Milestone VI: Design Implementation

UCF Athletics T-Shirt Launcher

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Executive Summary

At the 2023 Space Game, the question was asked “Why does UCF not have a unique space themed T-shirt launching tool?” After all, UCF is “Space-U” and has long standing ties to the space and aerospace industries, making this a valid question. Due to this, a motion was set forth to have UCF MAE Senior Design teams construct a new T-shirt launching tool to be used by UCF Athletics.

The main benefit of this project is having a launcher that is custom built to the needs of UCF Athletics and is a representation of the UCF Department of MAE. By having a custom built launcher, every factor, such as aesthetics, branding, launch distance, and power can be fine tuned to meet the exact needs of UCF Athletics.

The final launcher, Gemini 28-80, features a steel accumulator tank, barrel made of pressure rated pipe, an optional external scuba tank for portability, and significant UCF and Space-U branding. The team prioritized safety over all other considerations, performing robust FEA and testing on every pressure bearing component of the launcher.

Future iterations of Gemini 28-80 made for UCF Athletics should use the lessons learned from this project to improve the final product. Overall, reducing the weight and overall size of the launcher was identified as the largest area for improvement. This can be accomplished by using smaller, custom built pressure vessels where the SRBs are placed, and placing a barrel in between them.

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Terms and Abbreviations

Abbreviation	Meaning	Page
BSP	British Standard Pipe	57
CF	Cubic Feet	156
COTS	Commercial Off the Shelf	20
DOT	Department of Transportation	20
FEA	Finite Element Analysis	20
FOS	Factor of Safety	37
LOTO	Lock-Out / Tag-Out	20
MPH	Miles per Hour	48
NPT	National Pipe Thread	28
PETG	Polyethylene Terephthalate Glycol	24
PLA	Polylactic Acid	96
PTFE	Polytetrafluorethylene	68
PVC	Polyvinyl Chloride	24
OSHA	Occupational Health and Safety Administration	52
UCF	University of Central Florida	5
UV	Ultraviolet	24
NASA	National Aeronautics and Space Administration	15
SRB	Solid Rocket Booster	72

1.0 Introduction

Prior to constructing and testing the final system, the team has taken major steps this year to go through the design process that is used in engineering. In January, each team member selected this as their first choice for a Senior Design project. Shortly after, each team member individually conducted preliminary research on topics that were thought to be relevant to designing a T-shirt launcher. After this preliminary research, the team constructed system requirements, with the goal of addressing the end users' needs and guiding design decisions. Subsequently, major design decisions were made, followed by the detailed design of the T-shirt launcher.

Since then, the team has constructed prototypes, built the final system, and performed substantial testing on the final and prototype systems. This project has served as a major milestone, as it marks the end of the team's career as students at UCF and the beginning of professional careers across the engineering industry.

1.1 Project History

In recent years, UCF has made a noticeable effort to increase their branding and recognition as "Space-U", indicating UCF's long standing ties to the space industry. In 2018, UCF hosted the first annual football Space Game, where the team wore custom space themed uniforms. This has evolved into an entire new line of branding and merchandise for UCF.

At the 2023 Space Game, where UCF annihilated 16th ranked Oklahoma State [12], Pete Alfieris was representing the College of Engineering with various space themed clubs and activities. During the game, he noticed that T-shirts were being thrown into the stands by hand, not reaching very far. At this moment, he posed the question of why UCF does not have a unique space themed T-shirt launching tool that can reach all fans in the stadium. Since UCF was founded with the intention of providing talent for NASA [28] and still has deep connections to the space and aerospace industries [3], this was a completely valid comment.

After the game, Pete coordinated with UCF Mechanical and Aerospace Engineering Senior Design to set the project in motion. Three teams were to design and construct a unique T-shirt launching tool to be used by UCF Athletics starting with the 2024 football season.

1.2 Stakeholders and End Users

The primary stakeholder of the T-shirt launcher is the UCF Athletics Department. UCF Athletics will be the one to use the launcher at various sporting events in the future to engage the fans. A secondary primary stakeholder is Pete, who was previously mentioned as the person who initiated this project for Senior Design. Pete will be the one to store, maintain, and regulate access to the launcher in the future. Since this project was initially his idea, the launcher serves as a reflection on him and the Department of Mechanical and Aerospace Engineering. Additional primary stakeholders include members of the Black Team and project advisor, Rich DeBerardinis. This project marks a major academic milestone for the team and their transition to becoming an engineer.

The launcher has multiple potential end users. The primary and intended end user is members of UCF Athletics who will be using the launcher to launch T-shirts at sporting events. This could be staff, cheerleaders, mascots, or other UCF affiliated people. Pete is an additional end user, as he will be responsible for the launcher in the long run. Lastly, the fans are intended beneficiaries of the launcher, as they are the recipients of the T-shirts. All fans, regardless of where they are sitting, now have the opportunity to catch a T-shirt. Throughout each stage of the project, each of these groups of people were kept in mind when making design decisions, with special attention to the safety of each intended end user.

Other potential end users exist. Most likely, the College of Engineering may wish to display the T-shirt launcher during events such as E-Week or during campus tours to advertise the engineering program. Furthermore, the technology of the launcher can be easily adapted to fit other needs. Any soft object could be launched at sporting events, such as small balls, towels, or hot dogs. The launcher could also be used to launch baseballs or tennis balls to assist in training, or in the case of tennis balls to entertain a dog. The launcher could also be used as-is as a bait cannon, which launches a frozen slug containing a fish into the ocean for fishing, as shown in Figure 1.2.

Figure 1.2: Bait Cannon Slug [6]

The final possible end use the team identified is to throw climbing lines up tall trees prior to climbing them to cut them down. Normally, arborists would manually throw the lines, but they might not be able to reach the top of the tree with this method.

1.3 Problem to Be Addressed

There is currently a variety of T-shirt launchers available from various manufacturers commercially. These launchers, while functional, lack any sort of unique branding or customization with the exception of stickers, which can be applied to anything. Furthermore, not all of these launchers are capable of reaching the distances needed for UCF Athletics, while others far exceed the distance required to reach fans in the football stadium, meaning they are inefficient and pose an additional safety risk with the added power.

The multiple problems this project addresses includes:

- Representing UCF's engineering department.
- Representing UCF's ties to the space industry.
- Reaching all fans of UCF's football stadium, the largest sports venue on campus.
- Making the tradition of T-shirt launching more exciting.

1.4 Benefits of Project

The benefit of this project can be summarized by one word, bespoke. This means "specially made for a particular person" [7]. In this case, the person is UCF Athletics.

UCF could have very easily purchased multiple T-shirt launchers commercially, and likely for less money, that would suit most of their needs. However, the team was able to create a custom device that meets all of UCF's needs while being unique to UCF. Instead of using generic stickers to brand the launcher, the entire design of the launcher represents UCF's ties to the space industry. Instead of buying a launcher that exceeds or does not meet the required launch distance to reach all fans, this launcher is tuned to exactly meet the distance requirements for UCF's football stadium. Instead of leaving safety up to a largely uninterested third party, this launcher has a comprehensive, robust safety system that will keep the user and UCF fans safe. These are just a few of the aspects of the launcher that the team was able to customize for UCF. None of this would be possible with a commercially purchased launcher.

1.5 Report Overview

This report serves as a comprehensive overview of previous reports since January, as well as covering the final system prototype and performance parameters. The subsequent sections of this report include:

- 2.0 Project Objectives and Scope - The long term goals of the project as well as major milestones that were reached this semester.
- 3.0 Assessment of Relevant Existing Technologies and Standards - Overview and expanded discussion on relevant topics covered in Milestone I, patent search, and relevant engineering standards.
- 4.0 Professional and Societal Considerations - Impact of the project outside of the immediate scope of the project, such as safety and economic considerations.

- 5.0 System Requirements and Design Constraints - Derived from Milestone II, the system requirements that guided the development cycle and their related design constraints, as relevant to the final device.
- 6.0 System Concept Development - Derived from Milestone III, this includes the final system that was modeled, as well as any changes that were made during the design and manufacturing process.
- 7.0 Design Analysis - Models, calculations, simulations, and prototypes used to guide the design process.
- 8.0 Final Design and Engineering Specifications - Includes the final design, its parameters, and metrics it satisfies.
- 9.0 System Evaluation - Performance of final system compared to the system requirements written in Milestone II.
- 10.0 Significant Accomplishments and Open Issues - Major accomplishments made by the team throughout the design process. Additional tests, modifications, or changes the team would make if additional time was available or if the project was to start over.
- 11.0 Conclusions and Recommendations - Conclusion of the design process. Recommendations for future teams or recommendations for this team looking back.

2.0 Project Objectives and Scope

Senior Design I consisted of the preliminary design phase of the project, including preliminary research system requirements, and conceptual design. These steps are necessary for the successful completion of the major milestones of Senior Design II. In Senior Design II, the primary goal is to create a first prototype of the system. In a real scenario, the prototype at the end of Senior Design II would continue to be modified and go through design iterations until a final system is complete.

2.1 Current Semester Objectives

The semester, the team completed major milestones in the path toward building the final launcher. To track and maintain a schedule, the team made use of a Gantt Chart to guide deadlines and to determine the order in which tasks needed to be completed. This Gantt Chart is available in Appendix B. The major milestones completed this semester include:

- 6/1/2024 - Completion of Final CAD Models - After conceptual design, the system was modeled using SolidWorks to determine how the various COTS and custom built parts would interact. This step was essential to determine the materials the team needed to order and how the systems interact.
- 6/1/2024 - Completion of Analysis on CAD Models - This includes the FEA of the accumulator tank, barrel, and an investigation into the DOT requirements surrounding scuba tanks.
- 6/19/2024 - Ordering of Materials - All major material orders were placed and received prior to this date. A few small things were identified and later ordered, but those did not affect the flow of the project.
- 6/23/2024 - Completion of Safety System - LOTO devices were completed and trigger safety was completed.
- 6/23/2024 - Completion of Storage System - Storage system was purchased and tested to meet size and water resistance requirements.

- 6/25/2024 - Completion of Propulsion System - The accumulator tank, scuba tank, and compressor were readied to be used and relevant requirements were verified.
- 6/30/2024 - Completion of Reloading System - The barrel was constructed and joined to the propulsion system, enabling the team to test the launcher by launching shirts.
- 7/4/2024 - Completion of Space-U System - Space-U and UCF cosmetics were completed and ready to be placed on the launcher.
- 7/10/2024 - Completion of Electronics System - The arduino, battery, display, pressure transducer, and LED indicators were wired, coded, and mounted to the T-shirt launcher.
- 7/20/2024 - Final Test - Final launcher was tested in the football stadium.

2.2 Long Term Objectives

After this semester, the T-shirt launcher will be handed over to Pete and UCF Athletics for future use. For the Athletics Department, the long term objective is to utilize the T-shirt launcher to garner excitement during sporting events to keep the crowd engaged. The theme of the launcher is sure to accomplish this, as well as having the ability to reach all fans in UCF's sports venues.

For Pete, and the College of Engineering as a whole, the long term objective of this project is to have a functional display of UCF's engineering abilities at UCF sporting events. This will gain positive attention for the College of Engineering and possibly open up the doors to future projects for Athletics and other university departments that involve the talents of UCF engineering students. Pete also mentioned being able to display the launchers in the atrium in Engineering II on the UCF main campus. This will be a showcase piece for prospective students who are touring UCF and be a unique reminder to current engineering students that their ideas could one day leave an impact on the world.

3.0 Assessment of Relevant Existing Technologies and Standards

Before identifying user needs and writing system requirements, the team conducted preliminary research on topics that were thought to be of importance. Without knowing what the final design would be, the team covered a broad range of topics that had the possibility of being incorporated into the final design. Improving on the assessments made in the preliminary design review or Milestone III, resulted in some of the decision-making for some of the design choices. The most relevant technology used in the final design is the bead-seater tank where heavy analysis and simulations were done to ensure the safety factors of the device, Milestone V, Section 3. Finite element analysis on this device resulted in factors of safety beyond the goal of this project, and simulations for creep and fatigue also proved to withstand more than one million cycles while the pressure was in operating range. Comparing the team’s design to other competitors and other existing technologies is explained in further detail in Sections 3.1 and 3.1.1 below.

3.1 Existing Technologies

Other existing technologies encompass the usage of compressed air devices mainly. Only one device was discovered that uses a rubber band as propulsion, but this was a backyard project not intended for commercial usage. Compressed air is utilized in all existing technologies and depending on the scale of the technology, more or less can be utilized to achieve the intended purpose. For example a much larger T-shirt launcher utilizes large air storage tanks to keep up with the demand of compressed air required to fire several t-shirts. Some other larger devices utilized will be covered in the next section.

3.1.1 Competitor Overview

In reviewing other products to accomplish the same task, an abundance of applications used compressed air to achieve similar results. Other options included: manual loading, electromagnetic propulsion, and combustion. In conducting further research, it was discerned that compressed air was optimal for the use considering safety, practicality, availability, and budget. Other applications exist on the same scale and others on a much larger scale. One similarity between all other competitively marketed products is the use of compressed air. In general, products are made as a single-operator, small-scale package, some, such as the University of Nebraska's T-shirt launcher are much larger and can fire many T-shirts in rapid succession. Some of the differences that lie in the designs of these t-shirt launching devices are in the reloading system. One of the biggest and most varying decisions when creating this device is how the T-shirts will get loaded into the launcher. Some options involve: hand loading, top loading, back loading, and gravity loading. Other designs employ different methods of loading to make operation more convenient for the user. The budget is very large on a large-scale device with an intuitive and convenient loading system. It is important that these decisions are made surrounding budget limitations.

3.1.2 Materials

When designing the T-shirt launching system the team had to consider the purpose of the launcher, the type of system we want to implement, and the forces acting on the launcher. These qualities will help us identify what material would fit the purpose of the launcher and whether it would be the material needed to withstand multiple launches in rapid succession, long-term use of the device, the forces from our power system, in this case, compressed fluids, and being able to launch a variety of projectiles, T-shirts with an assortment of sizes, hot dogs, bait slugs, rubber ducks, and any other item that can fit in the launcher easily, and finally the launcher needed to be Space-U theme as required by Pete. With these items in mind, we can narrow down the materials to a steel pressure vessel, PVC piping, and PETG for 3D-printed parts.

The main component of our launcher is a bead blaster that uses a steel accumulator tank. Steel is a common material used in fabricating pressure vessels [27] due to its strength. Using a commercially manufactured steel pressure vessel offers a higher degree of safety compared to a pressure vessel built by the team.

PVC was used for our launcher as it is pressure-rated, corrosive resistant, lightweight, and flexible, and it is already manufactured to the perfect shape for the barrel. PVC piping is commonly used in the industry for both commercial and residential purposes due to its affordability, corrosive resistance, lightweight and waterproof properties, and ability to withstand high pressure [2]. PVC is also easy to machine and work with, which allows us to make more cosmetic parts of the launcher to achieve the Space-U themed rocket design.

Lastly, the cosmetic and miscellaneous parts not including the nuts and bolts of our launcher were 3D printed using PETG plastic. PETG has the benefits of excellent layer adhesion, warp resistance, reduced shrinkage, UV resistance, and being more flexible and durable than ABS plastic [25]. The purpose of the 3D printed part is to make the launcher Space-U themed as required by Pete. These parts can also be changed to have the launcher more tailored to the user's preference as the launcher is not exclusively just for T-shirt launching but can be used outside of UCF athletics in commercial or private industries and or other universities.

3.1.3 Safety

When creating our device, safety was of utmost importance during the design stage. Dealing with pressurized air presents many potential hazards, and we took these into careful consideration.

The first major component for safety was the pressure monitoring system. We decided to use both an analog pressure gauge and a digital one for added reliability. This monitoring system also incorporates a feature where a message is displayed on the screen if the pressure exceeds 80 PSI. Additionally, a ready-to-fire light will activate if the device is pressurized beyond 10 PSI.

To handle potential electronic malfunctions or shorts, we ensured that the entire electronic system could be easily disconnected by simply unplugging it from the battery. This provides a straightforward and effective method to shut off all electronics quickly.

To prevent unauthorized usage, we implemented a lockout/tagout system. This system locks the trigger assembly and the ball valve that pressurizes the accumulator tank, ensuring that only authorized personnel can operate the device.

An important safety feature we included is a pressure release valve. This valve is designed to release pressure in the event of over-pressurization of the accumulator tank. It also serves as a way to safely release pressure from the device without discharging a projectile.

Finally, to ensure the structural integrity of the device, we adhered to a minimum factor of safety of 3.5 for all energy storage components, excluding the battery. This precaution is crucial to prevent tank failure and potential serious injuries.

3.1.4 Control Methods

In January, significant research was performed on a variety of topics that the team thought may be useful to control and regulate energy stored in the T-shirt launcher. At that point, nothing was known about the final system, except for the fact that it had to launch T-shirts and be Space-U themed. Fortunately, significant research was performed on the control of compressed fluids, as that was easily identified as the most common method of launching T-shirts. Since then, other research had to be performed as the system became more defined and began to take shape.

3.1.4.1 Regulation of Pressurized Fluids

3.1.4.1 Pressure Regulators

Pressure regulators are used to reduce a supply of fluid stored at a higher pressure to a lower pressure. This is usually done to make the compressed fluid match the required input pressure of the tool utilizing the compressed fluid. To accomplish this reduction in pressure, a pressure regulator contains three main components, a poppet valve, diaphragm, and a spring, shown in Figure 3.1.4.1A. In this traditional pressure regulator, the user adjusts the screw, or sometimes a knob, to increase or decrease the downstream pressure. By turning this screw, which pushes the spring down, putting pressure on the diaphragm. On the other side of the air channel, the poppet reacts to the difference in pressure between the two sides, pushing a valve upwards towards the diaphragm [32]. Once the force from the poppet and spring equalize, the regulator reaches equilibrium and the upstream and downstream pressures are constant.

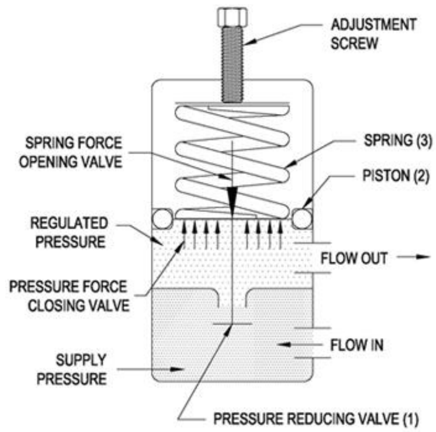

Figure 3.1.4.1A: Pressure Regulator Diagram [32]

In this project, pressure regulators are used to reduce the pressure from the compressed air supply to the accumulator tank. When using the air compressor, a built-in regulator is used to control the downstream pressure, shown in Figure 3.1.4.1B. This regulator uses a simple dial to adjust the pressure. Around the dial, there are painted marks to indicate what the pressure is set to.

Figure 3.1.4.1B: Compressor Regulator [4]

Pressure regulators are also used in this project to reduce the output pressure of the scuba tank to a usable pressure by the accumulator tank. In this case, a compound regulator is used since the pressure in the scuba tank is significantly greater than the pressure the accumulator tank is designed for. Using a compound regulator has two main advantages. First, it offers added safety between the high and low pressure sides. Since each regulator is handling a smaller change in pressure they are less likely to fail. Additionally, regulators to reduce high pressures can be very expensive. It is more cost effective to use a compound regulator to reduce the pressure. In the T-shirt launcher, there is a custom, commercially purchased regulator that reduces a 3,000 PSI scuba tank to 150 PSI, with the added benefit of being able to connect an NPT quick connect fitting. After this regulator, there is another commercially purchased regulator that is capable of up to 200 PSI. This regulator reduces the pressure down to 120 PSI, the maximum rated pressure of the accumulator tank. This compound regulator is shown in Figure 3.1.4.1C.

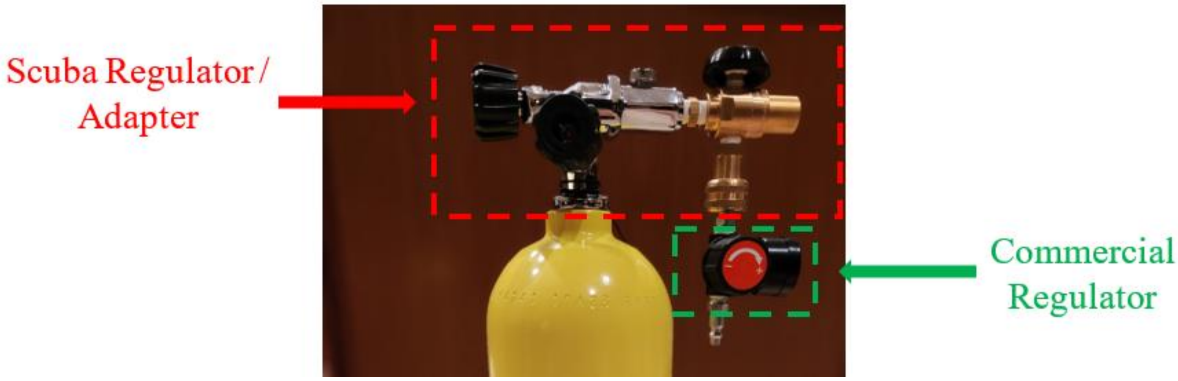

Figure 3.1.4.1C: Compound Regulator on Scuba Tank

3.1.4.2 Ball Valves

Ball valves are used to control the flow of compressed fluids. These valves are usually manual, being fully on or off. Ball valves contain five main components, shown in Figure 3.1.4.2. When the stem (A) is turned, usually 1/4 of a turn, the ball (D) is rotated. This ball has a hole drilled through it, allowing the compressed fluid to pass through [21]. If the stem is only partially turned, the hole will allow some pressurized fluid through, but the flow rate will be reduced.

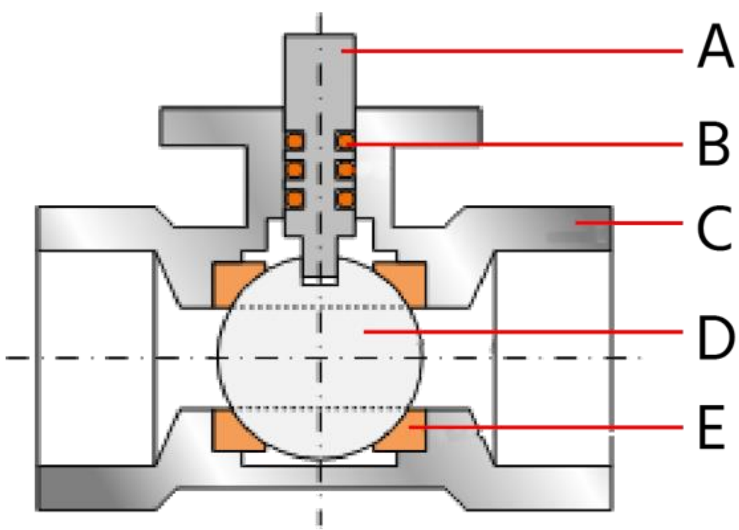

Figure 3.1.4.2: Ball Valve Diagram [21]

For the T-shirt launcher, a ball valve is used to allow compressed fluid into the accumulator tank. The specific ball valve used has a red lever that the user turns 1/4 turn to open or close. This offers a safe and simple way to fill the accumulator tank with compressed air.

3.1.4.3 Analog Pressure Gauges

A critical component of the T-shirt launcher, pressure gauges communicate vital information about the amount of compressed air being stored in a vessel, and therefore the overall safety of the vessel. Most commercial pressure gauges, and the ones used for this project, are Bourdon tube style. In this type of pressure gauge, a C shaped tube runs along the circumference of the gauge. As the tube is filled with compressed fluid, it changes shape, which is translated to the needle of the gauge via linkage [22]. This is shown in Figure 3.1.4.3.

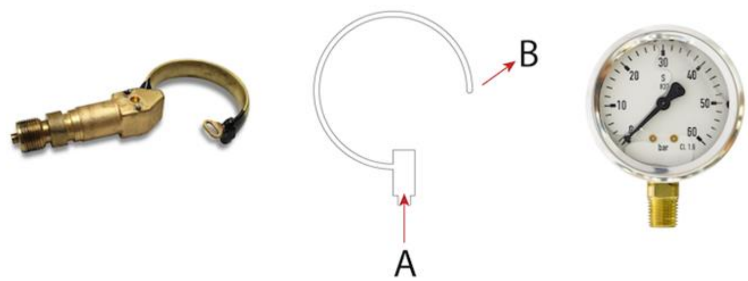

Figure 3.1.4.3: Bourdon Tube Pressure Gauge [22]

For the T-shirt launcher, two analog pressure gauges are utilized. The first one is placed on the accumulator tank. This large pressure gauge is a dry, mechanical pressure gauge. On the scuba to NPT adapter, there is a small, dry pressure gauge that can read up to 3,000 PSI. Dry and liquid filled pressure gauges are very similar in function. The fluid-filled pressure gauges are slightly easier to read and the fluid helps absorb vibration, preventing pulsation in the needle and prolonging the life of the gauge [23]. For this application, the dry pressure gauges are sufficient.

3.1.4.4 Pressure Relief Valves

Pressure relief valves are used as a safety against overpressurization. The internals of a pressure relief valve are similar to a regulator, but they are non adjustable and expel air into the open atmosphere. For the pressure relief valve, a set screw, which generally comes pre-adjusted, compresses a spring which is attached to a plate. The other side of the plate is open to the compressed air in the tank. Once the pressure in the tank exceeds that of the spring acting on the plate, the plate and spring is pushed up, allowing air to escape [29]. This is shown in Figure 3.1.4.4.

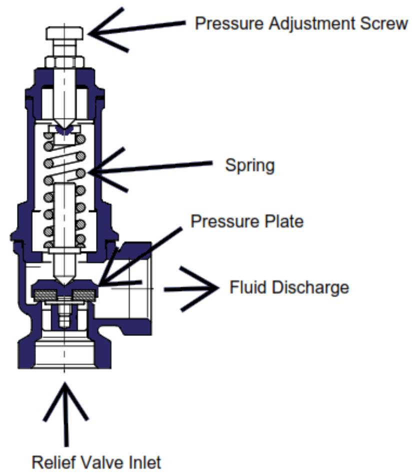

Figure 3.1.4.4: Pressure Relief Valve Diagram [29]

For the T-shirt launcher, a 120 PSI pressure relief valve is attached to the accumulator tank to ensure the tank is never filled past its maximum rated operating pressure. There are many other fail safes to prevent the pressure from reaching 120 PSI in the first place, but if it ever does, the pressure relief valve will quickly open to release the air from the tank.

3.1.4.5 Quick Exhaust Valves

The final control method used in the T-shirt launcher is a version of a quick exhaust valve. This component is what allows the accumulator tank to suddenly release a large volume of air, propelling the T-shirt forward. A quick exhaust valve has three ports: a supply, actuator, and exhaust port, shown in Figure 3.1.4.5. Pressurized air from the supply side pushes down a rubber flapper, creating an airtight seal with the exhaust. There is a small hole in the rubber between the supply and actuator. When air is quickly released from the actuator, the rubber seal flexes to allow the air to rush out of the exhaust port [14].

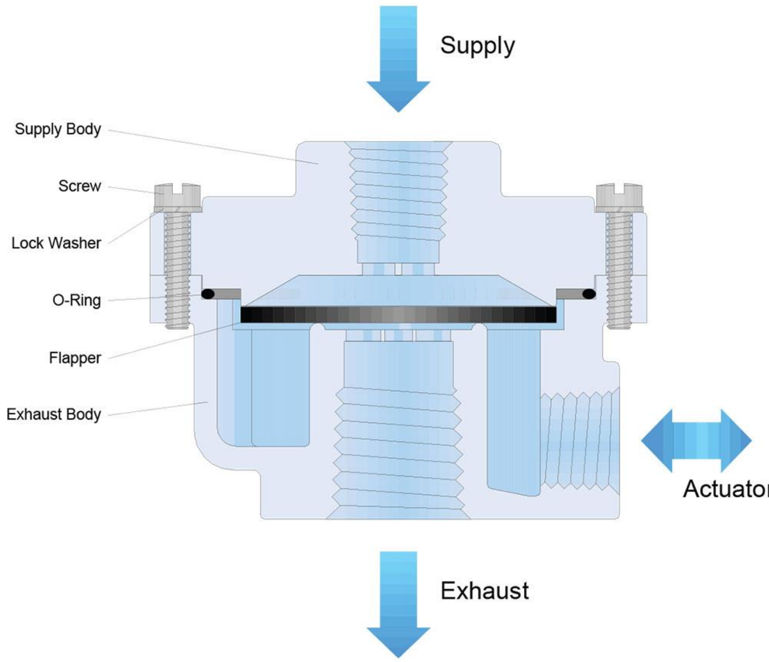

Figure 3.1.4.5: Quick Exhaust Valve Diagram [14]

As mentioned, the quick exhaust valve on the T-shirt launcher is what enables the sudden release of air. On the launcher, the actuator is connected to a type of pneumatic trigger. This pneumatic trigger normally seals the air in the hose of the actuator, and when pressed, allows the air to escape, causing the change in shape of the rubber seal.

3.2 Related Patents

There is a patent for a gas-powered chamber where a magazine is attached to the chamber. That magazine inserts items into the launcher [30]. The original idea suggested doing something similar. However, the team decided that manually inserting each T-shirt was a better idea. Due to this and the gas powered nature of the patented launcher, there is no potential infringement on this patent.

Another patent exists in which the launcher will receive its power from a tank of compressed inert gas, usually nitrogen [24]. It will be fitted with a regulator and a three way manifold with two air lines and a relief valve. The unit has two hoses attached to its rear housing plate. One line fills the accumulator tank while the auxiliary line ensures the pneumatic trigger always has gas pressure to complete the firing cycle. Again, the team did not utilize anything novel from this patent, eliminating the possibility of patent infringement.

3.3 Engineering Standards

Two major engineering standards are applicable to this project: ASME Section VII and DOT 3AL regulations for pressure vessels. Both standards are applicable to pressure vessels, with DOT regulations being legally required for high pressure storage devices, which were utilized in this project.

3.3.1 ASME Section VIII

ASME Section VIII is a general standard used when constructing custom pressure vessels for engineering applications. While not all pressure vessels are required to meet ASME standards, the standards provide a guideline when constructing or purchasing any pressure vessels. While the accumulator tank purchased for this project is built to ASME specifications, the standards associated with ASME Section VIII were applied when performing analysis to ensure the safety of the accumulator tank.

The major point of ASME Section VIII is that almost all pressure vessels should be subject to a minimum safety factor of 3.5 [11]. While there are some exceptions to this, they do not apply to this project, which is why the team used 3.5 as a required factor of safety.

3.3.2 DOT 3AL Regulations

Pressure vessels that are used to transport pressurized fluids on roads, planes, or boats are legally required to be DOT approved. These vessels do not necessarily have to be high pressure, but when companies are transporting pressurized fluids, it is to their benefit to do this at a high pressure to make the most use out of their space and transportation equipment. Since scuba tanks are generally transported while filled with compressed air, these requirements are applicable to this project. The scuba tank purchased for this project is made of 6061 Aluminum, a common choice for scuba tanks. 6061 Aluminum pressure vessels that are used to transport compressed fluids are subject to DOT Regulation 49 CFR 178.46, Specification for 3AL Seamless Aluminum Cylinders [26].

Section C.5 of this regulation specifies the testing that must be done by the manufacturer. There are two aspects of testing that must be completed. First, the pressure vessels must undergo significant cyclic testing where the air is filled, released, and filled again. To accomplish this, the manufacturer can use one of two approaches:

1. Subject three samples to 100,000 cycles between zero pressure and service pressure.
2. Perform 10,000 cycles between zero and the vessel's test pressure. For a vessel designed for use above 500 PSI, the test pressure is 5/3 of its stated operating pressure, so for a 3,000 PSI scuba tank, the test pressure is 5,000 PSI.

The next verification performed by the manufacturer is that three samples must be pressurized until failure, and the failure may not occur at any pressure less than 2.5 times the rated pressure. For the scuba tank purchased, this is 7,500 PSI. The DOT Regulation also states that when the vessel fails, it must remain in one piece, the failure must be in the sidewall (not the neck), and the crack must be longitudinal [26]. In addition to these requirements, 3AL pressure vessels must undergo an annual visual inspection and a hydro-test every five years, where the tank is filled with water and pressurized to 5/3 of its rated pressure.

4.0 Professional and Societal Considerations

The T-shirt launcher that was created can have an economic impact at UCF. The launcher can impact the various events by increasing fan engagement. By increasing fan engagement, more fans will come to events. This can potentially lead to increased monetary impacts that can benefit the team and UCF by boosting the attractiveness of school events. It can have a social impact as well. By using a launcher at team events, the school can increase school spirit and encourage inclusivity in school events. The launcher will increase social interactions between the fans and the team. By bringing the team and students together, it can promote a healthy campus and bring the school together. The launcher has safety guidelines that were set to reduce injury. There are manuals for using the launcher and storing it safely to reduce injury to the operator and students. There are also protocols to reduce damage to property. The launcher was designed with ease of manufacturability in mind. The launcher was made using easily accessible parts. It was also made using cost efficient items.

4.1 Major Safety Considerations

While numerous safety considerations and mitigations were outlined in Milestone V, Section 2, the largest safety concern of the T-shirt launcher is the potential of overpressurization of any part of the system. This could severely injure the user, fans, or anyone near the launcher. To mitigate this, the launcher utilizes a series of regulators and other safety measures to ensure the two major pressure vessels do not exceed their maximum pressures, shown in Figure 4.1.

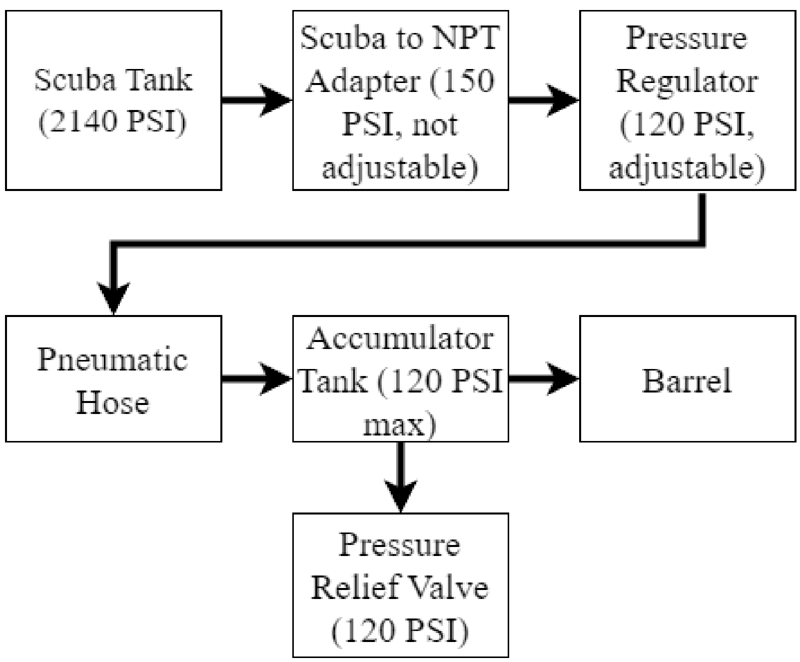

Figure 4.1: System Pressure Reduction

Starting with the scuba tank, it has a rated operating pressure of 3,000 PSI. The team is recommending to UCF to only fill the scuba tank to 2,140 PSI to meet a 3.5 FOS. The scuba tank itself contains burst disks to ensure an unsafe operating pressure is not reached. After the scuba tank, the purchased Yoke to NPT adapter is set to 150 PSI and not adjustable. This significantly reduces the 2,140 PSI output pressure of the scuba tank. After this device, a traditional regulator is used to reduce the air pressure down to 120 PSI. This regulator is rated for up to 200 PSI, meaning that it will never reach values close to its maximum rated operating pressure. A pneumatic hose will carry the compressed air to the accumulator, where the hose has a burst pressure of approximately 200 PSI. While this is higher than the maximum rated pressure of the accumulator, the accumulator would not burst at 200 PSI, meaning the hose would rupture prior to the accumulator rupturing. Finally, a pressure relief valve is attached to the accumulator tank in the event it is filled past 120 PSI. This robust pressure reduction system has multiple redundancies built in and makes the chance of overpressurizing the scuba or accumulator tanks very unlikely.

The second major safety impact this launcher has is that it could impact people, directly. In order to reach the top of the stadium, a relatively high exit velocity is needed. This poses a safety risk if the operator decides to launch a T-shirt at a high pressure towards the lower section. The team has communicated the following topics to Pete and UCF Athletics, and mentioned them in the user manual:

- Shirts should be launched at a high angle.
- Nobody should ever be using the T-shirt launcher for the first time during a game with people around them. Every user should have the opportunity to launch T-shirts in a safe environment to gain experience with different pressures and launch angles prior to gameday.
- Reserve high pressures when targeting the upper sections.

This risk would also be present for any T-shirt launcher that UCF could purchase commercially, however since this launcher is built by UCF students, it would reflect poorly on the University if it injured someone. After the launcher is handed over to Pete and Athletics, the long term safety and use of it is ultimately in their hands, but the team has made every effort to communicate the potential safety risks of the launcher and the best methods to avoid them.

4.2 Major Legal Considerations

There are two major legal considerations for a T-shirt launcher of this nature. The first one, which had the potential to shut down the entire project, is Florida Statute 790.001, which outlines what exactly is defined as a firearm and destructive device [31]. The definition for a firearm according to this statute is shown below in Figure 4.2A.

> (9) "Firearm" means any weapon (including a starter gun) which will, is designed to, or may readily be converted to expel a projectile by the action of an explosive; the frame or receiver of any such weapon; any firearm muffler or firearm silencer; any destructive device; or any machine gun. The term "firearm" does not include an antique firearm unless the antique firearm is used in the commission of a crime.

Figure 4.2A: Florida Statute 790.001 Section 9 [31]

While the compressed air does store a great amount of energy, it is not categorized as an explosive as mentioned in this statute. The definition of an explosive substance is given in section 6 of the statute, which is shown in Figure 4.2B. Due to this, the T-shirt launcher is not a firearm under Florida law. Despite this, the team still recommends that the launcher is only handled by individuals over the age of 18 as an extra precaution.

The second component of this statute is section 6, which defines what a destructive device is, as shown in Figure 4.2B.

(6) "Destructive device" means any bomb, grenade, mine, rocket, missile, pipebomb, or similar device containing an explosive, incendiary, or poison gas and includes any frangible container filled with an explosive, incendiary, explosive gas, or expanding gas, which is designed or so constructed as to explode by such filler and is capable of causing bodily harm or property damage; any combination of parts either designed or intended for use in converting any device into a destructive device and from which a destructive device may be readily assembled; any device declared a destructive device by the Bureau of Alcohol, Tobacco, and Firearms; any type of weapon which will, is designed to, or may readily be converted to expel a projectile by the action of any explosive and which has a barrel with a bore of one-half inch or more in diameter; and ammunition for such destructive devices, but not including shotgun shells or any other ammunition designed for use in a firearm other than a destructive device. "Destructive device" does not include:

(a) A device which is not designed, redesigned, used, or intended for use as a weapon;

(b) Any device, although originally designed as a weapon, which is redesigned so that it may be used solely as a signaling, line-throwing, safety, or similar device;

(c) Any shotgun other than a short-barreled shotgun; or

(d) Any nonautomatic rifle (other than a short-barreled rifle) generally recognized or particularly suitable for use for the hunting of big game.

(7) "Electric weapon or device" means any device which, through the application or use of electrical current, is designed, redesigned, used, or intended to be used for offensive or defensive purposes, the destruction of life, or the infliction of injury.

(8) "Explosive" means any chemical compound or mixture that has the property of yielding readily to combustion or oxidation upon application of heat, flame, or shock, including but not limited to dynamite, nitroglycerin, trinitrotoluene, or ammonium nitrate when combined with other ingredients to form an explosive mixture, blasting caps, and detonators; but not including:

(a) Shotgun shells, cartridges, or ammunition for firearms;

(b) Fireworks as defined in s. 791.01;

(c) Smokeless propellant powder or small arms ammunition primers, if possessed, purchased, sold, transported, or used in compliance with s. 552.241;

(d) Black powder in quantities not to exceed that authorized by chapter 552, or by any rules adopted thereunder by the Department of Financial Services, when used for, or intended to be used for, the manufacture of target and sporting ammunition or for use in muzzle-loading flint or percussion weapons.

Figure 4.2B: Florida Statute 790.001 Section 6 [31]

Subsection (a) of this part of the statute eliminates the possibility of the T-shirt launcher from being considered a destructive device. Since the intent of the T-shirt launcher is to simply launch T-shirts or other soft objects to fans, there is no design intent as a weapon.

After determining that the launcher poses no legal issues under Florida law, the team sought examples of times when fans were injured by T-shirt launchers. There is a longstanding precedent known as “the baseball rule”, which essentially states that fans at sporting events have a reasonable assumption they may be hit with flying objects, and therefore the team is not liable for any injuries [15]. While this was originally intended to cover foul balls at a baseball game, it has been expanded. One case in particular can be used to show how comprehensive this precedent is. In 2009, a fan at a Kansas City Royals game was struck in the eye with a hot dog that was thrown by the team’s mascot into the stands. The fan had to have surgery to repair their retina and cataract. Ultimately, the court decided that the Royals were not liable and did not have to pay the fan’s medical expenses [15]. While this precedent does exist, it does not excuse unsafe use of the T-shirt launcher. Even though it is highly unlikely UCF could be held liable for a fan being injured by a T-shirt, the team still took comprehensive safety precautions in the design of the launcher and has communicated the safety risks and how to avoid an injury to Pete and UCF Athletics.

5.0 System Requirements and Design Constraints

When going into the project our team needed to define the overall system requirements and design constraints to give us an outline of what the final product of the project should accomplish. By doing so our team used three main methods to break down what requirements and constraints to create. This helps create our house of quality that would give us an idea of what our client, UCF Athletics would like for our system.

Firstly, the team used a system engineering approach, using component and functional decomposition to define the corresponding aspects of a generic T-shirt launcher. The component and functional decompositions are available in Appendices C and D, respectively. By decomposing the T-shirt launcher into subsystems we get, propulsion, trigger, and reloading system as our three main launcher components. From there we can use the components lists to create a functional list, this list would define more requirements and constraints the components must have for the specific users that would be involved with the launcher whether directly or indirectly which includes operator, maintenance personnel, transporter, storage personnel, UCF athletics and fans.

Next, we gather requirements and constraints from the main stakeholders and client of the project, UCF Athletics to see what they desired from the launcher which helps us create our house of quality in Figure 5.0. The team's main point of contact was Pete Alfieris, the manager and facilities operations for UCF MAE, who provided the team with a list of characteristics of functional requirements they would like the system to perform. From the list of characteristics provided we can create the house of quality, which ranked what design or requirement features were most important to achieve. This translates directly to additional items into our existing engineering requirements but also constraints the team needed to further define what the overall launcher would look like and function.

			Column #	1	2	3	4	5	6	7	8		9	10	11	12	13	14	15	16
Row #	Customer Importance (1-10)	Relative Weight	Customer Requirement \ Engineering Design Specification	F1.2) Min exit velocity (MPH)	F1.3) Min distance (ft)	F1.1) Variable power (T/F)	S1.1-4) Energy indicators (T/F)	S2.1-2) ESD (steps & time)	S4.1) Lock-Out/Tag-Out (T/F)	S7.2) Trigger weight (lbs)	S9.1) Safety Factor (T/F)	G1.1) Launcher portability (T/F)	G1.2-3) Launcher weight (lbs)	ST1.2) Storage weight (lbs)	F2.2) Time to launch (sec)	E1.1) Cost per use ($)	E2.2) Project budget ($)	G6.1) UCF/Space-U theme (T/F)	F2.1) Shirt size & type (T/F)	G2.1) IP Rating (T/F)
1	10	0.17	Launches T-shirts into upper sections	9	9	3					-3		1			1	1		1	
2	10	0.17	Adjustable launching distance	3	3	9	1												1	
3	10	0.17	Safe for user and fans	-9	-9	3	9	9	9	9	9	3	3		3				1	
4	10	0.17	Portable									9	9	9						
5	8	0.13	Quickly launch multiple shirts			1				1		1	1		9					
6	5	0.08	Cost per use	1	1	1										9	3		1	
7	5	0.08	Space-U or UCF themed															9		
8	1	0.02	T-shirt capacity																3	
9	1	0.02	Weather resistant				-1													9

Figure 5.0: House of Quality

Finally, the team conducted research of commercially available T-shirt launchers, providing a baseline to compare our design to. Our project is specific to UCF Athletic sporting events so most commercial launchers did not meet all requirements set by UCF Athletic, but did provide excellent benchmark goals and outlines to achieve. Additionally if our design should meet commercially available system benchmarks it would make our system as competitive as any commercial system while still uniquely UCF specific in design.

5.1 General Requirements

General requirements are written to establish a general understanding of the type of device we will be creating and who will be able to operate it.

G1.1 - The handheld component of the T-shirt launching system must be operable by a single individual.

- This requirement is specifically intended for ease of use and transport, as UCF Athletics requested that the launcher be portable for all sports venues on campus, and analyzing competitor dimensions will provide guidance during the design process. This requirement indirectly limits the size and weight of the launcher, and makes ergonomics and important consideration in design decisions.

G1.2 - Individual parts of the T-shirt launching system intended to be carried by a single individual shall not exceed 51 pounds in total.

- This requirement, based on safety and to avoid lower back pain, adheres to the NIOSH recommended weight limit [37], and while competitor launchers typically weigh around

20 pounds, the design will follow the 51-pound maximum to accommodate necessary components. This requirement again affects every design decision. Every component will add weight to the launcher, making the team evaluate if each component is necessary and the optimal material for each component.

G1.3 - Individual parts of the T-shirt launching system intended to be carried by the user without the use of their hands, such as a backpack, shall not exceed 51 pounds, including handheld portions.

- This requirement adheres to the NIOSH recommended weight limit for moderate-duration work, and while some parts may exceed this weight, the design will need to accommodate this limit to ensure usability. The same constraints for Requirement G1.2 apply to this requirement.

G2.1 - Individual components with electronic or water-sensitive elements shall be IP44-rated.

- This ensures safe operation in foul weather, as the IP44 rating provides protection against solid objects of 1.0 mm diameter and greater, as well as protection against splashing water, adhering to the standards set by the International Electrotechnical Commission [38]. This requirement severely constrains the potential application of electronic components, as they are not inherently water resistant.

G3.1 - The launcher shall only be operated by individuals over the age of 18, and this will be validated by inspecting the training manuals for the age requirement.

- This ensures safe and legal use, as Florida Statute 790.22 restricts minors from possessing projectile launchers [33], safeguarding stakeholders and the University's reputation.

G4.1 - The T-shirt launching system shall come with a user training manual, the manual will provide comprehensive instructions on setting up the launcher, utilizing its various features during operation, and safely disassembling the equipment.

- This ensures safe use and helps new users understand the launcher’s functions, similar to how commercial launchers provide instructional videos.

G5.1 - There shall be an unobstructed path of at least 3 inches in front of the launcher's activation mechanism to allow use by individuals in mascot costumes.

- This ensures the launcher is usable by mascots, such as Knightro and the Citronaut, while considering the safety of accidental discharges. This requirement poses a potential safety concern. Normally, a device such as this would have a trigger guard to avoid accidental discharges, but having a device such as that would prevent someone in a mascot costume from utilizing the launcher.

G6.1 - The T-shirt launching system shall include a sensory indicator or effect when a T-shirt is launched.

- This requirement aims to enhance fan excitement and engagement, making the launcher unique. However, the team must ensure that the sensory effect does not create hazards for fans or operators.

G7.1 - The T-shirt launching system shall feature visual cues or branding clearly indicating its intended use for UCF or Space-U.

- This requirement ensures alignment with UCF Athletics' desire for thematic consistency and enhances fan engagement. Requiring this eliminates potential design decisions, as they were too generic or did not adequately represent UCF.

G8.1 - The T-shirt launching system shall be assembled by a trained operator within 20 minutes (excluding energy source refilling) and involve no more than 15 procedural steps.

- This requirement aims to ensure ease of setup and operational readiness with a generous buffer compared to competitors, while considering potential constraints such as initial energy supply. This limited the team's options for storage, as most storage systems would require significant disassembly of the launcher.

G9.1 - The energy source used for propulsion shall be refilled at UCF's main campus, at a location within the Orlando, FL area, or sourced from online retailers.

- Validation will involve documenting the purchase from a supplier in Greater Orlando or an online retailer. If refilled at UCF, evidence of the refill shall be provided. This requirement aims to streamline setup for UCF Athletics by ensuring convenient access to the energy source, while potential design constraints include availability issues requiring consideration of alternative designs.

5.2 Functional Requirements

Functional requirements are written to establish the functional capabilities that can be expected from the device.

F1.1 - The T-shirt launching system shall have a variable power control accessible to the user, allowing the user to adjust the launching distance at least 100 feet.

- This requirement aligns with UCF Athletics desire to reach all sections of their sport stadium stands and match that of other commercial T-shirt launchers. To be comparable to commercial launchers such as the Bleacher Reacher series of T-shirt launchers that offered variable control of distance by allowing the user to manually fill an accumulator tank to the desired pressure [10], our design offers the same function allowing for more control of the device's launching distance to aim at specific sections of the stands. This limits the time between shots, as the user must control the amount of air entering the tank between each launch.

F1.2 - The T-shirt launching system shall be capable of launching a T-shirt with a minimum exit velocity of 68.5 MPH.

- This requirement was to ensure the device satisfies the desire of UCF Athletics to launch T-shirts into the upper sections of the sporting venues after figuring how the distance and angle the launcher must fire at to reach the upper section, giving us a velocity of 68.5 MPH. This velocity initially posed a safety concern, and while it still could be dangerous, through testing the team determined that this is necessary to reach the upper sections and is still less powerful than some commercial launchers.

F1.3 - The T-shirt launching system shall be capable of launching a T-shirt a minimum of 180 feet.

- This requirement ensures the device satisfies the desire of UCF Athletics to launch T-shirts into the upper sections of the football stands as we found the distance from the field to the top row, including the horizontal and vertical changes, can be approximated by 180 ft on level ground. The constraints for this requirement are the same as Requirement F1.2.

F2.1 - The T-shirt launching system shall be capable of launching a small, medium, and large T-shirt at the target exit velocity and distance stated in Requirements F1.2 and F1.3.

- The requirement allows the device not to be limited on what shirt sizes can be fired into the stands. This can further engage UCF sports fans as there is a variety of shirts that can be launched into the crowds.

F2.2 - The T-shirt launching system shall be capable of launching one T-shirt every 15 seconds.

- After discussion with UCF Athletics, the window of time that the device can be used during a game is limited. This requirement is to ensure the device can fire as many shirts as possible to entertain fans and increase engagement during that window of time. This eliminated some reloading options from consideration.

F3.1 - The T-shirt launcher shall be capable of projecting a T-shirt within a 400-square-foot area of a target when fired at a distance of 180 feet from the target.

- To minimize the T-shirts from straying their shots this requirement was created so the user can more accurately fire at a targeted section. Accuracy of the device varies greatly based on how the T-shirt is fired out of the launcher and weather conditions but the design, how to use the device and way the T-shirts are rolled are chosen to ensure the device meets this requirement. This requirement requires a very trained user to accomplish, as it takes time for the user to become familiar with launching angles and pressures to be able to consistently launch T-shirts.

5.3 Safety Requirements

Safety requirements are written to ensure general safety for the users interacting or operating the device while handling or in use. These requirements are the most important, as safety is the team's and UCF Athletics' top priority.

S1.1 - The T-shirt launching system shall include a readout to communicate the amount of energy that is currently stored in the system and shall be clearly labeled.

- This ensures the operator or anyone who is handling the device is aware of when the device is loaded and how much energy is in the system while in use. Some propulsion methods considered would have been very difficult to quantify and communicate an energy level, which was one factor leading to the team utilizing compressed air.

S1.2 - The T-shirt launching system shall have an indicator to communicate if the system is holding ANY amount of energy (>0) and shall be clearly labeled.

- This is to ensure the operator or anyone handling the device knows if it is energized and needs to be de-energized for safe handling while not in use.

S1.3 - The T-shirt launching system shall have an indicator to communicate if the amount of energy stored is at a potentially dangerous level and shall be clearly labeled.

- This is to ensure the operator and anyone handling the device does not over energize the system and prevent accidents from firing an over energized system and potential failures that may occur. This requirement poses the issue of determining what a dangerous energy level is. The team initially intended to use the accumulator tanks maximum rated pressure of 120 PSI, but found that T-shirts could be launched out of the stadium at 80 PSI, making this the dangerous energy level.

S1.4 - The T-shirt launching system shall have an indicator to communicate if the system is ready to be fired and shall be clearly labeled.

- This is to provide an easy and clear way for the operator and anyone handling the device to know when the device is ready to fire and prevent misfires. This is easiest to achieve through an electronics system, which was integrated into the system. Without the electronics system, this requirement would have been difficult to integrate.

S2.1 - The T-shirt launching system shall have an Emergency Shut-Down mechanism (ESD) that is activated in fewer than 3 steps and within 10 seconds following initiation.

- This requirement will ensure the operator and anyone handling the device can quickly deactivate the device in emergency situations such as a malfunction.

S2.2 - The T-shirt launching system shall shut off all electronics upon activating the Emergency Shutdown System and shall be clearly labeled.

- This requirement will ensure the device's electronic system is also powered off while the device itself is de-energized to prevent the device from being used while in emergency shutdown mode and cause further problems.

S3.1 - The T-shirt launching system shall achieve a state of equilibrium after discharge of all energy sources, excluding energy in batteries.

- Due to OSHA Control of Hazardous Energy (1910.147) [1], our device must utilize a Lock-Out / Tag-Out procedure to perform maintenance and to safely store the device. This ensures the device is safe to handle after while not in operation and after every launch while in use.

S4.1 - The T-shirt launcher shall incorporate a Lock-Out / Tag-Out system to prevent unauthorized operation.

- This requirement specified by OSHA (1910.147) [1] requires our device to have a Lock-Out / Tag-Out system in place to prevent unauthorized access, misfires, and the device from going off while not operational, in storage, in transport, etc.

S5.1 - The T-shirt launching system shall be capable of releasing all stored energy without the need to fire a projectile, excluding batteries.

- This requirement is to allow the device to be de-energized in order to reload the launcher safely if accidentally energized or to safely store the device after while not in operation. This requirement made the team have a method to allow air to exit the system, other than through the barrel.

<u>S6.1</u> - The T-shirt launching system shall withstand 75 cycles of testing with no failures.

- This requirement is to ensure the device's designs can withstand long term and regular uses without failing. By doing so the device can be in service for long periods of time before the device's parts need to be replaced. This requirement faced significant challenges in the time required to test.

<u>S7.1</u> - The T-shirt launching system shall have a method to lockout the mechanism used to fire the launcher, preventing an accidental discharge.

- This requirement is designed to prevent the operator from accidently firing the device while setting up the launcher, and disassembling the launcher for storage. The lockout also functions as a safety measure to prevent maintenance personnel, transport personnel and any UCF staff handling the device from firing the device if not properly de-energized.

<u>S7.2</u> - If a traditional firearm-style trigger is used, the trigger shall require a minimum of 4 pounds of force to activate.

- This requirement is to prevent the trigger, if firearm-style based on the National Institute of Justice [19], from firing accidently while the operator or the user is handling the device due to the trigger being sensitive or very easily pressed.

<u>S8.1</u> - The T-shirt launching system shall be energized no earlier than 3 steps before the launcher is ready to be used.

- Due to the window of time the device can be used during UCF sporting events the device must be quick and easy to set up and operate in order for UCF athletics to maximize the usage of the device and greatly increase fans engagement and entertainment. Balancing this requirement to not energize the launcher too soon and still allowing decent timing in between launches took careful consideration of the team of the proper launch sequence.

S9.1 - Any energy storage devices, excluding batteries, shall adhere to a minimum safety factor of 3.5.

- This requirement as specified by ASME Section VIII states that the minimum factor of safety used for pressure vessels is 3.5 [11]. This also ensures that UCF Athletics and any user interacting with the device has peace of mind as the device is very unlikely to fail spontaneously with a factor of safety of 3.5. This requirement constrained the choice for the accumulator tank, and required the team to underfill the scuba tank to achieve this factor of safety.

5.4 Storage and Transportation Requirements

The storage and transportation requirements are written to ensure proper functionality and safety of transportation and storage of the device.

ST1.1 - If a storage system is in place, individual pieces of the storage system for the T-shirt launching system should not exceed 50 inches in any direction.

- Choosing a container that is practical and light for the application while also being weather-proof is a challenge that was faced by the team in an attempt to keep it budget-friendly.

This also constrained the overall dimensions of the launcher itself, as it would have to fit in the storage container.

ST1.2 - If a storage system is in place, individual containers shall not exceed 51 pounds, including device weight.

- This also poses a challenge as mentioned above, because thicker more durable containers would be heavier, which would compromise the requirement.

ST1.3 - If a storage system is in place, individual containers shall be IP44-rated.

- The container must be IP44-rated, which indicates that the container is protected against solid objects over 1mm and water splashes from any direction- this means that it provides adequate protection in most environments [38]. Achieving an IP44-rated protection with the case is also another challenge due to the selection of materials available and budget limitations involved with practicality and protection.

ST2.1 - A storage and transportation manual shall be included with the T-shirt launching system. The manual shall clearly state the launcher is not to be in possession of individuals under the age of 18. The manual shall also include how to package the launcher for storage, how to release the energy for storage, and how to safely transport the launcher to its destination.

- The dedicated manual provides a challenge as all information must be considered and discussed to provide the user with optimal detail and explanation on how to manage the device and follow proper procedures.

ST3.1 - The T-shirt launcher shall support disarming and disassembly ready for storage within 20 minutes, and no more than 15 procedural steps.

- Lastly, disassembling the device in under 20 minutes and 15 steps means that the device can not contain any complex components that require tools and disassembly to navigate. This also poses restrictions on the storage system itself, as it must accommodate a relatively quick process to load the container.

5.5 Maintenance Requirements

Maintenance requirements are established to outline the expectations of the maintenance system in the T-shirt launcher. These requirements highlight the need for a user manual, what should be included in that user manual, and other specifications.

M1.1 - A maintenance manual shall be included with the T-shirt launching system. The manual shall clearly state the launcher is not to be in possession of individuals under the age of 18. The maintenance manual shall also include how to take apart the launcher, how to clean the launcher, and how to replace parts on the launcher.

- Including this in the user manual allows for our user to recognize that no one under the age of 18 should be operating the device. This is critical to the safety of our design and implementation.

M2.1 - The hardware used to construct the T-shirt launching system shall cohere to a single system of units, Metric or Imperial.

- This was a significant challenge that we faced in the design process. The accumulator tank was designed using Imperial units, but British threads, which are not readily available. This made the team implement a solution that converted the British units to imperial, via an adapter. This adapter allows smooth connection between our NPT threads and the tank's BSP threads. The intent of this requirement was to only require one set of tools to work on the launcher, which was still met.

M3.1 - All commercial off-the-shelf (COTS) materials should be accessible within the Orlando, FL area or purchased online with reliability (product is received).

- This specific requirement created a thought process while designing the launcher to ensure that the team was choosing components that would work properly with the device and can be ordered online easily. The team also shopped at large warehouse stores such as Lowe's and Home Depot to ensure that these parts are accessible to the general public.

5.6 Economic Requirements

E1.1 - The cost to refill the energy source in between uses and package the payload shall not exceed a dollar amount to be determined by the UCF Athletics Department.

- This proves as to why the team chose compressed air as our method of propulsion. This is easy to access, cheap, and easy to use. This requirement would have posed a larger challenge if we decided on a different method of propulsion. By using the compressor, the cost of energy is negligible.

E2.1 - The total cost to manufacture the T-shirt launcher shall not exceed the budget levied by UCF Athletics and the UCF Department of Mechanical and Aerospace Engineering.

- This budget created some restrictions around the modularity and capabilities of the portable aspects of the T-shirt launcher. Some of these key factors were limited by the scuba tank and air compressor that the team could afford on the budget given.

6.0 System Concept Development

Throughout the course of the project, each system, and component, has undergone iterations in an effort to arrive at the optimal final design. The design process started with the conceptual design in Milestone III, Section 5, much of which is summarized in the following sections. The conceptual design largely focused on the feasibility and expected performance of the system. After finalizing the conceptual design, the detailed design of each system was completed. Since all systems are interconnected, most of the systems were modeled in tandem to ensure they interact properly. Some design iterations took place prior to beginning manufacturing if issues were able to be identified from the CAD model and assembly. After beginning manufacturing, some designs had to be further iterated to ensure the completed system functions properly.

6.1 Propulsion System Development

There are only two systems that are absolutely necessary to launch T-shirts, the propulsion and reloading systems. The propulsion system was defined early on as the components necessary to store, transport, and release energy in the direction of the T-shirt. The initial decision on the overall characteristics of the propulsion system during the conceptual design phase was the single most important decision of the project, as it had the largest impact on the other systems, safety, and performance.

6.1.1 Propulsion System Initial Concept

The first major decision during the conceptual design stage was the method used for propulsion, or rather the energy source. The main options that were considered included compressed fluid, electromagnetic, springs, or a catapult system. After the decision was made to utilize a compressed fluid based system, the type of fluid had to be determined.

6.1.1.1 Propulsion Method

The first propulsion method considered was using compressed fluid, which is the most commonly used method by commercially available launchers. To ensure the performance and feasibility of compressed fluid, preliminary calculations were performed to ensure key system requirements could be met, such as launch distance and variable power control. At this point, the team did not know what the propulsion system would consist of, but made the assumption it would contain some sort of accumulator tank to store the fluid, and a valve to release the fluid toward the T-shirt. From this, the team could use some simple engineering theories and relationships to obtain an idea about how this type of system would perform. Using calculations described in Milestone III, Section 5.1.1, a relation between pressure and barrel length can be found using Newton's Second Law, projectile motion equations, and general pressure equations. These calculations neglect friction, air losses, and the increasing volume as the T-shirt slides down the barrel. The result of these calculations is shown in Figure 6.1.1.1A.

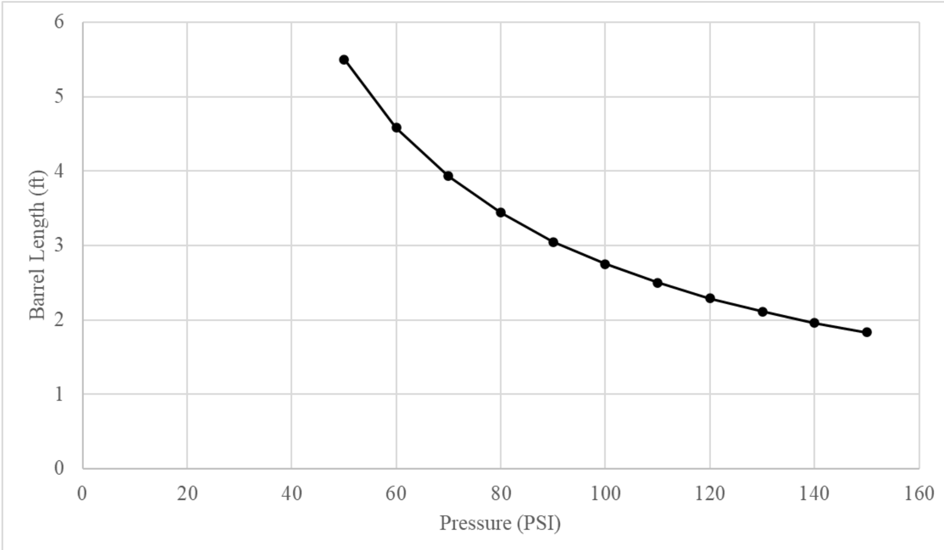

Figure 6.1.1.1A: Pressure vs Barrel Length for 68.5 MPH Exit Velocity

From these calculations, it can be seen that compressed fluid offers a feasible option to launch T-shirts with the required exit velocity of 68.5 MPH. Compressed fluid offers advantages in energy capacity and being relatively safe. Compressed fluids have also been already verified to work for T-shirt launchers, and parts for a compressed fluid system are readily available. The downsides of compressed fluids include the cost and weight, which pose issues when trying to meet requirements.

The second propulsion method considered was utilizing an electromagnetic system where an electromagnetic plunger would accelerate and contact the T-shirt, propelling it forward. This was quickly decided against as a safety concern, as the plunger would have to be traveling over 68.5 MPH to transfer enough energy to the T-shirt. However, it was then suggested to use the electromagnetic plunger to compress air to launch the T-shirt, as shown in Figure 6.1.1.1B.

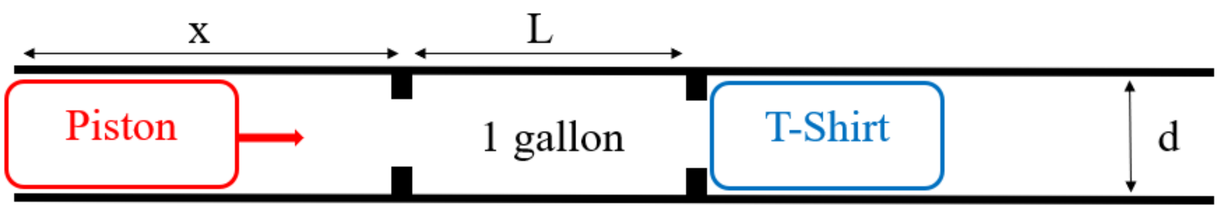

Figure 6.1.1.1B: Electromagnetic System Concept

To determine if this type of system would work, the team calculated the amount of space the piston would need to travel to compress 1 gallon of air to 80 PSI. From calculations described in Milestone III, Section 5.1.2, a 3 inch piston would need over 17 feet of travel space to compress the air to the desired pressure, making this option not feasible. While this method would be perfect for a space themed launcher and could be an interesting option to develop, it would require additional time and resources to create a feasible system.

After eliminating an electromagnetic system, a system that utilizes springs or elastic bands was considered. For the same reasons described for the electromagnetic system, it is not feasible to use the springs to compress air to the desired pressure. Instead, the springs would have to directly contact the T-shirt and propel it forward. Using the Law of Conservation of Energy, spring equations, and projectile motion equations, the amount of energy needed to propel a T-shirt to 68.5 MPH was found to be just over 60 lb ft, which is described in Milestone III, Section 5.1.3. Using this number as the required potential energy of the spring, the team analyzed every spring available from McMaster Carr with less than a 3 inch diameter. Of the 21 springs analyzed, only 4 met the minimum potential energy requirements when fully compressed, and 3 of those were only slightly above 60 lb ft. Since this does not take any losses into account, this option did not pose a viable solution.

The final option considered was a catapult or trebuchet. This type of propulsion would be capable of launching hundreds of feet, far exceeding the required values. However, this type of system would be extremely heavy and large, making it difficult to transport and maneuver. This type of system would also be storing a very large amount of energy, making the consequences of a potential failure more severe.

After eliminating electromagnetics and springs via analysis, the final decision came down to compressed fluid or a catapult. The compressed fluid option was the clear choice due to being safer, less expensive, and lighter than the catapult, while still being able to meet key requirements. This Pugh Matrix used to aid in this decision is shown in Figure 6.1.1.1C, and the ranking criteria is available in Appendix F.

		Propulsion Method Alternatives			
		Compressed Fluid		Catapult / Trebuchet	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Safety	40%	3	1.20	1	0.40
Energy Capacity	22.50%	4	0.90	1	0.23

# Consumable Parts	22.50%	2	0.45	4	0.90
Weight	10%	2	0.20	1	0.10
Build Cost	5%	2	0.10	4	0.20
Totals	100%		2.85		1.83

Figure 6.1.1.1C: Propulsion Method Pugh Matrix

6.1.1.2 Fluid Type

After determining the team would use a compressed fluid based system, the type of fluid also had to be determined, as that would drive purchasing decisions, as components are generally built for a specific type of fluid. The three alternatives the team considered were compressed air, CO_2, and nitrogen. Air and CO_2 are commonly used by commercial T-shirt launchers, with nitrogen being a wildcard.

Compressed air was the first option considered. The largest advantage of air is that it is easy to refill and inexpensive, as it can be refilled using a normal compressor. Additionally, the UCF Machine Shop has the ability to fill tanks up to 3,000 PSI with the proper adapters. Furthermore, air will not cause condensation to form on the tank as CO_2 would, and it is cleaner for the other parts of the system [18], helping reduce maintenance. The major drawback of this type of system is the cost, which is due to needing either a compressor or a high pressure storage option, such as a scuba tank.

CO_2 is the second most commonly used option for T-shirt launchers. Since CO_2 is a denser fluid than air, it allows the user to achieve more launches with the same amount of fluid when compared to air. Additionally the initial cost of CO_2 is less than that of compressed air [18]. However, using CO_2 would require additional cost each time UCF wants to refill the CO_2 source as it is not as available as compressed air. Furthermore, the CO_2 will cause condensation to form on the tank, making it cold and causing a potential shock hazard with electronics.

Nitrogen offers little advantage over the other two options. While it is a dryer gas, helping reduce corrosion on other components, finding components that are rated for nitrogen is difficult and more expensive. Additionally, since nitrogen is the least dense out of the three gasses, it would offer the worst performance. Since it has the most expensive upfront cost, use cost, and the worst performance, it can be eliminated.

The decision for the fluid type was reduced to compressed air or CO_2. While CO_2 was ranked higher than air, the team ultimately decided on using compressed air due to its availability and preliminary testing that confirmed that compressed air was capable of launching T-shirts at the required distance and exit velocity. The comparison between these two fluids is shown in Figure 6.1.1.2A, and the ranking criteria is available in Appendix F.

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		Fluid Type Alternatives					
		HPA		CO_2		Nitrogen	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating

Safety	50%	3	1.50	4	2.00	4	2.00
Refill Cost	20%	4	0.80	3	0.60	1	0.20
Refill Location	15%	4	0.60	3	0.45	1	0.15
Initial Cost	10%	2	0.20	3	0.30	2	0.20
Density	5%	3	0.15	4	0.20	3	0.15
Totals	100%		3.25		3.55		2.70

Figure 6.1.1.2A: Fluid Type Pugh Matrix

After determining that the propulsion system would utilize compressed air as the propulsion source, the preliminary CAD model was created to show the key components, shown in Figure 6.1.1.2B. The preliminary design consisted of a bead blaster tank, used to place tires on a wheel, its included hardware, and an additional grip towards the front of the bead blaster.

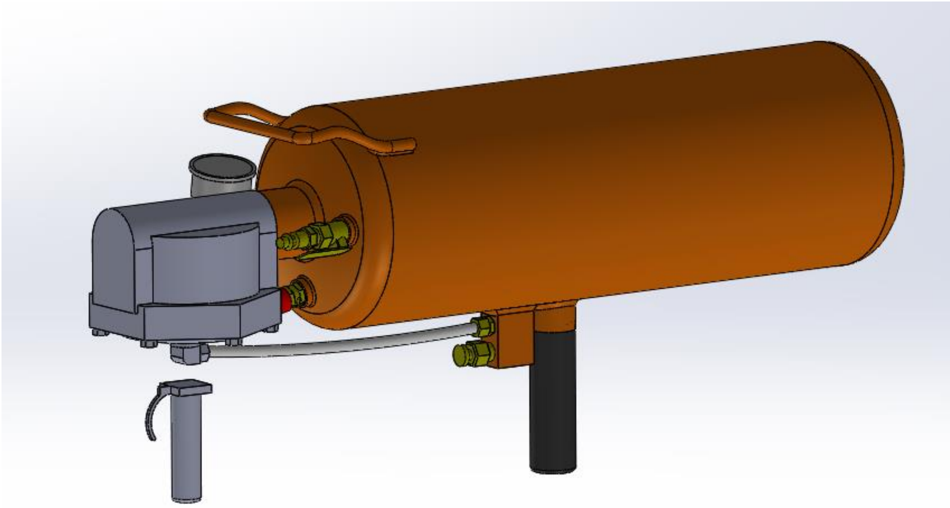


Figure 6.1.1.2B: Preliminary Propulsion System

6.1.2 Propulsion System Iteration and Implementation

The final propulsion system did not vary greatly from the initial concept. The final model for the propulsion system is shown in Figure 6.1.2, where items labeled in red came with the bead blaster, and items labeled in blue were purchased separately.

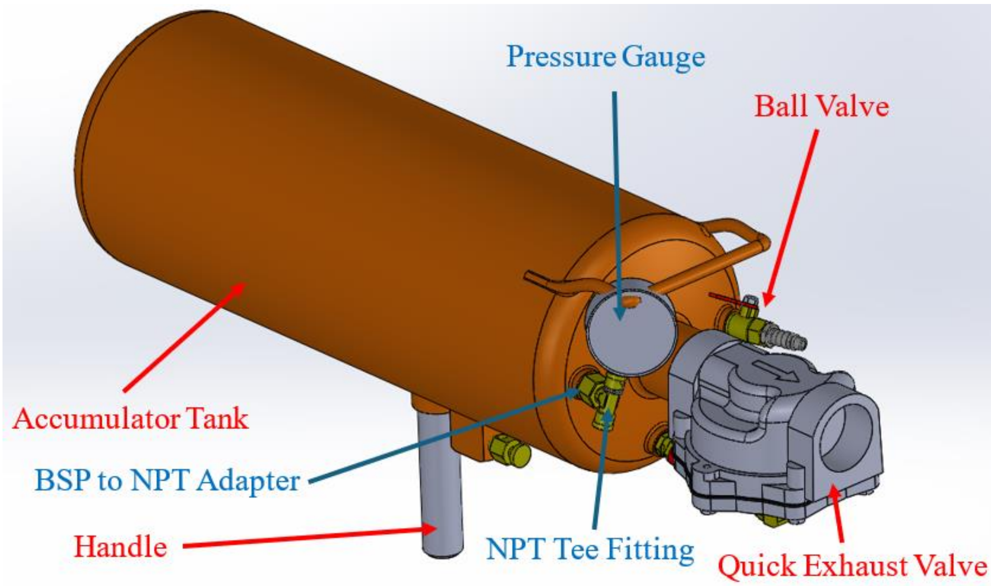


Figure 6.1.2: Final Propulsion System

The overall dimensions of the accumulator tank and quick exhaust valve were refined based on measurements and the manufacturer specifications. The fittings that came with the bead blaster were all labeled 1/4 inch, so the team assumed that they were 1/4 NPT, which is commonly used for pneumatic fittings. After some difficulties attaching store bought NPT fittings, the team determined that the bead blaster uses British Standard Pipe (BSP) threads. Due to this, the team had to purchase a BSP to NPT adapter to attach the Tee fitting to. The Tee fitting is used to consolidate the pressure gauge and pressure transducer that is used for the electronics system to a single area. Note that behind the valve in Figure 6.1.2A is the pressure relief valve, which is a critical, and possibly the most important, safety aspect of the launcher.

The other part of the propulsion system was thought of and designed after the conceptual design stage. This system consists of a scuba tank, Yoke to NPT adapter, and pressure regulator, shown previously in Figure 3.1.4.1C. Scuba tanks utilize special pneumatic fittings that are appropriate for their high operating pressures, and Yoke fittings are the most common in the US, as the US feels the need to use different units for everything than the rest of the world. The scuba tank is recommended to fill to 2,140 PSI to obtain a 3.5 FOS. The Yoke to NPT adapter is a custom part built by Preece Precision that reduces the 3,000 PSI standard output of a scuba tank to a constant 150 PSI. This 150 PSI output is then further connected to a pressure regulator set to 120 PSI, with a maximum operating pressure of 200 PSI. This setup provides a safe solution to reduce the pressure entering the accumulator tank, while still being able to utilize a scuba tank at a high pressure for storage.

The only issues the team encountered when assembling the propulsion system were minor leaks in pneumatic fittings. The accumulator tank came from the factory with a red pneumatic sealant applied to all of the threads, which made them difficult to remove and clean. One fitting in particular, the original pressure gauge, had to be heated using a heat gun and then a blow torch to soften the sealant to allow it to be removed. In doing this, it was forgotten to remove any plastic components from the accumulator tank, and the clear hose that connects the quick exhaust valve to the trigger was melted in the process. Luckily, the replacement hose only cost a few dollars and it was able to be fixed quickly after obtaining the replacement hose. In the course of the project, pneumatic fittings were removed and replaced countless times for numerous reasons. In doing this, the team found it best to apply a generous amount of PTFE tape to the threads to ensure a proper seal with no leakage.

6.2 Reloading System Development

The second critical system to launch T-shirts is the reloading system, which allows the T-shirts into the barrel and contains the barrel itself, which is responsible for directing the T-shirts into the crowd and focusing the compressed fluid on the T-shirt.

6.2.1 Reloading System Initial Concept

The options considered for the reloading system concept included manual reloading, belt fed reloading, revolver style reloading, and gravity fed reloading. The complete comparison of these options is available in Milestone III, Section 5.3. Manual reloading offered a simple solution with few moving parts, reducing the likelihood of a failure. However, this means that the user or an assistant has to reload a T-shirt with each shot. A manual reloading system also offers more design freedom for the aesthetic of the launcher, as bulky components do not have to be incorporated into the Space-U theme.

The next alternative was a belt fed reloading system, where each T-shirt is in a canister, and each canister is attached to the next one. This belt of canisters is then pulled through the barrel, the T-shirt is launched, and the canister exits the other side from where it entered. The main benefit of this system is the small amount of time between launches and the theoretical infinite belt length, increasing the number of T-shirts that can be launched before reloading. However, this system would consist of many moving parts, creating pinch points, and increasing the chance of a failure. This type of system would also significantly increase the weight of the launcher, decreasing its portability.

Another reloading option was a revolver style, where the T-shirts are loaded and rotated to a position in front of the barrel to be launched. This type of system would offer a quick time between launches, and the number of T-shirts the revolver holds could be optimized to meet UCF's needs. Alternatively, this system would again add weight and complexity to the system, reducing the useability and increasing the chances of a failure.

The final decision considered was a gravity fed reloading system, similar to the University of Utah design, shown in Figure 6.2.1A. In this system, the T-shirts are in cartridges that drop down into the barrel when ready to fire. After being fired, the cartridge is ejected to the side. This method again offers a reduced time between launches, and does not have as many moving parts as the previously mentioned methods. Another advantage is that the user, or an assistant, can have extra cartridges loaded with T-shirts that can be easily dropped into the hopper, increasing the number of launched T-shirts.

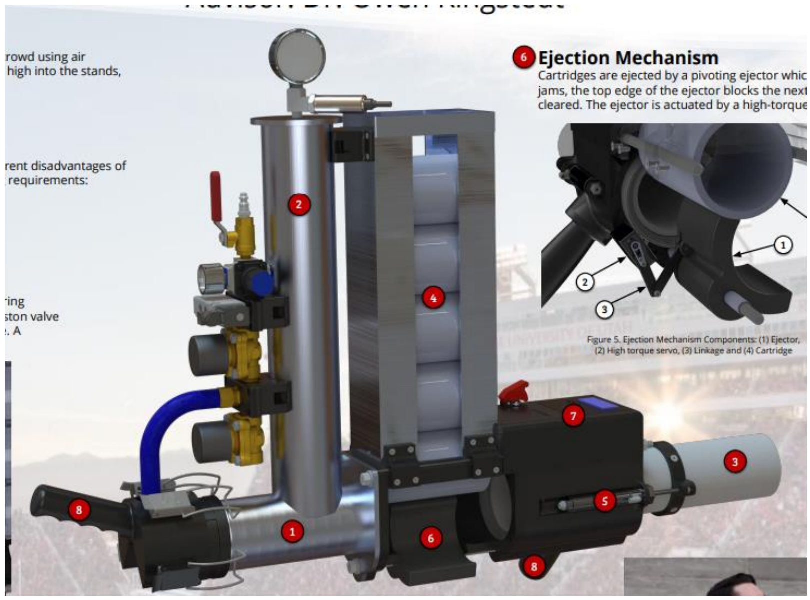


Figure 6.2.1A: Utah Launcher Reloading System [5]

At this point in the project, it was determined that the gravity fed reloading system offered the best solution. It combines the quick reloading time of the revolver and belt fed system, while being less complex and safer. This comparison is shown below in Figure 6.2.1B, and the rankings are available in Appendix F.

		Reloading System Alternatives			
		Manual / Single		Belt Fed	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Safety	35%	3	1.05	2	0.70
Time Between Shots	25%	1	0.25	4	1.00
Magazine Capacity	25%	1	0.25	4	1.00
Number of Parts	15%	4	0.60	1	0.15
Totals	100%		2.15		2.85

		Reloading System Alternatives, *Continued*			
		Revolver Barrel		Gravity Fed	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Safety	35%	2	0.70	3	1.05
Time Between Shots	25%	3	0.75	4	1.00
Magazine Capacity	25%	4	1.00	4	1.00
Number of Parts	15%	1	0.15	2	0.30
Totals	100%		2.60		3.35

Figure 6.2.1B: Reloading System Pugh Matrix

The team did not model the reloading system in the preliminary design stage as it could not be determined how to best implement the system without adding excessive weight, complexity, and interrupting the aesthetic of the launcher. This was an oversight to not attempt to model the system.

6.2.2 Reloading System Iteration and Implementation

The reloading system as a whole underwent the greatest number of iterations and testing before arriving at the final system. The first two concepts were brainstormed during a team meeting in the UCF library, shown in Figure 6.2.2A.

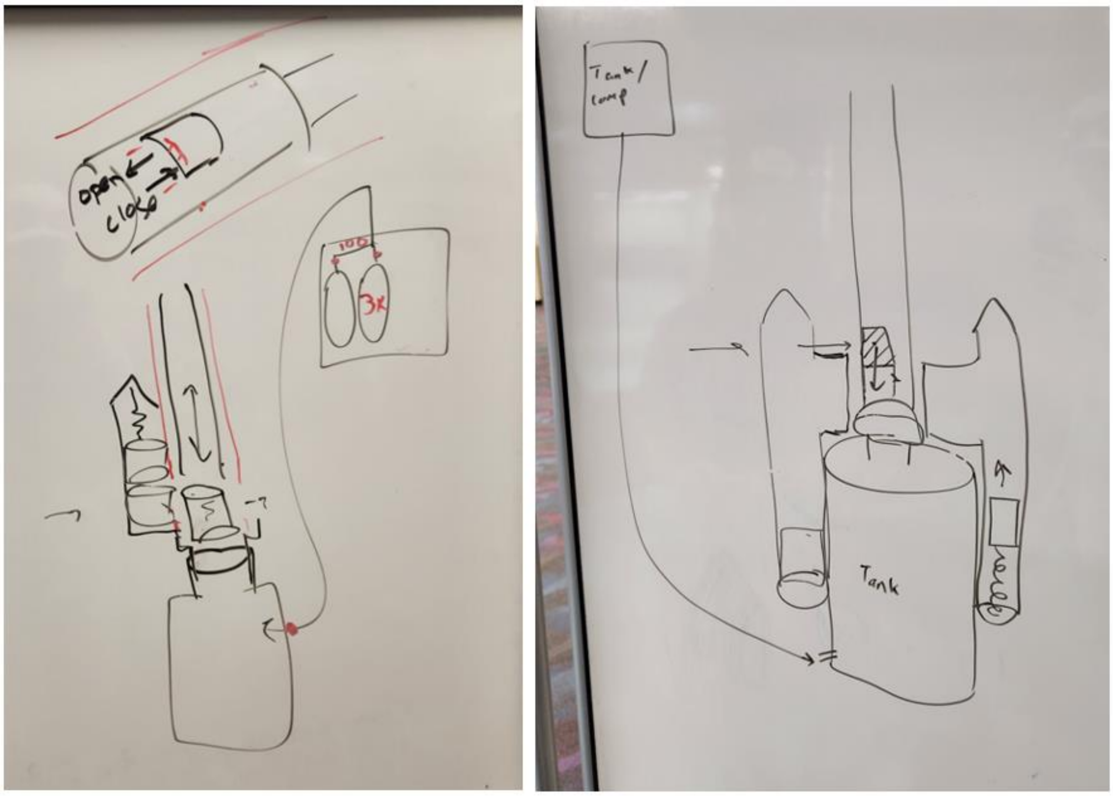


Figure 6.2.2A: First Reloading Concept

This concept included the initial design of the gravity fed reloading system. In this system, one side booster would serve as a storage area for T-shirts waiting to be loaded. A spring would push the T-shirts towards a trap door in the barrel that the T-shirts could slide in through. This design was ultimately decided against for a variety of reasons. First, the SRBs would have to be very long to accommodate a number of shirts that is significant enough to warrant having the reloading system. The initial conceptual design SRBs were long enough for 3 shirts, which is not a great capacity. Furthermore, the team could not brainstorm an idea to open the trap door and push the T-shirts into the barrel automatically. It would require human input, which largely defeats the purpose of a reloading system. Due to these factors, the team came to the conclusion that the advantages of a gravity fed reloading system were negated by the added complexity, cost, weight, and lack of T-shirt capacity.

The next iteration of the design, shown in Figure 6.2.2B, involved pre-loading each T-shirt into a small piece of pipe with a smaller diameter than the barrel, sliding the barrel forward, placing the T-shirt into the barrel, and sliding the barrel back to create a seal. The reasoning for wanting to slide the T-shirts in from the back of the barrel is because this allows the user to roll the T-shirt to be slightly larger, increasing the area, without having to worry about them sliding down the length of the barrel. With this design, the barrel is placed on a track to slide back and forth. The team could not identify a sufficient and safe way to ensure the barrel stays locked in place when firing, eliminating this design from contention.

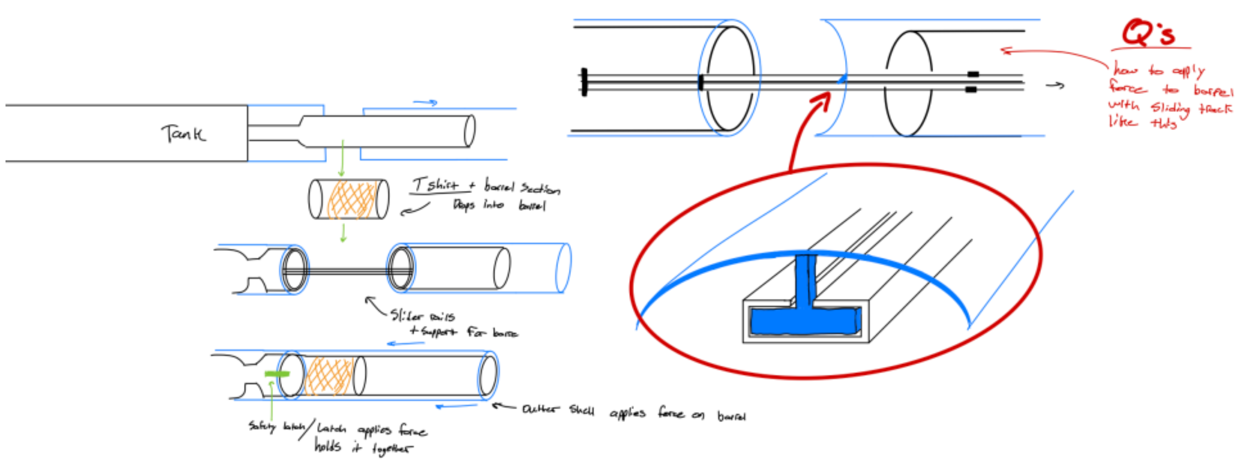


Figure 6.2.2B: Second Reloading Concept

While considering the previous method, other methods were also considered that involved sliding the barrel forward and backward to load the T-shirts. Other options included cutting a half circle in a piece of pipe to set the T-shirts in and sliding a complete piece of pipe over that section to launch, shown at the top of Figure 6.2.2C. The other alternative, shown in the bottom of Figure 6.2.2C, involved placing a handle on the barrel that was in a “L” shaped channel in the cosmetic barrel. This would allow the user to move the barrel forward with the handle, and the handle would lock the barrel into place. Ultimately, it was determined that the 3D printed cosmetic barrel would not be a safe, long term solution to hold the barrel in place when launching.

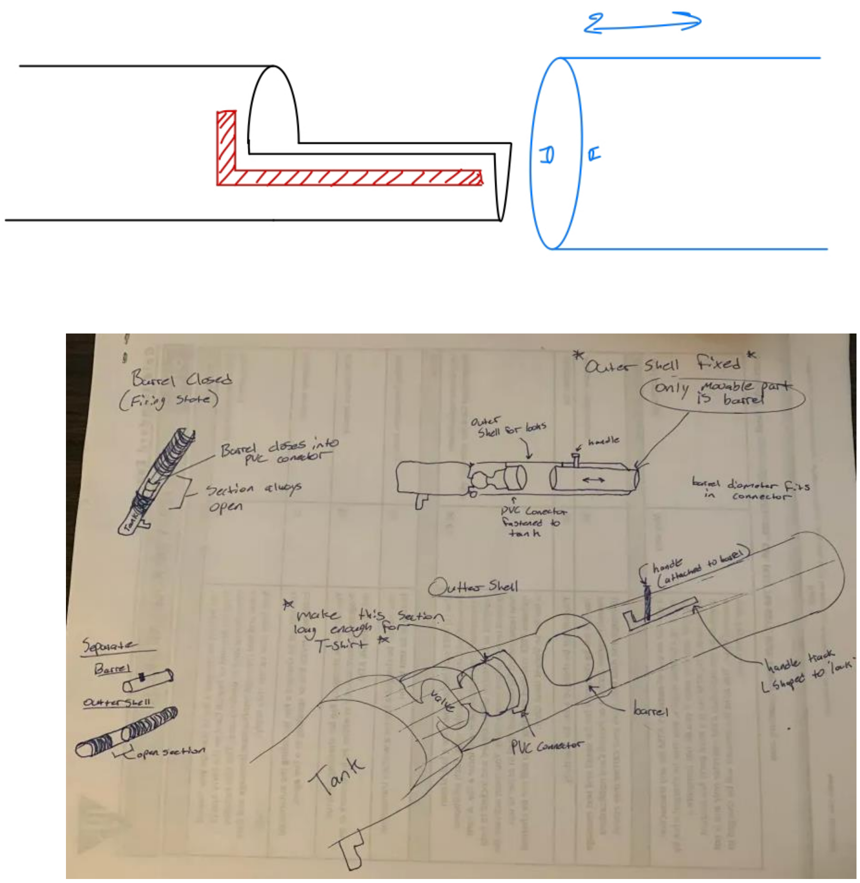


Figure 6.2.2C: Alternative Sliding Barrel Designs

The final alternative considered before arriving at the final design eliminated the need for the barrel to move forward and backward. With this design, shown in Figure 6.2.2D, there is a hole cut in the barrel, which itself is fixed. Then, a cover is placed over the barrel that slides to cover and uncover the hole, allowing T-shirts to be loaded. This design seemed promising, and the team determined to move forward testing this design and testing manual loading through the end of the barrel, such as a commercial T-shirt launcher.

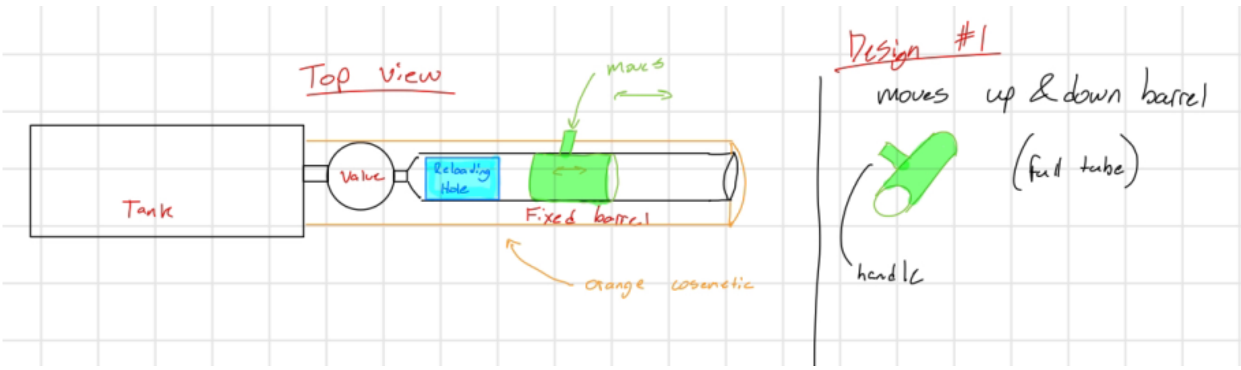


Figure 6.2.2D: Third Reloading Concept

The team prototyped a PVC barrel with a section cut out of it to test the loading method, shown in Figure 6.2.2E. The team also purchased a 3 inch PVC coupler to use to slide over the opening. However, this coupler was not capable of easily sliding over the barrel. Even after significant sanding of the coupler, which also reduced its strength, it would not slide with ease. This posed a question of how the open section would be sealed in an effective and safe manner, while still being easy to slide the coupler.

Figure 6.2.2E: Third Reloading Concept Prototype

On the day the team was supposed to test the prototype barrel, the team first tested a traditional barrel with no openings in it. The team had found a new method to roll the T-shirts, allowing them to easily slide all the way down the barrel, making this method effective. After testing the traditional barrel, the team decided to cut slits in the end of the barrel in an attempt to diffuse the sound of the launcher. The first attempt at this did not reduce any sound, but the barrel remained intact. For the second launch, the slits were widened, hoping more air would be allowed to escape to the sides. When doing this, the T-shirt caught the slits on the end of the barrel, causing it to rupture, shown in Figure 6.2.2F.

Figure 6.2.2F: Prototype Barrel Sound Deadening Failure

With this failure in mind, the team determined that cutting out any sections of the barrel, such as in the rear loading prototype barrel shown in Figure 6.2.2E, was not a safe decision. Even if the user manual states that the T-shirt must be slid up past the opening before firing, it is almost a certainty that at some point this recommendation would not be followed, causing the T-shirt to catch the side of the opening on the barrel, causing it to rupture. Due to this and having a new method to roll the T-shirts small enough to slide down the barrel, the traditional loading method was selected.

Furthermore, the team had many discussions about the benefits of a rear loading system. The main benefit seemed to be that the user would not have to place their fingers in front of the barrel to load the T-shirt, but during testing with the prototype shown in Figure 6.2.2E, it was determined that the user would end up putting their fingers inside the barrel, which posed an even greater safety risk. Additionally, a rear loading system was almost guaranteed to have additional energy losses, increase loading time, and increase the complexity of the system. With all of this in mind, the traditional loading method was selected. The team had determined that there was essentially no benefit of a rear loading system over the traditional loading method.

In hindsight, all of the reloading methods considered would have made the launcher more difficult and time consuming to load, create energy losses, and pose additional safety concerns. While the traditional method may not be the most innovative or exciting, it is the simplest and safest method, ensuring the long term success of the launcher.

The final reloading system was based heavily on the prototype barrels that were used for testing over the previous months and is shown in Figure 6.2.2G. This system is relatively straightforward. Starting from the left, there is a metal BSP to NPT adapter to accommodate the accumulator tank's threads. This is connected to a 1.5 inch Schedule 40 PVC NPT to slip fitting, which is further attached to a 1.5 to 3 inch Schedule 40 PVC adapter. This adapter is finally attached to the 3 inch barrel. All of the PVC used is Schedule 40, meaning it has thicker walls than normal, and is pressure rated. An additional 3D printed component, shown in orange in Figure 6.2.2G, is also part of the reloading system because it is placed in between the 1.5 inch slip and the 1.5 to 3 inch adapter and must be placed before assembling the barrel. This bracket is used to help stabilize the cosmetic barrel, which will be described in Section 6.5.2.1.

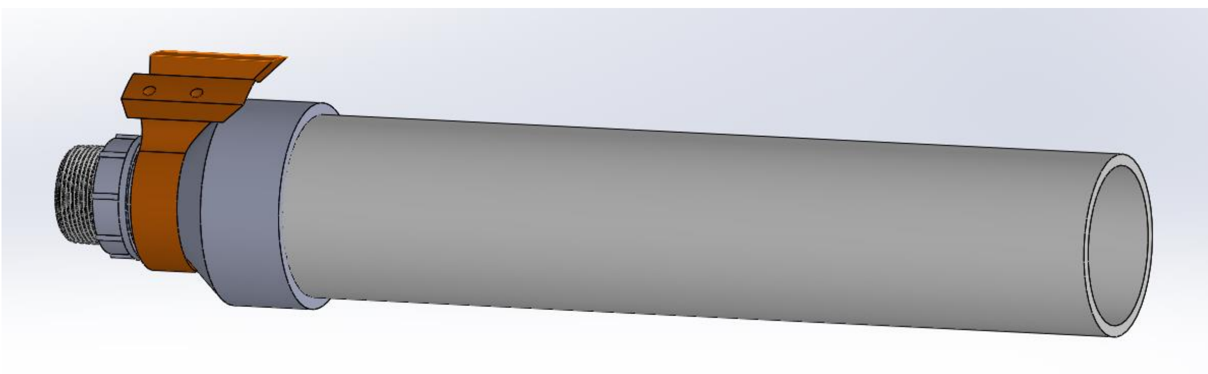


Figure 6.2.2G: Final Reloading System Model

When building the final reloading system, no major issues were encountered. The PVC was joined using cement rated for 180 PSI, far exceeding the maximum capabilities of the launcher. The cement was applied in accordance with the testing procedure documented in Appendix G, which ensured the safety of the cement. Lastly, a small hole was drilled at the bottom of the barrel, allowing air to escape when a T-shirt is sliding down the barrel, helping to reduce the likelihood of a jam. The constructed barrel is shown below in Figure 6.2.2H.

Figure 6.2.2H: Manufactured Reloading System

6.3 Electronics System Development

The electronics system started out as two different systems, the user interface and the launching indicator. As both systems were developed, it was determined that electronics would play a major role in those systems, and they would be joined to form the electronics system.

6.3.1 Electronics System Initial Concept

The electronics system contains two major components, a user interface to communicate the status of the launcher to the operator, and an indicator to alert the fans at the games that a T-shirt has been launched. These two components were developed independently, but ended up being integrated into a single system.

6.3.1.1 User Interface

Three main options were considered for the user interface: a digital display, LED indicators, and analog gauges. The complete discussion of these options is available in Milestone III, Section 5.6. Analog gauges offer the simplest solution with the least likelihood of failure. These gauges would be cheaper than any other option, require no external power source, and are easier to install and maintain than electronic options. Analog gauges are also easy to read and interpret, but lack the accuracy of digital options and could drift over time, leading to inaccurate readings. Analog gauges also lack the ability to meet certain requirements, such as indicating the launcher is ready to launch or that the pressure is at a dangerous level.

The next alternative considered was a digital one that utilizes a pressure transducer to display the pressure information on a display for the user. Using a display would allow the team to program in alerts at unsafe pressure and a pressure when the launcher is ready to launch, helping satisfy key requirements. Using an electronic pressure transducer would also make the pressure easier to read for the user and offer higher precision than analog gauges. A digital system would come with a higher upfront cost and increase the weight of the launcher, as wiring and batteries would be required.

The final alternative considered was to use LED indicators to communicate information about the launcher's status to the operator. These would be clearly labeled and easy to interpret for the user. Using LED indicators would also be lighter than using a digital display and use less electricity, opening up the opportunity for a smaller battery. On the other hand, LED indicators lack any sort of precision when compared to the other options and would be more complex to program than a digital display.

In the conceptually stage, it was determined that a mixture of analog gauges, digital interfaces, and LED indicators would be used to create the user interface, which would evolve into the electronics system. Utilizing a digital system as the main system allows the team to communicate more information to the operator than any other option. But, also having analog gauges present as a backup or in case the battery does not get charged before use still allows the operator to have an idea about the state of the system, but it may lack some context. Finally, the team initially intended on having an LED "ready to fire" indicator, which was carried through to the final design. The comparison between the three options is summarized in Figure 6.3.1.1A, and the criteria is available in Appendix F.

		UI Alternatives					
		Digital		Analog		LED Indicators	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Safety	40%	4	1.60	3	1.20	3	1.20
Cost	35%	2	0.70	3	1.05	3	1.05
Easy Interpret	15%	4	0.60	3	0.45	2	0.30
Simplicity	10%	2	0.30	4	0.60	2	0.20
Totals	100%		2.90		2.70		2.55

Figure 6.3.1.1A: UI Pugh Matrix

The preliminary design for the UI system included an Arduino with a display and a pressure gauge on the accumulator tank, shown in Figure 6.3.1.1B. At this stage, it was unknown how the Arduino and display would mount to the launcher.

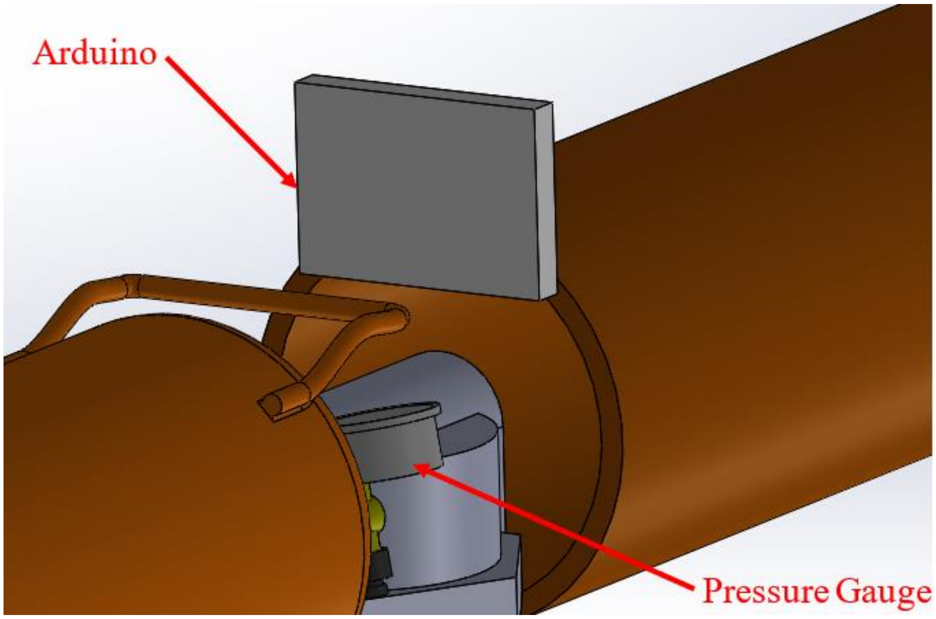


Figure 6.3.1.1B: Preliminary UI System

6.3.1.2 Launching Indicator

The launching indicator serves the purpose of satisfying the requirement to have an indicator to alert the fans that a T-shirt has been launched. The four options considered for the launching indicator include flashing lights, smoke, fire, a flag, or an audio indicator.

Flashing lights offered an ideal mixture of effectiveness and safety compared to the other options. Bright LED lights flashing when a T-shirt is launched is very likely to attract the attention of the audience if they were not already paying attention. This is also cost effective, as the launcher would already have an Arduino for the user interface, so the only addition is an LED strip. Using LED lights offers little downside.

The second option, smoke, would also attract attention to the launcher, but it is not as obvious as flashing lights. This option is more exciting than flashing lights, but it is less likely to be seen. This option would be more difficult to implement than flashing lights and could create panic if people who are unfamiliar with the launcher think something has caught on fire.

The most exciting option, fire, would be by far the most exciting option to alert fans that a T-shirt has been launched. No other T-shirt launchers offer this and it would certainly set apart Gemini 28-80 from the competition. However, using fire posed a serious safety risk. If any part of the launcher caught on fire, it would injure the operator and could cause the fire to spread in the grass on the field. Additionally, if a T-shirt caught on fire and was launched into the crowd, it would injure fans, create a liability issue for UCF, and would violate many federal and state laws, and the team would prefer to not see Knightro or the Citronaut on the evening news due to a launcher malfunction. Due to this, this exciting option cannot be considered.

The next option is a mechanical flag that would pop up when a T-shirt is launched, similar to a cartoon piston that has a flag on the end that says “bang.” This option is very safe, like the LED lights are, but is more complex, requiring mechanical parts. This option would also likely attract the least amount of attention, questioning if it is satisfying the intention of the requirement.

The final option was to use a speaker to play audio when a T-shirt is launched. This would be very safe and would not be any more complex than the LED lights. While this is a unique option, the speaker would likely be drowned out by the crowd or speakers at the football stadium, reducing its effectiveness.

In the conceptual stage, the team determined to use flashing LED lights as the launching indicator. Fire and smoke were both eliminated due to safety concerns. The potential failures associated with them pose a serious legal and ethical liability to UCF, which is not worth any amount of risk. Out of the remaining options, LED lights would be the most effective to attract attention, create excitement, and would be the easiest to implement. The comparison between the options is shown in Figure 6.3.1.2A, and the ranking criteria is available in Appendix F.

		Launching Indicator Alternatives			
		Flashing Lights		Smoke	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Safety	40%	3	1.20	2	0.80
Visually Enticing	30%	3	0.90	3	1.20
Cost	20%	3	0.60	1	0.40
Simplicity	10%	3	0.30	1	0.40
Totals	100%		3.00		2.80

		Launching Indicator Alternatives, *Continued*					
		Fire		Flag		Audio	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Safety	40%	1	0.40	4	1.60	4	1.60
Visually Enticing	30%	4	1.60	1	0.30	1	0.30
Cost	20%	1	0.40	3	0.60	3	0.60
Simplicity	10%	3	1.20	2	0.20	4	0.40
Totals	100%		3.60		2.70		2.90

Figure 6.3.1.2A: Launching Indicator Pugh Matrix

The initial design for the launching indicator included individual LEDs placed at the end of the barrel, shown in Figure 6.3.1.2B. This design would involve either connecting the LEDs in series or running a wire to each LED from the Arduino.

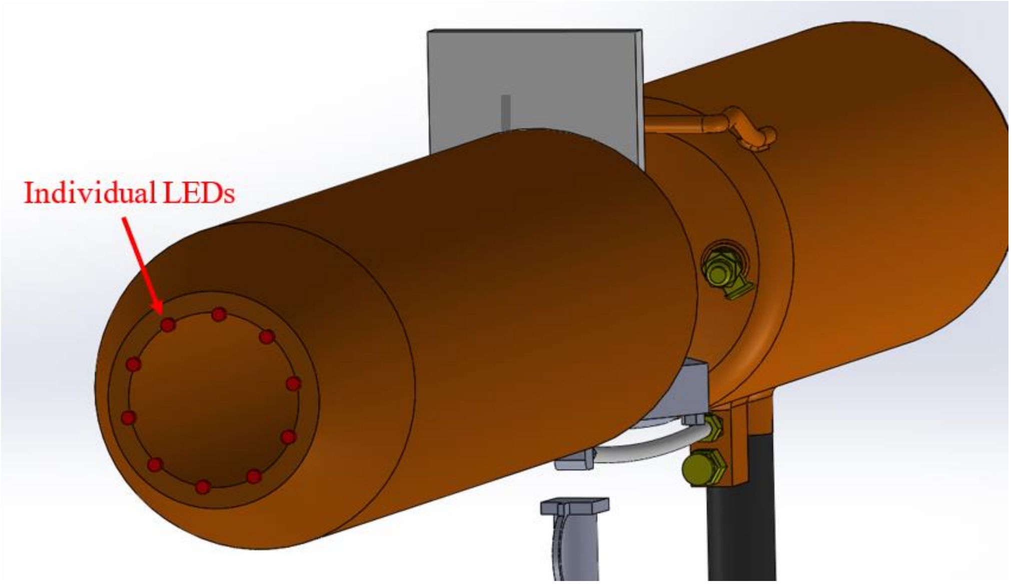


Figure 6.3.1.2B: Preliminary Launching Indicator

6.3.2 Electronics System Iteration and Implementation

The final electronics system closely resembles the originally designed one, just with more detail.

The main parts of the electronics system are shown in Figure 6.3.2A.

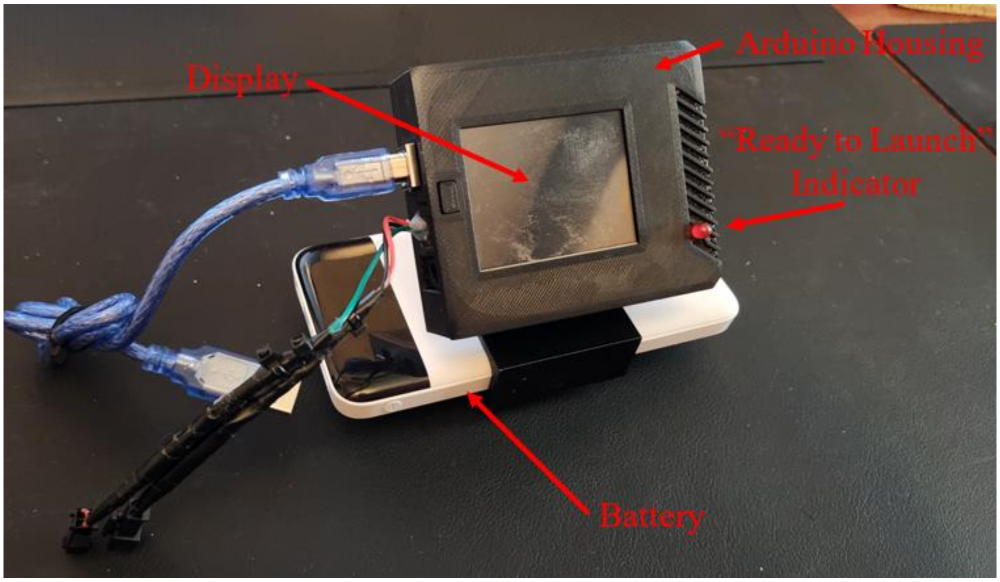


Figure 6.3.2A: Electronics System Arduino Subassembly

Connected to the Arduino is a pressure transducer and additional LED lights. The LED lights used are an LED strip, which differs from the initial design of using individual LEDs. The LED strip is easier to install, produces more light, and requires less wiring than individual LEDs. For the housing, it is connected to the top of the quick exhaust valve with heavy duty velcro. This allows quick removal for storage and charging the battery, while being strong enough to ensure it stays in place during use.

The electronics system satisfies many requirements, which is described in Section 9.0. When the electronics system is first turned on, it displays the UCF MAE logo, and then shows the name of the launcher with the names of each team member, shown in Figure 6.3.2B. This serves both as a representation of the College of Engineering and the members of this team.

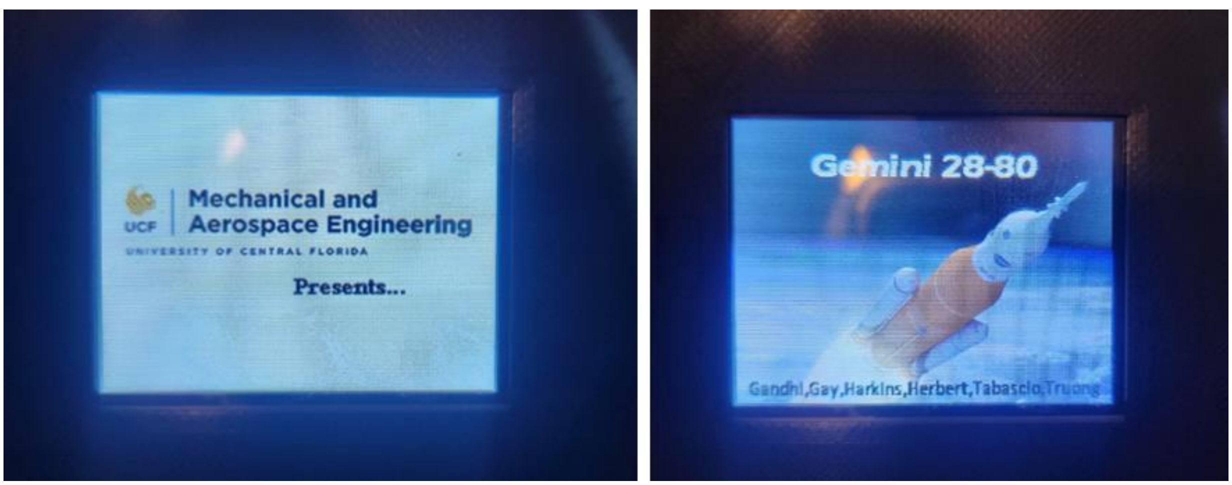


Figure 6.3.2B: Arduino Start Up Screen

After starting up, the display shows the pressure inside the accumulator tank, along with the approximate power level of the tank. Once the pressure exceeds 10 PSI, which is the minimum pressure for a T-shirt to reach the stands, a red LED indicator turns on, as shown in Figure 6.3.2C.

The power percentage was calculated using testing at the football stadium, which is described in Milestone V, Section 3.6.3.

Figure 6.3.2C: Arduino Pressure and Power Level

Once 80 PSI is reached, which will send a T-shirt to the top row of the stadium, a message, shown in Figure 6.3.2D, appears on the screen, alerting the user that the tank should either be depressurized or they need to increase the launch angle, both of which will ensure the T-shirt stays in the stadium. After the message disappears, the power percentage bar turns red as a reminder.

Figure 6.3.2D: Arduino Display at 80 PSI

Finally, when the pressure drops in the tank, which is measured by the transducer, the LED strip on the end of the barrel will light up, indicating a T-shirt has been launched.

6.3.3 Electrical Design Issues

While the electronic monitoring system may seem simple and intuitive, it took many iterations to develop the final product we present today. Coding was the main obstacle. As mechanical engineers, coding is not our strong suit, and our unfamiliarity with the Arduino platform added hurdles we needed to cross.

A large portion of the issues related to coding involved successfully displaying images in the Arduino during the introduction loading screen and the maximum PSI message. These functions were difficult to implement due to the lack of documentation and sample code online for the specific touchscreen display we chose. Despite this significant hurdle, after many attempts and trial and error, we established reliable code that displayed the images at the correct times without issue.

Another significant problem with the electrical system was finding usable pins for the pressure transducer signal wire, the "ready to fire" LED, and the firing indicator LED strip. While the LCD display we used for our project was intuitive, as it directly connected to all the pins of the Arduino to create a seamless box, it used almost every digital and analog pin. This created a problem when trying to designate other peripherals to the Arduino. To address this issue, we reviewed the manufacturer's pinout of the screen to understand each pin's function and determined which pins were not needed for our use. We found that analog pin A3 was not used at all, and digital pins 0 and 1, typically used for the serial monitor, were not needed since we displayed information on an

LCD screen. The serial monitor can only be viewed when the Arduino is connected to a computer and running the Arduino software.

In conclusion, the electrical system posed challenges when designing from scratch, but through research and perseverance, our team was able to resolve all issues and deliver a seamless and reliable product with a "wow" factor that is sure to put a smile on the operator's face. The final code used to implement the electronics system is available in Appendix N.

6.4 Safety System Development

The safety system serves the purpose of keeping any potential end users safe during operation, storage, maintenance, and transportation. This system is heavily derived from system requirements, such as incorporating a LOTO device and a trigger safety. Other safety features, such as the indicator that the pressure is at a dangerous level, were incorporated into other systems, such as the electronics system for this example.

6.4.1 Safety System Initial Concept

Interestingly, the team did not analyze alternatives for the safety system, instead modeling was started immediately. While the final components of the safety system did end up being effective, this was an oversight by the team to not consider all alternatives, as it is possible a better solution exists.

The first component of the safety system, the trigger LOTO, was the first component to be modeled. The idea for this system was to prevent the trigger from being pulled, which alone satisfies the requirement to have a LOTO system. This LOTO device works by sliding in between the face of the trigger and the portion that screws into the launcher, preventing the trigger from being depressed, as shown in Figure 6.4.1A. This design was effective to prevent the trigger from being activated, but had many issues. The main two were that the small tabs could be easily broken off and the component was divided into two parts, making it easier to lose.

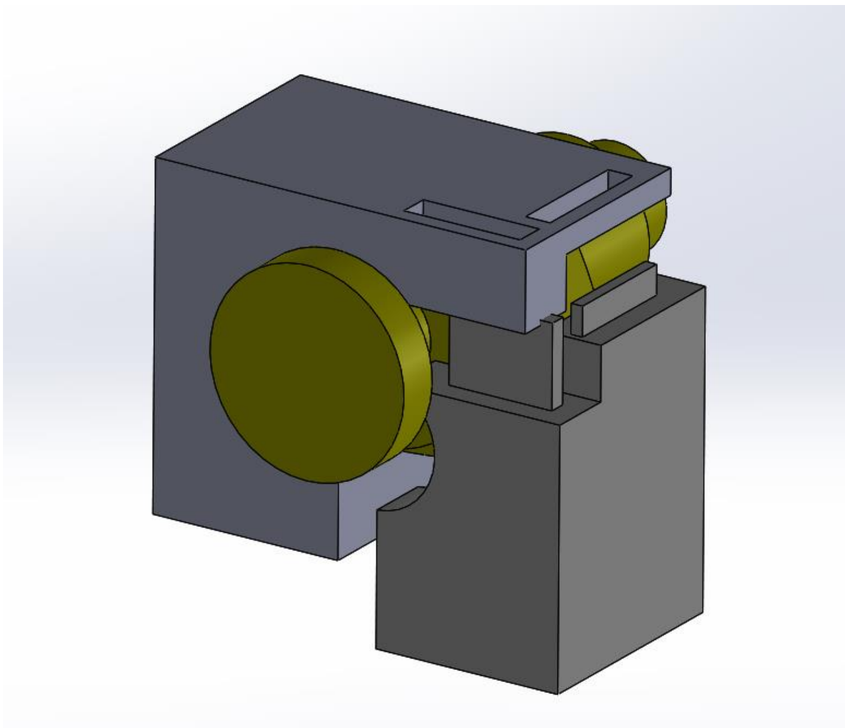


Figure 6.4.1A: Preliminary Trigger LOTO

Although the trigger LOTO alone satisfies the requirement to have a LOTO system, the air inlet LOTO offers a secondary method to prevent use by preventing any energy from entering the accumulator tank. The air inlet LOTO was designed after the design for the trigger LOTO was designed, finalized, and tested. Due to this, the lessons learned from the trigger LOTO could be applied to the air inlet LOTO, making the design process much faster with fewer iterations. Shown in Figure 6.4.1B, the preliminary air inlet LOTO features a hinges design that surrounds the air inlet to prevent a hose from being connected to it. This design also includes a hole on the left of the figure to place a lock on the device, ensuring it stays in place.

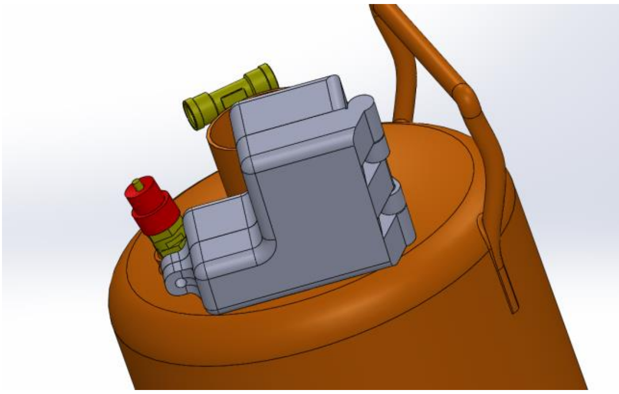


Figure 6.4.1B: Preliminary Air Inlet LOTO

The final part of the safety system, the trigger safety, shown in Figure 6.4.1C, is designed to quickly clip on the trigger, preventing it from being pulled. The trigger safety also has an additional loop, to use a keychain to tether it to the launcher so that it does not get lost.

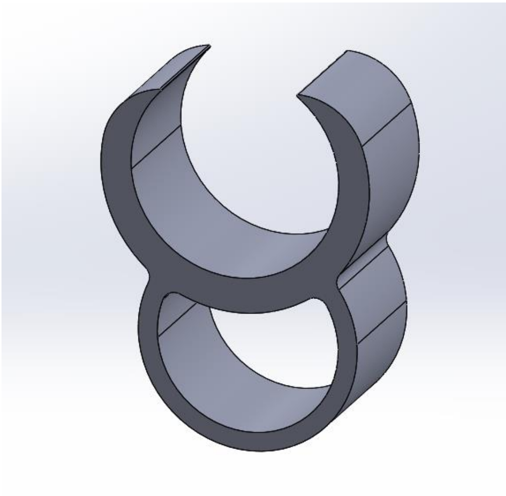


Figure 6.4.1C: Preliminary Trigger Safety

<u>6.4.2 Safety System Iteration and Implementation</u>

The three components of the safety system all went through various iterations of the design process to arrive at an optimal solution. The trigger LOTO was the first component to be designed, and the lessons learned from this device led to a quicker development time for the air inlet LOTO. Finally, the trigger safety was prototyped multiple times to determine the correct size to effectively stop the trigger, while still being durable enough for repeated use.

6.4.2.1 Trigger LOTO Iteration and Implementation

The preliminary version of the trigger LOTO, shown above in Figure 6.4.1A, was successful in stopping the trigger from being activated, but had many flaws. The main flaw is that it was a two piece component, meaning that it would be relatively easy for someone to misplace or lose one or both of the pieces, rendering it useless. After 3D printing the preliminary version, shown in Figure 6.4.2.1A, more issues appeared.

Figure 6.4.2.1A: Preliminary Trigger LOTO Prototype

First, the purchased locks would not close with the geometry of the LOTO device. The hole that the lock goes through was too close to the main part of the LOTO device, preventing it from being closed. The other significant issue was the overall strength of the device. Due to the small tabs that join the two parts together, it would have been easy for someone to break them apart, gaining access to the trigger.

Due to these issues, a completely new design, shown in Figure 6.4.2.1B, utilized a printed in place hinge to contain the LOTO device to a single part. This concept proved to be a better idea, but still had some flaws. Since the top part of the LOTO device had a "U" shaped opening to go around the trigger, it could not be slid in place, as there is an additional pneumatic fitting just above the trigger. Furthermore, the location of the holes for the lock made it impossible to slide over the slit in the trigger. Additionally, when printed, although the hinge did not break, it felt weak due to its relatively small size.

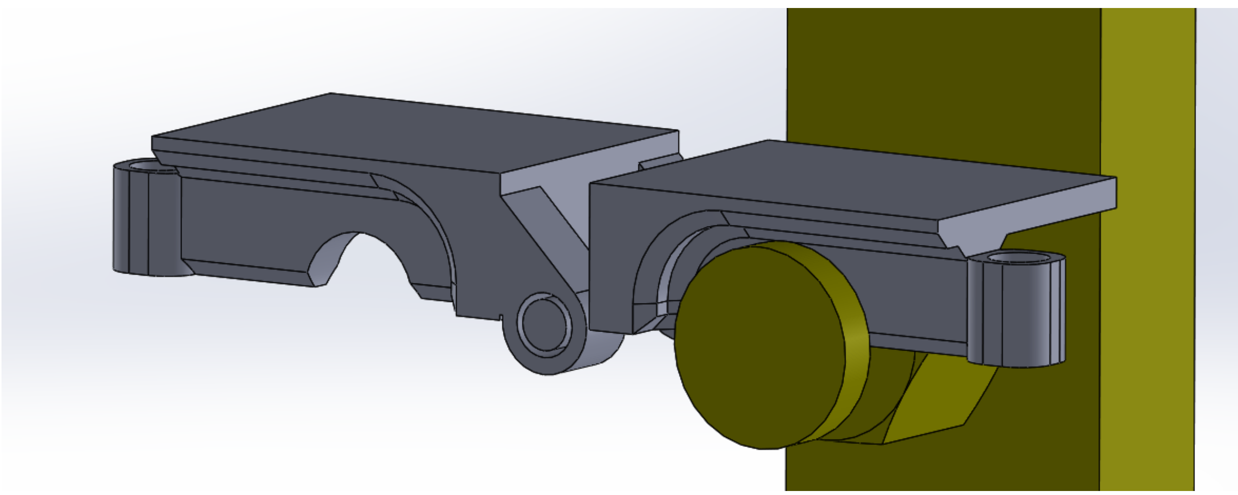


Figure 6.4.2.1B: Second Trigger LOTO Model

Fixing these issues, a third version was created, shown in Figure 6.4.2.1C. This model fixed many of the issues with the second version. First, the lock holes were moved to the front of the LOTO device so they did not interfere with sliding over the trigger. The top part of the LOTO device was made flat, instead of "U" shaped, so it could easily slide over the top of the trigger without interfering with the above pneumatic fitting. Finally, the hinge was made larger, to add strength.

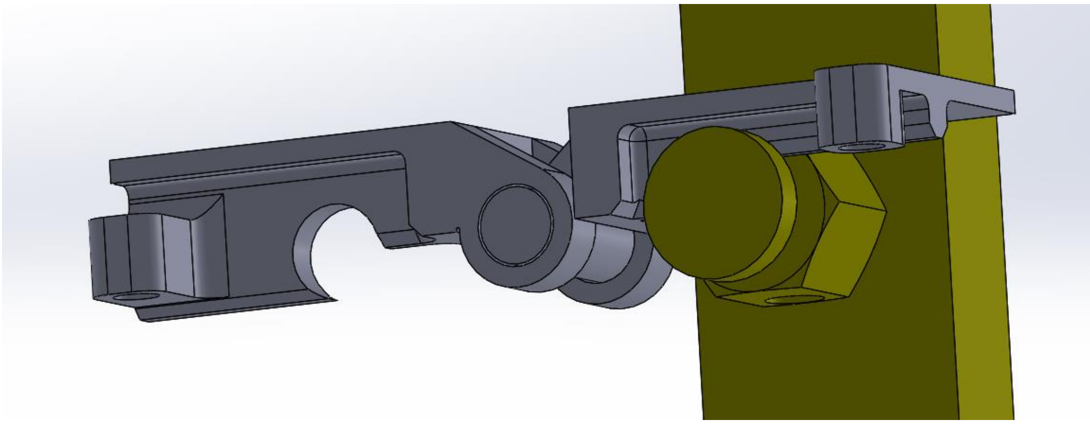


Figure 6.4.2.1C: Third Trigger LOTO Model

This model offered a more promising solution to lock out the trigger, and when 3D printed, shown in Figure 6.4.2.1D, it was overall the best solution to this point. After prototyping, two more minor issues were identified. First, the trigger could be slightly depressed. This was allowing air to leak out through the pneumatic trigger, but was not enough to fire the launcher. Also, the opening to the side of the LOTO device introduced a weak point to try to pry off the device or use a wrench to remove the pneumatic trigger, which is shown in the right of Figure 6.4.2.1D.

Figure 6.4.2.1D: Third Trigger LOTO Prototype

Both of these issues were relatively easy fixes. A wall was added to the side of the device to increase strength and prevent access to the nut part of the trigger. Additionally, the thickness of the wall that slides between the trigger was increased to prevent any movement in the trigger. These changes combined to make up the fourth version of the trigger LOTO.

After this, a final version was made with one more minor change, shown in Figure 6.4.2.1E.. An area to the side of the LOTO device was added with two holes cut out. One hole would be used to tether the trigger LOTO to the air inlet LOTO, reducing the chances of losing one of the devices. The second hole would be used for a “Remove Before Flight” keychain, adding to the space theme of the launcher.

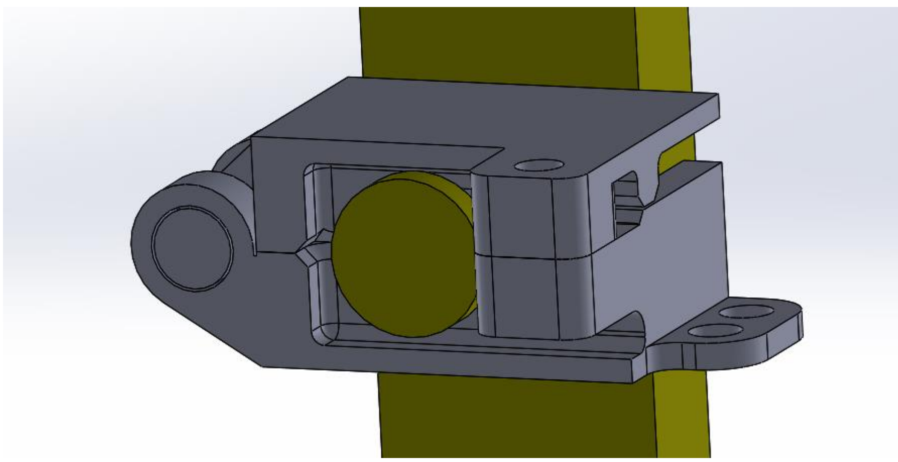


Figure 6.4.2.1E: Final Trigger LOTO Model

The final device with the attached keychains is shown in Figure 6.4.2.1F. The final device was printed using black PLA filament and a high infill percentage. Since this component is not structural, it does not need to be very strong. The team attempted to break the third and fourth versions of the LOTO device with no success, ensuring the final version cannot be broken.

Figure 6.4.2.1F: Final Trigger LOTO Device

<u>6.4.2.2 Air Inlet LOTO Iteration and Implementation</u>

Using the information learned from creating the trigger LOTO, developing the air inlet LOTO was much faster. The initial model, shown above in Figure 6.4.1B, utilized the same hinge design and dimensions as the trigger LOTO. One side of the device was cut out to accept the lever of the air inlet, but only if it is in the off position. When closed, a lock could be placed on it, ensuring an air hose could not be attached to the tank. When 3D printed, shown in Figure 6.4.2.2A, it was successful at keeping the air inlet in the off position and preventing an air hose from being connected to the tank.

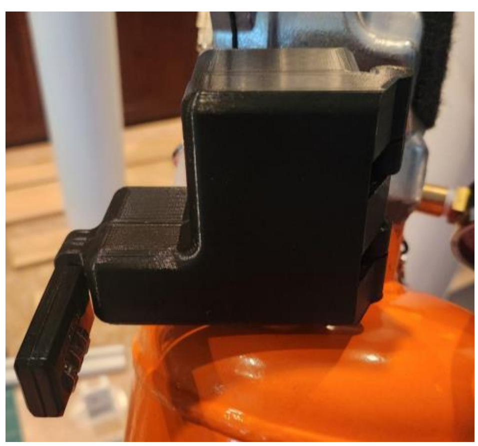


Figure 6.4.2.2A: Preliminary Air Inlet Prototype

The only issue with this design was observed when creating the overall assembly for the launcher in SolidWorks. It was noticed that the LOTO device would interfere with the SRB on that side of the launcher. This would mean that the SRB would have to be removed in order to use the LOTO device, which ultimately reduces the chances of the LOTO device actually being used. To fix this, the entire LOTO device was mirrored so that it does not stick out from the launcher. Additionally, two more holes were added for the keychains, as was done for the trigger LOTO. The final air inlet LOTO device is shown in Figure 6.4.2.2B.

Figure 6.4.2.2B: Final Air Inlet LOTO Device

6.4.2.3 Trigger Safety Iteration and Implementation

The final component of the dedicated safety system is the trigger safety. While the trigger LOTO does also technically satisfy the requirement to have a trigger safety, the intention of having a trigger safety was to have an option for the user to quickly prevent the trigger from being pulled, without having to manipulate something like the trigger LOTO and place a lock on it. The team determined the best solution for this was to have a simple clip that clips on the trigger, preventing it from being pressed. The preliminary design shown in Figure 6.4.1C underwent many iterations to find suitable dimensions that would be easy to clip over the trigger, while being strong enough to not break. The thickness of the safety used the same thickness as the trigger LOTO, eliminating the need to iterate that particular dimension.

The issue with the preliminary trigger safety came when the keychains arrived and were placed on the safety. Shown in Figure 6.4.2.3A, when the keychain is on the trigger safety, it cannot be placed completely over the trigger since the keychain interferes with the trigger.

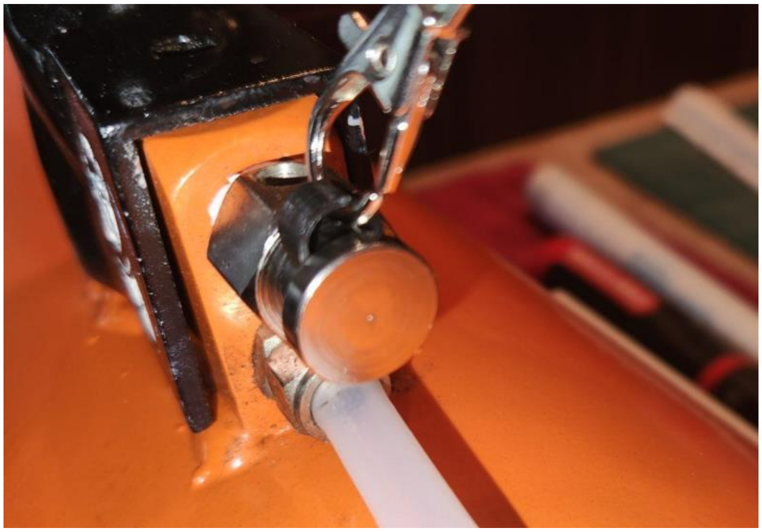


Figure 6.4.2.3A: Trigger Safety Keychain Interference

To solve this, the team originally planned on making the loop for the keychain slightly larger. This would have worked, but the team thought of another idea to add an additional piece of UCF branding to the launcher. The trigger safety would have UCF's Knight logo above the safety, shown in Figure 6.4.2.3B. This solves the issue of the hole for the keychain being too close to the trigger, adds UCF branding, and gives the user a larger area to grip to place or remove the safety.

Figure 6.4.2.3B: Final Trigger Safety Model

This design went through multiple iterations itself, which were mostly aimed at finding how small the Knight head could be 3D printed, while preserving its detail and being large enough for the keychain hole to have sufficient support. The iterations of the Knight head trigger safety, and the initial preliminary trigger safety are shown below in Figure 6.4.2.3C, where the final model is the one furthest to the right. The trigger safety was printed with white PETG, which is stronger than PLA. This will allow the trigger safety to be removed and replaced more times with a less likely chance of failure.

Figure 6.4.2.3C: Trigger Safety Iterations

6.5 Space-U System Development

The Space-U system, while not being necessary for the function of the launcher, is what makes the launcher unique and specific to UCF. Without this system, there would be no reason to have Senior Design groups build custom launchers, as UCF could have just purchased a generic commercially available launcher.

6.5.1 Space-U System Initial Concept

The initial idea for the overall look of the launcher came from Pete when the team was originally asking about the project. He mentioned that he would like the launcher to look like a rocket, such as the Ares I. After the team determined to use the bead blaster as the accumulator tank, it was brought up that since many rockets, such as the Space Shuttle and Space Launch System, utilize an orange fuel tank in the center with two white SRBs on the sides, the team’s design could mimic that. Since the purchased accumulator tank was already orange, this set the overall look of the launcher in motion.

The preliminary Space-U system consisted of only the SRBs and cosmetic barrel to make the launcher look like a rocket, shown in Figure 6.5.1. This preliminary design included a single piece cosmetic barrel to create the streamlined shape of a fuel tank in the center. The side boosters were intended to be completely 3D printed, but the team was not sure how they would be connected to the accumulator tank, as it is not natural to connect two circular surfaces side by side.

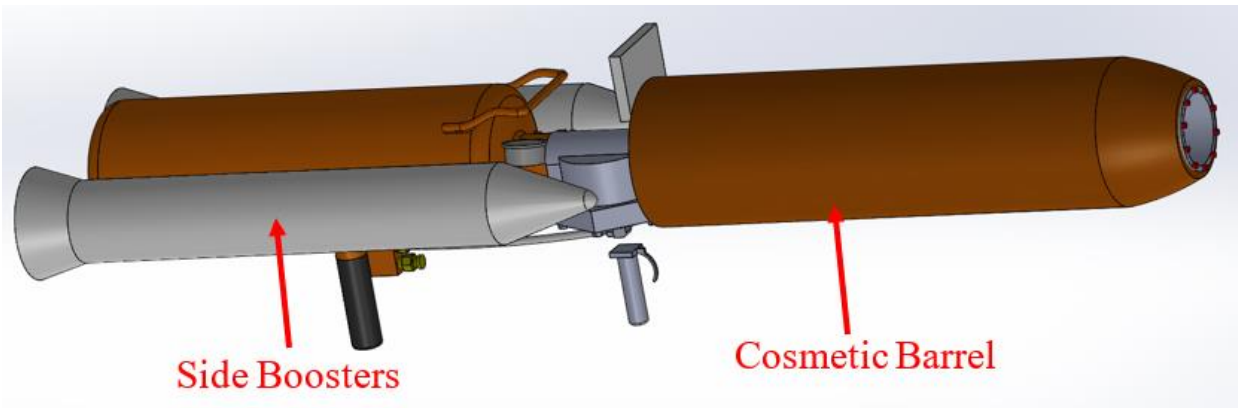


Figure 6.5.1: Preliminary Space-U System

6.5.2 Space-U System Iteration and Implementation

The Space-U system, as predicted in Milestone V, became the most time consuming system to integrate. Additionally, issues encountered with the SRBs became the most challenging and time consuming issue to fix in the project. While this system does not provide much additional function to the launcher, its execution is vital to the success of the project, which is to have a Space-U themed launcher.

6.5.2.1 Cosmetic Barrel Iteration and Implementation

The original design for the cosmetic barrel, shown in Figure 6.5.1, would have been near impossible to manufacture with a reasonable budget and materials. The main section was almost

21 inches long, which far exceeds the size constraints of most 3D printers. If this component were to be 3D printed, it would have had to be outsourced to a company with a larger 3D printer and would have taken up a significant portion, if not all of the team's budget. Due to this, the barrel was shortened to make the cosmetic barrel more manageable. This decision to shorten the barrel was also validated to meet distance and velocity requirements through testing.

The new cosmetic barrel featured three sections that were to be 3D printed with orange PETG, to match the accumulator tank. PETG was selected as it offers strength and is UV resistant, which is ideal for a device that will primarily be used outdoors. The new design had matching male and female pegs in each section of the barrel, allowing the sections to be aligned and glued together, as shown in Figure 6.5.2.1A. This design also featured small through holes for screws, to ensure the sections stayed together after gluing. Finally, additional slots were added to the design, to reduce the weight and to give a path for wires to travel down the barrel.

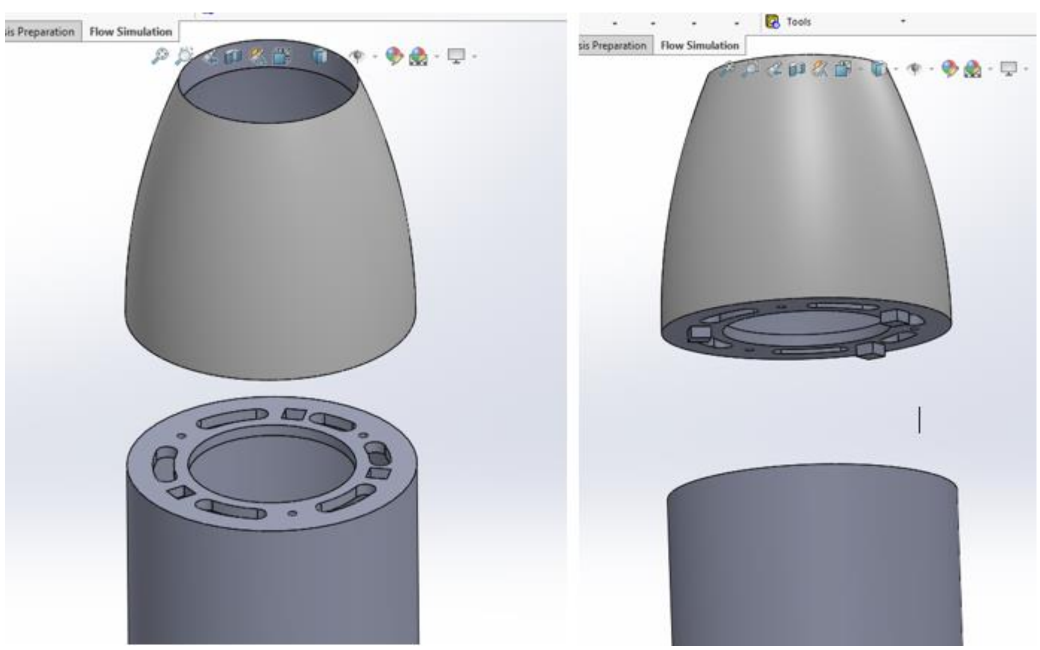


Figure 6.5.2.1A: Second Cosmetic Barrel Model

This design had many drawbacks. First, the chances that the glue would hold the sections together in the long run was slim. The screws would help, but it would be very difficult for someone to reach their arms through the entire section to put a screw on one side and a nut on the other. The other issue with this design was found during a test. The geometry of the ribs was printed to test how it fit around the barrel and how the pegs interfaced. While the fit around the barrel was perfect, the square pegs did not turn out to be a good solution. Mainly, they would only fit into each other one way, due to the print orientation. The part with the openings for the pegs had uneven dimensions in the squares, due to the plastic flaring out on the side that was touching the plate of the 3D printer. Also, after removing and replacing the parts multiple times, one of the square pegs failed, shown in Figure 6.5.2.1B. While these test prints used PLA, which is weaker than PETG, low infill percentage, and low wall count, this failure steered the team in a different direction.

Figure 6.5.2.1B: Second Cosmetic Barrel Prototype Failure

After this, the team decided to focus on a new design with special attention to the ease with which the cosmetic barrel could be assembled. Just prior to this, the team's project advisor recommended using heat set inserts in other 3D printed parts on the launcher instead of nuts, as it makes it significantly easier to assemble. With these, the threads are secured into the plastic, so there is no need to place a nut on the end of the screws. With this in mind, the team designed a new cosmetic barrel that utilized heat set inserts to secure the different sections, which are the small holes shown in Figure 6.5.2.1C. A trapezoid shaped feature was extruded from one side and cut into the other, making it so the sections are lined up when inserting the screws and giving the user only one way to assemble the sections.

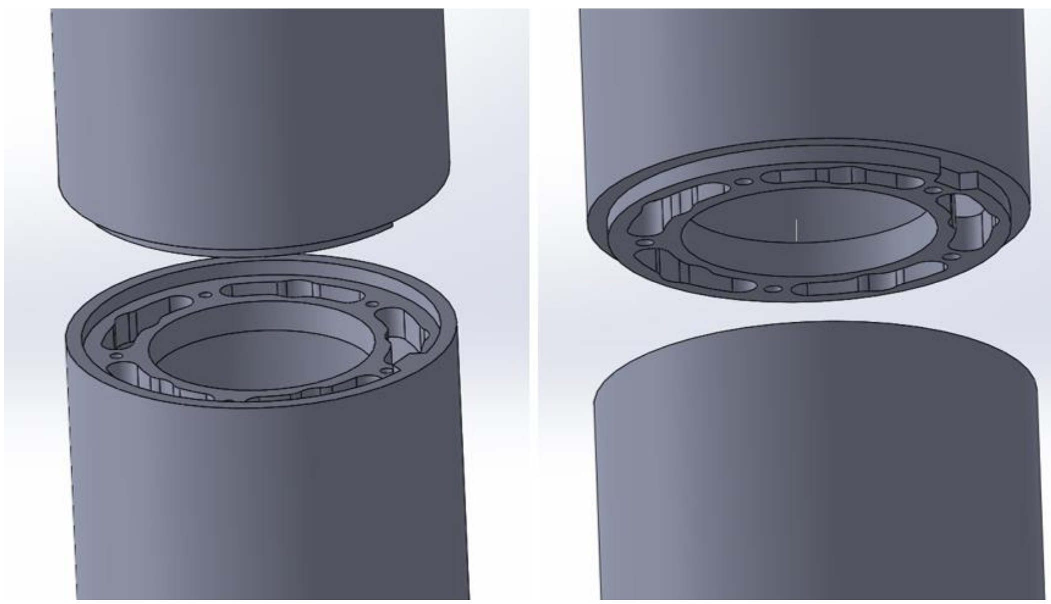


Figure 6.5.2.1C: Final Cosmetic Barrel Model

The main issue with this regarded how someone would get a tool through the cosmetic barrel section, which the largest is approximately 7 inches, to secure the screws. To fix this, the slots that were originally intended for wires and weight reduction had an additional hole placed in them that lines up with the corresponding heat set inserts. The holes were made large enough for a long 1/2 inch drive ratchet extension or just a long screwdriver, giving the user multiple tool options for assembly. The tool the team used to assemble the cosmetic barrel was a 1/4 inch drive ratchet with multiple extensions with a Phillips head screwdriver bit on the end.

The final cosmetic barrel is shown in Figure 6.5.2.1D. The barrel was printed from orange PETG, as planned, and is secured with just screws and no glue. This will allow future disassembly of the cosmetic barrel and make repairs easier if it ever breaks. The final touch added to the cosmetic barrel is the name of the launcher, “Gemini 28-80”. This decal, and all others on the launcher, was printed with UV and weather resistant vinyl, ensuring it is long lasting.

Figure 6.5.2.1D: Final Cosmetic Barrel

6.5.2.2 SRB Iteration and Implementation

The SRBs did not undergo significant design iterations, but the implementation of them did pose issues. Building from the original SRB concept shown in Figure 6.5.1, the team determined to use foam core PVC as the main body of the SRBs. This provides more strength than 3D printed materials, while being much smoother and easier to manufacture. Attached to both ends of the foam core PVC would be 3D printed end caps, shown in Figure 6.5.2.2A. These end caps were to be 3D printed from PETG, again for its high strength and UV resistance. The final piece of the SRBs was UCF branding on each side. The UCF side of the launcher would have “Knights” written down the side, and the Space-U side of the launcher would have “Space-U” written down the side. Additionally, a section was to be cut out of the SRBs to allow the user to store extra T-shirts in them between launches.

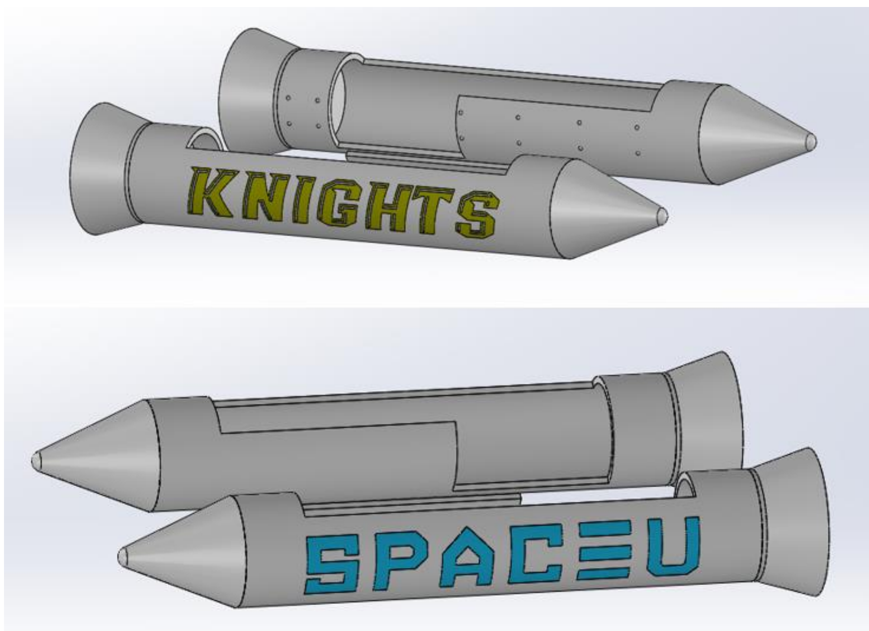


Figure 6.5.2.2A: Final SRB Model

To connect the SRBs to the tank, the team determined it would be best to use a rail system. The female side of the rail would be attached to the accumulator tank using heavy duty foam tape, and the male side of the rail would be attached to the SRBs using screws, shown in Figure 6.5.2.2B. The calculations performed to ensure the foam tape would support the SRBs is available in Milestone V, Section 3.5.2.1.

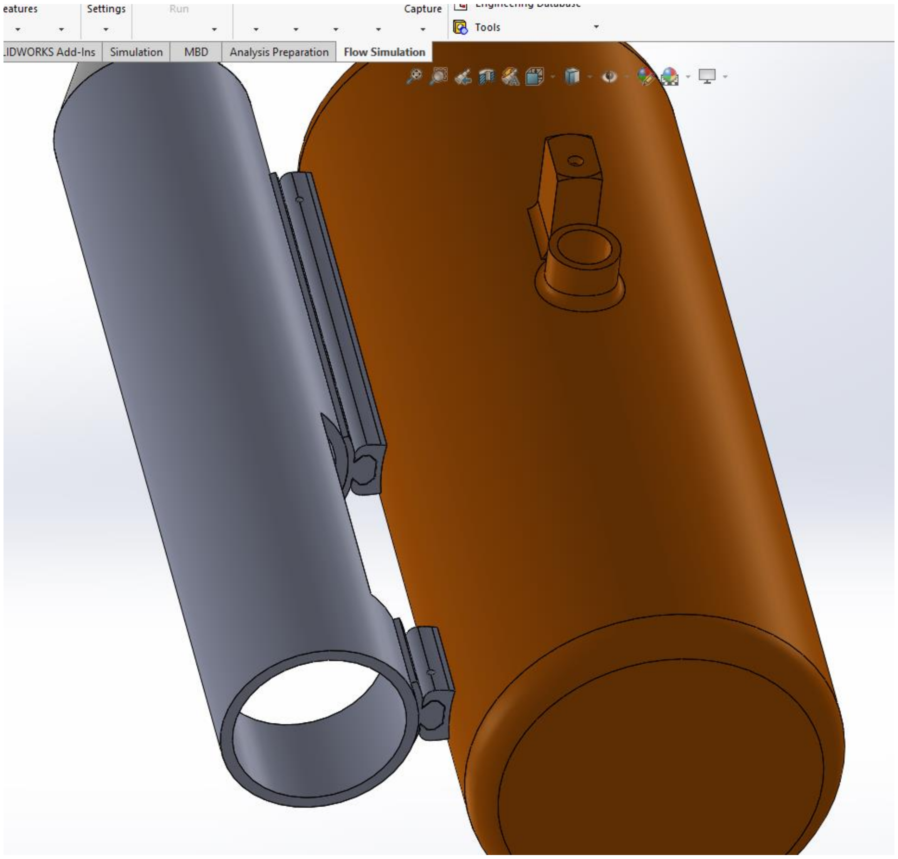


Figure 6.5.2.2B: Model of SRB Rails

The rails were effective, however there were issues with the mounting of the rails on the SRBs and the SRBs themselves. First, the channels cut out of the SRBs caused them to cave in towards the unsupported section, making the outside surface inconsistent. This caused the upper SRB rail to start pulling away from the tank, shown in Figure 6.5.2.2C. The force of the PVC pulling away from the tank was enough to pull the rail system off the tape over the course of a few days.

Figure 6.5.2.2C: Warped SRB Issue

Furthermore, the two sections of the rails on the SRBs were not lined up properly. When placing the rails on the SRBs to mark the location to drill the holes, the rails were placed with respect to the cutout in the PVC, which was both warped inward and not cut perfectly straight. This caused the rails to be out of line with each other, resulting in the lower rail barely contacting the accumulator tank, as shown in Figure 6.5.2.2D.

Figure 6.5.2.2D: Misaligned SRB Rail Issue

Both of these issues were more prevalent on the Space-U side of the launcher. The UCF side was slightly warped, but was able to be pulled into place ensuring no further issues. For the Space-U side, a variety of approaches were taken to ensure the team had options as the situation developed. When removing the original SRB, the foam tape damaged the existing rails, causing them to need to be reprinted. After reprinting these rails, the team continued to 3D print various random parts of the rail system to ensure whatever needed components were available at a moment's notice, and if not used, they could be given to UCF as spare parts. At the same time, the team started manufacturing a new Space-U SRB in the event the original one could not be fixed.

After cutting the slot in the new SRB, it was observed that the same issue occurred, the PVC warped and the outside was no longer straight. To fix this on the new SRB, the team used a heat gun to heat the outside of the PVC. Once heated, a spacer made out of a piece of 3 inch PVC was placed inside the SRB to push it outward, shown in Figure 6.5.2.2E. It was then allowed to cool for multiple hours and the spacer was removed.

Figure 6.5.2.2E: Warped SRB Solution

This method proved to be effective on the new SRB, so it was attempted on the existing Space-U SRB. The team was hesitant to try this on the existing Space-U SRB, as the heat could bubble or yellow the paint on the surface. However, since the new SRB proved to be a good fit, the team went ahead and heated the original SRB since a backup was already being manufactured. The heat did help some, but the PVC ended up gradually re-warping, reducing the effects of the heat. This is likely since the original SRB sat for a long time before being installed or heated, so it would be more difficult to deform it into the desired shape. Due to this, the team decided to focus its efforts on constructing the new SRB, which involved printing new end caps for the SRB, sanding, priming, and painting the surfaces.

While this solved the major problem, there was still the issue of the holes being aligned on the SRB. When aligning the rails to mark the hole locations, no reference to the SRB was used. Instead, a level was used to ensure the rails were square with the ground and collinear with each other. As a final adjustment, the lower SRB rails were slightly modified to have slotted holes instead of circular ones, as shown in Figure 6.5.2.2F. This allows the lower rail to be adjusted for alignment prior to taping the rails onto the accumulator tank.

Figure 6.5.2.2F: Rail with Slotted Holes

Using the methods mentioned, the Space-U rail had near perfect alignment and the warping issue was reduced to a manageable gap between the rails and accumulator tank. After the troubleshooting, the Space-U SRB actually ended up having a better fit with the accumulator tank than the UCF SRB. The final method used to ensure the SRBs stay secured to the tank was adding a second layer of foam tape to the upper, larger section of the SRBs. This gives slightly more thickness, allowing the tape to form to the contours of the PVC and tank, giving more contact surface area. The new fit of the Space-U SRB that exhibited the issues is shown in Figure 6.5.2.2G.

Figure 6.5.2.2G: New Fit of SRBs

The final SRBs are shown below in Figure 6.5.2.2H. The decals were cut from outdoor grade vinyl that is UV resistant and rated to last up to 6 years outside. As the launcher will not live outside for its entire life, these decals will last as long as the launcher is taken care of.

Figure 6.5.2.2H: Final SRBs

6.5.2.3 Handle Iteration and Implementation

The rear handle was not originally identified in the conceptual stage. Instead, a foregrip was to be included on the launcher. Due to the weight and ergonomics of the launcher, the team determined it was best to utilize the upper handle that was on the accumulator tank. Due to the weight of the launcher, it would be difficult to support it if both of the user's hands were placed underneath it, especially when it comes to stability.

The rear handle was designed to add an additional piece of UCF branding to the launcher. The team had the idea to make one side of the launcher all UCF themed and the other side of the launcher Space-U themed. Due to this, one side of the rear handle has a UCF logo and the other side has the Citronaut logo. The initial design for the rear handle was modeled and printed to be tested for comfort for the user, shown in Figure 6.5.2.3A.

Figure 6.5.2.3A: First Rear Handle Prototype

While the team was pleased with the logos and overall look of the handle, it was much too large to comfortably hold. It was near impossible for any team member to keep their hand wrapped around the bottom part of the handle and reach their index finger up to press the trigger. Due to this, the team modeled another handle, shown in Figure 6.5.2.3B, which was slimmer and featured a more upright posture, so the user does not have to reach their fingers as far to pull the trigger. The handle had to be printed with the logos parallel to the build plate on the 3D printer, creating significant layer lines. A combination of Bondo and primer was used to smooth it out, along with significant sanding before painting the handle black and the logos white.

Figure 6.5.2.3B: Final Rear Handle

6.6 Storage System Development

The storage system serves the purpose of providing a safe, water resistant, way to store the launcher when it is not in use or in transportation. There are various requirements for a storage system if one is in place, such as total weight, IP rating, and size, but a storage system is not specifically required.

6.6.1 Storage System Initial Concept

The initial concept for the storage system contained four main choices: plastic bins, a custom wood crate, a custom metal crate, or a fabric bag. Any of the options would be capable of storing the launcher, but during the conceptual stage, the team made a decision to move forward with one in particular.

Plastic bins served as the obvious option, as they are cheap and readily available from a variety of vendors. One bin in particular, from Home Depot, was identified as a possible candidate, as it boasts an IP-67 rating, exceeding the required value, and has a capacity of 110 lbs, exceeding the maximum weight of the storage system by over 50 lbs [13]. The main downside of the plastic bins is their size. Using one of these, the launcher would have to be partially disassembled to be placed in storage, adding to the setup and breakdown time of the launcher.

The next options considered were custom wood or metal containers that the team would build. These containers could be made watertight depending on the manufacturing method and could be custom built to the exact size of the launcher, making the most efficient use of space. However, these would end up being very heavy, reducing the weight of items that could be placed inside of them while still meeting key requirements. Additionally, these would take up resources such as time and money, which would be better spent working on the actual launcher itself.

The final option considered was a fabric bag, which is what commercial options such as the Bleacher Reacher use [9]. These bags are lightweight and inexpensive. These also do not require much time to configure, allowing the team to focus on the launcher itself. However, the fabric bags identified early on had low weight capacities, making them not suitable for this application.

At this point, plastic bins were identified as the optimal option for storage. They offered sufficient weight capacity, water resistance, size, and price to meet all storage system requirements. The only downside is that the launcher would have to be partially disassembled when in storage. The summarized decision is shown below in Figure 6.6.1, where the ranking criteria is available in Appendix F.

		Storage Alternatives			
		Plastic Bins		Wood Crate (Custom)	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Weight	15%	4	0.60	1	0.15
Cost	30%	3	0.90	1	0.30
Environment Sensitivity	35%	4	1.40	3	1.05
Carrying Capacity	20%	4	0.80	4	0.80
Totals	100%		3.70		2.30

		Storage Alternatives, *Continued*			
		Metal Container (Custom)		Fabric Bag	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Weight	15%	4	0.60	4	0.60
Cost	30%	1	0.30	4	1.20
Environment Sensitivity	35%	4	1.40	1	0.35
Carrying Capacity	20%	4	0.80	1	0.20
Totals	100%		3.10		2.35

Figure 6.6.1: Storage System Pugh Matrix

6.6.2 Storage System Iteration and Implementation

The storage system went through an overall change prior to finalizing the design of the system. The team originally planned on using plastic bins due to their low cast, water resistance, and capacity. The major downside of this type of storage device is that the launcher would have to be disassembled and possibly placed in multiple bins for storage instead of being in a single bin. This added complexity reduces the likelihood that the storage system would actually be used and the launcher would just be left sitting out.

When working on creating a bill of materials at the beginning of Senior Design II, a team identified a potential storage solution that had not been considered, a Christmas tree storage bag. These bags are lightweight, have a high weight capacity, are waterproof, dustproof, and inexpensive. The team considered this compared to the plastic storage bins and determined the Christmas tree storage bag offered a better solution. The purchased bag is only slightly larger than the launcher, ensuring a near perfect fit. Memory foam was added to the storage bag to pad the launcher, helping keep it in place and to protect against drops. Additional cutouts were made for the Arduino and pneumatic hose, so all components of the launcher are stored in the bag aside from the air source. This significantly helps reduce the setup time. The final storage system is shown in Figure 6.6.2.

Figure 6.6.2: Final Storage System

7.0 Design Analysis

The preliminary analysis of the design began with numerous simulations, mathematical models, and a prototype. As mentioned in Milestone III: Concept Design Review, Section 6.0, to gain a better idea of how certain parameters affect launching a T-shirt, we constructed a testing device to test the T-shirt packaging, the effect of different pressures, and the effect of the length of the barrel. The tests were performed using general fittings from a hardware store connected to the exit of a VEVOR Tire Bead Seater [36], shown in Figure 7.0.

Figure 7.0: Testing Device

The tire bead seater is usually used to seat a tire onto the wheel of a car by suddenly releasing a large blast of air, causing the tire to pop onto the wheel. The bead seater utilizes a 2.1-gallon steel tank and a pneumatic trigger connected to a modified exhaust valve. The quick-acting trigger and valve allow a substantial amount of air to exit in a very short amount of time, making it ideal for launching T-shirts. The testing device utilized a 3-inch barrel, as it was determined this size created the best seal around the T-shirt and has the added benefit of being readily available from any hardware store.

Creating this prototype allowed for further testing and analysis of individual components of the system, such as the barrel length, T-shirt delivery method, and optimal pressure. Originally detailed in Milestone III: Concept Design Review, Section 6.0 and further explored in Milestone V, Section 3.2, each subsystem has gone through rigorous analysis and testing.

7.1 Barrel Analysis

As described in Section 6.2, originally the reloading system of the launcher contained a barrel that would split to allow for the projectile to be loaded, however after some consideration this design proved to be risky and dangerous for spectators. Outlined in sections 7.1.1 through 7.1.5 the use of a stationary, solid barrel established itself with analysis and mathematical calculations.

Thorough investigations and analyses were done to determine the diameter, length, material, and adhesive compound used on the final product.

<u>7.1.1 Barrel Diameter</u>

Optimizing the barrel diameter played a critical role in maximizing the force applied to the T-shirt from the compressed gas. Through competitor research, most commercial launchers use a 3 to 3.5-inch barrel since the force is proportional to the pressure and the cross-sectional area. However, through mathematical calculations and technical evaluation, the larger the diameter of the barrel the volume also becomes larger and causes a pressure drop along the length of the barrel.

To find the optimal barrel diameter, we must calculate the change in pressure along the length of the barrel as the T-shirt travels down it. From the ideal gas equation, the product of the pressure, *P*, and volume, *V*, should be equal at any two points in a sealed system. This is shown in Equation 7.1.1A.

$$P_1 V_1 = P_2 V_2 \tag{7.1.1A}$$

In this equation, the initial pressure and volume are known and will be assumed to be 80 PSI and 2.1 gallons, respectively. The new volume, V_2, can easily be calculated using Equation 7.1.1B, where *d* is the diameter of the barrel, and *L* is the T-shirt's instantaneous location in the barrel.

$$V_2 = V_1 + \frac{\pi}{4} d^2 L \tag{7.1.1B}$$

This equation can be solved for various diameters along the length of the barrel. Once the volume is found at an instantaneous position, the pressure can be found at that same moment, which is P_2

in Equation 7.1.1A. Using this pressure and the cross sectional area, the force applied to the T-shirt at the corresponding moment can be found. Repeating this for a 2.5, 3, and 3.5-inch barrel yields the results shown in Figure 7.1.1.

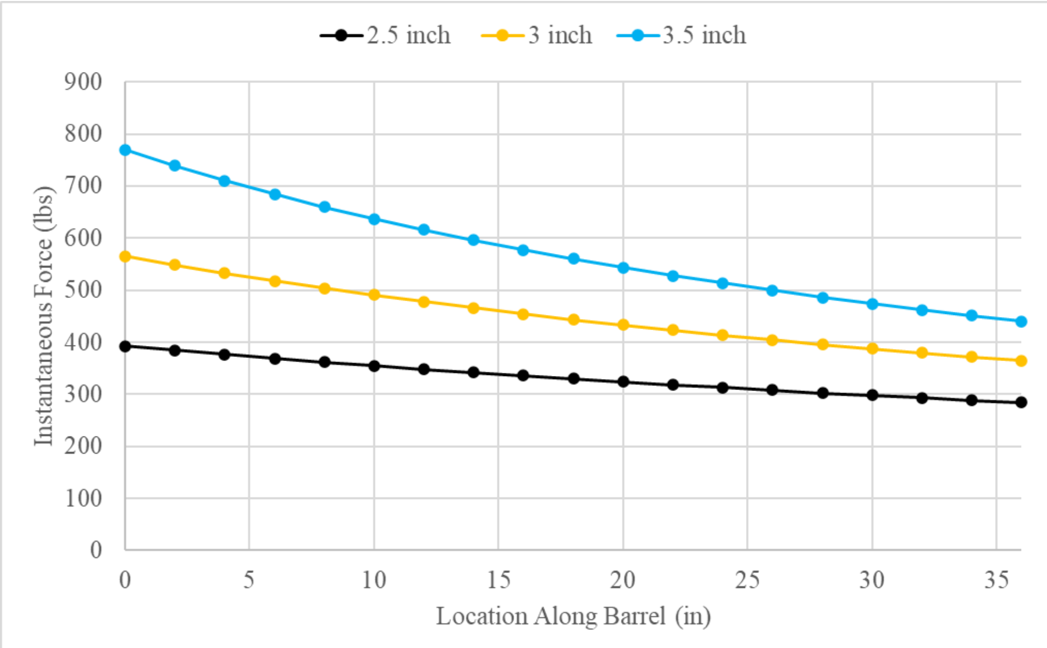


Figure 7.1.1: Instantaneous Force with Certain Barrel Diameters

From Figure 7.1.1, it is observed that for a barrel of length 3 feet or less, the larger the diameter, the larger the force applied to the T-shirt at any instant. Since the force lines on the plot never cross, there is no need to further integrate to find the total amount of work done on the T-shirt. If the lines did cross, it would be necessary to determine which barrel diameter results in the most work done to the shirt, and this crossing may happen at an unreasonable barrel length. While this calculation neglects air loss around the T-shirt, the air loss can be minimized by the packaging method and will be relatively similar regardless of the barrel size. Discussed in section 7.2 the T-shirt packaging method also plays a role in the efficiency of power used per each shot.

With this in mind and the availability of COTS components, the team decided to use a 3 inch barrel. During testing, the team was able to roll T-shirts to an appropriate diameter to slide down a 3 inch barrel, while not allowing an excessive amount of air to escape around the T-shirt. Furthermore, pipe diameters over 3 inches are uncommon and expensive, whereas a 3 inch pipe can be purchased from any hardware store relatively quickly.

7.1.2 Barrel Length

The barrel length was identified to be a key parameter in how far the T-shirt is launched. If the T-shirt created a perfect seal with the barrel, it would theoretically continue to accelerate until the pressure behind the T-shirt reached atmospheric pressure, so there are equal forces acting on both sides of the T-shirt. This theory was tested by launching T-shirts with the prototype launcher and slowly reducing the barrel length. Our experimentation supported the idea that a longer barrel will result in a longer launch distance. With the calculations, experiments, and analysis described in the next sections, the team decided to use an 18 inch barrel. This allows plenty of space for the T-shirt to accelerate and reach the required exit velocity and distance, while being short enough for the launcher to maintain its ergonomics and reduce weight.

7.1.2.1 Barrel Length Calculations

Using the exit velocity calculations in Section 7.1.2.1, the effect on barrel length can be further analyzed at 80 PSI, the optimal pressure. Equation 7.1.2.1A can be used to solve for the time of flight t, in terms of the launch angle, θ, gravity, g, and the initial velocity, V_0. Then, the time of flight can be substituted into Equation 6.4.1B to find the total distance traveled.

$$t = \frac{2V_0 sin\theta}{g} \quad (7.1.2.1A)$$

$$x = V_0 tcos\theta \quad (7.1.2.1B)$$

Approximating the initial launch angle of the experiments to be 10°, the results from the two equations are summarized in Table 7.1.2.1.

Table 7.1.2.1: Theoretical Launch Distance at 80 PSI for Different Barrel Lengths

Length (ft)	**Exit Velocity (MPH)**	**Distance (ft)**
1	145	483
2	183	769
3	205	963

Neglecting the large magnitude of these values, it can still be observed that at higher pressures, decreasing the length of the barrel will also decrease the distance the T-shirt travels. This is because as long as the pressure behind the T-shirt is greater than the atmospheric pressure and the friction force, the T-shirt will continue to accelerate. This means that in our final design, we can make the barrel as long as possible while still maintaining weight and ergonomic considerations. The seemingly large values for distance traveled will be discussed in the following section.

7.1.2.2 Barrel Length Experiments

During experimentation, the barrel length was adjusted after finding the optimal pressure of 80 PSI. To do this, we used a miter saw to cut the barrel down, 1 foot at a time, giving us tests at 1, 2, and 3 feet. The testing device with a 1-foot barrel is shown in Figure 7.1.2.2.

Figure 7.1.2.2: Test Device with 1-Foot Barrel

From this test, the distances at an approximate 10° launch angle and 80 PSI are summarized in Table 7.1.2.2.

Table 7.1.2.2: Experimental Launch Distance at 80 PSI for Different Barrel Lengths

Length (ft)	**Distance (ft)**
1	200
2	223
3	235

While these values come up far short of the theoretical values in the previous section, they still all satisfy the launch distance, and thus the exit velocity requirement. Reasons for the large discrepancies in the theoretical launch distance compared to the experimental include wind resistance, the T-shirt tumbling through the air, incorrect friction factor, or pressure loss around the T-shirt, plus multiple others.

7.1.2.3 Barrel Length Analysis

For modeling the effect of the length of the barrel, some assumptions can be made. First, a 2D cross-section with a height of 3 inches will be used for simplicity. Furthermore, the inlet pressure will be set to 120 PSI. In the actual system, there will not be a constant force of 120 PSI applied at the inlet. Instead, there is a set volume of air that is released toward the T-shirt. This analysis will show how quickly the flow develops in the barrel and how the wall affects the flow of the air. The density and viscosity of air were assumed to be at sea level. The results are shown in Figure 7.1.2.3.

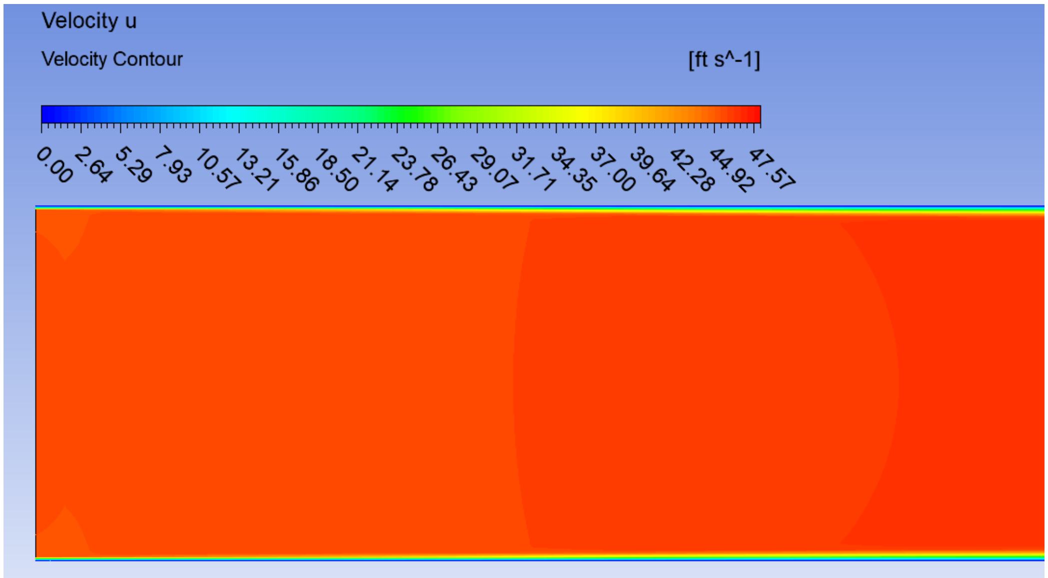


Figure 7.1.2.3: Velocity of Air in Barrel Using CFD

From the figure, it can be seen that the developing region is relatively small, becoming fully developed around 4 inches into the barrel. Furthermore, the no-slip condition on the top and bottom walls does not extend far down into the barrel. This indicates that the force will be acting on almost the whole area of the T-shirt, increasing the launching distance.

From the calculations, experiments, and analysis, the team determined to use a 18 inch barrel. This is long enough to exceed key distance and exit velocity requirements, while still being relatively short, allowing the launcher to be lighter and more maneuverable.

7.1.3 Barrel Materials Options

In determining the construction material of the barrel, numerous mathematical calculations were computed, along with simulations and analyses to determine the stress and strain in a given material. Other factors such as weight and adhesion methods were considered and tested, originally explained in Milestone III Section 6.6, and further analyzed in Milestone V Section 4.0 with a pressure test.

While the barrel is not intended to act as a pressure vessel, it will be subject to some amount of pressure while the T-shirt is still in the barrel, as it will seal in the pressure behind it. Additionally, if a T-shirt or other projectile ever became stuck, the barrel would then act as a pressure vessel. Due to this, it is important to investigate different materials for the barrel to determine what options are available to safely withstand the pressure behind the T-shirt.

Based on the calculations and analysis performed, the team determined to use pressure rated Schedule 40 PVC pipe. This provides a sufficient factor of safety to keep the user safe, is inexpensive, and lighter than the alternatives.

7.1.3.1 Barrel Materials Calculations

In a worst-case scenario, the T-shirt would create a perfect seal with the barrel and become stuck, pressurizing the barrel to slightly below the pressure of the pressure vessel, depending on where the T-shirt became stuck. To capture this, it will be assumed that the barrel is pressurized to 120 PSI, the maximum rated pressure of the pressure vessel used for testing. Using Equation 7.1.3.1, the hoop stress, σ_H, is said to be a function of pressure, *P*, the mean diameter of the vessel, *D*, and the thickness of the walls of the vessel, *t*. The hoop stress is used instead of the axial stress, as it is generally stated to be twice that of the axial stress.

$$\sigma_H = \frac{PD}{2t} \tag{7.1.3.1}$$

For each of the potential barrel materials, their geometry will differ based on what is commercially available. These parameters are listed in Table 7.1.3.1A.

Table 7.1.3.1A: Barrel Material Properties

Material	Yield Stress (PSI)	ID (in)	OD (in)
6061 T6 Aluminum	35,000	3.26	3.5
AISI 1020 Low Carbon Steel	47,900	2.76	3
Schedule 40 PVC	7,450	3	3.5
ABS	4,293	3	3.5

Using these material properties, the hoop stress can be found, as shown in Table 7.1.3.1B. This also shows the factor of safety for every material, which is found by dividing the yield stress by the hoop stress.

Table 7.1.3.1B: Barrel Factor of Safety

Material	Hoop Stress (PSI)	F.O.S
6061 T6 Aluminum	1,690	20.71
AISI 1020 Low Carbon Steel	1,440	33.26
Schedule 40 PVC	780	9.55
ABS	780	5.50

From these results, we can see that theoretically, each material meets the minimum safety requirement of 3.5, which is defined in our requirements and by ASME Section VIII [11].

7.1.3.2 Barrel Materials Analysis

To ensure the safe operation of the device and determine the most feasible material for the barrel, the team decided to create a simple preliminary CAD design for testing within the SolidWorks simulation add-in. After conducting theoretical calculations for 6061 T6 Aluminum, AISI 1020 Low Carbon Steel, Rigid PVC, and ABS, it was time to perform simulation testing within SolidWorks to validate our findings. To accomplish this, a rough drawing of the barrel was created with a 3-inch inner diameter, 0.25-inch wall thickness, and a 1.5-inch inlet diameter with a 135-degree expansion from inlet to outlet, shown in Figure 7.1.3.2A.

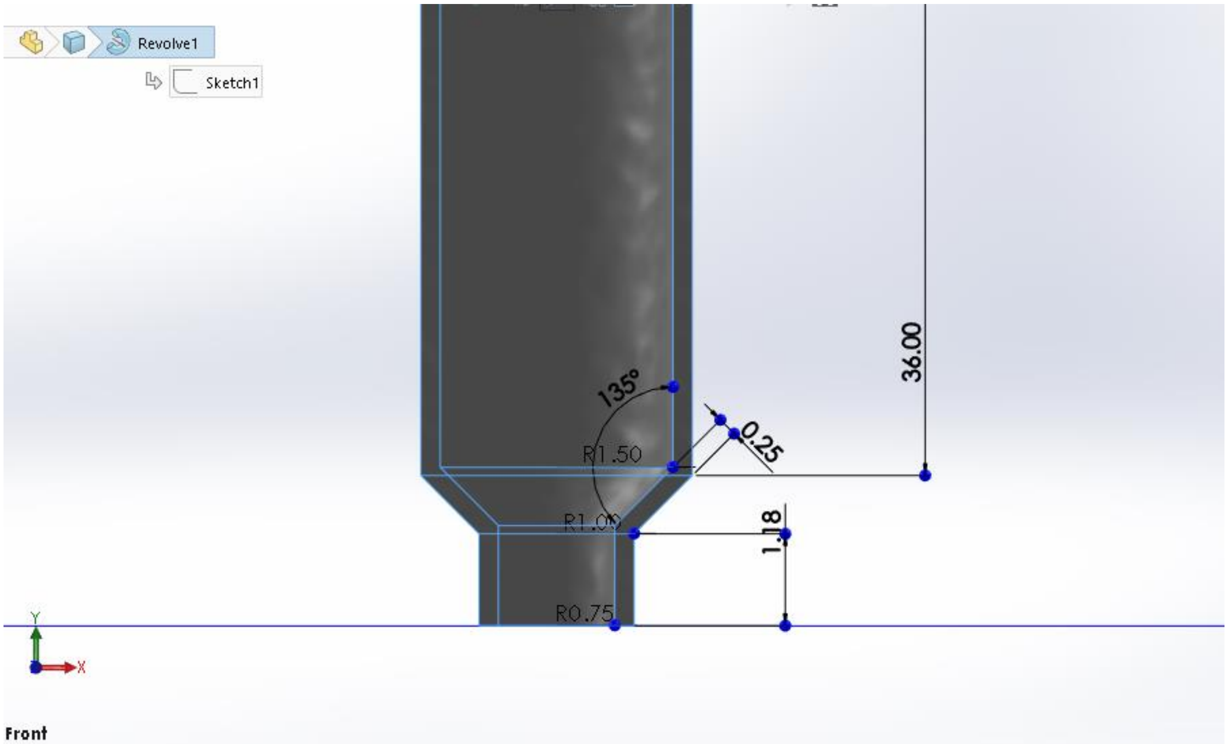


Figure 7.1.3.2A: Initial Barrel Dimensions using Revolve Feature

After creating the initial barrel model, it was time to utilize SolidWorks' simulation feature to test theoretical pressures and stresses on the interior of the barrel, simulating a pressure vessel release. According to the purchase listing of our pressure vessel, it clearly states that it is rated for a maximum of 120 PSI. Additionally, the pressure vessel incorporates a pressure release valve that activates at 120 PSI, making it the maximum pressure that can be tested in a worst-case scenario. Theoretical calculations have been conducted to determine the maximum shear force exerted on the inner wall, which is 565.49 lbs, as shown in Table 7.1.3.2A. These calculations follow the same method for determining the optimal barrel diameter size, outlined in Section 7.1.1.

Table 7.1.3.2A: Theoretical Max Force Applied Along 3" Barrel

Initial Pressure (PSI)	Location Along Barrel (in)	Force at Location (lb)

120	0	565
120	4	533
120	8	504
120	12	478
120	16	454
120	20	433

From Table 7.1.3.2A, it can be seen that the maximum force occurs at the very beginning of the barrel (closest to the pressure vessel), as expected, and sharply diminishes, caused by pressure loss as the forces reach equilibrium near the end of the barrel. While the maximum force of 565.49 lbs is only present at the beginning of the barrel, we will still test 565 lbs of force throughout the whole barrel for safety. This setup is shown in Figure 7.1.3.2B.

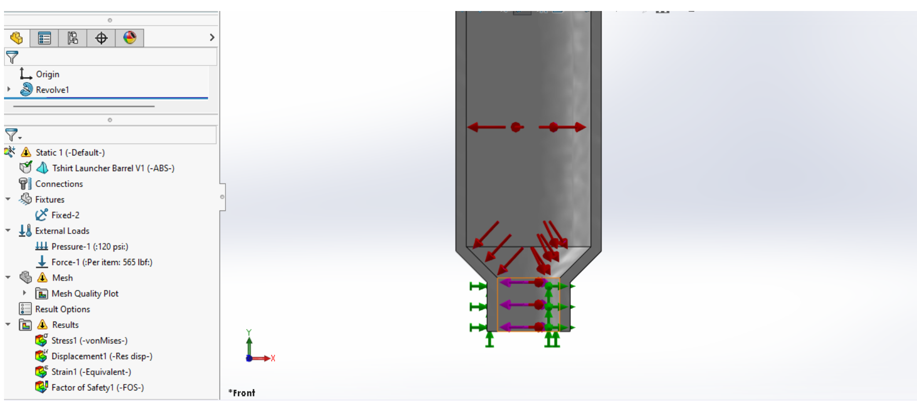


Figure 7.1.3.2B: Barrel Stress FOS Simulation Setup

After setting up the simulation, the only step left to do was to change the material and run the simulation, resulting in factors of safety and stress values that were essential for our project. The stress analysis results using 6061-T6 aluminum are shown in Figure 7.1.3.2C.

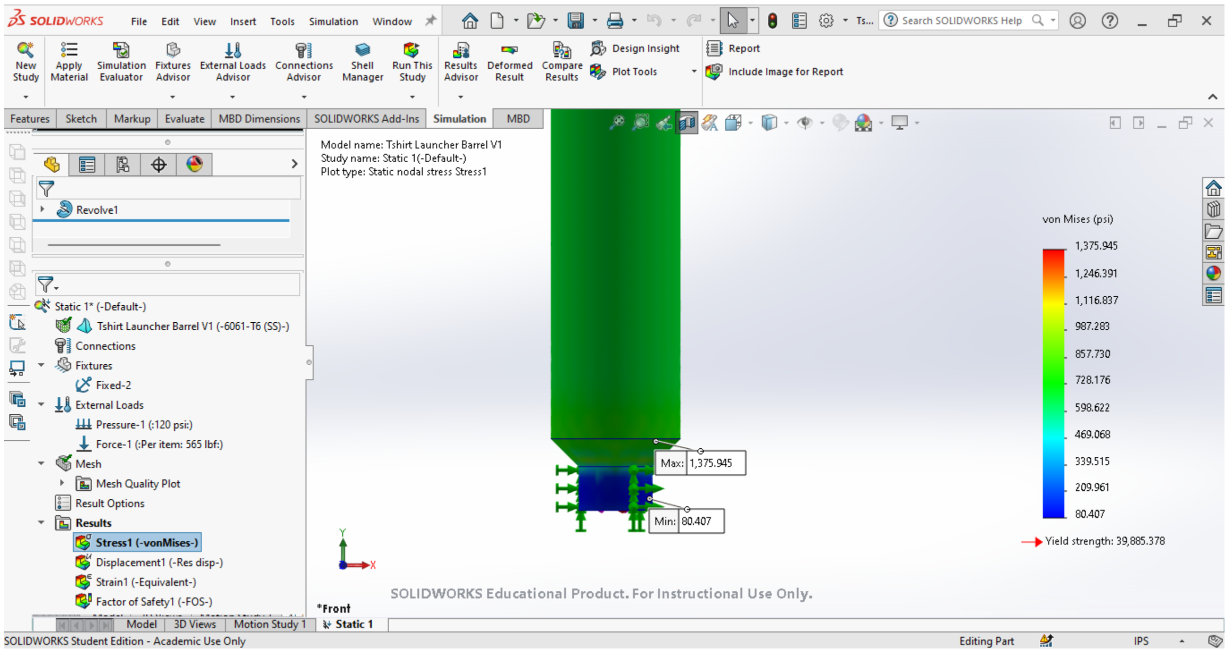


Figure 7.1.3.2C: Barrel Stress Results using 6061-T6 Aluminum

Changing the material to steel, PVC, and ABS, the minimum stress, maximum stress, minimum FOS, and maximum FOS can be found. This is summarized in Table 7.1.3.2B.

Table 7.1.3.2B: FOS for Different Barrel Materials

Material	**Min Stress (PSI)**	**Max Stress (PSI)**	**Min FOS**	**Max FOS**
6061-T6 Aluminum	80.41	1375.95	28.99	496.04
AISI 1020 Steel	92.60	1405.93	36.27	550.90
PVC, Rigid	62.10	1333.01	4.90	105.10
ABS	57.70	1322.89	4.39	100.50

As evidenced by the results, all materials performed admirably during testing, boasting a minimum factor of safety of 4.39. When selecting materials for a project of this nature, a multitude of factors must be considered, including weight, cost, strength, ductility, ease of manufacturing, among others.

Upon careful review of the findings, it's apparent that both 6061-T6 Aluminum and AISI 1020 Steel exhibit excessive strength and weight for our intended application. With a factor of safety exceeding 20 and their cost and weight significantly higher than that of their competitors, their necessity for this particular project is not warranted.

Comparatively, PVC and ABS yielded strikingly similar results in testing, particularly in stress and strength characteristics. Due to the greater availability of PVC and PVC fittings, it was chosen as the material for the barrel.

7.1.3.3 Pressure Testing Cement on Barrel

The final test to ensure the safety of the system involves rapidly pressurizing and depressurizing a piece of test PVC barrel that is enclosed, in order to test the strength of the PVC cement under cyclic loading. This test is intended to test what the PVC cement will experience over time as T-shirts are launched, which are short bursts of high-pressure air. The full testing procedures are described in Milestone V Section 4.2 and in Appendix G.

The results of the pressure test proved that the cement is capable of withstanding at least 144 PSI which is a 20% increase over the rating for the pressure release valve on the accumulator tank. The pressure test resulted in no failures and verified the use of the cement will withstand the specifications described in the design requirements. The test setup is shown below in Figure 7.1.3.3.

Figure 7.1.3.3: PVC Cement Test Setup

7.1.4 Barrel FEA and Factor of Safety

In order to ensure the barrel meets the design requirements, finite element analysis was done on the barrel to measure the factor of safety. Along with the FEA analysis, a high-pressure test of the cement glue used was performed to ensure every part of the barrel system holds up to the 3.5 factor of safety design requirement. The original FEA analysis of the barrel structure can be found in Milestone V Section 3.2.1.1, and the pressure test on the cement glue is under Section Milestone V Section 4.2..

Given that the reloading system will be stationary and fixed to the launcher, a thorough FEA analysis is required to ensure safety and minimize the risks. Using the same model in Figure

7.1.4A, the barrel was analyzed while under maximum pressure conditions. The worst-case scenario is 120 PSI, which is the maximum pressure the reloading system would endure. In this analysis, the reloading mechanism, the barrel, is subject to the highest possible pressure, and the material is set to be rigid PVC. Neglecting the small hole near the 3-inch reducer, the maximum stress observed over the part is 2,065 PSI, shown in Figure 7.1.4A. The result is a factor of safety of roughly 3.57.

This analysis all depends on the material used in the simulation, however using a material with lower yield strength in the simulation will ensure the material used on the model can withstand such pressures. Now accounting for the small hole at the base of the system, shown in Figure 7.1.4B, the maximum stress is observed to be 2,173 psi, a slight increase from scenario one. The stress increase around this pressure relief hole decreases the factor of safety to about 3.54. Despite the reduction, this value is still within acceptable limits for the project since the material that will be used has a much higher yield strength and will be PVC-rated for pressure.

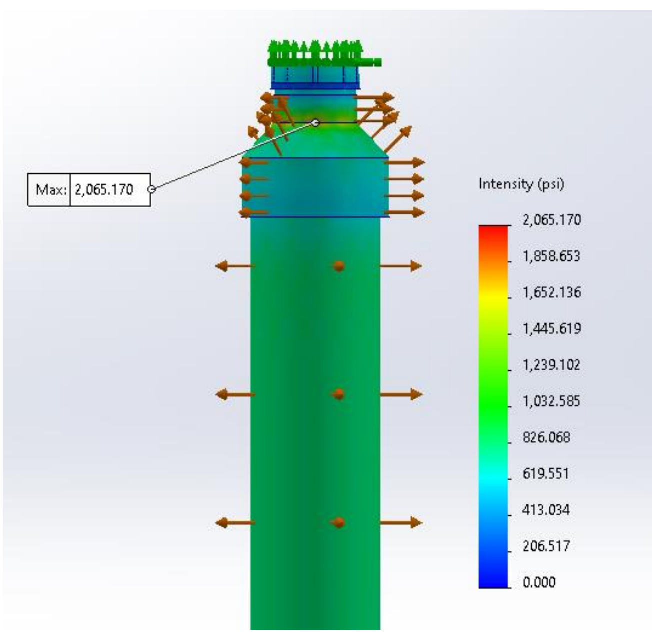


Figure 7.1.4A: Maximum Stress at 120 PSI

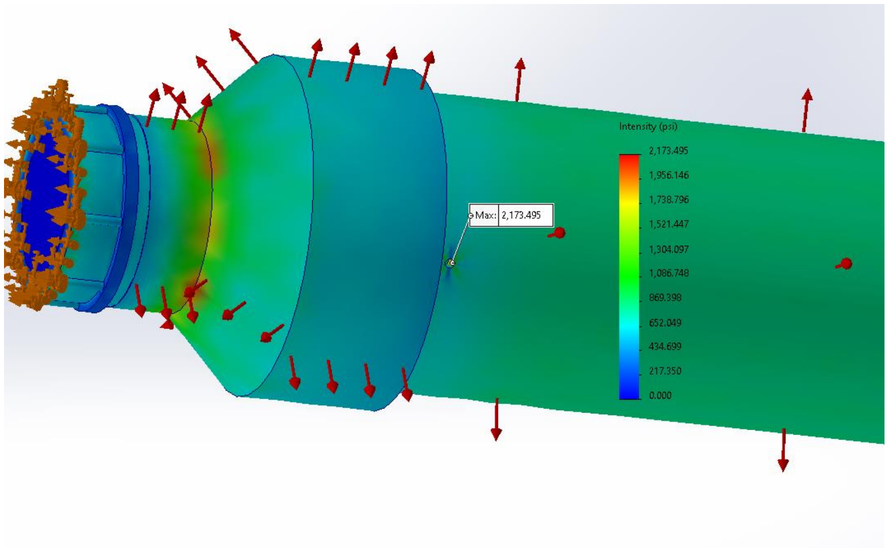


Figure 7.1.4B: Maximum stress around the reloading airflow hole at 120 PSI

The FEA analysis of the barrel confirms the structural integrity of the barrel/reloading system, under the conditions that the material strength is greater than the one used in the simulation. This analysis confirms that material selection is a huge decision impacting the safety and performance of the system as a whole. The pressure-rated PVC that will be used for the actual model is rated for 260 PSI which is more than twice the highest operating condition effectively giving 2 times the factor of safety from the manufacturer specification.

<u>7.1.5 CFD of Barrel</u>

To determine if the nozzle on the reloading system is efficient enough to provide maximum force to the T-shirt, CFD can be used as an approximation. In this situation, CFD is limited by the effect of the T-shirt creating back pressure and air losses around the T-shirt. To perform this simulation, the reloading system geometry was loaded into SolidWorks Flow Simulation. The boundary conditions include a pressure inlet at 120 PSI and a pressure outlet at 0 PSI at their respective ends.

When performing this simulation, and adding vectors to represent the flow of air, it can be seen in Figure 7.1.5 that as the air exits the 1.5-inch section of the barrel, the flow quickly expands in the nozzle to reach the full 3-inch diameter of the barrel. Furthermore, the flow appears to "bounce" off the walls of the barrel just after the T-shirt's resting location, and shortly thereafter becomes fully developed. Since the airflow acts on the entire surface area of the T-shirt for the entire length of the barrel, it can be said that the nozzle design is sufficient to provide the maximum amount of force to the T-shirt.

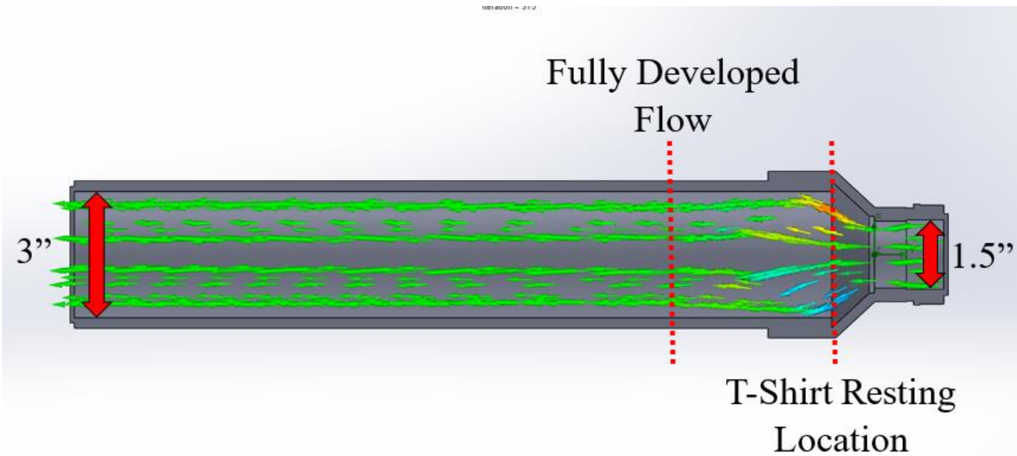


Figure 7.1.5: Velocity Vectors of Barrel

7.2 T-Shirt Packaging

Multiple packaging methods were considered for the project. While the end user can utilize any packaging method they want, it is important for us to determine the best packaging method, as well as be able to present the advantages and disadvantages of the other packaging methods to any potential end users. This was done by testing each method using the prototype launcher.

7.2.1 T-Shirt Packaging Experiments

Before testing the maximum distance of the testing device, we first set out to find out which delivery method allowed the T-shirt to travel the longest distance. Six different packing methods were tested, performing three trials for each method to determine the average distance traveled. These tests were performed at 40 PSI, as testing every launch at full power would take additional time and create unnecessary noise.

First, the T-shirt was rolled up and placed into the barrel with no special folding or packaging. With this method, the T-shirt quickly became unwrapped during flight, only reaching an average distance of 67 feet. While this is not very far, it does create a safer landing since the unwrapping of the T-shirt slows it down so that it lands softer. Next, two different methods of tucking the T-shirt into itself with no additional components were tested, called Method A and Method B, shown in Figure 7.2.1A.

Figure 7.2.1A: T-Shirt Folded Into Itself (Method B)

These two methods were similar, but utilized a different number of rolls, creating different lengths and diameters. Method A was found to have an average distance of 97 feet, while Method B only reached an average distance of 90 feet, as shown in Table 7.2.1A. These T-shirts still had a relatively soft landing, as the area where the shirt was tucked into itself was able to catch the wind and act as a parachute, slowing the shirt down.

Table 7.2.1A: T-Shirt Folded Into Itself, Method A vs Method B

Trail	Method A (ft)	Method B (ft)
1	94.5	68
2	95.5	107
3	100	96
Average	97	90

The next tested method is that recommended by the Bleacher Reacher series of launchers [10]. In this method, the T-shirt is folded in half, the sleeves are tucked in, then folded in half again, and finally rolled from the top down and secured with two rubber bands. This method creates an excellent seal on the barrel, minimizing air loss around the T-shirt. Additionally, the rubber bands hold the shirt together better than in previous methods, preventing it from acting like a parachute. Using this method, the average T-shirt distance was 197 feet, over double that of the T-shirts that were folded into themselves and satisfying Requirements F1.2 and F1.3.

As an extension of the rubber band method, the same folding procedure was used, but the T-shirt was then secured using painting tape, shown in Figure 7.2.1B. This method offers the same benefit as the rubber band method, where the T-shirt creates a good seal with the barrel, but offers less friction than the rubber band method. The rubber bands may bind on the barrel as the T-shirt travels down it, while the tape will slide along the barrel. Using this method, the average distance improved to 222 feet at 40 PSI.

Figure 7.2.1B: T-Shirt Secured with Painter's Tape

The final method tested involved wrapping the T-shirt in plastic wrap prior to launching. It was originally thought that the plastic wrap would both hold the T-shirt together and create a more aerodynamic surface. However, after only one test, this method had to be eliminated. The plastic wrap fell off the T-shirt during flight due to the high velocity, defeating the purpose of the added aerodynamics. More importantly, when launching using plastic wrap, the launcher created a very loud popping sound that could be confused for something such as a firearm. Due to this, testing was stopped on this method and it was eliminated.

Overall, the tape method offered the best range for the test launcher. This is due to its seal made with the barrel and the lack of friction between the tape and the barrel. Rubber bands offer a sufficient alternative if tape is not available, and if the end-user wants to slow down the T-shirts, they can fold them into themselves to create more drag. The results of the test are summarized in Table 7.2.1B.

Table 7.2.1B: Results of Testing Packaging Method

Trail	**No Packaging (ft)**	**Folded - Method A (ft)**	**Rubber Bands (ft)**	**Tape (ft)**	**Plastic Wrap (ft)**
1	58	64.5	200	220	138
2	70	95.5	210	240	N/A
3	73	100	180	205	N/A
Average	67	97	197	222	N/A

7.2 Accumulator Tank Analysis

Analyzing the results of the pressure vessel model on SolidWorks reveals nearly the same results as the theoretical calculations in section 7.2.2. The computer software is more robust and able to model different materials and initial conditions with ease. The geometry of the bead blaster is the same geometry modeled in SolidWorks. Following the same principle of using the absolute worst low-strength steel to test the strength of the designed tank. To simulate the force of the pressure on the tank, a model was created using steel alloy and tested at 120 PSI. The simulation shows more accurate results of the calculated estimation. In Figure 7.2A it can be observed that the stress on the pressurized tank is exerting a majority of force towards the back end of the tank. Modeled here is the most extreme case possible i.e, the weakest material and the highest pressure. Similar to how the calculations were done, using a low yield strength and a high pressure to test the worst-case scenario, the simulation was run with the same intention. The Steel alloy used in the simulation had a similar yield strength of roughly 26,000 PSI.

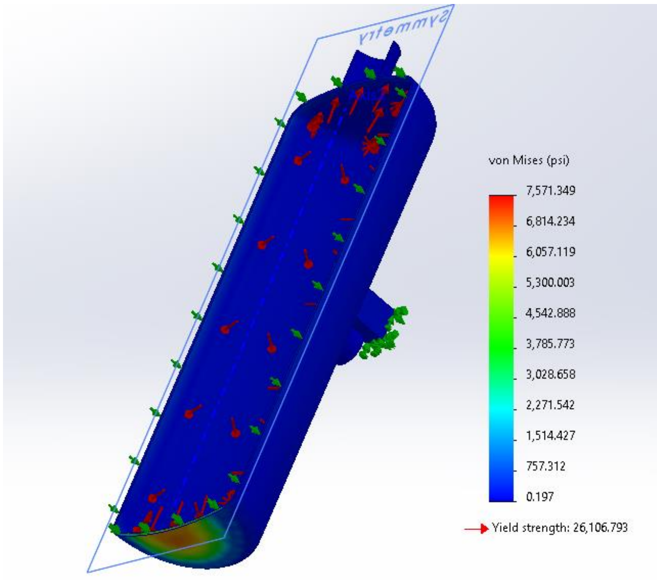


Figure 7.2A: Von Mises Stress Simulation at 120 PSI

More importantly, when modeling the pressurized vessel the desired outcome is the stress and strain capabilities of the object. As shown in Figure 7.2B the Hoop stress shows how much pressure the vessel will be able to withstand. In this simulation, the maximum hoop stress is a positive number because the material is in tension. When the number is negative, at the minimum, the material is in compression.

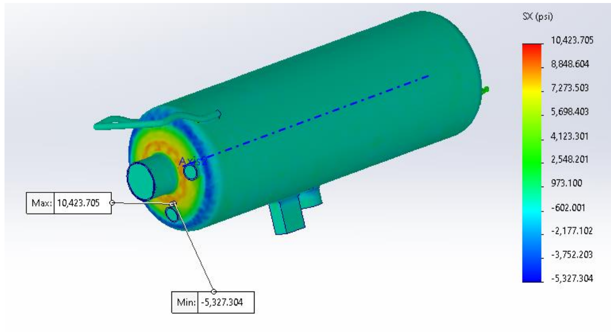


Figure 7.2B Hoop Stress at 120 PSI

Obtained from the analysis on the pressure tank the factor of safety was 5.395 (Figure 7.2C) at the critical state i.e. 120 PSI and a weak material steel alloy to visualize the worst-case scenario. The desired outcome of this analysis was to verify the integrity of the tank and authenticate that the tank meets the criteria set forth in the design requirements document. Since the results of the pressurized tank analysis reveal a high Factor of Safety, the system meets the safety standards in the safety requirement S9.1 “Any energy storage devices, excluding batteries, shall adhere to a minimum safety factor of 3.5.” In theory, this Tank shall adhere to the requirements set forth in the design requirement definition document M2.

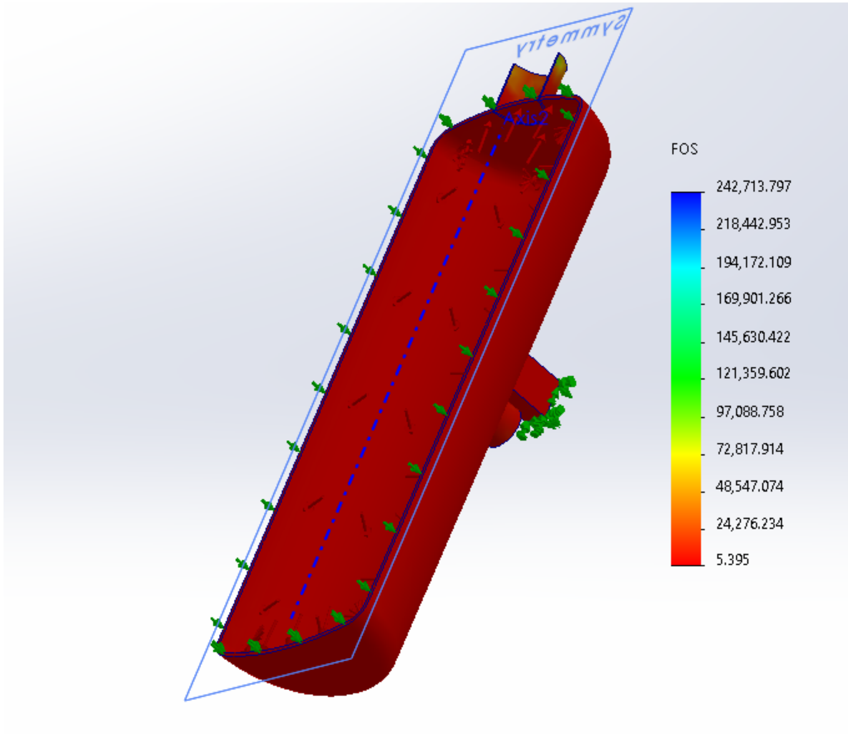


Figure 7.2C: Factor of Safety of Steel Alloy Tank at 120 PSI

Note that the analysis performed in this section was used to inform the initial design decision in Milestone III. Further FEA was performed on the accumulator tank with refined geometry, which is described in section 7.2.4.

7.2.1 Accumulator Materials Options

Similarly to the barrel material, the material of the pressure vessel is an important consideration. Unlike the barrel, the pressure vessels used are intended to hold pressurized air for prolonged periods of time, making them more susceptible to long-term failure. It is expected that commercial pressure vessels abide by ASME and DOT standards as previously stated, but it is still important to analyze the geometry and materials of commercial vessels to ensure their safety. Additionally, in case commercial vessels are not used, it is important to have a baseline for the safety of materials used for custom-built vessels.

7.2.2 Pressure Vessel Materials Calculations

Using the hoop stress method from Section 7.1.3.1, geometry obtained from the website the tire bead blaster was purchased from, and the maximum rated pressure of 120 PSI, the hoop stress of the bead blaster can be found to be 3,082 PSI. The listing only mentions that the vessel is made out of steel [36], so assuming that the international manufacturer that is not bound by US manufacturing laws took every cost-saving measure possible and used the absolute worst grade of low carbon steel, the yield stress can be approximated as 22,000 PSI [34]. In reality, it is likely much higher than this, but it is better to assume the lowest yield strength in this scenario for safety. Using this value, the factor of safety for the hoop stress is 7.14, which is still above the ASME Section VIII required value of 3.5. For this tank, it is likely that the fittings, such as pressure gauges or pressure relief valves, would fail first, depressurizing the tank well before the material or welds could ever fail.

7.2.3 Optimal Pressure

After determining the barrel diameter and optimal packaging, the optimal pressure must be found. This is the pressure at which the distance and velocity requirements are met. It was initially believed that the distance would increase as pressure increases, but it was determined that if the pressure is too high, the launch distance will start to reduce.

7.2.3.1 Optimal Pressure Calculations

Theoretically, the T-shirt will continue to accelerate if the pressure behind it pushing forward is greater than the atmospheric pressure. Using the same method to calculate the pressure at a point along the barrel as described in Section 7.1.1, extending the calculation to longer barrel lengths yields interesting theoretical results. Assuming the T-shirt creates a perfect seal with the barrel, at a vessel pressure of 80 PSI, a 25-foot-long barrel would still be over 100 PSI at its exit. This is due to the relatively small volume of the barrel compared to the pressure vessel. Similarly, at a vessel pressure of 20 PSI, at a point 9.8 feet from the beginning of the barrel, there would still be 50 PSI of back pressure pushing the T-shirt forward. These calculations, while interesting, are not incredibly useful, as the real system will experience air loss and friction, both of which are difficult to quantify.

7.2.3.2 Optimal Pressure Experiments

After determining that using tape resulted in the longest launching distances, we turned our attention to finding the optimal launching pressure for the test launcher. To do this, we packaged the T-shirt using the tape method and increased the pressure from 20 PSI to 100 PSI in increments of 20. We originally intended on reaching 120 PSI, which is the maximum rated pressure of the tank, but the pressure relief valve opened at 105 PSI, eliminating this possibility. From this test, it was found that a pressure of 80 PSI resulted in the longest launching distance, shown in Figure 7.2.3.2.

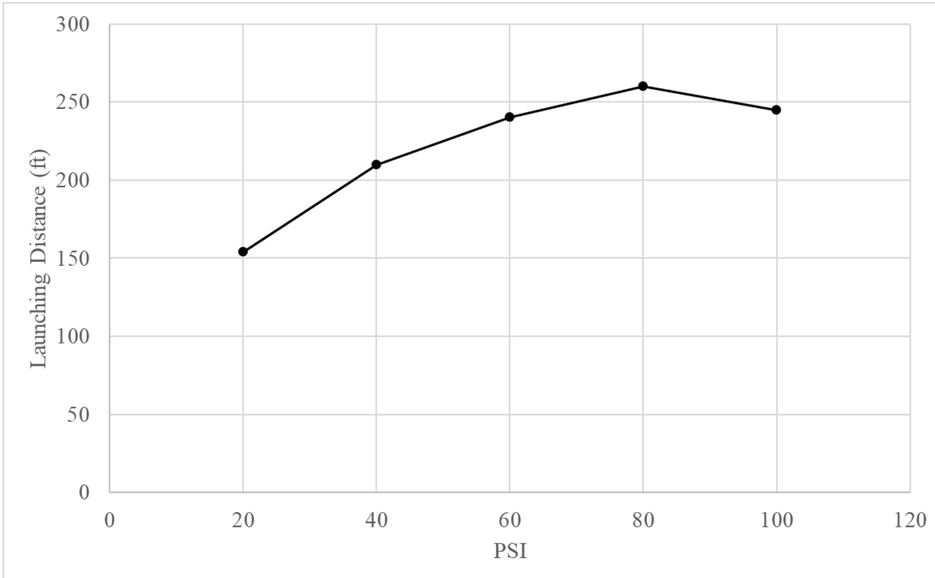


Figure 7.2.3.2: Launching Distance vs Pressure

It came as a surprise that the distance decreased from 80 to 100 PSI. There are two likely reasons for this. First, at pressures as high as 100 PSI, the tape packaging became damaged, allowing the T-shirt to slightly open during flight and create drag. Additionally, as the pressure increased, the T-shirt tended to tumble through the air instead of "floating" like a football would. This also increases the drag, affecting the launching distance. From this test, pressures as low as 40 PSI are capable of reaching the required distance, allowing the team to scale back some features of the propulsion system in order to increase the safety of the system.

This experiment takes additional factors into account that cannot be easily quantified for calculations. These include air loss around the T-shirt, friction, and damage to the T-shirt packaging at high pressures. While the theoretical understanding should not be completely ignored, it is best to base a decision such as this based on future testing once the system is more clearly defined.

7.2.4 Accumulator FEA and Factor of Safety

After the conceptual design stage, the geometry of the accumulator tank was refined based on measurements and manufacturer specifications. The analysis performed in this section reflects the values with the updated geometry. The most basic analysis of any pressure vessel involves calculating the hoop stress and comparing the value to the yield stress of the material. This was performed in a previous report, however the accumulator tank geometry has been slightly updated. The hoop stress is given in Equation 7.1.3.1.

For this case, the pressure is 120 PSI, and the manufacturer states the diameter is 6.7 inches with a wall thickness of 0.12 inches. Using these values, the hoop stress can be calculated to be 3,350 PSI. Comparing this to a conservative yield strength for steel of approximately 47,900 PSI [17], an initial factor of safety can be found to be 14.3. This calculation only takes the longitudinal walls of the vessel into account, therefore it is necessary to perform further analysis on the tank.

To determine the factor of safety of the accumulator tank, FEA must be performed at its maximum rated pressure, 120 PSI. This is also the pressure that the pressure relief valve opens at on the tank, ensuring the tank does not exceed this pressure. Since the accumulator tank is not rigidly fixed to anything, for the purposes of the simulation, additional solid bodies must be added to the model for the accumulator tank to rest on. These bodies are bonded to the accumulator tank using the connections feature in SolidWorks. This provides support to the accumulator tank, while still allowing the accumulator tank to be analyzed by itself after running the simulation. If the simulation used points on the accumulator tank itself as the fixed points, the simulation results will be inaccurate. The geometry used for the simulation is shown in Figure 7.2.4A.

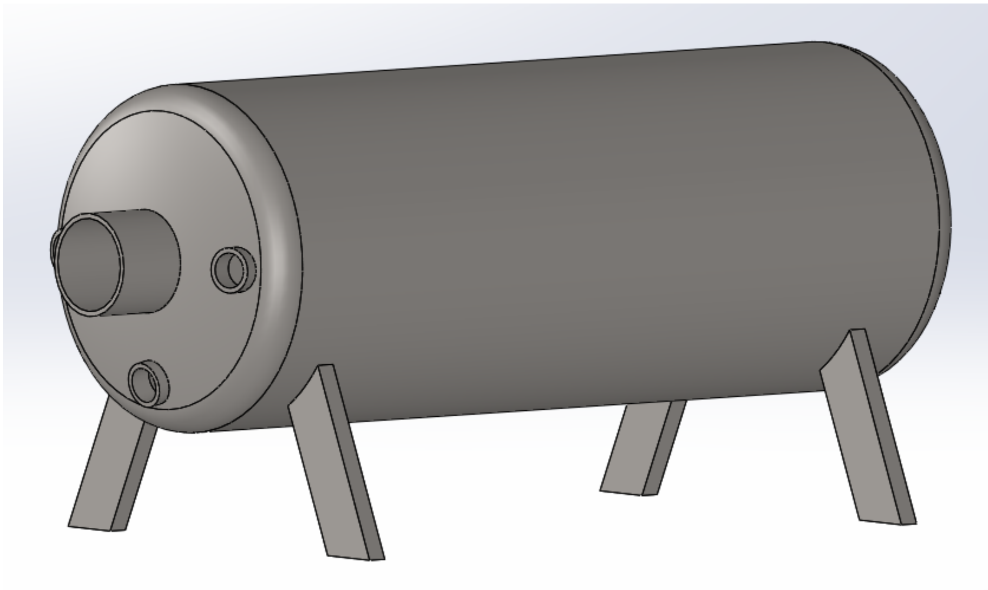


Figure 7.2.4A: Geometry for FEA of Accumulator

The setup of the simulation is shown in Figure 7.2.4B. In this figure, the fixed points are represented by the green arrows, which are the base of the four legs. Furthermore, the load is set to 120 PSI on all internal surfaces, representing a worst-case scenario that the accumulator tank might see. Finally, the legs are bonded to the accumulator tank using the component interactions feature. Using this method, the legs can be excluded from the final results.

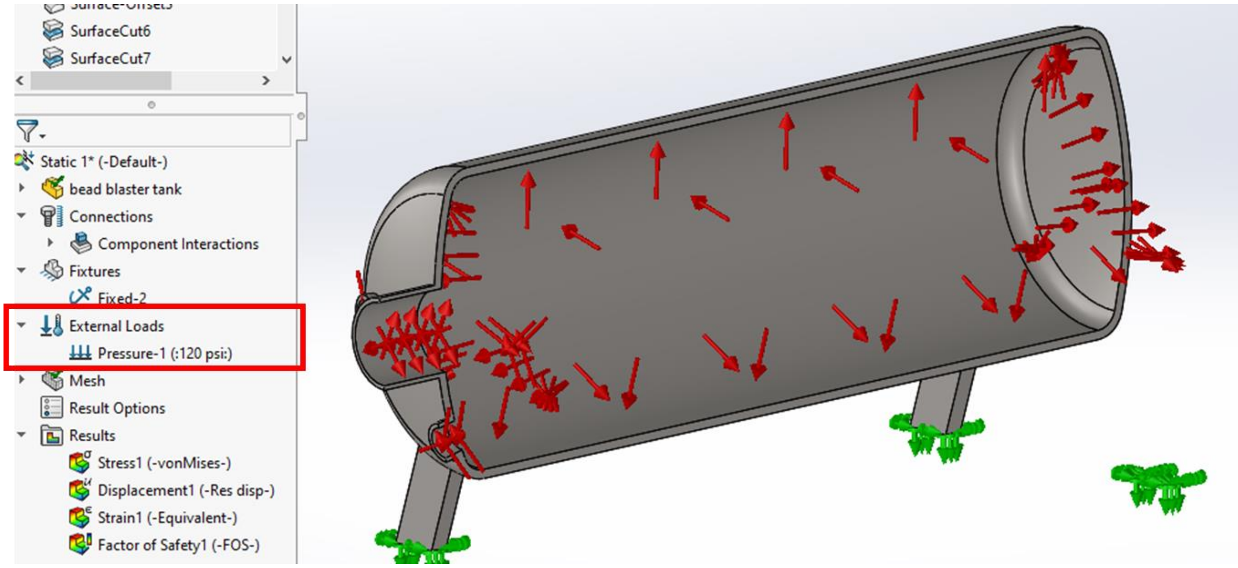


Figure 7.2.4B: FEA Simulation Setup for Accumulator

Using the described settings, the factor of safety is shown in Figure 7.2.4C. The minimum factor of safety of the tank is 3.96 and is located on the curvature at the rear of the tank. This factor of safety both satisfies Requirement S9.1 and general engineering standards, such as ASME Section VIII [11]. Furthermore, this simulation was performed using a low-carbon steel available on SolidWorks. The manufacturer only states that the tank is made out of steel, so the low-carbon steel on SolidWorks offers a conservative approach. In this case, when dealing with compressed air, it is better to be cautious when analyzing the safety of the tank. Additionally, the tank is powder coated, which could potentially further harden the steel from its initial state, also leading to an increase in strength.

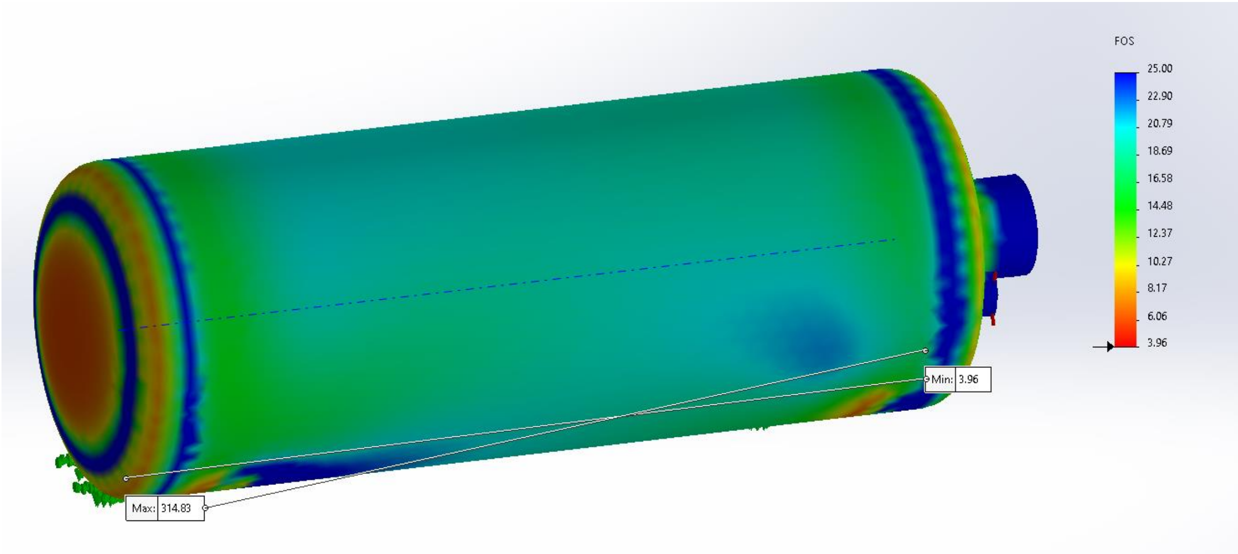


Figure 7.2.4C: Factor of Safety of Accumulator

This simulation verifies that the accumulator is safe when filled to 120 PSI, but in reality, the tank will not be kept at a constant 120 PSI. Instead, the tank will be filled and almost immediately discharged to launch T-shirts. Due to this, it is necessary to evaluate how fatigue will impact the accumulator tank. Using the same setup that was utilized for the FEA, a fatigue simulation can be performed in SolidWorks. Using a zero-based loading type, where the load varies from 0 to 120 PSI, and one million cycles, which is the maximum allowed in SolidWorks, it can be seen from Figure 7.2.4D that failure due to fatigue is not a likely occurrence for the accumulator tank. During the simulation, an error message occurred that the alternating stresses for the entire model were below the values of the ASME S-N Curve for the material, indicating infinite life from fatigue failure. Even if this is not the case, the entire tank is estimated to have a life of at least one million cycles from the simulation. It is highly unlikely that the launcher will be used this much over its lifespan. While impressive, this simulation does have some assumptions. This assumes that the tank is in perfect condition, with no scratches, chips, or corrosion.

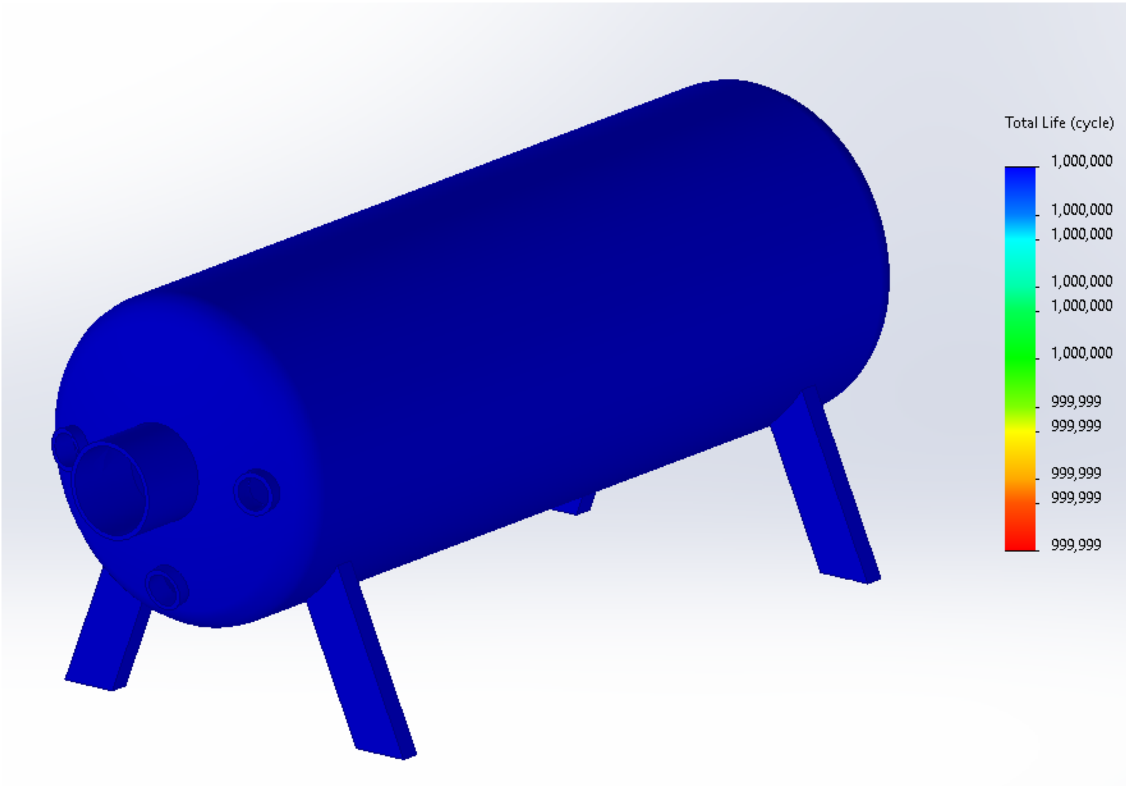


Figure 7.2.4D: Total Life of Accumulator Tank at 120 PSI

This finding raises the question of what pressure will lead to a fatigue failure of the accumulator tank. Starting from 150 PSI and increasing the load in 50 PSI increments, it was found that at 400 PSI, the internal walls will suffer a fatigue failure at approximately 450,000 cycles, as shown in Figure 7.2.4E. As one would expect, the failure takes place in the curvature of the rear walls, which is the same location as the minimum factor of safety. While the accumulator tank will never reach these pressures, it is a useful exercise to see how much buffer there is between the operating pressure of the accumulator tank and its failure pressure, from both a static and cyclic perspective.

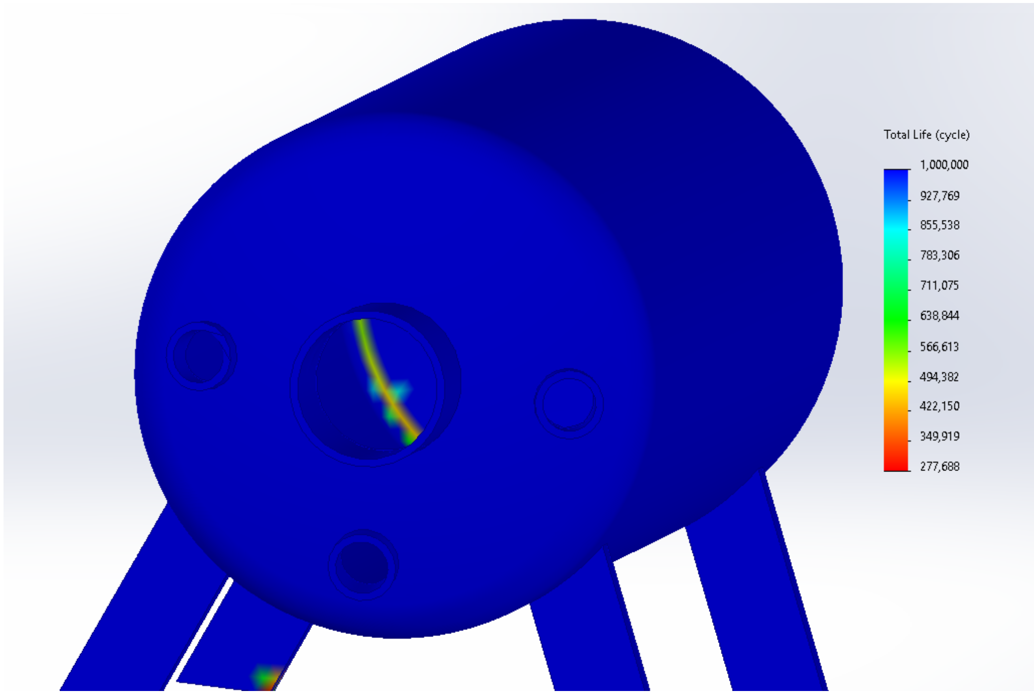


Figure 7.2.4E: Total Life of Accumulator Tank at 400 PSI

7.3 Scuba Tank Safety Analysis and DOT Regulations

Unlike the accumulator tank, the wall thickness and internal dimensions of the scuba tank are unknown, so FEA cannot accurately be performed on the scuba tank. These values, such as the wall thickness, could be estimated, but when dealing with a high pressure system such as this, such liberties should not be taken when doing calculations.

Pressure vessels that are used to transport pressurized fluids on roads, planes, or boats are legally required to be DOT approved. These vessels do not necessarily have to be high pressure, but when companies are transporting pressurized fluids, it is to their benefit to do this at a high pressure to make the most use out of their space and transportation equipment. The scuba tank purchased for this project is made of 6061 Aluminum, a common choice for scuba tanks. 6061 Aluminum pressure vessels that are used to transport compressed fluids are subject to DOT Regulation 49 CFR 178.46, Specification for 3AL Seamless Aluminum Cylinders [26], which is outlined in Section 3.3.2

While these requirements are very thorough to ensure the safety of the device, they come up short of Requirement S9.1, requiring a factor of safety of 3.5 for energy storage devices. This requirement was derived from ASME Section VIII, which generally requires a minimum factor of safety of 3.5 for pressure vessels [11]. In practice, a 2.5 factor of safety is more than sufficient for the scuba tank, as scuba tanks very rarely fail, and if they do fail it is in a controlled environment during hydro testing. In 2016, the University of Hawaii published a paper on a specific failure mode of scuba tanks, sustained load cracking. Prior to 1990, some scuba tanks were made out of 6351 Aluminum alloy, which was found to be subject to cracking under sustained loading. After this was found, manufacturers switched to 6061 Aluminum. Up to the time the report was written, it was estimated that 25.4 million scuba tanks were manufactured using 6351 Aluminum, and of those only 17 in the entire world were documented to have failed due to sustained load cracking. Since then, a particular manufacturer, Luxfer, has produced 19 million scuba tanks with no documented sustained load cracking [16]. These statistics show how modern scuba tanks are very well built with few failures.

Additionally, the magnitudes of the pressure values must be kept in mind. For example, it would be relatively easy to overfill a small vessel designed for 10 PSI to 35 PSI, assuming a 3.5 factor of safety. However, it would take a gross act of negligence or significant human failure to overfill a 3,000 PSI scuba tank with a 2.5 factor of safety to 7,500 PSI, as it takes a long amount of time to fill a scuba tank and most compressors would not even be capable of reaching 7,500 PSI. While this is all true, the magnitude of the effect must also be taken into account. A small pressure vessel bursting a 35 PSI is dangerous, but any humans nearby would likely walk away unharmed. A 7,500 PSI scuba tank bursting would absolutely cause a loss of human life if it was not done in a controlled environment.

Keeping these factors in mind, the user manual for the T-shirt launcher will state to fill the scuba tank to 2,140 PSI, which allows for a 3.5 factor of safety from the minimum DOT required burst pressure. This conservative filling value will satisfy Requirement S9.1 and ensure the safety of the user.

7.3.1 Scuba Tank Expected System Performance

After the safety of the propulsion system, the air capacity is the second most important factor, as this will determine how many T-shirts can be launched without the need to refill the storage source. To analyze this, the volume of air that is stored inside the scuba tank can be compared to the volume of air that is stored in the accumulator tank. The scuba tank purchased is 30 CF, which refers to the amount of air at atmospheric pressure that is inside of the tank when it is at its service pressure, 3,000 PSI. Since this scuba tank will only be filled to 2,140 PSI, it is necessary to determine how much air is inside the tank. The ideal gas law, shown in Equation 7.3.1A, where P is the pressure in PSI, V is the volume in cubic feet, n is the number of moles of the gas, R is the universal gas constant, and T is the temperature in Rankine, is known to be constant.

$$PV = nRT \tag{7.3.1A}$$

Since the pressure multiplied by the volume is constant, the volume of the scuba cylinder can be found using Equation 7.3.1B, where the subscript 1 denotes the atmospheric conditions and the subscript 2 denotes the conditions inside the scuba tank.

$$P_1V_1 = P_2V_2 \tag{7.3.1B}$$

Atmospheric pressure is known to be 14.7 PSI, and the amount of atmospheric air in the scuba tank is 30 CF, making the left side of the equation known. On the right side, the pressure of the tank is known to be 3,000 PSI. Solving for the volume of the tank results in a value of 0.147 CF. Now assuming that the tank is only filled to 2,140 PSI, the pressure multiplied by the volume of the tank, 0.147 CF, can be found to be constant. Dividing this value by the atmospheric pressure of air, 14.7 PSI, the amount of atmospheric air in the scuba tank can be found to be 21.4 CF, or about 71% of the tank's rated capacity.

To know how many launches this will support, the amount of air compressed in the accumulator tank must be calculated. The purchased accumulator tank is 2.1 gallons, or 0.281 CF. Unlike the scuba tank, this value refers to the volume of the tank itself, not the volume of the air inside of it at atmospheric pressure. Assuming an average launching pressure of 40 PSI, the pressure multiplied by the volume of the tank is found to be constant. Dividing this value by atmospheric pressure, 14.7 PSI, yields a result of 0.764 CF. This is the amount of atmospheric air in the accumulator tank when it is at 40 PSI. Dividing the amount of air in the scuba tank at 2,140 PSI, 21.4 CF, by the amount of air in the accumulator tank at 40 PSI, 0.764 CF, results in 28 launches before the scuba tank runs out of air.

7.4 Compressor Analysis

The first method used to refill the accumulator tank involves the use of a small air compressor provided by UCF Senior Design. The specific air compressor is a Dewalt 6 Gallon, 165 PSI Pancake Compressor, shown in Figure 7.4. The primary purpose of the compressor is for use during testing, as it allows the launcher to be tested anywhere with electricity. Certain UCF sporting venues also have access to electricity, allowing the compressor to be used during games to refill the accumulator tank. The main advantage of the compressor is that it delivers a theoretically unlimited amount of air to refill the tank, as long as electricity is available. This is also its greatest drawback, as the user will not always have easy access to electricity.

Figure 7.4: Dewalt Pancake Compressor [4]

7.4.1 Compressor Expected Performance

Using the same method from the previous section, the number of launches from the compressor can be calculated when the compressor is disconnected from the electricity. The compressor has a volume of 6 gallons and a maximum pressure of 165 PSI, making one side of equation 7.3.1B known. Dividing these two values by the pressure of atmospheric air shows that there is 9 CF of compressed atmospheric air in the compressor when it is completely filled. Dividing this value by the amount of air in the accumulator at 40 PSI yields a result of 11.78. This means that 11 launches could be performed at 40 PSI, with an additional 12th launch at a slightly lower pressure without refilling the air compressor. While this is not as many as the scuba tank, the air compressor can be refilled much faster and easier, making this a viable option.+

When using the compressor or scuba tank, it is not advisable to transport the T-shirt launcher to the sporting venue with air already in the accumulator tank in order to try to gain an extra launch. With a firearm, this would be referred to as having "one in the chamber", giving you an extra shot in addition to what is in your magazine, which in the case of the T-shirt launcher is compressed air in the accumulator. Since the accumulator tank is not DOT rated, it should not be transported in any sort of vehicle while filled with compressed air. This will be stated in the storage and transportation manual.

8.0 Final Design and Engineering Specifications

This section discusses the final design, engineering specifications, and design parameters utilized during the construction of this project. Highlighting the importance of risk assessment, modeling and analysis, and testing throughout the design process. A large section of the design consideration and cosmetics came from the end user, UCF Athletics.

8.1 System Requirements

To begin the design process the team considered all the possible requirements the system must fulfill, including functional, safety, and storage requirements. All of which the final system should satisfy, however, some requirements the system must accomplish, such as the general requirement G7.1 "The T-shirt launching system shall feature visual cues or branding that indicate clear intended use specifically for UCF or Space-U." This requirement is highly important to the end user and weighed heavily on the design process. Another important requirement is F1.3 "The T-shirt launching system shall be capable of launching a T-shirt a minimum of 180 feet." This requirement is essential for the launcher's operation. These are only two examples of how the team has used careful consideration in the design process to meet all requirements laid fourth in Milestone II. The full list of requirements set the parameters of the design and function of the launcher, and the objective is to satisfy all the demands of the end user, by setting requirements. See Appendix E for full list of system requirements, also see Section 9.0 for evaluation of system requirements.

8.2 Risk Assessment

Explained in greater detail in Milestone V, the risk assessment on the system revealed the aspects which pose a high criticality for possible failures. The risk assessment was broken down into two categories, component failures which detail the failures associated with individual components and functional failures which cover functional systems or human error. Shown in Appendix C and D, are the decompositions used for the FMEA performed in Milestone V. The methodology used to analyze the risk and mitigation for such components and functions in the decomposition is described in the Appendix M, and a more in depth study can be observed in Milestone V.

8.3 Modeling and Analysis

Modeling and analysis played a major role in the design process. The most important analysis on components is described in great detail under Section 7.0. Some of the leading analysis done on the project included FEA on the barrel, barrel testing, and accumulator tank analysis. The components which required the most analysis had the highest criticality due to the nature of pressurized vessels. The use of FEA and mathematical stress and strain analyses, has significantly improved the safety quality throughout the project. Modeling the pressure vessels and related components allowed the final design to maintain the factor of safety set forth in the design requirements. It was important to do the analysis on these specific components due to the dangerous attributes of the pressurized elements of the launching system. See section 7.0 for further details and results on analysis and mathematical calculations.

8.4 Prototype and Testing

One of the significant achievements accomplished during the design process includes the first prototype and testing of the system. Once analysis had been completed and the team had a rough idea of the system in design, a prototype was drafted and constructed. Ensuring the conditions matched the inputs of the theoretical computer modeling, the prototype allowed the testing and experimenting for other major components in the project. For example, the barrel length was determined through testing the prototype, measuring the results and computing the maximum efficiency of the barrel length versus the distance launched. The team also tested other important variables with the use of the prototype, such as the amount of power needed to launch a T-shirt the desired distance. The original prototype model can be seen in figure 8.4, and further tests and results can be seen in Section 7.0 of this report.

Figure 8.4: Original Prototype Launcher

8.5 Manufacturability and Cost

Accounting for the budget given by UCF, the team was diligent in trying to reduce costs and be thrifty with the sources available. Manufacturing a basic launcher seen in Figure 8.4 is easy as a \$80 tire bead blaster and attaching a barrel to the end. This method is cost effective and super efficient at completing the job of launching T-shirts. Not to mention the design of the prototype is repeatable with little steps with a low cost comparable to the whole budget. A majority of the parts used are low cost and customizable to the requirements of the designer. Comparing the cost of the proposed list to the actual build there is small deviation aside from the durable goods, i.e. 30 cubic foot scuba tank and a NPT adapter for the tank. These elements are not necessary for the success of the project, however they benefit the system and allow for more portability. The preliminary cost can be seen in Milestone III, Section 6.9.2, and the actual cost is in the Appendix H, totaling \$560. As stated above the main deviation of cost from the proposed and actual is the cost of the 30 cubic foot scuba tank, other than that the costs are similar to the original planned budget. UCF Senior Design provided a total budget of \$600, which the team remained under.

8.6 Final Design

The final design of the T-shirt launching system can be seen in Figure 8.6A. At the request of the end user, the team has designed the launcher in the appearance of a rocket with side boosters. In the final design the team has included a screen with visual cues when loading pressurized air into the accumulator tank, side boosters with UCF branding for the Space U theme, a cosmetic cover for the barrel to fit with the aesthetic of the build. The team also designed safety locks for maintenance and transport that are not included in Figure 8.6A. The source of high pressure air is also not included in Figure 8.6A, the system is designed to use a quick connect fitting to allow for high pressure air from a compressor or a scuba tank.

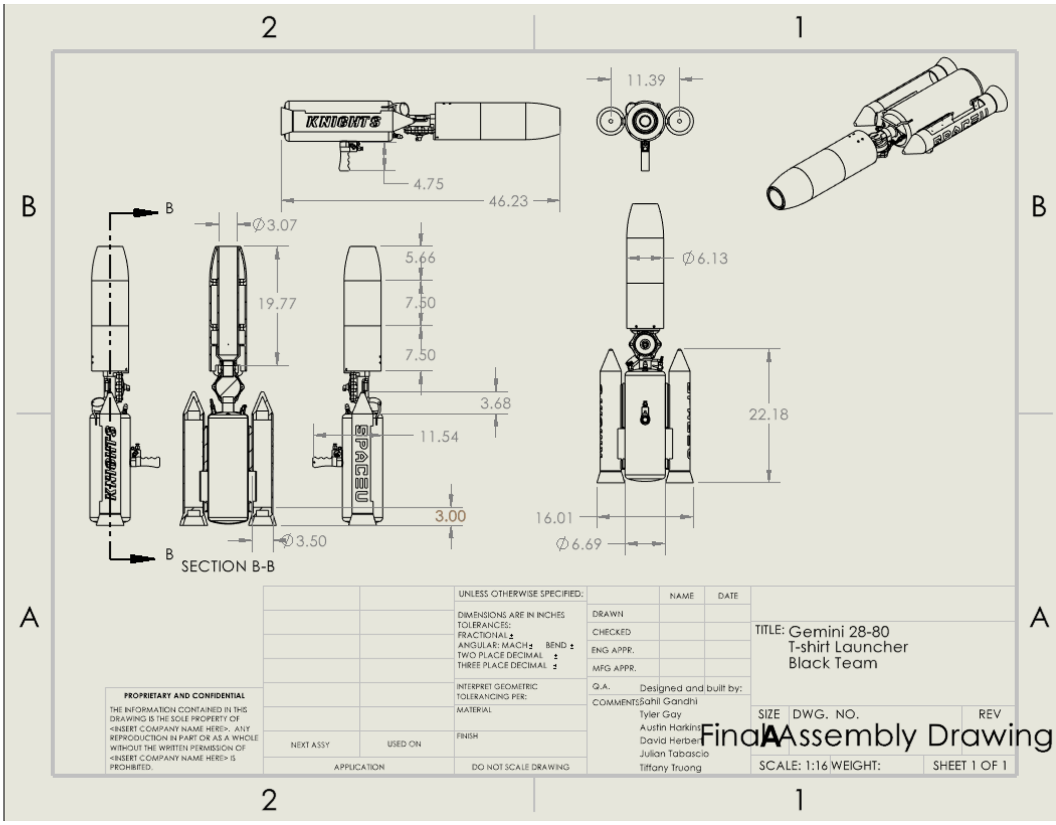


Figure 8.6A: Final Design CAD Drawing

The final built system is shown below in Figure 8.6B.

Figure 8.6B: Completed Launcher

9.0 System Evaluation

To determine the overall effectiveness of the system, the system had to be tested and verified against the original requirement written in Milestone II. The procedures and equipment used for each test are listed in Appendix I, if applicable.

Note that the maximum capable operating pressure of the T-shirt launcher is just under 120 PSI. Due to this, multiple launching related requirements were tested at 115 PSI, leaving a small amount of room so the pressure relief valve would not go off. This represents the maximum possible range and power of the T-shirt launcher. During testing, it was found that 80 PSI is capable of reaching the top row of the football stadium, so it is recommended that the accumulator tank is not filled past 80 PSI. A warning displays when the user fills it past 80 PSI, and the power percentage bar reaches 100% at 80 PSI. Performing requirement verifications at the higher pressure of 115 PSI represents the maximum possible performance of the T-shirt launcher, in case UCF ever desires to use it at other venues, such as a bowl game, or expands the football stadium.

9.1 General Requirements Evaluation

G1.1 - The component of the T-shirt launching system, which the operator holds to launch the T-shirts, must be handheld and operated by a single individual.

- *Verification* - Each team member was able to load a T-shirt, fill the accumulator tank, and launch a T-shirt unassisted. Due to the addition of the cosmetic SRBs, it made it difficult for some team members to be able to complete this task. In this case, the launcher could be placed on the ground, supported by the SRBs, to allow for loading the T-shirt and filling the accumulator tank.

G1.2 - Individual parts of the T-shirt launching system that are intended to be carried by a single individual shall not exceed 51 pounds in total.

- *Verification* - The final weight of the handheld portion of the T-shirt launcher is 26.7 lbs, as shown in Table 9.1. This weight comes in less than the largest Bleacher Reacher launcher, the Bleacher Reacher Mega, which is 27 lbs [8].

Table 9.1: Weight of T-shirt Launcher

Trial	**Weight (lbs)**
1	26.6
2	26.8
3	26.6
Average:	26.7

G1.3 - Individual parts of the T-shirt launching system that are intended to be carried by the user without the use of their hands, such as a backpack, shall not exceed 51 pounds, including handheld portions.

- *Verification* - The only component of the T-shirt launching system that is intended to be carried by the user is the launcher itself. Therefore, verification of Requirement G1.2 also verifies this requirement.

G2.1 - Individual components with electronic or water-sensitive elements shall be IP44-rated.

- Verification - Using the procedure in Appendix I, the T-shirt launcher is resistant to solid objects greater than 1 mm in diameter and is resistant against splashes of water from all directions. This means that if the launcher is left outside in the rain for a short period of time, the electronics will not be damaged. However, if it is left in the rain for longer than a few minutes or has something spilled on the electronics, the launcher will likely become damaged.

G3.1 - The launcher shall only be operated by individuals over the age of 18. This shall be stated in all included manuals.

- *Verification* - The following manuals are available in the Appendix and state that the launcher shall only be operated by individuals over the age of 18:
    - User Manual - Appendix J
    - Maintenance Manual - Appendix K
    - Storage and Transportation Manual - Appendix L

G4.1 - The T-shirt launching system shall come with a user training manual, the manual will provide comprehensive instructions on setting up the launcher, utilizing its various features during operation, and safely disassembling the equipment.

- *Verification* - The user manual is available in Appendix J.

G5.1 - There shall be an unobstructed path of length 3 inches in front of the activation mechanism for the launcher, allowing for use by individuals in a mascot costume.

- Verification - There are no obstructions in front of the trigger mechanism, satisfying this requirement. This is shown in Figure 9.1A. This will allow use by individuals in a mascot costume with gloves on, as there is nothing impeding someone wearing thick gloves from pressing the trigger.

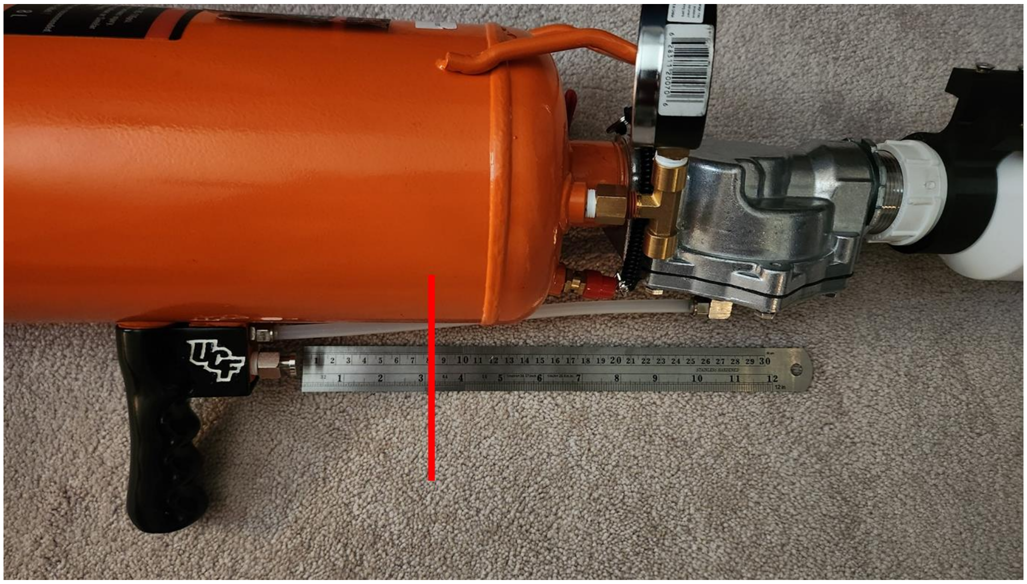


Figure 9.1A: Open Space in Front of Trigger

G6.1 - The T-shirt launching system shall contain a sensory indicator or effect when a T-shirt is launched.

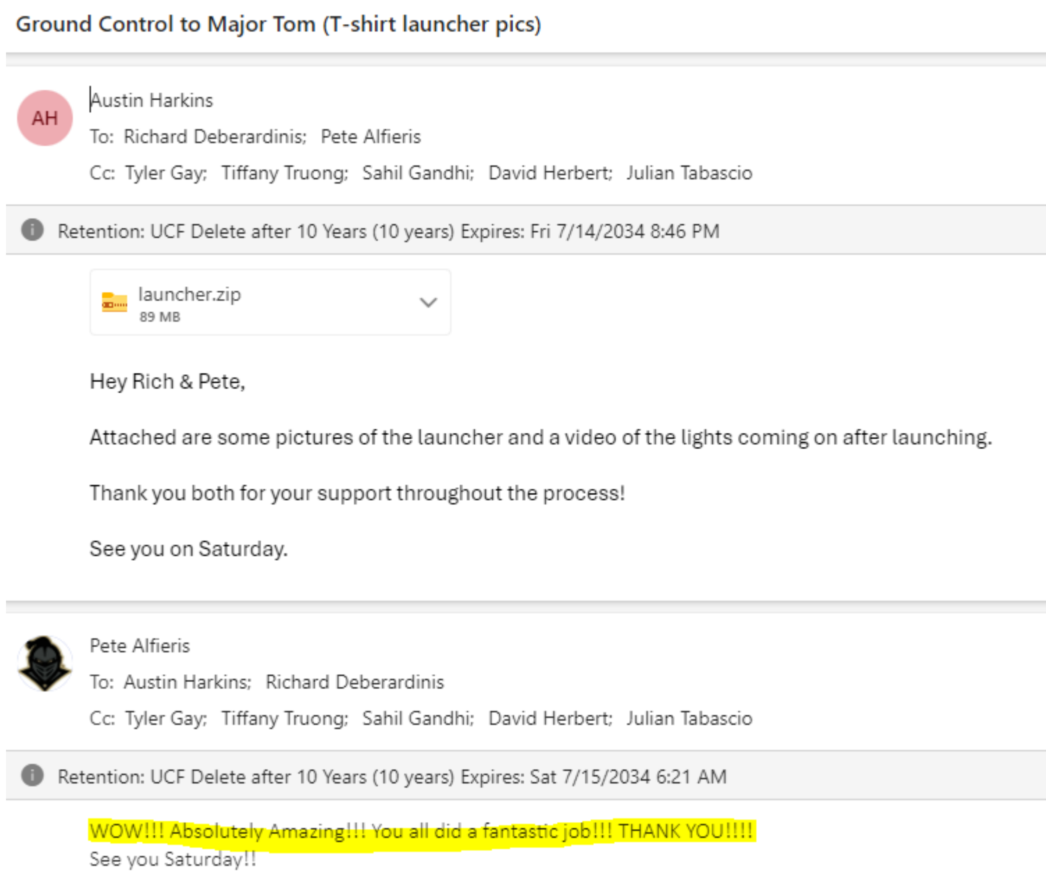
- *Verification* - The T-shirt launcher contains three sensory indicators when a T-shirt is launched. First, the launcher makes a very loud noise when launched, regardless of the accumulator pressure. This alone is sufficient to alert people to launched T-shirts. Additionally, the launcher has a smoke effect after a T-shirt is launched. A third indicator is placed at the end of the barrel in the form of LED lights. When a T-shirt is launched, the

LED lights turn on for a brief moment to draw attention to the launcher, shown in Figure 9.1B.

Figure 9.1B: LED Lights on End of Barrel

G7.1 - The T-shirt launching system shall feature visual cues or branding that indicate clear intended use specifically for UCF or Space-U.

- *Verification* - Approval of the final design was given by Pete, a key project stakeholder. This is shown below in Figure 9.1C.



Ground Control to Major Tom (T-shirt launcher pics)

Austin Harkins
To: Richard Deberardinis; Pete Alfieris
Cc: Tyler Gay; Tiffany Truong; Sahil Gandhi; David Herbert; Julian Tabascio

Retention: UCF Delete after 10 Years (10 years) Expires: Fri 7/14/2034 8:46 PM

launcher.zip
89 MB

Hey Rich & Pete,

Attached are some pictures of the launcher and a video of the lights coming on after launching.

Thank you both for your support throughout the process!

See you on Saturday.

Pete Alfieris
To: Austin Harkins; Richard Deberardinis
Cc: Tyler Gay; Tiffany Truong; Sahil Gandhi; David Herbert; Julian Tabascio

Retention: UCF Delete after 10 Years (10 years) Expires: Sat 7/15/2034 6:21 AM

WOW!!! Absolutely Amazing!!! You all did a fantastic job!!! THANK YOU!!!!
See you Saturday!!

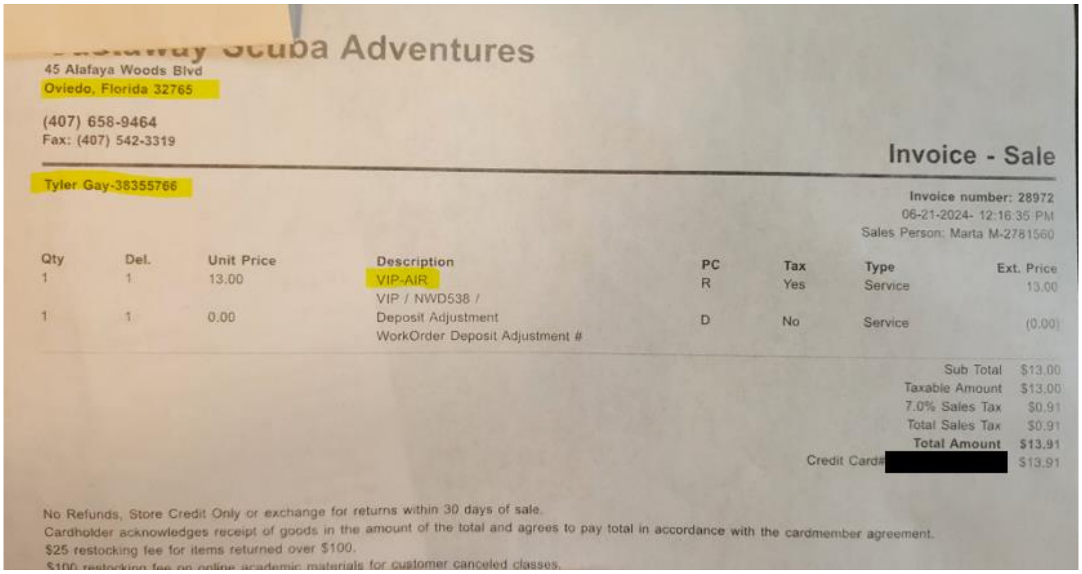
Figure 9.1C: Stakeholder Approval of Launcher

<u>G8.1</u> - The T-shirt launching system shall facilitate assembly by a trained operator within 20 minutes (excluding refilling any energy sources), with no more than 15 procedural steps.

- *Verification* - From storage, the launcher takes 2 minutes to assemble and 6 steps. See “Unloading Procedure” in the Storage and Transportation Manual in Appendix L.

<u>G9.1</u> - The energy source used for propulsion shall be refilled at UCF’s main campus, refilled at a location within the Orlando, FL area, or sourced from online retailers.

- *Verification* - During testing, the scuba tank was refilled at Castaway SCUBA Adventures in Oviedo, FL. The receipt is shown in Figure 9.1D. This is approximately 4 miles from the UCF main campus. The air compressor can be refilled anywhere using electricity.



Scuba Adventures
45 Alafaya Woods Blvd
Oviedo, Florida 32765

(407) 658-9464
Fax: (407) 542-3319

Invoice - Sale

Tyler Gay-38355766

Invoice number: 28972
06-21-2024- 12:16:35 PM
Sales Person: Marta M-2781560

Qty	Del.	Unit Price	Description	PC	Tax	Type	Ext. Price
1	1	13.00	VIP-AIR VIP / NWD538 /	R	Yes	Service	13.00
1	1	0.00	Deposit Adjustment WorkOrder Deposit Adjustment #	D	No	Service	(0.00)

Sub Total	$13.00
Taxable Amount	$13.00
7.0% Sales Tax	$0.91
Total Sales Tax	$0.91
Total Amount	**$13.91**
Credit Card# [redacted]	$13.91

No Refunds, Store Credit Only or exchange for returns within 30 days of sale.
Cardholder acknowledges receipt of goods in the amount of the total and agrees to pay total in accordance with the cardmember agreement.
$25 restocking fee for items returned over $100.
$100 restocking fee on online academic materials for customer canceled classes.

Figure 9.1D: Scuba Tank Filling Receipt

9.2 Functional Requirements Evaluation

F1.1 - The T-shirt launching system shall have a variable power control accessible to the user, allowing the user to adjust the launching distance at least 100 feet.

- *Verification* - From testing, the T-shirt launcher has a variable range of at least 143 feet, satisfying this requirement. The test data is shown in Table 9.2A. During testing in the football stadium, the team ensured that every row, from the first to the last, could receive a launched T-shirt. Since the maximum PSI that should be used in the football stadium is only 80 PSI, the range of 143 feet exceeds the needs of UCF.

Table 9.2A: Launching Range

Trial	PSI	Distance (ft)
1	100	180
2	100	219
3	100	213
	Average:	204
4	10	63
5	10	66
6	10	54
	Average:	61

F1.2 - The T-shirt launching system shall be capable of launching a T-shirt with a minimum exit velocity of 68.5 MPH.

- *Verification* - Using large T-shirts, the exit velocity of the T-shirt launcher is 143.75 MPH, satisfying this requirement. The first trial using a large T-shirt is shown below in Figure 9.2A.

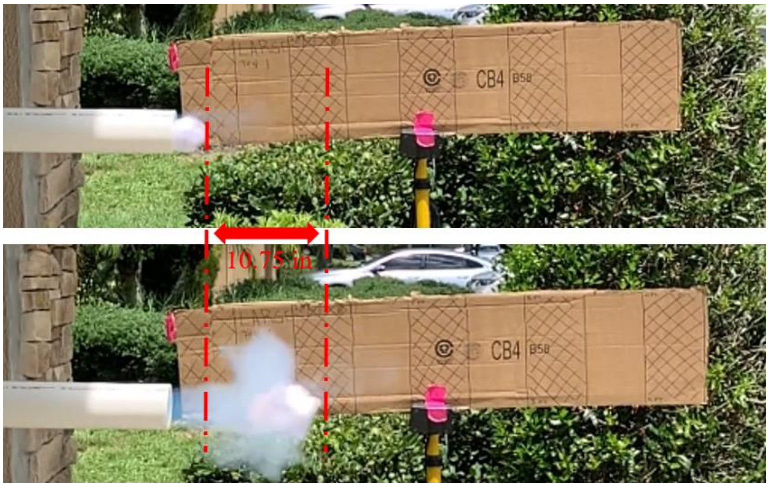


Figure 9.2A: Large Exit Velocity First Trial

Furthermore, the results of the three tests for the exit velocity of a large T-shirt are shown below in Table 9.2B. The camera used has a frame rate of 240 frames per second. The exit velocity was found using the equation in Appendix I.

Table 9.2B: Large T-shirt Exit Velocity

Trial	**Distance (in)**	**Exit Velocity (MPH)**
1	10.75	146.59
2	9.88	134.66
3	11.00	150.00
	Average:	143.75

The calculated exit velocity of over 143 MPH is a 110% increase over the required exit velocity of 68.5 MPH. This large buffer serves two purposes. First, it allows room for any error used in the calculation method of using a camera to measure the exit velocity. Second, it allows the launched T-shirts to meet the distance required in Requirement F1.3. The extra exit velocity helps counter any additional losses due to friction, air resistance, or packaging method, ensuring the T-shirt reaches the required distance.

F1.3 - The T-shirt launching system shall be capable of launching a T-shirt a minimum of 180 feet.

- *Verification* - Using large T-shirts, the average launch distance at 115 PSI is 190.5 feet, satisfying requirement F1.3. This is shown in Table 9.2C. Large T-shirts were used as this is the most likely size that UCF will be launching during games. The expected launching distance of small and medium T-shirts is available in Requirement F2.1

Table 9.2C: Launch Distance of Large Shirts

Trial	PSI	Launch Distance (ft)
1	115	213
2	115	222
3	115	225
4	115	207
5	115	174
6	115	162
7	115	156
8	115	171
9	115	189
10	115	186
	Average	190.5

During testing in the football stadium, it was found that only 80 PSI was needed to reach the top row. This requirement serves as a reflection on what the T-shirt launcher is capable of if it were to be used in a larger stadium or if the football stadium was ever expanded. The team recommends only filling the launcher to 80 PSI in an effort to prevent T-shirts from being launched outside of the stadium.

F2.1 - The T-shirt launching system shall be capable of launching small, medium, and large T-shirts at the target exit velocity and distance stated in Requirements F1.2 and F1.3.

- *Verification (Exit Velocity)* - Using the same procedure listed for Requirement F1.2, medium T-shirts have an exit velocity of 185.23 MPH and small T-shirts have an exit velocity of 153.41 MPH, satisfying this portion of Requirement F2.1. The trials conducted are shown below in Table 9.2D.

Table 9.2D: Small and Medium T-shirt Exit Velocity

Trial	**Small Exit Velocity (MPH)**	**Medium Exit Velocity (MPH)**
1	88.64	170.45
2	180.68	132.95
3	190.91	252.27
Average:	153.41	185.23

Upon watching the videos to calculate the exit velocities, it was found that the first small T-shirt launched became unwrapped before it left the barrel, limiting its exit velocity. It is likely that the exit velocity of a securely wrapped small T-shirt is significantly higher than the average found in this test.

- *Verification (Distance)* - Using the procedure outlined for F1.3, medium T-shirts reach a maximum distance of 255.6 feet, and small T-shirts reach a distance of 195 feet, shown in Table 9.2E. This surpasses the distance of large T-shirts, and satisfies Requirement F2.1

Table 9.2E: Launch Distance of Small and Medium Shirts

Trial	PSI	Small Launch Distance (ft)	Medium Launch Distance (ft)
1	115	186	246
2	115	201	273
3	115	192	219
4	115	189	216
5	115	186	273
6	115	225	288
7	115	183	225
8	115	201	261
9	115	186	285
10	115	201	270
	Average	195.0	255.6

When testing the different sizes, the medium T-shirts were tested prior to testing the small T-shirts. After finding that the medium shirts exhibited a significant increase in exit velocity and launch distance over the large T-shirts, the team expected the small T-shirts to be launched even further. However, that was not the case. It is likely due to the smaller surface area of the small T-shirts, they do not have as much work done on them in the barrel, reducing the exit velocity and thus the launch distance. Multiple other factors affect the launch distance, including:

- Pressure
- Size of T-shirt

- Thickness (weight) of the T-shirt
- Packaging method
- Rolling method
- Launch angle
- Wind
- User skill

F2.2 - The T-shirt launching system shall be capable of launching one T-shirt every 15 seconds.

- *Verification* - A trained user was able to launch 6 shirts at 40 PSI in 66 seconds, averaging for 11 seconds per launch. This satisfies requirement F2.2. This test was conducted launching one T-shirt at a time. During final testing on July 20th, the team launched four T-shirts at once and was still able to reach the top rows. Utilizing this method would significantly increase the frequency of T-shirts being launched.

F3.1 - The T-shirt launcher shall be capable of projecting a T-shirt within a 400-square-foot area of a target when fired at a distance of 180 feet from the target.

- *Verification* - This test was performed at a team member's house, launching into the road. The landing locations of the T-shirts were marked with chalk, and after all 10 shirts had been launched, measurements were taken to determine the spacing of the shirts, shown in Figure 9.2B, where the red line is the target distance and the green arrows are the 8 T-shirts that landed in the area. In addition, a detailed video was taken with landmarks for further evaluation.

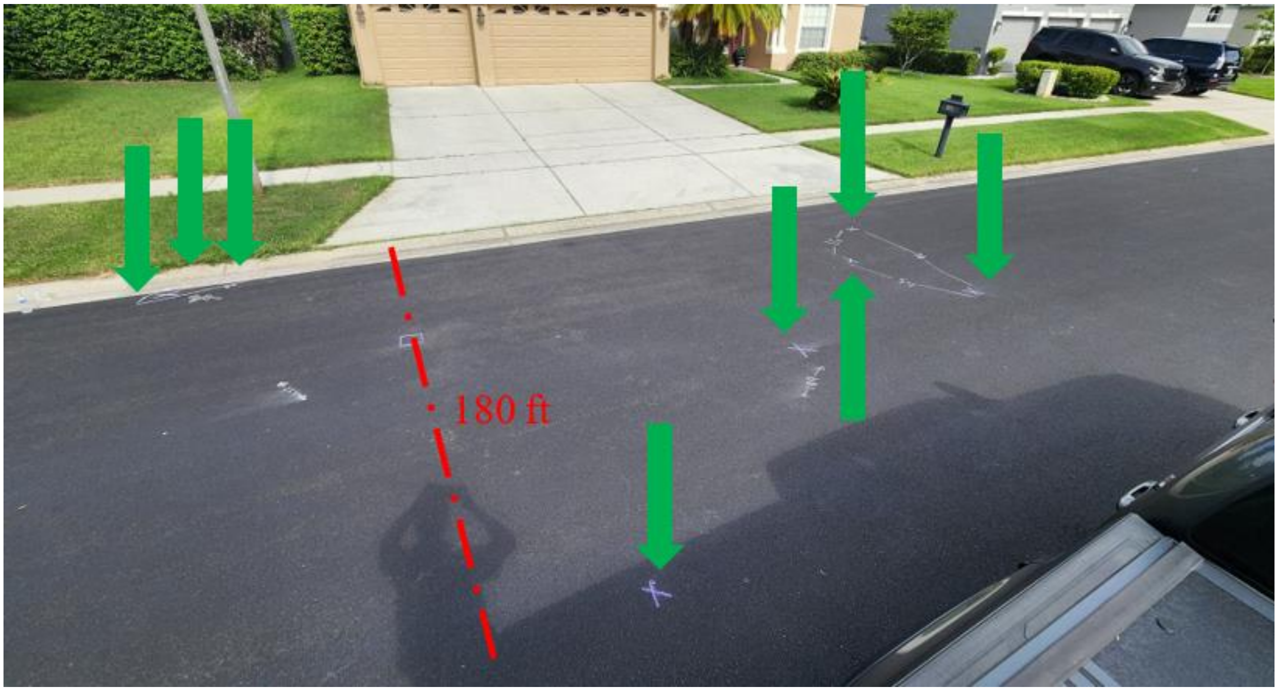


Figure 9.2B: T-shirt Accuracy Test Landing Location

After the test, the landing locations were plotted on a map along with the measurements taken to determine the area that the T-shirts landed in, shown in Figure 9.2C. The two red X shapes represent two T-shirts that did not land within 400 square feet of the other T-shirts.

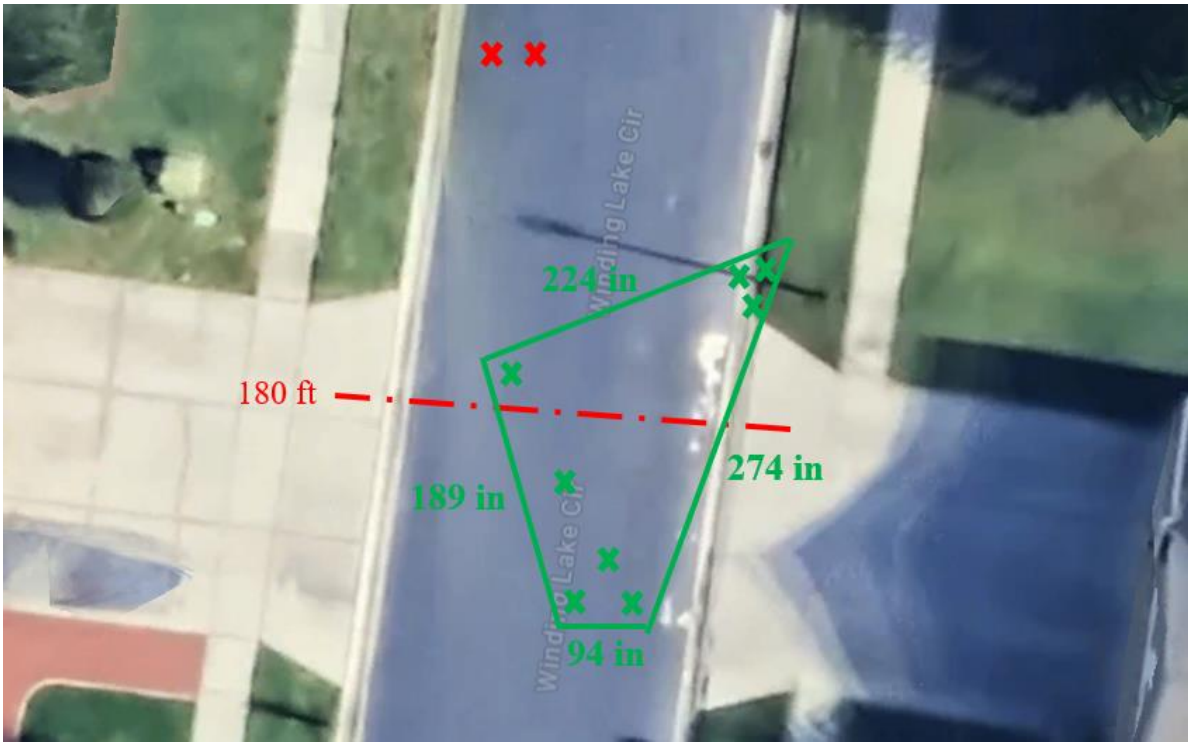


Figure 9.2C: T-shirt Accuracy Test Plotted on Map

Finally, the dimensions and angles found from the test were used to create a shape in SolidWorks and find the surface area, shown in Figure 9.2D. Using this method, the area was found to be 33,769 square inches, which is equal to 234.51 square feet, satisfying Requirement F3.1.

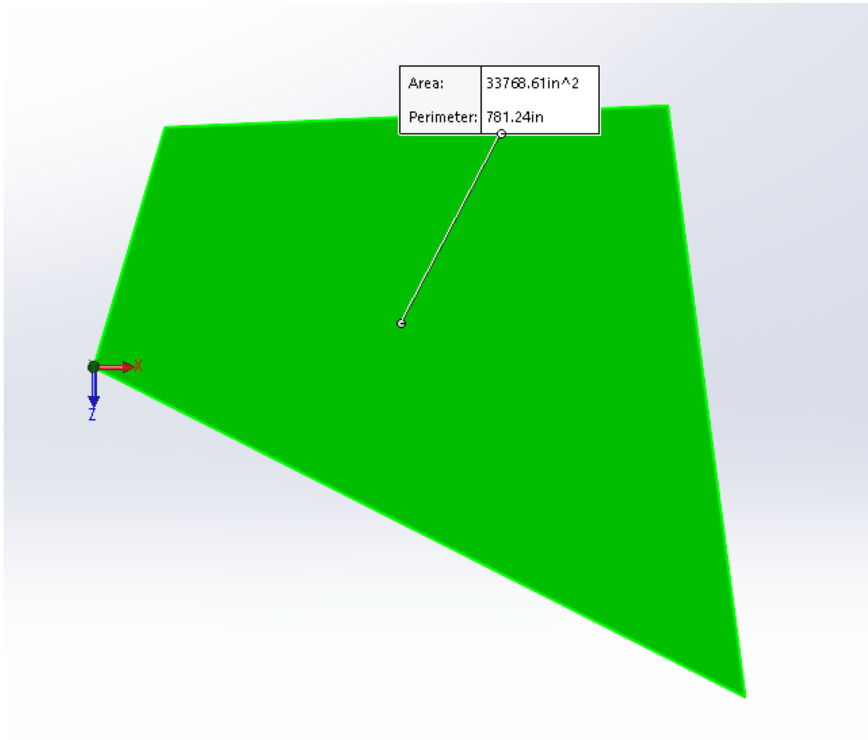


Figure 9.2D: T-shirt Accuracy Test Plotted in Solidworks

<u>9.3 Safety Requirements Evaluation</u>

<u>S1.1</u> - The T-shirt launching system shall include a readout to communicate the amount of energy that is currently stored in the system and shall be clearly labeled.

- *Verification* - Within the recommended range of operating pressures, the pressure gauge on the accumulator tank is within 3.33% of the regulator attached to the air compressor, as shown in Table 9.3A. This calculation is limited, since the resolution of both gauges is only 5 PSI, making it difficult to set the compressor to the exact value, and making it difficult to interpolate values. Furthermore, the Arduino display shows the pressure to the user, which matches the pressure gauge on the accumulator tank.

Table 9.3A: Accumulator Tank Pressure Gauge

Compressor Output Pressure (PSI)	Accumulator Pressure Gauge Reading (PSI)	Percent Error
10	10	0%
20	19.8	-1%
30	29	-3.33%
40	40	0%
50	49.5	-1%
60	58	-3.33%
70	69	-1.43%
80	78	-2.5%

After having the scuba tank filled at the dive shop, the scuba to NPT adapter was placed on the tank and the pressure gauge read close to 3,000 PSI, which is what the tank was filled to. Since the scuba tank cools after filling, the pressure will reduce slightly from the pressure it was filled to. Due to this and the small margin of error for the gauge on the accumulator tank, this requirement is satisfied.

S1.2 - The T-shirt launching system shall have an indicator to communicate if the system is holding ANY amount of energy (>0) and shall be clearly labeled.

- *Verification* - Verification of Requirement S1.1 in accordance with Appendix I also satisfies S1.2. Additionally, the included Arduino display clearly states the pressure in the accumulator tank.

S1.3 - The T-shirt launching system shall have an indicator to communicate if the amount of energy stored is at a potentially dangerous level and shall be clearly labeled.

- *Verification* - Since T-shirts will leave the football stadium at 80 PSI, an indicator appears on the Arduino display once 80 PSI is surpassed that the user needs to either reduce the pressure in the tank or increase the launch angle to keep the T-shirts in the stadium. This is shown below in Figure 9.3A. Note that 80 PSI is well within the safe operating range of the accumulator tank, but launching T-shirts outside of the stadium poses a unique safety risk that is accounted for with this indicator.

Figure 9.3A: Dangerous Energy Level Indicator

S1.4 - The T-shirt launching system shall have an indicator to communicate if the system is ready to be fired and shall be clearly labeled.

- *Verification* - During testing, it was found that at least 10 PSI was required to launch a T-shirt into the stands from the sideline. Due to this, 10 PSI is used as the benchmark for the ready to fire indicator. Once 10 PSI is reached, the red LED next to the Arduino display turns on, shown in Figure 9.3B. The meaning of this indicator is stated in the user manual, which is available in Appendix J.

Figure 9.3B: Ready to Fire Indicator

S2.1 - The T-shirt launching system shall have an Emergency Shut-Down mechanism (ESD) that is activated in fewer than 3 steps and within 10 seconds following initiation.

- *Verification* - The emergency shutdown mechanism for this launcher includes: pulling the pressure relief valve, disconnecting the Arduino, and disconnecting the LED lights, for a total of three steps. Furthermore, this process takes approximately four seconds for a trained user and is outlined in the user manual.

S2.2 - The T-shirt launching system shall shut off all electronics upon activating the Emergency Shutdown System and shall be clearly labeled.

- *Verification* - Performing the emergency shutdown procedure in accordance with the user manual and Requirement S2.1 ensures all electronics are turned off.

S3.1 - The T-shirt launching system shall achieve a state of equilibrium after discharge of all energy sources, excluding energy in batteries.

- *Verification* - After discharging all stored compressed air using the method described in Appendix I, both pressure gauges read 0, shown in Table 9.3B, satisfying this requirement. This requirement ensures that after use, the T-shirt launcher is in a neutral state to be transported or stored properly.

Table 9.3B: Equilibrium of Tanks

Gauge	Reading (PSI)
Accumulator	0
Scuba	0

S4.1 - The T-shirt launcher shall incorporate a Lock-Out / Tag-Out system to prevent unauthorized operation

- *Verification* (Trigger) - After testing the trigger LOTO according to the written procedure, it is not possible to fire the launcher with the trigger LOTO in place at any pressure, shown in Table 9.3C. Due to this, the requirement is satisfied.

Table 9.3C: Trigger LOTO Test

Pressure (PSI)	Pass / Fail
20	Pass
40	Pass
60	Pass
80	Pass

The trigger LOTO device is shown in Figure 9.3C. The device features a lock to ensure only authorized users can remove the device, as well as a “remove before flight” keychain, ensuring the user recognizes that it must be removed prior to use.

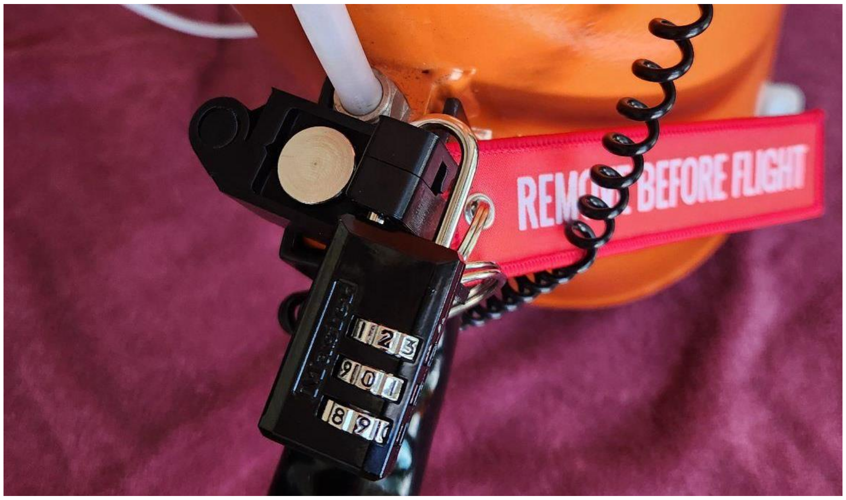


Figure 9.3C: Trigger LOTO Device

- *Verification* (Air Inlet) - The air inlet LOTO successfully prevents an individual from filling the accumulator tank with air, thus making it impossible to fire a projectile with it when it is in place. Due to this, the requirement is satisfied. The air inlet LOTO device is shown below in Figure 9.3D.

Figure 9.3D: Air Inlet LOTO Device

S5.1 - The T-shirt launching system shall be capable of releasing all stored energy without the need to fire a projectile, excluding batteries.

- *Verification* - Verification of Requirement S3.1 in accordance with the procedure outlined in Appendix I also satisfies S5.1

<u>S6.1</u> - The T-shirt launching system shall withstand 75 cycles of testing with no failures.

- *Verification* - During requirements testing, 126 T-shirts were launched with the finalized propulsion and reloading systems. Note that it was not required to launch this many for requirements, but before testing each requirement, the user practiced launch angles and packaging methods prior to beginning data collection. Since a cycle was defined as launching 6 T-shirts, an additional 324 T-shirts were launched with no failures such as leaks or jams.

<u>S7.1</u> - The T-shirt launching system shall have a method to lockout the mechanism used to fire the launcher, preventing an accidental discharge.

- *Verification* - The trigger safety was tested in the recommended operating pressure range of the launcher with no failures, therefore this requirement is satisfied. The test results are shown in Table 9.3D.

Table 9.3D: Trigger Safety Test

Pressure (PSI)	Pass / Fail
20	Pass
40	Pass
60	Pass
80	Pass

S7.2 - If a traditional firearm-style trigger is used, the trigger shall require a minimum of 4 pounds of force to activate.

- *Verification* - The launcher utilizes a pneumatic trigger, not a firearm style. Therefore, this requirement is not applicable.

S8.1 - The T-shirt launching system shall be energized no earlier than 3 steps before the launcher is ready to be used.

- *Verification* - The user manual, available in Appendix J, contains the proper launch sequence. This sequence specifies that energizing the accumulator tank is the last step prior to launching a T-shirt.

S9.1 - Any energy storage devices, excluding batteries, shall adhere to a minimum safety factor of 3.5.

- *Verification* - From FEA performed in Milestone V, shown in Figure 9.3E, the accumulator tank has a factor of safety of 3.96, exceeding the factor of safety of 3.5, which is derived from ASME Section VIII [11]. The scuba tank has a rated factor of safety of 2.5 at its operating pressure of 3,000 PSI due to related DOT requirements for 3AL pressure vessels [26]. Due to this, the recommended filling pressure of the scuba tank is only 2,140 PSI, which is stated in the user manual, which is available in Appendix J. Further discussion of this is available in Milestone V. Due to both containers meeting or exceeding a 3.5 factor of safety, this requirement is satisfied.

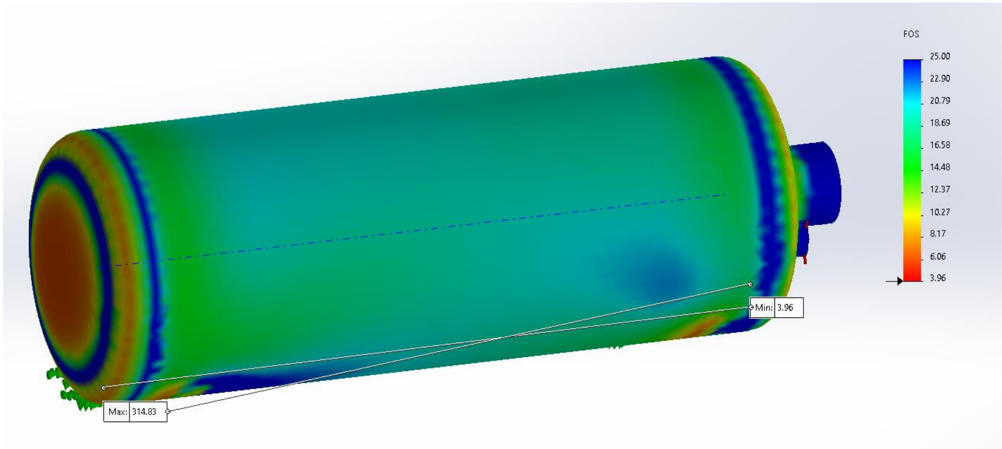


Figure 9.3E: FEA of Accumulator Tank Showing Factor of Safety

9.4 Storage and Transportation Requirements Evaluation

ST1.1 - If a storage system is in place, individual pieces of the storage system for the T-shirt launching system should not exceed 50 inches in any direction.

- *Verification* - The Christmas tree storage bag dimensions are 50” x 20” x 16”, satisfying this requirement.

ST1.2 - If a storage system is in place, individual containers shall not exceed 51 pounds, including device weight.

- *Verification* - The loaded storage system weighs 34.6 pounds, satisfying this requirement. The trials are shown in Table 9.4A.

Table 9.4A: Weight of Loaded Storage System

Trial	Weight (lbs)
1	34.6
2	34.5
3	34.6
Average:	34.6

ST1.3 - If a storage system is in place, individual containers shall be IP44-rated.

- *Verification* - After performing testing in accordance with the procedure outlined in Appendix I, the team confirmed the storage bag is IP44 rated, shown in Table 9.4B.

Table 9.4B: Storage System IP Test

IP-44 Criteria	Pass / Fail
Solid Foreign Object	Pass
Water	Pass

ST2.1 - A storage and transportation manual shall be included with the T-shirt launching system. The manual shall clearly state the launcher is not to be in possession of individuals under the age of 18. The manual shall also include how to package the launcher for storage, how to release the energy for storage, and how to safely transport the launcher to its destination.

- *Verification* - The storage and transportation manual, with the required information, is available in Appendix L.

ST3.1 - The T-shirt launcher shall support disarming and disassembly ready for storage within 20 minutes, and no more than 15 procedural steps.

- *Verification* - The launcher can be disassembled for storage in less than 2 minutes with only 7 steps, satisfying this requirement. This procedure is outlined in "Loading Procedure" in the Storage and Transportation Manual, available in Appendix L.

9.5 Maintenance Requirements Evaluation

M1.1 - A maintenance manual shall be included with the T-shirt launching system. The manual shall clearly state the launcher is not to be in possession of individuals under the age of 18. The maintenance manual shall also include how to take apart the launcher, how to clean the launcher, and how to replace parts on the launcher.

- *Verification* - The maintenance manual, with the required information, is available in Appendix K.

M2.1 - The hardware used to construct the T-shirt launching system shall cohere to a single system of units, Metric or Imperial.

- *Verification* - All hardware utilized to construct the launcher is intended to be assembled using Imperial sized tools, shown in Table 9.5. Due to this, the requirement is satisfied.

Table 9.5: Hardware Units

Item	Tool Size	Tool Units
Rear Grip Screw	#4-40 Flat Head	Imperial
Pneumatic Trigger Button	5/8 in	Imperial
Clear Tube Fittings	1/2 in	Imperial
Ball Valve	5/8 in	Imperial
Male NPT Quick Connect	9/16 in	Imperial
Pressure Relief Valve	9/16 in	Imperial
BSP to NPT Adapter	1 1/2 in	Imperial
NPT Tee Fitting	Adjustable Wrench	N/A
Pressure Gauge	9/16 in	Imperial
Pressure Transducer	9/16 in	Imperial
Valve Bolts	3/8 in	Imperial
Cosmetic Barrel Outer Screws	#10-24 Allen	Imperial
Cosmetic Barrel Inserts	#10-24 Heat Set Insert	Imperial
Cosmetic Barrel Inner Screws	#10-24 Phillips	Imperial

M3.1 - All commercial off-the-shelf (COTS) materials should be accessible within the Orlando, FL area or purchased online with reliability (product is received).

- *Verification* - From the expense report in Appendix H, all materials were purchased in the Orlando, FL area or purchased online and received. Therefore, this requirement is satisfied.

9.6 Economic Requirements Evaluation

E1.1 - The cost to refill the energy source in between uses and package the payload shall not exceed a dollar amount to be determined by the UCF Athletics Department.

- *Verification* - The cost per launch can be calculated by finding the dollar amount associated with launching one T-shirt. If using the air compressor, which is suggested, the cost to refill the air is negligible, as it is a small amount of electricity. Furthermore, packaging the T-shirts involves using common household items, such as tape or rubber bands, satisfying this requirement.

E2.1 - The total cost to manufacture the T-shirt launcher shall not exceed the budget levied by UCF Athletics and the UCF Department of Mechanical and Aerospace Engineering.

- *Verification* - The team was given a $600 budget from UCF for this project. The final cost of the launcher was $559.62, as shown in the expense report in Appendix H.

9.7 System Evaluation Summary

The findings of Requirements testing are summarized below in Table 9.7.

Table 9.7: System Evaluation Summary

Requirement	Description	Target Value	Actual Value
G1.1	Operated by single individual	Pass / Fail	Pass
G1.2	Launcher weight (individual parts)	< 51 lbs	27 lbs
G1.3	Launcher weight (backpack)	< 51 lbs	N/A
G2.1	IP rating of launcher	IP44	IP44
G3.1	Operated by people over 18	Pass / Fail	Pass
G4.1	User manual	Pass / Fail	Pass
G5.1	Clear path to trigger	3 in	No obstruction
G6.1	Indicator when fired	Pass / Fail	Pass
G7.1	UCF / Space-U branding	Pass / Fail	Pass
G8.1	Assembly time and steps	20 minutes / 15 steps	2 minutes / 6 steps
G9.1	Energy source availability	Orlando area or at UCF	Pass
F1.1	Variable power control	100 ft	143 ft
F1.2	Exit velocity	68.5 MPH	144 MPH
F1.3	Minimum distance	180 ft	191 ft
F2.1	Small and medium shirts velocity and distance	68.5 MPH / 180 ft	Small: 153 MPH / 195 ft Medium: 185 MPH / 256 ft
F2.2	Launching rate	15 seconds	11 seconds

Continued on Next Page

F3.1	Accuracy	8/10 shirts within 400 square feet	Pass
S1.1	Amount of energy readout	Pass / Fail	Pass
S1.2	Any energy readout	Pass / Fail	Pass
S1.3	Indicator for dangerous energy level	Pass / Fail	Pass
S1.4	Ready to fire indicator	Pass / Fail	Pass
S2.1	Emergency Shutdown	3 steps / 10 seconds	3 steps / 4 seconds
S2.2	Emergency Shutdown - electronics off	Pass / Fail	Pass
S3.1	Equilibrium after discharge	Pass / Fail	Pass
S4.1	LOTO system	Pass / Fail	Pass
S5.1	Release energy without firing	Pass / Fail	Pass
S6.1	75 cycles of testing	Pass / Fail	Pass
S7.1	Trigger safety	Pass / Fail	Pass
S7.2	Trigger weight	> 4 lbs	N/A
S8.1	Steps between energizing and launching	< 3 steps	0 steps
S9.1	Energy storage factor of safety	3.5	3.5, 3.96
ST1.1	Storage system size	< 50 in	50x20x16
ST1.2	Storage system weight	< 51 lbs	34.6 lbs
ST1.3	Storage IP rating	IP44	IP44
ST2.1	Storage and transportation manual	Pass / Fail	Pass
ST3.1	Disassembly time and steps	20 minutes / 15 steps	2 minutes / 7 steps
M1.1	Maintenance manual	Pass / Fail	Pass

Continued on Next Page

M2.1	Hardware units	Pass / Fail	Pass
M3.1	COTS parts online or in Orlando	Pass / Fail	Pass
E1.1	Energy source cost	TBD	$0
E2.1	Project cost	$600	$560

10.0 Significant Accomplishments and Open Issues

UCF athletics has reached out to UCF engineering department of aerospace and mechanical engineering and approached the Senior Design professor with a project to create T-shirt launchers for the UCF sporting events. The purpose of the launcher is to engage fans during games and increase school spirit among the students. The three main goals set by our client was to make a T-shirt launcher that can launch any size T-shirt from the field to the top row of the football stadium, can be carried and used by a single person, and must be Space U themed in its design. Using these three goals as our framework, we can create a list of requirements located in Appendix E to satisfy not only the three criteria for UCF athletics but add more defining features and safety measures to our design making it more unique and tailored to UCF.

10.1 Challenges

Based on the three main criterias UCF athletics provided we were able to break those goals further down into 41 requirements which help define and shape the outline of what our launcher should be by the end of senior design. Many of the requirements are safety requirements that will mitigate and prevent user harm, meaning anyone who will be interacting with the device directly and indirectly. Other requirements are design requirements that will ensure the launcher can be used by one person, can fire to all sections of the football stadium and will be Space-U themed to satisfy the client's demands.

10.2 Accomplishments

The single largest accomplishment for this project was establishing a strong team dynamic that led to the successful completion of every major project milestone. While the actual final product is very important, working cohesively as a team is a far greater accomplishment, as this is what will be required for all team members in their future careers. There was always open discussion on issues and solutions, and every team member felt free to make their opinion known.

The biggest challenge of our design was determining how to launch a T-shirt that could reach the football stadium's top row and making that a repeatable process. To figure that out, we needed to determine the method of launching the T-shirt, which, in the end, was compressed air, as broken down in Section 6.1, the propulsion system, which became the power system for launching T-shirts. The issue now was to find a device that could expel large amounts of compressed air in quick succession to give the launcher enough power to reach the back of the football stands, which was calculated to be around 180 feet. Our search for a pressure vessel that could fill in this criteria led the team to use a tire bead blaster, as it can expel a large amount of compressed air very fast. Using the bead blaster as our base, we attached a barrel to create our first prototype of the T-shirt launcher which we tested to find the bead blaster could launch large size T-shirts 50 to 60 yards in an open field, leading us to finally test the device in the football stadium where we found the launcher at 80 PSI, which is under the accumulator's maximum rated pressure, we can launch T-shirts out of the stadium. This solidified the core of the T-shirt launcher design as the bead blaster and met the launch distance goal.

With our prototype completed the team was successful in creating a hand held T-shirt launcher that can be operated by one user. The launch can be loaded with T-shirts of varying sizes as long as they are rolled tight enough to slide down the barrel. This also means any payload that can comfortably fit within the barrel can be fired with our launcher. This makes the launcher more versatile instead of just a device for launching T-shirts at sporting events but towels, small footballs, baseballs, tennis balls, carefully packaged food items, and other items UCF wishes to launch into the crowd to boost engagement with the fans.

Finally, after designing the launcher to meet the requirements set by UCF Athletics and the requirements created from our component and functional decompositions, our team needed to try and make sure the launcher looked uniquely designed for UCF. The accumulator tank chosen for our design has an orange tank which helped in the colors for the theme we went for to make sure the device stays within Space-U and UCF theme. To help the device have more Space-U theme, we added the SRBs, which also doubled as extra storage for T-shirts, and the cosmetic barrel to cover the PVC barrel, also acting as a protective cover for the PVC from UV damage and to hide electronics LED wiring. Other design aspectics was a custom handled with the Citronaut and UCF logo, giving the better grip to the device, a LOTO for the trigger containing a Knights design, and decals with NASA front to give a more space theme to the design while incorporating UCF’s logo and branding the device with the teams and project advisor’s name.

10.3 Shortcomings

The new issue that came into play was the Requirement F2.2, that the launcher must be able to fire a T-shirt every 15 seconds. Figuring out a reloading system for our launcher that stayed within the Space-U theme while also ensuring a sleek and non obtrusive design proved difficult as discussed in Section 6.2. While manual loading is the solution we came to for our final design, it does not provide a faster, unique or interesting design feature to complement the Space-U theme.

Another issue that came about our design that was not intended was the size of the device. In order to meet the client's Space-U rocket theme specification the launcher needed to look as close as possible to a rocket by adding side boosters, and a cosmetic barrel cover. These cosmetic additions made the launcher bulker than expected, especially the side booster as making them any smaller would not look proportional to the rocket design. In the end it made the launcher hard to maneuver especially for users that are smaller than the average person.

10.4 Recommendations and Modifications

The end product of the T-shirt launcher was a device that our team was very proud to have designed and put together. As amazing as the end product is, there are some aspects of the project that the team wished to change and modify.

The biggest change to our design would be the propulsion system, as our team was limited in time and budget due to the nature of our senior design semester being in the spring and summer semesters. In Section 6.1.1 we talked about a previous option of making an electromagnetic propulsion system as the power for our launcher, the issue with this would be the time it would take to design a completely unique T-shirt launching system, figuring out the safety logistics of said design and the cost to manufacture custom parts for this device. If the team had the time and budget to redo the project, this would likely be a feature that would be considered to explore in further detail.

Other modifications would be trying to make the design of the launcher smaller and easier to handle. This can be done by changing it so that the side boosters would act as the accumulator tanks instead of holding extra shirts, and the main body accumulator tank was changed to contain the solenoid value, electronics, and barrel. The side boosters could be custom built pressure vessels if the budget allowed, or using a simple material such as black steel pipe, which is rated for high pressures and would not be too heavy since only a small amount would be needed.

Smaller modification that could be made to the current design is adding a 90° NPT fitting to the air hose so that the hose does not stick out awkwardly from the launcher. One issue would be the analogue pressure gauge in an inconvenient position to read, which can be fixed with another 90° fitting so the pressure gauge is no longer blocked by the accumulator tank handle. Another change would be an electronic housing adjustment so that the electronics sit further back from the accumulator tank's handle, this will prevent someone's hand from hitting the electronics while holding the handle. We also found that it was hard to open the air intake valve as it required the operator to use one hand to open the valve and the other to hold the tank. Since the launcher is bulky it makes the device cumbersome to handle, so by adding an extension to the valve's handle the user could open and close the air intake with their thumb while holding the launcher with both hands would make it easier to operate and carry.

11.0 Conclusions and Recommendations

All in all, this project has given us incredible insight into the intricacies of product development and the importance of team building. Many design implementations were considered for every aspect of our final design. While most of these ideas were not used, it is important to think of the stakeholders and weigh the pros and cons of each option. Safety was our number one priority in this project, which is why we included numerous safety features and made certain design decisions. As long as the operator follows the instructions in the provided manuals, we confidently and proudly believe we have created a safe, reliable, and intuitive device that satisfies all the requirements stated in our previous documents.

For future teams assigned this project, or anyone brave enough to begin a design endeavor as intricate as this one, we have several recommendations. First, emphasize safety above all else. Ensure all components can handle the required force and pressure. Second, define clear objectives and requirements for your launcher early in the project to avoid unnecessary work. Third, use an iterative design approach, testing and refining your design based on feedback and test results. Lastly, design the launcher to be as user-friendly as possible. While you may understand the complex design, the general public may not be as technically savvy. Make troubleshooting straightforward for everyone. By following these recommendations, future teams can develop a safe, efficient, and impressive T-shirt launcher for any application.

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Appendix

A: ABET Design Competencies

ME Design Areas	Critical / Main	Strong contributor	Necessary, but not a primary contributor	Necessary, but only a minor contributor	Only a passing reference	Not included in this design project
Thermal-Fluid Energy	X					

Systems						
Machines & Mechanical Systems						X
Controls & Mechatronics		X				
Materials Selection	X					
Modeling & Measurement Systems	X					
Manufacturing	X					

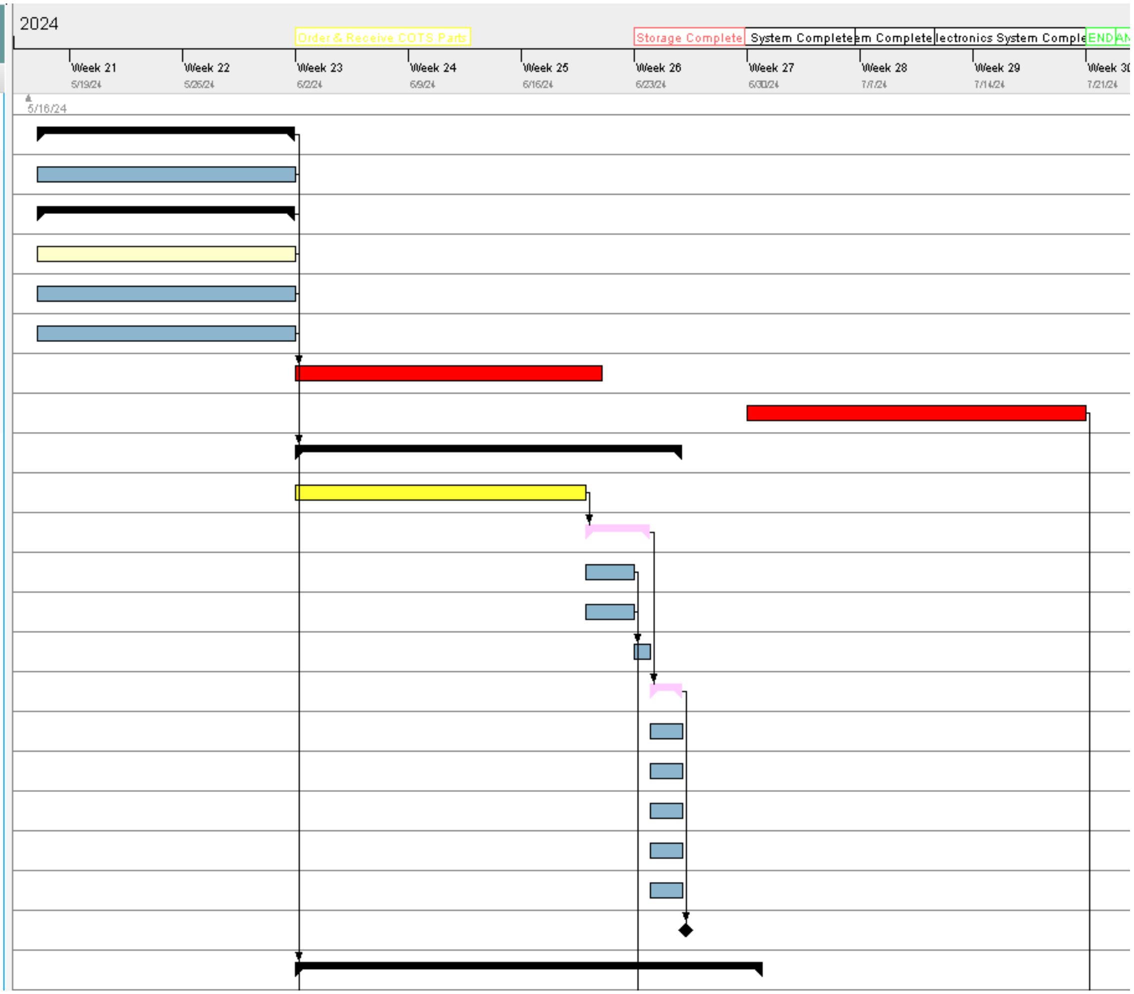
Topic	Criticality	Section	Page
Thermal-Fluid Energy Systems	Critical / Main	6.1: Propulsion System Development 7.1.5: CFD of Barrel 7.2.3: Optimal Pressure 7.3: Scuba Tank Safety Analysis 7.4: Compressor Analysis	59 138 147 154 158
Machines & Mechanical Systems	Not included	N/A	N/A
Controls & Mechatronics	Strong Contributor	4.1: Major Safety Considerations 6.3 Electronics System Development	36 79

Materials Selection	Critical / Main	7.1.3: Barrel Materials Options 7.2.1: Accumulator Materials Options 7.2.2: Pressure Vessel Materials Calculations	128 146 146
Modeling & Measurement Systems	Critical / Main	6.1.2: Propulsion System Iteration and Implementation 6.2.2: Reloading System Iteration and Implementation 6.3.2: Electronics System Iteration and Implementation 6.4: Safety System Development 6.5.2: Space-U System Iteration and Implementation 7.1.4 Barrel FEA and Factor of Safety 7.1.5: CFD of Barrel 7.2.4: Accumulator FEA and Factor of Safety	66 72 86 90 102 136 138 149
Manufacturing	Critical / Main	6.2.2: Reloading System Iteration and Implementation 6.4.2: Safety System Iteration and Implementation 6.5.2: Space-U System Iteration and Implementation	72 93 102

B: Gantt Chart

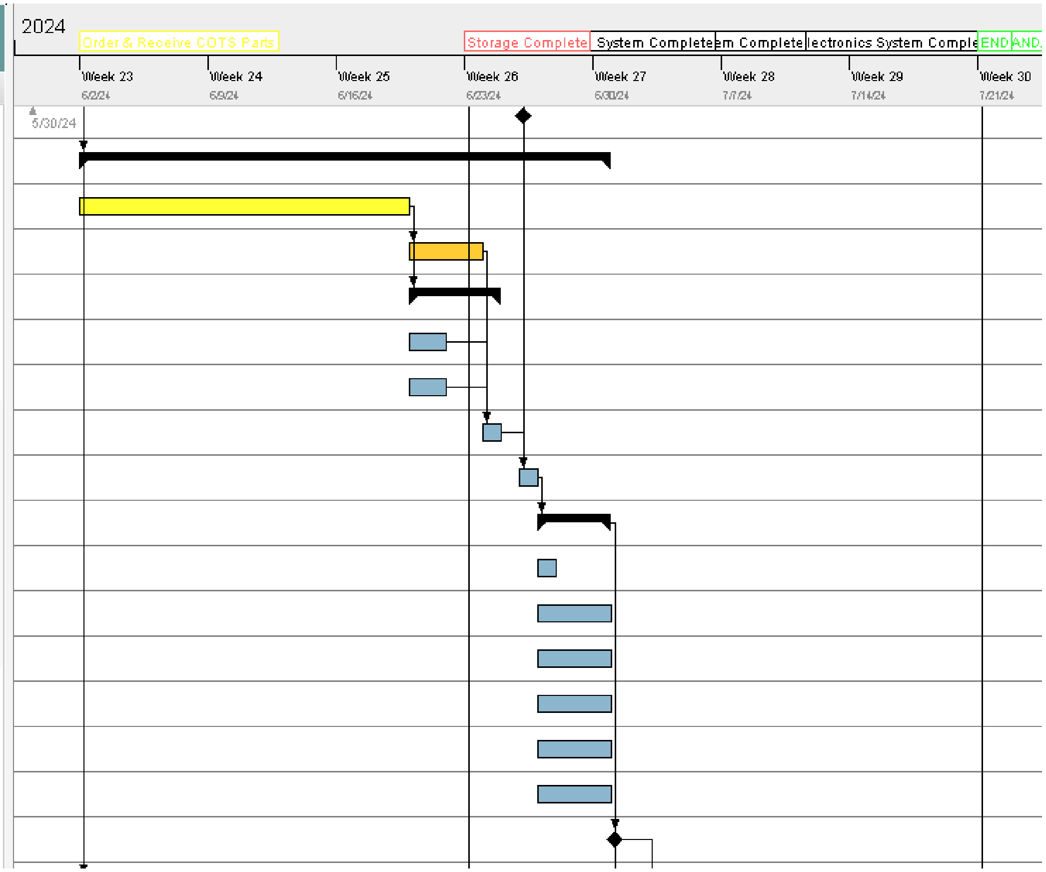
CAD Models and Propulsion System:

Name	Begin date	End date	Cost
Preliminary Analysis / Calcs	3/25/24	4/9/24	0
Final CAD Model	5/17/24	6/1/24	2,880
Final Propulsion CAD/Analysis	5/23/24	6/1/24	640
Final Electronics CAD/Analysis	5/17/24	6/1/24	960
Wiring Diagram	5/17/24	6/1/24	320
Final Reloading CAD/Analysis	5/17/24	6/1/24	640
Final Safety System Design	5/17/24	6/1/24	640
M5 Report	6/2/24	6/20/24	0
M6 Report	6/30/24	7/20/24	0
Propulsion System	6/2/24	6/25/24	1,280
Order and Receive COTS Parts	6/2/24	6/19/24	360
Assembly	6/20/24	6/23/24	440
Scuba Tank Assembly	6/20/24	6/22/24	120
Launcher Propulsion Assembly	6/20/24	6/22/24	120
Leak Test	6/23/24	6/23/24	40
Requirement Verifications	6/24/24	6/25/24	480
G5.1 - Open Space in Front of Tri...	6/24/24	6/25/24	80
G9.1 - Energy Source Refill	6/24/24	6/25/24	80
S1.1 S1.2 - Energy Readouts	6/24/24	6/25/24	80
S3.1 - Equilibrium After Discharge	6/24/24	6/25/24	80
S5.1 - Energy Release	6/24/24	6/25/24	80
Propulsion System Complete	6/26/24	6/26/24	0
Reloading System	6/2/24	6/30/24	1,880



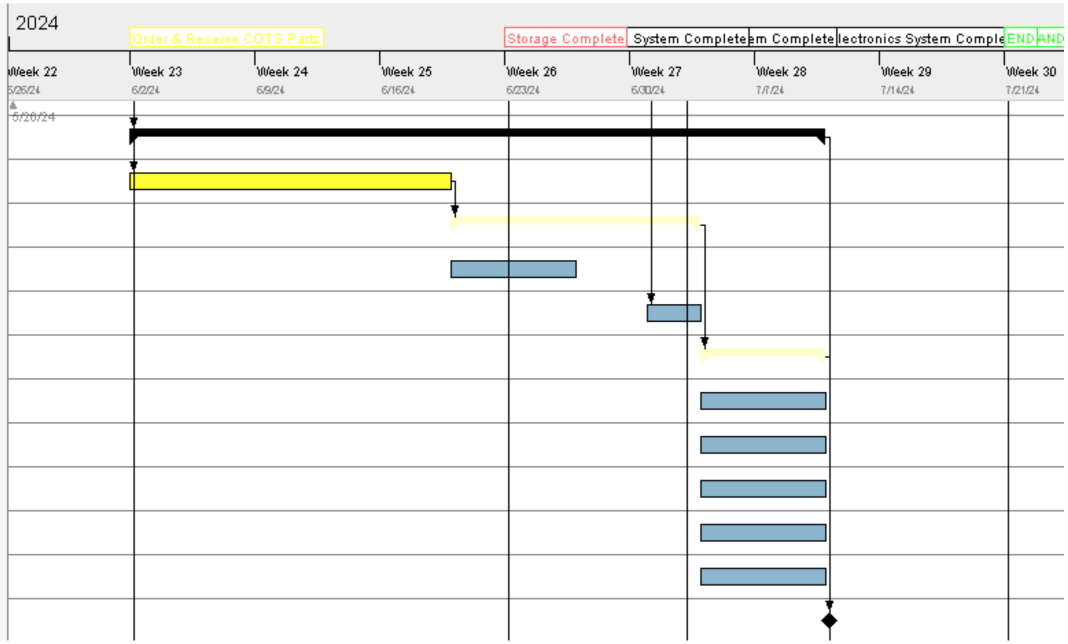
Reloading System:

Name	Begin date	End date	Cost
Propulsion System Complete	6/26/24	6/26/24	0
Reloading System	6/2/24	6/30/24	1,880
Order & Receive COTS Parts	6/2/24	6/19/24	360
3D Print Internal Bracket for Cosmet...	6/20/24	6/23/24	80
Assemble Reloading System	6/20/24	6/24/24	400
Attach PVC Pipe to 1.5 x 3 Adapter	6/20/24	6/21/24	80
Attach BSP x NPT adapter	6/20/24	6/21/24	80
Join Two Parts of Reloading System	6/24/24	6/24/24	40
Assemble Reloading & Propulsion S...	6/26/24	6/26/24	40
Requirement Verifications	6/27/24	6/30/24	1,000
F1.1 - Variable Power Control	6/27/24	6/27/24	40
F1.2 - Exit Velocity	6/27/24	6/30/24	160
F1.3 - Max Distance	6/27/24	6/30/24	160
F2.1 - Small & Medium Shirts	6/27/24	6/30/24	160
F2.2 - Fire Rate	6/27/24	6/30/24	160
F3.1 - Precision	6/27/24	6/30/24	160
Reloading System Complete	7/1/24	7/1/24	0



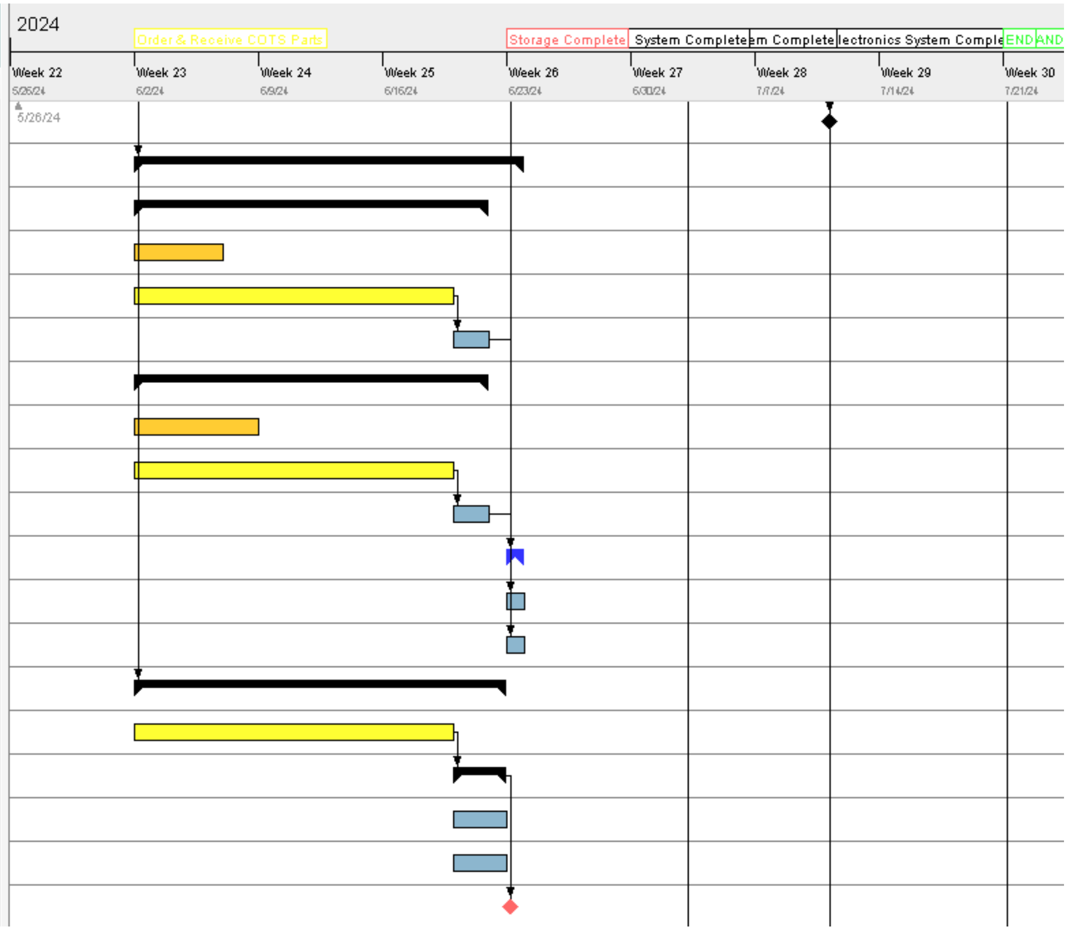
Electronics System:

Name	Begin date	End date	Cost
Electronics System	6/2/24	7/10/24	3,220
Order & Receive COTS Parts	6/2/24	6/19/24	720
Assemble Electronics	6/20/24	7/3/24	960
Wiring	6/20/24	6/26/24	280
Mounting	7/1/24	7/3/24	120
Requirements Verification	7/4/24	7/10/24	1,540
G6.1 - Sensory Indicator	7/4/24	7/10/24	280
S1.3 - Dangerous Energy Level	7/4/24	7/10/24	280
S1.4 - Read to Fire Indicator	7/4/24	7/10/24	280
S2.1 - ESD Time / Steps	7/4/24	7/10/24	280
S2.2 - ESD Electronics	7/4/24	7/10/24	280
Electronics System Complete	7/11/24	7/11/24	0

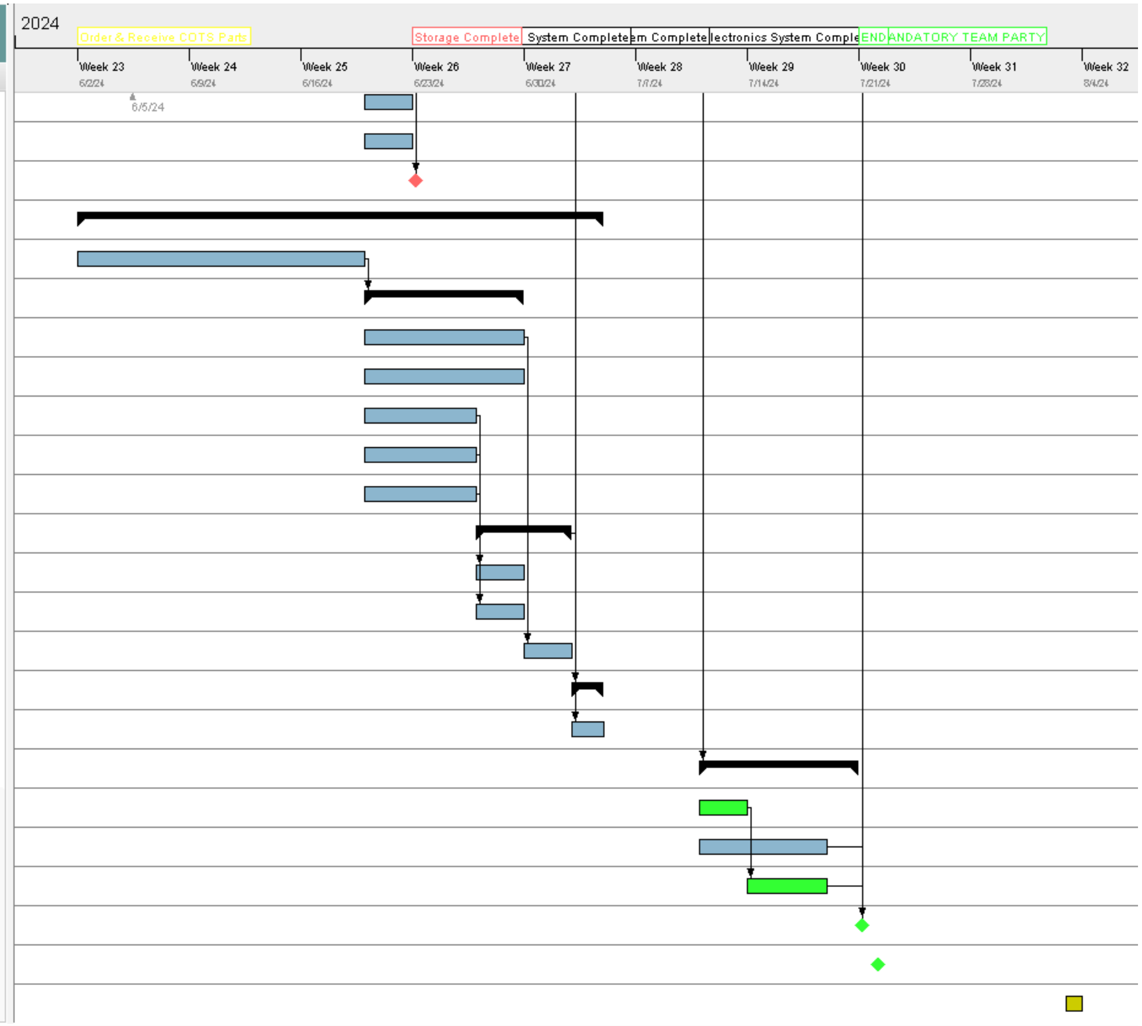


Safety and Storage Systems:

Name	Begin date	End date	Cost
Electronics System Complete	7/11/24	7/11/24	0
Safety System	6/2/24	6/23/24	2,060
LOTO System	6/2/24	6/21/24	860
3D Print LOTO Devices	6/2/24	6/6/24	100
Order & Receive COTS Parts	6/2/24	6/19/24	720
Assemble LOTO System	6/20/24	6/21/24	40
Trigger Safety System	6/2/24	6/21/24	1,040
3D Print Trigger Safety	6/2/24	6/8/24	280
Order & Receive COTS Parts	6/2/24	6/19/24	720
Assemble Trigger Safety	6/20/24	6/21/24	40
Requirement Verification	6/23/24	6/23/24	160
S4.1 - LOTO	6/23/24	6/23/24	60
S7.1 - Trigger Safety	6/23/24	6/23/24	60
Storage System	6/2/24	6/22/24	840
Order & Receive COTS Parts	6/2/24	6/19/24	720
Requirement Verification	6/20/24	6/22/24	120
ST1.1 - Dimensions	6/20/24	6/22/24	60
ST1.3 - IP Rating	6/20/24	6/22/24	60
Storage Complete	6/23/24	6/23/24	0

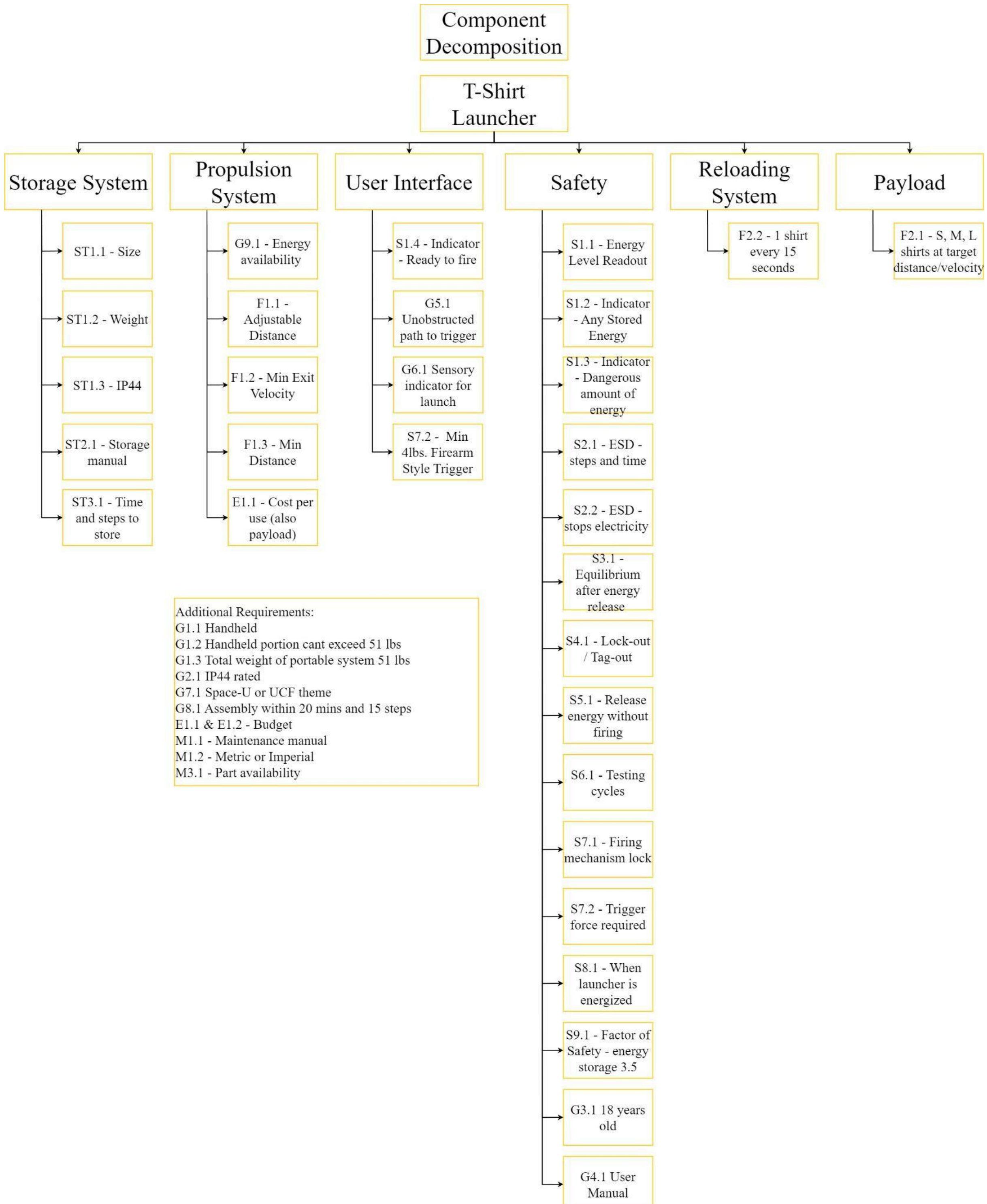


Space-U System, Final Assembly, Final Testing, and Manuals:

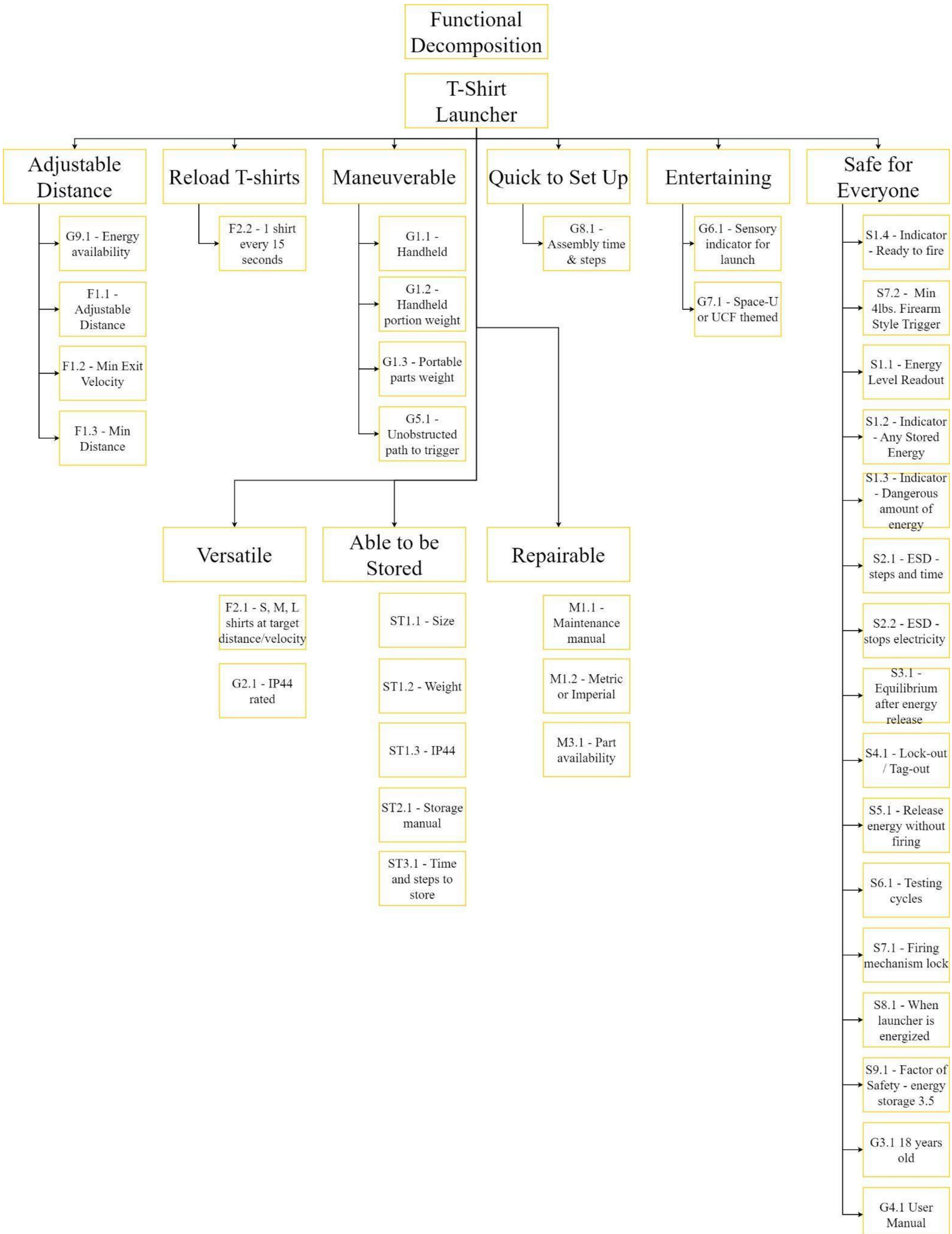


Name	Begin date	End date	Cost
ST1.1 - Dimensions	6/20/24	6/22/24	60
ST1.3 - IP Rating	6/20/24	6/22/24	60
Storage Complete	6/23/24	6/23/24	0
Space-U System	6/2/24	7/4/24	1,620
Order & Receive COTS Parts	6/2/24	6/19/24	360
Fabrication	6/20/24	6/29/24	820
3D Print Cosmetic Barrel	6/20/24	6/29/24	200
3D Print External Bracket for Cos...	6/20/24	6/29/24	200
3D Print End Caps for Side Boost...	6/20/24	6/26/24	140
3D Print Rails for Side Boosters	6/20/24	6/26/24	140
Print out Vinyl Logos for Side Boo...	6/20/24	6/26/24	140
Assembly	6/27/24	7/2/24	360
Rails	6/27/24	6/29/24	120
SRBs	6/27/24	6/29/24	120
Cosmetic Barrel	6/30/24	7/2/24	120
Integration	7/3/24	7/4/24	80
Cosmetic Barrel	7/3/24	7/4/24	80
Final Assembly & Test	7/11/24	7/20/24	1,860
Final Assembly	7/11/24	7/13/24	360
Requirement Verification	7/11/24	7/18/24	0
User Manuals	7/14/24	7/18/24	300
END	7/21/24	7/21/24	0
MANDATORY TEAM PARTY	7/22/24	7/22/24	0
GRADUATION	8/3/24	8/3/24	0

C: Component Decomposition



D: Functional Decomposition



E: System Requirements

System Requirements

Number	Requirement
G1.1	The component of the T-shirt launching system, which the operator holds to launch the T-shirts, must be handheld and operated by a single individual.
G1.2	Individual parts of the T-shirt launching system that are intended to be carried by a single individual shall not exceed 51 pounds in total.
G1.3	Individual parts of the T-shirt launching system that are intended to be carried by the user without the use of their hands, such as a backpack, shall not exceed 51 pounds, including handheld portions.
G2.1	Individual components with electronic or water-sensitive elements shall be IP44-rated.
G3.1	The launcher shall only be operated by individuals over the age of 18. This shall be stated in all included manuals.
G4.1	The T-shirt launching system shall come with a user training manual, the manual will provide comprehensive instructions on setting up the launcher, utilizing its various features during operation, and safely disassembling the equipment.
G5.1	There shall be an unobstructed path of length 3 inches in front of the activation mechanism for the launcher, allowing for use by individuals in a mascot costume.

G6.1	The T-shirt launching system shall contain a sensory indicator or effect when a T-shirt is launched.
G7.1	The T-shirt launching system shall feature visual cues or branding that indicate clear intended use specifically for UCF or Space-U.
G8.1	The T-shirt launching system shall facilitate assembly by a trained operator within 20 minutes (excluding refilling any energy sources), with no more than 15 procedural steps.
G9.1	The energy source used for propulsion shall be refilled at UCF's main campus, refilled at a location within the Orlando, FL area, or sourced from online retailers.
F1.1	The T-shirt launching system shall have a variable power control accessible to the user, allowing the user to adjust the launching distance at least 100 feet.
F1.2	The T-shirt launching system shall be capable of launching a T-shirt with a minimum exit velocity of 68.5 MPH.
F1.3	The T-shirt launching system shall be capable of launching a T-shirt a minimum of 180 feet.
F2.1	The T-shirt launching system shall be capable of launching a small, medium, and large T-shirt at the target exit velocity and distance stated in Requirements F1.2 and F1.3.

F2.2	The T-shirt launching system shall be capable of launching one T-shirt every 15 seconds.
F3.1	The T-shirt launcher shall be capable of projecting a T-shirt within a 20-square-foot area of a target when fired at a distance of 180 feet from the target.
S1.1	The T-shirt launching system shall include a readout to communicate the amount of energy that is currently stored in the system and shall be clearly labeled.
S1.2	The T-shirt launching system shall have an indicator to communicate if the system is holding ANY amount of energy (>0) and shall be clearly labeled.
S1.3	The T-shirt launching system shall have an indicator to communicate if the amount of energy stored is at a potentially dangerous level and shall be clearly labeled.
S1.4	The T-shirt launching system shall have an indicator to communicate if the system is ready to be fired and shall be clearly labeled.
S2.1	The T-shirt launching system shall have an Emergency Shut-Down mechanism (ESD) that is activated in fewer than 3 steps and within 10 seconds following initiation.
S2.2	The T-shirt launching system shall shut off all electronics upon activating the Emergency Shutdown System and shall be clearly labeled.
S3.1	The T-shirt launching system shall achieve a state of equilibrium after discharge of all energy sources, excluding energy in batteries.

S4.1	The T-shirt launcher shall incorporate a Lock-Out / Tag-Out system to prevent unauthorized operation.
S5.1	The T-shirt launching system shall be capable of releasing all stored energy without the need to fire a projectile, excluding batteries.
S6.1	The T-shirt launching system shall withstand 75 cycles of testing with no failures.
S7.1	The T-shirt launching system shall have a method to lockout the mechanism used to fire the launcher, preventing an accidental discharge.
S7.2	If a traditional firearm-style trigger is used, the trigger shall require a minimum of 4 pounds of force to activate.
S8.1	The T-shirt launching system shall be energized no earlier than 3 steps before the launcher is ready to be used.
S9.1	Any energy storage devices, excluding batteries, shall adhere to a minimum safety factor of 3.5.
ST1.1	If a storage system is in place, individual pieces of the storage system for the T-shirt launching system should not exceed 50 inches in any direction.
ST1.2	If a storage system is in place, individual containers shall not exceed 51 pounds, including device weight.
ST1.3	If a storage system is in place, individual containers shall be IP44-rated.

ST2.1	A storage and transportation manual shall be included with the T-shirt launching system. The manual shall clearly state the launcher is not to be in possession of individuals under the age of 18. The manual shall also include how to package the launcher for storage, how to release the energy for storage, and how to safely transport the launcher to its destination.
ST3.1	The T-shirt launcher shall support disarming and disassembly ready for storage within 20 minutes, and no more than 15 procedural steps.
M1.1	A maintenance manual shall be included with the T-shirt launching system. The manual shall clearly state the launcher is not to be in possession of individuals under the age of 18. The maintenance manual shall also include how to take apart the launcher, how to clean the launcher, and how to replace parts on the launcher.
M2.1	The hardware used to construct the T-shirt launching system shall cohere to a single system of units, Metric or Imperial.
M3.1	All commercial off-the-shelf (COTS) materials should be accessible within the Orlando, FL area or purchased online with reliability (product is received).
E1.1	The cost to refill the energy source in between uses and package the payload shall not exceed a dollar amount to be determined by the UCF Athletics Department.

E2.1 The total cost to manufacture the T-shirt launcher shall not exceed the budget levied by UCF Athletics and the UCF Department of Mechanical and Aerospace Engineering.

F: Concept Selection Rating Scales

Propulsion Method Ratings

Rating	**Safety (OSHA)**	**Energy Capacity (No. of Shots)**	**No. of Moveable / Consumable Parts**	**Weight (Pounds)**	**Build Cost ($)**
1	High risk, significant safety concerns	0 - 5	7 +	31 - 40	500 +
2	Moderate	6 - 10	5 - 6	21 - 30	376 - 500

	risk, some safety concerns				
3	Low risk, moderate safety concerns	11 - 15	3 - 4	11 - 20	250 - 375
4	Small risk, minimal safety concerns	16 +	0 - 2	0 - 10	< 250

Fluid Type Ratings

Rating	**Safety (PSI)**	**Refill Cost ($)**	**Refill Location (miles)**	**Initial Cost ($)**	**Density (lb / ft^3)**
1	4500 +	11 +	11 +	226 - 300	0.03 - 0.05
2	3000 - 4500	6 - 10	6 - 10	151 - 225	0.05 - 0.07
3	1500 - 3000	1 - 5	1 - 5	76 - 150	0.07 - 0.09
4	0 - 1500	Free	At UCF	0 - 75	0.10 +

Reloading Mechanism Ratings

Rating	**Safety (No. of Hazards)**	**Time Between Shots (Seconds)**	**Magazine Capacity**	**Number of Parts**
1	4 +	9 +	1	5 +
2	3	6 - 8	2 - 3	3 - 4
3	2	3 - 5	4 - 5	1 - 2
4	1	< 2	6 +	0

User Interface Ratings

Rating	Safety (% error)	Cost ($)	Build Time (Weeks)	Easy to Read & Interpret
1	> 10	76 +	< 4	Not easy to interpret
2	6.01 - 9.99	51 - 75	< 3	Relatively easy to interpret
3	2.01 - 6	26 - 50	< 2	Mostly easy to interpret
4	< 2	< 25	< 1	Anyone can interpret

Launching Indicator Ratings

Rating	Safety	Simplicity & Reliability (No. of Parts)	Exciting	Cost ($)
1	Severe Safety Risk	4 +	This makes me wish I went to USF	31 +
2	Moderate Safety Risk	3	Attracts attention	21 - 30
3	Some Safety	2	Exciting and	11 - 20

	Risk		attracts attention	
4	No Safety Risk	1	Very exciting and attracts attention	< 10

Storage System Ratings

Rating	Weight (Pounds)	Cost ($)	Environment Sensitivity (IP Rating)	Carrying Capacity (Pounds)
1	> 31	36 +	IP00 - IP11	< 20
2	21 - 30	26 - 35	IP11 - IP22	21 - 30
3	11 - 20	16 - 25	IP22 - IP33	31 - 40
4	0 - 10	< 15	IP33 +	> 41

<u>G: Prototype Cement Testing Procedure</u>

1. Cut 6” of Schedule 40 3” PVC pipe.
    a. A small section of pipe will allow the vessel to be more rapidly pressurized and depressurized, better mimicking the actual loading the barrel will undergo. Additionally, 3” PVC is used as that is the maximum barrel diameter, and will be subject to the most force.

2. Gather two 3” Schedule 40 end caps, shown in Figure G1.

Figure G1: Schedule 40 End Caps

3. On one end cap, drill two 7/16 holes through the cap, shown in Figure G2.
    a. Deburr the holes using 320 grit sandpaper.
    b. Tap the holes using a ¼ NPT tap.

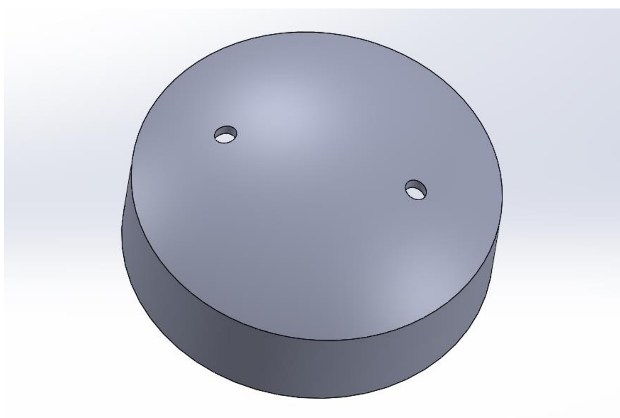


Figure G2: End Cap with Holes

4. Thoroughly rinse the drilled PVC with a hose to remove any shards, dust, etc., and let air dry. Do not dry in the sun.
5. Wrap two male NPT quick connect fittings with 3 passes of PTFE tape.

   a. Screw NPT quick connects into the two holes of the PVC. Secure on the inside using nuts.
6. Per PVC cement instructions, chamfer the end of the 6” section of pipe using a file.
7. Install the non-drilled end cap to the PVC pipe per cement instructions:
   a. Using the supplied brush, apply a thick, even coat of cement to the outside of the PVC pipe section to the depth of the edge of the PVC end cap.
   b. Using the supplied brush, apply a thin, even coat to the flat mating surface on the inside of the PVC cap.
   c. Apply a second, thin coat to the outside of the pipe section, recovering the initial thick coat.
   d. Place the PVC pipe on level ground, with the cemented side facing up.
   e. Press the end cap onto the PVC pipe. Once fully seated, turn the cap ¼ turn. Maintain full pressure on the end cap for 30 seconds.
   f. Wipe off excess cement from the outside of the pipe.
8. Add ¼ cup of dish soap to the inside of the PVC vessel with the one end cap.
9. Repeat step 7 to install the end cap with the NPT adapters.
10. Allow the cement to cure for at least 2 hours, per PVC cement instructions.
11. Connect two 25’ pneumatic hoses to the male quick connects.
12. Place the vessel in a clear bucket with the NPT fittings and hoses facing up, fill the bucket with water, and ensure the vessel is submerged using a weighted belt.
13. Connect one of the air hoses to a closed ball valve.
14. Connect the other end of the hose to a ball valve that is attached to a male NPT quick connect fitting. The total setup is shown in Figure G3.

a. Connect this end to a compressor that is at least 25’ away and set to 144 PSI, which is a 20% increase over the rating for the pressure relief valve on the accumulator.

b. Lean a piece of plywood against the compressor facing the vessel. This will act as a barrier between the vessel and people conducting the test.

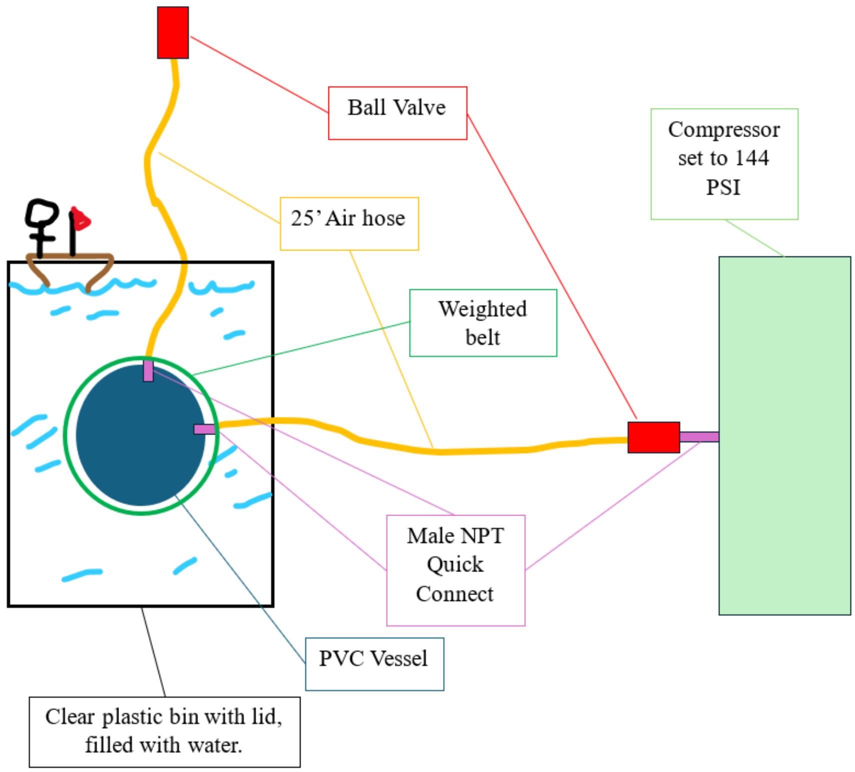


Figure G3: PVC Cement Test Setup

15. Place the bin at the location shown below in Figure G4. Wheel the compressor 25’ away and place the plywood leaning on the compressor. Route the second air hose back to the compressor. The closest objects to the pressure vessel are:

a. Pool screen 32’ away

b. House 38’ away

c. Fence directly behind the vessel, with a line of trees, and then open land.

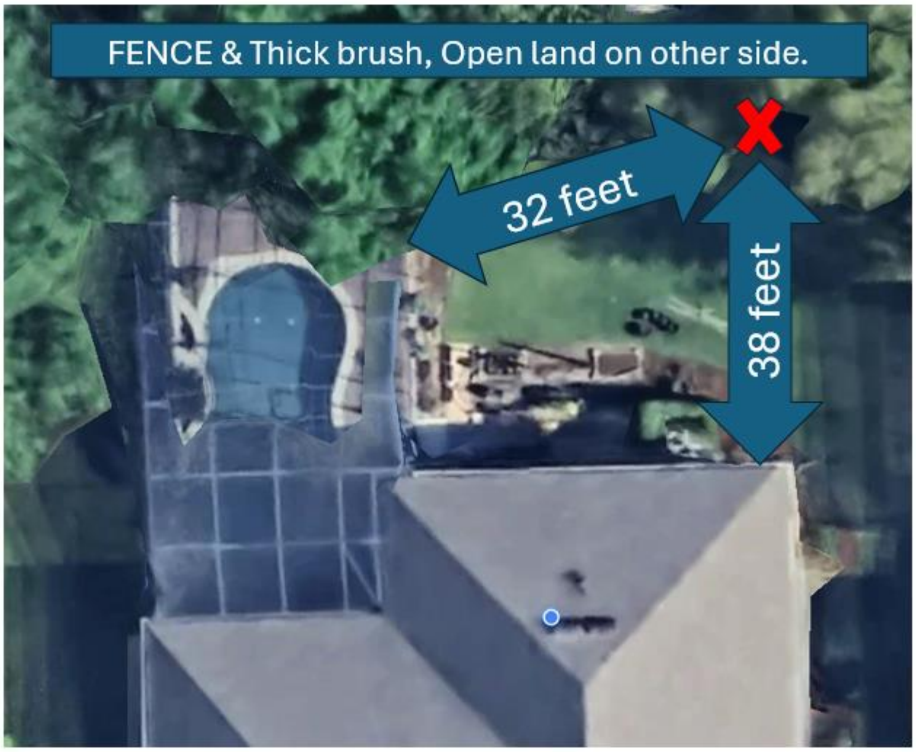


Figure G4: PVC Test Location

16. Once everything is in place:
    a. Quickly open the ball valve connected to the compressor. Close after 2 seconds.
    b. Immediately open the ball valve that is connected to the free hose to release the air.
    c. Repeat this 5 times.
17. After the 5th test, approach the vessel and observe if there are any soap suds in the water. If there are suds, stop the test and record the number of trials.
18. If there are no suds, repeat steps 16 and 17 a total of 20 times, for a total of 100 cycles.
19. After testing, remove and dry the male NPT quick connect fittings to eliminate the risk of any corrosion forming.

Additional comments about testing:

- Safety glasses will be worn at all times.
- Soap is used as it is environmentally friendly, and will not harm anything if it gets on the ground.

H: Expense Report

	A	B	C	D	E	F	G
1	Description	Already Have SD Inventory SD Purchase	Vendor	Link	Price	QTY	Total Price
2	Pancake Compressor	Inventory	Inventory / Already…			1	
3	Scuba Tank (30 cu ft)	UCF Purch…	Amazon	https://www.an	$189.99	1	$189.99
4	Scuba to NPT Adapter	UCF Purch…	Amazon	https://www.an	$89.95	1	$89.95
5	150 PSI Regulator	Team Purc…	Inventory / Already…	https://www.ha			
6	Recoil Hose Kit	UCF Purch…	Home Depot	https://www.ho	$14.60	1	$14.60
7	Bead Blaster	Already Have	Inventory / Already…	https://www.an			
8	1/4 BSP to NPT	UCF Purch…	Amazon	https://www.an	$7.99	1	$7.99
9	1/4 NPT Tee Fitting	UCF Purch…	Home Depot	https://www.ho	$3.98	1	$3.98
10	1/4 A Pressure Gauge	Inventory	Inventory / Already…	https://www.gr			
11	1/4 to 1/8 NPT Adapter	UCF Purch…	Home Depot	https://www.ho	$3.97	1	$3.97
12	5v 1/8 0-100PSI Transducer	UCF Purch…	Amazon	https://www.an	$19.99	1	$19.99
13	Wiring	UCF Purch…	Amazon	https://www.an	$14.35	1	$14.35
14	Arduino Uno	Inventory	Inventory / Already…	https://store-us			
15	Portable Charger	UCF Purch…	Amazon	https://www.an	$19.99	1	$19.99
16	Arduino Display	UCF Purch…	Amazon	https://www.an	$13.49	1	$13.49
17	5v LED Lights	UCF Purch…	Amazon	https://www.an	$6.99	1	$6.99
18	LOTO Locks	UCF Purch…	Amazon	https://www.an	$7.55	1	$7.55
19	Orange PETG Filament	UCF Purch…	Amazon	https://www.an	$13.99	2	$27.98
20	1.5" BSP to NPT	UCF Purch…	McMaster	https://www.m	$22.10	1	$22.10
21	3" x 2 ft Pressure Rated PVC	UCF Purch…	Home Depot	https://www.ho	$13.96	1	$13.96
22	1.5 x 3" PVC Adapter	UCF Purch…	Home Depot	https://www.ho	$7.61	1	$7.61
23	1.5" Female Threads to Slip PV(	UCF Purch…	Grainger	https://www.gr	$2.62	1	$2.62
24	PVC Glue	Already Have	Inventory / Already…	https://www.lo			
25	Painters Tape	UCF Purch…	Amazon	https://www.an	$5.99	1	$5.99
26	Micro SD Card	UCF Purch…	Amazon	https://www.an	$6.38	1	$6.38
27	Clear 5/16 Tube	Already Have	Inventory / Already…	https://www.ho			
28	Range Finder	Inventory	Inventory / Already…				
29	White PETG Filament	UCF Purch…	Amazon	https://www.an	$14.99	1	$14.99
30	T-Shirts	UCF Purch…	Amazon	https://www.an	$18.48	1	$18.48
31	Christmas Tree Storage Bag	UCF Purch…	Amazon	https://www.an	$16.99	1	$16.99
32	Coil Keychain	UCF Purch…	Amazon	https://www.an	$4.89	1	$4.89
33	Remove Before Flight Keychain	UCF Purch…	Amazon	https://www.an	$4.40	1	$4.40
34	#10-24 Heat Set Inserts	UCF Purch…	Amazon	https://www.an	$10.99	1	$10.99
35	#10-24 Allen Cap Machine Scre	UCF Purch…	Lowes	https://www.lo	$2.48	2	$4.96
36	#10-24 Phillips Machine Screws	UCF Purch…	Lowes	https://www.lo	$1.48	2	$2.96
37	#10 Flat Washers	Already Have	Lowes	https://www.lo	$1.48	1	$1.48
38							
39						Total	$559.62

I: System Evaluation Test Plans

G1.1 Procedure:

- Materials: Completed T-shirt launcher
- Procedure:
    1. Each team member must:
        a. Hold the launcher in a resting position.
        b. Retrieve a T-shirt from one of the SRBs.
        c. Load the T-shirt.
        d. Fill the accumulator tank to 80 PSI.
        e. Launch the T-shirt

G1.2 Procedure:

- Materials: Completed T-shirt launcher, scale
- Procedure:
    1. Place completed T-shirt launcher on scale. This is only the handheld portion.
    2. Record the weight on the scale.
    3. Repeat Steps 1 and 2 for a total of three trials.
    4. Average the three recordings to find the final weight.

G2.1 Procedure:

- Materials: Completed T-shirt launcher, 1 mm diameter wire, garden hose
- Procedure (Solid Foreign Objects):
    1. Attempt to insert the 1 mm diameter wire into critical components of the launcher, including:
        a. Pneumatic fittings
        b. Electronics
        c. Points where the barrel is joined
        d. Valve
- Procedure (Water):
    1. Turn the garden hose to the shower setting.
    2. Stand 5 feet away from the completed launcher.
    3. Using a back and forth motion, shower the launcher for 5 seconds.
    4. Verify the electronics still function properly and no water penetrated the pneumatic fittings.

G5.1 Procedure:

- Materials: Ruler, propulsion system
- Procedure:
    1. Place the propulsion system on a flat surface.
    2. Place the ruler in front of the trigger mechanism.
    3. Record the distance to the nearest obstruction directly in front of the trigger.

G6.1 Procedure:

- Materials: Completed T-shirt launcher
- Procedure:
    1. Fill the accumulator tank to 15 PSI, loaded T-shirts are not necessary.
    2. Fire the launcher and observe if the LED indicators turn on.
    3. Repeat Steps 1 and 2, increasing the pressure by 15 PSI until 75 PSI is reached.
    4. If the LED indicators turn on all five times, the requirement is satisfied.

G7.1 Procedure:

- Materials: Completed T-shirt launcher
- Procedure:
    1. Take photos of the launcher, ensuring to include all UCF and Space-U branding.
    2. Send an email to Pete Alfieris asking for his approval of the final design.

G8.1 Procedure:

- Materials: Completed T-shirt launcher, user manual, stopwatch
- Procedure (Time)
    1. Have all components of the T-shirt launcher and tools present.
    2. Have a trained user, such as a team member, assemble the launcher from its storage state to its ready to use state. Time this on a stopwatch.
    3. Report the recorded time.
- Procedure (Steps)

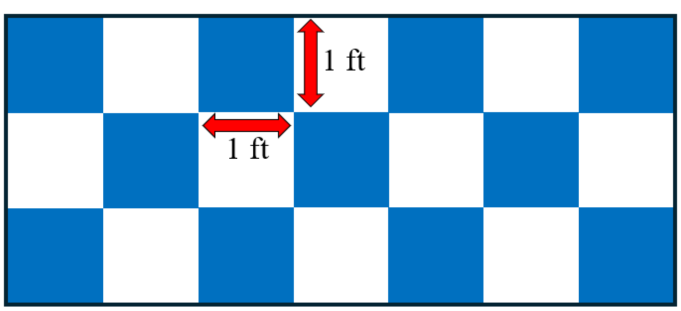
1. Review the user manual and count the number of steps listed to take the launcher from a storage state to a ready to use state.

F1.1 Procedure:

- Materials: Completed propulsion and reloading systems, rangefinder
- Procedure:
    1. Load a T-shirt into the barrel.
    2. Fill the accumulator tank to 80 PSI.
    3. Using an approximately 55° launch angle, launch the T-shirt. Using the rangefinder, record the distance to its resting point.
    4. Repeat the previous steps two more times, for a total of three trials. Average the distances.
    5. Repeat the previous steps at 10 PSI.
    6. Compare the average distance at 80 PSI and 10 PSI to find the difference in range.

F1.2 Procedure:

- Materials: Completed propulsion and reloading systems, camera, checkerboard (shown below)



- Procedure:
    1. Load a large T-shirt into the launcher.
    2. Fill the accumulator tank to 115 PSI.
    3. Hold the launcher horizontal to the ground, while another person holds the cardboard so it lines up with the end of the barrel.
    4. Fire the launcher, and record the launch using a slow motion camera.
    5. Find the exit velocity using the equation below, where *x* is the distance in ft, and *t* is the time between frames, in seconds.

$$v = \frac{x}{t} \cdot \frac{3600}{5280}$$

    6. Repeat the previous steps for a total of three trials, and find the average exit velocity.

F1.3 Procedure:

- Materials: Completed propulsion and reloading systems, rangefinder
- Procedure:
    1. Load a large T-shirt in the launcher. Fill the accumulator tank to 115 PSI.
    2. Launch the T-shirt using an approximately 55° launch angle.
    3. Use the rangefinder to record the launch distance.
    4. Repeat the previous steps for a total of 10 trials, and find the average launch distance.

F2.1 Procedure:

- Materials: Completed propulsion and reloading systems, rangefinder, checkerboard, camera
- Procedure:
    1. Complete Requirements F1.2 and F1.3 using a small and medium T-shirt.

F2.2 Procedure:

- Materials: Completed T-shirt launcher, stopwatch
- Procedure:
    1. Have a trained user, such as a team member, hold the launcher in a normal position. Ensure there is no T-shirt loaded and the accumulator tank is empty.
    2. Have another team member start a stopwatch.
    3. When instructed, the user will:
        a. Load a T-shirt in the barrel.
        b. Fill the accumulator to 40 PSI. This represents an average value the launcher might see during normal use.
        c. Launch the T-shirt
    4. The user will repeat step 3 a total of six times.
    5. The time to perform six launches will be recorded, stopping when the trigger is pulled for the sixth launch.

F3.1 Procedure:

- Materials: Completed propulsion and reloading systems, rangefinder, tape measure
- Procedure:
    1. Place a target, such as a cone, 180 feet from the launching location.
    2. Using repeated trials, determine the accumulator tank pressure and launch angle that corresponds to an approximate launch distance of 180 feet. Once the user is comfortable reaching the target, proceed.
    3. Launch 10 T-shirts using the determined pressure and launch angle and leave the T-shirt at their landing location.
    4. Using the tape measure, determine if a 400 square foot area can surround 8 of the 10 launched T-shirts. The area does not have to be a square.

S1.1 Procedure:

- Materials: Completed propulsion system, compressor with gauge
- Procedure (Accumulator):
    1. Connect the accumulator to an air compressor set to 0 PSI.
    2. Using the knob, increase the output pressure of the air compressor to 10 PSI. Record the reading on the pressure gauge of the accumulator.
    3. Increase the pressure in 10 PSI increments, until 80 PSI is reached, recording the accumulator tank pressure at each increment
- Procedure (Scuba Tank)
    1. Take the scuba tank to a dive shop and have the tank filled to its operating pressure.

2. Once fully cooled, have the dive shop connect a gauge and record the tank pressure.
3. Using the scuba to NPT adapter, verify the pressure in the tank and compare it to the pressure recorded by the dive shop.

S1.3 Procedure:

- Materials: Completed propulsion and electronics system
- Procedure:
    1. Turn on the electronics system and connect the accumulator tank to a source such as an air compressor.
    2. Fill the accumulator to just below 80 PSI.
    3. Continue to fill the accumulator over 80 PSI, and verify that the display shows a warning after 80 PSI is surpassed.

S1.4 Procedure:

- Materials: Completed propulsion and electronics systems
- Procedure:
    1. Pressurize the accumulator tank to just below 10 PSI.
    2. Continue to fill the accumulator tank past 10 PSI, and observe if the red LED indicator turns on once 10 PSI is reached and remains on.

S2.1 Procedure:

- Materials: Completed propulsion and electronics systems, stopwatch
- Procedure (Steps):
    1. Review the user manual and verify the number of steps to shut down the launcher is 3 or less.
- Procedure (Time):
    1. Fill the accumulator tank to 40 PSI and turn on the electronics system.
    2. When instructed, the user will shut down the launcher in accordance with the user manual.
    3. Another team member will time how long these steps take.

S2.2 Procedure:

- Materials: Completed electronics system,
- Procedure:
    1. After shutting down the launcher in accordance with the manual, verify that:
        a. All LED lights are off.
        b. The Arduino display is off.
        c. There is no power to the Arduino. Use a multimeter to probe the Arduino and confirm there is no voltage.

S3.1 Procedure:

- Materials: Completed propulsion system, scuba tank
- Procedure:
    1. Connect the scuba tank to the accumulator tank.
    2. Adjust the knob on the regulator to read 120 PSI.
    3. Open the ball valve on the accumulator tank, allowing it to be filled.
        a. The tank will fill and the pressure relief valve will open at 120 PSI, letting air out. Let this repeat until the pressure relief valve no longer opens.
    4. Fully open the regulator and hold open the pressure relief valve to let the remaining air out of the system.
    5. Once the air stops, record the reading of the pressure gauges on the accumulator and scuba tanks.

S4.1 Procedure:

- Materials: Completed propulsion and safety systems
- Procedure (Trigger LOTO):
    1. Install the trigger LOTO and lock it in place.
    2. Fill the accumulator tank to 20 PSI. Attempt to pull the trigger.
    3. Repeat Step 2 at 40, 60, and 80 PSI. If no air is released through the valve, the trigger LOTO is functional.
- Procedure (Air Inlet LOTO):
    1. Place the air inlet LOTO over the valve and lock it in place.
    2. Verify the accumulator tank cannot be filled with air when the LOTO is in place.

S6.1 Procedure:

- Materials: Completed propulsion and reloading systems
- Procedure:
    1. Complete this verification after all other requirements have been verified.
    2. Once the propulsion and reloading systems are completed and joined, begin to count the number of shirts launched throughout testing.
    3. Once all other testing is complete, subtract the number of launches from 450 to determine the remaining required launches.
        a. One cycle is defined as 6 shots, as the team intends for the launcher to launch 6 T-shirts during a 90 second commercial break.
    4. Fire the launcher until 450 T-shirts have been launched.

S7.1 Procedure:

- Materials: Completed propulsion and safety systems
- Procedure:
    1. Attach the trigger safety, not the LOTO, to the trigger.
    2. Fill the accumulator tank to 20 PSI. Attempt to pull the trigger.
    3. Repeat Step 2 at 40, 60, and 80 PSI, ensuring no air escapes through the valve.

S8.1 Procedure:

- Materials: Completed user manual
- Procedure:
    1. Review the user manual and ensure there are no more than 3 steps between when the accumulator tank is filled and a T-shirt is launched.

ST1.1 Procedure:

- Materials: Completed storage system, tape measure
- Procedure:
    1. Using the tape measure, measure the widest point of the storage system in each direction and record the results.
    2. Alternatively, provide documentation from the manufacturer or purchase location of the dimensions.

ST1.2 Procedure:

- Materials: Completed T-shirt launcher and storage system, scale
- Procedure:
    1. Place the storage container on a scale and record the weight.
    2. Repeat Step 1 for a total of three trials, and find the average weight.

ST1.3 Procedure:

- Materials: Completed storage system, 1 mm diameter wire, garden hose
- Procedure (Solid Foreign Objects):
    1. Attempt to insert the 1 mm diameter wire into the storage system.
- Procedure (Water):
    1. Turn the garden hose to the shower setting.
    2. Stand 5 feet away from the storage container.
    3. Using a back and forth motion, shower the storage container for 5 seconds.
    4. Dry the outside of the container.
    5. Open the container and observe if any water is present.

ST3.1 Procedure:

- Materials: Completed launcher and storage systems, stopwatch
- Procedure (Time):
    1. Have the assembled launcher, storage system, and necessary tools present.
    2. Have a trained user, such as a team member, disassemble the launcher and place it in storage in accordance with the manual.
    3. Record and report the time.
- Procedure (Steps):
    1. Review the storage and transportation manual and count the number of steps listed to take the launcher from a use state to a storage state.

J: User Manual

User Manual

UCF Athletics T-Shirt Launcher

Black Team

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August 2nd, 2024

UCF | Mechanical and Aerospace Engineering

UNIVERSITY OF CENTRAL FLORIDA

Table of Contents

1.0 Introduction

This user manual will highlight and include: how to safely operate the launcher, its capabilities, key features, and other useful information.

1.1 Purpose and Overview

This t-shirt launcher is named Gemini 28-80, the Gemini 28-80 was designed and built by a team of UCF Mechanical Engineering students featuring top quality products with an intention to elevate crowd entertainment and involvement in sporting events such as football games. With a sleek rocketship design, the Gemini 28-80 not only serves as a crowd entertainment tool, but a symbol of UCF Engineering, dedication, commitment, and passion of our university. The device is intended to bring excitement and energy to any sporting event or gathering.

Figure J1: Gemini 28-80

1.2 Key Features

Pressurized Accumulator Tank: The core of the Gemini 28-80 is its pressure tank. This component provides powerful launching capabilities to propel T-shirts long distances into crowds with remarkable accuracy. Under optimal conditions, this can be filled to 110 PSI and fire a T-shirt up to 288 feet. However, it is only recommended to fill this tank to 80 PSI in its typical use conditions for maximum effectiveness. This is the modular component of the device that allows for all attachments and adjustments to be made.

Figure J2: Accumulator Tank

Battery-Powered Pressure Indication System: The Gemini 28-80 comes equipped with a simple, yet intuitive and practical electrical system that allows the user to monitor the device. This gives the operator capability to read real-time pressure levels, and includes safety warnings to prevent over-pressurization. This component not only enhances the safety of Gemini 28-80, but provides a user-friendly interface to allow convenient indication of operating conditions.

Figure J3: Digital Display

Trigger Safety: The launcher includes a trigger safety attachment that prevents accidental firing. This ensures that the launcher can only be fired intentionally which provides an extra layer of safety to the overall design.

Figure J4: Trigger Safety

Lockout-Tagout System: For added safety, the Gemini 28-80 comes with a lockout-tagout system. This is a two-piece mechanism that latches over the trigger and pressure hookup to prevent access to the device when not in use. When utilized, this provides an ultimate safety measure when in storage or maintenance.

Portable Scuba Tank and Air Compressor: Included with the launcher are a scuba tank and small portable pancake compressor. These inclusions are meant to provide the user with options on portability and ease of use with the design. These allow freedom of motion in any environment and removes the necessity of a static air compressor unit and hose.

Cosmetic Rocket Ship Design: Aside from technical additions and specifications, the Gemini 28-80 is designed to resemble a rocket ship. This unique aesthetic enhances the experience during usage as it will stand out at any sporting event and represent UCF to all students and faculty who are in view.

2.0 Safety Instructions

Safety while operating the Gemini 28-80 is the most important practice when considering the components involved with its functionality. Ensure to periodically review these safety precautions to familiarize yourself with proper safety procedures when using the device.

2.1 General Safety Precautions

Please handle with caution, always treat the launcher with care. Never point the launcher at any people, animals, or targets you don’t intend to shoot. Operators should consider the use of protective gear such as gloves and glasses to safeguard against any accidental discharges or nearby debris.

2.2 Specific Warnings and Cautions

Pressurization: Do not pressurize the accumulator tank before you are ready to fire. Over-pressurization can be **extremely dangerous**. Always monitor the pressure levels of the accumulator tank and ensure to check for any malfunctions on the digital display or electrical system.

Figure J5: Digital Display Pressure Warning Symbol

Pressure Vessels: The Gemini 28-80 includes a 3000 PSI scuba tank and a portable pancake air compressor. Please handle these pressure vessels with caution as improper and unsafe handling may lead to severe injuries. Never fill the scuba tank to over 2140 PSI. This is for the added safety of the user, fans, and anyone nearby.

Close Range Firing: Never fire the launcher at anything under 30 feet. The force of a projectile at this distance may cause serious injury or damage to property. Always ensure a safe distance between you and the target before firing. Increase the launch angle for close targets.

2.3 Emergency Procedures

Depressurization: The first step in any malfunction or strange event should be to depressurize the accumulator tank. Immediately pull the discharge port on the side of the accumulator tank to release the pressure. After depressurization, engage the trigger safety and remove the projectile from the barrel. Now, disconnect the arduino USB and disconnect the LED USB to prevent any accidental damage to electrical components.

Figure J6: Pressure Relief Valve

Malfunction Protocol: In the event of a malfunction, it is most important to remain calm. The first step should always be depressurization, after following proper steps to disengage the device as highlighted above, it is then safe to carry out any operations to fix the malfunction. If any maintenance is required, the lockout-tagout system must be engaged.

Pressure Hose Removal: Always remember to remove the pressure hose from the Gemini 28-80 before attempting to perform any maintenance or inspect any pieces of the device.

2.4 Handling and Maintenance

Safe Handling: Always ensure the device is aimed in a safe direction when handling or preparing to fire. Never aim the T-shirt launcher at an unintended target. Never leave the T-shirt launcher sitting in an upright position for extended periods of time as depicted in Figure 1.

Routine Maintenance: Regularly inspect the launcher for any wear or damage. Ensure special attention to the accumulator tank and any fittings that are attached to the tank. Always ensure all components are in working order before using Gemini 28-80. Please refer to the separate Maintenance Manual for more detailed maintenance needs.

3.0 Parts and Components

Gemini 28-80 is composed of several key sections. These sections are separated into four main components. The barrel section, the cosmetic section, the accumulator tank section, and the electronics section. These sections will be discussed in this portion of the manual and describe the effects and implementation of them.

3.1 Cosmetics

This section gives the t-shirt launcher its unique rocket ship design and appearance. This section promotes school spirit and enhances user experience. The cosmetic section attaches to the barrel of the launcher in three separate pieces that are latched together securely. The side booster sections are additionally attached to the accumulator tank using strengthened two-way tape, completing the rocket ship look.

3.2 Accumulator Tank

The accumulator tank is one of the core components of Gemini-28-80. This component is responsible for storing and delivering pressurized air to the barrel, launching the T-shirts. It is a large pressure vessel designed with modularity to fit all other components in the device. The functionality of this unit consists of holding pressurized air necessary for launching the T-shirt and ensuring a stable delivery of force and efficiency in its performance.

3.3 Barrel

The barrel is where the T-shirts are loaded and launched. The barrel is a large PVC pipe that is designed to handle the pressure and force required to launch the T-shirt. This barrel is an attachment to the accumulator tank, via a threaded adaptor to ensure a secure and airtight connection.

3.4 Electronics

The electronics section includes all components necessary to monitor and gauge the pressure delivered to the accumulator tank prior to launching. The electronics section consists of an

Arduino, LED display, rechargeable battery, pressure transducer, and an LED strip. All of these components work in unison to create an exciting launch sequence and assist the user in proper identification of pressure levels.

Figure J7: Pressure Gauge and Transducer

4.0 Setup and Assembly

This section will include all required procedures and steps necessary to begin operation of the device.

4.1 Unpacking the Launcher

When assembling Gemini 28-80, ensure that all components are present in the container and in good condition, please verify all listed parts: Cosmetic barrel (3 pieces should be attached together), Cosmetic side-booster, accumulator tank, barrel (PVC Pipe), electronics section (Arduino, LED display, battery pack, pressure transducer, and LED strip.), and ensure the presence of any additional accessories such as hoses, secure straps, and any tools utilized.

Figure J8: Stored Launcher

4.2 Assembling the Launcher

Ensure both cosmetic sections are attached securely to the launcher, ensure the barrel is securely attached to the accumulator tank, ensure the two-way tape is securely fastening the side booster cosmetics. Take the arduino and LED display and attach it to the velcro attachment with the housing. Attach all necessary components to assembly (Pressure transducer and LED light strip). The launcher is now ready for use. Connect the hose to the desired compressed air source, and accumulator tank. Ensure that the accumulator tank is depressurized prior to assembly.

4.3 Checking for Proper Assembly

Check that all connections are secure and free from damage, verify that the accumulator tank is properly connected to barrel, ensure electronics section is securely attached to velcro and displaying accurate pressure readings, ensure the red light indicator activates at 10 PSI, indicating the launcher is "Ready-to-fire". Lastly, inspect the launcher for any visible signs of damage.

Figure J9: Electronics Assembly

5.0 Operating Instructions

This section will highlight the steps a user must take in order to use the device safely and correctly

5.1 Powering the device

First, hooking to compressed air is required to begin using Gemini-28-80. Securely connect compressed air to the accumulator tank and ensure the connection is tight to prevent any air leaks. At the other end, attach a compressed air source such as an air compressor or scuba tank.

Important: The scuba tank must not be filled to over 2140 PSI to ensure safe operation. Ensure that the rechargeable battery pack is fully charged.

5.2 Loading T-Shirts

To prepare the T-shirts, roll the T-shirts tightly to fit into the barrel and secure them with rubber bands. Now, load the T-shirts. Ensure that your rolled T-shirts fit snug into the barrel and slide all the way down. This is paramount to the correct operation of the launcher.

Figure J10: Rolled T-shirts

5.3 Launch Parameters and Pressurization

Now, ensure that once you are ready to fire, choose a target, trajectory, and desired PSI to hit that target. 80 PSI is maximum for highest stadium reach. Energize the launcher by opening the pressure filling valve, and fill to desired PSI. Remember to never point a loaded and pressurized launcher at any unintended targets. Now pull the trigger to fire the device, ensuring that you are launching at a high angle.

6.0 Technical Specifications

This section will highlight the capabilities and maximum recommendations for common use cases of the T–shirt launcher. It will dive into accumulator tank recommendations as well as operating range and capacity.

<u>6.1 Power Requirements</u>

Ensure you have a compressed air source capable of filling the accumulator tank to 80 PSI per shot, such as the ones provided with the launcher. You may use the provided scuba tank or provided pancake compressor. Ensure that the battery is charged using the provided cable.

Figure J11: Additional Launcher Pictures

<u>6.2 Operating Range and Capacity</u>

The maximum launching distance intended for Gemini 28-80 is approximately 288 feet in optimal conditions.

Maximum recommended PSI in the accumulator tank is no more than 80 PSI. Do not exceed this limit to ensure safe operation and avoid potential damage.

7.0 Support

The UCF engineering team was committed this year to providing athletics with a unique, practical solution to the T-shirt launching concept. We want to ensure that the best support is provided if any issues are encountered. As this project pertains to the Senior Design sections of mechanical engineering, all steps in the process to assemble this device have been highlighted and documented. If any outstanding issues require support, please contact the Department of Mechanical Engineering for further inquiries on the construction of this device.

Replacement Parts: Please consult the separate maintenance manual for any inquiries on parts, functionality, and disassembly/replacement instructions.

8.0 Legal and Compliance

This section will highlight any legal or compliance issues that a user may be interested in learning about in the operation in this device.

8.1 Safety

Please ensure that all safety standards highlighted in this manual are followed. The use of this device is restricted to individuals aged 18 and over. The mechanical engineering department and designers of this device are not liable for any injuries or damages resulting from misuse or improper handling of Gemini 28-80. Please replace any defective components immediately after discovery.

State and Local Laws: Always ensure to check with any local authorities for any specific restrictions or regulations surrounding the use of this device if it is unclear.

K: Maintenance Manual

Maintenance Manual

UCF Athletics T-Shirt Launcher

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August 2nd, 2024

Mechanical and Aerospace Engineering

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Table of Contents

1.0 Introduction

This manual serves as an overview of how to maintain and care for Gemini 28-80. Proper maintenance, troubleshooting, and general care are necessary for the long-term safe operation of the launcher.

1.1 Safety Precautions

- The launcher shall not be handled by any individuals under the age of 18.
- Always assume the launcher is loaded.
- Always keep the launcher pointed in a safe direction.
- Keep the accumulator tank empty whenever possible when performing maintenance.
- The threads on the orange accumulator tank are British Standard Pipe (BSP). DO NOT attempt to insert NPT-threaded components into the accumulator tank.
- All tools used to build the launcher are standard. Do not attempt to use Metric tools, as you will risk stripping the components.

1.2 Lock-Out / Tag-Out

Gemini 28-80 comes with a Lock-Out / Tag-Out system to prevent the accumulator tank from being filled and to prevent the trigger from being pressed. This system utilizes combination locks, ensuring unauthorized users cannot access the system. In the picture below, the air inlet LOTO is on the top right, and the trigger LOTO is on the bottom.

- ALWAYS leave the trigger LOTO in place when performing maintenance. The only exception to this is if the trigger itself requires maintenance.
- ALWAYS leave the air inlet LOTO in place unless a leak test is being performed.

Figure K1: LOTO for Air Inlet (Top Right) and Trigger (Bottom Left)

2.0 Cleaning Launcher

To clean the launcher's many surfaces, use the following solutions:

- Side Boosters - Damp cloth with warm water
    - Be gentle in areas with decals.
- Orange Accumulator Tank - Soap and water or rubbing alcohol.
    - DO NOT use rubbing alcohol on any decals. Be gentle around decals.
- Silver Valve - Soap and water
    - DO NOT use chemicals on the valve. This could degrade the rubber gasket.

- Arduino Display - Compressed air or microfiber cloth
- Pressure Gauge - Damp cloth
- Orange Cosmetic Barrel - Damp cloth
    - Be gentle in areas with decals.

3.0 General Maintenance

This section covers the general maintenance and inspection of Gemini 28-80 and the scuba tank.

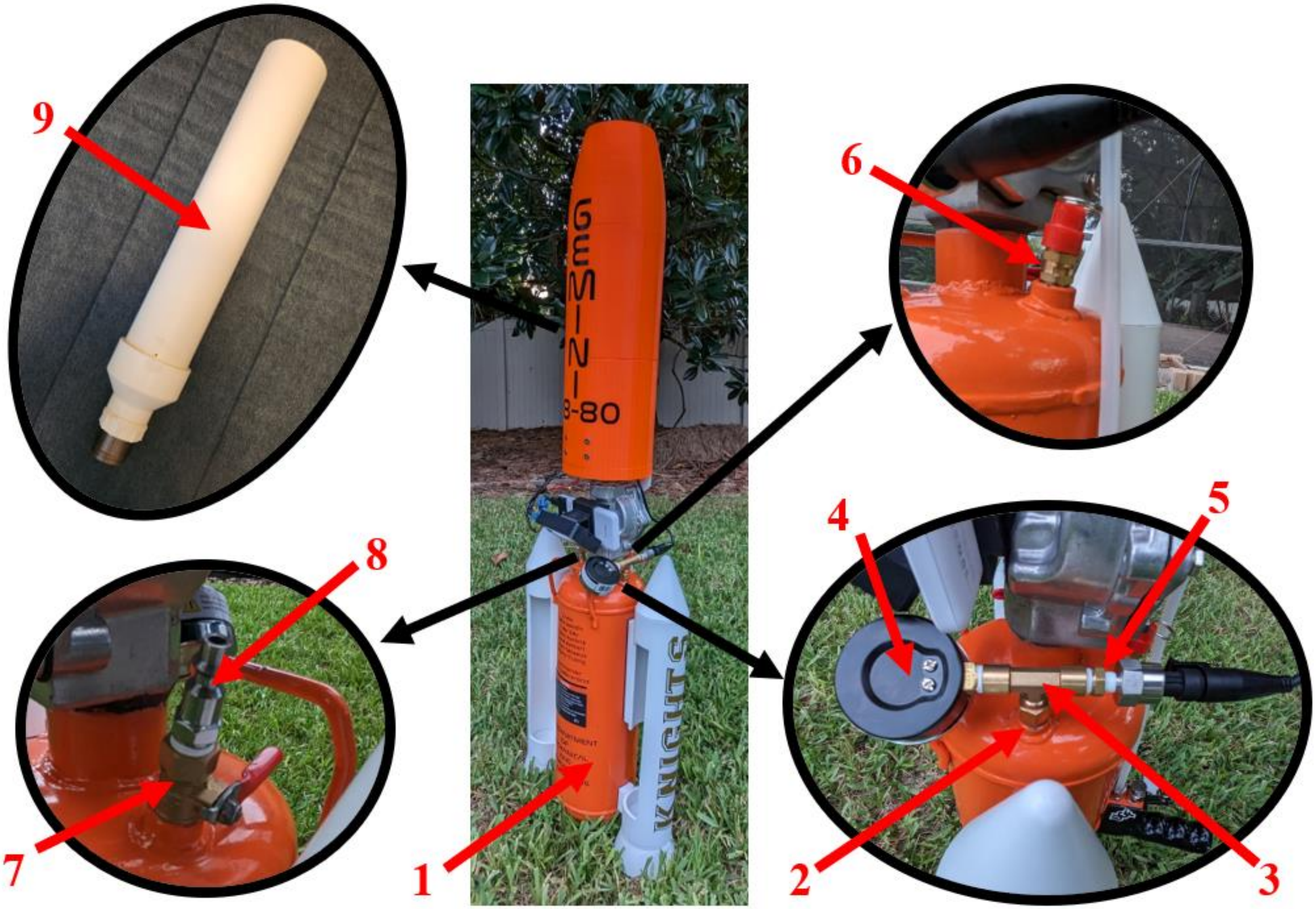
3.1 Gemini 28-80 Maintenance and Leak Test

Prior to using the launcher, visually inspect the following components for cracks, fractures, or other visible damage:

1. Orange Accumulator Tank
2. 1/4 BSP to NPT Adapter
3. 1/4 NPT Tee Fitting
4. Pressure Gauge
5. 1/4 to 1/8 NPT Adapter
6. Pressure Relief Valve
7. 1/4 BSP Ball Valve
8. 1/4 BSP Male Quick Connect
9. White PVC Barrel

If damage is found, do not operate the launcher until the damaged component has been replaced. The numbered components are shown on the next page.

Figure K2: Items That Need Visual Inspection Before Launching



To perform a leak test:

1. Remove air inlet LOTO.

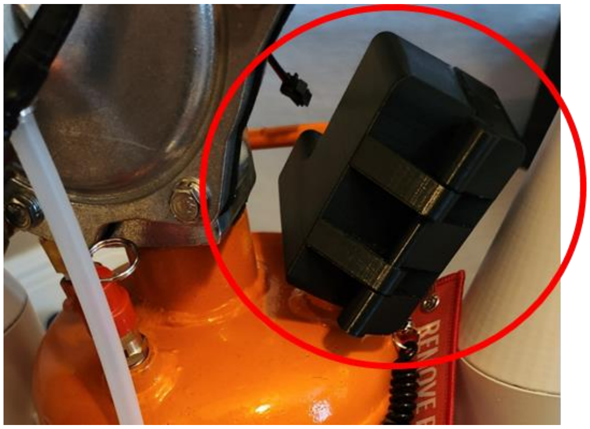


Figure K3: Air Inlet LOTO

2. Connect the pneumatic hose to the air inlet.
3. Open the air inlet valve to pressurize the accumulator to 20 PSI.
4. Listen for leaks.
    a. If a leak is heard, spray the area with soapy water to determine which fitting is leaking. (removing electronics before spraying)
    b. If a fitting is leaking:
        i. Remove fitting.
        ii. Remove PTFE tape and clean threads.
        iii. Replace PTFE tape using at least 3 passes.
        iv. Install the component.
        v. Recheck for leaks.
            1. If still leaking, replace the component. See Section 3.
5. Repeat steps 2 and 4, increasing the pressure in 20 PSI increments until the accumulator reaches 80 PSI.

6. When complete, release air from the accumulator using the pressure relief valve.

3.2 Scuba Tank Maintenance and Leak Test

Scuba tanks store compressed air at a very high pressure and are therefore very dangerous. Additionally, scuba tanks are built to Department of Transportation (DOT) standards so that they can legally be transported on roads while filled with compressed fluid. To comply with DOT standards and ensure the safety of the operator and anyone nearby:

- Have an annual visual inspection completed by a certified dive shop. The team recommends Castaway Scuba Adventures in Oviedo, FL, for its proximity to campus. The dive shop will visually inspect the tank for damage and fill the tank with air. A sticker will be placed on the scuba tank to indicate that the visual inspection was performed. Update the maintenance log in Section 5 with the inspection date.

Figure K4. Sticker Containing the Date of Visual Inspection

- Every 5 years, the scuba tank must undergo a hydro-test. This test fills the scuba tank with water and pressurizes it to 5,000 PSI in a controlled environment to ensure the tank is still safe to use. The tank was manufactured in October 2023, meaning a hydro test will need to be performed in October 2028, 2033, and so on. The tank will be stamped with the test date, where the first number is the month and the second number is the year. In the below picture, the test was performed in December of 2010. Record the test date in the maintenance log in Section 5.

Figure K5: Hydro Test Date Stamp

Failure to perform either of these tests at their required intervals is illegal, unsafe, and unethical.

Before using the scuba tank, check the following components for any cracks, fractures, or other obvious damage:

1. Scuba Tank
2. Yoke Valve
3. Yoke to NPT Adapter

4. NPT Male Quick Connect
5. Pressure Regulator
6. NPT Female Quick Connect

The numbered components are shown on the next page.

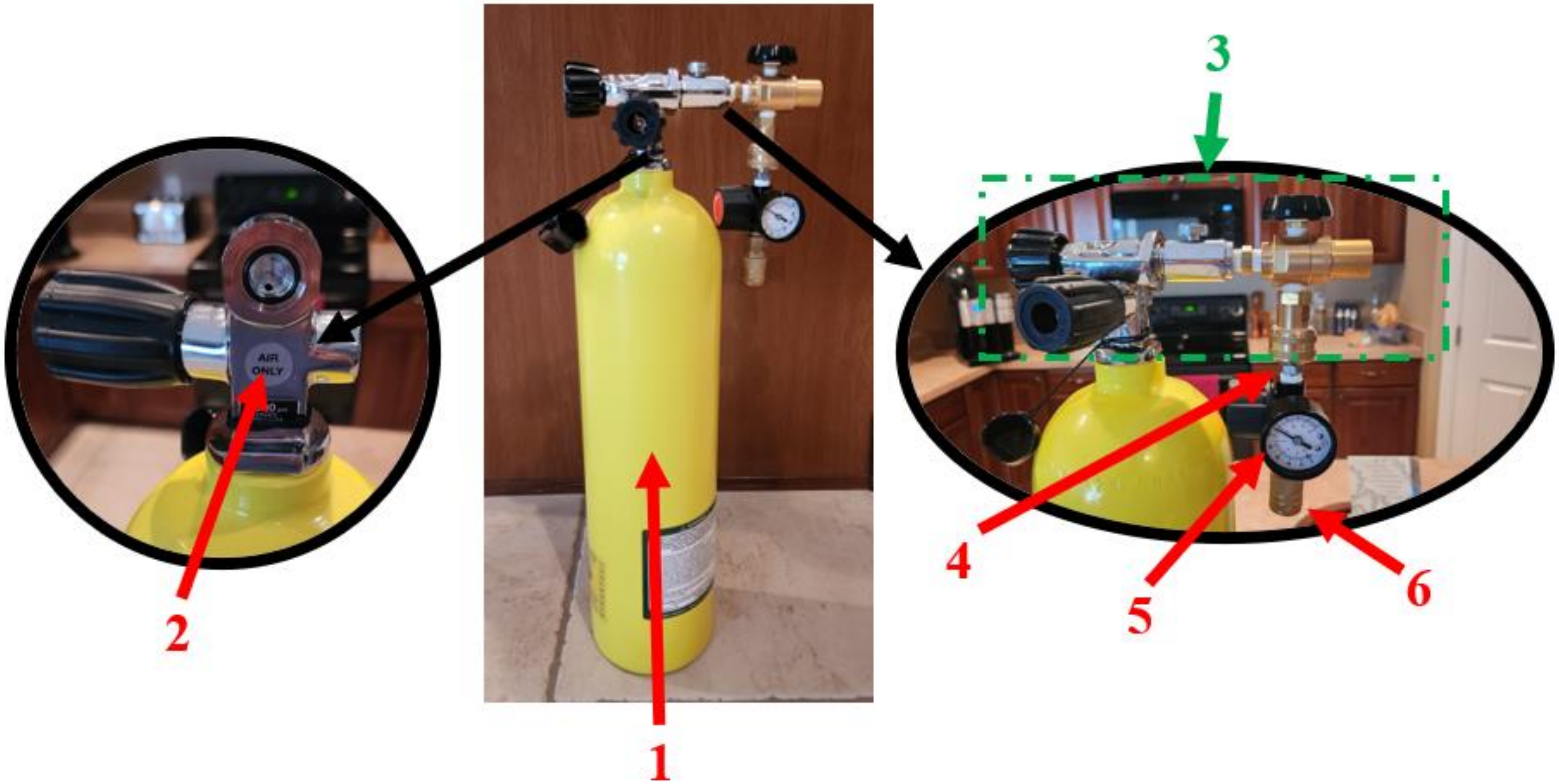

3
AIR ONLY
2
1
4
5
6

Figure K6: Items of the Scuba Tank that Need Visual Inspection Prior to Launching

To perform a leak test on the scuba tank:

1. Attach the adapter in the orientation shown.

Figure K7. Yoke to NPT Adapter

2. Turn the pressure regulator in the direction of the plus sign.
3. Open the scuba tank by turning the long black knob counterclockwise.
4. Listen for leaks, and use soapy water as needed to identify a leaking connection.
5. Close the scuba tank by turning the long black knob clockwise.
6. Turn the small silver knob on the adapter counterclockwise to release the air in the adapter.
7. Turn the pressure regulator towards the minus sign to release the air in the regulator.
8. Remove the adapter and replace the PTFE tape on any leaking connections, using at least 3 passes.
9. Repeat steps 1 through 7 to ensure the leak was fixed.

4.0 Launcher Disassembly and Part Replacement

This section will cover how to remove major components and replace them.

4.1 Side Booster Replacement

1. Remove the 4 screws (#6-32 x 1 1/4) on the rails of the side boosters.

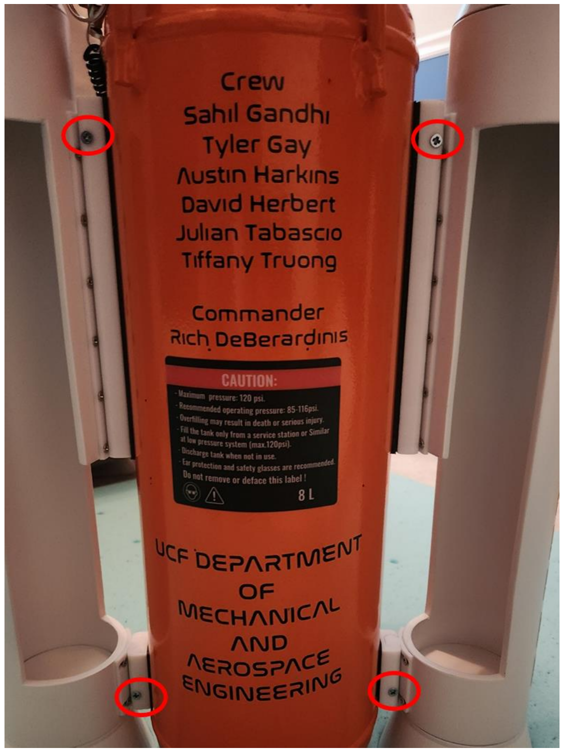


Figure K8. Location of Screws to Remove Side Boosters

2. Slide the side boosters towards the bottom of the launcher to remove.
3. If needed, remove the rails attached to the accumulator tank by heating the tape using a hair dryer or heat gun. DO NOT use an open flame.
4. Remove the rails from the side boosters by using a Phillips head screwdriver (#4-40 x 1/4, 16 per side booster).
5. Replace the rails back on the side boosters. Slide the tank rail over the side booster rail.
6. Replace the 4 screws that hold the rails together.
7. Apply heavy duty foam mounting tape to the rails while they are connected to the side booster.
8. Remove the tape, and stick the side booster assembly onto the tank.

4.2 Barrel Replacement

1. Remove the 6 (#10-24 Allen) screws from the orange barrel using a 1/8 inch allen wrench.

Figure K9. Barrel Mounting Screws Location

2. Slide the orange cosmetic barrel off of the launcher.
3. Turn the white PVC barrel counterclockwise to unthread it.
4. When reinstalling the PVC barrel, only hand tighten.
5. Slide the orange cosmetic barrel back over the white PVC barrel, and reinsert the 6 screws.

4.3 Pneumatic Fitting Replacement

1. Remove the desired fitting. A chart with the tool sizes for each pneumatic fitting is listed below.

Fittings Tool Sizes

Fitting	Location / Description	Tool Size
1/4 BSP to NPT adapter	Connects accumulator to Tee	1 1/2" socket

1/4 NPT Tee	Connects to pressure gauge	Adjustable wrench
Pressure Gauge	Connected to Tee	9/16” open end wrench
1/4 to 1/8 NPT adapter	Connects Tee to transducer	9/16” socket or open end
Pressure transducer	Connected to Tee via adapter	9/16” open end wrench
1/4 BSP ball valve	Connected to accumulator, has red lever	5/8" socket
1/4 BSP Quick connect	Connected to ball valve	9/16” socket
1/4 BSP pressure relief valve	Connected to accumulator, has red cap	9/16” socket

2. Remove the PTFE tape from the fitting. Use a nylon brush, toothpick, or other tool to remove the tape from the threads without damaging the threads.
3. Put at least 3 passes of new PTFE tape over the threads.
4. Reinstall the fitting until tight. Do not overtighten.
5. Check for leaks.

5.0 Maintenance Log

Sample Maintenance Log

Date	Performed By	Description	Next Maintenance Date	Locked for storage?
6/13/24	Tyler Gay	Scuba tank inspection	Prior to next use	Y
7/19/24	Austin Harkins	Cleaned launcher and checked for leaks	Prior to next use	Y
…	…	…	…	…

Storage and Transportation Manual

UCF Athletics T-Shirt Launcher

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Table of Contents

1.0 Introduction

This manual serves as an overview of how to store and transport Gemini 28-80. Proper storage and transportation are necessary for the long-term safe operation of the launcher.

1.1 Safety Precautions

- The launcher shall not be handled by any individuals under the age of 18.
- Always assume the launcher is loaded.
- Always keep the launcher pointed in a safe direction.
- Always keep approximately 20 PSI in the accumulator tank when storing the launcher.
    - Always transport the accumulator tank with 0 PSI of pressure.
- Always keep approximately 200 PSI in the scuba tank when storing.
- Always store the scuba tank vertically.

1.2 Lock-Out / Tag-Out

Gemini 28-80 comes with a Lock-Out / Tag-Out system to prevent the accumulator tank from being filled and to prevent the trigger from being pressed. This system utilizes combination locks, ensuring unauthorized users cannot access the system. In the picture below, the air inlet LOTO is on the top right, and the trigger LOTO is on the bottom.

- ALWAYS leave the trigger LOTO in place when storing the launcher.
- ALWAYS leave the air inlet LOTO in place when storing the launcher.

Figure 1: LOTO for Air Inlet (Top Right) and Trigger (Bottom Left)

2.0 Storage Guidelines

The launcher can be stored in various conditions. However, the following must be met in order for the launcher to ensure safe operations after removal from storage.

- Ensure the launcher and its accommodating tanks are stored in dry, cool places away from sunlight and heat. The maximum temperature should be less than 85°F.
- Do not store the scuba or accumulator tank on bare concrete or surfaces that can hold moisture.
- Do not store the accumulator tank for longer than 3 months without checking pressure.
- Protect the tanks from mechanical damage.
- Store the scuba tank in an upright position to maintain structural integrity.

3.0 Preparation for Storage

Before putting the launcher into storage, follow these steps to confirm the launcher is ready to be stored.

- Inspect it for any signs of damage or wear.
- Wipe down both tanks to remove dirt and reduce corrosion.
- Confirm that the valves, connections, and pressure settings are functioning correctly.
- Release the pressure from the scuba tank to have only 200 PSI in the tank.
    - Keeping some pressure in the tank keeps moisture out. Leaving too much pressure in the tank poses a safety risk and will reduce the lifespan of the tank.
- Release the pressure from the accumulator tank to have only 20 PSI in the tank.
- Check the LOTO is secured.

- Check for T-shirts in the barrel.
- Disconnect the air line from the launcher to the tank.
- Check to make sure there are no loose parts.

4.0 Loading Procedure

1. Disconnect the air line from the launcher to the tank.
2. Disconnect the wires connecting the Arduino and battery pack to the launcher.
3. Unzip the bag.
4. Place the air line and the Arduino in their respective cutouts.

Figure 2: Bag with Air Line (Left) and Arduino (Right) Ready for Storage

5. Place the launcher with the trigger facing up.

Figure 3: Launcher Placed Inside Bag with Trigger Facing Upwards

6. Using the buckles, buckle the launcher into the bag.

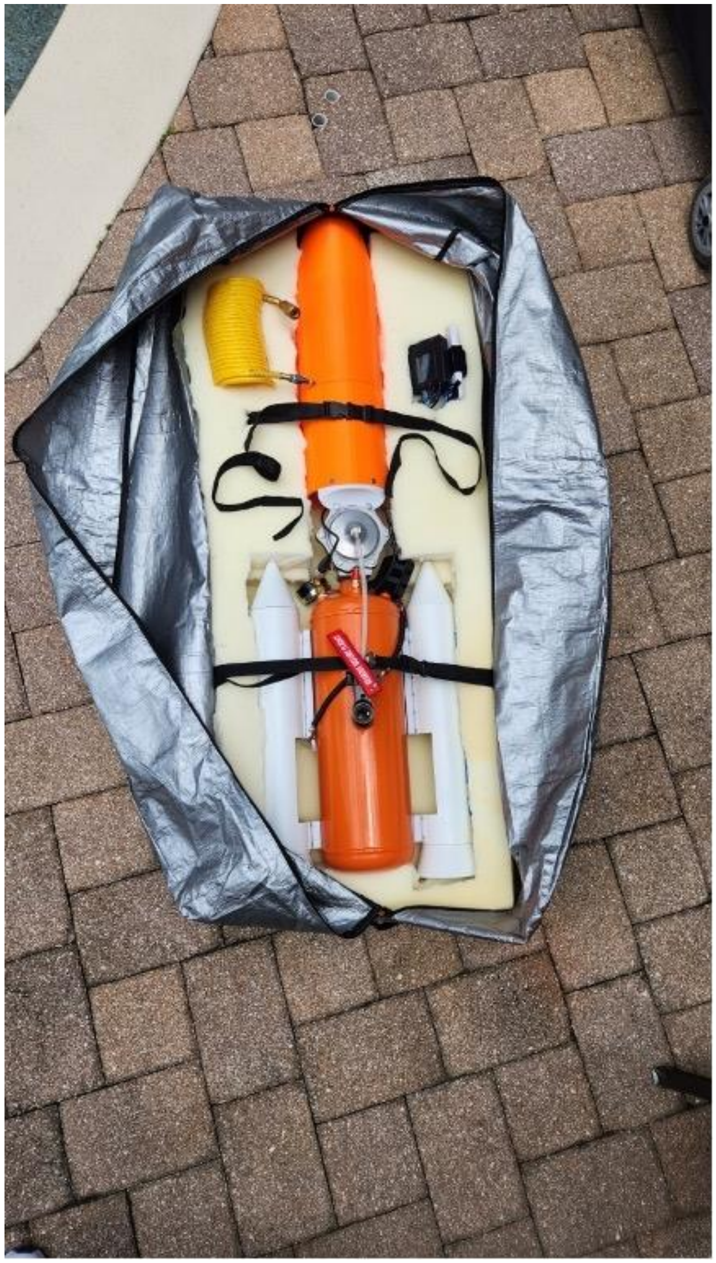

Figure 4: Launcher Buckled into Bag with Accessories

7. Zip the bag up.

<u>5.0 Unloading Procedure</u>

1. Unzip the bag.
2. Using the buckles, unbuckle the launcher.

Figure 5: Launcher is Unbuckled

3. Remove the launcher from the bag and place it standing up.

4. Remove the air line and the Arduino from their respective cutouts.
5. Connect the wires from the launcher to the Arduino and place it onto the Velcro piece on the launcher. Make sure it is snug.

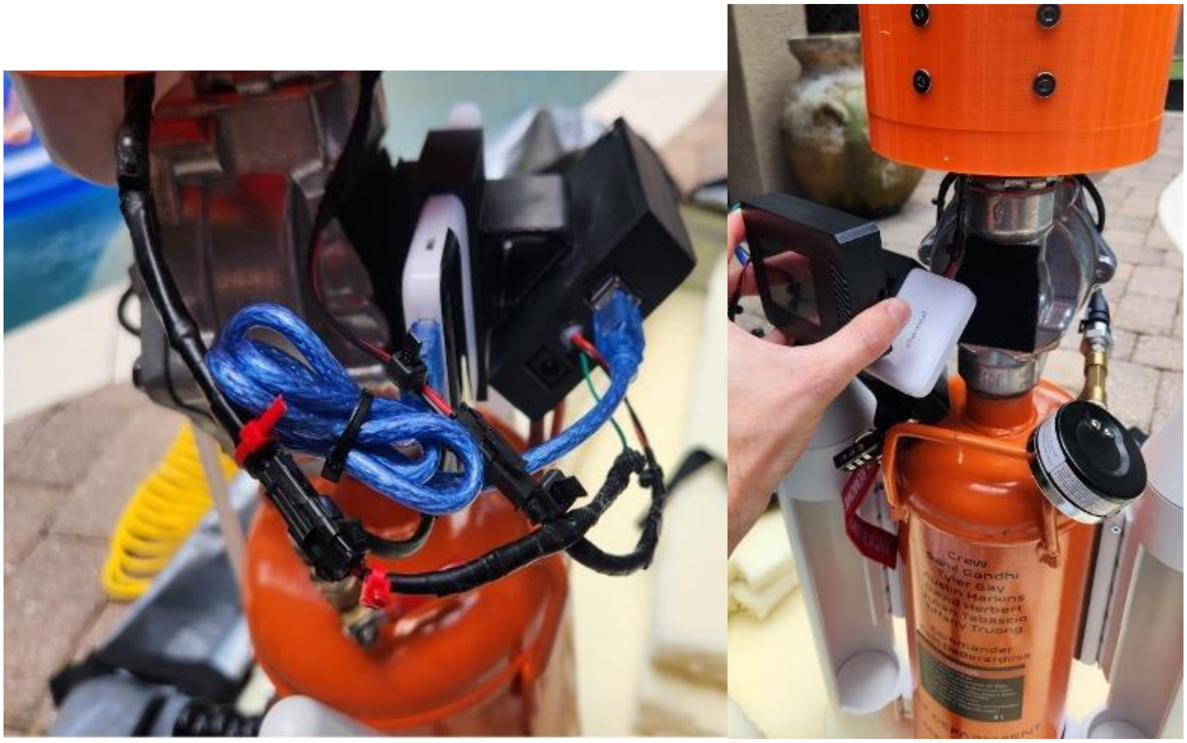

Figure 6: Arduino Connected and Attached to Velcro

6. Attach the air line to the launcher.

Figure 7: Launcher is Reassembled

6.0 Transportation

When transporting the bag carrying the launcher:

- Hold it with both hands on the bag handle
- Ensure the bag is zipped up

When transporting the scuba tank:

- Hold with both hands
- Keep the tank upright
- Secure the tank to keep it from falling over if transporting in a vehicle

After transporting the tanks:

- Check for any damage

M: Failure Mode Ranking Criteria

FMEA Likelihood Rankings

Rating	Short Description	Our Criteria
1	Remote	1 in 100M
2	Extremely Low	1 in 10M
3	Very Low	1 in 1M
4	Low	1 in 100k
5	Moderately Low	1 in 50k
6	Moderate	1 in 10k
7	Moderately High	1 in 1k
8	High	1 in 500
9	Very High	1 in 100
10	Extremely High	1 in 10

FMEA Criticality Rankings

Rating	Description	Monetary Impact	Human Impact
1	Negligible Effect	Negligible.	None.
2	Extremely Low Monetary Loss	Under $25.	None.
3	Very Low Monetary Loss	Under $50.	None.
4	Low Monetary Loss	Under $75.	None.
5	Moderately Low Monetary Loss OR Minor Injury	Under $100.	Minor injury. Bruise, scratch, etc.
6	Moderate Monetary Loss OR Multiple Moderate Injuries	Under $125.	Multiple minor injuries.
7	Moderately High Monetary Loss OR Moderate Injury	Under $150.	Moderate injury. Small fracture, stitches, etc.
8	High Monetary Loss OR Moderately Severe Injury	Under $175.	Moderately severe injury. Broken bones, concussion, etc.
9	Very High Monetary Loss OR Severe Injury	Under $200.	Severe injury. Hospitalization, amputation, etc. Could be life threatening.
10	Extremely High Monetary Loss OR Death	Over $200.	Death

FMEA Detection Rankings

Rating	Short Description	NASA Criteria
1	Almost Certain	There is an almost certain probability the Design will detect and/or anticipate the Failure Mode or its subsequent Failure Effect (> 99% probability for detection).
2	Very High	There is a Very High probability the Design will detect and/or anticipate the Failure Mode or its subsequent Failure Effect (90 > 99% probability for mitigation).
3	High	There is a High probability the Design will detect the Failure Mode or its subsequent Failure Effect (80 > 90% probability for detection).
4	Moderately High	There is a Moderately High probability the Design will Detect the Failure Mode or its subsequent Failure Effect (60 > 80% probability for Detection).
5	Moderate	There is a Moderate probability the Design will detect the Failure Mode or its subsequent Failure Effect (40 > 60% probability for detection).
6	Low	There is a Low probability the Design will detect the Failure Mode or its subsequent Failure Effect (30 > 40% probability for detection).
7	Very Low	There is a very low chance the Design will detect the Failure Mode or its subsequent Failure Effect (20 > 30% probability for detection).
8	Remote	There is a remote probability the Design will detect the Failure Mode or its subsequent Failure Effect (10 > 20% probability for Detection).
9	Very Remote	There is a very remote probability the Design will detect the Failure Mode or its subsequent Failure Effect (less than 10% probability for detection).
10	None	There is no Detection of the Failure Mode or its subsequent Failure Effect.

N: Arduino Code

```
#include <Adafruit_GFX.h>    // Core graphics library
#include <Adafruit_TFTLCD.h> // Hardware-specific library
#include <SD.h>
#include <SPI.h>

#define LCD_CS A3
#define LCD_CD A2
#define LCD_WR A1
#define LCD_RD A0
#define LCD_RESET A4

#define SD_CS 10     // Chip select line for SD card

#define BLACK   0x0000
#define WHITE   0xFFFF
#define RED     0xF800
#define GREEN   0x07E0
#define YELLOW  0xFFFF

#define LED_PIN1 0 // READY TO FIRE LED INDICATOR
#define LED_PIN2 1 // LED STRIP FIRING INDICATOR

Adafruit_TFTLCD tft(LCD_CS, LCD_CD, LCD_WR, LCD_RD, LCD_RESET);

#define PRESSURE_SENSOR_PIN A5

unsigned long previousMillis = 0;
unsigned long flashMillis = 0;
bool flashState = false;
float previousPressure = -1; // Use a value that cannot be valid as an
initial value
bool led2Active = false;
unsigned long led2StartMillis = 0;
```

```
int previousPressurePsiInt = -1; // Use a value that cannot be valid as an
initial value
int previousPowerPercentage = -1; // Use a value that cannot be valid as an
initial value
int previousBarWidth = -1; // Use a value that cannot be valid as an initial
value
int powerPercentage = 0; // Declare powerPercentage as a global variable

bool bmpDisplayed = false; // Flag to track if BMP is currently displayed
bool bmpAlreadyDisplayed = false; // Flag to track if BMP has already been
displayed after first time
unsigned long bmpDisplayStartMillis = 0;

#define BUFFPIXEL 20 // Adjust as per your requirement

void setup() {
  // Initialize LED pins
  pinMode(LED_PIN1, OUTPUT);
  digitalWrite(LED_PIN1, LOW);

  pinMode(LED_PIN2, OUTPUT);
  digitalWrite(LED_PIN2, LOW);

  // Initialize TFT display
  tft.reset();
  uint16_t identifier = tft.readID();
  tft.begin(identifier);

  // Initialize SD card
  if (!SD.begin(SD_CS)) {
    while (1); // If SD card initialization fails, halt execution
  }

  // Load and display BMP images
  bmpDraw("1.bmp", 0, 0);  // Display first image
  delay(1500);
  bmpDraw("2.bmp", 0, 0);  // Display second image
  delay(3000);
```

```
  // Rotate display and fill screen with black
  tft.setRotation(3);
  tft.fillScreen(BLACK);

  // Draw static elements
  tft.drawRect(20, tft.height() / 2 - 10, tft.width() - 40, 20, WHITE);
}

void loop() {
  // Main loop handling pressure sensor and updating TFT display
  unsigned long currentMillis = millis();
  int sensorValue = analogRead(PRESSURE_SENSOR_PIN);
  float voltage = sensorValue * (5.0 / 1023.0);

  // Convert voltage to PSI
  float pressurePsi;
  if (voltage <= 0.45) {
    pressurePsi = 0;
  } else if (voltage >= 4.5) {
    pressurePsi = 99;  // Cap at 99 psi because x-axis ranges from 0 to 99
psi
  } else {
    pressurePsi = (voltage - 0.45) * (99 / (4.5 - 0.45));  // Map voltage
to 0-99 psi
  }

  // Calculate power percentage using the quadratic equation
  float quadraticValue = -0.00015875 * pressurePsi * pressurePsi +
0.02544163 * pressurePsi - 0.01558974;
  // Scale to percentage range 0 to 100
  powerPercentage = constrain((int)(quadraticValue * 100.0), 0, 100);

  // Limit PSI to 0-99 range and ensure it's an integer
  int pressurePsiInt = constrain((int)pressurePsi, 0, 99);

  // Control LED 1 based on pressure threshold
  if (pressurePsi > 10) {
    digitalWrite(LED_PIN1, HIGH); // Turn on LED 1
  } else {
```

```
  digitalWrite(LED_PIN1, LOW);  // Turn off LED 1
}

// Check for rapid pressure drop for LED 2
if (currentMillis - previousMillis >= 1000) {
  previousMillis = currentMillis;
  if (previousPressure - pressurePsi > 10) {
    digitalWrite(LED_PIN2, HIGH); // Turn on LED 2
    led2Active = true;
    led2StartMillis = currentMillis;
  }
  previousPressure = pressurePsi;
}

// Maintain LED 2 on for 5 seconds
if (led2Active && currentMillis - led2StartMillis >= 5000) {
  digitalWrite(LED_PIN2, LOW); // Turn off LED 2
  led2Active = false;
}

// Display BMP "3.bmp" for 3 seconds when pressure hits 80 psi and above
if (pressurePsiInt >= 81 && !bmpDisplayed && !bmpAlreadyDisplayed) {
  bmpDisplayed = true;
  bmpAlreadyDisplayed = true;
  bmpDisplayStartMillis = currentMillis;
  bmpDraw("3.bmp", 0, 0); // Display "3.bmp" at position (0, 0)
}

// Check if BMP "3.bmp" is currently displayed
if (bmpDisplayed) {
  // Keep the display static during BMP display (don't update values)
} else {
  // Update displays as usual when BMP "3.bmp" is not displayed
  // Only update the display if the pressure has changed
  if (pressurePsiInt != previousPressurePsiInt) {
    // Update PSI value on TFT display
    tft.setTextSize(6);
    tft.setTextColor(BLACK);
    tft.setCursor(125, 40); // Adjusted position for two-digit display
```

```
      if (previousPressurePsiInt < 10) {
        tft.print("0"); // Print leading zero if necessary
      }
      tft.print(previousPressurePsiInt, DEC);

      // Display current PSI value in two digits with leading zeros if
necessary
      tft.setTextColor(WHITE);
      tft.setCursor(125, 40); // Adjusted position for two-digit display
      if (pressurePsiInt < 10) {
        tft.print("0");
      }
      tft.print(pressurePsiInt, DEC);
      tft.setTextSize(3);
      tft.print(" PSI");

      previousPressurePsiInt = pressurePsiInt;
    }

    // Update the percentage bar only if its width has changed
    int maxBarWidth = tft.width() - 40;
    int barWidth = map(powerPercentage, 0, 100, 0, maxBarWidth);

    // Adjust barWidth if powerPercentage exceeds 100%
    if (powerPercentage > 100) {
      int extraWidth = map(powerPercentage - 100, 0, 100, 0, maxBarWidth);
      barWidth = maxBarWidth - extraWidth;
    }

    // Set the bar color to RED if pressurePsiInt is 80 or above, regardless
of power percentage
    int barColor = (pressurePsiInt >= 80) ? RED : GREEN;

    if (barWidth != previousBarWidth || pressurePsiInt >= 80) {
      // Clear previous bar area (only the part that will change)
      if (barWidth < previousBarWidth) {
        tft.fillRect(20 + barWidth, tft.height() / 2 - 10, previousBarWidth
- barWidth, 20, BLACK);
      }
```

```
    // Draw new bar
    tft.fillRect(20, tft.height() / 2 - 10, barWidth, 20, barColor);

    // Draw constant border around the bar
    tft.drawRect(20, tft.height() / 2 - 10, maxBarWidth, 20, WHITE);

    previousBarWidth = barWidth;
  }

  // Only update the power percentage if it has changed
  if (powerPercentage != previousPowerPercentage) {
    // Update power percentage value on TFT display
    tft.setTextSize(4);
    tft.setTextColor(BLACK);
    tft.setCursor(110, 170);
    if (previousPowerPercentage < 10) {
      tft.print("  "); // Print two spaces to clear old single-digit value
    } else if (previousPowerPercentage < 100) {
      tft.print(" "); // Print one space to clear old double-digit value
    }
    tft.print(previousPowerPercentage); // Clear old value

    // Display current power percentage
    tft.setTextColor(WHITE);
    tft.setCursor(110, 170);
    if (powerPercentage < 10) {
      tft.print("  "); // Print two spaces for single-digit value
    } else if (powerPercentage < 100) {
      tft.print(" "); // Print one space for double-digit value
    }
    tft.print(powerPercentage); // Display current value
    tft.print("%");

    previousPowerPercentage = powerPercentage; // Save current value
  }
}

// Clear BMP display after 3 seconds and reset flags
if (bmpDisplayed && currentMillis - bmpDisplayStartMillis >= 3000) {
```

```
    tft.fillScreen(BLACK); // Clear the screen
    bmpDisplayed = false;
  }

  // Reset bmpAlreadyDisplayed flag when pressure drops below 80
  if (pressurePsiInt < 75) {
    bmpAlreadyDisplayed = false;
  }

  delay(250);  // Update every quarter second
}

// Function to load and display BMP images
void bmpDraw(const char *filename, int x, int y) {
  File bmpFile;
  int bmpWidth, bmpHeight;   // Width and height of BMP image
  uint8_t bmpDepth;          // Bit depth (currently must be 24)
  uint32_t bmpImageoffset;   // Start of image data in file
  uint32_t rowSize;          // Size of one row in the BMP file
  uint8_t sdbuffer[3 * BUFFPIXEL]; // Pixel buffer (R+G+B per pixel)
  uint16_t lcdbuffer[BUFFPIXEL];   // Buffer to hold image pixels
  uint8_t buffidx = sizeof(sdbuffer); // Current position in pixel buffer
  boolean goodBmp = false;    // Flag indicating valid BMP format
  boolean flip = true;        // Flag to flip image vertically
  int w, h, row, col;         // Width, height, row, and column counters
  uint8_t r, g, b;            // Red, green, blue color values
  uint32_t pos = 0, startTime = millis();
  uint8_t lcdidx = 0;
  boolean first = true;

  // Check if the image position is within display bounds
  if ((x >= tft.width()) || (y >= tft.height())) return;

  Serial.println();
  Serial.print(F("Loading image '"));
  Serial.print(filename);
  Serial.println('\'');

  // Attempt to open the requested file from the SD card
```

```
  if ((bmpFile = SD.open(filename)) == NULL) {
    Serial.println(F("File not found"));
    return;
  }

  // Verify BMP header
  if (read16(bmpFile) == 0x4D42) { // BMP signature
    Serial.print(F("File size: ")); Serial.println(read32(bmpFile));
    (void)read32(bmpFile); // Read and ignore creator bytes
    bmpImageoffset = read32(bmpFile); // Start of image data
    Serial.print(F("Image Offset: ")); Serial.println(bmpImageoffset, DEC);
    Serial.print(F("Header size: ")); Serial.println(read32(bmpFile));
    bmpWidth = read32(bmpFile);  // Read image width
    bmpHeight = read32(bmpFile); // Read image height
    if (read16(bmpFile) == 1) {  // Number of color planes (must be 1)
      bmpDepth = read16(bmpFile); // Bits per pixel
      Serial.print(F("Bit Depth: ")); Serial.println(bmpDepth);
      if ((bmpDepth == 24) && (read32(bmpFile) == 0)) { // Compression type
(must be 0 for uncompressed)
        goodBmp = true; // Valid BMP format found
        Serial.print(F("Image size: "));
        Serial.print(bmpWidth);
        Serial.print('x');
        Serial.println(bmpHeight);

        // BMP rows are padded to 4-byte boundary
        rowSize = (bmpWidth * 3 + 3) & ~3;

        // Adjust height for top-down BMPs
        if (bmpHeight < 0) {
          bmpHeight = -bmpHeight;
          flip = false;
        }

        // Crop to fit within TFT display bounds
        w = bmpWidth;
        h = bmpHeight;
        if ((x + w - 1) >= tft.width())  w = tft.width() - x;
        if ((y + h - 1) >= tft.height()) h = tft.height() - y;
```

```
// Set TFT address window to match image bounds
tft.setAddrWindow(x, y, x + w - 1, y + h - 1);

// Iterate through each row of the BMP file
for (row = 0; row < h; row++) {
  // Determine starting position of current row in BMP file
  if (flip) pos = bmpImageoffset + (bmpHeight - 1 - row) * rowSize;
  else pos = bmpImageoffset + row * rowSize;

  // Seek to the start of the current row
  if (bmpFile.position() != pos) {
    bmpFile.seek(pos);
    buffidx = sizeof(sdbuffer); // Reset pixel buffer position
  }

  // Read pixels from file into pixel buffer
  for (col = 0; col < w; col++) {
    // Time to read more pixel data?
    if (buffidx >= sizeof(sdbuffer)) {
      // Push buffered pixels to TFT display
      if (lcdidx > 0) {
        tft.pushColors(lcdbuffer, lcdidx, first);
        lcdidx = 0;
        first = false;
      }
      // Read next chunk of pixels from BMP file
      bmpFile.read(sdbuffer, sizeof(sdbuffer));
      buffidx = 0; // Reset pixel buffer index
    }

    // Extract RGB values from pixel buffer
    b = sdbuffer[buffidx++];
    g = sdbuffer[buffidx++];
    r = sdbuffer[buffidx++];
    // Convert RGB to 16-bit color and store in LCD buffer
    lcdbuffer[lcdidx++] = tft.color565(r, g, b);
  } // end col
} // end row
```

```
        // Push any remaining pixels to TFT display
        if (lcdidx > 0) {
          tft.pushColors(lcdbuffer, lcdidx, first);
        }

        // Display load time
        Serial.print(F("Loaded in "));
        Serial.print(millis() - startTime);
        Serial.println(" ms");
      } // end goodBmp
    }
  }

  // Close BMP file
  bmpFile.close();
  if (!goodBmp) Serial.println(F("BMP format not recognized."));
}

// Function to read 16-bit data from BMP file
uint16_t read16(File f) {
  uint16_t result;
  ((uint8_t *)&result)[0] = f.read(); // Read LSB
  ((uint8_t *)&result)[1] = f.read(); // Read MSB
  return result;
}

// Function to read 32-bit data from BMP file
uint32_t read32(File f) {
  uint32_t result;
  ((uint8_t *)&result)[0] = f.read(); // Read LSB
  ((uint8_t *)&result)[1] = f.read();
  ((uint8_t *)&result)[2] = f.read();
  ((uint8_t *)&result)[3] = f.read(); // Read MSB
  return result;
}
```