EML 4905 Senior Design Project

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BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

UNMANNED AERIAL VEHICLE WITH FIRE EXTINGUISHING GRENADE RELEASE AND INSPECTION SYSTEM
100% Report

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Miriam Carolina Freitas, Cesar Beltran and Alex Moribe and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Abstract

The ignition of certain materials that combust to create a fire is something that most of the times occurs without being wanted. The damages that a fire causes are proportional to the size of the fire. Sometimes, nothing happens to property and living beings, but other times, the emotional and economic losses are too great to afford to keep having fires that are difficult to control, and eventually extinguish.

For that reason, the intention of this design project is to improve the ways in which fires are prevented and extinguished. UAVs are apparatuses that have become popular in recent years thanks to not only their many capabilities to program, but also that a human being does not need to be on board in order to control it. Hence, this team decided to use them in an innovative and inventive manner to create a mechanism to release a fire extinguishing grenade in the desired location that will prevent fires or directly extinguish them.

1. Introduction

1.1 Problem Statement

Currently, there is a lack of unmanned aerial vehicles that are being used with the purpose of extinguish a fire or help prevent one. An unmanned aerial vehicle (UAV) is an aircraft without a human pilot on board. Its flight can be controlled autonomously by computers in the vehicle, or by remote control under the direct command of a human. In the United States and the rest of the world, most of the UAVs in existence are being used for defense purposes.

Fires that occur in homes and nonresidential buildings as well as fires in wild lands cause plenty of health issues; including death to humans and animals, in addition to great economic losses in structures, equipment and vegetation. Furthermore, the first response teams, such as firefighters, are exposing their lives to great risks in order to extinguish a fire.

In addition to those huge problems, there is another one that does not cause so many struggles, but it does have a negative effect when a fire occurs. One of the most popular ways to extinguish fires is to spray water in the area affected by the flames. The water can be delivered via hose using a pressurized fire hydrant, fire sprinkler system, pumped from water sources, such as lakes, rivers or tanker trucks, or dropped from aircrafts in the case of wild land fires. These techniques result effective in extinguishing the fire; however, the damages that they cause to large structures and its contents once the fire is extinguished, generally, are great. The main disadvantage of spraying water in the area of the fire is that water can damage the interior of the building. Especially in office buildings, where electronic equipment and important documents exist in abundance, the contents of the building are in great danger even if the fire is suppressed in a proper manner.

Also, the prevention of wildfires entails creating conscience among the population living near forests and large spaces of vegetation. Letting the residents know that they are the ones that can have the greatest impact in regards to starting a fire; therefore, they are the ones in charge of preventing them. If awareness is not raised successfully, there are still chances that fires can occur. Here is where our team plays a great role by generating new ways of preventing wildfires.

In order to help those that risk their life when a fire takes place, the living beings that can be potentially harmed and their surroundings, such as edifications and forests, to preserve the goods inside a building once a fire occurs, and to help avoid fires in open spaces, this team decided to focus this senior design project in the development of an UAV that is going to prevent fires and also assist in extinguishing them.

1.2 Motivation

The main reason why this team decided to build an UAV and integrate a fire extinguishing ball release mechanism is because of all the advantages that UAVs provide. Starting with the fact that UAVs do not need a pilot on board, they also can get access to places in which life can be in danger if entered. Another reason to use an UAV for this particular project is that it can be programmed to perform any mission desired, without having human error on board. Of course, it has to be taken into account that if any of the systems fail, the UAV will be in great risk of crashing, but those probabilities are too small in comparison to the probabilities of having a successful mission.

On the other hand, according to the U.S. Fire Administration National Fire Incident Reporting, in the year 2011, there were 364,500 residential building fires. A residential building is defined as a structure in which people live. Those fires caused 2,450 deaths, 13,900 injuries and more than $6.6 billion in losses. On the side of nonresidential buildings, they are defined as public or private enclosed structures in which businesses, educational facilities, underground buildings, hospitals and subway terminals are included. In the year 2011, there were 85,400 fires in nonresidential buildings in the U.S., causing 80 deaths, 1,100 injuries and more than $2.4 billion in losses.

A wildfire is defined as the ignition and burning of large extensions of vegetation in a wilderness area. Wildfires take place when the components of a fire triangle come together in a vulnerable and sometimes predisposed area. These components cause a fire when an ignition source is brought into contact with a combustible material, such as trees and dry leaves, that are exposed to enough heat and has a satisfactory supply of oxygen from the ambient air. A wildfire can be caused by natural events, such as spontaneous combustion, lightning, sparks from rock falls and volcanic eruptions; and can also be caused by human activities, such as, discarded cigarettes, discarded glass and plastic (magnifying the rays and heat of the sun), sparks from equipment, and power line arcs [3].

By the same token, in 2012, wildfires were responsible for burning more than 9.3 million acres in the United States, causing more than $450 million in property damages, putting at risk around $136 billion in properties and generated more than $270 million in fire suppression costs.

Regarding the ways in which fires are extinguished, lately two new techniques were introduced to the market. The first one uses a fire extinguishing ball that needs to be thrown in the location of the fire and once it is in contact with the fire, it self-activates within 3 seconds and releases fire extinguishing chemicals that work effectively in a room with a volume of approximately 9 m^3. The second technique consists of a similar method. It is called DSPA-5. It requires throwing the device with fire extinguishing agents inside the room, and someone has to pull a trigger to activate it. Presently, both devices are put in the location of the fire by a human. This puts the person in charge of this task in huge danger, since the person has to be very close to the fire.

Another important thing to keep in mind is that by the year 2030, Unmanned Aerial Systems will be allowed by the Federal Aviation Administration (FAA) to operate in the National Airspace system and provide a wide range of services.

As seen by all the facts described before, fires are causing plenty of human and monetary losses in this country; therefore, this team decided to change the application of the regular UAVs being constructed for military purposes, and build and design an UAV that can help a great amount of people being affected by flames and smoke, that most of the times cannot be prevented or well controlled in an effective and timely manner.

1.3 Literature Survey

1.3.1 Review History of Remote Control Vehicles

The beginning of the development of remote controlled devices started with the invention of the radio, back in the 1880's, when Nikola Tesla invented the induction coil, a necessary device to send and receive radio waves. At first, these radio signals were intended for communications purposes, but during World War I the Germans started using remote control stations for manipulating tanks loaded with explosives. Between 1914 and

1918, the development of various radio controlled unmanned aircraft were intended to be used for military purposes; however none of the prototypes was fully functional to be used during the war. This also marked the beginning of the use of radio waves for commanding machines and computers, such as power plants and satellites.

After the increasing development in computer technologies in the 1940's, the use of UAVs had opened new frontiers, mostly military purposes for reconnaissance missions and also pilot trainings, but their civilian applications were moving slowly along with research. One clear example is the incorporation of GPS technologies. Since World War II, the preliminary research into general relativity led to the base for our actual GPS technologies, this was called ground-based radio-navigation systems. Although, it was not until the 1990's that the US began incorporating this technology into the UAVs of that period.

1.3.2 Sensors and Software in UAVs

With the culmination of the programmable digital computer in the 1940's, the idea of having a totally independent machine has been the subject of multiple studies. While a fully independent machine was not developed, the components of such devices could work independently according to the input signals they compute from the surrounding areas, this signals vary from changes in:

- Altitude (altimeters)
- Acceleration (accelerometers)
- Temperature (thermocouples)
- Light (photo resistors)

Multiple lines of code can be used to control the most desired outcome after reading the sensor; this is done through computer software that uploads the necessary instructions for the UAV to follow.

The reason why sensors are important is because they are the main source of input information for a machine to have its decisions based on. GPS, ultrasonic, thermal sensors, cameras, are just a few of the different types of sensors that can be incorporated into an UAV; speed for this input is important, but what matters most is the code used in order to manipulate this information.

Technological advances in the performance of sensors were seen between the 1950 and 1990, improving the response for their tasks, which were mainly surveillance, bombing, and pilot training. It was not until the introduction of the GPS in the 1990's that UAVs took a major role in not only military but also civilian objective.

In these last years, the U.S. is spending more than $50 billion annually in UAV development and testing. This covers from drones to weather balloons, but advances in UAVs for firefighting technology has not been put together yet.

1.3.3 Firefighting Systems

The different types of firefighting systems that are currently used in the market are:

- Fire sprinkler systems: This system consists of a series of devices attached to the roof of each floor of a building or home, and water is connected to them. When the fire sprinkler detects smoke, it activates and releases water.
- Wet and dry chemical agents: This method to fight fires works by minimizing, isolating, or reducing the fuel or heat. Reducing or isolating the oxygen or inhibiting the chain reaction of the components. This method causes less damage than water but some agents can be harmful after long term exposure.
- Gaseous agents: Leaving the wet chemical agents aside for practical reasons like saving electronic devices in the affected area, dry chemical agents are the best solution to firefighting. They are similar to the gaseous systems but in most cases had been proved faster than other methods.

Extinguishing a fire is a dangerous task, especially if the place is not equipped with any firefighting system and in most cases a firefighter needs to enter a building if there are people inside. To avoid putting at risks more human lives, an aerial firefighting gadget can be send inside the building that is in fire to place a gaseous firefighting agent tool; for this purpose a quad copter works best because of its stability capabilities. Few companies in the US already sell generators of gaseous firefighting systems. They are small in size, portable, easily deployed and can cover a substantial damaged area. By adapting a generator to an UAV equipped with a front camera, one can easily enter a building in fire without risks, and the placing of the generator will be more accurate.

1.3.4 Regulations

Similar to what has happened with incorporating new technologies into our lives, UAVs are part of ethics discussions and companies that hold the technologies to create such flying devices, and their components, are waiting to start profiting from the results.

So far, the use of UAVs in the civilian sector is mainly for surveillance purposes, which is one of the functions of drones, for military purposes, but there are no limits for what they can be useful in research and governmental purposes. To name a few, Vertical Profiles of Shortwave Atmospheric Heating Rates, Imaging Spectroscopy, Topographic Mapping; and non-research, Coastal Patrol, Forest Fire Damage Assessment, Forest Fire Mapping, Invasive Plant Assessment. Most of these applications are in early developments and there is lack of regulations and specifications for starting with new projects. These regulations concern the following:

- Lack of airspace regulation that covers all types of UAV systems (encompassing 'sense and avoid')
- Affordability - price and customization issues
- Efforts to establish joint customer requirements
- Liability for civil operation

The lack of precise regulations has not stopped the enthusiasm of individuals and known universities, to create or modify existing UAVs into what could possibly be helpful in the future. The Swiss Federal Institute of Technology Zurich has a department focused only in the development of intelligent aircraft. In there, competitions are held often and individuals can share open source code for their UAVs.

The development of UAVs must be accompanied by a high ethical sense and preservation of privacy of everyone. This does not mean that research should be stopped or restricted, just the opposite, it should be open to everyone to get more contributions and increase the capabilities of any application. Until now, the computing and programming part of the UAVs had been moving along side, which means that the faster and more accurate technology becomes, better, more interesting and helpful ideas for UAVs can be designed.

1.4 Discussion

The eradication of fires in a manner that no lives are lost, and that the cost of extinguishing the flames is reduced to a minimum comes from prevention and having a well educated population. Nonetheless, there are certain situations in which fires occur in unexpected and fast ways; therefore, there have to be competent and cost efficient methods in order to approach the extinguishing of the flames and smoke without the losses that usually fires cause.

2. Project Formulation

2.1 Overview

Fires spread around the U.S. in an unpredictable way. Because of this, most of the times it is hard for firefighting departments across the country to control them, as well as eradicate the flames and smoke of the affected area in an inexpensive and timely manner.

Knowing these facts, this team will design and build an UAV that will have three purposes: fire prevention, firefighting and inspection. Fire prevention and firefighting will be achieved through the ejection of a fire extinguishing ball or grenade in the area in which the fire is taking place. Inspection will be accomplished by installing cameras in the UAV.

2.2 Project Objectives

The purpose of this project is to build an UAV and attach to it a release mechanism for the fire extinguishing ball. This mechanism will be entirely designed and manufactured by the members of this team. The UAV is going to be built using parts already in existence and this team is going to put them together in order to construct a vehicle that is able to comply with all requirements to extinguish, prevent and inspect a fire.

The UAV will be capable of delivering the grenade in an area that is hard to approach by conventional methods or is more expensive to do it in other ways. Once this system is up and running, a camera is going to be added to the vehicle. With this, the second application takes place, which is inspection by live video recording and pictures. In addition, the camera is also going to help in taking the vehicle to the place desired by the controller.

2.3 Design Specifications

The requirements of the UAV are the following: pick up one fire extinguishing grenade, drop it off in the area chosen by the operator, and have a camera that is recording what is going on in the surroundings of the UAV. In order to do this, this team decided to use a quadcopter vehicle. As seen in Figure 1, a quadcopter is a UAV with four or more rotors with capabilities of lifting and carrying a specific payload.

Figure 1: Quadcopter Model

The other main factor in this project is the payload, which is the fire extinguishing grenade shown in Figure 2. It has the form of a sphere, weights around 1.3 kilograms and is filled with a chemical that fights fires. The grenade activates by itself when fire is present (around it); therefore, it can also be used for fire prevention. The grenade can be located in an area prompt to fires, such as the kitchen of a home or restaurant or in a forest that is known for having fires in dry seasons, and once the grenade detects fire, it will activate by itself.

Figure 2: Fire Extinguishing Grenade [10]

It is also worth noticing that another one of the most relevant requirements of the multicopter is a GPS system. This will allow the operator to indicate the location of the fire and the release place, and will also specify the exact location of the UAV at all times. In addition with a ground station, the operator can have control of the vehicle in case it goes out of range or the mission has been rearranged. Furthermore, sensors of proximity and altitude will be incorporated to provide the multicopter the ability to avoid a collision with other objects.

2.4 Constraints and Other Considerations

The first limitation faced by the team is the fact that the university does not have the adequate facilities to test a UAV; therefore, designing the main components of the quadcopter according to the exact needs of integration of the release mechanism and placement of the camera was not a possibility.

Furthermore, one of the major constraints is the place in which the vehicle is going to release the fire extinguishing grenade. If the grenade is going to be released in an open space, such as a forest, the purpose of the grenade is for prevention. The open space location cannot be on fire when the UAV arrives, because the flames would melt the UAV. Another thing to keep in mind is that the grenade is more effective when it releases its chemicals inside a room that has a volume of less than 9.5 m^3; therefore, a perfect use of this grenade would be when the room of a house or the room of a tall building is on fire. The way to access specific rooms in a structure is through a window. To use the UAV to release the fire extinguishing grenade, this window has to be open and the UAV will release the ball in a way that will fall inside the desired room while it stays outside the area on fire, since the vehicle is in danger of suffering great damages if it is too close to the flames. In this situation, the window has to be open; otherwise the UAV will not have a way to accomplish its goal.

3. Design Alternatives

3.1 Overview of Conceptual Designs Developed

Three major designs were considered in order to accomplish our goal, which is release a fire extinguishing ball in a determined location, in addition to having a camera in the vehicle that is going to video record what is going on and also take pictures of its surroundings. These two main objectives of the quadcopter are what defined the characteristics of each design that is going to be presented in the following sections.

3.2 Design Alternative 1

This design has the purpose of dropping the fireball through a two door opening at the bottom of the box. A box was chosen as a way of protecting the fireball from the fire, so it does not activate before being located at the target. Servo motors control the two doors simultaneously from a computer program that is connected to the quadcopter through radio signal. The material of the mechanism is aluminum, which has a light weight and is easy to manufacture. The disadvantage of this design is the close distance to the fire the quadcopter has to get at the releasing point, since not only the ball has to be protected from the fire during the flight but also the motors and electronic components need to be isolated from high temperatures. This design can be seen in Figure 3.

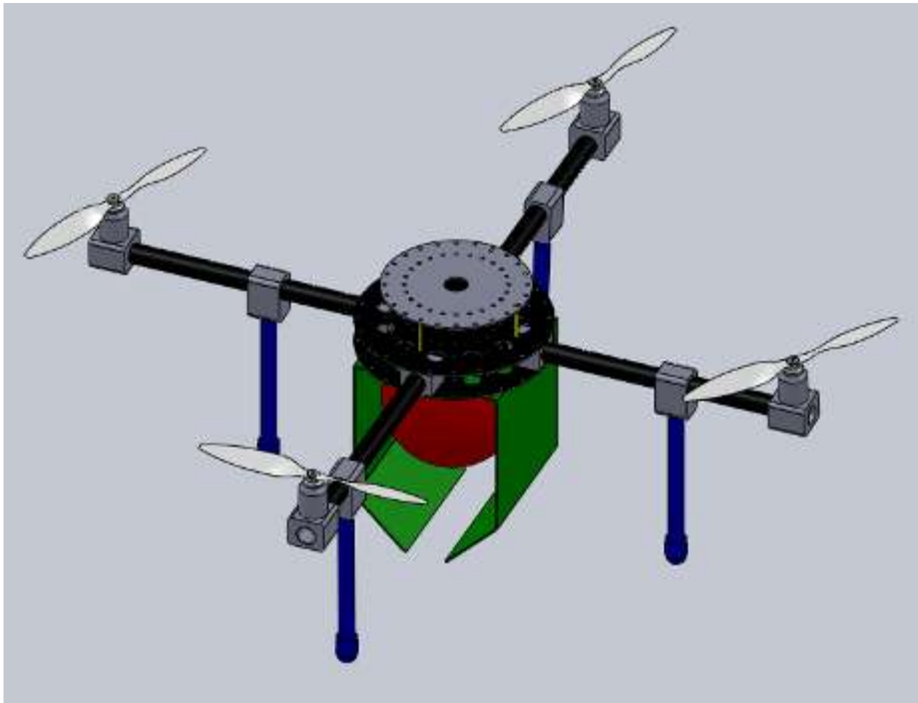


Figure 3: Design Alternative 1

3.3 Design Alternative 2

As a way of saving material for the mechanism, a cage design can be used for holding the fireball while making the releasing process easier at the same time. Two solid bars are placed at opposite sides of the bottom of the quad and are surrounded by metallic strings for holding the fireball in place and are connected to controlled locks at the bottom plate. The releasing process takes place when the bars are unlocked making the bottom platform of the mechanism to fall along with the ball. The disadvantage of this process is reloading the fireball. Since we want a system that can do multiple trips if needed, having this type of procedure requires having more than one bottom platform for holding the fireball in place, and putting the parts together can take an approximated time of five minutes. This design can be appreciated in Figure 4.

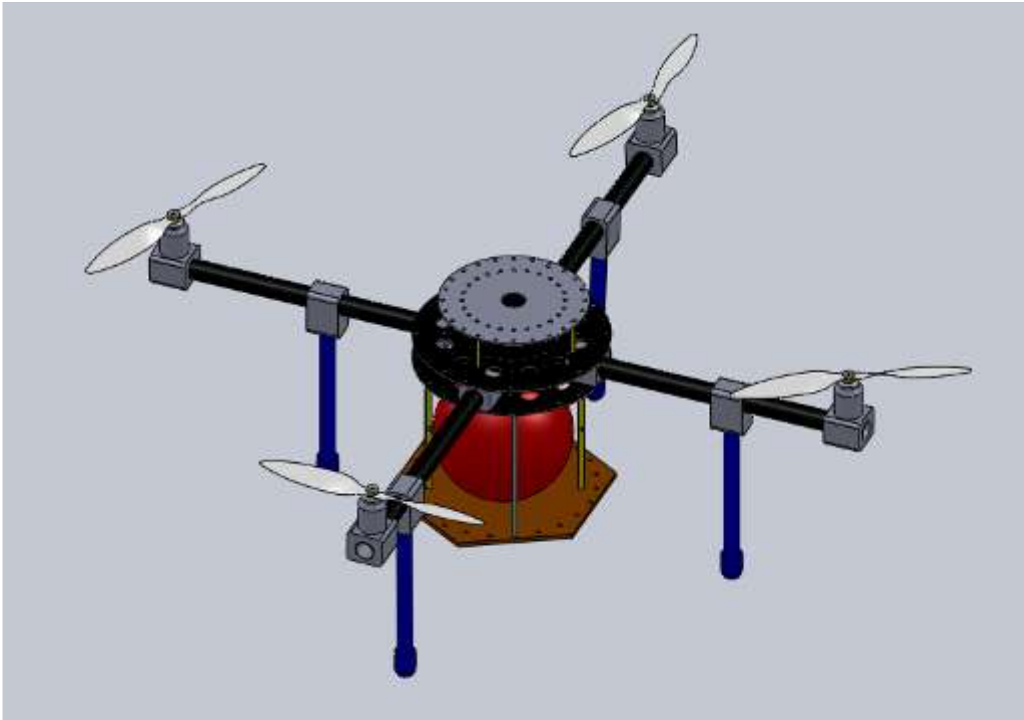


Figure 4: Design Alternative 2

3.4 Design Alternative 3

This design consists of having railing system connected to the bottom of the platform that holds the fire extinguishing ball, and this will be the release mechanism.

The cage design from the second alternative still stays attached to the quadcopter and just the rails are added. The rails will serve to guide the fire extingusihing ball to its target while at the same time keeps the quadcopter at a safe distance from the flames. A servo motor controls the angle at which the railing system is going to rotate. This will provide control over the velocity at which the fire extinguishing grenade is released.

When the vehicle reaches the desired location for releasing the grenade, the servo motor activates and lowers the railing system while at the same time it pushes the fire extinguishing grenade from the back of the cage.

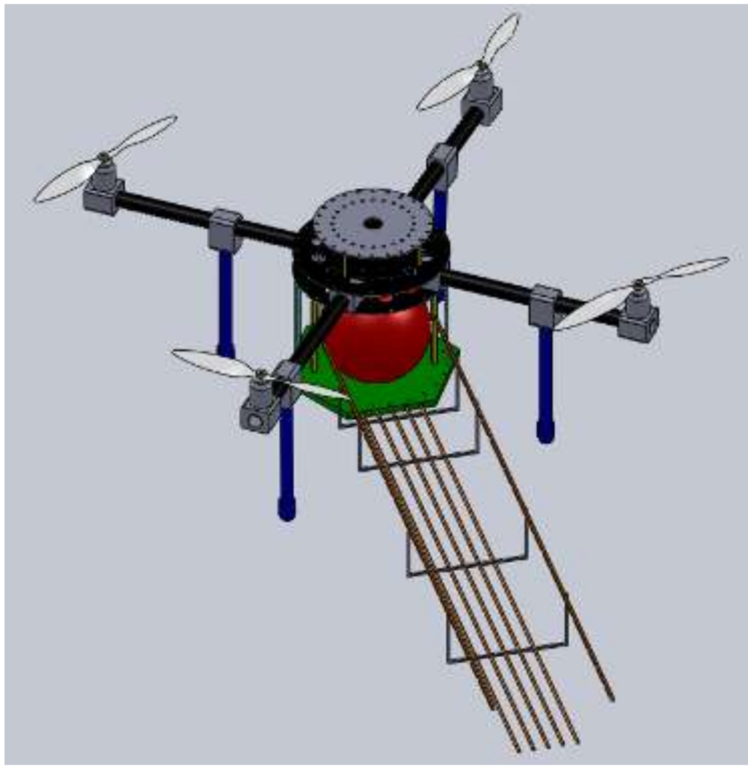


Figure 5: Design Alternative 3

3.5 Design Alternative 4

This design contemplates having the release mechanism on top of the frame of the quadcopter, and it can be seen in Figure 6. At the moment, there is no a defined way in which the release mechanism, consisting of a ramp and a launching ring, would be attached to the quadcopter. In Figure 6, the length of the ramp is exaggerated just to show how the ball will travel in the rails, but at this point there are no calculations made that can show what would be the best length for the rails. Furthermore, it is worth noticing that the assumption in this case is that the rails have to at least reach the end of the booms in order to throw the ball safely without touching the propellers.

This design may cause controversy because the assumption is that having the mechanism on top of the frame makes the vehicle more unstable than having it below the frame, but the software chosen for this project that is going to be in charge of maneuvering the quadcopter, will make it readjust everything it starts losing balance. Of course, to confirm the effectiveness of the software, the whole system needs to be tested when it is built.

The decision to have the mechanism on top of the frame arose, because the main objective of the mechanism is to throw the fire extinguishing grenade inside the window of a building. In order for the ball to reach a bigger distance once it is ejected, the rails need to be at an angle so the ball can follow a hyperbolic path and land inside the window. If the mechanism is at the bottom of the quadcopter and the rails have an angle, the components used to attach the mechanism to the frame would have to be much longer in order to allow clearance for a ramp at an angle, and longer components mean heavier components. Given that there are weight limitations for the system, it seems more reasonably to attach the release mechanism to the top of the frame. Of course, testing will prove this.

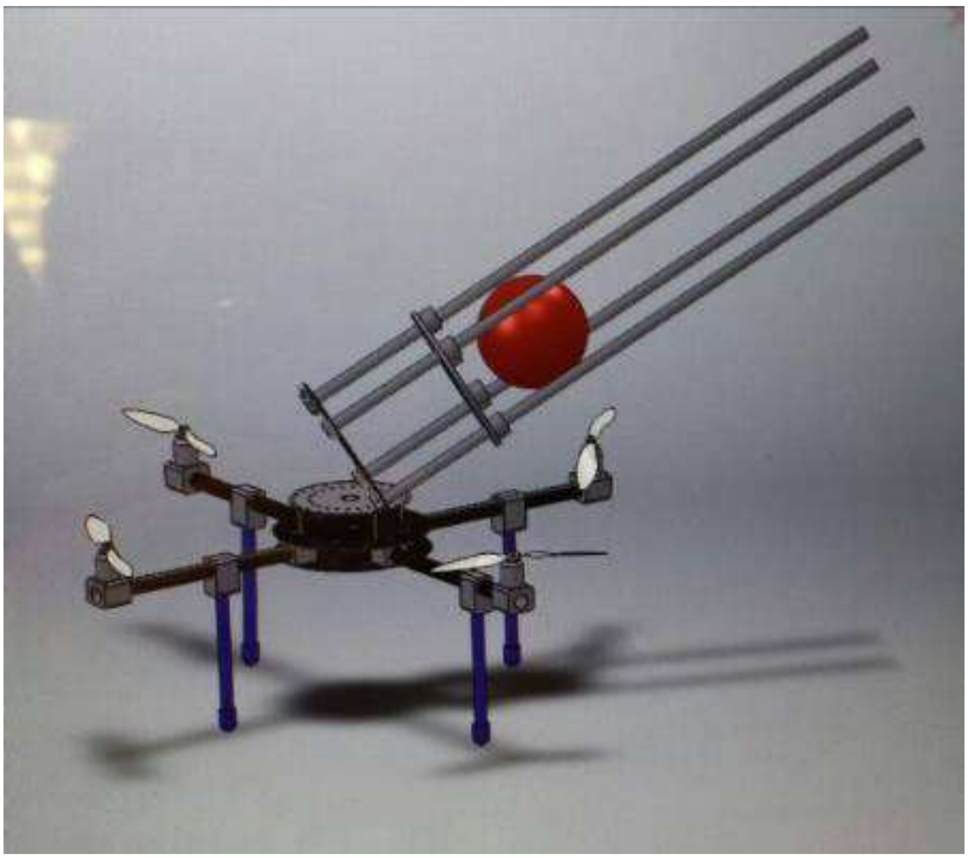


Figure 6: Design Alternative 4

3.6 Proposed Design

The chosen design for this senior project is alternative 4. After careful consideration, the members of this team realized that this design will not only provide safe release of the grenade, but also good support for the electronic equipment necessary in order for the vehicle to perform all the tasks defined in the objectives.

4. Project Management

4.1 Overview

The organization of the tasks needed to complete in order to have a successful project was made having in mind that commitment and efficiency were the keys. Having two semesters to accomplish the goal set up for this project, careful consideration was made choosing what were the main tasks needed to accomplish by the end of the spring semester. Consequently, it was decided that by the end of spring and beginning of summer the design of the release mechanism will be complete. In the meantime, the parts to build the quadcopter were going to be ordered and its construction would start as soon as all of them arrive, estimating that would happen in by the middle of May.

4.2 Organization of Work and Timeline

In Table 1 can be seen the timeline for this senior design project. Each stage of the project is shown along with the time frame required in order to complete all the tasks. In the table can also be seen what are the approximated dates in which each task should be completed.

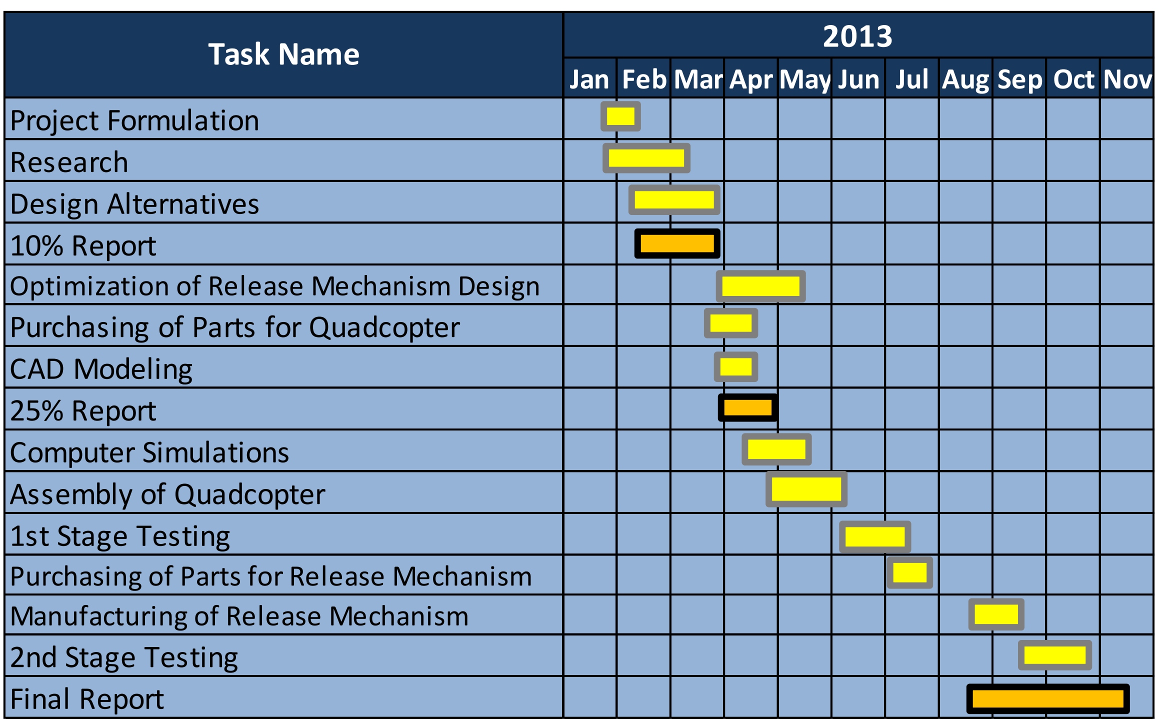


Table 1: Timeline

4.3 Breakdown of Responsibilities among Team Members

This team came up with the mains tasks needed in order to complete the designing, building and testing of this project. In table 2 these tasks can be seen along with the members in charge of them. Most of the tasks are going to be shared between the three members of this team, since they require an extensive amount of research and validation of all the team members. There are several tasks that are being performed by one team member. These tasks were distributed according to the level of expertise of each member in that determined area.

Task	Team Member (s)
Prototype Design	Miriam F., Alex M., Cesar B.
CAD Modeling	Miriam F.
Structural Analysis	Alex M. and Cesar B.
Optimization of Design	Miriam F., Alex M., Cesar B.
Purchasing of Parts	Miriam F.
Assembly of Quadcopter	Miriam F., Alex M., Cesar B.
Testing of Flight Capabilities of UAV	Miriam F., Alex M., Cesar B.
Testing of Release Mechanism	Miriam F., Alex M., Cesar B.
Analysis of Test Results	Miriam F., Alex M., Cesar B.
Simulations	Alex M.
Cost Analysis	Cesar B.
Manufacturing of Release Mechanism	Miriam F., Alex M., Cesar B.
Assembly of Quadcopter plus Mechanism	Miriam F., Alex M., Cesar B.
Reports	Miriam F., Alex M., Cesar B.

Table 2: Breakdown of Responsibilities

5. Engineering Design and Analysis

5.1 Major Components

There are many important components that are part of the quadcopter structure. Therefore, the UAV for fire extinguishing grenade release and inspection could be examined as a set of individual components according to the function of each system that conform a set. There are three main sets shown in the following list:

1) Fire Ball Extinguish Grenade.
2) Quadcopter Componets: Frame, motors, motor controller and flight controller, battery, first person view camera, GPS flight control system and Ardu-Pilot.
3) Release Mechanism: Release mechanism platform, rails and servo motor.

5.1.1 Fire Ball Extinguish Grenade

This grenade is filled with an aerosol capable of extinguish fires using nitrogen mixed with potassium. The aerosol compound contains 70% of nitrogen and 30% of very fine particles of potassium. Using these two components, this method of extinguishing fires is successful in fully developed and in early stages fire. This grenade was designed to replace a Halon fire extinguisher, since its method of operation is to cut off the oxygen supply of the area in which is used; therefore, it could cause serious harm to person if used inside a closed room.

The physical characteristics of the fire extinguishing grenade can be appreciated in Figure 1. This grenade has a solid material system that is filled with a minimal amount of extinguishing compound. The compound acts directly on the flame; hence, having an uninterrupted interaction with the burning surface once the fire extinguishing chemicals are released. This device can be activated by thermal reaction, electronically or manually. The grenade is going to eject the potassium solid as aerosol in a 360 degrees direction and the total deployment time will be 40 seconds.

Figure 7: Fire Extinguishing Grenade

One of the advantages of this dispositive is that it keeps oxygen levels intact in case humans are in close range when the grenade is activated. Another important point is that it increases the safety of firefighting personal when they try to extinguish a fire. The fire ball can extinguish 3 types of fires. One of them is type 1A, which is fire that blazes fueled by solids such as wood, plastic, paper and cloth. The second type is 5B fire class, which contains substances such as inflammable material. The third type is C fire class, which is used for electrical parts where water cannot be applied. The specifications of the fire extinguishing grenade are shown in Table 3.

Table 3: Specifications of the Fire Extinguishing Grenade

Feature	Value
Diameter (m)	0.145
Weight (Kg)	1.5
Volume of action (m^3)	9.12
Activate Time (sec)	3 to 10
Useful life (years)	5
Extinguish classes	1A - 5B – C
Fire Extinguishing Agent	Mono Ammonium Phosphate

5.1.2 Frame

The frame of the UAV is composed of three plates, two large main plates joined by pins and one small plate of top of them. This allows a configuration of up to 8 arms (or booms); however, this team decided to build a quadcopter, which has a configuration of four arms. The four booms that hold the motors are placed at 90˚ with respect to each other.

The three plates are made of a material called G-10, which is a fiber glass epoxy composite known for its high strength and resistance to high temperatures. Its properties are available in Appendix A.

The diameter of the two main plates is 8.125”. These booms are secured to the main plates by screws that are 1-1/8” long and they rest over two U blocks, one behind the other. The second half of the U blocks is added to the top to clamp the boom to the structure. Another main plate is installed on the top of the arms and the whole structure is going to be held together by adding nuts to the screws. For better support, screws of 3/8” in length are added around the main plates to help hold the structure in place. The motor is mounted at the end of each boom over a flat surface that is secured to the arm by two U supports and four 1-1/4” long screws. A small plate is placed at the top of the two main plates and the electronics components are located in this area, between the top small plate and the top main plate. All these data can be better appreciated in Table 4.

Table 4: Specifications of the Frame of the Quadcopter

Feature	Value
Main plates diameter (in)	8.125
Screws (in)	1-1/8
Outer Screws (in)	1-1/4
Support Plates Screws (in)	3/8
Tube length (in)	13
Material	Carbon fiber

The configuration of the frame of the quadcopter can be appreciated in Figure 11. The distance from the center of the plates to the center of the propellers is approximately

23” or 0.6 meters. This measurement has to be confirmed once the quadcopter is assembled.

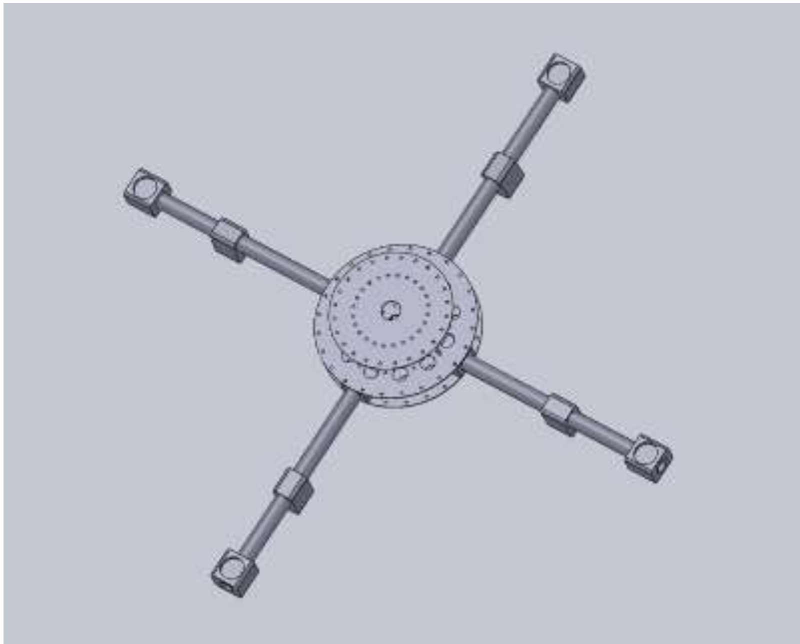


Figure 8: Quadcopter Frame

5.1.3 Motors

Having a symmetrical vehicle with four motors and placed at the same distance with respect to the center allows the pilot to have great maneuverability and trust. Out of the four motors, two have to rotate clockwise and the other two counter-clockwise to have a resulting net torque over the rotational axis as zero. This means that the quadcopter will be able to travel in any direction without rotating over its central axis. Figure 12 shows the actual motor.

Figure 9: Motor

The model of the motors used for this UAV is “SunnySky X2820 KV800” and its specifications are listed in Table 5.

Table 5: Specifications of the Motor

Feature	Value
Stator diameter (m)	0.028
Stator Height (m)	0.02
Outside Diameter (m)	0.035
Body Length (m)	0.04
Shaft Diameter (m)	0.005
Motor Kilovolts	800 RPM/Volt
Motor Weight (Kg)	0.14

5.1.4 Motor Controller and Flight Controller

The quadcopter has to include a motor and flight controller. Both components are in charge of receiving and processing the signal from the remote control. Using this signal, these two components provide stability once the quadcopter is on the air.

In case the vehicle suddenly loses balance, for a reason such as a wind current, the motor controller (Figure 13) and the flight controller (Figure 14) have the capability of resetting the quadopcter to its initial position and generate the final decision to operate the motors in such way that they stabilize the vehicle.

Both devices are extremely relevant at the time of releasing the fire extinguishing grenade, since they will provide the necessary stability in order for the quadcopter not to crash with the structure or lose steadiness and crash with the ground.

Figure 10: Flight Controller

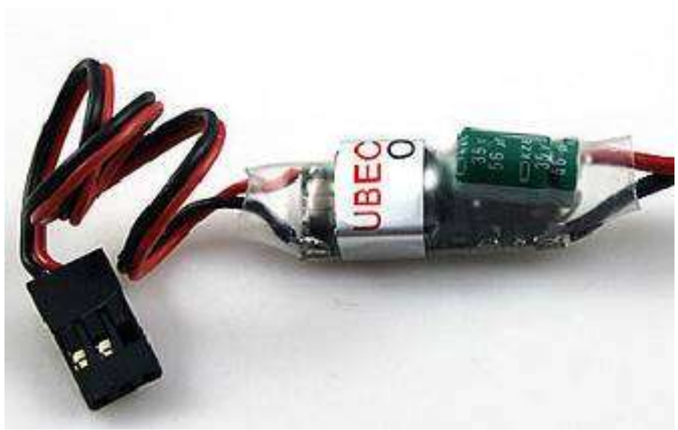


Figure 11: Motor Controller

The specifications of the flight controller and the motor controller are shown in Table 6.

Table 6: Specifications of Motor Controller and Flight Controller

Component	Feature	Value
Motor Controller	Current (A)	40
	Weight (Kg)	0.06
Flight Controller	Voltage (V)	5
	Current (A)	3
	Weight (Kg)	0.0115

5.1.5 Battery

The element that is going to provide energy to the quadcopter will be a set of two batteries that are going to offer approximately 20 minutes of flight. Having this period of time, the vehicle will have the ability of deploying and recharging the ball grenade several times, even though this still needs to be confirmed when the tests are performed. One of the batteries can be seen in Figure 14.

Figure 12: Zippy Battery

The batteries will have their own compartment in the quadcopter. This will allow a faster change of batteries in case the mission requires more time. The specifications of one battery are shown in Table 7.

Table 7: Specifications of the Battery

Feature	Value
Voltage (V)	22.2
Weight (kg)	0.834
Length (m)	0.156
height (m)	0.051
Width (m)	0.053

5.1.6 First Person View Camera

The camera selected to install in the quadcopter transmits a real time image to a remote viewer. With this system on board, the controller will have the capability of doing an inspection of the fire situation, coordinate the fire extinguishing operation, and at the same time will assist the controller in maneuvering the vehicle. This camera has a transmitter with a power of 250 mW and a frequency of 5.8 GHz.

The video this camera provides can be seen by the controller when he or she puts on goggles that show the images transmitted from the UAV. The first person view camera and the goggles can be seen in Figure 15.

Figure 13: First Person View Camera and Goggles

5.1.7 GPS Flight Control System

This system can be used to convert this quadcopter in a fully autonomous vehicle capable of performing programmed missions. However, in the vehicle, this device will be used as a locator while the mission is being performed. This system will work in conjunction an Ardupilot. This will provide refinement of the movements and behavior of the quadcopter during flight. The GPS weight is 0.2 kg and its frequency is 915 Mhz. The GPS can be seen in Figure 16.

Figure 14: GPS

5.1.8 Ardu-Pilot

ArduPilot is a software system based on the Arduino platform, which is an open computing system (hardware). This software contributes to autonomous stabilization and GPS navigation to allow the vehicle to accomplish missions without human control.

Another important function is that quadcopter will have autonomous landing in case the pilot loses visibility of the vehicle. In Figure 17 the Ardu-Pilot device can be seen.

Figure 15: ArduPilot

The platform has to have a diameter bigger than 145 mm, which is the diameter of the grenade. Since there have to be enough clearance for the columns and to charge the grenade inside the mechanism, it was decided that the diameter of the platform is 170 mm. The material has not been decided yet, even though using carbon fiber is a strong possibility.

5.1.9 Rails

The rails in which the fire extinguishing grenade is going to roll will be possible made of carbon fiber bars. They will have the shape of a cylinder and an approximate diameter of 4mm and their length will be approximately 1 meter. In Figure 19 the rails can be seen.

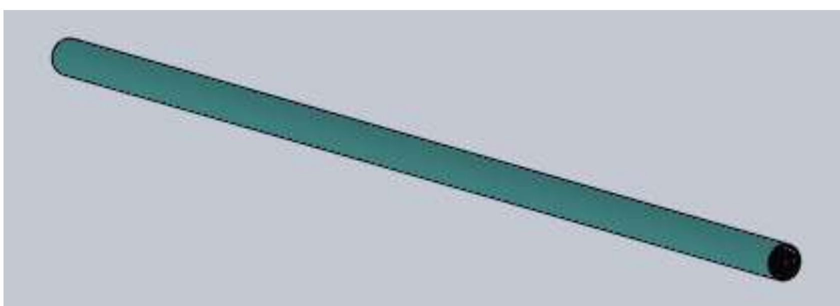


Figure 16: Rails

5.1.10 Servo Motor

In order to move the rails to the angle desired in order to release the grenade, a servo motor will be used. The specifications of this servo motor are not known yet, since this team is waiting to assemble the quadcopter and perform some tests in order to decide what will be the best servo motor for our mechanism.

5.2 Structural Design

The main focus of this project is the mechanism to release the grenade; therefore, the main factors taken into account to satisfy the requirements of the release mechanism are: Ease of access to load the fire extinguishing grenade, light and resistant materials, resistance to high temperatures and that the design cannot interfere with the aerodynamics or stability of the vehicle. These factors are going to be explained in the following sections.

5.2.1 Ease of Access to Load the Fire Extinguishing Grenade

Since the quadcopter will be used for emergency situations, it is required that the person in control can mount the fireball into the quadcopter without much work, also the reloading process has to be simple. A lock and load mechanism will be implemented for this purpose.

5.2.2 Light and Resistant Materials

The use light and resistant materials in order to construct the quadcopter and the release mechanism are of extreme importance, since it is necessary that the copter moves fast to the objective and can also withstand the stresses that the load carried can produce. The high reliability of the materials is also a main factor in the decision making about what material should be used for the structural components of the vehicle.

5.2.3 Resistance to high temperatures

Testing will be necessary to provide information about how close to the fire the copter can get, since not only the frame of the release mechanism will be closer to the flames, but also the electronics components of the quadcopter, such as motors, cables, antenna, and camera, will be in a considerable short distance to the high temperatures during the release process.

5.2.4 The design cannot interfere with the aerodynamics or stability of the quad

Normally, a quadcopter has a weight distribution that contributes to stability. An example of this is that heavier components, such as batteries and camera, will be mounted in the center of the body. In this design, the release mechanism has an extension that works as a slide to deliver the fireball as close as possible to the fire. Even though the flight controls can adjust the motors to work accordingly to the position of the quad, an abnormal weight distribution, like a heavy release mechanism coming outside of the center of the body, will require one or more motors to produce more thrust in order to maintain stability. Also, the motors need to be isolated at the top and bottom, so thrust can be created in an effective manner; therefore, the release mechanism has to have the most aerodynamic shape available and weight as less as possible.

5.3 Analytical Analysis

5.3.1 Problem understanding

The first task when this project started was to define what type of loading would be used in order to release it from the UAV. With the results obtained from this investigation, the team created a guide to follow in order to accomplish the goals established for this project. The first step was to understand the quadcopter components and how they related to each other. Once the team knows exactly how a UAV, the team will be capable of designing the release mechanism that will transport the grenade with and release it with precision. The second step is to make simulations about force, stress, strain and thermal analysis of the entire vehicle and the proposed design for the release mechanism. Having this simulation in place, the team will be able to choose the best configuration to deliver the grenade.

5.3.2 Mathematical Model

In order to identify the essential physical restriction of the release mechanism design, the team will translate all the parameters into a mathematical representation of the problem. The first stage is to calculate the thrust and the efficiency of the vehicle. The second stage is to represent the release mechanism as close as possible using CAD software. Once these two stages are completed, the team will be accurate in their calculations and we could predict with high precision how the quadcopter is going to perform the mission.

5.3.3 Computational Methods

The software selected to perform all the CAD modeling and simulations is SolidWorks 2010.

5.3.4 Force Analysis

Force analysis is an important parameter to be accounted for at the time of static distributed loads and dynamics effects in the quadcopter. The team will perform a careful analysis of these forces. This will provide a better approach in the design of the release mechanism.

It is worth noticing that the stresses are caused by loading coming from the weight of the grenade and the release mechanism. These stresses will be distributed along the release mechanism and the quadcopter frame. This distributed load is going to be variable because at the time of release, the grenade will be rolling throughout the deployment rail until the end. Having this ball in motion will make the linear momentum change at all times with respect to the UAV center. For that reason, the team will consider all the simulation results with this change of linear momentum in the deployment process.

5.3.5 Shear analysis

Shear stress data from the results of the CAD simulation will be compared to analytical analyses done on paper, and values from this should not vary from real life scenarios. Three point supports for each boom are taken into account when performing the shear calculations on the main plates, and the forces acting on the structure are caused from the weight of the components and the thrust produced by the four motors. The release mechanism will have these calculations performed separately, since this is our main concentration of the design. The weights of the ball along with the lifting force of the main frame are the principal forces acting on the device. Information about the young modulus of the material is provided so calculations about how much shear stress is felt on each joint of the structure can be performed.

5.3 Cost Analysis

Project cost analysis is the first step in the process of building the prototype. This will provide guidance in choosing the best components available in the market while taking into account financial constraints. The unmanned aerial vehicle for fire extinguishing grenade ejection and inspection project cost will be focused in three areas: Design cost, Prototype cost and Report and presentation costs.

5.3.1 Design cost

Design cost is calculated as the rate per hour that an engineer is paid to do a design. However, this project will be designed by students and software provided by Florida International University. For that reason, a traditional design cost analysis is not possible, since it would not reflect the real design cost. Instead, in Table 8 this team will provide an estimate of time spent in each task to develop this project.

Table 8: Design Cost

Category	Task	Hours Spent	Total Hours per Category
Research and Design	Literature Survey	20	100
	Parameters and Restrictions	15	
	CAD Modeling	30	
	Conceptual Drawings	20	
	CAD Prototype	15	
Analysis, Assembly and Testing	CAD Simulation	20	125
	Frame Grenade Holder	40	
	Grenade Deployment Frame	40	
	Stability	10	
	Flight Testing	15	
Report and Presentations	Senior Reports	100	131
	Presentations and Rehearsals	6	
	Engineering Drawings	10	
	Poster	15	
Total Time Cost (Hours)			**356**

5.3.2 Report and Presentation Cost

The cost associated with the report and presentation is relevant to be accounted into the final prototype cost. The printing cost of the reports required by the Senior Design Class is to be added to the calculations because a hard copy of the document has to be presented each time the dead line is reached. The process of printing a final document and a poster is an indicator of real world expenses that companies invest when presenting a final design. The costs of printing the report and poster for the presentations is described in Table 9.

Table 9: Report and Presentation Cost

Description	Price	Quantity	Partial Total
Print 25% Report	$15	1	$15.00
Print 50% Report	$30	1	$30.00
Print 75 % Report	$40	1	$40.00
Print 100% Report	$50	1	$50.00
Print Poster	$80	1	$80.00
Total			$215.00

6. Prototype Construction

6.1 Prototype System Description

The main structure of the quadcopter is conformed of three plates and four ooms. Two main plates are at the center of the quad. They are attached together by screws at four different but symmetrical positions. A smaller plate is placed at the top for holding the batteries and antenna. In between the main plates the arduflyer, three battery adapters, four flight and four motor controllers are connected together and hold in placed by screws and metallic straps. The four booms come out of the center of the main plates, and are secure in two points by plastic blocks and screws. Motors at the end of each boom are hold by squared metallic plates and their cables connected to the flight controllers are hidden inside the booms since these come hollow. The four legs are placed at an angle and attached to each leg to give the quadcopter a stable stand when in land. The delivery mechanism, which holds the fireball, is located at the bottom of quad; the position of the cage-like system is aligned in between two of the booms at a 45 degree angle, so it does not interfere with the thrust produced by the motors.

6.2 Prototype Cost Analysis

Prototype cost analysis for this project is important because the members of this team will pay for all the expenses this project requires. The largest up-front cost is the purchasing of the components to build the quadcopter.

The motors are one of the most relevant components of the vehicle, since they need to provide enough thrust and lift; therefore, motors with high revolutions per minute (RPM) have to be chosen. These motors are in the range of $20 - $80, even though the motor selection was based in the high RPM and torque obtained from them. Once the initial calculations have been made, the motors will be purchased and added to the vehicle. During testing the performance of the motors will be confirmed and if necessary, the quadcopter arms are able to adapt one more motor in the opposite side of the motor already in place to provide more lift force.

Another important component is the first person view camera (FPV). This device will provide a real time video of what the quadcopter has in front and can provide the pilot a better perspective to guide the vehicle. The cost of this camera is $280.

The second largest cost concern is the components of the release mechanism. This team made a rough estimate of $500 for these systems. However, these two structures have many factors to be considered. The deployment component has to be light and strong enough to allow the quadcopter lift the load and structure of the grenade without losing its balance. Proper balancing is necessary to complete the mission of deploying the grenade with precision. The quadcopter will be controlled by an ardupilot, which is an arduino based component that gives the quadcopter the ability to improve the stability and maneuver accuracy autonomously.

A detailed list of the parts necessary in order to build the quadcopter plus the release mechanism is provided in Table 9.

Table 10: Prototype Cost

Item	Description	Price	Quantity	Partial Total
1	Frame	$ 105.00	1	$ 105.00
2	Motors	$ 57.50	8	$ 460.00
3	Battery	$ 59.11	2	$ 118.22
4	GPS	$ 139.99	1	$ 139.99
5	Motor Controller	$ 20.50	8	$ 164.00
6	Propellers	$ 5.50	8	$ 44.00
7	Landing Gear Adjusters	$ 12.00	4	$ 48.00
8	Arm Tubes	$ 15.00	4	$ 60.00
9	Antenna	$ 34.89	1	$ 34.89
10	Camera Mount	$ 4.99	1	$ 4.99
11	Micro Camera FPV	$ 79.43	1	$ 79.43
12	Camera Signal Receiver	$ 198.99	1	$ 198.99
13	Camera Signal Transmitter	$ 69.99	1	$ 69.99
14	Camara FPV (First Person View)	$ 279.99	1	$ 279.99
15	Materials for Release Mechanism	$200.00	1	$ 200.00
16	Fire Extinguishing Ball	$ 75.00	1	$ 75.00
			Total	**$ 2,082.49**

6.3 Assembly of Electronic Components

In this section are going to be explained how were connected the different electronic components of the quadcopter that allow it to fly. Also, it is going to be specified the placement of each component in the frame of the UAV.

6.3.1 Arduflyer Board.

One of the most important electronic components of this UAV is the Arduflyer. This is the board where the majorities of the other electronic components are connected to, and are controlled by the Ardupilot software. It is important to locate this component in a safe spot on the frame of the quad, since it must be protected from humidity, direct heat or a sudden crash. The Arduflyer will be positioned in between the second and third plate, on the center of the quadcopter. The arrangement of the components is shown in Figure 20.

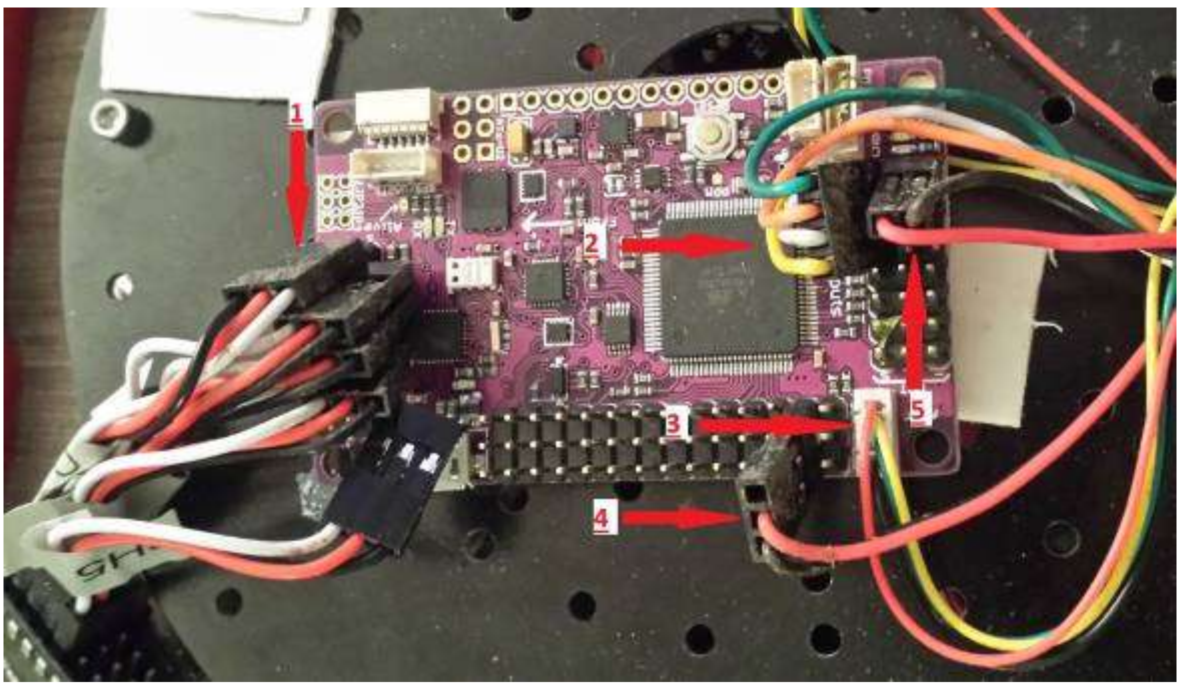


Figure 17: Arduflyer Board and its components (1.Remote Control Antenna, 2. Voltage Distributor, 3. GPS Antenna, 4. Power Supply from Voltage Distributor, 5. Voltage Regulator)

6.3.2 Global Positioning System

The Global Positioning System (GPS) controller is connected to the 3DR-Radio port on the Arduflyer, as shown in Figure 21. Its position has to be at the top of the main plates, since a good satellite signal without interference is needed for the GPS to work properly at all times.

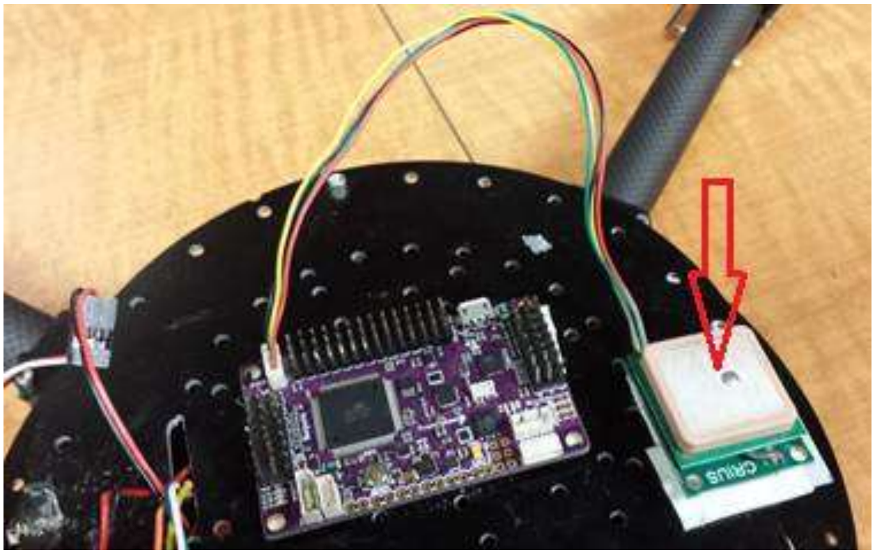


Figure 18: GPS Controller

6.3.3 Remote Control Antenna

This component works with the remote control, and is in charge of receiving the signals sent from ground. It has 7 channels that are used to control each main component of the quadcopter. Four channels are used to control the power provided to each motor, another channel is to activate the release mechanism, and the plan for the two free channels left in the Remote Control are for the camera and some other mechanism that is added to the vehicle. The Remote Control Antenna is connected to the “INPUTS” ports of the Arduflyer as shown in Figure 22.

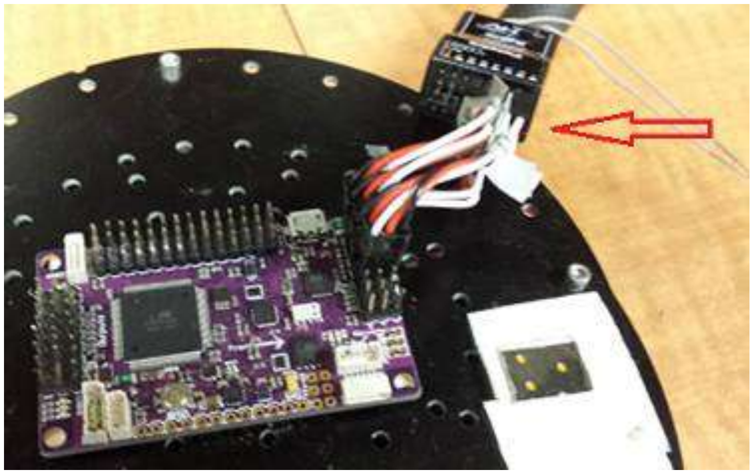


Figure 19: Remote Control Antenna

6.3.4 FPV Telemetry Antenna

The FPV telemetry antenna is used to connect the functions that the Arduflyer board provides to any laptop or computer. This is an open source software and can be modified so the quadcopter can perform missions automatically while analyzing data sent from any sensor mounted on the platform. Its location is important because it cannot interfere with the other antennas, so it is placed on the opposite side where the GPS and Remote Control antenna are. The FPV telemetry antenna is shown in Figure 23.

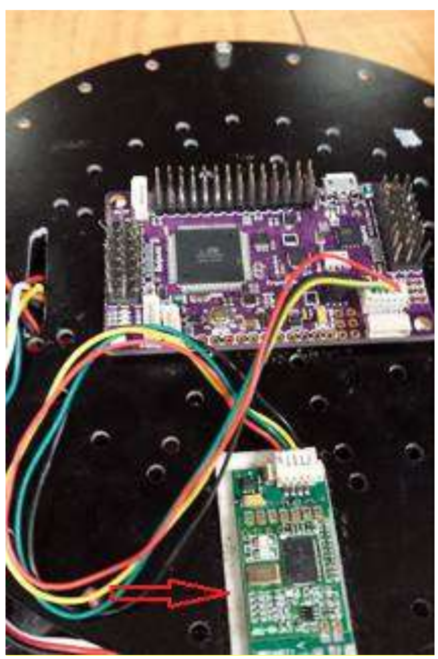


Figure 20: FPV Telemetry Antenna

6.3.5 Voltage Distributor and Voltage Regulator

The voltage regulator is connected from the voltage distributor to the Arduflyer (Figure 24) in order to provide 5 volts in a constant manner. A different set of cable connections come out of the Arduflyer to the voltage regulator directly to control the motors (Figure 25). At the same time, the battery is connected to the voltage distributor and from here power is distributed to each of the flight controllers (Figure 26).

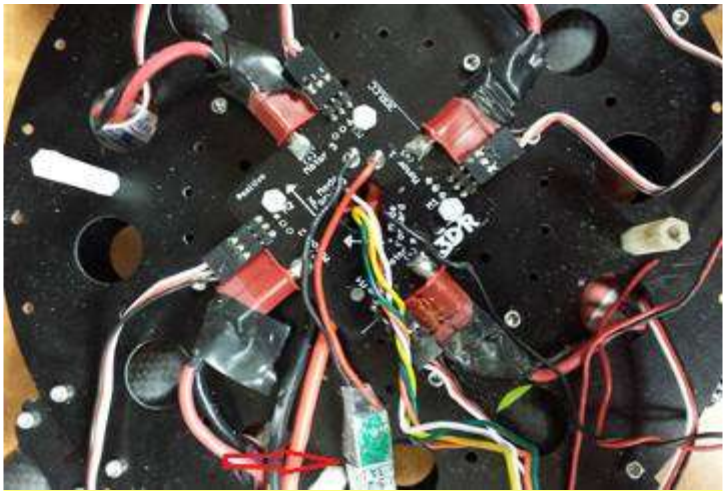


Figure 21: Voltage Distributor

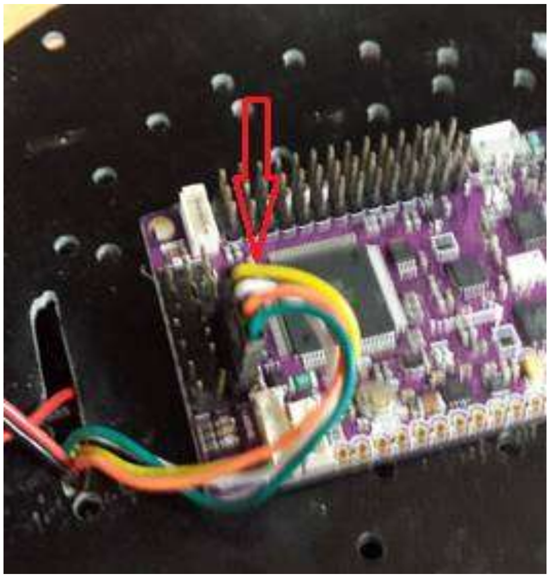


Figure 22: Cable Connections for the Motors

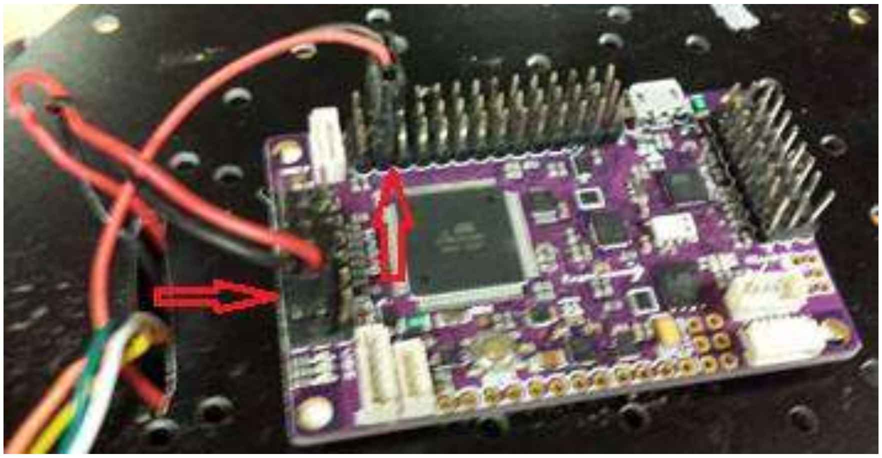


Figure 23: Cables connecting the Batteries

6.3.6 Flight Controllers and Banana Connectors

The banana connectors are a special type of plugs that can resist the high voltage that sparks from the voltage distributor and are connected to the flight controllers shown in Figure 27. The flight controllers are located in between the first and second plate. They are in charge of sending the power to the motors, and they also control the stability of the quad through a set of cables connected to the Arduflyer, by regulating the voltage provided at any time during the flight. They can be seen in Figure 28.

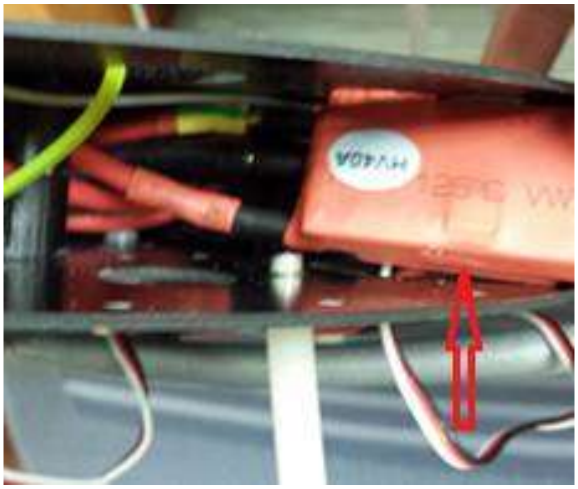


Figure 24: Banana Plugs in the Flight Controllers

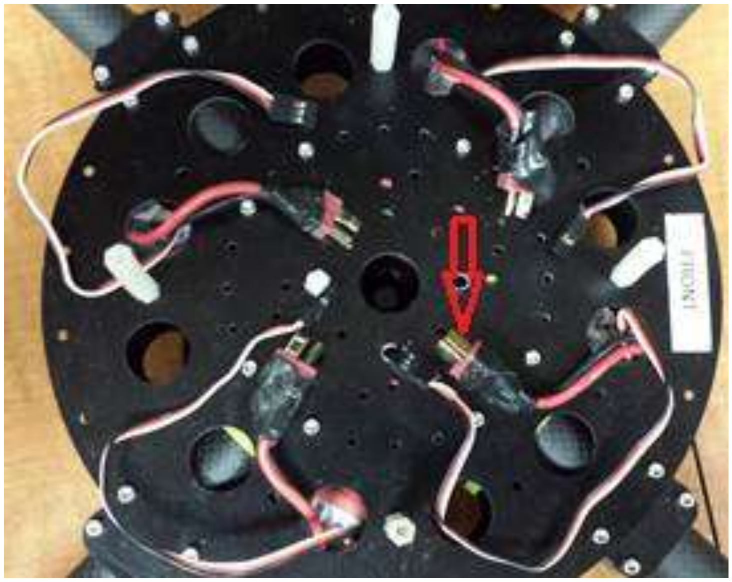


Figure 25: Banana Connectors

6.3.7 Battery

The battery is located at the bottom of the quadcopter for stability. It is strapped with plastic strips and secured with a Velcro lining. It is connected directly to the power distributor through a banana connector (Figure 29).

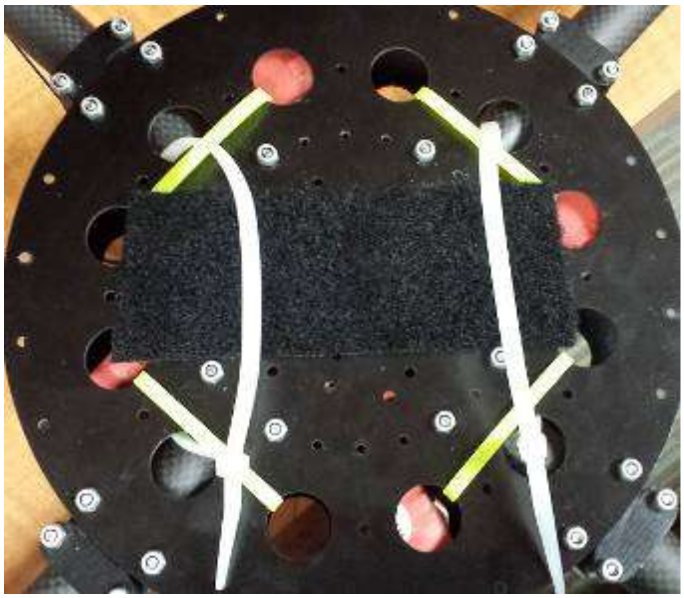


Figure 26: Battery Strapped

6.3.8 Motors

Each of the motors is located at the end of the carbon fiber arm. The cables are inserted inside the booms to prevent any entanglement. They are connected to the flight controllers at the center of the quadcopter (Figure 30).

Figure 27: Motor at the end of Boom

7. Release Mechanism

The goal of this project is to improve and innovate in ways to control and prevent fires on high rise buildings. Quadcopters are systems that have become popular in recent years, because they have the capacity of transporting objects while maintaining high stability levels. For that reason, this team decided to innovate mounting on the top of the frame of quad copter a release mechanism to throw the fire extinguish ball inside of a building.

7.1 Release Mechanism Description

The release mechanism in charge of launching the fire extinguishing grenade from the quadcopter consists of a ramp with a set of springs in compression. The function of the springs is to provide the force necessary to launch the ball.

How this mechanism works is that by having the quadcopter at a certain distance from the target, which is the window of a building on fire, when the release mechanism is activated, it will be able to throw the ball inside of the building, taking into account the clearance distance from the vehicle to the window. The way in which the springs are compressed is using a ring that has a diameter a little bigger than the diameter of the ball. The ring is going to be pushed back manually and it will be held in place by a servo motor. When the vehicle reaches the altitude and location desired to launch the ball, a button on the control remote is activated by the operator and the servo motor moves its leg, releasing the ring; therefore, the ring and the ball will move together through the ramp until its end. While the ball ejects from the ramp in a parabolic trajectory, the ring stays in the system thanks to stops that are located at the end of the rails.

While designing the ramp, several components came to mind in order to come up with the best and most lightweight configuration. Because of this, a number of parts with the same purpose were tried in order to find which one would satisfy the conditions desired. On the next subsections of this report it will be explained the evolution of the design of the release mechanism and how its main components changed. Explanations of the analysis made on each main component are also found on the next subsections.

The entire mechanism works in the following manner. In order to have one servo motor activating the launching ring, a way to hold back the launching ring uniformly needed to be found. The servo motor only has one leg, which gave the options to put the servo motor either at the top or the bottom of the ring. For both options, a structure for the servo motor needed to be added to the release mechanism, and this implied more work and weight; therefore, the came up with an alternative with regards on how to include the servo motor in the frame of the vehicle. Placing the servo motor on front of the frame of the quadcopter made it possible to only use one servo motor (one moving leg) and use nylon lines to maintain the launching ring pushed back. It was decided to use four nylon lines to hold the ring evenly while the springs are compressed and also a hook was added to the mechanism. These three components work together by having the four nylon lines coming out of the ring to the hook. The hook is attached to the base of the ramp and one more nylon line goes from the hook to the leg of the servo motor. When the servo motor is activated, its leg moves, moving the hook and this detaches the nylons coming out of the ring to the hooks; therefore, release the ring and the ball.

7.2 Design Process of the Release Mechanism

The first idea of this team was to have the ramp made up of carbon fiber rails, a servo motor, a sliding ring to compress all the springs while at the same time is holding back the ball, and enough springs capable of producing the force necessary to deliver the fire extinguishing ball to the area desired. While the main idea remained unchanged throughout the development of the release mechanism, some of its components changed several times. The main component that had 2 major modifications was the launching ring. This was done in order to reduce its weight and in this way contribute to the stability of the vehicle while launching the ball in the air. In addition, a component was taken out of the mechanism once it was tested, this is the base plate. Figure 28 shows the first assembly of the ramp. In this assembly it can be seen the base plate at the bottom of the ramp and also the launching ring with the fire extinguishing ball and the rails.

Figure 28: First Design of the Ramp

While doing tests in was shown that the base plate could not withstand the forces that the structure was supporting while the springs were compressed; therefore, it was replaced by a series of attachments that were bought for the frame of the quadcopter, but that were found useful once they were tried on the release mechanism.

7.3 Components of the Release Mechanism

In this section are explanations of each of the components that make up the ramp, including their CAD modeling. All of the components of the ramp, except for the launching ring and hook, were bought and assembled together according to the model of ramp that was required to comply with the purpose of the vehicle. The components that were designed and manufactured by this team were the launching ring and the hook. For the majority of the components it was decided that it was better to buy mass-produced components instead of manufacturing them, because this will reduce costs. Also, the components chosen can be arranged in any way to obtain the geometry desired.

7.3.1 Base of the Ramp

The base of the ramp serves to hold in place the the rails through which the ball is going to travel and also the legs that attach it to the quadcopter. This base is shown in Figure 29.

It was decided that the base of the ramp should be the same plate used in the frame of the quadcopter; therefore, an additional plate was bought for this purpose. The reasons of this decision are that there are more components that can be adjusted perfectly into this plate. Also, this plate is made of G-10 material, which is strong and lightweight at the same time; therefore, in this base, the holes are going to hold the rails of the ramp, keeping in mind that the rails have to fit the ball between them so it can roll. Of course, the holes already in this plate form a diameter that is smaller than that of the fire extinguishing ball; therefore, more holes had to be added to it, and this was easier and more economic than to manufacture an entire base.

Four more holes were cut in this base. The sum of the four distances from the center of each hole to the other is enough to account for the diameter of the ball plus the rails; therefore, the holes were cut closer to the outer edge of the base. The reason for this is that a minimum of 3 rails are needed to hold the ball while it is traveling through the ramp. One rail at the bottom of the plate to account for gravity and two more rails, one on each side of the plate in order to guide the ball through the ramp. The fourth hole was cut to have an even base, causing an even distribution of stresses when the springs are compressed and the base is sustaining those forces.

At the beginning, it was considered cutting 8 holes because there would be more freedom in the configuration of the rails that are going to be fitted in these holes, but having these 4 additional holes will decrease the area of the base and this may cause less structural stability by making the base more malleable and susceptible to deform.

The plan is to have one spring in each of the rails, with a minimum of 2 springs in the ramp, but if more force if needed in order to launch the ball, more springs can be added; therefore, more rails can be attached to the base of the ramp and the springs can be included.

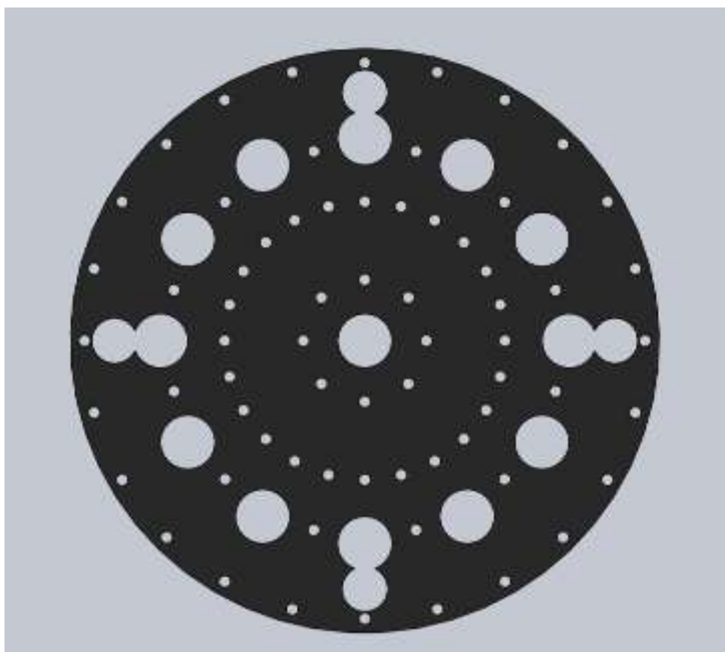


Figure 29: Base of the Ramp

According to what was said in the process of the design of the release mechanism, when the first round of testing was done in order to prove that the springs chosen were going to produce force to launch the ball to the distance desired, it was noticed that this base plate was flexing too much, compromising the structure of the ramp. It was noticed that the rails did not remain parallel to each other once the springs were compressed, since the plate was flexing and making the rails get closer to each other towards their end. For all these reasons, this base plate was taken out of the release mechanism and other components were found that could serve the same purpose of holding the rails in place while the springs were compressed.

7.3.2 Original Launching Ring

The launching ring is in charge of propelling the ball with the force of the springs. On one side of the ring, the ball is against it, and on the opposite side there are the springs. This ring is made of aluminum and was manufactured according to the dimensions of the diameter of the ball and the base of the ramp. Aluminum alloy 6061-T6 was the material chosen because the design needs to be lightweight and at the same time strong, while adjusting to the economic constraints of this project, and this material complies with all those requirements. The launching ring has a weight of 1000 grams. The thickness of the ring is 7mm and the thickness of the bushings around each hole of the ring is 8mm.

This ring was designed to have 8 holes that can fit the rails, and this gives freedom to configure the rails in the best possible way to achieve the distance desired for the ball to travel, but since the base of the ramp only has 4 holes that can fit the rails, this is also how the ring will work, with a maximum of 4 rails going through it.

In Figure 30 the original launching ring can be seen.

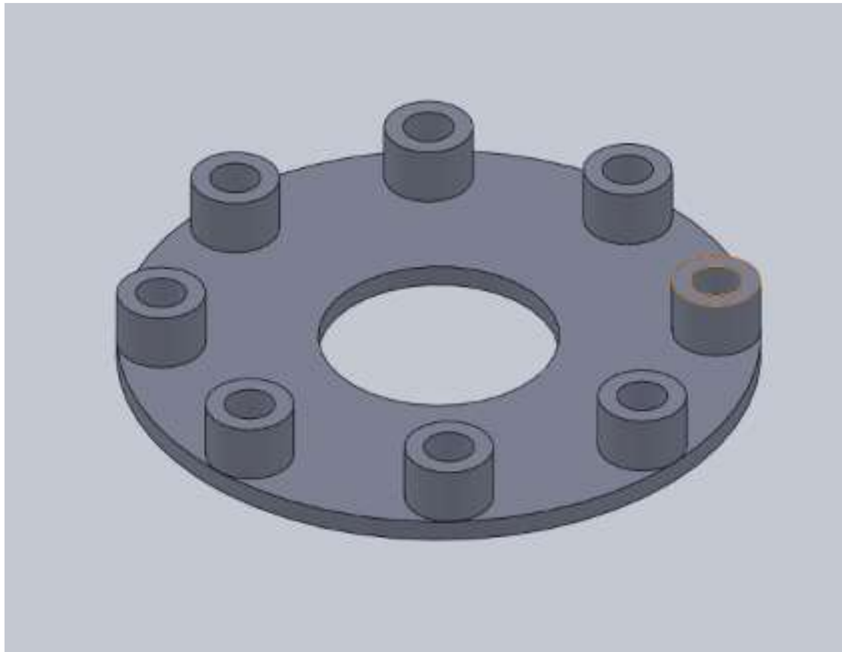


Figure 30: Launching Ring

This ring was used when the first stage of testing was performed, and it was noticed that it was too strong and heavy and that it can be optimized to reduce its weight while it could still withstand the force produced by the spring without compromising its structural performance. To confirm this, simulations were made and their results are going to be shown next.

While the first stage of testing of the release mechanism was done having the ring pushed back with the springs manually, the simulations were made using four nylon lines, as explained in the previous section.

The software in which the simulations were made was SolidWorks2013. The fixtures for the nylon lines were located in four holes of the ring and two additional fixtures were added to account for the rails going through the ring. All this is shown in Figure 31.

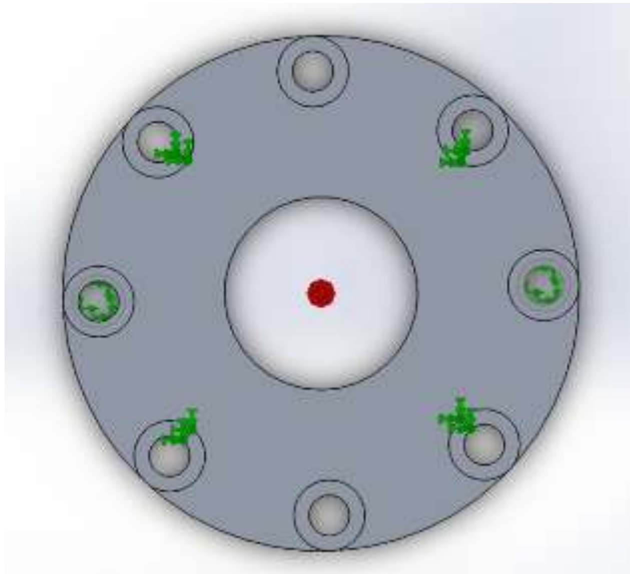


Figure 31: Fixtures Simulation Original Ring

The loads applied to the ring correspond to the location where the springs make contact with the ring. The thickness of the springs is what comes in touch with the bottom of the ring; therefore, a small area of the ring has to withstand all the forces produced by the springs and that is the reason this team thought the ring needed to have a large thickness. Once testing was performed and the results of these simulations shown, it is demonstrated that the ring could have been thinner. In Figure 32 can be seen the location of the loads applied. The value of each load is 123.25 Newtons. This value was obtained while performing testing.

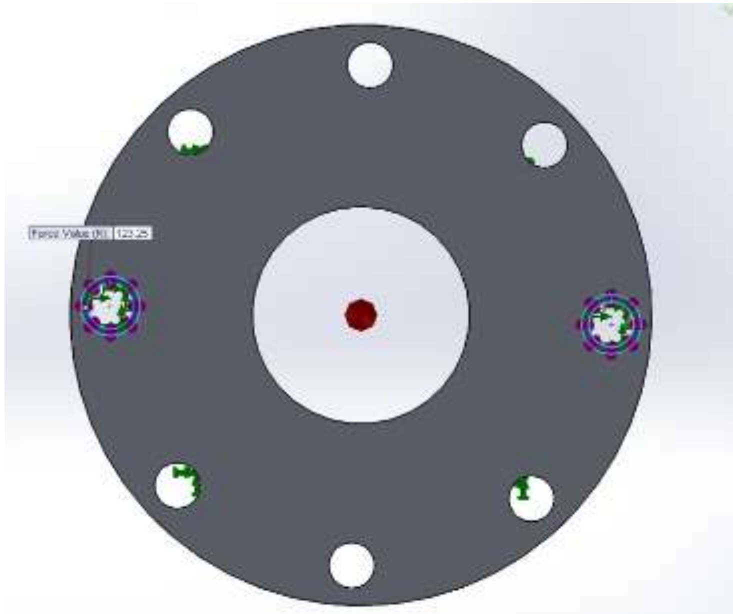


Figure 32: Loads applied to simulation original ring

The factor of safety obtained in the static study performed on this ring was 203.37, which is a really high value and confirmed that we could reduce the dimensions of this ring. This is shown in Figure 33.

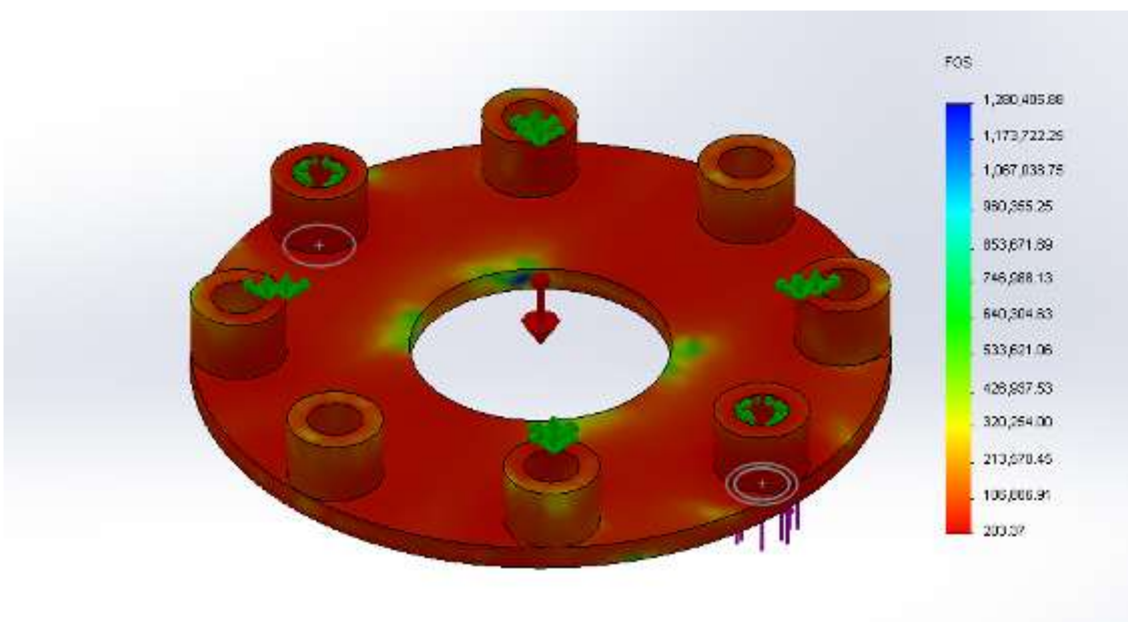


Figure 33: Factor of Safety Original Launching Ring

7.3.3 Modified Launching Ring

When the original launching ring was put into the assembly of the ramp, one of the worries that arose was that it was too heavy and at the moment of launching the ball, the quadcopter would have a big throwback because of this. Thanks to other reasons explained in the previous section, several ways were analyzed in order to reduce the weight of the ring, and the best solution found was to cut pocket holes in between each of the holes for the rails. The current weight of the modified ring is 545 grams and it can be seen in Figure 34.

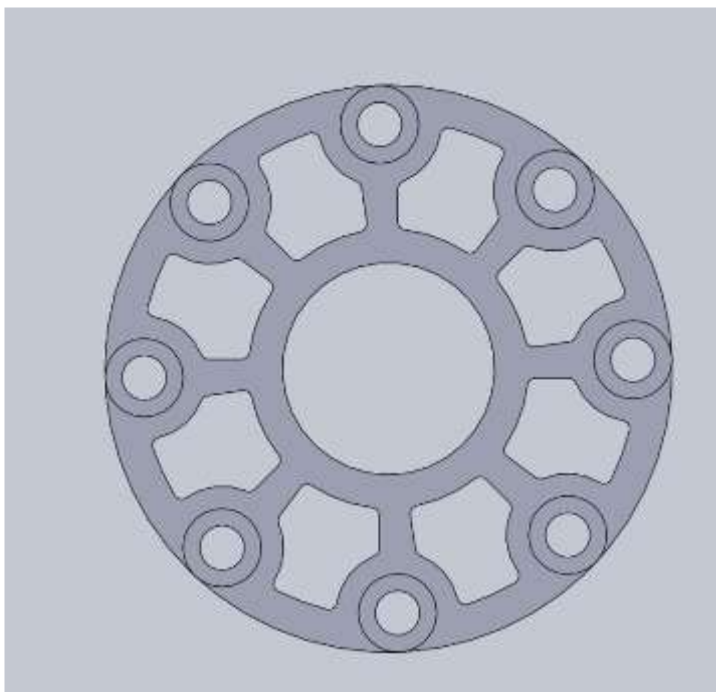


Figure 34: Modified Launching Ring

The setup of the static study performed for this ring is the same as the setup of the simulations performed on the original ring. The fixtures are the four nylon lines and the surfaces of the holes that are in contact with the rails. The locations of the fixtures are shown in Figure 35 and the location of the loads shown in Figure 36.

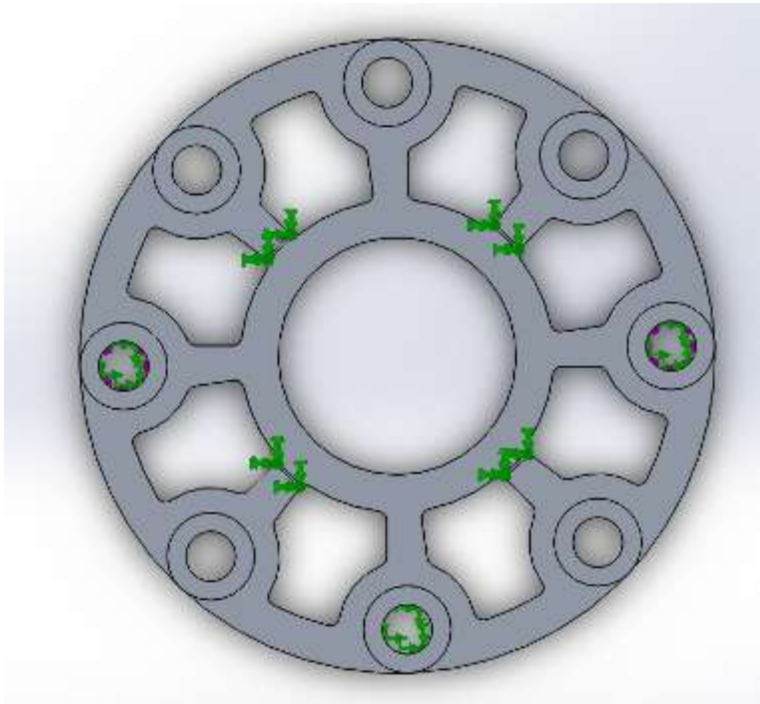


Figure 35: Top View of Ring - Location of Fixtures

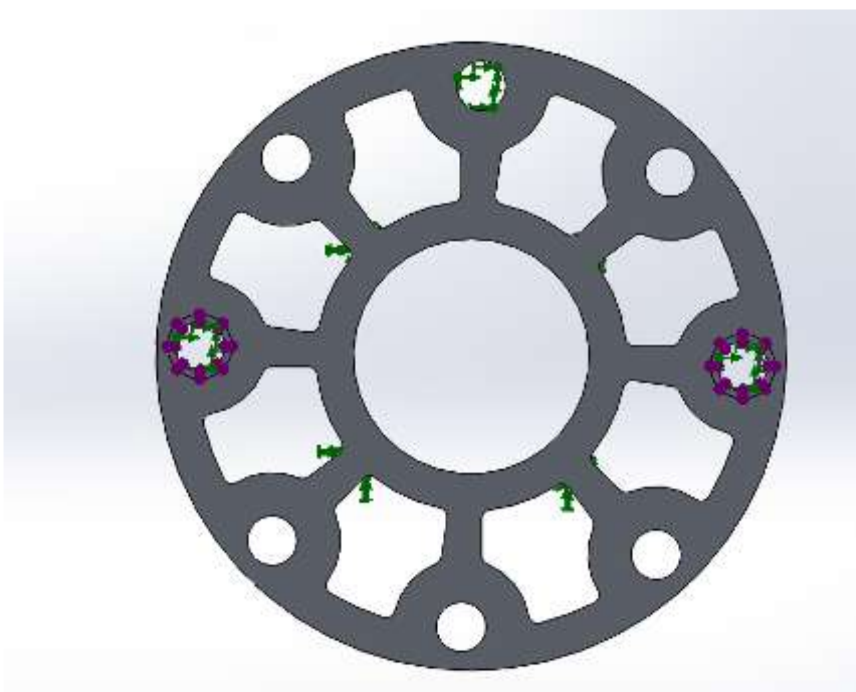


Figure 36: Bottom View of Ring - Location of the Loads

The results of the simulation are best shown with the value of the Factor of Safety. This modified ring now has a factor of safety of 180.29. This is shown in Figure 37.

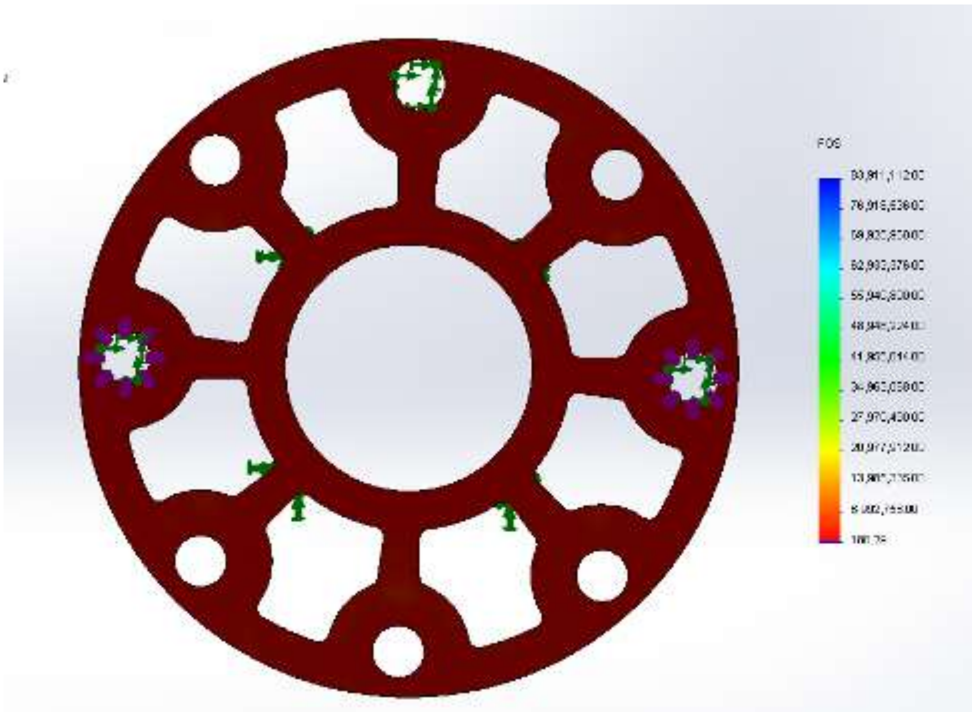


Figure 37: Factor of Safety - Modified Launching Ring

Even though the value of the factor of safety decreased in comparison to the original launching ring, there is still plenty of room to make modifications to this ring to obtain the most weight and performance efficient component for the release mechanism; therefore, a third modification was performed on the ring.

7.3.4 Modified Thin Launching Ring

Since there was a lot of room for improvement in this launching ring, a third modification was performed. The thickness of the ring was reduced from 7mm to 3.8 mm and the thickness of the bushings experienced a reduction of the 50% of their diameter. The detailed dimensions of this ring are shown in Appendix C.

The setup of the simulations performed on this ring changed a little bit. The rails were added to the structure of the ring and more details were given to the software in order to obtain more accurate results.

To create an analysis of displacement, stresses, and factor of safety taking into account the limitations of the software, a number of assumptions have to be followed:

- Fixed geometry points at the base of the aluminum tubes that guide the plate.
- Fixed geometry points at the center of the plate, which is an approximate location of the cables that hold the plate back at the starting position.
- Both, plate and booms have the same type of aluminum.
- Springs are acting on the plate with an equal distributed force at the base.
- The position of the plate is parallel to the ground.
- There is a friction coefficient of 0.3 (lubricated components).
- The ball weight is neglected.
- The ambient temperature is 298 Kelvin.

The assembly of the model used to study is shown in Figure 38.

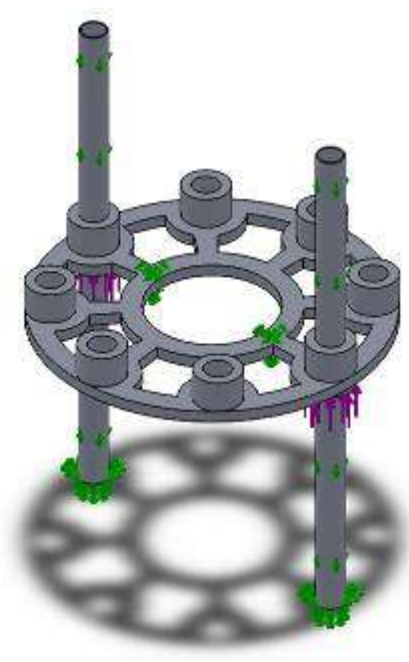
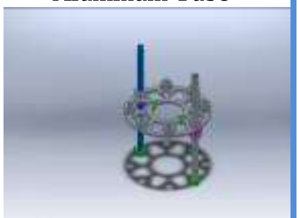
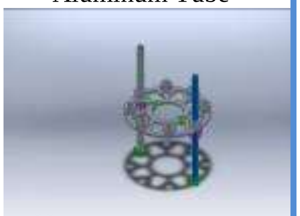
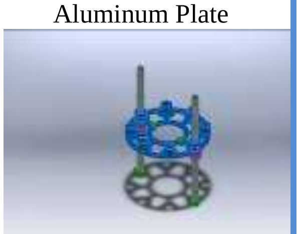


Figure 38: Assembly of Modified Thin Launching Ring with Rails

The properties of each of the elements of this assembly are shown on table 11.

Table 11: Properties of Elements in the Assembly of Ring plus Rails

Aluminum Tube 	Solid Body	Mass:0.0381704 kg Volume:1.41372e-005 m^3 Density:2700 kg/m^3 Weight:0.374069 N
Aluminum Tube 	Solid Body	Mass:0.0381704 kg Volume:1.41372e-005 m^3 Density:2700 kg/m^3 Weight:0.374069 N
Aluminum Plate 	Solid Body	Mass:0.49668 kg Volume:0.000183956 m^3 Density:2700 kg/m^3 Weight:4.86746 N

The setup used in the software is shown in table 12 and 13.

Table 12: Software Setup

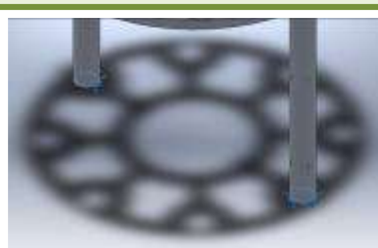
Study name	Study 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Solver type	FFEPlus
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	0.3
Use Adaptive Method:	Off

Table 13: Software setup – units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

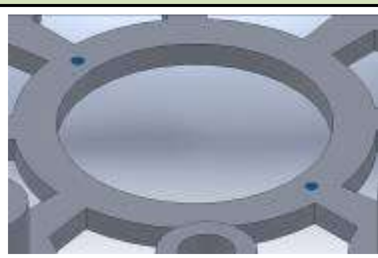
The loads and fixtures applied to the model are shown in table 14 and 15, respectively.

Table 14: Fixtures on the model

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** **2 face(s)** **Type:** **Fixed Geometry**

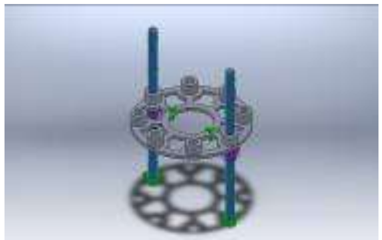
Resultant Forces

Components	**X**	**Y**	**Z**	**Resultant**
Reaction force(N)	**-0.0547809**	**0.0067716**	**-0.141231**	**0.151634**
Reaction Moment(N·m)	**0**	**0**	**0**	**0**

Fixture name	Fixture Image	Fixture Details
Fixed-2		**Entities:** **2 face(s)** **Type:** **Fixed Geometry**

Resultant Forces

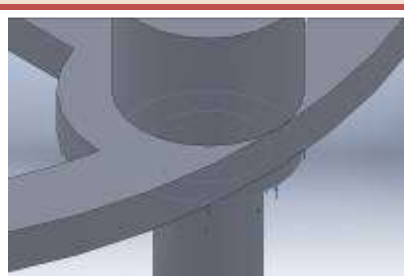
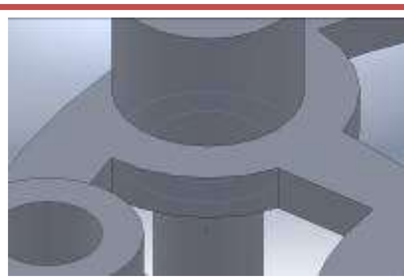
Components	**X**	**Y**	**Z**	**Resultant**
Reaction force(N)	**0.0547533**	**-188.204**	**0.141229**	**188.204**
Reaction Moment(N·m)	**0**	**0**	**0**	**0**

Fixture name	Fixture Image	Fixture Details
Roller/Slider-1		**Entities:** **2 face(s)** **Type:** **Roller/Slider**

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	**0.332702**	**-54.0193**	**3.92112**	**54.1624**
Reaction Moment(N·m)	**0**	**0**	**0**	**0**

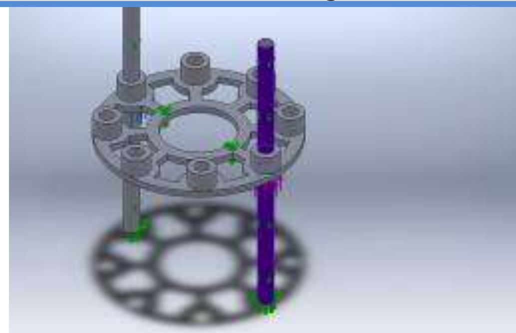
Table 15: Loads applied to the model

Load name	Load Image	Load Details
Force-1		**Entities:** **1 face(s)** **Type:** **Apply normal force** **Value:** **123.5 N**
Force-2		**Entities:** **1 face(s)** **Type:** **Apply normal force** **Value:** **123.5 N**

The contact information between the ring and the rails is shown in table 16.

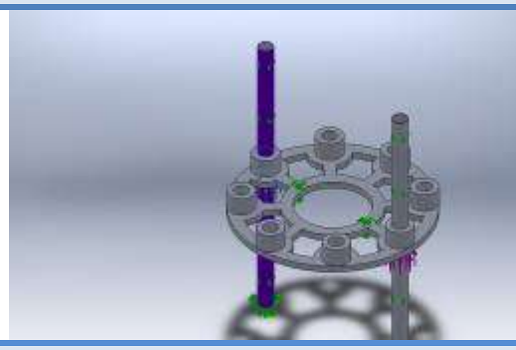
Table 16: Contact information between the ring and the rails

Contact	Contact Image	Contact Properties

Contact	Contact Image	Contact Properties
Contact Set-1		**Type:** **No Penetration contact pair** **Entites:** **2 face(s)** **Friction Value:** **0.3** **Advanced:** **Surface to surface**

Contact/Friction forces

Components	X	Y	Z	Resultant
Contact Force(N)	4.9689E-014	6.5095E-016	1.7764E-015	4.9725E-014
Friction Force(N)	-7.9797E-017	-2.5771E-014	6.6665E-017	2.5771E-014

Contact	Contact Image	Contact Properties
Contact Set-2		**Type:** **No Penetration contact pair** **Entites:** **2 face(s)** **Friction Value:** **0.3** **Advanced:** **Surface to surface**

Contact/Friction forces

Components	X	Y	Z	Resultant
Contact Force(N)	-1.1588E-015	6.3388E-016	8.6667E-015	8.7668E-015
Friction Force(N)	-9.6508E-017	7.1287E-014	-3.8896E-018	7.1287E-014

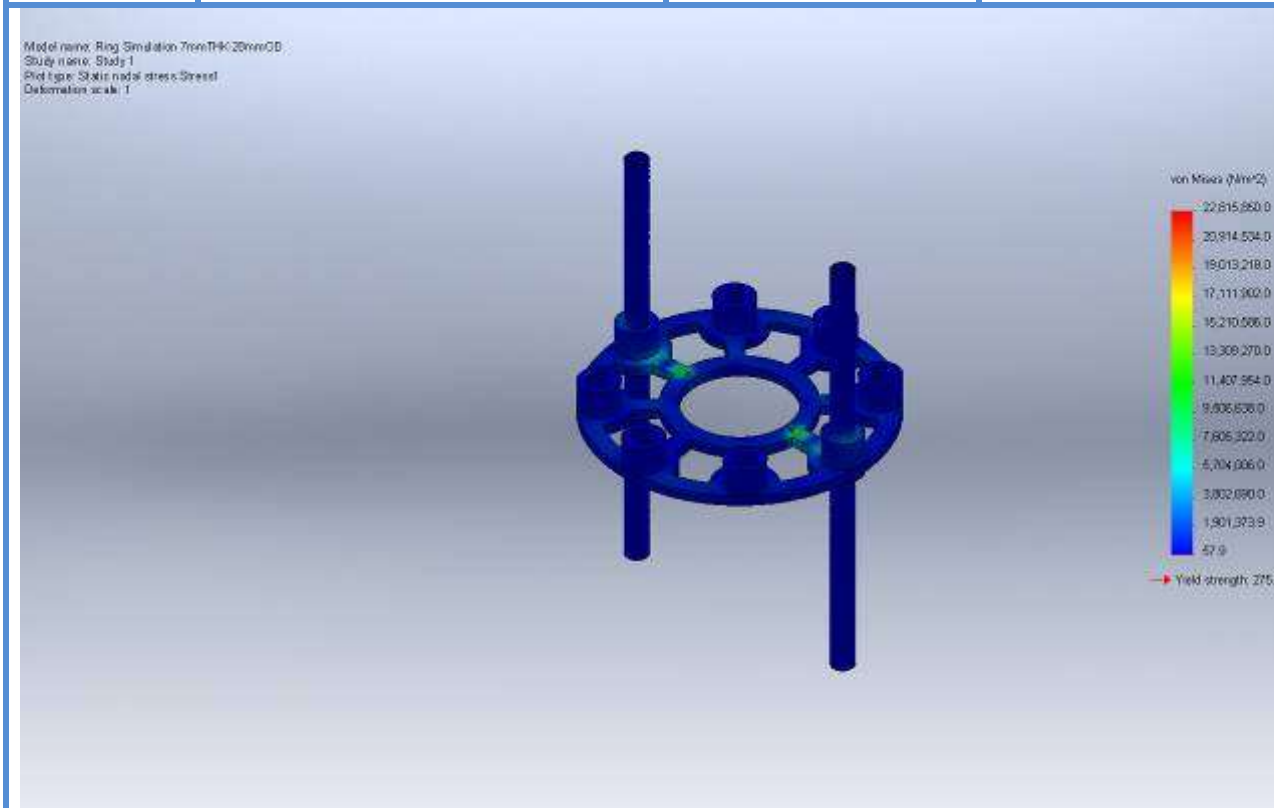
The details of the mesh used in this model are shown in table 17.

Table 17: Mesh specifications

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum element size	5.03946 mm
Minimum element size	1.00789 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

The results of the study are shown in the following figures.

Name	Type	Min	Max
Stress1	VON: von Mises Stress	57.8804 N/m^2 Node: 7150	2.28159e+007 N/m^2 Node: 20161



Ring Simulation 7mmTHK-28mmOD-Study 1-Stress-Stress1

Figure 39: Result - vonMises Stress

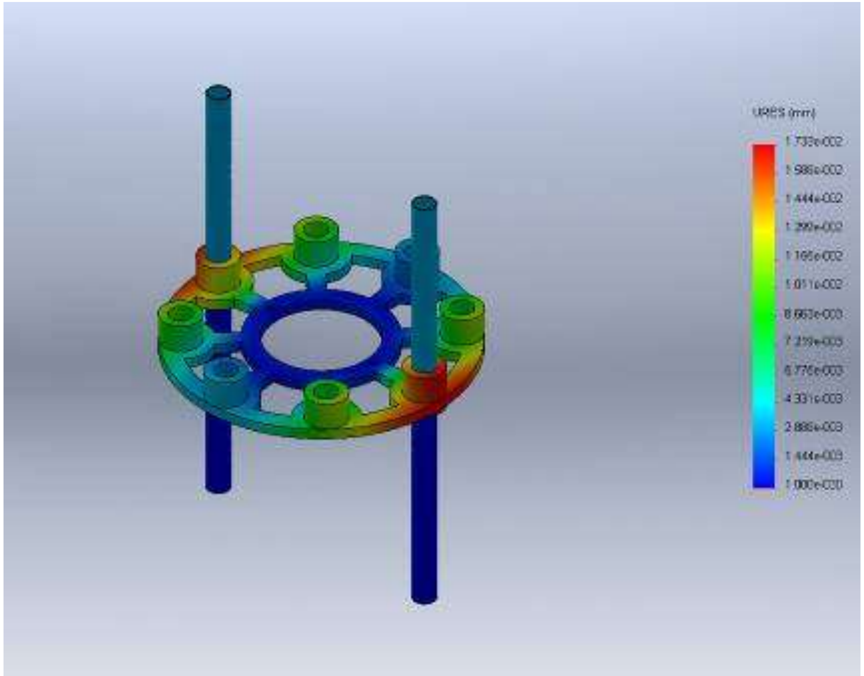
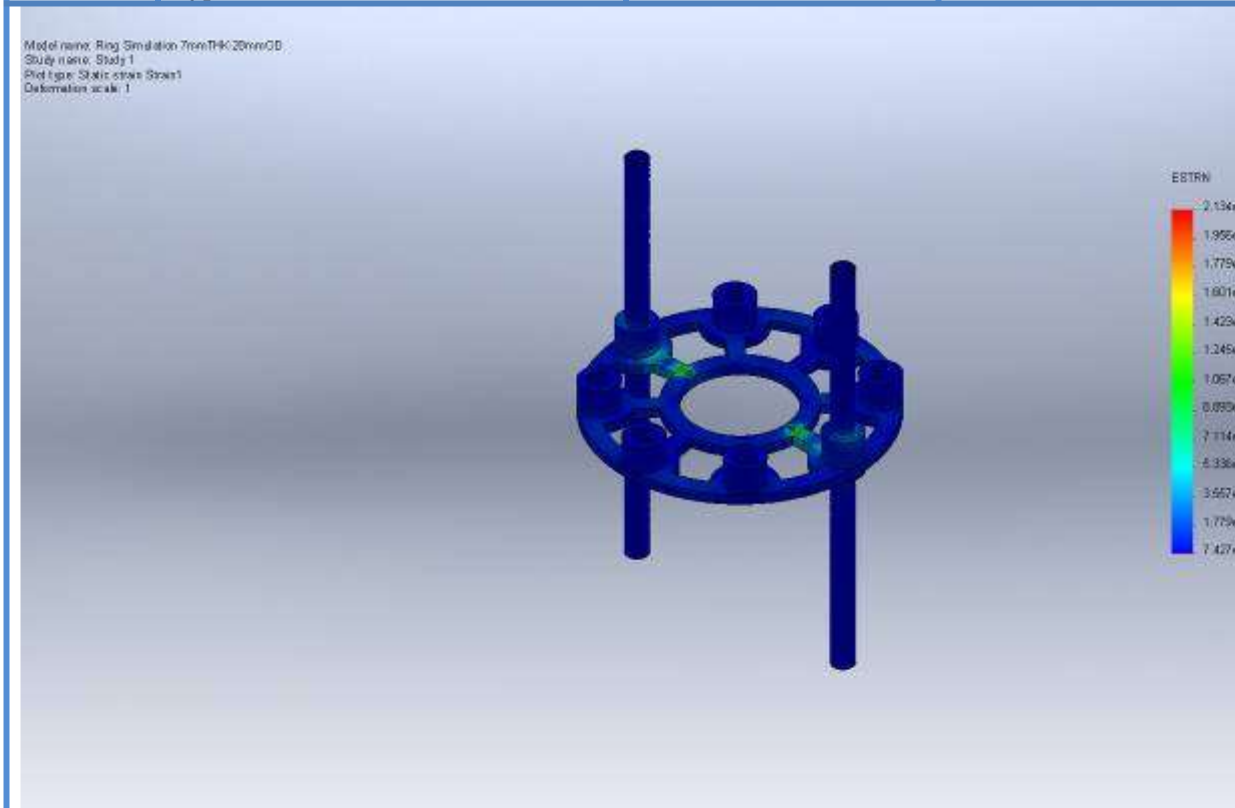


Figure 40: Results - Displacement

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	7.42685e-010 Element: 5568	0.000213423 Element: 13535

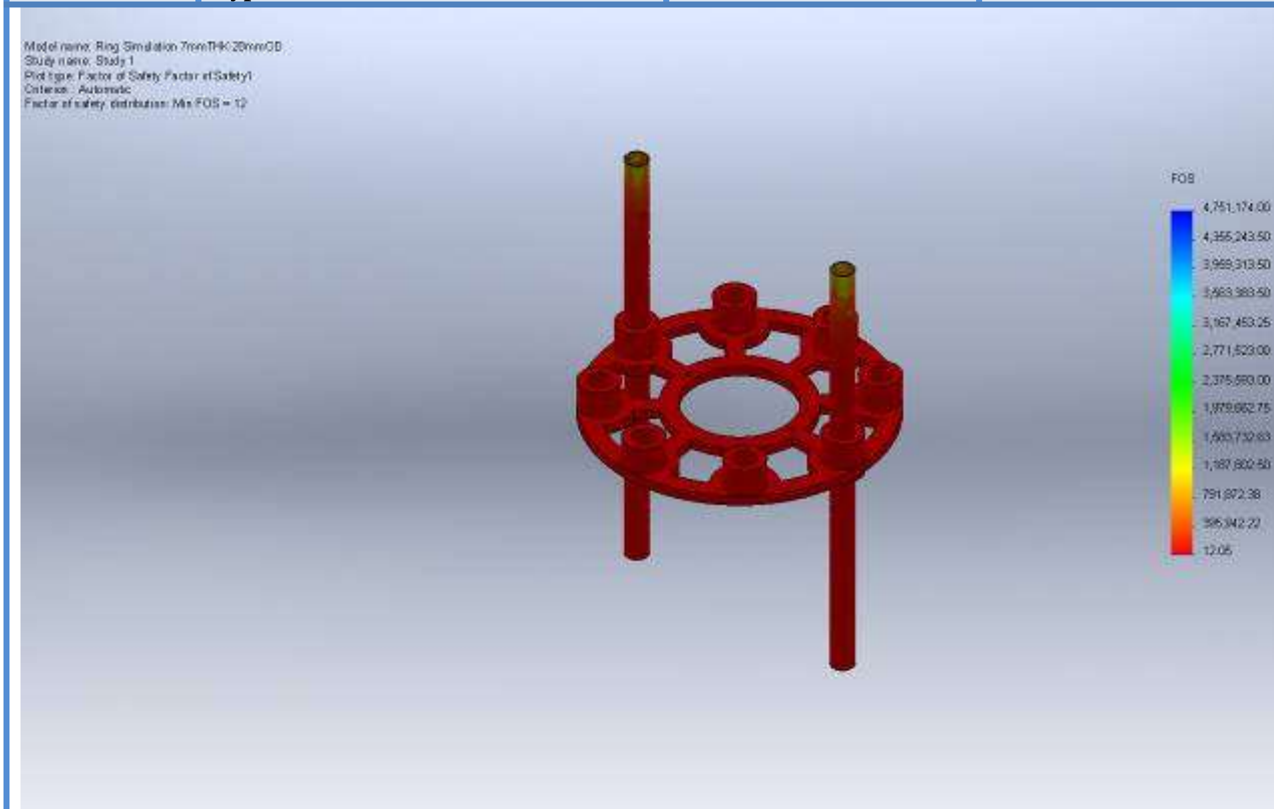
Name	Type	Min	Max



Ring Simulation 7mmTHK-28mmOD-Study 1-Strain-Strain1

Name	Type	Min	Max
Factor of Safety1	Automatic	12.053 Node: 20161	4.75117e+006 Node: 7150

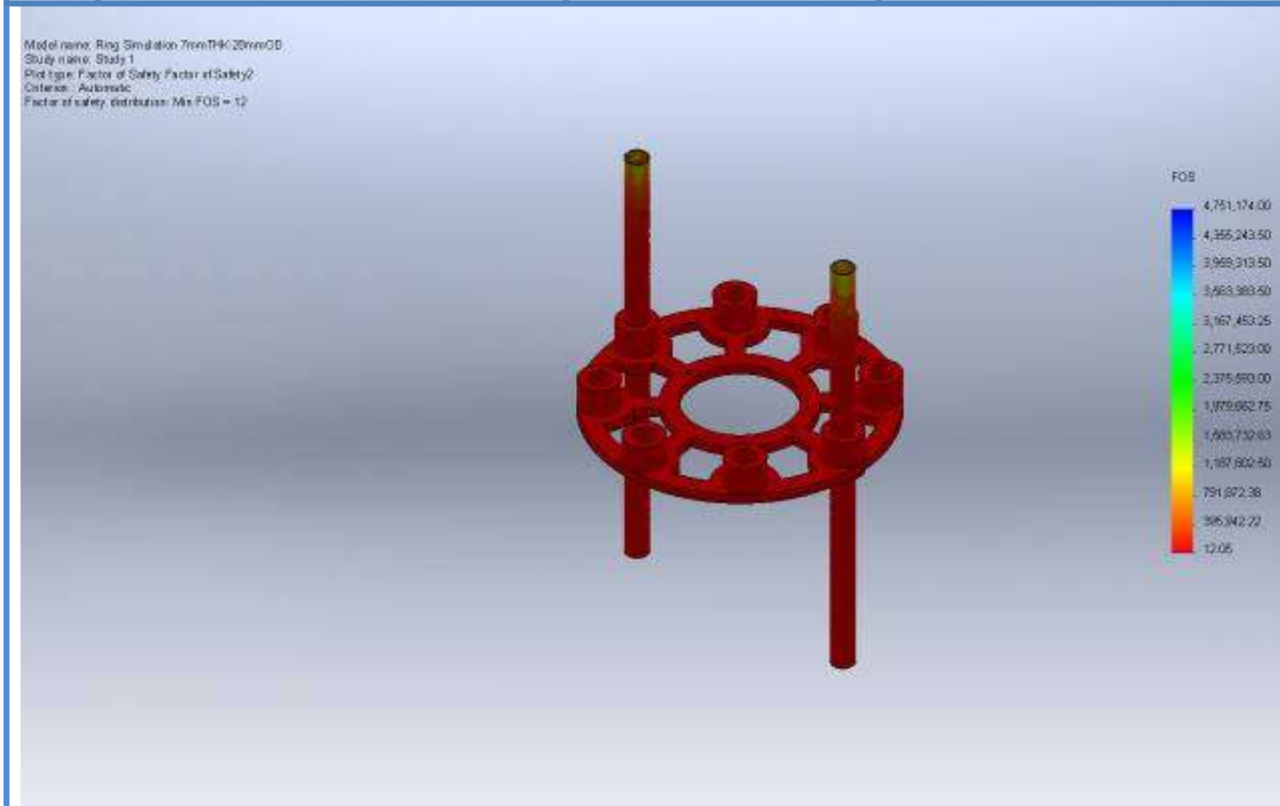
Name	Type	Min	Max



Ring Simulation 7mmTHK-28mmOD-Study 1-Factor of Safety-Factor of Safety1

Name	Type	Min	Max
Factor of Safety2	Automatic	12.053 Node: 20161	4.75117e+006 Node: 7150

Name	Type	Min	Max



Ring Simulation 7mmTHK-28mmOD-Study 1-Factor of Safety-Factor of Safety2

The purpose of this simulation was to verify that the components would not fail under the pressure of the springs. The factor of safety of this modified thin ring is 12.05. The confirmation that this ring will perform when subjected to the force of the springs is the second stage of testing, which is shown in section 9.

7.3.5 Springs

The final properties of the springs that are going to launch the ball have not been decided yet. At this time, what is known is that compression springs are going to be used and the same type of spring is going to be in each of the rails, depending on the number of springs decided to use. In figure 41 can be seen a general form of the spring in the minds of this team.

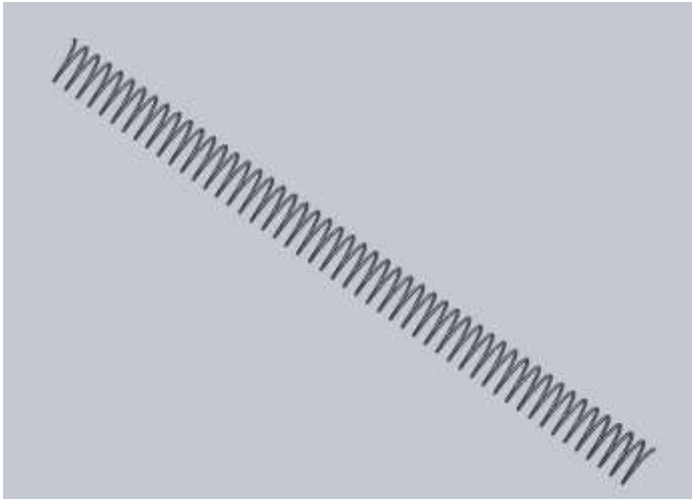


Figure 41: Spring

7.3.6 Rails

For the rails are going to be used the booms that the quadcopter has, but in a decreased internal diameter (16 mm instead of 21mm, the thickness is 1mm). The material is carbon fiber and the length has not been decided yet. After the calculations are made and tests done, the length of each rail will be known. In figure 42 a model of the rails can be seen.

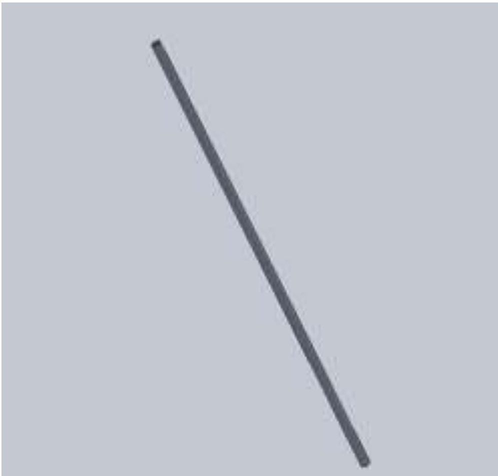


Figure 42: Carbon Fiber Rail

7.3.7 Attachment of Rails to the base of the ramp: Screws, Nuts and Small Plastic Pieces

In order to attach the rails to the base of the ramp, screws, nuts and small plastic pieces are going to be used. These are the same type of pieces that were used to put the quadcopter together. They are economic, strong and easy to obtain. In Figures 43, 44 and 45 they can be seen. Still it is not known how the ramp is going to be attached to the quadcopter, but there big probabilities that these same types of components are going to be used.

Figure 43: Screw

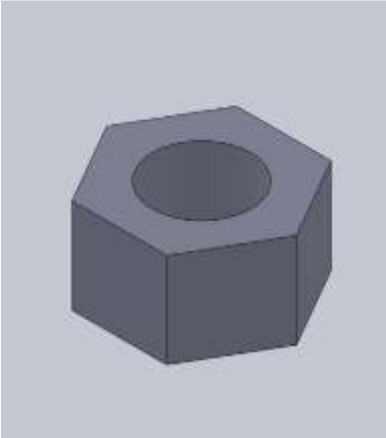


Figure 44: Nut

Figure 45: Small Plastic Piece

7.3.8 Hook

This a another main component of the release mechanism that was manufactured according to what was needed in order for the servo motor to be able to release the launching ring. It can be seen in figure 46. The exact dimensions of the hook are shown in appendix C.

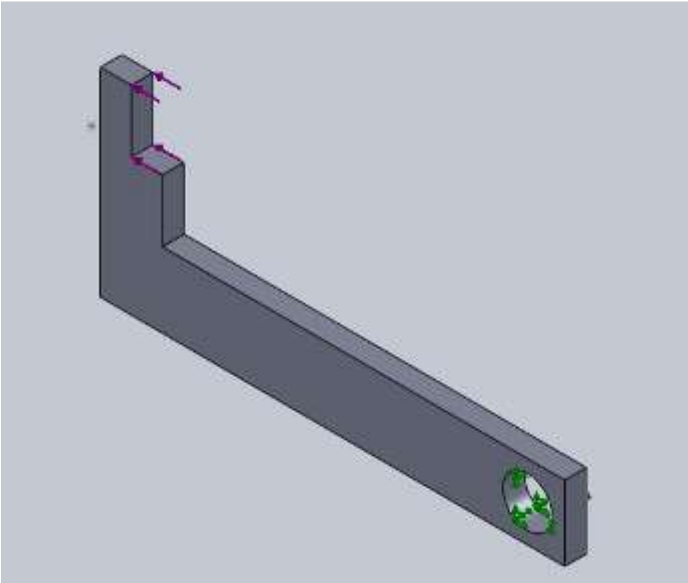


Figure 46: Hook

In order to know the effectiveness of the design of the hook, a static analysis was performed on the part. The force analysis is an important parameter to be accounted for the statics load that the hook is going to support. The team developed a design analysis of the force applied for two springs. The maximum force transmitted to the hook is 333.25 N that is going to be applied at the tip of the hook. Using this value as a reference, the team runs an analysis in solid work with this parameter to be sure that the hook is not going to fail for the force transmitted for the spring to the hook. One important aspect to be considered is the safety of factor (SF) generated by software. This value provides an important parameter to predict if the hook in going to fail under the maximum load. In order to get this value, we choose the hook material as an Aluminum 6061-T6 and the team run a simulation getting the SF= 6.17 showed in figure 47 Using this value as a reference, the team is making sure that the hook is not going to fail under the load applied to the tip of the hook.

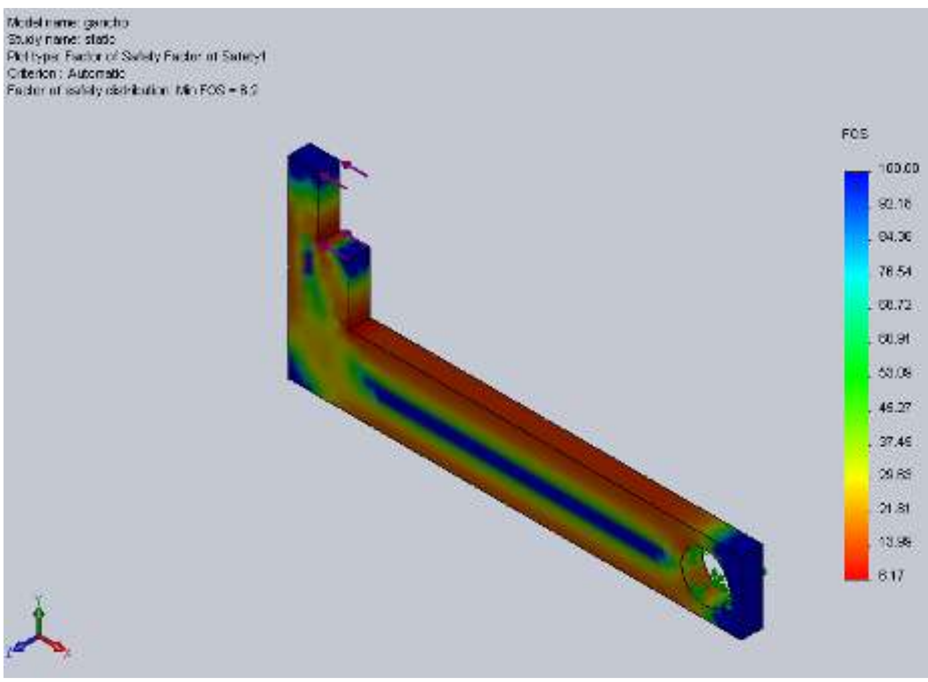


Figure 47: Simulation result

The stress caused by loading coming from the springs force is causing a stress through the entire hook. However, the yield strength of the aluminum 6061-T6 is high enough that the hook will never experiment a deformation because of the load applied. Using the yield strength as point of reference in the hook design, the team proved that the hook will never fail during the ball released operation.

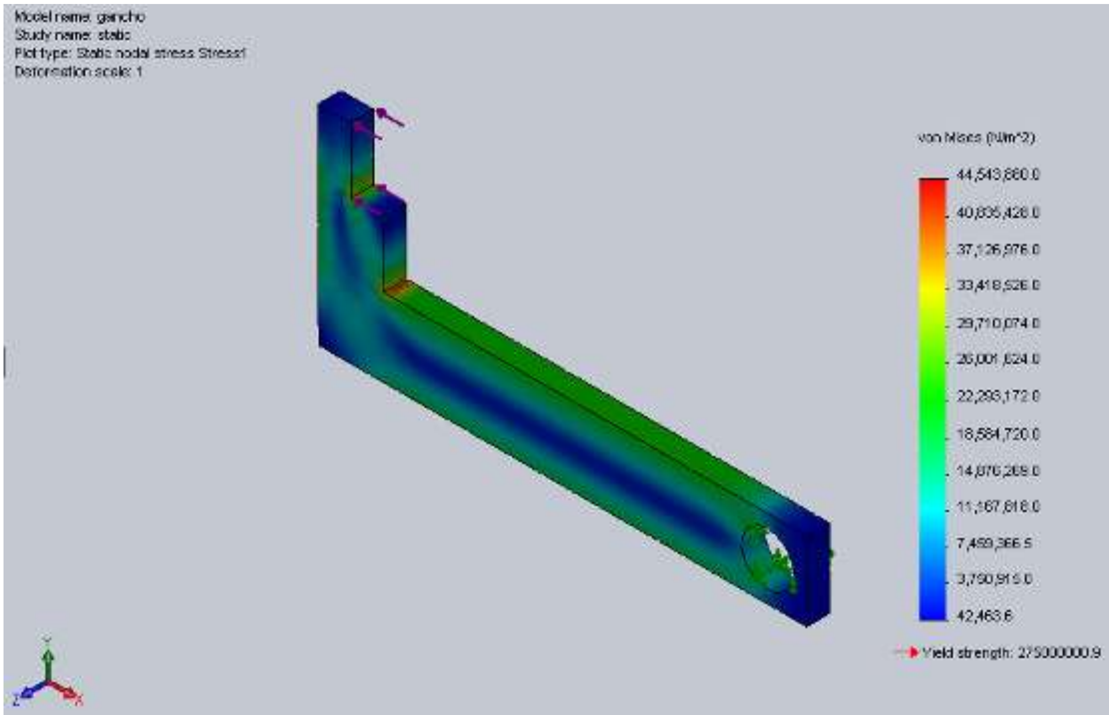


Figure 48: Simulation results

7.4 Calculations

In order to know the force that the springs need to produce to launch the ball and that it could achieve the distance desired, the Principle of Work and Energy was used.

Taking a look at the dimensions of the quadcopter, and taking into account that the ramp is going to be placed at the center of the frame, it is desired that the ball lands approximately 1.5 meters away of the point in which the ramp ends. Here, the distance of the ramp and the necessary clearance from the propellers of the vehicle to the building is a crucial value. The loss of stability in the quadcopter at the moment of launch can make it crash against the window; therefore, the landing distance is the main variable that is driving these calculations.

The principle of work and energy considers the location of the extinguishing ball and the velocity along path and analyzes the energy gained or lost while the ball moves between two specific points in the ramp. The difference of energy between two points is related to the variation of kinetic energy; this refers to the change of velocity from the initial to the final position. The following equation represents the principle of work and energy:

$$\sum U_{1-2} = \frac{1}{2} m v_2^2 - \frac{1}{2} m v_1^2 \quad \ldots\ldots\ldots\ldots \; 1$$

In this equation, "m" represents the mass of the ball plus the ring, and "v" is the velocity of the particle at the beginning and end of the motion. The right term of the equation defines the initial and final kinetic energy of the particle. The term of the left is the sum of the work done by all the forces acting on the extinguishing ball and the sliding ring. It is worth noting that in this problem, the fire extinguishing ball plus the sliding ring act as one, known as the particle. To calculate the total work, we integrate the work done from position one to two, and then this term is multiplied by the angle (Θ) at which the ramp is going to be inclined. This is shown in the next equation:

$$U_{1-2} = \int_{s1}^{s2} F \cos\theta \, ds \;\ldots\ldots\ldots\; 2$$

In this equation, "F" is the force necessary for the particle to travel from distance 1 (s1) to 2 (s2).

The work that friction caused by the ball and ring sliding should be included into the calculations, because there is friction present between the sliding ring and the tubes. This sliding motion will generate heat between the slide ring and the tubes. The heat will not be accounted as heat generation; it will be counted as a friction force opposite to the direction of motion.

$$Friction_{force} = N * \mu_K * L_{ramp} \text{ .... } 3$$

In this equation, "N" represents the normal force exerted by the ball plus the ring, "µk" represents the coefficient of friction of the ramp, and "Lramp" is the length of the ramp that the ball travels.

In Figure 49, the forces that are present in the ramp system are going to be shown in order to provide a better understanding of all the equations used while designing the ramp.

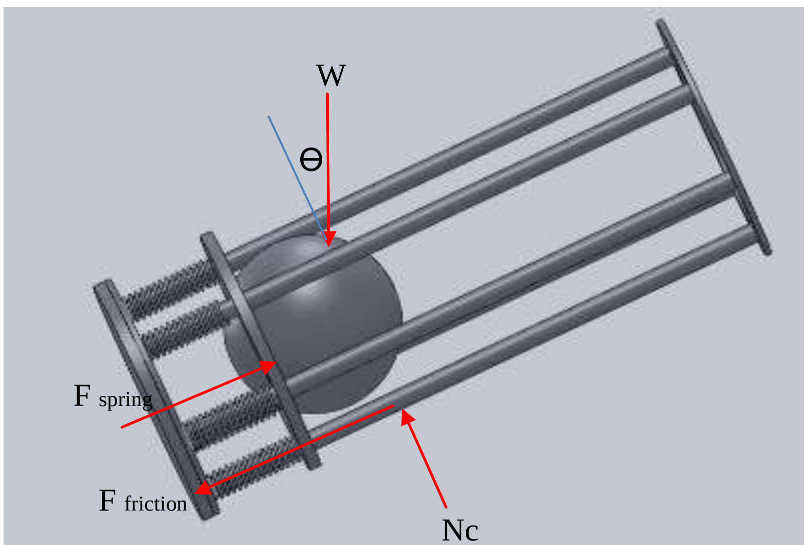


Figure 49: Free Body Diagram of the Ramp, including the Ball and the Springs.

Analyzing the free body diagram, the equations of work and energy and friction force can be put together into a final equation (shown next), and it is with this term that the velocity at which the balls is going to takeoff from the ramp was calculated.

$$\frac{1}{2}\, m{v_1}^2 - W\left(L_{ramp}\right)\sin\theta + \frac{1}{2}\, K\, s^2 - N * \mu_K * L_{ramp} = \frac{1}{2}\, m{v_2}^2 \text{ .... } 4$$

When the value of this velocity is known, the conservation of linear momentum was used in order to obtain the distances at which the ball is able to land.

Using this principle, we are going to calculate the motion of the whole system, based on external forces applied to the system and the behavior of its components. The starting point is that the release mechanism is going to throw the ball and the sum of the external impulses acting on the system is equal to zero. When the release mechanism shoots out the ball, this momentum will be compensated by a momentum in opposite direction as the velocity of the ball. This momentum will be the velocity at which the quadcopter is thrown back by the launch, and the conservation of the linear momentum will be shown in the following equation:

$$\sum m_i (v_i)_1 = \sum m_i (v_i)_2$$

Applying the principle of linear impulse and momentum, the impulse force applied to the fire extinguish ball can be found. The equation of motion applied to all the particles in the system is:

$$\sum m_i (v_i)_1 + \sum \int_{t1}^{t2} F_i \, dt = \sum m_i (v_i)_2$$

The sum of the external forces acting on the extinguishing ball between t1 and t2 plus the initial linear momentum is equal to the final linear momentum. Applying this equation, the force transmitted to the ball can be controlled by the selection of the springs.

To obtain the distance that the ball is going to travel, kinematics equations were used. Since the ball is traveling in a path resembled by a parabola, all the calculations will represent the maximum height (y coordinate) and the distance that the quad copter (x coordinate) will have to be away from the building to throw the ball inside of the window. The following equations are going to be used to calculate the parabolic trajectory of the extinguish ball.

Time of flight for the ball:

$$V = V_0 + a_c t$$

Where "t" is the time and "a" is the acceleration of gravity.

Height of the ball:

$$V^2 = V_0{}^2 + 2a_c (S - S_0)$$

Distance the ball travels:

$$S = V_{b0} t$$

Distance quad copter travels in the x direction:

$$S = V_{q0} t$$

Using the principle of work and energy, the team could have calculated the best ramp length. Following the equation 4, we concluded that the ramp length is going to affect the final velocity of the ball and the ring. For that reason, we have to choose the shortest ramp length, but taking into account the clearance between the end of the ramp and the end of the arm length of the propellers. Applying this clearance, we can make sure if the ball does not travel enough distance x, the ball does not damage the propellers in the launching process. From all the assumptions described before, data were plotted and the result was that the best ramp length for this project is 0.35 m, because it complied with the distance that the ball have to travel and the clearance between the end of the ramp and the propellers.

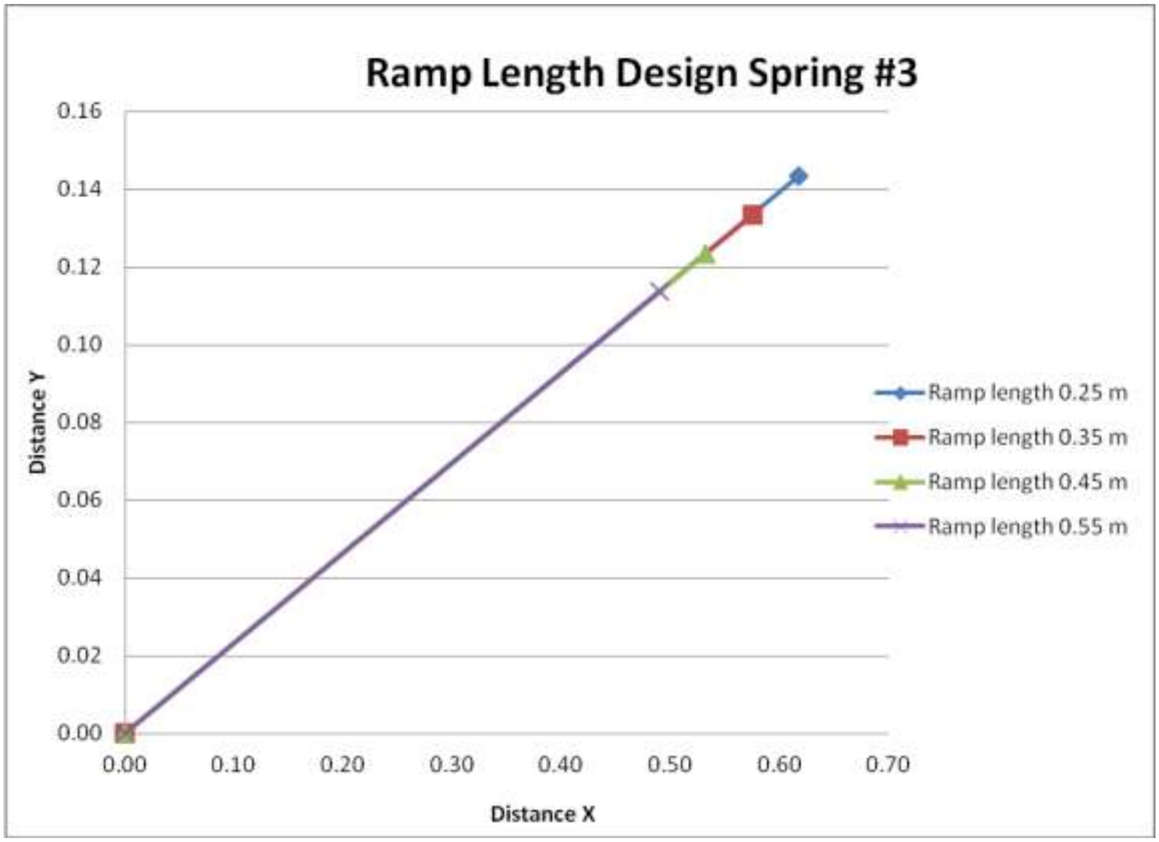


Figure 50: Ramp Length Design Spring #3

Having all the parameters in place, such as spring force, ramp angle, ramp length, friction, weight of the ball plus the sliding ring, this team created an Excel spreadsheet in order to calculate the springs that will work according to our needs and also to know what is the best angle at which the ramp can be positioned. After all the calculations were made and results were shown and analyzed, the team decided to choose two springs that will achieve the criteria for launching the extinguishing ball without being too close to the window of the building.

From all the assumptions described before, equations and data obtained, the following graphs (Figures 50, 51 and 52) were computed in order to show the distance at which the quad copter has to be away from the building to be capable of launching the extinguishing ball inside a building without crashing with it.

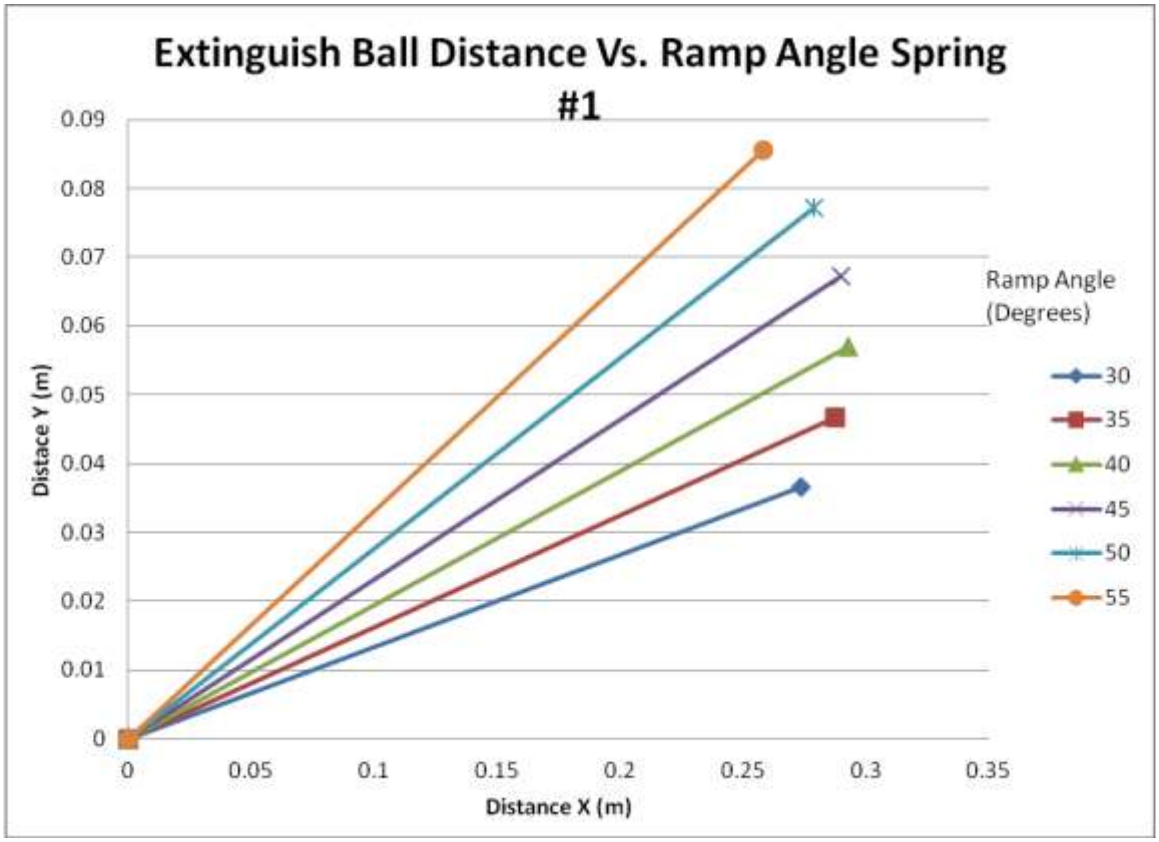


Figure 51: Graph of distance of landing of the fire extinguishing ball with the first choice of springs

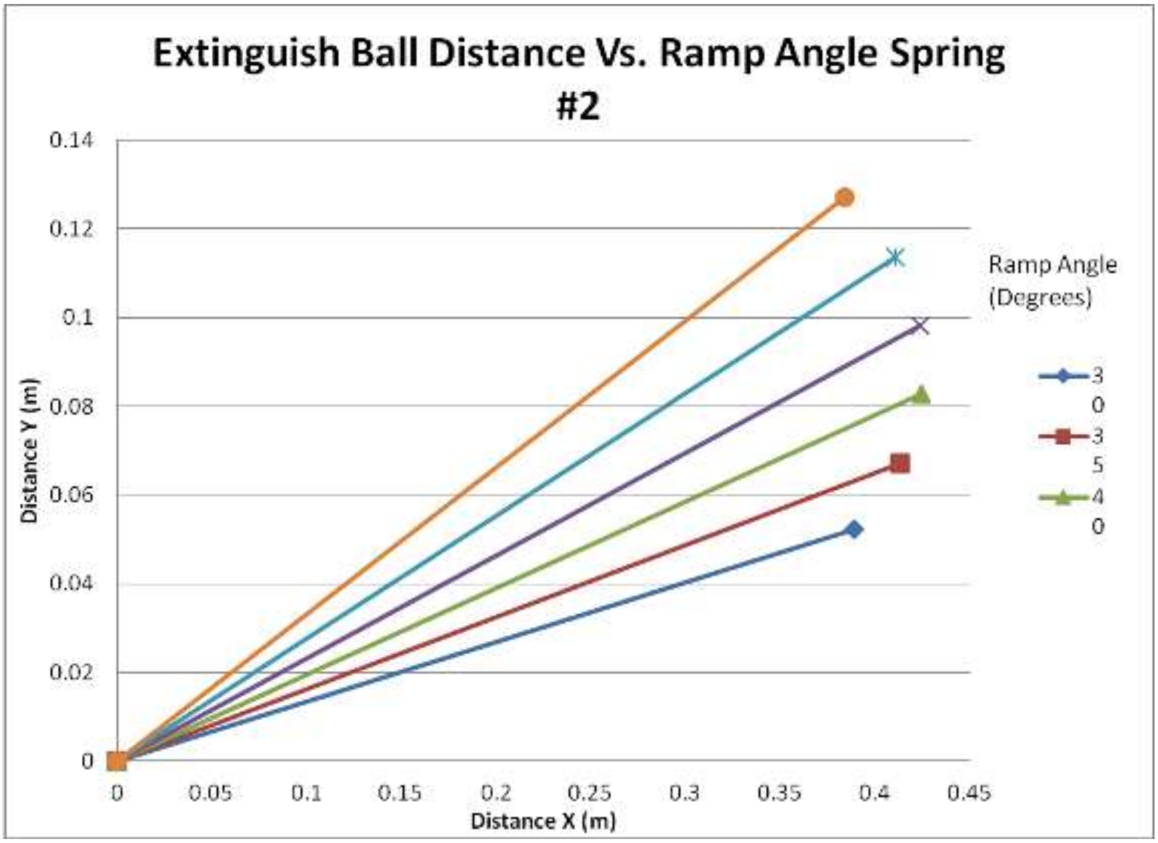


Figure 52: Graph of distance of landing of the fire extinguishing ball with the second choice of springs

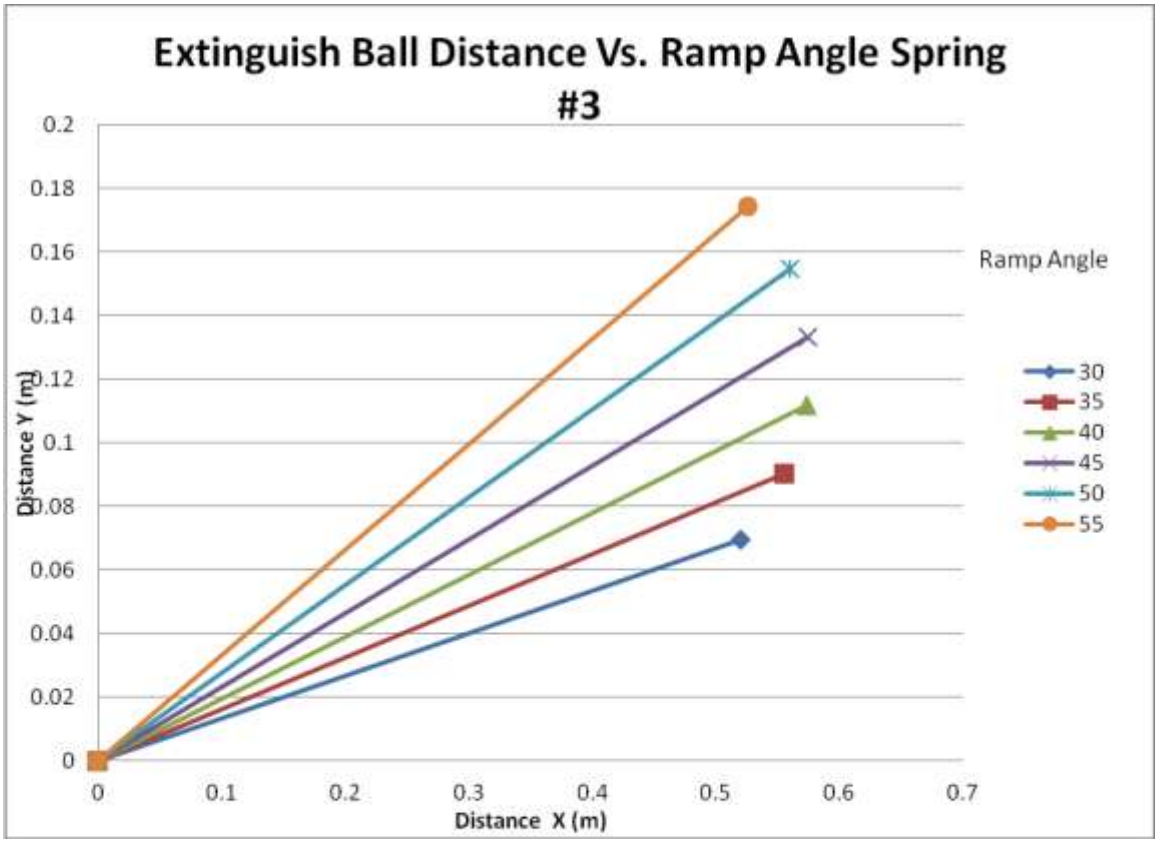


Figure 53: Distance the ball travels using the first choice of springs

The following table shows the theoretical data obtained with the equations described at the beginning of this section. These data is going to be confirmed by a set of experimental tests that are going to be performed after the ramp is built.

Table 18: Theoretical Data Obtained from Equations of Work and Energy Principle and Linear Momentum

w ball (N)	14.715		
m ball Kg	1.500		
w ring (N)	3.04		
m ring (kg)	0.31		
w total (N)	17.755		
m total (kg)	1.810		
m quad (kg)	3.900		
Length ramp (m)	0.35		
Nc (N)	12.55		
Ramp Angle	45		
UK	0.3		
Spring Option	Spring #1	Spring #2	Spring # 3
K (N/m)	656	856	1082
# of springs	2	2	2
S (m)	0.18	0.16	0.16

The vertical distance traveled by the ball (S) shown in Table 11 says that for spring 1, this distance is 0.154 m or 15.4 cm and for spring number 2 is 0.1121 m or 11.21 cm. The distance from the center of the frame of the quadcopter, which is where the base of the ramp is going to be placed, to the tip of the propeller is 44 cm. From the results obtained, these 2 springs are not going to work. The total distance traveled by the ball has to be bigger than the distance between the center of the quadcopter and the tip of the propeller plus a clearance of approximately 15 centimeters between the tip of the propeller to the building. From these rough calculations, the minimum distance the ball needs to travel is 44 cm plus 15 cm, which is equal to 59 cm.

It was decided that the clearance between the tip of the propeller and the building should be at least of 15 cm because the greater the distance the ball needs to travel, the greater the force the springs have to produce and this would case a greater loss of stability in the quadcopter.

Since the calculations with the previous springs show that they are not going to satisfy the distance that the ball needs to travel, the calculations were done with other springs. Their characteristics are shown in Section 9.1.

7.5 Location of the Release Mechanism

The release mechanism was assembled using the parts described in section 7.2. All the components are held together by screws and nuts. In Figure 43 can be seen how this assembly works. In this figure is also seen that no base plate is used. The decision to take it off the mechanism was made after the testing was done and the behavior of the entire mechanism was observed. Instead of using a base plate, a hook is going to be used to hold the ring and ball back when the springs are compressed. This hook is also going to be used as an arm of the servo motor to activate the release mechanism. Activating the release mechanism means that the part that is holding the launching ring back is going to be moved in order to let the ring slide while pushing the ball forward on the rails.

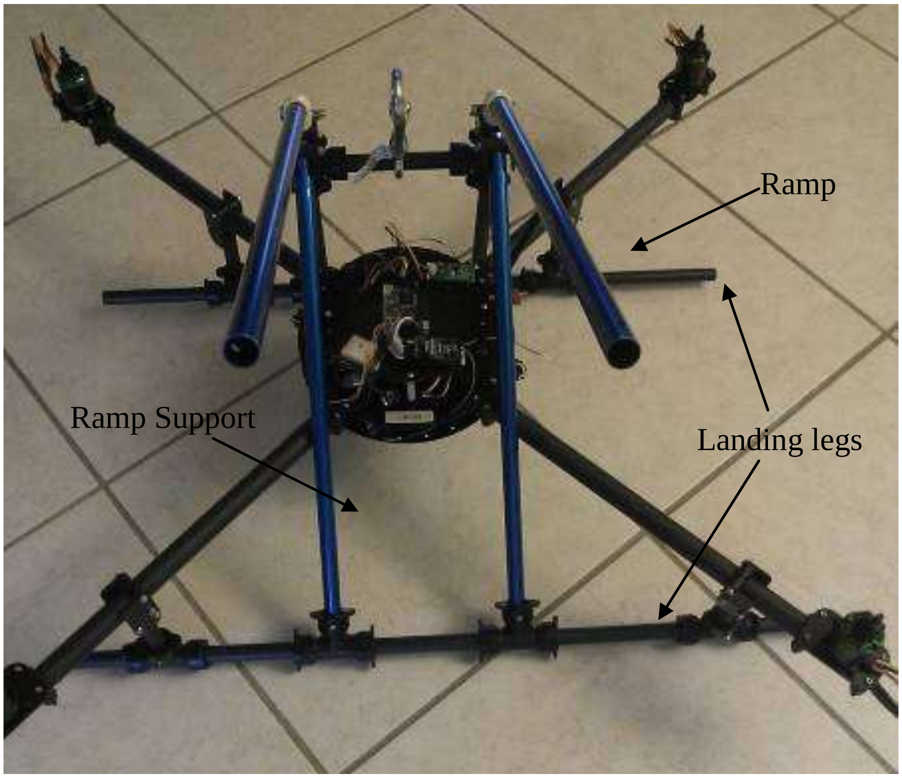


Figure 54: Attatchment of Release Mechanism to Vehicle

It was calculated that the ramp needed to have a 45 degree angle from the horizontal in order to optimize the launching distance of the grenade. To be able to build the ramp at the desired angle, the arms had to be positioned in a way that they will be supporting the ramp forming a shape of a right triangle. These arms were connected to 2 horizontal tubes, each one connected to 2 of the quadcopter arms. The reason to design the support of the ramp this way was that it could also serve the purpose of landing gear of the vehicle. The horizontal tube (landing leg) in the back was positioned closer to the center of the quadcopter to avoid contact of the propellers with the perpendicular arms supporting the ramp. The goal was to also use the ramp structure as a protective shield of the electric components of the quadcopter in case of a crash. Since the ramp structure is attached to the landing legs, the electrical components are protected between the top plate of the quadcopter and under the ramp structure.

8. Factors That Can Cause Failings In The System

After the quadcopter and release mechanism were assembled, the risks the system could face were assessed. They are presented in the following sections.

8.1 Components of the system

Due to the size, power and purpose of the vehicle, there are factors that have to be taken into account before, during, and after each flight. The following list describes each possible complication that has been identified during the course of the assembly and testing of the quadcopter.

8.1.1: Visual Inspection of System before flight

Failure to follow the procedure to verify location, physical adjustment, and calibration of components, connections between components, frame joints, ramp assembly, and propellers can cause failure on the vehicle, ramp or even total crash.

Before turning on the quadcopter, the user must check that all electrical components are connected and located in the correct position. There are chances that during a previous flight, the vibration and external forces were capable of loosening the cables or even detach a component. The same goes for the frame, the screws that hold the arms, main plates, ramp assembly, and propellers are subjected to high vibrations coming from the four motors when they are running, and the spring when it is released. To avoid a failure in the structure, all screws must be tightened before each flight.

8.1.2 Calibration of Motors

When the quadcopter is about to take off, a new calibration of the motors must be done. The calibration that the motors and the arduflyer have at the time of flight is the one from the previous flight; for this reason, to check if there is any unbalanced weight and in order to give the computer from the arduflyer enough time to adjust to the new position and parameters, the motors have to be calibrated before each flight.

8.2 Insufficient training flying and maneuvering a quadcopter

Controlling any flying system is complicated, and this quadcopter is not excluded. Knowing how to properly flight a quadcopter is of supreme importance to not crash it, since it has very sensitive controls. The user must not only learn how the different switches and sticks of the controller work, but also understand how responsive the quad is during liftoff, flight, and landing. There is no limit to the amount of hours that can be dedicated to learning how to fly this vehicle, because the skills of the user will improve with more experience in different scenarios; but a basic training is necessary from the beginning to avoid a crash to the ground, structures, or people. Learning how to flight a smaller version of a quadcopter before the Firefighter Quad is ideal to begin getting used to the controller and technique of flying.

8.3 Extreme weather conditions.

Like any other flying apparatus, extreme weather can be an issue during a flight. Although, the quadcopter design is made for resisting light rain and wind, heavy rain or snow can create a shortcut in the electronics or interference with the radio signals from the GPS and remote control. Wind gusts could also change the direction of the quad easily and thus, the user has to also change the way of operating it visually. Wind gusts are defined as an abrupt but momentary increase in the speed of the wind. Dust and heavy can also have a negative impact on the vehicle, since particles can block the GPS, or create a short cut among the electronics.

8.4 Electronics failure modes

8.4.1 Thermal

Since each electronic part has a temperature limit, overheating of components from an outer source or within the vehicle can melt the cables used for the connections or the component itself. The quad will not have a temperature control sensor during flight, but the battery charger has a sensor that can let the user know if the batteries are overheating. All other components will have to be checked through other means, such as visual inspection.

8.4.2 Vibration

Each motor has a crossed shape break metal part attached to the bottom to fix it to the end of the arm of the quadcopter. This prevents a direct contact from the heat of the motor to the boom, but after it has flown for a certain period of time, this metal part increases the vibrations from the motor. To reduce this vibration, a small piece of foam is installed below the break metal. Furthermore, it is also required to check for any loose screw at the critical points such at the base of the motor and at the end of the connection between the arms and main plates, since they can cause vibrations too.

8.4.3 Excess current or voltage

Damage due to water or dirt to the voltage controller can affect the voltage provided to the main components such as the arduflyer and flight controllers, and this may cause harm to the rest of the components connected to them.

8.4.4 Impact

Even though the main plates are serving as a protecting case to the electronic components, a high impact can misplace the arms or break the plates, thus, damaging anything in between.

8.4.5 End life of component

Each part has different end life period; a check on the manual of each individual component will help to know when to replace it before it begins to not functioning properly or a sudden fail happens.

8.4.6 Radio interference

There are two antennas coming out of the sides of the quadcopter. Not only the two antennas have to be placed apart from each other in order to not create interference, but also the user has to be careful not to locate or flight the quad close to a major source of radio waves.

9. Testing and Evaluation

Several tests were planned in order to confirm the capabilities of the vehicle and the release mechanism. The specifications of how the tests were performed, the results and the conclusions obtained from those results will be shown in the following sections.

9.1 Release Mechanism Performance Test

This test consists of seeing how the release mechanism is going to perform by itself, on the floor, when the ball is launched. This testing was divided in two stages. On the first stage the original launching ring was used, and the purpose of the second stage was to use the modified thin launching ring taking out the base plate.

This team started by assembling the release mechanism. After that, a testing strip was made of paper and had markings each 5 centimeters, in order to measure the distance the ball travelled when it was launched. This was achieved by visual inspection of the members of this team. The members were attentive of the point at which the ball touched the strip for the first time, and that was the horizontal distance the ball traveled from the end of the ramp (where the strip had drawn the marking 0 centimeters) to the floor, and this distance was recorded.

To simulate the fire extinguishing ball, a prototype was made. A ball made of foam (expanded polystyrene), with the same diameter of the original ball, 14.7 cm, was bought. The inside of the ball was cut in order to fit a metal cylinder that would make the prototype the same weight of the original ball, 1.5 kg. This system was put together using all-purpose glue that is non-toxic, dries fast and does not deform the foam. After the glue dried, clear adhesive tape was used all over the surface of the ball to make it stronger in order to support the crashes of the ball against the floor. Also, the surface of the fire extinguishing ball is covered with plastic; therefore, the use of the clear adhesive tape will help simulate similar surface roughness for the prototype. This is important because the coefficient of friction between the ball and the rails is important. It is desired the less amount of friction possible between them, so less energy is lost while the ball is rolling on the ramp.

The assembled ramp with the ball inside can be appreciated in Figure 55. In Figure 56 can be seen the ramp plus the strip with the markings of the distance in centimeters.

Figure 55: Release Mechanism with Ball

Figure 56: Release Mechanism with Testing Strip

With the calculations shown in Section 7.3, springs with different rates were used in order to obtain the most favorable results. Two springs were selected to test in the first stage of the testing of the release mechanism. Their characteristics are shown in Table 19. These characteristics are in SI units. The original units of these characteristics, given by the supplier, are English units, and they are shown in Appendix B.

Table 19: Characteristics of Springs for Testing of Release Mechanism (SI Units)

Characteristic	Spring 1	Spring 2
Type	compression	compression
Outside Diameter (m)	0.024587	0.024638
Inside Diamter (m)	0.0149964	0.019812
Overall Length (m)	0.2794	0.3048
Wire Diameter (m)	0.0023114	0.002413
Rate (N/m)	656.7	805.6
Load (N)	101.3305	137.45
Deflection at Load (m)	0.15441	0.17061

Pitch (m)	0.007112	0.0078994
Ends	open	closed and ground
Material	hard drawn	music wire
Finish	plain	plain

As shown in section 7.2.1, the base of the ramp has 4 holes that are going to fit with the holes of the ring and in those holes is where the rails are going to be placed. It is up to the members of this team to decide how many rails should be used and in what positions (holes) they should be placed, always having in mind that more rails, means more friction and this is more energy loss for the ball, which translates to decreasing the distance the ball can travel.

The length of the rails in this testing was 0.5 m, but this is not final. After all the data and results of this test are analyzed, a final decision on the length of the rails is going to be made.

Since the base plate has 4 holes, this means that there were several rail configurations that could be tried. In Figure 45 those positions are going to be shown with numbers, and at the time of showing the results, those numbers are going to be used in which positions the rails were located.

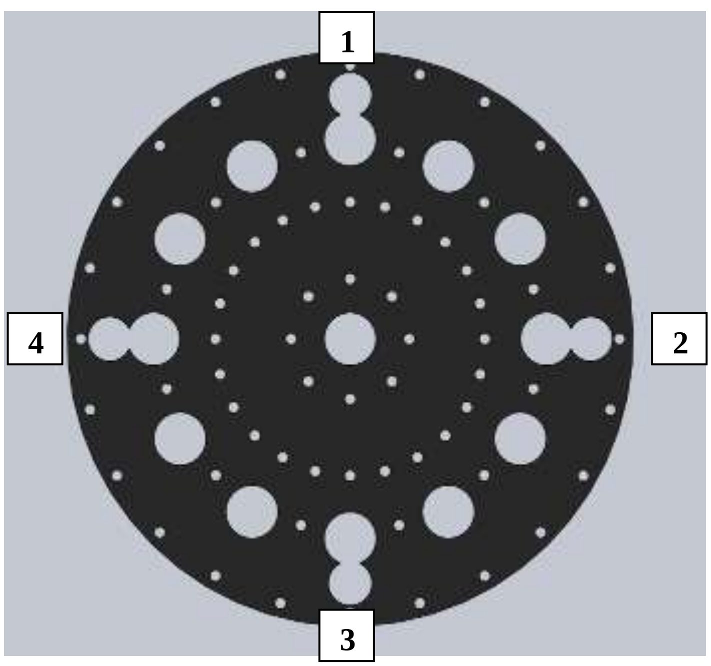


Figure 57: Base Plate with Named Holes

The procedure of this release mechanism performance test consists of compressing the springs manually by pulling the ring against the springs, which at the same time were against the base plate. Usually, the ring was pulled until the team member could not compress the springs anymore. Different forces were applied by the team member in order to compress the springs to different lengths and obtain different results of the distances traveled by the ball.

Once the springs were compressed, it was measured the length of the springs compressed and immediately after this, the ball was released. Other team member was paying attention to the exact spot that the ball touched the paper strip for the first time, and all those values were recorded and will be shown in the following tables. This team did 6 different configurations between springs and rails.

The first trial is shown in Table 13.

Table 20: Release Mechanism Testing - Trial 1

Configuration (Position of the rails on the base of the ramp)	K of the spring (N/m)	Location of springs in holes:	Length of Springs Compressed (m)	Distance travelled by the ball from the ramp (m)
2, 3 & 4	805.6 (Spring B)	2 & 4	0.155	0.4
			0.175	0.25
			0.145	0.9
			0.145	0.85
			0.145	1
		Average:	0.153	0.68

The rails were located in holes 2, 3 and 4 and spring B was used in the rails that were in holes 2 and 4. From the five times the springs were compressed, the shortest length they achieved was 0.145 meters in 3 occasions and this produced the longest distance the ball traveled, which is 1 meter. The average of compressed lengths in this trial 1 was 0.153 m and the average of the distance travelled by the ball is 0.68 m. From Section 7.3 it is known that the minimum distance the ball needs to travel is 59 centimeters; therefore, the average of this trial is favorable, meaning that the configuration of the springs and the type chosen are supposed to work.

Trial 2 is shown in Table 14.

Table 21: Release Mechanism - Trial 2

Configuration (Position of the rails on the base of the ramp)	K of the spring (N/m)	Location of springs in holes:	Length of Springs Compressed (m)	Distance travelled by the ball from the ramp (m)
2, 4 and rail in hole 3 was only attached to the ring and had a length of 17 cm.	805.6 (Spring B)	2 & 4	0.15	0.3
			0.155	0.25
			0.17	0.95
			0.155	0.95
			0.16	0.5
		Average:	0.158	0.59

The rails were located in holes 2 and 4, and in hole 3 a rail of only 17 cm long was attached to the ring to support the ball, but this rail was not attached to the base plate. Spring B was used in the rails that were in holes 2 and 4. From the five times the springs were compressed, the shortest length they achieved was 0.15 meters and this produced a traveled distance of 0.3 m. The longest distance traveled by the ball is 0.95 m. The average of compressed lengths in this trial was 0.158 m and the average of the distance travelled by the ball is 0.59 m. From Section 7.3 it is known that the minimum distance the ball needs to travel is 59 centimeters; therefore, the average of this trial is right on the limit. However, using this combination is too risky; trial 1 is better.

When the testing started, the members of this team planned on doing as many combinations as possible to find the most effective one. After 6 trials, results that satisfied the length needed were found and the testing was left up to there. Trial 3 is shown in Table 15, trial 4 is shown in table 16, trial 5 is shown in table 17 and finally trial 6 is shown in table 18.

All of these were analyzed in the exact same manner as in the first two trials and the conclusions will be said after these tables are shown.

Table 22: Release Mechanism Performance - Trial 3

Configuration (Position of the rails on the base of the ramp)	K of the spring (N/m)	Location of springs in holes:	Length of Springs Compressed (m)	Distance travelled by the ball from the ramp (m)
2, 4 and rail in hole 3 was only attachedto the ring and had a length of 17 cm.	656.7 (Spring A)	2 & 4	0.145	0.75
			0.145	0.75
			0.15	0.6
			0.145	0.8
			0.145	0.5
		Average:	0.146	0.68

Table 23: Release Mechanism Performance - Trial 4

Configuration (Position of the rails on the base of the ramp)	K of the spring (N/m)	Location of springs in holes:	Length of Springs Compressed (m)	Distance travelled by the ball from the ramp (m)
2, 3 & 4	656.7 (Spring A)	2 & 4	0.13	0.4
			0.145	0.2
			0.12	0.6
			0.13	0.4
			0.13	0.25
		Average:	0.131	0.37

Table 24: Release Mechanism Performance - Trial 5

Configuration (Position of the rails on the base of the ramp)	K of the spring (N/m)	Location of springs in holes:	Length of Springs Compressed (m)	Distance travelled by the ball from the ramp (m)
2, 3 & 4	656.7 (Spring A)	2, 3 & 4	0.155	0.45
			0.165	0.35
			0.185	0.2
			0.17	0.5
			0.16	0.3
		Average:	0.167	0.36

Table 25: Release Mechanism Performance - Trial 6

Configuration (Position of the rails on the base of the ramp)	K of the spring (N/m)	Location of springs in holes:	Length of Springs Compressed (m)	Distance travelled by the ball from the ramp (m)
2, 3 & 4	805.6 (Spring B)	2, 3 & 4	0.18	0.2
			0.18	0.35
			0.18	0.3
			0.19	0.15
			0.19	0.2
		Average:	0.184	0.24

Now, some observations that were noticed while doing the tests that might lead to have some errors in the results shown before:

1) The ball deforms every time it hits the ground (because of the material it is made) and that inside has the metal cylinder that makes it weight 1.5 kg.
2) The base plate deforms each time the springs are compressed. This happens because the springs compressed produce a great amount of force against the plate.
3) Having the third tube in position 3 without a spring only created more friction; therefore, it is more effective to add the 17 cm rail to hold the ball and that can be attached to the ring.
4) The distance the ball traveled was measured by visual inspection of the team members; therefore, this can lead to human error in the readings.

Reflecting on these observations, it can be said that the results obtained are not completely accurate, but good enough to make final decisions regarding the springs to be used and the placement of the rails. It is also worth noticing that the deformation of the base plate was of great concern for this team; therefore, it was decided to remove it from the mechanism and use an alternate part. This was explained in Section 7.5.

When all these trials are analyzed, it is noticeable that the best results are given by trial 1, in which the rails were in holes 2, 3 and 4 and there were also 2 springs type B in holes 2 and 4, providing a travel distance of 68 cm. From this observation, this is the configuration that is going to be used in the ramp, leaving the rails with the length used in the trial, 50 cm.

The force produced by these springs are shown in table 26.

Table 26: First Stage Testing - Force produced by springs #2

Configuration (Position of the rails on the base of the ramp)	K of the spring (N/m)	Location of springs in holes:	Length of Springs Compressed (m)	Distance travelled by the ball from the ramp (m)	Force exerted to compress the springs [F=KX*2 b/c there are 2 springs] (Newtons)	Force in lbf
2, 3 & 4	805.6	2 & 4	0.155	0.4	249.736	56.14315
	805.6		0.175	0.25	281.96	63.38743
	805.6		0.145	0.9	233.624	52.52101
	805.6		0.145	0.85	233.624	52.52101
	805.6		0.145	1	233.624	52.52101
	805.6	Average:	0.153	0.68	246.5136	55.41872

The average force produced by both springs is 246.4 Newtons, which was the value used when doing the statics studies of the main components of the release mechanism.

Everything shown in this section up to this point corresponds to the first stage of testing. The second stage of the testing not only consists of using the thin launching ring, but also compare the performance of springs 2 and 3.

The results obtained from using springs 2 are shown in table 27.

Table 27: Second Stage Testing - Force produced by springs #2

Trial	K of the spring (N/m)	Length of Springs Compressed (m)	Distance travelled by the ball from the ramp (m)	Force exerted to compress the springs [F=KX*2 b/c there are 2 springs] (Newtons)	Force in lbf
1	805.6	0.15	0.75	208.48928	46.87048
2	805.6	0.16	0.65	192.37728	43.24834
3	805.6	0.165	0.5	184.32128	41.43727
4	805.6	0.165	0.65	184.32128	41.43727
5	805.6	0.165	0.75	184.32128	41.43727
Average:	805.6	0.161	0.66	190.76608	42.88612

Looking at the average values of the 5 trials, it can be seen that similar results were obtained when compared to the results of the first stage of this testing. While on the first stage the average distance the ball traveled was 0.68 meters or 68 cm, on this second stage, that value is 0.66 meters or 66 cm. Even though this is subjected to human errors by the way the distance traveled is measured by visual inspection, the fact that both numbers are pretty close to each other says that at the time of performing in the air, the ball will travel a distance close to 0.65 m.

Now the results of the testing of springs #3 are shown in table 28.

Table 28: Second Stage Testing - Results Springs #3

Trial	K of the spring (N/m)	Length of Springs Compressed (m)	Distance travelled by the ball from the ramp (m)	Force exerted to compress the springs [F=KX*2 b/c there are 2 springs] (Newtons)	Force in lbf
1	1082	0.19	0.65	193.4616	43.4921
2	1082	0.19	0.55	193.4616	43.4921
3	1082	0.18	0.6	215.1016	48.35699
4	1082	0.18	0.55	215.1016	48.35699
5	1082	0.19	0.55	193.4616	43.4921
Average:	1082	0.186	0.58	202.1176	45.43806

Looking at the average distance the ball traveled when using springs #3 it can be seen that the distance is 0.58 meters or 58 cm, which is a smaller value than the 66 cm obtained using springs #2. Even though the rate of springs #3 is higher than the rate of springs #2, the distance at which the springs were compressed manually was higher; therefore, weakening the force the springs can produce and reducing the distance the ball can travel once launched. If a comparison is made between the average force produced by springs #2 and #3, it can be noticed that the previous statement is wrong because springs #3 in fact are producing a little bit more force than #2; therefore, something else is interfering with the distance the ball can travel.

In conclusion, springs #2 are confirmed to be part of the releasing mechanism.

9.2 Overall System Performance Test

Once the release mechanism is attached to the quadcopter, the effectiveness of the overall system will be tested by dropping the fire extinguishing ball in open spaces and recording the distance the ball traveled while the quadcopter was flying.

Since it is very dangerous for a person to be close to the quadcopter once the motors are on, a special structure was designed in order to know the exact distance the ball traveled. This structure is shown in figure 58.

Figure 58: Structure for testing of release mechanism while quadcopter is flying

The structure is made of three wood boards in the shape of the letter H. The board in the center has a ruler that can measure up to 1 meter. This structure was used by having the quadcopter stay still at the beginning of the ruler and a video was being recorded. At the moment of launch, the quadcopter needed to be at the zero marking of the ruler, and then by visual inspection of one of the team members the distance the ball traveled was going to be known. The team thought of doing 5 trials in order to come up with an average of the distance the ball traveled, the same number of trials as in the first stages of testing.

At the point of submitting this report, this testing was only done once, one trial. When the mechanism was activated to launch the ball, it was not located at the beginning of the ruler; therefore, it was not possible to measure the exact distance the ball traveled. On that trial one of the motors of the quadcopter burned unexpectedly and the vehicle crashed. It did not cause major damages on the quadcopter, but since this test was done less than a week before the submittal of this report and the motors are ordered online and come from another country, there was not enough time to repeat the testing. Even though, by the time this team has to present this project to the Industry Advisory Board, this testing will be completed and the results will be shown.

10. Lessons Learned

When the development of the design, assembly and testing of this unmanned aerial vehicle with fire extinguishing purposes was done, some ideas came to the mind of this team regarding the things and decisions that could have been done differently in order to obtain alternative and efficient results. These different decisions will be called the lessons learned while doing this project, and will be explained in the following paragraphs.

First of all, more time should have been allotted to performing the testing. Most of the components of this project are ordered online and come from different parts of the world; therefore, there is a significant amount of days between the day a part of ordered and the day the part is in the hands of the team members.

The second lesson learned while coming up with the designs of the ring and the hook was to look for different materials to manufacture those components. The material selected has excelled in its performance; but other materials that maybe were riskier to use should have also been tried just to compare between them.

11. Conclusions

The final intention of this design is to improve the existing ways in which fires are extinguished using a quadcopter as a vehicle of first fire response. Having this system in place, the fire department will have the ability of control a fire on high rise buildings by deploying one or more fire extinguishing balls.

In the future, the main goal is going to be that the UAVs with fire extinguishing purposes are going to be built with compliance of the fire department requirements for prevention and control of fires on buildings.

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13. Appendices

13.1 Appendix A: Properties of materials used in the prototype

13.1.1 Properties of G-10

Physical Properties	Metric	English	Comments
Density	1.80 g/cc	0.0650 lb/in³	ASTM D792
Water Absorption	0.10 %	0.10 %	24 hrs.; ASTM D570

Mechanical Properties	Metric	English	Comments
Hardness, Rockwell M	110	110	ASTM D785
Tensile Strength at Break	262 MPa	38000 psi	Crosswise; ASTM D638
	310 MPa	45000 psi	Lengthwise; ASTM D638
Flexural Strength	448 MPa	65000 psi	Crosswise; ASTM D790
	517 MPa	75000 psi	Lengthwise; ASTM D790
Flexural Modulus	16.5 GPa	2400 ksi	Crosswise; ASTM D790
	18.6 GPa	2700 ksi	Lengthwise; ASTM D790
Compressive Strength	448 MPa	65000 psi	ASTM D695
Izod Impact, Notched	6.41 J/cm	12.0 ft-lb/in	Crosswise; ASTM D256
	7.47 J/cm	14.0 ft-lb/in	Lengthwise; ASTM D256

Electrical Properties	Metric	English	Comments
Dielectric Constant	5.0 @Frequency 1e+6 Hz	5.0 @Frequency 1e+6 Hz	ASTM D150
Dielectric Strength	31.5 kV/mm	800 kV/in	Short Time; 1/8 inch; ASTM D149
Dissipation Factor	0.019 @Frequency 1e+6 Hz	0.019 @Frequency 1e+6 Hz	ASTM D150
Arc Resistance	100 sec	100 sec	ASTM D495

Thermal Properties	Metric	English	Comments
CTE, linear	9.90 µm/m-°C @Temperature 20.0 °C	5.50 µin/in-°F @Temperature 68.0 °F	Lengthwise; ASTM D696
CTE, linear, Transverse to Flow	11.9 µm/m-°C @Temperature 20.0 °C	6.61 µin/in-°F @Temperature 68.0 °F	Crosswise; Transverse to Flow; ASTM D696
Thermal Conductivity	0.288 W/m-K	2.00 BTU-in/hr-ft²-°F	ASTM C177
Maximum Service Temperature, Air	140 °C	284 °F	
Flammability, UL94	HB	HB	

13.1.2 Properties of Aluminum T6061

Physical Properties	Metric	English	Comments
Density			

Mechanical Properties	Metric	English	Comments
Tensile Strength, Ultimate	290 MPa	42000 psi	AA; Typical
Tensile Strength, Yield	255 MPa	37000 psi	AA; Typical
Elongation at Break	12 % @Thickness 1.59 mm	12 % @Thickness 0.0625 in	AA; Typical
Modulus of Elasticity	68.9 GPa	10000 ksi	AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.
Shear Strength			

Processing Properties	Metric	English	Comments
Solution Temperature	529 °C	985 °F	
Aging Temperature	160 °C	320 °F	Rolled or drawn products; hold at temperature for 18 hr

Component Elements Properties	Metric	English	Comments
Aluminum, Al	95.8 - 98.6 %	95.8 - 98.6 %	As remainder
Chromium, Cr	0.040 - 0.35 %	0.040 - 0.35 %	
Copper, Cu	0.15 - 0.40 %	0.15 - 0.40 %	
Iron, Fe	<= 0.70 %	<= 0.70 %	
Magnesium, Mg	0.80 - 1.2 %	0.80 - 1.2 %	
Manganese, Mn	<= 0.15 %	<= 0.15 %	
Other, each	<= 0.050 %	<= 0.050 %	
Other, total	<= 0.15 %	<= 0.15 %	

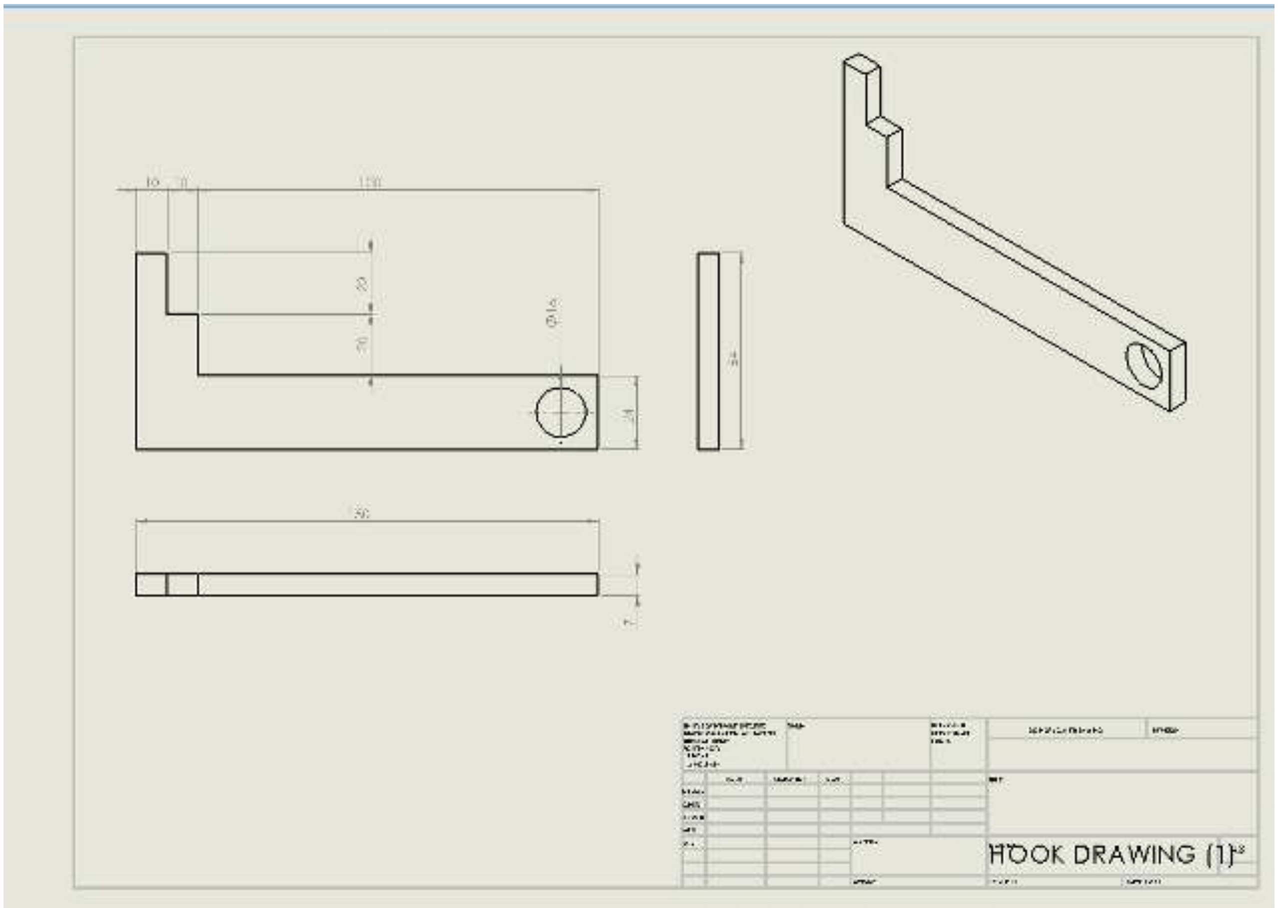
Silicon, Si	0.40 - 0.80 %	0.40 - 0.80 %
Titanium, Ti	<= 0.15 %	<= 0.15 %
Zinc, Zn	<= 0.25 %	<= 0.25 %

13.2Appendix B: Characteristics of springs in English Units.

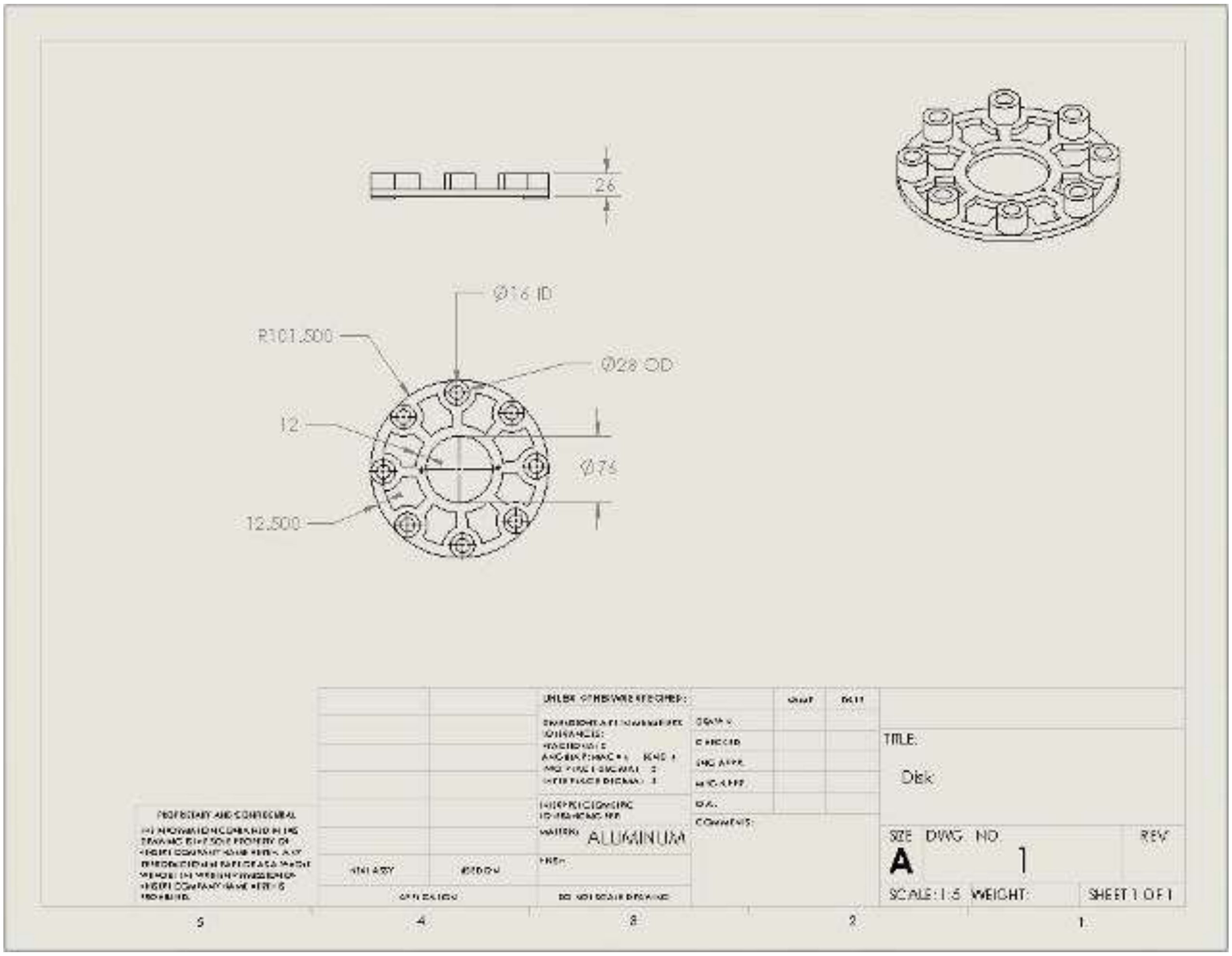
Characteristic	Spring A (Model 610)	Spring B (Model C32-095-384)
Type	compression	compression
Outside Diameter (in.)	0.968	0.97
Inside Diamter (in.)	0.786	0.78
Overall Length (in.)	11	12
Wire Diameter (in.)	0.091	0.095
Rate (lbs./in.)	3.75	4.6
Load (lbs.)	22.78	30.9
Deflection at Load (in.)	6.079	6.717
Pitch (in.)	0.28	0.311
Ends	open	closed and ground
Material	hard drawn	music wire
Finish	plain	plain

13.3 Appendix C: Engineering Drawings

13.3.1 Hook



13.2.2 Ring


26
Ø16 ID
R101.500
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1
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SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
DO NOT SCALE DRAWING