# Milestone II: Requirements Definition

## UCF Athletics T-Shirt Launcher

## *Black Team*


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## 1.0 Introduction and Problem Statement

The University of Central Florida (UCF) Athletics Department has tasked multiple groups of Senior Mechanical Engineering students with creating a unique T-shirt launcher to be used at football, basketball, and baseball games on campus. While commercial T-shirt launchers are available for purchase, they are generic and lack any sort of UCF or Space-U character that UCF Athletics has requested. Additionally, having a T-shirt launcher that is tailor-made for UCF's many sporting venues will allow for more optimal performance related to the size of the sporting venues.

## 1.1 Project Stakeholders and Users

The primary stakeholder of this project is the UCF Athletics Department. UCF Athletics initiated this product in conjunction with the UCF Department of Mechanical and Aerospace Engineering. Additional stakeholders include the members of the Black Team and project advisor Richard DeBerardinis.

The primary end users of this project are members of UCF Athletics, such as members of the cheer team or mascots who would use the T-shirt launcher during sporting events. Furthermore, the fans at UCF sporting events are the primary beneficiaries of this project, as they will be receiving the launched T-shirts. Additional people who will be required to interact with the T-shirt launcher include the individuals who will store the launcher while not in use, the individuals who will transport the launcher, and the individuals who will repair and perform maintenance on the launcher. These five groups of people are all essential to the successful, repeated use of the T-shirt launcher.

While the final design may not be able to be directly used for other projectiles, the principles can be easily adapted to fit other needs. Therefore, additional potential uses other than launching T-shirts exist. UCF Athletics could also use the launcher for other soft items, such as towels or hot dogs during a game. Individuals may use the launcher for other exciting moments, such as a confetti launcher or a launcher for a powder during a gender reveal party. The launcher could also be used for sports such as tennis or baseball, where it is beneficial to have the ability to launch the ball to a specific location for practice. Furthermore, an individual may want a tennis ball launcher to use for their dogs. A launcher could also be used in an educational setting as a demonstration of projectile motion and air resistance of projectiles. In a commercial setting, arborists throw a weight high up in the tree when establishing their climbing line. A launcher would allow them to throw the weight much higher and with more accuracy.

## 1.2 Project Status and Accomplishments

To date, the team has conducted preliminary background research on topics related to the design of a T-shirt launcher. These topics include but are not limited to propulsion methods, safety considerations, materials, control methods, and existing T-shirt launchers available for purchase. Additionally, the team has completed both a component and functional decomposition of a T-shirt launcher to determine important design characteristics and requirements.

Going forward, the team will be focusing on the conceptual design of a T-shirt launcher that satisfies the requirements listed in this document. The conceptual design will first focus on components, then systems, and finally system integration.

## 2.0 Methods Used to Collect Requirements and Constraints

To collect requirements and constraints, the team explored three main paths. First, the team explored potential requirements through both a component and functional decomposition. For the component decomposition, the team listed generic subsystems that would make up a T-shirt launcher, such as propulsion, trigger, and reloading systems. With each subsystem, a list of simple questions arises. These lists of questions are the basis for overall requirements and constraints. A similar approach was taken for functional decomposition. The team listed out all of the physical functions of the T-shirt launcher and a list of questions for each function that could be adapted into a requirement or constraint.

The second method used to collect requirements and constraints was to ask the UCF Athletics Department, the customer and main stakeholder of this project, what their desires are for the T-shirt launcher. UCF Athletics provided a list of characteristics they would like to see in the final system. The team then translated these characteristics into engineering design requirements and constraints that can be verified after the final system is built.

Lastly, the team conducted research on commercially available T-shirt launchers and bespoke T-shirt launchers as a basis for requirement values. Given that this project covers a very specific use case, which is to be used at UCF's sporting venues, not all benchmarks set by competing systems are relevant to the customer's goals. However, the competing benchmarks offer a guideline on characteristics that should also be required for this project, even if the value required for the team is less than that of competitors.

## 3.0 Requirements

Using the previously mentioned methods, a comprehensive list of requirements was created to satisfy the needs of UCF Athletics and the desires of the team. The requirements can be broken down into multiple categories: General Requirements (G), Functional Requirements (F), Safety Requirements (S), Storage and Transportation Requirements (ST), Maintenance Requirements (M), and Economic Requirements (E). Related requirements are grouped together, for example, G1.1 - G1.3 are related as they deal with the size and weight of different aspects of the T-shirt launching system.

### 3.1 General Requirements

**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.

- *Validation* - To satisfy this requirement, each team member will hold the launcher and launch T-shirts until there is no remaining energy. This requirement is satisfied if all team members can successfully use the launcher until the energy source is depleted.
- *Reasoning for Requirement and Value* - Requirement G1.1 is specifically intended for ease of use and transport. UCF Athletics requested that the launcher be portable, making it more suitable for all of the sports venues on campus. Analyzing competitor dimensions will also provide guidance as the team enters the design process.
- *Design Constraints* - A constraining issue may occur when limiting the dimensions to accommodate portability, hence no strict dimensional range is specified. Another constraint may be an individual part that makes the launcher difficult to maneuver, yet is necessary for functional operation.

**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.

- *Validation* - Satisfaction of this requirement will be determined by weighing the individual part which is intended to be portable and ensuring it does not exceed 51 pounds.
- *Reasoning for Requirement and Value* - Since the Occupational Health and Safety Administration (OSHA) does not have any limitations on lifting or carrying, Requirement G1.2 shall adhere to the National Institute for Occupational Safety and Health (NIOSH) revised lifting equation or recommended weight limit, Equation 1 [1]. In Equation 1, *RWL* is the recommended Weight Limit, *LC* is the Load Constant, *HM* is the Horizontal Multiplier, *VM* is the Vertical Multiplier, *DM* is the Distance Multiplier, *AM* is the Asymmetric Multiplier, *FM* is the Frequency Multiplier, and *CM* is the Coupling Multiplier.

$$RWL = LC \cdot HM \cdot VM \cdot DM \cdot AM \cdot FM \cdot CM \quad (1)$$

This equation can be used to determine the RWL and further calculations (refer [1] for further equations) can result in the lift index and the risk. The individual parts intended to be portable shall not exceed limits in Requirement G1.2 and shall adhere to the guidelines set by NIOSH. Following these guidelines, NIOSH recommends the maximum Load constant to be 51 pounds. This requirement stems from safety and the active consideration to avoid lower back pain. Analyzing competitor T-shirt launchers, a rough observation reveals weights of around 20 pounds. Using this as a general baseline, however, the system design will be based on Requirement G1.2 and NIOSH's recommended maximum load constant.

- *Design Constraints* - Possible constraints for this requirement include necessary parts being over the weight limit, a possible solution to this constraint may be to exclude heavy components from the portable system. Constraining the weight of the individual parts intended to be portable may also sacrifice material selection.

**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.

- *Validation* - Satisfaction of this requirement will be determined by weighing the individual part that is intended to be carried by the user, and ensuring it does not exceed 51 pounds.
- *Reasoning for Requirement and Value* - Adhering to the recommendations set forth by NIOSH and Requirement G1.2, Requirement G1.3 will follow the recommended weight limit Equation 1. Using 51 pounds as the maximum load constant, recommended by NIOSH, the Recommended Weight Limit (RWL) shall adhere to the guidelines of moderate-duration work provided by NIOSH.
- *Design Constraints* - Possible constraints to this requirement include specific individual parts that may exceed this weight limit, the design will need to be considered in this scenario where the requirement is met, yet parts that exceed the weight limit are still able to be used.

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

- *Validation* - Validation of this requirement will be done through testing the individual components, specifically the electronic housing, and testing the Ingress Protection rating. This requirement may also be validated through procurement of components previously IP-rated by a third party.
- *Reasoning for Requirement and Value* - The device shall be designed for any opportunity and during outside events, there is a possibility for foul weather, and rain or water is the largest concern. Requirement G2.1 stems from the idea of safe operation under all possible circumstances. Developed by the International Electrotechnical Commission, Ingress Protection, or IP ratings, is a quantifiable measure of how protective the device shall be [2]. In an IP rating, the first number represents protection against solid objects, and the second number represents protection against liquids. Referring to IEC's IP rating [2] a solid object protection rating of 4 is measurable by testing protection against solid foreign objects of 1.0 mm in diameter and greater. Similar to the liquid rating, a scale of 4 equates to protection against splashing water, meaning water splashed on the component shall have no harmful effects.
- *Design Constraints* - A possible constraint for this requirement may be testing the IP rating of the component, it will be hard to measure solid bodies 1.0 mm in diameter.

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

- *Validation* - Satisfying this requirement will require a visual inspection of the training manuals to validate that it states the age requirement.

- *Reasoning for Requirement and Value* - The team created this requirement to ensure the safe and legal use of the launcher in the future. Florida Statute 790.22 outlines purchasing, owning, and possessing weapons and firearms. The main topic is that a firearm can not be in possession of anyone under the age of 18, except in a few special circumstances [3]. While the T-shirt launcher is not a firearm, it could be argued that it is an "electronic weapon" or "gas-operated gun" mentioned in Statute 790.22 due to the fact that it is a projectile launcher. While it is highly unlikely that someone under the age of 18 would use the launcher and also highly unlikely for this to be thought of as a weapon, it is not worth any amount of risk to the project stakeholders, potential end users, or the reputation of the University. In an abundance of caution, the team must take every possible step to make anyone who comes in contact with the T-shirt launcher aware of this regulation.
- *Design Constraints* - Any warning to prohibit minors from using the t-shirt cannon may be overlooked or ignored by the user, which may result in improper use of the device. Our warning stands as a statement to heed for the team's and University's protection.

**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.

- *Validation* - Satisfying this requirement will require a visual inspection of the training manual to validate that it exists, states the age requirement, and includes the required information.
- *Reasoning for Requirement and Value* - The team created this requirement to ensure the safe use of the launcher in the future. Providing a training manual will allow new users to

become acquainted with the launcher's functions before use. Commercially available launchers, such as the Bleacher Reacher Series, have online videos demonstrating the use of the launcher [4]. Requirement G3.1 explains the importance of stating the minimum age requirement.

- *Design Constraints* - If there are more complex functions, it may be difficult to convey them in a traditional training manual. Videos may be required for supplemental information.

**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.

- *Validation* - Requirement G4.1 will be verified by measuring the distance in front of the activation mechanism. The distance of the measured path should be three inches or greater.
- *Reasoning for Requirement and Value* - The principle behind Requirement G4.1 pertains to that the device shall be usable by everyone, which includes the University's mascots, Knightro and the Citronaut. The value for Requirement G4.1 was obtained through the estimation of standard activation mechanisms plus a variable of tolerance, to allow for a mascot wearing gloves ease of operation. Benchmarking competitor devices and comparing them to Requirement G4.1 proves that some of the most popular T-shirt launchers, such as the Bleacher Reacher, have a trigger mechanism with a trigger guard [4]. This design would fail to meet Requirement G4.1, as it does not have a 3-inch path of unoccupied space in front of the activation mechanism. The mechanism will accommodate Requirement G4.1 and design will be driven as such.

- *Design Constraints* - A possible constraint for Requirement G4.1 is the safety of accidental discharges. With this requirement in mind, the aspect of safety shall also drive the design decisions. Something is to be designed to prevent the accidental activation of the mechanism; however, the design must still adhere to Requirement G4.1.

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

- *Validation* - To fully satisfy this requirement, a launching indicator will be placed on the system. However, the team will have a meeting to decide what kind of visual effect will be created when each T-shirt is launched.
- *Reasoning for Requirement and Value* - This requirement was created by the team to help create more excitement and engagement with the fans. Other T-shirt launchers do not have this. Having this requirement will make the team's T-shirt launcher stand out and bring more attention to the launcher.
- *Design Constraints* - An issue that the team may encounter is safety. The team has to ensure that the sensory effect we use does not create hazards for the fans or operator.

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

- *Validation* - To satisfy this requirement, the team will conduct a poll using a small sample of UCF students or a small sample of the UCF Athletics Department. 70% of participants must agree that the launcher is clearly intended for UCF or Space-U.

- *Reasoning for Requirement and Value* - This requirement was requested by the UCF Athletics Department to ensure the launcher has clear UCF or Space-U theming. This requirement is similar to other T-shirt launchers because other T-shirt launchers often have their team name and logo added after the launcher is purchased. UCF Athletics also indicated that they would like the launcher to be a reflection of the team and the Department of Mechanical and Aerospace Engineering.
- *Design Constraints* - An issue that the team may encounter is not implementing enough visual cues or branding for the launcher, causing the fans and UCF Athletics to be uninterested in the design of the launcher.

**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.

- *Validation* - Validation of Requirement G7.1 will require measuring the time and steps to go from a disassembled non-operational state to a ready-to-use state. To validate Requirement G7.1 the system shall be operational in no more than 20 minutes, and the operator must perform no more than 15 steps. Requirement G7.1 shall not include the energy refueling time or procedural steps.
- *Reasoning for Requirement and Value* - From the standpoint of ease of use, requiring a lengthy setup process is not the goal. Designing for the ability to take the system out of storage and be able to launch T-shirts with minimal effort. Requirement G7.1 allows for quantifiable measures on the term “easy” with a large buffer. Compared to competitors' designs, Requirement G7.1 has a large buffer and a large room for error.

- *Design Constraints* - A possible constraint for this requirement is that the setup time for the system could exceed the allowed 20 minutes. In that case, a pre-setup operation may be needed for example, energy is supplied to the system before the time requirement starts in Requirement G7.1.

**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.

- *Validation* - Document purchase of the energy source from a supplier that is in the Greater Orlando Area or from an online retailer. If the energy source is refilled at UCF's campus, evidence shall be provided.
- *Reasoning for Requirement and Value* - This requirement is intended to help UCF Athletics in the set up process of the launcher. Having a convenient source to refill the energy will cause UCF Athletics to be more likely to utilize the launcher.
- *Design Constraints* - An issue may occur if the energy source is obscure or not easily obtainable. In this case, a new design will need to be considered.

## 3.2 Functional Requirements

**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.

- *Validation* - To satisfy this requirement, a test will be performed by launching a T-shirt at the minimum and maximum power levels. If the T-shirts are launched at least 100 feet apart, the requirement is satisfied.

- *Reasoning for Requirement and Value* - This requirement comes from the project description provided by UCF Athletics, stating that "fans in the lower and upper sections alike are included in the age-old tradition." Subtracting 100 feet from the distance in Requirement F1.3, a launching distance of 80 feet would ensure the T-shirts go into the lower sections of the stadium. The Bleacher Reacher series of T-shirt launchers offer variable control of distance by allowing the user to manually fill an accumulator tank to the desired pressure [4]. This requirement will ensure the launcher has this basic function.
- *Design Constraints* - Having a variable power control does not pose any potential issues. Issues may arise when targeting certain values specified in separate requirements.

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

- *Validation* - There are two possible methods to validate this requirement. The first is to use a radar gun, which would require the help of the UCF Police Department. The second method is to use a flat panel, such as plywood or cardboard, with a checkerboard pattern of squares. Knowing the size of the squares, the launcher can be recorded in slow motion to find the amount of time it takes the T-shirt to cross a square when it is first launched. The exit velocity, *V*, in MPH, would be calculated using Equation 2, where $\Delta x$ is the distance traveled in feet and $\Delta t$ is the time it took to travel the distance in seconds.

$$V = \frac{\Delta x}{\Delta t} \cdot \frac{3600}{5280} \tag{2}$$

- *Reasoning for Requirement and Value* - This requirement exists to satisfy the desire of UCF Athletics to launch T-shirts into the upper sections of the sporting venues. Since the

football stadium (The Bounce House) is the largest, it was used for this calculation. Initially, the team measured the approximate distance from the sidelines to the top row of The Bounce House, finding that they were 144 feet apart horizontally and 60 feet vertically, as shown in Figure F1.2.

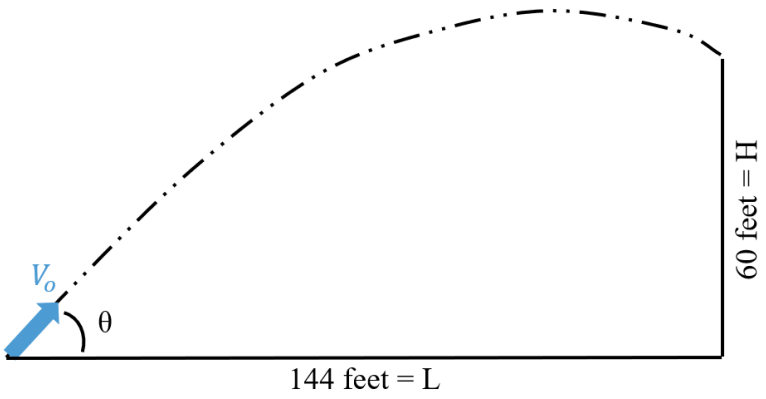


*Figure F1.2: Distance from Sidelines to Top Row*

Decomposing the initial velocity into x and y components and substituting into general projectile motion equations, Equations 3 and 4 can be found, where *t* is the flight time, *L* is the horizontal distance traveled, *H* is the vertical distance traveled, and *g* is gravity.

$$L = V_o cos\theta \cdot t \tag{3}$$

$$H = V_o sin\theta \cdot t + \frac{1}{2} g t^2 \tag{4}$$

Solving Equation 3 for $V_o$ results in Equation 5, which is the initial velocity in terms of *L*, *t*, and $\theta$. *L* is a constant, which is the desired horizontal distance traveled.

$$V_o = \frac{L}{t \cdot cos\theta} \tag{5}$$

Substitution Equation 5 into Equation 4, the vertical distance can be found as a function of the launch angle and flight time. Rearranging, the flight time is found to be a function of the initial angle when *H*, *L*, and *g* are known, as shown in Equation 6.

$$t = \sqrt{\frac{2(H - Ltan\theta)}{g}} \quad (6)$$

Solving Equation 6 for various initial angles, the corresponding flight times can be found. Using these flight times, the corresponding initial velocities can be found using Equation 5. Iterating through different launch angles and flight times, the optimal solution was found to be an initial velocity of 57 MPH at a launch angle of 55°. Since this does not take into account air resistance, wind, friction in the barrel, or any other external factors, a multiplier must be used to capture these factors and any error in the measurement taken of The Bounce House. Increasing the velocity found by the projectile motion equation by a factor of 1.2 results in a desired exit velocity of 68.5 MPH. No data is available for the exit velocity of other T-shirt launchers. Instead, Requirement F1.3 will be used to benchmark the team's launcher against competitors.

- *Design Constraints* - This requirement could pose a potential safety issue. If the user launched a T-shirt at the maximum exit velocity toward someone in the lower section, the T-shirt could potentially injure someone. Additionally, the calculation used to find this value makes many assumptions. It may be found in testing that a higher exit velocity is required. If this is the case, the team will adjust the required value to ensure all fans are included in the opportunity to catch a T-shirt.

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

- *Validation* - The team will launch 10 T-shirts from the same location at maximum power. If the average of these launches is greater than 180 feet, the requirement is satisfied.

- *Reasoning for Requirement and Value* - Using projectile motion equations, at the calculated exit velocity of 57 MPH, a projectile will travel 217 feet if there is no change in elevation. Using the same factor of 1.2 used in Requirement F1.2, the adjusted minimum launching distance can be found to be 180 feet. Satisfying this requirement also serves as another way to check if the T-shirts will reach the upper section, without having to test in The Bounce House. The maximum distance competing T-shirt launchers can launch a T-shirt are tabulated in Table F1.3.

| *Table F1.3: Competitor Maximum Distance* | |
|---|---|
| Launcher Name | Maximum Distance |
| Shockwave (Team 254) [5] | 450 feet |
| Bleacher Reacher Series (tshirtgun.com) [4] | Micro Mini: 150 feet<br>Dagger: 150 feet<br>Pro: 250 feet<br>Mega: 400 feet |
| Portable Rapid-Fire T-Shirt Cannon (University of Utah) [6] | 202 feet |

While this project's target value is less than that of some competitors, this project is specifically intended to be used at UCF's sporting venues, so the target distance and velocity can be optimized to just reach the top of The Bounce House. Furthermore, increasing the target distance to surpass all of the competition poses a safety risk, as launching a T-shirt out of the football or baseball stadiums poses a risk to bystanders outside of the stadium who are not looking for flying objects.

- *Design Constraints* - It is possible that one Requirement F1.2 and F1.3 could be satisfied, while the other is not due to external factors. This could cause the team to have to increase the launching power in order to achieve both requirements.

**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.

- *Validation* - Small, medium, and large T-shirts will be loaded into the launcher and fired. To satisfy this requirement, requirements F1.2 and F1.3 must be satisfied with a small, medium, and large T-shirt.
- *Reasoning for Requirement and Value* - UCF Athletics expressed that they would primarily be launching large T-shirts with this system. While the launcher will be designed to accommodate large T-shirts, it is important that performance is not altered if UCF Athletics ever decides to launch different sizes of T-shirts.
- *Design Constraints* - Potential issues for this requirement include the issues outlined in Requirements F1.2 and F1.3. Additionally, it is possible that energy could escape around the smaller T-shirts, since they will take up less space in the barrel. Likewise, there could be excess friction between the larger T-shirts and the barrel, hindering the launch distance.

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

- *Validation* - In testing, a stopwatch will be used to determine if a knowledgeable operator can fire, reload, and fire again in 15 seconds or less.
- *Reasoning for Requirement and Value* - An operator must be capable of firing a t-shirt at least once per 15 seconds. This requirement also includes extraneous functions that may not encompass reloading and firing consecutively (such as targeting, etc.). In general, commercially available T-shirt launchers can launch as fast as the operator can insert another T-shirt into the chamber and fill the secondary air tank. 15 seconds allows for a

reasonable benchmark as we navigate different firing options. Furthermore, a timeout in college football is 90 seconds. A 15 second interval between launches would allow the operator to launch 6 shirts during a time-out, which is sufficient to keep the crowd engaged.

- *Design Constraints* - If too many extraneous features are added, this may limit the capability of the operator firing the device faster than one shirt every 15 seconds. The team must be mindful of all functionalities that may limit the speed and efficiency of the device.

**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.

- *Validation* - The launcher will be placed on a test stand and launched with a power sufficient to reach 180 feet. At that power and test stand orientation, 10 T-shirts will be launched. If 80% of the T-shirts land within the 20 square foot area, the requirement has been satisfied.
- *Reasoning for Requirement and Value* - As accuracy isn't entirely a pivotal concept in this device, the operator should be able to hit a specific section of the stadium. The operator likely won't pick and choose exact people or targets in the stands, rather just firing towards a specific section that is making lots of noise.
- *Design Constraints* - Accuracy is entirely a personal skill. The device must be able to maintain consistent results under the same conditions. If this is achieved, accuracy is possible with a trained and skilled operator. If the device provides inconsistency or scattered results upon the same firing conditions, the device will not be accurate even under the operation of the most skilled and experienced users.

### 3.2 Safety Requirements

**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.

- *Validation* - To confirm that we met this requirement, the team will do testing using calibrated instrumentation to verify the accuracy of the readout on the display/gauge. This testing involves comparing the device readout with the actual stored energy in the system.
- *Reasoning for Requirement and Value* - This requirement is essential for ensuring operator safety and preventing potential accidents. The real-time readout of stored energy is considered crucial for the safe operation of high-energy systems. Compared to other T-shirt launchers, the inclusion of a readout for energy storage is not universally implemented in commercially available launchers. However, it provides a significant safety advantage by allowing operators to monitor and manage energy levels, thus reducing the risk of overcharging and accidental discharge. Adding a real-time readout on systems involving high-energy components ensures compliance with safety regulations and standards such as ANSI B11.20 [7] for mechanical power presses and OSHA regulations for machinery safety.
- *Design Constraints* - Ensuring the readout is visible, intuitive to interpret, and durable against environmental factors such as vibration or moisture may introduce challenges. Confidence in the calculation and implementation of the readout functionality will require thorough testing and validation during the design and prototyping phase.

**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.

- *Validation* - To confirm this requirement, operational tests and user feedback will be conducted. Tests will simulate various conditions to ensure indicator/LED activates when energy is stored.
- *Reasoning for Requirement and Value* - The team mandated the inclusion of an indicator to communicate stored energy to mitigate the risk of accidental discharge, which could lead to injury of persons or property. While this requirement does not have a value, it aligns with general safety principles in engineering. While it is industry standard to have multiple indicators on high-energy devices, most competitors in the T-shirt launching space do not include a dedicated indicator just for displaying that any amount of energy is stored in the system.
- *Design Constraints* - A few design constraints include; ensuring the indicator seamlessly fits into the system without compromising functionality or aesthetics, reliable power supply for continuous operation, environmental durability of the indicator, size and placement, and adherence to safety standards and regulations.

**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.

- *Validation* - Confirmation will involve conducting operational tests that verify the indicator activates when energy reaches or exceeds a dangerous level. Additionally, safety tests will be performed to evaluate different hazards with different levels of energy.
- *Reasoning for Requirement and Value* - This indicator serves as an early warning system that allows operators to take precautions before hazards arise. The chosen value aligns with established safety standards and common practices. While it is common for commercially

available hardware to have a pressure gauge on a high-power system, such as the Bleacher Reacher [4], it is less common to have a dedicated indicator for overpressurization alongside a pressure gauge.

- *Design Constraints* - Integration challenges, power source reliability, environmental durability, and regulatory compliance are all significant considerations in the development process.

**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.

- *Validation* - Confirmation involves operational tests to ensure the indicator activates when requirements are met and the system is ready to be fired. Functional testing will verify the indicator's reliability indicating system readiness.
- *Reasoning for Requirement and Value* - This indicator is essential for operator convenience and safety, ensuring that the operator is informed when the system is ready to fire. This value aligns with common engineering practices for safety-critical systems. This requirement is consistent with many high-energy systems in the engineering field, but after investigating many commercial t-shirt launchers, most of them lack the safety indicators implemented in our design.
- *Design Constraints* - Similarly the rest of the indicator requirements (S1.1 - S1.3), integration challenges, power source reliability, environmental durability, size/placement considerations, and ensuring regulatory compliance are design constraints that need to be taken into consideration.

**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.

- *Validation* - Satisfying this requirement involves operational tests to ensure the shutdown procedure meets specified requirements. Testing will simulate emergency shutdown scenarios to verify the system's response time and the number of steps required for the shutdown.
- *Reasoning for Requirement and Value* - This requirement is essential for operator safety in emergency situations. A swift shutdown of less than 10 seconds and fewer than 3 steps minimizes the risks of accidents and potential harm to operators and bystanders. The chosen values align with established engineering standards and best practices for emergency shutdown systems. While there are no specific equations to dictate these values, they are based on general safety principles prevalent in the field. This requirement may vary among different T-shirt launchers, depending on their complexity and intended use, but during research, no commercially available competitor t-shirt launcher explicitly states a set requirement for shutdown time or maximum steps required. The University of Utah launcher does have a general on/off switch, which also serves as an Emergency Shutdown switch. This switch is covered, requiring two steps to shut down the electronics [6]. Adding an additional extra step to the Utah design allows for a potential additional step to discharge the energy from the system.
- *Design Constraints* - Issues to consider include system complexity, interface design, safety interlocks, and regulatory compliance, which may pose challenges. Confidence in addressing these constraints comes from a thorough understanding of engineering principles and validation through testing.

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

- *Validation* - The team will conduct tests to verify the functionality of the emergency shutdown system, ensuring that all electronic and mechanical components capable of launching a T-shirt or discharging the system are effectively disabled.
- *Reasoning for Requirement and Value* - This requirement is paramount for ensuring safety. The emergency shut-off switch provides operators with a means to swiftly deactivate the device, subsequently preventing any potential harm to individuals. It serves as a crucial safety measure to mitigate risks associated with accidental or unauthorized firing of the launcher. Refer to requirement S2.1 for the University of Utah shutdown system.
- *Design Constraints* - Implementation of an electronic switch poses a constraint. We must devise a solution that enables the activation of the shutdown system with a single press of a button, effectively disabling all force-bearing and firing components within the system. This entails intricate programming to ensure seamless integration and reliable functionality of the emergency shutdown mechanism.

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

- *Validation* - To validate Requirement S3.1, a systems test will be performed to ensure a safe equilibrium state after discharge of energy. System equilibrium after discharge will confirm readiness for the next cycle. The system shall have a pass or fail rating for this

requirement. The system shall pass if the system is at a safe equilibrium state after the discharge of energy.

- *Reasoning for Requirement and Value* - Following the guidelines of the Occupational Health and Safety Administration (OSHA) Control of Hazardous Energy (1910.147) [8], the system shall utilize a Lock-Out / Tag-Out procedure to perform maintenance and for storage. Incorporating the safety concerns of Requirement S4.1, the system shall remain in a safe, equilibrium state until ready for launch. This includes storage, transportation, maintenance, and any other time the launcher is not being used. Compared to other models of T-shirt launchers, most designs are safe to handle after the energy is discharged.
- *Design Constraints* - A possible constraint for Requirement S3.1 may be the time in which it takes the system to equalize. There is no limitation on this so it may lead to ambiguous pass/fail, however, Requirement S3.1 is designed in this manner.

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

- *Validation* - Validation of Requirement S4.1 will be done through visual inspection with either pass/fail rating. The Lock-out / Tag-out system shall adhere to the OSHA specifications [8].
- *Reasoning for Requirement and Value* - Requirement S4.1 is designed to ensure the safety of the operator, transport person, and maintenance person. OSHA's Lock-Out / Tag-Out requires the isolation of the energy source capable of a lock-out mechanism. During periods of non-use, storage, transport, etc. the device shall be in an equalized locked-out state. Reference OSHA 1910.147 [8] for further Lock-out / Tag-out descriptions and procedures.

- *Design Constraints* - A possible constraint to Requirement S4.1 may be that one person has the key to the Lock-Out mechanism and when maintenance needs to be done that one said person needs to be available. For design consideration, how many end users will be in possession of the system, and how many personnel have access to the Lock-Out / Tag-Out mechanism?

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

- *Validation* - The team will confirm this by conducting visual tests to ensure all stored energy is released without firing a projectile, while simultaneously monitoring the pressure gauge and verifying that it reads 0 PSI, if applicable.
- *Reasoning for Requirement and Value* - This requirement ensures the safe disarming and unloading of the launcher to protect users and bystanders from accidental discharge. It sets a higher safety standard compared to other launchers that lack an energy release valve, which is why the team prioritizes comprehensive safety measures.
- *Design Constraints* - Challenges may include designing a mechanism that discharges energy separately from the barrel of the device. The reliability of the disarming mechanism must be rigorously tested. Confidence in the calculation depends on thorough design analysis and validation through prototyping and testing.

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

- *Validation* - To satisfy this requirement, the team will complete 75 cycles of testing to confirm that the launching system is durable. A cycle is defined as filling the energy source and launching T-shirts until the energy is depleted.
- *Reasoning for Requirement and Value* - This requirement was created by the team to ensure that the launcher is reliable. There were 75 total home football, baseball, men's basketball, and women's basketball games in the 2023-2024 school year. 75 cycles of testing will confirm that the launcher can withstand use throughout one full school year without the need for excessive maintenance.
- *Design Constraints* - An issue the team might run into is that the launcher cannot complete 75 cycles of testing. If that is the case, an optimal number of cycles that allow the launcher to be tested without putting unnecessary strain on the launcher and its components and fix the components that have failed.

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

- *Validation* - To validate that the lock-out mechanism works the team must test the design in a simulation, confirming that the design prevents a user from firing the gun before manufacturing the launcher. After confirming the design through a simulation, the team must physically test the design via a prototype, which allows the team to fully identify any flaws or errors that may occur for the lock-out mechanism
- *Reasoning for Requirement and Value* - Safety feature to protect the user and those affected by the device including but not limited to students, fans, and sports players. Almost all firearms have a safety to prevent accidental discharges. If they do not have a traditional

safety mechanism, there is usually a way to still prevent firing via manipulation of the hammer.

- *Design Constraints* - Designing a lock-out or safety lock system for potential trigger mechanisms that have not been determined. The lock-out system may alter the device form factor and it is unknown if the safety will have a single activation mechanism or multiple-step activation for the launcher.

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

- *Validation* - Using a trigger gauge to measure the trigger weight can ensure that the force to activate the device meets the minimum of 4 pounds of force.
- *Reasoning for Requirement and Value* - Based on the National Institute of Justice [9], the trigger weight of a .22 caliber rimfire rifle is a minimum of 3 pounds and a maximum of 5 pounds. For larger firearms, 4 to 7 pounds of force is the trigger weight. Meanwhile, Vickers Tactical recommends a trigger weight of 4 to 6 pounds, as anything under 4 pounds can be accidentally triggered under conditions of stress [10]. Firearm companies often tout their light triggers, but in this use case, a light trigger could be the cause of an accidental discharge.
- *Design Constraints* - Final design for the trigger for the launcher has not been decided whether it will be a button, finger trigger, switch, or any other modes of activation.

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

- *Validation* - After testing the device and confirming that activating the launcher in 3 steps, the team can confirm that it meets the requirement.
- *Reasoning for Requirement and Value* - This requirement is a safety feature to ensure that the user does not miss fire or accidentally discharge the device during handling. Setting 3 steps in order to energize the launch allows the user to activate the device in a timely manner but prevents the user from discharging the device without warning.
- *Design Constraints* - Limiting the energization of the device to the 3 steps. It should be fairly simple, the main concept lies in loading the projectile, aiming at the target, and firing the projectile, which consists of 3 steps, the team does not want the energy to charge any sooner than this.

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

- *Validation* - This requirement will be validated using an appropriate device to measure the amount of energy in the storage device. This amount must be 3.5 times less than the rated operating condition of the storage device. If the device is not COTS, then a stress analysis simulation is sufficient using a program such as SolidWorks or Ansys.
- *Reasoning for Requirement and Value* - This requirement is in place to ensure the safety of the operator and bystanders. The most common propulsion method for T-shirt launchers is compressed air. These launchers use pressurized tanks to store air until it is ready to launch. ASME Section VIII states that the minimum factor of safety used for pressure vessels is 3.5 [11]. Since pressure vessels are the most dangerous energy source that has been considered, it serves as a benchmark for a minimum factor of safety. There is no data

available for the factor of safety of commercial T-shirt launchers, however one can assume that any company selling launchers adhered to the ASME standard in order to minimize the risk of being liable for any potential injuries.

- *Design Constraints* - A factor of safety of 3.5 is quite large for a system such as a T-shirt launcher. This could constrict the amount of energy the launcher is able to store, thus reducing the launching distance.

### 3.3 Storage and Transportation Requirements

**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.

- *Validation* - To confirm that the team has met this requirement, any containers used for storage will be measured to ensure that they do not exceed 50 inches in any direction. 50 inches serves as a general guideline based on generic storage bins.
- *Reasoning for Requirement and Value* - Providing a requirement for handling/storage of the device will ensure the safety of not only the device but those handling the device during transport. Having the storage system meet the size requirement will allow the launcher's storage device to fit in the designated area that UCF athletics has provided (i.e, lockers, security cages). Many of the t-shirt launcher cases on the market are soft zipper cases, which help protect the device from dust, debris, and a little weathering, but the suggestion of a hard case or more solid storage system helps protect the device from impact, dust, and water.
- *Design Constraints* - Issues that may occur while designing this portion of the project include, getting the final dimension of the device once the designs are complete and

ensuring the design meets the size and weight requirement set by Requirements G1.1 and G1.2. If the device isn't modular, a larger case will be required.

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

- *Validation* - The total weight of the device while within one of the storage systems shall be weighed and not exceed 51 pounds.
- *Reasoning for Requirement and Value* - Based on the recommendations set by NIOSH and Requirement G1.2, one container storage system housing parts of the launcher must not exceed 51 pounds as calculated in Equation 1. The Bleacher Reacher T-shirt launchers weigh just under 7 pounds [4], which meets the requirements set by NIOSH.
- *Design Constraints* - Potential design constraints involve the modularity of the system, the space available for storage, and the strength of the storage system to support the weight of the launcher.

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

- *Validation* - Test the storage system's IP rating to ensure it meets the IP44 by attempting to insert a 1 mm diameter wire and splashing water at the containers. This will confirm if the storage system is protected from small objects and waterproof from water splashing on the container [2].
- *Reasoning for Requirement and Value* - By requiring the storage system's IP rating of IP44 will help protect the device during transport during unfavorable weather as well as accidents during transport. As stated in Requirement ST1.2, commercial launchers have a

soft zipper case to protect and store the T-shirt launcher, which will only protect the launcher from dust and a small amount of water, but not from falls or falling objects.

- *Design Constraints* - Finding and or designing a storage system large enough that will fit the device without issues while meeting the IP criteria.

**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.

- *Validation* - Satisfying this requirement will require a visual inspection of the storage and transportation manual to validate that it exists, states the age requirement, and includes the required information.
- *Reasoning for Requirement and Value* - This requirement was created by the team to ensure the safe storage and transport of the T-shirt launcher. There is no record of other T-shirt launchers coming with such a manual. For information on Florida Statute 790.22 regarding the minimum age of 18 [3], see Requirement G3.1.
- *Design Constraints* - If the storage and transportation of the device is too complex, it could lead to UCF Athletics neglecting the recommendations of the team. This could lead to premature wear to the system. The storage and transportation manual must be clear and concise to mitigate this risk.

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

- *Validation* - Validation of Requirement ST3.1 will require measuring the time and steps to go from a ready-to-use state to a disarmed, disassembled ready-for-storage state. To validate the requirement, the system shall be disassembled in no more than 20 minutes, and the operator must perform no more than 15 steps.
- *Reasoning for Requirement and Value* - The system is to be designed with ease of use in mind and a short simple breakdown process is the goal. Requirement ST3.1 provides a basic quantifiable measure of the process. Requiring a maximum time to break down the system will direct the design to be straightforward to construct. Compared to competitors' designs, Requirement ST3.1 has a large buffer and a large room for error.
- *Design Constraints* - A possible constraint for this requirement is if the system requires more than 15 procedural steps to disarm and disassemble.

## 3.4 Maintenance Requirements

**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.

- *Validation* - Satisfying this requirement will require a visual inspection of the maintenance manual to validate that it exists, states the age requirement, and includes the required information.
- *Reasoning for Requirement and Value* - This requirement was created by the team to ensure the longevity of the system and the long-term safety of the system. No available competing T-shirt launchers have a maintenance manual. The Bleacher Reacher does not offer any

maintenance plan or options. Instead, they offer a Limited Lifetime Warranty with many stipulations, such as not replacing seals or voiding the warranty if the launcher was modified [4]. For information on Florida Statute 790.22 regarding the minimum age of 18 [3], see Requirement G3.1.

- *Design Constraints* - The maintenance manual must be clear and concise, or else the instructions could be misinterpreted and lead to damage to the system.

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

- *Validation* - To satisfy this requirement, the team will have a meeting before starting to build the launcher and confirm the final system of units. All hardware and tools used will be tracked to validate they are all either Metric or Imperial.
- *Reasoning for Requirement and Value* - This requirement was created by the team to ensure that it is easy to fix and assemble the launcher. Having two systems of units can create problems when converting from one system to the other. This requirement is commonly seen in other T-shirt launchers in order to not confuse anyone.
- *Design Constraints* - If any design is done in a different set of units for any reason, the units must be converted into one synonymous system of units, or else it will be difficult to assemble the launcher. For consistency, calculations should be performed in the same set of units.

**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).

- *Validation* - To satisfy this requirement, the team will confirm that everything is purchasable from a store close to UCF's campus or online.
- *Reasoning for Requirement and Value* - This requirement was created by the team to ensure that all the parts are of high quality and accessible to UCF. This requirement is not found in other T-shirt launchers, but we want the launcher to be robust and be of good quality. Additionally, this will allow for future repairs by UCF Athletics.
- *Design Constraints* - An issue the team might run into is that not everything needed can be easily accessible in stores near UCF or online. This can lead to potential issues with scheduling and quality of parts.

## 3.5 Economic Requirements

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

- *Validation* - To satisfy this requirement, the team will have a source to refill the energy with the cost. Additionally, the team will prorate the cost of materials used to package the T-shirts for launching. Adding these two values together will result in the total cost to ready the launcher for use. If the energy source is something readily available at the UCF main campus or average home, such as electricity, the cost will be $0 for that aspect.
- *Reasoning for Requirement and Value* - This value was provided by UCF Athletics as a guideline for the amount of money they are willing to spend for each use of the launcher.
- *Design Constraints* - This cost constraint levied by UCF Athletics could potentially limit the options for the energy source, as some may exceed their target cost per use. It may also limit the team's options for a creative payload delivery system related to Space-U.

**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.

- *Validation* - The cost of materials used to manufacture the T-shirt launcher will be tracked and added at the end of the project. This does not include the cost of anything supplied by UCF Athletics or the Department of Mechanical and Aerospace Engineering.
- *Reasoning for Requirement and Value* - UCF Athletics and the Department of Mechanical Engineering sets a budget for every Senior Design project. For this project, it is important to stay on budget, allowing UCF Athletics to build additional launchers at the same cost in the future if desired.
- *Design Constraints* - A budget constraint may limit every aspect of the project. Electronics and control options can add up in cost very quickly. The team will have to make a comprehensive bill of materials and find the best prices for parts prior to manufacturing the T-shirt launcher.

## 4.0 Summary of Requirements

The previously mentioned requirements, requirement numbers, and validation techniques are summarized below in Tables 4A - 4F. The confidence is an indication of how confident the team is in the required value at this stage of the project.

Table 4A: General Requirements Summary

| Number | Requirement | Value | Validation | Confidence |
|---|---|---|---|---|
| G1.1 | Portability | True / False | Functional Test | 100% |
| G1.2 | Launcher weight - portable components | 51 lbs | Scale | 100% |
| G1.3 | Launcher weight - attached to user | 51 lbs | Scale | 100% |
| G2.1 | Launcher IP rating | IP44 | IP Test | 90% |
| G3.1 | Age Limit | 18 years old | Visual Inspection | 100% |
| G4.1 | Training manual | True / False | Visual Inspection | 100% |
| G5.1 | Space in front of activation mechanism | 3 in | Measurement | 100% |
| G6.1 | Indicator - launching T-shirt | True / False | Visual Test | 100% |
| G7.1 | UCF or Space-U themed | > 70% | Poll | 100% |
| G8.1 | Assembly time / steps | 20 minutes / 15 steps | Stopwatch / Count | 100% |
| G9.1 | Energy source availability | Orlando, FL area or online | Google Maps | 90% |

| Table 4B: Functional Requirements Summary | | | | |
|---|---|---|---|---|
| Number | Requirement | Value | Validation | Confidence |
| F1.1 | Variable power control | True / False | Visual Test | 100% |
| F1.2 | Minimum exit velocity | 68.5 MPH | Radar gun or measuring distance and time | 75% |
| F1.3 | Minimum launch distance | 180 feet | Measurement | 100% |
| F2.1 | T-shirt size | S, M, L | F1.2 and F1.3 | 100% |
| F2.2 | Fire rate | 15 seconds | Stopwatch | 100% |
| F3.1 | Launcher accuracy | 20 sq ft at 180 ft | Measurement | 100% |

| Table 4C: Safety Requirements Summary | | | | |
|---|---|---|---|---|
| Number | Requirement | Value | Validation | Confidence |
| S1.1 | Energy level readout | True / False | Visual Inspection | 100% |
| S1.2 | Indicator - any stored energy | True / False | Visual Inspection | 100% |
| S1.3 | Indicator - dangerous amount of energy | True / False | Visual Inspection | 100% |
| S1.4 | Indicator - ready to fire | True / False | Visual Test | 100% |
| S2.1 | ESD - steps and time | 3 steps / 10 seconds | Count / Stopwatch | 100% |
| S2.2 | ESD - stops electricity | True / False | Visual Test | 100% |
| S3.1 | Equilibrium after energy release | True / False | Visual Inspection | 100% |
| S4.1 | Lock-Out / Tag-Out | True / False | Visual Test | 100% |
| S5.1 | Release energy without firing | True / False | Functional Test | 100% |
| S6.1 | Testing cycles | 75 | Count | 85% |
| S7.1 | Firing mechanism lock out | True / False | Functional Test | 100% |
| S7.2 | Trigger force required | Min 4 lbs | Trigger Gauge | 100% |
| S8.1 | When launcher is energized | Steps | Count | 90% |
| S9.1 | Factor of Safety for energy storage | FOS | Calculation or simulation | 85% |

| Table 4D: Storage and Transportation Requirements Summary | | | | |
|---|---|---|---|---|
| Number | Requirement | Value | Validation | Confidence |
| ST1.1 | Storage container dimensions | < 50” in any direction | Measurement | 70% |
| ST1.2 | Storage pieces weight | 51 lbs | Scale | 100% |
| ST1.3 | Storage pieces IP rating | IP44 | IP Test | 90% |
| ST2.1 | Storage & Transportation manual | True / False | Visual Inspection | 100% |
| ST3.1 | Breakdown time/steps | 20 minutes / 15 steps | Stopwatch / Count | 100% |

| Table 4E: Maintenance Requirements Summary | | | | |
|---|---|---|---|---|
| Number | Requirement | Value | Validation | Confidence |
| M1.1 | Maintenance manual | True / False | Visual Inspection | 100% |
| M2.1 | Metric or Imperial | True / False | Track while purchasing items | 100% |
| M3.1 | Part availability | Orlando, FL area or online | Google Maps, receipts | 90% |

| Table 4F: Economic Requirements Summary | | | | |
|---|---|---|---|---|
| Number | Requirement | Value | Validation | Confidence |
| E1.1 | Cost per use | $TBD | Prorated materials cost | 100% |
| E2.1 | Cost of launcher | $TBD | Track while | 100% |

| | | | | |
|---|---|---|---|---|
| | | | purchasing items | |

## 5.0 Relationship Matrix

The following relationship matrix outlines the characteristics requested by UCF Athletics and the Engineering Design Specifications related to those characteristics.

| Row # | Customer Importance (1-10) | Relative Weight | Customer Requirement \ Engineering Design Specification | 1 F1.2) Min exit velocity (MPH) | 2 F1.3) Min distance (ft) | 3 F1.1) Variable power (T/F) | 4 S1.1-4) Energy indicators (T/F) | 5 S2.1-2) ESD (steps & time) | 6 S4.1) Lock-Out/Tag-Out (T/F) | 7 S7.2) Trigger weight (lbs) | 8 S9.1) Safety Factor (T/F) | 9 G1.1) Launcher portability (T/F) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 0.17 | Launches T-shirts into upper sections | 9 | 9 | 3 | | | | | -3 | |
| 2 | 10 | 0.17 | Adjustable launching distance | 3 | 3 | 9 | 1 | | | | | |
| 3 | 10 | 0.17 | Safe for user and fans | -9 | -9 | 3 | 9 | 9 | 9 | 9 | 9 | 3 |
| 4 | 10 | 0.17 | Portable | | | | | | | | | 9 |
| 5 | 8 | 0.13 | Quickly launch multiple shirts | | | 1 | | | | 1 | | 1 |
| 6 | 5 | 0.08 | Cost per use | 1 | 1 | 1 | | | | | | |
| 7 | 5 | 0.08 | Space-U or UCF themed | | | | | | | | | |
| 8 | 1 | 0.02 | T-shirt capacity | | | | | | | | | |
| 9 | 1 | 0.02 | Weather resistant | | | | -1 | | | | | |

| Row # | Customer Importance (1-10) | Relative Weight | Customer Requirement \ Engineering Design Specification | 10 G1.2-3) Launcher weight (lbs) | 11 ST1.2) Storage weight (lbs) | 12 F2.2) Time to launch (sec) | 13 E1.1) Cost per use ($) | 14 E2.2) Project budget ($) | 15 G6.1) UCF/Space-U theme (T/F) | 16 F2.1) Shirt size & type (T/F) | 17 G2.1) IP Rating (T/F) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 0.17 | Launches T-shirts into upper sections | 1 | | | 1 | 1 | | 1 | |
| 2 | 10 | 0.17 | Adjustable launching distance | | | | | | | 1 | |
| 3 | 10 | 0.17 | Safe for user and fans | 3 | | 3 | | | | 1 | |
| 4 | 10 | 0.17 | Portable | 9 | 9 | | | | | | |
| 5 | 8 | 0.13 | Quickly launch multiple shirts | 1 | | 9 | | | | | |
| 6 | 5 | 0.08 | Cost per use | | | | 9 | 3 | | 1 | |
| 7 | 5 | 0.08 | Space-U or UCF themed | | | | | | 9 | | |
| 8 | 1 | 0.02 | T-shirt capacity | | | | | | | 3 | |
| 9 | 1 | 0.02 | Weather resistant | | | | | | | | 9 |

*Figure 5.0: Relationship Matrix with Customer Weight*

## 6.0 Critical System Requirements

UCF athletics deemed launching into the upper sections, having an adjustable launching distance, and the launcher being safe for the fans and the operator to be the most important requirements. The requirements created to ensure a T-shirt can be launched into the upper sections are Requirements F1.2 and F1.3. These outline the desired exit velocity and launch distance of a T-shirt, respectively. Satisfying both of these requirements will ensure customer satisfaction, as the operator will be able to launch T-shirts into the upper sections of all UCF sports venues.

To ensure the launcher has an adjustable launching distance, Requirement F1.1 was created. This requirement outlines that the launcher must have variable power control. While Requirements F1.2 and F1.3 are intended for the upper sections, F1.1 ensures that the lower sections are also included in the opportunity to catch a T-shirt.

To ensure that the launcher is safe for the fans and the operator, Requirement S2.1 states that the launcher will be capable of shutting down in less than 3 steps and under 10 seconds after activating the Emergency Shutdown System. This will ensure that if needed the launcher will be inoperable quickly. No one will be able to use the launcher once the launcher is shut down. The launcher will also have a method which locks out the trigger used for firing the launcher, explained in Requirement S7.1. This requirement will prevent an accidental discharge.

## 7.0 Competitor Benchmark

Noting some common applications of other designs, this section will dedicate some information surrounding popular choices of specific mechanisms, applications, and design choices. The most

popular method of propulsion is overwhelmingly the compressed air method. This method allows for strong launch of projectiles while remaining relatively cost effective, safe, and replaceable. Most components and materials are chosen to withstand the given force for an extended period of time with almost no chance of failure. The most common application of the pressure vessel system relies on a smaller capacity tank which allows a variable amount of pressure to be designated to the chamber at a time. This mechanism allows for control over the distance fired and remains a safe method of propulsion. Generally barrel lengths lie somewhere in between 10" and 20" which allows for accurate propulsion of the object as well as time for force to completely transfer into the projectile over a controlled distance. Other attempts in finding a propulsion method include pioneering a new and unique method to transfer energy into a projectile safely and cost-effectively. Pneumanic triggers allow for the pressure of a pressure vessel to charge them, requiring no electronic or mechanical input, simply allowing a complete utilization of a pressure system in fundamental functionality.

## 7.1 Benefits of Proposed System

The largest benefit of the system defined by these requirements is that it is designed by UCF students, specifically for use at UCF. With this in mind, the team will be able to direct efforts toward satisfying the exact wants and needs of UCF Athletics. The most important characteristics to UCF Athletics are launching T-shirts into upper sections, having an adjustable launching distance, and safety.

Launching the T-shirt into upper sections is achieved by Requirements F1.2 and F1.3, which are the exit velocity and travel distance, respectively. Other T-shirt launchers on the market have a wide range of travel distances, from 150 - 450 feet, shown in Table F1.3. While launching a T-

shirt over 400 feet is very exciting, it is not necessary for any application on UCF's campus. A launching distance of over 400 feet would only be beneficial for large stadiums such as an NFL stadium. Therefore, a benefit of the proposed system is a more optimal use of energy. The team can precisely determine just how much energy is needed to reach the top of the stadium, so that none is wasted during use and there is not an excessive amount of energy being stored.

UCF Athletics also indicated that having an adjustable launching distance is very important. Only one commercially available launcher has this feature, the Bleacher Reacher [4]. The inclusion of an adjustable launching distance will elevate the team's launcher above the other commercial and bespoke launchers that do not have this feature. Launchers without this feature pose a safety risk, as any adjustment in range solely comes from the operator's ability to angle the launcher to change the trajectory of the T-shirt.

The final important characteristic is the safety of the operator and fans. No commercially available or custom-built launchers have a safety system as comprehensive as the one proposed from these requirements. The only launchers with some sort of safety system are the Utah launcher [6] with its 2-step shutdown system, and the Bleacher Reacher Mega [4], which requires the operator to press a button and pull the trigger simultaneously to fire. The other Bleacher Reacher models do not have this feature. The system proposed by the team places a much larger emphasis on safety than other systems and is the team's priority.

Finally, the proposed system has many additional features and requirements that will place it in a tier above the other T-shirt launchers. The launcher will be designed to be UCF or Space-U-themed, which would not be available commercially. The proposed system will also have

comprehensive training manuals covering all aspects of interaction with the device. The Bleacher Reacher [4] has very short online videos covering operations but does not cover storage, transportation, or maintenance. If a storage system is in place, this will also elevate the team's design over other T-shirt launchers. Most other launchers are stored in a soft bag or have no storage, exposing them to possible damage from drops or water damage. Having a storage system in place will help ensure the longevity of the launcher.

Overall, having a T-shirt launcher designed specifically for UCF Athletics and their desired characteristics will allow the team to focus on those key areas. Other launchers that have been built or can be commercially purchased are still impressive machines, but they make many sacrifices in order to facilitate mass production and stay general enough to appeal to a large audience. These are not issues for the team, as the most important customer is the primary project stakeholder, UCF Athletics.

### 7.2 Patent Study

One patent exists for a gas-powered chamber in which a magazine is attached to the chamber and feeds novelty items into a launcher [12]. Another patent exists where it receives its power from a tank of compressed inert gas (usually nitrogen) fitted with a regulator and a three way manifold with two air lines and a relief valve; the unit has two hoses attached to its rear housing plate. One line fills the accumulator tank while the auxiliary line ensures the pneumatic trigger always has gas pressure to complete the firing cycle. As long as the team does not infringe on the fundamental idea and copy the design, we will not fall under the jurisdiction of this patent [13].

## 8.0 Conclusion

In summary, the collaborative assignment to create a distinctive T-shirt launcher for the University of Central Florida (UCF) Athletics Department involves stakeholders from various entities, including UCF Athletics, the Department of Mechanical and Aerospace Engineering, and the project team. Employing systematic methodologies like component and functional decomposition, alongside direct engagement with the customer, has facilitated the identification and documentation of comprehensive requirements and constraints.

These requirements span different sectors such as functionality, safety, storage, maintenance, and economic considerations, with significant analysis and validation methods applied to each. Significant progress has been achieved, marked by preliminary research and a thorough examination of existing T-shirt launchers, which has informed the project's trajectory.

Looking ahead, the team will concentrate on conceptual design while consistently referencing established requirements to inform decision-making processes. By utilizing innovative design strategies and integrating stakeholder input, the final T-shirt launcher will not only meet UCF Athletics' specific demands but also hold promise for broader applications.

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## 10.0 Appendix

## Equations

$$RWL = LC \cdot HM \cdot VM \cdot DM \cdot AM \cdot FM \cdot CM \quad (1)$$

$$V = \frac{\Delta x}{\Delta t} \cdot \frac{3600}{5280} \quad (2)$$

$$L = V_o cos\theta \cdot t \quad (3)$$

$$H = V_o sin\theta \cdot t + \frac{1}{2} g t^2 \quad (4)$$

$$V_o = \frac{L}{t \cdot cos\theta} \quad (5)$$

$$t = \sqrt{\frac{2(H - Ltan\theta)}{g}} \quad (6)$$

## Figures

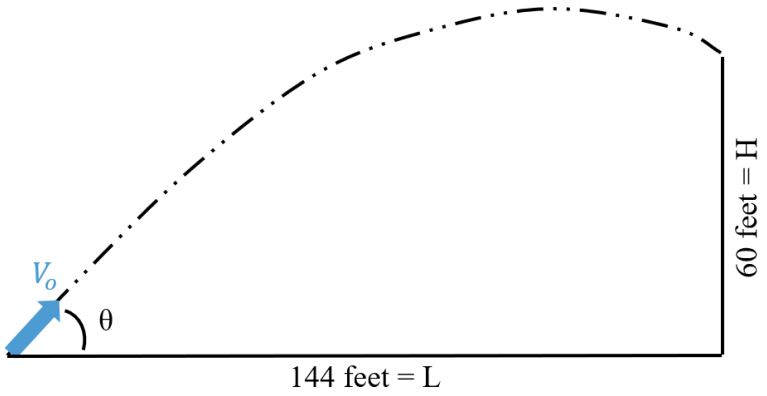


*Figure F1.2: Distance from Sidelines to Top Row*

| | | | Column # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Row # | Customer Importance (1-10) | Relative Weight | Customer Requirement \ Engineering Design Specification | F1.2) Min exit velocity (MPH) | F1.3) Min distance (ft) | F1.1) Variable power (T/F) | S1.1-4) Energy indicators (T/F) | S2.1-2) ESD (steps & time) | S4.1) Lock-Out/Tag-Out (T/F) | S7.2) Trigger weight (lbs) | S9.1) Safety Factor (T/F) | G1.1) Launcher portability (T/F) | G1.2-3) Launcher weight (lbs) | ST1.2) Storage weight (lbs) | F2.2) Time to launch (sec) | E1.1) Cost per use ($) | E2.2) Project budget ($) | G6.1) UCF/Space-U theme (T/F) | F2.1) Shirt size & type (T/F) | G2.1) IP Rating (T/F) |
| 1 | 10 | 0.17 | Launches T-shirts into upper sections | 9 | 9 | 3 | | | | | -3 | | 1 | | | 1 | 1 | | 1 | |
| 2 | 10 | 0.17 | Adjustable launching distance | 3 | 3 | 9 | 1 | | | | | | | | | | | | 1 | |
| 3 | 10 | 0.17 | Safe for user and fans | -9 | -9 | 3 | 9 | 9 | 9 | 9 | 9 | 3 | 3 | | 3 | | | | 1 | |
| 4 | 10 | 0.17 | Portable | | | | | | | | | 9 | 9 | 9 | | | | | | |
| 5 | 8 | 0.13 | Quickly launch multiple shirts | | | 1 | | | | 1 | | 1 | 1 | | 9 | | | | | |
| 6 | 5 | 0.08 | Cost per use | 1 | 1 | 1 | | | | | | | | | | 9 | 3 | | 1 | |
| 7 | 5 | 0.08 | Space-U or UCF themed | | | | | | | | | | | | | | | 9 | | |
| 8 | 1 | 0.02 | T-shirt capacity | | | | | | | | | | | | | | | | 3 | |
| 9 | 1 | 0.02 | Weather resistant | | | | -1 | | | | | | | | | | | | | 9 |

*Figure 5.0: Relationship Matrix*

**Tables**

| *Table F1.3: Competitor Maximum Distance* | |
|---|---|
| Launcher Name | Maximum Distance |
| Shockwave (Team 254) [5] | 450 feet |
| Bleacher Reacher Series (tshirtgun.com) [4] | Micro Mini: 150 feet<br>Dagger: 150 feet<br>Pro: 250 feet<br>Mega: 400 feet |
| Portable Rapid-Fire T-Shirt Cannon (University of Utah) [6] | 202 feet |

| Table 4A: General Requirements Summary | | | | |
|---|---|---|---|---|
| Number | Requirement | Value | Validation | Confidence |
| G1.1 | Portability | True / False | Functional Test | 100% |
| G1.2 | Launcher weight - portable components | 51 lbs | Scale | 100% |
| G1.3 | Launcher weight - attached to user | 51 lbs | Scale | 100% |
| G2.1 | Launcher IP rating | IP44 | IP Test | 90% |
| G3.1 | Age Limit | 18 years old | Visual Inspection | 100% |
| G4.1 | Training manual | True / False | Visual Inspection | 100% |
| G5.1 | Space in front of activation mechanism | 3 in | Measurement | 100% |
| G6.1 | Indicator - launching T-shirt | True / False | Visual Test | 100% |
| G7.1 | UCF or Space-U themed | > 70% | Poll | 100% |
| G8.1 | Assembly time / steps | 20 minutes / 15 steps | Stopwatch / Count | 100% |

| | | | | |
|---|---|---|---|---|
| G9.1 | Energy source availability | Orlando, FL area or online | Google Maps | 90% |

| Table 4B: Functional Requirements Summary | | | | |
|---|---|---|---|---|
| Number | Requirement | Value | Validation | Confidence |
| F1.1 | Variable power control | True / False | Visual Test | 100% |
| F1.2 | Minimum exit velocity | 68.5 MPH | Radar gun or measuring distance and time | 75% |
| F1.3 | Minimum launch distance | 180 feet | Measurement | 100% |
| F2.1 | T-shirt size | S, M, L | F1.2 and F1.3 | 100% |
| F2.2 | Fire rate | 15 seconds | Stopwatch | 100% |
| F3.1 | Launcher accuracy | 20 sq ft at 180 ft | Measurement | 100% |

| Table 4C: Safety Requirements Summary | | | | |
|---|---|---|---|---|
| Number | Requirement | Value | Validation | Confidence |
| S1.1 | Energy level readout | True / False | Visual Inspection | 100% |
| S1.2 | Indicator - any stored energy | True / False | Visual Inspection | 100% |
| S1.3 | Indicator - dangerous amount of energy | True / False | Visual Inspection | 100% |
| S1.4 | Indicator - ready to fire | True / False | Visual Test | 100% |
| S2.1 | ESD - steps and time | 3 steps / 10 seconds | Count / Stopwatch | 100% |
| S2.2 | ESD - stops electricity | True / False | Visual Test | 100% |
| S3.1 | Equilibrium after energy release | True / False | Visual Inspection | 100% |
| S4.1 | Lock-Out / Tag-Out | True / False | Visual Test | 100% |
| S5.1 | Release energy without firing | True / False | Functional Test | 100% |
| S6.1 | Testing cycles | 75 | Count | 85% |
| S7.1 | Firing mechanism lock out | True / False | Functional Test | 100% |
| S7.2 | Trigger force required | Min 4 lbs | Trigger Gauge | 100% |
| S8.1 | When launcher is energized | Steps | Count | 90% |
| S9.1 | Factor of Safety for energy storage | FOS | Calculation or simulation | 85% |

| Table 4D: Storage and Transportation Requirements Summary | | | | |
|---|---|---|---|---|
| Number | Requirement | Value | Validation | Confidence |
| ST1.1 | Storage container dimensions | < 50” in any direction | Measurement | 70% |
| ST1.2 | Storage pieces weight | 51 lbs | Scale | 100% |
| ST1.3 | Storage pieces IP rating | IP44 | IP Test | 90% |
| ST2.1 | Storage & Transportation manual | True / False | Visual Inspection | 100% |
| ST3.1 | Breakdown time/steps | 20 minutes / 15 steps | Stopwatch / Count | 100% |

| Table 4E: Maintenance Requirements Summary | | | | |
|---|---|---|---|---|
| Number | Requirement | Value | Validation | Confidence |
| M1.1 | Maintenance manual | True / False | Visual Inspection | 100% |
| M2.1 | Metric or Imperial | True / False | Track while purchasing items | 100% |
| M3.1 | Part availability | Orlando, FL area or online | Google Maps, receipts | 90% |

| Table 4F: Economic Requirements Summary | | | | |
|---|---|---|---|---|
| Number | Requirement | Value | Validation | Confidence |
| E1.1 | Cost per use | $TBD by Athletics | Prorated materials cost | 100% |
| E2.1 | Cost of launcher | $TBD by Athletics / MAE | Track while purchasing items | 100% |