# EFFECTIVE-1

## Rocket Team at UC Santa Cruz

1156 High Street

Santa Cruz, CA 95064

NASA Student Launch Initiative

Preliminary Design Review

November 3, 2017

# 1. Summary

## 1.1 Team Summary

| | |
|---|---|
| **Team Name:** | Rocket Team at UC Santa Cruz |
| **University:** | University of California, Santa Cruz |
| **Mailing Address:** | Kent Roberts<br>311 Main Street Apt. 5<br>Santa Cruz, CA 95060 |
| **Mentor Name:** | David Raimondi |
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| **Certification level:** | 3 |
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## 1.2 Vehicle Summary

By using a combination of SolidWorks, a custom written flight simulation script, and OpenRocket for, the following general vehicle characteristics were established to fit the team's minimalist design strategy.

| Length | Outer/Inner Diameter | Mass | Rocket Mass with Wet Motor | Motor Selection | Recovery System |
|---|---|---|---|---|---|
| 6.74 ft | 3.1 in / 3.0 in | 7.45 lbs | 9.85 lbs | AeroTech J540 | 18 in drogue chute; 48 in main chute |

The diameter of the rocket is selected to minimize the rocket's drag, which is proportional to the cross sectional area of the rocket. This diameter is also selected for its compatibility with many of the commercially available high powered airframe and nose cone parts. The rocket's height is selected to house the electronics, maximize the rocket's stability margin, and minimize the overall mass. Our final CAD model yields a rocket mass of 7.45 lb. This mass, in addition to an allotted 0.5 lb of ballast, will propel the rocket to a projected altitude of 5588 feet (1.06 miles). This overshot of the apogee target is intentionally selected to allow the Adaptive Drag Aerobraking System (ADAS) to correct the rocket's vertical flight profile in the case of wind and turbulence uncertainties. In order to gently bring the rocket safely back to its terrestrial origin, a two staged recovery consisting of a 18 in drogue chute and a 48 in main chute were found to meet the needed safety factors.

## 1.3 Payload Summary

The team has elected to participate in the target tracking challenge using TARS, the TArget Recognition System. TARS is housed in a clear payload bay and relies on a wide-angle video camera pointed downward to track the positions of the competition tarps in real time. Tracking will be performed with a custom software package run on a Raspberry Pi 3b. The camera system was selected to maximize the camera's viewing time of the targets and medium- and high-altitudes.

# 2. Changes Made Since Proposal

Several changes were made to the rocket design to maximize efficiency, safety, and build simplicity.

## 2.1 Vehicle

| Change | Rationale |
|---|---|
| Motor selection changed from J293 to J540 | A more powerful motor was required to accommodate the added mass of the rocket. |
| Airframe material changed from fiberglass to Blue Tube 2.0 | Blue Tube 2.0 offers significant weight savings with margin reductions in airframe strength. |
| Recovery bay has swapped places with clear payload section | The new configuration unifies the upper and lower avionics sleds into one joined avionics sled. This simplies rocket construction and allows for a more consolidated layout of our avionics devices. |
| Fin profile adjusted, total surface area increased | The larger fins offer an increased stability margin; lower risk of breaking upon landing; and lower risk of flutter. |
| Avionics sled material changed | Leveraging the team's newly-gained access to an advanced 3D Resin printer, the avionics sled will be made of high strength resin. This allows for flexibility in the design and structural mating of the payload to the rocket airframe, as well as reduced tolerances. |
| Avionics framework changed | The avionics bay has a more robust substructure capable of sustaining increased bending loads. |
| ADAS motor changed to a higher torque motor | This will ensure that the fins deploy at high drag |
| The primary flight computer has been changed from a Raspberry Pi Zero to an Arduino 101 | The Arduino 101 is found to be a more versatile and capable inflight computer that could more efficiently execute the corrective calculations necessary for the ADAS. |
| Inflight control algorithms switched from acceleration differencing to PID | A literature study revealed that a Proportional Integral Derivative control loop would be best-suited to control the aerobraking system, ADAS. |

| | |
|---|---|
| Nose cone profile changed from Von Karman to Tangent Ogive | Detailed flow simulations show that the Von Karman profile is only slightly more efficient than the Tangent Ogive shape in low velocity regimes, but the Tangent Ogive cones are more available for purchase. |
| Redundant altimeter/ejection charge added | The new design includes two PerfectFlite Stratologger altimeters to record altitude and redundantly trigger parachute release. |

## 2.2 Payload

| **Change** | **Rationale** |
|---|---|
| TARS: changed from mirrored camera geometry to a mirrorless, down-facing camera configuration | A detailed study of the optical system has showed that the mirror design yielded an inferior field of view in comparison to the alternatives. The more optimal solution involves a single camera pointed downward, peering through a clear window section. The new design provides wider field coverage for a larger fraction of the vehicle's ascent. |
| Lengthened the clear section of the rocket | The increased length of the window section reduces the blind spot imposed by the rocket, yielding a wider field of view, closer to the launch pad. |

## 2.3 Project plan

| | |
|---|---|
| Team size and administration | The Team has grown to include ~40 members from a wide array of disciplines. |
| Logo | Concerns over copyright and University policy motivated a new, more original logo. |
| Modeling software: RockSim replaced with OpenRocket | OpenRocket is a free alternative to RockSim with most of the same modeling functionality. |
| The Team has partnered with the Sustainability Lab on campus | Being a part of the Sustainability Lab will give the team access to a variety of additional resources. |
| The Team will be working on atmospheric research professor Patrick Chuang in the Earth Science department | The long-term sustainability of the Team will be helped through academic partnerships. |

# 3. Vehicle Criteria

## 3.1 Selection, Design, and Rationale of Launch Vehicle

### 3.1.1 Mission Statement and Success Criteria

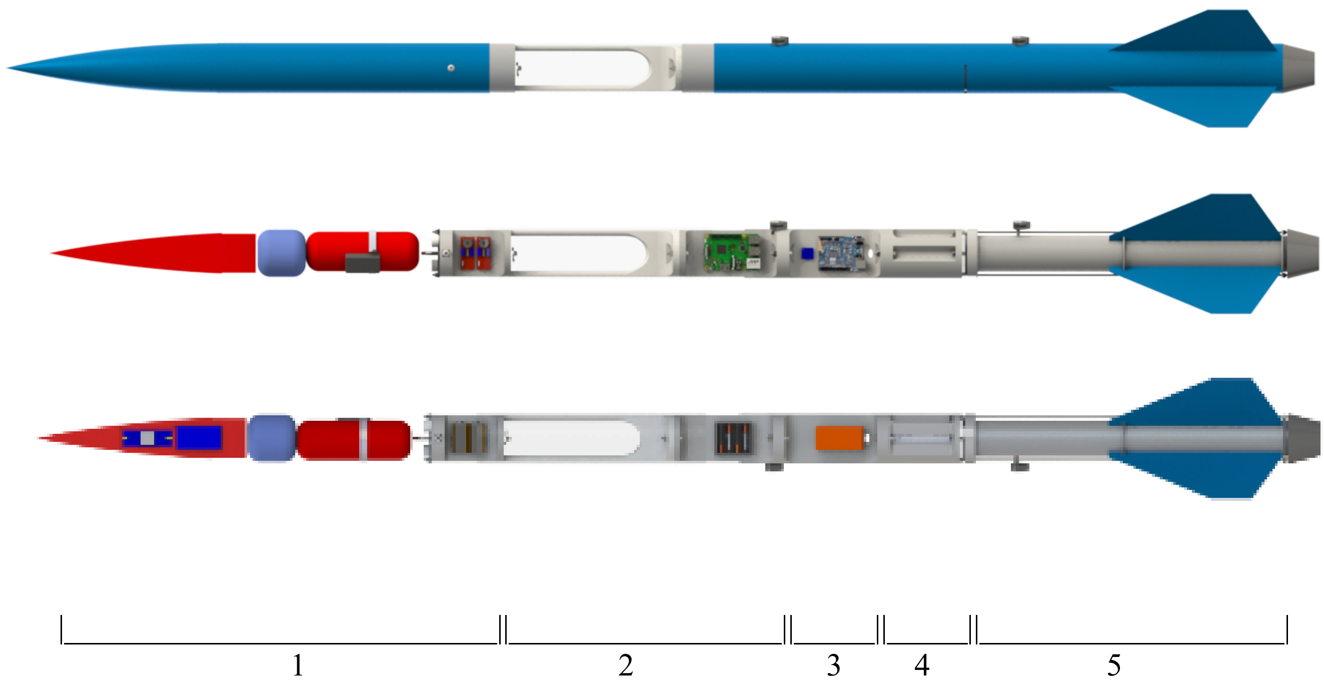
The rocket design is optimized to be lightweight, durable, easily serviceable, and have a modular internal structure, while minimizing its drag coefficient and maximizing its competition performance. The rocket was also designed with safety in mind, with redundant systems and safety features. Ultimately, the vehicle's purpose is to successfully perform corrective inflight adjustments to fit a model of the vertical flight profile while tracking ground targets in real time.

The following is a list of requirements that serve as criteria for a successful mission. Green items are primary objectives, and are required for mission success. Blue items are secondary objectives, which demonstrate mastery of the flight systems, but are not contingent for successful flights.

The vehicle must:

- Meet all safety criteria for pre-launch activities, and all FAA flight requirements and restrictions
- Be fully recoverable and reusable
- Follow a near-vertical trajectory
- Successfully deploy a drogue parachute at apogee and primary parachute at pre-specified altitude
- Record precise sensor measurements throughout the duration of the flight
- Use sensor measurements to determine the its flight parameters at each time step
- Deploy ADAS if the demanded by the flight profile
- Perform fine adjustments to a model flight profile at a rate of 10 Hz
- Achieve a pre-specified apogees to within 5%
- Activate TARS to locate and track tarps of different colors, even at high spin rates
- Achieve pre-specified apogees to within 0.5%
- Pair TARS with the avionics system to correct the video feed for angular velocity
- Repurpose TARS to track and observe topographical and atmospheric features

### 3.1.2 Technical Design



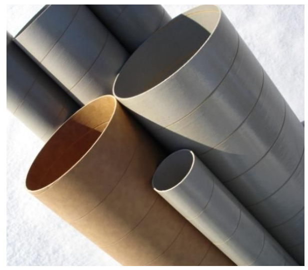

1. Recovery Section
2. TArget Recognition System (TARS)
3. Avionics Bay
4. Adaptive Drag Aerobraking System (ADAS)
5. Thrust Section

<u>General Rocket Properties</u>

| Rocket Mass | Rocket Length | Rocket Outer Diameter | CG, Wet | Wet Motor Mass | Dry Motor Mass | Rocket with Wet Motor |
|---|---|---|---|---|---|---|
| 7.452 lbs | 6.74 ft | 3.1 in | 3.73 ft | 2.39 lb | 1.04 lb | 9.84 lb |

#### 3.1.2.1 Airframe

Three materials were initially considered for the rocket airframe: fiberglass, phenolic paper, and Blue Tube 2.0.

| Fiberglass | Phenolic Paper | Blue Tube 2.0 ✦ |
|---|---|---|
|  |  |  |
| Linear Density: 0.044 lb/in<br>Cost: $1.89/in | Linear Density: 0.014 lb/in<br>Cost: $0.27/in | Linear Density: 0.026 lb/in<br>Cost: $0.62/in |
| Pros:<br>● Very strong | Pros:<br>● Lightweight<br>● Low-cost | Pros:<br>● Strong and durable<br>● Lightweight<br>● Low-cost<br>● Heat resistant |
| Cons<br>● Costly<br>● Dense | Cons:<br>● Brittle<br>● Low density | Cons:<br>● Single source<br>● One kind |

Fiberglass was the first airframe material considered for its strength and widespread application to rocketry. Upon closer analysis, phenolic paper and Blue Tube were also valid options for the airframe. Phenolic paper was found to be significantly less dense and less costly compared to fiberglass, but also more brittle. Blue Tube 2.0 has a good combination of the optimal properties of fiberglass and phenolic paper: it is strong, durable, inexpensive, lightweight, and heat resistant. It is also less susceptible to shattering and deformation than phenolic paper, and has a much lower density than fiberglass. After evaluating the three main options, Blue Tube 2.0 is selected as the leading option.

Stress analysis was carried out on a Blue Tube 2.0 airframe to ensure that it is a suitable material for the airframe and the results show that the maximum stress induced on the airframe from the motor is 38 MPa, well below the breaking threshold for Blue Tube 2.0.

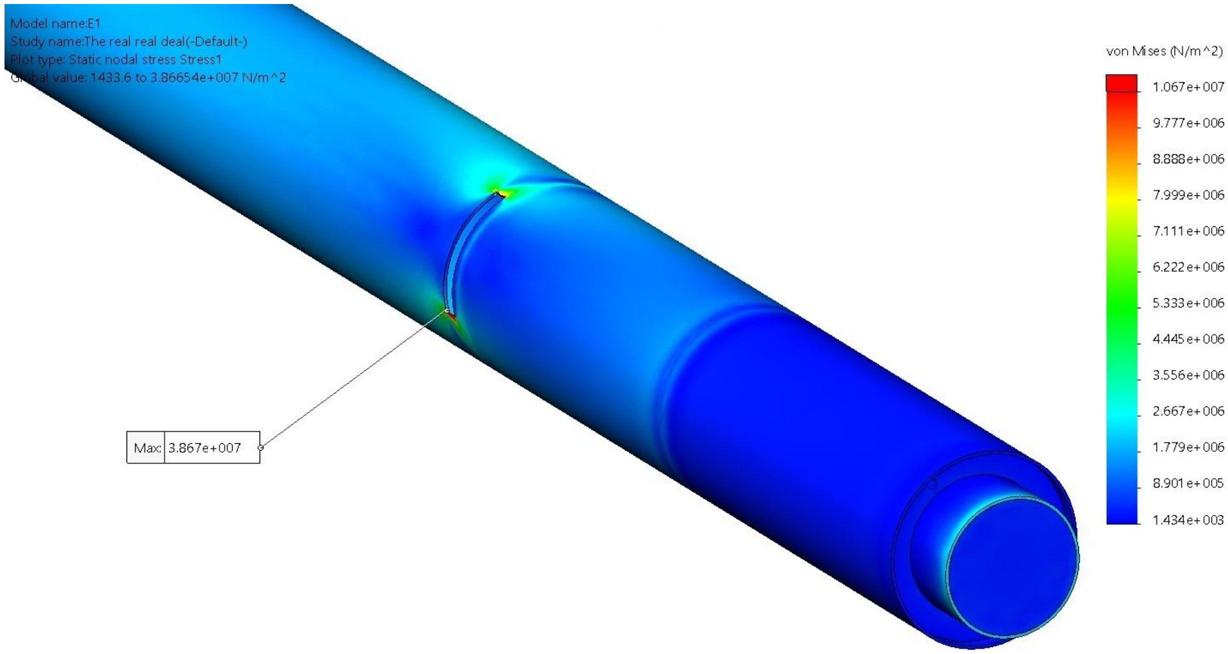
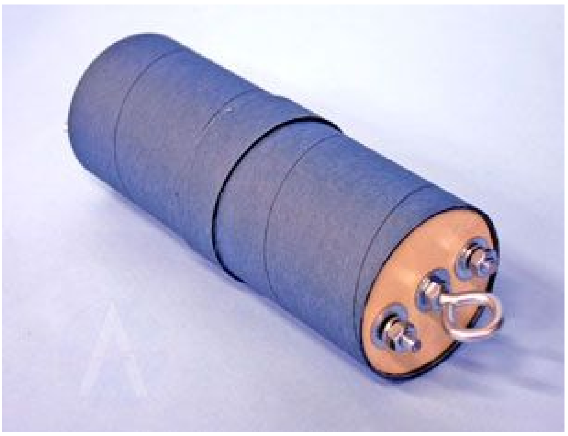
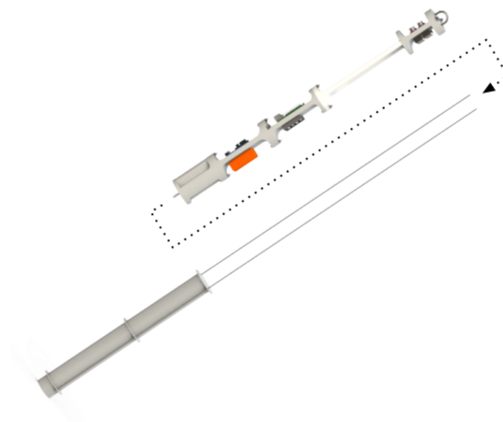



Figure 1: Stress analysis on the motor mount and surrounding region, a force of 650N was used as it is towards the higher end of the range of forces exerted by J class motors. The results show that most of the stress occurs near the bulkhead transferring the pressure to the airframe.

The entire airframe will consist of three body tubes: a 35” bottom tube encompassing the motor bay, ADAS, and the avionics bay, a 14” transparent plexiglass tube that houses TARS, and a 17” body tube that encases the recovery payload.

Two structural configurations were investigated to support the avionics: a rail substructure of two parallel all-threads, and a traditional avionics bay segment. The difference between mounting the electronics horizontally versus vertically was also explored. The vertical option was selected to complement the rocket's small diameter and to investigate the ability to more efficiently house electronics.

| Avionics Bay Segment | All-Thread Substructure ✦ |
|---|---|
|  |  |
| Pros:<br>● Allows for rocket segmentation<br>● Provides modularity | Pros:<br>● Eliminates the 'box-within-a-box' redundancy of the avionics bay segment<br>● Easily accessible<br>● Supports modularity<br>● Redirects the strains of parachute ejection, takeoff, and landing impact around the avionics bay |
| Cons<br>● Requires encapsulation within a coupling segment<br>● Potential to induce wobbling in the rocket if shoulders are insignificant.<br>● Incompatibility with ADAS system<br>● Decreases the effective volume of the avionics bay<br>● Heavy<br>● Risks being 'yanked' out of the airframe during a sub-nominal parachute ejection | Cons:<br>● Heavy<br>● Absorbs RF signal |

The all-thread substructure is selected for its structural support and its ability to support a modular avionics payload. This solution gives the payload bay flexibility in its modularity and more accessibility overall, making the entire system much more serviceable. Additionally, the all-threads act as redundant structural support throughout the vehicle's airframe, mitigating the risk of high-acceleration events damaging the sensitive onboard electronics.

#### 3.1.2.2 Motor Mount

The 21" length of the motor mount is selected to accommodate a wide range of motor lengths in the J and K impulse class. This adds a level of adaptability to the vehicle's flight profile, with approximately a ±3000 ft envelope apogee range for a given vehicle mass. There are tens of allowable motors in this size range. This also allows for significant changes in the vehicle's mass without requiring significant rebuilding.

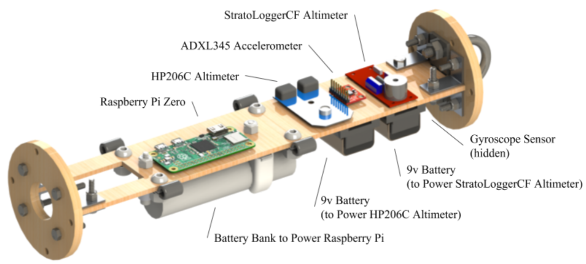
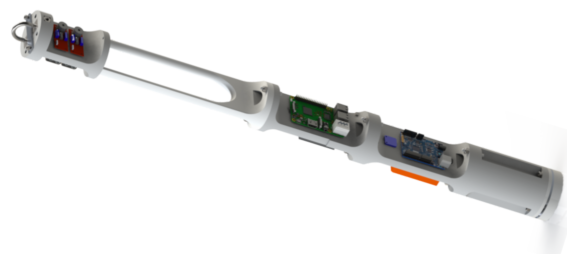
Figure 1: The motor bay is an integral part of the rocket's substructure. It contains two centering rings, a bulkhead, and two steel all-threads that extend through the majority of the airframe. The motor housing is 21" in length, meaning that it can accommodate a mid-range K-class motor.

The motor mount and associated bulkhead and centering rings will be constructed out of fiberglass due to its increased strength and durability relative to Blue Tube. The motor mount will act as the core foundation of the rocket, anchoring its upper body with a pair of ¼"-20 all-threads. The motor mount will be secured with two centering rings and a bulkhead that separates the sensitive electronics from the motor bay. The motor mount will be held in place with a fiberglass bulkhead rather than a plywood bulkhead due to its superior bonding properties and its lower mass.

The motor will be held in place by an aluminum engine block/tail cone combination that improves the aerodynamics at the rear end of the vehicle. This solution yields a lower effective drag coefficient when compared to a simple motor retainer.

#### 3.1.2.3 Avionics Sled

Two options were explored for the mounting of the avionics bay: a simple wooden sled that slides over the all-threads, and a 3D-printed substructure.

| Wooden framework | 3D-printed substructure ✦ |
|---|---|
|   |  |
| Pros:<br>● Simple to build<br>● Traditional<br>● Lightweight | Pros:<br>● Provides more structural support<br>● More efficiently consolidates components, batteries, and wires<br>● Lightweight<br>● Customizable shape<br>● Modular<br>● Firmly encases ADAS motor |
| Cons:<br>● Inefficient use of space<br>● No structural support | Cons:<br>● Costly |

The 3D-printed design is superior to the standard wooden sled design due to its improved modularity, its additional structural support, its customizable shape, and its more efficient consolidation of components. The printed sled will consist of multiple individual sections which integrate with the vehicle's all-thread structure. Additionally, the printed sled will better house the ADAS motor, fixing it in place and attaching it to the all-thread substructure.

#### 3.1.2.4 Fins

Four fins are selected to lower the center of pressure (CP) point to improve stability at low velocities and to preserve radial symmetry with the internal all-thread rods. The area of the fin is optimized to yield a margin of stability sufficiently high for low velocity flight, but not so high as to increase the effects of weathercocking. The static margin of stability for this airframe is 2.1, and the dynamic margin of stability at exit velocity is 2.57. These stability margins meet SL handbook regulation 2.16.

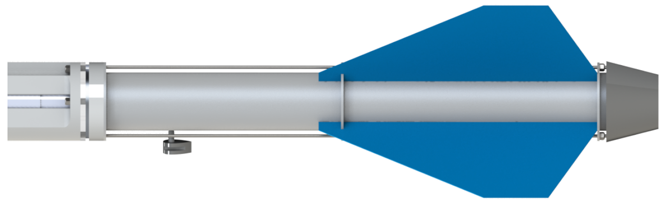
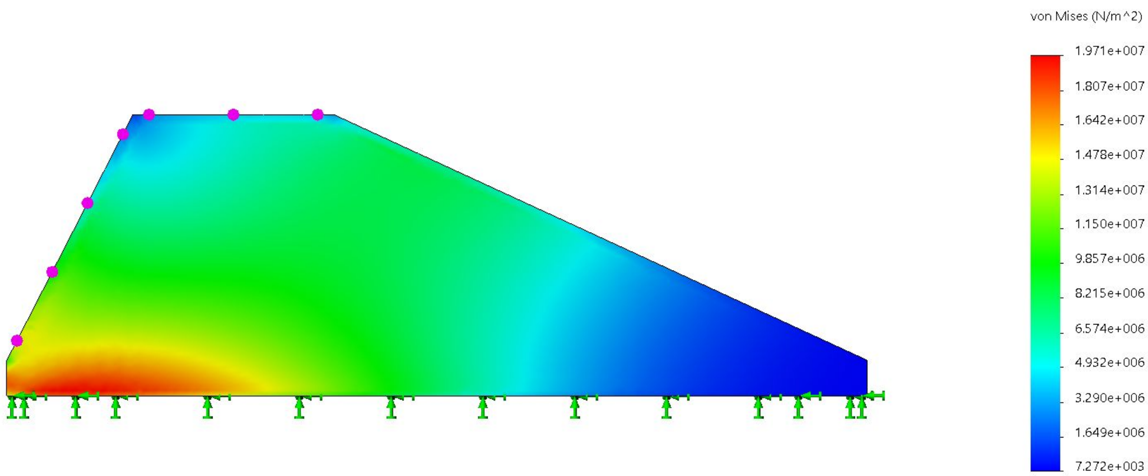
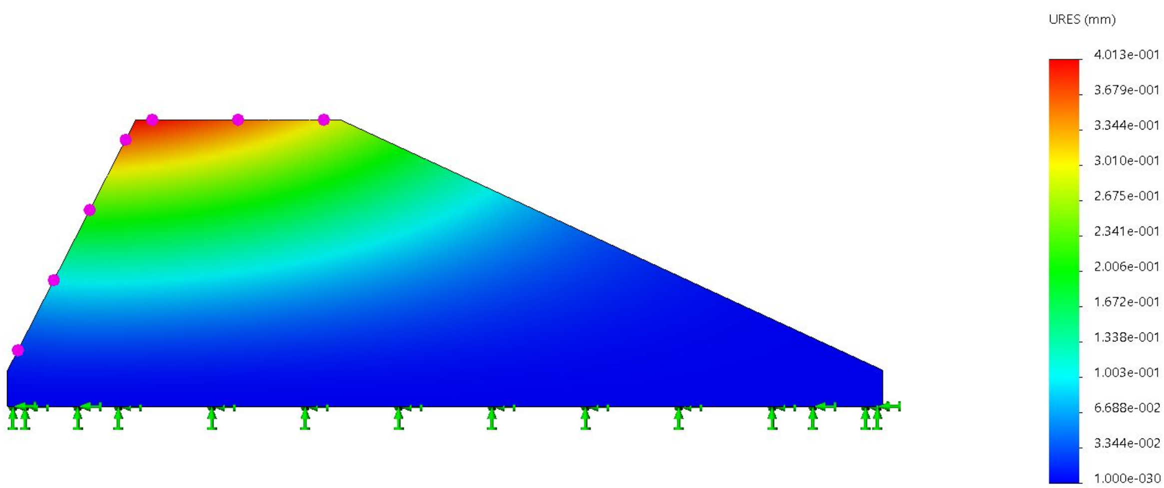


Figure 2: The low-profile shape of the fins is selected to minimize the risk of high-velocity “flutter” and damage upon landing and transportation.




Above image shows stress on Fin for a force applied on the outer edge of 30N




The above image shows the displacement of the fin under a force of 30N on the outer edge.

This simulation was intended to replicate the rocket resting on one of its fins after landing. The max displacement is approximately 4mm and max stress is approximately 20 MPa. This is just around the breaking point of the fiberglass at 3mm thickness. However, this is an overestimation as it is unlikely that the rocket will be resting entirely on a single fin.

#### 3.1.2.5 Nose Cone

The nose cone originally considered for the vehicle was a Von Karman (LD-Haack) nose cone, which is known for its aerodynamic efficiency at high velocities. These cones, however, are not readily available. Comparisons of fluid flow simulations between the Von Karman profile and the tangent Ogive profile at Mach 0.7 show that the differences in aerodynamic performance are negligible.

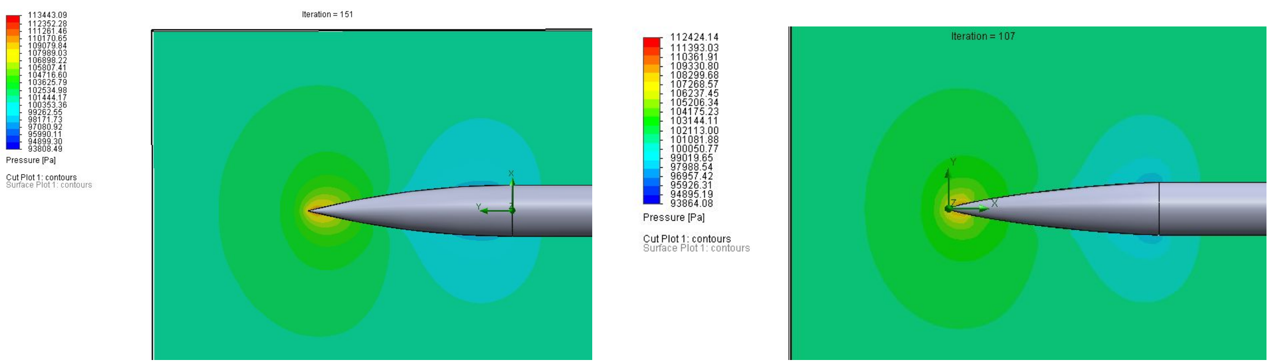



Figure 3: A fluid flow simulation of a tangent Ogive (left) and von Karman (right) nose cones. The measured drag coefficient for the tangent Ogive profile is virtually identical to that of the Von Karman nose cone at speeds less than Mach 1.

Von Karman nose cones are also found to have less variety in shape, material, and dimensions. We therefore select the tangent Ogive nose cone shape for its simplicity, availability, and comparable aerodynamic performance to the Von Karman cone.

#### 3.1.2.6 ADAS

The total impulse of any given rocket motor (the mean thrust multiplied by the total burn time) can vary by approximately ±10% from motor to motor due to minute differences in production and grain size. Our models show that this variation in a motor's total impulse can correspond to variations in apogee of a similar or greater magnitude, ~ ±10%, though our three miniature-scale test flights have shown that composite motors are more likely to underperform than overperform. Similar apogee decreases are caused by weathercocking, which, as models show, can angle the rocket significantly. We consider these apogee disparities unacceptable for the competition flight, and strive to achieve an arbitrary level of accuracy in reaching an apogee of 5280 feet. To precisely reach pre-specified apogees, we introduce Corrective Envelope (CE) and Corrective Fineness (CF): two concepts that best summarize our efforts in the design process. CE refers to the maximum reduction in apogee that can be achieved assuming maximum aerobraking is applied at the instant of transition from motor burnout to coast phase, and CF refers to the level of small-scale accuracy the system can achieve with high-frequency adjustments, ideally within a few feet. We therefore design the Adaptive Drag Aerobraking System (ADAS) to perform both fine and coarse inflight adjustments to the rocket's acceleration. The system is integrated with the flight avionics payload and is part of a live control loop that tracks the rocket's angle, acceleration, altitude, and inertial velocity in real time. The hardware and design are discussed here, and the control software is discussed in the next section.

Our models indicate that in order to achieve a ~15% reduction in apogee, the rocket must experience at least a 25% increase in cross-sectional area and a corresponding 50% increase of the drag coefficient within 1 second of motor burnout. To improve the rocket's CF to sub-meter precisions, we require that ADAS makes fast adjustments, at a frequency of ~10 Hz. These are our baseline correction requirements, which we believe will optimize the rocket's CE and CF to allow us to mitigate the effects of wind and small turbulence-related uncertainties alike. We also aim to minimize turbulence, which adds uncertainty to the rocket's flight profile. The result is a streamlined pair of drag fins that extend perpendicularly to the rocket's velocity vector, driven by a motor/encoder pair. The two fins have a net surface area of 14.5 $cm^2$, which increases the rocket's cross-sectional area by 30.0%, which meets our threshold requirement. Using flow simulations, we find that the drag coefficient of the rocket with ADAS fully deployed increases by 75% to 0.49 at subsonic velocities. The fin shape is selected after multiple iterations of fluid simulations, where the drag force on the fins is maximized, and the turbulence in their wake is minimized.

The fins are composed of thin aluminum, and are mounted between two plastic plates. They mesh with a gear in the center of these plates, and are rotated out of the rocket body with a shaft connected to the motor/encoder. The motor was selected for its high torque (350 oz-in) and high speed (160 RPM), which are both necessary to deploy ADAS precisely. The combination of the motor's high torque and high frequency will allow the fins to deploy effectively, even at high velocities. The friction force between the fins and the plates is significantly smaller than the torque rating of the selected motor. ADAS communicates with the avionics bay, and is situated flush against the aft motor bay bulkhead to lower the rocket's CP during deployment. This is a safety measure to minimize the risk of the rocket tipping due to destabilizing lateral torques. Indeed, fluid flow simulations show that the dynamic margin of stability is 1.8 calibers during flight at 100 m/s with full ADAS deployment, which indicates that the rocket will continue in stable flight after deployment. This takes into account the change in CG due after motor burnout. Flow simulations show that ADAS increases the rocket's overall drag coefficient ($C_d$) by 75%, which meets our threshold requirement. The entire drag system, as well as the avionics bay, are mounted onto a sled that slides into the rocket along the two all-thread rods that structurally support the rocket.

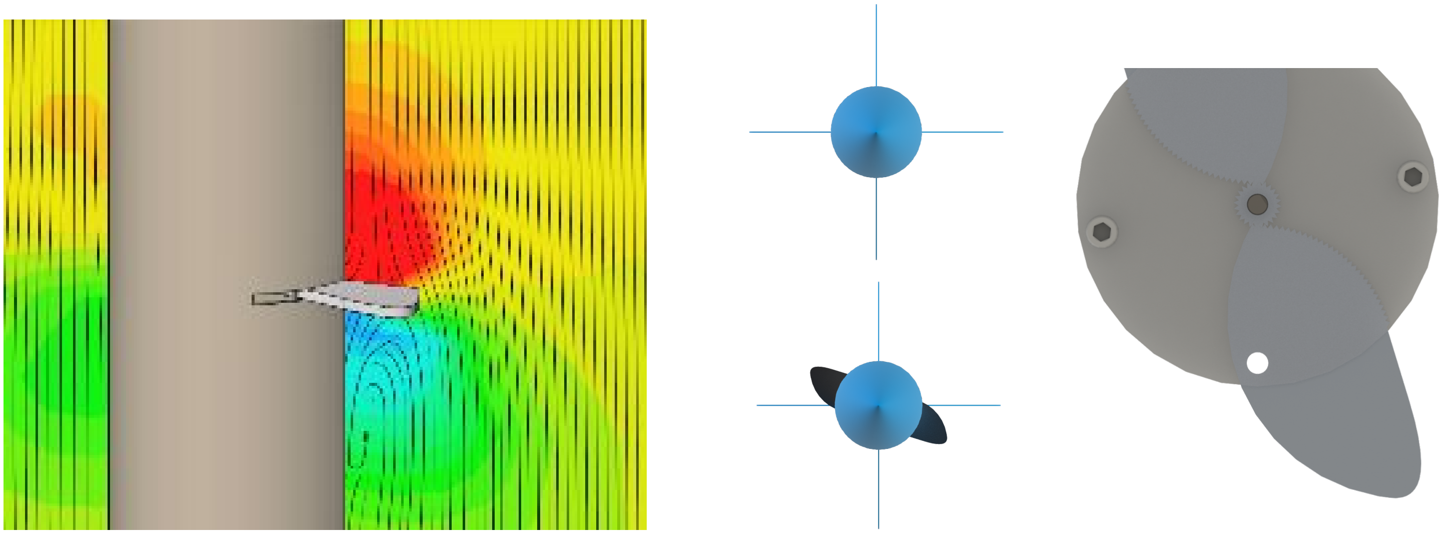


Figure 4: A fluid simulation of the flow pattern around ADAS at full deployment. A view of the vertical cross section at full deployment. The $C_d$ of the rocket at full fin deployment is 0.49, and the total aerobrake area is 14.5 $cm^2$.

#### 3.1.2.7 ADAS Motor

The ADAS motor was upgraded to the Andymark NeveRest Classic 40 Gearmotor from the one specified in the proposal. This change was implemented to increase performance of ADAS. The increased torque remedied concerns of the mechanism jamming when under a heavy aerodynamic load. The upgraded motor does require a significant increase to the system's mass, but the reassurance and performance gains justified the additional mass.

#### 3.1.2.8 ADAS Software

The software will be written in C, using PID (proportional-integral-derivative) control theory to properly feed information to the ADAS motor.

The avionics system will continuously run a loop that measures and records linear and angular acceleration data from the accelerometer and gyroscope, respectively. At each timestep, the acceleration values are numerically integrated along all three axes twice: once to solve for linear/angular velocity, and again for linear/angular position. Numerical integration of the linear and angular acceleration components will follow the logic

```
while velocity > 0.0:

                    dt = t_i - t_(i-1)

    v_linear(x,y,z,t) += a_linear(x,y,z,t)*dt

  position(x,y,z,t) += v_linear(x,y,z,t)*dt

   v_angular(u,v,w,t) += a_angular(u,v,w,t)*dt
```

```
angle(u,v,w,t) += v_angular(u,v,w,t)*dt
    |angle(t)| = max(angle(u,v,w,t))
                      acceleration(t) +=
a_linear(x,y,z,t)*dt/sin(|angle(t)|)
   velocity(t) += a_linear(z,t)*dt/sin(|angle(t)|)
   altitude(t) += v_linear(z,t)*dt/sin(|angle(t)|)
```

Variables in blue indicate control variables that will be processed by the onboard systems. Green indicates mathematical operations performed by the computer, such as multiplication, summation, division, the sine operator, and finding a maximum value. All of these parameters will be stored in a simple text file in a high capacity flash drive, and parameters in blue will be passed to the avionics loops.

The ADAS control loop will be adaptive, meaning that it will make live changes to the deployment of the aerobraking fins to fit an idealized coast phase deceleration curve. This will require that the system pulls values of the rocket's cross sectional area and drag coefficient as a function of the fins' opening fraction from interpolated function that are derived from fluid models and test flights.

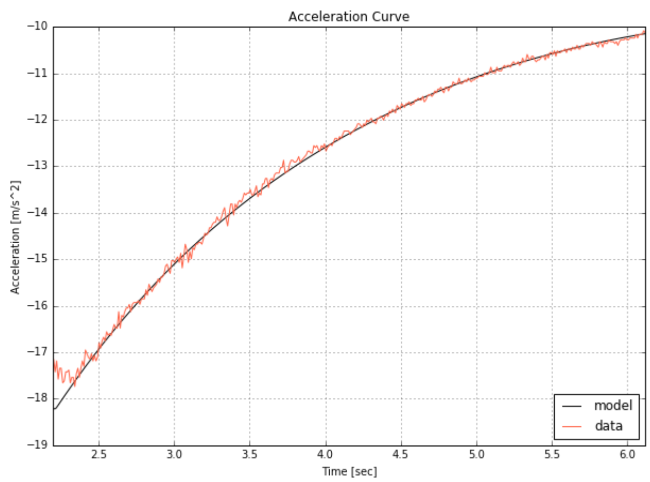



Figure 5: Coast phase deceleration data, as measured aboard **E-0.25**. The model was fitted to the data, but **E-1** will be actively fitting its acceleration to a model with ADAS.

The drag force experienced by a moving body is given by

$$F_D = \frac{1}{2}\rho_{air}(z)\, v(t)^2\, C_D\, A$$

Where $C_D$ is the drag coefficient and $A$ is the cross sectional area. These parameters will both be a function of the aerobrake opening fraction, $f$, and can be compartmentalized into one braking term, $\boldsymbol{B(f) = C_D A}$. $f$ ranges from 0% to 100%, and the resultant $C_D$ and $A$ vary non-trivially in intermediate values due to fluid microphysics and the non-standard geometry of the fins. Rewriting the formula to the corresponding deceleration, we find that

$$a = \frac{\rho_{air}(z)\, v(t)^2}{2M} B(f)$$

At small timesteps (t ~ .01 sec), the change in acceleration imparted by the drag system can be written as

$$\Delta a = \frac{\rho_{air}(z)\, v(t)^2}{2M} \Delta B(f)$$

assuming a constant velocity and air density throughout the timestep. This formula is run by the computer in real time, applying tiny shifts to the opening fraction $f$ by finding the difference between $a_{measured}$ and $a_{model}$ and solving for the corresponding correction. This is one option for the control algorithm, and requires further investigation and flight testing.

#### 3.1.2.9 Flight Computer

| Board | Bits | I/O | Voltage | MicroController | Clock Speed | Memory | Physical size |
|---|---|---|---|---|---|---|---|
| Arduino Uno | 8 | 14 digital pins (6 PWM) and 6 analog inputs | 5V | ATmega328P | 16Mhz | 32kb FLASH, 2kb SRAM, 1kb EEPROM | 2.7” x 2.1” @ 25 grams |
| Arduino Zero | 32 | 20 digital I/O pins (18 PWM)) | 3.3V | ATSAMD21G18 | 48 Mhz | 256kb FLASH, 32kb SRAM, 0kb EEPROM | 2.7” x 1.2” @ 12 grams |
| Arduino 101 | 32 | 14 Pins (4 PWM) | 3.3V | Intel Curie | 32 Mhz | 196kb FLASH, 24kb SRAM | 2.7” x 2.1” @ 34 grams |
| Raspberry Pi Zero | 32 | 40 Pins (0 PWM) | 5V | BCM2835 | 1Ghz | 512 MB FLASH | 1.18” x 2.55” @ 9 grams |

We compared several possible boards for the position of Flight computer. Our original proposal included the use of the Raspberry Pi Zero because of its weight to computational power ratio. After discussion between the electrical and software teams, it was decided that each board had enough computational power and clock speed to produce any calculations needed in real-time. The zero was then immediately discarded from consideration because of the needs of ‘real-timers’ for our array of sensors and because it holds no PWM I/O pins which is needed for operating the ADAS system. Once narrowed down to the three remaining boards, the Arduino 101 was chosen because it possessed more onboard memory than the Arduino Uno, and also included an onboard altimeter that the electrical team could use as a backup sensor. The Arduino Zero was discarded from consideration as well because it contained more clock speed, memory, and pins then was necessary for our needs.

In order to avoid potential failures or overloads with the motor and Arduino microcontroller, an h-bridge was added to ensure that the motor would not cause an overflow of current and ultimately sever connection with the 101. Although this adds some slight delay in response time, it is not actively noticeable and will ensure a safe dialogue between the controller and motor during flight. The fuse between the ADAS motor's supply battery and the h-bridge is there to protect against any additional current spikes that persist for too long and ensure equipment safety to an even higher degree.

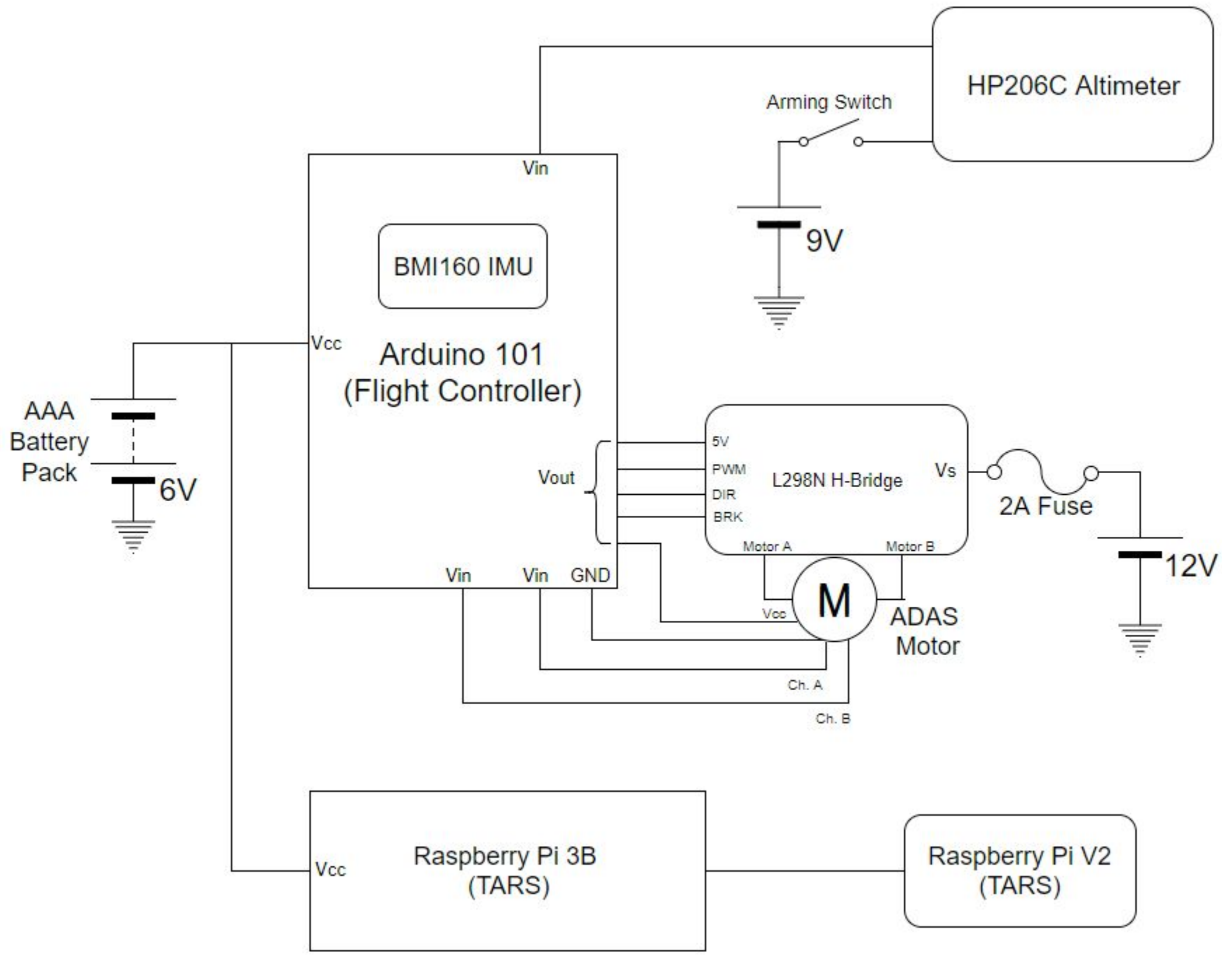



Figure 6: Flight controls and computers circuit diagram. Note the use of the batteries for both microcontrollers to save on battery weight and space. The motor will be controlled and powered by the H-Bridge (a technique used to provide a safe control between the Arduino board and the high power motor), while its encoder will only communicate with the Arduino 101 board to analyze and adjust the motor during flight.

#### 3.1.2.10 Avionics Sensors

Assuming ideal hardware, the Corrective Fineness (CF) of **E-1** is limited to the precision with which it can measure the rocket's altitude ($z$), velocity ($v$), and angle ($\theta$) at every timestep during coast phase, and the precision with which it can deliver aerobraking commands to ADAS. This requires a powerful onboard computing system that can simultaneously read flight data from multiple sensors, deliver commands to ADAS, and record flight data for later analysis. As per handbook requirements 2.2, 2.3, 2.4, and 2.5, the vehicle will carry multiple commercially available barometric altimeters with proper externally accessible arming switches, and dedicated power supplies.

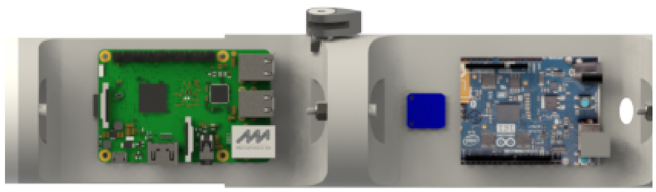


Figure 7: The lower payload bay consists of the avionics system mounted onto a 3D-printed sled. Not visible are the two ¼”-20 steel all-threads that pass through the assembly. Wires are also not pictured.

Our experience with the miniature rocket **E-0.25** has shown that these software goals are technically feasible. Our test three-axis accelerometer can relay measurements at a rate of 200 Hz, and the altimeter can output reliable absolute altitudes at 10 Hz. The gyroscope, which measures angular acceleration, can achieve similar data rates of ~200 Hz.

#### 3.1.2.11 Motor Selection

Our detailed SolidWorks model of **E-1** indicates that the rocket’s total mass, without adhesives, paint, or ballast, is 7.45 lbs. A wide array of J-class motors are potential candidates for the competition flight, as they meet the rail velocity requirement (2.17), the exit margin of stability requirement (2.16), the maximum impulse class requirement (2.15), the motor grain requirement (2.21.3 and 2.21.4), and the velocity requirement (2.21.7). The main selection criterion is an optimization of the nominal apogee, the exit rail velocity, and the maximum acceleration experienced during motor burn.

An exhaustive search of commercially-available rocket motors turned up five optimal candidates. Their properties, as well as their simulated flight properties without ballast mass or active ADAS control, are listed in the table below. Values in green meet handbook requirements closely, values in yellow meet the handbook requirements somewhat, and values in red are less than ideal for successful flights. We remind the reader that the corrective envelope of the vehicle with ADAS is 15% at maximal fin deployment 1 second after motor burnout. The values in the apogee column are red if they are outside of the corrective envelope of ADAS, or if they are below the intended apogee of 5280 ft.

| Motor | Total Impulse (lbfs) | Mass (lb) | Burn time (s) | Velocity off Launch rod (ft/s) | Max velocity (ft/s) | Max acceleration (ft/s^2) | Projected Apogee (ft) |
|---|---|---|---|---|---|---|---|
| J400 | 246.2 | 2.71 | 2.6 | 62.3 | 694 | 309 | 5446 |
| J401 | 250.8 | 2.01 | 2.8 | 70.4 | 744 | 339 | 5918 |
| J540 | 261.0 | 2.39 | 2.2 | 83.3 | 774 | 470 | 6018 |
| J355 | 267.4 | 2.59 | 3.4 | 64.3 | 732 | 285 | 6137 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| J295 | 268.9 | 2.47 | 4.0 | 63.8 | 703 | 275 | 6239 |

A second iteration of models with an added 10% mass to account for potential mass overruns and ballast (as per regulation 2.21.8) showed that the apogee of each motor flight was effectively reduced by approximately 500 ft.

| Motor | Velocity off Launch rod (ft/s) | Max velocity (ft/s) | Max acceleration (ft/s$^2$) | Projected Apogee (ft) |
|---|---|---|---|---|
| J400 | 59.3 | 641 | 284 | 5019 |
| J401 | 67.1 | 685 | 310 | 5492 |
| J540 | 80.5 | 714 | 431 | 5617 |
| J355 | 61.8 | 676 | 261 | 5701 |
| J295 | 61.2 | 650 | 252 | 5783 |

The vehicle apogee is very sensitive to wind speeds. We model the apogee of the motors at two wind speeds and evaluate their performance. The underperforming motor, J400, is not considered.

| Motor | Wind speed (mph) | Projected Apogee (ft) |
|---|---|---|
| J401 | 10 | 5445 |
| | 20 | 5372 |
| J540 | 10 | 5584 |
| | 20 | 5533 |
| J355 | 10 | 5657 |
| | 20 | 5556 |
| J295 | 10 | 5728 |
| | 20 | 5672 |

This series of simulations has revealed that wind speeds do not significantly affect the apogee performance of the vehicle. Surprisingly, even a 20 mph wind only lowers the vehicle apogee by 100-200 feet. This could be a modeling inaccuracy, or a true physical effect. Future analysis will reveal the importance of wind on apogee.

The clear candidate motor after this analysis is the J540. It yields a very high exit velocity, thus giving the rocket a much higher dynamic stability margin at takeoff. Its projected apogee is well within the corrective envelope of ADAS and leaves plenty of buffer room for mass overruns, weathercocking in high wind, higher-than-expected humidity, and uncertainties in turbulence. This motor also meets all handbook requirements, including regulation 2.21.3. The team therefore selects the Aerotech J540 Redline motor for full-scale flights.

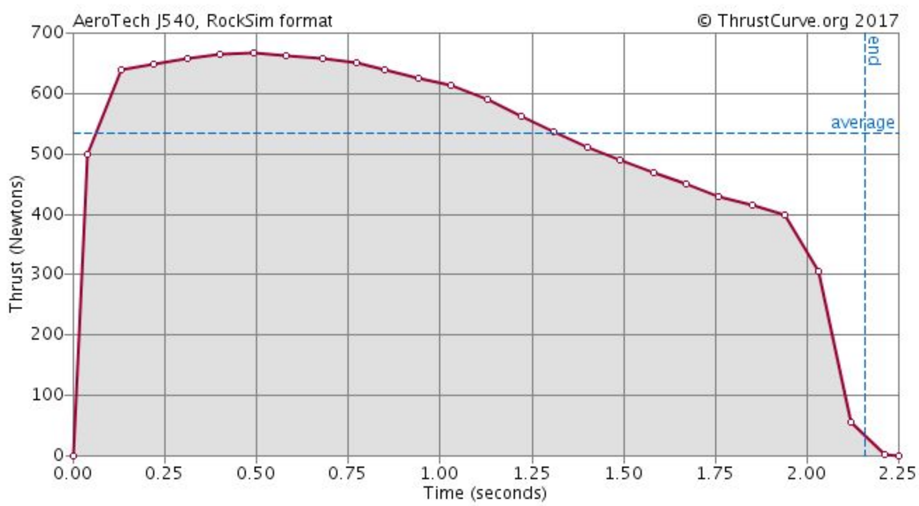



Figure 8: The Aerotech J540 motor features a short, front-heavy burn and a rapid burnout. This is ideal for maximizing the coast phase duration and thus allowing for more ADAS corrections.

### 3.1.3 Recovery Subsystem

The recovery bay is situated above the avionics, and the rocket will segment into two sections between the clear upper avionics bay and the aft avionics bay. A shock cord with high tensile strength will be secured between two U-bolts connected to each section's bulkhead. The ejection phase will be controlled by the StratoLogger CF system, which will send a command to an ignitor connected to a black powder charge. The rocket will employ a dual-deploy recovery system, with a small drogue chute followed by a large main chute. This will be facilitated by a Jolly Logic Chute Release mechanism, which has a dedicated altimeter to detect apogee and the main chute deployment altitude.

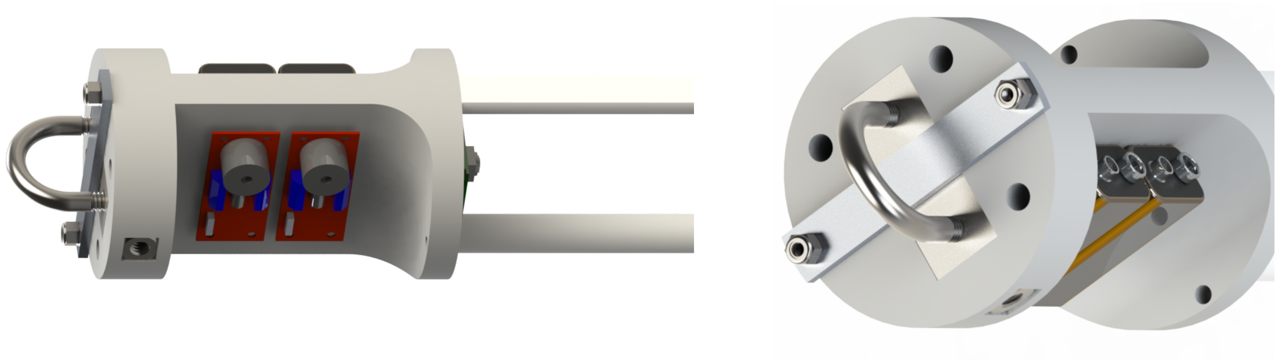


Figure 9: The recovery payload is sandwiched between the two avionics payloads, held in place with a strong shock cord and two U-bolts.

The rocket houses an onboard Eggfinder GPS tracking system, housed in the RF-transparent nose cone. This finder has a range of ~8000 feet and operates at 900 MHz, a frequency that does not require special permits.

#### 3.1.3.1 Ejection Charge Trigger

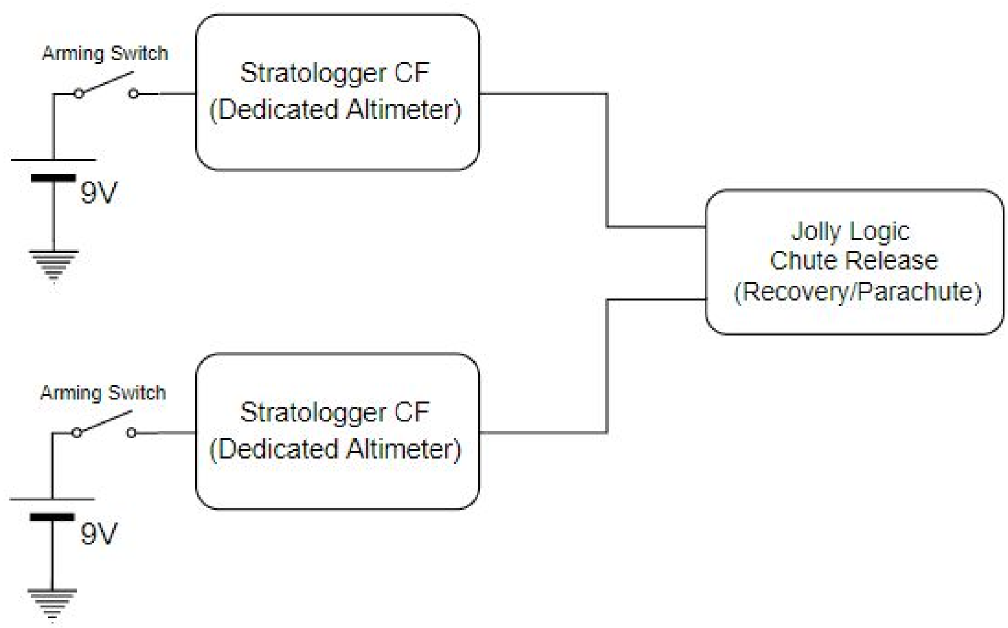



Figure 10: Circuit schematic of the recovery system's on-board electronics handling the drag chute deployment.

The option that the team considered was to use the PerfectFlite Stratologger CF or incorporate a custom circuit to trigger ejection charge detonation. It was found that a custom circuit would prove a greater risk than the more proven, and ready made PerfectFlite Stratologger CF. To keep the design complexity to a minimum, the PerfectFlite Stratologger CF was selected.

#### 3.1.3.2 Recovery Phasing System

The primary options considered to facilitate staged deployment were the Tender Descender mechanism versus the Jolly Logic Chute Release. The Tender Descender option requires an additional black powder charge, which the team would require the aid of the mentor to test. The Jolly Logic Chute Release was a lower energy alternative, which could accomplish the same staged deployment without the necessity of another altimeter/charge detonator. Thus the Jolly Logic Chute Release was selected.

#### 3.1.3.3 Locator

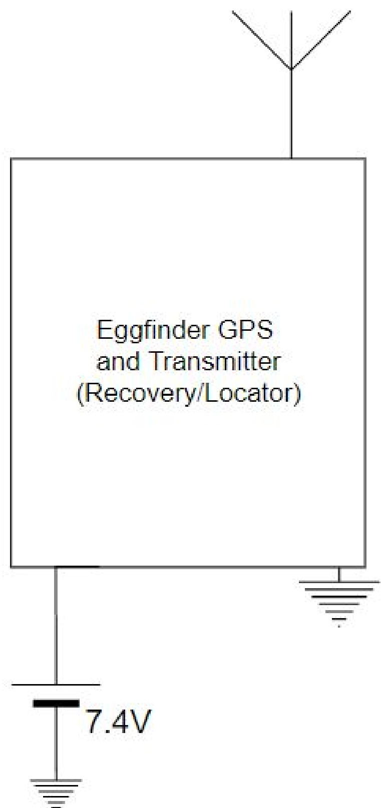



Figure 11: Circuit diagram for the Eggfinder module located in the nose cone of the rocket, acting as the locating side of the rocket's recovery system.

Different electronic tracking systems were looked into for locating the rocket once it has landed. At first, we had looked into combining GPS, radio transmitters, and receivers from different manufacturers, or buy a professionalized kit containing all necessary components that could send navigation data to a ground base. However, the restrictions placed on radio frequency use from federal law prohibits most premium or luxury radio communication without a license. We ultimately decided the Eggtimer Rocketry "Eggfinder" GPS was the perfect fit as the primary electronic locator for the rocket. Its transmitter broadcasts real-time coordinates over the 900MHz frequency, making it appropriate for use without the need for an amatuer radio license. GPS data comes from a Qualcomm SiRFstar IV 4e device, and is sent to the receiver of the Eggfinder module, which can be wired to an Android or Windows device so that data can be read with a navigational interface like Google Maps. Eggfinder sends data up to 8000 feet away, meaning that it has some limitations should the rocket drift far away from intended flight patterns, but this was seen as a low-risk scenario and the only inherent flaw for its price point. The transmitter will be powered using a commercial 7.4V battery with the entire circuit built into the cone of the rocket, and will be part of the safety checkoff list before takeoff to make sure the device is on and has the necessary connection to satellites.

#### 3.1.3.4 Parachute Sizing and Selection

To compute the parachute diameter required to avoid the maximum kinetic descent energy of the rocket, we use the formula for the terminal velocity of a falling object:

$$V_t = \sqrt{\frac{2ma}{C_d \rho A}}$$

Where $m$ is the mass of the rocket, $a$ is the acceleration due to gravity, $C_d$ is the vehicle's drag coefficient, $\rho$ is the density of air, and $A$ is the cross-sectional area of the vehicle. The kinetic energy of a mass moving at velocity $v$ is given by the equation:

$$KE = \tfrac{1}{2}mv^2$$

Rule 3.3 in the Student Launch handbook stipulates that our vehicle does not exceed a kinetic energy upon landing of 75 ft-lbf. The maximum descent velocity for an 8 lb rocket to satisfy this energy requirement is 24.5 ft/s. We assume that this is the terminal velocity, and solve for the minimum parachute diameter using reasonable assumptions for the density of air (1.225 kg/m$^3$) and a typical parachute's drag coefficient (~1.5). We find that the minimum surface area of the parachute must be 7.5 ft$^2$, corresponding to a diameter of 37.1". Typical commercially-available parachutes come in 36", 48", and 58" diameters. We therefore consider the 48" and 58" parachutes as viable candidates for further study. To ensure a safe main chute deployment and a contingency for main chute failure, we stipulate that the descent vehicle with the drogue chute deployed has a terminal velocity of < 60 ft/s. Assuming main parachute deployment takes 0.5 seconds, the corresponding deceleration during drogue chute-main chute transition is 100 m/s$^2$, which is similar to the acceleration the vehicle experiences during takeoff. To reduce the stress on the airframe and minimize the risk of shock cord failure, we require that the deceleration felt by the vehicle upon main chute deployment is less than 100 m/s$^2$. Performing a similar calculation as above, we find that the drogue chute should have a surface area of 0.9 ft$^2$, corresponding to a diameter of 14.6". Parachutes with 15" and 18" diameters are readily available, and we consider those options for further study.

OpenRocket is used to simulate the two-phased parachute descent from a worst-case-scenario apogee of ~6000 ft with varying wind speeds, parachute size configurations, and main chute deployment altitudes. We require that the main parachute deploys at an altitude of least 500 ft to minimize the risk of a faulty or slow deployment, tangling during descent, and a total lateral drift that exceeds 2500 ft (handbook requirement 3.9). We therefore explore two deployment altitude options: 1000 ft and 500 ft. We perform multiple simulations at varying wind speeds and wind speed turbulences. For the low-wind cases (0, 5, 10, 15 mph), only the two extreme options are explored: a small drogue chute-small main chute pair coupled with a low altitude main chute deployment, and a large drogue chute-large main chute pair coupled with a high-altitude main chute deployment. For the worst-case scenario of 20 mph winds, we model a sweep of possible configurations. Values listed in green meet our requirements, values in red fail our requirements, and values listed in yellow nearly fail our requirements. The models are run 3 times for each configuration, and their average is calculated.

## Descent Simulations: 0 mph wind

| Main Chute Size (in) | Drogue Chute Size (in) | Main Deploy Height (ft) | Drift Distance 1 (ft) | Drift Distance 2 (ft) | Drift Distance 3 (ft) | Average Drift Distance (ft) | Main Chute Descent Velocity (ft/s) | Landing Kinetic Energy (ft-lb) | Transition Deceleration (ft/s^2) |
|---|---|---|---|---|---|---|---|---|---|
| 48 | 15 | 500 | 8 | 9 | 8 | 8 | 21.5 | 57.3 | ~100 |
| 58 | 18 | 1000 | 8 | 8 | 8 | 8 | 17.4 | 37.6 | ~100 |

## Descent Simulations: 5 mph wind

| Main Chute Size (in) | Drogue Chute Size (in) | Main Deploy Height (ft) | Drift Distance 1 (ft) | Drift Distance 2 (ft) | Drift Distance 3 (ft) | Average Drift Distance (ft) | Main Chute Descent Velocity (ft/s) | Landing Kinetic Energy (ft-lb) | Transition Deceleration (ft/s^2) |
|---|---|---|---|---|---|---|---|---|---|
| 48 | 15 | 500 | 392 | 405 | 423 | 407 | 21.5 | 57.3 | ~100 |
| 58 | 18 | 1000 | 726 | 772 | 715 | 738 | 17.4 | 37.6 | ~100 |

## Descent Simulations: 10 mph wind

| Main Chute Size (in) | Drogue Chute Size (in) | Main Deploy Height (ft) | Drift Distance 1 (ft) | Drift Distance 2 (ft) | Drift Distance 3 (ft) | Average Drift Distance (ft) | Main Chute Descent Velocity (ft/s) | Landing Kinetic Energy (ft-lb) | Transition Deceleration (ft/s^2) |
|---|---|---|---|---|---|---|---|---|---|
| 48 | 15 | 500 | 827 | 876 | 918 | 874 | 21.5 | 57.3 | ~100 |
| 58 | 18 | 1000 | 1527 | 1502 | 1467 | 1499 | 17.4 | 37.6 | ~100 |

## Descent Simulations: 15 mph wind

| Main Chute Size (in) | Drogue Chute Size (in) | Main Deploy Height (ft) | Drift Distance 1 (ft) | Drift Distance 2 (ft) | Drift Distance 3 (ft) | Average Drift Distance (ft) | Main Chute Descent Velocity (ft/s) | Landing Kinetic Energy (ft-lb) | Transition Deceleration (ft/s^2) |
|---|---|---|---|---|---|---|---|---|---|
| 48 | 15 | 500 | 1375 | 1488 | 1420 | 1428 | 21.5 | 57.3 | ~100 |
| 58 | 18 | 1000 | 2357 | 2386 | 2332 | 2360 | 17.4 | 37.6 | ~100 |

## Descent Simulations: 20 mph wind

| Main Chute Size (in) | Drogue Chute Size (in) | Main Deploy Height (ft) | Drift Distance 1 (ft) | Drift Distance 2 (ft) | Drift Distance 3 (ft) | Average Drift Distance (ft) | Main Chute Descent Velocity (ft/s) | Landing Kinetic Energy (ft-lb) | Transition Deceleration (ft/s^2) |
|---|---|---|---|---|---|---|---|---|---|
| 48 | 15 | 1000 | 2316 | 2680 | 2605 | 2544 | 21.5 | 57.3 | ~100 |
| 48 | 15 | 500 | 1894 | 2029 | 1765 | 1896 | 21.5 | 57.3 | ~100 |
| 48 | 18 | 1000 | > 2500 | > 2500 | > 2500 | > 2500 | 20.6 | 52.7 | ~70 |
| 48 | 18 | 500 | 2468 | 2576 | 2519 | 2521 | 20.6 | 52.7 | ~70 |
| 58 | 15 | 1000 | >2500 | >2500 | >2500 | >2500 | 17.6 | 38.5 | ~150 |
| 58 | 15 | 500 | >2500 | >2500 | >2500 | >2500 | 17.6 | 38.5 | ~150 |
| 58 | 18 | 1000 | >2500 | >2500 | >2500 | >2500 | 17.4 | 37.6 | ~100 |
| 58 | 18 | 500 | >2500 | >2500 | >2500 | >2500 | 17.4 | 37.6 | ~100 |

All parachute configurations yield kinetic energies well below the maximum requirement of 75 lbf-ft. The 15” and 18” drogue parachutes paired with the 48” and 58” main parachutes are both viable options for low wind speeds. Their drift does not exceed 2500 ft. With wind speeds of 20 mph, however, nearly all possible permutations exceed the drift limit imposed in handbook regulation 3.6. The 15” - 58” combination, however, yields high transition deceleration values, similar to the acceleration felt by the rocket at launch. To minimize the stress on the airframe and substructures, we rule out this option. The 15” - 48” combination shows the lowest drift distances at a low-altitude deployment, but the transition acceleration is high. The 18” - 48” combination at a 500 ft deployment experiences the least amount of transition forces, and lands well within the required drift distance for low- and mid-range wind speeds. At 20 mph wind speeds (assuming a worst-case scenario apogee of 6000 ft), this configuration yields values somewhat larger than the allowed landing radius. We recompute the average drift distances for this configuration, now using a near-nominal apogee of 5300 ft, to evaluate the projected drift distances.

Near-Nominal Apogee Descent Simulations: 18”/48” parachute pair

| Wind speed (mph) | Main Deploy Height (ft) | Drift Distance 1 (ft) | Drift Distance 2 (ft) | Drift Distance 3 (ft) | Average Drift Distance (ft) |
|---|---|---|---|---|---|
| 0 | 500 | 8 | 8 | 8 | 8 |
| 5 | 500 | 370 | 378 | 412 | 387 |
| 10 | 500 | 904 | 846 | 838 | 862 |
| 15 | 500 | 1433 | 1428 | 1425 | 1429 |
| 20 | 500 | 2375 | 2240 | 2229 | 2281 |

The 18” drogue - 48” main combination, with main chute deployment at 500 ft, minimizes the stress on the rocket, and meets the drift requirements at all wind speeds for a near-nominal flight apogee of 5300 ft. This combination is therefore selected for the launch vehicle.

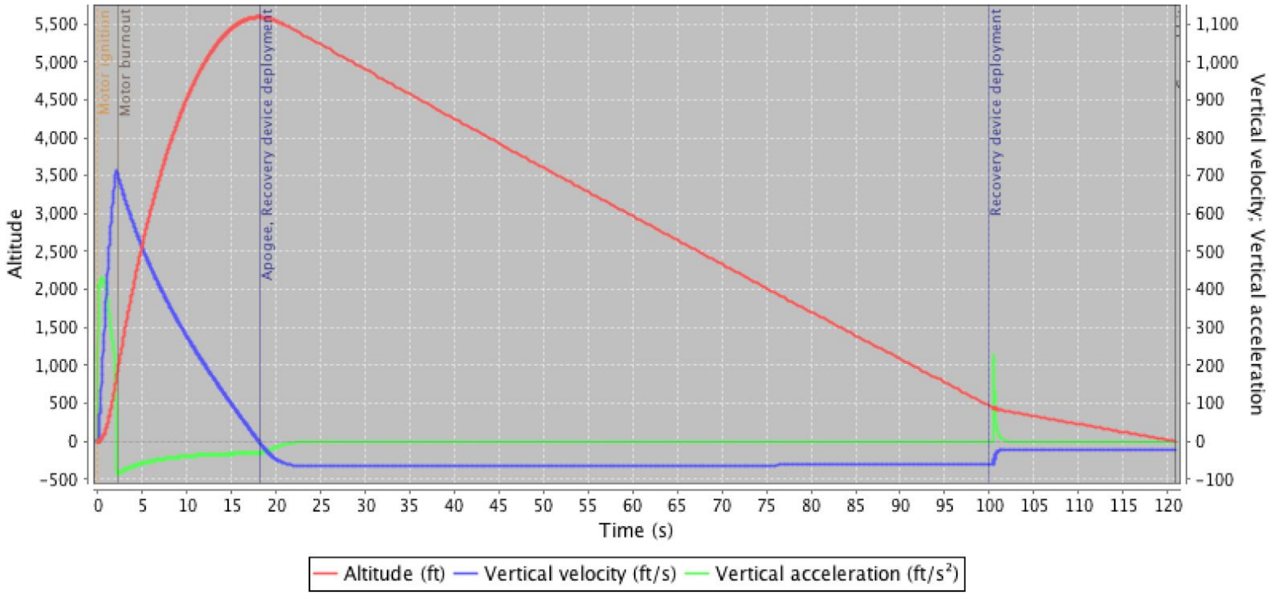
#### 3.1.3.5 Redundancy

Two PerfectFlite Stratologger CF altimeters are incorporated into the ejection charge trigger system. With independent battery sources and two separate charges, if one altimeter fails, the other can still trigger the deployment of the parachutes. One altimeter will be programmed with a short time delay from apogee in order to prevent both ejection charges from detonating simultaneously and potentially damaging the rocket or parachutes.

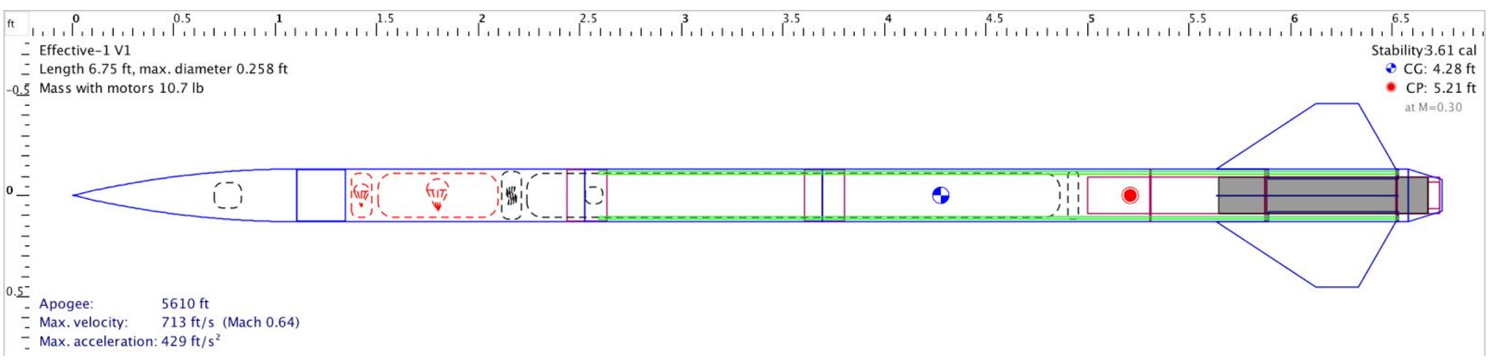
### 3.1.4 Mission Performance Predictions

Models show that **E-1** will have a peak velocity of 204 m/s, and a peak acceleration of 81 $m/s^2$. The coast phase will last 16.0 seconds, which is ample time for the required ADAS corrections. The rail velocity is 21 m/s, which is well above handbook regulation 2.17, and has a dynamical margin of stability of 2.57 at this point, in accordance with regulation 2.16. E-1 will fly with the J540 motor. The flight profile is modeled with Open Rocket assuming a 10% mass overrun with ballast, amounting to a total mass of 8.3 lbs. The models are run with a 10 mph wind at a resolution of 0.01 seconds.

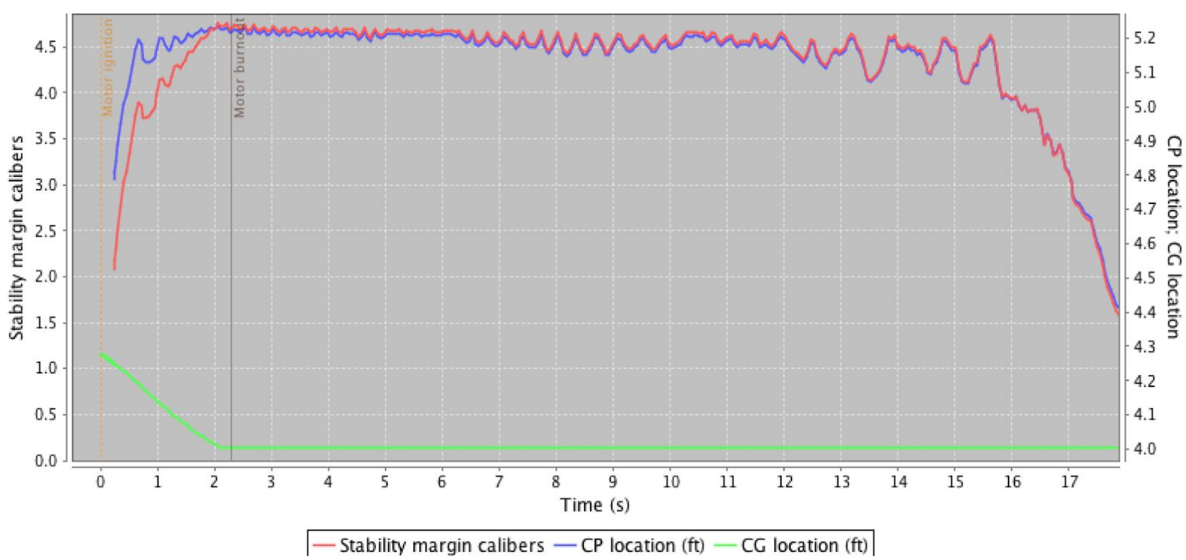
| Apogee (ft) | Max acceleration ($ft/s^2$) | Max velocity (ft/s) | Rail exit velocity (ft/s) | Dynamic margin of stability at rail exit (cal) | Total drift distance (ft) | Landing Kinetic Energy (ft-lb) |
|---|---|---|---|---|---|---|
| 5588 | 429 | 713 | 81.2 | 2.08 | 986 | 57.3 |



Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
Altitude
Vertical velocity; Vertical acceleration
Time (s)
Altitude (ft)
Vertical velocity (ft/s)
Vertical acceleration (ft/s²)

Effective-1 V1
Length 6.75 ft, max. diameter 0.258 ft
Mass with motors 10.7 lb
Stability: 3.61 cal
CG: 4.28 ft
CP: 5.21 ft
at M=0.30
Apogee: 5610 ft
Max. velocity: 713 ft/s (Mach 0.64)
Max. acceleration: 429 ft/s²

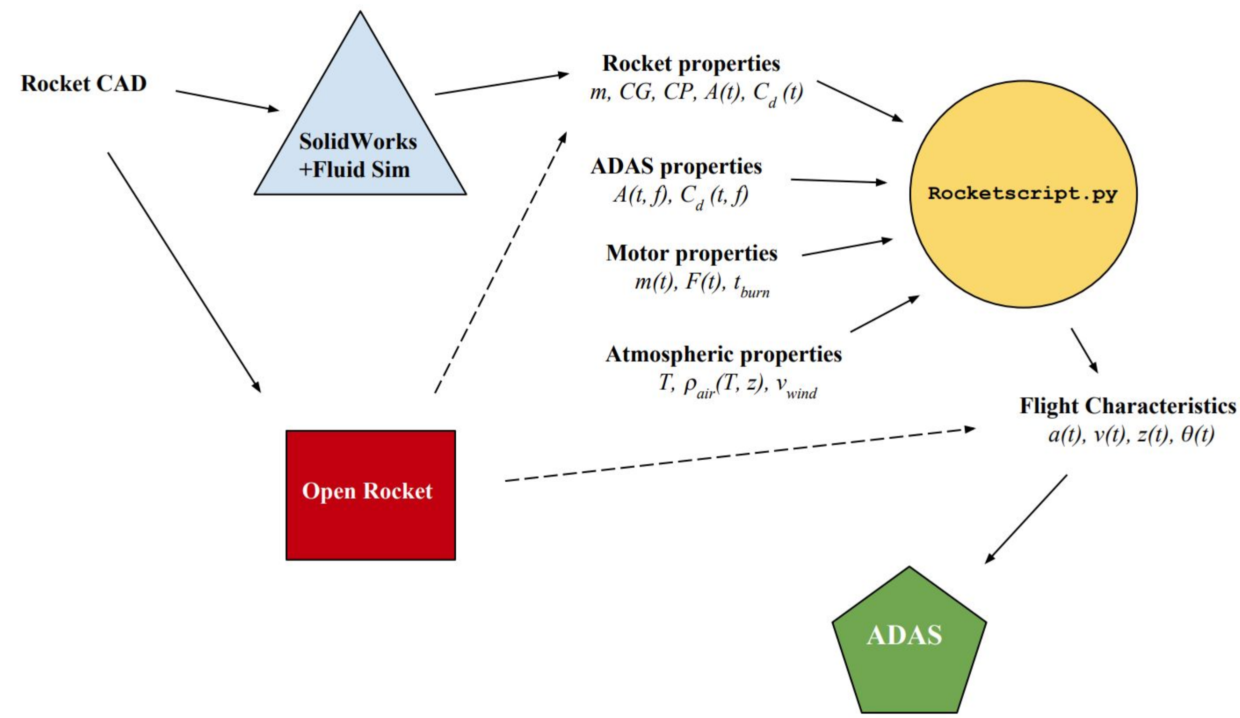



Motor ignition
Motor burnout
Stability margin calibers
CP location; CG location
Time (s)
Stability margin calibers
CP location (ft)
CG location (ft)

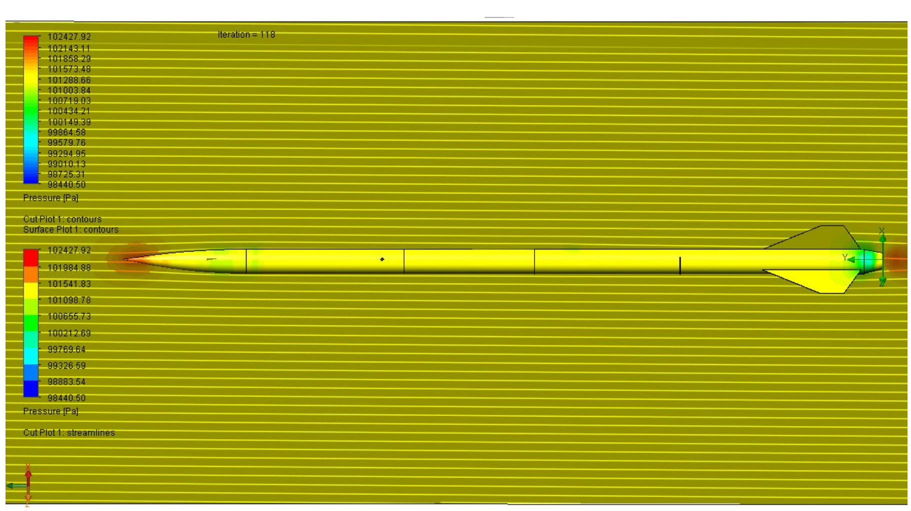
| Wind speed (mph) | Average Drift Distance (ft) |
|---|---|
| 0 | 8 |
| 5 | 387 |
| 10 | 862 |
| 15 | 1429 |
| 20 | 2281 |

In addition to the Open Rocket simulations, we use our custom-written Rocketscript.py integrator to compute the flight parameters. We find a nominal apogee of 5774 ft, ~200 ft above the predicted OpenRocket value. This difference is likely due to the fact that our script does not yet perform wind calculations, which would lower the apogee of the rocket. Nonetheless, the two values are in agreement, suggesting that the OpenRocket calculation is valid. A detailed stress analysis was performed on airframe (section 3.1.2.1). It was found that the maximum stress induced on the airframe by the motor is 38 MPa, which is well below the breaking threshold for Blue Tube 2.0.

### 3.1.4.1 Verification




The majority of the design modeling and flow simulations for this project have been done in SolidWorks, and all flight modeling has been done with a custom-written forward integrator script called `Rocketscript.py`. The script accommodates time-variable changes to rocket parameters, such as its mass, aerodynamics, and motor thrust profile. It has been validated with two test flights that fit our model acceleration profiles well. We also use OpenRocket to model the vehicle flight, and as a sanity check for our CAD designs and our rocket code. OpenRocket is more robust than our python integrator, and has several more physical inputs and outputs. However, the python integrator is useful in the sense that all of the input values are clearly visible and the math is readily accessible.



# 4. Safety

## 4.1 Responsibilities and Compliance

### 4.1.1 Safety Officer

The team's Safety Officer is Michael Scudder. The Safety Officer is responsible for ensuring team safety in the design, construction, assembly, and testing of the rocket, and all other activities listed in 5.3.1 of the SL Handbook. The Safety Officer is responsible for the team's compliance with regulations on Class 2 high powered rockets contained in:

- NFPA Code 1127
- FAA regulations, most notably CFR Title 14, Chapter 1, subchapter F, Part 101, Subpart C: Amerature Rockets
- CFR Regulation 27 Part 55: Commerce in Explosives
- NAR Code

The Safety Officer is responsible for writing and implementing an assembly and pre-launch checklists, pre-launch briefings, hazard analyses and mitigation, and keeping up to date MSDS data as manufactures and materials are finalized.

### 4.1.2 Team Mentor

The team's NAR mentor is David Raimondi. The mentor is responsible for maintaining a NAR HPR class 2 certification according to the definition given in NFPA 1127 3.3.4. The Mentor is responsible for purchasing, handling, assembling of rocket motors and black powder charges and ensuring that the motor is certified as defined in NFPA 1127 3.3.3 and in accordance with requirements set in NFPA 1125. The Mentor will also oversee launch safety, including the launch pad assembly of ignition mechanisms, and ensure that regulations in section 4.13 of NFPA 1127 are strictly adhered to.

The team's Mentor shall purchase rocket motors and other required devices through well established vendors when requested upon by the team. Once the NRA/TRA mentor receives these devices, it is their responsibility to ensure the safe storage and transport of these devices per NFPA 1127 4.5. The NRA/TRA Mentor is then expected to arrive to the designated launch site on a previously agreed upon date with the energetic devices. Procedures to prepare these devices and integrate them into the rocket will then be taken by the NRA/TRA mentor with supervision of the safety officer and other present team members.

## 4.2 Risks and Delays

The following is a chart of major risk and delays associated with major milestones of the project's completion:

| **Risk** | **Likelihood** (High, Med, Low) | **Impact** (High, Med, Low) | **Mitigation/Effects** |
|---|---|---|---|
| Delay in securing funding to build the rocket | Med | High | The initiation of a renewed funding campaign with a changing of strategy, reduction of scope of the rocket with interests of conserving cost. |
| Devastating launch failure during Subscale launch | Med | Med | Ensure all pre-flight checks are documented. Investigation following the event, with a formal review presented in the CDR where corrective actions will be explored to eliminate failure in the full scale test. |
| Devastating launch failure during Full Scale launch | Low | High | Ensure all pre-flight checks are documented. There will be approximately a month to investigate launch failure, identify corrective action and rebuild the rocket for competition, pending approval to continue in the competition. |
| Failure to meet funding goals for competition travel | Med | Low | Stay on track with funding deadlines to ensure necessary teammates can travel. Reduction in the number of members attending the competition, or member funded travel. Ensure attending team members are educated regarding every aspect of the rocket. |

| | | | |
|---|---|---|---|
| Missing documentation deadlines | Med | High | Point reduction, potential elimination from competition if excessive. |
| Failure to complete payload and avionics manufacturing prior to subscale launch | Med | Low | Stay on track with team timeline, manage teams time effectively. Subteam leads appointed to ensure all deadlines of their team are met.. The subscale launch shall use a mass simulator which is completely acceptable and will have little to no effect. |
| Failure to complete payload and avionics manufacturing prior to full scale launch | Low | High | Stay on track with team timeline, manage teams time effectively. Subteam leads appointed and specialized to ensure every deadline is met. This will result in a delay and possibly point reduction. |
| Rain during a sub/full scale launch attempt | Med | Med | Launch will be moved to the secondary date, if the timeline is critical this event will cause a delay in the completion of the corresponding document, CDR in the case of a sub scale launch delay, or the FRR in the case of a full scale launch delay. |
| Injury to team member during team activities | Low | Med | Pending the severity of such an injury the day’s activities may be halted and events delayed. The overall effect on the timeline should be minimal barring catastrophe. |
| Team member subject to prolonged illness and is unable to work on rocket | low | Med | Team members should prioritize their health and well being, and in the event of an important team member being unable to contribute their responsibilities will be delegated evenly amongst the team. |

| | | | |
|---|---|---|---|
| Parts or materials needed for construction are backordered or unavailable. | Low | Med | Take into account material or part availability when designing and finding manufacturers. |

## 4.3 Hazard Analysis

### 4.3.1 Personnel Hazard Analysis

All members must complete a university mandated online lab safety course prior to entering our lab space in Thimann Labs 372. The lab includes access to a router, epoxies, and saws and other tools, as well as a chemical fume hood. In compliance with University policy, members will perform online and in-person lab safety training, which includes locating fire extinguishers, eyewash stations, and chemical showers. It also includes learning about the various risks and hazards associated with lab equipment. Team members will be briefed on safety rules multiple times, and these rules will be enforced by the Safety Officer. The main tools that will be used in the lab are saws, drills, and a belt sander. Members will be trained by the lab supervisor on the proper operation of these instruments, and safety gear will be worn at all times. The lab facility also has dedicated staff members trained in operating specific complex machinery (mills, lathes, 3D Printers, etc.). Additionally a complete catalog of all hazardous materials and their accompanying MSDS are kept in the lab space, and are published on the website (https://ucscrocketry.org/documents.html). This catalog is updated and maintained by all organizations operating within the lab space. This system shall be upheld to the highest standard by the rocket team.

| **Hazard** | **Cause** | **Effect** | **Likelihood and Severity (RAC)** | **Mitigation** |
|---|---|---|---|---|
| Allergic Reaction | Member exposed to allergen | Allergic reaction, severity is largely dependent on individual case | 2E | Ensure that members with allergies avoid relevant foods and carry medication, safety officer to be aware of any allergies. |
| Sunburn | Solar UV exposure | Sunburn | 3D | Provide sunscreen to team members during outdoor event. |
| Improper handling of epoxy | Lack of proper training, accidental spillage, misuse of safety equipment | Injury of team member(s) | 3C | Team members dealing with the resin will wear full sleeve clothing, protective gloves, respirator and eyewear. A |

| | | | | |
|---|---|---|---|---|
| | | | | eyewash station and shower are located in the hallway within 20 yards of the lab. |
| Improper handling of fiberglass (during cutting) | Lack of proper training, misuse of safety equipment | Injury of team member(s) | 3C | Team members dealing with the resin to wear full sleeve clothing, protective gloves, respirator and eyewear. |
| Improper use of hand tools | Lack of proper training or experience | Injury of team member(s) | 3C | When team members are in the lab space, it is necessary for a highly trained individual to be present with them, overseeing work. A first aid kit containing adequate supplies is easily accessible in the lab space. |
| Improper use of drill press | Lack of proper training or experience | Injury of team member(s) | 3D | All guidelines in the Drill Press operator's manual will be adhered to. Team members have access to this manual on the website (https://ucscrocketry.org/documents.html) |
| Catastrophe At Take-Off (CATO) | Poor motor handling or assembly | High-velocity shrapnel and debris injuring team and spectators. | 3E | The team will follow the NAR Code when conducting all launches including the minimum distance guidelines in Appendix B. NOTE: The NAR minimum distances will be used, not the NFPA 1127 minimum distances because the NAR distances are safer. This will ensure all individuals are at the least possible risk of harm during a launch event. |
| Improper recovery | Lack of recovery training during pre-flight briefing | Injury of team member(s) and/or spectators | 3E | The team will follow the NAR provision on recovery safety located in Appendix C part 13. |
| Misfire (Team members/spectators approaching rocket after a misfire) | Improper ignition installation | Injury of team member(s) and/or spectators | 3D | The team will follow the NAR provision on misfire's located in Appendix C part 5. |
| Improper handling of | Lack of certification | Injury of team | 3E | The team will abide by |

| | | | | |
|---|---|---|---|---|
| rocket during ignition installation | or knowledge | member(s) and/or spectators | | regulations in NFPA 1127 4.13, especially 4.13.6 which mandates the rocket be pointed away from spectators during ignition installation. |

## 4.3.2 Success of SL Hazard Analysis

| Hazard | Cause | Effect | Likelihood and Severity (RAC) | Mitigation |
|---|---|---|---|---|
| Failure to meet deadlines | Improper planning and assignment of responsibilities | High impact to the timeline of the project which could also impact the team's performance | 3D | Dedicated weekly team meetings devoted to discussing deadlines; subteam meetings partially devoted assessing progress and timelines. A highly detailed schedule is maintained and updates with major milestones. |
| Overly ambitious functionality | Improper planning | High impact on the time and budget of the project | 3D | Keep the design within the team's abilities and the resources available. Adhere to a series of reassessments of the project's achievability before implementing a major design change. |
| Failure to secure funding | Improper planning | High impact to the budget of the project | 3D | An aggressive funding campaign is being planned targeting a variety of potential sources. |
| Loss of access to on campus resources | Violating any campus or lab space regulations | High impact on all aspects of the project | 2E | Maintain good standing with the university by respecting all of its policies and equipment. |
| Failure to implement proper safety procedures | Time constraints, cutting corners due to pressure/deadlines | High impact to the safety of the team members and potential degradation of standing with the university. | 2D | The safety officer shall ensure that the proper safety procedures |

| | | | | |
|---|---|---|---|---|
| Improper handling of black powder charge | Lack of supervision, inadequate training/safety briefings | Possible injury, and failure of launch | 1E | All handling of volatiles are to be done by a certified mentor in accordance with NAR code in Appendix C part 1, and NFPA 1127. |
| Failure to meet deadline | Inadequate planning; insufficient membership and engagement | Potential disqualification from the competition | 2D | Proper time management, continuous comparisons of current situation to the project timeline. Reduction of project scope if necessary. |
| Personnel Unavailable | Scheduling conflict | Event cancellation or Delay | 3C | Arrange events well in advance and plan for backup dates |
| Failure to complete test flights before documentation deadline | Improper scheduling | Documentation is delayed with an accompanying point penalty if delay is minor, potential disqualification if delay is major | 2D | Plan to launch subscale and full scale flights well before documentation deadlines and plan back up dates. |

## 4.4 Failure Modes and Effects Analysis (FMEA)

| **Failure Mode** | **Cause** | **Effect** | **Likelihood and Severity (RAC)** | **Mitigation** |
|---|---|---|---|---|
| Rocket motor failure, Catastrophe At Take-Off (CATO) | Poor motor handling or assembly | High-velocity shrapnel and debris | 3E | The team will follow the NAR High Powered Rocket Safety Code in Appendix C when conducting all launches to ensure all individuals are at the least possible risk of harm during a launch event. |
| Misfire | Ignitor failure | Potentially live rocket appearing inert on the launch pad | 3C | Per NAR High Powered Rocket safety code in Appendix C part 5. the proper procedures will be followed to disarm the rocket, before further investigation is |

| | | | | |
|---|---|---|---|---|
| | | | | taken. |
| Midflight airframe failure | High g-load; improper load analysis | High-velocity shrapnel and debris | 4E | Preflight inspection to ensure the rocket is prepared for flight, preflight modeling to ensure proper flight |
| Rocket tipping; horizontal flight | Fin or airframe failure; low stability margin | Direct impact with rocket; property damage | 4D | Preflight inspection to ensure rocket structural integrity. Detailed analysis of rocket dynamics, high stability margin. |
| Parachute failure | Weak material; tangling; improper folding; tears; fire damage; faulty shock cord | Terminal velocity impact | 4E | Proper packing; vetting and testing of ejection and release mechanisms, shock cord strength testing; usage of fire retardant wadding. |

## 4.5 Environmental Concerns

| **Failure Mode** | **Cause** | **Effect** | **Likelihood and Severity (RAC)** | **Mitigation** |
|---|---|---|---|---|
| Severe weathering of the rocket | Extended exposure to weather | Prolonged neglect in an outdoor environment | 3E | The rocket shall be stored in the lab facility during all times other than launches or travel to said launches. |
| Minor weathering of the rocket | Minor exposure to weather | Exposure to the elements during transport or launch | 3D | Weather conditions shall be taken into account during the transport and launch of the rocket. |
| Noise Pollution | Combustion | Disturbance to nearby animal populations | 3D | NAR minimum distance chart in Appendix B will apply to animals, and launches will take place in remote areas such as the planned launch site Snow Ranch in Farmington, CA |
| Contamination of ecosystem | Launch without a jet deflector or near a | Soil and water contamination to | 3E | Adhere to NFPA 1127 4.12.2 which requires an adequately |

| | | | | |
|---|---|---|---|---|
| | stream | unnatural chemicals | | sized jet deflector on the launch pad. |
| Fire on launchpad | Improper jet deflector size and flammable materials below launch pad | Possible severe fire, injury of spectators and team, environmental destruction. | 3D | Adhere to NFPA 1127 4.12.2 which requires an adequately sized jet deflector on the launch pad, and make sure all flammable materials are away from launch pad. Also a fire extinguisher will be brought by the safety officer as a safety precaution to every launch. Pre-Flight Checklist will be strictly adhered to. |
| Harmful emissions | Use of unfriendly materials to the environment | Pollution | 2E | Restriction to rocket motors not containing titanium sponge per handbook guideline 2.21.3. |
| Improper disposal of materials during manufacturing process | Improper training or misinformed members | Pollution | 2E | Procedure are in place to follow all necessary protocol when it comes to the disposal of hazardous waste. The university has established pathways to dispose of such waste. All members dealing with material requiring unique disposal on trained in these procedures. |

# 5. Payload

## 5.1 Objective, Results, Success

**E-1**'s payload will satisfy this year's target detection experiment requirement with TARS, the TArget Recognition System. Items in green are required for success, and items in blue are secondary criteria.

The system must:

- Identify all ground targets based on predefined color criteria in real time
- Provide proof of target identification via saved data which can be recovered after the flight
- Obtain at least 10 frames with successful target detections during ascent
- Perform well at high spin rates

- Use gyroscope measurements to spin-stabilize the video feed in real time

The result of the system will be a recorded video of the rocket's ascent from the onboard camera's perspective with the ground targets identified and outlined. System success will be determined by a quality analysis of the footage, focusing on the clear identification of the ground targets.

## 5.2 System Design and Alternatives

The fundamental optics of TARS have undergone multiple redesigns since inception to provide more ground coverage throughout the flight. We discuss the different optics options for TARS, their respective attributes, and the rationale for the option we selected.

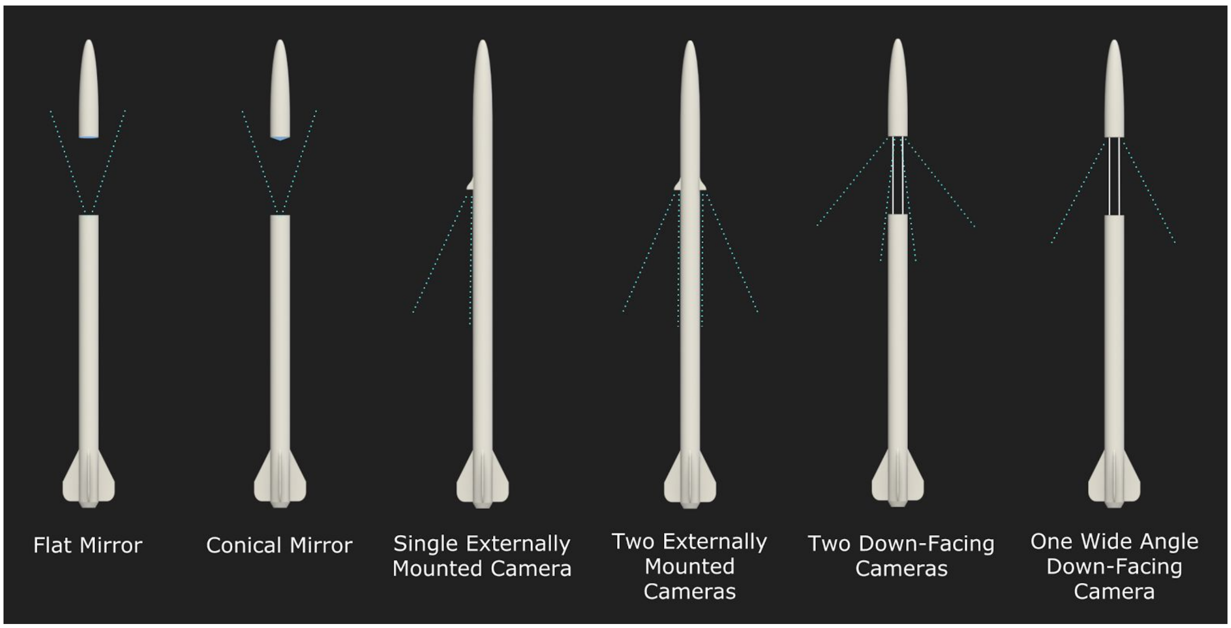



Figure 7: Sketches of the optical path options explored for TARS. Blue dotted lines represent the extent of the camera field of view (FOV). The first two options were initially considered in the Proposal, and the last option is chosen for the final rocket design for its efficiency. The white lines are the structural all-threads that extend through the clear section.

Camera options with external protrusions are immediately ruled out, as they introduce aerodynamic inefficiency, turbulence, and stress on the rocket's airframe, but will serve as a baseline to compare the alternative options. The optical properties of the all options and their resultant fields of view are modeled at intervals of 1000 ft between 0 and 1 mile in SolidWorks to determine the best candidate.

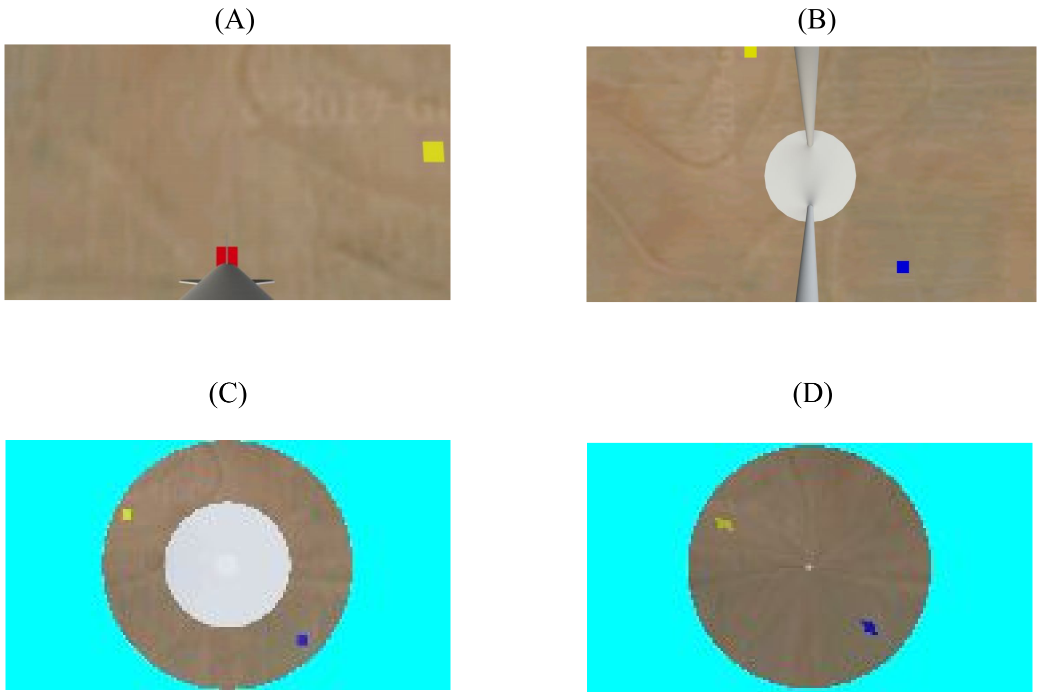



Figure __: The FOVs of the exterior camera (A), downward facing camera (B), flat mirror (C), and the conical mirror (D) layouts. The three tarps are placed at distances of 0, 1394, and 1476 feet from the launch pad, and the perspectives shown is a bird's-eye-view from 1000 ft. The FOVs of the mirror layouts are predominated by sky, and part of the down-facing layout's FOV is obstructed by the structural all-threads. The mirror camera images (C & D) 17º viewing angle, and the other two images (A & B) have a more standard 48º viewing angle.

The flat mirror option utilizes only a small fraction of the FOV for ground tracking. The tarps would be in view for a short fraction of the rocket's flight. In the downward facing camera layout, the tarps fill a larger fraction of the FOV, and are in view for a larger fraction of the flight.

The following is a table of pros and cons of each system configuration. Highly concerning disadvantages are designated in red, mild concerns in orange, highly beneficial benefits in green, and mild benefits in blue.

| One Camera | Two Cameras | Flat Mirror | Conical Mirror | Two Down-Facing Cameras | Down-Facing Camera |
|---|---|---|---|---|---|
| Asymmetric aerodynamic drag<br><br>Blind to half of the potential target area<br><br>Single video feed<br><br>Targets are in frame entire duration of ascent<br><br>No blind spots | Significant additional aerodynamic drag<br><br>Two camera feeds; computationally complex<br><br>Targets are in frame entire duration of ascent<br><br>No blind spots | Significant blind spot due to self-reflection<br><br>Small target-to-pixel mapping<br><br>Targets are in-frame for small duration of ascent<br><br>Small blind spot below rocket<br><br>Single video feed<br><br>No additional Aerodynamic drag | The target-to-pixel mapping is small<br><br>Targets are in-frame for small duration of ascent<br><br>Conical mirror manufacturing is complex<br><br>Single video feed<br><br>No additional Aerodynamic drag | Two camera feeds; computationally complex<br><br>Small blind spot below rocket<br><br>Targets are in-frame for majority of ascent<br><br>No additional Aerodynamic drag<br><br>Very large ground FOV | Small blind spot below rocket<br><br>Targets are in-frame for majority of ascent<br><br>Single video feed<br><br>No additional Aerodynamic drag<br><br>Large ground FOV |

Table N: A comparison of the payload optical layout options. Major benefits and major drawbacks are listed in green and red, respectively. General properties are listed in blue.

The downward-facing camera option is the most ideal due to its technical simplicity and its superior FOV coverage. The camera will be controlled and its video feed analyzed by a Raspberry Pi 3b with custom-written image analysis software that tracks objects with pre-specified RGB values. The selected camera can support recording up to 60 frames per second with a resolution of 720p. Other leading alternatives to this design would be variation of the downward-facing camera with varying window lengths.

## 5.3 Drawings, Schematics, and estimated Masses

Figure 5.3.1 From right to left, an isometric view of TARS looking up at TARS, a front perspective, and an isometric view looking down at TARS

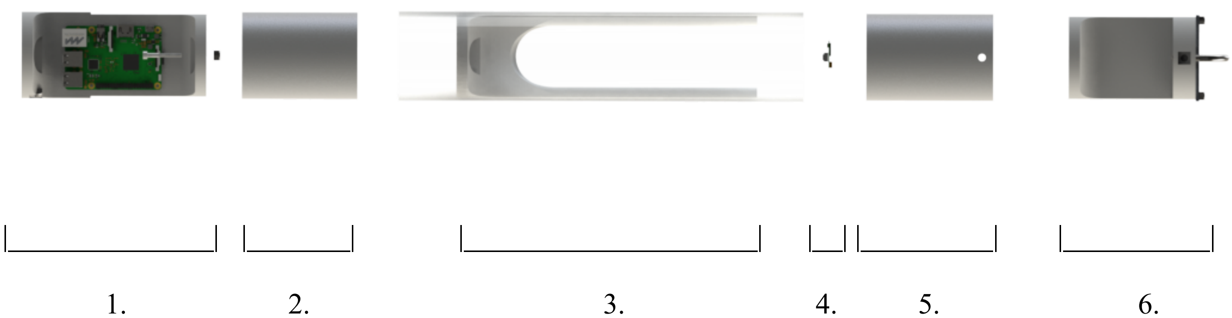



Figure 5.3.2 An exploded view of TARS with labeled components and masses:

1. TARS Computer Bay [0.57 lb]
2. Lower window coupler [0.25 lb]
3. Window internal structure [0.28 lb] (within window [0.29 lb])
4. Camera [0.0066lb]
5. Upper window coupler [0.28lb]
6. Recovery altimeter bay without electronics [0.38 lb]

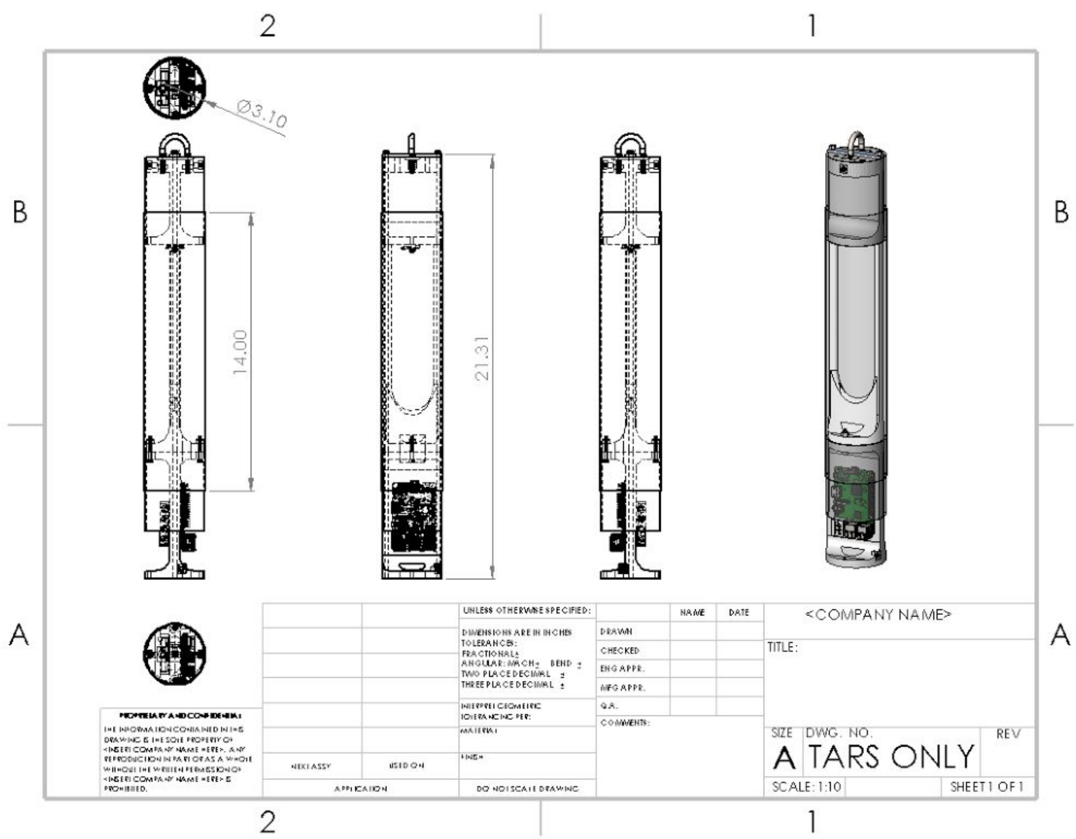



Figure 5.3.3 An assembly drawing of TARS with major dimensions

The physical design of the TARS payload was chosen to maximize the field of view of the camera while still allowing the structural pass through of the all thread substructure. The internal components of the payload shall be a series of 3D printer sleds, one to house the image analysis computer at the base, another to encase the all-threaded through the window section, and the final sled to house the ejection charge detonation electronics which also serves as the camera mount.

The exterior of the payload was designed to interface with the body tubes above and below the section via the window coupler pieces. The window itself is designed to seamlessly transition from the body tube and then back to minimize the payload effect on the aerodynamics of the vehicle.

The payload shall interface with the rest of the vehicle structurally through the all-thread rails and it integration into the avionics sled. The payload image processing computer (the Raspberry Pi 3) shares a common power supply with the flight computer, but is otherwise electrically isolated (See Section 3.1.2.9 for electrical schematic).

## 5.4 Software

The software-architecture contains three separate modules to satisfy the requirements of the TARS system. The first and last modules will be absolutely necessary for the completion of this challenge and any primary criteria, and the second module satisfies any secondary criteria.

Our first module wraps the interface of capturing live video feed and breaking it into individual frames that are then passed to the second module, and possibly to the third module. We are defining a standard that the first module will write the broken down video feed by frame to the file system in an organized manner. This allows each module to work in parallel on individual frames instead of entire video reels.

The second module will be a C++ module that will perform stabilization and standardization for each frame. This module will be given gyroscopic data to help with the stabilization, as well as defining anchor points within the image once the rocket reaches a certain altitude. Although not completely necessary for identifying targets, this module will allow us to be able to introduce a ‘confidence’ aspect to our third module.

The third module will be written in python and will be identifying targets in flight. We currently have some of the module built and plan on using the following plan for identification:

1. Adjust gamma correction on frame to account for possible light differences.
2. Gaussian blur to reduce image noise.
3. Create a threshold diagram and contour identification to outline all possible shapes.
4. Use Euclidean distance from provided RGB values to output a distance between target RGB and true RGB.
5. If distance is within an accepted threshold, outline shape on frame.

6. If module 2 is completed, implement confidence level decision making on area of frame targets are being identified on.


Output of preliminary stages of image-processing software. As you can see there are two separate sets of identifiable targets depending on levels of gamma correction we choose. The top row is a lower gamma correction value, the bottom row is a higher and more normal gamma correction value (closer to 1). The left column is the threshold diagram and the right column is outputted frames.

# 6. Project Plan

## 6.1 Requirements Verification

### 6.1.1 Sections 1-5 Requirements

1. General Requirements

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).

**The team is in close contact with the NAR-certified mentor who has agreed to handle motor assembly, black powder charges, and electric matches. All work on the project has so far been done by students and will continue to be done in that way.**

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 assigned, educational engagement events, and risks and mitigations.

**The team has a running schedule of deadlines and milestones for all aspects of the project.**

1.3. Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during these activities.

**One team member has been identified as a Foreign National**

1.4. The team must identify all team members attending launch week activities by the Critical Design Review (CDR).

**There is a running list of team members which will be finalized by the CDR.**

1.4.1. Students actively engaged in the project throughout the entire year.

**The Subteam leads push students to be engaged and willingly contribute their skills to the team.**

1.4.2. One mentor (see requirement 1.14).

**The team has one NAR certified mentor.**

1.4.3. No more than two adult educators.

**The team has one adult educator.**

1.5. The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by FRR. An educational engagement activity report will be completed and submitted within two weeks after completion of an event. A sample of the educational engagement activity report can be found on page 31 of the handbook. To satisfy this requirement, all events must occur between project acceptance and the FRR due date.

**The team is communicating with the University and local primary schools to discuss the options of doing an educational outreach program. This will include a miniature lesson on the physics of rocketry and a hands-on build component where students will build their own bottle rockets.**

Sections 1.6-1.11:

**We will ensure that all formatting, submission, presentation, and accessibility rules will be adhered to. Proper formatting will be check and verified by a team member prior to a document's submission.**

1.12. All teams will be required to use the launch pads provided by Student Launch's launch service provider. No custom pads will be permitted on the launch field. Launch services will have 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use. 5

**The team will use only the launch pads provided by the launch services and has designed the rocket to accommodate such a configuration.**

1.13. Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194) Subpart B-Technical Standards (http://www.section508.gov): § 1194.21 Software applications and operating systems. § 1194.22 Web-based intranet and Internet information and applications.

**The team will only use commercially-available parts that comply with all government standards.**

1.14. Each team must 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 must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry 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 attends launch week in April.

**The team has a mentor.**

2. Vehicle Requirements

2.1. The vehicle will deliver the payload to an apogee altitude of 5,280 feet above ground level (AGL).

**The flight profile of the rocket has been carefully modeled to meet this goal.**

2.2. The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner. Teams will receive the maximum number of altitude points (5,280) if the official scoring altimeter reads a value of exactly 5280 feet AGL. The team will lose one point for every foot above or below the required altitude.

**The rocket design include redundant stratologger cf altimeter, both capable to serve as the official scoring altimeter.**

2.3. Each altimeter will be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.

**Three arming switches are included in the design of the rocket, capable of locking in the on or off position.**

2.4. Each altimeter will have a dedicated power supply.

**The electronics of the rocket were designed such that each altimeters has a dedicated power supplies.**

2.5. Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).

**The arming switches will be key based mechanism capable of locking in the on or off positions.**

2.6. 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.

**The rocket is designed to be fully recoverable via its parachutes and locating devices and reusable via its robust design.**

2.7. 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.

**The rocket separates into two tethered components for recovery.**

2.8. The launch vehicle will be limited to a single stage.

**The rocket designed with a single-stage.**

2.9. The launch vehicle will be capable of being prepared for flight at the launch site within 3 hours of the time the Federal Aviation Administration flight waiver opens.

**The rocket's simple design allows for a short preparation time.**

2.10. The launch vehicle will be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board components. 6

**The rocket's batteries are at a high enough capacity for the rocket to remain in a pre-launch state for a minimum of an hour until launch. This shall be tested and verified once the system is fully constructed with a endurance test.**

2.11. 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 Range Services Provider.

**The vehicle will use the standard NASA-designated ignition system.**

2.12. The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).

**The rocket's functionality will be fully self-contained prior to launch, during launch, and during ascent.**

2.13. 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).

**The vehicle will use a standard, commercially-available, certified, APCP rocket motor.**

2.13.1. Final motor choices must be made by the Critical Design Review (CDR).

**It is the intention of the primary designers of the team to meet this requirement.**

2.13.2. Any motor changes after CDR must be approved by the NASA Range Safety Officer (RSO), and will only be approved if the change is for the sole purpose of increasing the safety margin.

**If such a change is necessary, the proper protocol will be observed. It is the responsibility of the primary designers initiate such a process if necessary.**

2.14. Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:

**No pressure vessels will be used on the vehicle.**

2.15. The total impulse provided by a College and/or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).

**The viable motors for our vehicle do not exceed K-class.**

2.16. 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.

**Models indicate that the rocket's static stability margin at takeoff is greater than 2.0 at rail exit. These models will be run with each major design revision, and the fulfillment of this requirement verified.**

2.17. The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.

**For all the motors being considered for selection, all exceed a 60 fps velocity when launched from an 8 ft rail. Flight data will be analyzed post launch to verify that the exit velocity was a predicted.**

2.18. All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets.

**A subscale rocket is being developed, and multiple subscale flights are being planned. (See Section 6.3 Timeline )**

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.

**The subscale model will be very similar to the full scale rocket, with the exception of the motor tube, which will house a 38 mm I-class motor. The internals of the subscale rocket are planned to be reused for the full scale rocket, but this plan can be altered if it is found in violation of this requirement.**

2.18.2. The subscale model will carry an altimeter capable of reporting the model's apogee altitude.

**The subscale model will carry three redundant altimeters, each capable of reporting the model's apogee altitude. Data from these sensors are of extreme importance to the team.**

2.19. All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate 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 a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full-scale demonstration flight:

**A full scale rocket flight is being planned. (See Section 6.3 Timeline ) and shall be the identical vehicle to that flown on launch day.**

2.19.1. The vehicle and recovery system will have functioned as designed.

**Ground testing of the recovery system will verify that the system will function during the full scale test.**

2.19.2. The payload does not have to be flown during the full-scale test flight. The following requirements still apply:

**It is the intention of the team to fly the payload during the full scale test, but shall observe the applicable requirements if the team is unable to do so.**

2.19.2.1. If the payload is not flown, mass simulators will be used to simulate the payload mass.

**A mass simulator will be designed and constructed prior to the full scale launch.**

2.19.2.1.1. The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.

**The mass simulator will be designed such that this requirement is met.**

2.19.3. If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale demonstration flight.

**The payload window section shall be included as a part of the full scale rocket, and can be included separate from the camera system itself.**

2.19.4. The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification. If the full-scale motor is not flown during the full-scale flight, it is desired that the motor simulates, as closely as possible, the predicted maximum velocity and maximum acceleration of the launch day flight.

**The full-scale motor is intended to be identical to the competition motor, but if that is altered, careful modeling will be performed to verify that the proper characteristics are present in the full scale test flight.**

2.19.5. The vehicle must be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.

**If the vehicle is determined to include ballast, it shall be included during the full scale flight. This shall be verified during the preparations for the full scale flight.**

2.19.6. 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).

**This requirement shall be observed and is the responsibility of the team member making the modification make it known to the team leadership who shall contact the RSO.**

2.19.7. Full scale flights must be completed by the start of FRRs (March 6th, 2018). If the Student Launch office determines that a re-flight is necessary, then an extension to March 28th, 2018 will be granted. This extension is only valid for re-flights; not first-time flights.

**It is the intention of the team to complete the full scale flight prior to March 6th, if an extension is required it is the responsibility of the team leadership to contact the proper personnel.**

2.20. Any structural protuberance on the rocket will be located aft of the burnout center of gravity. 2.21. Vehicle Prohibitions

**The only structural protuberance on the rocket would be the deployed ADAS fins during flight corrections, which are located aft of the burnout center of gravity as modeled and verified in CAD.**

2.21.1. The launch vehicle will not utilize forward canards.

**The rocket design does not use forward canards.**

2.21.2. The launch vehicle will not utilize forward firing motors.

**The rocket does not use forward firing motors.**

2.21.3. The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)

**All motors being considered do not expel titanium sponges as verified by information provided the vendors.**

2.21.4. The launch vehicle will not utilize hybrid motors.

**The rocket design does not include hybrid motors.**

2.21.5. The launch vehicle will not utilize a cluster of motors.

**The rocket design does not include a cluster of motors.**

2.21.6. The launch vehicle will not utilize friction fitting for motors.

**The motor shall be held in black by a threaded motor retainer.**

2.21.7. The launch vehicle will not exceed Mach 1 at any point during flight.

**Models indicate that the vehicle shall not exceed Mach 1 during any point in the flight.**

2.21.8. Vehicle ballast will not exceed 10% of the total weight of the rocket.

**The design of the rocket has taken this into consideration. It will be checked during anytime that ballast is added to the rocket that this requirement is respected.**

3. Recovery System Requirements

3.1. The 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.

**The rocket is designed to deploy a drogue chute at apogee, triggered by redundant altimeters, and then deploy a main chute at a low altitude, slowing the vehicle down to meet the maximum Kinetic energy requirement.**

3.2. Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launches.

**The system shall be designed to accommodate such a test successfully.**

3.3. At landing, each independent sections of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf. 8

**Detailed modeling was done to select the proper parachute size to meet this requirement.**

3.4. The recovery system electrical circuits will be completely independent of any payload electrical circuits.

**The electronics of the rocket are designed such that the recovery and payload circuits are completely separate.**

3.5. All recovery electronics will be powered by commercially available batteries.

**The recovery system was designed with this in mind.**

3.6. The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.

**The Recovery system include two PerfectFlite Stratologger CF altimeters, each wired to separate ejection charges to ensure full redundancy.**

3.7. Motor ejection is not a permissible form of primary or secondary deployment.

**The motor shall be held within the rocket by a threaded retainer which shall be in place during the entirety of the rocket’s flight.**

3.8. Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.

**The vehicle design includes plans for such shear pins.**

3.9. Recovery area will be limited to a 2500 ft. radius from the launch pads.

**Detailed drift models have been performed to meet this requirement. (See section 3.1.3.4 Parachute Sizing and Selection)**

3.10. An electronic 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.

**The vehicle includes a GPS transmitter in the nosecone which shall serve such a purpose. The system shall be verified via multiple ground tests prior to launch.**

3.10.1. Any rocket section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.

**The rocket design will consists of two sections, tethered to one another.**

3.10.2. The electronic tracking device will be fully functional during the official flight on launch day.

**A number of ground tests and inclusions on the sub and full scale test flight shall verify this system's functionality.**

3.11. The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).

**The recovery system designed to be completely isolated from any other potential form of interference.**

3.11.1. 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.

**The recovery system altimeters are designed to be located on the avionics sled which is in a separate compartment than the GPS transmitter which is located in the nose cone.**

3.11.2. The recovery system electronics will be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.

**The recovery system electronics will be shielded from the GPS transmitter by the parachutes, metallic avionics sled securement plate and the avionics sled upper bulkhead.**

3.11.3. 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.

**The rocket design does not include any of these devices.**

3.11.4. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.

**Extensive ground testing shall be done to verify that this is the case.**

4. Experiment Requirements

4.1. Each team will choose one design experiment option from the following list.

**The team has chosen to participate in the target detection experiment.**

4.2. Additional experiments (limit of 1) are allowed, and may be flown, but they will not contribute to scoring.

**The team does not plan to fly additional payloads.**

4.3. If the team chooses to fly additional experiments, they will provide the appropriate documentation in all design reports, so experiments may be reviewed for flight safety. Option 1 Target detection Option 2 Deployable rover Option 3 Landing coordinates via triangulation 9

**The team does not plan to fly additional payloads.**

4.4. Target detection

4.4.1. Teams will design an onboard camera system capable of identifying and differentiating between 3 randomly placed targets.

**The rocket design incorporates the TARS (TArget Recognition System) to identify these ground targets. (See section 5. Payload)**

4.4.1.1. Each target will be represented by a different colored ground tarp located on the field.

**The team shall use the sample provided to catalog these different targets.**

4.4.1.2. Target samples and RGB values will be provided to teams upon acceptance and prior to PDR.

**The team has measured the RGB values of these targets from the samples provided.**

4.4.1.3. All targets will be approximately 40’X40’ in size.

**This shall be taken into account during all testing and evaluation of the payload performance.**

4.4.1.4. The three targets will be adjacent to each other, and that group will be within 600 ft. of the launch pads.

**This has be taken into account during the design of the system and shall be considered during all testing of the TARS.**

4.4.2. Data from the camera system will be analyzed in real time by a custom designed on-board software package that shall identify, and differentiate between the three targets.

**The rocket design incorporates custom software to identify the targets in real time (See section 5.4 Software).**

4.4.3. Teams will not be required to land on any of the targets.

**This was taken into account during the design of the rocket.**

4.5. Deployable rover

**The team did not select to participate in the rover challenge**

4.6. Landing coordinates via triangulation

**The team did not select to participate in the triangulation challenge**

5. Safety Requirements

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.

**The safety officer is developing the launch and safety checklist, that will be ready prior to the subscale launch, and thus used at all following launches with updated items if such an update is necessary.**

5.2. Each team must identify a student safety officer who will be responsible for all items in section 5.3.

**The team identifies Michael Scudder (mscudder@ucsc.edu) as the team's safety officer. Note that the individual in this position has changed since the proposal.**

5.3. The role and responsibilities of each safety officer will include, but not limited to:

5.3.1. Monitor team activities with an emphasis on Safety during:

5.3.1.1. Design of vehicle and payload

**The safety officer shall be kept informed of the vehicle's design by the lead designers.**

5.3.1.2. Construction of vehicle and payload

**The safety officer shall actively oversee, and be responsible for the team to adhere to all safety regulations and recommendations during the construction of the vehicle.**

5.3.1.3. Assembly of vehicle and payload

**The safety officer shall accompany the team during all launch activities and be present at any major system tests where the vehicle or payload are assembled.**

5.3.1.4. Ground testing of vehicle and payload

**The safety officer shall be informed of all ground testing being performed and will ensure that the proper procedures are followed during such tests.**

5.3.1.5. Sub-scale launch test(s)

**The safety officer shall accompany the team during all launch activities to ensure that proper safety procedures are followed.**

5.3.1.6. Full-scale launch test(s)

**The safety officer shall accompany the team during all launch activities to ensure that proper safety procedures are followed.**

5.3.1.7. Launch day

**The safety officer shall attend Launch day and personally ensure that all safety regulations are respected and followed.**

5.3.1.8. Recovery activities

**The safety officer shall be present during vehicle recovery and warn all team members about improper recovery prior to launch.**

5.3.1.9. Educational Engagement Activities 10

**The safety officer shall approve all educational activities prior to the event.**

5.3.2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities

**The safety officer shall research the proper techniques and procedures involved in these activities compose a collection of documents to be strictly followed by the members involved in these activities.**

5.3.3. Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data

**The safety officer has taken full responsibility for this task and has taken steps to host the documents on the team's website, accessible to all team members. Additional physical copies ahll be kept in the lab space with the materials.**

5.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.

**The safety officer takes a leading role in the development of this documentation.**

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 Initiative does not give explicit or implicit authority for teams to fly those certain 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.

**The team shall respect the judgement of all higher level authorities on the rocket's safety, configuration, or other concerns.**

5.5. Teams will abide by all rules set forth by the FAA

**The team has all intentions of abiding by the regulations put forth by the FAA by launching at designated launch sites during cleared times.**

### 6.1.2 Team Requirements

#### 6.1.2.1 Vehicle

Follow a near-vertical trajectory

**The rocket was designed with this goal in mind, minimizing asymmetrical aerodynamic protrusions from the rocket when possible.**

Record precise sensor measurements throughout the duration of the flight

**This was a primary concern during the team's selection process of on board sensors. It was found that the Arduino 101 with it's embedded IMU yield the highest frequency, and precise data.**

Use sensor measurements to determine the its flight parameters at each time step

**This requirement is accomplished with the successful implementation of the software to control the ADAS. The most efficient way for the onboard computer calculate this data is the subject of ongoing research for the team.**

Deploy ADAS if the demanded by the flight profile

**All measures shall be taken to ensure that ADAS is in working order for the rocket's launch.**

Perform fine adjustments to a model flight profile at a rate of 10 Hz

**ADAS was designed with this in mind.**

Achieve a pre-specified apogees to within 5%

**Flight data shall be analyzed post flight to evaluate how well the team met this requirement and design modifications shall be made to meet this requirement if necessary.**

(Secondary Requirement) Achieve pre-specified apogees to within 0.5%

**A continuous effort will be put forth to update the control algorithm of the ADAS system with every flight and simulation.**

(Secondary Requirement) The vehicle shall be capable of supporting atmospheric research efforts at the university

**The vehicle is design to accommodate large motors, and the with avionics bay section completely removable and modular to allow for additional configurations.**

#### 6.1.2.2 Payload

Activate TARS to locate and track tarps of different colors, even at high spin rates

**Extensive testing of TARS shall be performed including testing the performance of the system during a roll. The data from these tests will then be used to improve the system and ensure that this requirement is met.**

(Secondary Requirement) Pair TARS with the avionics system to correct the video feed for angular velocity

**If it is found that TARS performs well beyond its requirements then there are preliminary plans to correct the footage generated from TARS for roll by coupling the system to a gyroscope.**

(Secondary Requirement) Repurpose TARS to track and observe topographical and atmospheric features

**If the performance of the target detection software for TARS is sufficiently developed, an additional algorithm will be developed to recognize topographical features.**

#### 6.1.2.3 Recovery

The team shall not lose the rocket after a flight

**Team members will track the rocket by eye to ensure that if the location system fails, the rocket is still recoverable.**

#### 6.1.2.4 Safety

The team shall exceed the safety requirements mandated

**The safety officer shall take responsibility for enacting a comprehensive safety plan covering all relevant activities and hazard that the team could potentially encounter.**

#### 6.1.2.5 General

Maintain a professional relation with all organizations which the team interfaces with

**All external communication shall be held to a high standard of professional courteous.**

## 6.2 Budget

### 6.2.1 Expenses

The complete budget of the team comes out to **$6394**. A breakdown of the Effective-1 Rocket Budget, Subscale Rocket Budget, Travel Budget, and General Budget are included in the following tables. These budgets are subject to change.

#### 6.2.1.1 Effective-1 Rocket Budget

| **Airframe** | | | | | | |
|---|---|---|---|---|---|---|
| **Item** | **Vendor** | **Unit Price** | **Qty.** | **Shipping** | **Tax** | **Price** |
| Blue Tube 2.0 3"x48" | Always Ready Rocketry | 29.95 | 1 | 12.95 | 2.24 | 45.14 |
| CNC Fin Slots | Always Ready Rocketry | 16.00 | 1 | | 1.20 | 17.20 |
| CNC Fin Templates | Always Ready Rocketry | 1.00 | 4 | | 0.30 | 4.30 |
| 3" FIBERGLASS 4:1 OGIVE NOSE CONE | Apogee | 30.95 | 1 | 50.00 | 2.32 | 83.27 |
| AERO PACK 54L/3" TAILCONE RETAINER | Apogee | 47.08 | 1 | | 3.53 | 50.61 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 54MMX48" G12 THIN-WALL FIBERGLASS FW AIRFRAME TUBE | Apogee | 65.77 | 1 | | 4.93 | 70.70275 |
| Centering Ring G10 FIBERGLASS CR 54MM/3" | Apogee | 13.18 | 2 | | 1.97 | 28.337 |
| 3" Fiberglass Bulkhead | Apogee | 5.41 | 1 | | 0.40 | 5.81 |
| Class 8.8 Medium-Strength Steel Threaded Rod | McMaster-Carr | 9.52 | 2 | 20.00 | 1.42 | 40.46 |
| Fiberglass Resin | Homedepot | 20.00 | 1 | | 1.50 | 21.50 |
| Fin Material | Apogee | 27.00 | 1 | | 2.02 | 29.02 |
| Launch Lugs | Apogee | 10.00 | 1 | | 0.75 | 10.75 |
| Fasteners | McMaster-Carr | 10.00 | 1 | | 0.75 | 10.75 |
| **Airframe Sub Total** | | | | | | 417.87 |
| | | | | | | |
| **Avionics Sled** | | | | | | |
| **Item** | **Vendor** | **Unit Price** | **Qty.** | **Shipping** | **Tax** | **Price** |
| Altimeter HP206C | Control Everything | 26.95 | 1 | 10 | 2.02 | 38.91 |
| Arduino 101 | Arduino | 30.00 | 1 | 10 | 2.25 | 42.25 |
| Sled Raw Material (Resin) | Kudo | 110.00 | 1 | | 8.25 | 118.25 |
| U-bolt Parachute Fastener | McMaster-Carr | 1.00 | 2 | | 0.15 | 2.15 |
| Fasteners | McMaster-Carr | 10.00 | 1 | | 0.75 | 10.75 |
| C&K YM061U SPST Arming Switch | Mouser | 18.90 | 1 | 2.30 | 1.61 | 22.81 |
| **Avionics Sled Sub Total** | | | | | | 235.18 |
| | | | | | | |
| **Adaptive Drag Aerobraking System (ADAS)** | | | | | | |

| Item | Vendor | Unit Price | Qty. | Shipping | Tax | Price |
|---|---|---|---|---|---|---|
| NeveRest Classic 40 Gearmotor | Andymark | 28.00 | 1 | 30 | 2.10 | 60.10 |
| Drag fin raw material | McMaster-Carr | 16.64 | 1 | 20 | 1.24 | 37.88 |
| Slide plate raw material | McMaster-Carr | 16.00 | 1 | | 1.20 | 17.20 |
| Electric Motor Battery | Amazon | 28.00 | 1 | | 2.10 | 30.10 |
| Fuse (2A) | Hobbyking | 4.00 | 1 | | 0.30 | 4.30 |
| Fasteners | McMaster-Carr | 10.00 | 1 | | 0.75 | 10.75 |
| L298N Motor Module | Amazon | 7.00 | 1 | 6.52 | 0.00 | 13.52 |
| **Adaptive Drag Aerobraking System (ADAS) Sub Total** | | | | | | 173.88 |
| | | | | | | |
| **Recovery** | | | | | | |
| **Item** | **Vendor** | **Unit Price** | **Qty.** | **Shipping** | **Tax** | **Price** |
| PERFECTFLITE STRATOLOGGER ALTIMETER CF | PerfectFlite | 58.80 | 2 | 20 | 8.82 | 146.42 |
| Drogue Chute 18" NYLON ROUND PARACHUTE | Apogee | 8.00 | 1 | | 0.60 | 8.60 |
| Main Chute 48" NYLON PARACHUTE | Apogee | 35.60 | 1 | | 2.67 | 38.27 |
| Eggfinder GPS Tracking System | Eggtimer Rocketry | 100.00 | 1 | 30 | 7.50 | 137.50 |
| Jolly Logic Chute Release | Jolly Logic | 130.00 | 1 | 15 | 9.75 | 154.75 |
| 2 Cell 7.4V Lipo Battery for GPS | Amazon | 8.00 | 1 | | 0.60 | 8.60 |
| 9v Batteries | Local | 3.00 | 2 | | 0.45 | 6.45 |
| 9v Battery holders | Amazon | 5 | 2 | | 0.75 | 10.75 |
| Fasteners | McMaster-Carr | 10 | 1 | | 0.75 | 10.75 |

| | | | | | | |
|---|---|---|---|---|---|---|
| C&K YM061U SPST Arming Switch | Mouser | 18.90 | 2 | 4.60 | 3.22 | 45.62 |
| **Recovery Sub Total** | | | | | | 567.71 |
| | | | | | | |
| **Payload (TARS)** | | | | | | |
| **Item** | **Vendor** | **Unit Price** | **Qty.** | **Shipping** | **Tax** | **Price** |
| U-bolt Parachute Fastener | McMaster-Carr | 1.00 | 1 | | 0.07 | 1.07 |
| Raspberry Pi B | Amazon | 48.99 | 1 | 10 | 3.67 | 62.66 |
| Raspberry Pi Battery Pack | Amazon | 7.00 | 1 | | 0.52 | 7.52 |
| AAA Batteries (large pack) | Local | 10.00 | 1 | | 0.75 | 10.75 |
| Raspberry Pi Camera | Amazon | 35.00 | 1 | | 2.62 | 37.62 |
| Clear Cast Acrylic Tube | McMaster-Carr | 42.00 | 1 | 10 | 3.15 | 55.15 |
| Fasteners | McMaster-Carr | 10.00 | 1 | | 0.75 | 10.75 |
| **Payload (TARS) Sub Total** | | | | | | 185.53 |
| | | | | | | |
| | | | | | | **Total Cost** |
| **Effective-1 Rocket Total** | | | | | | **$1580.17** |

#### 6.2.1.2 Subscale Rocket Budget

The modular design of the rocket allows for a unique structure for the team's subscale rocket manufacture and testing. The plan is for the subscale rocket to be nearly identical to the full scale Effective-1 rocket in all aspects except the diameter of the motor housing. A 38mm motor housing on the subscale rocket will allow for a greater number of test flights at a lower cost per flight. Once the project has progressed to the point of manufacturing the full scale rocket, nearly all of the rocket's internal components will be directly transferable with the ease of sliding the avionics sled out of the subscale rocket and into the full scale rocket. Thus all the transferable components were included in the Effective-1 budget. The Subscale Rocket Budget includes the items required to build the sub scale airframe.

| **Subscale Airframe** | | | | | | |
|---|---|---|---|---|---|---|
| **Item** | **Vendor** | **Unit Price** | **Qty.** | **Shipping** | **Tax** | **Price** |
| Blue Tube 2.0 3"x48" | Always Ready Rocketry | 29.95 | 1 | 12.95 | 2.24 | 45.14 |

| | | | | | | |
|---|---|---|---|---|---|---|
| CNC Fin Slots | Always Ready Rocketry | 16.00 | 1 | | 1.20 | 17.20 |
| CNC Fin Templates | Always Ready Rocketry | 1.00 | 4 | | 0.30 | 4.30 |
| 3" FIBERGLASS 4:1 OGIVE NOSE CONE | Apogee | 30.95 | 1 | 50.00 | 2.32 | 83.27 |
| AERO PACK 54L/3" TAILCONE RETAINER | Apogee | 47.08 | 1 | | 3.53 | 50.61 |
| 38MM G12 FIBERGLASS FILAMENT WOUND TUBE 48" LONG | Apogee | 58.85 | 1 | | 4.41 | 63.26 |
| Centering Ring G10 FIBERGLASS CR 54MM/3" | Apogee | 13.18 | 2 | | 1.97 | 28.33 |
| 3" Fiberglass Bulkhead | Apogee | 5.41 | 1 | | 0.40 | 5.81 |
| Class 8.8 Medium-Strength Steel Threaded Rod | McMaster-Carr | 9.52 | 2 | 20.00 | 1.42 | 40.46 |
| Fiberglass Resin | Homedepot | 20.00 | 1 | | 1.50 | 21.50 |
| Fin Material | Apogee | 27.00 | 1 | | 2.02 | 29.02 |
| Launch Lugs | Apogee | 10.00 | 1 | | 0.75 | 10.75 |
| Fasteners | McMaster-Carr | 10.00 | 1 | | 0.75 | 10.75 |
| **Subscale Airframe Total** | | | | | | **$410.43** |

#### 6.2.1.3 Travel Budget

Any additional funds raised beyond those necessary to build the rockets and support general team activities shall be directed towards increasing the number of members able to attend the competition. However, in the state of California,

“state-funded travel to any states that have enacted a law that voids or repeals any existing state or local protections against discrimination based on sexual orientation, gender identity, and gender expression or have the enacted laws that have the effect of voiding or repealing any of these protections" (Bill AB 1887).

Which Governor Brown signed into law on September 27, 2016. Since Alabama is among the states listed as of June 23, 2017, all travel to the competition must be funded via sources not associated with the state. For this reason it is critical for the team to adopt a well-rounded funding campaign as described in Section 6.2.2.

| **Item** | **Vendor** | **Unit Price** | **Qty.** | **Tax** | **Price** |
|---|---|---|---|---|---|
| Roundtrip Flight | Most competitive airline TBD | 700.00 | >3 | 70 per | 2310.00 |
| Hotel Room | The Hotel reserved for competition participants if possible | 100.00 per night per room of four people | 1 room for 4 nights | 40 | 440.00 |
| Rental Car | TBD | 50.00 per day | Four days | 20 | 220.00 |
| Travel Total | | | | | $2970.00 |

#### 6.2.1.4 General Budget

| **Item** | **Vendor** | **Unit Price** | **Qty.** | **Tax** | **Price** |
|---|---|---|---|---|---|
| T-Shirts | TBD | 20.00 | 30 | 60.00 | 660.00 |
| Outreach Materials | TBD | 100.00 | 1 | 10.00 | 110.00 |
| Spare parts, (%20 of rocket cost) | Various | - | - | - | 300 |
| Subscale Motor (I600) | Aerotech | 67.40 | 3 | 20.22 | 222.42 |
| Full Scale Motor (J540) | Aerotech | 101.64 | 2 | 20.32 | 223.61 |
| General Total | | | | | $1516.03 |

### 6.2.2 Funding

An aggressive funding campaign is planned to draw capital from a variety of sources.Between the submission of the proposal and the submission of this document, members of the team have reach out to a variety of organizations on campus. The team has gained the support of the engineering department, and access to a variety of manufacturing resources through partnering with the sustainability lab. Team members are also actively composing a crowdfunding campaign to be hosted on the popular GoFundMe platform. Additional crowd funding will be obtained through participation in Giving Day 2018, which is a unique funding event hosted by the university to fund a variety of student projects.

The team is also pursuing corporate partnerships to fund our activities. In exchange for displaying their company logo on our shirt and banners we expect to receive a respectable portion of our funding. Members have already completed applications for the Gene Haas foundation grant and grants from Google and Coca Cola. Individual email are currently being drafted in preparation to be sent to major aerospace companies.

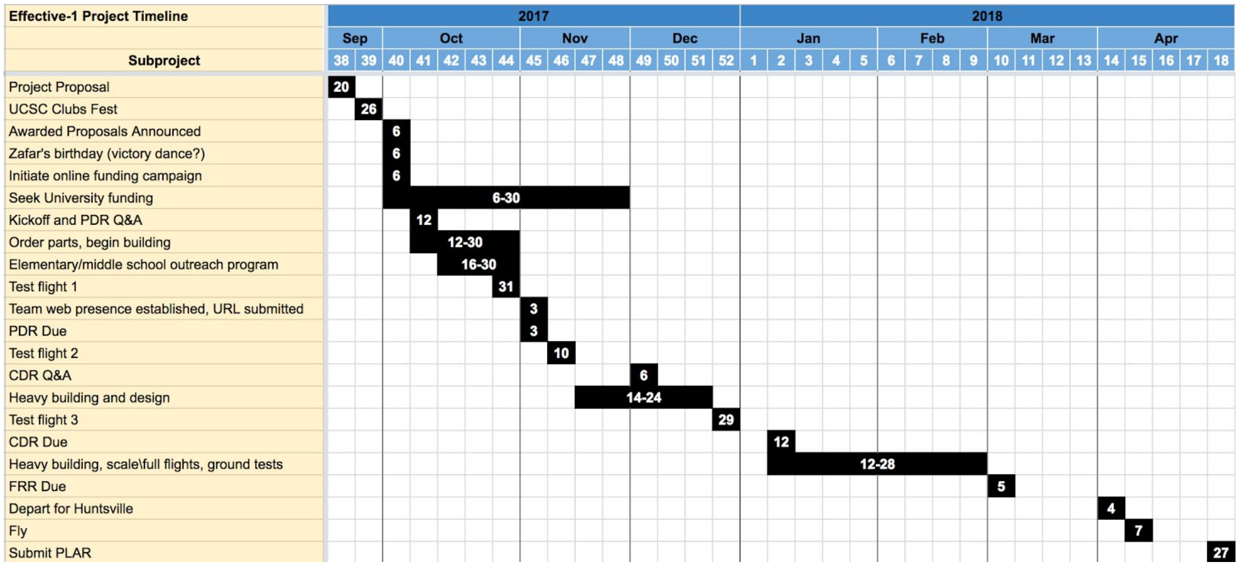
The team shall also be funded via funds awarded for research undertaken by the team.

The following table is the projected income from each aspect of the funding campaign:

| Source | Projected Income |
|---|---|
| Corporate Sponsorships | 3000.00 |
| Crowd funding via GoFundMe | 1500.00 |
| Giving Day 2018 | 1000.00 |
| Research Grants | 1000.00 |
| Total Projected Income | 6500.00 |

If the team is able to meet these goals for each aspect of the funding campaign, all necessary expenses will be covered.

## 6.3 Timeline




The team also has an detailed GANTT chart which is divided into sub team tasks and actively updated by team members; however, such a file is difficult to reasonably display in PDF form.

# Appendix A - Safety Form

All members shall be required to sign the following form before admission into the team, and prior to engaging in team activities:

I, Zafar Rustamkulov, agree to observe the following laws, regulations, rules, and guidelines, in addition to all others not listed which pertain to my activity as a member of the UCSC Rocketry Team:

Laws and Regulations:

1. Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets
2. Code of Federal Regulation 27 Part 55: Commerce in Explosives
3. NFPA 1127
4. Local laws regarding amateur rocketry

Launch Rules:

1. Range safety inspections of each rocket before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program.
2. The Range Safety Officer has the final say on all rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.
3. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

Safety Guidelines

1. As specified in the UCSC online lab safety training curriculum
2. As briefed by the safety officer

By signing this document, I acknowledge that I have read and understood the information listed above, and agree to abide by the aforementioned laws, regulations, rules, and guidelines. Failure to do so will result in immediate discharge from the team.

Zafar Rustamkulov
(Name Print)

(Signature)

9/20/17
(Date)

# Appendix B - Minimum Distance Chart

MINIMUM DISTANCE TABLE

| Installed Total Impulse (Newton-Seconds) | Equivalent High Power Motor Type | Minimum Diameter of Cleared Area (ft.) | Minimum Personnel Distance (ft.) | Minimum Personnel Distance (Complex Rocket) (ft.) |
|---|---|---|---|---|
| 0 — 320.00 | H or smaller | 50 | 100 | 200 |
| 320.01 — 640.00 | I | 50 | 100 | 200 |
| 640.01 — 1,280.00 | J | 50 | 100 | 200 |
| 1,280.01 — 2,560.00 | K | 75 | 200 | 300 |
| 2,560.01 — 5,120.00 | L | 100 | 300 | 500 |
| 5,120.01 — 10,240.00 | M | 125 | 500 | 1000 |
| 10,240.01 — 20,480.00 | N | 125 | 1000 | 1500 |
| 20,480.01 — 40,960.00 | O | 125 | 1500 | 2000 |

Note: A Complex rocket is one that is multi-staged or that is propelled by two or more rocket motors

Revision of August 2012

Adapted from NAR - "High Power Rocket Safety CodeEffective August 2012." *National Association of Rocketry*, Aug. 2012, www.nar.org/safety-information/high-power-rocket-safety-code/.

# Appendix C- NAR Code

1. Certification. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.
2. Materials. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.
3. Motors. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.
4. Ignition System. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.

5. Misfires. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
6. Launch Safety. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.
7. Launcher. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.
8. Size. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.
9. Flight Safety. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.
10. Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).
11. Launcher Location. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.
12. Recovery System. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

13. Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

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