NASA STUDENT LAUNCH

2022-2023

Flight Readiness Review

University of South Florida

Society of Aeronautics and Rocketry

4202 East Fowler Avenue, MSC Box #197

March 6th, 2023

UNIVERSITY of SOUTH FLORIDA
College of Engineering

Table of Contents

Table of Contents 2
Table of Figures 4
1. Summary of CDR Report 7
a. Team Summary 7
i. Team name and mailing address 7
ii. Declared final launch location 7
iii. Mentor name, TRA#, certification level, and contact information 7
iv. Documented hours spent working on the FRR milestone 7
v. Summary of STEM engagements 7
b. Launch Vehicle Summary 7
c. Payload Summary 7
i. Payload title 7
ii. Summarize payload experiment 7
2. Changes Made Critical Design Review 8
a. Changes made to vehicle criteria 8
b. Changes made to payload criteria 8
c. Changes made to project plan 9
3. Vehicle Criteria 9
a. Design and construction of vehicle 9
i. Changes made in launch vehicle design since CDR 9
ii. Final locations of separation and energetic locations 9
iii. Recovery features 10
iv. Flight reliability confidence 10
v. Documentation of full vehicle construction 11
vi. Schematics of as-built rocket 16
vii. Discussion of differences between built rocket and previous models 16
b. Recovery subsystems 16
i. Discussion of robustness of as-built, as-tested recovery system 16
ii. Sensitivity of recovery system to onboard devices generating electromagnetic fields 20
c. Mission performance predictions 21
i. Flight profile simulations 21
ii. Stability margin and as-built Center of Pressure/Center of Gravity 22
iii. Kinetic energy calculations 23
iv. Descent time calculations 25
v. Drift calculations 25

vi. Alternative calculation method data presentation 28
vii. Discussion of differences between calculation methods 30
viii. Performance of simulations to verify results 31
4. Payload Criteria 32
a. Payload design and testing 32
i. Changes in payload design from CDR 32
ii. Unique features of payload 33
iii. Flight reliability confidence 35
iv. Documentation of construction of payload 36
v. Schematics of as-built payload 37
vi. Differences between constructed payload and previous models 39
vii. Discussion of planned Payload Demonstration Flight 39
5. Demonstration Flights 40
a. Information of all flights flown 40
6. Safety and Procedures 41
a. Safety and environment (vehicle and payload) 41
i. Risk Level Definition 41
1. Severity 41
2. Probability 42
3. Risk Assessment Levels 42
i. Personnel Hazard Analysis 43
ii. Failure Modes and Effects Analysis 47
iii. Environmental Concerns 51
iv. Discussion of concerns moving forward 54
b. Launch operations procedures 54
i. Recovery preparation 54
ii. Payload preparation 55
iii. Electronics preparation 56
iv. Rocket preparation 57
v. Motor preparation 58
vi. Setup on launch pad 58
vii. Igniter installation 59
viii. Launch procedure 59
ix. Troubleshooting 59
x. Post-flight inspection 60
7. Project Plan 60
a. Testing 60

i. Discussion of test methodology and results 60
ii. Discussion of success of tests 62
iii. Lessons learned from tests conducted 62
iv. Differences between predicted and actual results of tests 63
b. Requirements compliance 63
i. Updated verifications plan 63
ii. Updated team-derived requirements 89
c. Budgeting and funding summary 92
i. Updated line item budget 92
ii. Updated funding plan 93
8. References **94**

Table of Figures

Fig 1: Final locations of separation and energetic locations 10

Fig 2: Creation of nose cone 12

Fig 3: Bulkheads cut using X-Carve 13

Fig 4: Cut carbon fiber ellipsoid fin prior to sanding 13

Fig 5: Epoxying rear centering ring 14

Fig 6: Epoxying front and middle centering rings 14

Fig 7: Orange fin guide used to keep fins 120 degrees apart 15

Fig 8: Fillets on booster tube and fins 15

Fig 9: Assembled launch vehicle. 16

Fig 10: 1 of 2 Bulkhead for avionics bay 16

Fig 11: 1 of 3 eye bolts for avionics bay 17

Fig 12: 1 of 6 D-links for avionics bay 17

Fig 13: Avionics Bay configuration 18

Fig 14: Assembled avionics bay 19

Fig 15: Wiring Schematic for Avionics Bay 20

Fig 16: Drawing of Avionics Bay 20

Fig 17: Flight Profile Simulation 21

Fig 18: Motor Thrust Curve of Cesaroni K780. 22

Fig 19: Diagram with marked center of pressure and center of gravity 23

Fig 20: NO WIND(Ballast weight of 15 oz) 26

Fig 21: 5 MPH WINDS (Ballast weight of 14 oz) 26

Fig 22: 10 MPH WINDS (Ballast weight of 12 oz) 27

Fig 23: 15 MPH WINDs (Ballast weight of 9 oz) 27

Fig 24: 20 MPH WINDS (Ballast weight of 9 oz) 28

Fig 25: Fruity Chutes! Descent Rate vs. Weight for Main Parachute 28

Fig 26: Fruity Chutes! Impact Energy Joules vs. Weight for Main Parachute 29

Fig 27: Fruity Chutes! Descent Rate vs. Weight for drogue parachute 29

Fig 28: Fruity Chutes! Impact Energy Joules vs. Weight for drogue Parachute 30

Fig 29: Matlab simulation values obtained. 31

Fig 30: OpenRocket simulations. 31

Fig 31: Closed payload. 33

Fig. 32: Retracted 34

Fig. 33: Expanded 34

Fig 34: Most Vertical Angle Algorithm 35

Fig 35: Dremel progress of Upper Body Tube (left) and result (right) 36

Fig 36: Position of Piston relative to Dummy Coupler 36

Fig 37: Wire management of Payload Sled 37

Fig. 38: Electronics Connection Diagram 37

Fig 39: Schematic of major payload components 38

Fig 40: Schematic of built payload sled, side one 38

Fig 41: Schematic of built payload sled, side two 38

1. Summary of CDR Report

a. Team Summary

i. Team name and mailing address

Society of Aeronautics and Rocketry (SOAR) at the University of South Florida. Mailing address: 4202 East Fowler Avenue MSC Box 197 Tampa, Florida 33620

ii. Declared final launch location

The final launch will be located in Huntsville, Alabama during the launch week at the NASA Launch Complex.

iii. Mentor name, TRA#, certification level, and contact information

Jonathan Fitzer. Member, Previous SOAR President (TRA# 17393, Certification Level III) (813) 389-3876, fitzer@mail.usf.edu

iv. Documented hours spent working on the FRR milestone

Table 1: Documented hours

Name	Hours	Name	Hours
Frank Alvarez	12	John Turner	6
Enrique Hernandez	12	Samantha Artega	5
Junior Cardenas	5	Cesar Briones	2
Alvaro Lazaro	6	Juan Peñaranda	2
Matthew Montes	3	Jacob Loufek	1

v. Summary of STEM engagements

SOAR participated in Engineering Expo 2023 at USF. A total of 252 students were engaged in an informational workshop utilizing magnets to create a tethered, hovering UFO origami craft.

b. Launch Vehicle Summary

Table 2 : Launch vehicle summary

Component	Info	Component	Info	Component	Info
Nose Cone	24"/635g	WO Ballast, Dry	8733g	Vehicle, Landing	9293g
Upper Body	51"/4122g	WO Ballast, Wet	10524g	Motor	K780 Cesaroni
Avionics Bay	12"/1300g	Vehicle, Wet	10524g	Target Apogee	4500ft
Booster Tube	38"/2676	Vehicle, Burnout	9293g	Recovery System	Dual deployment
				Rail System	1515 Aluminum

c. Payload Summary

i. Payload title

Our payload design name is the Servo Stabilized Camera System (SSCS).

ii. Summarize payload experiment

The payload design will extend a camera and servo outside the airframe using a rack and pinion. Once the camera is aligned in the z-axis, it will follow a series of tasks transmitted through radio frequency commands.

2. Changes Made Critical Design Review

a. Changes made to vehicle criteria

Due to certain payload and recovery constraints, the upper body tube of the launch vehicle was extended such that the full length of the launch vehicle increased from 113 to 119 inches. Such constraints were due to the fact that the packing size of the main parachute was too large to fit comfortably into the upper body tube, due to the payload requiring the majority of the available volume. Extending the length of the tube provided the parachute with ample room to properly deploy when needed. Due to safety concerns, the type of weights used in the ballast system were changed from small steel wheel weights, to thin, circular, glass weights. This was done out of an abundance of caution, given that in the event of total system failure in which the weights were separated from the launch vehicle, glass weights would not damage any nearby farm equipment/machinery, or any vehicles at the Huntsville launch site that could possibly drive over the weights as they would simply break apart. Steel, however, is much more durable than glass, and is much more likely to cause significant damage. The primary motor choice for the launch vehicle was also changed. With a slight increase in weight that is accompanied with manufacturing, and to ensure the vehicle is capable of being launched/re-launched in all conditions, the average thrust of the motor was increased from a K520 to a K780. This increase raised our simulated apogee value to just over our target altitude of 4,500 feet, and based on the day-of-launch environmental conditions, this projected altitude/stability can be adjusted by adding or subtracting ballast weight.

b. Changes made to payload criteria

One of the major goals of the payload team was to reduce the number and amount of wires used in the payload system. Throughout manufacturing, efforts were taken to reduce the number and amount of wires used to connect each component of the payload. This included attempts to carefully place each component on the sled first, and then determine the shortest possible wire length for much of the wiring. This could easily be done with components that were side by side on the payload sled. However, once the wiring was complete, even with multiple wire connections being less than three inches, the wiring was determined to be excessive. Having excess wire makes assembly, testing, and replacing parts very difficult. Moving forward, we intend to use a printed circuit board to replace much of the wiring.

c. Changes made to project plan

No changes have been made to the funding plan or budget to SOAR's NASA Student Launch project. The funding provided by Student Government has been enough to sustain the entirety of the project, and the budget categories have been sufficient to acquire materials required for the project.

The line item budget, expanded upon in Section 7.c.i, has been updated to reflect new items purchased by SOAR.

The team-derived requirements have remained consistent from the CDR.

3. Vehicle Criteria

a. Design and construction of vehicle

i. Changes made in launch vehicle design since CDR

The fin shapes have changed from trapezoidal to elliptical, as the team has decided it to be more aesthetically pleasing. The motor used has been resized from a Cesaroni K520 to a K780. The updated static margin of stability is detailed in section 3.c.ii to reflect the changes in mass and fin shapes.

ii. Final locations of separation and energetic locations

Following consideration from the NSL review panel, SOAR has shifted the location of the main parachute deployment energetic package to the opposite side of the parachutes, as indicated below. This will be mounted to the "dummy coupler" bulkplate with CPVC wells as if it were the bulkplate of the avionics bay. The locations of separation are on either side of the avionics bay. The locations of energetics in the diagram below are shown in yellow.

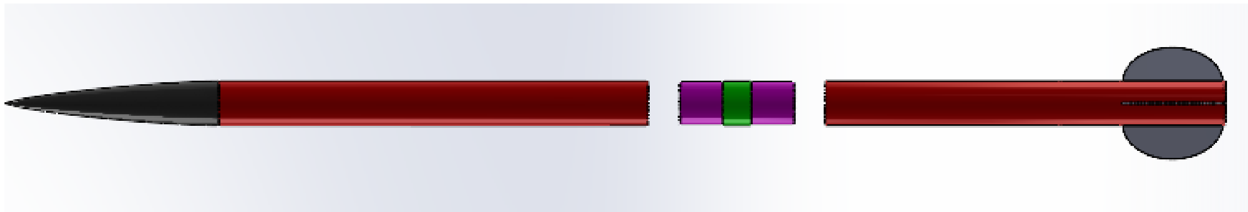

Fig 1: Final locations of separation and energetic locations

iii. Recovery features

The avionics bay sled which holds the recovery electronics was decreased in size from 11” to 10.5”. This was due to the fact that the original print of this avionics sled came into contact with the steel eye bolt nuts at the ends of the avionics bay. Decreasing the size did not affect the ability to mount our 2 altimeters and GPS module. The altimeters used are Missile Works RRC3 altimeters, which function as both deployment altimeters and recording altimeters. The GPS will be a Missile Works RTx Rocket Telematics module.

The final launch vehicle will utilize a 15” drogue and a 60” main parachute in its dual deployment recovery system, purchased from Fruity Chutes.

iv. Flight reliability confidence

The first test launch of the full-scale launch vehicle was unsuccessful. This was due to a faulty actuator that had been working up until the time of launch. However, this allowed our team to take note of changes that could be made to better the launch vehicle. The faulty component has since been replaced with a new actuator and our team is confident that the next test launch will be successful.

The team is unsure of the flight characteristics of the full scale vehicle as SOAR has been unsuccessful in staging a full scale vehicle demonstration flight. The upcoming launches detailed in Section 5a expand upon the anticipated objectives to be accomplished during the launches.

v. Documentation of full vehicle construction

Initially the full-scale vehicle was modeled in accordance with the NSL flight parameters within OpenRocket. The team made modifications to the design and then created a SolidWorks assembly for the vehicle to ensure that the components would all fit well and there would be enough space within the tubing to accommodate for the payload. After finalization of the design process, the materials for construction were ordered from outside suppliers, one being Wildman Rocketry. As of the date of writing, SOAR does not have the capabilities to wind the properly sized body tubes for the launch vehicle.

Once the materials arrived, a 5-foot G12 fiberglass tube was cut down to 38-inches for the booster tube to account for the space required for the 16-inch motor tube, shock cord, and internal parachutes that will be placed within this tube. Another section of the tubing was cut to be 46-inches for the upper body tube which will house the payload, main parachute, and shock cord. The cutting of the fiberglass tube was performed using a miter saw, additionally the ends of the tubing was sanded down to remove any slight chipping that resulted from cutting. The nose cone and motor tube were purchased from Wildman Rocketry. The motor tube initially had a length of 24-inches that had to be reduced to 16-inches to fit within the booster tube. This was cut using the same method that was used in the initial cutting of the booster tube. Personal protection equipment (PPE), specifically respirators, safety glasses and ear protection, was used in all cutting operations performed in the SOAR workshop.

Fig 2: Creation of nose cone

The centering rings were cut from a sheet of G12 fiberglass using the X-Carve CNC machine located in the workshop. Respirators, safety glasses and ear protection are all used when using the X-carve CNC machinery. The dimensions of the centering rings were input into Fusion 360 to create a path that the machining tool would follow. The centering rings had to be modified with the use of a dremel to allow for the shock cords to pass through. The machining tool utilizes the 1/8th inch tool bit. The bulkheads for the launch vehicle were also created in the same manner, with adjustments being made to the input dimensions in Fusion 360 for the bulkheads. There were some issues encountered with the X-Carve when cutting out the bulkheads, however these issues were overcome, and the necessary components were manufactured.

Fig 3: Bulkheads cut using X-Carve

The elliptical fins were cut from a sheet of 3/16th carbon fiber. The cutting process required the use of Fusion 360 to create a path that the machining tool of the X-Carve could follow to cut the fins most accurately with the predetermined dimensions. The fins were then sanded down to reduce the force of drag on them when set in motion. Gloves and respirators were used to reduce contact with carbon fiber particles that resulted from sanding.

Fig 4: Cut carbon fiber ellipsoid fin prior to sanding

The centering rings were attached to the motor tube using JB weld epoxy. Using a marker, a line was made in the position in which the centering

ring would sit by using a measuring tape to measure distance from one end of the motor tube. A level was used to ensure that the centering rings were placed parallel to the motor tube. A stand was used to hold the motor tube up while the epoxy was setting, and the rear centering ring was clamped to the stand to avoid any shifting during the 24-hour setting period. This process was repeated for the front and middle centering rings. The shock cord was also epoxied onto the motor tube.

Fig 5: Epoxying rear centering ring

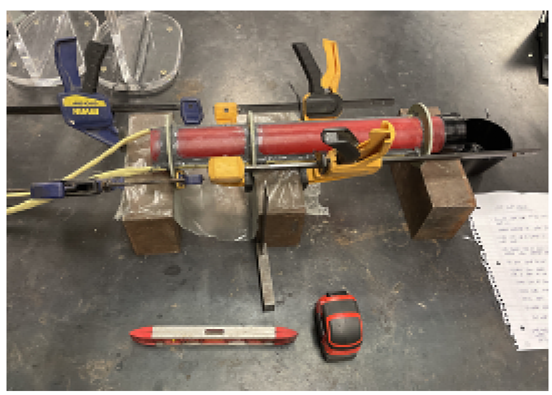

Fig 6: Epoxying front and middle centering rings

Cuts were made into the booster tube to add the motor tube to the assembly. The fins were then attached to the motor tube using epoxy. A fin guide was 3D printed and sustained in place using zip ties to keep the fins straight and 120 degrees apart from each other during the setting process.

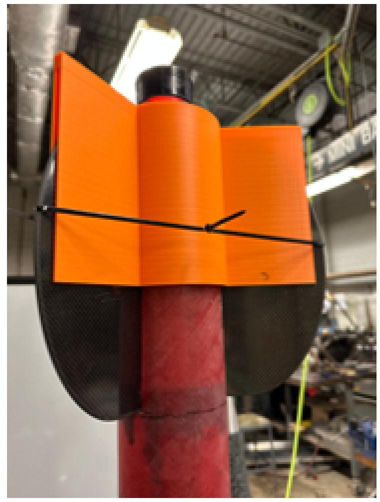

Fig 7: Orange fin guide used to keep fins 120 degrees apart

After a 24-hour period in which the epoxy was allowed to set, the fins were further reinforced by creating fillets between the fin faces and the booster tube using the JB weld epoxy.

Fig 8: Fillets on booster tube and fins

Each component was weighed prior to construction as well as after joining components together. This was done to ensure that the team could account for any unprecedented added weight, such as that from the use of epoxy, within OpenRocket so the simulations can be conducted as accurately as possible.

vi. Schematics of as-built rocket

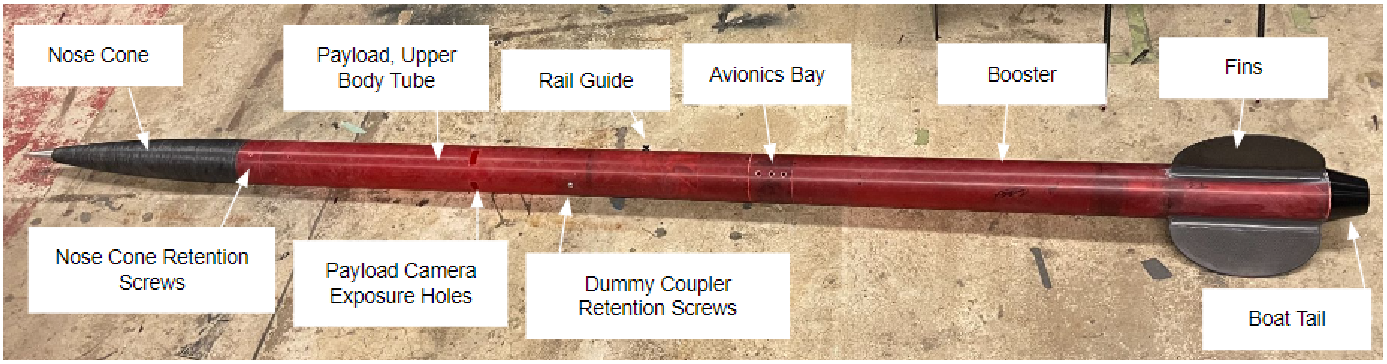

Fig 9: Assembled launch vehicle.

vii. Discussion of differences between built rocket and previous models

The full-scale rocket has three elliptical fins as opposed to trapezoidal fins. The size of the upper body tube has increased due to the addition of the piston system for the payload. The altimeter bay has increased as well to incorporate the GPS module in the avionics bay. The size of the motor tube was increased in length to account for the increase in size of the motor.

b. Recovery subsystems

i. Discussion of robustness of as-built, as-tested recovery system

a. Structural elements

The components used for the avionics bay can be see in the photography below. Most of the parts were purchased via McMaster.carr or were in abundance in SOAR's workshop.

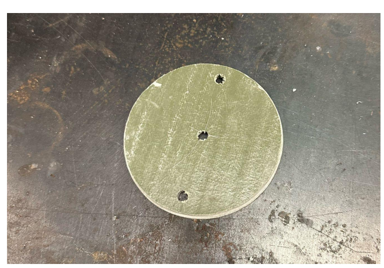

Fig 10: 1 of 2 Bulkhead for avionics bay

The bulkheads were cut from a G10 fiberglass sheet that was ⅛" thick. This was done via our X-carving CNC machine. The toolpath used was created by Fusion 360 CAM.

Fig 11: 1 of 3 eye bolts for avionics bay

The galvanized steel eye bolt is used as the attachment point for the connection of the shock cord to the avionics bay. These are attached via D-links shown below.

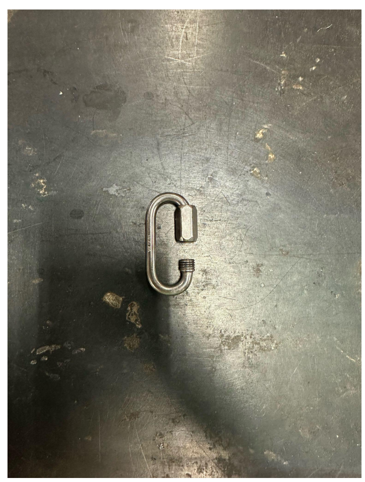

Fig 12: 1 of 6 D-links for avionics bay

There are 6 D-links used in the full-scale rocket that attach to the dead space coupler, the parachutes, and to the avionics bay. These have been reliable hardware that have been used by SOAR since the creation of the club in 2013.

Two, ¼" - 20 threaded rods were used to house the avionics sled, and each are 16" in length such that the nuts on the end can be threaded on to lock in the bulk heads.

b. Electrical Elements

The electrical elements of the avionics bay can be seen with photos of the avionics sled assembly.

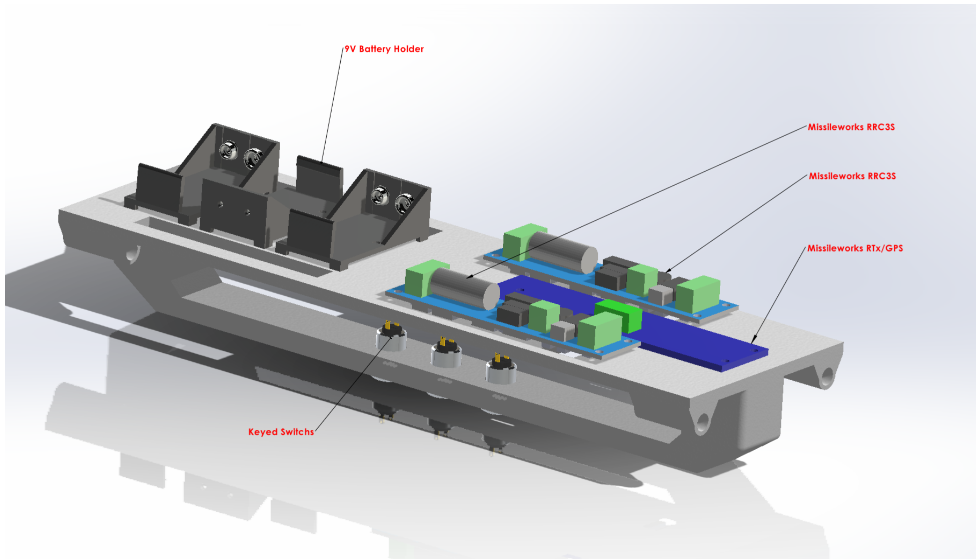

Fig 13: Avionics Bay configuration

The electronics bay consists of 2 Missileworks RRC3s, a Missileworks Rtx/GPS module, and three 9V battery holders to power each device. There are three keyed switches to turn on and off the electronic devices when they are on the pad for launch.

c. Redundancy Features

There are two altimeters for redundancy in case of a failure from one during the launch. If in the case that a battery gets dislodged for one of the altimeters, a secondary altimeter will be there to initiate the deployment charges.

d. Parachute sizes and descent rates

Parachute	Parachute Size (in)	Descent Rates (ft/s)
Drogue	15	102.97
Main	60	19.98

e. Drawings/ Diagrams/ Schematics

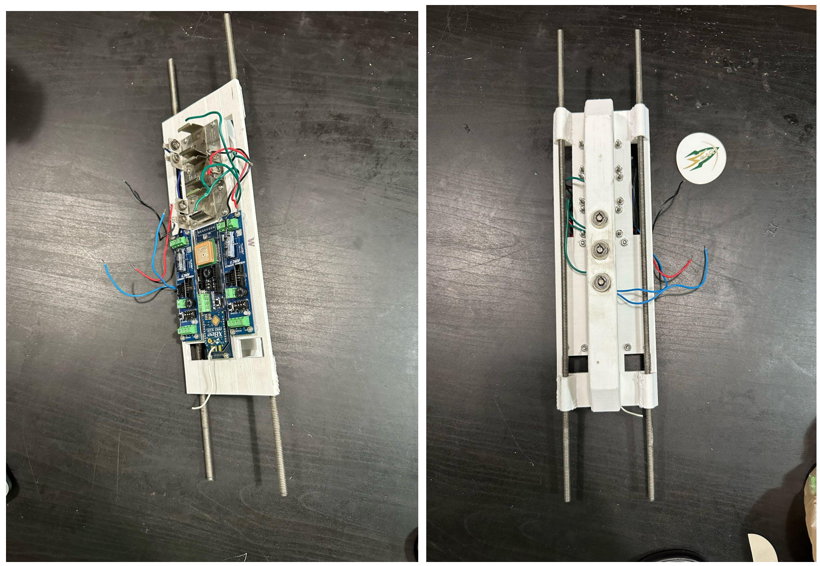

Fig 14: Assembled avionics bay

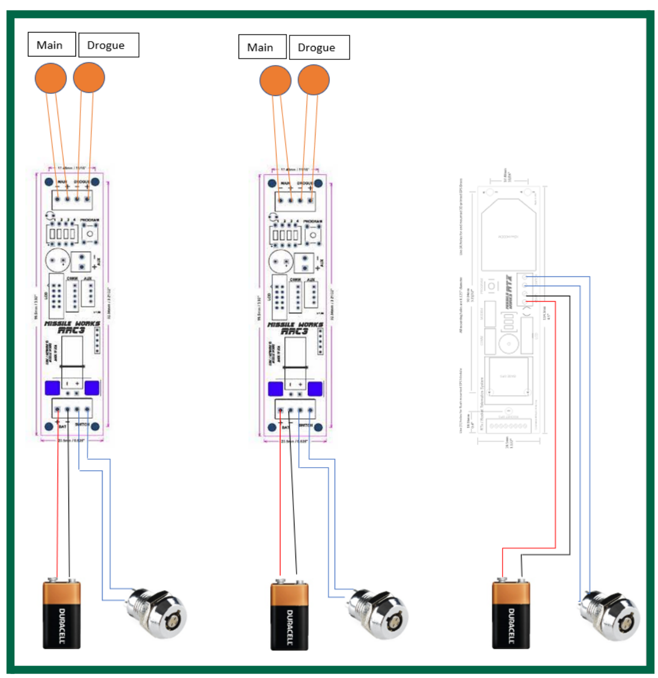

Fig 15: Wiring Schematic for Avionics Bay

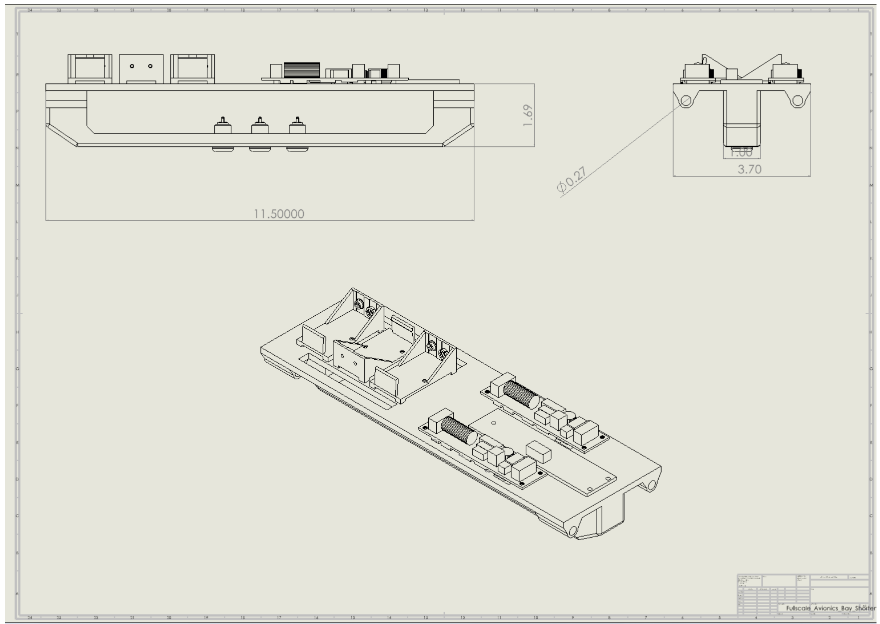

Fig 16: Drawing of Avionics Bay

ii. Sensitivity of recovery system to onboard devices generating electromagnetic fields

The Missileworks Rtx/GPS module is suited for use with the Missileworks RRC3s altimeters during flight. SOAR has not tested our full-scale rocket with the included RF acceptance modules in the payload system. Because of this, an issue may arise where the GPS module in the avionics bay interferes with the incoming transmission instructions.

c. Mission performance predictions

i. Flight profile simulations

The flight profile simulations were done using the OpenRocket software. This plot can be seen below.

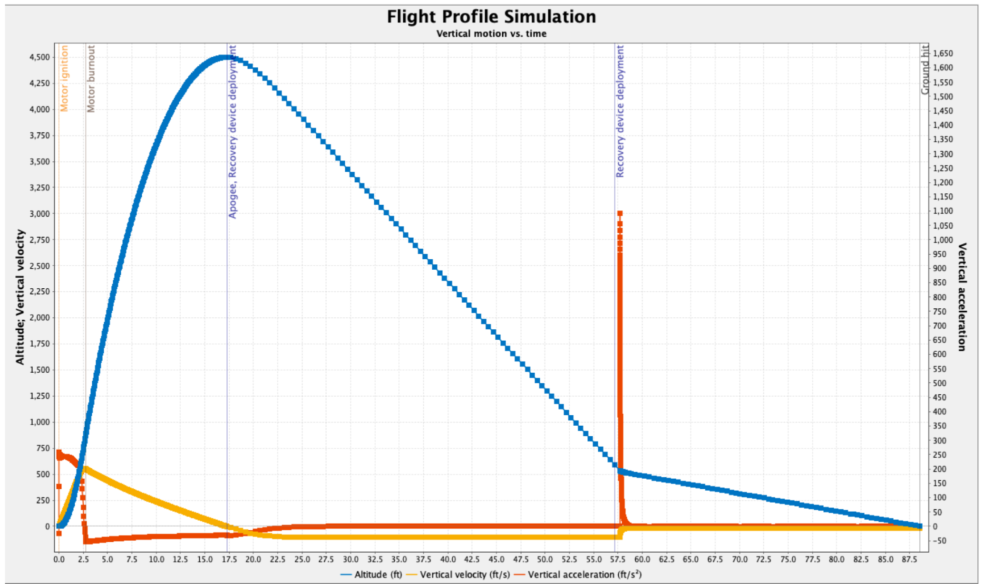

Fig 17: Flight Profile Simulation

The thrust curve of the cesaroni K780 was obtained with OpenRocket's motor database, and was verified to be the same as the one in thrustcurve.org catalog.

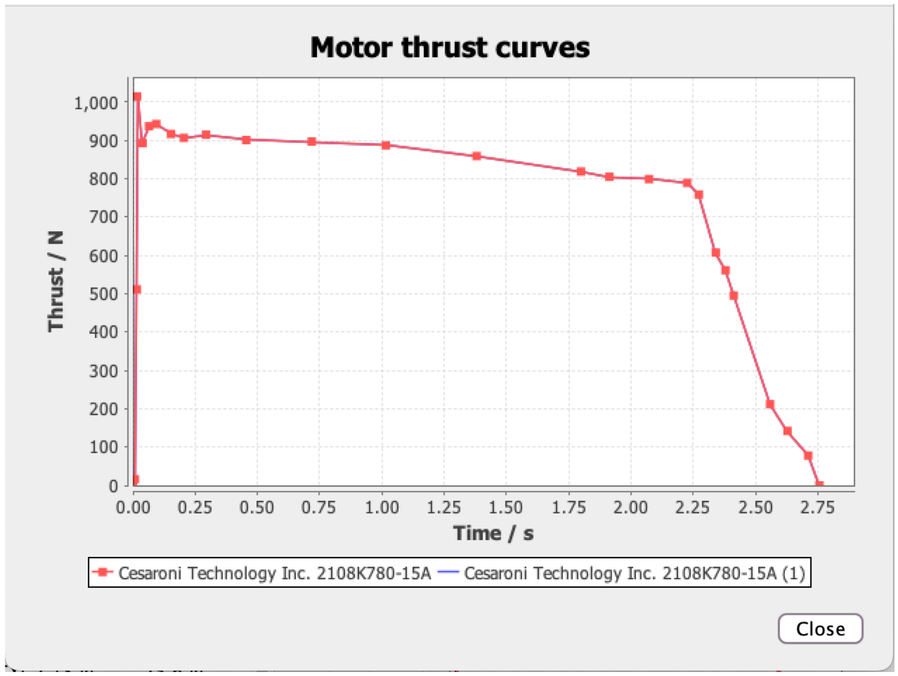

Fig 18: Motor Thrust Curve of Cesaroni K780.

As stated in Section 1.b, the components used in these simulations are shown below with their associated weights.

Component	Info	Component	Info	Component	Info
Nose Cone	24"/635g	WO Ballast, Dry	8733g	Vehicle, Landing	9293g
Upper Body	51"/4122g	WO Ballast, Wet	10524g	Motor	K780 Cesaroni
Avionics Bay	12"/1300g	Vehicle, Wet	10524g	Target Apogee	4500ft
Booster Tube	38"/2676	Vehicle, Burnout	9293g	Recovery System	Dual deployment
				Rail System	1515 Aluminum

Table 3: Launch vehicle summary

ii. Stability margin and as-built Center of Pressure/Center of Gravity

The center of pressure (denoted by the red dot) of the full-scale launch vehicle is located 82.414 inches from the top of the nose cone and the center of gravity (denoted by the blue dot) is located 71.308 inches from the top of the nose cone when loaded. When unloaded, the center of gravity shifts to 64.264 inches from the top of the nose cone. The static margin of stability margin of the loaded full-scale launch vehicle is 2.76

calibers. An off-the-rail stability of 1.25 is expected according to simulations by OpenRocket.

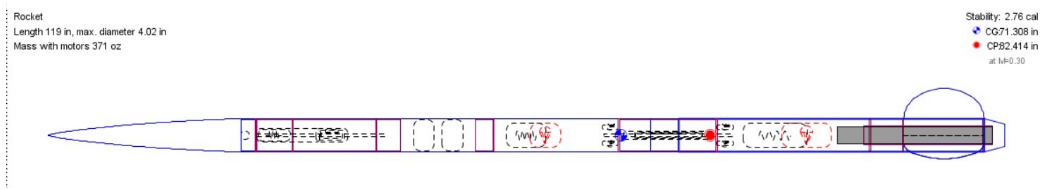

Fig 19: Diagram with marked center of pressure and center of gravity

iii. Kinetic energy calculations

The kinetic energy calculations were concluded by finding the descent velocity of the flight vehicle with the configured main and drogue parachute. With the descent velocity found, we can find the kinetic energy of each member of the rocket using the equation below.

$$K = \frac{1}{2} * m * v^2$$

To find the descent velocity of our launch vehicle, SOAR utilized the equations from the apogee newsletter titled "Properly Sizing Parachutes for Your Rocket" [1].

Knowing our diameter of our main parachute, 60" = D, we need to find the surface area, S, of our parachute:

$$S = \frac{D^2 * \pi}{4}$$

With the surface area found, we can now solve for the velocity of our rocket coming down. This was done using the equation below:

$$V = \sqrt{\frac{2 * g * m_g}{S * \rho * C_D}}$$

Where,

g = gravity

m_g = mass of rocket in grams

S = surface area of the parachute

ρ = density of the air

C_d = the coefficient of drag of the parachute specified (2.2)

At a burnout weight of 20.5 lbs without ballast, the calculated descent velocity for a 60” main parachute was 19.98 ft/s.

Substituting the velocity value and the mass of each independent section, the kinetic energy for each component of our rocket is as follows:

Upper Body Tube:

Total Mass: 10.49 lbs

Total Kinetic Energy: 65.850 ft-lb

Avionics Bay:

Total Mass: 2.87 lbs

Total Kinetic Energy: 18.016 ft -lb

Booster Tube:

Total Mass: 7.13 lbs

Total Kinetic Energy: 44.758 ft-lb

To rapidly test different size parachutes and the effects that they have on velocity and kinetic energy, SOAR utilizes a coding software called MATLAB, where a coding program has been made such that changing the mass and parachute size used in the rocket provides the kinetic energy on each component of the rocket and the updated descent times from these changes.

iv. Descent time calculations

The descent times found for the rocket were primarily done by setting the main deployment of our rocket at 600ft and dividing the feet per second found for our rocket and obtaining the time it takes through these measures.

From the apogee of 4,500ft to the altitude of 600 ft, we have found that it takes 37.88 seconds using a drogue parachute of 15" with a 102.97 ft/s descent rate. From 600 ft to ground takes 30.03 seconds using our 60" main parachute.

The total time would then place our rocket at 67.9 seconds to touchdown.

v. Drift calculations

The drift calculations were done using OpenRocket software and running test simulations at specific wind speeds specified by the NSL 2023 handbook. The launch location simulated was at the Huntsville, Alabama launch complex where the competition will be held. The launch rod has been canted 5 degrees upwind. The main parachute will deploy at 600ft and the drogue parachute will be at apogee.

With the wind coming from the east in these simulations, here are the drift calculations:

:

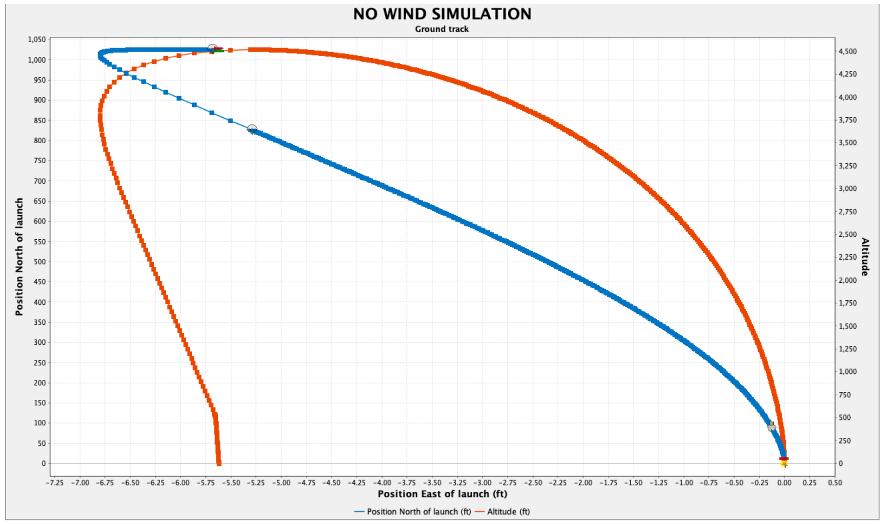

Fig 20: NO WIND(Ballast weight of 15 oz)

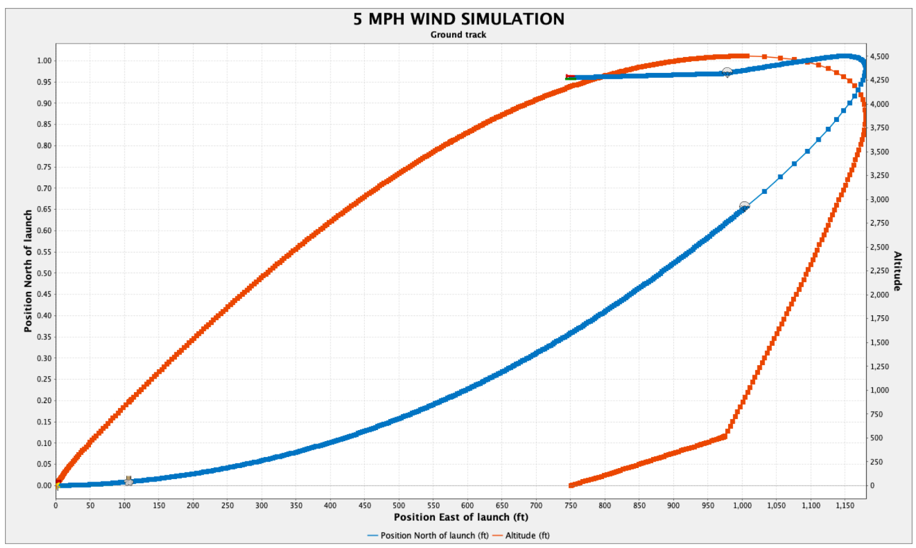

Fig 21: 5 MPH WINDS (Ballast weight of 14 oz)

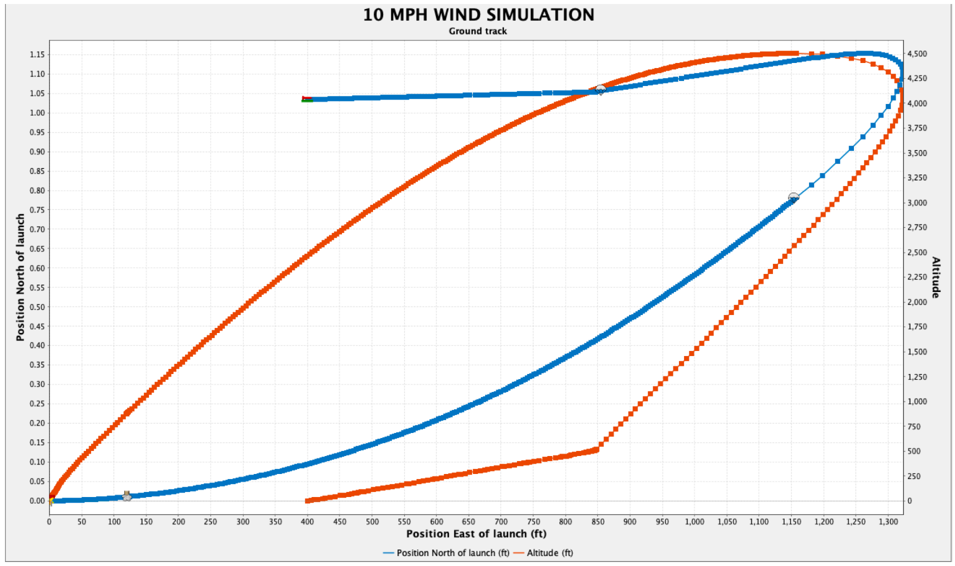

Fig 22: 10 MPH WINDS (Ballast weight of 12 oz)

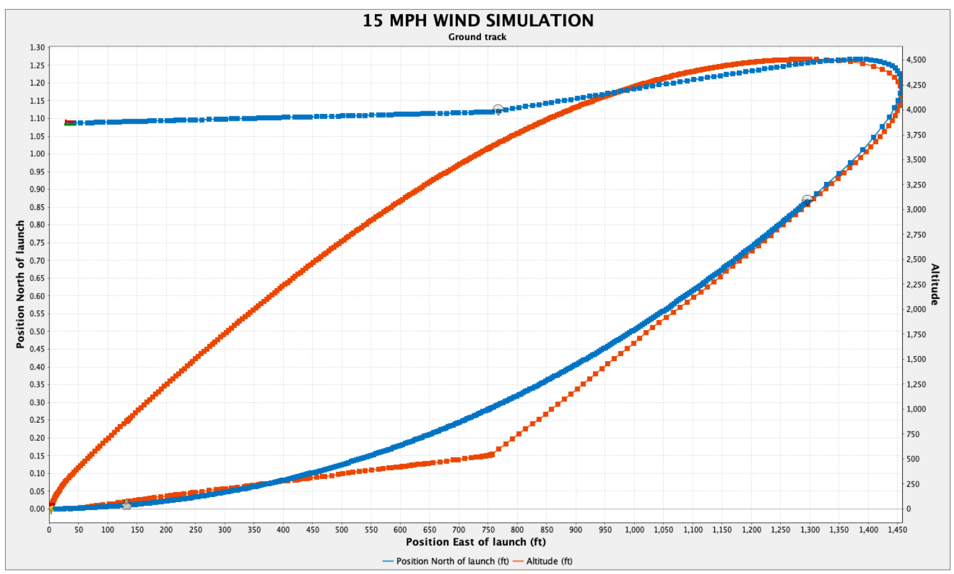

Fig 23: 15 MPH WINDs (Ballast weight of 9 oz)

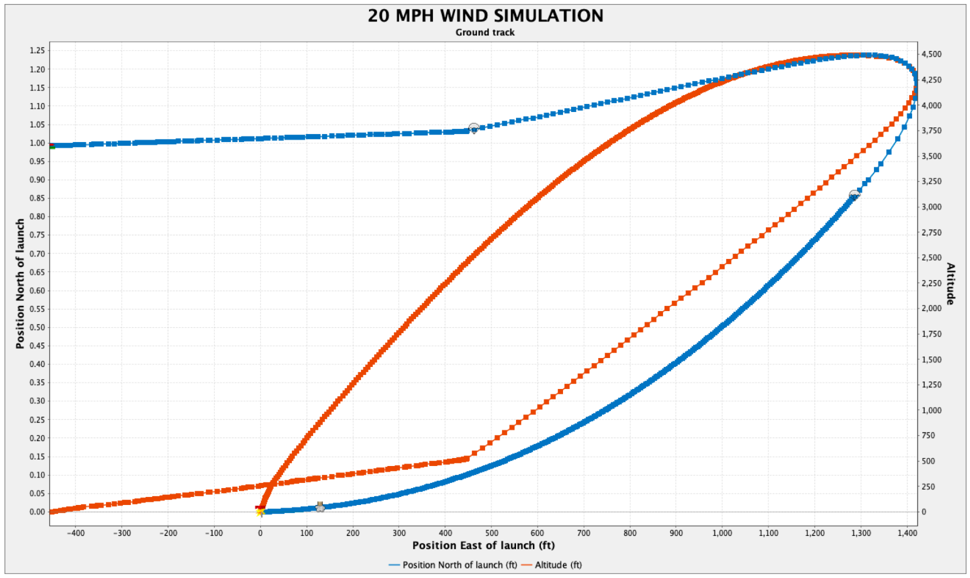

Fig 24: 20 MPH WINDS (Ballast weight of 9 oz)

vi. Alternative calculation method data presentation

Utilization of Fruity Chutes! "Parachute Descent Rate Calculator" [2] provides SOAR with the confirmation of the calculated kinetic energy values of our full-scale rocket and the descent rates.

Main Parachute:

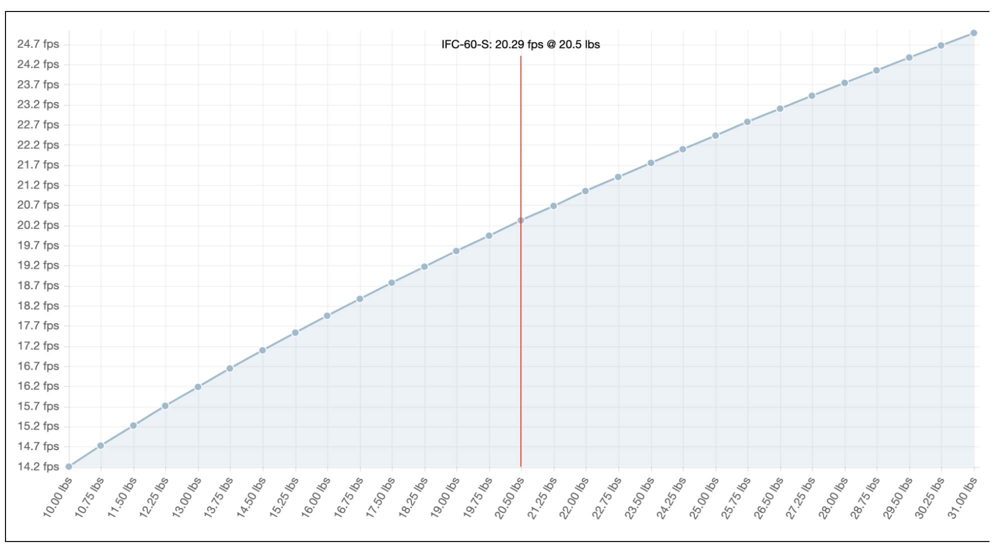

Fig 25: Fruity Chutes! Descent Rate vs. Weight for Main Parachute

SOAR's calculated velocity of the full-scale rocket with the corresponding weight is 19.98 ft/s compared to 20.29 ft/s of Fruity Chutes!

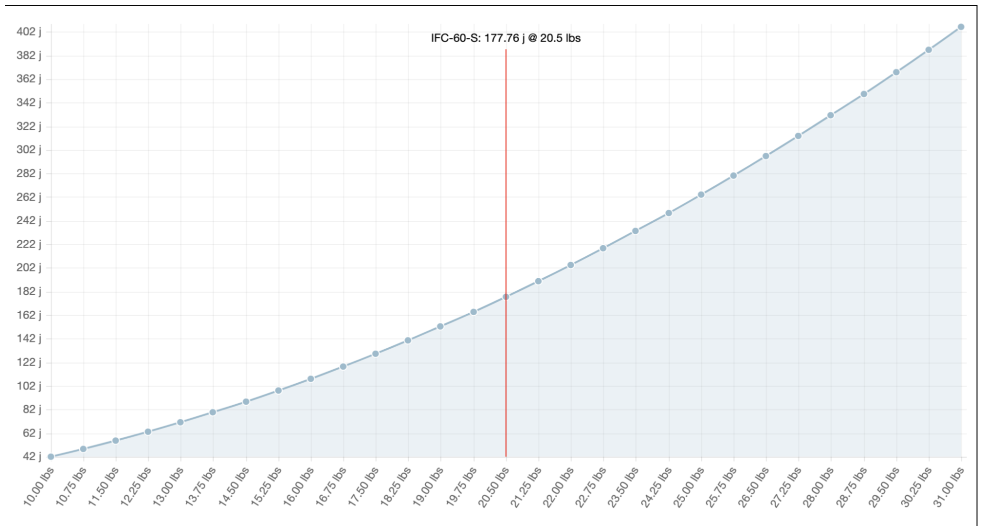

Fig 26: Fruity Chutes! Impact Energy Joules vs. Weight for Main Parachute

SOAR's calculated kinetic energy for the full-scale rocket was 172.31 J compared to the value obtained by Fruity Chutes! Of 177.76.

Drogue Parachute:

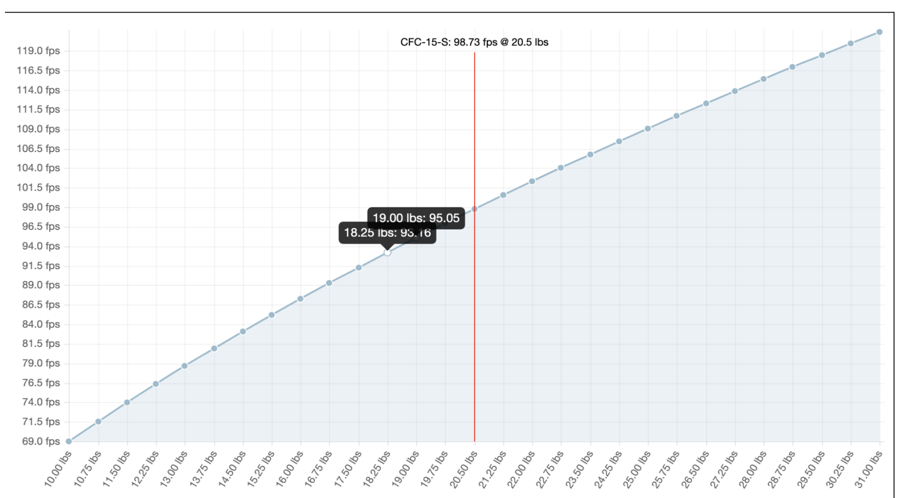

Fig 27: Fruity Chutes! Descent Rate vs. Weight for drogue parachute

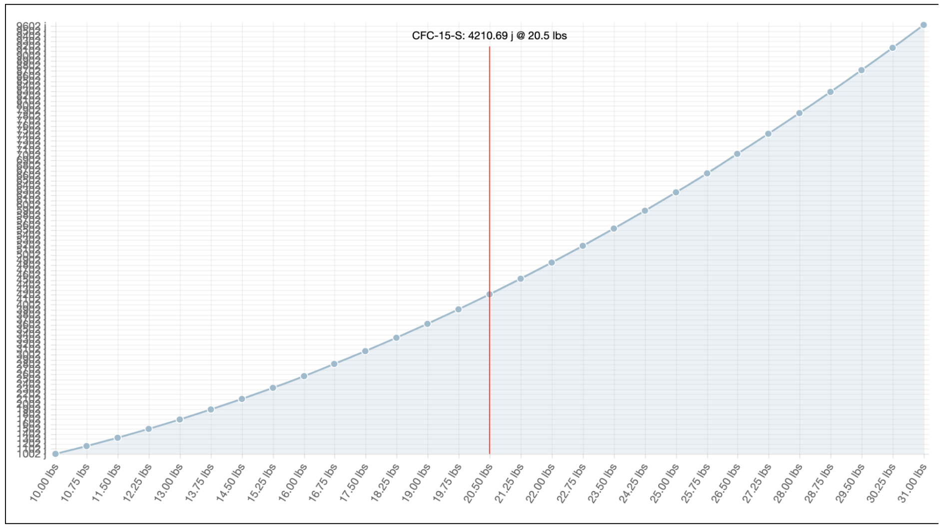

Fig 28: Fruity Chutes! Impact Energy Joules vs. Weight for drogue Parachute

SOAR's value for the descent rate and impact energy was calculated to be:

- 102.97 ft/s
- 3819.75 ft-lb

vii. Discussion of differences between calculation methods

The Fruity Chutes! calculation alters the diameter of the main and drogue parachute, leading to the difference in descent velocity and impact amount. Since SOAR is using Fruity Chutes! Parachutes, the data given for these values have been used to calculate the descent time for our rocket. The amount of kinetic energy coming from the drogue parachute was of concern for SOAR, and with a full-scale test launch, SOAR will determine if the 15" drogue is too small. The main concern is of zippering on the side of the rocket from the impulse of the main being deployed.

Since the descent time for the flight vehicle was calculated to be 67.9 seconds, SOAR is looking to increase the drogue size to 18", which would still have the full-scale rocket coming down at a time of 75.47 seconds.

viii. Performance of simulations to verify results

The use of OpenRocket simulations provides a ballpark of the calculated descent times and velocity of the rocket hitting the ground.

The matlab code results are shown below:

```
      ~~~~~~DROGUE DEPLOYMENT INFO~~~~~~

The velocity with the drogue parachute is 102.971358 ft/s

The TIME it takes to reach main deployment from apogee is 37.874610 seconds

The kinetic energy of the rocket is 3819.750520 ft-lb

      ~~~~~~MAIN DEPLOYMENT INFO~~~~~~


The velocity with the main parachute is 19.981297 ft/s
The total kinetic energy of the rocket is 127.091161 ft-lb
The kinetic energy of the upper body tube is 65.119203 ft-lb
The kinetic energy of the upper body tube is 17.816217 ft-lb
The kinetic energy of the Booster tube is 44.261193 ft-lb

The descent TIME from 600.000000 feet is 30.028081

      ~~~~~~TOTAL DESCENT TIME~~~~~~

The total descent time is 67.902690 seconds>>
```

Fig 29: Matlab simulation values obtained.

Using OpenRocket's simulation tab, SOAR calculated the descent times and descent velocities of the rocket at 0 MPH, 5 MPH, 10 MPH, 15 MPH, 20 MPH.

	Name	Configuration	Velocity off rod	Apogee	Velocity at depl...	Optimum delay	Max. velocity	Max. acceleration	Time to apogee	Flight time	Ground hit velo
!	NO WIND SIMULATI...	[K780-7]	78.9 ft/s	4619 ft	100 ft/s	14.7 s	568 ft/s	263 ft/s²	17.4 s	89.1 s	16.8 ft/s
!	5 MPH WIND SIMUL...	[K780-7]	78.9 ft/s	4588 ft	100 ft/s	14.6 s	568 ft/s	263 ft/s²	17.4 s	90.4 s	16.9 ft/s
!	10 MPH WIND SIM...	[K780-7]	78.9 ft/s	4548 ft	100 ft/s	14.6 s	568 ft/s	263 ft/s²	17.3 s	88.8 s	16.9 ft/s
!	15 MPH WIND SIM...	[K780-7]	78.8 ft/s	4513 ft	100 ft/s	14.5 s	567 ft/s	263 ft/s²	17.2 s	89.1 s	16.8 ft/s
!	20 MPH WIND SIM...	[K780-7]	78.8 ft/s	4471 ft	100 ft/s	14.4 s	565 ft/s	263 ft/s²	17.1 s	87.9 s	16.9 ft/s

Fig 30: OpenRocket simulations.

* Note: The values of the apogee are different here because of the fact that the ballast has not been changed during these test simulations.

As we can see from these simulations. The flight vehicle is expected to come down at a lower velocity than calculated, and the flight time is slightly higher at between 70 seconds to 72 seconds.

SOAR is looking forward to the full-scale test flight to verify which results are more accurate. Once the results have come back from the full-scale launch, the more accurate data from the simulations will be used in place of the main simulation data used.

4. Payload Criteria

a. Payload design and testing

i. Changes in payload design from CDR

In order to reduce the number of wires used in the payload, our team plans on incorporating a printed circuit board, or PCB. By using a PCB, certain components with male pins can simply be inserted into the ports on the PCB and soldered to the port, thus reducing the number of wires needed. The PCB will be integrated into a duplicate of the original sled. By creating a second sled with all the required payload components, multiple teams and members can run different test programs written for the payload at once, by testing one program per sled simultaneously. This will increase our efficiency when it comes to testing programs and fine tuning the code as needed. Lastly, to accommodate the shape and dimensions of the PCB, additional 3D printed parts were designed and fabricated for this second sled.

Next, our team was able to successfully incorporate the piston design into the rocket. As intended, our team was able to test the piston's functionality at ground testing outside of launches. But, improvements could still be made. First, though the piston did smoothly slide within the upper body tube, we did not account for the mechanical limit of the servo motor. Though the piston still completely covered the opening in the body tube, the location at which the piston system is mounted could be moved a couple inches closer to the payload coupler. This will give more space to the recovery team to put parachutes into the upper body tube. With this, a new upper body tube will be used to redrill all the mounting hardware such as the adhesive nuts.

Lastly, our team found the angle in which the first microstepper tilted the camera base to be unreliable. Our team modified the pendulum component, which held the camera base (which holds the microstepper that rotates about the z-axis) to mount a servo instead of a microstepper. Though our design will keep the microstepper to rotate the camera about the z-axis, the servo should provide a more consistent angle of the camera base when the program runs. This part was modified for the servo, reprinted, and integrated into the existing sled. This modification is represented on both the original sled and the PCB sled.

ii. Unique features of payload

Four equally spaced rectangular openings of 1.5” by 0.5” were implemented on the upper body to allow the automated camera system to exit the body. It should be mentioned that the implications of having holes in the body were considered. As a way to deal with the pressure difference, an inside covering powered by a piston was inserted. As shown in the following figure, during flight time, this automated system will minimize the drag and possible entry of disrupting air into the payload environment.

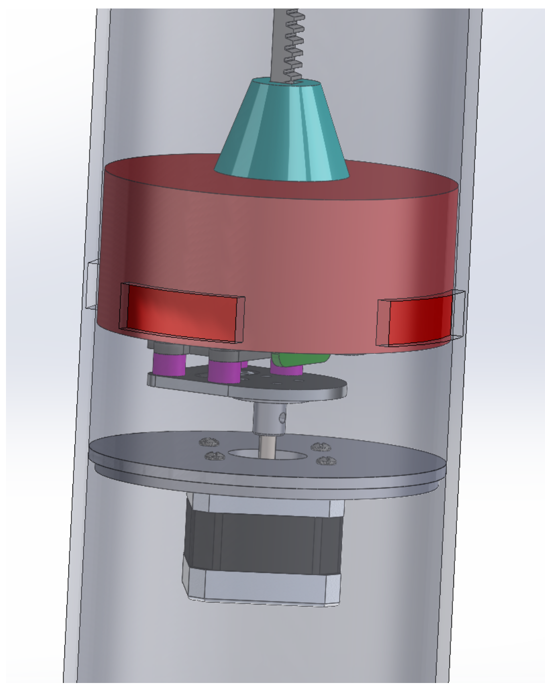

Fig 31: Closed payload.

In order to push the camera outside of the body and give it the necessary rotation, three motors were used: a 17HD34008 stepper motor and two

GS-5010 micro servos. The former holds the entire apparatus through a 3D printed bracket. Its main function is to automatically rotate and align the system with one of the four openings. Secondly, the first GS-5010 micro servo, through a rack and pinion gearing system, pushes the camera holder outside of the upper body tube, as shown in Figure 32, and 33. Finally, the second micro servo permits the rotation of the camera holder outside of the body.

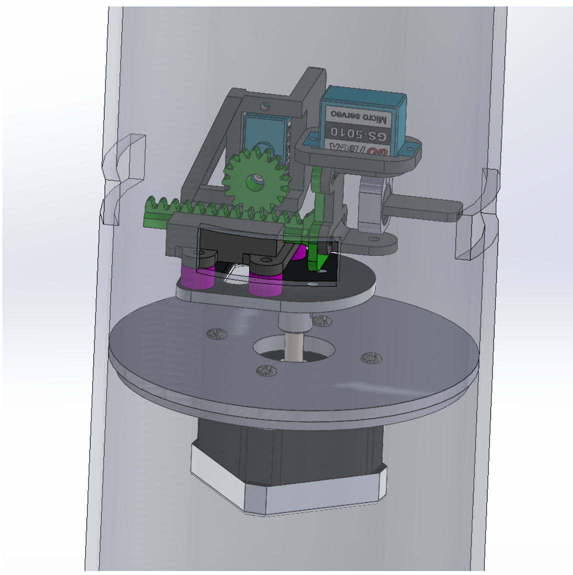

Fig. 32: Retracted

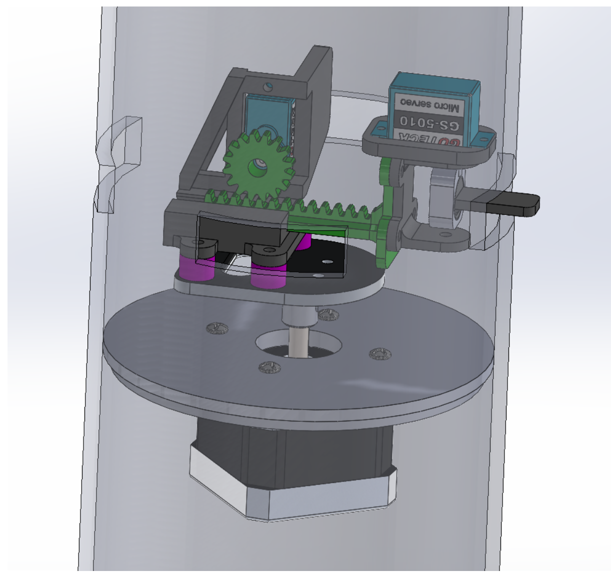

Fig. 33: Expanded

To achieve closest proximity to the vertical axis the payload's main computer uses an algorithm that takes data from both IMU sensors and uses the direction of what has been labeled the 'gravity' vector of both sensors to compute the correct angle the motor must move:

```python
#Important: Positive Angle Means counterclockwise viewed from the Front Endcap of the Stepper Motor
def GetTravelAngle():
    #Project the gravity vector into the plane made by ref_vectors[0] and ref_vectors[1]
    imu1_gravity=projection_on_plane(imu1_data.refVectors[0], imu1_data.refVectors[1], imu1_data.gravityVector)
    imu1_vertical = -1 * imu1_gravity
    vertical_angle = getAngleFromCoordinate(imu1_vertical[0], imu1_vertical[1])
    #Second get the hole which is closest to the vertical angle
    imu1_hole_angle = closestAngle(holeList, vertical_angle)
    #Third get the angle between the vertical angle and the hole
    vertical_deviation = getAngleBetween(imu1_hole_angle, vertical_angle)
    #Fith invert the imu2 gravity vector
    imu2_gravity = projection_on_plane(imu2_data.refVectors[0], imu2_data.refVectors[1], imu2_data.gravityVector)
    imu2_vertical = -1 * imu2_gravity
    imu2_vertical_angle = getAngleFromCoordinate(imu2_vertical[0], imu2_vertical[1])
    #Sixth add the vertical deviation to the imu2 vertical angle
    imu2_hole_angle = imu2_vertical_angle + vertical_deviation
    #Get the angle between the align vector of imu2 and the hole
    camera_2d = projection_on_plane(imu2_data.refVectors[0], imu2_data.refVectors[1], camera_vector)
    camera_angle = getAngleFromCoordinate(camera_2d[0], camera_2d[1])
    travel_angle = getAngleBetween(imu2_hole_angle, camera_angle)
    #Return the angle to travel
    return travel_angle, imu1_hole_angle
```

Fig 34: Most Vertical Angle Algorithm

iii. Flight reliability confidence

As we have reused the same physical components of the sled, we have placed extra emphasis on creating a fully functioning program that is fine tuned to meet all the NSL requirements. With our design, we have conducted many ground tests of the individual payload subsystems and they all work as expected. Through testing we have also figured out many major points of failure of the system and developed error handling software that will take care of 2 primary cases:

A. An error in sensor or motor command that can be solved by repeating the procedure over and over until a valid state is achieved
B. An error in some hardware connection that may not be solved by the software therefore the priority becomes making sure that connection will not crash the rest of the system

We have identified most of the points of failure in our system through the software so we are confident on launch day the onboard computer will be able to identify these pitfalls and proceed as successfully as possible on launch day. Something we must mention though is some struggle we've been having assembling the whole system together, from what we have tested the slave-master connection, imu connections, servo motors, camera connections and even micro steppers have all been successfully integrated in the whole system and work as expected, however the main stepper motor we are using will sometimes interfere with the electrical system and produce unexpected results. We're continuously testing and modifying this specific subsystem of the mission to try to get it back to work as it did in our previous two launches but at least we can say with confidence we have isolated our current problems to this subsystem only.

iv. Documentation of construction of payload

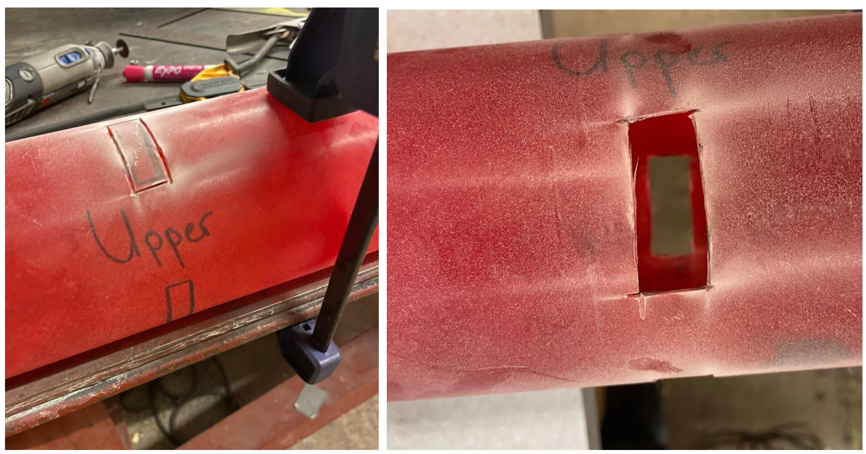

Fig 35: Dremel progress of Upper Body Tube (left) and result (right)

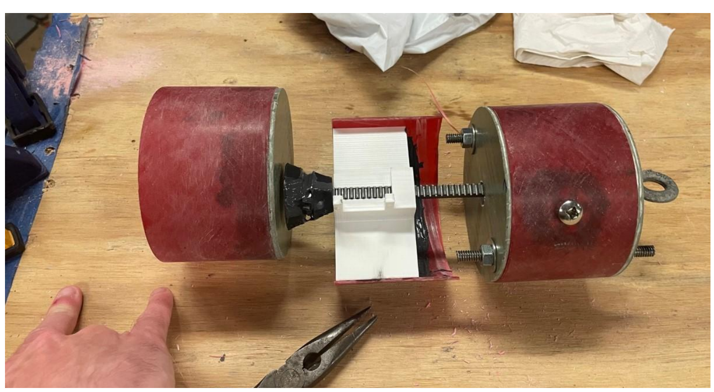

Fig 36: Position of Piston relative to Dummy Coupler

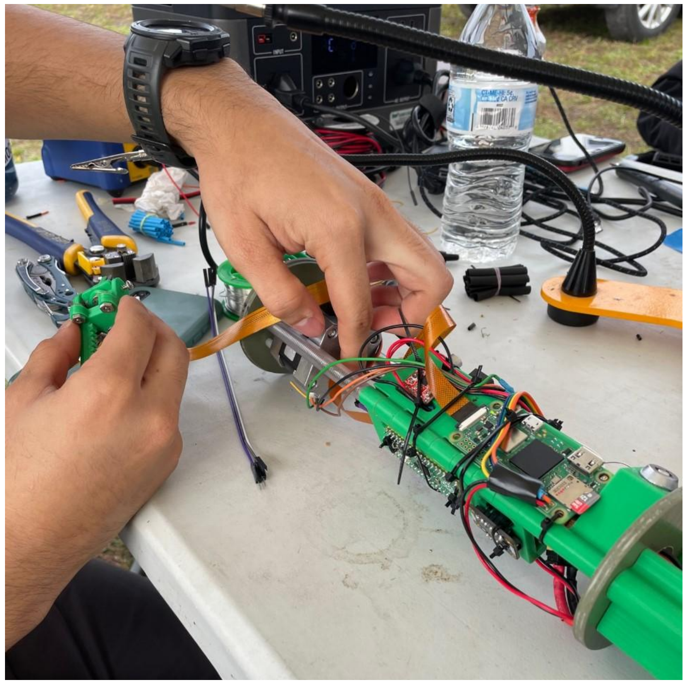

Fig 37: Wire management of Payload Sled

v. Schematics of as-built payload

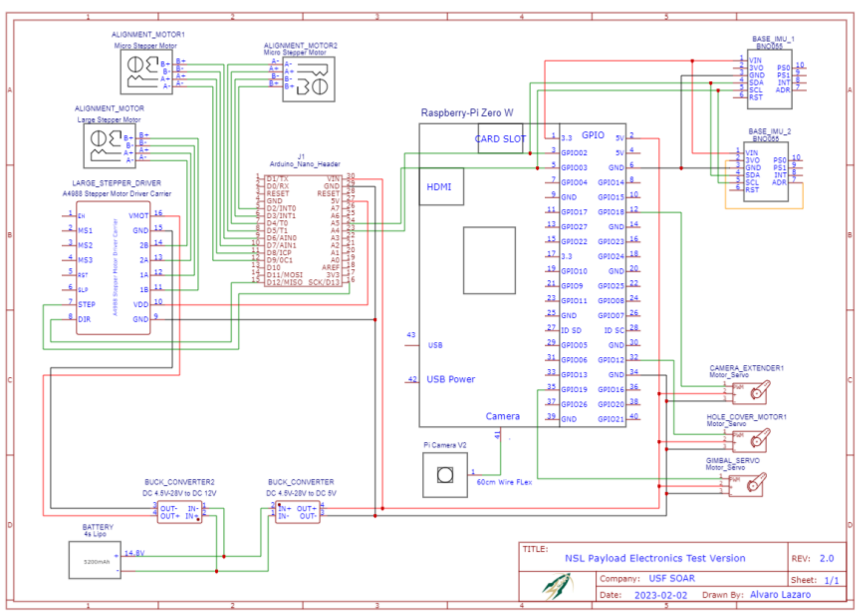

Fig. 38: Electronics Connection Diagram

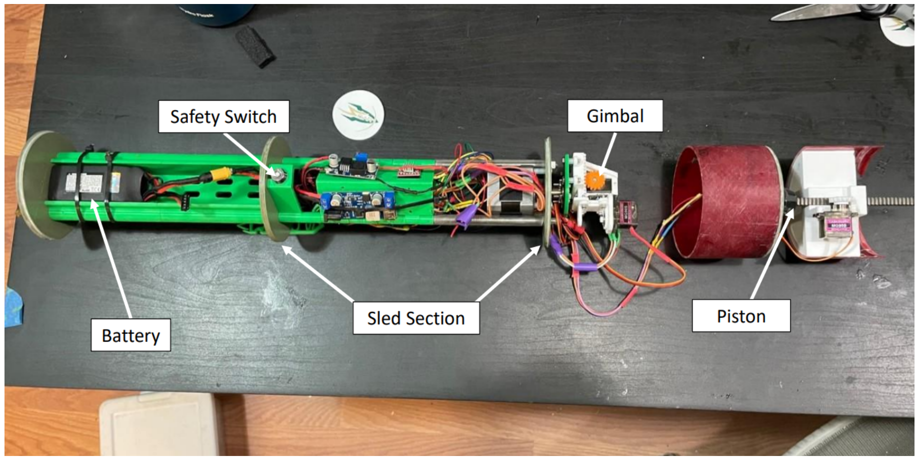

Fig 39: Schematic of major payload components

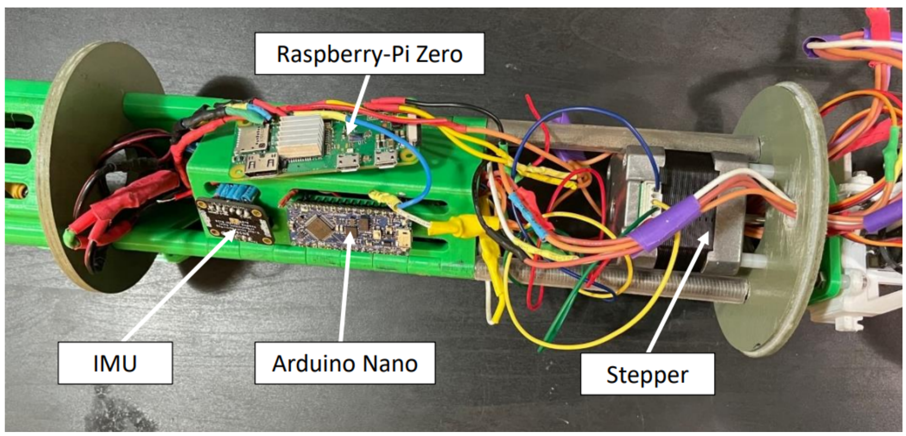

Fig 40: Schematic of built payload sled, side one

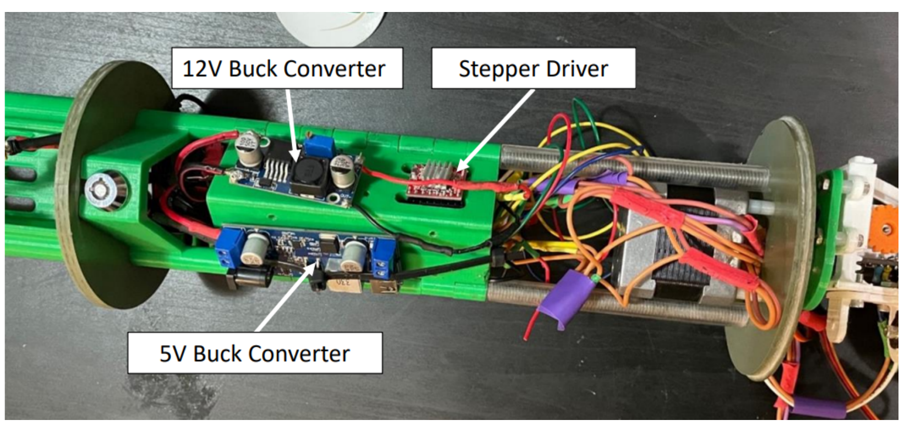

Fig 41: Schematic of built payload sled, side two

vi. Differences between constructed payload and previous models

As noted, much of the physical components of the payload sled have been reused from previous launches, including the subscale flights. Though our team is rebuilding an additional sled, all of the gimbal components, motors, and batteries will be identical to the original sled. The only changes will be to the door hinge sled pieces. To accommodate the flat dimensions of the PCB, a largely flat piece will be used. This 3D printed component will be similar in shape to the avionics bay, where a large flat tray has components mounted to it, and the cylindrical openings for the threaded rods running beneath this surface.

Some other small yet important changes to note:

1. Improved connection between main computer and camera, before we were using a 3D printed piece to hold together our cables with the camera, now he have the appropriate cables and connectors to make that more reliable
2. Changed slave microcontroller, now we are using an Arduino which is capable of providing the 5V our micro stepper motors require to operate properly
3. Moved all servo motors to the main computer side. Given that our microcontroller needs it's full 5v to move the micro stepper motors and the main stepper we have relieved it from voltage drain by handing of the servo motors controls to the main computer/

vii. Discussion of planned Payload Demonstration Flight

Our planned demonstration flight will be the March Spaceport launch and the March Tampa Tripoli launch to conduct final payload tests in an official launch setting. This gives our team a chance to fully test the integrity of the PCB-based sled when subjected to the forces of a full scale launch. All components of the payload system will be complete and ready for the launch, including but not limited to the servo stabilized camera system, piston, and RF modules. When the payload system is first turned on at the launch pad, the first step in the program is ensuring the piston is fully extended to cover the openings in the body tube. The main program will activate when the IMU detects a large change in acceleration. After a timed two minute delay, the payload sequence will run, first retracting the piston to reveal the openings in the body tube, rotating the stepper based on position, extending the camera out of the airframe, and lastly adjusting for the z axis, and then await the launch day commands provided by NASA.

It's important to note for the demonstration flights we won't be conducting any RF testing, given that we do not wish that our testing commands interfere with any of the operating equipment of the launch bases we will launch from, however we can say the RF frequency commands have been unit tested and work as expected, and to make a full system test we are planning to do that in a ground test by itself.

The Payload Demonstration Flights will be completed with a surplus of motors available to SOAR, which will be used to conduct multiple flights at each launch and verify the endurance capabilities of the vehicle and payload.

5. Demonstration Flights

a. Information of all flights flown

The final, active payload has not yet been flown. In addition, SOAR has failed to stage a full scale vehicle demonstration flight. For this reason, SOAR is now participating in NASA Student Launch as a noncompetitive team.

SOAR is planning to perform two launches this month (March 2023). First, a full scale flight to demonstrate both vehicle and payload will be performed at the Palm Bay launch site (NAR#342). The objective of this launch will be to document the flight characteristics of the launch vehicle. Information on stability and payload functionality will be gathered. Ballast configuration will be heavily informed upon the completion of a launch at Spaceport Rocketry Association. We will bring a surplus of motors to allow for repetitive testing of the launch vehicle and payload.

A second launch event will be conducted at Varn Ranch in Plant City, FL (TRA#17). This launch will be used to verify the information gathered from the Spaceport launch the week prior. Final flight characteristics will be judged and verified for the Launch Week flight.

6. Safety and Procedures

a. Safety and environment (vehicle and payload)

i. Risk Level Definition

1. Severity

The severity of each risk is determined by comparing the possible outcomes to criteria based upon human injury, vehicle damage, and environmental damage. Severity is graded on a scale between 1 and 4, with 1 being the most severe.

Table 4: Risk severity criteria.

Description	Personnel Safety and Health	Launch Failure	Project Plan	Environmental
1: Catastrophic	Loss of life or permanent injury.	Operations are not permitted by the RSO and the mission cannot proceed.	Budget overruns or lack of mission critical components result in project termination.	Severe, irreperable environmental damage that is in violation of laws or regulations.
2: Critical	Severe injury or illness.	Operations not permitted by the RSO occur and the mission is suspended due to a violation of laws or regulations.	Budget overruns or delay of mission critical components that jeopardize mission scope.	Repairable environmental damage that is in violation of laws or regulations.
3: Marginal	Minor injury or	Operations are	Minor delays or	Repairable

	illness.	permitted by the RSO, but hazards related to flight hardware occur.	increased budget.	environmental damage that is not in violation of laws or regulations.
4: Negligible	Injury or illness treatable via first-aid.	Operations are permitted by the RSO and no hazards occur.	Minimal or no delays of components or budget increase.	Minimal or no environmental damage.

2. Probability

The probability of every risk has been assigned a level between A and E, with A being the most probable. The scale of probabilities is determined by analyzing the risks and estimating the likelihood of an accident occurring.

Table 5: Probability matrix.

Description	**Qualitative Definition**	**Quantitative Definition**
A: Frequent	High likelihood to occur immediately or continuously.	Probability $> 90\%$
B: Probable	Likely to occur frequently.	$90\% \geq$ Probability $> 50\%$
C: Occasional	Likely to occur occasionally.	$50\% \geq$ Probability $> 25\%$
D: Remote	Unlikely to occur, but can be expected at some point in time.	$25\% \geq$ Probability $> 1\%$
E: Improbable	Very unlikely to occur and is not expected.	$1\% \geq$ Probability

3. Risk Assessment Levels

Table 6: Risk assessment matrix.

Probability	**Severity**			
	1 - Catastrophic	**2 - Critical**	**3 - Marginal**	**4 - Negligible**

A - Frequent	1A	2A	3A	4A
B - Probable	1B	2B	3B	4B
C - Occasional	1C	2C	3C	4C
D - Remote	1D	2D	3D	4D
E - Improbable	1E	2E	3E	4E

i. Personnel Hazard Analysis

Potential risks to health and safety are outlined in the table below.

Table 7a: Personnel hazard analysis and mitigation.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Post-RAC	Verification
Use of power and hand tools (saws, drills, dremels, etc.)	Improper training on use of power and hand tools.	Mild to severe cuts, burns, etc. to personnel or launch vehicle.	4C	Individuals must be trained to properly use power and hand tools, as well as wear correct PPE at all times.	4D	Safety officers more closely oversee manufacturing, reprimanding offenders when necessary.
Inhalation of ingestion of debris	Improper use of PPE or lack of workspace cleanliness	Mild irritation to skin, eyes, or throat. Severe lung irritation or asthma aggravation	3C	Long sleeves will be worn when sanding or or grinding surfaces and proper PPE will be worn when in close proximity	3D	Respirators will be provided to all members in close proximity to debris. Anyone without respirators will be required to

				to debris		stand away from the workspace.
Sharp edges on launch vehicle	Improperly finished surfaces or edges of component s, often in difficult to reach places.	Mild to severe cuts, scrapes, or splinters while handling the launch vehicles.	4D	Attention to detail when finishing launch vehicle surfaces during manufactur ing.	4E	Safety officer and Aerostructu res lead will inspect launch vehicle surfaces to ensure edges are sufficiently finished.
Contact with chemicals	Improperly handling chemicals, resulting in fumes or bodily contact due to chemical splashes or spills.	Mild to severe burns on skin, lung damage, or asthma aggravatio n.	3C	Proper PPE worn at all times when handling chemicals and MSDS sheets will be available and reviewed before working with chemicals.	3D	Respirators and nitrile gloves will be provided to all personnel working with chemicals. Safety officer will ensure their use.
Fumes while soldering	Soldering iron is too hot or personnel have exposed contact with soldering iron.	Personnel may feel sick or unwell due to toxic fumes.	3D	Personnel will conduct soldering in well ventilated areas.	3E	Only Payload and Recovery members are authorized to use soldering irons. Any

						and all soldering must be done in the lower floor of the ENR facility.
Harmful contact with metal debris	Utilizing equipment necessary to machine metal parts.	Metal splinters in eyes or skin.	3D	Personnel must wear safety glasses and wear long sleeves when machining metal parts.	3E	Safety glasses are provided in the ENR facility. Long sleeves, long pants, and closed toed shoes are required for official manufacturing sessions.
Allergic reactions caused by epoxy resin and hardener	Prolonged skin contact with epoxy resin and hardener, and fumes caused by epoxy resin and hardener.	Mild rashes or chemical burns; irritation in respiratory system or sensitization to epoxy resin and hardener.	3C	Gloves should be worn when handling epoxy resin and hardener.	3D	Nitrile gloves are provided in the ENR facility. Safety officer will oversee their use during the manufacturing process.
Premature ignition of solid motor propellant or black powder	Contact with sparks or heat sources.	Smoke inhalation and severe burns; mild to massive property damage.	1D	Motors and black powder will be kept in a firebox away from heat	1E	Black powder and solid motors are stored in a firebox in the ENR facility, to

				sources when in storage and supervised by club officers during launch operations.		which only club officers have access to. During launch operations, black powder and motors are overseen by the safety officer.
Launch vehicle loses stability during ascent and loss of vehicle control	Improper model of launch vehicle design or incorrect manufacturing processes.	Extreme bodily harm or death; severe property damage.	1D	Launch vehicle must be accurately modeled in OpenRocket and attention to detail must be used when manufacturing.	1E	Center of Gravity (CG), Center of Pressure (CP), and stability will be validated by the Aerostructures lead and Safety officer before launch.
Debris from launch vehicle falling on personnel during flight	Sections of launch vehicle breaking off and returning to the ground in an uncontrolled fashion.	Risk of bodily harm if the debris falls into populated areas.	2C	Launch vehicle should be constructed to withstand the forces inherent with flight and separation; deployment charges	2D	Ground deployment testing will be conducted to produce successful separation and deployment without excessive force.

				should be kept to the minimum amount necessary for a successful separation.		

ii. Failure Modes and Effects Analysis

Table 7b: Failure modes and effects analysis.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Post-RAC	Verification
Igniter fails to activate	Mechanical or electrical failure.	Vehicle does not leave the launch pad.	4C	Electronic match will be replaced, ground support equipment will be tested if hazard persists.	4D	Safety officer will ensure that e-matches are connected to electrical leads, and will carry extra e-matches if necessary.
Failure of components	Improper installation or general wear and tear.	Project is delayed or the launch vehicle is damaged.	2D	Replace failed parts when practical; review rocket design or final integration and preflight	2E	Care will be taken when designing parts to ensure maximum strength. Extra components will be manufactured if time

				checklists when applicable.		and materials allow.
Unstable launch platform	Launch platform is poorly anchored due to ground conditions.	Undesired/unpredictable rocket trajectory when leaving launch rail.	4C	Ensure launch platform is secured prior to launch.	4D	Ground support equipment will be verified by the RSO before launch procedures continue.
Altimeter failure	Electrical failure; improper programming.	Parachutes will deploy early/late, causing premature/lack of separation of rocket sections.	2D	Test altimeter programming prior to transit to launch site. Two altimeters are used for redundancy, and wiring/programming will be checked during final integration.	2E	The sound sequence provided by the altimeters will be validated to ensure that the altimeters are functioning.
Parachute deployment failure	Altimeter/electronic failure; parachutes and shock cord become entangled.	Launch vehicle will not decelerate before reaching the ground; the launch vehicle has	1D	Packaging of parachute and shock cords will be checked before final integration.	1E	Launch vehicle weight and weather will be recorded to ensure parachutes and shock cord are

		potential to become ballistic.				selected correctly.
Sections fail to separate	Black powder charges are insufficient to separate sections; shear pins do not shear.	Parachutes do not deploy, causing vehicle to become ballistic and causing damage to launch vehicle.	1D	Adequate black powder tests will be conducted to ensure that quantity is sufficient for separation. Attention to detail will be paid when sanding interior surfaces required for separation.	1E	Black powder charges will be weighed to ensure the correct amount was inserted. Igniters will also be checked for continuity to the altimeters.
Sections separate prematurely	Black powder charges fire early due to programmin g error; fabrication error.	Structural failure, loss of payload, damage to launch vehicle.	2D	Calculate amount of shear pins necessary to negate drag separation; ensure altimeters are programmed correctly.	2E	Shear pins will be inspected for abnormaliti es or defects; altimeters will be checked to ensure proper programmi ng.
Catastrophic failure of motor	Improper motor assembly.	Launch vehicle is severely	1D	Ensure that motors are stored,	1E	Safety officer will inspect

		damaged or destroyed; ground fires upon landing.		handled, and assembled properly. All personnel should be a safe distance from the launch pad before final countdown occurs.		motor component s and oversee motor assembly.
Motor retaining ring failure	Recovery system separates with enough force to separate the motor from the booster section.	Motor and motor casing become ballistic; launch vehicle breaches 90 second descent requirement.	2D	Ensure that centering rings and retaining rings are secured to the interior of the booster section.	2E	Verify that the retaining ring is properly secured to the booster section.
Loss of stability during flight	Damage or loss of fin(s); poor fabrication.	Rocket follows an erratic and unpredictabl e flight trajectory; loss of launch vehicle.	1D	Ensure that fins are epoxied to the motor tube and outer body tube, as well as filletted properly.	1E	Using preflight checklists to ensure that all component s necessary for flight are thoroughly inspected for any abnormaliti es.
Change in mass	Payload/avi onics sled	Decrease in stability of	3D	Rocket design will	3E	Ensure batteries

distribution during flight	shift during flight.	launch vehicle.		include adequate hardware to securely mount avionics and payload to their respective body tubes.		and all component s housed within the airframe are secured to their respective housings.
Increase in mass during construction	Unplanned addition of components; overuse of epoxy.	Launch vehicle does not reach the desired altitude.	4D	Review OpenRocket design to ensure that accurate weights are taken for each part.	4E	During manufactur ing, weigh each component separately and place the appropriate mass into the OpenRock et simulation.
Igniter fails to activate	Mechanical or electrical failure.	Vehicle does not leave the launch pad.	4C	Electronic match will be replaced, ground support equipment will be tested if hazard persists.	4D	Validate e-match continuity and check for grounding.

iii. Environmental Concerns

Table 7c: Environmental concerns and mitigation efforts.

Hazard	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Post-RAC**	**Verificatio**

						n
Motor exhaust scorching the ground	Hot exhaust or flames leave the vicinity of the launch pad and burn the surrounding area	Potential fires or damage to launch pad and surrounding area	3D	If possible, make sure the launch pad is located in a sparsely vegetated area. Furthermore, the launch pad should have an adequate flame deflector	3E	Inspect the launch pad to ensure that it is placed over an area with sparse vegetation and that a large metal plate is used to deflect the exhaust.
Increased descent velocities	Parachutes are inadequate to slow launch vehicle	Potential damage to the ground, foliage, vehicles, or structures	2D	Ensure that selected parachutes are sufficient to slow rocket to acceptable descent speeds	2E	Launch vehicle mass will be accurately recorded to ensure accurate simulations. Parachutes will be folded properly.
Wire waste material	Wires or wire related material used in electrical components	Pieces of wire being ingested by local livestock or wildlife	3D	Ensure all wire debris is disposed of in proper receptacles	3E	PPE will be used when handling the sharp ends of wires; specified bins will

						be provided exclusively for wire waste.
Plastic waste material	Plastic used in wrapping of various components or debris from sanding/grinding components	Plastic splinters could be ingested by local livestock or wildlife; debris could find its way into the water system	3D	Ensure all plastic debris is disposed of in proper receptacles	3E	All plastic waste will be removed as soon as practical and the ENR facility will be inspected at the conclusion of manufacturing sessions. Recyclable 3D printing plastic will also be used.
Spray painting	The rocket will be painted using spray paint	Water contamination; fumes released into air	4D	All spray painting will be done by trained professionals in a dedicated workspace. Should any team members need to spray paint	4E	Check any and all spray-painting locations to ensure no spray paint is left.

				any portion of the rocket, it will be done in a well ventilated area		
Harmful substances permeating into soil or water	Improper disposal of chemicals	Impure soil and water can eventually affect the health of livestock, wildlife, and humans	1D	Chemicals should be disposed of in accordance with their MSDS sheets. Should a spill occur, all proper measures must be taken as soon as possible	1E	Inventory of batteries and chemicals will be taken after usage.

iv. Discussion of concerns moving forward

As SOAR has not yet staged a successful fullscale flight attempt, the flight characteristics and payload behavior are not yet understood completely. Further testing and the completion of the upcoming March flights will address these concerns.

b. Launch operations procedures

i. Recovery preparation

Table 9a: Recovery preparation checklist.

Prior to Flight	**Safety Officer Signature**
Inspect parachutes for tears, burns, or any	

other form of damage. ● Skipping this step could result in an unsafe velocity after parachute deployment.	
Inspect shock cords for tears, burns, or any other form of damage.	
Ensure all parachutes are attached to the correct shock cord.	
Ensure eye bolts are secured tightly to bulkheads.	
Ensure tape and other foreign objects are removed from shock cords and parachutes.	
Measure and cut e-matches to their proper length.	
Note: Nitrile gloves MUST be worn when handling black powder. Measure black powder into each charge port and cover with a nonflammable insulation.	

ii. Payload preparation

Table 9b: Payload preparation checklist.

Prior to Flight	**Safety Officer Signature**
Ensure all wires are secured within the payload housing.	
Ensure the RaspberryPi Zero is secured to the 3D printed part immediately below it.	
Ensure the 3D printed part attached to the ribbon cable is secured tightly using the small, electronic screwdriver.	
Ensure the motor is attached to the payload with enough freedom to allow it to spin. ● Improperly attaching the motor will	

result in the motor becoming unplugged or not spinning.	
Push the wires for the micro stepper motor through the hole in the bulkhead.	
Ensure the ribbon cables for the camera are not tight or tangled.	
Ensure the camera is rotated 90 degrees to the right of the IMU. This will cause the camera to be aligned with the large buck converters.	
Ensure all wire connections are secure.	
Insert payload into the payload body tube, with the switch aligned to the correct hole. **Payload lead must confirm inspection.**	

iii. Electronics preparation

Table 10a: Electronics preparation checklist.

Prior to Flight	**Safety Officer Signature**
Replace all disposable batteries.	
Ensure all rechargeable batteries are fully charged.	
Ensure all batteries are plugged in correctly and secured to their proper housings. ● Failure to complete this step may result in payload/altimeter failure.	
Ensure altimeters are operable and receiving power.	
Program altimeters to correct altitudes. ● Failure to complete this step accurately will result in failure to reach desired altitude or damage to the launch vehicle upon landing	

All wires are secured to their proper connections.	
Wires are safely inserted within the airframe to ensure no wire is caught between sections.	
Payload wires are routed through the bulkhead and not tightened, in accordance with payload assembly instructions.	
Payload is turned on prior to launch. This is indicated by a green light from within the payload and a sound made by the RaspberryPi Pico.	
Connect e-matches to altimeters to ensure continuity.	

iv. Rocket preparation

Table 10b: Rocket preparation checklist.

Prior to Flight	**Safety Officer Signature**
Inspect fins and fillets for cracks, faults in epoxy, or any other issue that may prevent flight. ● Failure to complete this step could result in catastrophic failure during flight or erratic trajectory.	
Inspect all bulkheads for cracks or other damage, especially near hardware such as eye bolts for shock cord attachment. ● Failure to complete this step could result in catastrophic failure of bulkheads during flight.	
Inspect metal hardware such as D-links, retaining rings, and threaded rods for corrosion.	
Ensure the boattail is undamaged and shows no signs of separation from the rest of the airframe.	

Ensure the interior of the booster section is clean and clear of any debris.	
Ensure nuts are tightened adequately.	

v. Motor preparation

Table 11: Motor preparation checklist.

Prior to Flight	**Safety Officer Signature**
Inspect the motor and all associated parts.	
Assemble the motor in accordance with the assembly instructions (if assembly instructions are provided).	
Apply a sufficient amount of silicon gel to parts that require it.	
Ensure parts that do not require silicon gel are not cross contaminated. ● Failure to complete this step may result in the motor not igniting.	

vi. Setup on launch pad

Table 10: Launchpad setup checklist.

Prior to Flight	**Safety Officer Signature**
Ensure power between launch control and the launch pad is disconnected.	
Slide the launch vehicle onto the launch rail, ensuring that all access holes in the airframe are accessible.	
Orient rail to the angle determined by OpenRocket simulations.	
Turn on payload, ensuring that the system is engaged via the green light and Pico.	
Turn on altimeters, listening for the three	

short beeps that indicate continuity in dual-deploy mode.	
Ensure all systems are active before evacuating the launch pad.	

vii. Igniter installation

Table 12: Igniter installation checklist.

Prior to Flight	**Safety Officer Signature**
Insert the e-match into the motor until it cannot go any farther, then retract it by one (1) inch. ● Failure to complete this step accurately may result in the motor not igniting.	
Secure the e-match in place using a piece of tape.	

viii. Launch procedure

Table 13: Launch procedure checklist.

Prior to Flight	**Safety Officer Signature**
Launch vehicle is oriented on the launch rail correctly.	
All personnel are evacuated from the launch pad ● Failure to complete this step may result in bodily harm.	
Launch vehicle is allowed to sit undisturbed after landing for two (2) minutes.	

ix. Troubleshooting

Table 14: Troubleshooting matrix.

	Safety Officer Signature

E-match fails to ignite: • Check continuity between the e-match and launch control. • If necessary, replace e-match.	

x. Post-flight inspection

Table 15: Post-flight checklist.

	Safety Officer Signature
Once the launch vehicle has touched down, start a two (2) minute timer to ensure payload deployment.	
Once the timer has elapsed and the RSO gives permission, retrieve the launch vehicle.	
Bring the payload and altimeter bay to the judges for scoring.	
Deactivate all electronics onboard the launch vehicle.	
Disassemble the launch vehicle and clean any parts contaminated with black powder residue to prevent corrosion.	

7. Project Plan

a. Testing

i. Discussion of test methodology and results

The payload team has worked through the requirements in a sequential order based on when each motor is used in the program. The servo that moves the piston into the closed position is associated with being the first motor, as it is the first to create movement when the payload is switched on. When ready, the program then moves to the next motor in the sequence, the main stepper motor, and continues moving through the functions for each motor until the last motor, the microstepper (responsible for rotation about the z axis) runs successfully. Throughout fabrication and testing, our team has classified a motor as complete when it performs its function between a given percent of its desired output, which is generally a change to a final position. To this point, our team has been able to run unit tests on every motor, in sequence, with high accuracy during ground testing.

Testing of the IMU sensors has been done without the activation of the motors to allow us to place the sensors in critical positions that are possible to occur and observe how the program handles the reading and the algorithm, our baseline for success has been within 10 degrees of the desired angle. The following tests will need to be completed to ensure success.

1. Static Tests: Conduct static tests to verify that the gimbal system operates correctly while stationary. This includes verifying that the gimbal motors can move smoothly and precisely in all four degrees of freedom (pitch, yaw, roll, and translation).
2. Ground Tests: Conduct ground tests to verify that the gimbal system operates correctly while the rocket is on the ground. This includes verifying that the gimbal system can handle the vibrations and shocks of rocket engine ignition, and that it remains stable during pre-launch preparations.
3. Flight Tests: Conduct flight tests to verify that the gimbal system operates correctly during the rocket's ascent and descent phases. This includes verifying that the gimbal system can track the rocket's position and orientation accurately and respond to commands from the ground station.
4. Payload Tests: Conduct payload tests to verify that the gimbal system can handle different payloads and maintain stability during payload deployment.

ii. Discussion of success of tests

Our payload team has been able to run the program with all the motors and as previously mentioned, all servo motors and the micro stepper motor works as intended and activates in a timely matter of the procedure, so those can be considered a success, we have also run the program with the main stepper motor by itself and in conjunction with the rest of the program and so far this is the only test that has given unreliable results.

The next measure of success has been in the accuracy in the final position of each motor, each building towards the final position of the camera. From our algorithm results we have observed the program does output the correct data for the motors to move, so far every servo motor has been able to move within the 10 degrees of success of that desired angle we command it to move, and the micro stepper motors have an even more precise movement within 5 degrees of success. Thankfully even though our main stepper is not as reliable, the error handling system we have incorporated acts as a PID controller to make sure the stepper motor keeps turning until the desired position within 10 degrees of success is achieved, however it would be ideal for this PID controller to take less iterations of the commands to achieve success.

iii. Lessons learned from tests conducted

Though each motor moves at the desired time in the sequence, our team must continue to fine tune the final position of each component. When it came to the tilt angle of the camera base (which does the final alignment to the z-axis), we found that this system was unreliable. As noted in payload changes, this led us to replace the microstepper with a servo motor, to create a stronger bond between the motor and the camera base component.

Furthermore our current analysis indicates that our problem with the main stepper motor has to do with it interfering directly with our electrical system, so we're continuously testing and working with the best circuit configuration that will result in more reliable results when testing the system as a whole.

iv. Differences between predicted and actual results of tests

Our payload team predicted a very close tolerance between the intended final position of the camera and the actual position of each component and thus the camera position. Whether it is because we did not account for mechanical limitations of the specific motor or certain resistances to motion, we are aiming for a higher accuracy to the intended position.

b. Requirements compliance

i. Updated verifications plan

GENERAL REQUIREMENTS

Table 16: General Requirements

Req #	Requirements	Identification	Verification
1.1	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams will submit new work. Excessive use of past work will merit penalties.	Inspection	Only students are allowed to participate in USF SOAR. Each team lead will ensure that only USF students are attending SOAR meetings, design/build days, and writing sessions. The team's mentor will handle the motor and black powder assembly, see section 1.1.3 Team Mentor. Previous reports will only be used for reference to ensure consistency in standards.

1.2	The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	Inspection	The Team Lead and Vehicle Lead will communicate with the sub-team leads to ensure completion of the project plan in accordance with each sub-team's needs. The Team Lead will communicate project milestone requirements with the team. The Team Lead will work with the sub-team leads to organize community outreach events for the STEM engagement requirement. The Vehicle Lead will create and maintain an accurate budget. The Safety Officer will create checklists during the project and design risk/mitigation charts.
1.3	The team shall identify all team members who plan to attend Launch Week activities by the Critical Design Review (CDR). Team members will include: 1.3.1. Students actively engaged in the project throughout the entire year. 1.3.2. One mentor (see requirement 1.13). 1.3.3. No more than two adult educators.	Inspection	The list of team members who plan to attend Launch Week activities has been created and verified with the team. The tentative number of team members who plan to attend is 14. One mentor will be attending. No adult educators plan to attend.
1.4	Teams shall engage a minimum of 250 participants in Educational Direct Engagement STEM activities in order to be eligible for STEM Engagement scoring and awards. These activities can be conducted in person or virtually. To satisfy this requirement, all events shall occur between project acceptance and the FRR due date.	Inspection	The STEM engagement events are being organized and planned by the team leads. The requirement of 250 minimum participants will be verified by documenting all past and future events. These events will be verified before the FRR deadline (03/07/2022).

1.5	The team will establish and maintain a social media presence to inform the public about team activities.	Inspection	The Team Lead has created an Instagram account for the SOAR NSL 2023 competition. This account is separate from the main SOAR account and will be used to promote/communicate all team events and updates. The main SOAR account will occasionally promote the NSL account for further outreach.
1.6	Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient. Late submissions of PDR, CDR, FRR milestone documents shall be accepted up to 72 hours after the submission deadline. Late submissions shall incur an overall penalty. No PDR, CDR, FRR milestone documents shall be accepted beyond the 72-hour window. Teams that fail to submit the PDR, CDR, FRR milestone documents shall be eliminated from the project.	Inspection	The Team Lead will send each deliverable to the appropriate NASA project management team personnel by the accurate deadline. In the event that the Team Lead is unavailable to send the deliverable, the Vehicle Lead or a sub-team lead will send the deliverable. If the file is too large, the Team Lead will provide a link for the NASA management team.

1.7	Teams who do not satisfactorily complete each milestone review (PDR, CDR, FRR) shall be provided action items needed to be completed following their review and shall be required to address action items in a delta review session. After the delta session the NASA management panel shall meet to determine the teams' status in the program and the team shall be notified shortly thereafter.	Inspection	SOAR understands this requirement and will cooperate with providing any information that NASA requires from our team.
1.8	All deliverables shall be in PDF format.	Inspection	The Team Lead will ensure each deliverable has been proofread, properly formatted, and saved in PDF format before submission.
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.	Inspection	The team will continuously update the table of contents with each section/sub- section that is written. The Team Lead will verify the final table of contents before submission.

1.10	In every report, the team will include the page number at the bottom of the page.	Inspection	The Team Lead will verify each page has been numbered during the proofreading session.
1.11	The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	Inspection	The SOAR team can provide adequate computer equipment for video teleconferences. A secure, quite room will be booked for each Milestone Presentation with the College of Engineering Department at USF.
1.12	All teams attending Launch Week will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions.	Inspection	The full-scale rocket will be appropriately designed to support the launch pads and rails provided by NASA during Launch Week. Will be verified with the vehicle design section of the design review documents.

1.13	Each team shall identify a “mentor.” A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor shall maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry 8 General and Proposal Requirements Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to Launch Week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend Launch Week in April.	Inspection	The Team Mentor has been identified and meets the qualifications set by the NSL 2022 Handbook. See section 1.a.iv Team Mentor.
1.14	Teams will track and report the number of hours spent working on each milestone.	Inspect	Each team member will be responsible for reporting the date and amount of time spent working on each milestone. See section 1.1.5 Hours Spent Working on the CDR Milestone.

VEHICLE REQUIREMENTS

Table 17: Vehicle Requirements

Req #	Requirements	Identification	Verification
2.1	The vehicle will deliver the payload to an apogee altitude between 4,000 and 6,000 feet above ground level (AGL). Teams flying below 3,500 feet or above 6,500 feet on their competition launch will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.	Analysis	The target apogee altitude of this vehicle is identified as 4,500 feet. OpenRocket analysis will be used to verify this target altitude. The subscale launch will also be utilized as data to verify our final motor choice for the full-scale design.
2.2	Teams shall declare their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team’s altitude score.	Inspection	The target altitude was identified as 4,500 feet by the PDR Milestone.
2.3	The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Analysis/Inspection	The launch vehicle will be modeled in OpenRocket, and significant calculation analysis will be done to determine the descent velocities and kinetic energies of the two separately falling pieces. The four-parachute system will be utilized to ensure the safe recovery of the launch vehicle sections. The Safety Officer will inspect the vehicle to determine the reusability of the launch vehicle after the launch.

2.4	The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute. 2.4.1. Coupler/airframe shoulders which are located at in-flight separation points will be at least 2 airframe diameters in length. (One body diameter of surface contact with each airframe section). 2.4.2. Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.	Inspection	Three independent sections are designed for the full scale vehicle. Coupler/airframe requirements will be followed and nose cone shoulder requirements will be followed as well.
2.5	The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	Testing	The launch vehicle will be assembled various times beforehand to ensure a timely assembly on launch day. An assembly checklist will be created by the Safety Officer, and the assembly will be timed.
2.6	The launch vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.	Testing	The payload system and avionics bay system will be provided with adequate battery systems to sustain power for the 2-hour minimum time. The launch vehicle will be appropriately secured to maintain flight readiness on the pad.

2.7	The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.	Demonstration	The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.
2.8	The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).	Inspection	All required electrical components and circuitry will be secured within the avionics bay and payload section. The only equipment to initiate launch will be the 12-volt firing system provided.
2.9	Each team shall use commercially available e-matches or igniters. Hand-dipped igniters shall not be permitted.	Inspection	Commercial e-matches will be used for the avionics black powder charges. Ematches for the motor will be provided by the manufacturer when purchased.
2.10	The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR). 2.10.1. Final motor choices will be	Inspection	The selected motor will be a commercially available solid motor propulsion system using APCP. The final motor selection will be identified by the CDR Milestone, see section 1.b Launch Vehicle Summary

	declared by the Critical Design Review (CDR) milestone. 2.10.2. Any motor change after CDR shall be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment will not be approved. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason		
2.11	The launch vehicle will be limited to a single motor propulsion system.	Inspection	The launch vehicle will only contain a single motor for the flight.
2.12	The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-Seconds (L-class).	Analysis	OpenRocket analysis will be used to determine the total impulse of the launch vehicle. The vehicle will be designed with a total impulse less than 5,120 N-sec.. The final motor selection is not bigger than an L-class, see section 1.2 Launch Vehicle Summary.

2.13	Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria: 2.13.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews. 2.13.2. Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank. 2.13.3. The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.	Inspection	Final vehicle design does not include pressure vessels.
2.14	The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	Analysis	OpenRocket analysis will be used to determine the static stability of the launch vehicle at the rail exit. The center of pressure and center of gravity measurements will determine the rocket's static stability. The rocket will be designed to have a minimum of 2.0 at the rail exit.

2.15	The launch vehicle will have a minimum thrust to weight ratio of 5.0 : 1.0.	Analysis	OpenRocket analysis will be used to determine the minimum thrust to weight ratio. The vehicle will be designed to have a minimum of 5.0:1.0 thrust to weight ratio.
2.16	Any structural protuberance on the rocket will be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.	Analysis	No structural protuberances are present in the final launch vehicle design. A camera mount may be implemented on the upper airframe tube in accordance with requirements if desired
2.17	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	Analysis	OpenRocket analysis will be used to determine the vehicle's rail exit velocity. The launch vehicle will be designed to accelerate to a velocity of 70 ft/s feet/sec. at rail exit.
2.18	All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Success of the subscale is at the sole discretion of the NASA review panel. The subscale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data shall be reported in the CDR report and presentation at the CDR milestone. Subscales are required to use a minimum motor impulse class of E	Demonstration / Inspection	Construction of subscale rocket in accordance with competition requirements demonstrated in PDR and CDR milestones. Successful flight data from the 12/17/22 test flight included in CDR milestone. See 3.b.i Recorded Flight Data Selected motor for

	(Mid Power motor). 2.18.1. The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the full-scale will not be used as the subscale model. 2.18.2. The subscale model will carry an altimeter capable of recording the model's apogee altitude. 2.18.3. The subscale rocket shall be a newly constructed rocket, designed and built specifically for this year's project. 2.18.4. Proof of a successful flight shall be supplied in the CDR report. 2.18.4.1. Altimeter flight profile graph(s) OR a quality video showing successful launch, recovery events, and landing as deemed by the NASA management panel are acceptable methods of proof. Altimeter flight profile graph(s) that are not complete (liftoff through landing) shall not be accepted. 2.18.4.2. Quality pictures of the as landed configuration of all sections of the launch vehicle shall be included in the CDR report. This includes but not limited to nosecone, recovery system, airframe, and booster. 2.18.5. The subscale rocket shall not exceed 75% of the dimensions (length and diameter) of your designed full-scale rocket. For example, if your full-scale rocket is a 4" diameter 100" length rocket your subscale shall not exceed 3" diameter and 75" in length.		subscale demonstration flight (I120) meets motor requirements. Subscale design

2.19	All teams will complete demonstration flights as outlined below. 2.19.1. Vehicle Demonstration Flight—All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown shall be the same rocket to be flown for their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria shall be met during the full-scale demonstration flight: 10 General and Proposal Requirements 2.19.1.1. The vehicle and recovery system will have functioned as designed. 2.19.1.2. The full-scale rocket shall be a newly constructed rocket, designed and built specifically for this year's project. 2.19.1.3. The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply: 2.19.1.3.1. If the payload is not flown, mass simulators will be used to simulate the payload mass. 2.19.1.3.2. The mass simulators will be located in the same approximate location on the rocket as the missing payload mass. 2.19.1.4. If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight. 2.19.1.5. Teams shall fly the competition launch motor for the Vehicle	Analysis/Demonstration	Vehicle demonstration flight will be performed and reported in accordance with competition timeline. The primary vehicle demonstration flight launch date is scheduled to occur on February 19th at the Tripoli Tampa launch site. The backup date for the demonstration flight is March 5th at the Tripoli Fort Myers launch site. Data from successful flight will be included in a manner adjacent to subscale flight results by the FRR milestone deadline. Further modifications to launch vehicle after test flight will be performed as deemed acceptable by NSL requirements and issues addressed in the redesign will be explicitly stated in the FRR milestone deadline

	Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the competition launch motor or in other extenuating circumstances. 2.19.1.6. The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the competition launch flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle. 2.19.1.7. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO). 2.19.1.8. Proof of a successful flight shall be supplied in the FRR report. 2.19.1.8.1. Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet this requirement. Altimeter flight profile graph(s) that are not complete (liftoff through landing) shall not be accepted. 2.19.1.8.2. Quality pictures of the as landed configuration of all sections of the launch vehicle shall be included in the FRR report. This includes but is not limited to nosecone, recovery system, airframe, and booster. 2.19.1.9 Vehicle Demonstration flights shall be completed by the FRR submission deadline. No exceptions will be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight shall submit an FRR		

	Addendum by the FRR Addendum deadline. 2.19.2. Payload Demonstration Flight—All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown shall be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria shall be met during the Payload Demonstration Flight: 2.19.2.1. The payload shall be fully retained until the intended point of deployment (if applicable), all retention mechanisms shall function as designed, and the retention mechanism shall not sustain damage requiring repair. 2.19.2.2. The payload flown shall be the final, active version. 11 General and Proposal Requirements 2.19.2.3. If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum arenot required. 2.19.2.4. Payload Demonstration Flights shall be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED.		

2.20	An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASArequired VehicleDemonstrationRe-flight after the submission of the FRR Report. 2.20.1. Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly a final competition launch. 2.20.2. Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly a final competition launch. 2.20.3. Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.	Inspection	SOAR will submit an FRR Addendum in the case of not completing a Payload Demonstration Flight prior to the FRR Milestone Report deadline.
2.21	The team's name and Launch Day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.	Inspection	Each individual section of the launch vehicle will have the team's name and contact information visible without requiring the vehicle to be opened or further separated.

2.22	All Lithium Polymer batteries will be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.	Inspection	The Safety Officer will ensure that all Lithium Polymer batteries are appropriately secured and protected to prevent impact with the ground. They will all be clearly marked and designated as fire hazards and will be distinguishable from the rest of the payload hardware
2.23	Vehicle Prohibitions 2.23.1. The launch vehicle will not utilize forward firing motors. 2.23.2. The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.) 2.23.3. The launch vehicle will not utilize hybrid motors. 2.23.4. The launch vehicle will not utilize a cluster of motors. 2.23.5. The launch vehicle will not utilize friction fitting for motors. 2.23.6. The launch vehicle will not exceed Mach 1 at any point during flight. 2.23.7. Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would Sit on the pad (i.e. a rocket with an unballasted weight of 40 lbs. On the pad may contain a maximum of 4 lbs. of ballast). 2.23.8. Transmissions from onboard transmitters, which are active at any point prior to landing, will not exceed 250 mW of power (per transmitter). 2.23.9. Transmitters will not create excessive interference. Teams will utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from	Analysis/Inspection	Forward firing motors are not included in the final launch vehicle design. The motor selected for the full-scale flights (K520) does not expel titanium sponges. Only a single launch motor will be utilized for each flight. Maximum flight velocity as predicted by OpenRocket will not exceed Mach 1. Only up to 4 lbs of ballast may be included in the launch vehicle. LORA transmitters will not exceed 250 mW of power per transmitter. Dense metal will not be utilized in the launch vehicle design and lightweight metals will be included only in areas deemed necessary by large expected operating stresses.

	other teams. 2.23.10. Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.		

RECOVERY REQUIREMENTS

Table 18a: Recovery Requirements

Req #	Requirements	Identification	Verification
3.1	The full-scale launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue stage descent is reasonable, as deemed by the RSO.	Analysis	The drogue, streamer, and main parachute will be programmed to release at the appropriate altitudes with a reasonable kinetic energy during the drogue stage descent for the streamer in the upper section.
3.1.1	The main parachute shall be deployed no lower than 500 feet.	Analysis	The main parachute will be programmed to deploy at an altitude above 500 feet with a back-up deployment in case of initial failure.
3.1.2	The apogee event may contain a delay of no more than 2 seconds.	Analysis	The apogee event will be simulated accordingly to remain within a 2 second window
3.1.3	Motor ejection is not a permissible form of primary or secondary deployment.	Inspection	The motor will remain secured in the launch vehicle for the duration of the flight
3.2	Each team will perform a successful	Demonstration	The Safety Officer and

	ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full-scale vehicles.		Recovery Sub-Team Lead will conduct ground ejection tests for the electronically initiated parachutes/drogue/streamer before each launch.
3.3	Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.	Analysis	Hand calculations will be used to determine the launch vehicle's kinetic energy at landing. The upper-section and lower-section of the rocket will be designed to have a kinetic energy at landing below 75 ft-lbf.
3.4	The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	Inspection	The launch vehicle's design included commercially available, redundant altimeters. There will be two altimeters responsible for deployment.
3.5	Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries.	Inspection	Each altimeter will be powered by its own individual battery. New batteries will be tested and inserted for each launch to remove any possibility of battery failure
3.6	Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Inspection	The avionics bay will have mechanical arming switches to activate the altimeters. The launch vehicle will be designed to allow for switches to be accessible from the exterior.
3.7	Each arming switch will be capable of being locked in the ON position for launch (i.e., cannot be disarmed due to flight forces).	Demonstration / Inspection	The arming switches can only be activated by inserting and turning the switch keys. The avionics

			bay will be appropriately secured to verify that it will remain locked in the ON position despite flight forces that will occur. Verification can be found by simulating flight forces on the avionics bay.
3.8	The recovery system electrical circuits will be completely independent of any payload electrical circuits.	Inspection	The avionics bay will be located in a separate section of the rocket. The electronics of each section will be completely isolated from the other.
3.9	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Inspection	The launch vehicle will be designed with spots for shear pins to be inserted. Each separation point will be utilizing shear pins.
3.10	The recovery area will be limited to a 2,500 ft. radius from the launch pads.	Analysis	Calculations for drift will be completed to verify the launch vehicle will land within the 2,500 feet radius from the designated launch pad.
3.11	Descent time of the launch vehicle will be limited to 90 seconds (apogee to touch down).	Analysis	Written code was used to determine the total descent time of the launch vehicle. The separate sections will both be analyzed to land within the limited 90 second window
3.12	An electronic GPS tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver. 3.12.1. Any rocket section or payload	Inspection	The avionics bay will include a GPS tracking device to verify the landing position of each section. The GPS system will be tested and supplied with ample

	component, which lands untethered to the launch vehicle, will contain an active electronic GPS tracking device. 3.12.2. The electronic GPS tracking device(s) will be fully functional during the official competition launch.		power before each launch.
3.13	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing). 3.13.1. The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device. 3.13.2. The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics. 3.13.3. The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves and Tesla coils) to avoid inadvertent excitation of the recovery system. 3.13.4. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	Inspection	The electronics will be placed separately in the avionics bay to provide ample room between the transmitters. The Payload electronics will be placed in a separate section of the launch vehicle to prohibit any further interference. Any other onboard devices that may interfere with the recovery system electronics will be properly shielded from the recovery system.

PAYLOAD EXPERIMENT REQUIREMENTS

Table 18b: Payload experiment requirements

Req #	Requirements	Identification	Verification
4.1	College/University Division—Teams shall design a payload capable upon landing of autonomously receiving RF commands and performing a series of tasks with an on-board camera system. The	Inspection / Demonstration	The payload system will undergo a series of unit tests for each component of the mission: alignment after landing, gimbal alignment, RF processing,

	method(s)/design(s) utilized to complete the payload mission shall be at the team's discretion and shall be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge. 13 General and Proposal Requirements An additional experiment (limit of 1) is allowed, and may be flown, but will not contribute to scoring. If the team chooses to fly an additional experiment, they will provide the appropriate documentation in all design reports so the experiment may be reviewed for flight safety.		picture storage. And it will also undergo a series of drop tests to ensure it's capable of landing still operational and capable of performing the series of tasks outlined by the RF commands
4.2.1	The Launch Vehicle shall contain an automated camera system capable of swiveling 360º to take images of the entire surrounding area of the launch vehicle. 4.2.1.1. The camera shall have the capability of rotating about the z axis. The z axis is perpendicular to the ground plane with the sky oriented up and the planetary surface oriented down. 4.2.1.2. The camera shall have a FOV of at least 100º and a maximum FOV of 180º. 4.2.1.3. The camera shall time stamp each photo taken. The time stamp shall be visible on all photos submitted to NASA in the PLAR. 4.2.1.4. The camera system shall execute the string of transmitted	Inspection / demonstration	A gimbal system was created with two micro servos, where one motor produces 360 degrees of rotation about the camera base and a second adjusts the camera face to be completely upright and thus aligned with the z axis. The program will run the string two minutes after the initial acceleration of the launch. The program will also note the time stamps of the photos taken.
4.2.2	NASA Student Launch Management Team shall transmit a RF sequence that shall contain a radio call sign followed by a sequence of tasks to be completed. The list of potential commands to be given on launch day along with their radio transcriptions which shall be sent in a RF message using APRS transmission in no particular order are: A1—Turn camera 60º to the right B2—Turn camera 60º to the left C3—Take picture D4—Change camera mode from color to grayscale	Inspection / Demonstration	The software inside the main computer shall be revised to check it contains a dictionary list that's accurate to the given potential commands. The software will also be thoroughly revised to ensure the call sign input can be easily set by only modifying a minimal part of the codebase.

	E5—Change camera mode back from grayscale to color F6—Rotate image 180º (upside down). G7—Special effects filter (Apply any filter or image distortion you want and state what filter or distortion was used). H8—Remove all filters. 4.2.2.1. An example transmission sequence could look something like, "XX4XXX C3 A1 D4 C3 F6 C3 F6 B2 B2 C3." Note the call sign that NASA will use shall be distributed to teams at a later time		
4.2.3	The NASA Student Launch Management Panel shall transmit the RAFCO using APRS. 4.2.3.1. NASA will use dedicated frequencies to transmit the message. NASA will operate on the 2-Meter amateur radio band between the frequencies of 144.90 MHz and 145.10 MHz. No team shall be permitted to transmit on any frequency in this range. The specific frequency used will be shared with teams during Launch Week. NASA reserves the right to modify the transmission frequency as deemed necessary. 4.2.3.2. The NASA Management Team shall transmit the RAFCO every 2 minutes. 4.2.3.3. The payload system shall not initiate and begin accepting RAFCO until AFTER the launch vehicle has landed on the planetary surface.	Inspection / Demonstration	(Before arriving at the launch site) A member of SOAR, with a level at or above ham radio technician license, will send a series of commands over the 2m radio band, the computer will listen through the DRA818V module and output the commands to a log file. The log file must have most of the commands exactly as they were sent for this aspect to be working.
4.2.4	The payload shall not be jettisoned.	Inspection	The payload is bolted to a coupler tube that is slid into the main body tube. Once in the body tube, the payload is securely bolted in with ¼ inch screws that bolt into adhesive nuts on the inside of the body tube.
4.2.5	The sequence of time-stamped photos taken need not be transmitted back to	Analysis / Inspection	The current payload design and components don't have the

	ground station and shall be presented in the correct order in your PLAR.		functionality to send any data back to base over RF. The main computer wll be tested to ensure a series of images are stored in its main memory without data loss.
4.3.1	Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics shall not be permitted for any surface operations.	Inspection	The launch vehicle will only utilize energetics during in-flight recovery systems. SOAR will not have any surface operations for this competition.
4.3.2	Teams shall abide by all FAA and NAR rules and regulations.	Inspection	The team leads will ensure to read the FAA and NAR regulations and keep them in mind during development and tests.
4.3.3	Any secondary payload experiment element that is jettisoned during the recovery phase will 14 General and Proposal Requirements receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement the CDR milestone by NASA	Inspection	No secondary payload experiment is currently projected to be performed
4.3.4	Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.	Inspection	SOAR's payload current design doesn't implement a UAS.
4.3.5	Teams flying UASs will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112–95 Section336; see https://www.faa.gov/uas/faqs).	Inspection	SOAR's payload current design doesn't implement a UAS.
4.3.6	Any UAS weighing more than .55 lbs shall be registered with the FAA and the	Inspection	SOAR's payload current design doesn't implement a UAS.

	registration number marked on the vehicle.		

SAFETY REQUIREMENTS

Table 19: Safety Requirements

Req #	Requirements	Identification	Verification
5.1	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.	Demonstration	The Safety Officer will create launch and safety checklists to be included in the FRR report and used during the LRR, as well as distribute copies to the various team leads.
5.2	Each team shall identify a student safety officer who will be responsible for all items in section 5.3.	Demonstration	SOAR conducts interviews for the Chief of Safety (CoS) position at the end of each academic year in order to be prepared for the following NSL competition.
5.3	The role and responsibilities of the safety officer will include, but are not limited to: 5.3.1. Monitor team activities with an emphasis on safety during: 5.3.1.1. Design of vehicle and payload 5.3.1.2. Construction of vehicle and payload components 5.3.1.3. Assembly of vehicle and payload 5.3.1.4. Ground testing of vehicle and payload 5.3.1.5. Subscale launch test(s) 5.3.1.6. Full-scale launch test(s) 5.3.1.7. Competition Launch 5.3.1.8. Recovery activities 5.3.1.9. STEM Engagement Activities 5.3.2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities. 5.3.3. Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data. 5.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analyses, and	Inspection/Demonstration	The Safety Officer will be present during all sanctioned fabrication sessions to ensure all safety guidelines are being followed during the manufacturing process. During ground testing, the safety officer oversees all tests to ensure that they are being conducted in a safe manner. The safety officer will also monitor activities during launch operations and use various checklists to maintain correct assembly processes in order to facilitate a successful launch and recovery. These checklists include but are not limited to payload assembly, launch vehicle integration, and recovery. The safety officer will also create and update

	procedures.		documentation regarding workspace safety and material/chemical inventory.
5.4	During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	Analysis	SOAR has established a working relationship with their local TRA Prefecture and works closely with them to ensure all launch vehicles and payloads are authorized under TRA and NAR guidelines.
5.5	Teams will abide by all rules set forth by the FAA.	Analysis	The Safety Officer will stay up to date with FAA guidelines regarding high powered rocketry and forward any new information to the rest of the organization.

ii. Updated team-derived requirements

Table 20: Team Derived Vehicle Requirements

Requirements	Method of Meeting Requirement	Verification
The launch vehicle reaches the target altitude of 4,500 feet, within a margin of ± 50 feet.	Data Analysis	Multiple simulation tools, such as OpenRocket Software and Rocketpy (MATLAB/Python), will be utilized to provide as accurate predictions as possible before flight, allowing adjustments to be made to the ballast system as needed.
The launch vehicle is able to withstand all aerodynamic forces sustained during flight, with negligible effects on	Visual confirmation (any structural damage)/Data Analysis	The use of a boattail, and the switch from Fiberglass to Carbon Fiber fins aim to increase the performance of the vehicle, which can be verified

performance.		through the use of CFD (Computational Fluid Dynamics).
The launch vehicle is able to withstand the force of impact with the ground in the event of recovery system failure, to the point where, if need be, the vehicle can be launched again within a time period of 2 hours.	Structural Analysis	Proper material selection, as well as efficient configuration of the launch vehicle can be verified through the use of FEA (Finite Element Analysis).

Table 21: Team Derived Recovery Requirements

Requirements	**Method of Meeting Requirement**	**Verification**
Obtain an accurate altitude reading to compare to simulations	Utilization of a designated altimeter to use its recorded max altitude	The altimeter set to being the main altimeter in the avionics bay will have its data used for comparing projected apogee
Verify that parachute can deploy during recovery event	Black powder testing prior to vehicle launch	Main and drogue parachute must be able to escape the body tube during these tests with an acceptable amount of black powder while being in accordance with safety protocols.
Altimeter bay arming	Manufactured holes in switch band must be large enough to allow a key to enter and arm altimeters	Sanding of the key hole will be done if the size is too small to activate the switch.
Pre-Launch altimeter flight configuration	Assurance that altimeters are set to current flight conditions of launch day.	Using the accompanying LCD display with the Missileworks RRC3 provides the team with easy diagnosis of what settings the altimeters are on.
GPS Configuration	Proper coordinate position is showing correctly on LCD screen	Calibration of Missileworks Rtx/GPS device during launch

		day to set the proper position. Verifying that the GPS module at the ground station is for the ground.

Table 22: Team Derived Payload Requirements

Requirements	**Method of Meeting Requirement**	**Verification**
The payload system must be able to activate in a timely manner upon landing	The main computer will continuously read from the IMU until it detects a significant change in velocity, then it will wait for 2 minutes (it's supposed to have landed by then) and check again if the payload is stationary to start the mission.	10 trials will be conducted, where the whole payload will be moved around with great force to simulate the launch. The computer will make sounds with a small piezo once the program starts running. The sound must be emitted through all the trials to confirm activation is working.
The camera system must be aligned as close as possible to the vertical axis	The payload tube will have 4 specific openings, one of the openings will be chosen by the computer based on the IMU data on which could be the closest one to the vertical axis, to account for any slight misalignment a gimbal system attached to the camera will finish aligning to the vertical axis	10 trials will be conducted, where the whole payload will be dropped and placed at different angles and the camera system must come out of the right opening most of the time, which will ensure the first part of the system is working. The gimbal system must also align correctly in most of the trials independent if the right hole was chosen for the second part to be working.
The payload system will be able to store the images from the camera safely	The Main Payload computer will be directly connected to the camera via a ribbon cable. Upon taking a picture it will be immediately stored in main memory, if any processing is needed it will be retrieved and then modified.	The main computer will take a series of pictures, with different post processing commands. After some of the images are taken different scenarios will be simulated: the breaking of the ribbon cable, a power failure, among others we might deem necessary to simulate. Afterwards, if inside its main

		memory at least some images were preserved and the program didn't get stuck due to the complications, it will be ready.

c. Budgeting and funding summary

i. Updated line item budget

SOAR has slightly updated the line item budget to reflect new resource acquisitions made in this stage of the project. The updated line item budget follows.

Table 23: Line item budget.

Component	Vendors	Total Cost
4in Fiberglass Body Tube, 5'	Wildman Rocketry	$128.43
4in Fiberglass Coupler Tube, per inch	Wildman Rocketry	$2.86
Boat-tail adapter	Wildman Rocketry	$78.00
Raspberry Pi Zero	Amazon	$15.99
Raspberry Pi Pico	Amazon	$13.25
4S LiPo Battery	Amazon	$98.99
Raspberry Pi Camera Board	Adafruit	$29.95
Raspberry Pi Camera Cable	Adafruit	$3.95
IMU Sensor (Pack of 10)	DFRobot	$39.50
IMU Breakout Board	Adafruit	$29.95
Photosensitive Sensor Module (Pack of 10)	Amazon	$7.99
128 GB Micro SD Card with Adapter	Amazon	$17.21
Cesaroni 5G Case	Wildman Rocketry	$87.90
Cesaroni 5G Motor	Wildman Rocketry	$219.43
Servomotor	Amazon	$15.00
54mm Fiberglass Motor Tube, 2'	Wildman Rocketry	$31.68
4in Von Karman Fiberglass Nose Cone	Wildman Rocketry	$93.50
Metal Pinion	McMaster-Carr	$20.44

Metal Rack	McMaster-Carr	$19.29
J-B Weld 8281 Steel-Reinforced Epoxy (10oz)	Amazon	$17.98
Structural Fiberglass 4'x4'x3/16"	McMaster-Carr	$283.31
Ham amateur radio module	Tindie	$9.98
800g White Polymaker PLA Filament	Amazon	$32.99
RockSim V10 License	Apogee Components	$247.20
Speed Tiger ISE Carbide End Mills	Amazon	$25.54
RRC3 Sport Altimeter	Wildman Rocketry	$104.53
Leatherman SIGNAL Multitool	Leatherman	$150.45

ii. Updated funding plan

SOAR has not made any changes to its funding plan since the CDR. In that sense, SOAR will still fund NASA Student Launch entirely from Student Government funding. An updated budget breakdown is included below.

Table 24: Updated budget breakdown.

CATEGORY	BUDGET	EXPENSES	AMT. REMAINING
Consumables	$ 1,000.00	$ 900.81	$ 99.19
Aerostructures	$ 3,000.00	$ 2,970.96	$ 29.04
Payload	$ 3,000.00	$ 1,220.16	$ 1,779.84
Avionics & Recovery	$ 1,457.63	$ 1,171.01	$ 286.62

The project is nearing completion and the budget may be shifted to accommodate unexpected expenses from categories with lower remaining budgets. However, overall, the budget will not require extension or compensation from other projects within SOAR.

8. References

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[2] *Parachute descent rate calculator*. Fruity Chutes! (n.d.). Retrieved March 5, 2023, from https://fruitychutes.com/help_for_parachutes/parachute-descent-rate-calculator.htm