UC Athletics T-Shirt Cannon

Senior Design Final Report submitted to the
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by

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1. Problem Statement

The current T-shirt cannon used at UC home football and basketball games experiences frequent failures, particularly with the air pipe breaking due to the robot's sensitivity to the controller inputs while driving. Additionally, the cannon's firing range is limited, launching T-shirts an average distance of only 49.36 feet, which is insufficient for reaching a larger audience. Our goal is to redesign critical components of the cannon to enhance its durability and reliability, reducing the frequency of breakdowns. Furthermore, we will reprogram the control system to improve both the precision of the driving mechanism and the firing range, ensuring the cannon performs consistently over longer distances.

2. Research

a. Background of the Problem

There are several critical issues with the current T-shirt cannon that need to be addressed to improve its performance and reliability. The most apparent problem is the frequent breakage of the back PVC pipe, which carries compressed air from the secondary holding tank to the barrel. This pipe has broken multiple times due to the sensitivity in controlling the robot transporting the cannon. The current design makes it easy for the robot to accidentally collide with objects and lead to damage. These design flaws limit the amount that the cannon can be used in the games. For instance, the T-shirt cannon was only operational for one football game last year. When it is not at the games the fans are not able to engage with the robot and the T-shirts are instead only thrown by hand. The original purpose of the cannon was to launch the T-shirts further into the stands than one would be able to do by hand to improve the engagement at the game. The second major issue lies in the pressure limitations of the cannon. The current design restricts the amount of pressure that can be applied, resulting in a slower launch velocity. As a result, T-shirts are not traveling farther than they could be thrown by hand, which undermines the primary goal of the cannon: to reach fans in the upper sections of the stands, that cannot be reached by hand and enhance crowd engagement. Overall, the current design lacks both consistency and durability. The combination of sensitive controls and limited air pressure means that the cannon often fails to meet its intended purpose. By addressing these specific design flaws these issues can be resolved, resulting in a more reliable and impactful fan experience.

b. Applicable Standards

The T-shirt cannon operates using compressed air stored in a scuba diving tank, which transfers the air into a secondary holding tank before being released into the barrel to launch memorabilia. It is crucial that all components of the air system are appropriately rated for the pressures they will encounter, as the safe operation of the cannon depends on maintaining these pressure standards. The scuba tank, which stores the compressed air, must undergo an annual visual inspection by a certified professional to ensure it continues to meet safety regulations (1). Currently, the secondary air tank is made of PVC, with a pressure rating of 120 psi (1), while the connecting tubing is rated for 200 psi. These ratings limit the pressure the system can safely handle, and any upgrades in pressure capacity will need to consider these standards. Ensuring that all components, including any potential replacements or upgrades, are rated for the appropriate pressure levels is vital to avoid equipment failure or accidents. The cannon also relies on several electrical components, including two 12-volt batteries, a wireless relay, three motors, two sabretooth motor drivers, a linear actuator, and Arduino controllers, all controlled by a Spektrum DX6i 6-Channel Controller (2) . Safety is a critical consideration when working with electrical components. To minimize the risk of electrical shock, all power sources must be disconnected before any maintenance or handling of the wiring or controllers is performed. Ensuring that all wiring is properly insulated and securely fastened will further reduce the risk of accidental exposure to electrical hazards.

Other standards we need to comply with are those of the NCAA contest rules. We will be firing the cannon during TV timeouts. A TV timeout length ranges from 2 minutes to 3 minutes and 20 seconds depending on the broadcaster and if the game is nationally televised (3). Therefore, we must be able to drive the cannon to the designated area and fire, ideally all 25 T-shirts, within this timeframe.

c. State of the Art

The state of the art is the already designed T-shirt cannon before we have made any revisions. However, we can also look at T-shirt cannons used at other sporting events to get an idea for the state of the art. T-shirt cannons, in general, are fired using compressed air. When the launch trigger is activated, a valve is released allowing the compressed air out through the barrel which propels the T-shirt (4).

Many professional sports teams use T-shirt cannons to get the crowd engaged. One example we looked at was the Redszilla cannon used at the Cincinnati Reds games. Redszilla is a larger scale cannon that functions as a gatling gun fed T-shirt cannon fueled by 160 pounds of CO_2 and generates nearly 1,000psi. It has 57 barrels and can fire up to 171 soft baseballs or 114 T-shirts into the upper decks of Great American Ballpark (5).

Another example of a major sports team using a T-Shirt cannon is the Wisconsin Badgers t-shirt cannon which is the most powerful t-shirt cannon in college athletics capable of reaching the 45th row of the student section in Camp Randall, only 25 rows from the very top (6). This T-shirt cannon is also a gatling style cannon that can fire off 114 T-shirts in 10 seconds using six 20lb CO_2 Tanks.

The Badger's cannon is only second in the world to the Milwaukee Bucks, known for firing 186 T-shirts in 15 seconds (7). Like the first two cannons, this cannon also runs on CO_2. This cannon is known as being the most powerful in the world and is termed as being a front runner in the T-shirt cannons used during sporting events to improve fan engagement during ‘dead ball’ time. It was also the among the first T-shirt cannons to be designed using the Gatlin process to fire the T-shirts.

The state of the art of the University of Cincinnati’s current T-shirt cannon is compressed oxygen fueled where the compressed air travels through a regulator into a secondary tank made of PVC. From this point, when fired, a valve is opened to allow air to flow through the barrel of the cannon and propel a T-shirt. The cannon can hold up to 10 T-shirts in a gatling gun style barrel but only fires one T-shirt at a time. The Cannon is on motorized wheels and can be controlled using a remote control. However, it cannot be fired from the remote control (8).

d. End User

The primary end users of the T-shirt cannon are UC students, alumni, and sports fans attending football and basketball games. These groups directly benefit from the cannon as it plays a key role in enhancing their game day experience by distributing T-shirts and other memorabilia. The cannon acts as an interactive tool that engages fans, generating excitement and increasing overall involvement in the event. This added layer of interaction helps build a lively atmosphere at the games. By extending its reach to fans seated in all areas, including the upper sections, the T-shirt cannon serves as a bridge to ensure that all attendees feel included and energized. Its purpose is not just to distribute merchandise, but to create moments that enhance the communal aspect of attending live sports events, deepening the sense of shared experience and school loyalty.

e. Summary of Research

One of the main goals of this design project is to increase the T-shirt cannon's firing distance. To achieve this, much of our research has focused on understanding how to optimize the system's performance. Upon reviewing similar T-shirt cannons, we found that many are constructed using metal or other strong materials, which allow for higher pressure capacities. In contrast, the current cannon is built with PVC and plastic tubing, which imposes limitations due to the lower pressure ratings of these materials.

Recognizing this as a key issue, we explored whether upgrading the entire system to stronger materials, such as metal or higher-rated composite materials, would be feasible. By investigating the kinematics involved in launching a projectile, we found that doubling the velocity of a projectile would theoretically result in the projectile traveling four times further. The limiting factor in the current design is the PVC secondary air tank, which has a maximum pressure rating of 120 psi. Through research, we identified a potential replacement secondary tank rated for up to 200 psi. By using this upgraded tank and applying the kinematic equations, we project that the cannon could achieve a firing range of 120 to 130 feet at maximum pressure.

In addition to improving the firing range, we also focused on addressing the control issues that have contributed to the cannon's operational difficulties. The current system is extremely sensitive to controller inputs, leading to frequent malfunctions and occasional damage to the machine. We researched several ways to reduce this sensitivity, including reprogramming the existing controller, optimizing the robot's code, or even adding another degree of control through an additional Arduino module. The inclusion of another Arduino would not only allow for better control but also provide the flexibility to integrate new controllers if needed. This opens the door for added features, such as the ability to fire the cannon remotely, further enhancing the user experience.

In conclusion, our research has provided several avenues for improving both the performance and control of the T-shirt cannon. By upgrading key components and refining the control system, we aim to create a more efficient, durable, and engaging solution that meets the needs of our end users.

f. Customer features

Some of the customer features that we have found from the research are:

- Extended firing range
- Improved durability
- Enhanced precision on controls
- Team branding/appearance
- Efficient reloading mechanism
- Variety of merchandise fired from cannon
- Firing alarms (Lights or speakers)

These features aim to make the T-shirt cannon more fun and engaging for fans. At the end of the day the whole purpose of this project is to get more fans engaged with the game.

3. Quality Function Deployment

a. Survey Methodology and Results

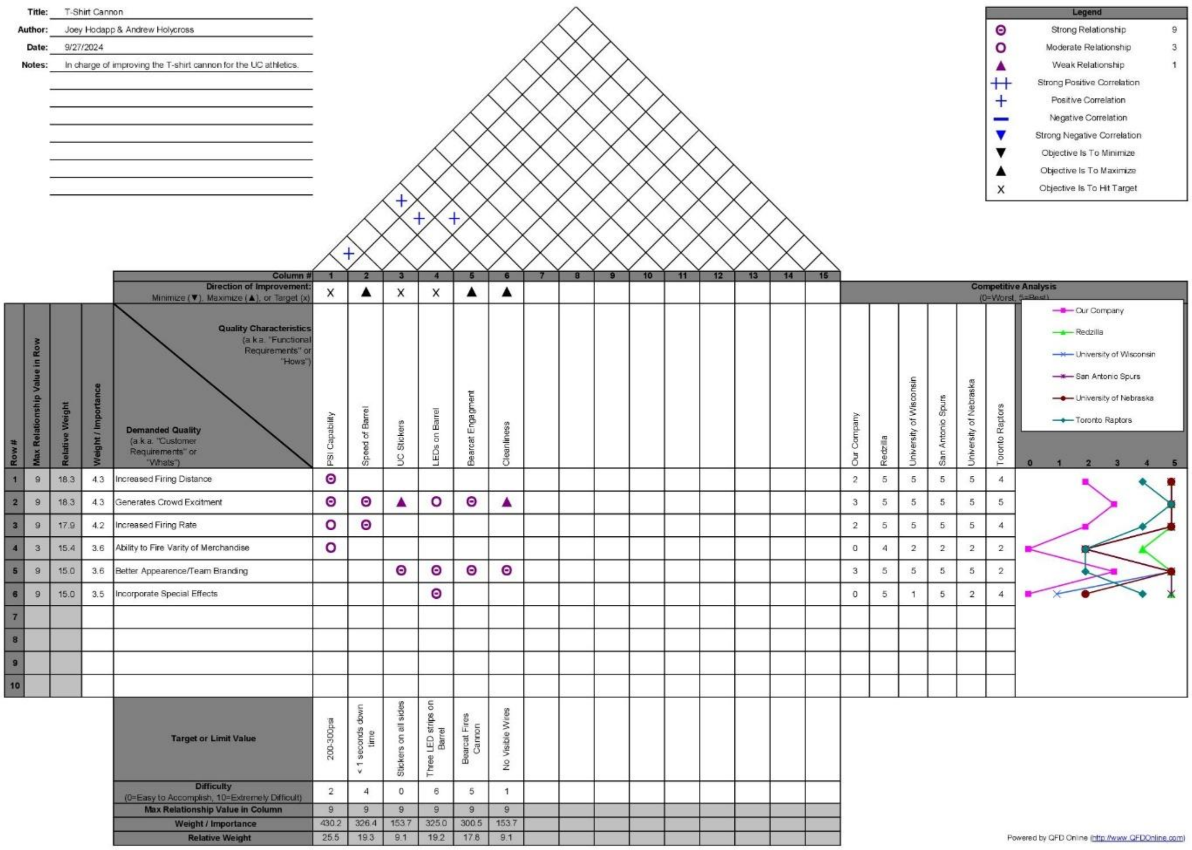
i. Sites used to gather information:

We created a survey using Google forms and then spread the link around to students at the University of Cincinnati via an online server dedicated to students who attend sporting events to gather information from the specific group of students the cannon would be interacting with. Our findings are shown below.

ii. Survey Results Table

		Importance of the feature		Satisfaction with the feature in the current technology	
Customer Feature	Total Surveyed	Average Rank	Standard Deviation	Average Rank	Standard Deviation
Distance the T-shirts are launched	40	4.33	0.8	2.44	0.94
Visual appeal and team branding of the cannon	40	3.55	0.9	2.97	0.99
Number of T-shirts able to be fired during a single T-shirt toss	40	4.23	0.95	2.23	1.18
Level of excitement generated in the crowd	40	4.33	0.86	3.41	1.04
Ability to fire a variety of merchandise	40	3.63	0.86	N/A	N/A
Special effects (lights/sounds) when firing	40	3.53	1.15	N/A	N/A

iii. House of Quality



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality	Our Company	Redzilla	University of Wisconsin	San Antonio Spurs	University of Nebraska	Toronto Raptors
1	9	18.3	4.3	Increased Firing Distance	2	5	5	5	5	4
2	9	18.3	4.3	Generates Crowd Excitment	3	5	5	5	5	5
3	9	17.9	4.2	Increased Firing Rate	2	5	5	5	5	4
4	3	15.4	3.6	Ability to Fire Varity of Merchandise	0	4	2	2	2	2
5	9	15.0	3.6	Better Appearence/Team Branding	3	5	5	5	5	2
6	9	15.0	3.5	Incorporate Special Effects	0	5	1	5	2	4

Column #	1	2	3	4	5	6
Quality Characteristic	PSI Capability	Speed of Barrel	UC Stickers	LEDs on Barrel	Bearcat Engagment	Cleanliness
Direction of Improvement	x	▲	x	x	▲	▲
Target or Limit Value	200-300psi	< 1 seconds down time	Stickers on all sides	Three LED strips on Barrel	Bearcat Fires Cannon	No Visible Wires
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	2	4	0	6	5	1
Max Relationship Value in Column	9	9	9	9	9	9
Weight / Importance	430.2	326.4	153.7	325.0	300.5	153.7
Relative Weight	25.5	19.3	9.1	19.2	17.8	9.1

b. Engineering Characteristics

Our plan is to revise the current T-shirt cannon to meet all the identified customer features, with the goal of enhancing the gameday experience for fans. To improve the cannon's performance, we will focus on several key areas.

i. Increasing Firing Distance:

To extend the distance at which T-shirts can be launched, we plan to increase the air pressure used in the firing mechanism. This will involve testing different psi levels to determine the optimal pressure for maximum range, ensuring that T-shirts can reach the farthest sections of the stands. By increasing the air pressure, we will be able to achieve a longer firing distance that enhances all fan engagement and not just those in the first few rows.

ii. Enhancing Firing Rate:

To increase the number of T-shirts fired during the games, we plan to modify the control system that rotates the barrel after each shot. By increasing the rotation speed, we will reduce the time between each launch, allowing more T-shirts to be fired within the same time. This will improve the overall pace of the T-shirt toss, keeping the crowd excited and engaged.

iii. Improving Aesthetics and Branding:

Currently, the cannon's design lacks refinement, with exposed wires and no visible team branding. To address this, we plan to encase the base of the cannon with black acrylic panels to conceal the electronics and create a cleaner, more professional appearance. In addition, we will add University of Cincinnati stickers and other branding elements to align the cannon with the team's identity, further enhancing the visual appeal.

iv. Incorporating Special Effects:

To add a dynamic element to the T-shirt launch, we will install programmable LED strips along the barrel of the cannon. These lights will be synchronized to follow the T-shirt as it is fired, creating a visual trail that adds excitement to the launch. The LED effects will increase the entertainment value and captivate the audience.

v. Increasing Crowd Excitement:

By making these strategic improvements to the cannon's performance, appearance, and interaction with fans, we aim to elevate the level of excitement in the stadium. These changes will not only make the T-shirt toss more efficient and engaging but also create a visually stimulating experience that resonates with the crowd, fostering a greater sense of school spirit.

c. Product Objectives

The data gathered from the House of Quality and customer survey provided valuable insights that will guide the development of the T-shirt cannon's product objectives. While the overall results aligned with our expectations, some specific findings surprised us, especially how closely the objectives ranked in importance.

i. Key Findings and Priorities

According to the survey responses, most participants were most interested in the T-shirt cannon's ability to generate excitement during game breaks. The final ranking of product objectives, based on the importance level assigned by our respondents, is as follows:

1. Increasing Firing Distance (18.3 relative weighting)
2. Excitement Generated (18.3)
3. Enhancing Firing Rate (17.9)
4. Ability to Fire a Varity of Merchandise (15.4)
5. Appearance/Team Branding of the Cannon (15)
6. Incorporating Special Effects (15)

This prioritization is in line with what we anticipated, but the satisfaction ratings provided some unexpected insights. Contrary to our initial belief that firing distance would be the most disappointing feature, respondents rated the firing rate—the number of T-shirts launched—as the least satisfactory aspect of the current cannon. This shifted our focus, making it clear that enhancing the firing rate needs to be just as much of a priority as increasing the firing distance.

ii. Refining Our Focus

As a result, our primary design focus will be on improving both the firing rate and distance simultaneously to address the top concerns expressed by fans. Once we have optimized these functional elements, we will turn our attention to aesthetic improvements, such as enhancing the appearance of the cannon and adding special effects. These changes will help the cannon capture more attention during games and foster a greater sense of school spirit.

In addition, while team branding and the ability to fire other types of merchandise ranked lower on the list, they will still play a key role in the final product, as they contribute to the overall fan experience and engagement.

4. Concepts Design

For our project to been deemed successful we must improve the fan engagement and experience at home football and basketball games during the T-shirt toss segment of the game. Based on our QFD process this will require us making the cannon shoot farther and faster along with increasing the team branding and visual appeal of the cannon including the addition of special effects. We believe that making these changes will increase the overall goal of the cannon which is to increase fan engagement, excitement, and game experience. We see clearly this is where the current cannon is lacking when comparing it to the state of the art.

a. Function #1: Drivable

The T-shirt cannon must be remote control driven to get the cannon to the designated location during the games. While not only being able to be driven it is very important that the robot is easy to drive and control. This is since we will need to be able to drive the cannon on the field while there are many other people and things around us, the cannon needs to be able to be easy controlled to the point it can safely maneuver around a busy area. The current cannon's controller is very sensitive and not easy to control.

b. Function #2: Lauch T-shirt adequate distance

A T-shirt cannon is not a T-shirt cannon if it can't launch T-shirts into the crowd. Additionally, the purpose of a T-shirt cannon is to launch T-shirts farther than a person can through a T-shirt. It is very important that the cannon can launch a T-shirt into the upper rows of the student section. If this function is not met, then the T-shirt cannon is useless. Currently the cannon launches less than 50 feet.

c. Function #3: Excite the crowd and increase fan engagement

The goal of the cannon is to pump up and excite the crowd during a TV timeout. If the cannon is not exciting enough to give energy to the crowd, then it is not meeting its goal. Getting T-shirts out faster and farther is the most ideal way to increase the amount of excitement that the crowd experiences. Adding more team branding, special effects, or getting the Bearcat involved in the launching of the cannon are all ways to increase the amount of excitement the cannon creates.

d. Concepts:

Since our project is slightly different in nature as we are not designing something new but rather revising an already existing device, we do not necessarily have concepts, per say, to decide between but rather needed revisions/additions to make to improve the overall usage of the cannon. Listed below are specifics about the robot that needs to be addressed.

Concept 1 – The remote control the cannon is powered by is very sensitive and therefore difficult to control. The slightest movement of the joystick will result in rapid movement of the robot which can be very problematic when trying to drive through confined places.

Concept 2 – The back pipe leading from the solenoid to the barrel hangs beyond the back end of the robot and due to the sensitivity of the control it is common stance for the robot to run into things resulting in the back pipe breaking multiple times.

Concept 3 – The cannon can only launch a T-shirt 49.36 feet which is equivalent to only roughly a third of the way up the student section. This is due to the pressure limit of the PVC tubing that is used being 120 psi.

Concept 4 – Firing can currently only take place by pressing a small button located on the front of the robot. A small button is not ideal for attempting to increase excitement in the stands and is also not the most convenient when we have a remote control.

Concept 5 – The cannon's wires are not well organized, and all internal components are clearly visible resulting in the robot not being as eye pleasing as it could be. There is also no University of Cincinnati branding on the robot other than the colors.

5. Project Management

a. Team Members and Responsibilities:

Our team members are Andrew Holycross and Joey Hodapp. As listed below, our timeline for when we would like certain tasks completed by are designated by the dates of when the remaining home football games are. This is because we have the overall goal of making sure that the cannon is better each game for the remainder of the season. For this reason, we do not have specific functions that either of us will be responsible for, however, we will both be working together to make sure that we are on the same page about what next steps are and how our time is best spent to make sure that each game is better than the last in some way. Each of us will be involved in every aspect of the project to ensure that each necessary function of the robot is met in time for the next game and to the best possible ability.

b. Budget Limit:

We have applied for the Herman Schneider Foundation Grant requesting $1,600 to fund the changes we plan to make to the T-shirt Cannon. The grant would go towards: a new secondary tank that allows for an increase in pressure ($200), an addition scuba tank to cut down of the frequency need to refill (including inspection and fill cost, $600), replace PVC piping with metal piping to allow for greater integrity ($120), new lithium batteries to allow the cannon to go longer without needing charged and always have a backup ($460), and upgrade visuals (lights, encloser, decals, etc. $220).

c. Key Milestones:

Milestone	**Goals**	**Date**
Introduced to Project		September 3rd 2024
First Home Football Game with Cannon	Fix back pipe to get the cannon working again	September 21st 2024
Final Proposal Due		October 11th 2024

Home Football Game	Get the cannon firing farther and faster, replace acrylic, and add decals	October 19th 2024
First Home Basketball Game		November 4th 2024
Home Football Game	Add large firing button	November 9th 2024
Home Football Game	Add LED strips	November 30th 2024
Senior Design II Presentation due		December 6th 2024
End of Fall Semester		December 13th 2024
CEAS EXPO 2025	Have cannon complete and poster designed	April 8th 2025
Final Presentation	Have Power Point completed	April 29th 2025

6. 2024-25 Modifications

a. Back Pipe fixed/Shortened

When we first received the T-shirt cannon, the PVC pipe connecting the solenoid to the barrel was broken, rendering the cannon unable to fire. Fixing this was our first priority, but we also wanted to redesign the pipe to prevent future breakages. This wasn’t the first time the pipe had snapped; it had happened multiple times before. The issue stemmed from the controller’s sensitivity, which made the robot prone to accidentally backing into walls. To solve this, we shortened the pipe, so it no longer extends as far behind the robot. Now, the base of the robot is the first point of contact if it backs into a wall, shielding the pipe from damage and ensuring the cannon remains functional.

b. Adjusted Controller Sensitivity

Controller sensitivity was a critical issue to address early on, as it made the cannon difficult to control and prone to collisions that could damage components like the back pipe. To resolve this, we researched online and consulted the controller manual, where we discovered how to adjust the output values. By reducing the maximum speed from 100% to 25%, we not only slowed the robot's top speed but also reduced its acceleration. This allowed the driver to have much finer control over the robot's speed. These changes made the robot far easier to drive and maneuver, greatly reducing the risk of accidental impacts.

c. Replaced Secondary Tank

Replacing the secondary tank was crucial for achieving our main goal: increasing the cannon's shooting distance. We conducted research and calculations to determine the optimal pressure limit and tank size. Using pressure, volume, and energy equations we estimated how much farther the cannon could shoot at different PSI levels and researched how tank volume affects shooting distance. This helped us balance having enough air volume behind the T-shirts while efficiently using the scuba tank's capacity. Our analysis showed that 250 PSI would be ideal, but we wanted to keep the tank volume under 1.5 gallons, as a larger secondary tank would deplete the air from the scuba tank too quickly, reducing the number of shots before needing to refill the scuba tank. Since we couldn't find a tank that met both requirements, we chose a 200 PSI tank with a 1.5-gallon capacity, which provided the best balance between pressure and volume given the limitations of the scuba tank. The calculation below justify mathematically why we chose to select the Vlair 1.5 gallon at 200psi secondary tank as opposed to keeping the 1 gallon at 120 psi PVC secondary tank, improving the distance from roughly 50 ft to 78 ft traveled for the t-shirts.

Step 1-Basic Model:

The W done by expanding air is given by the equation for adiabatic expansion:

$$W = \frac{P_1 V_1}{\gamma - 1}\left(\left(\frac{V_2}{V_1}\right)^{\gamma-1} - 1\right)$$

Where:

- P_1 and V_1 are the inital presure and volume of the air in the tank.
- V_2 is the volume of the barrel or the volume of the air discharged from the cannon.
- γ is the adiabatic index for air, typically $\gamma = 1.4$

However we can simplify this situation by focusing on the energy involved, we can get a energy approximation using the pressure-volume work equation:

$$E = P \times V$$

Where:

- P is absolute presure of the air in the secondary tank in Pascals.
- V is the volume of the the air in the secondary tank in cubic meters.

The energy is then converted into kinetic energy as the t-shirt leaves the cannon. The distance traveled by the t-shirt will be related to the amount of kinetic energy.

Step 2-Relating Energy to distance:

The kinetic energy of the t-shirt is given by:

$$E_{kin} = \frac{1}{2}mv^2$$

Where:

- $\mathrm{m\ is\ the\ mass\ of\ the\ t-shirt.}$
- V is the velocity of the t-shirt as it exits the cannon.

The velocity of the t-shirt is determined by the energy given to it by the expanding air. Therefore, the relationship between the energy and distance travel depends on how the kinetic energy is converted into both motion and drag forces acting on the t-shirt.

We can assume that drag influences the t-shirts motion and this can be simplified to give an approximation of distance traveled of:

$$d = \frac{v^2}{C_d}$$

Where:

- $\mathrm{d\ is\ the\ distance\ the\ t-shirt\ travels.}$
- $\mathrm{v\ is\ the\ initial\ velocity\ from\ the\ cannon.}$
- $\mathrm{C_d\ is\ the\ drag\ coefficient\ which\ is\ dependent\ on\ the\ size\ and\ shape\ of\ the\ t-shirt.}$

Step 3-Comparison of the two configurations:

We must start by laying out the specs of both configurations:

- Current setup:
  - $\text{Volume} = 1 \text{ gallon} \times 3.785 \frac{\text{liter}}{\text{gallon}} = 3.785 \text{ liters} \times \frac{1 \text{ m}^2}{1000 \text{ liters}} =$ $3.875 \times 10^{-3} \text{ m}^3$
  - $\text{Pressure} = 120 \text{ psi} \times \frac{6894.76 \text{ Pa}}{1 \text{ psi}} = 827{,}321 \text{ Pa}$
- Upgraded setup:
  - $\text{Volume} = 1.5 \text{ gallon} \times 3.785 \frac{\text{liter}}{\text{gallon}} = 3.785 \text{ liters} \times \frac{1 \text{ m}^2}{1000 \text{ liters}} =$ $5.678 \times 10^{-3} \text{ m}^3$
  - $\text{Pressure} = 200 \text{ psi} \times \frac{6894.76 \text{ Pa}}{1 \text{ psi}} = 1{,}378{,}952 \text{ Pa}$

We can then find out the current and upgraded energy of the systems knowing:

$$E = P \times V$$

$$E_{\text{Current}} = 827{,}371 \times 0.003785 \approx 3{,}130.3 \text{ J}$$

$$E_{\text{Current}} = 1{,}378{,}952 \times 0.005678 \approx 7{,}832.4 \text{ J}$$

Assuming that drag force and other factors remain constant we find that distance is roughly proportional to the square root of the energy. With that being said we can use the following approximation:

$$\frac{d_{\text{upgraded}}}{d_{\text{current}}} = \sqrt{\frac{E_{\text{upgraded}}}{E_{\text{current}}}} = \sqrt{\frac{7{,}832.4}{3{,}130.3}} \approx \sqrt{2.5} \approx 1.58$$

This shows us that with this new tank we can expect to see a 58% increase in distance. Making the final distance with the new secondary tank being:

$$49.36 \text{ ft} \times 1.58 \approx 78 \text{ ft}$$

This is what justified our reasoning for purchasing and installing the new secondary tank.

d. Firing Distance Testing with New Tank

Distance in feet
63.33
74.33
79.17
80.42
84.5
93.42
96
108
115.54
Average = 88.3

After selecting and installing the new secondary tank, we took the cannon out to the football field for testing. The larger tank significantly increased the cannon's average firing distance, raising it from 49.36 feet to 88.3 feet. However, as expected, the larger tank also caused the scuba tank to deplete much faster. Now, the scuba tank needs to be refilled after every 2 uses or every 4 full shots (10 shots per full fire). While this means more frequent refills, we're okay with this trade-off since increasing the firing distance is our primary goal, and refilling the scuba tank is relatively inexpensive.

e. Barrell Rotation Speed Testing

Full Fire Time in Seconds
21.23
21.25
21.24
21.18
21.19
21.24
21.20
21.20
21.04
21.15
21.17
21.28
21.20
21.18
21.17
Average = 21.19

Based on our survey, most respondents preferred a shorter time between shots, so we decided to reduce the dwell time in the code to speed up the cannon's firing rate. Before making any code changes, we first tested how long it took for a full fire to complete. After testing, we found that the average time for a full fire (10 shots) was 21.19 seconds. Given that we typically have about 45 seconds to fire the cannon at football and basketball games, our goal was to get the full rotation time down to under 20 seconds. This would allow us to fire two full rounds at each game, totaling 20 T-shirts. Using this data, we determined how to adjust the code to reduce the time between shots and meet our goal.

f. Changed Time Between Shots

After testing the cannon's firing time for ten shots, we decided to reduce the dwell time from 1 second to 0.75 seconds. With an average time of 2.12 seconds per shot, this adjustment would bring the time down to 1.87 seconds per shot, or 18.69 seconds for a full fire. This not only gets us under our goal of 20 seconds per full fire, but also ensures that the barrel has enough time to fully return to position before firing again.

g. Added Battery Display

Before adding the battery display, there was no way to check the battery's charge level. We would simply plug it in to charge occasionally, without knowing what percentage it was at. This created the risk of the battery dying unexpectedly during a game. To fix this, we decided to wire in a battery display that shows the current charge percentage. This allows us to monitor the battery level and know exactly when it needs charging, ensuring we're never caught off guard by a dead battery during a game.

h. Replaced Acrylic

The original acrylic had cracked in several places and was falling off. Additionally, the clear acrylic made the internal components, like wires and motors, visible, which resulted in a less-than-appealing look. To improve both aesthetics and durability, we decided to replace the clear acrylic with black acrylic. This not only concealed the internal components but also aligned with the University of Cincinnati's school colors, making the cannon more on-brand. We also opted for slightly thicker acrylic to increase durability and reduce the risk of cracking.

i. Firing Distance Testing After Changing Code

Distance in feet	Circumference of rolled T-shirt in inches
56.25	~8
67.42	~8.5
69	~8.5
69.25	~8
70	~8.5
71.25	~8.25
74.17	~8
74.42	~8.5
81.96	~8.5
103	~8.75
119.25	~8.75
Average = 77.82	

After adjusting the dwell time in the code to reduce the time between shots, we took the cannon out for another round of testing. The results showed an average firing distance of 77.82 feet, which was roughly 11 feet shorter than the distance before the code change. This decrease in distance can be attributed to the fact that reducing the dwell time gave the secondary tank less time to refill, resulting in less pressure behind each shot. Given this, we determined that the change wasn't ideal. After further testing and observing the cannon in action during the football game on 10/19/2024, we decided to explore adjusting the solenoid's open time instead. Additionally, during these tests, we noticed a correlation between the T-shirt diameter and the distance traveled. We found that an ideal circumference of around 8.75" helped maximize distance, and standardizing the way we roll the T-shirts could further improve performance.

j. Added University of Cincinnati Decals

Based on feedback from our survey, a common suggestion was that the cannon lacked school branding and overall appearance. To address this, we added decals to the newly replaced black acrylic. These decals greatly enhance the cannon's look, featuring the Bearcat eyes logo on the front for appearance, the University of Cincinnati's 'C-paw' logo on both sides for team branding, and a decal on each side to credit the College of Engineering and Applied Sciences. This addition improved both the appearance and the school spirit of the cannon.

k. Added Large Red Firing Button

After surveying the student body at the University of Cincinnati, we found that many wanted the cannon to create more excitement. The original 'fire' button was a small (roughly 0.25") blue button on the control panel, which lacked the impact we were aiming for. To make the cannon more engaging, we replaced it with a four-inch red button featuring the UC logo. This larger button not only provides a more exciting way to launch the cannon but also allows the Bearcat mascot to activate it, increasing fan involvement and boosting excitement during the games.

l. Solenoid Timing Testing

Solenoid Time Open in milliseconds	Test 1 Distance in feet	Test 2 Distance in feet	Test 3 Distance in feet	Average
100	75	74.17	70.75	73.31
120	76.83	80.58	94	83.8
160	75	80	86.33	80.44
180	80.25	87	98.17	88.47
190	83	85.25	84.5	84.25
200	86.25	93.42	106.33	95.33

In the original code, the solenoid opened for 100ms with each shot. With the goal of optimizing performance, we tested different solenoid open times to find the ideal duration that would maximize firing distance without wasting too much air from the scuba tank. The test results, shown in the table above, helped us determine that the optimal solenoid open time falls between 180ms and 200ms. Additionally, we took not that at 200ms, approximately 100 PSI is released from the secondary tank per shot, which provides a balance between performance and efficiency.

m. Changed Time Between Shots and Time Solenoid is Open

After completing the solenoid timing tests, we calculated that it takes approximately 3.2 seconds for the scuba tank to refill 100 PSI after each shot. Given this, we determined that the average 7-foot increase in distance from using a 200ms solenoid open time wasn't worth the faster depletion of the scuba tank. As a result, we decided to set the solenoid open time to 180ms. Additionally, we reverted the time between shots back to the original 1 second to give the secondary tank enough time to refill fully after each shot. While survey feedback indicated a desire for quicker shot times, we found that failing to allow the secondary tank time to refill would cause the pressure to decrease with each shot. This would ultimately result in insufficient pressure to fire the T-shirts after just a few shots. To optimize performance, we also alternated the solenoid's open time between 180ms and 100ms, allowing the secondary tank to refill while also ensuring a more even distribution of T-shirt distances. This not only ensures the cannon performs at its best but also ensures that fans closer to the cannon have a better chance of catching a T-shirt.

Calculations:

<u>Convert tank volume from gallons to cubic fee:</u>

Volume of secondary tank = 1.5g × 0.1337ft^3/gallon = 0.2006 ft^3

<u>Calculate the equivalent volume of air at atmospheric pressure (15 psi):</u>

Target refill volume = 0.2006ft^3 × (100psi / 15psi) = 1.337ft^3

<u>Calculate the time to refill at 25 CFM:</u>

Time = 1.337ft^3 / 25CFM = 0.053 min = 3.2 sec

n. Repainted And Glued Down Barrel

The long barrel that the T-shirts travel through to reach the stands had significant paint chipping, and it was only held in place by zip ties. This setup allowed the barrel to move slightly, creating an air gap where pressure could escape as the T-shirt flew out, which likely reduced the efficiency of each shot. To improve both appearance and performance, we removed the barrel, repainted it for a cleaner look, and used epoxy to securely attach it to the cannon. This change has allowed the barrel to create a better seal around the revolving section of the cannon, minimizing air loss. The barrel is now more durable, looks better, and stays securely in place, helping the cannon perform more efficiently.

o. Added Quick Release

Removing the scuba tank to refill it was originally a frustrating and time-consuming task. Without a quick release valve, the only way to detach the tank was to spin it around the hose to unscrew it, often requiring two people to pass the tank back and forth while slowly rotating it. This method not only made the process inefficient but also increased the risk of damaging the hose or fittings. To solve this, we installed a quick release valve between the scuba tank and the hose. Now, instead of needing to rotate the entire tank, the hose can be easily snapped on and off. This change has made tank swaps significantly faster, safer, and more manageable for a single person.

p. Added LEDs to The Barrell

To improve aesthetics and boost crowd engagement, we added a spiral LED light strip along the barrel of the cannon. The lights are programmed using the Arduino to sync with each shirt launch. When the solenoid opens to fire a T-shirt, the LEDs activate at the base of the barrel and light up in sequence toward the tip, mimicking the path of the projectile. This visual effect happens in real time with each shot, creating a more dynamic and exciting experience for the audience. In addition to looking great, the lighting draws attention to the cannon during operation, making it easier for the crowd to follow the action.

7. Future Work

a. Adding a Firing Button to the Remote

One improvement to consider in the future is adding a firing button directly to the controller. While the large red firing button added a big excitement factor during the initial shot, a secondary firing button on the controller could make operation more convenient. Typically, we fire the cannon twice during a game. Having a remote button would allow us to maintain the excitement of the first shot with the big red button, while making the second firing feel more seamless, triggered quickly from the controller. A firing button on the controller could also be useful for testing purposes, allowing the operator to fire the cannon from a distance, such as near the landing zone, rather than being stationed next to it.

b. Repaint or Replace the Barrel Frame

Another potential upgrade would be repainting or replacing the rotating barrel frame. The red paint on the existing frame is starting to chip and wear off, which negatively impacts the look of the cannon. We think switching to a black color scheme for this part would better match the rest of the design and give the cannon a cleaner, more modern appearance. Since the material used is naturally black and was only painted red, a simple fix could be to cut a new piece from the same material and leave it unpainted. We believe the red accents are best reserved for the barrels themselves to create a sharp, intentional contrast.

c. Improve Wire Management

Wire management inside the control box is another area that could benefit from improvement. Currently, the wiring is tangled and unorganized, which not only looks messy but also increases the risk of connections coming loose or becoming damaged. Tidying up the wire layout with labeled connections, cable ties, or a wire tray would make maintenance easier and reduce the chance of electrical issues during operation. A cleaner setup would also make the system easier to understand for future students working on the cannon.

d. Fix or Replace the “Go Home” Limit Switch

Fixing or replacing the limit switch used for the “Go Home” button is another worthwhile project. Right now, the go-home function is disabled because the small acrylic piece meant to trip the switch broke off. This feature was designed to automatically align the barrel to ensure a proper seal before firing. While manually aligning the barrels before firing currently works and allows for a physical check, it would be nice to restore and improve the go-home feature for added convenience.

e. Upgrade to a Digital Pressure Regulator

Lastly, we recommend replacing the current analog pressure regulator with a digital one. A digital regulator would allow for faster and more accurate pressure adjustments, making it easier to stay within the safe pressure limits of our components. If a programmable digital regulator can be integrated, it could potentially be adjusted through software or the remote control. This would open the door for dynamic firing distance control—spreading out shirts more in a football stadium or dialing it back in a tighter basketball arena. It would also help adapt quickly to different air levels or game situations.

8. Conclusion

The UC T-shirt cannon redesign project successfully addressed a range of mechanical, electrical, and user-experience issues that previously limited the cannon's effectiveness and reliability during athletic events. From the beginning, our primary objective was to improve fan engagement through greater reliability, enhanced firing performance, and a more visually striking presence. By targeting the most critical design flaws—namely, fragile components, a sensitive control system, and inadequate firing distance—we transformed the cannon into a more powerful, durable, and exciting device that better meets the expectations of UC fans and athletics staff.

Through extensive research and testing, we were able to quantify the limitations of the original design and make informed decisions about each modification. The replacement of the secondary air tank, combined with optimized solenoid timing and improved code, nearly doubled the cannon's average firing distance from 49.36 feet to over 88 feet. This major improvement directly addressed the top concern identified in our student surveys: the cannon's inability to reach the upper rows of the stands. At the same time, we improved the firing rate by refining the barrel rotation timing and optimizing dwell intervals, balancing fan feedback for faster shots with the practical limitations of air pressure recharge time.

Beyond performance, we also emphasized usability and visual impact. Key upgrades like the addition of a large red firing button, University of Cincinnati branding, LED barrel lights, and improved wire concealment all served to elevate the aesthetic and engagement factor of the cannon. These upgrades weren't just cosmetic; they made the cannon safer, more professional-looking, and easier to operate in the fast-paced environment of live events. By integrating both engineering functionality and crowd appeal, we ensured the cannon fulfilled its role not just as a machine, but as an entertainment centerpiece.

Finally, our work lays the groundwork for future improvements. While the current redesign meets most of our performance and usability goals, we've identified areas—such as digital pressure regulation, improved wire management, and a remote fire control option—that can further elevate the cannon's capabilities. This ongoing process reflects the spirit of engineering design: iterative improvement grounded in testing, feedback, and user experience. Overall, we believe this project not only revitalized an important piece of game-day tradition but also provided a lasting resource for future UC engineering students to build upon.

9. References

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Appendix A: Operators Manual

READ BEFORE OPERATING

DO NOT PROCEED until this section has been read and understood. The following points are essential for safe and responsible operation of the T-shirt cannon:

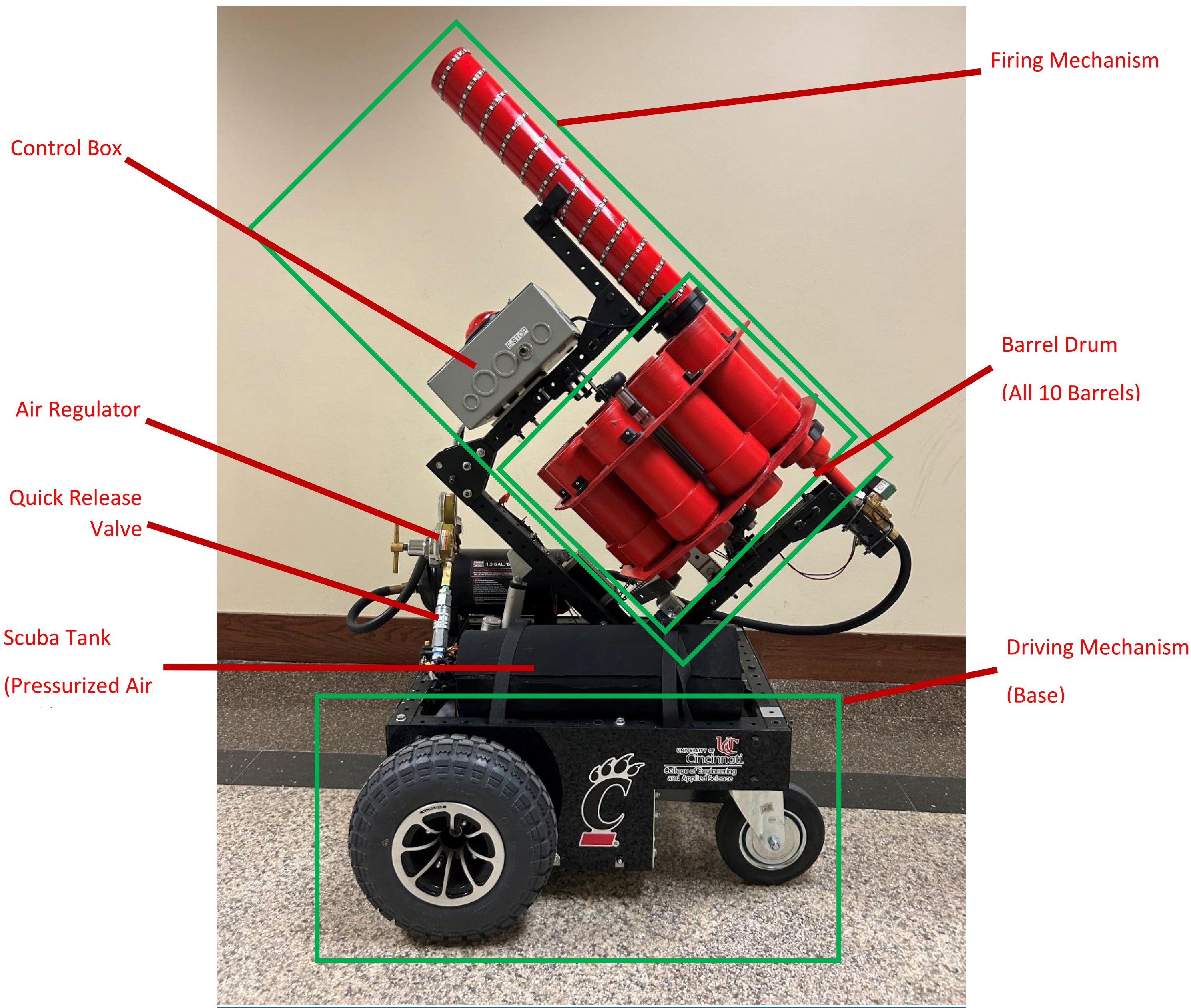
- **Do not exceed 200 psi operating pressure.**
    - Exceeding this limit could result in equipment failure or personal injury.
    - See Sections 6.1 and 6.2 for details.
- **The pressure regulator valve handle must be unscrewed before and after each use** so that the Operating Pressure Gauge reads 0 psi.
    - See Sections 6.2 and 6.3 for procedures.
- **Never pressurize the system while transporting or driving the cannon.**
    - The air system should only be activated immediately before firing and must be fully depressurized immediately afterward.
    - See Sections 8.3 and 8.4 for full event protocol.
- **Always power off the firing mechanism when the cannon is not actively firing.**
    - The firing switch should remain off during transport, staging, and idle periods to prevent unintentional activation.
    - See Section 3.3 and 8.3 for further instruction.
- **Use the emergency stop systems immediately in the event of unexpected behavior.**
    - The E-stop button on the side of the control box will shut down all firing and rotation functions.

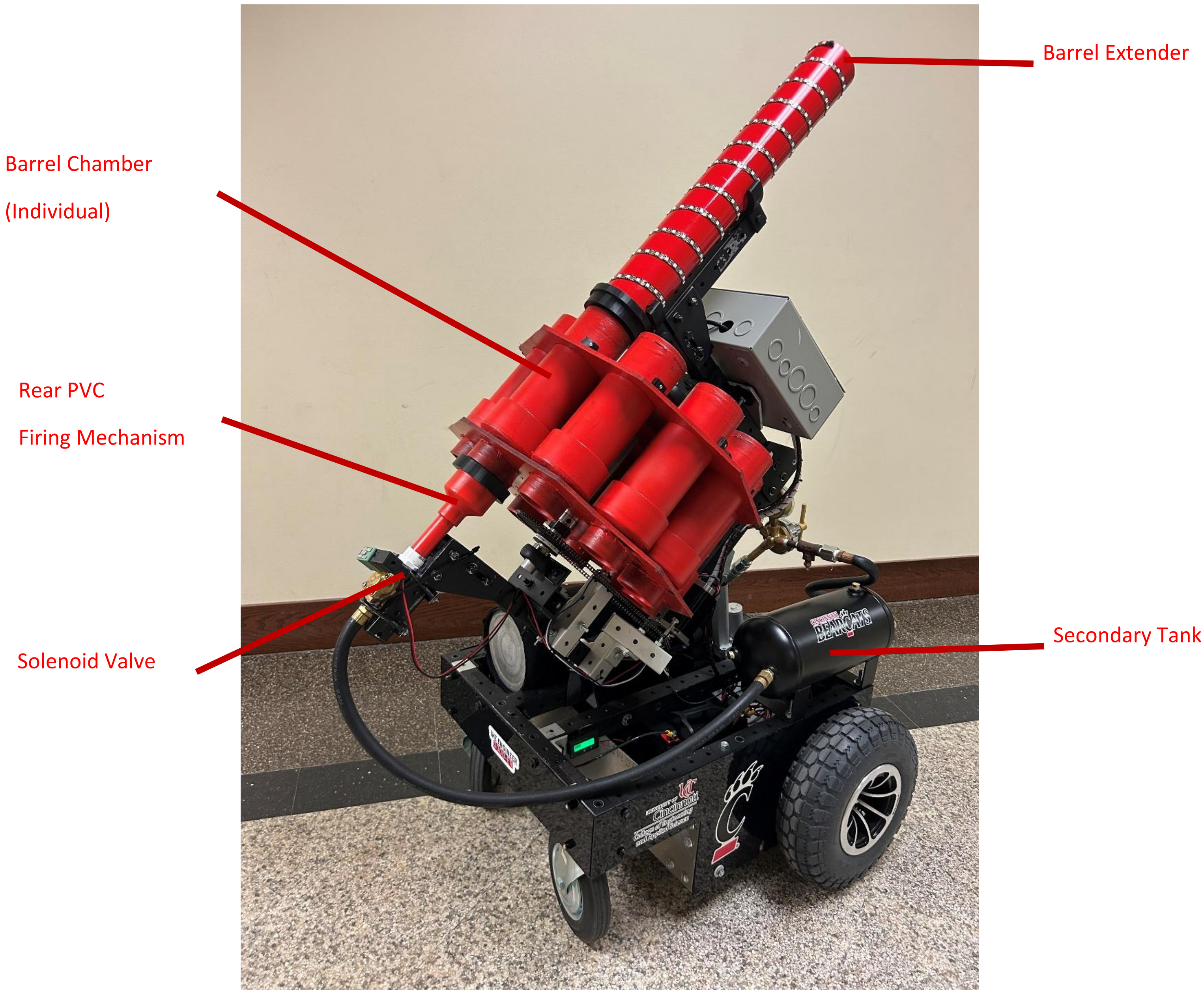
  - The OFF button on the key fob, attached to the remote controller, will immediately stop all driving functions, disabling the base motors.
  - Operators should understand the location and purpose of both emergency stops.
  - See Sections 3.2, 4.4, and 8.5 for more information.
- **Maintain line of sight between the cannon and operator at all times.**
  - Never fire the cannon without clear visibility of the direction and area of launch.

See Section 8.5 for safety guidance during live events.

1. Terminology

1.1 Diagram of the Robot




Barrel Extender
Barrel Chamber
(Individual)
Rear PVC
Firing Mechanism
Solenoid Valve
Secondary Tank

2. Electrical Power

2.1 Driving Mechanism Batteries

When the battery display indicates a charge below 50%, the two 12V batteries powering the Driving Mechanism (Base) should be recharged using the designated charger that was purchased with the system, as shown in Figure 1. The charger includes multiple settings, and it is essential that it is set to a 24 Volt, 2 Amp charging mode to ensure compatibility and safe operation.

Figure 1. Battery Charger

To connect the charger, attach the positive charging lead to the positive terminal of the battery, and the negative lead to the negative terminal (shown in Figures 2 and 3). Always make these connections before plugging in the charger to avoid short circuits or electrical hazards. Once charging is complete, unplug the charger promptly to prevent overcharging or battery damage.

Figure 2. Positive Terminal

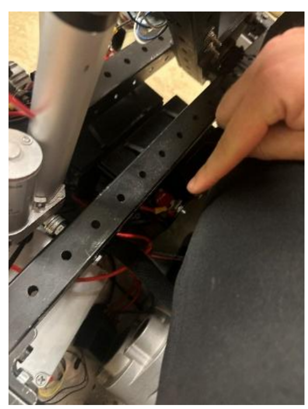


Figure 3. Negative Terminal

A full recharge cycle will take approximately 12 hours. Regularly monitoring the battery level using the battery display and maintaining an adequate charge is essential to ensure uninterrupted operation of the robot.

3. Turning Systems On/Off

The T-shirt cannon system consists of two main subsystems, each controlled by a dedicated switch:

- The Driving Mechanism uses a waterproof circuit breaker fuse holder with a manual reset toggle switch.
- The Firing Mechanism is controlled by a standard on/off toggle switch located on the firing control box.

To operate the robot, both subsystems must be powered on.

3.1 Driving Mechanism (Main Power)

Location: Mounted on the top of the base frame in front of the linear actuator (Figure 4)

Controls: Stepper Motor, Linear Actuator, Solenoid, and two 12V Batteries powering the wheel motors.

To power on the base, push the lever on the waterproof circuit breaker until it clicks into the locked position (Figure 5). To shut it off, press the button on top of the breaker to release the lever, which will pop back out (Figure 6).

Figure 4. Location

Figure 5. On Position

Figure 6. Off Position

3.2 Driving mechanism (Safety Switch)

Location: Operated via key fob clipped to the remote control (Figure 7).

Controls: Left and right base motors.

After turning on the battery supply and binding the controller to the receiver (see Section 5.1), confirm the connection by raising and lowering the firing mechanism using the right joystick. If the actuator does not respond, cycle power on both the battery supply and the controller, then attempt the binding process again.

Once confirmed, ensure both joysticks are centered. Press the "ON" button on the key fob to activate the wheel motors and enable drive functionality. The key fob includes both an "ON" and "OFF" button, providing a secondary control layer for added safety. The "OFF" button serves as an emergency stop (E-stop) to immediately disable the drive system and should also be used to keep the system off whenever the robot is stationary or not in use. The cannon will not move unless the key fob's "ON" button has been pressed following power-up, acting as an additional safety lockout.

Figure 7. Drive Motor Key Fob

3.3 Firing Mechanism

Location: Mounted on the front of the firing control box (Figure 8)

Controls: Arduino, Stepper Motor Driver, Relay System, and two 3.7V lithium-ion batteries.

To power on the firing mechanism, flip the toggle switch toward the "ON" label (Figure 9). To turn it off, flip the switch toward the "OFF" label (Figure 10).

Ensure this system is powered on **after** setting the operating pressure and loading the T-shirts. Never activate the firing system without verifying pressure safety and proper loading.

Figure 8. Location *Figure 9. On Position* *Figure 10. Off Position*

4. Functions

This section outlines the programmed firing functions of the T-shirt cannon. These functions are activated using physical buttons located on the front and side panels of the firing control box (see Figures 11 and 12). Each button corresponds to a specific action controlled by the Arduino microcontroller and related components.

Figure 11. Front Panel

Figure 12. Side Panel

4.1 Full Fire (Big Red Button)

Function: Automatically rotates the barrel drum and fires one T-shirt from each of the 10 barrels in sequence.

Operation: Pressing the large red button initiates the full-fire routine. The system begins by rotating the drum once and then opens the solenoid to launch a single T-shirt. This process repeats for all 10 barrels in succession.

Purpose: Used during games to rapidly launch a full round of T-shirts into the crowd, maximizing excitement and crowd interaction.

4.2 Go Home (Currently Out of Order)

Function: Rotates the barrel drum until it aligns with the home position using a mechanical limit switch.

Operation: When functional, pressing the “Go Home” button causes the drum to rotate until a designated barrel chamber triggers a limit switch, aligning the system to its default firing position.

Purpose: Ensures the cannon starts from a known, aligned position to guarantee an effective seal between the air chamber and the selected barrel.

Note: This feature is currently non-functional due to a damaged limit switch trigger. Manual alignment is required prior to operation. See the Final Report's "Future Work" section for recommendations.

4.3 Single Fire

Function: Fires a single T-shirt without rotating the barrel drum.

Operation: Pressing the "Single Fire" button activates the solenoid, releasing compressed air to fire the currently aligned barrel. The drum remains stationary.

Purpose: Primarily used for testing purposes

4.4 E-Stop

Function: Immediately terminates any active firing or rotation operation.

Operation: Pressing the E-Stop button interrupts power to the rotation and firing systems, halting any ongoing Full Fire or Go Home sequences.

Purpose: Serves as a critical safety function to stop the cannon mid-operation in the event of a malfunction, misalignment, or other emergency. The E-Stop should be tested before events and used whenever unexpected behavior occurs.

5. Remote Controller

The Spektrum DX6i remote control is used to operate the base motors of the T-shirt cannon and to adjust the firing angle via the barrel's linear actuator. This remote allows for precise and responsive control of both movement and aiming functions. A labeled layout of the controller and its components is provided in Figure 13 to assist with operation and familiarization.

Figure 13. Remote Control Button Layout

5.1 Binding the Transmitter to Receiver

The Spektrum DX6i remote controller must be manually bound to the robot's receiver each time the system is powered on. Binding establishes the wireless communication link between the controller and the base system.

Binding Procedure:

1. Power on the robot's base system using the battery supply toggle switch (see Section 3.1).
2. While holding the Binding Switch on the top of the Spektrum DX6i controller (see Figure 14), turn the controller on.

3. Continue holding the binding switch for approximately 5 seconds (or until the light on the transmitter begins flashing more rapidly), then release.

Once the binding process is complete, the light on the transmitter should turn solid (this may take a couple seconds so be patient) and the controller should automatically establish a connection with the base.

Figure 14. Remote Binding

Verification:

- To confirm a successful bind, attempt to raise or lower the firing mechanism using the right-hand joystick.
- If the actuator responds, the controller is successfully bound.
- If there is no response, turn off both the controller and the base system. Restart the process from step 1 (sometimes this takes multiple attempts).

Unbinding:

- To unbind the remote, simply power off the controller.

A video walkthrough of the binding process is available in the shared OneDrive folder for visual reference (T-Shirt Cannon 2024-25/Media/Videos/Training Reference Videos).

Note: Always verify a successful bind before attempting to drive or operate the cannon.

5.2 Controls

The Spektrum DX6i features two primary joysticks that control the robot’s mobility and barrel positioning:

- **Left Joystick**:
  - Controls base motor movement.
  - Pushing the stick forward propels the cannon forward.
  - Pulling the stick backward puts the cannon in reverse.
  - Moving the stick left or right enables turning in place or while moving.
- **Right Joystick**:
  - Controls the linear actuator, which adjusts the barrel angle.
  - Pushing the stick up raises the barrel.
  - Pulling the stick down lowers the barrel.
  - Releasing the stick to its center (neutral) position will stop the actuator and maintain the current angle.

6. Pressurized Air Tank

The T-shirt cannon operates using compressed air stored in a SCUBA tank (primary container) and delivered to a secondary tank through a regulated system. It is critical that operators understand how to safely read pressure gauges, regulate air supply, and refill or service the tank according to standard safety procedures.

Important Safety Note: The air system should only be pressurized immediately before firing. **The cannon must never be pressurized while driving or transporting**, as this presents a serious safety hazard in the event of a collision or fall. For example, at sporting events, the cannon should remain unpressurized while idle and during transit to the field. Only pressurize once you are positioned and instructed to fire. Always depressurize the system immediately after use and before moving the cannon again.

6.1 Reading the Gauges

There are two primary gauges located on the air regulator assembly:

- **Operating Pressure Gauge**
  - Indicates the pressure within the secondary tank, which controls the force behind each T-shirt launch.
  - The gauge has a maximum reading of 1,000 psi.
  - **Do not exceed 200 psi**, as this is the maximum safe operating pressure for the system components.
- **Container Pressure Gauge**
  - Displays the internal pressure of the SCUBA tank (the main air reservoir).

- This gauge has a maximum reading of 4,000 psi. A fully charged tank typically reads around 3,500 psi.
- This pressure will decrease with each shot as air is released.

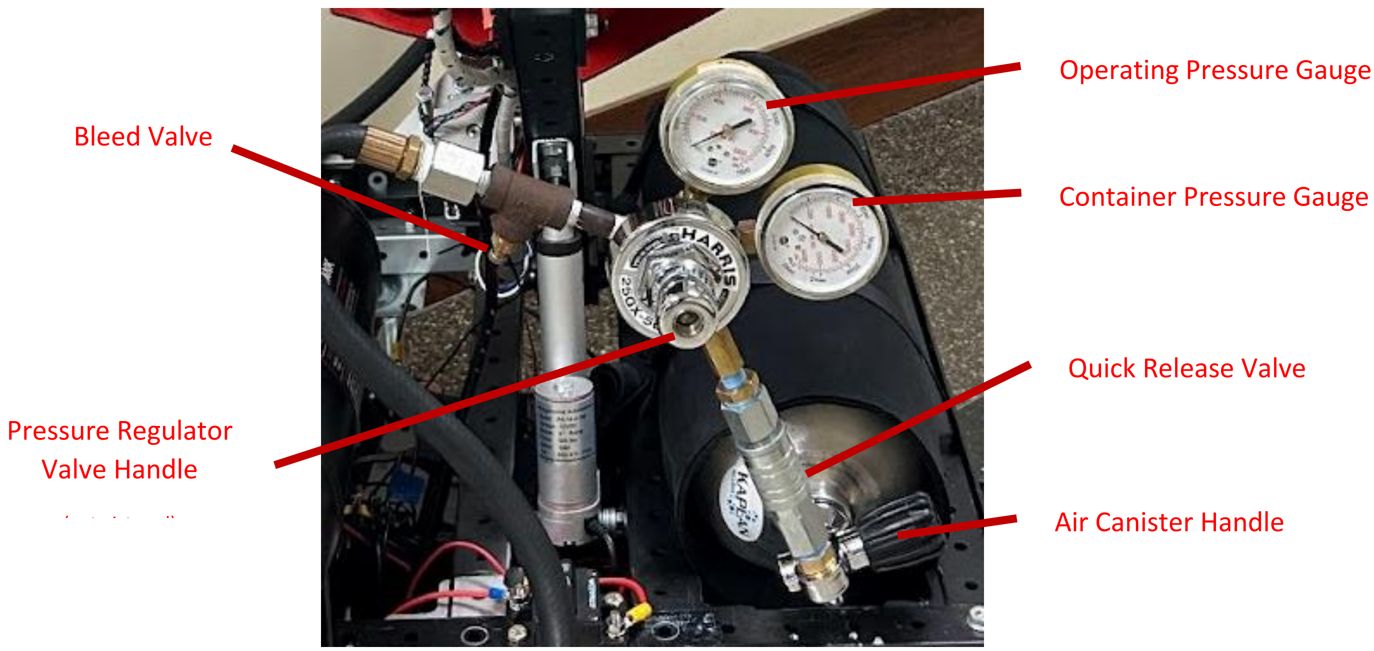


Figure 15. Pressure Gauges and Fittings Layout

6.2 Turning On Air Supply

To safely pressurize the system, follow the steps below in order:

1. Ensure that the bleed valve is closed and remove the pressure regulator valve handle.
    - At this point, the operating pressure gauge should read 0 psi, otherwise open the bleed valve to release air and then close it again.
2. Slowly turn the SCUBA tank’s air valve to begin pressurizing the system.
    - Continue until the valve is fully open.

- The container pressure gauge should now display the SCUBA tank's current pressure.
- The operating pressure gauge should still read 0 psi.

3. Insert the pressure regulator valve handle and slowly adjust the regulator handle until the operating pressure gauge reads exactly 200 psi.
   - **Do not exceed 200 psi** under any circumstance.

6.3 Turn Off Air Supply

To safely depressurize and shut down the system:

1. Close the SCUBA tank valve completely. The container pressure gauge should return to 0 psi.
2. Open the bleed valve fully to purge all air from the secondary tank.
   - Ensure the operating pressure gauge also returns to 0 psi.
   - Keep hands and fingers away from the spout when releasing air.
3. Remove the pressure regulator valve handle after all pressure has been released.

These steps must be followed after each use to ensure system safety and prolong component lifespan.

6.4 Refilling the Tank

To safely refill the SCUBA tank, it must first be removed from the cannon and transported to a certified SCUBA gear shop. Follow the detailed procedure below to ensure safe disassembly and reassembly:

Removing the Tank:

1. Close all valves on both the SCUBA tank and the pressure regulator.
   - **Confirm the container pressure gauge reads 0 psi before proceeding**
2. Disconnect the quick-release valve by pulling back the collar and gently removing the air hose from the tank fitting.
3. Unclip the two securing straps that hold the SCUBA tank in place on the cannon base.
4. Lift the SCUBA tank vertically off the base, taking care not to bump or open the valve.
   - Opening the valve at this stage would result in a rapid and unsafe loss of air pressure.
5. Once the tank is standing upright and stable on the floor, use a wrench to unscrew the threaded adapter from the top of the tank.
   - Do not over-tighten or use excessive force during removal to avoid damaging the threads.
6. Remove the protective sleeve from around the SCUBA tank.
7. Transport the tank to a certified refill location.
   - Refills typically cost $10–15 depending on air pressure level and whether additional services are required.

Reminder: Do not pressurize the system until you are actively preparing to fire.

Most recent refill location:
In Too Deep Scuba
8148 Vine St, Cincinnati, OH 45216
(513)761-3986

Important: Refilling must only be performed by trained professionals. Do not attempt to refill the tank yourself under any circumstances.

Note: If using departmental or university funds, notify the shop that the purchase should be tax-exempt.

Reinstalling the Tank After Refill:

1. Wrap PTFE (Teflon) tape around the threads of the tank adapter to ensure an airtight seal.
    - Apply 3-5 full wraps of tape in the direction of the threading.
2. Use a wrench to reinstall the adapter into the SCUBA tank securely.
    - Avoid overtightening but ensure a firm and snug fit.
3. Slide the protective sleeve back over the tank.
4. Lay the tank horizontally onto the cannon base, aligning it with the strap slots.
5. Reconnect the quick-release valve to the adapter fitting.
    - If necessary, gently rotate the tank to prevent any kinks or tension in the hose.
6. Secure the tank by reattaching the two fastening straps firmly around the body of the tank.

6.5 Servicing for a SCUBA Tank

In addition to regular refills, SCUBA tanks must undergo routine safety inspections to remain in compliance with Department of Transportation (DOT) regulations:

- Visual Inspection (Annually)
    - Required once every 12 months.

- A dated inspection sticker is typically located on the exterior of the tank.
- Cost: Approximately $20, which often includes a refill.
- If permitted, observing the inspection can be an informative learning experience.

- Hydrostatic Testing (Every 5 Years)
    - This test measures the tank's ability to safely hold high pressure.
    - The manufacturing date and hydro-test dates are stamped onto the tank exterior.
    - If the tank is 5+ years old and no prior test date is visible, it must be hydrotested.
    - Cost: Approximately $30.

Reminder: Always request tax exemption when using departmental or university funds.

7. Operation Guide

7.1 General Operating Procedure

The steps below outline the full operation cycle for using the T-shirt cannon. This includes power-up, loading, firing, and shutdown procedures. These should be followed in sequence each time the cannon is operated.

1. Turn on the base power system (see Section 3.1).
2. Bind the remote controller to the receiver (see Section 5.1).
3. Activate the wheel motors by pressing the ON button on the key fob (see Section 3.2).
4. Use the controller to drive the robot to the desired firing location. For stadium transport, refer to Section 7.2.
5. Load 10 rolled T-shirts into the barrel chambers.

6. Before pressurizing the system, ensure the pressure regulator handle is removed and the bleed valve is closed (see Section 6.2).
7. Once in position and ready to fire, gradually open the SCUBA tank valve
8. Insert the pressure regulator handle then adjust the regulator until the operating pressure gauge reads 200 psi. **Do not exceed this value.**
9. Turn on the firing mechanism (see Section 3.3).
10. Use either the Full Fire or Single Fire function (see Section 4) to launch T-shirts.
11. After firing is complete, immediately flip off the switch for the firing system and close the SCUBA tank valve to stop airflow.
12. Open the bleed valve fully to depressurize the system.
13. Unscrew and remove the pressure regulator valve handle to prevent pressure buildup in the secondary tank.
14. Drive the cannon back to the lab or storage area using the controller.
15. Turn off the wheel motors via the key fob.
16. Power down the base.
17. Turn off the remote controller.

7.2 Transport Route

Use the following instructions to safely transport the cannon from the Robotics Lab in Baldwin Hall to the field-level entrance of Nippert Stadium:

1. Exit the robotics lab and make an immediate left, followed by another quick left down the adjacent hallway.

2. Proceed through the double doors at the end of the hall and turn right into the hallway of faculty offices, make your way to the end of the hallway.
3. At the end of the hallway, take the elevator located on your left.
    - **Tip**: Back the cannon into the elevator for easier maneuvering.
    - Have one person hold the elevator door open while the other guides the robot in.
4. Take the elevator to the 6th floor.
5. Upon exiting, the bridge to the Mantei Center is directly to your left. Cross the bridge and continue straight down the hallway.
6. When the hallway ends, use the elevator on your left to go down to the 3rd (ground) floor.
    - Again, back the cannon into the elevator for better control.
7. Exit through the mechanical door on your left.
    - One person should repeatedly press the door-open button while the other slowly and carefully drives the cannon through.
8. Once outside, turn right and follow the sidewalk ramp down to Nippert Stadium.
    - Use caution when driving over grates or uneven pavement. Move slowly to prevent tipping or jostling the cannon.

A video walkthrough is available in the shared OneDrive folder for visual reference of the route (T-Shirt Cannon 2024-25/Media/Videos/Training Reference Videos).

8. Event Operation Protocol

This section outlines the recommended procedure for preparing, staging, and operating the T-shirt cannon during a live event such as a football or basketball game. Adhering to these guidelines ensures safe operation, maintains system performance, and maximizes crowd engagement.

8.1 Pre-Event Preparation

- Charge batteries the day before the event
  - **Tip:** have batteries charging while you roll the T-shirts the day before the event.
- Pick up T-shirts and field access wristbands from designated contacts (see Section 8.6).
- Coordinate a meeting time and location for day-of transport with designated contact (see Section 8.6).
  - For football games, this is typically 2.5 hours before kickoff at the top of the stadium tunnel.
- Inspect the cannon for signs of damage, air leaks, or electrical disconnections.
- Pack and confirm the following:
  - SCUBA tank (confirmed to have sufficient air and securely installed with adapter and sleeve)
  - Remote controller and key fob
  - 20+ pre-rolled T-shirts (See T-shirt Rolling Addendum, Appendix B)
    - 10 T-shirts may be preloaded into the cannon; 10 extras can be carried in a bag for reloading
  - Quick-release air fittings and all necessary adapters securely in place

8.2 Transport and Staging

- Follow the route outlined in Section 7.2 to transport the cannon from the Robotics Lab to the stadium or arena.
- Once onsite, stage the cannon in a secure, low-traffic area (e.g., near a wall or tunnel entrance) and power off all systems.
- Do not power on or pressurize the cannon while transporting or idling. This is a critical safety protocol to prevent accidental discharge or system damage.

8.3 Game-Time Operation

- At the designated time (most likely end of the first quarter for football), move to the field or court level and wait for final instructions.
    - You may power on the base system and bind the controller at this time, but do not engage the drive motors or pressurize the system until cleared to proceed.
- When instructed to begin preparing:
    - Activate the drive motors using the key fob.
    - Drive the cannon into firing position using the controller.
    - Once positioned, follow these pressurization steps:
        - Ensure the bleed valve is closed
        - Insert the pressure regulator valve handle
        - Open the SCUBA tank valve and adjust pressure to 200 psi
    - Leave the firing system switch OFF until just before the shot.
- At the appropriate moment:
    - Turn on the firing system.

- Fire using the large red Full Fire button.
- While the cannon is firing:
  - One person should rotate the base ~45° left and right to distribute T-shirts across the crowd.
  - The second operator should stand on the left side of the cannon, reloading barrels as they are emptied.
- Once the first 10 shirts have been launched, the system will pause.
  - Quickly verify that all barrels are reloaded, then press the Full Fire button again to launch the second round.

Note: The firing system should be flipped on as the MC appears on the jumbotron and the launch should occur immediately after the T-shirt cannon is mentioned, not before.

Tip: For added crowd engagement, consider inviting the Bearcat to press the large red button during the first firing sequence.

8.4 Post-Firing Procedure

- Immediately after firing:
  - Switch the firing system toggle to OFF
  - Drive the cannon to a secure out-of-the-way location
  - Turn off the drive motors via the key fob
  - Close the SCUBA tank valve
  - Open the bleed valve fully to release remaining pressure
  - Remove the pressure regulator handle

- At halftime, once the sideline is clear, return the cannon to the Robotics Lab using the same route. Ensure the unit is powered off and fully depressurized before transport.

8.5 Safety Reminders

- Never operate or transport a pressurized cannon. Pressurize the system only when you are in position and ready to fire.
- Always maintain line of sight between the cannon and operator when firing.
- Use the E-stop immediately if any malfunction or misalignment is observed.
- Keep the firing system powered off until just before launch to prevent accidental discharge.

8.6 Contacts

Game-day responsibilities and contacts may change over time. As of Fall 2024, the following individuals are your primary points of contact:

- **T-shirt Pickup**

  Gabby Hogan

  Email: hogange@ucmail.uc.edu

- **Field Access, Wristbands, and General Coordination**

  Marc Brafman

  Email: Marc.Brafman@BearcatsSportsProperties.com

  Phone: (513) 375-4137

- **Previous Years Seniors**

  Andrew Holycross

Phone: (614) 506-7637

Joey Hodapp

Phone: (513) 430-9070

9. Arduino Code

The Arduino code is responsible for controlling the firing mechanism, including the barrel drum rotation, solenoid timing, LED light effects, and the programmed firing modes (Full Fire, Single Fire, and Go Home).

All Arduino files are stored in the shared OneDrive folder associated with this project. The folder includes:

- The main .ino file that governs the firing sequence logic
- Definitions for solenoid open time and dwell time between shots
- Code for controlling the LED light strip, which visually simulates a T-shirt being fired
- Interrupts and routines for the E-stop and Go Home functions

Modifications and Notes:

- Adjusting the solenoid open time or dwell time requires changes to predefined constants in the code.
- The LED sequence is timed to align precisely with the solenoid trigger and can be modified to change color, speed, or direction of the effect.
- If re-uploading the code to the Arduino, ensure the correct board and port are selected in the Arduino IDE.

- If unexpected behavior occurs during operation, reviewing the code logic is a good first troubleshooting step—especially for timing-related issues.

Note: Only qualified team members or future design teams should modify the Arduino code. Any changes should be documented in the final project records and tested thoroughly before deployment at an event.

Appendix B: T-shirt Cannon T-shirt Rolling Guide

1. **Prepare a Measuring Tool**

   Cut a piece of string, yarn, foam tape, fabric or any other material of your choice to a length of 8.75 inches. This will be used later to quickly check the circumference of each rolled T-shirt. Through testing, we've determined that T-shirts with a circumference of approximately 8.75 inches perform best when launched.

2. **Cuff the Bottom of the T-shirt**

   Lay the T-shirt flat on a clean surface, front side facing down.

   Fold the bottom hem up about 4 inches to create a cuff. This flap will later be used to secure the rolled shirt.

3. **Fold One Third of the Shirt Over**

Take one side of the shirt and fold it inward toward the center, so the edge lines up approximately with the outside edge of the collar.

4. **Fold the Sleeve Back In**

Fold the sleeve from that same side back over the folded portion so that it lies flat across the body of the shirt.

5. Repeat for the Opposite Side

Fold the opposite side of the shirt inward using the same method: fold the body toward the center, then fold the sleeve over. When complete, the shirt should now be in thirds, roughly the width of the collar.

6. Flip the Shirt

Rotate the folded shirt so the collar is closest to you, and the cuffed end is furthest away.

7. Tuck the Edge of the Collar Inward

Slightly fold or roll the top edge of the collar inward to keep it from sticking out while rolling. This helps create a tighter, more uniform shape.

8. Begin Rolling the Shirt

Starting at the collar end, begin gently and evenly rolling the shirt toward the cuff.

- Avoid rolling too tightly, as this will result in a shirt that is too narrow and will noy fire as well.
- Likewise, avoid rolling too loosely, which may prevent the shirt from fitting in the barrel.

9. **Secure the Roll Using the Cuff**

Once the shirt is fully rolled, take the flap created by the initial cuff and fold it over the rolled end. This will hold the roll together.

10. Check the Circumference

Wrap your 8.75-inch measuring tool around the middle of the roll.

- If it wraps too far around, the shirt was rolled too tightly.
- If it won't wrap around completely, the roll is too large and should be redone more loosely.

11. Test Fit in Cannon Barrel

Insert the rolled T-shirt into one of the cannon's barrels.

- It should slide in with a light push, enough to reach the back of the barrel.

- If it fits loosely won’t fire as far.
- If it requires excessive force, it is too large and must be re-rolled.

Note:

After rolling at least 20 T-shirts, we recommend pre-loading the 10 thickest rolls into the cannon. These tend to take slightly more effort to load and are best handled ahead of time. Reserve the 10 skinniest rolls for mid-game reloading, as they slide in faster and more easily during time-sensitive moments.

A video walkthrough of rolling a T-shirt is available in the shared OneDrive folder for visual reference (T-Shirt Cannon 2024-25/Media/Videos/Training Reference Videos).