ST. MARY'S UNIVERSITY

School of Science, Engineering and Technology

Department of Engineering

Safety Parachute System

By

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Senior Design Project Presented to the Department of Engineering

In Partial Fulfillment of the Requirements

For the Degree of

Bachelor of Science

In

COMPUTER ENGINEERING

MECHANICAL ENGINEERING

San Antonio, Texas

April 2021

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ABSTRACT

The use of drones in the past years has been on the rise. They are being used for surveillance, filmmaking, photography, disaster relief, real estate, among other uses. This type of device, like any other, is prone to fail for a variety of reasons. Some of the known issues and risks drones have are battery failure, environmental hazards, communication error, structural failure, and pilot error. This project aims to create a parachute-emergency system that will add a safety feature to drones of different uses and specifications to safeguard the drone from the previously mentioned issues. The technology built will be a last-resort system that will protect most drones from unrecoverable damage.

This project will involve two areas of engineering, those being Computer Engineering and Mechanical Engineering. In this project, we will put into practice important concepts in mechanical design, aerodynamics, materials science, electronics, microprocessors, and signals and systems. These concepts should enable us to theorize the proof of concept, design, analyze, build, and test a parachute system that adds a safety feature to a drone. Our combined efforts will form an interdisciplinary project that will cover all the necessary areas to improve upon commercial designs of parachutes and mitigate as many risks as possible.

ACKNOWLEDGEMENTS

We would like to express our deep appreciation to all the people who helped us directly or indirectly during this project. We are particularly grateful to Dr. Juan Ocampo and Dr. Ben Abbott who guided us throughout the project as our project advisors. We want to give our special thanks to Professor Dante Tezza and Dr. Rezaie Bahman, our project sponsors, who gave us their support and input. We would also like to extend our thanks to Nicole Webb, who has aided us considerably in the lab. We would also like to extend our gratitude to Mr. Vernon Wier, who helped us in the manufacturing and testing of several of this project. Finally, we would like to give special thanks to Gabriela Santos Bolanos, who coached us on our presentations.

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1. INTRODUCTION

Drones are susceptible to failure, which can become a hazard. In the event of the failure of a drone, it could cause damage to people, private property, animals, and the drone itself. To address this hazard, we developed a modular parachute system that adds a safety feature to drones. To ensure adherence to engineering standards, we took into consideration a list of desired features set by the project sponsor, as well as a set of standards for drone parachute systems for the development of this project. Working under both lists of requirements, we developed a working prototype that will be thoroughly discussed in this report.

1.1 PROBLEM STATEMENT

A safety parachute system must be designed so that it can detect a failure and deploy a parachute. A parachute and mechanical deployment system will be developed for a drone, as well as an electronics system capable of detecting drone failure.

1.2 OBJECTIVES

The main objective of this project is to design and build a functioning safety parachute for drones. To accomplish this, we have identified the following sub-objectives:

- An onboard system will be added to an existing drone system that will detect a failure and deploy the parachute.
- A parachute and a deployment mechanism will be developed to work in conjunction with the failure detection system.
- The parachute must be deployable by either machine decision or manual control from the drone pilot.
- The communication protocols between the pilot and the drone will also be improved, in hopes of using more communication lines in case of failure.

The minor objectives we have identified are the following:

- Implement a secondary parachute deployment trigger.

- Make the parachute system partially or completely reusable.

The system should allow the user to easily exchange the parachute or mechanical aspects to one that fits better his or her purposes.

1.3 DIVISION OF LABOR

Division of labor is shown in Table 1 where even distribution of work was ensured for each member.

Team Member	Task
Juan Luna	• Design a modular kit for the electronics and onboard computer that works for different drone models. • Design the necessary circuitry that will be able to read the vitals of the drone and relay this data to the pilot. • Implement two RF receivers that will allow the pilot to communicate with the drone in various lines. • Design and implement the algorithm used to detect critical points of failure and to what scenarios should the parachute be deployed. • Design and implement a semi-autonomous computer that can interpret the vitals and decide if the parachute should be deployed or not
Sebastian Castro	• Design, build and test a parachute that has the appropriate size for the drone and meets ASTM F3322 standards. • Design, build and test a mechanical triggering system for the parachute that can rapidly and reliably deploy parachute. • Design, build and test a casing to house electronic components, parachute, and trigger system. • Design, build and test a modular attachment system that works for a set of different drone models.

Table 1 - Division of Labor

1.4 LITERATURE REVIEW

A search for similar commercial products was conducted to set a standard of what is currently out there. The products listed are parachute systems that correspond to the drone size that we will be working with on this project. Table 2 gives us an overview of important data about current products including price, weight, and important features.

Product Name	Product Price	Product Weight	Product Features
Skycat X48 [1]	$519.15	0.250 kg	This parachute system operates with a fuse system. Kit includes launcher, parachute, fuse set, and harness kit. Bullet method for parachute deployment. Has dedicated launch battery in case of power loss. The parachute is manually triggered. Can be mounted on different drone models.
MARS 58 V2 [2]	$389.00	0.278 kg	Has an auto-deployment system, includes a parachute system and mounting set, high energy compression spring deployment, capable to be mounted on different drone models, servo trigger.
Parazero SafeAir Mavic [3]	$2,499.00	0.165 kg	Compliant with ASTM-3322 standards, compatible with DJI Mavic 2 Series, automatic trigger, data logs stored in black box device, includes mounting equipment, easy to repack.
Parazero SafeAir Phantom [4]	$2,499.00	0.160 kg	Compliant with ASTM-3322 standards, compatible with DJI Phantom 4, automatic trigger, data logs stored in black box device, includes mounting equipment, easy to repack.

Table 2 - Details of Existing Parachute Systems

Product	Product Image
Skycat X48 [1]	
MARS 58 V2 [2]	
Parazero SafeAir Mavic [3]	
Parazero SafeAir Phantom [4]	

Table 3 - Images of Commercial Parachutes

The products' websites provided some valuable information. Firstly, there are two price ranges, the Skycat and the Mars parachute systems were on the \$380-\$520 price range, and the Parazero parachute systems were on the \$2,500 price point. The biggest differences that we found were that the Parazero parachute systems were compliant with ASTM F3322 parachute regulations, and the others not. Additionally, the different Parazero parachute systems were designed for specific drone models. The other two parachutes were designed to fit two different models within a certain size and weight range. Three of the four products had automatic parachute deployment, and just one, the Skycat, had manual deployment. All the models come with a parachute and mounting devices. The parachute systems were lightweight, keeping within a range of 0.160 kg and 0.278 kg. The parazero parachutes were the lighter ones.

1.5 PROBLEM CONSTRAINTS, REQUIREMENTS, AND SPECIFICATIONS

A set of constraints, requirements, and specifications were identified with our technical advisor. The constraints, requirements, and specifications outlined are the following:

- The maximum weight that will be allowed for the parachute system is 400g.
- The cost of producing one parachute system should be below \$390.
- The parachute system must use the watchdog system to analyze the vitals and determine if the parachute must be deployed.
- The parachute system must have a secondary safeguard receiver as an alternative to activate the parachute.
- The center of mass of the drone with the parachute system should not cause the thrust output of the motors to be beyond 10% of each other.
- The parachute system should be easily modified for drones of varied sizes.
- The overall drone must be capable of following the 2:1 ratio; the drone must be able to carry twice its weight.
- The parachute system should be able to deploy effectively while the drone is tumbling.
- The parachute system must align with ASTM F3322 standards.

1.6 PROPOSED SOLUTIONS

Two different options for the mechanical triggering system were identified that could be implemented. The first one involves a high compression spring, and the second one a CO2 cartridge. Both are considered ballistic ejection methods.

The first option, the alternative with the spring, has been sketched and can be seen in Figure 1. A spring will be compressed inside the casing. The cap of the casing would be held in place by a servo or actuator. When the parachute must be deployed, the servo would allow the spring to decompress, launching the parachute upwards. The advantage of this method is that the parachute is completely reusable. The parachute would just require to be loaded every time the drone would be used.

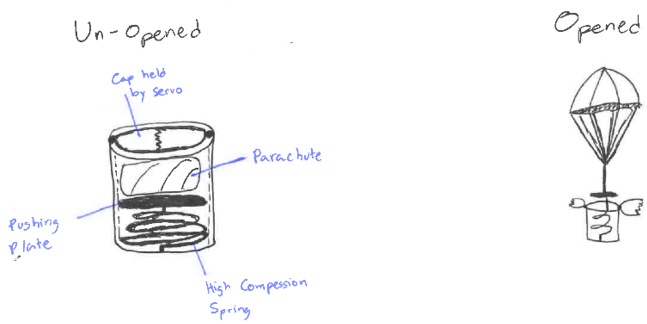


Figure 1 - Spring Deployment System Sketch

The second option, the alternative using CO2 cartridges, has been sketched and can be seen in Figure 2. This option would require a CO2 cartridge to be attached to the casing with a valve. The valve would be controlled with a servo, which would receive instructions from the onboard computer. When the parachute is to be deployed, the servo will allow enough air to push the pushing plate, deploying the parachute.

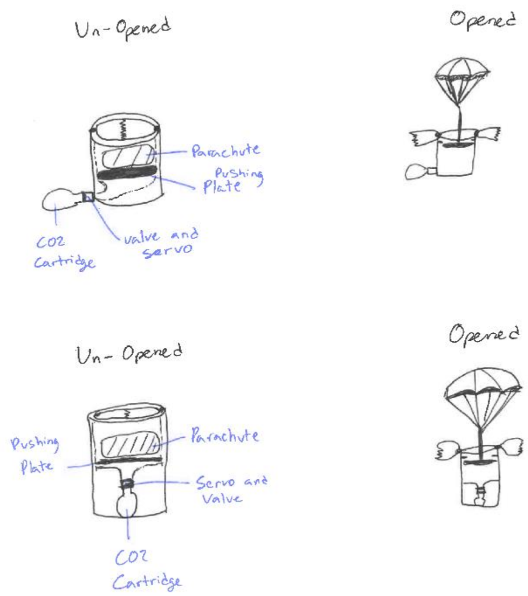


Figure 2 - CO2 Cartridge Deployment System Sketch

For the electronics system, we propose to update the current software of the drones and implement an onboard ESP32 microcontroller board (As the one seen in Figure 3). As the drone stands right now, they come with various sensors (accelerometer, gyroscope, barometer, GPS, and magnetometer). We want to write various communication protocols that will continuously monitor these sensors and detect the vitals of the drones. With all the information being received, we would like to display this information to the pilot of the drone and define well what parameters are critical for the health of the drone. Once we design what parameters are critical for the drone, we can send a flag signal to the semi-autonomous system that will decide to deploy the parachute by itself or alert the drone pilot that the parachute should be deployed.

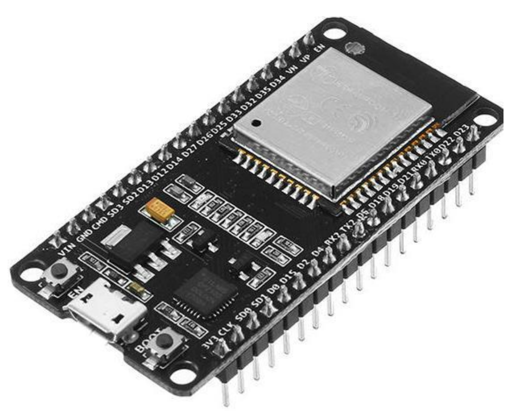


Figure 3 - ESP32 Board to Replace the Raspberry Pi

We have also started working on the high-level abstraction of the software. We envision a software that will be fed preflight parameters to inform the onboard computer what a successful flight path is. The electronics will continuously monitor the vitals of the drone, check if the communication status of the drone and the state of the battery. If any of the critical points fail and the flight has not been completed, then the drone will deploy the emergency system; else, it keeps monitoring for these conditions. This can be visualized in the flow diagram in Figure 4.

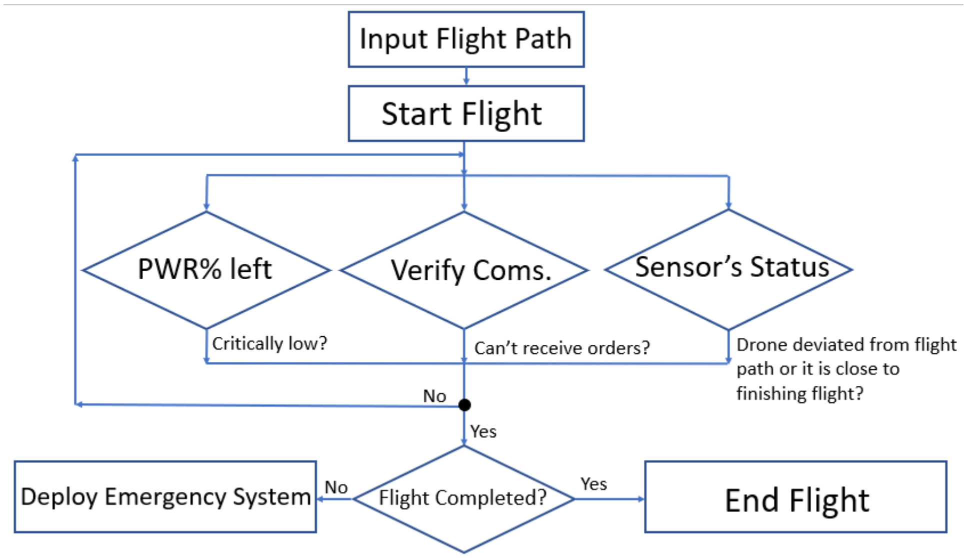


Figure 4 - Flow Diagram of the Safety Parachute System

For the circuitry, a block diagram (Figure 5) has been created to envision how it should look like. This block diagram discusses the various I/O boards that will take place and how they will interact with each other. The purpose of this block diagram is to envision the logical devices required to maintain proper communication. As evidenced from the block diagram, the onboard computer will be responsible for communicating with the various devices and ensuring that decisions are communicated throughout all the components. All the data collection will take place in the drone sensor board, which will then be relayed to the I/O board to decide whether a deployment is necessary.

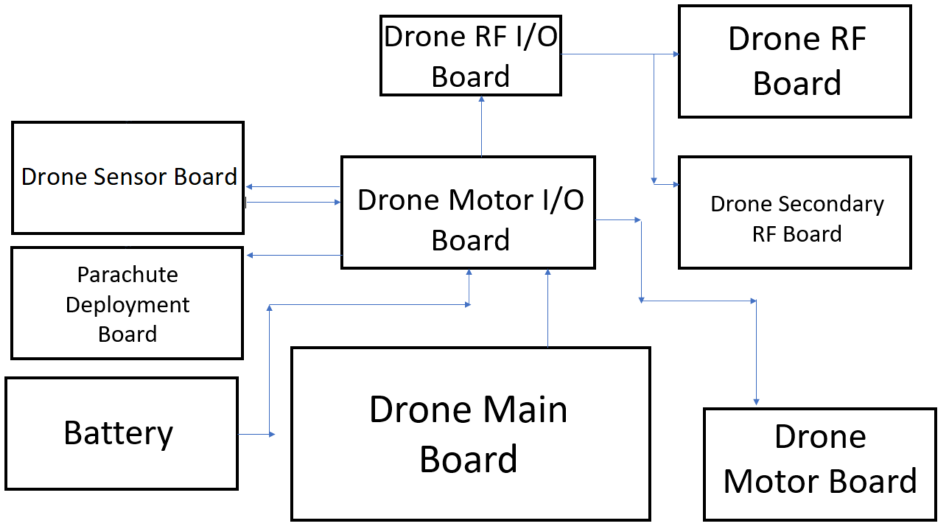


Figure 5 - Block Diagram

2. OVERVIEW OF SYSTEM

The Mechanical System considers two components, the ejection system that will launch the parachute upward, and the flight terminations system that will stop the drone propellers from spinning. Considerations have been made regarding the approach to be taken for each and will be discussed in detail in a further section.

For the parachute ejection, it was decided that a CO2 canister method would be preferable because the burst of air released by the cartridge will aid in the opening of the parachute. A CO2 canister is non-reusable, so every time the parachute is deployed the cartridge must be replaced, but the price of these components is low and would not discourage a user from wanting this product.

For the Flight Termination System, different approaches were considered such as cutting power from the motors and physically stopping the propellers from spinning. The problem of attempting to cut-off the power from the motors is that it reduces the modularity of the parachute system. Additionally, ASTM F3322-18 standards warn that even if power is cut from motors, residual energy may pose a hazard on pinwheeling propellers [5]. For that reason, it was decided to physically stop the propellers. Some of the approaches considered were to have some type of net that shoots onto the propellers, to shoot a small string to each propeller, to shoot synthetic spiderweb to slow down the propellers, to have the casing rotate so that a flap stops the propellers, to have extendable flaps, and to mount on each arm a mechanism to stop the propellers.

The software and electrical components of the system will work in the following manner: The onboard computer will constantly check for the status of the drone and communicate that back to the user. The onboard computer will have an alarm system consisting of a speaker, an accelerometer, gyroscope, compass, and barometer. The electronic components will also contain a secondary receiver through which the pilot can connect in case of an emergency, guarantying extra security in case of a communication loss. Finally, the system contains two power sources that consist of primary and secondary lithium cell batteries of 3V, which will be put together in series so it can supply a total of 6V.

The software has also been refined to the point that communication protocols have been established. The user will be able to input data into the drone via a website, which will contain a table that will preliminarily define the kind of flight that will take place. An encryption system will be placed to secure a connection between the Bluetooth modules, ensuring no malicious user hijacks the connection.

3. ITERATIVE DESIGN

Throughout the development of this project, its different components have undergone a series of iterations. On every iteration, the design has improved upon the mistakes and aspects where the system falls short. A description of the design process of the different components is outlined below.

3.1 ELECTRICAL DESIGN

[write a brief introduction]

ELECTRIC COMPONENTS

The electrical and software components of the system have transformed significantly since their initial design. Details have been refined to the point that they are descriptive enough to complete the initial design phase and move on to the practical testing. More complex diagrams have been incorporated for deeper analysis and greater depth, such as the context diagram that contains 2 levels that describe the software components. Besides the context diagram, a circuit design has been created with the breakout boards that will be used for quick prototyping. The rapid deployment of the breakout boards will ensure smooth testing and will lead our team one step closer to circuit fabrication. The progress done can be seen by the following figures, which compared to Figure 4 and Figure 5, demonstrate a greater grasp on how to tackle this project.

BLOCK DIAGRAM

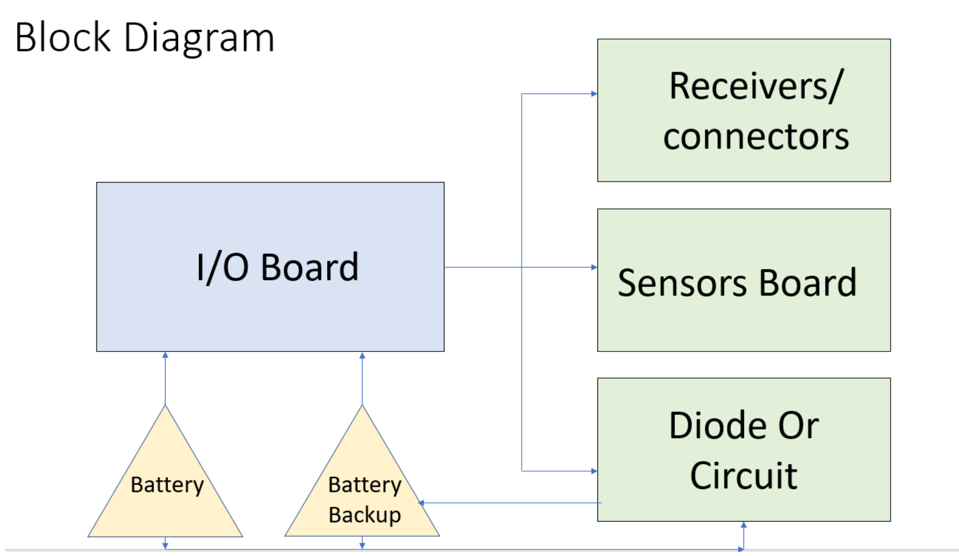


Figure 6 - Improved Block Diagram

Figure 6 improved diagram highlights fundamentally what components are required to satisfy the initial client requirements. The I/O board is going to be the central device responsible for hosting the wireless communication via BLE technology and interpreting the gathered data by the peripherals. The triangles are the power source of the entire system (it is going to be a small power source, as it is powering a low-power system) Finally, there are three distinct categories of peripherals connected to the central device. Receivers and connectors peripherals are going to be used to connect to the auxiliary receiver, which is a requirement, and external connectors that might be used later in the design (such as servo motors.) The peripherals sensors are going to houses several sensors that will gather data in flight-time and report back to the central device if a deployment is necessary or not. The sensors must be able to gather the speed of the drone, altitude, flight time, and other measurements. Then there is the Diode Or circuit, which is going to be used to regulate between the primary and backup battery. This peripheral will ensure that the system can power up when the primary battery fails.

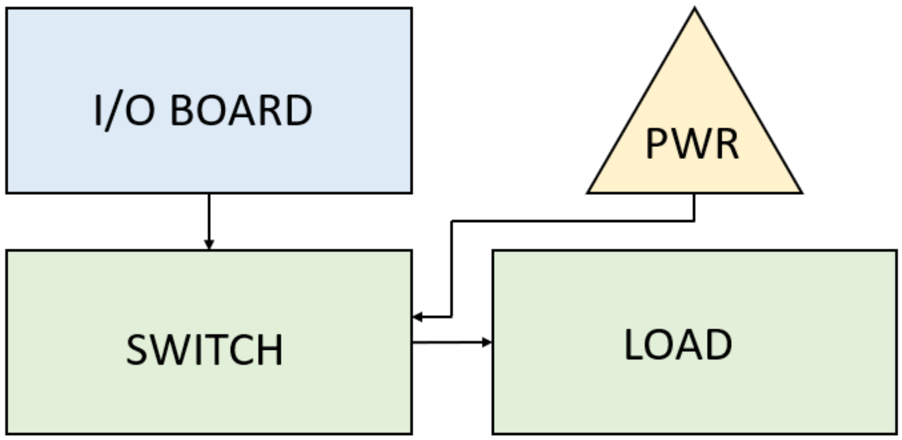


Figure 7 – CAPTION!!!

[ANALYSIS TO BE WRITTEN]

SCHEMATIC DIAGRAM

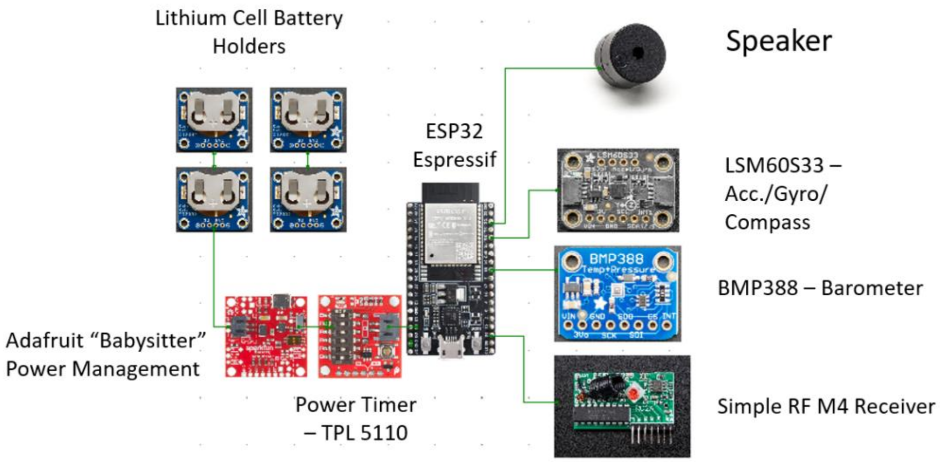


Figure 8 - Breakout Boards Design

In Figure 8, the transition from Block Diagram to prototype boards is shown. The conceptual blocks have been materialized into actual components that can be quickly set up and be ready for rapid testing. The power source is going to be two lithium coin cell batteries in series to generate a total voltage of 6V and a backup battery connected right next to it. The power consumption and switching between the primary and backup battery are going to be managed by the "Babysitter" breakout board. This breakout board will be responsible for communicating back to the central device the status of the batteries and apply a power-saving technique to prolong the lifeline of the complete system. In the center of the schematic, we have the central device, which is the ESP32 board proposed at the initial phase of the project. The ESP32 board was chosen for its ease of managing wireless communication and power consumption. The ESP32 board will be coded in an Arduino virtual environment and it will be utilizing its BLE communication technology. To the right of the schematic, we have the rest of the peripheral devices. At the top is a speaker that will be used to sound the alarm, alerting bystanders that the drone is falling. Then we have the sensors LSM 60S33 and BMP388. These sensors will be used to measure the altitude, position, velocity, acceleration, and direction of the system. The sensors will be responsible for collecting this data and packaging it for the central device to be interpreted. Finally, there is a simple receiver that is put in there as an emergency requirement. The secondary receiver will allow the pilot to be communicating with the drone without interruption, thus giving more control to the pilot in case of any incident.

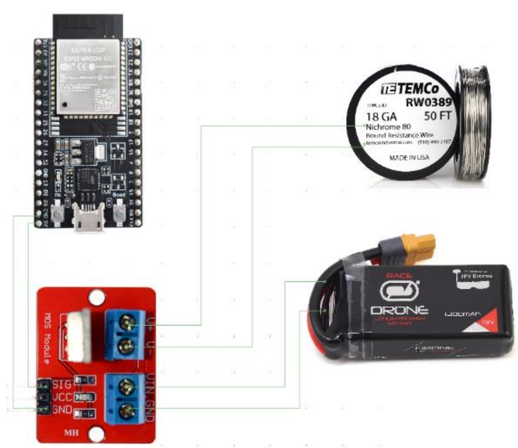


Figure 9 - Breakout Boards Design (to be changed)

[TO BE WRITTEN]

FABRICATION OF CIRCUIT

[This section will be written this weekend once I obtain results from the stripboard]

3.2 SOFTWARE COMPONENTS

[Add brief intro about the high-level aspect and its transformation into practical applications]

CONTEXT DIAGRAM LEVEL 0

Figure 10 describes the level 0 context diagram of the project, which houses the systems and user interactions of the overall system. The main interaction is going to take place between the flight controller and the onboard computer. They will be interacting in a constant loop, feeding back information on the status of the drone and if the deployment is necessary. If at any point deployment is necessary, then an alert is sent to the parachute system to deploy. If a deployment is made, the decision and a report of why the parachute was launched will be sent back to the user. The user also has the option of changing between manual/autonomous mode and overriding the system by triggering a manual choice of deployment, bypassing the decision-making step of the two main systems.

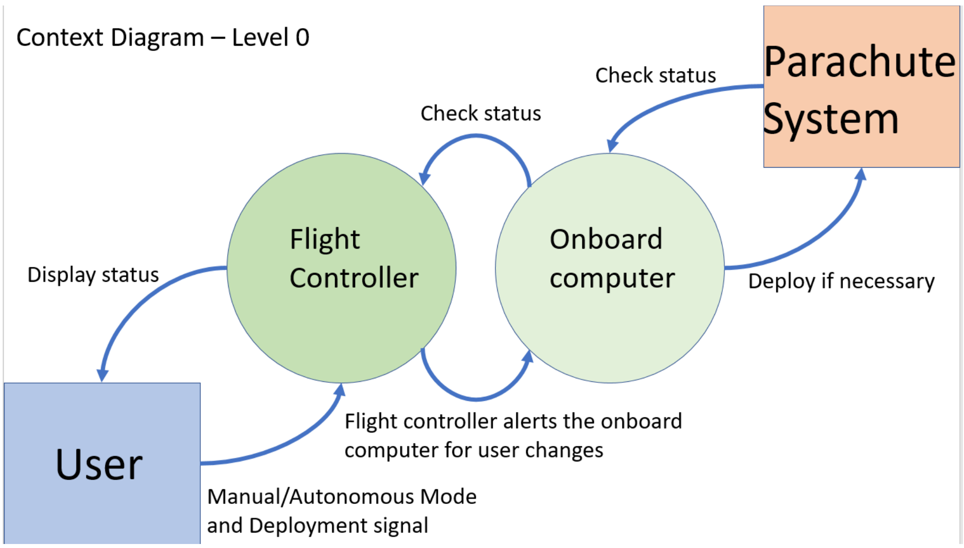


Figure 10 - Level 0 Context Diagram

Figure 11 illustrates the tools used to host the graphical interface. This project will use an LLP configuration: Linux, Lighttpd, and PHP. Lighttpd was chosen due to its quickness in hosting light websites and speed. No database is needed now, as we are not required to save the inputted data of the user on our systems. Finally, PHP is being used to add the functionalities onto the .h file that will be used by the ESP32 board.

PHP 7.4.13 | Lighttpd 1.4.55 | Ubuntu 20.04.1

Figure 11 - Tools Used for the Website

Figure 12 contains a screenshot of the first version of the website. On this site, the user has a table in which he can input the pre-flight parameters and download them in a .h file. The website will also contain a homepage, documentation, and contact information.

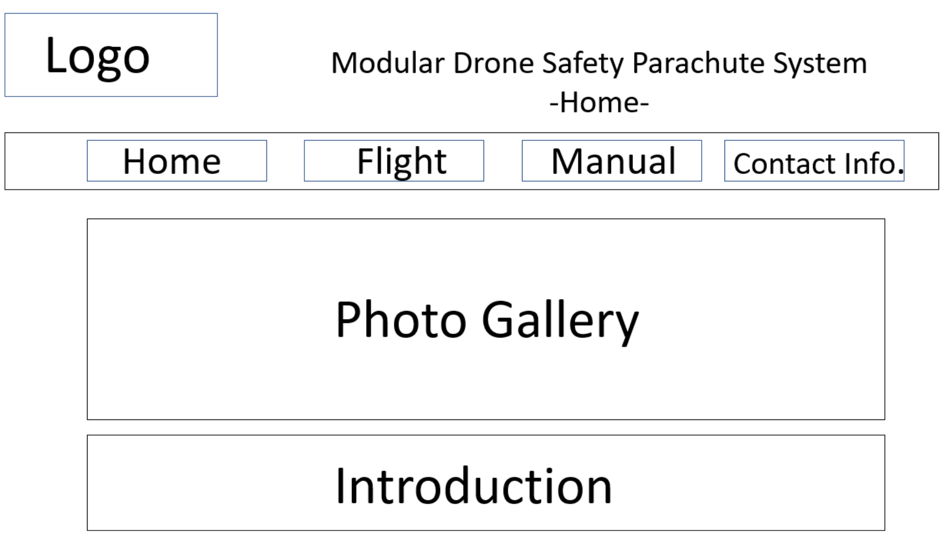
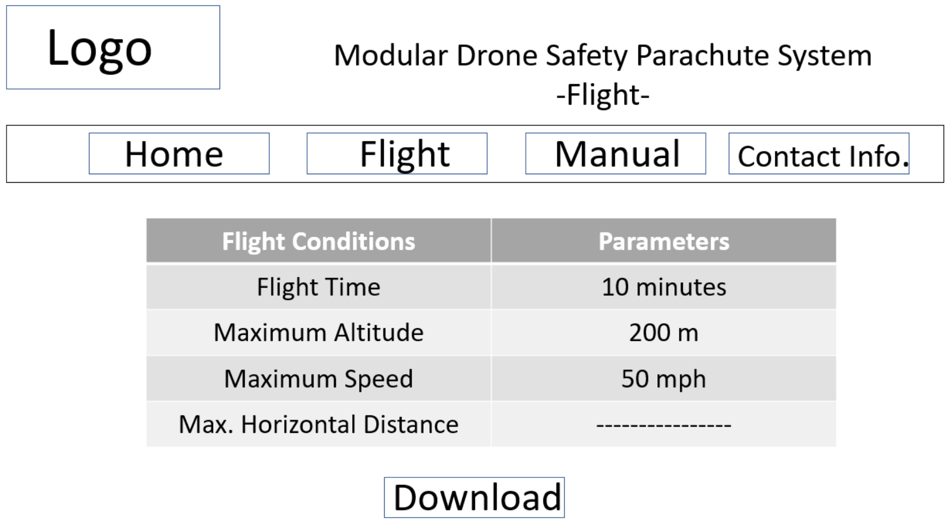


Figure 12 - TE ODIO JUAN



Flight Conditions	Parameters
Flight Time	10 minutes
Maximum Altitude	200 m
Maximum Speed	50 mph
Max. Horizontal Distance	----------------

Figure 13 - TE DETESTO CON MI VIDA

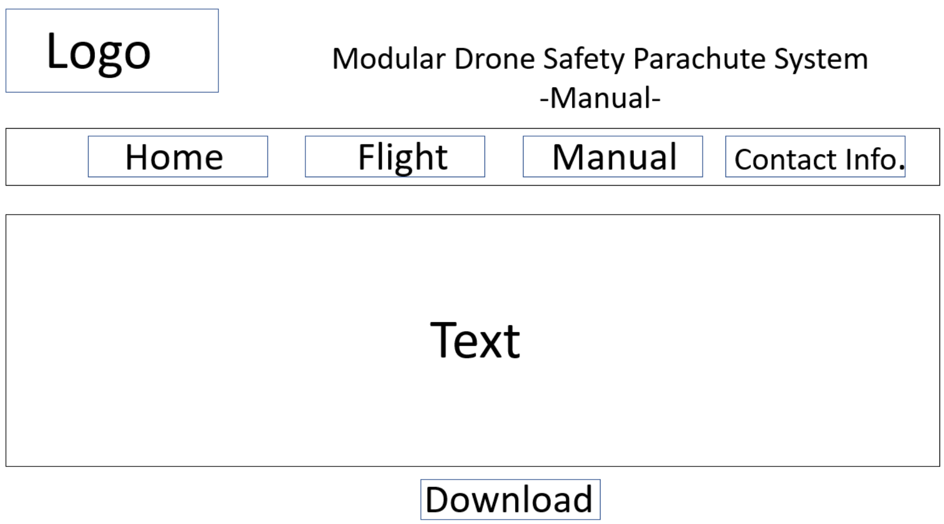


Figure 14 - SOS UN IDIOTA

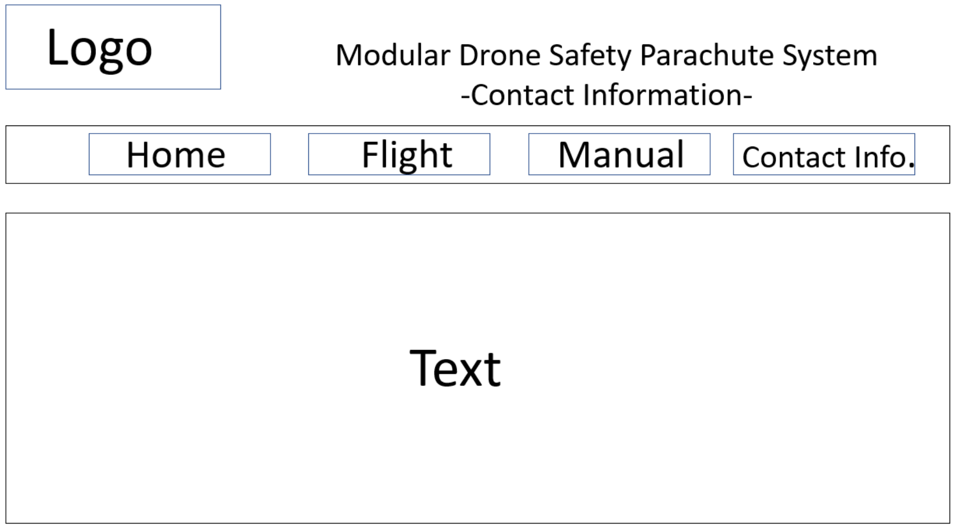


Figure 15 - ME LA PELAS

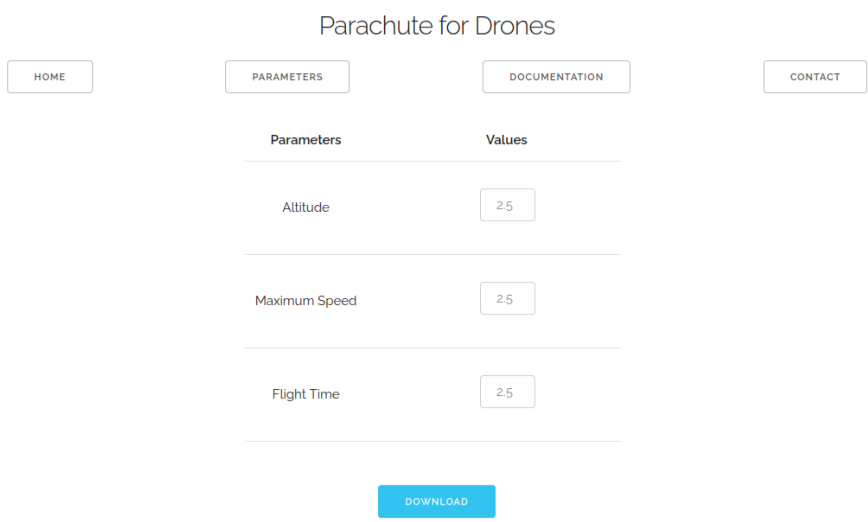


Figure 16 - Screenshot of the Parameters Button

CONTEXT DIAGRAM LEVEL 1 (INPUT AND COMMUNICATION)

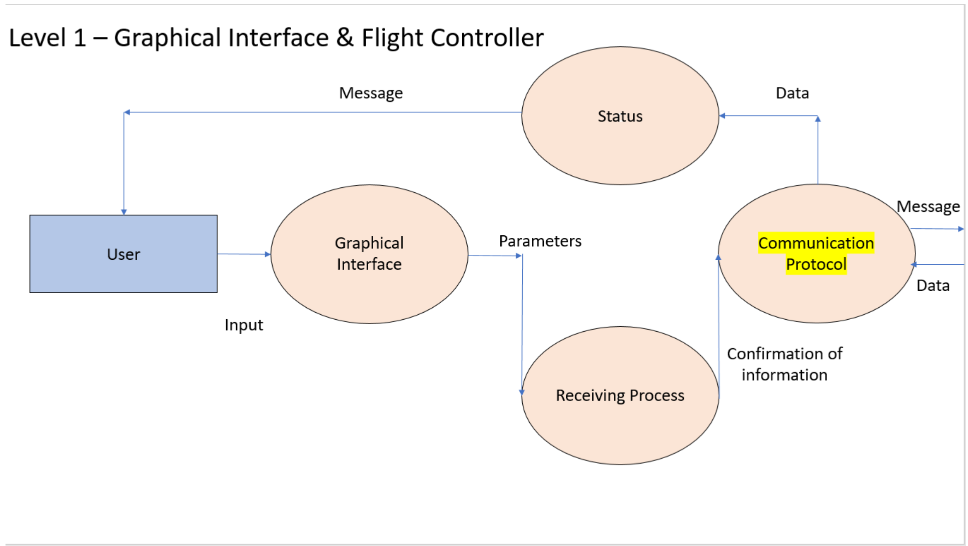


Figure 17 - Level 1 Context Diagram

In Figure 17, we have the level 1 Context diagram of the graphical interface and flight controller. In this picture, we can see that the user will input information through a graphical interface (a website in this instance) in which the user will be able to put the pre-flight parameters. Then there will be a receiving process that will receive data and send it to the emergency parachute system via a communication protocol. The receiving process will be the .h file that will contain all the information inputted by the pilot and passed to the system via USB connection. The communication protocol is going to the central device communicating the parameters to the rest of the peripherals. To report back to the user in the case that an event took place or to just report the status of the drone, a status process will take place that will compile the report and encode it a readable document for the user, which will then be sent in the form of a message to the user.

CONTEXT DIAGRAM LEVEL 2 (STATUS, SECURITY, AND DEPLOYMENT)

The level 2 context diagram shown in Figure 18 explains the communication protocol between the central device and the emergency parachute system release system. The process starts with the status interface, in which the peripheral sensors will be used to mine and gather data used to pinpoint the location of the drone. The raw data will then be packaged and encrypted via a security protocol, ensuring that no malicious users hijack the drone. After the data is encrypted correctly, it is then sent to a status process. This process is responsible for deciding if a deployment is necessary or not. If the deployment is necessary, a signal is sent to the parachute emergency system to deploy. The status confirmation verifies the successful deployment of the parachute. This flag would trigger again if deployment failed, or if it were successful, alert the user and send a report detailing exactly what happened.

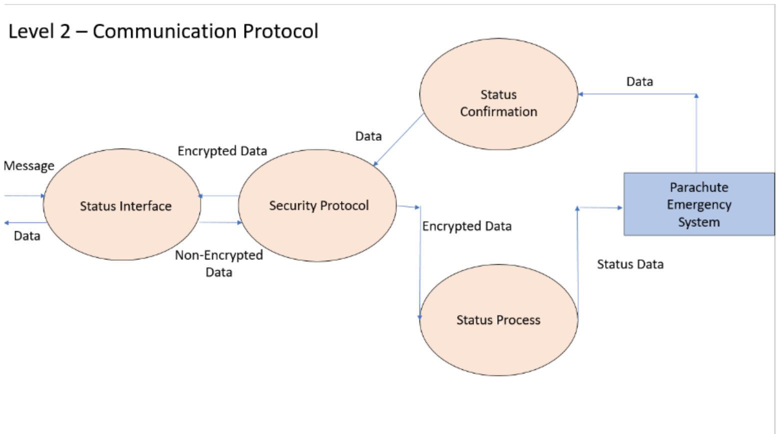


Figure 18 - Level 2 Context Diagram

[MORE INFORMATION AND PICTURES TO BE ADDED]

3.3 MECHANICAL DESIGN

The Mechanical components of the system have undergone some changes from the initial designs. In this section, the distinct phases of the mechanical component of the system will be presented. The changes are a result of the suggestions and redesign discussed during the weekly meetings held with the sponsor and our advisors.

The initial design of the deployment system used a compressed spring for parachute ejection. The system can be seen in Figure 19.

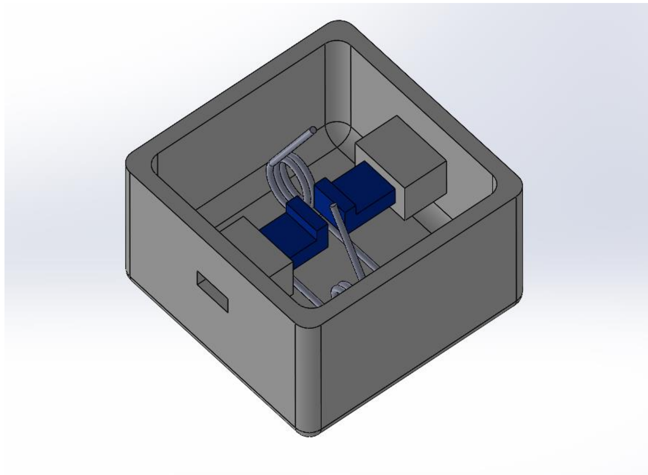


Figure 19 - Level First Iteration of Spring-Loaded System

This system was envisioned to work with two torsional springs, held down by the blue tabs seen in Figure 19. Those tabs would be each pulled by an actuator or solenoid. A problem with this system that two actuators would add a lot of mass to the system, would increase the cost and would have a high-power requirement.

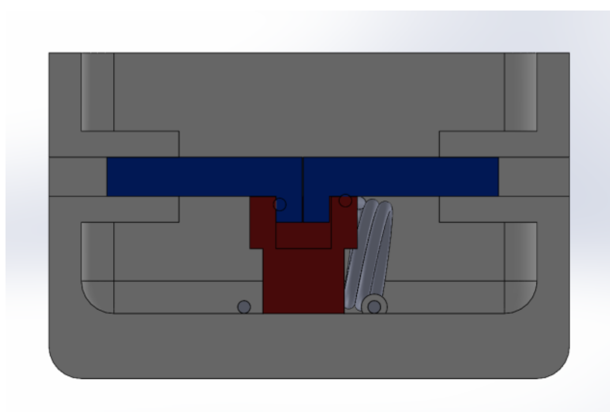


Figure 20 - Spring-Loaded System Iteration 2

The second iteration of the spring-loaded system modified the placement of the tabs. This system included a piece that acts as a pin that keeps the blue tabs together, as seen in Figure 20. This design would have one extension spring at the end of each blue tab. Whenever the red pin is moved downwards the blue tabs would move back and the torsional springs would be allowed to decompress, colliding with a small cage holding the parachute. The problem of having two actuators has been solved, but now having a single actuator moving vertically requires that the complete system must be taller. A taller system would bring some difficulties when creating the flight termination system, and so this design was abandoned.

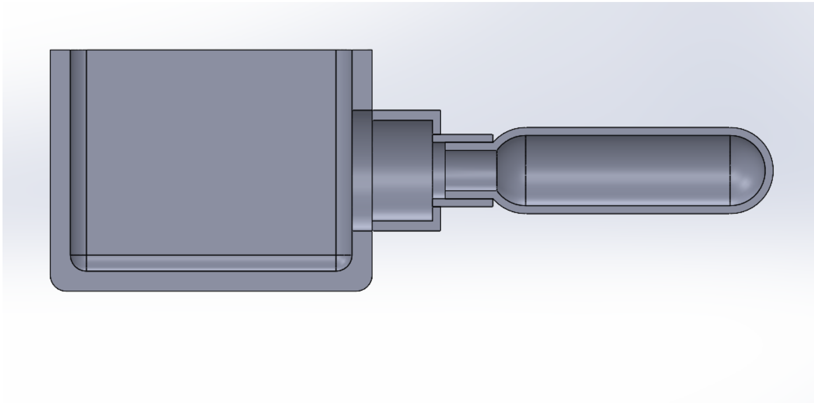


Figure 21 - CO2 System Iteration 1

At the same time as the spring-loaded system was being designed, the first iterations of the CO2 system were developed. The first iteration of the CO2 system can be observed in Figure 21. The most distinctive characteristic of this system is that it would use a valve to control the release of CO2 from the cartridge. The cartridge would be punctured as it was screwed in place. The valve would then release the CO2 whenever the parachute needed deployment.

A problem with this design is that the valves that could operate with the involved pressure are expensive and heavy. Another problem is that a cartridge would be used every flight, and it would be preferable to use a cartridge only when the parachute was deployed.

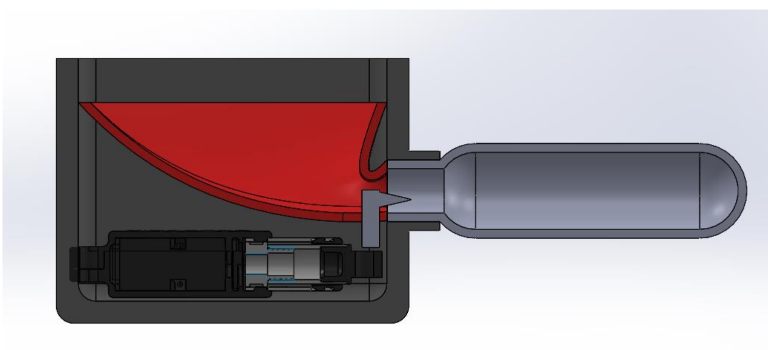


Figure 22 - CO2 System Iteration 2

On the second iteration of this design, the valve was removed, and it was decided that the cartridge would be punctured only when the parachute needs to be deployed. The second iteration, as seen in Figure 22, features a linear actuator, to which a puncturing needle is attached. The actuator would move forward the puncturing pin whenever the parachute would need deployment. A complication about this is that the actuator would require to provide the necessary force to puncture the cartridge. Such actuators are expensive, heavy, and bulky, so this approach was discarded. This iteration also includes a piece called the air director, which would allow the CO2 to flow in the right direction towards the parachute.

The third iteration is like the second one, the difference is the puncturing device. As seen in Figure 23, this iteration would use a rotary actuator or a DC motor to puncture the cap of the CO2 cartridge, but similarly to iteration 2, this would require a bulky device capable of delivering the required force.

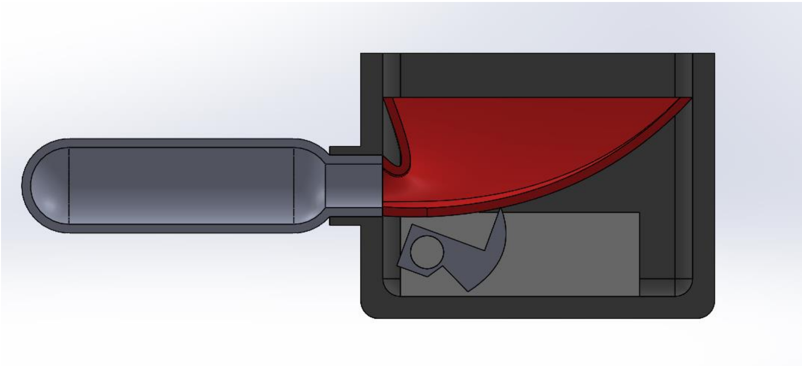


Figure 23 - CO2 System Iteration 3

The third iteration would have a similar pin, that would rotate and hit the cap of the CO2 cartridge.

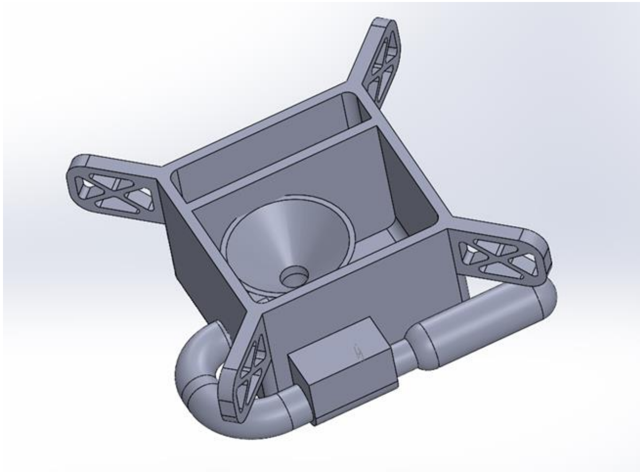


Figure 24 - CO2 System Iteration 4

On the fourth iteration of the CO2 system, various changes were implemented. The casing for this iteration can be seen in Figure 24. This system firstly changed the position of the CO2 cartridge. The reason for it is that the position of the previous versions would significantly shift the center of mass of the system. Placing it on the side would reduce the effect of the mass of the cartridge on the shift of the center of mass. Secondly, this design includes a section of the casing for the electronics, as well as a funnel-shaped air director. Additionally, the system now features a spring-loaded firing pin that will puncture the canister. The firing pin can be observed in Figure 25.

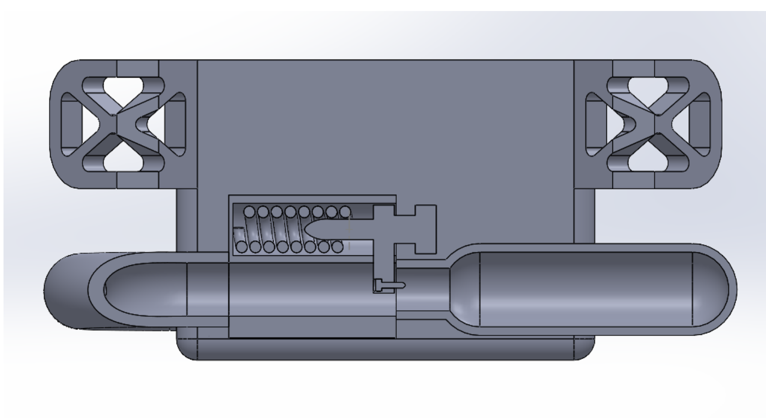


Figure 25 - Cross Section of CO2 System Iteration 4

The pin would be spring-loaded and held in place by some mechanism. This idea of having a spring deliver the impact allows for the use of less expensive and specialized electromechanical components.

Another feature that this iteration includes is the flaps at the top of the casing. The flaps would act as the flight termination system.

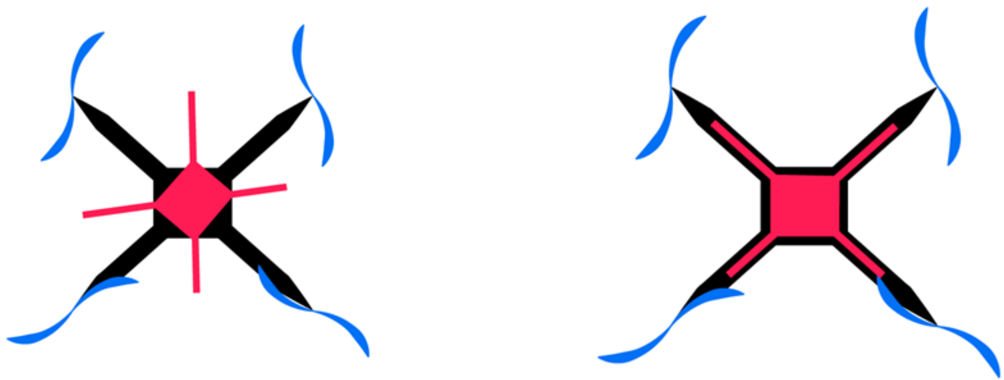


Figure 26 - Flight Termination System Concept

The flight termination system would activate simultaneously with the CO2 cartridge puncturing. The system would be positioned on the drone as seen on the left diagram in Figure 26, and when the system is deployed, the system would rotate 45°, getting into a position where the flaps would get in the way of the propellers, causing them to stop. A problem with this system is that the size of the flaps would not be universal. Drones of specific sizes would require a set of flaps with a certain length. This reduces the modularity of the system, and so this idea was modified.

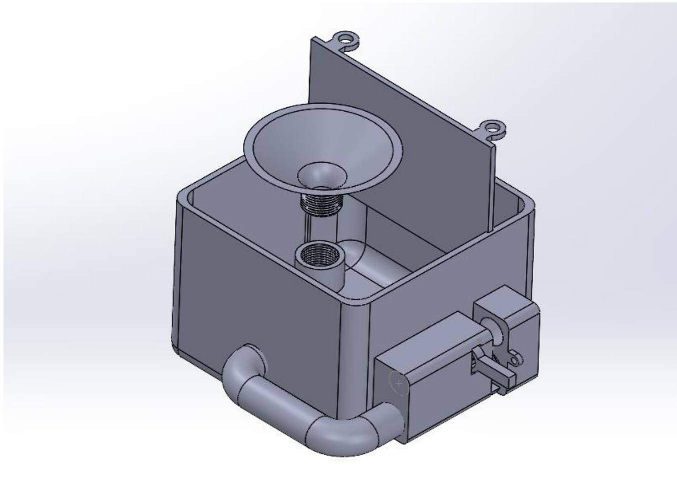


Figure 27 - CO2 System Iteration 5

The fifth iteration of the system modified and added some components to the previous iteration, as seen in Figure 27. This system made the funnel removable so that components inside the system were easily accessible. Similarly, the electronics would be mounted onto a removable plate that would allow for easy access. This iteration also includes a safety pin, that the user can place so that the system will not fire under any circumstance. This iteration also includes a pin that will connect to an electromechanical component, as seen in Figure 28.

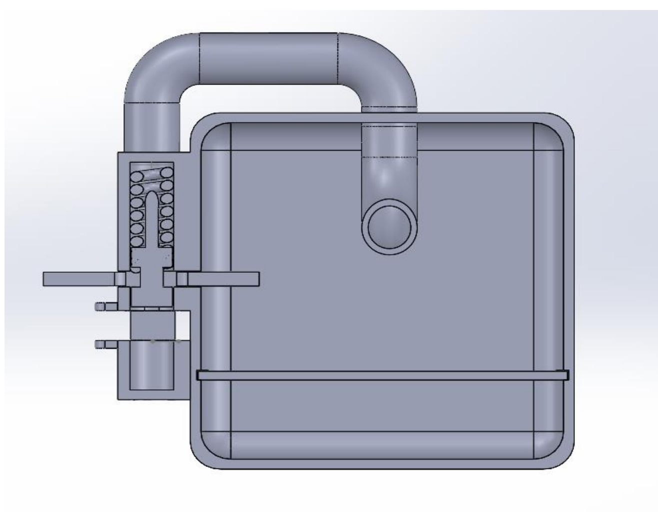


Figure 28 - Top Cross-Section of CO2 System Iteration 5

As seen in the figure above, this design features two pins, one that the user places while the system is not to be deployed, and the second one on the inside that will retract for system deployment.

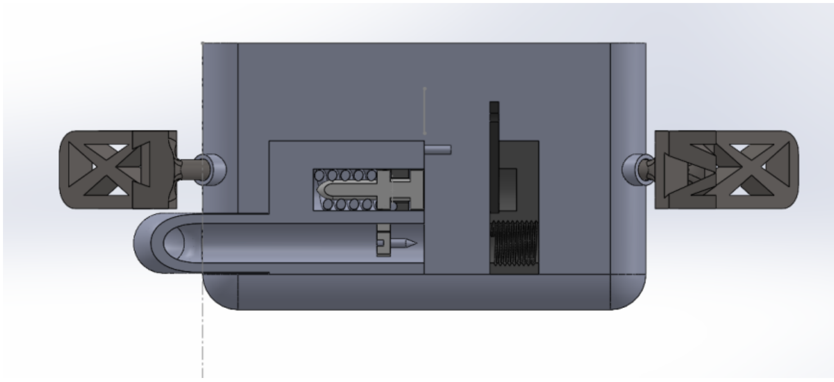


Figure 29 - CO2 System Iteration 6

Figure 29 shows the sixth iteration of the system, which is a modification of the previous iteration. This version features a cap that will stop the firing pin after deployment. This system also has the safety pin placed vertically.

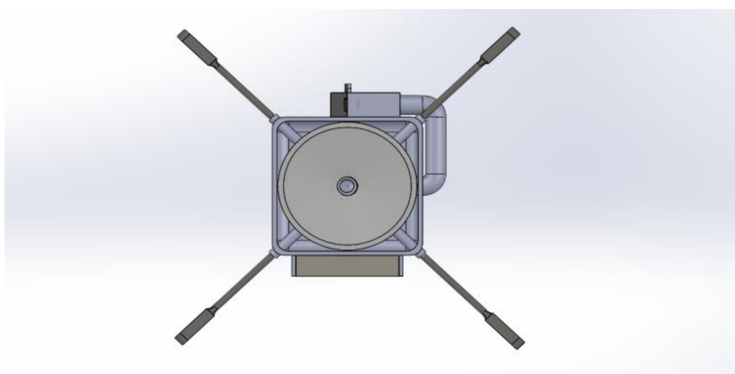


Figure 30 - Top View of CO2 System Iteration 6

This iteration also features a flight termination system of extendable flaps. As seen in Figure 30, the system has flaps that will extend whenever the system is deployed. The flaps will be pushed by the released CO2 cartridge. This version also has the electronics placed on the outside of the case. The reason for this is that the funnel can be bigger now, the electronics will be farther away from any metal components used, and it helps to balance the center of mass of the complete system more effectively in that position. This system will feature a power screw system paired with a DC motor to drive the internal deployment pin connected to the firing pin.

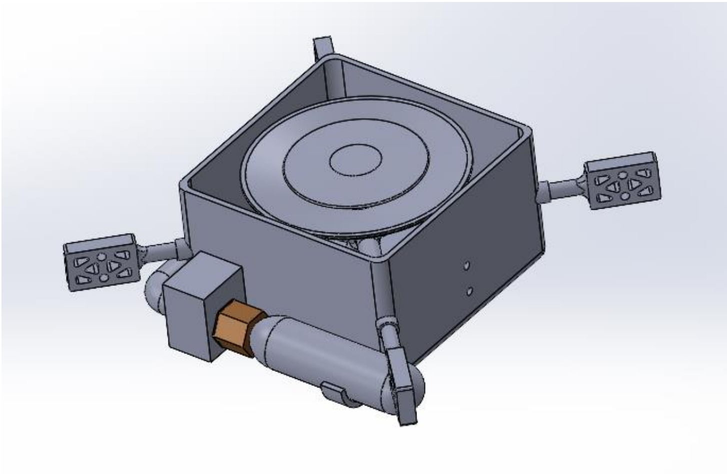


Figure 31 - CO2 System Iteration 7

Figure 31 shows the seventh iteration of the system. The two main changes between this iteration and the sixth iteration are the deployment method of CO_2 and the air director. This iteration uses a fusible plug. As seen in Figure 32, the fusible plug has a needle that will pierce the CO_2 as it is screwed in. The blue tablet will stop the pressurized CO_2 from escaping. Whenever the parachute is to be deployed, the nichrome wire that passes in front of the tablet will heat up, melting the tablet and releasing the CO_2.

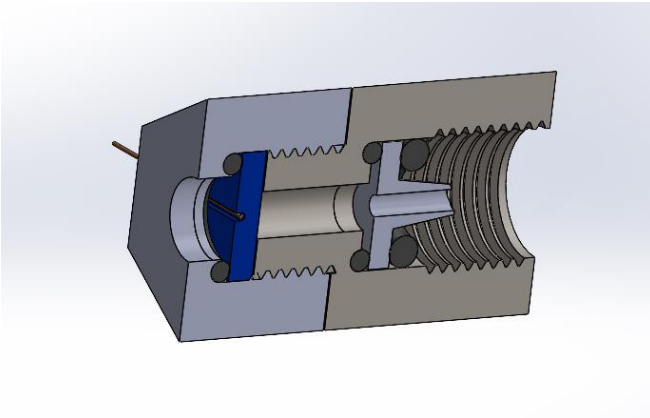


Figure 32 - Cross-Section of the Fusible Plug

Figure 33 shows the air director of Iteration 7. This director features an upper part that will help the CO_2 flow along the bottom part. With this director, the parachute is to be placed above the director and held in place with a rubber band along the grooves at the top of the lower part. This design is to make the parachute inflate like a balloon. This would speed up the opening of the parachute.

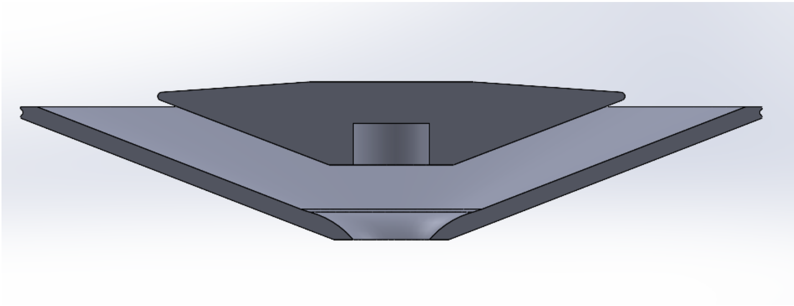


Figure 33 - Cross-Section of Air Director Iteration 7

4. OVERVIEW OF FINAL DESIGN OF SYSTEM

5. UNEXPECTED PROBLEMS AND SOLUTIONS

6. STANDARD DISCUSSION

For this project ASTM F3322-18 standards were followed. These is the Standard Specification for Small Unmanned Aircraft System (sUAS) Parachutes [5]. These standards outline a set of design parameters that we took into considerations as the parachute system was designed. Some of said parameters will be discussed below.

7. RESULTS

8. PROTOTYPE FABRICATION AND TESTING

Throughout the development of this project, a series of prototypes were constructed, and tests were conducted in order to develop a successful final working prototype.

9. ECONOMICAL, SAFETY, AND WELFARE ANALYSIS OF RESULTS

10. FURTHER IMPLEMENTATION

11. REFERENCE

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[2] Mars Parachutes, "MARS 58 V2," [Online]. Available: https://www.marsparachutes.com/product/mars-58-v2/.

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[5] ASTM, "Standard Specification for Small Unmanned Aircraft System (sUAS) Parachutes". Patent F3322 − 18, 2018.

12. APPENDICES

13. SMC CAPSTONE REFLECTIONS