Milestone III: Concept Design Review

UCF Athletics T-Shirt Launcher

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Executive Summary

The UCF Athletics Department approached the Department of Engineering in need of a T-shirt launcher for the football team and other teams at various events. This would allow for faculty and staff to launch UCF-themed T-shirts into the crowds of these events as a way to give out free merchandise to those attending the event. Instead of electing to purchase something generic and likely overpriced, a team of mechanical engineering students was tasked with the objective of designing an ergonomic, cost-effective, convenient, and powerful tool to complete that task in a manner and design that will be themed towards UCF's Space-U aspects while also completing the task with elegance and precision. During this process we have come to the conclusion of a compressed air propulsion system, and are currently working on some decisions that will fit the criteria of looks, and technical requirements, while also staying under a hypothetical budget. Success of this design allows for UCF to not only have an effective T-shirt launcher, but also represent the Department of Engineering's ingenuity and resourcefulness when coming to a conclusion on the design. The team has decided on the method of propulsion, and are currently exploring different possibilities to implement this surrounding a reloading mechanism, safety, delivery, and other components that are going to be utilized in the final design. Testing at this point is imperative to gain information on the mechanics and dynamics of the system and how the T-shirt launcher and T-shirts will interact with the environment. Proceeding this milestone of the project, the team will explore deeper into some options for all aspects of the design and decide what to implement when the decisions are vetted, designed, and agreed upon by all parties involved in the success of this project. With proper execution, the UCF department of athletics will be able to fire several t-shirts into the crowds of sporting events which will be entertaining for fans during game intermissions or breaks, and allow for UCF merchandise to be spread to more people.

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Terms and Abbreviations

Abbreviation	Meaning	Page
AC	Alternating Current	30
CAD	Computer Aided Design	115
CFD	Computational Fluid Dynamics	155
CO_2	Carbon Dioxide	53
COC	Certificate of Conformance	152
DC	Direct Current	30
FEA	Finite Element Analysis	179
Ft	Feet	47
HPA	High Pressure Air	53
HVAC	Heating, Ventilation, and Air Conditioning	79
Lb	Pound	47
MAE	Mechanical and Aerospace Engineering	17
MPH	Miles Per Hour	37
NASA	The National Aeronautics and Space Administration	15
P/N	Part Number	47
PSI	Pounds per Square Inch	24
PVC	Polyvinyl Chloride	24
Space-U	Space University	22
STEM	Science, Technology, Engineering, and Mathematics	20
UCF	The University of Central Florida	22
UI	User Interface	83

1.0 Introduction

A T-shirt launcher is a classic way to excite the crowd during a game and keep the fans engaged during breaks in the game. Many professional and college-level sports teams have commercially bought, generic launchers that they use to accomplish this task. The level of customizability is largely limited to stickers and decals with team logos. However, a few examples exist of people or universities building custom-built T-shirt launchers to represent their teams and schools.

UCF has tasked the team with building a T-shirt launcher to display the engineering principles that are learned over the course of earning a degree in Mechanical Engineering. This launcher will not only serve as an example of engineering principles, but also as a representation of UCF itself and its deep ties to the engineering industry.

1.1 Purpose

The team has made substantial progress in the areas of needs analysis, preliminary research, and system requirements. This report will first provide a summary of the work already accomplished, and go further in detail about areas that have been determined to be of added importance. After this, the report will focus on the preliminary conceptual design of the T-shirt launcher. All of the options for major systems and subsystems will be described and analyzed in order to arrive at the optimal solution for the T-shirt launcher, culminating into the preliminary design of the T-shirt launcher. The report will also address the team's schedule for the remainder of the project and identify any potential areas of failure for the project.

1.2 Background Information and History

Since 2018, UCF football has had an annual “Space Game.” This started out with just having custom uniforms for a single football game, but has since evolved into a large shift in branding by UCF. Now every sport participates in having space-themed uniforms and graphics, and the university has made a major push in branding itself as Space-U. The availability of Space-U-themed merchandise on the campus bookstore exemplifies this shift in branding.

Before the 2023 football Space Game against Oklahoma State, the UCF College of Engineering Facilities Operations Manager, Pete Alfieris, posed the question, “Why is the College of Engineering not represented in the Space Game?” Since UCF is the top supplier of graduates to the aerospace industry [5] and was founded in 1963 with the intention of providing workers for NASA and the rapidly growing space industry in Central Florida [32], Pete posed a valid question.

At the 2023 Space Game, Pete ensured multiple UCF engineering clubs and organizations, such as Knights Experimental Rocketry, were included in the Space Game festivities. During the game, Pete noticed that the UCF cheer team was throwing T-shirts into the stands by hand, not reaching a very far distance. It was then he knew UCF Athletics needed a unique, space-themed T-shirt launching tool that was custom-built by the College of Engineering to be used at all UCF sporting events. After consulting with the UCF MAE Senior Design Coordinator, Kurt Stresau, the project was set in motion for a group of undergraduate mechanical engineering students to create a T-shirt launcher for the athletics department, to be used starting in the 2024 football season.

1.3 Problem Statement

T-shirt launchers are essential to enhancing fan engagement and inciting school spirit during sporting events, yet existing commercial options lack the level of customization desired by institutions such as UCF. While many professional and collegiate teams utilize generic launchers with limited customizability and features, UCF seeks to showcase its engineering prowess by constructing a bespoke T-shirt launcher. This unique launcher will offer adjustability and features not available on the market today, providing a tailored solution to UCF's specific needs. The purpose of this endeavor extends beyond crowd excitement; it serves as a representation of UCF’s commitment to innovation and its deep ties to the engineering industry. However, the current method of manually distributing T-shirts during games falls short of reaching fans effectively, prompting the need for a unique, space-themed T-shirt launching tool tailored to UCF’s identity and aspirations. This project aims to bridge the gap between traditional game-day rituals and UCF’s dynamic engineering legacy, providing a solution that not only excites the crowd but also embodies the university’s spirit of innovation and excellence.

1.4 Motivation and Benefits

The motivation behind the endeavor to create a custom T-shirt launcher for the UCF Athletics Department stems from a deep-seated commitment to enhancing the game-day experience for fans and promoting a sense of pride within the UCF community. By leveraging our engineering skills to design a T-shirt launcher tailored specifically to UCF’s identity and aspirations, we aim to elevate school spirit and showcase the innovative atmosphere that defines our institution. Beyond the excitement of game days, this project offers invaluable opportunities for hands-on learning and skill development, empowering us as future engineers to tackle real-world challenges with creativity and expertise. Additionally, our efforts contribute to enhancing UCF's athletics events, leaving a lasting impact on the university's legacy and allowing for a stronger sense of unity among students, alumni, faculty, and fans alike.

1.5 Solution Approach

To solve the stated problem, the team is following the process presented by the UCF MAE Senior Design Coordinator and our project advisor. Both of these approaches take an approach similar to that of a systems engineer or a product designer.

Initially, preliminary research is done on other T-shirt launchers and any technology that may be relevant to the design and manufacturing of our own T-shirt launcher. The goal is not to learn every small detail that may be necessary, but instead to cast a wide net to create a solid foundation. Next, through team brainstorming and customer interviews, a comprehensive list of requirements is created to benchmark what the system needs to do. Then, a conceptual design is formulated and preliminary analysis is conducted, which is outlined in Sections 5 and 6 of this report, respectively. Finally, the team will continue to create the final model and begin constructing the T-shirt launcher, while still performing analysis and considering engineering practices along the way.

1.6 Report Organization

This report follows the chronological progression that the team has made to this point, including new content beginning in Section 5.

- Section 1 - Introduction and Problem Statement

- Section 2 - This section identifies all parties with an interest in the project and all potential end users.
- Section 3 - This section summarizes preliminary research that was done on the technologies related to T-shirt launchers prior to making any design decisions.
- Section 4 - This section summarizes the requirements created by the team to ensure the final product meets the needs of the UCF Athletics Department and all major stakeholders.
- Section 5 - This section begins the new content for this report. In this section, alternatives for major systems were considered, and analyzed, and a decision was made on how to proceed with the design of the T-shirt launcher.
- Section 6 - This section covers preliminary calculations and experiments that were conducted to ensure the T-shirt launcher is capable of reaching the team's goals, takes all engineering principles into account, and does not violate any laws of physics.
- Section 7 - This section outlines the team's intended schedule for the remainder of the project as well as major milestones that the team will reach.
- Section 8 - This section describes the issues that the team may encounter, such as time constraints or physical constraints on the T-shirt launcher.
- Section 9 - This section covers the risks associated with the T-shirt launcher, their likelihood, severity, and remedies.
- Section 10 - This section allows the team to take credit for any significant accomplishments and recommends future activities for the team.
- Section 11 - Conclusion

2.0 Needs Analysis

While the primary stakeholders and end users of this project may seem obvious, there are other scenarios where the technologies from this project could be applied in different applications. Additionally, the intended end users and primary stakeholders have needs that are specific to their use case, and may not apply to the additional potential end users identified.

2.1 Stakeholders

The primary stakeholder of this project has been identified to be the UCF Athletics Department. The Athletics Department will be the one using the T-shirt launcher as a tool to interact with fans during the games. It was initially believed that UCF Athletics initiated this project, but the team now knows that Pete Alfieris initiated this project as described in Section 1.2, making him an additional primary stakeholder. Pete has expressed his willingness to assist the team in any way possible in the design, funding, procurement of parts, and manufacturing of the T-shirt launcher. He has also indicated that he will be the one to store, maintain, and regulate access to the T-shirt launcher after the conclusion of this project.

Members of the Black Team are also stakeholders in this project. The completed T-shirt launcher will be a representation of the engineering principles learned by the team while studying at UCF and the final step before becoming a UCF graduate. Project advisor, Rich DeBerardinis, is an additional project stakeholder. Rich has been instrumental in the early stages of preliminary research, system requirements, and conceptual design, and will continue to provide guidance to the team as the team enters the design, analysis, manufacturing, and testing phases of the project.

Secondary stakeholders include the UCF College of Engineering and the UCF Department of MAE. The T-shirt launcher is intended to be a representation of the UCF College of Engineering to be on display at sports events. A poorly built, dangerous, or non-functional T-shirt launcher would be a poor representation of the UCF College of Engineering. The UCF Department of MAE will continue to provide project guidance and will be providing project funding.

2.2 End Users

End users are the individuals or groups of people who will be utilizing the T-shirt launcher after the team completes Senior Design. Members of the UCF Athletics Department are the primary end users, but other potential end users are possible in the future.

2.2.1 Intended End Users

The UCF Athletics Department is the primary and intended end user of the T-shirt launcher. The systems that comprise the final product will be designed specifically with UCF Athletics in mind. Members of UCF Athletics who may use the launcher include, but are not limited to, members of the cheer team, members of the marching band, and university mascots, Knightro and the Citronuat. Additionally, Pete will be the individual to maintain and store the T-shirt launcher while it is not in use, making him an additional primary end user. Lastly, the fans at sporting events are the primary beneficiaries of the T-shirt launcher, as they will have the opportunity to catch a shirt at a game. These three groups of people are all essential for the long-term success of the project.

The UCF College of Engineering may also decide to use the T-shirt launcher as a demonstration for the Department of MAE at events such as STEM Day and E-Week. The T-shirt launcher could also be placed on display in the UCF Engineering Atrium.

2.2.2 Potential Additional End Users

Outside of use by UCF Athletics and UCF MAE, the final T-shirt launcher could likely be easily adapted to fit the needs of other groups of people, or the technologies behind the T-shirt launcher could be applied to entirely different products. Any university or professional sports team could use the T-shirt launcher to launch a variety of soft objects, such as shirts or towels.

The T-shirt launcher could be modified to fire small projectiles for an educational setting. In this case, a professor may want to demonstrate a real application of projectile motion equations, Newton's second law, or even fluid dynamics concepts such as air resistance.

The working mechanisms of the T-shirt launcher could be adapted to fire baseballs or tennis balls for training. This would allow the user to place the ball in a certain location, allowing the athlete to prepare for various conditions.

Commercially, arborists usually throw lines in trees to establish their climbing line. Being able to stuff their line into a projectile launcher, aim into the tree, and launch it all the way to the top would save time and physical strain in their already demanding job.

2.3 Methods to Collect User Needs

The team used three main steps to create a comprehensive list of user needs. First, the team created functional and component decompositions for the T-shirt launcher. These decompositions allowed the team to identify key functions and systems that would make up the final T-shirt launcher and their characteristics. After finalizing the decompositions, the team conducted research on other T-shirt launchers to compare their characteristics to the ones identified from the decompositions. This provided some baseline when writing requirements, described in Section 4.0. After writing a preliminary list of requirements, the team met with Pete to gauge his intentions and desires for the T-shirt launcher. The team posed further questions based on Pete's expectations to further tailor the system requirements. The decompositions used are available in Appendix C.

2.4 Summary of User Needs

A summary of the user needs identified using the aforementioned method are listed in Table 2.4.

Table 2.4: User Needs

Number	User Need	Description
1	Launch Distance	Athletics needs the launcher to reach the upper sections of the stadiums and arenas on campus.
2	Adjustability	Athletics needs the launching distance to be adjustable in order to include as many fans as possible.
3	Safety	Athletics needs the launcher to be safe for the operator and fans.
4	Portability	Athletics needs the launcher to be able to be transported to all of the stadiums and arenas on campus.
5	Quickly Launch	Athletics needs to be able to launch multiple shirts in a short amount of time.
6	Cost per Use	Athletics needs the launcher to be affordable to use.
7	Space-U and UCF Themed	Athletics needs the launcher to represent UCF and Space-U.

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These user needs, along with additional considerations made by the team, are translated into engineering requirements specified in Section 4.

2.5 Key User Needs

In the conversation with Pete, the team asked him to rank the 10 most important aspects of the T-shirt launcher on a scale from 1 to 10. This will allow the team to focus on those key parameters, and ensure that those are satisfied before other parameters that are not required. The rating of each aspect and relative weight are shown in Table 2.5.

Table 2.5: Key User Needs

Rating	Relative Weight	User Need
10	0.17	Launch Distance
10	0.17	Adjustability
10	0.17	Safety
10	0.17	Portability
8	0.13	Quickly Launch
5	0.08	Cost per Use
5	0.08	Space-U and UCF Themed
1	0.02	T-shirt Capacity
1	0.02	Weather Resistance

A House of Quality, relating the user needs to system requirements, is provided in Appendix D and further discussed in Section 4.

3.0 Technology Assessment

Before identifying user needs and writing system requirements, the team conducted preliminary research on topics that were thought to be of importance. Not 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. Since then, the team has conducted additional research on areas determined to be important, and broadened the scope of the research to include additional topics.

3.1 Competitor Overview

In the analysis of existing products, formats, and design choices, it has been noticed that nearly every design created for a T-shirt launcher utilized compressed gas to propel the projectile. It is no surprise as to why this method is selected over other options. It is relatively inexpensive, easy to assemble, and capable of launching projectiles at large distances. Some downsides to the compressed air method include refilling gas, component durability, and possible moisture buildup which could expedite the deterioration of design components. The general positive consensus on compressed gas remains since it is relatively inexpensive to operate, only requiring paying to refill the gas, far outweighing the possibility of other propulsion methods failing entirely in terms of the mechanical system. Combustion would not be a practical option as an explosion could damage the T-shirt, or even catch fire in case of a misfire, compromising safety and quality. In terms of PSI required to launch the projectile, about 120 PSI is a median for an acceptable range. Some designs utilize a larger tank that feeds a smaller chamber to allow for one shot at a time, which allows safe manipulation of the compressed gas in a way that is quick and efficient. Other large-factor designs use compressed air tanks of much higher volume, such as scuba tanks around 3300 PSI.

Some materials utilized in the construction of other T-shirt launchers include PVC, plastic, or other sturdy but relatively cheap materials. Lexan was also utilized in one design which is a polycarbonate resin thermoplastic that is 30 times stronger than acrylic and deforms at 300 degrees

Fahrenheit [30]. The biggest decision for material lies in the barrel. The most force is going to be withstood in the barrel, and it is necessary for the material to be capable of safely handling the pressure of launching. Every other component in the design as long as it does not directly correlate to accuracy, precision, or come into direct contact with the chamber, can be selected in terms of cost-effectiveness and practical application.

Trigger selection is basic when it comes to compressed air, a pneumatic trigger would be the most convenient option as it allows for activation through pressure, which already makes up the main component of the system. Electronic controllers could possibly be utilized in the case of a large-factor design or if remote controlling was necessary. The downsides to this option allow for greater chance of malfunction, so it is to be considered as a possible unreliability.

3.2 Propulsion Methods and Energy

Observing and analyzing all the possibilities of a propulsion method, the pneumatic system utilizing compressed air reveals to have the highest potential at effectively reaching the end goal. Compressed fluids, springs/elastic bands, electromagnetic, and catapult/trebuchet are some of the propulsion methods researched in the technology memorandum, and evaluated using small calculations in combination with Pugh matrices. While each method researched presents advantages and drawbacks, some of which are greater than others. A further analysis of weighing such advantages and disadvantages appears in Section 5.1..

3.3 Control Methods

For each propulsion method explored, the team identified a list of the critical parts that would be necessary in order to control the release of energy from the propulsion system. While some components were explored for a propulsion method that was not selected, they could still be used for other functions in the designed propulsion system.

3.3.1 Pressure Specific Controls

From the competitor overview described in Section 3.1, compressed fluid is the most popular choice for the propulsion of a T-shirt launcher. While the team still explored other options, it was determined to place an emphasis on pressure controls to gain an understanding of how competing T-shirt launchers functioned.

3.3.1.1 Movement Controls of Compressed Fluids

In order to use compressed fluid to launch a T-shirt, the fluid would have to be moved from a large storage tank to a smaller accumulator tank, and then released from the accumulator tank to be fired. In order to be able to launch a large number of shirts, the storage tank will not only have to be larger than the accumulator tank, but also hold fluid at a higher pressure. In order to step down the pressure from the storage tank to the accumulator tank, a pressure regulator can be used. To adjust the pressure difference, the user turns a knob on the regulator, which pushes a spring and piston into a diaphragm. On the other side of the diaphragm, a poppet valve uses the pressure difference to push a stem up on the diaphragm [42]. The balance of forces between the knob, poppet valve, and pressure difference allows the user to adjust the regulator. Cheaper pressure regulators are often made of plastic, but high quality brass or steel regulators are available for large changes in pressure. For this project, whichever of the brass or stainless steel pressure regulators is most cost effective would be the best option.

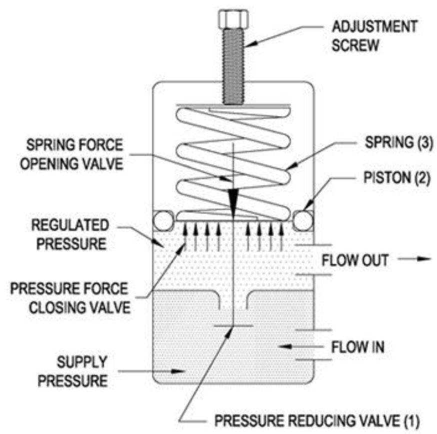


Figure 3.3.1.1A: Pressure Regulator Diagram [41]

To release the compressed fluid in the direction of the T-shirt, the team initially had the idea of using a solenoid to quickly open the accumulator tank in the direction of the T-shirt. A solenoid is essentially an electromagnetic plunger, where the magnetic field from the current causes the plunger to quickly extend or retract [25]. A solenoid can also come in the form of a valve that quickly opens and closes, which is ideal for controlling fluid flow. Using a solenoid between the accumulator tank and T-shirt would provide an almost instantaneous burst of fluid to propel the T-shirt forward. Additionally, solenoids can be used in between the storage and accumulator tanks to regulate the pressure flow. If there was only a pressure regulator between the two tanks, when the fluid is released to launch the T-shirt, additional fluid would leak out past the regulator when the pressure suddenly changes. A solenoid can be used to isolate the two tanks, and only be opened when the accumulator tank needs to be filled.

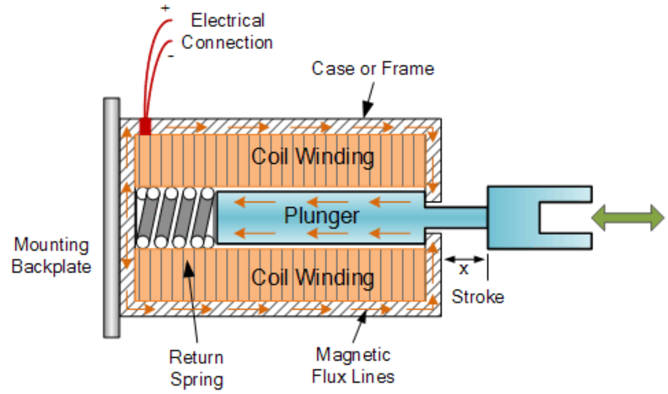


Figure 3.3.1.1B: Solenoid Diagram [25]

After the initial research into solenoids and pressure controls, the team determined that using a solenoid to release the fluid to propel the T-shirt could restrict the fluid flow since the opening of a solenoid is small, and thus limiting the launching distance. Therefore, the team researched quick exhaust valves as a method to propel the T-shirts. A quick exhaust valve relies on a piston that can move in a way to either keep fluid contained or release the fluid [33]. To contain the fluid, the higher pressure storage tank would fill a chamber behind the piston, pushing it forward to block the exit. Once that fluid is released, the accumulator tank can push back on the piston and escape toward the T-shirt. Commercially available quick exhaust valves are small, but other custom built T-shirt launchers have used custom quick exhaust valves of up to 3 inches in diameter. This will allow the fluid to escape faster, mitigating any problems posed by using a solenoid to release the fluid.

3.3.1.2 Safety Controls of Compressed Fluids

Using a pressurized system comes with a unique set of safety concerns. Over-pressurizing any tank, line, hose, or component could lead to the rapid unscheduled disassembly of the launcher, projecting debris toward anyone in the area. To ensure the launcher does not become over-pressurized, a pressure relief valve should be attached to any section of the propulsion system that has to stay below a certain pressure. A pressure relief valve functions almost exactly like a pressure regulator does, as described in Section 3.3.1.1. The only difference is that instead of comparing the pressure inside of two tanks, it is comparing the pressure inside of a tank to the atmospheric pressure. If the relative pressure inside of the tank exceeds the pressure set by the user, fluid will discharge into the atmosphere until the tank reaches the set pressure [31].

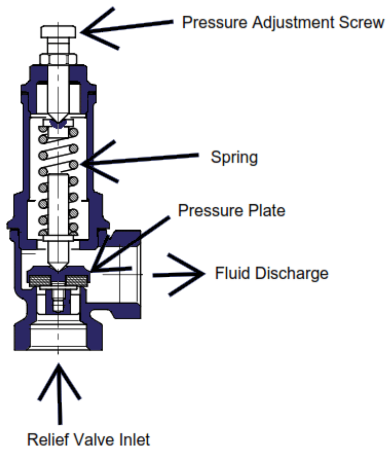


Figure 3.3.1.2: Pressure Relief Valve Diagram [31]

The most obvious safety control for a pressurized system is the use of a pressure gauge. This will allow the user to know exactly how much pressure is being stored inside any section of the propulsion system. Pressure gauges will also be essential to the calibration of any pressure regulators and pressure relief valves.

<u>3.3.2 General Control Methods</u>

These control options were originally explored for propulsion options other than compressed fluid, however they may still be found to be useful for the design of a compressed fluid based propulsion system.

3.3.2.1 Electric Motors and Servos

Electric motors convert electrical energy into rotational mechanical energy. Electric motors fall into two main categories, AC and DC. The functional differences between the two are summarized in Table 3.3.2.1. Most small electric motors can be controlled using a board such as an Arduino, eliminating the need for a dedicated motor controller.

Table 3.3.2.1: AC vs DC Motors [14]

AC	DC
• More powerful • Higher torque • Longer lifespan	• More energy efficient • Quicker response time • More affordable • Easier to control

Servo motors are specialized electric motors. In servo motors, an AC or DC electric motor is attached to a series of gears to control positional output. Servos have an integrated feedback controller to monitor their angular position [23]. The combination of the gears and feedback controllers offers positional output at a higher accuracy and much lower cost than if the team were to design motors to control positional output. For this project, electric motors and servos will be used on an as needed basis as the systems are designed.

Servos and electric motors will be used on an as-needed basis as the design is finalized. A potential use is using a servo or motor to turn the knob on a pressure regulator or pressure relief valve, in order to manage the amount of fluid being stored in the accumulator tank. Electric motors and servos can also be used to provide sensory effects on the launcher that are not essential to the function of the launcher, but make it more interesting to look at.

3.4 Reloading Mechanisms

After analyzing the different reloading mechanisms, the team decided that the gravity-fed mechanism would be the most effective reloading mechanism . Only one operator is needed to use this mechanism. The T-shirts are rolled into the shape of a cylinder and inserted into a plastic cylinder. That cylinder will act as our casing similar to how bullets operate. The cylinders are inserted into a box that is attached on top of the launcher. Once the T-shirt is launched, the cylinder will be ejected out from the launcher. The next cylinder will slide down and set itself to be fired. Using a gravity-fed mechanism, we can load five to eight cylinders. This will help our shooting time and reloading time. Further discussion on the reloading mechanisms that were researched is available in Section 5.3

3.5 Materials

Taking into consideration the propulsion methods considered for this project, compress fluids, electromagnetic rail system, elastic/springs, and mechanical kinetic energy or catapult/trebuchet the material options for this project we will be sticking with is steel sheets, aluminum, PVC, and ABS plastics. These were the materials that best stood out during our initial material analysis for this project.

Aluminum is known as a strong and relatively lightweight metal, shown in Figure 3.5A, that is easy to manufacture due to its malleability and while strong can still be cut into shape without special tools [35]. This makes it extremely useful and is used in plenty of items, from planes, boats, cars, and household items [36]. Steel is also a great material to use for this project as it is known to be stronger than aluminum with higher quality of steel, also shown in Figure 3.5A. Both materials are also known to be used in pressure vessels [37] and steel and aluminum are very strong metals able to withstand large amounts of stress.

Types of metals	Yield strength (PSI)	Ultimate tensile strength (PSI)
Stainless Steel 304	40,000	90,000
Aluminum 3003	21,000	22,000
Steel grade 50	50,000	65,000
Aluminum 6061-T6	40,000	45,000
Titanium Ti-6Al-4V (Grade 5)	160,000	170,000
Steel A36	36,000	58,000
AISI 1065 Carbon steel	71,000	92,100

Gensun Precision Machining www.china-machining.com

Figure 3.5A: Metal Tensile Strength Table [29]

PVC and ABS are known to be able to handle pressurized gas and liquids as they are commonly used in water treatment plants where fluids may be moving at high velocities and under high temperatures, pressurizing the system. PVC and ABS are plastic materials that are mainly used in building and construction products such as pipes, cables, flooring, roofing, and 3D printing filament. PVC is used for vent piping systems, making it a potential candidate for a T-shirt launcher with pressurized gas as the propulsion system. PVC is also a flexible plastic and can be used for a T-shirt launcher that is more mechanical in nature. Another benefit is the ability to hand pressurize liquid, giving us the option to use a hydraulic actuating system as a propulsion system for the launcher. PVC is also known to be used in 3D printing which allows us to create unique and cheap parts that could be used in the project. The downside of PVC is the longevity of the material depends on the amount of stress that is applied over time; the greater the stress, the sooner failure will occur. The fatigue strength of PVC and ABS is shown in Figure 3.5B.

Plastics	Fatigue strength at 10^7 times application of external stress kg/mm² (MPa)
PVC	1.7 (17)
PS	1.02 (10.0)
PE	1.12 (11.0)
PP	1.12 (11.0)
ABS	1.2 (11.8)

Source: " Plastics almanac" by Kogyo Chosakai Publishing Co. Ltd.

Figure 3.5B: Plastic Pressure Strength Table, Fatigue Strength at 10^7 *MPa [34]*

ABS plastic is stronger than PVC and more resistant to temperature and extreme temperature changes. ABS piping is generally used outdoors and underground, whereas PVC is used indoors [4]. ABS is also more shock-resistant and better at handling severely cold temperatures but can warp in sunlight. ABS just like PVC can also be used in 3D printing giving us the ability to create parts for the project. Both ABS and PVC will warp and can be shaped under heat, allowing us to shape the plastic to any desired shape needed for the project.

3.6 Safety

There will be various safety considerations in the development of the UCF Athletics T-Shirt Cannon, as safety emerges as a paramount concern throughout the project's lifecycle. From its conceptualization to its operational implementation, a proactive approach to identifying and addressing potential hazards is essential.

3.6.1 Materials Selection

Material selection is pivotal for ensuring the cannon's safety and longevity. The chosen materials must possess sufficient strength, chemical compatibility, and thermal stability to withstand the forces generated during T-shirt propulsion. Additionally, cost-effectiveness is essential to maintain project viability. By carefully considering these factors, potential hazards such as structural failures or chemical degradation can be mitigated, ensuring the cannon operates safely and reliably.

3.6.2 Operator Safety & User Training

Operator safety and thorough user training are fundamental for accident prevention. Strict protocols, including the use of personal protective equipment, adherence to operational procedures, and mandatory training sessions, minimize the risk of accidents during cannon operations. By empowering operators with the knowledge and skills to safely operate the device, the likelihood of injuries or mishaps is significantly reduced. Various user manuals are specified as requirements for this project.

3.6.3 Emergency Shut-Off Mechanism/Lock-Out Tag-Out

Emergency shut-off mechanisms, such as Emergency Shut-Down (ESD) devices and Lock-out Tag-out (LOTO) systems, are crucial safety features. These mechanisms swiftly deactivate the cannon in emergency situations, preventing accidents and unauthorized operation during maintenance or troubleshooting activities. By implementing robust emergency shut-off protocols, potential hazards associated with technical failures or human error are effectively mitigated. A LOTO system is specified as a project requirement.

3.6.4 Regulatory Compliance

Adherence to regulatory standards is imperative to ensure project success and legal compliance. This includes aligning with university policies, maintaining comprehensive documentation, collaborating with academic advisors, and following facility usage regulations. By complying with established guidelines and regulations, the project can proceed smoothly while upholding the highest standards of safety and professionalism.

4.0 System Requirements

Requirements were chosen based on the key needs of the device. The UCF Athletics Department laid out some key factors that they were interested in the final product having. The main component of this requirement was a UCF-themed device, which caught the attention of the crowd. The biggest component of requirements was driven by safety and reliability. The safety of the operator and the reliability of the device are crucial to maintaining a valid design. Each requirement was tailored to a specific section of the design idea and concept.

The requirements were grouped into general functions, functionality, safety, storage and transportation, maintenance, and economics. The separation of these requirement categories allows for a precise indicator of exact functions and design restrictions for our final product. Most general requirements allow us to outline some design constraints when it comes to ease of use, weight parameters, ratings, and possible systems to be implemented into our final design. The functional requirements allow us to outline some unique features that express the power and capabilities of the final design. Launching distances, velocities, delivery methods, flight times, and some overall specific parameters we feel the design needs to follow and accomplish. Safety encompasses all design parameters in which we ensure the proper placements are taken to provide safe and reliable use of the device. This section pertains to labeling, informing the user of potential hazards, design specifications that call for safety measures, and possible things to avoid in the process to maintain the integrity of the t-shirt launcher. Some storage and transportation requirements were set into place to set parameters for our transportation and storage systems for the device to allow for a comprehensive approach to how the case will be designed, how much room is allowed for the case, weight requirements, modularity of the device, etc. A comprehensive list of all design specifications and categories is provided in Appendix E.

4.1 Key Functions and Features

The UCF department of Athletics specifically outlined that they want the device to be themed towards UCF in some sort of way. Specifically mentioned was Space-U-themed. This means that the device in some way has to represent UCF as Space-U. Another specification made by UCF is that they want the device to be able to reach the upper sections of the bleachers. The most significant requirements outlined in the M2 document were launching T-shirts into the upper sections of the stands, adjustable launching distance, safe for user and fans, portable, quickly launch multiple shirts, cost per use, Space-U themed, T-shirt capacity, and weather resistance. These requirements allow the device to execute the fundamental operations that define the key utilizations of the device, which satisfy an overall function of firing t-shirts at the top rows of the stands while maintaining an excellent excitement factor for the fans. The key requirements described are listed in Table 4.1.

Table 4.1: Key Requirements

Number	Requirement

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

4.2 Theory of Operation

At this stage of the project, it was unknown what the energy source would be, if there would be a reloading system, or any other specifics about the system. The only known facts about the system is that it would need any energy source, the energy source needs to be adjustable, the energy level must be communicated, and other facts stated in our team requirements. At this stage, the system concept is at its most basic level with many systems left to be determined and integrated. This general system is represented by Figure 4.2, where the red arrows indicate the flow of energy. While very basic, it is important to enter the conceptual design phase with no preconceived notions of what the final system may look like, in order to objectively look at the proposed alternatives and select the best option with as much objective evidence as possible.

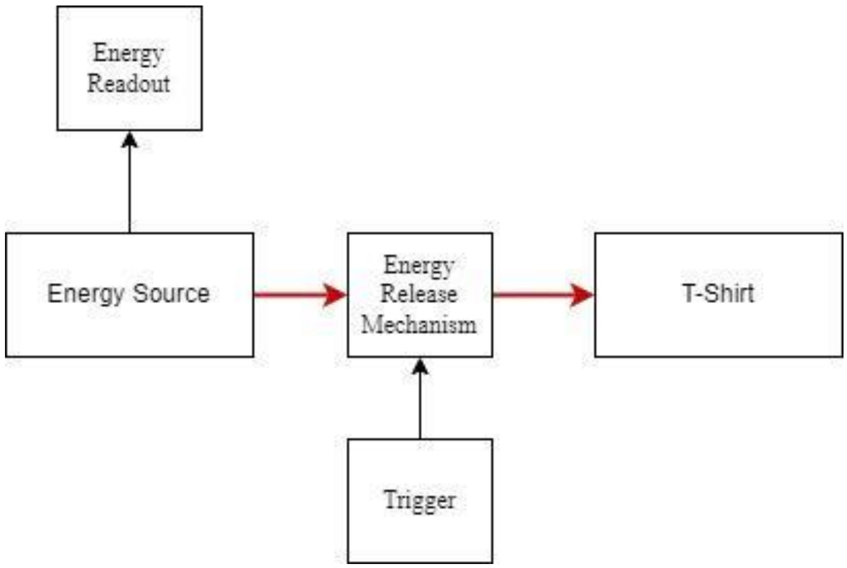


Figure 4.2: Initial Theory of Operation

4.3 Benchmark Analysis

Our requirements are tailored to the UCF Athletics Department requirements and what UCF requires out of the design. Most competitors allow for an air pressurized chamber capable of launching the T-shirt long distances with a minimal compact design. Our design differs from the competitors by including a more substantial user interface and safety system. We will utilize pressure gauge readouts where appropriate and a way to discharge any accumulated pressure after use. The requirements set by the team focus on overall performance and usage of the device not just encompassing firing a T-shirt, but maintaining the reliability and integrity of the safety of our users and fans. We set weight requirements, safety requirements, functional requirements, and overall transportation requirements to ensure that our design qualifies as a legitimate and safe device for UCF to utilize.

5.0 Concept Generation and Selection

Prior to generating concepts for the T-shirt launcher, the team conducted functional and component decompositions of a generic T-shirt launching system. Using the component decomposition, the team was able to identify major systems of the T-shirt launcher that required a design decision, such as the propulsion system and the reloading system. Using both the functional and component decompositions, the team was able to write requirements as specified in Section 4. From these requirements, the team was able to identify other decisions that were necessary in order to meet the stated requirements.

Once the major decision areas were identified, the team used brainstorming and competitor research to identify alternatives for each decision. Competitor benchmarks have been an ongoing task throughout the entirety of this project, as they can provide valuable insight into relevant standards, best practices, and the most common designs used for T-shirt launchers.

After listing alternatives for each decision, the team went through each major decision, assigned the criteria that they would be graded by, and weighted the importance of the criteria, with safety always being the most important. When possible, the team assigned quantitative values to rate each alternative, eliminating as much subjectivity as possible. The ranking values for the Pugh Matrices used in this section are available in Appendix F.

5.1 Propulsion Method

The propulsion method used to project the T-shirts is the single most important design decision for this project. With no propulsion method, the T-shirts will not be able to be launched. This decision also has the biggest safety concern, as the propulsion method will involve energy storage and release, which has been identified as the biggest safety risk for the T-shirt launcher. Furthermore, the propulsion method used influences the implementation of many other decisions. For example, belt-fed reloading may be difficult to implement for a catapult, but is feasible for compressed fluid.

5.1.1 Compressed Fluid

The general idea of utilizing a compressed fluid came from competitor designs, one of which being the most accessible [13]. The concept of using compressed fluid met the Requirement F1.1 variable power control and Requirement F1.3 minimum launch distance of 180 feet. Not only does compressed fluids have potential at completing these requirements, this propulsion method has good integration with other components, such as energy readout level mechanisms being simple pressure gauges. Additionally, since a trigger is being considered, a pneumatic trigger can easily be integrated to a compressed fluids system.

Preliminary analysis was done on a compressed fluid system to ensure it is physically possible to launch a T-shirt at the desired exit velocity and desired distance. For this type of propulsion method, the most likely design is to have fluid stored in an accumulator tank that is suddenly released to propel the T-shirt forward. Theoretically, as long as the T-shirt is still in the barrel and the pressure behind the T-shirt is greater than the atmospheric pressure, it should continue to accelerate. The relationship between the amount of force acting on the T-shirt from pressurized fluid is shown in Equation 5.1.1A, where F is the force, P is the pressure, and A is the cross sectional area of the barrel. This force neglects pressure losses and losses due to friction.

$$F = PA \tag{5.1.1A}$$

Assuming that the barrel is circular, the cross sectional area, *A*, can be found as a function of the diameter, *d*, represented by Equation 5.1.1B.

$$A = \frac{\pi}{4} d^2 \tag{5.1.1B}$$

Newton's Second Law relates force, *F*, mass, *m*, and acceleration, a, as shown in Equation 5.1.1C. Rearranging Equation 5.1.1C, the acceleration can be found as a function of force and mass, shown in Equation 5.1.1D. The weight of a large T-shirt is approximately 0.385 pounds.

$$F = ma \tag{5.1.1C}$$

$$a = \frac{F}{m} \tag{5.1.1D}$$

Substituting Equations 5.1.1A and 5.1.1B into Equation 5.1.1D for *F* and *m*, respectively, the acceleration can be found to be a function of pressure, diameter, and mass, shown in Equation 5.1.1E.

$$a = \frac{P\pi d^2}{4m} \tag{5.1.1E}$$

Since the team is required to have an exit velocity of at least 68.5 MPH, it is necessary to calculate the exit velocity from this acceleration. From projectile motion equations, the final velocity of a particle, V_f, is found to be a function of the initial velocity, V_i, acceleration, and the distance traveled, *L*, which is the length of the barrel. This is shown in Equation 5.1.1F.

$$v_f^2 = v_i^2 + 2aL \tag{5.1.1F}$$

Since the T-shirt is initially at rest, the initial velocity can be set equal to zero. Then, the length of the barrel can be described by Equation 5.1.1G.

$$L = \frac{v_f^2}{2a} \tag{5.1.1G}$$

Since the mass of the T-shirts and barrel diameter is constant, Equation 5.1.1E can be solved for varying pressures, resulting in their corresponding accelerations. Using these corresponding accelerations and the desired exit velocity of 68.5 MPH, the barrel length can be found for each pressure by using Equation 5.1.1G. These results are summarized in Figure 5.1.1.

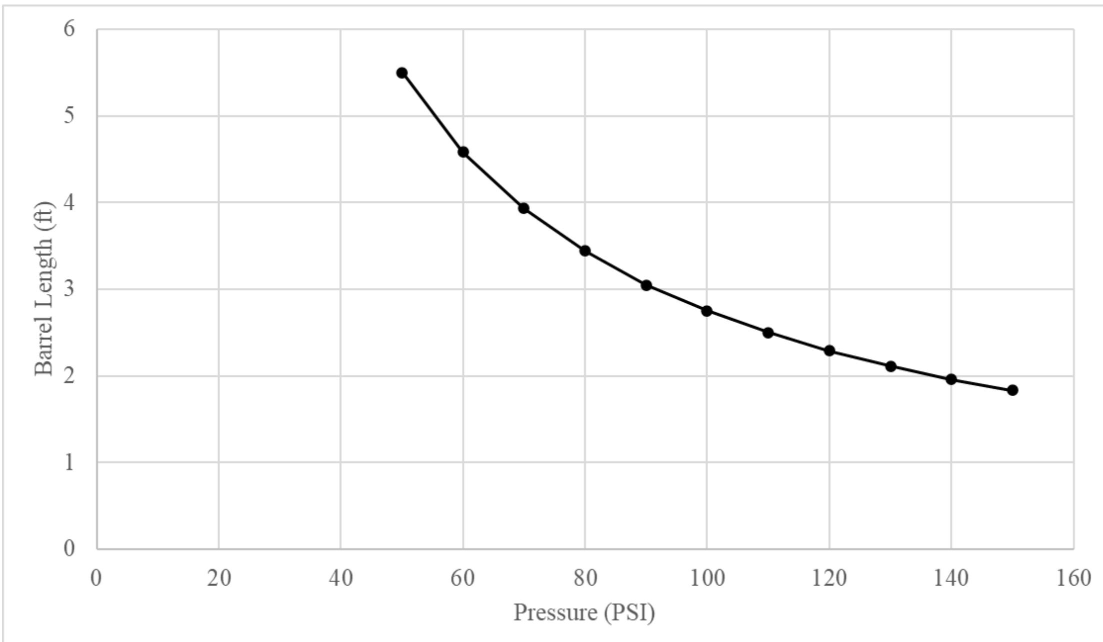


Figure 5.1.1: Pressure vs Barrel Length for 68.5 MPH Exit Velocity

Observing the results in Figure 5.1, it can be seen that it is possible to reach the desired exit velocity by using pressures attainable by commercial pressure vessels. While these calculations neglect pressure losses around the T-shirt, friction in the barrel, and the changing volume as the T-shirt moves down the barrel, this serves as a starting point to reaching an exit velocity of 68.5 MPH.

<u>**5.1.1.1 Compressed Fluid Advantages**</u>

Advantages of using compressed fluid as the propulsion method include, potential at meeting numerous requirements, high energy capacity, and relatively safe. Observing the Pugh matrix in Figure 5.1.5A, compressed fluid scored the highest in energy capacity where the scale is based on shooting 16 plus shots per one tank of compressed fluid. Compressed fluid also scored a 3 in safety being that there is low risk with moderate safety concerns. In comparison to the other propulsion methods, a 3 is the highest score for safety.

5.1.1.2 Compressed Fluid Disadvantages

Disadvantages of utilizing compressed fluid include, the cost, the weight, and the complexity of the components. In comparison to the other options compressed fluid requires refilling when the tank is empty thus requiring an additional cost. Another disadvantage to compressed fluids is the weight of the tank, a standard aluminum 40 cubic foot tank roughly weighs 15 pounds plus 2 pounds when the tank is full. Requirement G1.3 states the launcher weight can not exceed 51 pounds, a compressed fluids tank would account for a large percentage of this weight. Designing a compressed fluid launcher may also increase the complexity of the parts required for proper function.

5.1.2 Electromagnetic

Early on in the project, one team member suggested investigating the feasibility of a T-shirt launcher that utilized electromagnets to propel the T-shirt forward. This unique idea would set the team's T-shirt launcher apart from anything else and starts to enter the realm of science fiction, which is perfect for a Space-U themed T-shirt launcher.

The team's first thought was that a magnetic plunger would be propelled by a magnetic field and directly contact the T-shirt, propelling it forward. With this method, the plunger would have to be traveling at over 68.5 MPH in order to transfer enough energy to the T-shirt for it to have the desired exit velocity. This was deemed a safety risk, as having a plunger that is likely metal and heavy traveling at that speed could cause serious harm if it experienced a rapid unscheduled disassembly.

After this, another team member suggested using the plunger to compress air to propel the T-shirt forward, similar to how a piston compresses air in a car engine. A simplified version of the electromagnetic system is shown in Figure 5.1.2.

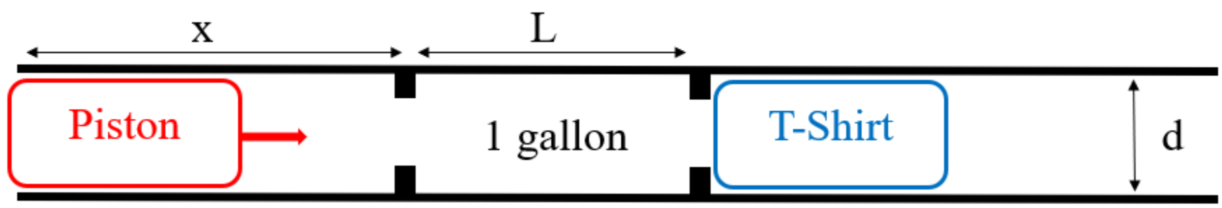


Figure 5.1.2: Proposed Electromagnetic System

To know if this system will work, the first step is to find how much space the piston needs to compress the air adequately. First, some assumptions must be made. Assuming a barrel diameter of 3 inches, and that we need 1 gallon of compressed air, the length of the chamber for the compressed air can be found to be 32.68 inches. While this is considerably long, further calculation is necessary to determine how long the piston must travel to compress the air adequately.

Assuming that the compressed chamber needs to be held at 80 PSI, the distance the piston travels can be found. The ideal gas equation, Equation 5.1.2A, relates pressure, P, volume, V, the number of moles, n, the ideal gas constant, R, and temperature, T of a gas.

$$PV = nRT \tag{5.1.2A}$$

According to the ideal gas equation, the pressure multiplied by the volume is a constant value. Since the final volume and pressure are known, 1 gallon and 80 PSI respectively, as well as the initial atmospheric pressure, the initial volume can be found using Equation 5.1.2B.

$$V_1 = \frac{P_2 V_2}{P_1} \tag{5.1.2B}$$

From this equation, the initial volume can be found to be 1488 cubic inches. Since the chamber is circular, the volume can be divided by the area of a 3 inch circle, to find the length, x in Figure 5.1.2, to be 211 inches.

This result eliminates the need to do further calculation for the force required to move the electromagnetic piston to create the needed pressure. Since the piston would have to travel over 17 feet, there is simply not enough space on the sidelines of the football field or in the basketball arena to maneuver a device that large. Additionally, it is likely that the force required to accomplish this is quite large and the components would be very heavy.

An electromagnetic system would have to be supplemented by a compressed fluid system, where the electromagnetic piston only further compresses already compressed fluid. This would add unnecessary complexity to the system if a compressed fluid system already has to be used.

5.1.3 Elastic / Springs

An elastic or spring based system was first thought of when looking at trigger mechanisms for Nerf guns. When researching the trigger mechanisms, the team learned that Nerf guns function similarly to the electromagnetically powered launcher, except instead of an electromagnetic field driving a piston forward, springs push or pull the piston to compress the air in the firing chamber, pushing the dart out. The main advantage of a spring system such as a Nerf gun is that it requires no external energy source, so the user can simply pull the spring back, release it, and watch the T-shirt be launched. Since the electromagnetic system was unable to achieve the pressures to launch the T-shirt, the same limits apply to the spring system.

However, it was worth investigating if a spring system that directly pushes the T-shirt is capable of propelling the T-shirt at the desired exit velocity. A simplified diagram of a spring pushing a T-shirt is shown in Figure 5.1.3. In this figure, the spring with a spring constant of k is compressed by a length δx, propelling the T-shirt forward at a speed, V_o.

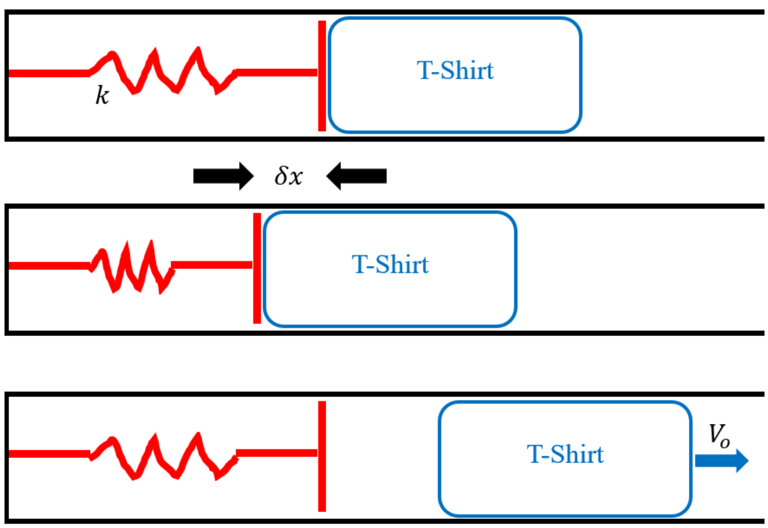


Figure 5.1.3: Proposed Spring System

Using the law of conservation of energy, the initial kinetic and potential energy, K_1 and U_1 respectively, are equal to the final potential and kinetic energy, K_2 and U_2 respectively, as shown in Equation 5.1.3A. This neglects any losses due to friction or other factors.

$$K_1 + U_1 = K_2 + U_2 \tag{5.1.3A}$$

For the spring system, the initial condition is when the spring is fully compressed, as shown in the second part of Figure 5.1.3. At this instant, the T-shirt has no potential or kinetic energy, but the spring has potential energy stored within it. The potential energy of a spring is described by equation 5.1.3B, where *k* is the spring constant and δx is the distance the spring is compressed.

$$U_s = \frac{1}{2}k(\delta x)^2 \tag{5.1.3B}$$

After the spring is released and returns to its unstretched position, the spring has no energy and the spring's potential energy is transferred to the T-shirt in the form of kinetic energy. The kinetic energy of the T-shirt after losing contact with the spring is defined by Equation 5.1.3C, where *m* is the mass of the T-shirt and V_o is the T-shirt's velocity.

$$K = \frac{1}{2}mV_o^2 \tag{5.1.3C}$$

The mass of the T-shirt and desired exit velocity are known, making Equation 5.1.3C fully defined where the kinetic energy is 60.35 lb ft. By equating the potential energy of the spring and kinetic energy of the shirt, the spring deflection and stiffness can be found. Assuming that there is a space constraint and the spring must be under 12 inches long and less than 3 inches in diameter, every spring available from the McMaster Carr catalog [21] that meets these size requirements was analyzed to determine if it would provide enough potential energy. These springs are shown in Table 5.1.3. The potential energy was calculated using only 80% of the springs maximum deflection, as in a real world scenario, it is unlikely to be pulled back the full distance every time.

Table 5.1.3: Spring Potential Energy

McMaster Carr P/N	Diameter (in)	Length (in)	k (lb/in)	Compressed Length (in)	Potential Energy (lb ft)

9657K321	0.875	6	26.64	3.76	9.94
9657K212	0.875	6	13.96	3.5	5.96
96485K141	1.938	6	116.9	3	63.13
96485K135	1.938	6	38.2	2.33	27.23
9622K56	2.438	6	800	4.69	168.45
96485K152	1.938	8	547	5.86	39.23
96485K386	1.938	8	215	5.23	29.54
96485K174	2.188	8	371.8	5.57	36.93
96485K164	2.188	8	61.8	3.63	24.68
96485K156	2.188	8	32.3	2.59	20.77
96485K197	2.438	8	575	5.86	41.24
9622K57	2.438	8	600	6	36.00
96485K191	2.438	8	276	5.16	40.30
96485K182	2.438	8	123	4.21	35.50
96485K222	2.688	8	637.5	5.57	63.32
96485K214	2.688	8	230	4.5	55.20
96485K205	2.688	8	104.3	3.67	40.80
96485K242	2.906	8	697	5.63	65.00
96485K236	2.906	8	185	4.31	50.20
96485K397	2.906	8	53	3.16	26.62
96485K229	2.906	10	42	3.86	14.84

Continued on Next Page

Of the 21 part numbers analyzed, only 4 meet the minimum potential energy requirement. Immediately, this is an indication that this method of propulsion is not suitable since the vast majority of springs will not provide enough energy. Further analysis of the appropriate springs shows more shortcomings. Three of the four springs with enough potential energy are just above the required potential energy. Since the calculations did not take into account friction or any other losses, it is likely that these springs would come up short of launching the T-shirt at the required exit velocity. The final spring, P/N 9622K56, would provide sufficient energy, but the spring constant of 800 lb/in is far too high for any person to use. It would have to be assisted by some sort of machinery that would likely take up a large amount of space, be heavy, and require another energy source to operate. Having to use an additional energy source to pull the spring defeats the entire purpose of a spring system. Due to this, a spring system is not a viable option.

5.1.4 Catapult / Trebuchet

The final method considered to propel T-shirts was a catapult or trebuchet. While these systems are similar, the main difference is that a catapult utilizes tension from a spring or elastic material, while a trebuchet utilizes a counterweight to accelerate the T-shirt. While there are no commercially available catapults or trebuchets that would be a suitable reference for this project, there is a large number of people who have devices such as these in their garages that are capable of launching multiple hundreds of feet, satisfying the needs for this project.

5.1.4.1 Catapult / Trebuchet Advantages

The main advantage of this system is its low cost and overall simplicity. If this system was used, most of the material cost would be in the material used to construct the frame, which would likely be wood or aluminum. Both of these materials are readily available, relatively inexpensive, and easy to work with. This will help satisfy Requirement E2.1, the project budget. The only expensive material would be the energy source, which would be springs for a catapult or a counterweight for a trebuchet.

Along with the low cost, these systems are relatively simple. Since there is only one driving factor for the energy source, the spring tension or counterweight, they would be easy to optimize to reach target distance in the Functional Requirements. Furthermore, the lack of complex parts such as pressure fittings will make the long term use and maintenance of the system easier.

5.1.4.2 Catapult / Trebuchet Disadvantages

A catapult or trebuchet system scored very low in the areas of safety, energy capacity, and weight. The system would be moving at a high rate of speed and have a large amount of stored energy before firing, in the form of spring tension or the counterweight. If either of these systems were to fail, they could send debris through the air at a high velocity. Furthermore, the overall structure will be subject to fatigue over repeated use, weakening any welds or connection points.

For energy capacity, all energy stored in the system is released with every shot, with the need to reload the energy source in between launches. While there is no need to refill something such as an air tank, the time to energize the potential energy in the system could be prohibitive to launching multiple T-shirts.

Finally, this system would be the heaviest and most difficult to move. A catapult or trebuchet capable of launching at the required speed and distance would have to be built to withstand a large amount of energy, inevitably adding weight to the system. Additionally, while a storage system is not required, finding a place to store this system would be difficult. It would likely be too large to fit through standard doors without some disassembly. It would likely take multiple people and a trailer to effectively move the launcher to stadiums and arenas.

5.1.5 Propulsion Method Decision

After analyzing the different propulsion options, it was apparent that there is good reason all commercial T-shirt launchers utilize a compressed fluid based system. An electromagnet or handheld spring based system is not physically feasible, leaving only compressed fluid and a catapult or trebuchet.

Between these two options, the compressed fluid system offers higher safety, which is the most important factor in any decision. The compressed fluid system also offers a much higher energy capacity, with the opportunity to launch T-shirts at a much higher rate. Finally, a compressed fluid system will be much more portable than a large system such as a catapult, which is an important factor to project stakeholders.

While a catapult or trebuchet is much simpler and less expensive, it introduces new issues in the areas of weight, size, and transportation. These limitations could cause the project to be unsuccessful if it cannot be effectively and inexpensively transported where it needs to be. These findings are summarized in Figure 5.1.5A, where the rating criteria is available in Appendix F.

	Propulsion Method Alternatives	
	Compressed Fluid	Electromagnetic

Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Safety	40%	3	1.20	3	1.20
Energy Capacity	22.50%	4	0.90	4	0.90
# Consumable Parts	22.50%	2	0.45	2	0.45
Weight	10%	2	0.20	2	0.20
Build Cost	5%	2	0.10	1	0.05
Totals	100%		2.85		2.80

		Propulsion Method Alternatives, *Continued*			
		Elastic / Springs		Catapult / Trebuchet	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Safety	40%	2	0.80	1	0.40
Energy Capacity	22.50%	1	0.23	1	0.23
# Consumable Parts	22.50%	3	0.68	4	0.90
Weight	10%	3	0.30	1	0.10
Build Cost	5%	3	0.15	4	0.20
Totals	100%		2.15		1.83

Figure 5.1.5A: Propulsion Method Pugh Matrix

Since compressed fluid is the energy source for the system, we can begin to formulate an idea of what the system will consist of, with special attention to the major components. From competitor research, it is likely that our system will consist of a high pressure storage tank feeding a smaller, lower pressure accumulator tank. The fluid in the accumulator tank is quickly released to propel the T-shirt. The basics of this system along with other important components is shown in Figure 5.1.5B, where the flow of fluid is represented by the blue arrows.

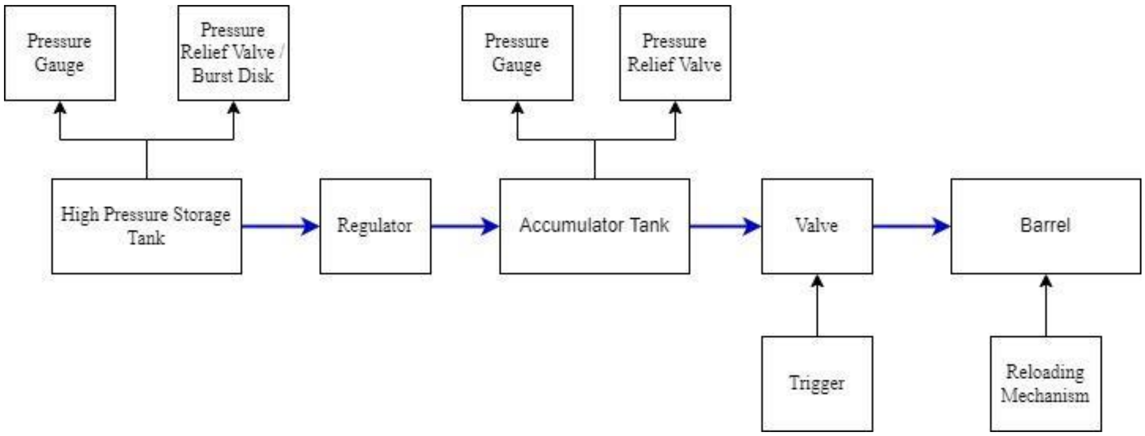


Figure 5.1.5B: Compressed Fluid System Schematic

5.2 Fluid Type

After determining that compressed fluid offered the best solution to launch T-shirts, a new question arises as to what compressed fluid to use. Most commercially available and custom built T-shirt launchers, and projectile launchers in general, use HPA or CO_2 as the energy source. Nitrogen was also identified as a common compressed fluid that is able to be obtained by everyday individuals [20]. All of these fluids will work, but one must be chosen for the design, as pressure vessels, fittings, and adapters, for each fluid, are not necessarily interchangeable due to the different properties of the fluids.

5.2.1 Air

Most commercial and custom built T-shirt launchers utilize compressed air to launch T-shirts. In most cases, the T-shirt launcher has an on-board HPA tank, such as a paintball tank, to store a large amount of air to refill the accumulator. The Bleacher Reacher series takes this approach [13].

Alternatively, some designs, such as The University of Utah design, have the user carry a larger HPA tank, such as a scuba tank, on their back [11].

5.2.1.1 Air Advantages

Compressed air has a long list of advantages over other fluid types. The air pressure inside the tank will stay constant regardless of the ambient temperature. This is beneficial from a safety standpoint as the pressure inside the tank will not increase to a dangerous point. Another benefit regarding the temperature is that the tank itself will not heat or cool as the air is released. Lastly, air is cleaner for any small components it comes in contact with [27].

The single largest benefit of compressed air is that the UCF Machine Shop in Engineering II has a high pressure compressor that is capable of up to 3000 PSI. This means that after the conclusion of the project, Pete will be able to conveniently fill the HPA tanks on campus at no cost. This will help ensure the T-shirt launcher will be utilized in the future.

5.2.1.2 Air Disadvantages

The main drawback of an HPA system is the initial cost. A 68 cubic inch paintball tank capable of 3000 PSI can cost close to $200, taking funds away from other areas in the project. Likewise, scuba tanks, while much larger, cost around $100 for a used tank. A scuba tank would also require an adapter to fill with the Machine Shop compressor.

Using a scuba tank also poses an ergonomic issue. A 40 cubic foot scuba tank weighs around 15 lbs when not filled with air [1]. If this method was used, it would be necessary for the tank to be on a backpack or placed on the ground during use.

5.2.2 CO_2

After air, CO_2 is the most popular choice for compressed fluids. Before HPA tanks were widely available, most paintball guns utilized CO_2 and many still do today, as most paintball destinations have the capability to refill CO_2. Commercially, the Bleacher Reacher series offers CO_2 alongside HPA [13].

5.2.2.1 CO_2 Advantages

The main advantage of CO_2 is the increased number of launches that would be possible. CO_2 is significantly denser than air, allowing the user to get more shots out of the same amount of fluid. CO_2 tanks are more widely available than HPA tanks and are cheaper [27]. For this application, the team would likely need a 5 lb CO_2 cylinder to feed the accumulator.

5.2.2.2 CO_2 Disadvantages

While CO_2 would make a great fluid choice for the launcher, there are many drawbacks. First, it will take time and cost money to refill. UCF does not have any CO_2 source that is available for use, creating a barrier for when the Athletics Department wants to use the launcher in the future. This means that in the future, it will take both someone's time and money to refill the CO_2. In the team's conversation with Pete, he emphasized the importance of having a low operating cost to ensure the T-shirt launcher will be used as often as possible.

Another disadvantage of CO_2 is that the tanks will get cold and create condensation as the fluid is released [27]. While the cold is not a major concern, the condensation is. During design, it could be necessary to place a fluid tank near electronics, and the condensation from the tank could drip onto a wire, causing an electrical issue, which brings in further risks such as electrical shocks and electrical fires. Without knowing the exact placement of the tanks in relation to electronics, it cannot be determined yet if this would be an issue.

5.2.3 Nitrogen

The idea to use nitrogen as the fluid came from the automotive industry. Tires on cars are usually filled with a simple air compressor, but many mechanics also offer nitrogen as a source to fill car tires. For tires, the larger nitrogen molecules are slower to leak out compared to air, allowing the tire to go longer without the need to refill. Additionally, nitrogen holds less moisture than air, helping to prevent the tires from rotting [9].

5.2.3.1 Nitrogen Advantages

The main advantage with nitrogen is its lack of moisture, as previously mentioned. This will be easier on the internals of the T-shirt launcher, and prevent issues such as rust in the future. Nitrogen tanks are about the same price and size as CO_2 tanks.

5.2.3.2 Nitrogen Disadvantages

Nitrogen is not as accessible as air or CO_2 to refill. While some mechanics do keep nitrogen, it is possible that they would not want the liability of refilling someone else's tanks. This means that in the future, someone will have to travel to a welding supply store, such as Airgas, to refill the tanks.

Nitrogen is also slightly less dense than air, and significantly less dense than CO_2. Due to this, the T-shirt launcher will be capable of fewer shots in between refills.

5.2.4 Fluid Type Decision

Constructing the Pugh Matrix shown in Figure 5.2.4, it can be seen that nitrogen is clearly the least optimal choice. Nitrogen would be the worst performing fluid due to its lower density, and at the same time be the most expensive since it can not be refilled near the UCF main campus. Due to this, nitrogen can be eliminated as a choice for the type of fluid to be used.

From the Pugh Matrix, CO_2 outweighs HPA due to its lower initial cost, lower storage pressure (safety), and higher density. While all of these statements are true, the team is instead going to utilize HPA for the following reasons. While safety is the primary concern for all decisions, especially ones that involve energy storage such as this, all commercial pressure vessels are built to high standards, and ones that reach high pressures such as HPA tanks will follow ASME Section VIII [17] guidelines and DOT requirements defined under 49 CFR 173.315 [3]. HPA tanks have burst disks, preventing them from being filled to a dangerous point. These burst disks paired with a pressure regulator offer multiple points to prevent a dangerous situation.

Furthermore, while HPA tanks do have a higher initial cost, it is significantly easier to find additional components rated for air pressure compared to compressed CO_2. This will save the team time and likely funds when searching for fittings, gauges, or other pressure control components. Lastly, while CO_2 does offer a higher density, and therefore more power, compressed air was found to be sufficient to meet the exit velocity and distance requirements during testing, which is described in later sections.

The single largest advantage of HPA that cannot be overlooked is the time and cost associated with refilling the tanks. Since there is a source of HPA available in the Engineering building at the UCF main campus, it will be significantly easier, quicker, and cheaper to refill the tanks. This will increase the likelihood of the T-shirt launcher actually being used in the future, instead of just collecting dust. The criteria for ranking the fluid types in Figure 5.2.4 is available in Appendix F.

		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 5.2.4: Fluid Type Pugh Matrix

5.3 Reloading System

For the analysis of the reloading system, safety is the highest priority while the number of moving parts is the lowest priority. The other two factors that were used to implement significance were the time between shots and the magazine capacity. Using the Pugh Matrix, it was determined that the gravity fed mechanism was the most effective loading mechanism. Using the same matrix, we were able to conclude that the manual reloading system is the least effective mechanism.

5.3.1 Manual Reloading

Manual reloading is one of the options that was considered for the loading mechanism. It was considered for its simplicity design. However, having a simple design meant that it was not very effective in the other factor that we used to determine which mechanism was going to be used in our launcher. For the analysis of manual reloading, it did very well in the number of moving parts but it lacks any type of magazine capacity. The reload time is also bad in comparison to the other loading mechanisms.

5.3.1.1 Manual Reloading Advantages

Some advantages of manual reloading is the number of parts and the safety aspect. The main advantage of manual reloading is the simplicity of it. There are no moving parts which means it is less prone to failure. In regards to safety, there is a lower chance of parts getting stuck and breaking. There is also a lower chance of the T-shirt getting jammed in between shots and having a malfunction and potentially injuring the operator.

5.3.1.2 Manual Reloading Disadvantages

One disadvantage of manual reloading the T-shirt launcher is the time it takes to reload. The launcher has to be put down and the t-shirt has to be stuffed into the launcher. Then it has to be set up to launch again. The magazine size is also a disadvantage. It is a single shot which means you can only fire once and then you must start the reloading process. There is very little time in games where you can launch the T-shirt out. Every second counts and we want as many fans to have a chance to get a T-shirt as possible.

5.3.2 Belt Fed Reloading

A belt fed loading mechanism was inspired by machine guns. This mechanism does very well in the time in between shots and also the magazine capacity. However, it falls short in safety and the number of parts that is needed to operate this system.

5.3.2.1 Belt Fed Reloading Advantages

An advantage of a belt fed loading system would be its time between shots. Using a belt fed system would allow the shirts to be launched immediately after one another. Another advantage would be the magazine capacity. The magazine size would be as big as needed. UCF would be able to use the belt clips to bring as many T-shirts as they wanted to give away that game.

5.3.2.2 Belt Fed Reloading Disadvantages

A disadvantage of the belt fed system would be the number of parts. Having a belt fed system requires something that would hold the T-shirts together. It also requires something that would hold the T-shirt containers together while they are in a line. Another disadvantage is the safety. Having a belt fed system means more parts which could cause malfunctions. The belt must be fed into the slot exactly right or it will get jammed. If the belt is jammed, it could damage the launcher. It will reduce the amount of shirts that are able to be shot out as it would have to be fixed. Having a belt fed system will require either the belt to drag on the ground or someone to hold the belt up. Both of those options are not ideal as having the belt drag on the ground will cause the shirts to get dirty and having someone hold the belt up will tire them out and make the launcher require two people to operate.

5.3.3 Revolver Barrel Reloading

The revolver barrel loading mechanism was inspired by a revolver. This loading mechanism does exceptionally well in magazine capacity. It also ranks decently well from a safety standpoint. However, it does very poorly in the number of parts required to make this system work. It also does not rank the highest in the time it takes between shots.

5.3.3.1 Revolver Barrel Reloading Advantages

One advantage of using a revolver barrel is magazine capacity. We can design the barrel to be as big as we want to hold as many shirts as we want. This would allow us to be very efficient in getting as many T-shirts as we want out to the crowd. Another advantage is the time between shots. Although we can’t have the T-shirt launcher shoot round after round immediately, it would be able to shoot as fast as the barrel rotates and aligns the next shirt.

5.3.3.2 Revolver Barrel Reloading Disadvantages

The revolver barrel mechanism's biggest disadvantage would be its size. Having a big disk that can hold 6 shirts by our barrel would greatly increase the size of our launcher. It would make it difficult to move, store, and carry. It would reduce its usability. We want our T-shirt launcher to be mobile and having a revolving barrel would remove that. Another disadvantage would be the number of parts. More parts reduces our reliability which is another thing that is important as we don’t want our launcher to break in the middle of the game.

5.3.4 Gravity Fed Reloading

A gravity fed reloading system was also considered for the launching mechanism. It is more commonly seen in reloading systems. It is not the most simple, but it has a very good magazine capacity and the time between shots is minimal. Using the Pugh Matrix, we can see why this is the choice that most people use in their T-shirt launcher. It is effective in each criteria while also being one of the safest options.

5.3.4.1 Gravity Fed Reloading Advantages

One advantage for the gravity fed loading mechanism is the time between shots. Using natural forces reduces the number of parts that are needed for this system. There are not as many parts as some of the alternate loading systems that were previously mentioned. The other advantage is the magazine capacity. This system can hold multiple T-shirts as needed while also being mobile. Additionally, adding more T-shirts is as simple as dropping another one into the magazine. The magazine system will not interfere with the usability and mobility of the T-shirt launcher. The biggest advantage that the gravity fed loading mechanism has is that it can do everything efficiently.

5.3.4.2 Gravity Fed Reloading Disadvantages

One drawback of the gravity fed system is the number of parts. Although gravity will do the work in reloading, we need to design a structure to place on top of the launcher that will hold the T-shirts in place until it is time to shoot. We also need a flap so the T-shirts can drop down into the barrel without getting stuck or not fitting in properly.

5.3.5 Reloading System Decision

While the manual reloading system is very simple, simple doesn’t always mean better. Although it is very safe, it lacks magazine capability and has a very long time between shots. Due to these negatives, this loading mechanism can be eliminated.

The belt fed loading mechanism is very good at having a short time in between shots and also having a very good magazine capacity. However the benefits do not outweigh the negatives in regards to how unsafe this mechanism is. There is a much higher risk of something malfunctioning while using this loading mechanism. Due to ranking poorly in the safety criteria, this loading mechanism has been eliminated.

The revolver barrel loading mechanism is also good at having a short time between shots and a large magazine capacity. However, it falls behind the belt fed system in the timing between shots. It also ranks poorly in regards to safety. It also removes the mobility and usability that we need in our t-shirt launcher. Due to being unsafe and also removing mobility from the launcher, this method is also eliminated.

The gravity fed loading mechanism is good at everything. The only downfall is having a slightly high number of parts. This loading mechanism was determined to be the best solution from the Pugh Matrix. This mechanism ranks well in every criteria meaning that this is the most effective loading mechanism. Therefore, the decision was made to use a gravity fed reloading mechanism. These results are summarized in Figure 5.3.5.

		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 5.3.5: Reloading System Pugh Matrix

5.4 Firing Mechanism

Deciding the mechanism to use for the activation of launching the device was determined by evaluating the criteria and the importance of two options: the trigger and button. Observing Figure 5.4.3 the overall evaluation shows that a trigger scores slightly higher than a button. The following sections will include further detail as to how the trigger scores slightly higher than the button.

5.4.1 Button

The criteria which the firing mechanism was observed against includes, safety (Requirement S7.2) rated by pounds of force to activate, safety lock (Requirement S7.1) rated by the number of steps, and space for the mascot to activate (Requirement G5.1). Overall the button is a strong competitor for the firing mechanism, and if there are any complications with the trigger mechanism, the button is a good alternative.

5.4.1.1 Button Advantages

Some advantages to utilizing the button as a firing activation mechanism include a set activation force, a low number of steps for a safety lock, and a maximum amount of space for a mascot to activate the button. Since Requirement S7.2 requires the system to have an activation force greater than 4 pounds, a button will either pass or fail this requirement. A button will also have a low number of steps for a lockout (Requirement S7.1) something as simple as covering the button will suffice for a lockout mechanism.

5.4.1.2 Button Disadvantages

A disadvantage to using a button as the mechanism for activation is the lack of adjustability when it comes to activation force. Adjusting the activation force on a button is not as simple as adjusting that of a trigger, this is the reason why the button did not receive a perfect score on the weighted rating table, Figure 5.4.3.

5.4.2 Trigger

Same for the button, the trigger was based on the same criteria, trigger activation force, number of steps for lockout, and the space available for a mascot to activate. Typically a trigger has a guard and this was accounted for in the evaluation of the trigger.

5.4.2.1 Trigger Advantages

The advantages of using the trigger as the activation mechanism on the launching system include adjustability to the activation force and the low numbers to activate the safety lock. The trigger is capable of adjustable activation force, and in the viewpoint of safety a greater activation force results in a greater safety factor. The safety lock for the trigger scores similar to the button, this is an advantage because the number of steps to activate the safety lock is low. A trigger can utilize something such as a pin to lock out the user and ensure the system is safe.

5.4.2.2 Trigger Disadvantages

The disadvantage to the trigger activation mechanism is the room for the mascot (Requirement G5.1), this is an essential requirement and the trigger accounts for a trigger guard. A large trigger guard would be necessary for a requirement G5.1 to verify.

5.4.3 Firing Mechanism Decision

After analyzing Figure 5.4.3 and weighing the possible criteria of the two options, the results show the trigger is more suitable for the job, slightly. Both options are a suitable fit for the system but the trigger shows to have a greater safety rating. Accounting for the weight of the criteria the safety and safety lock are weighted majority at 35% each and space for the mascot is weighted at 30%.

For the system, we are pursuing a trigger mechanism due to the higher safety rating and similar safety lock rating to the button. If it is determined during the detailed design stage that a button will better satisfy the system requirements, if it offers a viable alternative.

		Firing Mechanism Alternatives			
		Button		Trigger	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Safety	35%	3	1.05	4	1.40
Safety Lock	35%	3	1.05	3	1.05
Space (for mascot)	30%	3	0.90	2	0.60
Totals	100%		3.00		3.05

Figure 5.4.3: Firing Mechanism Pugh Matrix

5.5 Delivery Method

In the deliberation of the delivery method, the factors identified to decide the significance were: safety, cost, and aerodynamics. In the comparison of all methods, the Pugh Matrix shown in Figure 5.5.7 showed a numerical tie between rubber bands and tape. The determination was made through physical testing methods, which will be covered in Section 6.2. Through physical testing, it was determined that tape was a more effective method of delivery than rubber bands. Something to account for is the friction generated by the rubber within the barrel versus the friction generated by generic masking tape.

5.5.1 No Container

In the analysis of a "no container" delivery method, it rates very high in terms of safety and cost, but lacks majorly in the aspect of aerodynamics. It is noteworthy that this method is incredibly safe, since the T-shirt will not have any additional items tied to it, which would theoretically lower the impact on a person, and cut costs since a disposable method of containing the shirt will not need to be purchased. The main deliberation on the "no container" method is that it lacks so severely in the aerodynamics category, that it is not a viable or usable option because it does not hold enough structure to meet Requirements F1.2 and F1.3 of the project, therefore, it is not considered anymore, but could be offered as a packaging method to UCF Athletics for smaller venues, such as the volleyball arena.

5.5.1.1 No Container Advantages

The advantages of this method are the safety aspect, and the cost aspect. Since it is the least aerodynamic option, the T-shirt will not have as much of an impact on a person, and since nothing will need to be attached to the T-shirt, it will cost nothing.

5.5.1.2 No Container Disadvantages

The one major drawback of this method is the aerodynamics. It is common for the shirt to come unraveled mid-flight, compromising the integrity of the structure and causing it to lose major distance. This issue is detrimental to the requirements of the project, which entirely rules it out as an option for the design.

5.5.2 Plastic Wrap

Plastic wrap is another option to be considered for a delivery method. In testing, we used flat plastic wrap, rolled the T-shirt, and wrapped it in the plastic securely and tightly to withhold the structure of the T-shirt. In terms of criteria, it rates excellent in safety and aerodynamics. Some of the testing observations will be listed within the respective section, the ultimate conclusion is that it provides reliable results, but the plastic is susceptible to coming unwrapped, compromising the integrity of the structure. Additionally, the plastic wrap created a strong seal on the barrel, creating a very loud popping sound, which could cause confusion for the operator and fans.

5.5.2.1 Plastic Wrap Advantages

Some advantages to this design are the safety aspect and aerodynamics. Plastic wrap can act as somewhat of a barrier to absorb force from a moving projectile. Since the shirt is wrapped, it acts as a flat vessel for the T-shirt to move through the air with great aerodynamics if it remains intact.

5.5.2.2 Plastic Wrap Disadvantages

Although the advantages sound promising in writing, the biggest downside to this is the ability for the plastic to come unraveled in mid air, which entirely ruins the aerodynamics of the shirt and ruins the launch. Another massive disadvantage is that since it is plastic, it will be wasteful and possibly expensive over many uses to continuously use. We also have a concern of fans unwrapping the plastic and throwing it on the floor which contributes to littering and environmental damage.

5.5.3 Rubber Bands

Rubber bands were another delivery method considered for use. This method scored very high in terms of aerodynamics, cost, and safety. Some things to consider were uncovered during testing and allowed for the team to discover some of the ways that rubber bands interact with the device and how it can affect flight and distance.

5.5.3.1 Rubber Bands Advantages

The biggest advantages to the rubber bands are their cost-effectiveness, ease of use, convenience for the fans, etc. This allowed for excellent flight, delivery, and overall well-roundedness of the usage. During testing, this method was the second best and it was heavily considered for selection based on comparison of results.

5.5.3.2 Rubber Bands Disadvantages

The biggest disadvantage of rubber bands in observation was the friction caused with the inside of the barrel. Initially this was not something that was considered, but after some testing, it was noted that we were consistently losing distance on launches presumably because the rubber was causing rubbing and friction within the barrel and losing kinetic energy on the way out during the launch sequence. That is the one thing that ended up placing this method into the number two slot rather than number one.

5.5.4 Parachute

A parachute could be considered for a method of delivery, a parachute would have to be attached to the T-shirt, launched high in the air, and then cause a slow descent into the crowd which would create an interesting spin on the generic T-shirt launching experience. There are some key advantages and disadvantages that will be discussed next.

5.5.4.1 Parachute Advantages

This creates an incredibly exciting, unique, and fun experience for fans to receive the T-shirt from the device as it is seamlessly falling on their head slowly with a parachute. This could in some way contribute to the Space-U themed requirement as a parachute may fall under a similar category of space-inspired designs and applications.

5.5.4.2 Parachute Disadvantages

The biggest and most detrimental disadvantage that essentially rules this option out is the cost. For every single T-shirt, the UCF Athletics Department will have to purchase a parachute that is disposable and only single-use. Pricing may not be major, but over time delivering many T-shirts over many sporting-events could incur major costs over time. Another thing to consider with this method is similar to the plastic method, as fans will likely dispose of the parachute beneath their feet which will create a mess for staff to clean, or possibly littering and leaving the trash out undisposed of.

5.5.5 Tape

Tape was another consideration for the delivery method, as it is cheap, easy to use, safe, and effective to maintain the integrity of the T-shirt during launch conditions, and provide minimal cost implications, complications, and confusion amongst fans. During testing, this method actually gave the best results and placed number one for us. Considering some of the advantages and disadvantages, it is easy to see why it is so effective, considering it functions almost the same as the rubber bands, but negates some of the issues implied by that method.

5.5.5.1 Tape Advantages

The most significant advantages of this method follow the same theme as the rubber band method. It is cost-effective, easy to apply, excellent moving through the air at high speeds, and continues to maintain the shirt properly in flight with no observed failures if applied correctly. The main distinction between this method and the rubber band is the friction caused during launch. The tape used in testing was a generic masking tape. This tape created significantly less friction within the barrel during launch due to the material the tape is made of, and the more flat profile of the tape over the T-shirt, rather than a band which bulges out slightly. The testing results reflected improvement on the distance, accuracy, and ease of use, which is why this was deemed the number one method after testing and consideration.

5.5.5.2 Tape Disadvantages

Some disadvantages to this method is, it uses a moderate amount of tape, it takes about twice the circumference of the shirt worth of tape to ensure that it is properly secured and maintaining the profile of the T-shirt during launch. Another thing to consider is that fans may unwrap the tape from the T-shirt and dispose of it on the ground. This seems to be a commonality between all delivery methods, as all methods are disposable, and in general, there will always be people who will just dispose of it on the floor rather than finding a proper location to get rid of the excess. However, tape is less of an environmental concern when compared to plastic wrap , rubber bands, or a large parachute.

5.5.6 Plastic Cylinder

The general idea of the plastic cylinder method was perhaps a capsule that the T-shirt fit in, and this capsule was perfectly designed to fit within a barrel, which would maximize translation of energy from the pressure vessel to the delivery method, as no air will be allowed to escape from any inconsistencies in the barrel, maximizing distance and perhaps accuracy.

5.5.6.1 Plastic Cylinder Advantages

The advantages of this method are mainly in the ease of loading, and energy translation. As highlighted above, the energy translation from the barrel to the cylinder will be maximized because the limitation of gaps between the cylinder and barrel will allow for excellent energy translation and much less energy will be wasted during the process. Another great advantage would be that the operator would have no issues loading this because the cylinder is already designed for maximized efficiency, and the only concern for them would be stuffing the T-shirt into the capsule, which would occur prior to using the launcher during a game.

5.5.6.2 Plastic Cylinder Disadvantages

The glaring disadvantage of this method and the only thing ruling this out as an excellent option would be the safety factor. A hard plastic vessel traveling towards fans at a high rate of speed could be incredibly damaging if an unsuspecting fan is hit with this. Since safety is a primary concern for our device, it is not feasible to use this method without the possibility of someone getting severely injured. Perhaps if there was a way to use a softer plastic which could cushion an impact, then it could be ideal, but then we run into the issue of cost and environmental concerns. It would be incredibly expensive over time for the UCF Athletics Department to continuously purchase plastic vessels for the shirts, and as we want to minimize use of plastic to reduce environmental effects, it seems like the disadvantages here stack up enough to eliminate this as a practical method of delivery, leaving the tape and rubber bands as our primary contenders for a well-balanced, cheap, effective, and overall excellent choice.

5.5.7 Delivery Method Decision

From a safety standpoint, plastic wrap and a plastic cylinder can be eliminated. Even if the fans are all paying attention, a hard plastic cylinder traveling at a high rate of speed could break small finger bones or cause a head injury if someone was hit in the head. Plastic wrap is mainly eliminated due to the large popping sound created and the environmental concerns of plastic wrap being left on the ground.

A parachute, while being space themed, is the highest cost option for the delivery of the T-shirt. Since key project stakeholders indicated that the cost per use needs to be kept low, this option will not be used for testing to meet requirements, but it could be further researched and suggested as an alternative to UCF Athletics.

The no container method, while the cheapest, struggles to meet the distance requirements. Similarly to the parachute, this can be suggested as an alternative packaging method, but is not the optimal solution.

Using rubber bands or tape was found to be the best solution from the testing described in Section 6. Both of these methods use the same rolling technique of the T-shirt, so the only difference is the material used to secure the T-shirt. Tape was found to consistently launch further than rubber bands, due to the reduced friction in the barrel. While these methods do technically cost some money, these are common materials that everyone has access to or can be purchased for a very low cost and used over a long period of time.

		Delivery Method Alternatives			
		No Container		Plastic Wrap	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Safety	40%	3	1.20	2	0.80
Cost	35%	4	1.40	3	1.05
Aerodynamics	25%	1	0.25	4	1.00
Totals	100%		2.85		2.85

		Delivery Method Alternatives, *Continued*			
		Rubber Bands		Parachute	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Safety	40%	2	0.80	4	1.60
Cost	35%	4	1.40	2	0.70
Aerodynamics	25%	3	0.75	2	0.50
Totals	100%		2.95		2.80

		Delivery Method Alternatives, *Continued*			
		Tape		Plastic Cylinder	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Safety	40%	2	0.80	1	0.40
Cost	35%	4	1.40	2	0.70
Aerodynamics	25%	3	0.75	4	1.00
Totals	100%		2.95		2.10

Figure 5.5.7: Delivery Method Pugh Matrix

5.6 User Interface

The user interface of the T-shirt launcher mainly serves as a safety feature to communicate the status of the launcher to the user. Most people think of a user interface as a digital display, but that is only one option that was considered, in addition to analog options and LED indicators.

5.6.1 Digital

Digital pressure transducers represent sophisticated instruments utilized across various industries for precise measurement and monitoring of fluid pressure within systems. These transducers typically consist of a digital sensor interfaced with electronic circuitry to convert pressure readings into digital signals, enabling accurate and real-time data acquisition. Key components include the sensing element, signal conditioning circuitry, microcontroller, and digital display interface. Unlike analog gauges, digital pressure transducers offer enhanced accuracy, resolution, and versatility in data processing capabilities. They can provide detailed pressure readings with high precision, making them valuable for applications requiring precise control and monitoring. Additionally, digital transducers often feature advanced functionalities such as programmable alarms, data logging, and communication interfaces for seamless integration into automated systems. While digital transducers may require external power sources and entail higher initial costs compared to analog gauges, their superior performance and advanced features justify their adoption in critical applications across industries such as aerospace, automotive, healthcare, and manufacturing. When selecting digital pressure transducers, factors such as accuracy, resolution, response time, and compatibility with data acquisition systems must be carefully considered to ensure optimal performance and reliability in specific operational environments. A diagram of a digital pressure transducer is shown in Figure 5.6.1.

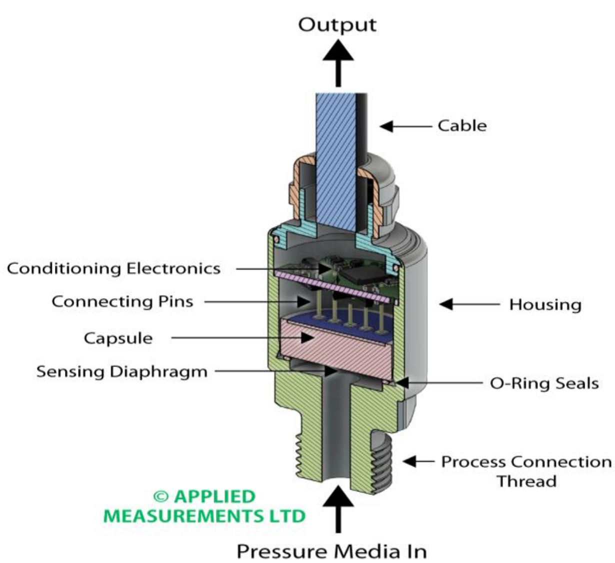


Figure 5.6.1: Digital Pressure Transducer [7]

5.6.1.1 Digital Advantages

Using digital pressure transducers for our T-shirt launcher project provides several key advantages. Firstly, they offer high accuracy and precision in pressure measurement, ensuring reliable performance critical for safety and operational efficiency of the launcher. Digital transducers also boast versatile data processing capabilities, including programmable alarms, data logging, and communication interfaces, enabling seamless integration into the launcher's automated systems. With a wider dynamic range and better resolution than analog gauges, they provide comprehensive insight into pressure variations, essential for optimizing the launcher's performance. Additionally, digital transducers offer long-term stability and reliability, minimizing the need for frequent calibration and maintenance, which is crucial for the sustained functionality of the launcher during its operational lifespan. Overall, their performance, functionality, and flexibility make digital pressure transducers a practical option for precise pressure monitoring and control in our T-shirt launcher project.

5.6.1.2 Digital Disadvantages

Digital pressure transducers, despite their advantages, also have some drawbacks to consider. Firstly, they generally have a higher initial cost compared to analog gauges, which can impact the overall budget of the project. Additionally, digital transducers require external power sources for operation, adding complexity to the system design and potentially increasing energy consumption. Moreover, their sophisticated electronics and digital interfaces may introduce points of failure or susceptibility to environmental factors such as electromagnetic interference. In some cases, digital transducers may also have slower response times compared to analog gauges, which could be a limitation in applications requiring real-time pressure monitoring. Furthermore, digital transducers may require specialized knowledge or training for proper setup, calibration, and troubleshooting, which could pose challenges for inexperienced users. Overall, while digital pressure transducers offer significant advantages, it is essential to carefully weigh these disadvantages against the project's requirements and constraints.

5.6.2 Analog

Analog pressure gauges serve as essential mechanical instruments in various industries, facilitating the measurement of fluid pressure within systems. Their fundamental structure typically comprises a dial with a moving needle or pointer, enabling instant visualization of pressure readings. These gauges are composed of several key components, including a pressure sensing element such as a Bourdon tube, diaphragm, or bellows, along with a movement mechanism housed within a protective case. Bourdon tube, diaphragm, and bellows gauges represent common variants, each offering distinct operational principles. Despite their variance, analog gauges uniformly provide simplicity, reliability, and real-time assessment capabilities without necessitating external power sources, rendering them suitable for deployment across diverse environments and applications. However, limitations in accuracy may cause periodic calibration and maintenance efforts. Regardless, analog pressure gauges remain extensively utilized in sectors such as HVAC, hydraulic and pneumatic systems, industrial machinery, and process control applications owing to their cost-effectiveness and user-friendly nature. When selecting analog gauges for specific applications, users should consider accuracy requirements and environmental factors to ensure optimal performance. The working mechanism of an analog pressure gauge is shown in Figure 5.6.2.

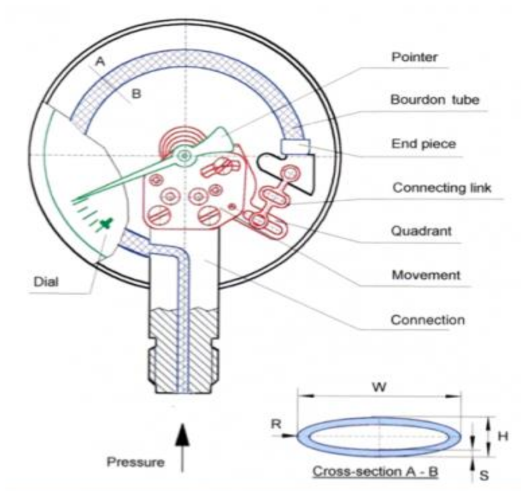


Figure 5.6.2: Analog Pressure Gauge [26]

5.6.2.1 Analog Advantages

Analog pressure gauges offer several advantages for our T-shirt launcher project. Firstly, they typically have a lower initial cost compared to digital transducers, which can help in meeting budget constraints. Additionally, analog gauges do not require external power sources for operation, simplifying the system design and reducing energy consumption. Moreover, analog gauges are generally less susceptible to electromagnetic interference and do not have the same points of failure associated with digital electronics. Their simple design also often results in faster response times, making them suitable for applications requiring real-time pressure monitoring. Furthermore, analog gauges are generally easier to install and calibrate, requiring less specialized knowledge or training for setup and maintenance. Overall, analog pressure gauges offer a cost-effective, reliable, and straightforward solution for pressure monitoring in our T-shirt launcher project.

5.6.2.2 Analog Disadvantages

Analog pressure gauges, while offering advantages, also come with some drawbacks to consider. Firstly, they may not provide the same level of accuracy and precision as digital transducers, which could be a limitation in applications where precise pressure control is essential. Additionally, analog gauges are typically less versatile in terms of data processing capabilities, lacking features such as programmable alarms and data logging. Their mechanical nature also makes them more susceptible to wear and drift over time, requiring more frequent calibration and maintenance to ensure accuracy. Moreover, analog gauges may have limited compatibility with modern automation and control systems, making integration more challenging. Furthermore, their analog display format may be less intuitive for users accustomed to digital interfaces. Overall, while analog pressure gauges offer simplicity and reliability, these limitations should be carefully considered in the context of our T-shirt launcher project.

5.6.3 LED Indicators

LED indicators for pressure serve as intuitive visual interfaces, employing light-emitting diodes arranged to represent different pressure levels or ranges. With each LED corresponding to a specific pressure threshold, users can easily interpret pressure variations at a glance without the complexity of analog gauges or digital readouts. These indicators offer simplicity, energy efficiency, and durability, making them ideal for diverse applications such as pneumatic systems, hydraulic machinery, and automotive settings. While lacking the precision of digital transducers, LED indicators provide a cost-effective solution for basic pressure monitoring needs, enhancing operational awareness and safety. When selecting LED indicators, considerations such as visibility, durability, and compatibility with the operating environment should be taken into account to ensure optimal performance and user satisfaction. The parts of a potential LED indicator are shown in Figure 5.6.3.

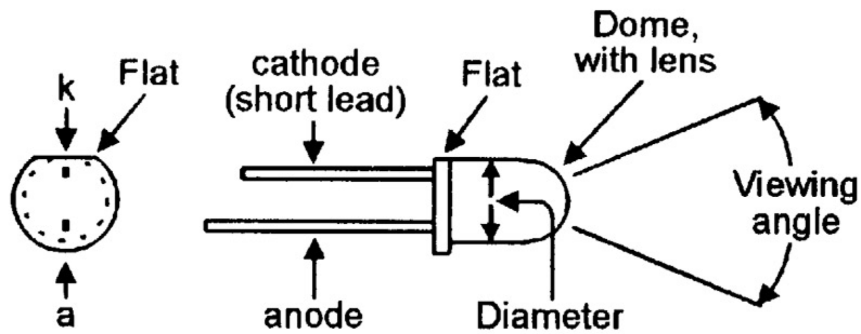


Figure 5.6.3: LED Indicator [16]

5.6.3.1 LED Indicators Advantages

LED indicators offer several advantages for our T-shirt launcher project. Firstly, they provide a simple and intuitive visual representation of pressure levels, allowing users to quickly assess the status without the need for interpretation. Their compact size and low power consumption make them energy-efficient and suitable for integration into the launcher's design without adding significant weight or complexity. Their solid-state construction also results in durability and resistance to mechanical shock and vibration, enhancing reliability in rugged operating conditions. Furthermore, LED indicators can be easily customized to display different pressure ranges or statuses using different colors or blinking patterns, providing flexibility in design and enhancing user experience. Overall, LED indicators provide a cost-effective, reliable, and user-friendly solution for pressure monitoring in our T-shirt launcher project.

5.6.3.2 LED Indicators Disadvantages

While LED indicators offer certain advantages, they also present several drawbacks that must be taken into account. Firstly, LED indicators typically lack the precision of numerical displays, making it difficult to accurately gauge pressure levels within narrow ranges. Moreover, assembling and calibrating LED indicators to work with our application requires backend and coding knowledge, along with a microcontroller that necessitates a power input. Furthermore, LED indicators may not be well-suited for applications requiring continuous monitoring or precise adjustment of pressure parameters, as they provide only visual feedback without numerical data. Additionally, LED indicators may have limited visibility at certain viewing angles or under extreme lighting conditions, potentially diminishing their effectiveness in specific environments. Therefore, while LED indicators offer simplicity and reliability, it's crucial to carefully consider these limitations within the context of our T-shirt launcher project.

5.6.4 User Interface Decision

After analyzing each alternative, it was decided that a mixture of digital and analog user interface devices will be used. While LED does present an interesting and visually pleasing option, it is not as easy to interpret as the other options, while being more complex.

A digital UI offers the highest precision to display important information. Additionally, a digital UI can be modified to display information in different ways. For example, instead of having just a digital readout showing the pressure, the pressure could be converted to a power level as a percentage or to an approximate distance found via testing, making it easier for the user to understand the state of the system. Analog options, while not as customizable, are robust and simple, offering an excellent option as a second choice or backup. As a general safety decision, all pressure tanks will have an analog gauge on them. With this, anyone will be able to see the pressure without having to power on the system and this offers a fail safe in case the digital system malfunctions. This system will satisfy all requirements related to displaying information regarding the launcher's energy level. These differences are summarized in Figure 5.6.4A.

		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 5.6.4A: UI Pugh Matrix

Knowing that LED indicators will not be utilized and we will instead use a combination of digital readouts and analog gauges, the UI system can be visualized at a basic level before entering the detailed design phase. Paying special attention to system requirements, the simplified UI system is shown in Figure 5.6.4B. The essential parts of the UI system are shown, with digital components indicated by the green arrows.

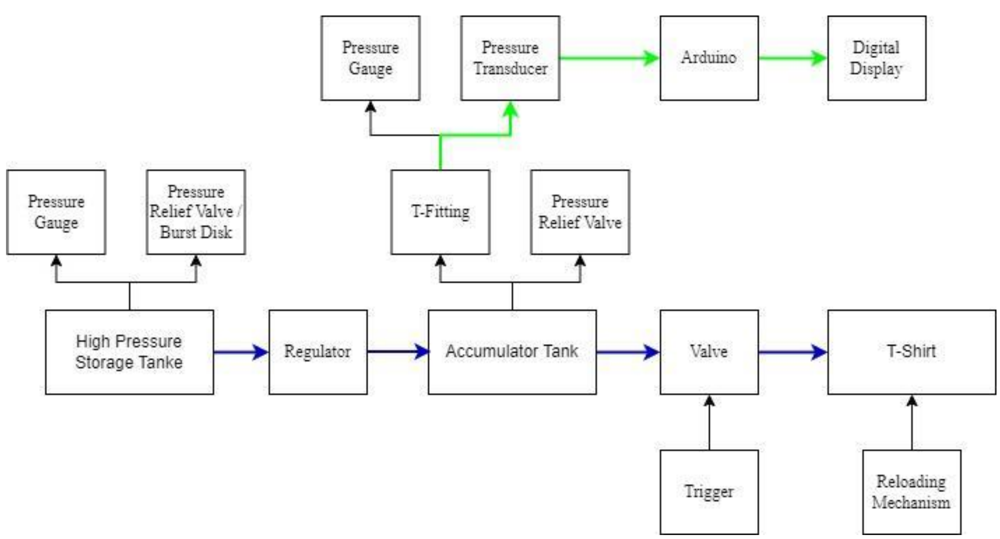


Figure 5.6.4B: UI Block Diagram

5.7 Launching Indicator

When brainstorming ideas for the system, the team decided that it was important to have some sort of indicator when a T-shirt is being launched. This not only serves as a safety aspect of the function to let the crowd know that a T-shirt is about to be launched, but also adds excitement to the process of catching a T-shirt. This is important enough that it was listed as Requirement G6.1, which is available in Appendix E. No other T-shirt launchers on the market contain any additional effects.

5.7.1 Flashing Lights

Flashing lights serve as an indicator in many everyday scenarios to alert individuals of something important, such as flashing yellow stop lights outside of a fire station. At a sporting event, flashing lights would be a good way to attract the attention of the fans. Since they are usually going to be looking toward the field or court, a flashing object would likely attract their attention.

5.7.1.1 Flashing Lights Advantages

Flashing lights serve as a perfect middle ground for most criteria. Flashing lights are almost guaranteed to attract attention. The only time this may not be the case is if it is being used outdoors when it is bright outside. This method is also relatively simple and cost effective, as the only required hardware is a LED strip and a microcontroller, which will already be utilized for other aspects of the T-shirt launcher. Lights also offer some unique options if the final form factor of the launcher resembles a rocket. The lights could be placed where the boosters would be to create a glowing effect, adding to the Space-U theme.

5.7.1.2 Flashing Lights Disadvantages

The only disadvantage of using flashing lights is a safety concern if any individuals suffer from epilepsy or seizures. While this is a legitimate concern, most sporting events feature flashing lights at some point, and the lights on the T-shirt launcher will not be nearly as bright or powerful as lights from the football stadium or basketball arena.

5.7.2 Smoke

Initially, to create a smoke effect, we considered a misting machine or small fog machine. Both of these would require additional fluids, tanks, and create additional cost. However, during preliminary testing, it was discovered that at high pressures and at night time, the air expelled from the T-shirt launcher creates a visible smoke effect, shown in Figure 5.7.2.

Figure 5.7.2: Smoke Effect from Compressed Air

5.7.2.1 Smoke Advantages

The main advantage of smoke is that it looks exciting to people in the stands. A cloud of smoke coming from the launcher either before or after a T-shirt is launched is a unique feature that no other T-shirt launchers have, apart from the natural smoke from the compressed fluid.

5.7.2.2 Smoke Disadvantages

There are multiple disadvantages of using smoke. The system would be complex, requiring many additional parts and circuity, incurring additional cost. In an already complex system, it may not be worth it to add unnecessary complexity when the smoke effect is already somewhat achieved naturally.

The main disadvantage of smoke is that it could confuse people nearby, as they may think the launcher or something in the area is on fire. This could create an unsafe situation if someone misidentifies the smoke effect as a fire.

5.7.3 Fire

Perhaps the most exciting option, flames shooting out of the T-shirt launcher will ensure that this is the most exciting T-shirt launcher on the market. This system would either use a mini fireshooter which is available online, or a scaled down version of a flamethrower.

5.7.3.1 Fire Advantages

Fire is by far the most exciting option for a sensory effect. Similarly to the flashing lights, it will attract attention, but the added fact that it is real fire will impress anyone watching. The fire system is also relatively simple, as the parts are all COTS or easily manufactured. Unfortunately, this is where the advantages of fire end.

5.7.3.2 Fire Disadvantages

While this is the most exciting option, it is also the most dangerous. The fire would have to be directed away from where the T-shirts exit so that they do not catch fire. This means that the fire will be directed elsewhere, where there could be someone standing or something flammable. Another potential issue is that if the T-shirt launcher was placed on the ground outside and accidentally discharged, it could catch the grass on fire. If used indoors, it would not be ideal to bring combustible fluids, such as propane, into the arenas. Furthermore, this method has the same danger as smoke, where someone could mistake it for an uncontrolled fire and create unnecessary panic.

5.7.4 Flag

This option would consist of a simple flag or bright colored object that is placed on an actuator that extends or pivots when a shirt is launched. The flag could be made to be UCF or Space-U themed, but apart from that little customization is possible. The flag would be similar to a stereotypical cartoon pistol, with a flag sticking out the end that says “bang”.

5.7.4.1 Flag Advantages

This is by far the safest option for a launching indicator. Any risk associated with a flag popping out is minimal. This option would also be very cost effective, as the only required materials would be the flag itself and likely a pneumatic piston, which can be found for relatively little money. This system would also be very simple and not require an extensive amount of effort to code and implement.

5.7.4.2 Flag Disadvantages

While this is the safest option, it is also the most boring. A flag popping out with each shot is unlikely to attract much attention, if any at all. Since the purpose of this system is to create excitement and draw attention, this is not an ideal choice.

5.7.5 Audio

Originally, it was thought that the indicator would purely be a visual one, but a team member recommended an auditory indicator. This could be a small, powerful speaker attached to the launcher that plays something each time a shirt is launched. The T-shirt launcher will also create a considerably loud noise when it is discharged, offering yet another natural option to satisfy this need.

5.7.5.1 Audio Advantages

An audio system is both relatively safe and simple. Since any speaker used would be constrained by space, they will not be large enough to the point where hearing loss would become an issue. This system would also be relatively simple to implement with the already existing microcontroller that will be used.

5.7.5.2 Audio Disadvantages

An audio system will not attract any visual attention, and the sound may be drained out by the already loud atmosphere in a stadium or arena, mitigating its purpose. Furthermore, the launcher itself will already be considerably loud, so it may not be wise to add additional noise to the system.

5.7.6 Launching Indicator Decision

From the Pugh Matrix shown in Figure 5.8.6, using audio or a flag as an indicator comes in very short of the other options. While these are the safest options, they are not very exciting. Other options are much more exciting while still having little safety risk.

From a safety standpoint, both smoke and fire should be eliminated. While fire did rank the highest on the Pugh Matrix, the potential risk of a flaming T-shirt being launched, accidental burns, or lighting something else on fire is not acceptable.

This leaves using lights as an indicator. This option will still adequately convey the message that a T-shirt is being launched, while having a very small safety risk and being relatively easy to implement. These lights will be in addition to the natural smoke and sound made from the launcher. These three items give fans multiple opportunities to recognize that the T-shirt launcher is being used.

		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 5.7.6: Launching Indicator Pugh Matrix

5.8 Storage System

When looking into readily available storage systems the first item that came to mind that is affordable in terms of our decision matrix, shown in Figure 5.8.5, and easily sourced (can be ordered online and shipped to UCF or found in stores locally around UCF). The storage system's main criteria included the system’s total weight while empty of one container, the cost of a storage system, IP rating, and the carrying capacity of one storage system. Other factors such as cost per carrying capacity, looks, dimensions, and obtainability were also factors to consider while choosing a storage system which helped us narrow down a list to plastic bins, wooden crates or boxes, metal containers, and fabric bags but were not the main factors for narrowing down this list to which system was the best for our purposes. The criteria used to rate the storage system options are available in Appendix F.

5.8.1 Plastic Bins

Plastic bins are common options for storing items, making them a possible option for housing our T-shirt launcher. These bins are commonly used for housing items in household, industrial, and commercial settings.

5.8.1.1 Plastic Bins Advantages

Advantages of using plastic bins are the fact they are affordable, easily obtained, as previously stated in Section 5.8, durable, and have a high carrying capacity. The plastic bin we used as a reference point for the decision matrix was found on the Home Depot website with a price of $19.98, an IP rating of IP-67, and a capacity of 110 lbs (50kg) [22].

5.8.1.2 Plastic Bins Disadvantages

Depending on the type of plastic storage bin, the container can be fragile, and easily damaged. For this storage system to meet the criteria of the decision matrix, plastic bins that are IP-rated and or made for heavy objects must be chosen, plastic bins that are for clothing, shoes, and general household uses may not be applicable as they tend to be of lower quality plastics or made with thinner walls which may not met the requirements.

5.8.2 Custom Wood Crate

Wooden crates were an option to consider as they are used to hold large items for industrial and commercial purposes. Many companies use wooden crates as they are considered cost-efficient, sustainable and easy to accommodate the size of what needs to be shipped out which is why this was an option to consider.

5.8.2.1 Custom Wood Crate Advantages

The benefit of wooden crates is their durability; the wooden crate used as a reference for the decision matrix was a wooden toy chest found on Walmart’s website [38] which states the container can stand a static load of 400 lbs (180 kg) as its carrying capacity. Made of hardwood this makes the environmental sensitivity as a 4 rating, being able to withstand heavy objects falling onto the box and being waterproof enough to give us an IP around IP33 and IP44.

5.8.2.2 Custom Wood Crate Disadvantages

Wooden crates sold commercially are more in line with wooden toy boxes for kids and the commercial wooden crates do not really adhere to the pros and cons that were stated in [19] as commercial wooden crates they are limited in size and solid wood boxes/crates tend to be on the heavier side compared to other options using the reference wooden crate used for the decision matrix [38] the container was roughly 25.3 lbs while empty. Price is also a big disadvantage, with the price at $52.99 [38], making it a more pricey option based on our decision matrix. If we were to use a wooden shipping crate as our reference, we find that weight, and cost is still a big disadvantage for this project [24]. Crates that could be purchased tend to be around the price of $150 upwards to $1,000 or more. These crates were also very large and not necessary for the project as a full-size shipping crate of 48"x48"x96" is excess in size and would be hard to move around and put into storage. So wooden crates may be great for big businesses to ship items around the world may not be the best option for this project.

5.8.3 Custom Metal Container

Custom metal containers were considered for our storage system as metal is a resilient material that will provide great protection. Metal is also a sustainable material because it can be used forever and recycled indifferently, unlike plastic. Depending on the metal, the container could withstand heavy loads but can also be light.

5.8.3.1 Custom Metal Container Advantages

Metal custom containers have the advantage of durability and a high environmental sensitivity rating. The Metal crate that was found and used as the reference to our decision matrix showed a cost rating of 1 due to the high price for an IP rated metal container.

5.8.3.2 Custom Metal Container Disadvantages

Metal custom crates using the reference we found for the decision matrix showed the disadvantages of cost. Cost is a big disadvantage for this option as [45] was shown to go up to $102.89 on Home Depot which gives a 1 rating on the decision matrix, the cost for this option was the biggest decision factor as we do not want to spend a large budget on storage systems.

5.8.4 Fabric Bag

Lastly fabric bags as a storage system were a possible option for our T-shirt launcher. This storage system is commonly found in supermarkets, house decor stores, and online retailers like Amazon. It is a simple storage system that can fit the needs of our project and be stored easily no in use.

5.8.4.1 Fabric Bag Advantages

Fabric bags are relatively cheap based on our decision matrix (Figure 5.8.5) the [12] we found through Amazon was around $10 a piece as the item listed had 2 bags for $19.99 as when this report was made making the cost rating a 4. The bag is also lightweight, making the weight rating on the decision matrix (Figure 5.8.5) also a 4 rating. The bag can also be easily found through online shopping websites that can deliver the item in a week or less time, giving the benefit of obtaining the item for the project in a timely manner.

5.8.4.2 Fabric Bag Disadvantages

Fabric bags have a big disadvantage in environmental sensitivity, containing an IP rating of 1 as the bag does not have much waterproofing and can not withstand or protect the device from any physical blows but may protect from light scratching based on the bag we found on Amazon [12] we used for our reference. There is no official IP rating for this item but based on what we described, the bag would not be the best storage method for environmental sensitivity and carrying capacity of 11 lbs since the description of the product does note its carrying capacity of 11 lbs.

5.8.5 Storage System Decision

From the previous analysis, it is clear that commercially available plastic bins offer the best solution. They are significantly lighter than wood or metal, while still being able to hold enough weight for the purposes of this project. The only category the plastic bins did not score a 4 in was cost. However, the plastic bins are only marginally more expensive than the fabric bags, not making it a major factor.

		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 5.8.5: Storage System Pugh Matrix

6.0 Preliminary Engineering Analysis

Before moving forward with designing the physical system, it is important to gain an understanding of what parameters must be met to satisfy the key system requirements. These parameters can be analyzed using a combination of calculations, experiments, and analysis using software.

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 [46], shown in Figure 6.0.

Figure 6.0: 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 allows 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.

6.1 Barrel Diameter

The main function of the barrel, and hence its diameter, is to maximize the force applied to the T-shirt from the compressed fluid. Most commercial T-shirt launchers utilize a 3 - 3.5 inch barrel, such as the Bleacher Reacher with a 3.25 inch barrel [13]. From Equation 5.1.1A, it can be seen that the force applied on an object is proportional to both the pressure and cross sectional area. However, in the case of the T-shirt launcher barrel, as the cross sectional area increases, so does the volume of the barrel. Because of this and the ideal gas law shown in Equation 5.1.2A, the larger the barrel diameter is, the more the pressure will 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 6.1A.

$$P_1 V_1 = P_2 V_2 \tag{6.1A}$$

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 6.1B, where d is the diameter of the barrel, and L is the T-shirts instantaneous location in the barrel.

$$V_2 = V_1 + \frac{\pi}{4} d^2 L \tag{6.1B}$$

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 6.1A. 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 6.1A.

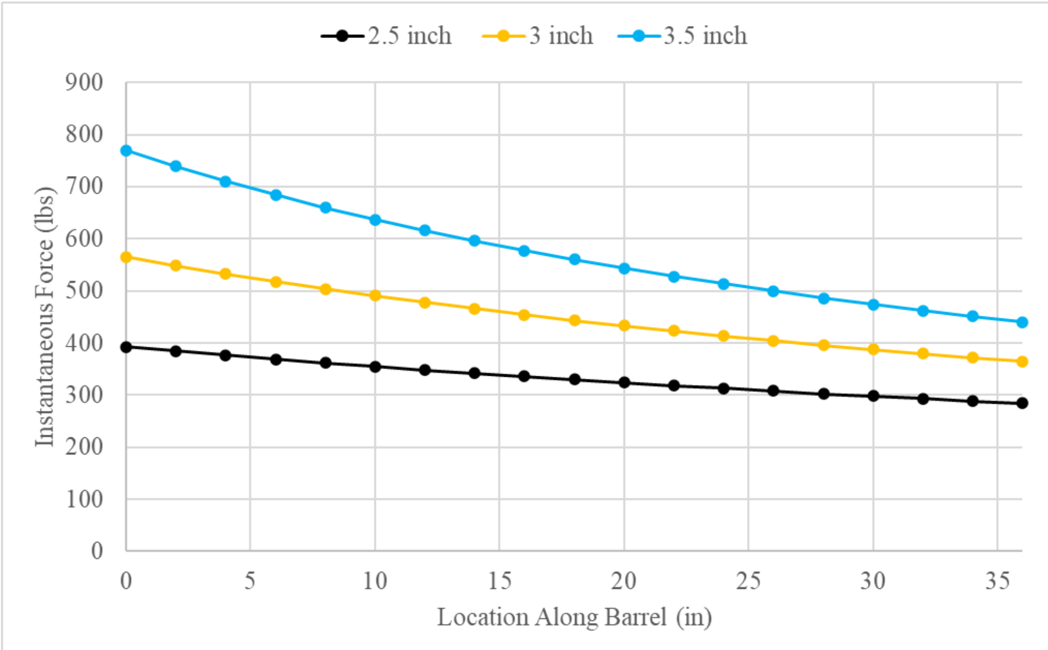


Figure 6.1A: Instantaneous Force with Certain Barrel Diameters

From Figure 6.1.1A, it is observed that for a barrel of length 3 feet, 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.

Another consideration for barrel diameter is how tight a T-shirt can and should be rolled. If it is too tight, it could become stuck, creating a dangerous situation. If it is too loose, a large amount of air will escape around the shirt, limiting its distance. During experimentation, we were easily able to roll the T-shirt to approximately 3 inches, shown in Figure 6.1.1B, with no jams.

Figure 6.1B: T-Shirt Rolled to 3 Inch Diameter

6.2 T-Shirt Packaging

As described in Section 5, 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 being able to present the advantages and disadvantages of the other packaging methods to any potential end users.

6.2.1 T-Shirt Packaging Experiments

Before testing the maximum distance of the testing device, we first set out to find out which delivery method described in Section 5.5 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 the 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 6.2.1A.

Figure 6.2.1A: 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, shown in Table 6.2.1A. 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 6.2.1A: 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 [13]. 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 lost 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 6.2.1B. 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 6.2.1B: 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 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 6.2.1B.

Table 6.2.1B: Results of Testing Packaging Method

Trail	No	Folded -	Rubber	Tape (ft)	Plastic Wrap

	Packaging (ft)	Method A (ft)	Bands (ft)		(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

6.3 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.

6.3.1 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 6.1, 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.

6.3.2 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 6.3.2.

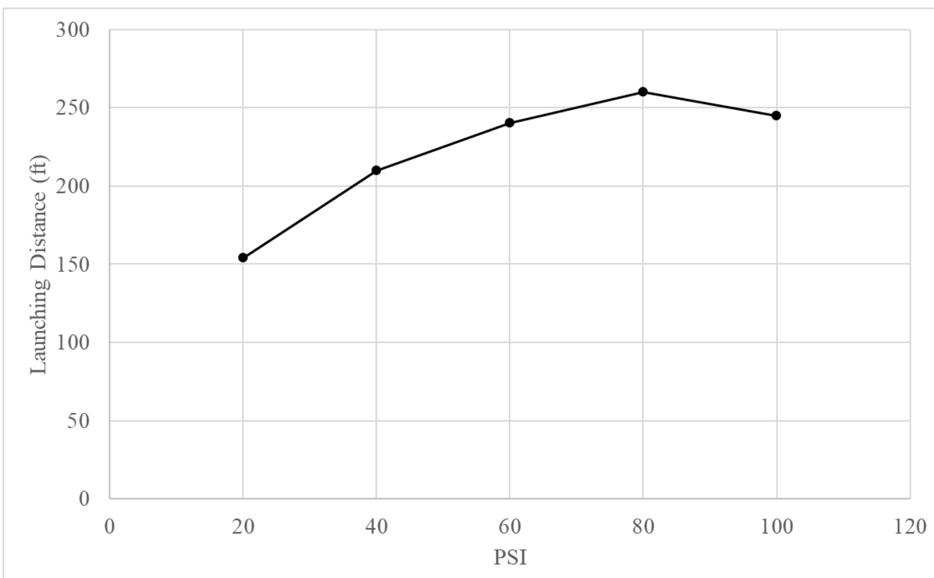


Figure 6.3.2: Launching Distance vs Pressure

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.

6.4 Exit Velocity

From Requirement F1.2, the exit velocity of the T-shirt must be greater than 68.5 MPH. While this seems like a large value, it is necessary in order for the T-shirts to reach the upper sections of the football stadium. The theoretical exit velocity can be calculated at various pressures and barrel lengths, as well as determined from experimentation.

6.4.1 Exit Velocity Calculations

From the exit velocity calculations shown in Section 5 for compressed fluid, preliminary analysis determined that launching a T-shirt at the required exit velocity is possible. However, that specific calculation neglected many factors, including but not limited to friction, the changing volume of the barrel, and air losses around the T-shirt. A group of physics students from Wabash College has conducted research and posted equations to determine the exit velocity of a projectile, accounting for mass, initial pressure, pressure vessel volume, the length of the barrel, the area of the barrel, and a friction factor [39]. Using the case where air isothermally expands, the relation is shown in Equation 6.4.1, where m is the mass of the T-shirt, P_0 is the absolute pressure vessel pressure, V_0

is the pressure vessel volume, A is the cross-sectional area of the barrel, L is the length of the barrel, P_{atm} is the atmospheric pressure, and f is the friction coefficient.

$$v = \sqrt{\frac{2}{m}\left(P_0 V_0 ln\left(1 + \frac{AL}{V_0}\right) - ALP_{atm} - Lf\right)} \tag{6.4.1}$$

While this equation still neglects air losses around the T-shirt, the size of the opening from the pressure vessel to the barrel, and the speed at which the valve between the pressure vessel and barrel opens, it offers better insight to the exit velocity than the calculations in Section 5. Assuming a friction coefficient of 0.5, which is common for fabrics, that the pressure vessel is the size of the experimental one, and a barrel diameter of 3 inches, the results are shown in Figure 6.4.1 when the initial pressure and barrel length are varied.

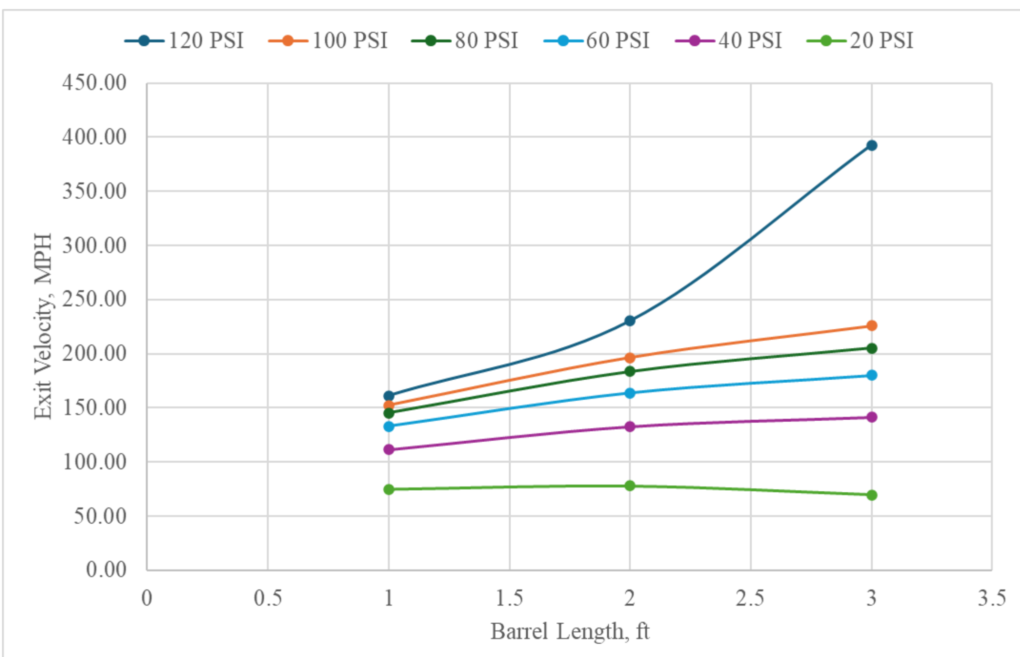


Figure 6.4.1: Exit Velocity Calculations

Observing the results, theoretically, pressures above 40 PSI will achieve the desired exit velocity of 68.5 MPH, regardless of barrel length. For 20 PSI, it is seen that the exit velocity drops as the barrel length increases. This is because the pressure towards the end of the barrel approaches atmospheric pressure, so the force from the fluid is overpowered by the friction force. If these calculations hold true, we will be able to either reduce the size of the pressure vessel or operate at a lower range of pressures, both of which offer greater safety for everyone.

6.4.2 Exit Velocity Experiments

To test the exit velocity of the testing device, it was filled to 80 PSI with a 3-foot-long barrel. A piece of cardboard was then marked in 1-foot intervals, up to 5 feet. The marked cardboard was held at the end of the barrel so that the T-shirt would travel past it once launched, as shown in Figure 6.4.2.

Figure 6.4.2: Measuring Exit Velocity

Knowing the frame rate that the camera was recording in, the time between frames can easily be calculated. Using that time and the distance traveled in between frames, the exit velocity can be calculated using Equation 6.4.2, where *v* is the speed in ft/s, *x* is the distance in ft, and *t* is the time in seconds.

$$v = \frac{x}{t} \tag{6.4.2}$$

Using this equation, the exit velocity was found to be approximately 370 ft/s, which is equivalent to 252 MPH. This speed is over 3.5 times larger than the required exit velocity of 68.5 MPH, ensuring that the T-shirts will reach the upper sections of the stadium. From the previous section, the theoretical exit velocity at 80 PSI with a 3 foot barrel is 205 MPH, less than the experimental value. This could be due to the friction coefficient used in the theoretical calculations. Other possibilities include an inaccurate pressure gauge reading or a faster valve than was considered for the theoretical calculations.

After learning the T-shirts were being launched at such a high speed, we were first very excited that we knew it was very possible to satisfy the corresponding requirement. However, we quickly came to the realization that launching a T-shirt at over 250 MPH posed some concerns. Mainly, if a shirt was launched that fast at someone who was nearby, it could cause harm to that person. Additionally, it is possible under the right conditions that the T-shirts could be launched outside of the football stadium, where there could be people standing by that are not looking for flying objects. Another possible issue is hitting and breaking a sprinkler in the basketball arena, postponing the game. Due to these factors, it will be important to optimize the parameters such as pressure and barrel length to ensure the T-shirts are launched in a safe manner.

6.5 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. Our experimentation supported the idea that a longer barrel will result in a longer launch distance.

6.5.1 Barrel Length Calculations

Using the exit velocity calculations in Section 6.5.1, the effect on barrel length can be further analyzed at 80 PSI, the optimal pressure. Equation 6.5.1A 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.

$$t = \frac{2V_0 sin\theta}{g} \tag{6.5.1A}$$

$$x = V_0 t cos\theta \tag{6.5.1B}$$

Approximating the initial launch angle of the experiments to be 10°, the results from the two equations are summarized in Table 6.5.1.

Table 6.5.1: Theoretical Launch Distance at 80 PSI for Different Barrel Lengths

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

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.

6.5.2 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 6.5.2.

Figure 6.5.2: Test Device with 1-Foot Barrel

From this test, the distances at an approximate 10° launch angle and 80 PSI are summarized in Table 6.5.2.

Table 6.5.2: 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.

6.5.3 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 that at sea level. The results are shown in Figure 6.5.3.

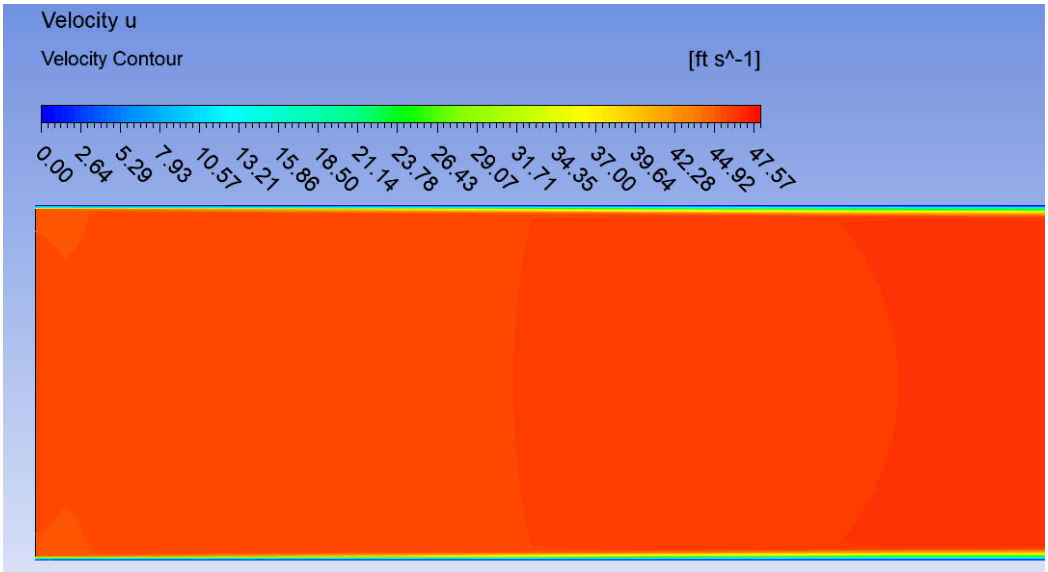


Figure 6.5.3: Velocity of Air in Barrel Using CFD

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. A future step will be to learn how to model the inlet conditions more accurately to show how the pressure changes along the barrel when the inlet pressure is not kept constant.

6.6 Barrel Materials

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.

6.6.1 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 6.6.1, 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.

$$\sigma_H = \frac{PD}{2t} \tag{6.6.1}$$

For each of the potential barrel materials, their geometry will differ based on what is commercially available. These parameters are listed in Table 6.1.1A.

Table 6.6.1A: 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, shown in Table 6.6.1B. This also shows the factor of safety for every material, which is found by dividing the yield stress by the hoop stress.

Table 6.6.1B: 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 [17].

6.6.2 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 6.6.2A.

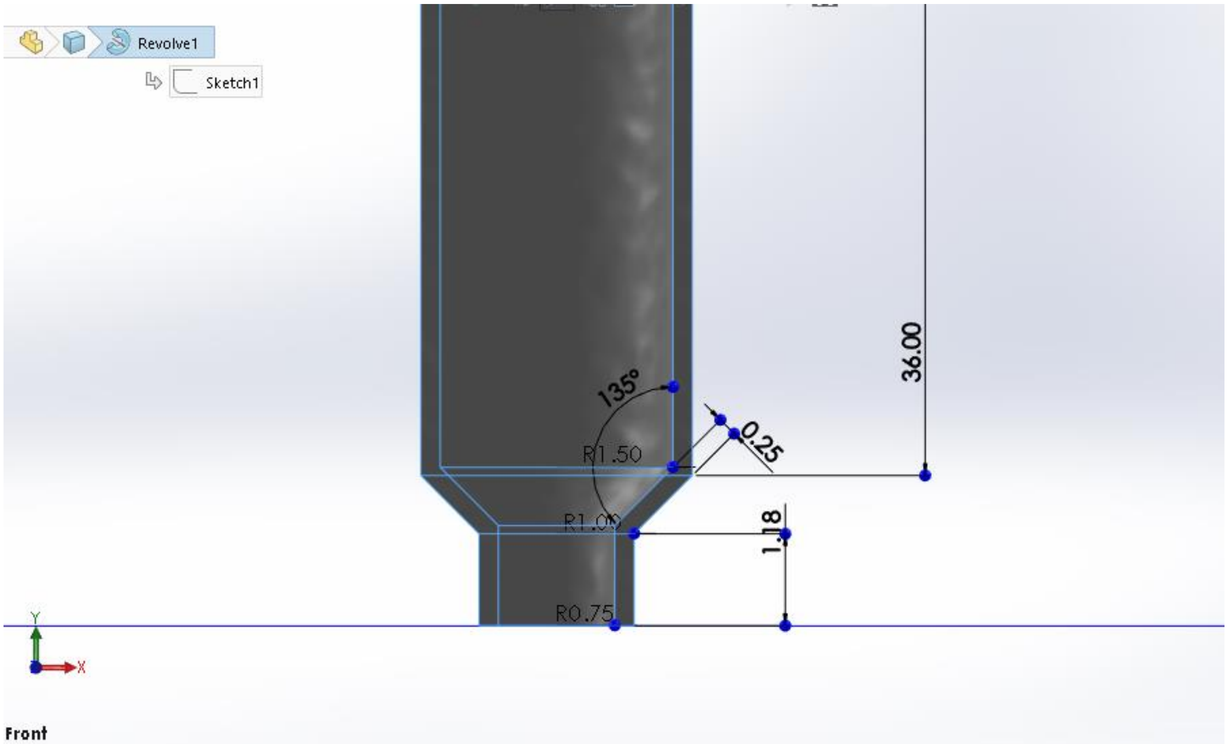


Figure 6.6.2A: Initial Barrel Dimensions using Revolve Feature

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 6.6.2A. These calculations follow the same method for determining the optimal barrel diameter size, outlined in Section 6.1.

Table 6.6.2A: 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 6.6.2A, 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 6.6.2B.

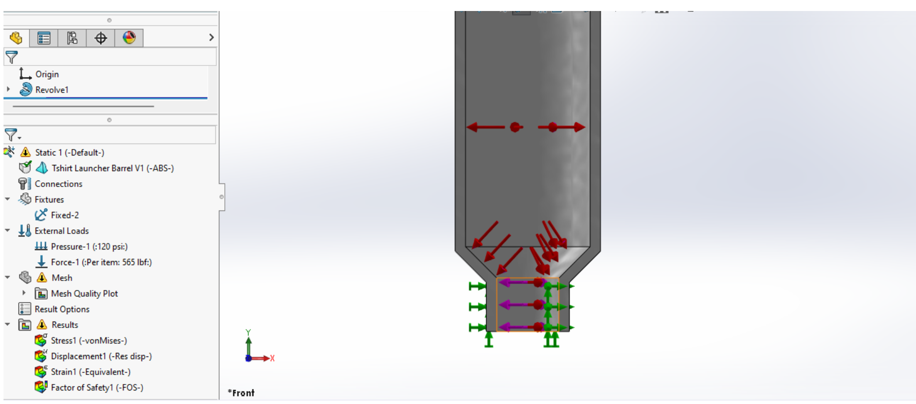


Figure 6.6.2B: Barrel Stress FOS Simulation Setup

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 is shown in Figure 6.6.2C.

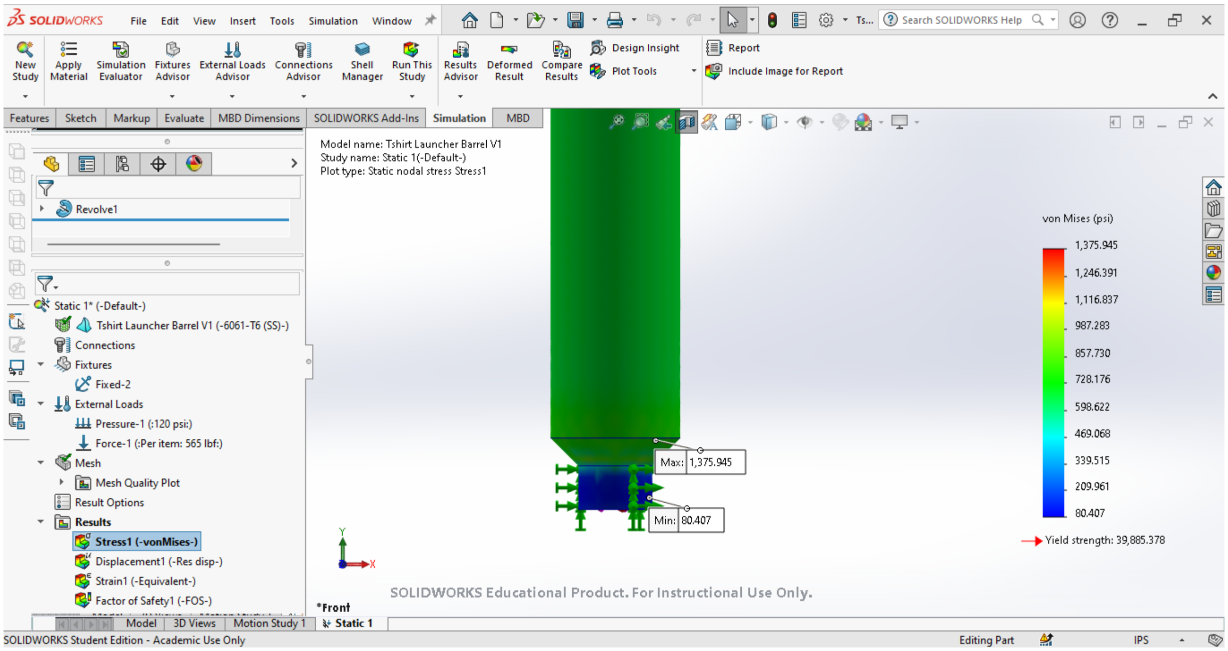


Figure 6.6.2C: Barrel Stress Results using 6061-T6 Aluminum

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 6.6.2B.

Table 6.6.2B: 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. However, PVC tends to be pricier and heavier than ABS. Considering the remarkable 3D printing capabilities of ABS, it emerges as an optimal choice for the barrel of our t-shirt launcher. Through rigorous testing, ABS has unequivocally proven its suitability for our project.

6.7 Pressure Vessel Materials

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.

6.7.1 Pressure Vessel Materials Calculations

Using the hoop stress method from Section 6.6.1, 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 [46], 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 [44]. 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.

For custom built pressure vessels, we can use the same geometry and yield stresses specified in Section 6.6.1. Since the bead blaster is capable of up to 120 PSI, the same factor of safety values found for the barrel apply for the pressure vessel. However, it is likely that the pressure vessel would need to be larger in volume than the barrel, therefore requiring multiple vessels or larger vessels.

6.7.2 Pressure Vessel Analysis

Analyzing the results of the pressure vessel model on SolidWorks reveals nearly the same results as the theoretical calculations in section 6.7.1. The computer software is more robust and able to model different materials and initial conditions with ease. The geometry of the bead blaster used in section 6.7.1 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 6.7.2A 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 simulation had a similar yield strength of roughly 26,000 PSI.

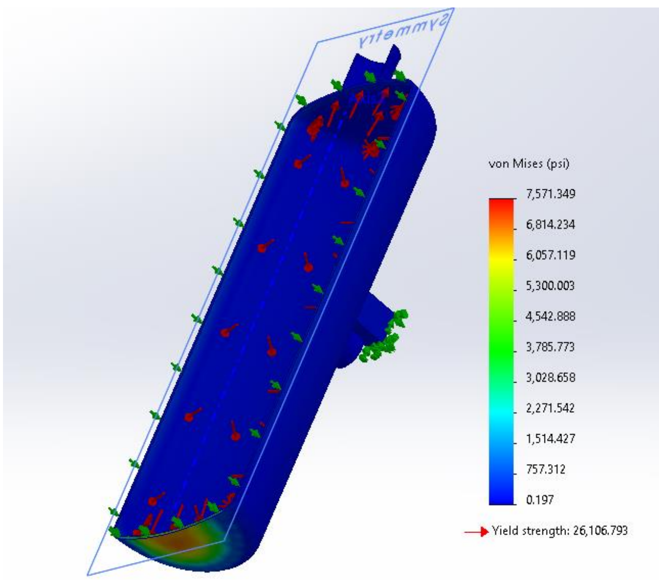


Figure 6.7.2A: Von Mises Stress Simulation at 120 PSI

More importantly, when modeling the pressurized vessel the desired outcome is the stress and strain capabilities of the object. As shown in Figure 6.7.2B 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.

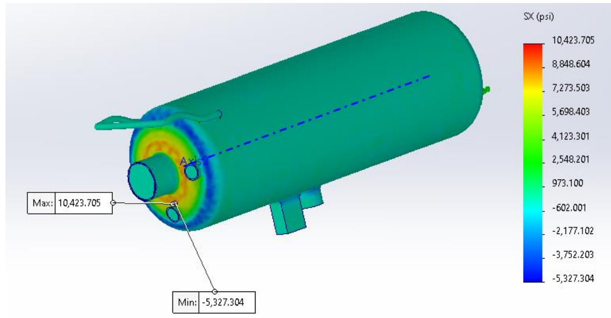


Figure 6.7.2B Hoop Stress at 120 PSI

Obtained from the analysis on the pressure tank the factor of safety was 5.395 (Figure 6.7.2C) 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.

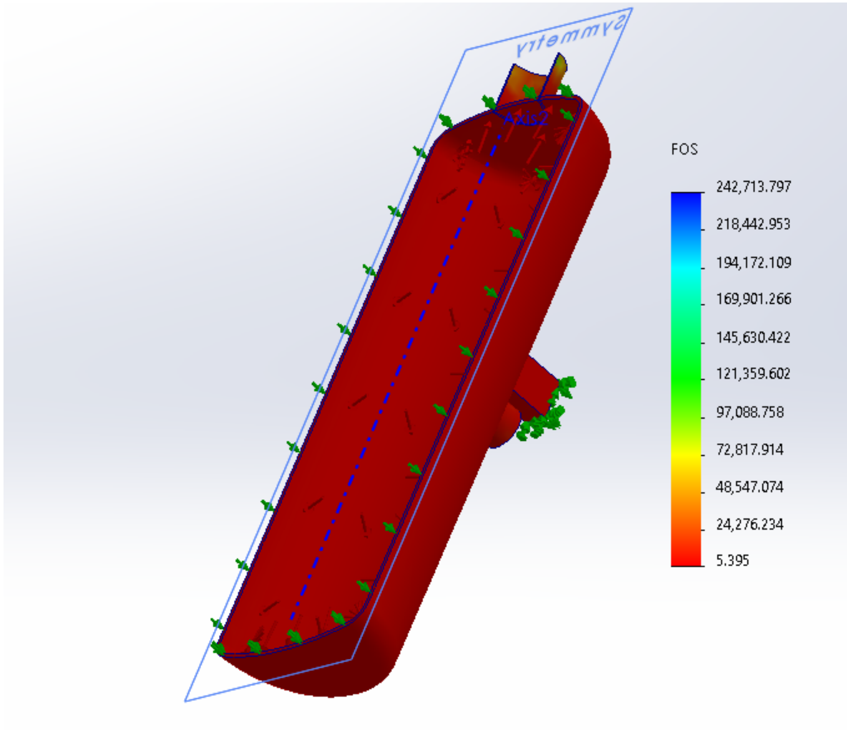


Figure 6.7.2C: Factor of Safety of Steel Alloy Tank at 120 PSI

6.8 Theory of Operation

After determining the major system components and performing additional analysis on related components, the entire system can start to take shape. The first step in this is to create a block diagram containing all of the key decisions made to this point.

6.8.1 System Concept

From Sections 5 and 6, many major decisions were made on the design of the T-shirt launcher. These major decisions include:

- Compressed fluid propulsion system using air
- Gravity-fed reloading system
- Traditional firearm-style trigger

- Tape packaging
- Analog and digital UI
- Flashing lights launching indicator
- Plastic bin storage system
- 3-inch barrel diameter
- Barrel length is likely between 1 and 3 feet
- Use of steel, aluminum, PVC, or ABS for pressure-withstanding materials

Before starting to design the entire system using software, we can lay out the major components to see how they will interact and to ensure that there is a plan in place to meet all system requirements. This block diagram is shown in Figure 6.8.1A, where blue represents the fluid flow, green represents the UI system, and red represents the movement of the T-shirts.

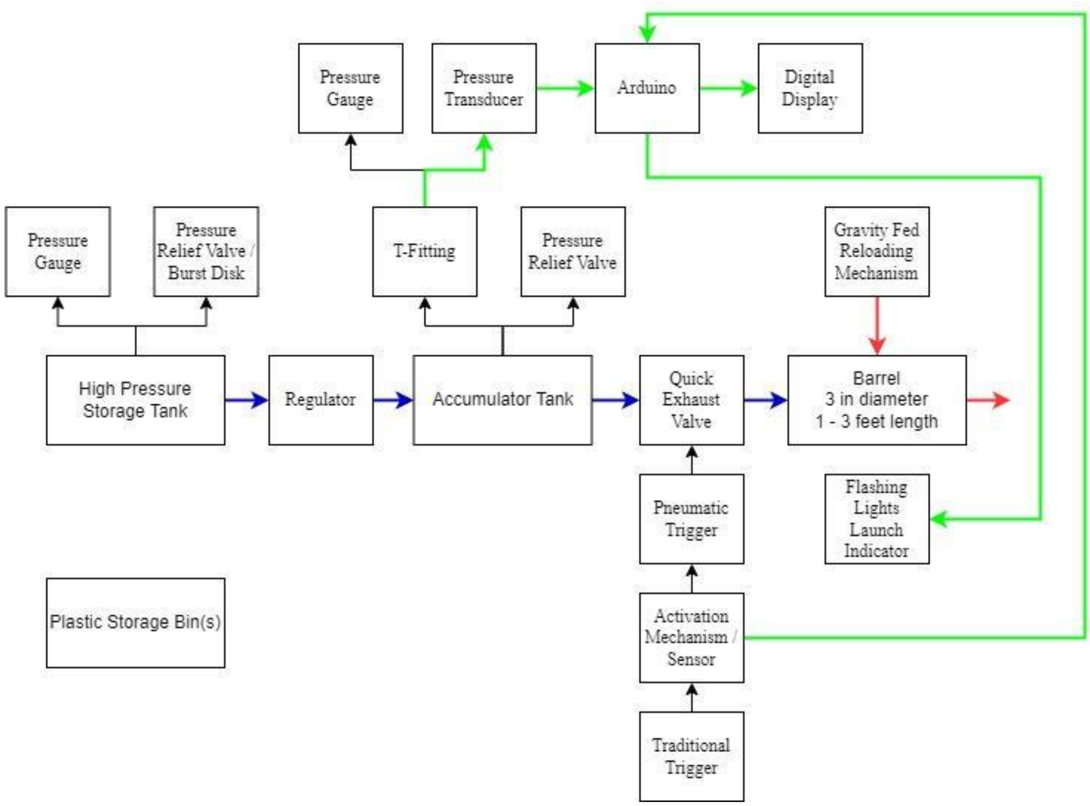


Figure 6.8.1A: System Concept Block Diagram

To ensure all requirements are met, some additional characteristics of the system need to be defined. Some requirements, such as the total weight of the system, will have to be taken into consideration during the detailed design phase, however other parameters can be specified now and designed into the system to ensure those requirements are met. The total list of requirements is available in Appendix E. The aspects of the system that we can specify to meet certain requirements include:

- G1.1 - The system will have two handles. One will be placed under the accumulator tank and house the trigger mechanism. The other handle will either be placed in front of that handle, similarly to a firearm, or on top of the accumulator tank. This will ensure one person can hold the launcher.
- G2.1 - The only concern for water and dust intrusion for this system is with the UI system. All wires will have to be insulated and contain heat shrink tubing on their connections. Additional measures will have to be taken to protect the Arduino from water and dust, such as placing it in a box with a gasket to keep the elements out.
- G2.1 - All manuals and storage bins included with the launcher will clearly state that the launcher is not to be operated by anyone under the age of 18.
- G4.1 - The user training manual will be created and placed in the storage bins.
- G6.1 - Flashing lights will be used to indicate the launcher is being used.
- G7.1 - The overall form factor of the launcher will resemble some sort of spacecraft. As of now, the team is heavily considering making the launcher resemble the Space Shuttle.
- G8.1 - The launcher will be able to be broken down into subcomponents for storage, if necessary. These components include the accumulator tank, storage tank, barrel, and

reloading system. By keeping the larger systems together, the launcher will be able to be assembled in less than 15 steps and 20 minutes.

- G9.1 - High pressure air is available in the UCF Machine Shop.
- F1.1 - The handle that the user places their non-dominant hand on will feature a lever that can be squeezed to fill the accumulator tank. By squeezing the lever for different amounts of time, the pressure in the accumulator tank will vary, allowing variable launch distance.
- F1.2 and F1.3 - Compressed air system will meet exit velocity and distance requirements, as seen in initial testing.
- F2.1 - A 3 inch barrel is large enough to accommodate a large T-shirt, and can thus accommodate small and medium T-shirts.
- F2.2 - The inclusion of the gravity fed reloading system and lever to fill the accumulator tank will ensure the user can launch a T-shirt every 15 seconds. It only takes about 6 seconds to fill the tank to its max pressure from an air compressor, meaning the user has an additional 9 seconds to launch the shirt.
- F3.1 - The initial barrel design is intended to include rifling to increase the accuracy of the launcher. If rifling poses a manufacturing issue, other measures will be explored to improve the accuracy of the launcher.
- S1.1, S1.2, S1.3 - Analog pressure gauges and the UI system will communicate information about the amount of energy stored in the system.
- S1.4 - The UI system will use feedback from the pressure transducer and reloading system to determine if the launcher is ready to fire.
- S2.1 - To shut down in 3 steps, the switch for the electronics system will be switched off and the pressure relief valve will be pulled.

- S4.1 - A trigger lock will be designed and manufactured to prohibit access to the trigger mechanism while the launcher is not being used. Additional lock outs may be designed to limit access to other components.
- S5.1 - The pressure relief valve on the accumulator tank will be capable of releasing the energy in the system without firing.
- S7.1 - A switch will be designed that when activated prevents the trigger from being used.
- ST1.2 - Plastic bins have been identified that exceed the required IP rating at a reasonable cost.
- ST3.1 - See G8.1.

With these aspects of the system in mind, a preliminary CAD model of the system was created. This model does not have every detail of the system, but includes the major components and space is left to add in other, smaller components that are necessary to meet our requirements. This preliminary CAD model is shown in Figure 6.8.1B. Note that this preliminary CAD model neglects the reloading system. The reloading system has been identified to be the most complex aspect of the system and will require additional time to determine the best way to integrate the system while maintaining proper weight distribution, aesthetics, and minimizing energy loss. If this is deemed to be unattainable, a different reloading system may be considered.

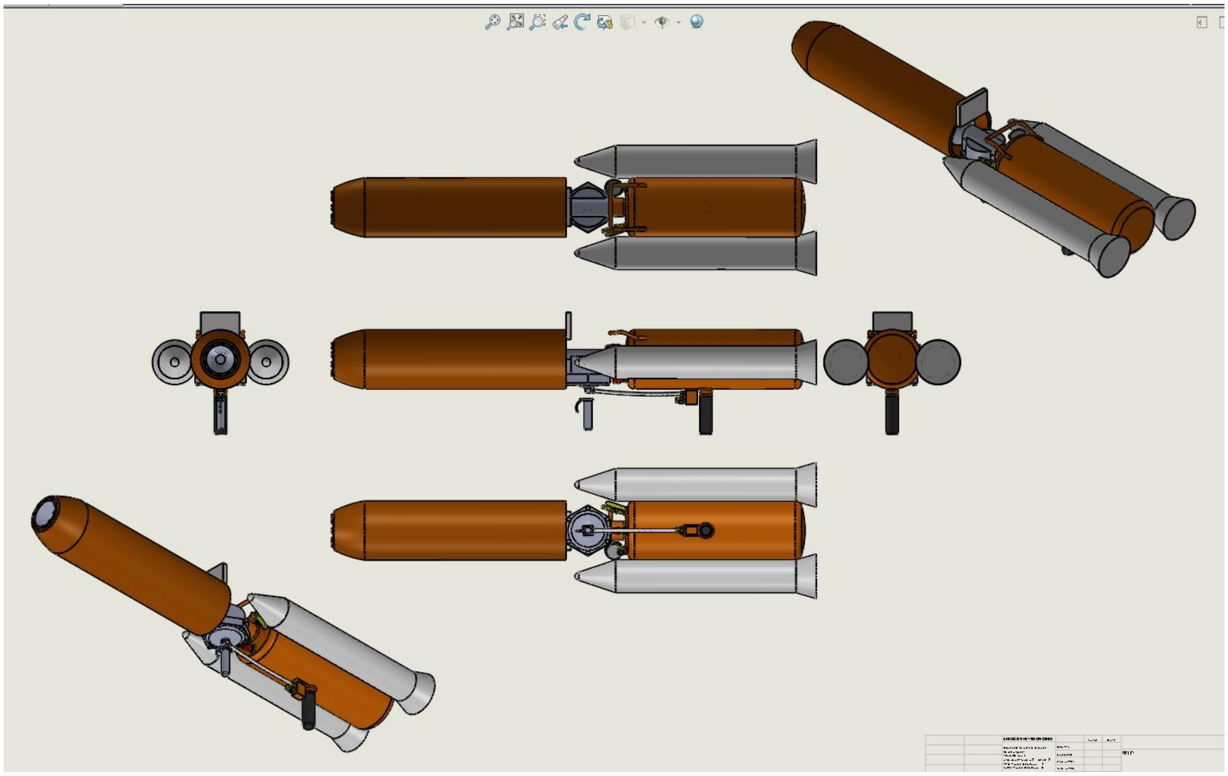


Figure 6.8.1B: Preliminary System CAD Model - Multiple Views

From the rear isometric view in Figure 6.8.1C, a few aspects of the launcher can be seen. First, the digital display that will communicate the power level and contain the ready to fire indicator is seen. This will satisfy all of the energy readout and indicator requirements, which are mostly related to safety. The accumulator tank is the tire bead seater that was used in testing. The barrel for this model is 25 inches long and housed within the external orange cylinder. From testing, a 25” barrel will satisfy our distance and velocity requirements. The orange cylinder is purely for aesthetics, so it can be 3D printed to save weight. Finally on this view, the solid rocket boosters can be used as extra storage for T-shirts or house additional electronic components, helping satisfy the IP rating requirements.

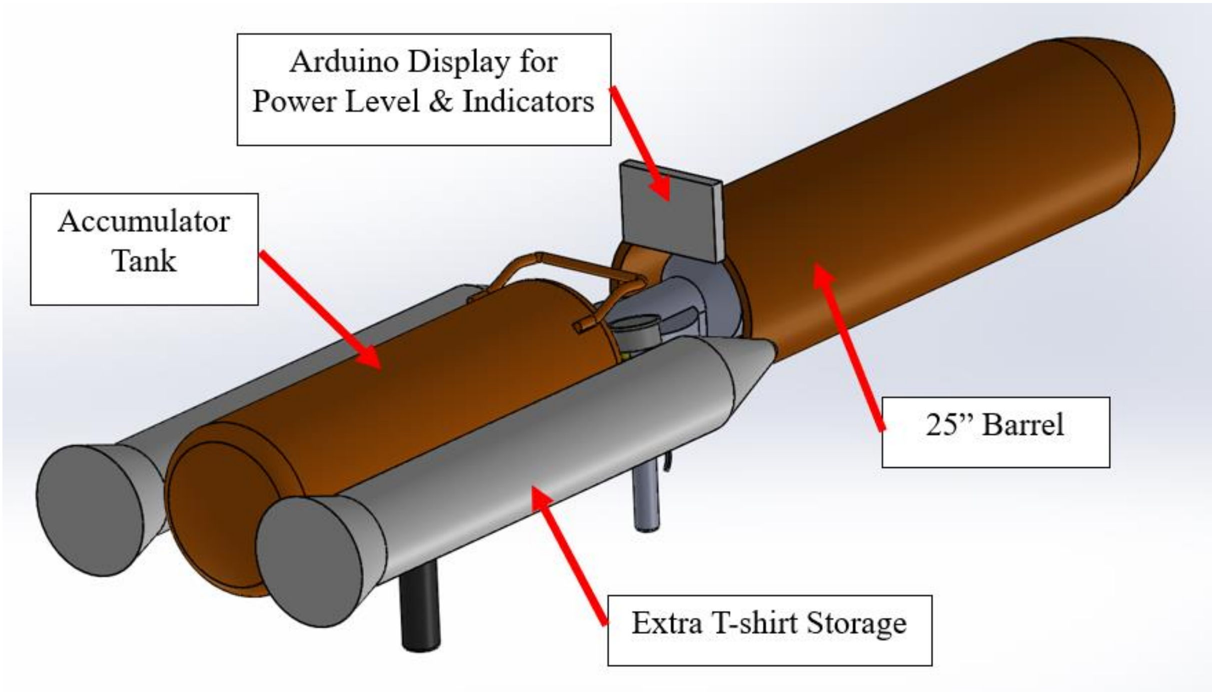


Figure 6.8.1C: Rear Isometric View of CAD Model

The next view, Figure 6.8.1D, the front isometric view, shows two more main components. First, the launching indicators on the front of the barrel are represented by the red dots around the end of the barrel. The wiring for these can run in between the actual barrel and the orange housing, so there will not be any loose wires hanging. The other component shown is the foregrip. This provides better ergonomics and more control when aiming the launcher. Attached to the foregrip will be a lever that the user can squeeze, allowing air to fill the accumulator tank. There will be a hose running from external high pressure storage device, to the lever, and finally into the accumulator through the air inlet. By allowing the user to control the air going into the accumulator tank, the requirement for an adjustable launching distance will be met. Currently, the foregrip is floating in space. It will be necessary to create a bracket to connect the foregrip to the body of the valve.

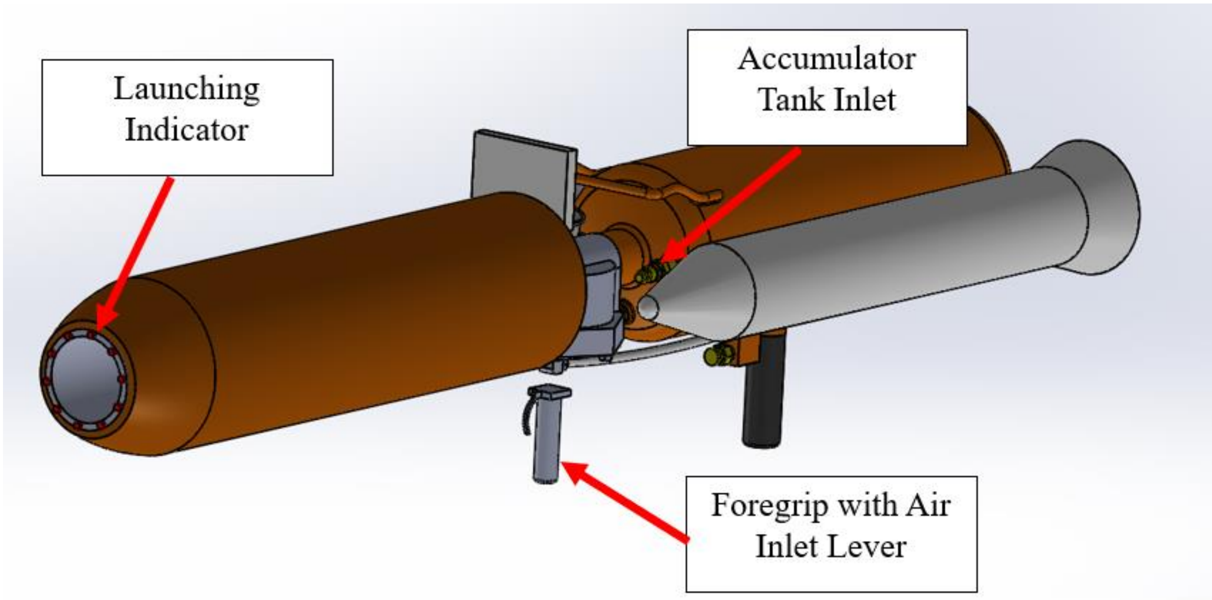


Figure 6.8.1D: Front Isometric View of CAD Model

The final view, Figure 6.8.1E, shows a close up of the pressure fittings on the accumulator tank. The pneumatic trigger is what allows the valve to suddenly release a large burst of air. The pressure relief valve is present as a safety mechanism and to satisfy multiple requirements, such as being able to drain the energy from the system without firing the launcher. Finally, there is a tee fitting that contains both an analog pressure gauge and pressure transducer. The pressure transducer will send information to the Arduino for interpretation. The analog pressure gauge is present for calibrating the pressure transducer and as a backup in case the electronics system fails.

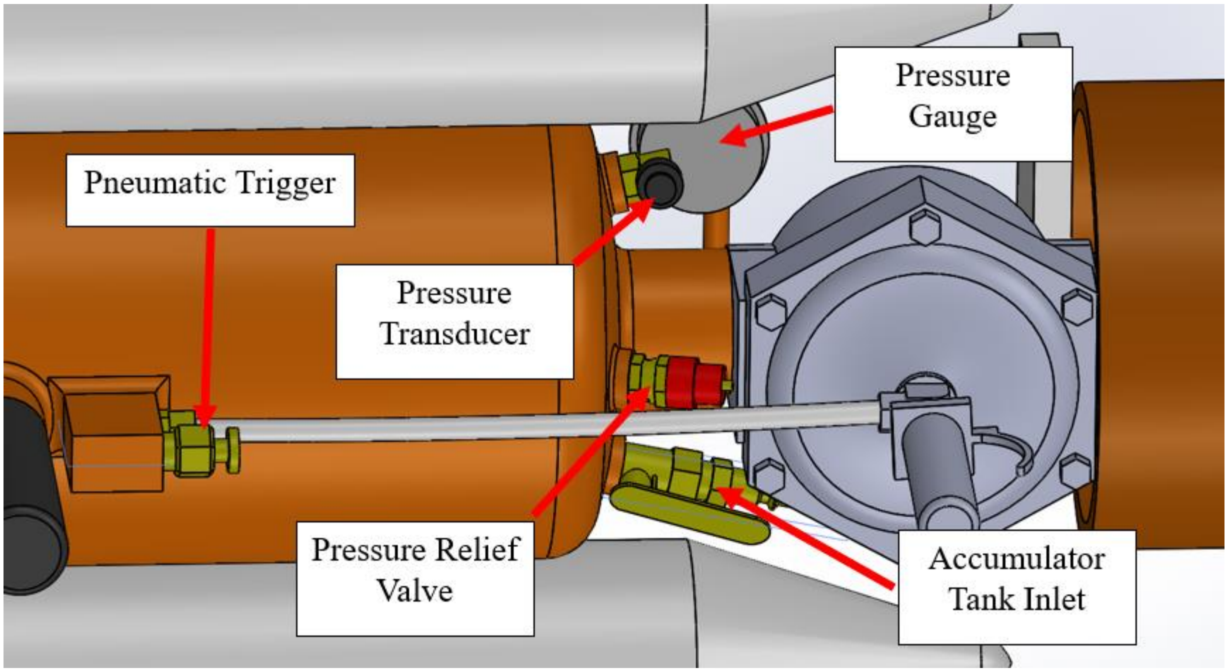


Figure 6.8.1E: Close-Up of Pressure Fittings

Not shown in the CAD models is the high pressure storage tank. This auxiliary tank will be connected to the lever on the foregrip, which then allows air into the accumulator tank. The size and weight of the high pressure storage tank chosen will affect how they are connected. For example, a scuba tank is likely too heavy to be worn as a backpack, so there will be a longer compressed air hose so the user can walk around within a range of the tank. On the other hand, if a paintball tank is used, it could certainly be worn as a backpack and the hoses could be connected cleanly along the T-shirt launcher.

With this proposed system, the only requirements that are not explicitly designed into the system are ones regarding the assembly time and steps, disassembly time and steps, storage size, the Lock-Out/Tag-Out system, and trigger safety. The assembly, disassembly, and storage will be finalized in the final detailed design, which will likely include components that are modular and easy to remove and install. On the proposed system. It would be simple to remove the barrel assembly and store it separately from the rest of the launcher to save space. For the Lock-Out/Tag-Out system and trigger safety, these are extremely important requirements to meet. While they are not explicitly shown in the preliminary CAD model, these two systems will largely function independent of the T-shirt launcher itself, making them easy to model around the T-shirt launcher in the future and still meet those important requirements. It is likely that the Lock-Out/Tag-Out system will be a completely independent system from the T-shirt launcher. Currently, the method being considered for this is designing two devices: one to prevent the trigger from being pressed, and another to encapsulate the air inlet for the accumulator tank, preventing it from being filled. Using both methods offers redundancy against any potential accidents.

6.8.2 UI Concept

Apart from the physical interaction of the mechanical systems of the launcher, the electronics, specifically the UI, will pose a significant challenge to integrate into the system. The UI system will have to take feedback from various sensors, convert that feedback into useful information, and display that information in a way that is simple and intuitive to use. The electronic aspects of the UI system, along with the different display modes that will be available on the screen, are shown in Figure 6.8.2A.

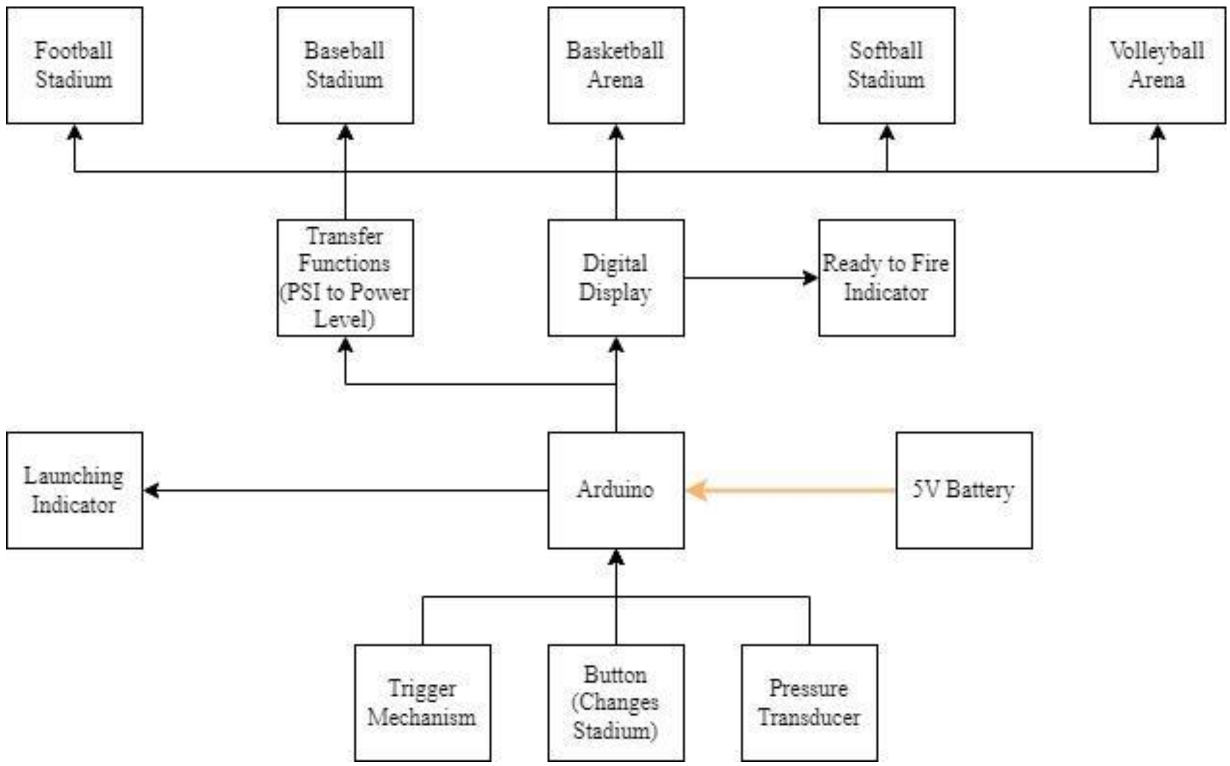


Figure 6.8.2A: UI System Block Diagram

In this diagram, the Arduino is supplied with information from the trigger mechanism, the pressure transducer, and a button. The Arduino uses the feedback from the trigger mechanism to activate the launching indicator. Coded into the display, there will be different pages depending on what stadium the launcher is being used in. These pages can be cycled through using a button. For each stadium, we will test the launcher at various pressures to create a regression line fitting the data, shown as the transfer functions in the block diagram. The information from the pressure transducer will be converted to a power level, expressed as a percentage, that is appropriate for that stadium. For example, if the football screen is selected and the transfer function calculates a power level of 50%, the user can expect the launched T-shirt to go about half way up the stands.

While this may seem like a significant undertaking, the coding aspect of it is relatively simple. We had already planned to convert the pressure to a distance or power level reading, the only difference with this system is that there will be multiple different functions to convert the pressure depending on the stadium, the rest of the code can be copied from case to case. The most time consuming aspect of this will be gathering the data from the different stadiums. It may not be possible to do this in every stadium, and in that case we will prioritize the football stadium and basketball arena, as they host the most popular sports.

6.9 System Feasibility

The preliminary system concept contains mostly COTS hardware and any custom components can be 3D printed or built using simple materials from a hardware store, such as ABS or PVC pipe for the barrel. The components included in the preliminary system model and how that material will be acquired or manufactured include:

- Bead Blaster - COTS
- Rear Handle - Included with Bead Blaster or can be 3D printed
- Trigger - COTS, included with Bead Blaster
- Pressure Fittings - COTS, some included with Bead Blaster
- Pressure Gauges - COTS, some included with Bead Blaster
- Pressure Transducer - COTS
- Wiring - COTS
- Exhaust Valve - Included with Bead Blaster
- Barrel - COTS or 3D printed
- Solid Rocket Boosters - COTS or 3D printed

- Foregrip - 3D printed
- Air Inlet Lever - COTS
- Arduino - COTS
- Arduino Display - COTS
- Barrel Housing - COTS or 3D printed
- LED Lights - COTS
- Miscellaneous (Bolts, screws, washers, etc.) - COTS

As seen, all major components can be easily purchased or made using 3D printing and no advanced manufacturing techniques are necessary. Furthermore, the geometries that may be 3D printed are relatively simple and would not be limited by the capabilities of commercial 3D printers.

Furthermore, from the testing earlier described, a launcher with the characteristics listed will meet the functional requirements set by the team.

6.9.1 Benefits of Proposed System

The largest benefit of this system is that it represents UCF better than any other available T-shirt launchers. Commercial T-shirt launchers take a “one size fits all” approach when it comes to the design, and lack creativity. Once the final launcher is built, resembling a rocket, and UCF and Space-U branding is added, it will be unmistakable who this launcher belongs to. One of Pete’s major criteria was that the launcher needed to be unique and stand out among other T-shirt launchers.

This launcher will also be able to launch in excess of 200 feet, as seen from testing, allowing all UCF fans to be included in the opportunity to catch a T-shirt. The ranges of already built T-shirt launchers fall in a wide range from less than 100 feet to over 400 feet. While launching a T-shirt 400 feet is an impressive task, it is unnecessary for UCF's athletic venues and would add additional weight and reduce the ergonomics of the system. This launcher is tailor built for UCF, so we can make the best use of space, weight, and energy.

The proposed T-shirt launcher also has an adjustable launching distance. This is controlled by the user squeezing the lever on the foregrip, allowing air to fill the accumulator tank to the desired level. The Bleacher Reacher models have this feature [13], but most other T-shirt launchers only shoot at a single pressure, limiting the number of people who will be included in the opportunity to catch a T-shirt. This is an essential requirement for this T-shirt launcher, as one of the driving factors in this project is to include all fans in this tradition.

Finally, this system has a much more robust safety system than any other available T-shirt launcher. The UI will display important system characteristics in a way that is easy to digest for someone who may not know exactly what a certain PSI means in terms of power and range. Additionally, the use of COTS pressure vessels increases the safety of the system compared to at home built systems that utilize plastic materials to hold pressure. While these materials are not necessarily dangerous, they are more likely to fail than commercial pressure vessels. The addition of items such as pressure relief valves and regulators provide additional safety against overpressurization and potential failures.

6.9.2 Cost of Proposed System

Important to any project is the total budget. For this project, the budget will be provided by UCF MAE. The current bill of materials, along with additional components that are likely to be needed, is shown in Table 6.9.2. Some materials the team already has or are available through Senior Design, which is indicated in the last column.

Table 6.9.2: Cost of Proposed System

Part	**Make / Buy**	**Cost**	**Comments**
Bead Blaster	Buy	$63.99	Already have
Pressure Fittings	Buy	$40	
Pressure Hose / Line	Buy	$19.99	
Pressure Gauges	Buy	$9.99	
Pressure Transducer	Buy	$23.05	
Wiring	Buy	$14.85	May be available at UCF
Barrel	Either	See Filament	Filament or Pipe
Solid Rocket Boosters	Either	See Filament	Filament or Pipe
Foregrip	Make	See Filament	Filament
Air Inlet Lever	Buy	$24.99	
Arduino	Buy	$27.60	Available at UCF
Arduino Display	Buy	$15.99	
5V Battery	Buy	$13.99	
Barrel Housing	Either	See Filament	Filament
LED Lights	Buy	$4.99	
Pressure Regulator	Buy	$14.99	
HPA Tank	Buy	$80	
Filament	Buy	$42	May be available at UCF
	Total	$396.42	

Prior to creating the preliminary model, a budget of $400 was proposed by the team to UCF MAE. This was taking major components into account that we thought at the time were likely to be needed. This budget was verbally agreed to by UCF, but is subject to change going into Senior Design 2. Subtracting the Bead Blaster and Arduino, since they will not have to be purchased, the current system cost is approximately $305. This leaves extra space as the final detailed design is completed and we identify additional, likely small, components that are necessary for the system. This also leaves a budget for the reloading system to be designed.

7.0 Gantt Chart and Major Deliverables

During the conceptual design phase, we constructed a Gantt Chart to outline the timeline for the rest of the project. This will ensure that we stay focused on specific tasks and stay on schedule to complete the project before the final deadline. The current Gantt Chart is shown in Figures 7.0A - 7.0I. This Gantt Chart is subject to change, as tasks may be completed before or after the planned deadline, affecting other tasks. It is the team's intention to run ahead of schedule when possible, to allow time for any unforeseen issues. Additionally, certain group members will be assigned future tasks once the conceptual design is finalized. Not visible in the figures is the relationship between different systems. For example, the reloading system must be completed before the propulsion system can be assembled, and all subsystems must be completed prior to final assembly.

Before constructing the Gantt chart, the team created a flowchart of the project path with preliminary dates, provided in Appendix G. After the tasks on the flowchart were transformed to a Gantt chart, we could better identify the dates for certain tasks to avoid having too many items to complete at once.

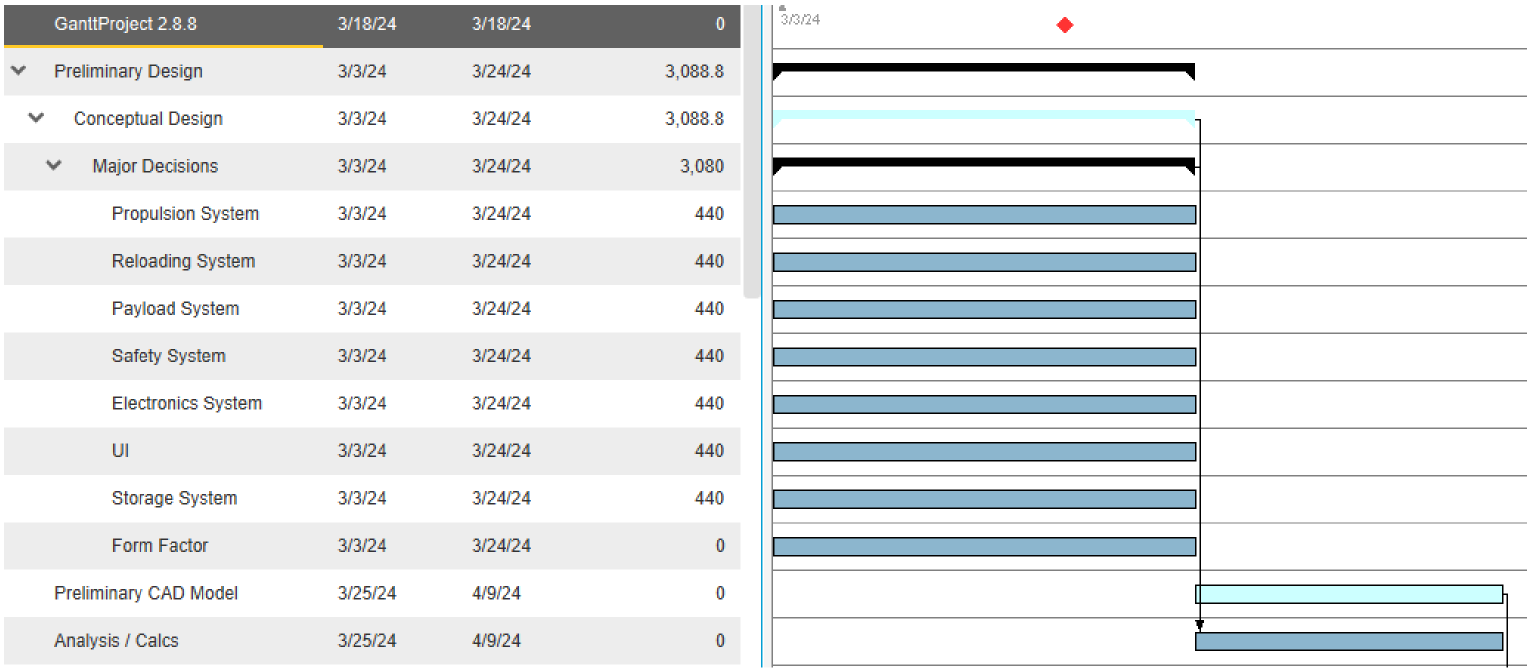


Figure 7.0A: Gantt Chart: Preliminary Design

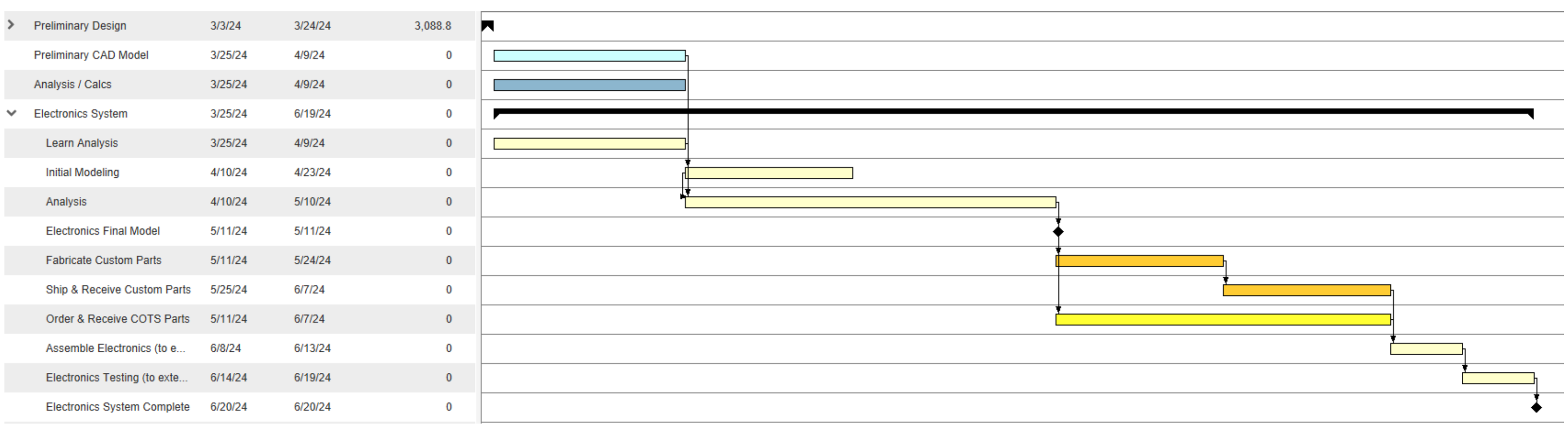
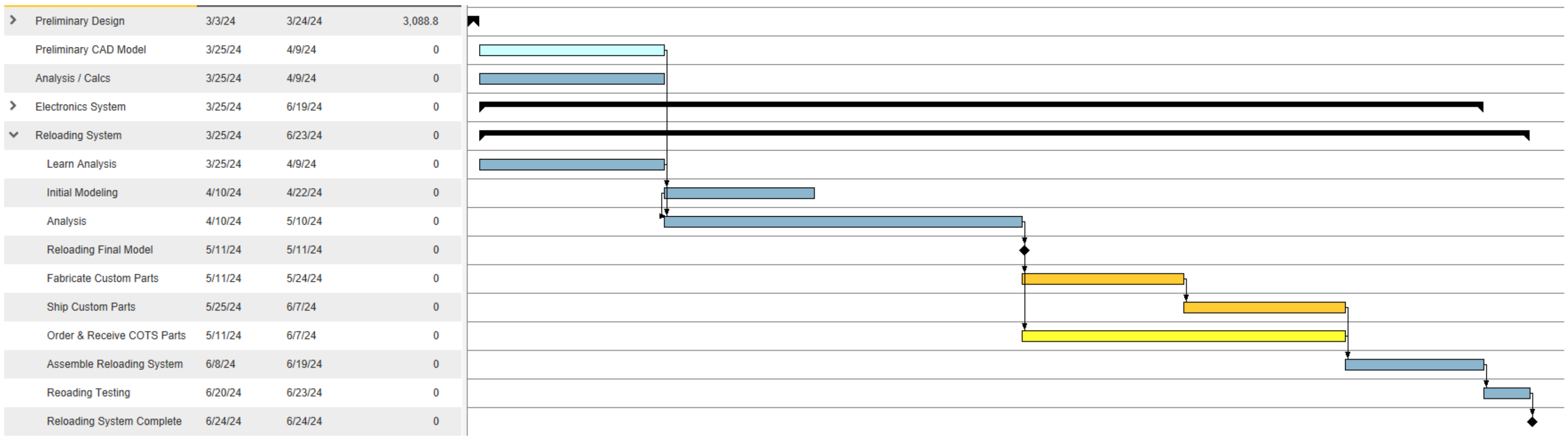
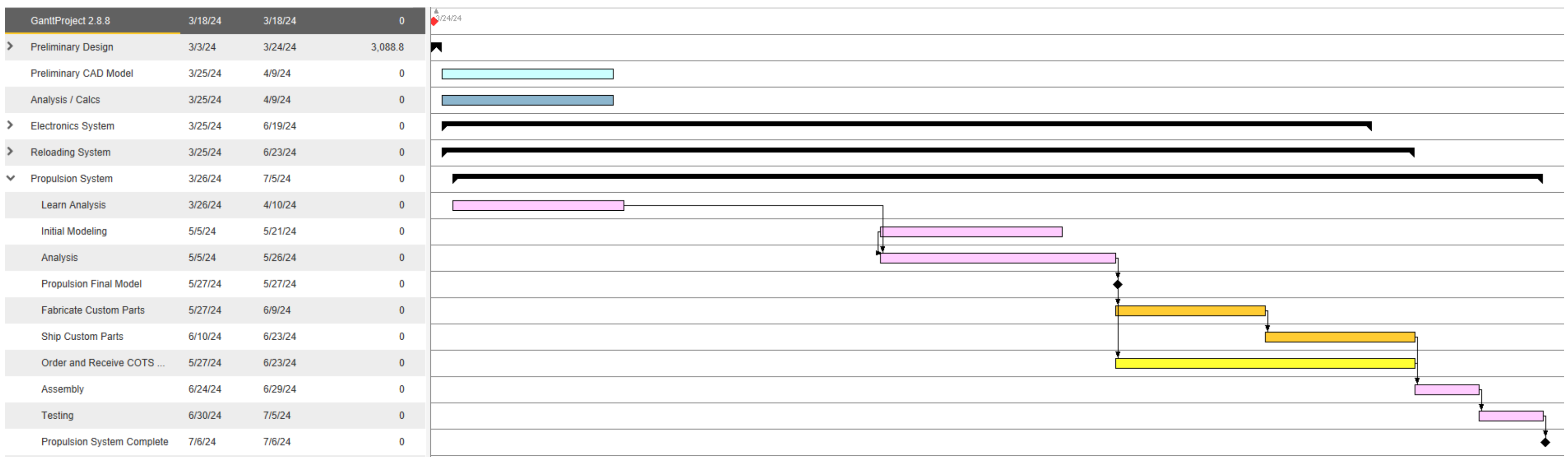


Figure 7.0B: Gantt Chart: Electronics System



Preliminary Design	3/3/24	3/24/24	3,088.8
Preliminary CAD Model	3/25/24	4/9/24	0
Analysis / Calcs	3/25/24	4/9/24	0
Electronics System	3/25/24	6/19/24	0
Reloading System	3/25/24	6/23/24	0
Learn Analysis	3/25/24	4/9/24	0
Initial Modeling	4/10/24	4/22/24	0
Analysis	4/10/24	5/10/24	0
Reloading Final Model	5/11/24	5/11/24	0
Fabricate Custom Parts	5/11/24	5/24/24	0
Ship Custom Parts	5/25/24	6/7/24	0
Order & Receive COTS Parts	5/11/24	6/7/24	0
Assemble Reloading System	6/8/24	6/19/24	0
Reoading Testing	6/20/24	6/23/24	0
Reloading System Complete	6/24/24	6/24/24	0

Figure 7.0C: Gantt Chart: Reloading System

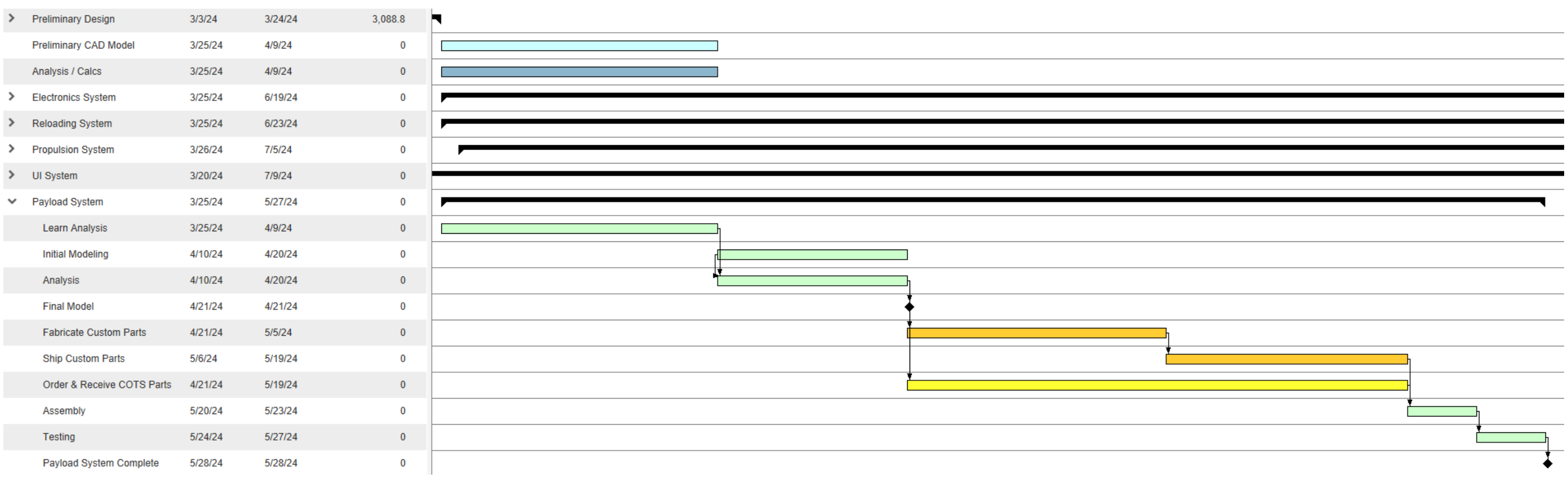


GanttProject 2.8.8	3/18/24	3/18/24	0
Preliminary Design	3/3/24	3/24/24	3,088.8
Preliminary CAD Model	3/25/24	4/9/24	0
Analysis / Calcs	3/25/24	4/9/24	0
Electronics System	3/25/24	6/19/24	0
Reloading System	3/25/24	6/23/24	0
Propulsion System	3/26/24	7/5/24	0
Learn Analysis	3/26/24	4/10/24	0
Initial Modeling	5/5/24	5/21/24	0
Analysis	5/5/24	5/26/24	0
Propulsion Final Model	5/27/24	5/27/24	0
Fabricate Custom Parts	5/27/24	6/9/24	0
Ship Custom Parts	6/10/24	6/23/24	0
Order and Receive COTS ...	5/27/24	6/23/24	0
Assembly	6/24/24	6/29/24	0
Testing	6/30/24	7/5/24	0
Propulsion System Complete	7/6/24	7/6/24	0

Figure 7.0D: Gantt Chart: Propulsion System

Preliminary Design	3/3/24	3/24/24	3,088.8
Preliminary CAD Model	3/25/24	4/9/24	0
Analysis / Calcs	3/25/24	4/9/24	0
Electronics System	3/25/24	6/19/24	0
Reloading System	3/25/24	6/23/24	0
Propulsion System	3/26/24	7/5/24	0
UI System	3/20/24	7/9/24	0
List of UI Functions	3/20/24	3/25/24	0
Design	3/20/24	4/12/24	0
Order & Receive COTS Parts	4/13/24	4/26/24	0
Coding	4/27/24	6/1/24	0
Fabricate Custom Parts	6/2/24	6/15/24	0
Ship Custom Parts	6/16/24	6/30/24	0
UI Assembly	7/1/24	7/4/24	0
UI Testing	7/5/24	7/9/24	0
UI Complete	7/10/24	7/10/24	0

Figure 7.0E: Gantt Chart: UI System



Preliminary Design	3/3/24	3/24/24	3,088.8
Preliminary CAD Model	3/25/24	4/9/24	0
Analysis / Calcs	3/25/24	4/9/24	0
Electronics System	3/25/24	6/19/24	0
Reloading System	3/25/24	6/23/24	0
Propulsion System	3/26/24	7/5/24	0
UI System	3/20/24	7/9/24	0
Payload System	3/25/24	5/27/24	0
Learn Analysis	3/25/24	4/9/24	0
Initial Modeling	4/10/24	4/20/24	0
Analysis	4/10/24	4/20/24	0
Final Model	4/21/24	4/21/24	0
Fabricate Custom Parts	4/21/24	5/5/24	0
Ship Custom Parts	5/6/24	5/19/24	0
Order & Receive COTS Parts	4/21/24	5/19/24	0
Assembly	5/20/24	5/23/24	0
Testing	5/24/24	5/27/24	0
Payload System Complete	5/28/24	5/28/24	0

Figure 7.0F: Gantt Chart: Payload System

Preliminary Design	3/3/24	3/24/24	3,088.8
Preliminary CAD Model	3/25/24	4/9/24	0
Analysis / Calcs	3/25/24	4/9/24	0
Electronics System	3/25/24	6/19/24	0
Reloading System	3/25/24	6/23/24	0
Propulsion System	3/26/24	7/5/24	0
UI System	3/20/24	7/9/24	0
Payload System	3/25/24	5/27/24	0
Safety System	4/11/24	6/7/24	0
ID Requirements	4/11/24	4/16/24	0
Meet Requirements Plan	4/17/24	4/23/24	0
Fabricate Custom Parts	4/24/24	5/10/24	0
Ship Custom Parts	5/11/24	5/25/24	0
Order & Receive COTS Parts	4/24/24	5/25/24	0
Safety Assembly	5/26/24	5/31/24	0
Safety Testing	6/1/24	6/7/24	0

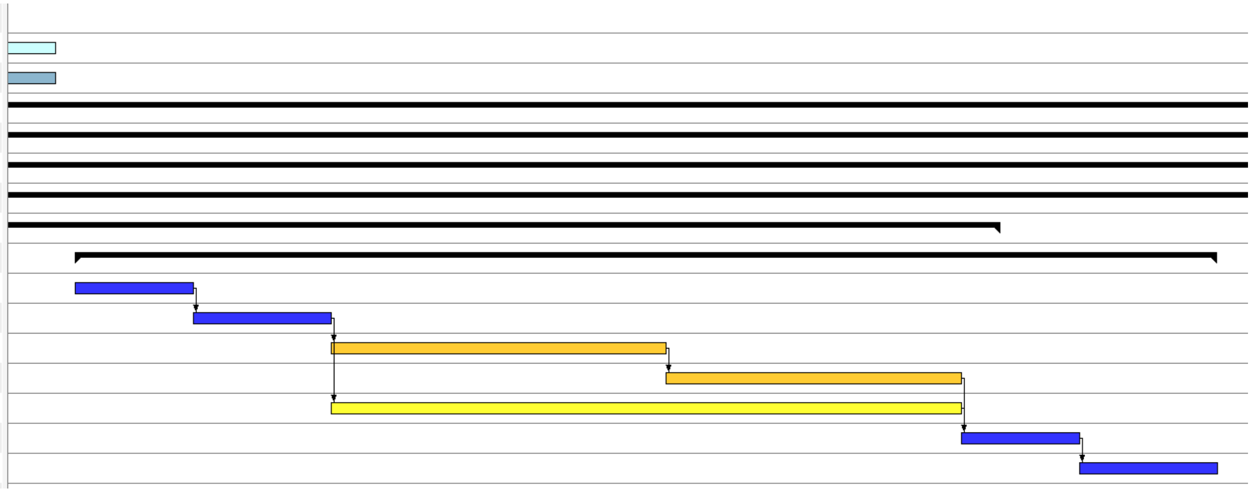


Figure 7.0G: Gantt Chart: Safety System

Preliminary Design	3/3/24	3/24/24	3,088.8
Preliminary CAD Model	3/25/24	4/9/24	0
Analysis / Calcs	3/25/24	4/9/24	0
Electronics System	3/25/24	6/19/24	0
Reloading System	3/25/24	6/23/24	0
Propulsion System	3/26/24	7/5/24	0
UI System	3/20/24	7/9/24	0
Payload System	3/25/24	5/27/24	0
Safety System	4/11/24	6/7/24	0
Storage System	4/10/24	6/1/24	0
Design Storage	4/10/24	4/19/24	0
Fabricate Custom Parts	4/20/24	5/3/24	0
Ship Custom Parts	5/4/24	5/17/24	0
Order & Receive COTS Parts	4/20/24	5/16/24	0
Storage Assembly	5/18/24	5/25/24	0
Storage Testing	5/26/24	6/1/24	0
Storage Complete	6/2/24	6/2/24	0

Figure 7.0H: Gantt Chart: Storage System

Preliminary Design	3/3/24	3/24/24	3,088.8
Preliminary CAD Model	3/25/24	4/9/24	0
Analysis / Calcs	3/25/24	4/9/24	0
Electronics System	3/25/24	6/19/24	0
Reloading System	3/25/24	6/23/24	0
Propulsion System	3/26/24	7/5/24	0
UI System	3/20/24	7/9/24	0
Payload System	3/25/24	5/27/24	0
Safety System	4/11/24	6/7/24	0
Storage System	4/10/24	6/1/24	0
Final Assembly & Test	7/10/24	7/25/24	0
Final Assembly	7/10/24	7/14/24	0
Final Test	7/15/24	7/19/24	0
M6 Report	7/21/24	7/25/24	0
END	7/26/24	7/26/24	0

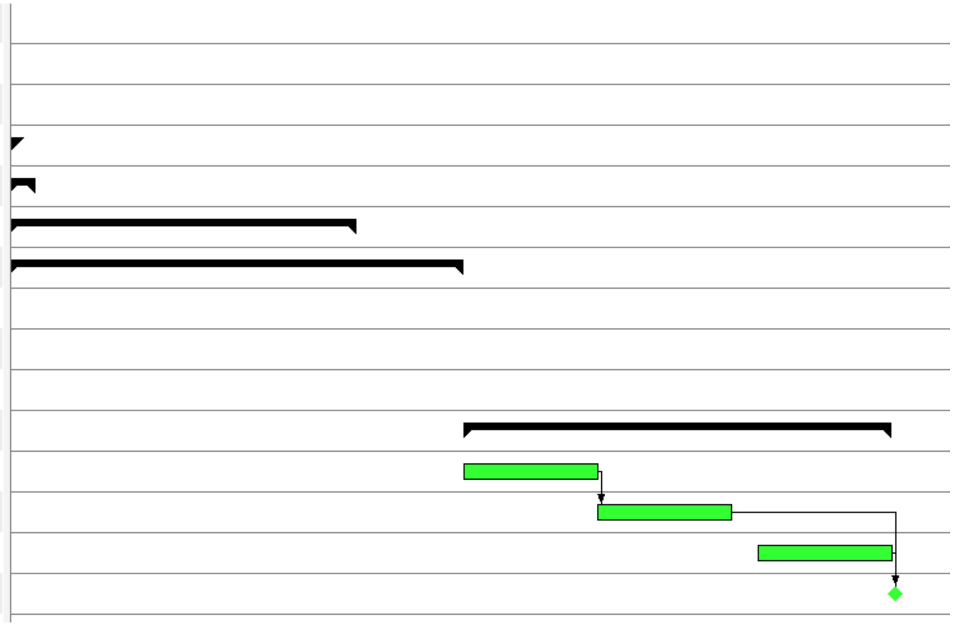


Figure 7.0I: Gantt Chart: Final Assembly and Test

Derived from the Gantt chart, Table 7.0 identifies the major project deliverable and milestones.

Table 7.0: Major Deliverables and Milestones

Completion Date	Milestone
April 9, 2024	Preliminary Design Complete
April 22, 2024	M3 Report Complete
May 20, 2024	Begin Senior Design II
May 28, 2024	Payload System Complete
June 2, 2024	Storage System Complete
June 7, 2024	Safety System Complete
June 20, 2024	Electronics System Complete
June 24, 2024	Reloading System Complete
July 6, 2024	Propulsion System Complete
July 10, 2024	UI System Complete
July 26, 2024	Final Testing Complete
August 2, 2024	Final Day of Project
August 3, 2024	Graduation

8.0 System Concept Evaluation Plans

Throughout the course of the project, there will be roadblocks that are not related to the systems themselves, but instead the project as a whole. These roadblocks can be divided into two categories: project risks and concept evaluation. The project risks do not directly affect the final system. The concept evaluation will occur after the final system is complete to evaluate the success of the project.

8.1 Project Risks

Different from the Failure Modes and Effects Analysis in Section 9, there are other risks that affect the project from a managerial perspective and do not affect the final system, the safety of the final system, or the satisfaction of the system requirements. These risks would be present for many engineering projects in the industry and would undoubtedly be risks for any Senior Design team that is building a complete system for the first time.

8.1.1 Lack of Experience

Lack of experience is the single most significant risk to the project and could encompass the other risks mentioned in this section. While completing an undergraduate degree, we have learned the fundamentals and concepts about various topics. This is generally from an analysis standpoint, where a final system is given, and we are asked to perform analysis on the arbitrary system. An example of this would be calculating the factor of safety of a bridge. Now, we are being tasked with designing a system from the ground up in order to meet certain criteria, applying the concepts we have learned to design and perform analysis along the way. An example of this would be designing an entire bridge, knowing what loads it needs to support and the desired factor of safety. This is a new skill that is being practiced during Senior Design, and something we will continue to encounter after graduation.

Certain areas that require some experience for the successful completion of this project include performing FEA, performing CFD, manufacturing, project management, and working with a team. While some of these will require us to learn as we go, some steps can be taken to mitigate certain areas where we lack knowledge.

To mitigate these risks, the team decided that it was essential to learn how to perform specific tasks before we needed the skill. For example, in late March and early April, half of the team was assigned to learn how to perform FEA, and the other half was assigned to learn CFD. After a couple of weeks, we had enough collective skill in those areas to address any needs that will arise in the future, and perform the analyses shown in Section 6. In any future occupation, we will first have to learn how to perform the job to a high level before being solely responsible for meaningful work, which is no different from this scenario.

Another area where we lack experience is working as a team from the beginning to the end of a project. While we do have experience working in lab groups or with coworkers, it is not exactly the same as meeting a new group of people for the first time and immediately having tasks and assignments to complete that are high stakes. To mitigate this, we have weekly internal team meetings, weekly advisor meetings, and are usually in contact every day to communicate the status of the project. This has proven an effective way for us to divide the work while still all working toward a common goal.

8.1.2 Time Constraints

After a lack of experience, constraints due to time are the second biggest risk to the project. In an interview with the Washington Post, a professor at Oxford University states that only 8.5% of infrastructure engineering projects are completed on time and on budget [8]. It is almost commonplace in engineering for projects to run severely behind schedule, pushing back promise dates and release dates. A famous example of this is the F35 fighter jet, which was delivered far behind schedule, but still considered a major success. Unfortunately, delivering a product behind schedule is not an option for us.

To mitigate the risk of time, we have already taken proactive steps to effectively manage the short time we have to complete this project. Starting from the very beginning, the team has set internal deadlines for almost all major tasks in order to stay ahead of schedule. For example, this report was mostly completed on April 12th, allowing ample time to prepare an advisor presentation, receive feedback, make changes, and submit before the final deadline on April 22nd.

To project future schedules, we created the Gantt Chart shown in Section 7. While this Gantt Chart is a living document that will continue to be updated, it emphasizes the point that one mistake could derail the timing of the entire project. To combat this, we allowed extra time for every task in the Gantt Chart, especially for things that are out of our control such as ordering parts. Constructing the Gantt Chart also allowed us to distribute the construction of subsystems out over the Summer, instead of trying to construct 6 subsystems at once. This will allow us to make the best use of our time instead of trying to construct the entire system at once.

8.1.3 Budget Constraints

The third major risk to this project is the budget. Similarly to time, it is common for engineering projects to be completed over budget. If a project takes too long, then in industry it will incur a significant extra labor cost, which is not an issue for this project. However, the cost of a project can also be driven up by external factors, such as parts shortages, supply chain issues, or inflation.

To mitigate this risk, we have already been communicating with the Senior Design coordinator to obtain a project budget. A preliminary bill of materials that consists of major components that we are likely to need was constructed, totaling around $400, which was given verbal approval from the Senior Design coordinator. This figure does not include that some parts will be available through the Senior Design class at no cost. However, there are still items that will be identified during the final detailed design stage that will drive up the cost of the project. To stay within budget, we will first take inventory of what is available through Senior Design or what we may already have available to us. With the parts and materials that will have to be purchased, the final design will have to take the budget into consideration. Every purchased part will have to be analyzed for alternatives to find the best combination of cost and performance, without taking too long to be obtained, causing time to become a risk.

8.1.4 Procurement and Manufacturing

A specific area that could pose a risk to the project is the procurement of parts and materials and the manufacturing of those materials. If procurement of materials takes too long, it will take time away from building and testing the system, both of which are essential to the project. To mitigate the issue of potential long lead times for parts, we have built-in extra time for shipping in the project Gantt Chart. In the Gantt Chart, a minimum of 2 weeks is allowed for obtaining COTS parts, and a minimum of 4 weeks is allowed for ordering custom fabricated parts, such as a piece of sheet metal that is laser cut and bent. If the materials arrive sooner than expected in the Gantt Chart, we can move forward with the next tasks, which allows an extra buffer in case a different issue arises later on. Furthermore, we will mitigate shipping issues by ordering parts from reputable retailers that can quickly ship parts. COTS parts will mostly be ordered online from

Amazon or from local retailers such as Ace Hardware. These options are fast and reliable, allowing us to adhere to the time allowed in the Gantt Chart and pull in future dates.

Another area that poses a risk to the project is manufacturing. Designing something in CAD is a relatively straightforward task that the team has past experience with. However, actually manufacturing that part involves a new set of skills. To mitigate this, two approaches can be taken.

First, we can utilize COTS parts as much as possible in the design to minimize the amount of manufacturing that must occur. An example of this would be using nuts and bolts to fasten two pieces of metal together instead of welding them together. They both involve manufacturing, but using nuts and bolts can be done easily on campus or in a garage, while welding requires more skill, equipment, and money to complete.

The second approach is to take manufacturing into account when designing. When designing parts, we must design it in a way that is easily manufacturable and accessible. If something does require welding, laser cutting, or metal bending we have to ensure that service is accessible to us for a reasonable cost before finalizing the design.

8.1.5 Stakeholder Dependency

The final risk to the project is the dependency on key project stakeholders for some decisions. While we do have ownership of the project, the final customer is Pete and the UCF Athletics Department, making their input valuable. It is our intention to include them as much as possible in the design process, but their feedback has the potential to delay timelines or increase costs. This could come in the form of taking time to answer questions or asking to redesign something to meet certain criteria. While neither of these has been an issue to this point, the possibility remains.

To mitigate this, the team has proactively met with the project stakeholders to gauge their expectations for the T-shirt launcher. By doing this, we were able to write requirements that satisfy their needs, which will be the targets that are kept in mind when designing the T-shirt launcher. If we had waited to meet with the project stakeholders after the initial design was complete, it is likely that the system would need to be majorly redesigned. To further mitigate this risk, we will continue to have an open line of communication between the team and the key project stakeholders, providing updates along the way. By doing this, any potential issues or shortcomings can be identified and addressed as soon as possible.

8.2 Final System Evaluation

The final system will be evaluated by the project stakeholders and the team by comparing the final system to the requirements defined previously. This could be a time consuming and potentially expensive process, so it is imperative that a plan is in place to evaluate the system. An example of this would be when the barrel lengths were tested in Section 6, we first performed all other testing with a longer barrel before shortening the length, as that was considered a destructive test to the length of the barrel. The validation of requirements can be broken down into two main sections, with corresponding subsections:

1. Validation that does not involve firing the launcher. Many of these validations can be completed before the final system is complete. These do not take much time and can be determined with ease. These validations can be further divided into multiple categories:

a. Analysis - Computer-aided analysis of the T-shirt launcher or analysis of a procedure intended for the user of the launcher.
b. Certificate of Conformance - Documentation must be provided to show where something was purchased or that a purchased component meets a requirement.
c. Measurement - Simple characteristics of the system, such as weight and length.
d. Poll - A poll was sent to the UCF Athletics Department to receive feedback on if an aspect of the design meets their needs.
e. Test - Any testing that can be done on the system without the need to fire the launcher.
f. Tracked - These requirements will be tracked throughout the course of the project and compared to the desired value at the end, for example, the budget.
g. Visual - Visual inspection to confirm that a certain aspect of the system exists and performs its intended purpose.

2. Validations that involve firing the launcher. These validations will be more time consuming and will require a dedicated time and location to be able to repeatedly fire the launcher.
    a. Measurement - Measurement of trigger weight.
    b. Test - Firing the launcher and measuring the appropriate launch characteristics.
    c. Visual - Firing the launcher and observing that a certain requirement is met.

The purpose of dividing the system validation plan into two sections is to promote efficient use of time during the project. For validations that do not require firing the launcher, many requirements can be verified at the subsystem level, prior to final integration. The requirements that will be validated without firing the launcher are shown in Appendix H, along with the validation technique and estimated time. Assuming a minimum time of 5 minutes for simple validations, it is estimated that these validations will take just over 4 hours.

Requirements that involve firing the launcher will be more involved to verify. We will have to first find an area where we can repeatedly fire the launcher without garnering any noise complaints. Furthermore, we will need electricity and an air compressor to eliminate the need to leave to refill the pressure vessels. An ideal location is the football field on campus or one of the practice facilities, both of which provide electricity and ample space to launch the T-shirts. Since this will be a time-consuming process, it is important to order the validations in a way that maximizes the use of our time. For example, one requirement requires 75 cycles of testing, which can be done last so that all of the testing up to that point can count towards the 75 cycles. Due to this, the validations that require launching T-shirts have been ordered in a way to best optimize the time spent testing. The validations, order they will be performed, estimated times, and number of shirts launched is shown in Table 8.2.

Table 8.2: Requirement Verification Involving Launching T-Shirts

Order	Requirement Number	Verification	Estimated Time (mins)	Number of Shots	Total Shirts Launched
1	S7.2	Use a spring scale or similar device to measure trigger weight.	5	1	1
2	G1.1	All team members will be required to hold any handheld components and fire the T-shirt launcher.	15	6	7

3	G6.1	Observe indicator uses one of the five senses.	5	1	8
4	S7.1	Try to fire with the lockout mechanism activated.	5	1	9
5	S1.4	Verify the indicator activates when requirements are met to fire.	5	1	10
6	F2.2	Stopwatch will be used to determine how long it takes the operator to fire a T-shirt.	5	2	12
7	F1.2	Place a checkerboard pattern behind the launcher, record firing in slow motion, and calculate the time to travel over one checkered box.	10	1	13
8	F1.3	Launch 10 T-shirts from the same location, and measure the average of the 10.	20	10	23
9	F1.1	Launcher will be fired at maximum and minimum power, and measuring the difference in the launched T-shirts.	10	1	24
9	F2.1	Completion of F1.2 and F1.3 with all sizes.	60	22	46
10	F3.1	10 T-shirts will be launched from the same location, if 80% land within the target area, requirement is met.	20	10	56
11	S6.1	Complete 75 cycles of testing.	60	19	75

Continued on Next Page

Using these estimated times, it should take less than 4 hours to verify the aspects of the system involving firing the launcher. Between the two groups of validations, both could be completed in a single day if necessary. However, many will be validated prior to the final testing and the team

Gantt Chart allows 4 days for final system verification, leaving time to ensure all requirements are validated.

8.2.1 Additional Modeling and Analysis

While the team has taken steps to begin modeling the launcher and performing analysis on its various components, the final system will have to undergo a complete analysis to ensure its safety. As each component of the T-shirt launcher is designed, any appropriate analyses can be performed at the component level, such as a stress and CFD analysis on the final barrel geometry. The geometry analyzed earlier was a generalized model and will not reflect the final geometry. Unless the safety factor is stated by the manufacturer, any purchased pressure vessels will undergo a stress analysis using SolidWorks to ensure they meet the minimum safety requirements.

Furthermore, prototyping can be done at the subsystem level. The UI will be tested as soon as the pressure transducers are purchased and the code is written, as it only needs the accumulator tank to be tested. The barrel can also be tested independent of many system components, only needing the accumulator tank to be able to fire the launcher. It could be connected to an air compressor for the purpose of testing.

9.0 Failure Modes and Effects Analysis

For the failure modes and effects analysis, every major component and system was analyzed to determine the various associated failure modes. Additionally, other smaller components were identified that will be required to be used based on the decisions made and analysis performed in Sections 5 and 6, respectively. These items were components previously identified in our component decomposition as major items within our design. Pressure vessels, pressure gauges, pressure regulators, pressure release valves, air intake valves, exhaust valves, UI, storage, reload system, delivery system, trigger mechanism, pressure lines/hoses, air fill adaptors, and electronics were the components that are recognized as potential failure points.

The criteria for ranking the likeliness, criticality, and detection of failures was derived from the Standard for Performing a Failure Modes and Effects Analysis, published and used by NASA [40]. The NASA version is specifically geared toward the aerospace industry and spacecraft, but its principles can be adapted to the needs of our team. For likelihood and detection, the NASA definition can be used with some modification. For detectability, NASA focuses on if the failure will be able to be detected by the design, for our project we will quantify if the failure can be detected by the user. For criticality, NASA instead uses severity, which is broken down into three subsections: mission impact, lost mission time, and safety or mission loss. This method is not the best fit for this project, so we instead created our own criteria to rank criticality. For criticality, the monetary cost and risk to human health is considered, with the ranking being assigned based on whichever outcome is less favorable. The ranking scales used are available in Appendix I.

In the process of completing the FMEA, we identified 66 potential failure modes for the system, ranging in likelihood, criticality, and detection. We are now aware of all 66 modes, with there being a significant amount of overlap between some modes. However, for the purposes of this project, a decision had to be made on which failure modes to focus on. We first took any failure modes with a criticality score of 7 or above, which includes any modes that would cause a moderate injury, such as small fractures or the need for stitches. Since safety is the top priority of the team, this ensures that we look at all of the modes that pose a safety risk, regardless of their total risk score. This resulted in 12 failure modes that pose a risk to human safety. Most of these modes had a high overall risk score, so to round out the list, the next 6 failure modes with the highest risk score were selected. The modes that were not selected for this report will still be considered throughout the design process. A list of all 66 failure modes, their scores, and mitigations is available in Appendix J.

9.1 Pressure Vessel Failure Modes

Pressure vessels are perhaps the greatest risk in terms of criticality in this project. Since these containers are going to be storing large amounts of compressed air or gas, this poses many risks identified in the matrix. The main concern for these failure modes is the pressure vessel failing, thus causing some sort of loss of pressure, cracking, or worst case, an explosion. The team needs to assess the risks associated with pressure vessels thoroughly and ensure a proper factor of safety and precautions are taken into account.

9.1.1 Over Pressurization of Pressure Vessels

Over pressurization of the vessel is one component discussed as a mode of failure for the tank. The tank is going to be rated for a specific PSI, the concern is that it is possible to continuously push air into the vessel until it reaches a point of failure. The failure of this would be catastrophic as we are dealing with a high pressure environment surrounded by metal that cannot withstand the force.

The failure mode was rated as a 3 in likeliness, which indicates incredibly low chance of failure considering the engineering of the pressure vessels, and competency of operators. The criticality was rated 10, as if the over pressurization of this system could cause a catastrophic explosion that not only will hurt the operator, but injure people in the vicinity. Detection was rated 6, as it may be incredibly difficult to recognize when the pressure vessel is being overfilled without a proper gauge of time and amount of compressed air loaded into the vessel.

This is one of the most significant failure modes of the entire design as the ramifications are catastrophic, but there are precautions that can be taken to easily mitigate this and prevent it from ever occurring. One mitigation that will be implemented is a pressure gauge, the pressure gauge will allow the operator to identify how much compressed air has been loaded into the vessel, and assess the current state of the vessel's capacity. The other implementation will be an emergency pressure release valve. This valve will act as a safety net for overfilling the vessel, because once it hits a large enough PSI, it will give and release all the pressure, preventing the vessel from being continuously filled [43]. Another mitigation that applied to all risks involving pressure vessels is to buy commercial vessels or build multiple small vessels instead of one large one. Commercial vessels will be stronger than something that can be easily built for this project. If we did end up manufacturing pressure vessels, making multiple small vessels will minimize the amount of damage caused by a vessel failing.

9.1.2 Pressure Vessel Creep

Creep is a major failure that can occur in pressure vessels. It is defined as time-dependent deformation with constant stress causing deformation. The usual cause of creep to occur in a pressure vessel is if the tank’s internal pressure is constant during expansion; this would decrease the thickness of the walls and increase the load the walls would experience [10]. This would lead to the wall thickness decreasing and the load acting on the wall increasing until the point of failure, fracturing the vessel. Creep's main factor is constant stress over a long period of time, so overpressurizing the pressure vessel and having it sit in storage can cause a creep failure.

Creep failure received a 3 in likeliness to occur, an 8 in criticality, and a detection score of 7, making the RPN score 168. Likeliness of 3 was chosen for creep failure due to section 6.7.1, where the pressure vessel we modeled and analyzed has a safety factor of 5.395, making the likelihood of failure low. However, if the vessel were to fail, this could cause extensive harm to the user and anyone near the pressure vessel, giving us the criticality of 8. For detecting these failures, we have a score of 7 as creep is a deformation from loads over time, so small deformation over time can be unnoticeable at a glance, eventually leading to cracks rapidly depressurizing the tank and or a violent spontaneous kinetic disassembly. Due to these factors, the RPN score resulted in a 168, making it one of the main risks for this project as a failed pressure vessel not only results in severe harm to the user and those close by but also a failure of the device.

To mitigate the creep failure of the pressure vessel, do not over pressurize the system; standard commercial pressure vessels have a specific PSI rating to prevent the tanks from experiencing more loads than they are capable of. If failure is unavoidable, multiple smaller pressure vessels can be used as a substitute to minimize the damage a large pressure vessel may cause. Another way to prevent failure is maintenance; according to Cornell Law School [2], pressure vessels in service must be examined or tested every 5 years but does not mean maintenance can not be performed monthly or biweekly depending on the usage to ensure the device is fit for service.

These examinations or tests should determine whether the pressure vessel is in satisfactory condition and fit for its intended service [2].

9.1.3 Pressure Vessel Fatigue

Fatigue failure occurs when fluctuating loads act on a structure, forming fractures and cracks that eventually cause the structure to collapse. This type of failure may occur if the pressure vessel is overpressurized and unpressurized over a long period of time. Other factors that could induce fatigue failure include thermal cycling and vibrations from turbulence when releasing the compressed fluid [42].

When considering this type of failure, we concluded that the likeliness rating was a 3, the criticality rating was an 8, and the detection rating was a 6. Due to the nature of this failure as a time-dependent occurrence, it was ranked the likeliness as a 3, as fatigue failure theoretically would not happen with a brand-new pressure vessel. However, once the pressure vessel is acquired and used to perform testing, fatigue failure may occur as the tank is now under use. As for the criticality rating, it is the same as what was stated previously in section 9.1.2 as this assumes it is the same type of pressure vessel that will fail. Lastly, detection of fatigue failure similar to creep in section 9.1.2 biggest factor is stress over time, as fatigue failure develops micro fractures which over time develops into cracks that eventually grows to a point in which the pressure vessel fails. These fractures and micro cracks may not be detachable till a larger crack has formed and or a failure has occurred.

Mitigation methods that could be applied to fatigue failure is maintenance, making sure that the tank is fit for service. Ensuring that the tanks are properly filled to the standards set by the manufacturer will greatly decrease the likelihood of fatigue failure as constant expansion and contraction of the tank would cause fatigue. Storing the pressure vessel in a temperature control climate would prevent the thermal cycling that could also prevent constant expansion and contraction of the pressure vessel. Lastly to prevent vibrations that could cause fatigue is ensuring the tank's exhaust valve or nozzle is clear of debris to prevent flow turbulence that could cause the tank to vibrate.

9.1.4 Pressure Vessel Manufacturing Defects

Manufacturing defects are rare occurrences and are not caused by design flaws. These defects are generally imperfections in the material and or manufacturing process where manufacturers deviate, change, or remove parts and or steps while producing the product [18]. Due to these changes, a small number of products will experience defects that could affect the integrity of the product or become a benign cosmetic change.

The potential likelihood of failure occurring due to manufacturing defects is a 2, the criticality of the failure is an 8, and the detection rating is 8, giving us an RPN of 162. The likelihood of buying a defective pressure vessel is low due to manufacturing standards that no more than 1% of a batch can be defective if the number of defectives exceeds that number, the whole batch is scrapped [15]. Due to this 1% limit manufacturing defect standard, there is a potential case where the pressure vessel acquired for this project may not meet the advertised standards, giving us a likeliness rating of 2. Due to what was previously stated in section 9.1.2, we set the criticality as 8, as a failed pressure vessel can cause severe injury. Detection of manufacturing defects was rated as an 8 as it is extremely hard to identify material defects and manufacturing defects that are minor or unnoticeable to the naked eye.

Preventing these failures and mitigating the risk when using a pressure vessel with manufacturing defects is very important. Due to the likeliness, criticality, and detection values, we reach an RPN of 128 as another one of the major risk factors in our project. Methods to prevent this risk include inspecting the pressure vessel when acquired to identify these manufacturing defects and or route maintenance of the pressure vessel to observe if the pressure vessel is performing within the expected range set by the manufacturer.

9.2 Pressure Regulators Failure Modes

Pressure regulators will be used to control the rate of flow of pressure between the main tank and accumulator tank in our device. This component is essential so that the accumulator tank is not filled too quickly and overpressurized. Because the pressure in the main tank is much higher than the accumulator tank, pressure regulators serve as an important safety measure in preventing accidents and allowing for gradual filling of air. Just like any component, there are multiple failure points for pressure regulators that can be identified, such as creep and overpressurization. While these failures can be catastrophic, there are ways to mitigate these risks as mentioned below.

9.2.1 Pressure Regulator Creep

Creep failure in a pressure regulator poses a significant risk, potentially leading to gradual but damaging deformations and eventual system failure. If the pressure regulator were to exhibit creep under sustained pressure, it could compromise its ability to maintain proper pressure levels, resulting in reduced performance and potential damage to the launcher's components over time. Such failures not only jeopardize the safety of operators and bystanders but also undermine the overall effectiveness and longevity of the project.

This failure mode has a likelihood rating of 3, a criticality rating of 6, and a detection rating of 7, resulting in an RPN of 126. While the likelihood is considered very low risk due to creep occurring slowly over time and being detectable through performance metrics, the criticality rating of 6 is attributed to the moderate monetary loss and potential for multiple moderate injuries resulting from failure. The detection rating of 7 is due to its very low detectability, as gradual internal failures are much harder to detect.

To address these risks, it is essential to select a pressure regulator that is resistant to creep and capable of maintaining stable pressure levels over time. Regular maintenance and inspections are vital for identifying early signs of creep or deterioration before they escalate into serious issues. Implementing additional safety measures, such as periodic performance testing, can further enhance the system's resilience against creep-related failures.

9.2.2 Pressure Regulator Overpressurization

Overpressurization presents a substantial risk, potentially triggering catastrophic failures throughout the system. If the pressure regulator were to malfunction under excessive pressure, it could lead to a cascade of issues, from ruptured hoses to damage to the launcher's mechanical components. Such failures not only pose immediate dangers to operators and bystanders but also threaten the integrity and longevity of the entire project.

This failure mode has a likelihood rating of 4, a criticality rating of 6, and a detection rating of 3, resulting in an RPN of 72. While the likelihood is considered low risk due to potential mitigation measures, the criticality rating of 6 is attributed to the moderate monetary loss and potential for multiple moderate injuries resulting from failure. The detection rating of 3 is due to its high detectability through the senses. To mitigate these risks, careful attention must be paid to selecting a pressure regulator that meets the system's requirements and ensures robust construction and reliable performance. Regular maintenance and inspections are crucial to identifying signs of wear or stress before they become serious issues. Implementing additional safety measures, such as pressure relief valves or redundant pressure regulators, can further enhance the system's resilience against overpressurization incidents. Prioritizing these precautions and taking a proactive approach to risk management will ensure the smooth, safe, and dependable operation of our t-shirt launcher project, providing reassurance to all involved.

9.3 Pressure Lines and Hoses Failure Modes

Pressure lines will be used to connect the high-pressure storage tank to the accumulator tank and will be subject to pressures of up to 120 PSI. While these lines will be relatively small, 120 PSI is a significant amount of pressure. If a line at this pressure were to fail, it could become disconnected, hitting other components or the user. As a team, we discussed the possibilities of how this component could fail, some of the discussion topics included standardized valves, material selection, maintenance, and building conditions to name a few. The criteria at which the team categorized these failure modes was related to the quantification of how NASA classifies their failure modes. Each failure mode was then ranked with an RPN score, and the reason a majority of the pressure-related components made it onto this list is due to the fact the criticality of the failure is greater than other components.

9.3.1 Human Error in Installation

The first failure mode for pressure lines is human error in installation. If the lines are not installed properly, the lines would leak air, depleting the energy source without firing the launcher. This will lead to an inefficient use of energy, diminished launching capacity, and could potentially cause the lines to free themselves, causing damage to other parts.

This failure mode received a likeness, criticality, and detection score of 5, creating a RPN of 125. The likeliness score of 5 indicates a moderately low chance of this failure occurring. The pressure lines will likely be threaded or have quick connect adapters on the ends that are used to secure the lines. These lines are commercially made to a high degree of accuracy, and are unlikely to cause issues. The criticality score of 5 indicates that this failure mode could cause minor injury. If the lines became dislodged, they could fly back and hit the user, causing light bruising or scratching. The detectability score of 5 indicates a moderate chance of detectability from 40% to 60%. When the lines are connected, the person installing the lines will likely be able to tell if the threads are aligned and completely inserted. Furthermore, if the installation was not sufficient, it would leak air, which can be heard audibly or felt by touch. If it is a small leak, it may take longer to identify by the pressure gauges dropping, hence the detectability score of 5.

To mitigate this failure mode, many simple steps can take place. First, high quality commercial pressure lines can be purchased, along with the appropriate connectors. This will ensure a clean connection with no leaks. Additionally, the required maintenance manual will include checking all pressurized fittings when performing maintenance. If the lines are threaded, thread tape can be used to further seal the connection and prevent any leaks.

9.3.2 Fatigue of Pressure Lines and Hoses

The second failure mode for the pressure lines and hoses is fatigue. Fatigue is defined as the accumulation of small cracks that can propagate into a large crack and lead to failure. The cycles and the extent or extremity also play a factor in the fatigue on such parts [42]. Not only is this extremely critical for the system but it is avoidable with simple maintenance. The team discussed the likeliness, criticality, and detectability carefully and came up with the following results.

Fatigue on the pressure lines and hoses received a likeliness of a 3 out of 10, this was based on the same likelihood ratings NASA uses for FMEA analysis, Appendix I. A likeness rating of 3 is equivalent to one in a million. The odds of a pressure line rupturing due to fatigue would require the absence of maintenance and the oversight of routine inspection. In team discussion, not only is this preventable with repeated maintenance, but the material selection plays a big part in how long the hoses last before falling victim to fatigue. It is important to keep in mind when designing pressure lines, that they have a high criticality and can contribute to significant failure modes, so material selection or scheduled maintenance will require more resources to mitigate this failure mode. In combination with a likeness of 3, this topic scored a 9 on criticality, that is monetary loss up to $200 or severe injury, hospitalization, amputation, or life-threatening, Appendix I. Losing a pressure line would be a severe failure to the system as a whole, not accounting where on the system or with how much energy. After team discussion about ease of maintenance and part selection, the team arrived at a detection score of 2. The combination of the likeliness, criticality, and detection rating resulted in this failure mode being high on the priority list and an important topic for mitigation.

Mitigation of fatigue in pressure lines and hoses is as simple as regular maintenance and at minimum a regular or routine inspection of the pressurized vessel and the lines/hoses connected to it. For a part that is highly critical yet inexpensive, regular maintenance should include oversight of the pressure lines and hoses. Not only can this failure be mitigated with regular maintenance but part selection and material properties can play a huge role in the fatigue on the pressure lines over time. Team discussion for mitigation also revealed the use of regulated valves and lines allows for the confirmation of safety ratings before installation on the system. With the help of the ASME standards for pressure vessels and piping [17] the design of this component will factor in that hoses are rated for specific pressures and the team will utilize this information to reduce the possibility of a failure mode occurring.

9.3.3 Environmental Effects on Pressure Lines and Hoses

Pressure lines and hoses are also subject to environmental factors such as bad weather, rain, sunlight, etc. Over long periods environmental factors can fatigue and wear away the system, especially without maintenance. As discussed in team meetings this issue may not be likely however this failure mode is highly critical and poses a threat to the whole system and the safety of the operator.

The effect of damaged or destroyed airlines/hoses is the same, the only difference is the primary failure of the component. For this scenario, pressure lines and hose failure due to environmental factors scored a likeliness of 3. That is the likeliness of a pressure line rupturing or failing due to environmental factors is less than one in a million. Taking into account regular maintenance, this failure mode would likely never occur; however, the failure is highly critical since the rapid release of pressure can be dangerous. Accounting for the criticality of the effect, which is rated at 9. A pressure line failing would be detrimental to the system and would not allow other systems to operate properly. Finally, the pressure line failure due to environmental factors scored a 2 in detection. The team agreed that a pressure line failure due to environmental factors may not be as simple as finding the hole in the airline; however, it could be as straightforward as using a little soap and water to determine the point of the leak.

Mitigation to this failure would include regular maintenance on highly critical components such as the propulsion system, including all of the pressurized components. A secondary solution to the failure would be material selection, instead of lines that may rupture due to environmental factors in 2-3 years, invest in nice pressurized lines that are capable of lasting 10-15 years. The likeliness of this failure happening is reduced per the material chosen. The team agrees to be cognizant when designing pressure lines and vessels due to the naturally high criticality of the failure modes for the components. Mitigation efforts may not reduce the criticality of the failure, but they can help reduce the likeness of the failure mode happening.

9.3.4 Rupture of Pressure Lines and Hoses

The last type of failure mode for the pressurized lines and hoses is the hose rupture. The primary failure in this scenario is the hose rupture, where a rapid loss in pressure is applicable. Uncontrolled rapid pressure loss is very dangerous for the operator as well as bystanders and fans. Similar to the failure modes in section 9.3.2 and 9.3.3 the likeliness of this failure mode may be low and there may be ways to mitigate this failure however, the criticality and potential hazard will remain high.

The likeness of a random hose rupture is very low, with a score of 1, Appendix I. The team believes that with correct installation, correct preventative maintenance, and careful inspection before use, results in the likelihood of this failure to be extremely low. Nearly one instance in one hundred million is the equivalent of a score of 1. Nonetheless, the failure mode must be accounted for when designing the system as a whole, this failure mode must be accounted for since the criticality is high with a score of 8. This score represents monetary loss up to $175 and or moderately severe injury, broken bones, concussion, etc. This is a majority of why this failure mode is included on this list. Since the likeliness was very low the hazard score given to this failure mode was low which made the item low priority on the list, yet still important due to the dangers associated with pressurized vessels and lines.

Proper mitigations to this failure mode include stronger hoses or reinforced air lines, and routine inspection of pressurized lines. These two options aim to effectively mitigate the failure mode in the first place. With effective FMEA and design, the system shall perform and produce results to that stated in the design requirements document.

9.4 Pressure Relief Valve: Prolonged Overpressurization

Prolonged overpressurization poses a significant threat, potentially initiating catastrophic failures across the system. If the pressure relief valve fails to function adequately due to prolonged overpressurization, it could set off a chain reaction of problems, from deformed internal valve components to the explosion of the pressure vessel. These failures not only present immediate hazards to operators and bystanders but also jeopardize the integrity and durability of the entire endeavor.

This failure mode carries a likelihood rating of 4, a criticality rating of 5, and a detection rating of 5, resulting in an RPN of 100. While the likelihood is deemed very low risk due to potential mitigation strategies, the criticality rating of 5 is attributed to the moderately low financial loss and minor injury resulting from failure. The detection rating of 5 stems from a moderate probability that the user will detect the failure mode through sensory means.

To mitigate these risks, meticulous attention must be devoted to selecting a pressure relief valve that aligns with the system's specifications, ensuring robust construction and dependable performance. Regular maintenance and thorough inspections are imperative for identifying indications of wear or strain before they escalate into serious concerns. Another mitigation method includes a human factor that involves not allowing the accumulator tank to be overpressurized repeatedly by using gauges for reference. The implementation of supplementary safety protocols, such as pressure monitoring systems, can further fortify the system's resilience against overpressurization incidents. The accumulator tank should also not be stored with an excessive amount of pressure in order to reduce the prolonged stress on components.

9.5 Clogging of Pressure Gauges

The only failure mode for the pressure gauge is the risk of clogging the gauge. If the pressure gauge becomes clogged, the reading will become inaccurate. This will give you the wrong reading and can throw up a system failure warning.

This failure mode has a likelihood rating of 4, a criticality rating of 2, and a detection rating of 8, resulting in an RPN of 64. The likeliness score of 4 indicates a low chance of this failure occurring. The criticality score of 2 indicates that this failure mode can cause little to no damage to the launcher. Having low pressure will only result in the t-shirt not being shot at the intended force. The detectability score of 8 indicates that this failure mode has a very low chance of being detected. It will be very hard to determine if the pressure that is being shown is the correct pressure. You will have to confirm it with the analog gauge to confirm that the pressure is correct.

Proper mitigations for this failure mode include regular cleaning and maintenance of the pressure gauge. Regularly cleaning the pressure gauge will ensure that the pressure gauge will stay clean and not show signs of clogging. The pressure gauge will have several maintenance intervals that will also ensure that the pressure gauge does not become clogged and results in unnecessary warnings. Furthermore, having both an analog and digital pressure reading will give the user a better opportunity to recognize that something is wrong with the system.

9.6 Electronics Failure Modes

Electronics pose a unique risk to the system in the form of electrical shorts and potential thermal runaway. These are not issues that mechanical engineers are accustomed to dealing with, but almost any mechanical system will be backed by some degree of electronics, making the understanding and mitigation of these risks important.

9.6.1 Electronics Shorting

An electronic short can occur in multiple ways. The most common way is that a metal carrying an electrical current, such as a wire, makes contact with another piece of metal that it is in a neutral state. This could be caused by wires or improper grounding of electrical components. If the short is significant enough, it will cause sparks, potentially creating a fire in the launcher or surrounding area.

This failure mode has a likeness score of 6, criticality score of 5, and detection score of 2, leading to a RPN of 60. The likeness score of 6, indicating a moderate chance of occurring, is due to the teams' lack of experience using electrical components. This lack of understanding could lead to improper use of wiring or electrical components. The criticality score of 5 represents minor injury to the user. An electrical short usually does not cause significant damage, especially in a system such as the T-shirt launcher where the voltages will be relatively low. The short could cause the user to be shocked. The detection score of 2 indicates that the failure mode has over a 90% chance of being detected. A short can usually be seen visually, smelled, and felt if a shock occurs. There could be other potential indicators such as sudden loss of power that will indicate to the user that a malfunction has occurred.

To mitigate this potential failure, heat shrink tubing can be used on wires. This will effectively insulate the wires from their surroundings, ensuring they do not come into contact with other metals. Additionally, a simple electronics system will be used that does not require the fabrication of complex wiring harnesses. Adding additional wires means taking extra considerations into their routing to avoid pinching or environmental effects, making it best to keep the electronics isolated to as few areas as possible. Finally, a relatively low-voltage system will be utilized. An Arduino Uno, the proposed computer for this system, operates on 5V, which is a small amount of electricity that is unlikely to cause human harm.

9.6.2 Electronics Thermal Runaway

Thermal runaway is a risk associated with the use of lithium-ion batteries. In this scenario, the rate at which heat is generated by the battery vastly exceeds the rate at which the heat is dissipated, causing it to heat up rapidly [47]. This can be caused by defective battery cells, damage to battery cells, or long-term overcharging of the battery cells.

This failure mode received a likeness score of 1, a criticality score of 10, and a detection score of 1, creating a RPN of 10. While the RPN is very low, the criticality of 10 makes it necessary to consider during the design process. The likeliness score of 1 indicates that this is a remote possibility. Any batteries used for this project will be commercially purchased and have gone through rigorous testing with thousands of use cases by other individuals. The criticality score of 10 indicates that this failure mode could result in death or severe injury. Due to the nature of thermal runaway, the battery cells generally rapidly engulf in flames with little build up. This could catch the user off guard, causing them to be burned. If the launcher is on the ground, it could catch the grass or floor on fire, causing it to spread. Finally, the detection score of 1 indicates that the failure and its effects are almost certain to be recognized.

To mitigate this, commercial batteries will be used for this project. There is no sense in attempting to create a battery pack that would likely end up being heavier, bulkier, and less efficient than what is available for a low cost on the commercial market. Furthermore, the various manuals that will be included with the T-shirt launcher will contain warnings to not overcharge the batteries and to replace the batteries in case of any damage. This way, the user and owner of the T-shirt launcher are aware of this critical risk and can avoid a dangerous situation with the batteries. While thermal runaway is a very unlikely event, it poses serious safety concerns that should be considered.

9.7 Trigger Mechanism: Human Error

The only failure mode for the trigger mechanism is human error. If the trigger is not correctly operated or is misclicked, the launcher could misfire. This can become a safety hazard to spectators who are unready or not paying attention.

This failure mode has a likelihood rating of 4, a criticality rating of 8, and a detection rating of 1, resulting in an RPN of 32. The likeliness score of 4 indicates a moderately low chance of this failure occurring. It would be very hard for someone to accidentally pull the trigger and misfire a T-shirt. The criticality score of 8 indicates that this failure mode can cause major injury. If the launcher is misfired and a shirt is launched, the shirt hitting an unsuspecting person can cause major bodily harm depending on where the shirt hits them. The detectability score of 1 indicates that this failure mode is going to be detected as you will be able to tell when the launcher is fired due to the loud noise that is associated with the launcher when it releases all the pressure. Although the likeliness is low, the dangers associated with misfiring the launcher are very high and can cause harm to others.

Proper mitigations to this failure mode include using additional safety features. The launcher will have a weighted trigger. The operators of the launcher will also undergo training to make sure this does not happen. There will also be a safety on the trigger to prevent accidental bumps and a LOTO system to prevent unauthorized use as a whole.

9.8 Air Adapters Failure Modes

Air adapters assume a critical component in the functionality of the device, these fittings allow for the translation of compressed air between segments of the device and need to be adequately capable of handling PSI loads of greater than or equal to the bounds of the device. The failure of these components is critical because this could cause injury to the operator or bystanders in the vicinity of the launcher.

9.8.1 Air Adapters Fatigue

Over time, fatigue will overtake the air adapters, this will occur after significant use or significant weathering of the components. It is crucial to consider these components' integrity and avenues of maintenance to provide the safest and most consistent use. Failure of these components means that we could see either depressurization at least, and at worst, a rapid disassembly of the device.

The likeliness of this occurring was rated 2, very low, because the device will be engineered to withstand the pressures and the environment it will see over time, so the only concern would be either improper assembly or improper maintenance. The criticality is a 7, because the failure of this component will almost certainly injure the operator or destroy the device. Lastly, detectability is a 2, because it can be easily observed when a fitting or adapter is starting to become loose or the integrity of the structure is beginning to fail.

The mitigation for this failure mode is to utilize components that are rated to withstand the continuous use of the device and the capabilities of this device. This will ensure that the pressurization will not cause a failure at the point of the adapter if it is weak. Another mitigation to consider is an inspection of the part upon delivery. Consider all possible manufacturing defects and vet the component to ensure it is safe to the best of our ability. Lastly, performing routine maintenance on the device will allow maintenance personnel to identify when the correct time to replace the component is, to mitigate fatigue.

9.8.2 Air Adapters Overload

Air adapters are also subject to overload in our system. Overload in this case is when the pressure being shoved through the system is too high and too fast for the adapter to handle, which will certainly cause a failure. This failure will either cause the device to break and become unusable, or cause a catastrophic disassembly of parts. Similarly to section 9.8.1, the failure is a significant concern for the integrity of the device and is addressable.

The ratings given in our analysis were a 2 in likeness as if we engineer the device correctly, this should not occur, the only possibility of occurrence being a manufacturing defect that was possibly identifiable by the team or by a maintenance crew. Criticality was rated a 7, as a large pressure blast overloading the adaptor will certainly cause an explosion of air from the weak point and possibly throw components and injure the operator or bystanders. The detectability is very low, rated a 1, this is very easy to detect because an overpressurization and blast will certainly cause failure of the device and deem it unusable.

The device will be engineered to withstand the pressure at these adapter locations, which will mitigate the possibility of a user error in overpressurizing the vessel and blasting past the rating of the adapters. All components in the device will work in conjunction to ensure that this can not occur. The only possibility of failure falls on a manufacturing error, so the team will analyze the component upon delivery and ensure the integrity of the object to the best of our ability. This should act as a mitigation completely for this failure mode.

9.9 Delivery System: Human Error

The only failure mode for the delivery system is human error. If the t-shirts are not inserted, they can jam the launcher. If the T-shirts are not seated properly, they can also jam the launcher. This can cause damage to the launcher.

This failure mode has a likelihood rating of 1, a criticality rating of 7, and a detection rating of 2, resulting in an RPN of 14. The likeliness score of 1 indicates a very low chance of this failure occurring. It would be very hard for someone to insert the t-shirt improperly and not correct it.

The criticality score of 7 indicates that this failure mode can cause major damage to the launcher. If the launcher is jammed and the shirt is attempted to be launched, the shirt can get jammed into the barrel. This can cause the barrel to become damaged and require replacement. This will cost UCF and cause the launcher to be out-of-service. The detectability score of 2 indicates that this failure mode has a very high chance of being detected as you will be able to tell when the t-shirt is not seated. You will be able to visually inspect the launcher and notice the t-shirt not seated properly. Although the likelihood is low, the damage that can be caused by a t-shirt getting jammed is very high. We want the launcher to function as intended and have as few problems as possible.

Proper mitigations for this failure mode include a visual inspection before each T-shirt is launched. Verifying that the t-shirt is seated properly will reduce the risk of damage to the barrel and the launcher. Another mitigation to this failure mode is the barrel material. Having a slightly flexible barrel material will allow the T-shirt to have a little bit of wiggle to work its way into the barrel.

10.0 Significant Accomplishments and Future Work

Throughout the initial phase of senior design, our team has dived deeply into various key processes, including the identification of problem statements, their systematic breakdown into manageable components, and the assessment of potential risks inherent in project execution. This structured approach closely mirrors the methodology employed by experienced system engineers, offering invaluable insights to emerging professionals. As we embark on our senior design journey, engaging with major stakeholders and end users emerges as a paramount necessity. Their input not only outlines the project's scope but also establishes the criteria and constraints vital for its success. The use of scheduling software, such as GanttProject, has been instrumental in providing us with invaluable insights into effective time management, particularly crucial in the depth of this senior design project.

Additionally, our project has begun to achieve several significant milestones, each playing a pivotal role in our development as engineers. One notable advancement is the ongoing optimization and research of launcher performance. This endeavor involves utilizing simulation, theoretical analysis, and iterative refinement to enhance the launcher's capabilities. By employing advanced simulation techniques, including finite element analysis, we aim to assess and select the most suitable materials for components such as the pressure regulation system, nozzle design, and overall launcher geometry. Through this process, we anticipate achieving improvements in launch velocity, accuracy, and range, all while prioritizing user safety. Moreover, our exploration into integrating advanced control mechanisms aims to enhance user control and versatility in targeting and firing sequences. It's important to note that while these achievements mark significant progress, our project remains in the preliminary design phase. This report serves as a stepping stone for our ongoing efforts, and many aspects of our design process are still under consideration and subject to refinement.

In addition to technical achievements, our project has also emphasized sustainable engineering practices, including the use of simulation and analysis tools to minimize material waste and energy consumption. This holistic approach has been underscored by interdisciplinary collaboration and teamwork, essential elements in tackling the multifaceted challenges included in real-world engineering projects. Leveraging the diverse expertise within our team, encompassing mechanical, electrical, and software engineering disciplines, has allowed for the development of innovative solutions that go beyond conventional boundaries.

Looking ahead, our project presents numerous opportunities for future work. These include further optimization of launcher performance metrics, exploring innovative control strategies, and integrating additional features into the t-shirt launcher. Continued research and implementation of industry practices within the field will guide us as we aim to advance our understanding of mechanical systems and contribute to engineering innovation.

11.0 Conclusions and Recommendations

During this semester, we have learned a lot about our t-shirt launcher. We have successfully created reasonable expectations that our t-shirt launcher should meet. We also picked out which mechanisms will best suit our launcher. We met with stakeholders at UCF to understand what is most important for them. We determined multiple safety systems that will help reduce our risk of injury.

Moving forward into Senior Design 2, a timeline has been set to help the team stay focused and organized. The team will start to send out a list of materials to purchase. We will begin to assemble the base of the t-shirt launcher. If we run into logistical issues with shipping, we will continue to work around it as best as we can. We will use the base to test our launching mechanism to confirm it is working and efficient. Many safety features will be implemented as the launcher gets further into development. As the semester continues, the team will continue to work efficiently as a team and help each other as needed. The team will also conduct a small survey using a sample of UCF students to determine the best design that will implement the Space-U theme. The team will make decisions and continue to work on assembling the final version of the t-shirt launcher as the semester comes to an end. If the team comes to a disagreement, both sides will have a chance to explain themselves and a vote will be held on which way to move forward. By following this path, the project can move forward with confidence and this path will maximize the success of the t-shirt launcher.

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13.0 Appendices

A: ABET Design Competence Matrix and Topic Criticality Matrix

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

Topic	Criticality	Section	Page	Comments
Thermal-Fluid Energy Systems	Critical / Main	3.1 Competitor Overview 3.2 Propulsion Methods 5.1.1 Compressed Fluid 5.2 Fluid Type	24 25 40 53	Driving factor for project is compressed air system
Machines & Mechanical Systems	Necessary, but not a primary contributor	3.4 Loading Mechanisms 5.1.3 Elastic / Springs 5.1.4 Catapult / Trebuchet 5.3 Reloading System	31 46 49 58	Loading mechanisms, considered propulsion methods
Controls & Mechatronics	Critical / Main	3.3 Control Methods 5.1.2 Electromagnetic 5.6 User Interface 9.6 Electronics Failure Modes	26 43 75 165	Control of pressure, electronic interfaces
Materials Selection	Critical / Main	3.5 Materials 3.6.1 Materials Selection	31 34	Pressure withstanding materials
Modeling & Measurement Systems	Strong contributor	6.0 Preliminary Eng. Analysis.	95	Calculations, FEA, CFD, prototypes, CAD model
Manufacturing	Necessary, but not a primary contributor	8.1.4 Procurement & Manufacturing 9.1.4 Pressure Vessel Manufacturing Defects	142 154	Will play a larger role going forward

B: Conversions Used

All values reported in this report were reported using the US Standard System due to the fact that most pressure rated devices sold in the US are rated using PSI and use fittings based on the US Standard System. During some intermediary calculations, the Metric system was used for ease and the following conversions were used to report the values in the US Standard System:

$$1\ PSI = 6894.76\ Pa$$

$$1\ in = 25.4\ mm$$

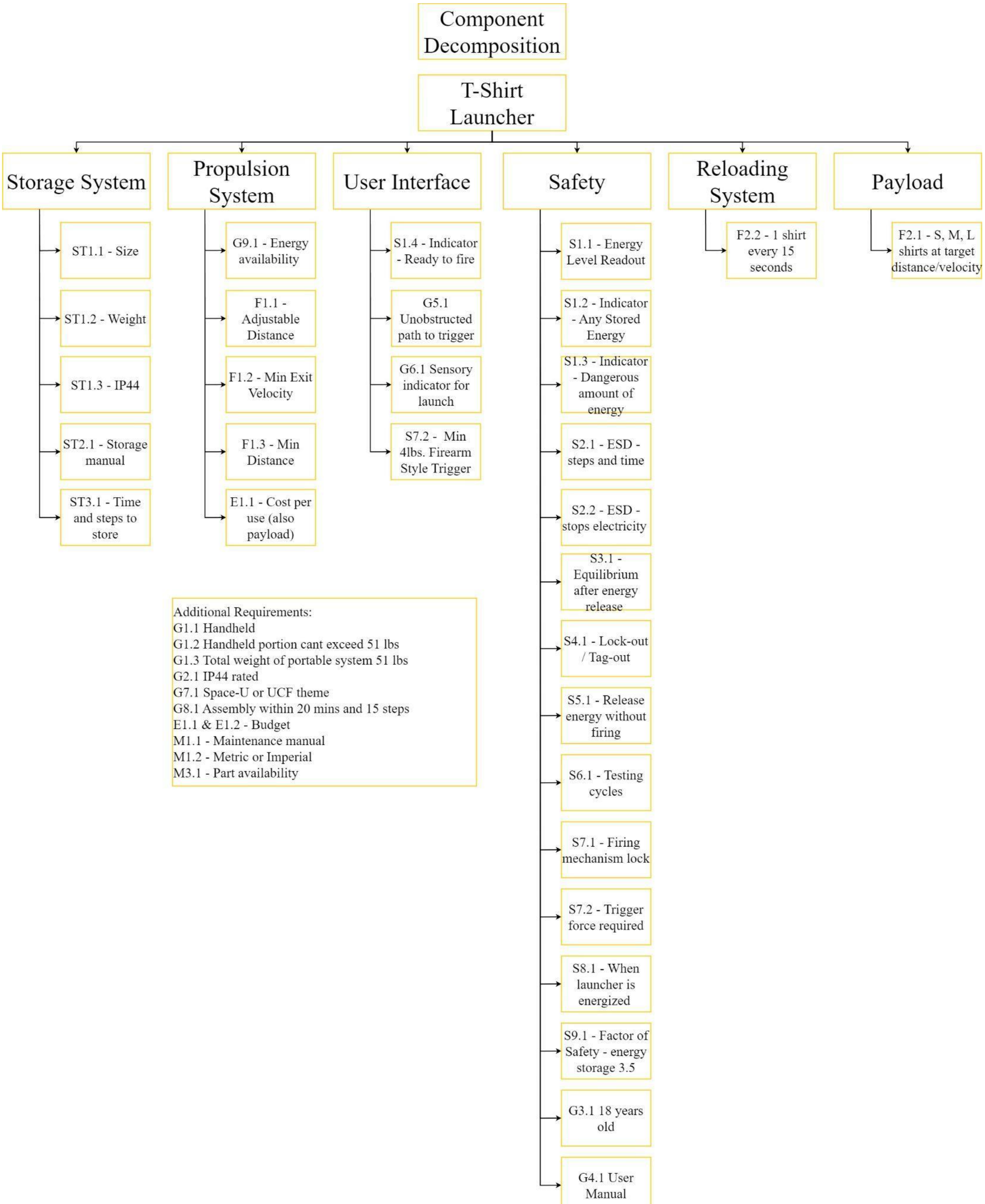
$$1\ lb = 0.4536\ kg$$

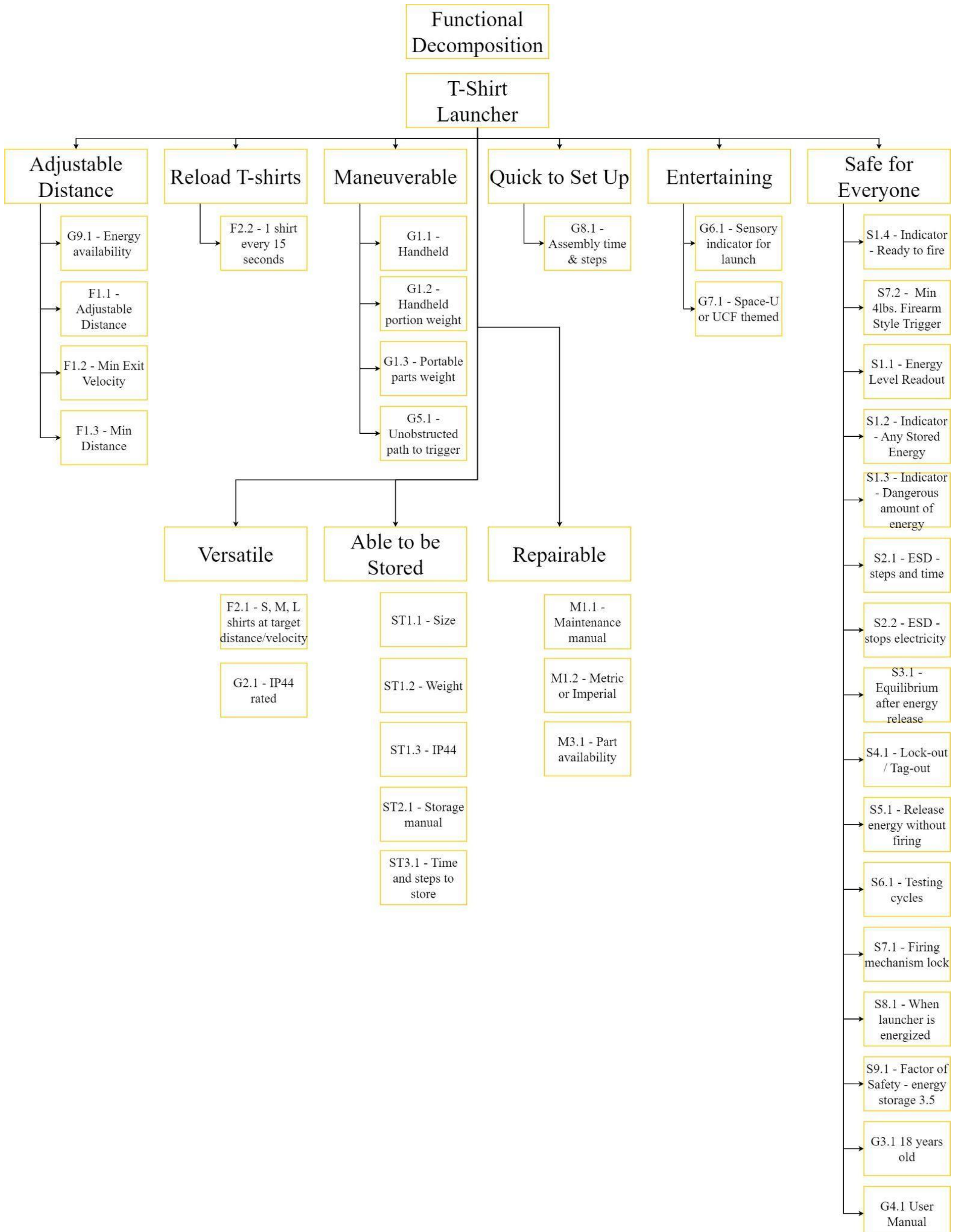
$$gravitational\ acceleration = g = 32.2\frac{ft}{s^2} = 9.81\frac{m}{s^2}$$

$$1\ gallon = 231\ in^3 = 0.00378541\ m^3$$

$$1\ \frac{ft}{s} = 0.3048\ \frac{m}{s}$$

C: Component and Functional Decompositions





Functional Decomposition
T-Shirt Launcher
Adjustable Distance
Reload T-shirts
Maneuverable
Quick to Set Up
Entertaining
Safe for Everyone
G9.1 - Energy availability
F1.1 - Adjustable Distance
F1.2 - Min Exit Velocity
F1.3 - Min Distance
F2.2 - 1 shirt every 15 seconds
G1.1 - Handheld
G1.2 - Handheld portion weight
G1.3 - Portable parts weight
G5.1 - Unobstructed path to trigger
G8.1 - Assembly time & steps
G6.1 - Sensory indicator for launch
G7.1 - Space-U or UCF themed
S1.4 - Indicator - Ready to fire
S7.2 - Min 4lbs. Firearm Style Trigger
S1.1 - Energy Level Readout
S1.2 - Indicator - Any Stored Energy
S1.3 - Indicator - Dangerous amount of energy
S2.1 - ESD - steps and time
S2.2 - ESD - stops electricity
S3.1 - Equilibrium after energy release
S4.1 - Lock-out / Tag-out
S5.1 - Release energy without firing
S6.1 - Testing cycles
S7.1 - Firing mechanism lock
S8.1 - When launcher is energized
S9.1 - Factor of Safety - energy storage 3.5
G3.1 18 years old
G4.1 User Manual
Versatile
Able to be Stored
Repairable
F2.1 - S, M, L shirts at target distance/velocity
G2.1 - IP44 rated
ST1.1 - Size
ST1.2 - Weight
ST1.3 - IP44
ST2.1 - Storage manual
ST3.1 - Time and steps to store
M1.1 - Maintenance manual
M1.2 - Metric or Imperial
M3.1 - Part availability

D: Relationship Matrix of User Needs and Engineering Requirements

			Column #	1	2	3	4	5	6	7	8	9
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)
1	10	0.17	Launches T-shirts into upper sections	9	9	3					-3	
2	10	0.17	Adjustable launching distance	3	3	9	1					
3	10	0.17	Safe for user and fans	-9	-9	3	9	9	9	9	9	3
4	10	0.17	Portable									9
5	8	0.13	Quickly launch multiple shirts			1				1		1
6	5	0.08	Cost per use	1	1	1						
7	5	0.08	Space-U or UCF themed									
8	1	0.02	T-shirt capacity									
9	1	0.02	Weather resistant				-1					

			Column #	10	11	12	13	14	15	16	17
Row #	Customer Importance (1-10)	Relative Weight	Customer Requirement / Engineering Design Specification	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	1			1	1		1	
2	10	0.17	Adjustable launching distance							1	
3	10	0.17	Safe for user and fans	3		3				1	
4	10	0.17	Portable	9	9						
5	8	0.13	Quickly launch multiple shirts	1		9					
6	5	0.08	Cost per use				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								9

E: Technical System Specifications

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 risk, some	6 - 10	5 - 6	21 - 30	376 - 500

	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

Firing Mechanism Ratings

Rating	Safety (Pounds Force to Activate)	Safety Lock (No. of Steps)	Space (Inches)
1	< 4	5 - 6	< 3
2	Adjustable	3 - 4	3
3	≧ 4	1 - 2	> 3
4	Adjustable and ≧ 4	N/A	N/A

Delivery Method Ratings

Rating	Safety (Speed)	Cost ($ / Shirt)	Aerodynamics
1	Little to No Slowing of Shirt	$1 +	None
2	Slightly Slows Shirt	$0.50 - $1	Parachute
3	Moderately Slows Shirt	$0 - $0.50	Tape, Rubber Bands
4	Significantly Slows Shirt	Free with Household Items	Plastic Wrap, Hard Cylinder

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 Risk	2	Exciting and attracts attention	11 - 20
4	No Safety Risk	1	Very exciting and attracts attention	< 10

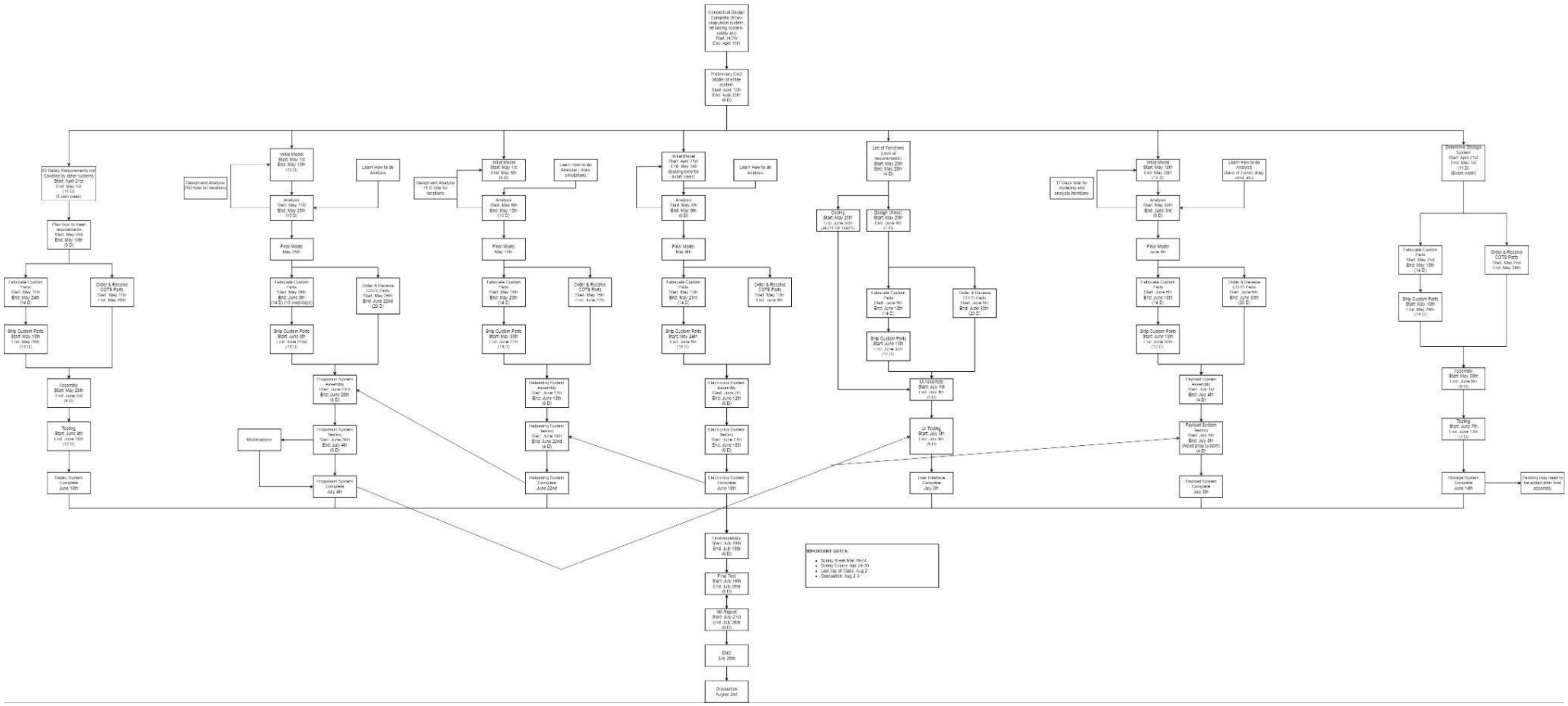
Storage System Ratings

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

G: Preliminary Project Flowchart

The preliminary project flowchart was created prior to the Gantt Chart. This allowed the team to see the order of events that needs to take place to successfully complete the project.



H: Test Plans

Validations Not Requiring Firing the Launcher

Number	Verification	Verification Category	Estimated Time (mins)
S8.1	Analysis of steps to ready the launcher.	Analysis	5
S9.1	Stress analysis.	Analysis	30
ST3.1	Analysis of steps to disassemble launcher for storage.	Analysis	5
G9.1	Documentation of location of energy source.	COC	5
G1.2	Using scale to weigh portable components.	Measurement	5
G1.3	Using scale weighs handheld components.	Measurement	5
G5.1	A ruler or tape measure will be used to measure the free space in front of the activation mechanism.	Measurement	5
ST1.1	Using tape measure to measure storage container dimensions.	Measurement	5
ST1.2	Use of a scale to weigh containers.	Measurement	5
G7.1	Poll with 70% of participants agreeing.	Poll	30
G8.1	Counting the number of steps and time to assemble.	Test	20
S2.1	Simulate emergency shutdown procedure, measuring time and steps.	Test	5
S2.2	Verify electronics are not powered.	Test	5

G2.1	Testing or documentation from the manufacturer.	Test or COC	15
ST1.3	Testing or COC.	Test or COC	15
M2.1	All hardware will be verified to abide by one system of units.	Tracked	10
M3.1	The purchase location and delivery of all COTS materials will be tracked.	Tracked	10
E1.1	Receipts	Tracked	5
E2.1	Purchased parts will be tracked as parts are ordered.	Tracked	10
G3.1	Inspection of training manuals.	Visual	5
G4.1	Inspection of user training manual.	Visual	5
S1.1	Inspection of launcher to verify energy readout.	Visual	5
S1.2	Inspection of launcher to verify energy readout.	Visual	5
S1.3	Inspection of launcher to verify energy readout.	Visual	5
S3.1	Visual inspection of energy readouts.	Visual	5
S4.1	Visual inspection of LOTO.	Visual	5
S5.1	Visual inspection of energy readouts.	Visual	5
ST2.1	Inspection to verify a storage and transportation manual is included.	Visual	5

M1.1	Inspection to verify a maintenance manual is included.	Visual	5

I: FMEA Rating Scale

FMEA Likelihood Rankings

Rating	NASA Short Description	NASA Criteria	Our Criteria
1	Remote	Failure rate of less than 0.2 FIT/Probability of Failure During Mission <0.00001	1 in 100M
2	Extremely Low	Failure rate of less than 1 FIT/Probability of Failure During Mission <0.00005	1 in 10M
3	Very Low	Failure rate of less than 2 FIT/Probability of Failure During Mission <0.0001	1 in 1M
4	Low	Failure rate of less than 10 FIT/Probability of Failure During Mission <0.0005	1 in 100k
5	Moderately Low	Failure rate of less than 20 FIT/Probability of Failure During Mission <0.001	1 in 50k
6	Moderate	Failure rate of less than 100 FIT/Probability of Failure During Mission <0.005	1 in 10k
7	Moderately High	Failure rate of less than 200 FIT/Probability of Failure During Mission <0.01	1 in 1k
8	High	Failure rate of less than 1 FPMH/Probability of Failure During Mission <0.05	1 in 500
9	Very High	Failure rate of less than 2 FPMH/Probability of Failure During Mission <0.1	1 in 100
10	Extremely High	Failure rate of less than 5 FPMH/Probability of Failure During Mission <0.2	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	Under $200.	Severe injury. Hospitalization, amputation,

	Injury		etc. Could be life threatening.
10	Extremely High Monetary Loss OR Death	Over $200.	Death

FMEA Detection Rankings

Rating	NASA Short Description	NASA Criteria	Our 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).	Users will detect and/or anticipate the failure or subsequent effect > 99% of the time.
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).	Users will detect and/or anticipate the failure or subsequent effect > 90% of the time.
3	High	There is a High probability the Design will detect the Failure Mode or its subsequent Failure Effect (80 > 90% probability for detection).	Users will detect and/or anticipate the failure or subsequent effect > 80% of the time.
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).	Users will detect and/or anticipate the failure or subsequent effect > 60% of the time.
5	Moderate	There is a Moderate probability the Design will detect the Failure Mode or its subsequent Failure Effect (40 > 60% probability for detection).	Users will detect and/or anticipate the failure or subsequent effect > 40% of the time.

6	Low	There is a Low probability the Design will detect the Failure Mode or its subsequent Failure Effect (30 > 40% probability for detection).	Users will detect and/or anticipate the failure or subsequent effect > 30% of the time.
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).	Users will detect and/or anticipate the failure or subsequent effect > 20% of the time.
8	Remote	There is a remote probability the Design will detect the Failure Mode or its subsequent Failure Effect (10 > 20% probability for Detection).	Users will detect and/or anticipate the failure or subsequent effect > 10% of the time.
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).	Users will detect and/or anticipate the failure or subsequent effect < 10% of the time.
10	None	There is no Detection of the Failure Mode or its subsequent Failure Effect.	Users will be unable to detect the failure or effect.

J: Complete FMEA

Component	Primary Failure	Secondary Failure	Effect	Likeliness (1-10)	Criticality (1-10)	Hazard Score (L x C)	Detection (1-10)	RPN (HS x D)	Mitigation
Air Adapters	Environmental	Moisture in air	Moisture in tanks, corrosion	4	2	8	7	56	Keep a small amount of air in tank
Air Adapters	Fatigue	Fittings Crack	Part damage, potential minor injury	2	7	14	2	28	Use brass or SS fittings, limit pressure in tanks
Air Adapters	Poor Connection	Fittings Leak	Cannot fill tank completely, longer fill time, pressure loss	9	1	9	2	18	Use loctite or thread tape

Air Adapters	Chemical	Contacts corrosive material	Part damage	1	2	2	7	14	Avoid contact with dissimilar metals
Air Adapters	Overload	Fittings Burst	Part damage, damage to tanks, potential moderate injury	2	7	14	1	14	Use brass or SS fittings, limit pressure in tanks
Air Intake Valve	Connection/Fitting	Leaks	Pressure loss over time, lowers power	9	1	9	2	18	Ensure fitting and connectors are tight and secure
Air Intake Valve	Environmental	Clogs, cracks,	Device takes longer to fill up, valve my break, cause fittings or intake to lose air flow	4	2	8	2	16	Clearing out and checking valves during maintenance

Air Intake Valve	Thermal Change	Rapid cooling/heating, fatigue	Dmg over time	3	2	6	2	12	Inspect valves
Delivery System	Human Error	Barrel gets jammed	Damage to device	1	7	7	2	14	Barrel material, FOS, geometry
Delivery System	Rapid Unscheduled Disassembly	T-Shirt opens during flight	Shirt does not go as far	8	1	8	1	8	Wrap shirt according to manual
Electronics	Short	Sparks, fire	Launcher, shirts, or grass catch on fire	6	5	30	2	60	Use heat shrink tubing on wires
Electronics	Environmental	Water intrusion	Shorts out electronics	5	3	15	2	30	Add waterproofing to electronics, sealant, gaskets, etc

Electronics	Power Loss	Dead / Non-functioning battery	Electronics will not function	9	2	18	1	18	Use a larger battery, use fewer electronics components
Electronics	Thermal Runaway	Ablazing fire	Launcher rapidly engulfed in flames, would likely spread to other areas	1	10	10	1	10	Random, no mitigation other than using the smallest amount of electrical power possible
Exhaust Valve	Environmental	Clogs, cracks,	Device takes longer to fill up, cause fittings or exhaust to lose air flow	4	2	8	2	16	Clearing out and checking valves during maintenance

Exhaust Valve	Thermal Change	Rapid cooling/heating, fatigue	Dmg over time	3	2	6	2	12	Inspect valves
Exhaust Valve	Connection/Fitting	Leaks	Pressure release is not contained	9	1	9	1	9	Ensure fitting and connectors are tight and secure
Pressure Gauges	Clogging	Inaccurate readings	Inaccurate readings/Warning System Failure	4	2	8	8	64	Regular cleaning/maintenance
Pressure Gauges	Abuse/Mishandling	Broken components	Broken Gauges/Bent Connection/Loss of functionality or accuracy	5	4	20	2	40	Training operator/establish procedures

Pressure Gauges	Corrosion	Cracks/Leaks	Deterioration of gauge/Loss of accurate values/ Warning system failure	3	3	9	4	36	Protective coating/material selection/environmental control
Pressure Gauges	Overpressurization	Inaccurate readings	Gauge internals broken/Electronic failure	1	4	4	8	32	Pressure release valve/regulator
Pressure Gauges	Pressure Leak	Inaccurate readings	Gauge Inaccuracy/Loss of Pressure	6	2	12	2	24	Don't cross thread sensor, use teflon tape or sealant on threads, torque to spec
Pressure Gauges	Pressure Spikes	Wear on components	Wear on Gauge Internals/	2	3	6	4	24	Pressure release valve/regulator

			Inability to read values						
Pressure Gauges	Overvoltage	Electronic Failure	Electronics Failure/Digital Gauge inaccuracy/failure/fire	1	5	5	2	10	voltage regulator/grounding
Pressure Gauges	Mechanical Vibration	Internal Failures	Gauge Inaccuracy/Internal Gauge Failures	1	2	2	4	8	Mineral oil in gauge to dampen readings
Pressure Gauges	Pulsation	Failure of components	Gauge Inaccuracy/Internal Gauge Failures	1	2	2	4	8	Mineral oil in gauge to dampen readings

Pressure Gauges	Extreme Temperature	Failure of components	Gauge Casing Failure/Electronics Failure/Fire	1	5	5	1	5	Keep device in cool storage, do not operate in extremely hot environment
Pressure Lines / Hoses	Human error installation	system leaks	inefficient use of compressed fluid	5	5	25	5	125	maintenance, check systems twice
Pressure Lines / Hoses	Fatigue	pressure loss / explosion	high safety concern, explosion or rapid pressure loss	3	9	27	2	54	regular maintenance
Pressure Lines / Hoses	Environmental	hose degradation	instrument failure / rapid pressure loss	3	9	27	2	54	material selection, regular maintenance

Pressure Lines / Hoses	lack of maintenance	corrosion/ hose failure	system leaks, inefficient, leads to rupture	2	5	10	2	20	material selection, regular maintenance
Pressure Lines / Hoses	hose rupture	pressure loss	uncontrolled rapid loss of pressure	1	8	8	1	8	stronger hoses, tape to seal a leak quickly
Pressure Regulators	Creep	Regulator deforms slowly	Failure below yield stress/Regulator failure/Personal Injury	3	6	18	7	126	Selection of high quality regulator/proper sizing/material selection
Pressure Regulators	Overpressurization	Regulator failure or damage	Releases High Pressure/Damage to equipment/Personal Injury	4	6	24	3	72	pressure relief valve/monitoring system

Pressure Regulators	Contamination	Regulator Seal Failure	Blockage/Regulator seized closed or open	4	2	8	6	48	Regular cleaning/maintenance
Pressure Regulators	Design/Fabrication Defects	Leaks/ Loss of pressure	Loss of pressure/Microfractures/Leaks	2	3	6	6	36	Select high quality regulator/Do research on supplier
Pressure Regulators	Corrosion	Cracks/Leaks	Loss of pressure/Cracks /Inability to control air pressure	4	4	16	2	32	Protective coating/material selection/environmental control
Pressure Regulators	Embrittlement	Cracks/Regulator failure	Regulator failure/Microfractures/Pressure loss	1	4	4	6	24	Material selection/Corrosion prevention

Pressure Regulators	Blockage/Clogging	Regulator failure/damage	Regulator failure/Regulator seized open or closed	4	2	8	2	16	Regular cleaning/maintenance
Pressure Regulators	Pressure Leak	Regulator Inaccuracy	Loss of pressure/Inability to control pressure	4	2	8	2	16	Dont crossthread regulator, use teflon tape or sealant on threads, torque to spec
Pressure Relief Valve	Prolonged Overpressurization	Deformed internal components	Deformed relief valve/Relief valve failure/Inaccurate Relief Valve	4	5	20	5	100	Proper relief valve sizing/Set pressure verificaition
Pressure Relief Valve	Spring Failure	Metal Deformation/	Valve seized open or closed/	3	4	12	3	36	High quality spring/spring testing

		Failure/Inaccuracy	Relief Valve Inaccuracy/ Leaks						
Pressure Relief Valve	Contamination	Relief Valve Seal Failure	Seal Failure/Inaccurate pressure release/Seized Relief Valve	4	2	8	3	24	Regular cleaning/maintenance
Pressure Relief Valve	Blockage/Clogging	Relief Valve Seal Failure	Seal Failure/Inaccurate pressure release/Seized Relief Valve	4	2	8	3	24	Regular cleaning/maintenance
Pressure Relief Valve	Corrosion	Cracks/Leaks /Failure	Loss of pressure/Risk of overpressurizati	2	3	6	3	18	Protective coating/material

			on/Pressure Vessel failure						selection/environmental control
Pressure Relief Valve	Pressure Leak	Relief Valve Inaccuracy	Inaccurate relief valve	3	2	6	2	12	Don't cross thread valve, use teflon tape or sealant on threads, torque to spec
Pressure Vessels	Over pressurization	Explosion	Loss of pressure/Injury	3	10	30	6	180	Implement a pressure release valve
Pressure Vessels	Creep	Tanks cracks	Failure of device	3	8	24	7	168	Keep up with maintenance
Pressure Vessels	Fatigue	Tank cracks	Failure of device	3	8	24	7	168	Keep up with maintenance

Pressure Vessels	Manufacturing Defects	Weak Points	Loss of pressure/Failure of device	2	8	16	8	128	Inspect device upon delivery
Pressure Vessels	Heat	Slight inefficiency	Slight loss of power	8	1	8	2	16	Don't use excessively in heat, include a heat sheath?
Pressure Vessels	Environmental / Corrosion	Tanks cracks, rust	Failure of device/Injury	1	5	5	1	5	Keep up with maintenance
Reloading System	T-shirt misalignment	Barrel gets jammed	Damage to device	1	3	3	2	6	Inspect T-shirts in the holder after each launch to ensure they are aligned properly

Reloading System	Fatigue/ Fracture	T-shirt holder cracks	Damage to device	1	2	2	2	4	Inspect entire device carefully before taking it out of storage
Storage	Fatigue/ Fracture	Casing cracks	Damage to container	7	2	14	1	14	Use with care, perform routine maintenance
Storage	Environment / Corrosion	Casing cracks	Damage to container/device	7	2	14	1	14	Keep up with maintenance
Storage	Human error	Device damaged in transit	Damage to device	4	3	12	1	12	Design a perfect fit for device into case/allow no room to misplace

Trigger Mechanism	Human Error	Misfire	safety hazard to unready spectators	4	8	32	1	32	additional safety parameters
Trigger Mechanism	mechanical trigger lock failure	Safety switch malfunction	mechanical failure, safety switch may fail	2	6	12	2	24	secondary safety switch
Trigger Mechanism	Environmental	corrosion	slowly degrades metals	3	2	6	3	18	material selection, painting or coating the material
Trigger Mechanism	Fatigue/ Fracture	Trigger failure	trigger fractures, or does not function as designed	3	3	9	2	18	Include a secondary backup system, use different materials

Trigger Mechanism	trigger misalignment	Trigger failure	trigger fails to work as designed	3	3	9	2	18	include a backup system
UI	Mechanical Vibration	inaccurate pressure gague readings, incremental damage	Inaccurate reading, micro dmg over time to the equipment	1	2	2	6	12	Inspect UI displays
UI	Power overload	Electrical failure	Dmg to electronics, dead displays, loss of all electronic UI	2	3	6	2	12	Check wiring

UI	Power loss	Digital display non functional	No digital display of the system diagnostic	9	1	9	1	9	Check batteries
UI	Connection/Fitting	analogue/digital display non functional	No analogue display of the system diagnostic	3	2	6	1	6	Ensure fitting and connectors are tight and secure