	N/A
23	1	AIR HOSE	SS BRAIDED
24	1	RELEASE PIN SLEEVE	RUBBER
25	2	SUPPORT BRACKET	SS

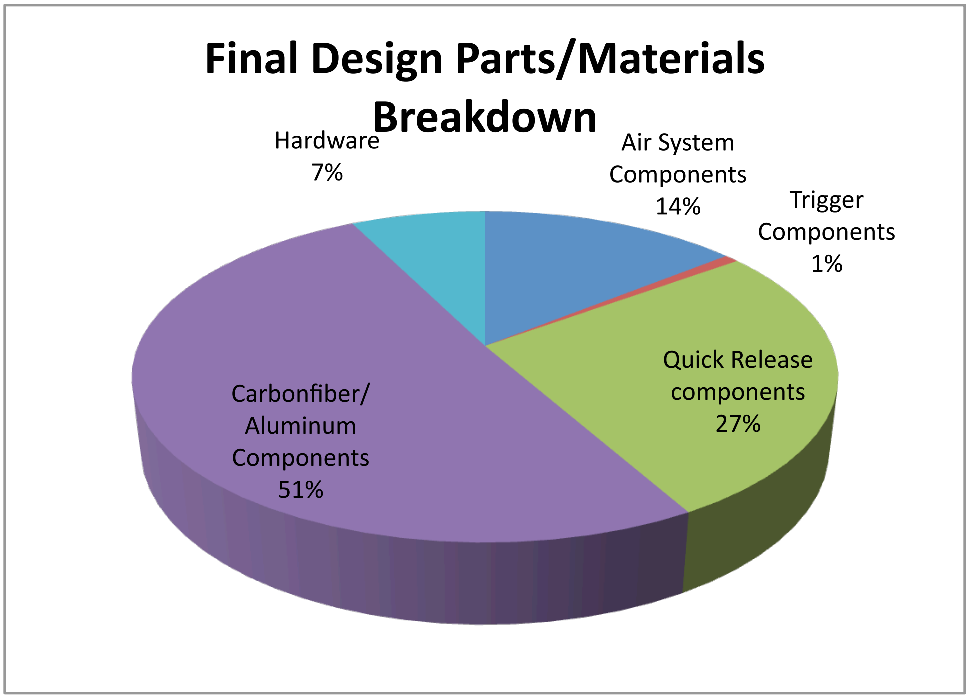
Bill of Materials
PROJECT: Pneumatic UAV Launcher
DRAWN BY: Sr. Design Group 3
DATE: 04/09/09

FAMU-FSU College of Engineering

Appendix J

Part/Material Expenses

Item	Quantity	Vendor	Part Number	Total Price
5"1/2x36"x1/8" Carbon fiber/aluminum tube	1	Nim-Cor	Custom Part	$600.00
High Pressure reservoir tank	1	E-Paintball.com	100992	$154.95
Tank Regulator	1	Sakworld Paintball	144891330	$99.95
Schrader Valve	1	Advanced Auto Parts	04134-8	$6.96
Quick Release Pin	1	Big Sky Precision	Custom Part	$423.00
Quick Release receiver	1	Big Sky Precision	Custom Part	$80.00
12"x12"x1/8" aluminum sheet	1	McMaster-Carr	1924T61	$57.78
Pressure gauge	1	Home Depot	TC2104	$9.46
5"x12"x1/8" Carbon fiber/aluminum tube	1	Nim-Cor	Custom Part	$350.00
High Pressure steel braided line	1	Sakworld Paintball	N/A	$10.03
Hammer Trigger Release	1	Home Depot	N/A	$14.54
5/8" ID 1" OD O-Ring	1	Home Depot	M32-L	$0.98
5"x1/8" O-rings	1 pack	McMaster-Carr	4061T27	$14.88
1/8" Cable strong grip end fittings	2	McMaster-Carr	3475T885	$18.69
Cable	1	McMaster-Carr	3459T72	$19.30
Pressure sealing washers	1 pack	Home Depot	M32-N	$2.17
Silicone II sealant	1	Home Depot	GE5003TG	$6.93
1/8" to 1/4" NPT fitting	1	Capital Rubber	s406-4-2	$0.75
5/8" Rubber Tube	1	Machine Shop	N/A	$0.00
			Total=	$1,870.37


Final Design Parts/Materials Breakdown
Hardware
7%
Air System Components
14%
Trigger Components
1%
Quick Release components
27%
Carbonfiber/ Aluminum Components
51%

Appendix K

Senior Design Group 3

FAMU/FSU College of Engineering

11/17/08

ATTN: John Deep, Jeff Wagener

Eglin Air Force Base/Air Force Research Laboratories

SUBJECT: Request for a 2.5 lb weight specification increase for the pneumatic UAV launcher design.

Justification:

Our group was unable to find any existing air tanks that met our volume/pressure requirements while remaining lightweight. The lightest nitrogen/compressed air tank that met our pressure requirement weighs 1.8 lbs empty, and our group could not complete the rest of the design with 0.7 lbs remaining. In order to meet the other specifications (esp. repeatability) with a practical design, the group is requesting a less stringent weight constraint.

UAV Dimensions

FAMU-FSU Senior Design Group 3 show details Nov 13 Reply
to jeffery.wagener

Hey Jeff,
We are working on our final drawings and paper for the launcher, but we really need the dimensions of the UAV. If not all of the dimensions, we need the maximum width or height of the UAV or the minimum inner diameter of a launch tube. This way, we can more accurately calculate forces and pressures.

Thanks,

--
Senior Design Project Group 3
Compact Pneumatic UAV Launcher
Sponsored by Eglin Air Force Base
FAMU-FSU College of Engineering

Weight Constraint Request

FAMU-FSU Senior Design Group 3 See Attached. Nov 17

Deep, John S CIV USAF AFMC Det 6 AFRL/SES show details Nov 19 Reply
to **Jeffrey**, me

Gentlemen,

After reviewing your request and discussing it with Mr. Wagner we agreed to relax the max system weight constraint to 5.5 lbs. If you have any questions let us know.

John Deep
Senior Engineer
Det 6 AFRL/SES Eglin AFB, FL
e-mail: john.deep@us.af.mil
Voice: (850) 882-3781
DSN: 872-3781
FAX: (850) 882-1580

UAV dimensions

FAMU-FSU Senior Design Group 3 show details Nov 24 (10 days ago) Reply
to John, jeffery.wagener

Hey Jeff and John,

Last week we received electronic documents from Jeff that were supposed to be the dimensions of the UAV. We tried to open it multiple times with multiple programs and got it to open in pro E but it was dimensionless. We tried to access the sketch of the UAV, but to no avail. So we are still dimensionless. If we could just get an estimate of the minimum diameter with the wings closed, it would be really helpful in our calculations. Thanks for your time.

--
Senior Design Project Group 3
Compact Pneumatic UAV Launcher
Sponsored by Eglin Air Force Base
FAMU-FSU College of Engineering

Weight Extension Request

FAMU-FSU Senior Design Group 3 show details 12:29 AM (15 hours ago) Reply
to John, jeffery.wagener

Hi John,

We are still waiting for the minimum possible tube diameter the UAV can fit in (we need the pro-e drawing with the wings closed). After knowing this dimension we can reduce the size of the diameter of the launch tube to further reduce the weight. We still feel after reducing the diameter we will still be over the set weight limit. As of right now we are over the new set weight limit. This was with using carbon fiber. We tried considering having the launch tube machined out of lighter weight plastics; however no manufacturer we spoke to would allow the required pressure rating. The plastic theoretically can withstand the pressures, but no manufacturer we spoke to really tests them for pressures. The following table gives the total weight for our current design.

Carbon Fiber Carriage	0.723279375
Aluminum in Carriage	0.785737508
Carbon Fiber Tube	3.0414825
Aluminum in Tube	0.801284825
Reservoir Tank	1.8
Pin/Receiver	1
Nuts/Washers	0.3
Fasteners	
regulator	0.3
Grace weight	0.5
Rod Protectors	0.38748699
total	9.639271198

From	**Deep, John S CIV USAF AFMC Det 6 AFRL/SES** <john.deep@eglin.af.mil>
to	FAMU-FSU Senior Design Group 3 <launchteam09@gmail.com>
date	Mon, Apr 13, 2009 at 9:20 AM
subject	RE: Final report
mailed-by	eglin.af.mil

Gentlemen,

The change in weight to 11lbs Max is approved. I probably will not be able to make the breakfast as I doubt I can get out of here at 4am. Where (what building) are the final presentations being done and do you have an agenda/schedule? I will see you Thursday.

John Deep
Senior Engineer
Det 6 AFRL/SES Eglin AFB, FL
e-mail: john.deep@us.af.mil
Voice: (850) 882-3781
DSN: 872-3781
FAX: (850) 882-1580

- Show quoted text -

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Zephyr Paintball Inc., Reservoir tank information and product research, www.zephyrpaintball.com

Nees@berkeley --- Home. 09 Apr. 2009 <http://nees.berkeley.edu/Facilities/pdf/Instrumentation/Setra_141.pdf>.