Milestone V: Critical Design Evaluation

UCF Athletics T-Shirt Launcher

Black Team

Sahil Gandhi

Tyler Gay

Austin Harkins

David Herbert

Julian Tabascio

Tiffany Truong

Advisor: Richard DeBerardinis

June 21st, 2024

UCF | Mechanical and Aerospace Engineering

UNIVERSITY OF CENTRAL FLORIDA

Table of Contents

List of Figures

Continued on Next Page

Continued on Next Page

List of Tables

Terms and Abbreviations

Abbreviation	Meaning	Page
BSP	British Standard Pipe	41
CF	Cubic Foot	43
COTS	Commercial Off The Shelf	43
CFD	Computational Fluid Dynamics	58
DOT	Department of Transportation	12
FEA	Finite Element Analysis	25
LOTO	Lock-Out / Tag-Out	64
mAh	Milliampere Hour	29
NPT	National Pipe Thread	11
PETG	Polyethylene Terephthalate Glycol	28
PSI	Pounds per Square Inch	12
SRB	Solid Rocket Booster	70
TFT	Thin Film Transistor	62
UCF	The University of Central Florida	9
UV	Ultraviolet	27

1.0 Introduction

This phase of the team's engineering design development requires a comprehensive understanding of project objectives, with a detailed plan to achieve them. Each team member has clearly defined roles and responsibilities, allowing tasks to be executed in a concerted and deliberate manner. As the project advances, there is the potential for unforeseen challenges and the team is committed to continuous risk assessment and mitigation. The approach taken includes using Failure Modes and Effects Analysis (FMEA), developing mathematical models, and conducting calculations to predict system performance. As the multiple subsystem prototypes come together, various tests will be performed on the system, sub-systems, and components to validate the expected performance of critical design parameters. Throughout this process, the team will monitor the project schedule and make necessary adjustments to ensure all major milestones are accomplished on time. Key questions concerning risk assessment, modeling and analysis, prototyping and testing, and development planning will guide the team's efforts to ensure a successful project outcome.

1.1 Gemini 28-80

The name of the launcher device was inspired by two key elements: Gemini Blvd., the road encircling UCF, and the coordinates 28, 80, which correspond to the Kennedy Space Center. The latitude of the UCF main campus is also 28, another link between UCF and the space industry. The T-shirt launcher's branding is designed to clearly indicate its association with UCF and its Space-U theme. Although these branding elements are not essential for the launcher's functionality, they are crucial to meet the preferences of the primary stakeholder, UCF Athletics.

2.0 Risk Assessment

When the previous Failure Modes and Effects Analysis was completed, the design was still in the conceptual stage, meaning that not all failure modes could be identified and mitigated. As the final design of the T-shirt launcher was completed, additional failure modes were identified and appropriately mitigated to ensure the final design is safe for the operator, fans, and owner of the launcher. The potential failure modes of the launcher can be categorized into two categories: component failures and functional failures. While some failures could fall into either category, component failures will be defined as physical components failing while functional failures relate to the performance of the launcher or human error. These failures are derived from the component and functional decompositions, available in Appendix A and B, respectively. The criteria used to assign likeliness, criticality, and detection scores for each failure mode are available in Appendix C. The criteria for detection are derived from NASA's official FMEA standards.

Not all failures are significant enough to warrant comprehensive investigation into the root cause of the failure and potential mitigations. For example, the tape unwrapping off the T-shirt during flight only reduces the total launch distance, but has no impact on safety and is a one time issue when it happens. Therefore, any failures that involve injury to humans will be investigated, meaning they have a criticality score of 5 or higher. Then, the risks with the highest RPN score were selected until the total number of risks mitigated reached 30.

2.1 Component Failures

Component failures make up the majority of the potential failures that are significant enough to warrant investigation and mitigation to improve the safety of the launcher. Since the entire system is based on compressed air, component failures have the potential to be very serious and cause injury. Over pressurization, the most significant failure mode, will be looked at on its own to prevent this failure mode from occuring in the entire system. After this, each component will be analyzed with its failure modes.

2.1.1 Overpressurization of System

The single largest failure point of the T-shirt launcher is the overpressurization of any pressure-bearing components. While each component can be individually overpressurized, in order to effectively mitigate this risk, the system must be looked at as a whole. The components that can be impacted by overpressurization include the scuba tank, scuba to NPT adapter, pressure regulator, pneumatic hose, accumulator tank, pressure gauge, and barrel. The flow of compressed air is shown in Figure 2.1.1. Avoiding over-pressurization of all components starts with properly mitigating the risk of over-pressurizing the scuba tank, but additional measures can be taken for each component.

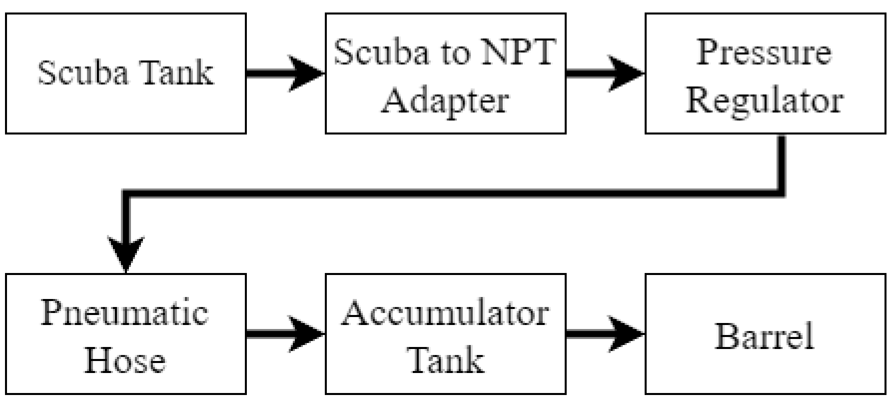


Figure 2.1.1: Flow of Compressed Air

2.1.1.1 Over Pressurization of Scuba Tank

Without mitigations, the chances of overpressurizing any part of the system are relatively high. The likeliness of over-pressurizing the scuba tank is ranked with a score of 9, indicating a very high probability of over-pressurizing the tank. This is due to the fact that scuba tanks take a very long time to fill, increasing the chance that someone may allow one to overfill. Furthermore, individuals may be tempted to slightly overfill the tank past its rated operating pressure because the pressure will decrease slightly as it cools down after it is filled. The scuba tank receives a criticality score of 10 when it comes to over-pressurization. The scuba tank is rated for 3,000 PSI and has a burst pressure of 7,500 PSI which is required by related DOT Standards [16]. While DOT standards do mandate that in the event of a burst, the vessel stays in one piece, it is likely that shrapnel will be sent through the air or the tank itself could become airborne at a high rate of speed. In any case, a vessel bursting at these pressures would almost certainly injure someone, if not cause death. While this failure mode does receive a favorable detection score of 1, this is only due to the fact that it would be impossible to miss an exploding scuba tank at over 7,500 PSI.

To effectively mitigate this risk, several approaches have been taken. First, all scuba tanks come factory installed with burst disks, which rupture at 5/3 of the operating pressure, so in this case 5,000 PSI [13]. This is also the pressure that the scuba tank is hydro-tested every five years, per DOT regulations [16]. Due to this, the likelihood of the scuba tank being over-pressurized to the point of failure is significantly reduced. Additional measures that the team is taking to further mitigate the risk of over-pressurizing the scuba tank include recommending the tank is only filled to 2,140 PSI to achieve a 3.5 factor of safety and filling the scuba tank in a container of water, such as a trash can, in case of a rupture. Further discussion of the recommended filling pressure is available in Section 3.1.1.2. The final mitigation to this risk is including a pressure gauge on the scuba tank to show the user what the current pressure is, increasing the user’s ability to detect unsafe pressure.

2.1.1.2 Over-Pressurization of Scuba to NPT Adapter

Moving past the scuba tank to the scuba to NPT adapter, this component has the same likeliness of overpressurization as the scuba tank, receiving a likeness score of 9. This is because this adapter is designed to work with a scuba tank at 3,000 PSI. Therefore, if the scuba tank is over-pressurized, this adapter will also be over-pressurized, so the chance of overpressurization is the same. Where this adapter differs from the scuba tank is in its criticality and detection scores. If this component is over-pressurized, the pressure gauge or fittings on it would burst and let air out. The adapter would likely not completely explode in the fashion that the scuba tank would. Due to this, over-pressurization of this adapter receives a criticality score of 5, meaning that there is a monetary loss of under $100 and someone could sustain minor injuries. Finally, over-pressurization of this adapter receives a detection score of 5, meaning there is about a 50% chance the failure will be detected. It is possible that by over-pressurizing the adapter, an item such as a pressure gauge could lose its calibration or there could be a small air leak that would not be noticed. On the other hand, if the adapter completely fails, it could rapidly disassemble. Due to this the detection score represents the midpoint of these two categories of failures.

To prevent this component from becoming over-pressurized, the most effective solution is to prevent the scuba tank from becoming over-pressurized. Using the mitigations discussed in the previous section, it is highly unlikely that the scuba to NPT adapter will over-pressurize, and a failure is very unlikely to occur.

2.1.1.3 Over-Pressurization of Pressure Regulator

After the air flows through the scuba yoke to the NPT adapter, it will flow into a second pressure regulator to further reduce the pressure. Again, the likeliness of this component being over-pressurized is 9, as it depends on the pressure of the scuba tank. The pressure regulator also receives the same criticality and detection scores as the scuba-to-NPT adapter for similar reasons. For criticality, the regulator could burst, or it could cause an increase in downstream pressure if the regulator was internally damaged. Detection is also a 5 due to the fact that it depends on exactly how the regulator fails. The failure could be very obvious, such as the knob blowing off, or there could be internal damage that allows an increase in the downstream pressure that is hard to detect.

To mitigate this risk, a pressure regulator was purchased with a rated operating pressure of 200 PSI, as shown in Figure 2.1.1.3. The scuba to NPT adapter has a rated constant output pressure of 150 PSI, giving a 33% factor of safety to the pressure regulator. It is likely that the scuba to NPT adapter would fail before the pressure regulator would ever reach its operating pressure of 200 PSI.

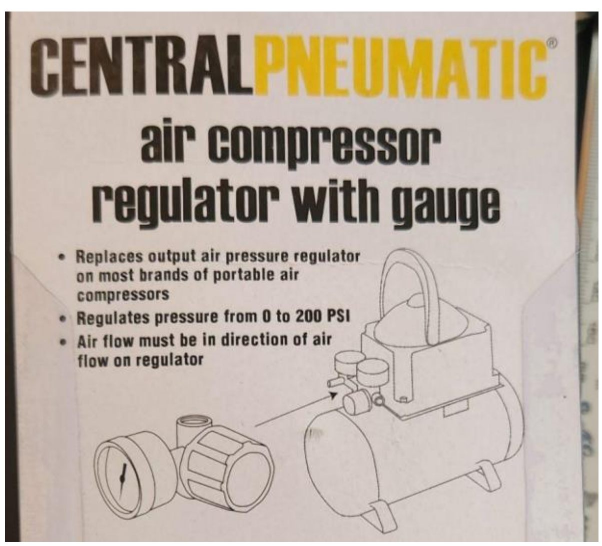


Figure 2.1.1.3: PSI Rating of Pressure Regulator

2.1.1.4 Over-Pressurization of Pneumatic Hose

The pneumatic hose will be used to connect the pressure regulator to the accumulator tank. Like the other components to this point, the over-pressurization of the pneumatic hose depends on the over-pressurization of the scuba tank, giving it a likeness score of 9. However, this component is much less critical, receiving a criticality score of 2, for low monetary loss. Over-pressurization of the pneumatic hose would result in the burst or rupture of the hose, which is easy to identify, giving it a detectability score of 1.

To prevent this failure, multiple upstream components are used to reduce the pressure down to an acceptable pressure for the hose. Most pneumatic hoses are rated in excess of 200 PSI operating pressure. To achieve this, the scuba to NPT adapter reduces the pressure to 150 PSI, and the regulator will further reduce this to below 120 PSI, which is well within the operating pressure of the pneumatic hose. Additionally, taking proper mitigation to avoid over-pressurizing the scuba tank will ensure the safety of all downstream components.

2.1.1.5 Over-Pressurization of Accumulator Tank

Assuming that no mitigations have taken place and the accumulator was directly connected to the scuba tank, the accumulator has the highest likelihood of over-pressurization, receiving a score of 10. The reason for the higher likelihood score is that the user has to fill the accumulator tank with a lever. If they leave the lever open even a few seconds too long, they could risk filling the accumulator tank past its maximum rated operating pressure of 120 PSI. Similarly to the scuba tank, this receives a criticality score of 10 and a detectability score of 1. This is because overpressurization of the accumulator tank could cause the tank to explode, which could be a risk to human life. This failure would be very obvious, but there might not be any obvious clues that it is about to occur.

Several measures have been taken to prevent this failure. First, all of the upstream components previously mentioned will gradually reduce the pressure down to an acceptable level. By setting the pressure regulator to 120 PSI, the team can ensure that the accumulator tank will not be over-pressurized. Furthermore, many of the upstream components would fail before the accumulator tank could reach a critical pressure. Through analysis described in Section 3.1.1.1, the accumulator tank has a factor of safety of 3.96 at 120 PSI. Due to this, the team is confident that other upstream components would fail prior to the accumulator tank rupturing. The final measure to prevent over pressurization is a pressure relief valve that opens at 120 PSI. Even if the upstream components allowed over 120 PSI into the tank, the pressure relief valve would quickly open to release the energy. To improve the detectability of this failure, a pressure gauge will be used to show the user what the current pressure is, as well as a comprehensive discussion of acceptable pressures in the user manual. Finally, the Arduino will utilize a pressure transducer and display information about the pressure on a display for the user to easily read and interpret.

2.1.1.6 Over-Pressurization of Barrel

The final pressure-bearing component is the barrel of the T-shirt launcher. If this occurred, the barrel would fracture, and possibly send small projectiles through the air, achieving a criticality score of 7 for moderate injury. The likeliness of this type of failure is only a 5, due to the fact that the barrel is not sustaining constant pressure. Another way the barrel could over-pressurize is if the T-shirt is packed in the barrel too tightly. The barrel will receive short bursts of reduced pressure, as a significant amount of air will escape around the T-shirt. This failure receives a detection score of 5, as there could be small cracks or fractures that are hard to notice, or the barrel could completely fail at once.

All of the previously mentioned mitigations work to ensure the pressure leaving the accumulator into the barrel is at a safe pressure. Through analysis in Section 3.2.1.1, the factor of safety of the barrel leaves a significant margin for error. To prevent a T-shirt from being stuffed too tightly in the barrel, detailed instructions will be included on how to roll the T-shirts and a piece of test barrel will be provided with the launcher to test the fit of the T-shirts prior to using the launcher. Finally, the cosmetic barrel offers some protection against a ruptured barrel, as it will stop or slow any fragments in the case of a failure.

2.1.2 Scuba Tank Failures

Portability was one of the main factors in designing the T-shirt launcher, with the intention to ensure the device is easy to handle and was not limited by the accumulator tank's max capacity or by the conveniences of an electrical outlet for an air compressor to recharge the launcher. Using a scuba tank as a backup system, the launcher can be re-energized without the need for electricity. The main risks that could occur while using the scuba tanks include creep and fatigue failures.

2.1.2.1 Scuba Tank Creep

Creep failure is a type of failure that occurs when a pressure vessel undergoes deformation at elevated temperature and constant stress [6]. Due to this, deformation, cracks, and warping of the tank walls may occur which can cause the tank to leak or even explode in worse-case scenarios.

This type of failure is low in its likeness, receiving a score of 4 because scuba tanks have a very low rate of any type of failure and meet strict DOT requirements, as described in Section 3.1.1.2. The criticality of this failure, as with any scuba tank failure is a 10, because if there are any people nearby it would cause significant harm if the tank were to rupture. Creep is very hard to identify, as it occurs slowly over time, receiving a detection score of 2. The final failure of the tank is easy to identify, but not the creep that occurs beforehand.

To mitigate this failure, the team will communicate proper handling, fill the tank correctly to its indicated pressure limit, and inspect the tank for potential deformation. Pressure vessels are also required to be hydro-tested every 5 years and visually inspected every year by DOT regulations [16] as mentioned in Section 2.1.1.1 to ensure the tank is safe to use for its intended purpose. Scuba tanks are required to undergo a visual inspection annually, improving the detectability of creep. This visual inspection targets the inside of the tank and the threads, where cracks are most likely to occur. Finally, the storage manual will specify that it is not safe to store the scuba tank with a large amount of pressure. Instead, it should be stored with between 100 and 200 PSI [3]. This will help keep moisture out of the tank, while not being a high enough pressure to cause long-term creep in the tank.

2.1.2.2 Scuba Tank Fatigue

Fatigue is a progressive, localized, permanent structural change from repeated or fluctuating stresses that is passed the tensile strength of the material over time [19]. This would mainly be caused by the cycle of filling and releasing of air from the tank but can be accelerated by overpressurization of the scuba tank. Similarly to creep, this failure mode receives a criticality score of 10 and a likeness score of 4 for the same reasoning. However, fatigue has a less favorable detectability score of 4, because the annual inspections of the scuba tank are not able to identify fatigue as easily as creep.

Methods to prevent overpressurization are mentioned in Section 2.1.1.5. By preventing the constant over-filling and depressurizing of the tank, the walls of the tank will not be osculating which would weaken the walls, forming cracks and eventual failure of the integrity of the tank's walls. Other mitigations of this failure include inspecting the tanks before use and performing hydro tests as required by DOT every 5 years as required for all DOT rated pressure vessels [16]. If the tank has been subject to fatigue, the hydro test will push the tank past its new yield point due to the fatigue, ensuring it fails in a safe environment. Additionally, scuba tank manufacturers are required to perform significant cyclic tests as described in Section 3.1.1.2 that ensure scuba tanks are safe to be cycled within their operating and test pressures.

2.1.3 Pneumatic Fittings Failures

This section covers some potential failures involving pneumatic fittings. It will also cover safeguards that are implemented in order to reduce wear and tear and reduce risk of injury. These pneumatic fittings will be used in critical places in the launcher. The three main issues with pneumatic fittings include creep, fatigue, and leakage. The pneumatic fittings failures will not hurt the launcher by itself, but prolonging replacement can cause other issues to arise and increase the risk of injury. Failure of the pneumatic fitting will cause air to leak out which will reduce the performance of the launcher.

2.1.3.1 Pneumatic Fittings Creep

Creep is not a common failure for pneumatic fittings, but can occur if proper precautions are not taken. Creep will cause gradual deformation and leaks over time. If not treated properly, the leaks can become bigger and more detrimental to the launcher. This was given a 4 in likeliness because this is a wear-and-tear piece that gains creep over time, but the failure ultimately depends on the proper storage pressure of the launcher. This was given a 7 for criticality because air leaking out can cause issues when launching a shirt such as not meeting the correct PSI to hit the target that the user was aiming for. Additionally, if the fittings are fractured, small pieces of metal could hit someone causing injury. This was given a 5 in detection because it could be identified during an inspection as a small fracture in a fitting, but it could also easily go unnoticed and suddenly fail.

In order to mitigate this, all the fitting sizes will be stated in the maintenance manual to prevent use of the wrong size and the fittings will all be checked to be torqued to specification to reduce the chance of creep. Furthermore, all fittings used are either brass or stainless steel, which are capable of handling multiple thousand PSI of pressure [12]. The maximum pressure any pneumatic fittings will see in the launcher is 150 PSI, which is vastly less than their rated pressure. Finally, proper mitigation of overpressurization of all parts of the system and using low storage pressures as described in previous sections will help decrease the likeliness of a failure due to creep.

2.1.3.2 Pneumatic Fittings Fatigue

Due to the cyclic nature of the T-shirt launcher, the fittings could become brittle over time which will cause them to crack and break. This was given a 5 in likeliness because it is slightly more likely than a failure due to creep due to the fact that the fittings will experience more cyclic loading than sustained loading. This was given a score of 7 for criticality for the same reasons mentioned for a pneumatic fitting failing due to creep. For detection, this was given a 5 as it can be noticed but only if looking specifically for it. The fittings could show signs of failure, or suddenly fail.

The mitigations for this failure mode are very similar to the mitigations for creep of the pneumatic fittings. Using and identifying the proper size tools to install the hardware will ensure the parts are not damaged during installation and have no human-added weak points. Furthermore, brass and stainless steel fittings are capable of handling high pressures and constant fluctuations in pressures, making them an ideal material choice for the launcher.

2.1.3.3 Pneumatic Fittings Leakage

A poor connection involving the pneumatic fittings will result in air leakage. This could be caused by improper installation, incorrect thread sizes, or not applying enough torque to the fittings. This was given a 9 in likeliness as the team will assume the worst in terms of predicting operator competence. Even during initial testing, leakage through fittings occurred almost every time a fitting was removed and replaced. For criticality, the team gave this a score of 1 as pressure leaking out of fittings does not risk an injury or monetary risk, and would only affect the performance of the launcher. This scored a 3 in detection because the air leaking out can be easily identified by the sound it makes or the user feeling the air against their skin.

In order to mitigate this, all fitting sizes will be stated in the maintenance manual to ensure the correct tool is used to install each fitting. Additionally, the types of threads for each fitting will be specified to ensure that the user does not try to install hardware with the incorrect threads, which would pose a safety issue when the threads become stripped. Finally, all fittings will utilize PTFE tape to create an airtight seal around the threads, bringing a potential air leakage to an insignificant level.

2.1.4 Pressure Regulator Failures

This section will cover the potential failures involving the pressure regulator. It will also cover mitigations that will be implemented to reduce wear and tear and reduce the risk of injury. The two issues that will be covered in this section are corrosion and pressure creep. Failure of the pressure regulator comes with a high risk of losing pressure control and increasing the chance of injury. Any issues involving the pressure regulator will require removal and replacement with a new part in order to reduce injury and cost while also preventing a bigger issue from arising.

2.1.4.1 Pressure Regulator Corrosion

Over time, the pressure regulator has the potential to gather rust on its internal components. Due to the climate in Florida, it is inevitable that moisture will get into the internals of the pressure regulator. For the likeliness of this happening, it was given a 4 because while moisture will be able to get in the regulator, it will take a long time for a large enough amount of water to get into the pressure regulator and cause rust. The criticality is a 2 because it will not pose a risk of injury and the cost to replace is negligible. The detection on this issue is a 9 because it would be very hard for the user to look into the pressure regulator and find rust. Additionally, the effect of this failure could be a small increase in the downstream pressure, which could only be identified by comparing the pressure regulator setting to the pressure gauge on the tank.

To mitigate this failure, the regulator can be stored in junction with the accumulator tank, allowing for a small amount of constant pressure inside the regulator, preventing moisture accumulation. Additionally, the entire launcher will be stored in a waterproof bag, preventing water penetration from rain. Finally, the maintenance manual will include testing the regulator by comparing its set pressure to the pressure on the pressure gauge attached to the accumulator tank to ensure it is still accurately reducing the pressure.

2.1.4.2 Pressure Regulator Creep

One of the most common failures of pressure regulators is pressure creep. Different from the mechanical creep described in earlier sections, pressure creep is a gradual shift in downstream pressure from the pressure set on the regulator [7]. This can be caused by contamination within the pressure regulator, damage to the internal components, or misalignment from the factory of the poppet within the regulator. For the likelihood, this was given a 7 due to the fact that there are a variety of unrelated factors that could cause this failure. For criticality, this was given a 8 because increased downstream pressure can cause a more significant issue in the accumulator tank that could harm the user or anyone nearby. The detection for this failure ranks poorly with a score of 7, because this is not something that the average user will be looking for. It would take a trained eye or careful instruction to make the user aware of this type of failure.

In order to mitigate pressure creep, the yoke to NPT adapter has been limited to 150 PSI, which is less than the max rating of 200 PSI for the pressure regulator. Due to this, even if the pressure regulator experiences pressure creep, the downstream pressure will never exceed 150 PSI. This is a low enough pressure that the pressure relief valve on the accumulator tank will be sufficient to maintain the tank at or below 120 PSI as the higher pressure air tries to enter the tank. The final mitigation is an effort to improve detection. Similarly to the last failure, the maintenance manual will include testing the regulator and ensure its output is accurate to ensure safe operation.

2.1.5 Accumulator Tank Failures

In order for the system to launch T-shirts efficiently, the accumulator tank is filled and all of its air is released to launch a T-shirt, before being refilled by the scuba tank or compressor. The accumulator tank expected failures are creep and fatigue due to the pressurized air used for the launcher system. If the accumulator tank were to fail in either of these manners, the consequence could range from a small leak to an explosion of the tank.

2.1.5.1 Accumulator Tank Creep

Creep is a possible failure that may occur to the accumulator tank due to pressurized air being left in the tank for a prolonged period of time. Since the accumulator tank is being rapidly filled and emptied during use, the only opportunity for this to occur is during storage, leading to a low likeliness score of 4. As with creep for the scuba tank, the criticality of this failure receives a score of 10, because a pressure vessel failing at a high pressure could pose a risk to human life. Finally, the detection is the same as that of the scuba tank, a score of 2, due to the fact that creep occurs over a long period of time and is hard to identify.

Unlike scuba tanks, general pressure vessels are not mandated to undergo any sort of regular testing. Instead, FEA was performed on the accumulator tank using conservative material properties, finding a factor of safety of 3.96, exceeding the requirements of ASME Section VIII [5]. This analysis is shown in Section 3.1.1.1. Furthermore, the pressure relief valve on the tank will ensure the accumulator never exceeds its maximum rated working pressure. Finally, the storage manual will state to store the accumulator tank with 10 to 20 PSI of air, being enough to keep moisture out of the system, while being small enough to not cause long term creep.

2.1.5.2 Accumulator Tank Fatigue

As mentioned in Section 2.1.2.2, fatigue failure is due to deformation from stress over time which is caused by the cyclic pressurizing and depressurizing of a pressure vessel. As the accumulator tank will undergo more cyclic loading than sustained loading, this failure receives a slightly worse likeliness score of 3 when compared to creep. The criticality and detection scores are the same as creep of the accumulator tank for the same reasons previously mentioned, with scores of 10 and 2, respectively.

Methods to prevent over pressurization of the accumulator tank are mentioned in Section 2.1.1.5. While over pressurization is not the main cause of fatigue, it can reduce the number of cycles needed to achieve fatigue failure. Building on the FEA performed on the accumulator, a fatigue analysis was performed at 1,000,000 cycles as described in Section 3.1.1.1. With the load case of 120 PSI, there is no risk of a fatigue failure. The pressure must be increased to 400 PSI before the accumulator would suffer a fatigue failure at less than 1,000,000 cycles. With the equipment provided with the launcher, including the multiple regulators, fittings, and hoses, it would be near impossible to fill the accumulator tank to that point.

2.1.6 Barrel Failures

Barrel failures are one of the major component failures for our system. If this component were to fail during use, it could make the launcher unusable and, in a worst-case scenario, harm the user and people around the device. Potential barrel failures that are most likely to occur within our system are overpressurization, as mentioned in 2.1.1.6, barrel fatigue, and UV exposure.

2.1.6.1 Barrel Fatigue

Fatigue failure on the barrel is a risk that is unavoidable but can be mitigated. As the system gets pressurized and launches its payload, the barrel itself will undergo expansion from the pressure built up from the compressed fluid and payload within the barrel. The likeliness of this type of failure is moderate, receiving a rating of 6. The criticality of this type of failure is high with a score of 7, because if the barrel failed, small pieces could be sent through the air and cause moderate injuries. Finally, the detection of this type of failure receives a score of 7, as this type of failure on a PVC barrel will likely result in a sudden fracture or disassembly of the barrel with no warning.

To reduce the likelihood of this type of failure, the pressure in the accumulator tank is regulated to a maximum of 120 PSI, which through analysis in Section 3.2.1.1, produces a factor of safety of the barrel of over 3.0. Additionally, pressure rated PVC and PVC cement were used. To reduce the criticality of this failure, the cosmetic barrel that surrounds the actual barrel would contain the majority of any shrapnel caused by a failure of the barrel. By containing any potential projectiles, it is unlikely that anyone would become injured by this type of failure.

2.1.6.2 Barrel UV Exposure

The barrel component of the T-shirt launcher is made of PVC pipe, which is known to be lightweight, flexible and can withstand compressed fluids. A major downside of PVC is its degradation under UV rays, making the material brittle which can cause the barrel to fail when under pressure while in use. The likelihood of UV exposure of the barrel is extremely high, with a score of 10. The launcher is intended to be used at all UCF sporting events, most of which are outside. The criticality of UV exposure is the same as fatigue of the barrel, because the end failure would be very similar. Finally, UV exposure receives a favorable detection score of 2. In sunlight, the PVC will gradually yellow or brown in color, making it easy for the user to see this failure occurring over time [22].

The primary mitigation for this type of failure is use of a cosmetic barrel that is made of PETG. PETG was selected as the material for this component as it is UV resistant, so it will not be weakened by the sun over time and will help protect the components hidden by it from UV radiation. The secondary mitigation to this failure is the storage bag. By placing the launcher back in the storage bag when not in use, the UV radiation will not be able to reach the PVC components, making this type of failure highly unlikely.

2.1.4 Electronic Failures

The main electronics system of the T-shirt launcher consists of a battery, Arduino, and Arduino display, along with other small additions. To this point, all of the discussed failures are mechanical in nature, but this system poses a different set of failures that are electrical in nature.

2.1.7.1 Battery Degradation

The energy storage device for the electronics system is a 10,000 mAh portable charger most commonly used for recharging phones, but will be repurposed for the T-shirt launcher. Battery degradation in portable chargers powering an Arduino occurs due to repeated cycles, high current draws, and temperature changes, gradually reducing capacity over time. Any lithium ion battery experiences battery degradation as it is cycles, with a lifespan of about 300 - 500 cycles if it is fully charged and discharged [2], receiving a likeness score of 9. The criticality of this type of failure is also low, receiving a score of 2 for low monetary loss. The battery degradation will not directly cause a short or fire, and would only cause the electronics system to shut off unexpectedly. The detection of this type of failure is not very likely, receiving a score of 7. The launcher will generally not be used for prolonged periods of time, masking the potential effect of a reduced battery capacity.

To mitigate this, a charger with a higher capacity than needed will be used, the battery will be kept within optimal temperatures by shielding it from the sun, complete battery discharges will be avoided, and the purchased battery includes protective circuits. To reduce the potential impact of this type of failure, an analog pressure gauge is also attached to the accumulator tank. This ensures that if the battery does die prematurely, the user can still gauge the amount of energy being stored in the tank.

2.1.7.2 Battery Overheating

Battery overheating can result from high current draws, environmental heat, or internal faults, leading to reduced performance and potential damage. While in normal conditions this is unlikely to happen, since the launcher will be used outside, the chances of this increases, creating a likeness score of 6. This type of failure is much more critical, as the battery could swell, releasing harmful chemicals, or catch on fire, injuring a person or damaging other components. This results in a criticality score of 7 for a monetary loss under $125 and the potential for moderate injuries. The detection of this type of failure is favorable, with a score of 3. Batteries will usually swell or exhibit very short battery life if they are overheating, which will indicate to the user that there is a potential issue.

To mitigate this, use a charger with sufficient capacity, ensure good ventilation, avoid exposure to high temperatures, and use chargers with thermal protection features. Regularly checking for signs of overheating and replacing the battery if it frequently gets hot can also help maintain safe operation.

2.1.7.3 Arduino Microcontroller Overvoltage/Overcurrent

Overvoltage or overcurrent issues in Arduino microcontrollers can damage components and reduce lifespan. The likelihood of this type of failure is very low, with a rating of 1. This is because the battery used for the Arduino outputs 5V, which is what the Arduino is intended to run on. The criticality of this failure is a 3, for a monetary loss under $50. This failure would not affect the performance or safety of the launcher, but would require replacing components. The detection is favorable, with a score of 2, as an overvoltage to the Arduino would likely short the Arduino, burn the display, or show some other obvious sign of failure.

To mitigate these risks, the battery selected outputs 5V, matching the required power input for the Arduino. This significantly reduces the risk of an overvoltage or overcurrent to the Arduino. Additional fuses or circuit breakers can also be used to offer additional protection in the case of a failure within the battery itself that also results in an overvoltage.

2.1.7.4 Arduino Display Connectivity

Ensuring reliable connectivity between an Arduino and a display requires proper wiring, compatible libraries, and secure connections. The likeliness of this failure is moderately low, receiving a score of 5. This is due to the fact that it largely depends on the initial installation of the display, which can go through any troubleshooting prior to delivering the final launcher. The criticality of this is negligible, with a score of 1, as any effect would only be of monetary nature and very low at that. The detection is very favorable with a score of 1, as any disconnections will be visually obvious via the display turning off or flickering.

To mitigate issues, use appropriate resistors, verify correct pin connections, and ensure the display is compatible with the Arduino model. Regularly check connections for wear or looseness, and use breadboards or soldered connections for stability. Properly managing power supply and grounding can also enhance connectivity and performance. The Arduino display will be thoroughly tested prior to delivering the final system, allowing time for any connectivity issues to arise and be corrected.

2.1.7.5 Arduino Display Power Supply Issues

Power supply issues with Arduino displays can lead to flickering, dimming, or complete failure of the display. The likelihood of this type of failure receives a score of 3, as the odds of the battery having an actual defect are very low. The criticality is also low, with a score of 1. There is no safety risk to this failure, and the most expensive possible component failure is that of the battery, which is very inexpensive. The detection rates favorably at 1, because the user will be able to easily see the display flickering or shutting off.

To mitigate these problems, use a stable power source that meets the voltage and current requirements of both the Arduino and the display. Implement capacitors to smooth out voltage fluctuations and ensure proper grounding. Regularly check connections for stability and use quality power supply components to maintain consistent performance. As with other electronics failures, a backup analog pressure gauge is attached to the accumulator tank in case the electronics system fails in any way.

2.1.7.6 Arduino Wiring Issues

Wiring issues in Arduino projects can cause erratic behavior, component failure, or non-functioning circuits. Similarly to the display connectivity, this failure receives a likelihood score of 5, as it is up to the human fabrication and installation of the wiring, which can undergo troubleshooting during the build process. The criticality of this failure receives a score of 5, for the risk of a minor injury. With only 5V traveling through the system, it is highly unlikely that a person would be injured by a shock. However, if a wiring issue caused a short or overvoltage, the damage could be more severe. The detection of this is relatively high with a score of 3. It is not as obvious as the display turning on and off, but there would be many clues such as display issues, a burning smell, or features not functioning properly with the Arduino.

To mitigate these problems, ensure all connections are secure and correctly matched to the corresponding pins. Use color-coded wires to avoid confusion, and keep wiring neat and organized to prevent shorts or disconnections. Regularly inspect and test connections, and use breadboards or soldered connections for more permanent setups. Proper wire management and adherence to wiring diagrams can significantly reduce the risk of issues. The wiring will be utilized in the prototype prior to delivering the final model, ensuring it can be handled under normal use with no failures.

2.2 Functional Failures

This section stands to point out all the failures that may occur throughout the common usage of the T-shirt launcher. Instead of diving into mechanical failure, breakdown, and general wear concerns, this section will highlight some key components that need to be considered for the safety of the users and the longevity of the device. The team has identified some possible issues which will be discussed in sections: reloading system, storage system, and device assembly.

2.2.1 Reloading System Failures

The reloading system has been a concern of the team's since the beginning of the design process. The question is, how to safely allow operators to load the launcher without adding any additional features that may compromise the integrity of the barrel or other critical components in the design.

Two major reloading systems were considered. One consisted of a hole cut out in the back of the barrel that had a rotating cover over it, allowing the user to slide the T-shirt in the back of the barrel and seal the barrel using the rotating portion, shown in Figure 2.2.1.

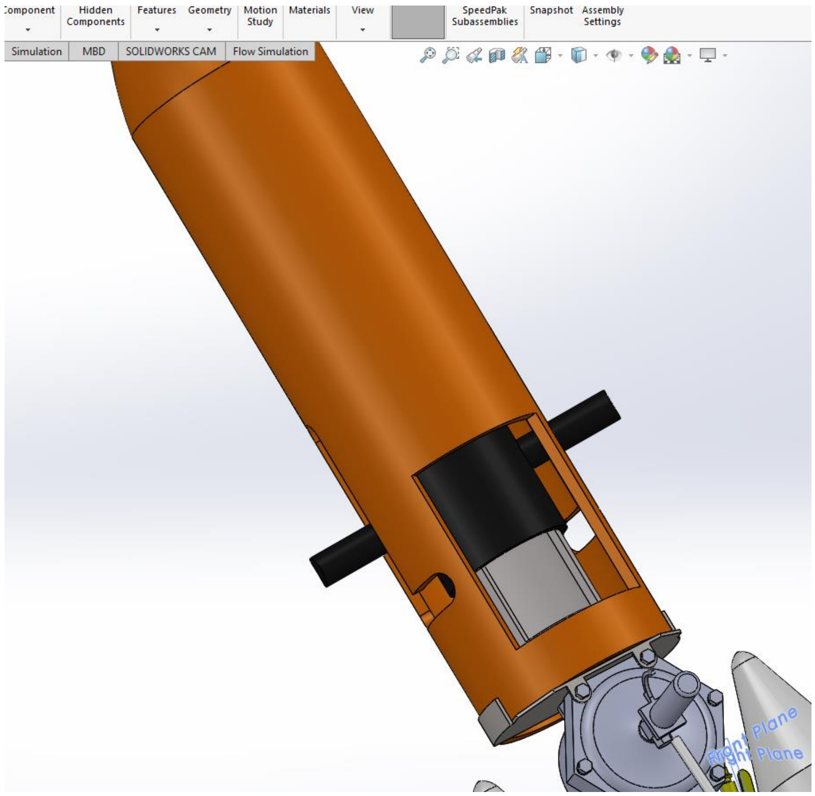


Figure 2.2.1: Alternate Reloading Design

This design was ultimately decided against because it offered little advantage over a traditional reloading system, where the user simply drops the T-shirt in the end of the barrel, and adds unnecessary complexity. The alternative design introduces weak points to the barrel and would allow for some additional amount of air escape, reducing the safety and performance of the system. It was originally thought that this design would prevent the user from having to place their fingers in front of the barrel, but ultimately when testing with a sample piece of barrel, the user would naturally slide their fingers into the barrel when loading a T-shirt, which is more dangerous than the user placing their fingers in front of the barrel with a traditional loading method.

2.2.1.1 T-Shirt Does Not Slide Down Barrel

It is difficult to test the likelihood of this occurring, as this is an error that is caused entirely due to human error. The problem lies in the preparation of the T-shirt prior to being loaded into the barrel, and the method that the operator uses to load the barrel. A generous rating of 9 has been chosen for the likelihood as the team will assume the worst in terms of predicting operator competence. The criticality is 5 as it may cause a minor injury, but nothing major or extensive. The worst case scenario is that the T-shirt becomes stuck, which is discussed in the following section. This failure is most likely to simply reduce the launch distance of the T-shirt, which while it is an important performance parameter, does not affect the safety of anyone. The detection on this issue is a 1, because it will be incredibly obvious to the operator if the shirt is not sliding into the barrel like it should.

The mitigation to this failure mode lies in the prevention of any discharging of pressure out of the barrel while the operator works on loading the T-shirt properly. The user manual will highlight the proper loading sequence which is, depressurize launcher, attach clip-on safety lock to prevent trigger discharge, load a T-shirt into the unpressurized system, and finally fill the accumulator tank, to ensure that no pressure could be directed at the operator during loading.

2.2.1.2 T-Shirt Gets Stuck In Barrel

This failure mode is very similar to the last failure mode, but the issue lies in the jamming of a T-shirt, rather than the failure to slide into the barrel. Much like the last section, this issue is caused by user error. The ratings are similar, with the likeliness dropping from a 9, to an 8. This is because jams are still likely to occur, but less likely than the T-shirt being rolled improperly and not sliding.

The reason that this failure mode is rated slightly less likely, is because the rolling of the T-shirt and loading method both have to be entirely wrong for this to occur as the operator has to continue to jam a T-shirt into the barrel that is not properly staged for loading. The criticality of this failure rises to a 6. The worst case scenario is that the T-shirt creates a perfect seal with the barrel, and it pressurizes to 120 PSI and ruptures. This is a very small possibility, but could occur. Finally, the detection is very high, with a value of 1, as the operator will be aware that a T-shirt was not launched when they pulled the trigger.

The mitigation is the same as the last section. Include a section in the user manual on how to properly roll T-shirts, load T-shirts, and safely depressurize the device and engage the safety mechanism before attempting to clear any jams or issues pertaining to the barrel and reloading system. As long as pressurization of the tank is the last step to occur in the launching process, it will ensure that our operator is entirely safe while troubleshooting. Furthermore, the user manual will advise against using something such as a rod to stuff the T-shirts down the barrel, as this could cause a jam. Additional testing will be performed on a test section of PVC. This testing is designed to test the strength of the PVC cement, but will also be testing the PVC itself. This test procedure is outlined in Section 4.2

2.2.1.3 Fingers In Front of Barrel

With a likeness of 10, guaranteeing that this happens nearly every time an operator loads the cannon, this could raise an eyebrow to some safety concerns with the device. As previously mentioned, the alternative design to combat this caused more issues than it solved, so the team transitioned back to the original approach of loading it from the tip. A criticality score of 7 is intended to represent the possibility of broken fingers if the user has their fingers in front of the barrel and accidentally discharges the device. The detection is 1, meaning that the operator will have to willingly disregard his or her own safety to allow this to happen, and even then, the chances of serious injury are still very slim.

The approach now to maintain operator safety while loading the device relies on the correct usage of the device. The user manual will highlight the order of operations which includes pressurizing the device as the last step to discharge the launcher. If the operator ignores the user manual and decides to pressurize the device anyways, that will be covered in the next section, 2.2.1.4.

2.2.1.4 Pressurizing Accumulator Prior to Loading

This functional failure occurs when the user disregards the recommended launch sequence for a T-shirt by pressurizing the accumulator tank prior to loading a T-shirt in the barrel. The likelihood of this failure is relatively high, with a score of 7. This is because the user will likely be excited to launch more T-shirts and could end up rushing the loading procedure and become careless. The detection for this failure is a 1, because the operator will have to willingly pressurize the accumulator prior to loading a T-shirt. The criticality of this failure is the same as the previous failure, with a score of 7 for the potential of broken fingers.

Given that the operator continues to disregard proper firing sequence and pressurizes the launcher prematurely, the team has introduced some extra layers of protection to ensure that the chances of an opportunity to injure someone are minimized. A safety mechanism has been set in place for the usage of our launcher, this safety mechanism clips to the trigger to prevent unintended discharge.

After firing the launcher, the operator will insert the trigger safety and begin the reloading sequence. The operator needs some level of control over the device to ensure all functionalities are accessible and user-friendly, therefore the team added these extra measures to ensure that if the operator unintentionally pressurizes the launcher before loading, then there is still another preventative measure to stop chances of unintentional discharge and further decrease risk of a minor injury.

2.2.2 Storage System Failures

This section will cover some of the possibilities of the storage container failing and the preventative measures to improve the likelihood, criticality, and detection of the failures. This is an incredibly inexpensive component to our system with little to no safety risk, resulting in overall low criticality scores.

2.2.2.1 Water Intrusion

The likelihood that the storage container is exposed to water is relatively high, receiving a score of 8. This is due to the fact that most UCF sporting events are outdoors, where it may often rain. The criticality of this failure is relatively low, as most of the launcher components are inherently water resistant, receiving a criticality score of 3. The components that are not naturally water resistant can be easily replaced at little cost. Water intrusion into the container will be obvious, as it will not dry easily and can be spotted the next time the container is opened, receiving a detection score of 2.

A waterproof storage container was purchased for the T-shirt launcher, ensuring it will stay dry when stored outdoors during sporting events. Additional testing will be performed on the storage container to test its waterproof rating, per the system requirements.

2.2.2.2 Tears in Storage Container

Tears in the storage container could be caused by anything sharp or anything hitting the container too quickly with enough force or from the long term loading of the container. The likeliness of this is relatively high, with a score of 2. Through natural use of loading and unloading the container, placing it down on concrete, or throwing it in the back of a car, it is inevitable that it will eventually tear. The criticality is higher than one might expect, with a score of 7 for monetary loss under $150. If the container completely tore, the launcher would fall onto the ground, which could damage critical components such as the accumulator or scuba tank. Finally, the detection score is favorable at 2, because tears in fabric are easy to identify.

The mitigation for this failure mode is to ensure that the operator transports the launcher carefully and safely, which will be outlined in the manual. The maintenance manual will also include inspecting the container for any damage at regular intervals, to prevent the launcher from being dropped.

2.2.3 Assembly Failures

This section covers the issues that the team or owner of the launcher may run into while assembling the device. These are purely design constraints that the team needs to consider and work around to achieve an easy assembly and ensure that the device can be put together and torn down without complications. The one identified issue in our initial design is the construction of our cosmetic fitting over the barrel.

2.2.3.1 Inaccessible Nuts and Fittings

Ranking incredibly low on the risk assessment, the issue with this failure mode is not causing incredible cost or danger to an operator, the concern lies within the ability to construct the device appropriately with ease. The team has come up with a solution to this assembly issue with the use of heat set inserts. These heat set inserts will allow the team to fit an insert into perfectly printed gaps in the cosmetic barrel and cosmetic barrel brackets, to allow for strong and guided screw threading. The main concern was the ability for a human hand to reach into the cosmetic due to the cylindrical and narrow shape. The solution that was implemented for this is an offset rotation of the cosmetic barrel pieces. This rotation allows for all points on the bracket to be accessed with a long-neck screwdriver. Anyone can identify the screw that needs to be removed, and slide the screwdriver through the openings in the brackets to allow for access to the desired screw.

3.0 Modeling and Analysis

The final model for the T-shirt launcher was modeled at the subsystem and individual part level, but as each system is closely related, these various systems were modeled simultaneously. For the purposes of design, analysis, and manufacturing, the launcher has been broken down into five main subsystems: the propulsion system, the reloading system, the electronics system, the safety system, and the Space-U system. The final CAD model with all of the included systems is shown in Figure 3.0.

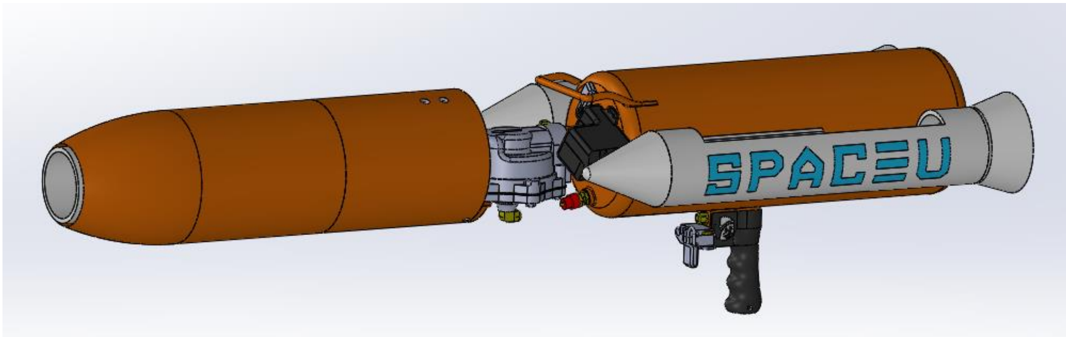


Figure 3.0: Final CAD Model

3.1 Propulsion System

The propulsion system includes the components that are needed to store and deliver the compressed air used for launching the T-shirts. These components include the accumulator tank, valve, trigger, and various pneumatic fittings. The propulsion system also includes the devices used to refill the accumulator tank, which include both a pancake compressor and a scuba tank system.

Attached to the accumulator tank are various pneumatic fittings to allow the transfer of compressed air from the storage source to the T-shirt, shown in Figure 3.1A. Of these fittings, most were included with the purchase of the accumulator tank. During initial testing, it was discovered that the threads on the accumulator tank are British Standard, or BSP. Due to this, it is required to use a BSP to NPT adapter to connect the NPT Tee fitting to the accumulator tank. Although the threads differ, the fittings still utilize the imperial system of measurement, being 1/4 inch, satisfying Requirement M2.1 which states all fittings must use one system of measurements.

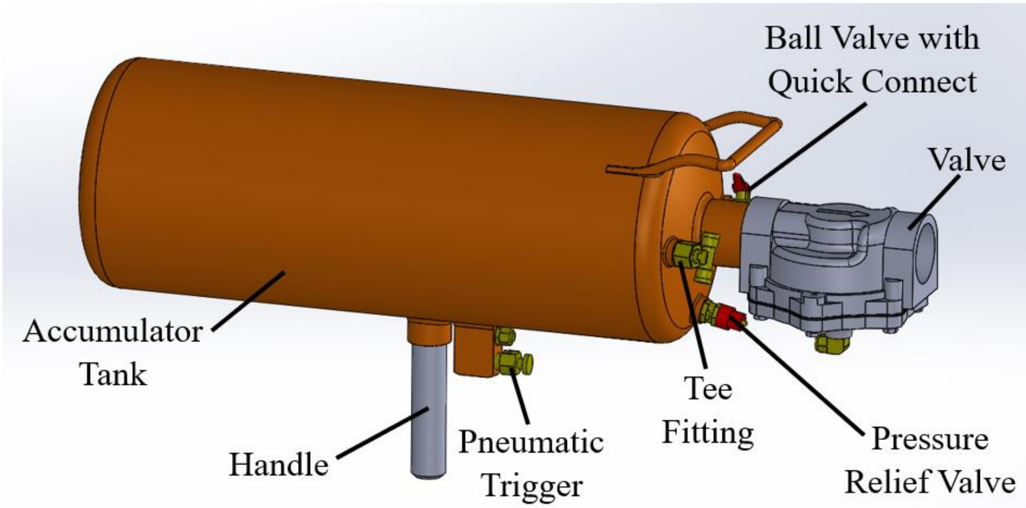


Figure 3.1A: Propulsion System Accumulator Tank

The first method used to refill the accumulator tank involves the use of a small air compressor provided by UCF Senior Design. The specific air compressor is a Dewalt 6 Gallon, 165 PSI Pancake Compressor, shown in Figure 3.1B. The primary purpose of the compressor is for use during testing, as it allows the launcher to be tested anywhere with electricity. Certain UCF sporting venues also have access to electricity, allowing the compressor to be used during games to refill the accumulator tank. The main advantage of the compressor is that it delivers a theoretically unlimited amount of air to refill the tank, as long as electricity is available. This is also its greatest drawback, as the user will not always have easy access to electricity.

Figure 3.1B: Dewalt Pancake Compressor [8]

The final part of the propulsion system is a further subsystem, the scuba tank refilling system. This system utilizes a 30 CF scuba tank and various adapters to safely regulate the compressed air down to a pressure that is safe for the accumulator tank. The scuba tank holds air at 3,000 PSI, making it imperative that the reduction of pressure to the accumulator tank is done in a safe manner. Due to this, this entire system is composed of COTS parts, which are listed in Table 3.1 in the order the compressed air travels, starting at the scuba tank.

Table 3.1: Scuba System Components

Sequence	Part	Max Pressure (PSI)
1	30 CF Scuba Tank	3,000
2	Yoke to NPT Adapter	150
3	Male NPT Quick Connect Fitting	150
4	150 PSI Regulator	120
5	Male NPT Quick Connect Fitting	120

The compressed air starts off in storage in the scuba tank at up to 3,000 PSI. Scuba tanks use unique air fittings that are capable of high pressures instead of standard fittings, such as NPT. To reduce the 3,000 PSI scuba tank to a more manageable 150 PSI that has an NPT fitting, a commercial adapter was found that screws into the yoke fitting in the scuba tank and allows a male NPT quick connect fitting to be attached, shown in Figure 3.1C [18]. This adapter is not adjustable, and outputs the air at a constant 150 PSI. This adapter has the added benefit of having a pressure gauge included, helping to satisfy requirements related to indicating the amount of energy stored in the system. After this adapter, a traditional pressure regulator with male quick connect fittings further regulates the air down to 120 PSI to be used by the accumulator tank. This regulator is attached to the accumulator tank via pneumatic hose.

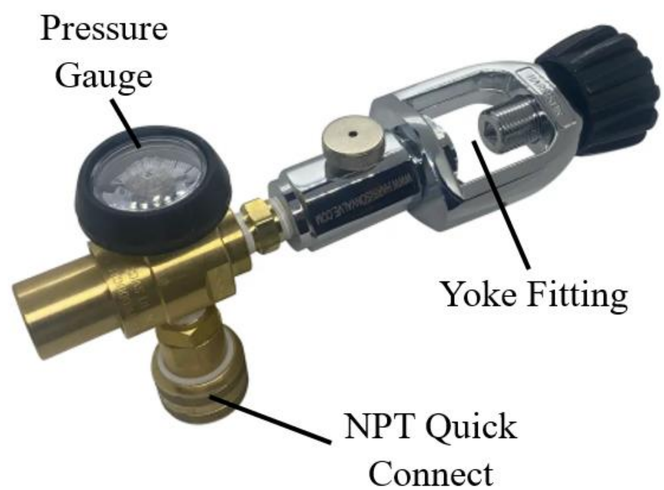


Figure 3.1C: Yoke to NPT Adapter [18]

The scuba system allows the T-shirt launcher to be used in any environment, regardless of the availability of electricity. This makes the launcher much more portable, as the scuba tank does not have to be tethered to an electrical outlet like the compressor does. Both the compressor and scuba systems have their unique characteristics, but both are useful options to ensure UCF Athletics can use the T-shirt launcher in any environment.

3.1.1 Propulsion System Analysis

The propulsion system is the primary working component of the T-shirt launcher, thus a thorough analysis of its performance and safety is critical. The accumulator tank was analyzed using FEA and its maximum rated working pressure, 120 PSI. Performing FEA on the scuba tank poses some issues, as the exact internal geometry and material properties are unknown. In this case, research was done regarding the federal standards the tank abides by and additional information provided by the manufacturer. Finally, the performance of the propulsion system can be calculated for both the scuba system and compressor as a function of how many launches are capable without refilling the energy source.

3.1.1.1 FEA of Accumulator Tank

The most basic analysis of any pressure vessel involves calculating the hoop stress and comparing the value to the yield stress of the material. This was performed in a previous report, however the accumulator tank geometry has been slightly updated. The hoop stress is given in Equation 3.1.1.1, where P is the pressure, D is the diameter of the tank, and t is the wall thickness.

$$\sigma_H = \frac{PD}{2t} \tag{3.1.1.1}$$

For this case, the pressure is 120 PSI, and the manufacturer states the diameter is 6.7 inches with a wall thickness of 0.12 inches. Using these values, the hoop stress can be calculated to be 3,350 PSI. Comparing this to a conservative yield strength for steel of approximately 47,900 PSI [11] , an initial factor of safety can be found to be 14.3. This calculation only takes the longitudinal walls of the vessel into account, therefore it is necessary to perform further analysis on the tank.

To determine the factor of safety of the accumulator tank, FEA must be performed at its maximum rated pressure, 120 PSI. This is also the pressure that the pressure relief valve opens at on the tank, ensuring the tank does not exceed this pressure. Since the accumulator tank is not rigidly fixed to anything, for the purposes of the simulation, additional solid bodies must be added to the model for the accumulator tank to rest on. These bodies are bonded to the accumulator tank using the connections feature in SolidWorks. This provides support to the accumulator tank, while still allowing the accumulator tank to be analyzed by itself after running the simulation. If the simulation used points on the accumulator tank itself as the fixed points, the simulation results will be inaccurate. The geometry used for the simulation is shown in Figure 3.1.1.1A.

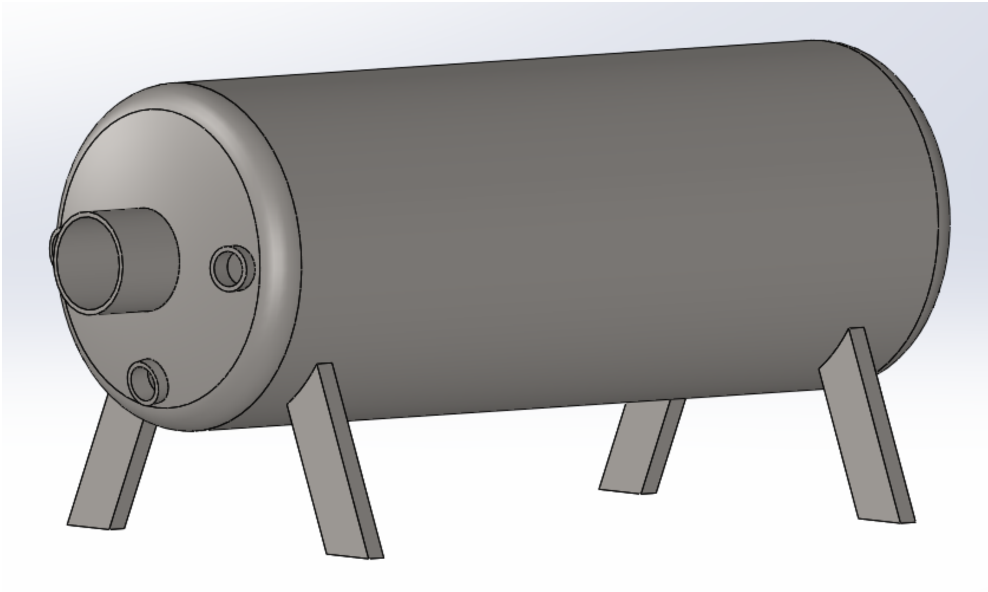


Figure 3.1.1.1A: Geometry for FEA of Accumulator

The setup of the simulation is shown in Figure 3.1.1.1B. In this figure, the fixed points are represented by the green arrows, which are the base of the four legs. Furthermore, the load is set to 120 PSI on all internal surfaces, representing a worst case scenario that the accumulator tank might see. Finally, the legs are bonded to the accumulator tank using the component interactions feature. Using this method, the legs can be excluded from the final results.

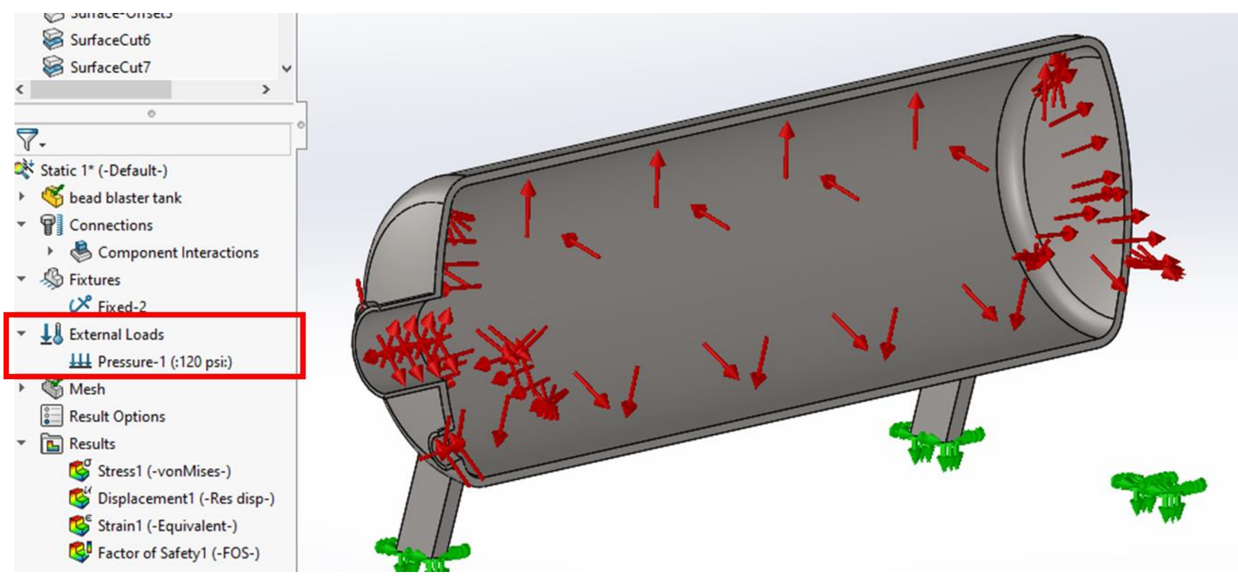


Figure 3.1.1.1B: FEA Simulation Setup for Accumulator

Using the described settings, the factor of safety is shown in Figure 3.1.1.1C. The minimum factor of safety of the tank is 3.96 and is located on the curvature at the rear of the tank. This factor of safety both satisfies Requirement S9.1 and general engineering standards, such as ASME Section VIII [5]. Furthermore, this simulation was performed using a low carbon steel available on SolidWorks. The manufacturer only states that the tank is made out of steel, so the low carbon steel on SolidWorks offers a conservative approach. In this case when dealing with compressed air, it is better to be cautious when analyzing the safety of the tank. Additionally, the tank is powder coated, which could potentially further harden the steel from its initial state, also leading to an increase in strength.

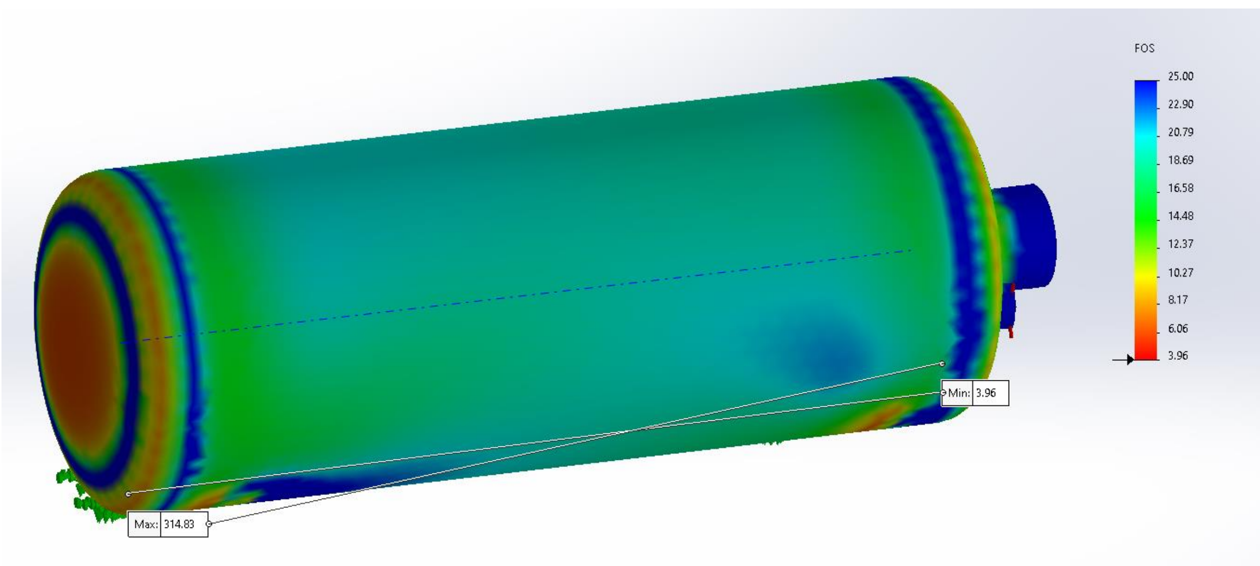


Figure 3.1.1.1C: Factor of Safety of Accumulator

This simulation verifies that the accumulator is safe when filled to 120 PSI, but in reality, the tank will not be kept at a constant 120 PSI. Instead, the tank will be filled and almost immediately discharged to launch T-shirts. Due to this, it is necessary to evaluate how fatigue will impact the accumulator tank. Using the same setup that was utilized for the FEA, a fatigue simulation can be performed in SolidWorks. Using a zero-based loading type, where the load varies from 0 to 120

PSI, and one millions cycles, which is the maximum allowed in SolidWorks, it can be seen from Figure 3.1.1.1D that failure due to fatigue is not a likely occurrence for the accumulator tank. During the simulation, an error message occurred that the alternating stresses for the entire model are below the values of the ASME S-N Curve for the material, indicating infinite life from fatigue failure. Even if this is not the case, the entire tank is estimated to have a life of at least one million cycles from the simulation. It is highly unlikely that the launcher will be used this much over its lifespan. While impressive, this simulation does have some assumptions. This assumes that the tank is in perfect condition, with no scratches, chips, or corrosion.

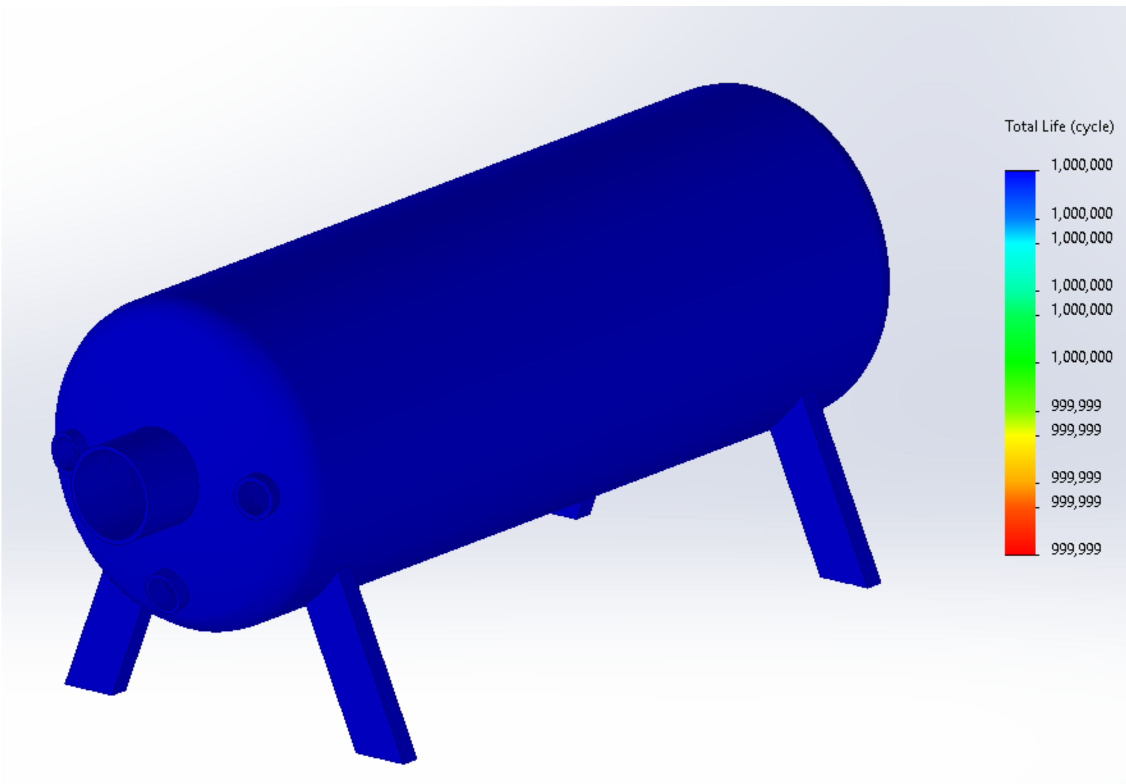


Figure 3.1.1.1D: Total Life of Accumulator Tank at 120 PSI

This finding raises the question of what pressure will lead to a fatigue failure of the accumulator tank. Starting from 150 PSI and increasing the load in 50 PSI increments, it was found that at 400 PSI, the internal walls will suffer a fatigue failure at approximately 450,000 cycles, shown in

Figure 3.1.1.1E. As one would expect, the failure takes place in the curvature of the rear walls, which is the same location as the minimum factor of safety. While the accumulator tank will never reach these pressures, it is a useful exercise to see how much buffer there is between the operating pressure of the accumulator tank and its failure pressure, from both a static and cyclic perspective.

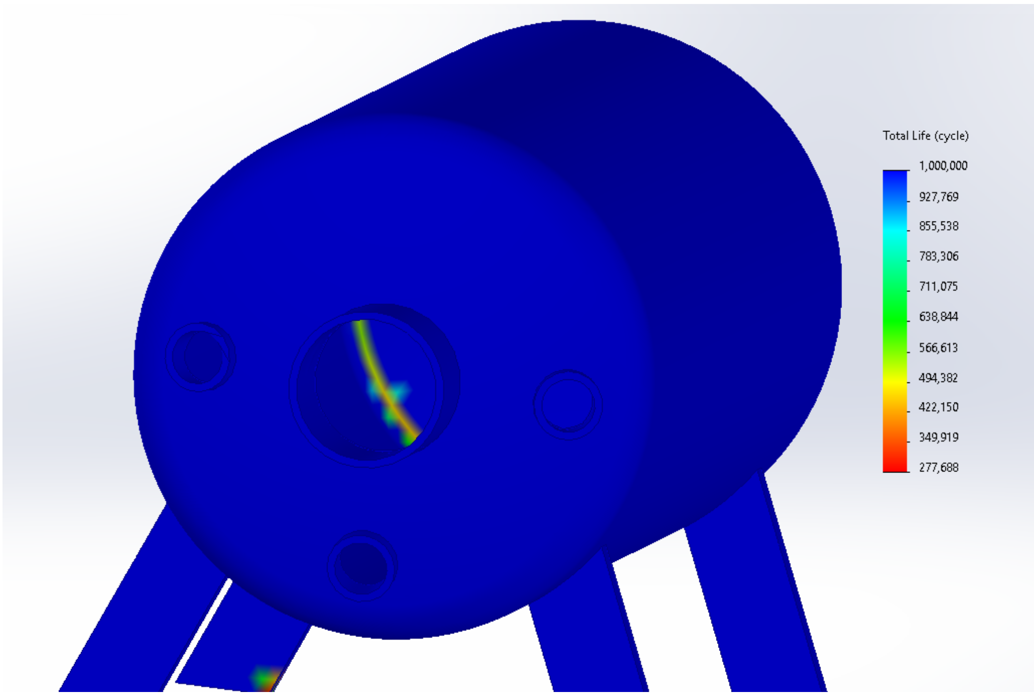


Figure 3.1.1.1E: Total Life of Accumulator Tank at 400 PSI

3.1.1.2 Safety of Scuba Tank

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

Pressure vessels that are used to transport pressurized fluids on roads, planes, or boats are legally required to be DOT approved. These vessels do not necessarily have to be high pressure, but when companies are transporting pressurized fluids, it is to their benefit to do this at a high pressure to make the most use out of their space and transportation equipment. The scuba tank purchased for this project is made of 6061 Aluminum, a common choice for scuba tanks. 6061 Aluminum pressure vessels that are used to transport compressed fluids are subject to DOT Regulation 49 CFR 178.46, Specification for 3AL Seamless Aluminum Cylinders [16].

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

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

The next verification performed by the manufacturer is that three samples must be pressurized until failure, and the failure may not occur at any pressure less than 2.5 times the rated pressure. For the scuba tank purchased, this is 7,500 PSI. The DOT Regulation also states that when the vessel fails, it must remain in one piece, the failure must be in the sidewall (not the neck), and the crack must be longitudinal [16]. In addition to these requirements, 3AL pressure vessels must undergo an annual visual inspection and a hydro-test every five years, where the tank is filled with water and pressurized to 5/3 of its rated pressure.

While these requirements are very thorough to ensure the safety of the device, they come up short of Requirement S9.1, requiring a factor of safety of 3.5 for energy storage devices. This requirement was derived from ASME Section VIII, which generally requires a minimum factor of safety of 3.5 for pressure vessels [5]. In practice, a 2.5 factor of safety is more than sufficient for the scuba tank, as scuba tanks very rarely fail, and if they do fail it is in a controlled environment during hydro testing. In 2016, the University of Hawaii published a paper on a specific failure mode of scuba tanks, sustained load cracking. Prior to 1990, some scuba tanks were made out of 6351 Aluminum alloy, which was found to be subject to cracking under sustained loading. After this was found, manufacturers switched to 6061 Aluminum. Up to the time the report was written, it was estimated that 25.4 million scuba tanks were manufactured using 6351 Aluminum, and of those only 17 in the entire world were documented to have failed due to sustained load cracking. Since then, a particular manufacturer, Luxfer, has produced 19 million scuba tanks with no documented sustained load cracking [10]. These statistics show how modern scuba tanks are very well built with few failures.

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

PSI scuba tank bursting would absolutely cause a loss of human life if it was not done in a controlled environment.

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

3.1.1.3 Scuba Tank System Performance

After the safety of the propulsion system, the air capacity is the second most important factor, as this will determine how many T-shirts can be launched without the need to refill the storage source. To analyze this, the volume of air that is stored inside the scuba tank can be compared to the volume of air that is stored in the accumulator tank. The scuba tank purchased is 30 CF, which refers to the amount of air at atmospheric pressure that is inside of the tank when it is at its service pressure, 3,000 PSI. Since this scuba tank will only be filled to 2,140 PSI, it is necessary to determine how much air is inside the tank. The ideal gas law, shown in Equation 3.1.1.3A, where P is the pressure in PSI, V is the volume in cubic feet, n is the number of moles of the gas, R is the universal gas constant, and T is the temperature in Rankine, is known to be constant.

$$PV = nRT \tag{3.1.1.3A}$$

Since the pressure multiplied by the volume is constant, the volume of the scuba cylinder can be found using Equation 3.1.1.3B, where the subscript 1 denotes the atmospheric conditions and the subscript 2 denotes the conditions inside the scuba tank.

$$P_1V_1 = P_2V_2 \tag{3.1.1.3B}$$

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

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

3.1.1.4 Compressor Performance

Using the same method from the previous section, the number of launches from the compressor can be calculated when the compressor is disconnected from the electricity. The compressor has a volume of 6 gallons and a maximum pressure of 165 PSI, making one side of equation 3.1.1.3B known. Dividing these two values by the pressure of atmospheric air shows that there is 9 CF of compressed atmospheric air in the compressor when it is completely filled. Dividing this value by the amount of air in the accumulator at 40 PSI yields a result of 11.78. This means that 11 launches could be performed at 40 PSI, with an additional 12th launch at a slightly lower pressure without refilling the air compressor. While this is not as many as the scuba tank, the air compressor can be refilled much faster and easier, making this a viable option.+

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

3.2 Reloading System

Aside from the propulsion system, the reloading system is the only other system that is completely required for the T-shirt launcher to function, as it stores the T-shirt before being launched and directs the T-shirt where the user is aiming. This system, while simple, is the only other pressure bearing part of the T-shirt launcher, making its safety important. The reloading system is shown in Figure 3.2.

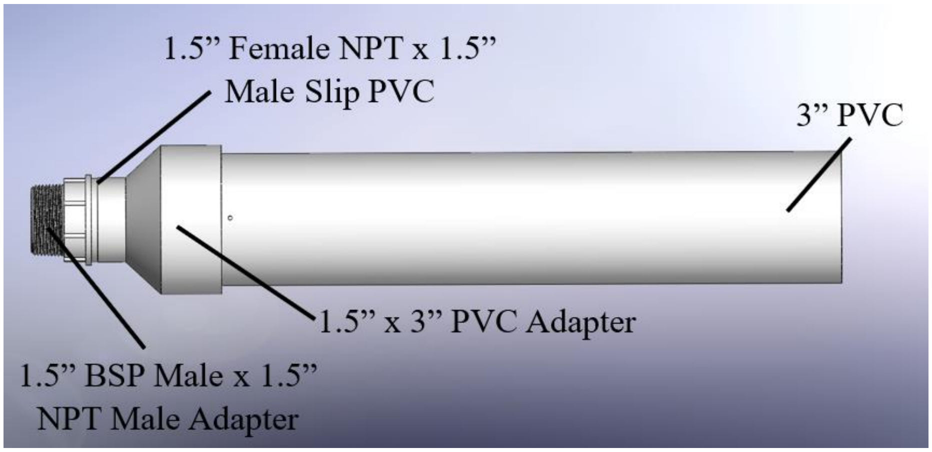


Figure 3.2: Reloading System

This system consists of 4 components. The first component is a 1.5 inch BSP to NPT adapter. This adapter is metal and threads directly into the valve on the accumulator tank, which is also metal. Connected to this adapter is a PVC adapter with 1.5 inch female threads on one side, and a male slip fitting on the other side. Connected to the male slip fitting is a 1.5 inch to 3 inch PVC adapter, which is finally connected to a 3 inch PVC barrel. To ensure the safety of the system, all of the PVC purchased is Schedule 40, meaning that it has thicker walls than standard PVC. Additionally, the PVC is pressure rated. While the PVC will not be subject to sustained pressure loads, it will undergo fast cyclic loading as the compressed air travels through it pushing the T-shirt out.

At the base of the 3 inch PVC, there is a small hole drilled using a 7/64 drill bit. While a tightly rolled T-shirt will slide down the barrel unassisted, this small hole gives somewhere for the air to escape as the T-shirt slides down the barrel, letting the T-shirt slide all the way to the bottom quicker. From testing, it was determined that this hole does not impact the performance of the launcher.

3.2.1 Reloading System Analysis

As mentioned earlier, the reloading system is the only other component of the T-shirt launcher that comes in contact with compressed air, making its safety an important factor to analyze. This was done using FEA. Additionally, the time it takes to load a new T-shirt can be tested as well as the expected launch distance, which is a factor of the length of the barrel.

3.2.1.1 FEA of Reloading System

Given that the reloading system will be stationary and fixed to the launcher, a thorough FEA analysis is required to ensure safety and minimize the risks. Using the same model in Figure 3.2, the barrel was analyzed while under maximum pressure conditions. The worst case scenario is 120 PSI, which is the maximum pressure the reloading system would endure. In this analysis the reloading mechanism, the barrel, is subject to the highest possible pressure and the material is set to be rigid PVC. Neglecting the small hole near the 3-inch reducer, the maximum stress observed over the part is 2,065 PSI, shown in Figure 3.2.1.1A. The result, a factor of safety roughly 3.57.

This analysis all depends on the material used in the simulation, however using a material with lower yield strength in the simulation will ensure the material used on the model can withstand such pressures. Now accounting for the small hole at the base of the system, shown in Figure 3.2.1.1B, the maximum stress is observed to be 2,173 psi, a slight increase from scenario one. The stress increase around this pressure relief hole decreases the factor of safety to about 3.54. Despite the reduction, this value is still within acceptable limits for the project since the material that will be used has a much higher yield strength and will be PVC rated for pressure.

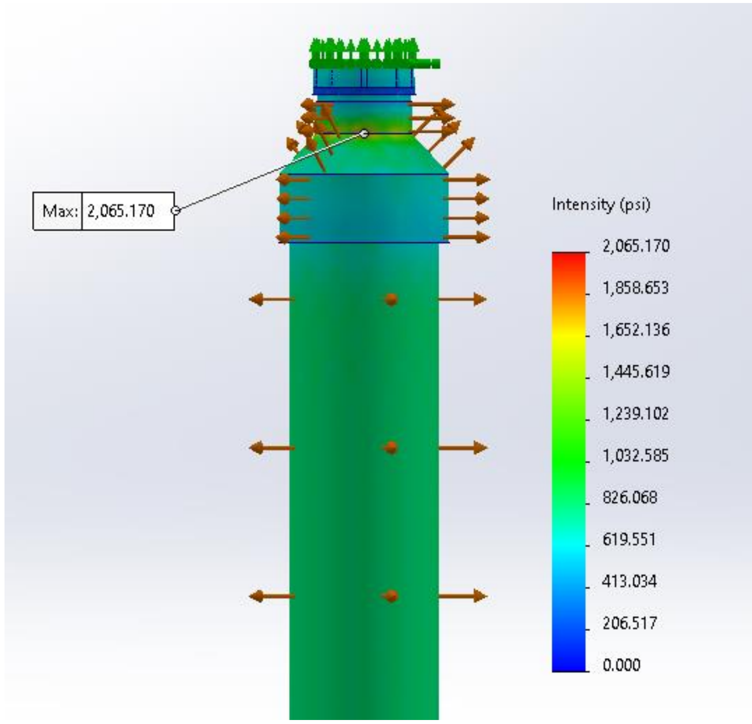


Figure 3.2.1.1A: Maximum Stress at 120 PSI

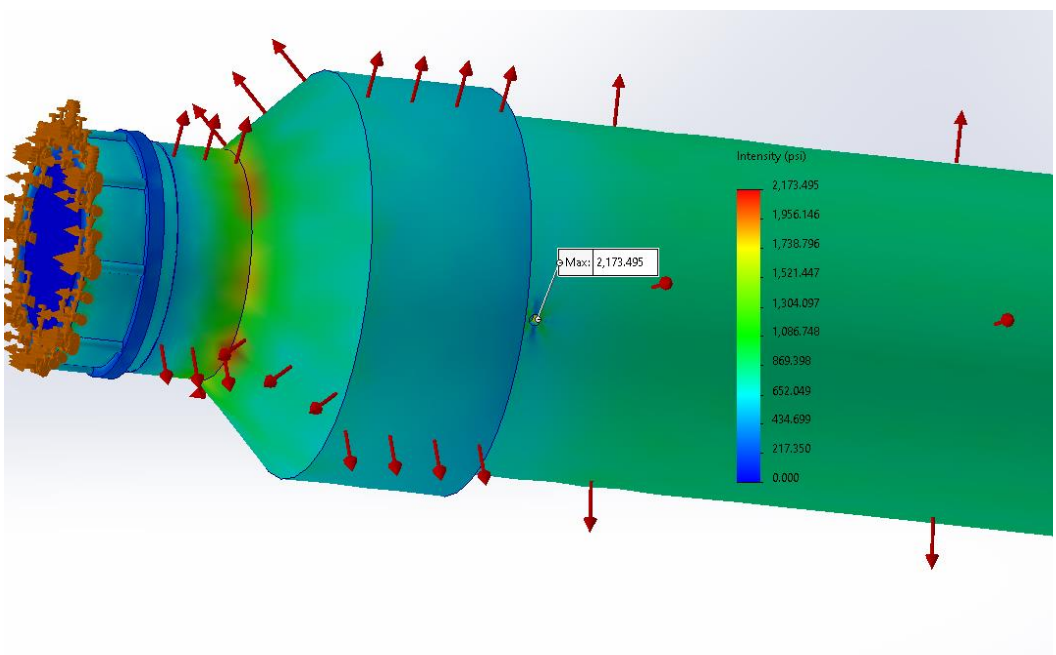


Figure 3.2.1.1B: Maximum stress around the reloading airflow hole at 120 PSI

The FEA analysis of the barrel confirms structural integrity of the barrel/reloading system, under the conditions that the material strength is greater than the one used in simulation. This analysis confirms that material selection is a huge decision impacting the safety and performance of the system as a whole. The pressure rated PVC that will be used for the actual model is rated for 260 PSI which is more than twice the highest operating condition effectively giving 2 times the factor of safety. The next subject in question is the cement glue holding the PVC reducer to the 3 foot tube. A test plan has been drafted and will be conducted to ensure the bonding agent is capable of withstanding such pressures, and meets the safety requirements. This test has not been conducted yet, but the procedure is documented in Section 4.2 The test will take place on June 22nd, 2024 and the results will be available in the final report.

3.2.1.2 CFD of Reloading System

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

When performing this simulation, and adding vectors to represent the flow of air, it can be seen in Figure 3.2.1.2A that as the air exits the 1.5 inch section of the barrel, the flow quickly expands in the nozzle to reach the full 3 inch diameter of the barrel. Furthermore, the flow appears to “bounce” off the walls of the barrel just after the T-shirt resting location, and shortly thereafter becomes fully developed. Since the airflow acts on the entire surface area of the T-shirt for the entire length of the barrel, it can be said that the nozzle design is sufficient to provide the maximum amount of force to the T-shirt.

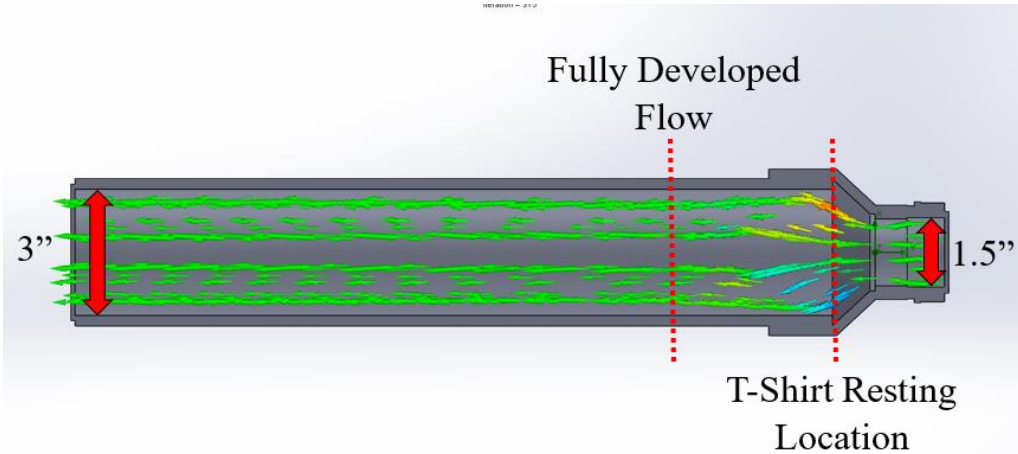


Figure 3.2.1.2: Velocity Vectors of Barrel

<u>3.2.1.2 Reloading Time</u>

An important reloading parameter is how long it takes the user to load a T-shirt in from the position they ended the previous launch in. To test this, a team member held the launcher in a firing position, and when instructed, picked up a T-shirt from a counter, and slid it down the barrel. The time was recorded from when the user was given the instruction to start to when the T-shirt finished sliding down the barrel. In the actual system, the T-shirts will be stored on the launcher. The time to retrieve a T-shirt from the storage location on the launcher should be comparable to having to reach over to a counter to pick up a T-shirt. The results of this experiment are shown in Table 3.2.1.2.

Table 3.2.1.2: Reloading Time Test

Trial	**Time (s)**

1	4.51
2	4.27
3	4.16
4	3.90
5	4.36
6	4.10
7	4.53
8	3.56
9	3.87
10	3.54
Average:	**4.08**

When conducting this test, the team member was not specifically trying to reload the T-shirt as fast as possible, but instead trying to simulate the pace that might be seen during actual use. Requirement F2.2 requires that one shirt can be launched every 15 seconds. With the recorded reloading times, the user still has almost 11 seconds to fill the accumulator tank, aim, and fire the launcher. This requirement will be further verified once the final system is constructed.

3.3 Electronics System

The electronics system is the portion of the launcher that allows complete user interface and control in the desired distance. A pressure transducer will relay information from the accumulator tank pressure to an Arduino, which will then be programmed and calibrated to identify proper pressure benchmarks for launch distance. This allows the operator to select a distance and read an accurate target for necessary PSI. As the electronics system is an implementation to the finished device, a schematic will be used to represent a visual in the order of operations it will follow. The main goal of this system is to allow for precise control over the operators intentions and outcome so that a desired target is reachable within one shot attempt.

3.3.1 Schematic

A drawing has been created to help identify the flow of processes that will allow for complete functionality of this system, shown in Figures 3.3.1A and 3.3.1B.

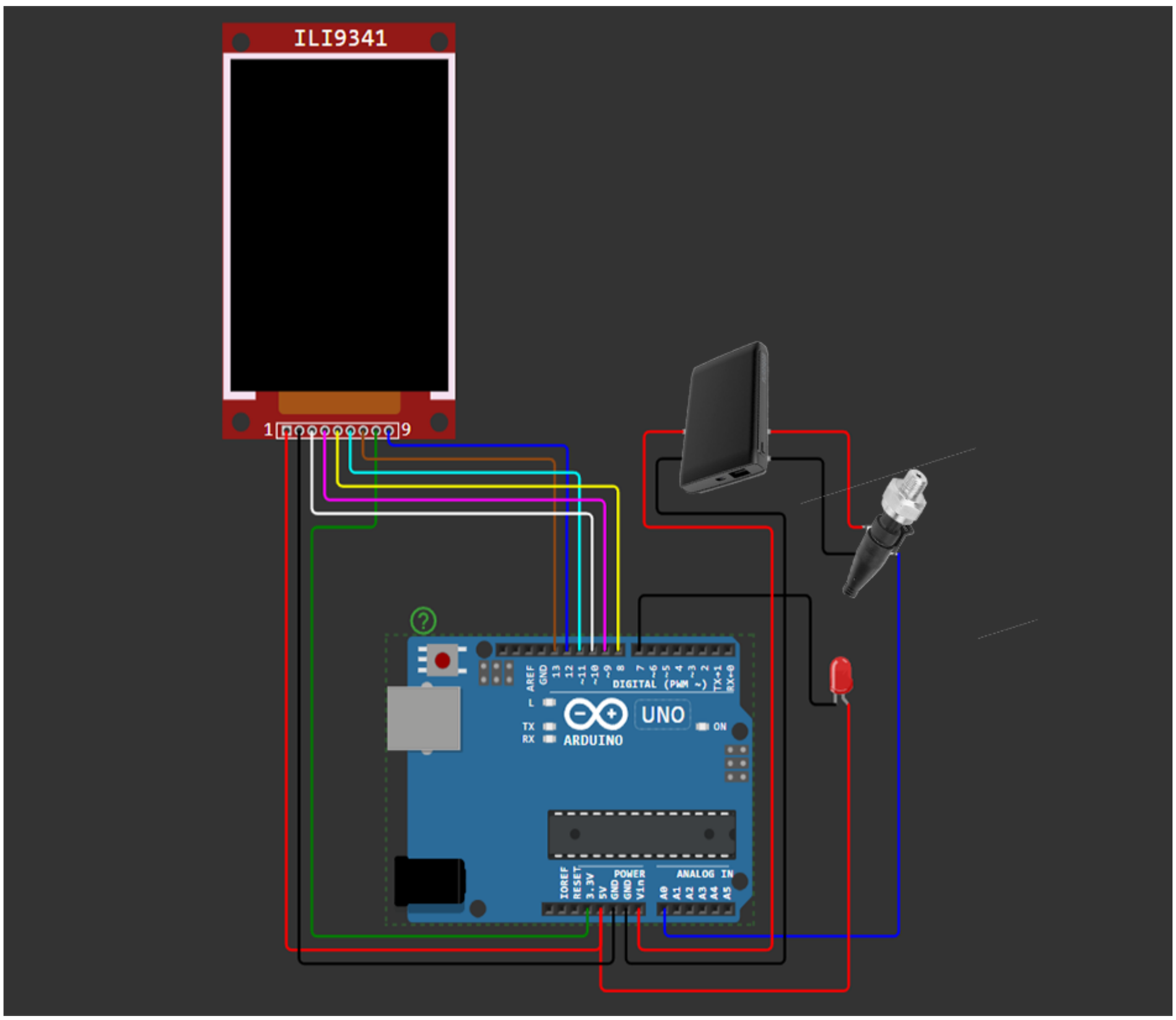


Figure 3.3.1A: Arduino Wiring Schematic.

```
     TFT Display                Arduino Uno
 +-----------------+         +-----------------+
 |      VCC        |---------|       5V        |
 |      GND        |---------|       GND       |
 |      CS         |---------|       D10       |
 |      RESET      |---------|       D9        |
 |      DC/RS      |---------|       D8        |
 |      SDI (MOSI) |---------|       D11       |
 |      SCK        |---------|       D13       |
 |      LED        |---------|      3.3V       |
 |      SDO (MISO) |---------|       D12       |
 +-----------------+         +-----------------+
```

Figure 3.3.1B: Wiring Definitions for TFT Screen.

3.3.2 Process Analysis

The power source for this electronic system is a dual USB-A header portable charger with a 10,000 mAh capacity. This portable charger will directly power the Arduino microcontroller and the electronic pressure transducer separately to mitigate potential voltage drops from the Arduino's current draw. An electronic pressure transducer is very sensitive to voltage drops as it reads pressure based on voltage levels. Both the Arduino and the pressure transducer will be powered by 5 volts, with connections spliced into separate USB-A connectors for easy disconnection.

The TFT display and LED firing indicator will be powered by the Arduino Uno. The TFT display must be wired to the Arduino to facilitate two-way communication, displaying current data on the screen. The LED indicator will be powered by the 5 volt header and digital pin on the Arduino, allowing it to be turned on and off as programmed.

The blue wire connected to the digital pressure transducer, as shown in Figure 3.3.1A, is a signal wire connected to the Arduino's analog pin A0. This wire communicates voltage changes from the sensor, which correlate to different pressures on a 5-volt scale. As pressure increases, voltage increases; as pressure decreases, voltage decreases. The Arduino interprets these changes.

Together, the Arduino, TFT screen, pressure transducer, and LED indicator create a system that displays live pressure readings on the screen and activates the firing indicator when the Arduino detects a sudden drop in pressure, indicating the release of a T-shirt.

As the testing and implementation of all features of the T-shirt launcher approaches, the calibration of the electronic system will take place. To ensure consistency across all conditions, the launcher will be fired under expected operator use conditions, and the outcomes will be recorded. The goal of this calibration is to provide the necessary information for the team to program into the Arduino. A meter will display for the operator during filling, allowing a visual reading of the expected distance the T-shirt will achieve at the current pressure.

3.3.3 Expected Electronics System Performance

This system will perform excellently as a stable circuit, allowing the pressure transducer to accurately read values to the Arduino and control the display and LED lights appropriately. The success of this system is attributed to the simplicity and logic of its parts and design. The team tested a system similar to this configuration and encountered no issues with performance. No failures were observed, and the operation was as intended. As this was an unofficial test, there is no documentation, but it provides insights into how to assemble the circuit and how it will function. The ease of use of this system will be incredibly intuitive for operators and allow for precise control over operations. Some external factors will influence the exact performance of this system. Factors such as weather conditions, temperature, T-shirt wrapping technique, type of T-shirt, loading technique, and launch angle will all affect the trajectory. With consistent operating methods, this system will always give the operator an idea of how far the T-shirt will travel upon launch.

3.4 Safety System

The safety system for the T-shirt launcher comprises three main components: the trigger LOTO, the air inlet LOTO, and the trigger safety. The LOTO system has the objective of restricting unauthorized use of the T-shirt launcher and keeping it in a safe state while it is in storage or being worked on, while the trigger safety is intended for while the T-shirt launcher is in use.

3.4.1 Trigger LOTO

The first part of the LOTO system is the trigger LOTO, which prevents the trigger from being pressed while it is in place. The trigger, shown in Figure 3.4.1A, has a button that slides in and out of a hex-shaped fitting. This sliding is indicated by the red arrow in Figure 3.4.1A.

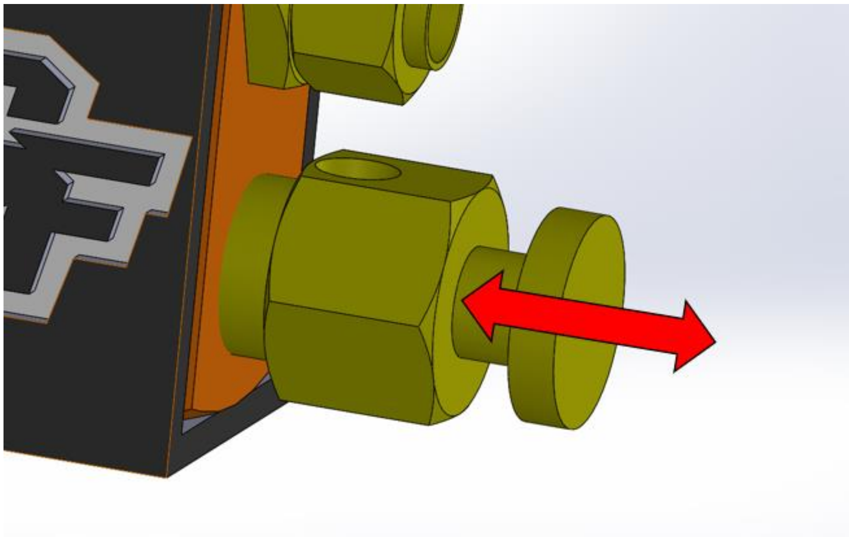
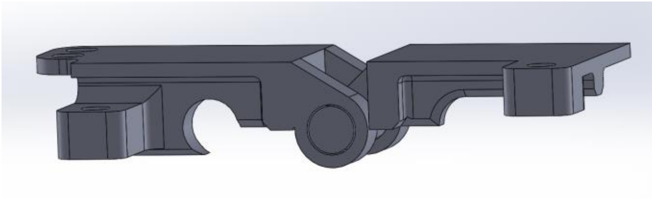
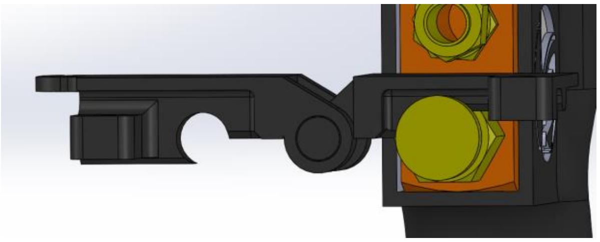


Figure 3.4.1A: Trigger Button

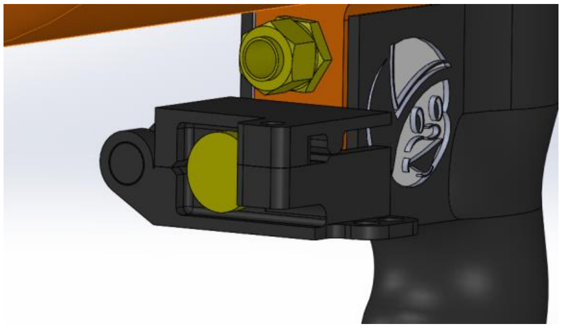
The trigger LOTO works by sliding in between the face of the button that the user presses and the hex-shaped fitting, preventing the button from being pressed, thus preventing air from being released by the valve. The operation of the trigger LOTO is shown in Figure 3.4.1B.



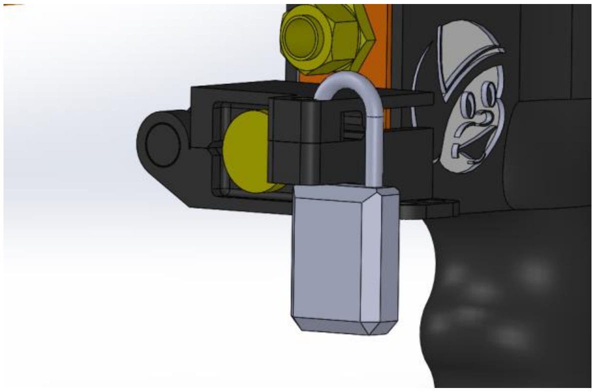
Step 1: Open LOTO Device



Step 2: Slide Top Part of LOTO Over Trigger



Step 3: Pivot Bottom Part of LOTO Around Trigger



Step 4: Lock Device

Figure 3.4.1B: Trigger LOTO Operation

The trigger LOTO prevents the launcher from being fired, regardless of if there is compressed air in the accumulator tank. This ensures that if the accumulator tank is ever put in storage with any amount of air in it, it can not accidently be fired by someone handling the launcher who is unaware there is air stored in the accumulator. The trigger LOTO is also useful when performing maintenance on the launcher. If performing a task such as a leak test, the person performing the test may want to lock out the trigger to prevent any accidental bumps to the trigger, which could make the launcher slide off a table it is sitting on, alarm people nearby, or launch a projectile if one was left in the barrel.

3.4.2 Air Inlet LOTO

A secondary LOTO device was designed to prevent the accumulator tank from being filled with compressed air in the first place. For this system, the lever on the air inlet must be positioned in the off position, which is perpendicular to the fitting, shown in Figure 3.4.2A.

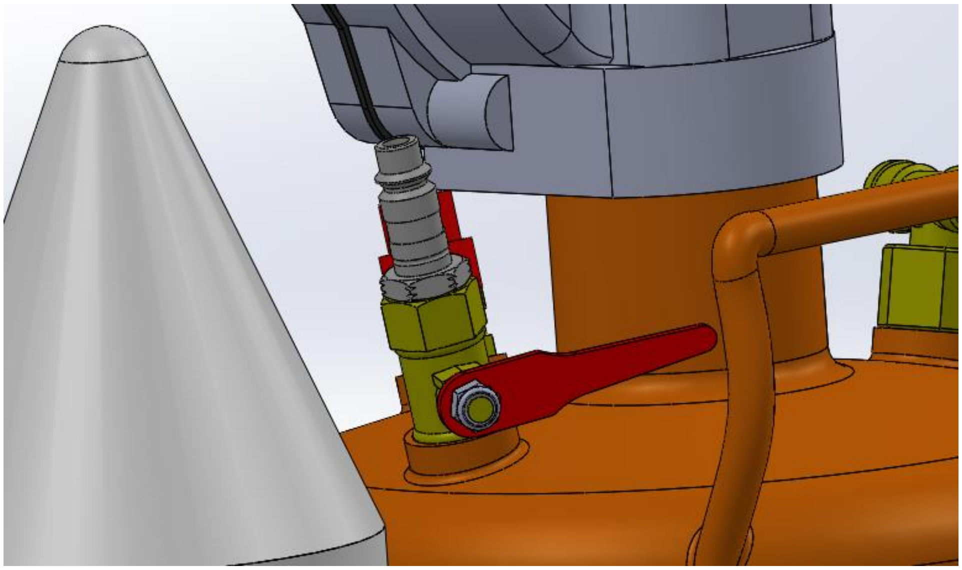


Figure 3.4.2A: Air Inlet in Off Position

After the air inlet is in the off position, the LOTO device can be placed over the air inlet and locked, ensuring that an air hose can not be connected to the accumulator tank. This is shown in Figure 3.4.2B.

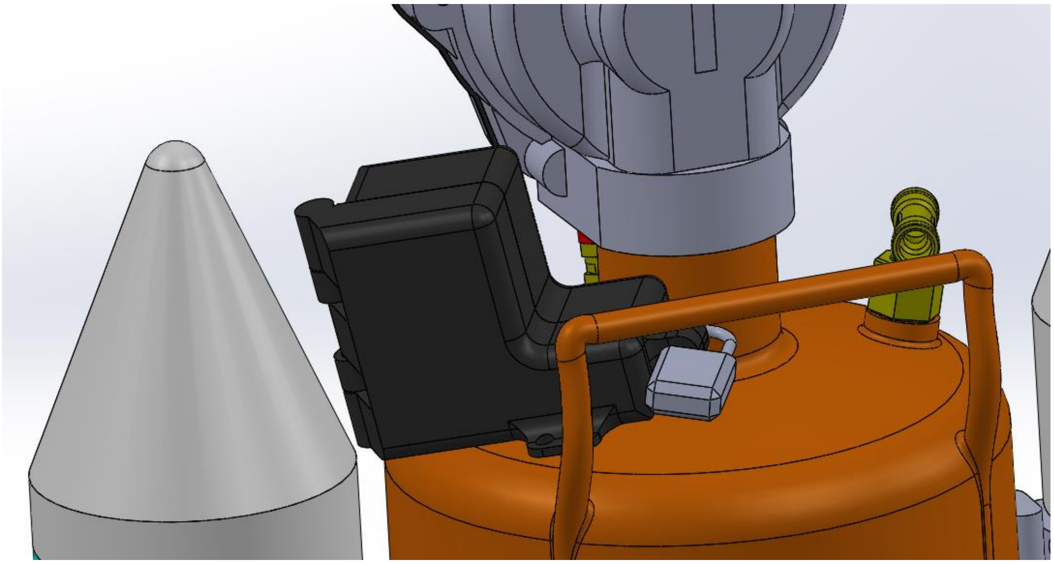


Figure 3.4.2B: Air Inlet LOTO

Using both the air inlet and trigger LOTO devices provides two opportunities to prevent unauthorized use for the launcher, as well as providing safety options when performing maintenance or testing the launcher.

3.4.3 Trigger Safety

Unlike the LOTO devices, the trigger safety is intended to be used while the T-shirt launcher is being used at a sporting event. This may be placed on the trigger in between launches, when transporting from storage to the stadium, or when the launcher is done being used at an event. This safety functions similarly to the trigger LOTO, by sliding between the button and the hex fitting, preventing the trigger from being pressed. The main difference is that the trigger safety is much smaller and does not require any focus to slide on. The trigger safety in its installed position is shown in Figure 3.4.3A.

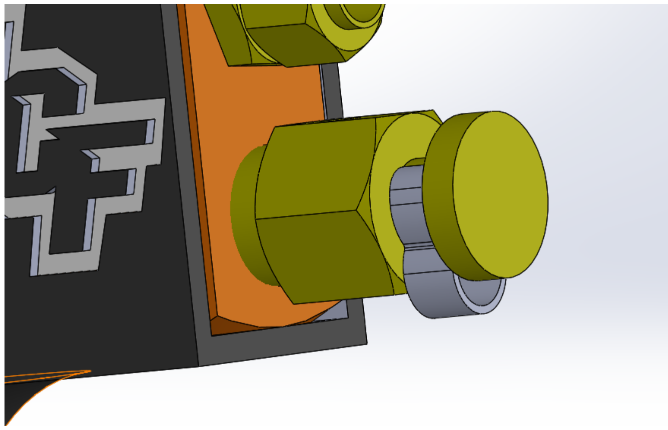


Figure 3.4.3A: Trigger Safety CAD Model

To ensure the trigger safety stays tethered to the T-shirt launcher and to make it easier to remove, the loop on the bottom of the trigger in the above figure will be attached to a coiled keychain that is attached to the launcher on the other end. This both keeps the safety on the launcher at all times and makes it easier for the user to pull off. An example of this setup is shown in Figure 3.4.3B, but the final version will use a different keychain purchased by UCF Senior Design. The end of the coiled blue part will be attached to the hole on the bottom of the handle in the actual version.

Figure 3.4.3B: Trigger Safety Prototype

3.5 Space-U System

The final system, the Space-U system, includes various cosmetic pieces to make the T-shirt launcher look like a rocket and add UCF branding to the launcher. This system has no impact on the performance of the launcher, but is very important, as the purpose of this project is to create a unique, UCF / Space-U branded T-shirt launcher. The Space-U system includes a handle with UCF and Space-U logos, a cosmetic barrel, and two cosmetic pieces on the side of the accumulator tank to resemble solid rocket boosters (SRBs). The components of the Space-U system are shown in Figure 3.5.

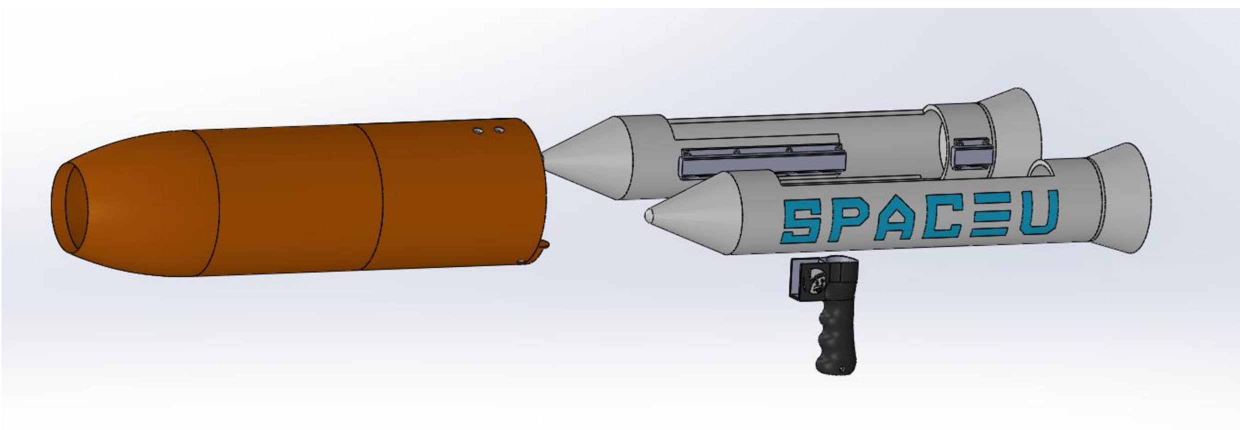


Figure 3.5: Space-U System

3.5.1 Cosmetic Barrel

The cosmetic barrel, the orange parts of Figure 3.5, slides over the actual barrel of the reloading system to give a streamlined look to the launcher. The circumference of the cosmetic barrel matches that of the accumulator tank, to help the launcher resemble a rocket. The cosmetic barrel is divided into three sections to allow for the barrel to be 3D printed. Additionally, the cosmetic barrel will be printed with PETG, which offers high UV resistance, which is ideal since this launcher will be used outdoors, while still being affordable and easy to print with [1]. Each part of the concentric barrel has concentric rings to guide it down the actual barrel. These rings are keyed to ensure a proper alignment, along with having holes available for heat set inserts, allowing each piece to be aligned and screwed together, shown in Figure 3.5.1A. If after screwing the three parts together it is determined the cosmetic barrel is not secure enough, additional glue can be applied where they mate. The cosmetic barrel also has slots in the rings, which both reduce the weight of the barrel and give a path for wires to run down the barrel for electronics.

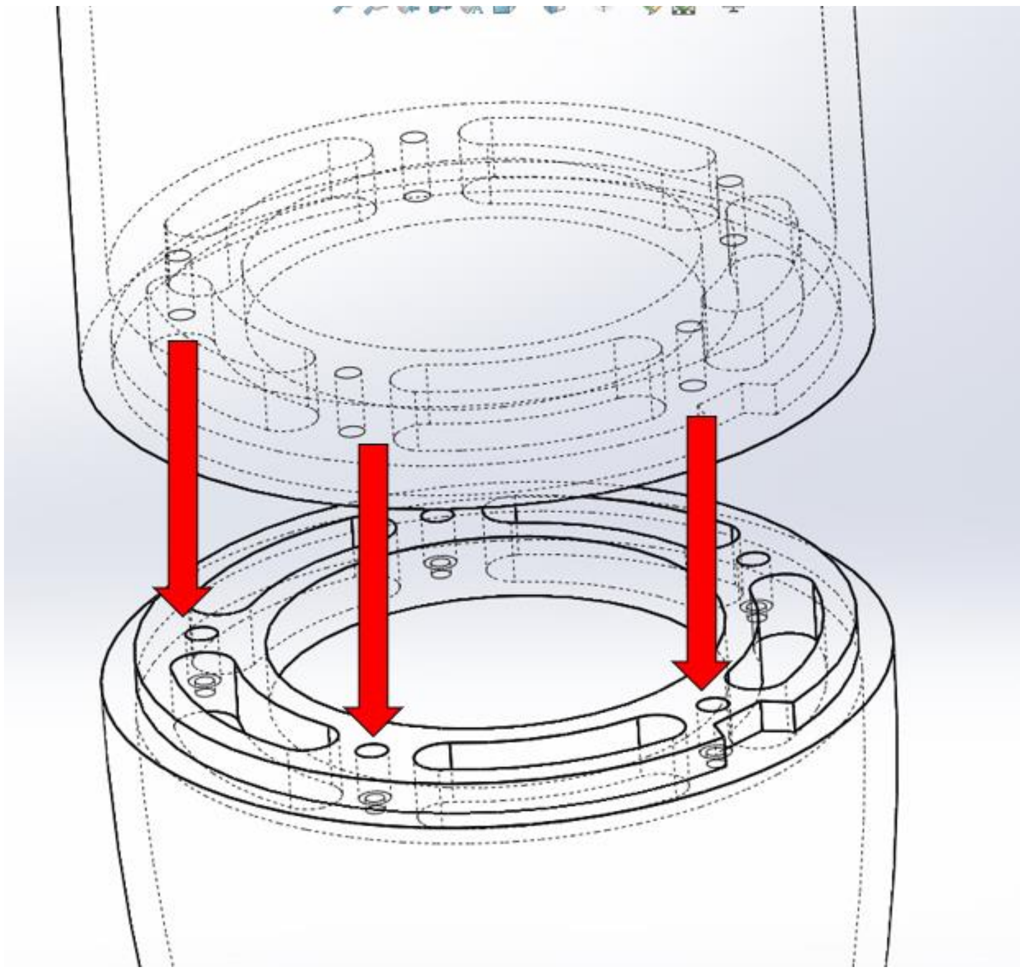


Figure 3.5.1A: Cosmetic Barrel Alignment

Two test rings were printed using PLA to test the fit of the fit around the barrel, shown in Figure 3.5.1B. The diameter used for the inside opening allows a tight fight around the barrel, while still being very easy to slide down. While the tolerances are for a different material and a different 3D printer than the final ones will use, they offer a starting point for test prints when using the final material and printer.

Figure 3.5.1B: Cosmetic Barrel Structure Test

It was initially thought that extra brackets would be necessary to support the cosmetic barrel, but after testing the structure with 3D printing, it was determined that the brackets only need to secure the cosmetic barrel from sliding or twisting. These brackets are shown as the teal components in Figure 3.5.1C.

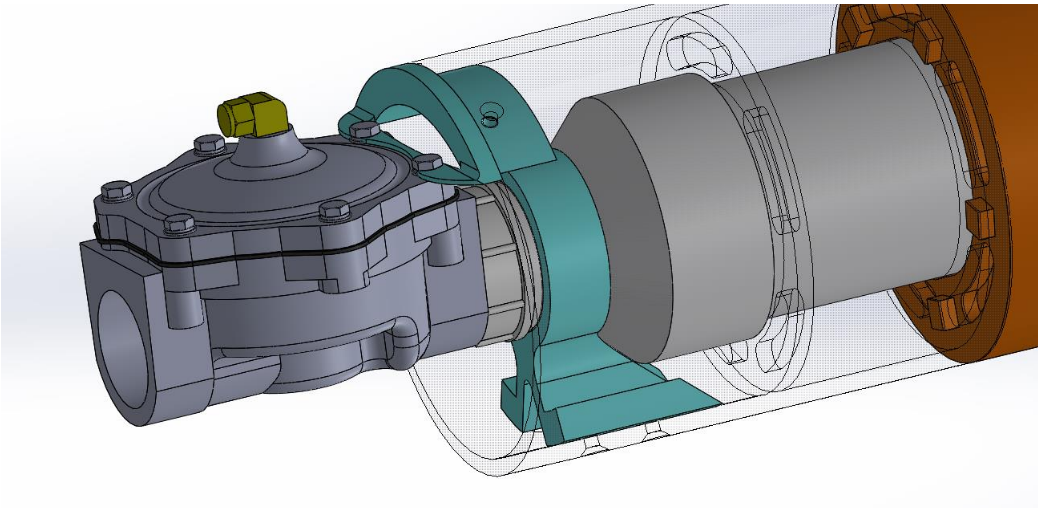


Figure 3.5.1C: Cosmetic Barrel Brackets

The top bracket mounts to the valve that is attached to the accumulator tank and has two screw holes to attach the cosmetic barrel. The bottom bracket slides around the 1.5 inch to 3 inch PVC adapter, and has four screw holes to attach to the cosmetic barrel. It is important to note that the bottom bracket must be slid on the PVC adapter prior to attaching the 1.5 inch female NPT to male slip PVC adapter. In the event the bracket fractures in the future, a backup bracket was modeled that is split in half, allowing it to be installed on a complete reloading assembly. The upper bracket will be 3D printed using the same orange PETG as the cosmetic barrel since it is visible from the outside. However, the lower bracket will be printed using extra white PETG from the other cosmetics, in order to make the most efficient use of material. Both brackets are thick enough and have large enough holes to utilize heat set inserts, shown in Figure 3.5.1D. These threaded inserts, when heated, sink into the 3D printed parts, creating a strong bond. Having the threads permanently fixed in the parts will make installation easier, as the user just has to thread in the screws from the outside and not worry about holding nuts on the inside.

Figure 3.5.1D: Heat Set Inserts [17]

3.5.2 Solid Rocket Boosters

The SRBs are attached to the accumulator tank to complete the aesthetic of a rocket, while also providing additional storage for T-shirts. Each SRB has three components: the nose cone, the exhaust cap, and the main body. This is shown in Figure 3.5.2A. The main body is constructed of foam core PVC that the team already has available to them. This type of PVC is significantly lighter than the pressure rated PVC used for the barrel, which is ideal for this non load bearing component. The nose cone and exhaust cap will be 3D printed using white PETG, for the same reasons PETG is used for the cosmetic barrel.

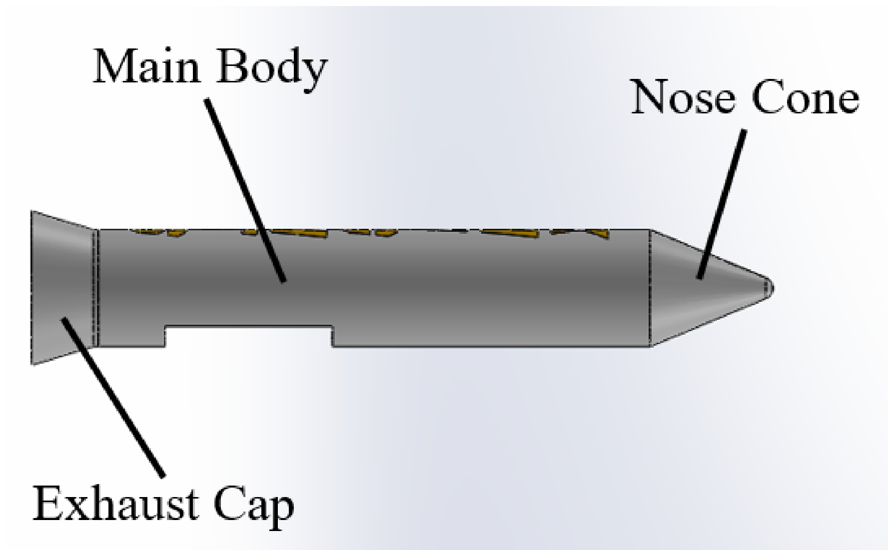


Figure 3.5.2A: SRBs

The SRBs will be attached to the accumulator tank using a rail system, shown in Figure 3.5.2B. With this system, the SRBs can easily be slid on or off the accumulator tank, allowing for more transportation and storage options, as well as offering an easy assembly solution. The rails will be attached to the SRBs using small #4-40 machine screws, while they will be attached to the accumulator tank using heavy duty foam tape.

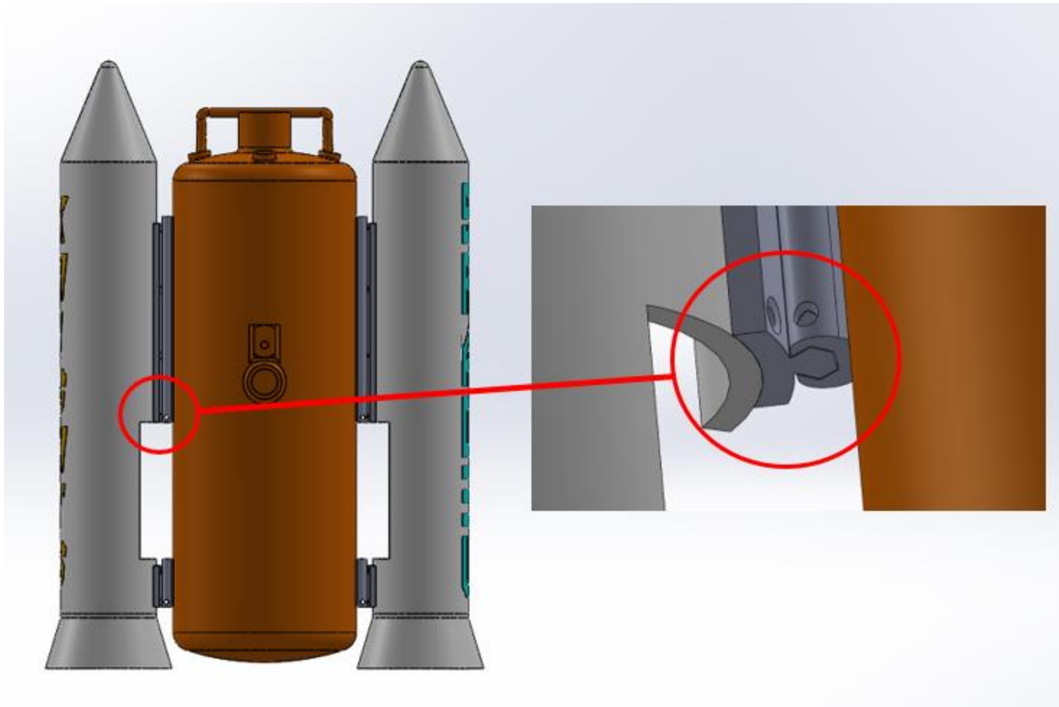


Figure 3.5.2B: SRB Rail System

3.5.2.1 Solid Rocket Booster Analysis

To determine if the foam tape will support the SRBs, the weight of each side must be known. Using Cura to slice the nose cone and exhaust cap, the final weight of the combined parts is found to be approximately 0.57 pounds. Assuming that 3 inch PVC weighs 1.41 pounds per foot [20], the total weight of one SRB can be calculated to be 2.45 pounds. The design for the rails includes 1.75 inches of tape on the lower section, and 7.5 inches on the upper section, for a total of 9.25 inches of heavy duty foam tape. Using a general heavy duty foam mounting tape, such as Scotch-Mount Extreme, the tape can hold up to 1 pound for every 2 inches of tape [23]. Using this figure, 9.25 inches of tape can hold 4.63 pounds, which is almost twice that of a SRB. Other mounting tapes are available that hold more weight, making this a viable option to secure the SRBs to the accumulator tank.

3.5.3 Rear Handle

The final physical component of the Space-U system is a rear handle that includes UCF and Space-U branding. The rear handle was modeled using surface lofts in SolidWorks to create an ergonomic grip that matches the contours of the user's hand. The grip went through two design iterations, shown in Figure 3.5.3A. After prototyping the first version, it was determined that the grip was overall too large to fit in the user's hand comfortably. The lower section of the grip was too far backwards, making it difficult to reach the trigger with the user's pointer finger. The second version features a more upright posture, making the reach from the grip to the trigger more natural.

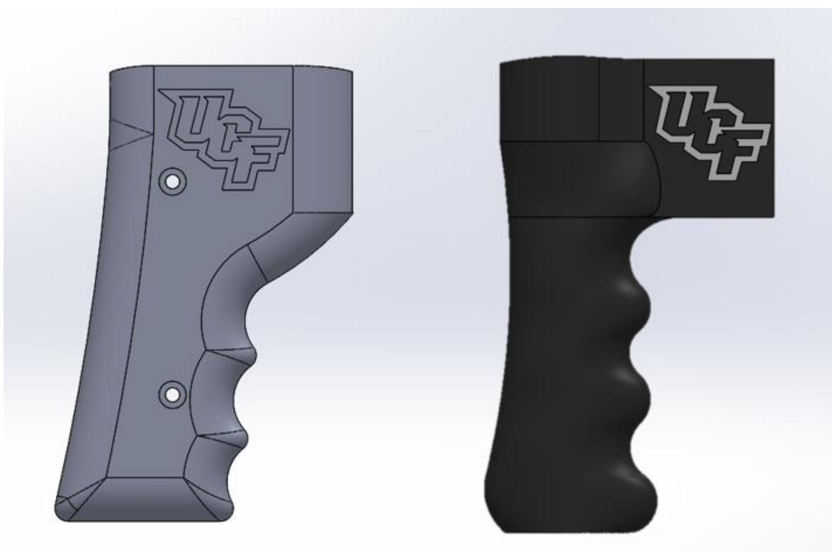


Figure 3.5.3A: Grip Version 1 (Left) and Version 2 (Right)

The final grip was printed using black PLA and finished using bondo, primer, and black paint. The grip has a logo on each side, one being the traditional stacked UCF logo, and the other being the Citronaut, which is UCF's second mascot for Space Games. The final grip is shown in Figure 3.5.3B. The grip is secured to the metal handle that came with the accumulator tank using a countersunk #4-40 machine screw with a nut.

Figure 3.5.3B: Final Grip

3.5.4 UCF and Space-U Branding

The final aspect of the T-shirt launcher is branding to make it clear that the launcher belongs to UCF and that the launcher is Space-U themed. While these aspects are not required to make the launcher function, they are necessary to satisfy the wants of the stakeholder, with the primary one being UCF Athletics.The first piece of UCF branding incorporated was the rear grip, shown in the previous section. After designing the rear handle to have both UCF and Space-U aspects, the team determined to make one side of the launcher UCF themed, and the other side Space-U themed. To maintain this theme, the terms “Space-U” and “Knights” will be placed on the sides of the SRBs, as shown in Figure 3.5.4A. These decals will be cut out in vinyl with an adhesive backing that is suitable for outdoor use. The team has access to a machine to do this, making this a better alternative to creating a stencil and trying to paint the logos on the SRBs.

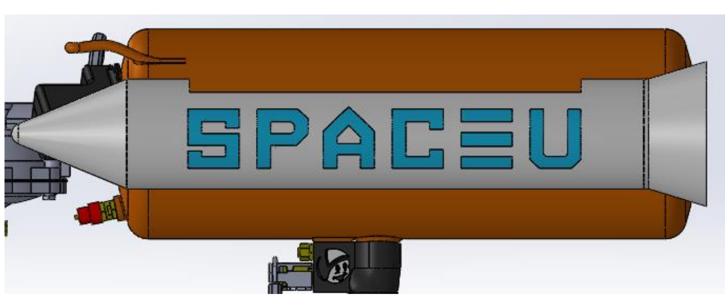


Figure 3.5.4A: SRB Decals

An additional piece of Space-U branding that will be present on the launcher are “Remove Before Flight” keychains, shown in Figure 3.5.4B. These keychains are used on aircraft to notify the maintenance crew that an item needs to be removed before flight [9]. For the T-shirt launcher, these keychains will be attached to the two LOTO devices, to alert the user that they need to be removed prior to using the launcher. These also add another cosmetic aspect to the finished launcher that represents UCF’s ties to the Aerospace and Space industries.

Figure 3.5.4B: Remove Before Flight Keychains [9]

The final branding that will be on the launcher is the name of the launcher, “Gemini 28-80.” This name will be printed using the same method as the SRB decals and placed vertically on the orange cosmetic barrel of the T-shirt launcher. The Gemini part of the name represents the main road that circles around UCF’s main campus, as well as the NASA Gemini program that occurred prior to the Apollo missions, and around the same time UCF was founded [15]. Furthermore, 28-80 represents the coordinates of Kennedy Space Center and the Cape Canaveral Space Force Station, where the Gemini rocket launches and all current rocket launches occur in Florida. 28 is also the latitude of UCF's main campus, meaning that the campus lines up perfectly with Kennedy Space Center.

3.6 Expected System Performance

In Senior Design I, significant testing was done to determine the relation between certain design parameters and system performance. These include the barrel diameter, barrel length, optimal pressure, and exit velocity. However, these tests were performed with the intention of guiding the team on important design decisions and were not intended to benchmark the performance of the final system. For example, comprehensive preliminary testing was performed with a barrel 3 feet in length, but the final barrel is only 18 inches, which will significantly influence the performance of the final system. Additionally, substantial analysis was performed on different materials for pressure bearing surfaces to inform design decisions. The analysis with the final materials was provided in the previous sections for the accumulator tank and reloading system.

Now that the final system characteristics have been determined, the team must analyze a system with those specific characteristics in order to appropriately estimate the performance of the final system. To do this, an example propulsion and reloading system was constructed out of materials already available to the team, shown in Figure 3.6.

Figure 3.6: Benchmarking System

The key characteristics of this system that influence the performance are summarized in Table 3.6. These characteristics were determined by the team by using the testing and analysis from previous reports.

Table 3.6: Design Characteristics

Characteristic	**Dimension**
Barrel Diameter	3 in
Barrel Length	18 in
Barrel Material	Pressure Rated Schedule 40 PVC
T-Shirt Packaging	Tape

3.6.1 Expected Exit Velocity

Calculating the expected exit velocity poses many challenges. First, it is difficult to quantify how much of the air escapes around the T-shirt and therefore does not provide work done on the T-shirt. The friction is also difficult to quantify, as fabric on PVC is not a common scenario. Therefore, the friction coefficient can be approximated to be 0.55, which was tested by a Professor at Minia University in Egypt [14]. Proposed by Physics students from Wabash College, Equation 3.6.1 incorporates the aforementioned factors, as well as the changing volume as the air escapes through the barrel [21]. In this equation, *m* is the mass of the T-shirt, P_0 is the absolute accumulator pressure, V_0 is the accumulator 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. This equation was used previously to identify the effect of barrel length on exit velocity, but can now be used to analyze the system with its final parameters.

$$v = \sqrt{\frac{2}{m}\left(P_0 V_0 ln\left(1+\frac{AL}{V_0}\right) - ALP_{atm} - Lf\right)} \tag{3.6.1}$$

Using this equation, and varying the pressure of the accumulator tank, the theoretical exit velocity is shown in Figure 3.6.1A. As seen in the figure, there is a diminishing return between the accumulator tank pressure and exit velocity. This is similar to the team's previous finding that there is a diminishing return between the barrel length and the launch distance. As the pressure increases, there will be greater energy loss around the T-shirt and increased friction, accounting for the diminishing return.

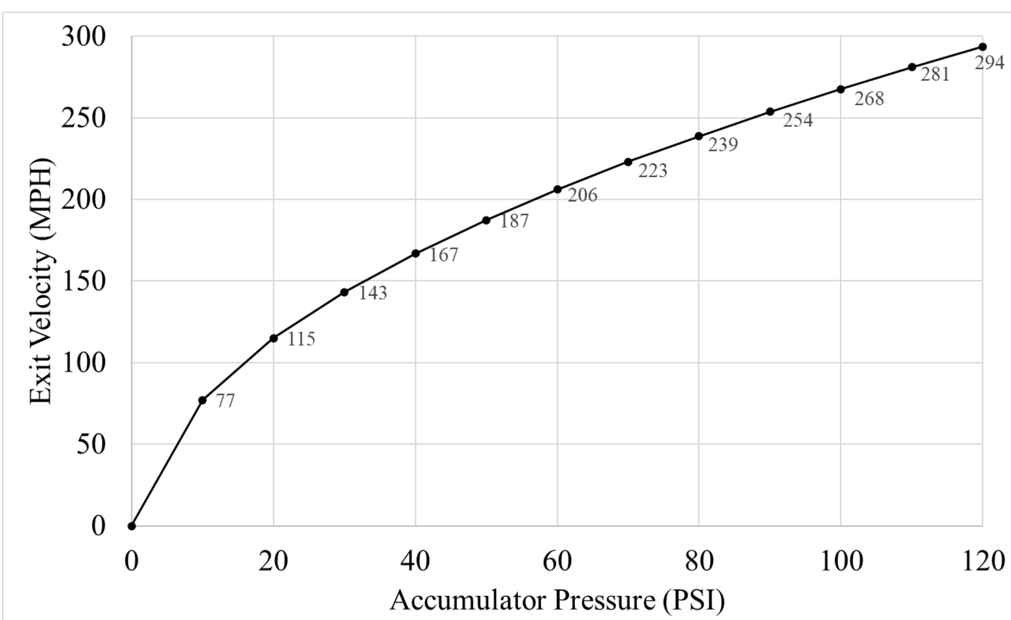


Figure 3.6.1A: Theoretical Exit Velocity

The actual exit velocity can be calculated using the method described later in Section 4.3.2. In short, this method involves using a piece of cardboard with a checkerboard pattern, where the dimensions of the squares are known. Using a slow motion camera with a known frame rate, the distance traveled in between two frames can be calculated using the number of squares the T-shirt travels over. Using this method, the actual exit velocity is shown in Table 3.6.1. Due to the weather on the testing day, the team decided to only test the exit velocity at 80 PSI, since it was found that it is possible to launch a T-shirt out of the football stadium at this pressure.

Table 3.6.1: Actual Exit Velocity

Pressure (PSI)	**Exit Velocity (MPH)**
80	82

This significantly exceeds the required exit velocity of 68.5 MPH, while coming up short of the theoretical exit velocity. There are two main reasons for this. First, the theoretical calculation is very limited due to the many factors of launching projectiles including but not limited to friction, air loss, the amount of air being used, the pressure of the air being used, and the speed at which the air is released. Additionally, the method used to measure the actual exit velocity is not full proof. While the team does know the exact frame rate of the camera and how far it traveled in between two frames, the T-shirt rotated slightly after being shot and the video was taken at a slight angle. There is enough margin of error in the calculation to ensure that the actual exit velocity exceeds the required one, especially if the pressure was increased past 80 PSI. The two frames used to calculate the exit velocity are shown in Figure 3.6.1B, where each section of the cardboard represents 6 inches. The expression on the face of the person holding the cardboard is not one of fear, but of bravery.

Figure 3.6.1B: Exit Velocity Experiment

3.6.2 Expected Launch Distance

Building off the expected exit velocity, the expected launch distance is the other critical system performance parameter. The launch distance will dictate how effective the T-shirt launcher is at including fans in the upper sections, and be very important for displaying energy levels on the Arduino display. Through testing on June 21st, a prototype launcher, a very close replica of the final barrel, was used to find the launch distances. This data was gathered behind the softball field at the UCF main campus, after launching T-shirts in the football stadium, which is discussed in the next section. Due to weather, the team could not gather as much data as possible, but sufficient data was gathered during testing to verify the launcher meets the minimum distance requirements.

The original test plan was to test the launcher in 20 PSI increments, up to 120 PSI, with 5 trials at each pressure. Due to the weather and the fact that T-shirts can be launched out of the stadium at 80 PSI, which is discussed in the next section, the test had to be modified. The data from this test is shown in Table 3.6.2, where 3 trials were taken at each tested pressure.

Table 3.6.2: Horizontal Launch Results

Pressure (PSI)	Average Distance (ft)
20	108
60	169
80	177
100	197

One can assume that increasing the pressure to 120 PSI would cause a launch distance well in excess of 200 feet. However, before testing, the team spoke to a police officer at the softball field to receive permission to test, and the team was told that it was acceptable to test, but to try to keep the noise to a minimum. Regardless of being unable to test at 120 PSI, launching at 100 PSI exceeds the requirement to launch a T-shirt 180 feet. Additionally, the launcher was held at a less severe angle for these tests than the tests in the stadium. If the launcher was held at a higher angle for these tests, the launch distances would have been much greater. The launcher was held at a shallow angle to try to improve the repeatability of the experiment.

3.6.3 Expected Launch Distance in Football Stadium

While the distance that a T-shirt can be launched on a horizontal surface is an important statistic, in reality the T-shirt launcher will be launching shirts vertically and horizontally into the stands in UCF’s many stadiums. To test this, the team scheduled a preliminary testing day, June 21st 2024, to gather data in the football stadium to relate pressure to launch distance. Due to the weather, the test had to be cut short, but valuable information was still gathered. The initial planned testing procedure is as follows:

1. Gather the following materials: T-shirt launcher, large T-shirts, tape, Dewalt air compressor, extension cord, pneumatic hose, scuba tank system, and a laptop or paper to record results.
2. Wrap all T-shirts using the same method and secure them with tape. Test that the T-shirts will slide down a piece of 3 inch PVC prior to beginning testing.
3. Obtain a map of the stadium using ticketing websites such as Ticketmaster or using Google Earth. Number each row on the map, starting at 1, until the top of the stadium is reached. For the football stadium, Figure 3.6.3A can be used. Note that for this example, this is the Northwest corner of the stadium.

Figure 3.6.3A: Football Stadium Map [4]

4. After arriving at the stadium, use sticky notes, index cards, or tape to label the rows in an appropriate increment. Position, at minimum, one person in the lower section and one

person in the upper section. If more people are available, position them evenly along the sections.

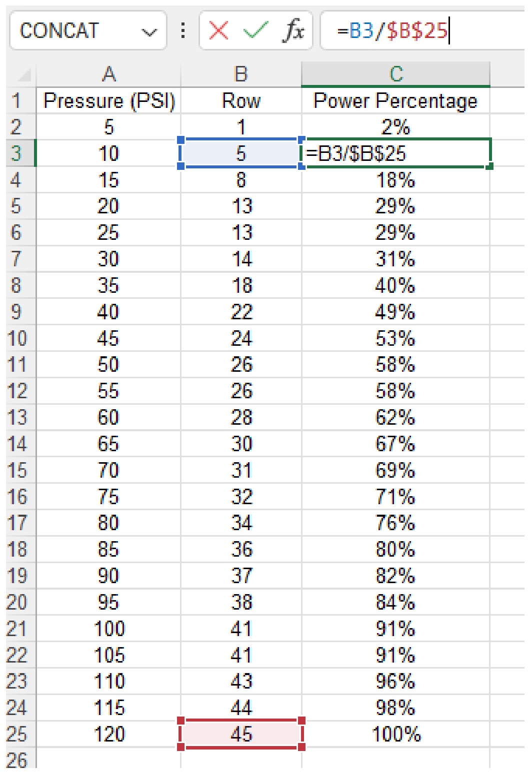
5. Using 20 PSI, launch a T-shirt from the red “X” in Figure 3.6.3A.
6. Have the individuals in the stands observe where the T-shirt initially lands. Note this is not where the T-shirt comes to rest. For example, if the T-shirt lands in Row 15, but bounces off the seat into Row 16, Row 15 should be recorded.
7. Repeat steps 5 and 6 a total of 5 times.
8. Repeat steps 5 through 7 up to 120 PSI, in increments of 20 PSI. Hold the T-shirt launcher at the same launch angle for all trials. Record the results in Table 3.6.3A.

Table 3.6.3A: Football Stadium Launch Results Template

Pressure (PSI)	**Average Row**
20	*TBD*
40	*TBD*
60	*TBD*
80	*TBD*
100	*TBD*
120	*TBD*

9. Remove the numbers placed on the rows and dispose of them. Gather all materials and leave the stadium.
10. Using Excel, input the pressures and corresponding average row in two columns of data.
11. Add a third column, and name it “Power Percentage.” In this column, divide the row number for that pressure by the highest row that was reached and format the data as a

percentage. For example, if at 10 PSI the T-shirt reached Row 5, and at 120 PSI the T-shirt reached Row 45, the Power Percentage for Row 10 will be 5 / 45 = 11%. An example is shown in Figure 3.6.3B.



	A	B	C
1	Pressure (PSI)	Row	Power Percentage
2	5	1	2%
3	10	5	=B3/B25
4	15	8	18%
5	20	13	29%
6	25	13	29%
7	30	14	31%
8	35	18	40%
9	40	22	49%
10	45	24	53%
11	50	26	58%
12	55	26	58%
13	60	28	62%
14	65	30	67%
15	70	31	69%
16	75	32	71%
17	80	34	76%
18	85	36	80%
19	90	37	82%
20	95	38	84%
21	100	41	91%
22	105	41	91%
23	110	43	96%
24	115	44	98%
25	120	45	100%
26			

Figure 3.6.3B: Sample Power Percentage Calculation

12. Plot the Pressure and the Power Percentage as a line graph, with Pressure on the x-axis and Power Percentage on the y-axis, as shown in Figure 3.6.3C.

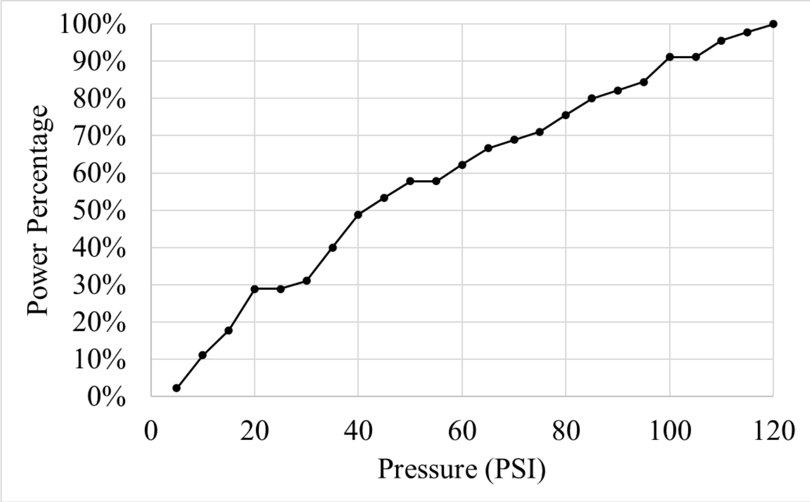


Figure 3.6.3C: Sample Chart of Pressure vs Power Percentage

13. Add a trendline to the chart, display the equation, and display the R Squared value. Target a R Squared value of above 0.99, but if that is not possible, target as high of a R Squared value as possible. In this example, a second order polynomial resulted in a R Squared of 0.9929, shown in Figure 3.6.3D.

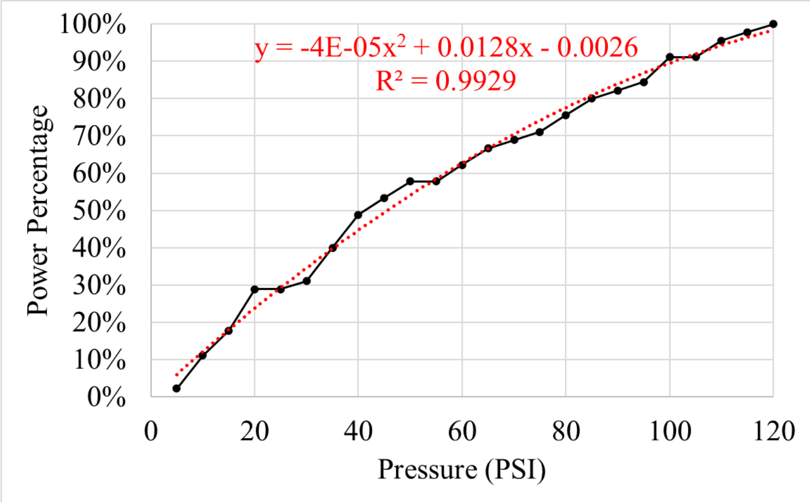


Figure 3.6.3D: Sample Equation of Fit for Power Percentage

14. Use the equation of fit to program the Arduino to display the appropriate Power Percentage based on the pressure.

As previously mentioned, the test was cut short due to incoming rain. Additionally, it was discovered that it is possible to launch a T-shirt outside of the football stadium at only 80 PSI, eliminating the need to do significant testing past this point. Due to these factors, the team had to change the test plan on the fly to gather enough data to create an equation to relate pressure and launch distance. The data gathered is shown in Table 3.6.3B.

Table 3.6.3B: Football Stadium Launch Results

Pressure (PSI)	Trial 1 Row	Trial 2 Row	Trial 3 Row	Trial 4 Row	Trial 5 Row	Average Row
10	14	5	-	-	-	9.5
20	14	20	21	18	19	18.4
40	33	33	33	39	35	34.6
80	45	45	-	-	-	45

Since at approximately 80 PSI the launcher can reach the top row, the calculated power percentage will actually reflect approximately how high the shirt will go in the stadium, instead of reflecting the power percentage of the launcher itself. For example, if at max pressure the T-shirts only made it halfway up the stadium, 100% power would just barely reach the second section. In the case recorded through experimentation, max power will represent the top row, 50% will represent the midpoint, and so on. Using the average row reached, the power percentage can be found for each PSI. Adding an additional data point at 0 PSI and 0% power, a line of best fit can be found using Excel, shown in Figure 3.6.3E.

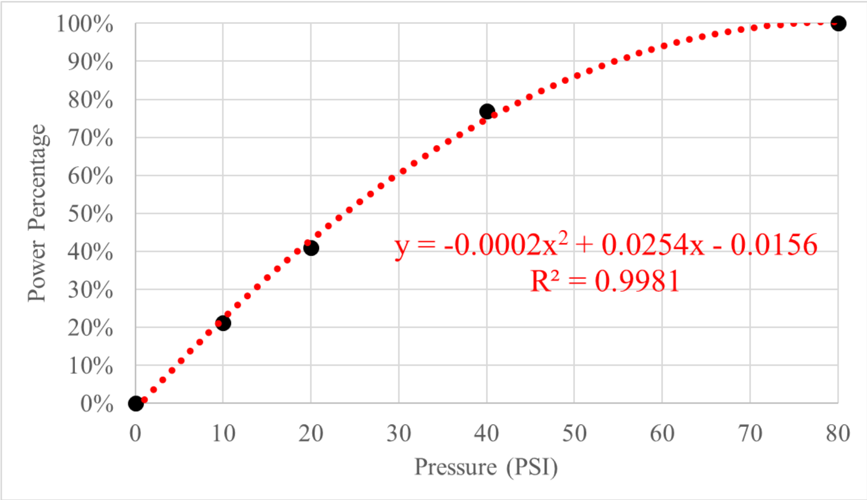


Figure 3.6.3E: Stadium Power Percentages

As seen in the figure, a second order quadratic equation fits the data very well, with a R squared value of over 0.99, indicating a very strong fit. Increasing the equation to be third or fourth order, the R squared value becomes very close to 1. This figure does not have to be perfect, as there will be many other factors during use that will affect the launch distance. Going forward, the team will use the equation shown in Figure 3.6.3E to calibrate the Arduino to show the user the approximate power level. If the team has the opportunity for further testing in the stadium, this equation may be refined.

4.0 Prototype and Testing

To date, the team has conducted prototyping of the system components that are vital to the primary function of the system, which is to launch T-shirts. The team has also prototyped 3D printed parts in preparation for the final manufacturing of the system. The team still has one final prototype test to complete, which involves testing the strength of the cement used to join the PVC barrel.

4.1 Prototype

So far, multiple components of the T-shirt launcher have been prototyped using 3D printing to verify their function prior to constructing the final version of each component. These components include the LOTO devices, trigger safety, and test prints to test tolerance of parts that fit around COTS parts.

4.1.1 Trigger LOTO Prototyping

The trigger LOTO went through five design iterations before reaching the final design. The first design consisted of two separate components that had matching slots to join together, along with a hole to lock the pieces together, shown in Figure 4.1.1A. This design, while functional, had many flaws. Mainly, since the two parts were not joined together, they would be easy to misplace, rendering the LOTO useless. Furthermore, the pins that align the two pieces are relatively thin, and when 3D printed, it appeared that they would be easy to snap off and break in order to access the device. Due to these factors, the design was scrapped and a new direction was taken.

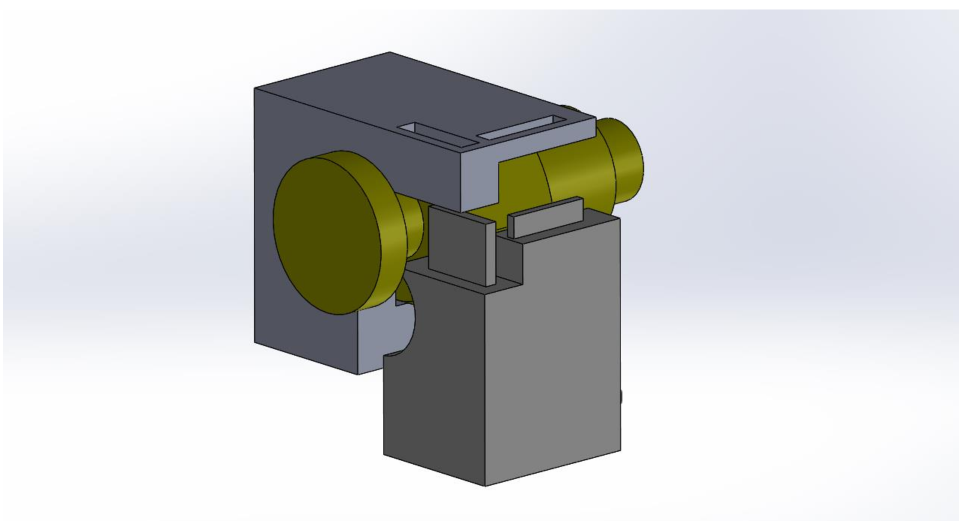
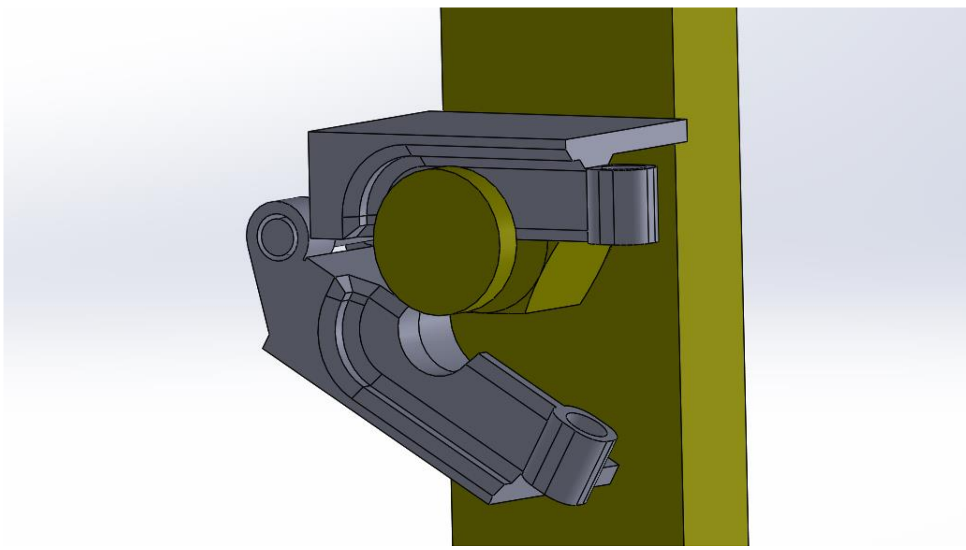


Figure 4.1.1A: Trigger LOTO V1

For Version 2, the new design utilized a 3D printed hinge that allowed the two components to be permanently joined, while still being able to be rotated about each other. This design also allowed for the lock to be placed to the side of the trigger, which is easier to assess. However, this design still had some drawbacks. First, the hinge was relatively small, and with enough force someone would be able to break the 3D printed material. Additionally, since there is an additional pneumatic fitting just above the trigger that was not taken into account, the LOTO device was unable to slide over the trigger, rendering it useless. This design is shown in Figure 4.1.1B.



4.1.1B: Trigger LOTO V2

Building upon the second version, the third design iteration solves the main problems, shown in Figure 4.1.1C. First, the hinge was made much thicker, making it stronger and more difficult to break. Additionally, the top part of the device was made straight so that it can slide over the top of the trigger without having to wrap around it. Finally, the lock was moved to the front so it does not interfere with installation. This design is fully functional, but is still not perfect. First, the inner wall of the device that prevents the trigger from being pressed was not thick enough, allowing the trigger to be slightly pressed. It was not enough to fully open the valve, but would allow air to leak out through the trigger. Additionally, the opening on the side could allow someone to use a wrench to remove the trigger mechanism, giving them a greater chance at using the device unauthorized.

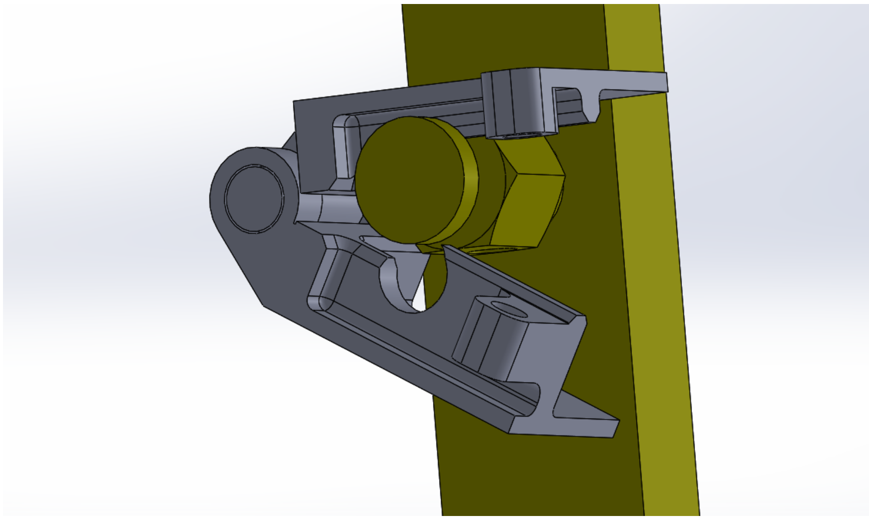


Figure 4.1.1C: Trigger LOTO V3

The fourth version, shown in Figure 4.1.1D, closely resembles the final version. For this version, the thickness of the inside wall was increased to ensure the trigger could not be depressed any amount. A wall was also added to block off access to the trigger with a wrench. The only issue with this design is that when it was added to the final assembly, it was discovered that the lock hole may be too close to the body of the device, interfering with the lock. This issue was corrected in the final version by extending the locking hole farther away from the device. The final version also features two additional holes on the side to allow for keychains to be attached.

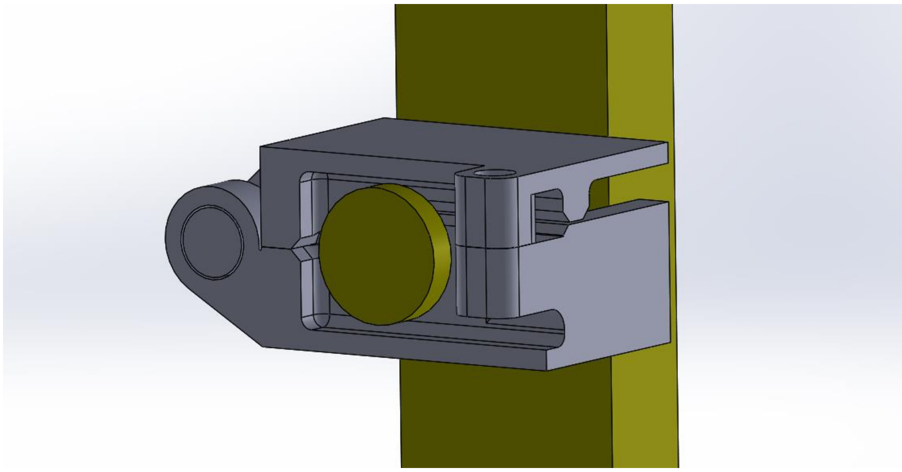


Figure 4.1.1D: Trigger LOTO V4

Prototyping the trigger LOTO allowed the team to flush out any small issues and arrive at the optimal final design. All four prototypes, along with the final design, are shown in Figure 4.1.1E.

Figure 4.1.1E: 3D Printed Trigger LOTO Prototypes

4.1.2 Air Inlet LOTO Prototype

Using the information learned from prototyping the trigger LOTO, the air inlet LOTO was able to be designed much quicker. The main difference between the initial prototype and the final model is the direction it faces. The original version originally called for the ball valve lever to be pointing away from the accumulator tank, but when put in a SolidWorks assembly, it was seen that this would cause the LOTO device to interfere with the SRB. To fix this, the design was mirrored for the lever to face inward, and two extra holes were added to the design to include keychains. The two models are shown in Figure 4.1.2.

Figure 4.1.2: Air Inlet LOTO Iterations

4.1.3 3D Print Tolerance Tests

During the final manufacturing, two critical 3D printed components must fit around other COTS parts to ensure a secure assembly of the system. Both of these items are related to the cosmetic barrel, with one being the cosmetic barrel itself, and the other being the internal bracket for the cosmetic barrel. To test the internal bracket, an offset of 0.025 inch around the 1.5 inch PVC was used to test the fit. Using an extra PVC adapter, the 3D printed component was tested as shown in Figure 4.1.3, exhibiting a secure fight while still being loose enough to slide on.

Figure 4.1.3: Cosmetic Barrel Internal Bracket Prototype

The other component, the cosmetic barrel itself, needed to be prototyped to test its fit around the barrel and the fit of the pins for alignment. This prototype was shown in Figure 3.5.1B. Using the same tolerance of 0.025 inch as the internal bracket, the test parts were able to slide over the barrel easily, while still offering a strong structure.

4.2 Further Prototype Testing

The final test to ensure the safety of the system involves rapidly pressurizing and depressurizing a piece of test PVC barrel that is enclosed, in order to test the strength of the PVC cement under cyclic loading. This test is intended to test what the PVC cement will experience over time as T-shirts are launched, which are short bursts of high pressure air. This test will be conducted on June 22nd, 2024, but the test will occur as follows:

1. Cut 6” of Schedule 40 3” PVC pipe.
    a. A small section of pipe will allow the vessel to be more rapidly pressurized and depressurized, better mimicking the actual loading the barrel will undergo. Additionally, 3” PVC is used as that is the maximum barrel diameter, and will be subject to the most force.
2. Gather two 3” Schedule 40 end caps, shown in Figure 4.2A.

Figure 4.2A: Schedule 40 End Caps

3. On one end cap, drill two 7/16 holes through the cap, shown in Figure 4.2B.
    a. Deburr the holes using 320 grit sandpaper.
    b. Tap the holes using a ¼ NPT tap.

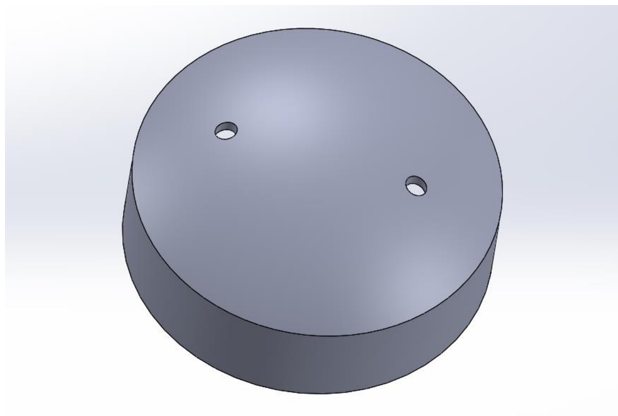


Figure 4.2B: End Cap with Holes

4. Thoroughly rinse the drilled PVC with a hose to remove any shards, dust, etc., and let air dry. Do not dry in the sun.
5. Wrap two male NPT quick connect fittings with 3 passes of PTFE tape.
    a. Screw NPT quick connects into the two holes of the PVC. Secure on the inside using nuts.
6. Per PVC cement instructions, chamfer the end of the 6" section of pipe using a file.
7. Install the non-drilled end cap to the PVC pipe per cement instructions:
    a. Using the supplied brush, apply a thick, even coat of cement to the outside of the PVC pipe section to the depth of the edge of the PVC end cap.
    b. Using the supplied brush, apply a thin, even coat to the flat mating surface on the inside of the PVC cap.

c. Apply a second, thin coat to the outside of the pipe section, recovering the initial thick coat.
d. Place the PVC pipe on level ground, with the cemented side facing up.
e. Press the end cap onto the PVC pipe. Once fully seated, turn the cap ¼ turn. Maintain full pressure on the end cap for 30 seconds.
f. Wipe off excess cement from the outside of the pipe.

8. Add ¼ cup of dish soap to the inside of the PVC vessel with the one end cap.
9. Repeat step 7 to install the end cap with the NPT adapters.
10. Allow the cement to cure for at least 2 hours, per PVC cement instructions.
11. Connect two 25’ pneumatic hoses to the male quick connects.
12. Place the vessel in a clear bucket with the NPT fittings and hoses facing up, fill the bucket with water, and ensure the vessel is submerged using a weighted belt.
13. Connect one of the air hoses to a closed ball valve.
14. Connect the other end of the hose to a ball valve that is attached to a male NPT quick connect fitting. The total setup is shown in Figure 4.2C.
    a. Connect this end to a compressor that is at least 25’ away and set to 144 PSI, which is a 20% increase over the rating for the pressure relief valve on the accumulator.
    b. Lean a piece of plywood against the compressor facing the vessel. This will act as a barrier between the vessel and people conducting the test.

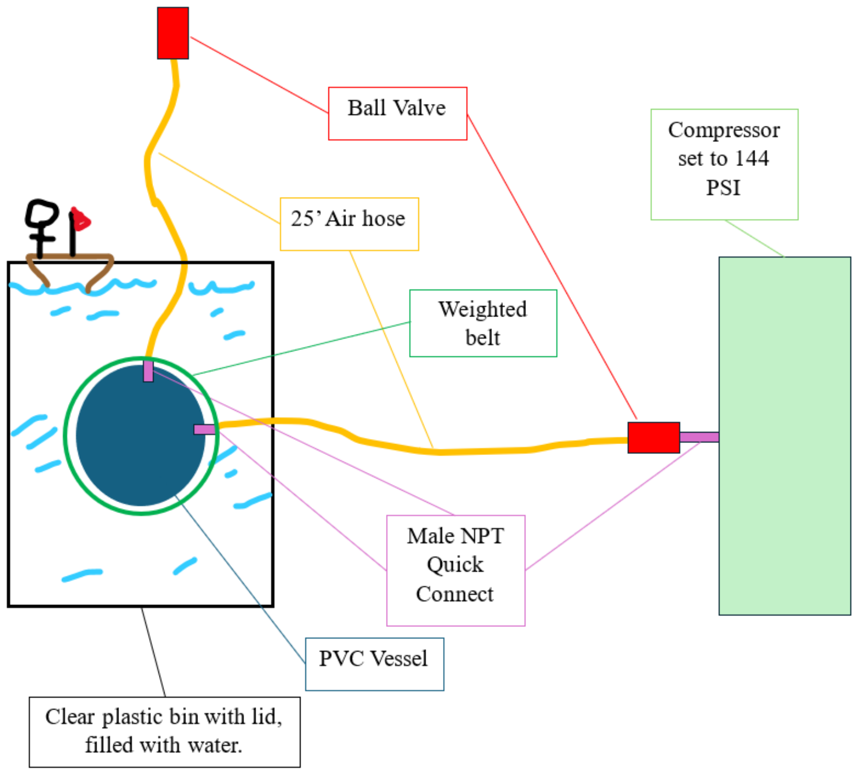


Figure 4.2C: PVC Cement Test Setup

15. Place the bin at the location shown below in Figure 4.2D. Wheel the compressor 25' away and place the plywood leaning on the compressor. Route the second air hose back to the compressor. The closest objects to the pressure vessel are:

    a. Pool screen 32' away

    b. House 38' away

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

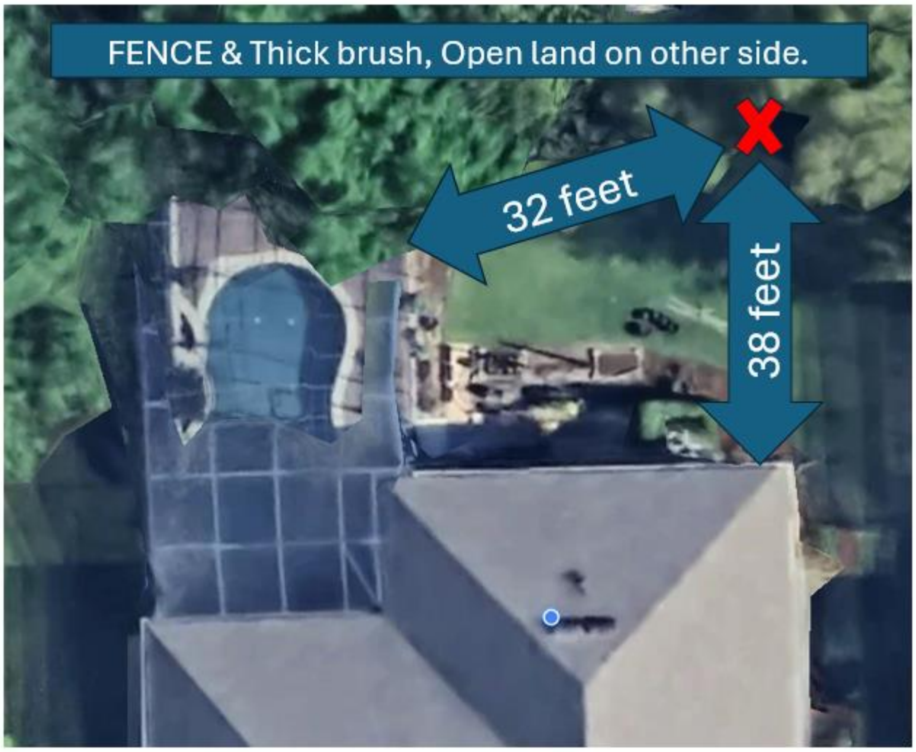


Figure 4.2D: PVC Test Location

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

Additional comments about testing:

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

After completing this test, the team will be able to make an informed decision if it is safe to proceed with constructing the barrel as initially planned. The results of this test will be documented in a future report.

4.3 Final System Testing (Requirement Verification)

To test the overall performance of the T-shirt launcher, each system requirement will be verified to assess the system performance. Each requirement requires a unique testing procedure and may require additional resources to verify. Additionally, some requirements may be verified at the subsystem level, before the T-shirt launcher is completely assembled. While the initial requirements were grouped into categories including General, Functional, Safety, Storage and Transportation, Maintenance, and Economic, testing will instead be grouped by the system, including: propulsion, reloading, electronics, safety, and storage.

4.3.1 Propulsion System Testing

Completing the propulsion system is the first major milestone in constructing the T-shirt launcher. This system must be complete prior to the reloading system, which will then enable the team to launch T-shirts for further tests. The requirements that can be verified with the propulsion system alone include Requirements G5.1, G9.1, S1.1, S1.2, S3.1, and S5.1.

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.

- Test Procedure - Using a ruler or tape measure, measure the length directly in front of the pneumatic trigger to the first obstruction. Take a picture of the ruler or tape measure in the measurement location and record the distance to the first obstruction.

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

- Air Compressor - The Dewalt air compressor provided by UCF Senior Design can be refilled on the main campus using outlets in the stadiums or in the UCF Machine Shop.
- Scuba Tank Test Procedure - If the scuba tank is refilled in the UCF Machine Shop or at the UCF Fire Department, document with written approval from the appropriate point of contact that the scuba tank is able to be refilled at their location. If the scuba tank is refilled at a local store, provide a receipt that shows the location of the store.

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

- Accumulator Test Procedure - First, connect the accumulator tank to the Dewalt air compressor at 0 PSI. Increase the output pressure of the air compressor in increments of 10 PSI and allow the accumulator tank to fill to the new pressure. Repeat this process from 0 to 110 PSI. Record the reading of the pressure gauge on the accumulator tank for each increase in PSI. Use Table 4.3.1 to record the results.

Table 4.3.1: Accumulator Tank Pressure Gauge

Compressor Output	**Accumulator Pressure**

Pressure (PSI)	**Gauge Reading (PSI)**
10	*TBD*
20	*TBD*
30	*TBD*
40	*TBD*
50	*TBD*
60	*TBD*
70	*TBD*
80	*TBD*
90	*TBD*
100	*TBD*
110	*TBD*

- Scuba Tank Test Procedure - Fill the scuba tank to its maximum working pressure of 2,140 PSI. Allow the scuba tank to cool to room temperature. Attach the scuba to NPT adapter and observe the pressure gauge reading. Record the pressure the scuba tank was filled to and the pressure gauge reading once the scuba tank has cooled to room temperature.

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.

- Test Procedure - Verification of Requirement S1.1 will also verify that the accumulator tank and scuba tank have an indicator if there is any amount of pressurized air being stored in them.

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

- Test Procedure - Connect the scuba tank to the accumulator tank using the pneumatic hose and NPT regulator. Adjust the knob on the regulator to read 120 PSI, which is the maximum rated pressure of the accumulator tank. The pressure relief valve should open at this pressure, letting out a burst of air. After the valve closes, the accumulator tank will refill to 120 PSI, where the pressure relief valve will reopen. Allow this process to repeat until the pressure relief valve will no longer open, meaning there is less than 120 PSI remaining in the scuba tank. Then, fully open the regulator and manually open the pressure relief valve until no more air can be heard escaping. After all air has been discharged from the system, record the reading of the pressure gauges on the accumulator and scuba tanks.

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

- Test Procedure - Verification of Requirement S3.1 will also verify that all energy can be released without firing a projectile.

4.3.2 Reloading System Testing

After verifying the requirements related to the propulsion system, the reloading system will be integrated with the propulsion system in a short period of time. With the propulsion and reloading systems completed, the T-shirt launcher will be fully functional and capable of launching T-shirts at the same distance as the complete system. The requirements that can be verified at this stage include Requirements F1.1, F1.2, F1.3, F2.1, F2.2, and F3.1.

<u>F1.1</u> - 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.

- Test Procedure - Load a T-shirt into the barrel of the T-shirt launcher. Increase the pressure of the accumulator tank to its maximum rated pressure, 120 PSI. Launch the T-shirt and record the distance using the rangefinder. Repeat this two more times for a total of three trials at 120 PSI.

  Repeat the previous step at a low PSI, such as 10 PSI, recording the distance of each of the three launches. Record the results in Table 4.3.2A. Subtract the two averages.

Table 4.3.2A: Launching Range

Trial	PSI	Distance (ft)
1	120	*TBD*
2	120	*TBD*
3	120	*TBD*
	Average:	*TBD*
4	10	*TBD*

5	10	*TBD*
6	10	*TBD*
	Average:	*TBD*

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

- Test Procedure - Using a piece of cardboard or similar object, create a grid pattern using squares that measure 1 square foot, as shown in Figure 4.3.2A.

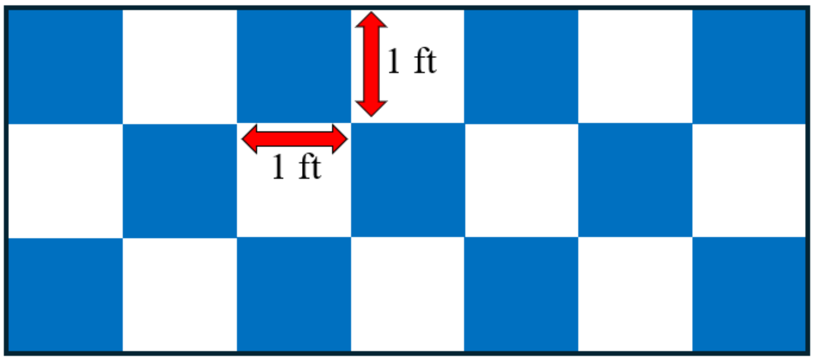


Figure 4.3.2A: Cardboard Checkerboard

Load a T-shirt into the barrel and fill the accumulator tank to its maximum working pressure. Then, have another individual hole the cardboard just at the end of the barrel. Using a slow motion camera, record the T-shirt being fired past the checkerboard pattern. It may be necessary to repeat this until the T-shirt can be seen in two separate frames. Use Equation 4.3.2, where *v* is the velocity in MPH, *x* is the distance the T-shirt traveled between consecutive frames in ft, and *t* is the inverse of the frame rate of the camera.

$$v = \frac{x}{t} \cdot \frac{3600}{5280} \quad (4.3.2)$$

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

- Test Procedure - Load a large T-shirt into the barrel, fill the accumulator tank to its maximum working pressure, launch the T-shirt, and record the launch distance using the rangefinder. Repeat this nine more times, for a total of 10 trials and record the results using Table 4.3.2B.

Table 4.3.2B: Launch Distance

Trial	**Launch Distance (ft)**
1	*TBD*
2	*TBD*
3	*TBD*
4	*TBD*
5	*TBD*
6	*TBD*
7	*TBD*
8	*TBD*
9	*TBD*
10	*TBD*
Average:	*TBD*

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

- Test Procedure - Verification of Requirements F1.2 and F1.3 using small, medium, and large T-shirts will also verify Requirement F2.1.

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

- Test Procedure - Starting with no T-shirts in the barrel and no compressed air in the accumulator tank, a user will be asked to launch as many T-shirts as possible in 90 seconds at 40 PSI. 40 PSI is chosen as an average that might be seen during actual use. Another individual will time the user and record the number of launches in 90 seconds. If 6 T-shirts or more are launched during the 90 seconds, Requirement F2.2 is satisfied.

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.

- Test Procedure - First, launch as many T-shirts as necessary to determine the pressure that results in a launch distance of 180 feet. Then, launch 10 T-shirts using the same power and launch orientation, leaving the T-shirts on the ground where they land. Once all 10 T-shirts have landed, determine if a 20 square foot rectangle can be outlined around 8 of the 10 shirts. If 8 shirts fall within a 20 square foot area, the requirement is met.

4.3.3 Electronics System Testing

After testing the reloading and propulsion systems, the electronics system can be integrated into the launcher. The electronics system consists of the pressure transducer, arduino, display, battery, and LED lights. The Requirements that can be verified with these three systems in place include Requirements G6.1, S1.3, S1.4, S2.1, and S2.2

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

- Test Procedure - Launch 5 shirts at various pressures and visually confirm that the LED lights turn on approximately when a T-shirt is launched. The lights must turn on for all 5 trials.

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.

- Test Procedure - With the electronics system turned on and fully charged, pressurize the accumulator tank to 115 PSI. Visually confirm that the Arduino display shows a warning message at this moment and take a picture.

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.

- Test Procedure - With the electronics system turned on and fully charged, pressurize the accumulator tank to approximately 5 PSI. Visually confirm that the Arduino display shows an indicator at this moment and take a picture.

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.

- Test Procedure - While a user is holding the launcher, they will be instructed to suddenly shut off the launcher. At this time, a stopwatch will start and the number of steps will be counted until shutdown is complete. This will also be verified in the number of steps stated in the user manual to shut down the launcher.

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

- Test Procedure - After the Emergency Shutdown System has been activated, confirm that:
    - The LED lights are off. This can be done visually.
    - The Arduino display is off. This can be done visually.
    - There is no power to the Arduino. Use a multimeter to probe the Arduino and confirm there is no voltage.

4.3.4 Safety System Testing

The safety system can be tested with only the propulsion system complete, meaning it can be tested without the reloading or electronics system. The dedicated safety system consists of the LOTO devices and trigger safety, but there are many more safety features of the launcher incorporated into other systems. The requirements that can be verified with the safety and propulsion systems complete include Requirements S4.1 and S7.1.

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

- Trigger LOTO Test Procedure - Place the trigger LOTO over the trigger and secure it using a lock. Fill the accumulator tank to 20 PSI and attempt to pull the trigger. Repeat this at 40, 60, 80, 100, and 120 PSI. If no air is released through the valve during any of these trials, the trigger LOTO is deemed effective.

- Air Inlet LOTO Test Procedure - Place the air inlet LOTO over the air inlet and secure it using a lock. Verify that the accumulator tank cannot accept compressed air with the LOTO device in place.

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

- Test Procedure - Clip on the trigger safety that is intended to be used while the launcher is in use. Pressurize the accumulator to 20 PSI and attempt to pull the trigger. Repeat this at 40, 60, 80, 100, and 120 PSI. If no air is released through the valve during any of these trials, the trigger safety is deemed effective.

4.3.5 Storage System Testing

The final system that can be tested prior to final system integration is the storage system. Certain aspects of this system can be tested without input from other systems, including Requirements ST1.1 and ST1.3.

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.

- Test Procedure - Obtain documentation from the point of purchase for the dimensions of the storage container.

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

- Solid Foreign Objects Test Procedure - Using a wire 1 mm in diameter, attempt to insert it in the closed container. If the container blocks the object from entering, the container has a rating of 4 against solid foreign objects.
- Water Test Procedure - Close the storage container and using a hose, spray it with water. Thoroughly dry the outside of the container, open the container, and observe if any water entered the container. If the inside is dry, the container has a rating of 5 against water, exceeding the requirement.

4.3.6 Final System Testing

After verifying all subsystems and integrating them, final testing can occur to verify the remainder of the requirements. These requirements can be grouped into two categories: those which do not require firing the launcher and those that do require firing the launcher. Firing the launcher involves determining a time and place to safely test. In addition, since this testing will be taking place in mid to late July, and the team would prefer to optimize the time spent outside testing due to the weather in Florida, consisting of unfathomable heat and humidity, as well as unpredictable thunderstorms.

4.3.6.1 Final System Testing without Launching

Many of the remaining requirements that can be tested without launching can be verified by a simple visual check to ensure that something exists and meets certain parameters. In total, 18 final requirements can be verified without firing the T-shirt launcher.

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.

- Test Procedure - Fully assembly the T-shirt launcher, including any additional T-shirts that can be stored in the SRBs. Using a scale, weigh the complete system and record the result.

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.

- Test Procedure - No additional components are intended to be carried by the user. Therefore, satisfying Requirement G1.2 will also satisfy Requirement G1.3.

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

- Solid Foreign Objects Test Procedure - Using a wire 1 mm in diameter, attempt to insert it in the electronics system. If the wire can enter the electronics system, the electronics do not have sufficient protection against solid foreign objects.
- Water Test Procedure - Using your hands, splash water on the water sensitive components for 10 seconds. If the components still function properly after splashing, they exhibit sufficient rating to 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.

- Test Procedure - Verify that the user, storage and transportation, and maintenance manuals state that the T-shirt launcher shall not be in possession of anyone under the age of 18.

<u>G4.1</u> - 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.

- Test Procedure - Verify that a user manual is completed and contains the required information.

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

- Test Procedure - After assembling the completed launcher, send photos and videos to project stakeholder Pete Alfieris and obtain confirmation that the launcher is themed appropriately.

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

- Test Procedure - Using a stopwatch, time how long it takes a trained operator to assemble the propulsion, reloading, electronics, safety, and Space-U systems from their subsystem state. The number of procedural steps will be counted in the user manual.

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

- The final design utilizes a pneumatic trigger that is in the form of a button, therefore this requirement does not have to be validated.

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

- Test Procedure - Observe the steps in the user manual that tell the user to fill the accumulator tank and fire the T-shirt. If there are 3 steps or more between these two tasks, the requirement has not been met.

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

- Accumulator Test Procedure - Perform an FEA analysis on the accumulator tank at its maximum rated pressure, 120 PSI, using conservative steel material properties, as described in Section 3.1.1.1.
- Scuba Tank Test Procedure - Relate DOT Regulations for 3AL pressure vessels to the allowed pressure inside the scuba tank and determine the maximum fill pressure to be compliant to a factor of safety of 3.5, as described in Section 3.1.1.2.

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

- Test Procedure - Place all items that are intended to be stored in their respective containers. Using a scale, record the weight of each fully loaded container.

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.

- Test Procedure - Verify that a storage and transportation manual is completed and contains the required information.

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

- Test Procedure - Using a stopwatch, time how long it takes a trained operator to disassemble the propulsion, reloading, electronics, safety, and Space-U systems from their subsystem state. The number of procedural steps will be counted in the storage and transportation manual.

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.

- Test Procedure - Verify that a maintenance manual is completed and contains the required information.

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

- Test Procedure - Track the tool size and system of units used to install all parts using Table 4.3.6.1.

Table 4.3.6.1: Hardware Units

Item	Tool Size	Tool Units
Rear Grip Screw	#4-40 Flat Head	Imperial
Pneumatic Trigger Button	5/8 in	Imperial
Clear Tube Fittings	1/2 in	Imperial
Ball Valve	5/8 in	Imperial
Male NPT Quick Connect	9/16 in	Imperial
Pressure Relief Valve	9/16 in	Imperial
BSP to NPT Adapter	*TBD*	*TBD*
NPT Tee Fitting	*TBD*	*TBD*
Pressure Gauge	*TBD*	*TBD*
Pressure Transducer	*TBD*	*TBD*
Valve Bolts	3/8 in	Imperial

Cosmetic Barrel Screws	#10-24 Allen	Imperial
Cosmetic Barrel Inserts	#10-24 Heat Set Insert	Imperial

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

- Test Procedure - Using the team parts list saved in the team shared folder, list the part, where it was purchased, and if it was 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.

- Test Procedure - The air compressor can be refilled anywhere on the UCF main campus using electricity. The scuba tank can be refilled at the UCF Machine Shop. The team may also send an inquiry to the fire department on campus about the possibility of refilling the scuba tank there. Regardless of the outcome of the fire department inquiry, this requirement is met, as the energy source can be refilled for free on campus.

E2.1 - The total cost to manufacture the T-shirt launcher shall not exceed $600. This is the budget levied by UCF Senior Design.

- Test Procedure - Using the parts list used for Requirement M3.1, list and total the cost of all purchased parts.

4.3.6.2 Final System Testing with Launching

The final two requirements require the entire system to be complete and to fire the launcher in order to verify, including Requirements G1.1 and S6.1.

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.

- Test Procedure - All six team members must hold the launcher, retrieve a T-shirt from one of the SRBs, load the T-shirt, and fire the launcher unassisted.

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

- Test Procedure - Starting with the verification of the integrated propulsion and reloading systems, the team will track how many T-shirts are launched over the testing process. After all other requirements are verified, the number of T-shirts remaining to be launched to verify this requirement can be calculated using Equation 4.3.6.2. Note that a cycle is defined as launching 6 T-shirts, as it is the team's intention that the launcher can launch 6 T-shirts (1 every 15 seconds) during a 90 second commercial break.

$$Remaining\ Launches\ =\ 450 - Launches\ to\ Date \qquad (4.3.6.2)$$

4.4 Requirement Verifications as of 6-21-2024

As of June 20th, some requirements have already been verified out of order of the original plan. Additionally, some requirements were verified during testing on June 21st. The results of these requirements will be provided in a future report, but the list of requirement verifications to date, including the June 21st tests, are provided in Table 4.4.

Table 4.4: Verifications to Date

Requirement Number	Requirement	Validation
G5.1	There shall be an unobstructed path of	No obstructions

	length 3 inches in front of the activation mechanism for the launcher, allowing for use by individuals in a mascot costume.	
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.	Can be refilled at UCF or at any scuba shop.
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.	6/21 - Difference of 114 ft from 20 PSI to 100 PSI
F1.2	The T-shirt launching system shall be capable of launching a T-shirt with a minimum exit velocity of 68.5 MPH.	6/21 - 80 MPH
F1.3	The T-shirt launching system shall be capable of launching a T-shirt a minimum of 180 feet.	6/21 - 197 ft at low launch angle
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.	Pressure gauges on accumulator and scuba tanks.
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.	Pressure gauges on accumulator and scuba tanks.
S4.1	The T-shirt launcher shall incorporate a Lock-Out / Tag-Out system to prevent unauthorized operation	LOTO devices prevent firing the launcher and filling the accumulator tank.
S7.1	The T-shirt launching system shall have a method to lockout the mechanism used to fire the launcher, preventing an accidental discharge.	Additional trigger safety prevents firing the launcher.
S9.1	Any energy storage devices, excluding	Scuba tank FOS: 3.5 (DOT Rating)

	batteries, shall adhere to a minimum safety factor of 3.5.	Accumulator FOS: 3.96 (FEA)

5.0 Development Planning

To guide the team towards major project milestones, a Gantt Chart was created in Senior Design I and has been continuously updated. The initial Gantt Chart used generalizations based on various systems that had been identified, but since the systems were not designed, it was difficult to add detailed tasks to the Gantt Chart. As the final system was designed, the Gantt Chart was continuously updated to better reflect the tasks ahead. The current Gantt Chart includes all tasks and the team members responsible for those tasks. Each task in the Gantt Chart includes a description when the task is opened. At the time of writing this report, the team is finalizing the purchase of all commercial components and beginning the construction of the T-shirt launcher.

5.1 Finalizing CAD Models

The first few weeks of Senior Design II was used to finalize the detailed design of the T-shirt launcher. This was broken down into the various subsystems, and each system was led by a team member. The portion of the Gantt Chart for these tasks is shown in Figure 5.1.

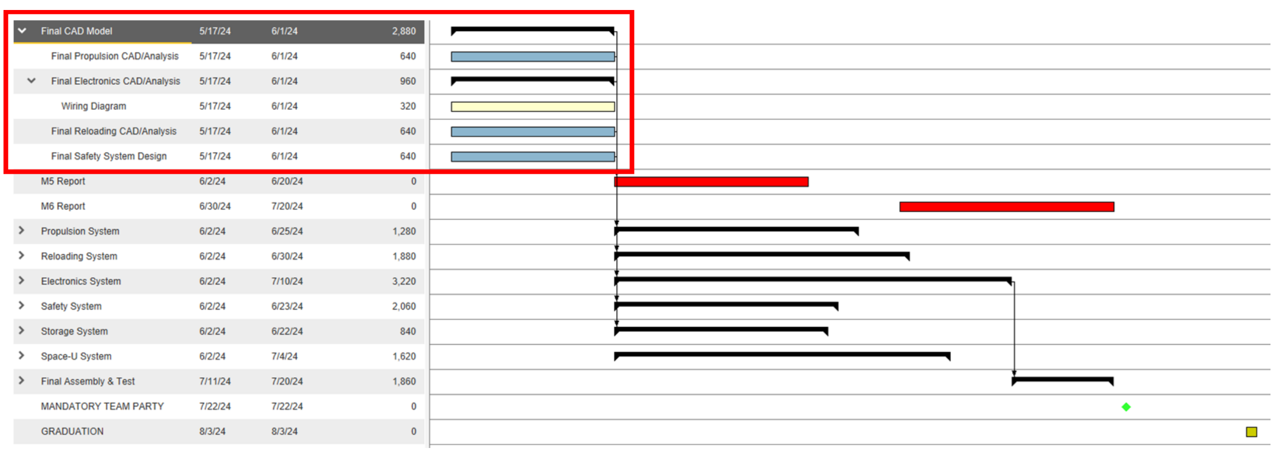


Figure 5.1: Gantt Chart: Final CAD Models

As the Gantt Chart has grown larger and more detailed, it has become difficult to portray its detail through screenshots. Therefore, the above section of the Gantt Chart is summarized in Table 5.1.

Table 5.1: Final CAD Model Tasks

Task	Lead	Due Date	Completion Date	Notes
Propulsion CAD & Analysis	Austin	6/1/2024	5/30/2024	None
Electronics CAD & Analysis	Julian	6/1/2024	6/1/2024	Was completed to extend possible without Arduino display and pressure transducer. Time is allocated during building to complete coding, testing, etc.
Reloading CAD & Analysis	Tyler	6/1/2024	6/2/2024	Team did final testing on different reloading methods on 5/31/2024 and used an extra day to ensure the CAD model was sufficient.
Safety CAD & Analysis	David	6/1/2024	5/31/2024	None

5.2 Procuring Components

After finalizing the CAD models for the various systems, the team moved to order the commercial parts that would be used to construct the T-shirt launcher. This task was not able to be started as soon as the team would have preferred due to external factors, such as waiting for account numbers and funding to be finalized. However, all components have been ordered and delivered or picked up as of June 20th, just one day after the last allocated day for accumulating parts. The status, items, and price of all orders is shown in Table 5.2. The team acknowledges additional purchases may be necessary, and they will have to be placed as soon as the need arises to not delay any timelines. The Gantt Chart allowed from June 2nd to June 19th to order all components. The team used this time to write this report, as it offered the best time to complete while not taking time away from building the systems.

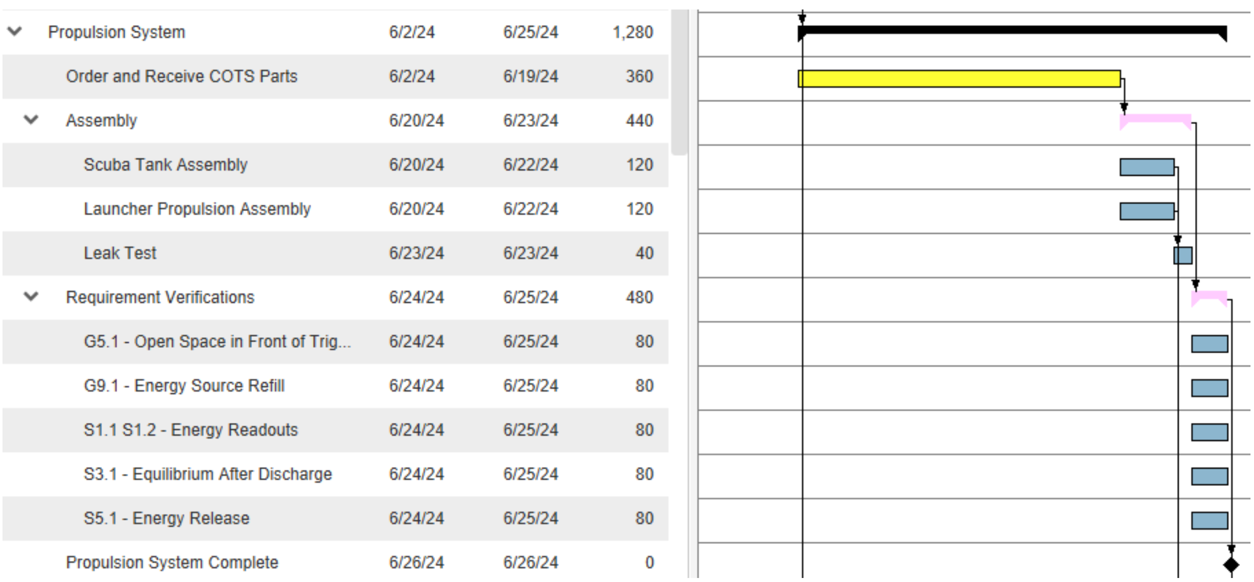
Table 5.2: Purchases to Date

Vendor	Price	Date Placed	Status	Components
Amazon	$192.65	6/2/2024	Received	Pressure fittings, electronics, PETG, T-shirts, storage device, keychains
Amazon	$279.94	6/2/2024	Received	Scuba tank, scuba adapter
Home Depot	$21.57	6/2/2024	Received	PVC, PVC adapters, pressure hose, pressure fittings
Grainger	$2.62	6/2/2024	Received	PVC adapter
McMaster Carr	$11.33	6/2/2024	Received	Metal BSP to NPT adapter
Amazon	$10.99	6/11/2024	Received	Heat set inserts
Lowes	$27.62	6/18/2024	Received	PVC end caps, screws,

washers

5.3 Propulsion System

After gathering the materials needed, the various subsystems will be built independently and gradually integrated to complete the final system. The propulsion system has been identified as the base of the entire launcher, as all other systems attach to it. Therefore, the propulsion system will receive first priority in building. The portion of the Gantt Chart for constructing the propulsion system is shown in Figure 5.3.



Propulsion System	6/2/24	6/25/24	1,280
Order and Receive COTS Parts	6/2/24	6/19/24	360
Assembly	6/20/24	6/23/24	440
Scuba Tank Assembly	6/20/24	6/22/24	120
Launcher Propulsion Assembly	6/20/24	6/22/24	120
Leak Test	6/23/24	6/23/24	40
Requirement Verifications	6/24/24	6/25/24	480
G5.1 - Open Space in Front of Trig...	6/24/24	6/25/24	80
G9.1 - Energy Source Refill	6/24/24	6/25/24	80
S1.1 S1.2 - Energy Readouts	6/24/24	6/25/24	80
S3.1 - Equilibrium After Discharge	6/24/24	6/25/24	80
S5.1 - Energy Release	6/24/24	6/25/24	80
Propulsion System Complete	6/26/24	6/26/24	0

Figure 5.3: Gantt Chart: Propulsion System

The propulsion system is composed of all COTS parts, making its assembly very straightforward. The scuba tank system will first be assembled, which involves attaching the scuba tank to the scuba adapter, which is further attached to the pressure regulator. While this is occurring, other team members will be attaching the pressure fittings to the accumulator tank. Once both components are complete, they can be leak tested to ensure the fittings are securely attached. As described in

Section 4.3.1, five requirements can be verified at this stage. The tasks to complete the propulsion system are shown in Table 5.3.

Table 5.3: Propulsion System Tasks

Task	Team Members	Due Date
Assemble Scuba System	Austin	6/22/2024
Assemble Accumulator Tank	Sahil	6/22/2024
Leak Test	Austin, Sahil	6/23/2024
Requirement Verification	Austin, Sahil	6/25/2024

5.4 Reloading System

While the propulsion system is being built and tested, the reloading system will be constructed to be completed just after the propulsion system to enable further testing involving launching T-shirts. The completion of the reloading and propulsion systems marks a major milestone, as it will be the first time the team has a functioning launcher with the exact performance characteristics of the final system. The portion of the Gantt Chart for the reloading system is shown in Figure 5.4.

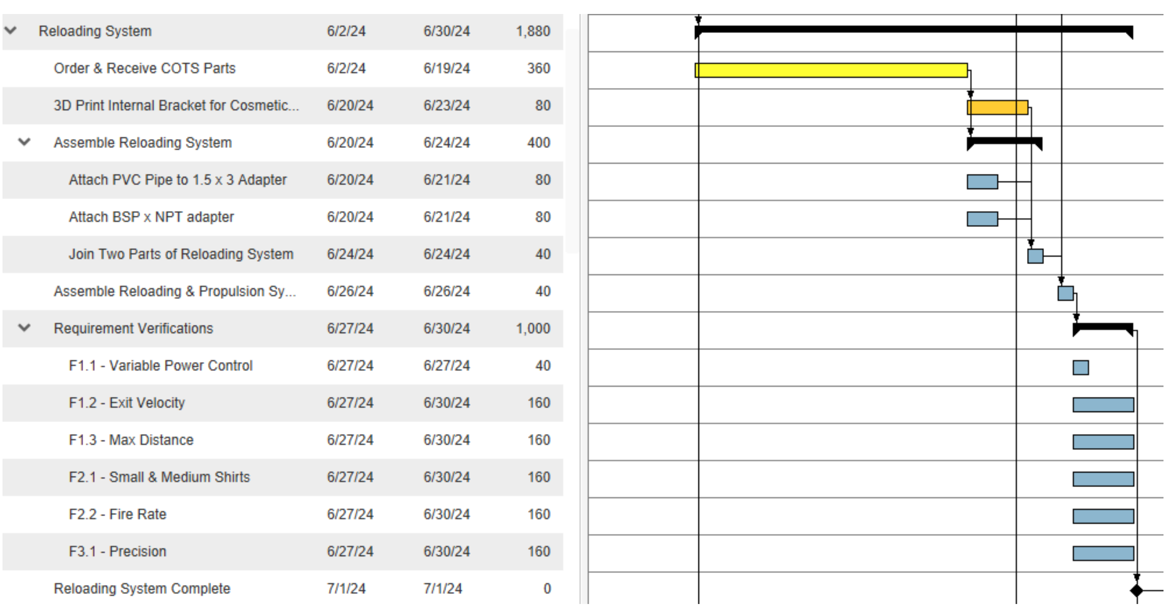


Figure 5.4: Gantt Chart: Reloading System

Similarly to the propulsion system, the reloading system is composed of mostly COTS parts. The only caveat to this is that the internal bracket for the cosmetic barrel, part of the Space-U system, must be installed as part of the reloading system. This component has already been 3D printed, making this not an issue. The two parts of the reloading system that go on either side of the bracket will first be assembled separately. Once fully cured, the two sides will be joined together, sandwiching the bracket in the middle. As described in Section 4.3.2, there are six requirements that can be verified with the propulsion and reloading systems complete, which will occur after they are mated. The tasks for the reloading system are shown in Table 5.4. Note how the reloading and propulsion systems are joined on June 26th, only one day after completing the propulsions system as described in the previous section. Timely execution of all tasks is essential to stay on target.

Table 5.4: Reloading System Tasks

Task	Team Members	Due Date
3D Print Cosmetic Barrel Bracket	Austin	6/23/2024 (Completed 6/9/2024)
Assemble Barrel	Tyler	6/21/2024
Assemble Adapter	Tiffany	6/21/2024
Join Barrel and Adapter	Tyler, Tiffany	6/24/2024
Join Reloading & Propulsion Systems	Tyler, Tiffany	6/26/2024
Requirement Verification	Tyler, Tiffany	6/30/2024

5.5 Electronics System

The electronics system poses unique challenges as it is the only system that could not be designed in completion during the stage of finalizing the CAD models. Due to this, significant time is allotted to iteratively working on the coding of the electronics system, as shown in Figure 5.5.

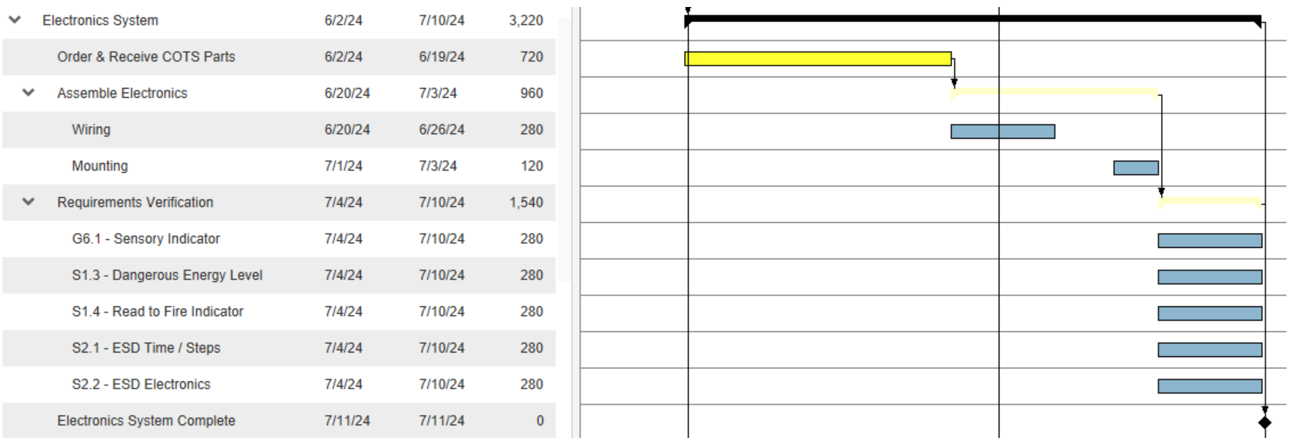


Figure 5.5: Gantt Chart: Electronics System

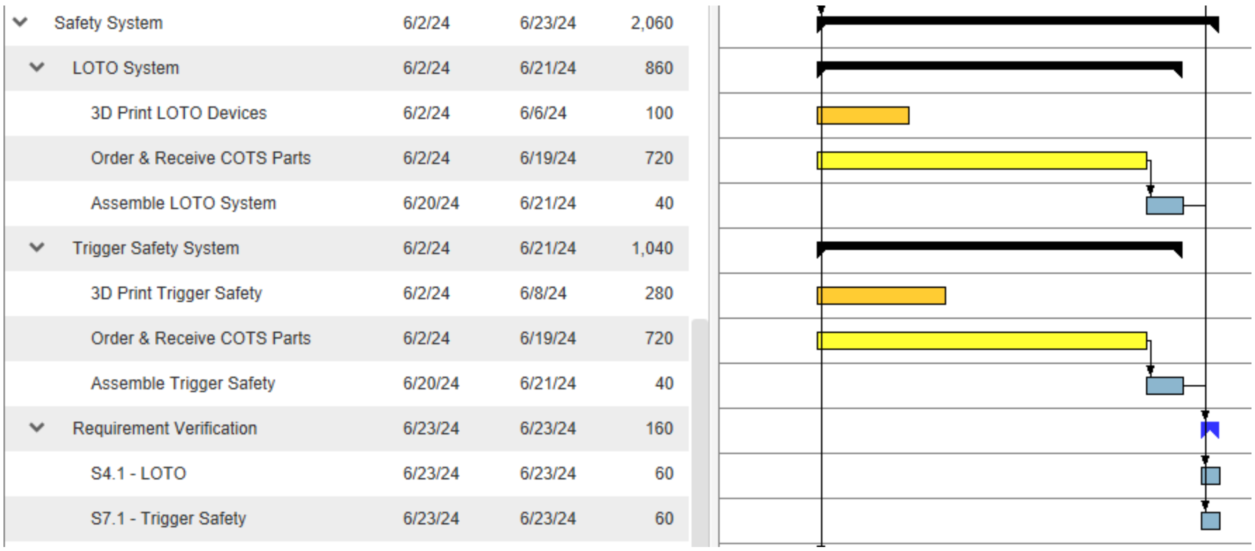
The first part of the electronics system is relatively straightforward, which involves wiring the system and mounting the Arduino to its housing. Approximately two weeks is allocated to this, although it should only take a few days. After this, one week is allowed for requirement verification. Between the excess time in wiring and requirement verification, there is additional time allowed for troubleshooting, adjusting code, and verifying the system functions. The tasks are shown in Table 5.5. While two team members are responsible for the electronics system, it will likely take the collective effort of the team to troubleshoot and effectively integrate the electronics system.

Table 5.5: Electronics System Tasks

Task	Team Members	Due Date
Wiring	Julian, David	6/26/2024
Mounting	Julian, David	7/3/2024

5.6 Safety System

Possibly the most important system, the safety system has already largely been completed using 3D printed parts. The complete list of tasks for the safety system is shown in Figure 5.6.



Safety System	6/2/24	6/23/24	2,060
LOTO System	6/2/24	6/21/24	860
3D Print LOTO Devices	6/2/24	6/6/24	100
Order & Receive COTS Parts	6/2/24	6/19/24	720
Assemble LOTO System	6/20/24	6/21/24	40
Trigger Safety System	6/2/24	6/21/24	1,040
3D Print Trigger Safety	6/2/24	6/8/24	280
Order & Receive COTS Parts	6/2/24	6/19/24	720
Assemble Trigger Safety	6/20/24	6/21/24	40
Requirement Verification	6/23/24	6/23/24	160
S4.1 - LOTO	6/23/24	6/23/24	60
S7.1 - Trigger Safety	6/23/24	6/23/24	60

Figure 5.6: Gantt Chart: Safety System

The first set of tasks, which has already been completed, involved 3D printing the LOTO devices and trigger safety, as well as verifying their function. The only COTS parts needed for this system are locks for the LOTO devices and a keychain to tether the trigger safety, both of which have been ordered and received. They can quickly be placed on their respective components to ensure a proper fit. After this, the system can be verified. These tasks are shown in Table 5.6.

Table 5.6: Safety System Tasks

Task	Team Members	Due Date
3D Print LOTO Devices	Austin	6/6/2024 (Completed 6/7/2024)
Assemble LOTO System	Sahil	6/21/2024
3D Print Trigger Safety	Austin	6/6/2024 (Completed 6/4/2024)
Assemble Trigger Safety	Sahil	6/21/2024
Requirement Verification	Austin, Sahil	6/23/2024

5.7 Storage System

Being the simplest system, the storage system does not require any assembly. Instead, the storage container being used must be purchased and tested, which is shown in the Gantt Chart in Figure 5.7.

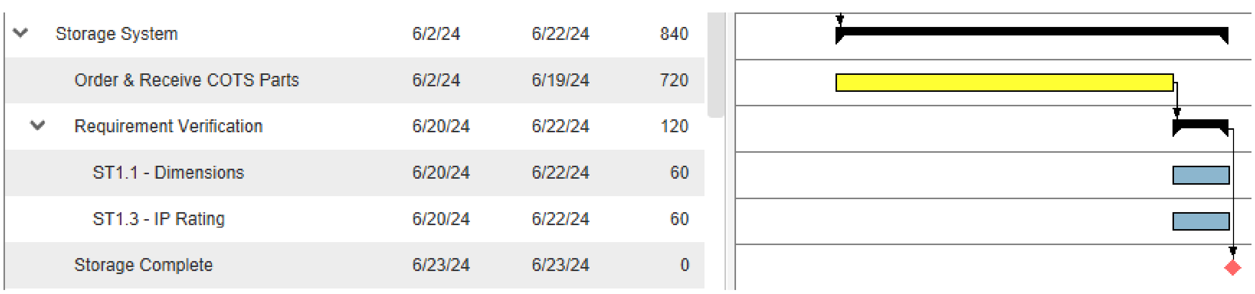
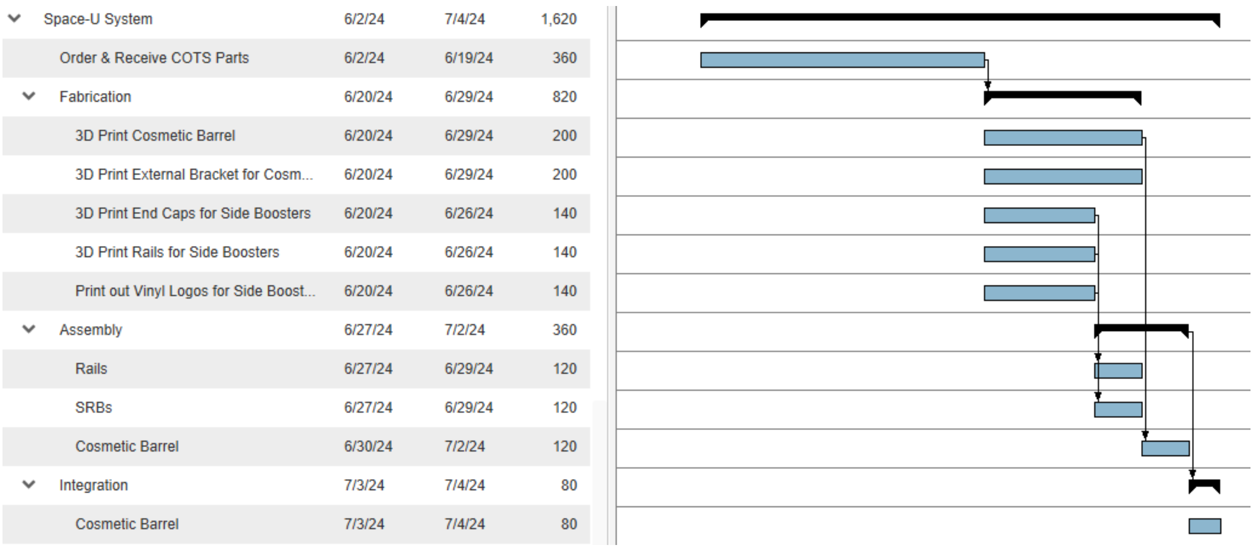


Figure 5.7: Gantt Chart: Storage System

After receiving the storage device, it can quickly be tested to verify it meets the related requirements, which is outlined in Section 4.3.5. These tasks will be performed by Austin and Tyler, as they will have the easiest ability to coordinate a time to test the storage device.

5.8 Space-U System

The Space-U system offers a unique dilemma. It is the most labor intensive and time consuming system to construct, while being unnecessary to the function and safety of the launcher and serving the sole purpose of making the launcher special for UCF, which is still very important. Due to this, the construction of the Space-U system will be spread out over a longer period of time, as seen in Figure 5.8, as it does not postpone any requirement verifications.



Space-U System	6/2/24	7/4/24	1,620
Order & Receive COTS Parts	6/2/24	6/19/24	360
Fabrication	6/20/24	6/29/24	820
3D Print Cosmetic Barrel	6/20/24	6/29/24	200
3D Print External Bracket for Cosm...	6/20/24	6/29/24	200
3D Print End Caps for Side Boosters	6/20/24	6/26/24	140
3D Print Rails for Side Boosters	6/20/24	6/26/24	140
Print out Vinyl Logos for Side Boost...	6/20/24	6/26/24	140
Assembly	6/27/24	7/2/24	360
Rails	6/27/24	6/29/24	120
SRBs	6/27/24	6/29/24	120
Cosmetic Barrel	6/30/24	7/2/24	120
Integration	7/3/24	7/4/24	80
Cosmetic Barrel	7/3/24	7/4/24	80

Figure 5.8: Gantt Chart: Space-U System

The first part of this system is the most time consuming aspect of the project, which involves 3D printing most of the components for the system, including the cosmetic barrel, side booster caps, and side booster rails. At the same time, the bodies of the side boosters need to be cut to size and the decals need to be created. The size of the cosmetic barrel makes it time consuming to 3D print. The filament and 3D print files were delivered to the UCF TI Lab on June 21st, with an expected delivery date of June 25th by the TI Lab. The tasks and responsible team members for the Space-U system is shown in Table 5.8.

Table 5.8: Space-U System Tasks

Task	Team Members	Due Date
3D Print Cosmetic Barrel	Julian	6/29/2024
3D Print Bracket for Barrel	Tyler	6/29/2024
3D Print Side Booster End Caps	Austin	6/26/2024
3D Print Side Booster Rails	Julian	6/26/2024
Print Vinyl Logos	Austin	6/26/2024
Assemble Rails	Julian, Tyler	6/29/2024
Assemble SRBs	Austin	6/29/2024
Assemble Cosmetic Barrel	Julian, Tyler	7/2/2024
Install Cosmetic Barrel	Julian, Tyler	7/4/2024

5.9 Final Assembly and Test

Once all of the subsystems are complete, the final T-shirt launcher can be assembled and tested. At this point, all systems will have been integrated with the exception of the electronics system. The portion of the Gantt Chart for Final Assembly and Test is shown in Figure 5.9.

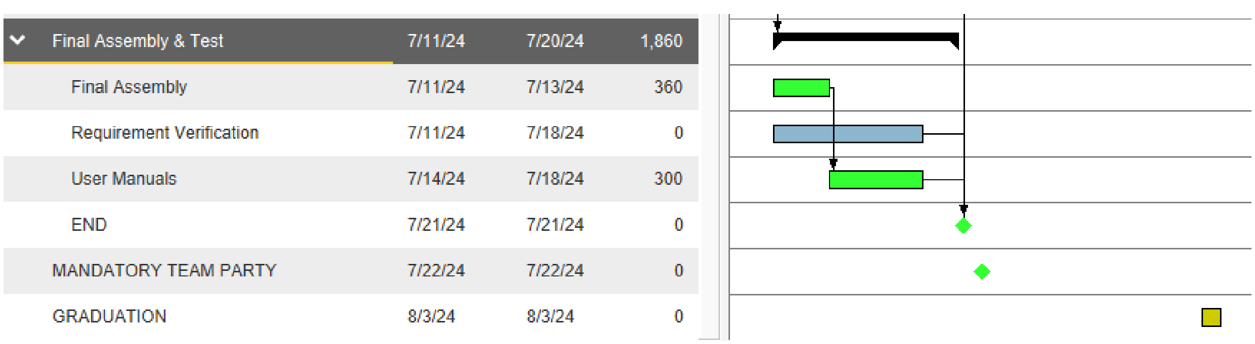


Figure 5.9: Gantt Chart: Final Assembly and Test

After ensuring all subsystems are joined, the Gantt Chart allows a full week for verifying the remaining requirements which were outlined in Section 4.3.6 and writing the various manuals that are required for the launcher. The manuals can be started before this, but the final system will be required to take pictures of various steps in each manual. Starting at the beginning of July, the team will begin working on the M6 Report. The final week of testing and manual writing will also be used to finish this report. The team has the UCF football stadium reserved on July 21st for a final test, which will mark the completion of the project. The current schedule ends the project approximately 12 days before the end of the semester. This is intentional to have some extra padding to account for the unknown or any unforeseen issues. These final tasks are shown in Table 5.9.

Table 5.9: Final Assembly and Test Tasks

Task	Team Members	Due Date
Final Assembly	Entire Team	7/13/2024
Requirement Verification	Entire Team	7/18/2024
User Manuals	Tyler, Tiffany, Austin	7/18/2024
End of Project	Entire Team	7/21/2024

6.0 Conclusion

As the analysis, risk assessment, and testing conclude and the team enters the final stages of the project, it is important to note the importance of maintaining consistency with testing, analysis, and documentation. The team strives to provide accurate reflections and displays on the devices performance and ensure that all components of the design are completely safe before final implementation and usage. Some key notes to follow up with while moving away from this report are to ensure that accurate testing is utilized and observations are accurately noted. The next steps in the process will be to assemble a prototype, test systems such as the electrical system, adjust the cosmetic design of the device and ease of applications, and allow ample time to test all requirements that were set in the M2 documentation.

7.0 References

[1] Boxen, E. (2023, July 5). *Materials for UV-resistant 3D printing*. Slimprint. https://slimprintshop.com/blogs/home-decor/uv-resistant-3d-printing

[2] *BU-808: How to prolong lithium-based batteries*. Battery University. (2023, October 11). https://batteryuniversity.com/article/bu-808-how-to-prolong-lithium-based-batteries

[3] Burman, F. (2021, February 24). *Cylinder safety*. Divers Alert Network. https://dan.org/alert-diver/article/cylinder-safety/#:~:text=Store%20cylinders%20that%20will%20not,(10%20and%2020%20bar).

[4] *Cincinnati at UCF Tickets in Orlando (FBC mortgage stadium) - oct 12, 2024, Time TBD*. SeatGeek. (2024). https://seatgeek.com/ucf-knights-football-tickets/ncaa-football/2024-10-12-3-30-am/6370906

[5] Clark, M. (2018, July 25). *ASME Section VIII BPV Code & the Pressure Vessel Safety Factor*. Think CEI. https://info.thinkcei.com/think-tank/asme-standards

[6] Creep and creep failures, https://www.nationalboard.org/Index.aspx?pageID=181 (accessed Jun. 19, 2024).

[7] *Creep in Regulators - Cause, Effect and Prevention*. Swagelok. (n.d.). https://bangalore.swagelok.com/en/knowledge/pressure-regulators/prevent-creep-in-regulators

[8] *Dewalt 6 gal. 165 Psi Electric Pancake Air Compressor DWFP55126*. The Home Depot. (2024, February 28). https://www.homedepot.com/p/DEWALT-6-Gal-165-PSI-Electric-Pancake-Air-Compressor-DWFP55126/205298243?g_store=&source=shoppingads&locale=en-US&pla&mtc=SHOPPING-BF-CDP-GGL-D25P-025_028_COMP_AIRTOOL-NA-NA-NA-PMAX-NA-NA-NA-NA-NBR-NA-NA-NA-Compressors_PMAX&cm_mmc=SHOPPING-BF-CDP-GGL-D25P-025_028_COMP_AIRTOOL-NA-NA-NA-PMAX-NA-NA-NA-NA-NBR-NA-NA-NA-Compressors_PMAX-71700000117165771--&gad_source=1&gclid=CjwKCAjw34qzBhBmEiwAOUQcF_Qqv6Euk_Hu9IIHr2MmY-gqv-3JrcpQ5kZ2-OsvtGeUB2h2Jjq46BoCAoYQAvD_BwE&gclsrc=aw.ds

[9] Dough, J. (2021, October 21). *What are "remove before flight" tags for?* National Aviation Academy. https://www.naa.edu/remove-before-flight/

[10] High, B. (n.d.). *Cracking and Ruptures of SCBA and SCUBA Aluminum Cylinders*. hawaii.edu. http://www.hawaii.edu/ehso/wp-content/uploads/2016/07/Cracking-and-Ruptures-of-SCBA-and-SCUBA-Aluminum-Cylinders.pdf

[11] *How strong is carbon steel?*. TechTalk Blog. (2020b, February 7). https://www.polycase.com/techtalk/steel-enclosures/how-strong-is-carbon-steel.html#:~:text=AISI%201020%20steel%2C%20a%20low,tensile%20strength%20of%2065%2C300%20psi.

[12] Joyce, J. (2023, December 15). Brass vs. stainless steel fittings. Brennan Industries Blog. https://blog.brennaninc.com/brass-vs-stainless-steel-fittings

[13] Kinney, D. (2023b, February 26). Burst discs - the ignored safety device. Cylinder Training Services. https://cylindertrainingservices.com/burst-discs-the-ignored-safety-device/#:~:text=Therefore%2C%20the%20burst%20disc%20should,and%20multiply%20it%20by%201.66.

[14] M., M. M., & A., I. A. (2016). Friction Coefficient and Triboelectrification of Textiles. Journal of Multidisciplinary Engineering Science and Technology (JMEST), 3(2), 3970–3976.

[15] NASA. (2023, October 3). Project gemini. NASA. https://www.nasa.gov/gemini/

[16] National Archives. (2020, December 28). *178.46 Specification 3AL seamless aluminum cylinders*. Code of Federal Regulations. https://www.ecfr.gov/current/title-49/subtitle-B/chapter-I/subchapter-C/part-178/subpart-C/section-178.46

[17] Orias. (2017, April 17). *Tips and Tricks: Heat-Set Inserts* . Lulzbot. https://lulzbot.com/learn/tips-and-tricks-heat-set-inserts

[18 Preece Precision. (2023, April 23). *Series 1000 fixed flow scuba tank air regulator for running air tools and inflating tires*. https://preeceproducts.com/shop/ols/products/series-1000-fixed-flow-co2-regulator-srs-100-fxd-flw

[19] Pressure vessel fatigue, https://www.nationalboard.org/index.aspx?pageID=164&ID=441 (accessed Jun. 19, 2024).

[20] *PVC and CPVC Pipe Sizes and Weights*. PVC Pipe Supplies. (n.d.). https://pvcpipesupplies.com/pvc-cpvc-pipe-sizes-and-weights

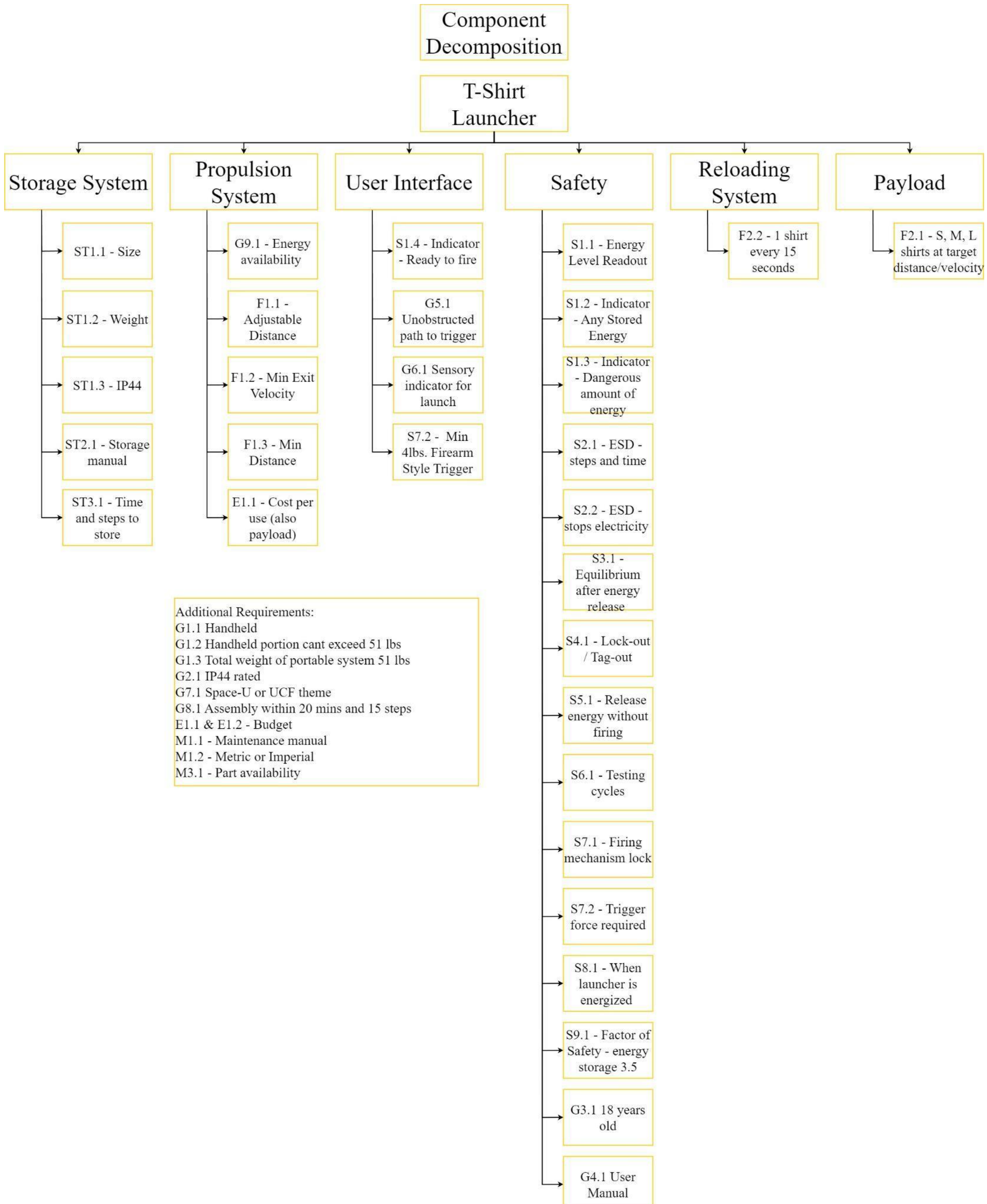
[21] Rohrbach, Z. J., T. R. Buresh, and M. J. Madsen. “The Projectile Velocity of an Air Cannon.” Wabash Journal of Physics 4.3 (May 6, 2011): 1–9.

[22] *The effects of sunlight exposure on PVC pipe and Conduit*. JM Eagle. (2009, January). https://www.jmeagle.com/sites/default/files/TB10SunlightEffectsonPVC.pdf

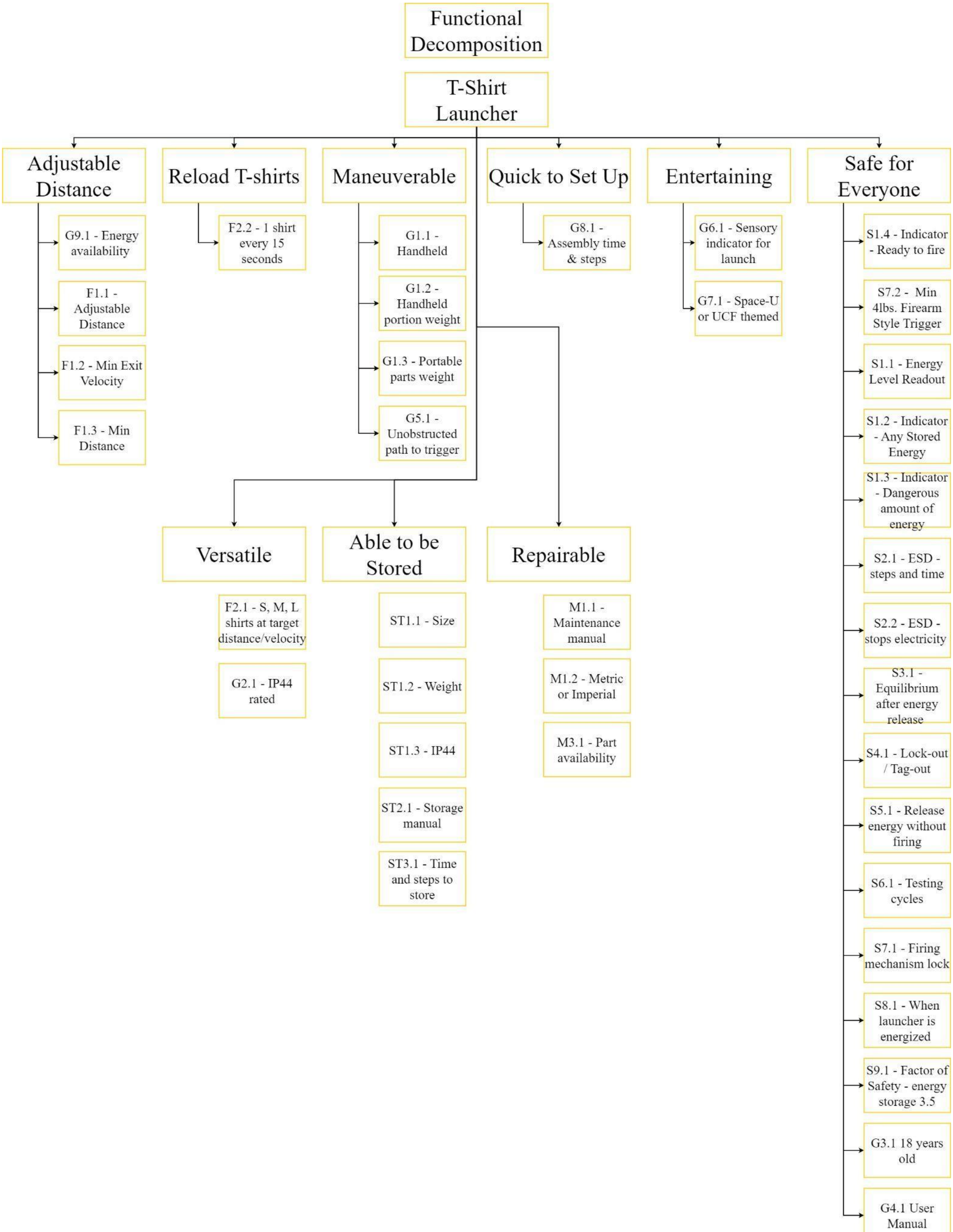
[23] *United States*. 3M United States. (n.d.). https://www.scotchbrand.com/3M/en_US/p/d/cbgnawus1861/

<u>Appendix</u>

A: Component Decomposition



B: Functional Decomposition



C: Failure Mode Ranking Criteria

FMEA Likelihood Rankings

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

FMEA Criticality Rankings

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

FMEA Detection Rankings

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

D: System Requirements

System Requirements

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

G5.1	There shall be an unobstructed path of length 3 inches in front of the activation mechanism for the launcher, allowing for use by individuals in a mascot costume.
G6.1	The T-shirt launching system shall contain a sensory indicator or effect when a T-shirt is launched.
G7.1	The T-shirt launching system shall feature visual cues or branding that indicate clear intended use specifically for UCF or Space-U.
G8.1	The T-shirt launching system shall facilitate assembly by a trained operator within 20 minutes (excluding refilling any energy sources), with no more than 15 procedural steps.
G9.1	The energy source used for propulsion shall be refilled at UCF's main campus, refilled at a location within the Orlando, FL area, or sourced from online retailers.
F1.1	The T-shirt launching system shall have a variable power control accessible to the user, allowing the user to adjust the launching distance at least 100 feet.
F1.2	The T-shirt launching system shall be capable of launching a T-shirt with a minimum exit velocity of 68.5 MPH.
F1.3	The T-shirt launching system shall be capable of launching a T-shirt a minimum of 180 feet.

F2.1	The T-shirt launching system shall be capable of launching a small, medium, and large T-shirt at the target exit velocity and distance stated in Requirements F1.2 and F1.3.
F2.2	The T-shirt launching system shall be capable of launching one T-shirt every 15 seconds.
F3.1	The T-shirt launcher shall be capable of projecting a T-shirt within a 20-square-foot area of a target when fired at a distance of 180 feet from the target.
S1.1	The T-shirt launching system shall include a readout to communicate the amount of energy that is currently stored in the system and shall be clearly labeled.
S1.2	The T-shirt launching system shall have an indicator to communicate if the system is holding ANY amount of energy (>0) and shall be clearly labeled.
S1.3	The T-shirt launching system shall have an indicator to communicate if the amount of energy stored is at a potentially dangerous level and shall be clearly labeled.
S1.4	The T-shirt launching system shall have an indicator to communicate if the system is ready to be fired and shall be clearly labeled.
S2.1	The T-shirt launching system shall have an Emergency Shut-Down mechanism (ESD) that is activated in fewer than 3 steps and within 10 seconds following initiation.

S2.2	The T-shirt launching system shall shut off all electronics upon activating the Emergency Shutdown System and shall be clearly labeled.
S3.1	The T-shirt launching system shall achieve a state of equilibrium after discharge of all energy sources, excluding energy in batteries.
S4.1	The T-shirt launcher shall incorporate a Lock-Out / Tag-Out system to prevent unauthorized operation.
S5.1	The T-shirt launching system shall be capable of releasing all stored energy without the need to fire a projectile, excluding batteries.
S6.1	The T-shirt launching system shall withstand 75 cycles of testing with no failures.
S7.1	The T-shirt launching system shall have a method to lockout the mechanism used to fire the launcher, preventing an accidental discharge.
S7.2	If a traditional firearm-style trigger is used, the trigger shall require a minimum of 4 pounds of force to activate.
S8.1	The T-shirt launching system shall be energized no earlier than 3 steps before the launcher is ready to be used.
S9.1	Any energy storage devices, excluding batteries, shall adhere to a minimum safety factor of 3.5.
ST1.1	If a storage system is in place, individual pieces of the storage system for the T-shirt launching system should not exceed 50 inches in any direction.

ST1.2	If a storage system is in place, individual containers shall not exceed 51 pounds, including device weight.
ST1.3	If a storage system is in place, individual containers shall be IP44-rated.
ST2.1	A storage and transportation manual shall be included with the T-shirt launching system. The manual shall clearly state the launcher is not to be in possession of individuals under the age of 18. The manual shall also include how to package the launcher for storage, how to release the energy for storage, and how to safely transport the launcher to its destination.
ST3.1	The T-shirt launcher shall support disarming and disassembly ready for storage within 20 minutes, and no more than 15 procedural steps.
M1.1	A maintenance manual shall be included with the T-shirt launching system. The manual shall clearly state the launcher is not to be in possession of individuals under the age of 18. The maintenance manual shall also include how to take apart the launcher, how to clean the launcher, and how to replace parts on the launcher.
M2.1	The hardware used to construct the T-shirt launching system shall cohere to a single system of units, Metric or Imperial.
M3.1	All commercial off-the-shelf (COTS) materials should be accessible within the Orlando, FL area or purchased online with reliability (product is received).
E1.1	The cost to refill the energy source in between uses and package the payload shall not exceed a dollar amount to be determined by the UCF Athletics Department.

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