EXPLORER POST 1010
PRELIMINARY DESIGN REVIEW REPORT

October 31, 2021

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I) Summary of PDR report

Team Summary

Team Name: Flamingos
Institution: Explorer Post 1010
Mailing Address: Rockville Science Center, PO Box 1084, Rockville, MD 20849

Team Leaders: Jack Sherling, Samuel Troost
Safety Officer: Peter Camobreco
STEM Coordinator: Jayden Ku
Media Coordinator: Ethan Goldberg

Our team is sponsored by the Rockville Science Center. They help us find qualified adults to mentor our teams and work with the library to provide meeting space. We help the Center with staffing their outreach events which allows our student members to earn Student Service Learning hours. Post families financially support the Center and participate in other Center programs. 30 cumulative hours have been spent on the PDR.

Mentor

Jonathan Rains (L2 Certification)
jrains@comcast.net

Launch Vehicle Summary

Official Target Altitude

3750 ft

Preliminary Motor Choice

Cesaroni J357-14

Size and Mass of Individual Sections

Upper Section: 10.16 cm diameter, 58.3 cm long, mass of 713 grams
Lower Section: 10.16 cm diameter, 112 cm, mass of 1704 grams

Recovery system

The lower section will be recovered by a 12” drogue chute and a 36” main parachute. The upper section will be recovered by a guided parafoil.

Payload Summary

Payload Title

Autonomous Guided Recovery System

Experiment Summary

The upper section of the rocket will deploy a guided parafoil after apogee. A servo motor will actuate brake lines on the parafoil to autonomously guide it back to the launch site.

II) Changes made since Proposal

Changes made to vehicle criteria

The new payload requires a separable section of the rocket which will be recovered separately under its own guided parafoil. This section will consist of an upper portion of the airframe including the rocket's nose cone. The rocket diameter was increased from 3 inches to 4 inches to better accommodate avionics, and the rocket length is now 64.6 inches.

Changes made to payload criteria

Our team decided to revise the payload due to the feasibility and constraints of the project. Building, designing, and deploying an autonomous quadcopter in the allotted time would be very difficult. Therefore, the payload is no longer a quadcopter, but a guided parafoil system (see Payload Criteria). The payload will autonomously return to the launch site during descent under the parafoil.

Changes made to project plan

The budgeting and funding plan remains largely the same as originally proposed, although more donations and contributions are now expected to be collected. This is mostly to accommodate our new payload and rocket criteria. The project timeline is very similar to what was proposed, but we expect to begin building and testing the payload earlier due to its new scope.

III) Vehicle Criteria

Selection, Design, and Rationale of Launch Vehicle

Mission Statement

The mission is to successfully launch the rocket to 3750 feet, carry and deploy the payload, and recover the rocket safely. After apogee, the payload will actively guide itself back to the launch site. This technical challenge supports our team mission to promote engineering careers in younger students.

Mission Success Criteria

In order for the mission to be successful, the rocket must adhere to all specific requirements outlined by NASA. The rocket must reach an altitude of between 3,500 and 5,500 ft. The rocket and payload must be recovered safely. The payload must autonomously return to the launch site within a reasonable distance.

Subsystem Design

Upper Section

The upper section is the portion of the rocket above the avionics bay and drogue chute, including the payload. This section will be recovered separately from the rest of the rocket, under a guided parafoil. The nose cone will be tangent ogive shaped. We considered ellipsoid and parabolic nose cones, but based on simulations tangent ogive shapes performed the best. Fiberglass and polypropylene plastic were considered as nose cone materials, but fiberglass was ruled out because of its high cost and mass. The rocket won't be travelling past subsonic speeds, so polypropylene nosecones will be structurally sound enough.

Lower Section

The lower section is the portion of the rocket, including the avionics bay, below the drogue chute separation point. Similar to the upper section, we had a choice between a fiberglass or thick walled paper tube airframe. The obvious benefit of fiberglass is its high strength and rigidity, but again it suffers from high cost and mass. Another large drawback of composites are their inherent difficulty to work with in a student lab environment.

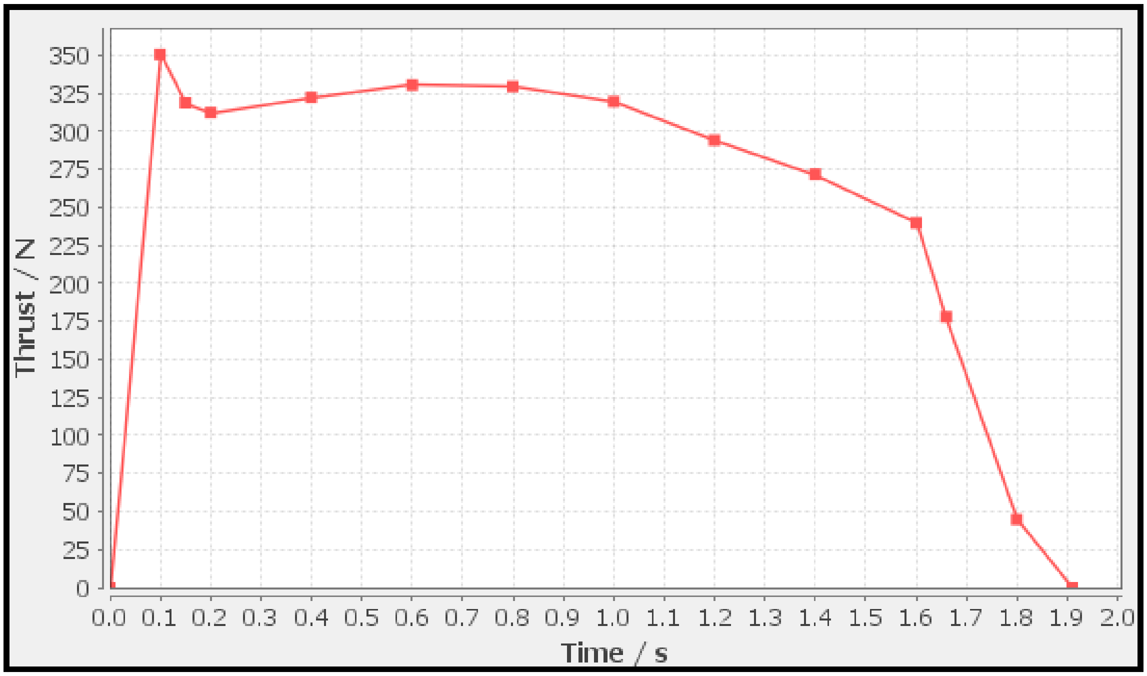
Possible materials for the centering rings and fins were fiberglass and plywood, but for the reasons stated earlier plywood was selected. There were several alternatives for the fin shape, such as trapezoidal fins, tapered swept back fins, or clipped delta fins. Trapezoidal and clipped delta fins are strong and aerodynamic shapes. Tapered swept back fins ideally move the center of pressure farther back, but could experience flutter if the fin isn't built strong enough. Alternatives for the motor mount varied in dimensions.

29mm to 54mm diameters for the motor mount were options, however for the power required a 38mm mount was the most suitable. Both a 3" and 4" body tube diameter were considered. Originally, the rocket was to use a 3" tube diameter and launch on an I-class motor. Our team decided to increase the diameter to 4" and use a J-class motor to give more margin for our payload, especially avionics.

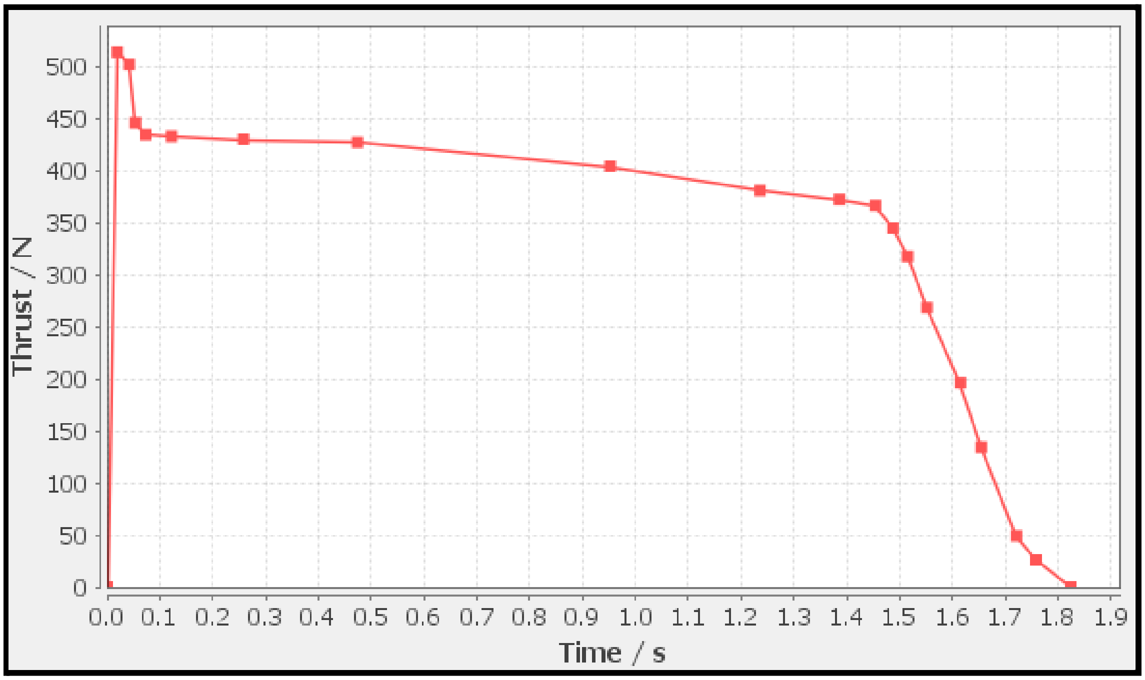
Our team considered guiding the entire rocket under the parafoil during descent. This would reduce the complexity of the system, but introduce more risk to the rocket's recovery. We decided to have the payload be recovered entirely separate from the rest of the rocket under the parafoil, so the payload (including the nose cone) will separate from above the avionics bay.

Many options for motors were considered. Through openrocket, different motors were experimented with to see their performance on the flight. The Cesaroni I285-14, which has a mass of 601 grams, was considered at first but was dropped after the decision was made to increase the diameter from 3" to 4".

The thrust curve for the Cesaroni I285-14 is shown below.



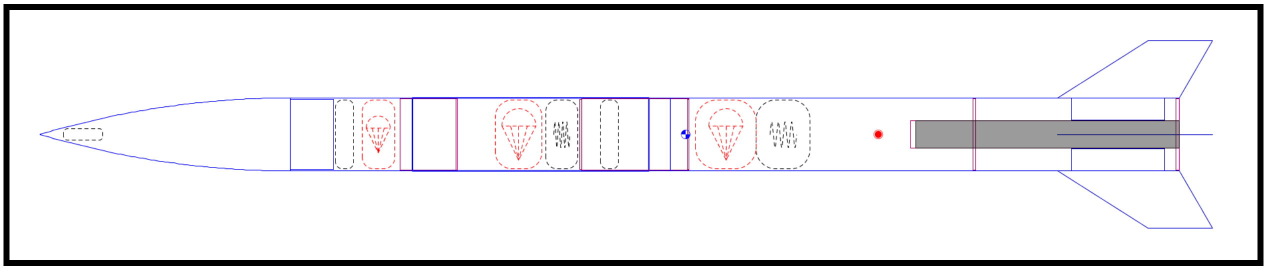
The current leading motor is the Cesaroni J357-14, which has a mass of 601 grams. The thrust curve for the Cesaroni J357-14 is shown below.



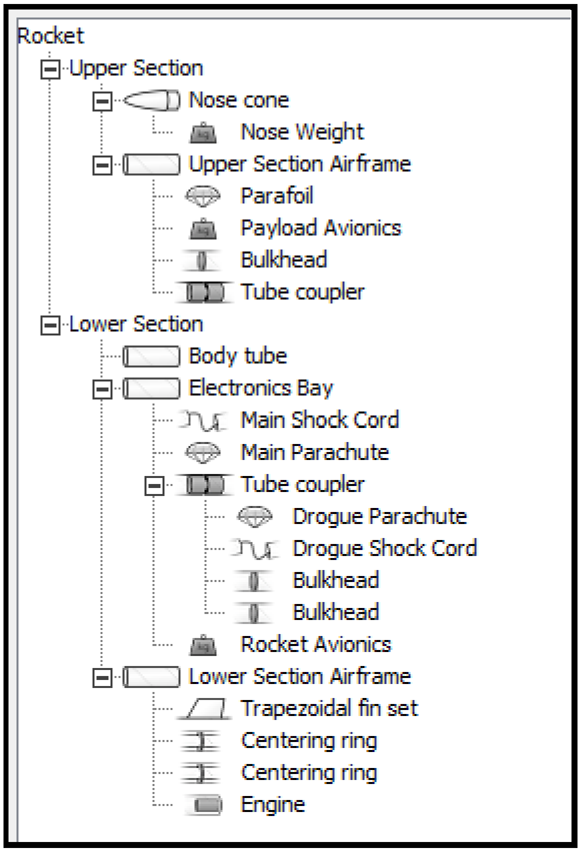
Leading Design

The upper section will be 58.3 cm long including the nose cone. As explained earlier, the nose cone material was chosen to be polypropylene due to its inexpensiveness and light weight. The nose cone will be tangent ogive shaped because of its aerodynamic properties. The upper section will be recovered separately from the rest of the rocket under its guided parafoil. This entire upper section will have a mass of approximately 713 grams.

The lower section will be 112 cm long. The air frame will be made out of thick walled paper tubes again due to their inexpensiveness and light weight. The larger 4 inch diameter was selected to allow more space for avionics. The fins will use “through-the-wall” mounting, which allows for the use of internal fillets to increase fin strength. The lower section will have a mass of approximately 1704 grams, including the motor.



Current leading design of launch vehicle diagram



- Rocket
  - Upper Section
    - Nose cone
      - Nose Weight
    - Upper Section Airframe
      - Parafoil
      - Payload Avionics
      - Bulkhead
      - Tube coupler
  - Lower Section
    - Body tube
    - Electronics Bay
      - Main Shock Cord
      - Main Parachute
      - Tube coupler
        - Drogue Parachute
        - Drogue Shock Cord
        - Bulkhead
        - Bulkhead
      - Rocket Avionics
    - Lower Section Airframe
      - Trapezoidal fin set
      - Centering ring
      - Centering ring
      - Engine

Launch vehicle part tree

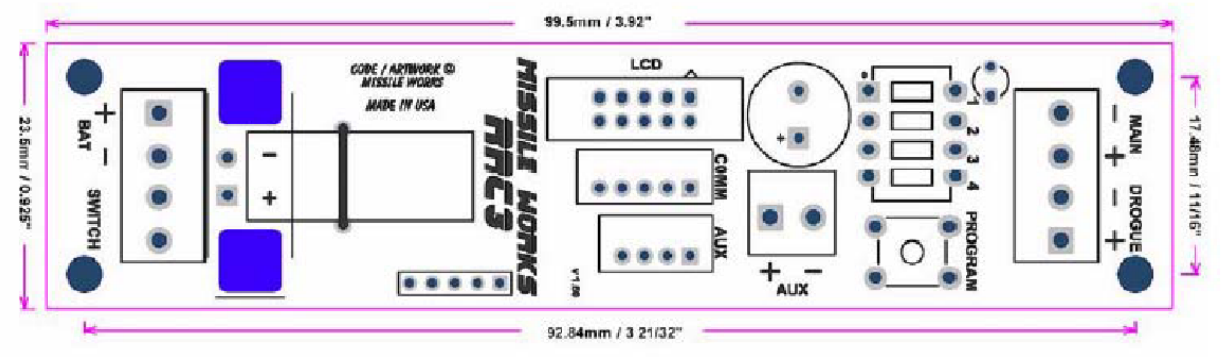
Recovery Subsystem

We decided for the ideal launch vehicle impact velocity to be between 5 m/s and 7 m/s. Experimenting in OpenRocket and using the predicted mass of the launch vehicle, our team decided to use a 36” main parachute which put our impact velocity at an acceptable 6.12 m/s.

Our team compared several options of primary parachutes, such as the 36” Elliptical Fruity Chute or Apogee Rocket’s Printed Nylon Parachute. The Fruity Chute offers tight packing lightweight cloth and heavy strength, the downside being high cost. Options of drogue chutes were generally the same, with Fruity Chutes having the most suitable options but significantly more expensive parachutes. Our team ultimately chose to use the 36” Elliptical Fruity Chute.

The rocket shock cords for both the drogue chute and the main chute need to be strong enough to absorb the force of parachute deployment. The two possible material choices were tubular nylon and kevlar line. Tubular nylon is far weaker than kevlar, but has a lower chance of zippering the rocket body tube. We chose to use kevlar line due to it’s high strength. Kevlar line comes in different strength ratings, 1000 lb rated line is the most suitable option for our purposes because it matches the strength the shock cord will require. Kevlar line is not very elastic, so a 609.6 cm line is needed to absorb the force of drogue parachute deployment.

The electronics bay will be 15 cm long. The bay consists of a coupler, a body tube section, bulkheads, and an electronics sled for the dual-deploy computer. The bulkheads will have eyebolts for both the main and the drogue parachute. Our team chose the RRC3 “Sport” Altimeter due to its specifications and popularity for rocketry use. The RRC3 altimeter comes completely assembled out of the box, which reduces the chance of human error while assembling and soldering. Furthermore, the rocket will use two redundant altimeters and charges in the unlikely chance one fails to function. The electronics bay will have a mass of approximately 699 grams.

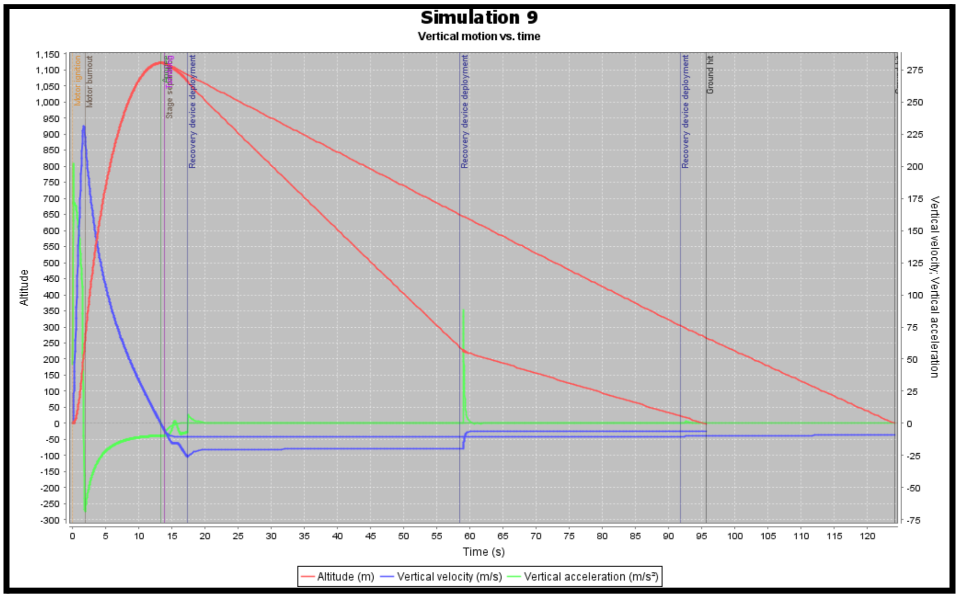


RRC3 Pinout Diagram

Mission Performance Predictions

The goal of the flight is to exactly reach an apogee of 3750 feet and meet all of the earlier outlined mission success criteria.

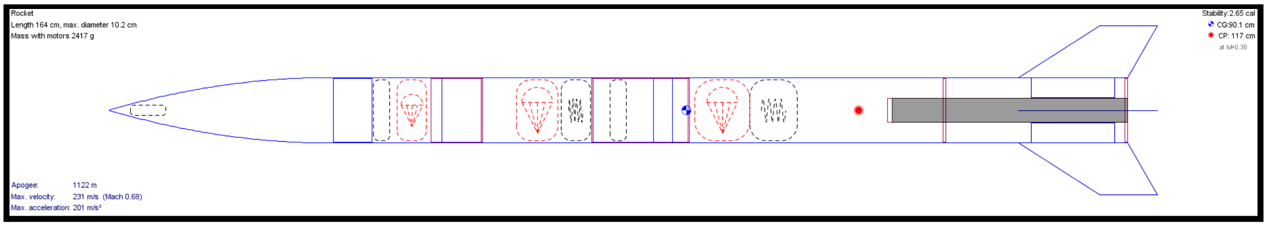
Flight profile simulations



Flight simulation of altitude (red), vertical acceleration (blue), and vertical velocity (green) over time on a Cesaroni J357-14. The lower red line represents the launch vehicle, and the upper is the payload descending under a placeholder parachute. Simulated by OpenRocket.

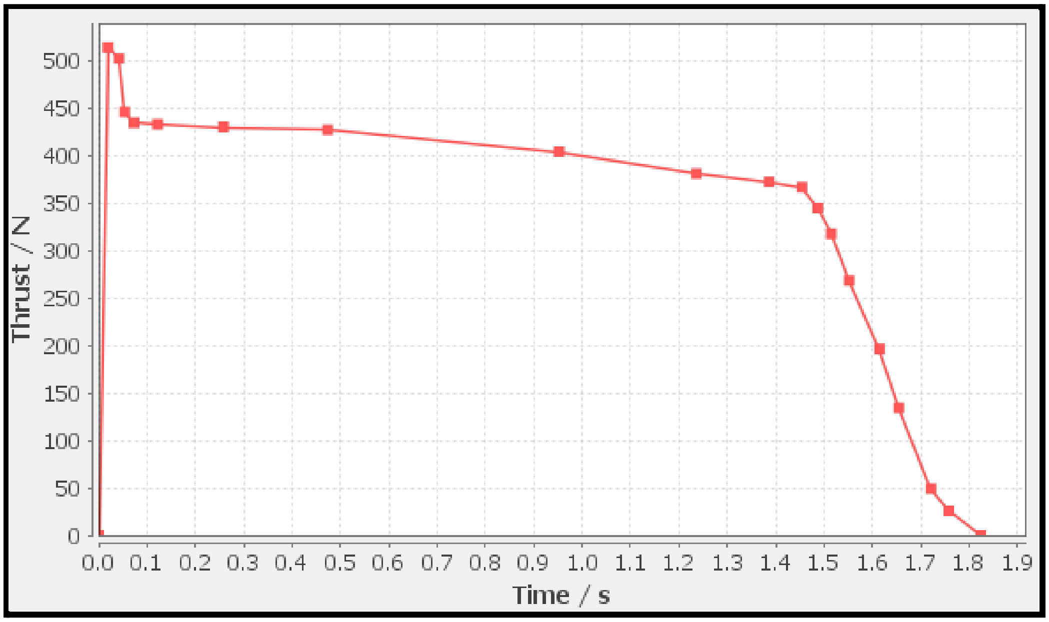
Note:

- *Figures on graph are in meters, not feet*
- *Payload (red line on far right) is under a placeholder parachute in OpenRocket, actual descent time will be less than 90 seconds using a chute release system*



Model of the launch vehicle in ready to fly configuration.

Before ignition, the center of pressure of the rocket is approximately 117 cm from the tip. The center of mass is approximately 90.1 cm from the tip. The rocket has a stability margin of 2.65 calibers upon liftoff. The total mass with the unburned motor is 2417 grams.



Simulated thrust curve of the Cesaroni J357-14 motor.

Kinetic Energy Analysis

Based on openrocket simulations, the ground hit velocity is predicted to be approximately 6.12 m/s. The empty mass of the rocket is about 1816 grams. Using the formula $Ke = mv^2/2$, the kinetic energy at impact with the ground can be determined.

Subsection	Kinetic Energy (Ft-lbs)
Electronics Bay	9.65
Lower Section	18.88
Upper Section (Payload)	12.86

Kinetic energy at impact of each subsection

Wind Drift Analysis

The following table lists the drift distances in winds of 0 mph, 5 mph, 10 mph, 15 mph, and 20 mph. The drift distance was derived by multiplying descent time (87.33 seconds) by wind speed.

Drift distance using descent time multiplied by wind speed

Wind speed (mph)	Drift distance (ft)
0	0
5	640.4
10	1280.9
15	1921.3
20	2561.7

Drift distance found using OpenRocket's predictions

Wind speed (mph)	Drift distance (ft)
0	0
5	368.4
10	761.2
15	1161.7
20	1560.0

The distances derived from OpenRocket were increasingly less than those calculated by hand, because those calculated show the worst case scenario conditions when the rocket's drift matches the wind speed. OpenRocket shows the more realistic scenario.

IV) Payload Criteria

Selection, Design, and Rationale of Payload

Parafoil Design

The payload is a parafoil, which will guide itself as it descends. Two servo motors will actuate the brake lines to bank the parafoil left and right. A successful experiment will consist of servos correcting the parafoil's angle with the payload landing at the desired location. The payload will use onboard GPS data to determine how the parafoil should be oriented.

Our team decided on this payload because of its practical use. Designating a location for the rocket to land can promote efficiency because launch crews will know--within a reasonable margin of error--where the rocket will land. In addition, it promotes safety because the rocket is unlikely to land on top of infrastructure or personnel.

There are multiple options for parafoil design, such as a ram-air inflated parafoil and a single skin paraglider. A single skin paraglider wing would offer much better performance under flight, but it's very difficult to deploy. For that reason, our team opted to use a ram air parafoil.

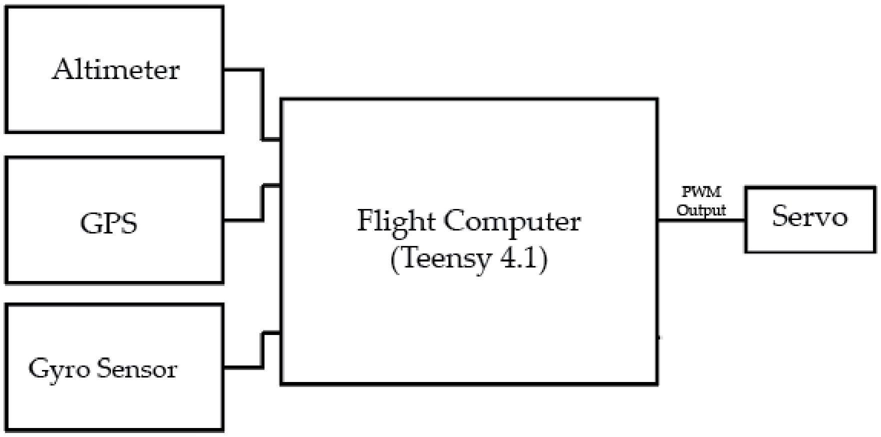
The ram air parafoil will need a drogue parachute to extract the parafoil. The onboard computer will verify if the parafoil is extracted by using its change in vertical speed. Once the parafoil is deployed, special 3D printed winches will actuate a parafoil brake line to guide the payload back to the launch site.

A brake line will control the parafoil. One line is longer than the other and attached to a servo. Initially, the servo is set so that the long line is relatively equal in length to the shorter line outside the rocket. To turn one direction, we let the line out more so that drag affects that direction more. To turn the other direction, we pull the line in more so that the shorter line is relatively longer outside the rocket, making air resistance affect that direction more. Therefore, we can direct the payload section anywhere so long as the rocket is high enough to reach the location.

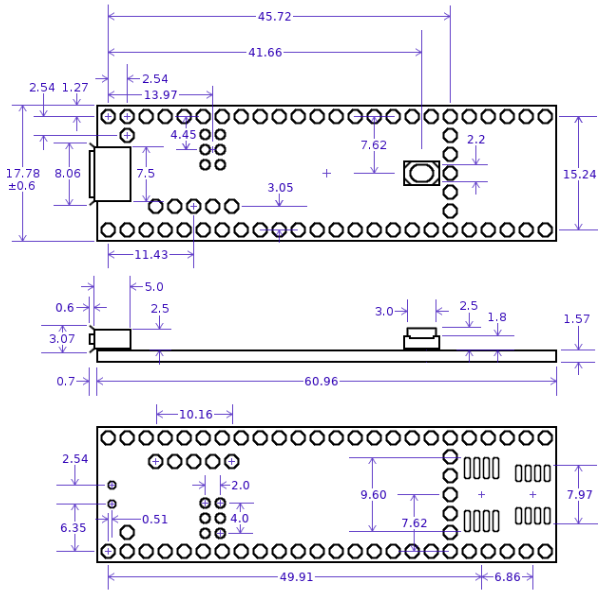
We have a chute release on the parafoil that will release the parafoil at 600 feet. The bundled up parafoil acts as a drogue prior to 600 feet.

Payload Avionics

Many options of microcontrollers are commercially available, including Teensy, Adafruit, and various Arduino boards. Our team chose to use the Teensy 4.1 board due to its comparatively high performance.



Block Diagram of Payload Avionics



Dimensioned diagram of the Teensy 4.1

Before adjusting the parafoil lines, we will determine the direction of the rocket's velocity using the gyro sensor. If the rocket is already heading toward the target, no adjustments are needed. The gyro sensor also determines how much we need to adjust the parafoil line.

A known problem with parafoil guidance is the tendency to oscillate out of control while turning. There are a few methods to stop this occurrence. One option is to limit the maximum bank angle of the parafoil, however this will severely limit the turning range of the payload. Our team decided to use a “bang-bang” feedback controller to retain control, by only measuring direction while the control input is neutral. The control input will constantly reset back to zero preventing uncontrolled spiralling.

Interfaces Between Payload and Launch Vehicle

The payload will be retained inside a body tube for the entire flight. After apogee, the upper section of the rocket with the payload will separate and descend independently from the rocket.

V) Safety

All members of the Post undergo safety training from qualified makerspace personnel prior to using any of the equipment. All construction machinery used will be supervised by at least one other person. A Fire Extinguisher will be accessible during any construction activity There will be adult support when using any construction machinery. Motors will be handled and transported by Jonathan Rains, a NAR member with a L2 certification.

SAFETY KEY

Severity	**Likelihood Scale**
1 - Low	1 - Not Likely
2 - Medium	5 - Very Likely
3 - High	

Personnel Hazard Analysis

Hazard	**Cause of Hazard**	**Effect of Hazard**	**Severity**	**Likelihood**	**Mitigation**
Sharp objects	Misuse of cutting tools during rocket construction	Personal injury to user and damage to hardware	2	3	Proper tool training for all team members
Toxic Fumes	Use of adhesive and glue without proper safety precautions	Exposure to carcinogens	2	2	Wear proper safety equipment and take necessary precautions
Glue in eyes and hands	Improper use of glue	Bonding of glue to skin and eyes	1	1	Use of proper PPE while working with adhesives
Burns	Laser cutters,	Need for	2	3	Limit

	hot glue, soldering	medical attention, burns			exposure to hot materials and use insulation
Electrical shock	Tools grounded incorrectly, battery malfunctions	Burns	3	2	Insure a proper ground and use electric safe equipment
Exposure to loud noises	Heavy machinery, rocket motors	Partly or severe hearing loss	1	1	Ear plugs and other forms of hearing protection
Splinters	Working with wood	Infection	1	1	Gloves
Lasers getting in eyes	Working with laser cutter	Blindness	3	2	Eye protection
Falling Debris	Rocket recovery failure, falling boxes	Concussion, Bruising	3	2	Head protection and awareness of your surroundings
Tripping hazards	Loose cords and debris on floor	Concussion, broken wrist and bones	2	4	Awareness of surroundings
Black powder explosion	Misuse of black powder	Burns, blindness	3	2	Limit exposure to black powder

Environmental Concerns

Hazard	**Cause of Hazard**	**Effect of Hazard**	**Severity**	**Likelihood**	**Mitigation**
Wind	High wind speeds	Launch rail falling over Rocket going off course	3	2	Test wind speeds before launching rocket
Rain	Rainy weather	Damage to electronics, deterioration of rocket, and causing the rocket to go off course	3	1	Make sure we are launching on a clear day with no rain
Snow/Cold Weather	Low temperature outside	Damage to rocket, altimeters not reading	3	1	Check weather before launch and do not launch when weather is to cold
Litter caused by rocket	Wadding materials escaping the rocket	Damage to the local environment	2	3	Use proper amounts of wadding

Before every launch we will check our rocket to make sure everything is working correctly and we have no broken parts. We will also obey the High Power Rocket Safety Code provided by NASA.

All launch activities will be monitored by NAR officials. All launches are conducted by a range safety officer in compliance with the Safety Code of the National Association of Rocketry as well as NFPA 1127: Code for High Power Rocketry.

For launch sites, we have access to locations previously used for the Tripoli LDRS National event and the National Battle of the Rockets competition.

On the launch pad, only team members, mentors, and NAR officials will be present. We will ensure that no power is on the igniter leads before loading. We will ensure that the rocket is stable on the launch rail after placing it on. We will activate the electronics and drone and ensure that they are working properly with radio signals and LED displays that signify statuses. We will then load up igniters.

The team will exercise extreme caution before launching any rocket. The team will not launch:

1. At any altitude where clouds or obscuring phenomena of more than five tenths coverage prevails;
2. At any altitude where the horizontal visibility is less than five miles;
3. Into any cloud;
4. Between sunset and sunrise without prior authorization from the FAA;
5. Located within 9.26 kilometers (5 nautical miles) of any airport boundary without prior authorization from the
6. In controlled airspace without prior authorization from the FAA;
7. Unless you observe the greater of the following separation distances from any person or property that is not associated with the operations applies:
   (1) Not less than one quarter the maximum expected altitude;
   (2) 457 meters (1,500 ft.);
8. Unless a person at least eighteen years old is present, is charged with ensuring the safety of the operation, and has final approval authority for initiating high-power rocket flight; and
9. Unless reasonable precautions are provided to report and control a fire caused by rocket activities.

Project Risks FMEA

Hazard	**Cause of Hazard**	**Effect of Hazard**	**Severity**	**Likelihood**	**Mitigation**
Damage during transportation	Mishandling the rocket before flight	Broken parts	3	2	Proper handling and protective case for the rocket
Broken launch lugs	Improper placement on	Unable to launch rocket	3	1	Proper installation

	launch rail				on launch rail
Misfire	Bad ignitor	Rocket would not launch	1	3	Check ignitors before launch
Ejection charge not deploying	Problems with coding in the ejection charge, black powder, or ignitor	Parachutes would not deploy, rocket landing speed substantially increases	3	2	Check the black powder and ignitor before launching
Premature ejection charge	A problem with the coding	Damage to the landscape, launch rail, and rocket	3	2	Review coding before flight, ensure altimeters read accurate data
Parachute not inflating	Tangling of Parachute,	Increased landing velocity of Rocket, damage to hardware	3	2	Ensure parachute lines are not tangled

All team members understand and will abide to the following safety regulations:

1. Range safety inspections will be conducted on each rocket before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program.
2. The Range Safety Officer has the final say on all rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.
3. The team mentor is ultimately responsible for the safe flight and recovery of the team's rocket. Therefore, a team will not fly a rocket until the mentor has reviewed the design, examined the build and is satisfied the rocket meets established amateur rocketry design and safety guidelines.
4. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

VI) Project Plan

Requirements Verification

Vehicle

To confirm that our rocket's flights observe NASA's regulations of an apogee between 3,500 and 5,500 feet as well as no more than 2,500 feet of drift, we will perform test launches of the rocket and perform post-launch analysis. We have also ensured that our design observes NASA's design requirements, such as couplers being at least 1 body in diameter and the rocket having no more than 4 separation points.

We will record all flight data, not only as evidence of flight for NASA's regulation, but to determine changes we can make to the design, such as small weight differences, to improve future flights.

Recovery

The lower section of the rocket will be recovered via drogue and main parachute, observing NASA's regulation. The upper (payload) section of the rocket will be recovered via its own recovery system, the parafoil, abiding NASA's regulation.

Each section of the rocket's descent is less than 90 seconds.

Payload

We will only adjust parafoil lines below 400 feet, complying with NASA's regulation. We will also have override control from the ground.

We will also have override functionality so we can control the parafoil from the ground.

The requirement for our payload is to autonomously return to the launch site within a reasonable distance. This will be verified by measuring the distance of the payload section to the target after launch.

Budgeting and Timeline

Complete Budgeting Outline

Item	**Description** (If applicable)	**Quantity**	**Cost**

Cesaroni J357-14 Motor	Rocket motors	3	240
Rocket Body Tubes	4 inch diameter paper body tubes	2	35
Subscale Rocket Body Tubes	2.6 inch diameter paper body tubes	2	25
Main Parachute	36 inches	1	30
Drogue Parachute	15 inches	1	20
Parafoil	Ram-Air System	1	50
GPS Unit		1	40
PCB Fabrication		N/A	60
Jumper Wires	Male to Male and Male to Female Package	1	10
Teensy 4.1	Microcontroller	1	30
Servo motor	Pulls Parafoil Lines	1	15
Battery	Lithium Ion Battery; Powers Electronics	2	40
Ejection Charges		12	60
Altimeter	RRC3 “Sport”	2	150
Nose Cones	For Main and Sub-scale Rockets	2	50
Maintenance Expenses	General Repairs and Replacements	N/A	200
TOTAL			1055

Funding Plan

Source	**Amount**

Organization Earnings from The American Rocketry Challenge 2nd Place Finish	1000
Membership Fees	1600
Donations and Contributions	600
Total	3200

Project Timeline

Date(s)	**Description**
Late Oct.	Submit Preliminary Design Review
Nov.	STEM Engagement Events 1 and 2
Nov.-Dec.	Build Sub-scale Rocket
Dec.	STEM Engagement Events 3 and 4
Late Dec.	Launch Sub-scale Rocket
Dec. 2021-Jan. 2022	Write and Submit Critical Design Review
Jan.	STEM Engagement Events 5 and 6
Feb.	Finish Build Final Rocket and Payload
Feb.	Flight Test 1 (Vehicle Demonstration)
Feb.	STEM Engagement Event 7
Mar.	Flight Test 2 (Payload Demonstration)
Mar.	STEM Engagement Event 8
Apr. 20	Huntsville Launch Week
May	Post-Launch Assessment