UC Santa Cruz Rocket Team

NASA Student Launch Initiative Proposal

September 20, 2017

Written by Zafar Rustamkulov and Kent Roberts

1. General Information

1.1 School Information/Project Title

University: University of California, Santa Cruz

Organization: UC Santa Cruz Rocket Team

Location: University of California, Santa Cruz
1156 High St, Santa Cruz, CA 95064

Launch Site: Snow Ranch, Farmington, CA

Project Title: *Effective-1 (E - 1)*

Project Motto: *Effectivus ad astra.*

1.2 Team Leadership

Team Leaders:

Kent Roberts

Role: Co-Captain, Vehicle Design Lead

Email: kent@ucsc.edu

Phone: 619-846-6223

Kent is a 3rd year student studying Physics at UCSC. His hope of seeing humanity become a multi-planetary civilization drives his interests in aeronautical and astronautical subjects. With a wide range of experience ranging from leading a FIRST Robotics to working as a Project Engineering Intern at General Atomics, Kent has a broad understanding of engineering principles and their practical application.

Zafar Rustamkulov

Role: Co-Captain, Data Analysis and Control Systems Lead

Email: zafar@ucsc.edu

Phone: 760-587-7120

Zafar is a junior studying astrophysics and planetary science. He has two years of research experience in modeling the atmospheres of exoplanets and has co-authored a published research paper on the TRAPPIST-1 system of seven Earth-sized exoplanets. He enjoys creating models and analyzing data, and has been building model rockets for nearly a decade. His preferred font is Times New Roman, and his preferred programming language is Python.

Safety Officer:

Nicholas Hammond

Role: Safety and Risk Assessment Lead

Email: nickhammond@ucsc.edu

Phone: 626-235-4642

Nicholas is a 3rd-year studying Bioengineering with a concentration in Assistive Technology (Motor). After his undergraduate at UCSC, he plans on earning an entry-level master's in nursing followed by an eventual second master's for nurse practitioner. Until then, he will do his best to prevent participants from needing medical attention by making sure that all safety procedures and regulations are properly followed.

Advisors and Mentors:

David Raimondi

Role: Mentor, Livermore Unit NAR President (LUNAR)

Email: d.raimondi@sbcglobal.net

Phone: 408-742-5173

Ian Garrick-Bethell

Role: Faculty Advisor

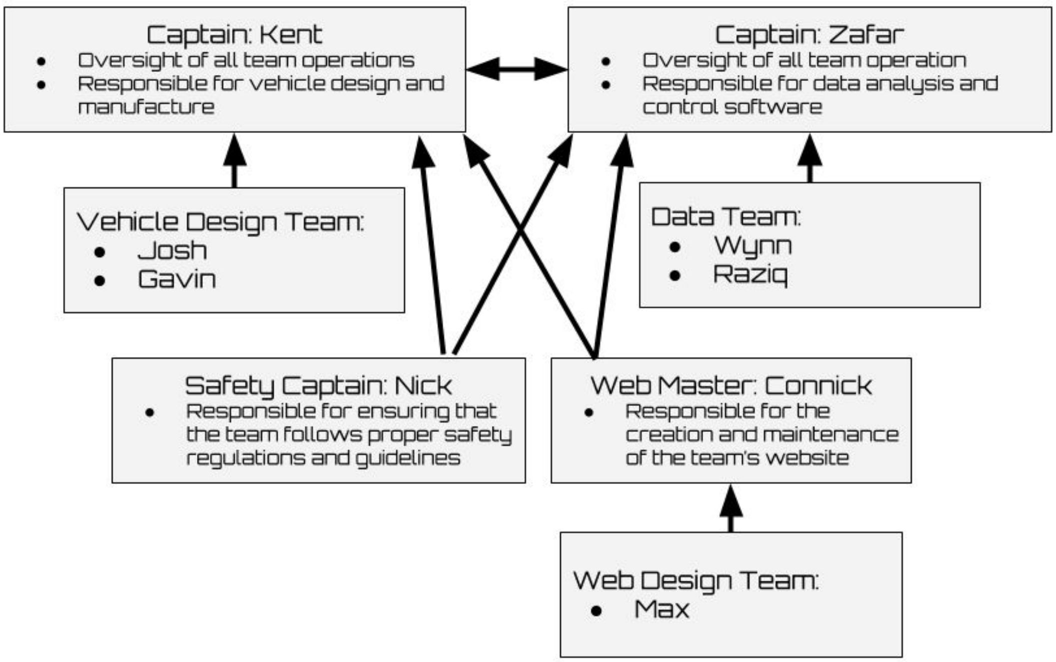
Email: igarrick@ucsc.edu

Phone: 831-459-1277

Ian is an Associate Professor of Planetary Sciences at UCSC whose research focuses on lunar geophysics, planetary magnetism, and low-cost cubesat missions. He also has experience in aerospace engineering, with a degree in the field from MIT.

1.3 Team Organization

Our approach to the organization of our team is focused on efficiency. We aim to keep the team highly productive and tightly-knit as a means to simplify communication and encourage quality work.



Anticipated member count: Approx. 9+

Anticipated Members: Zafar, Kent, Max, Nicholas, Josh, Wynn, Connick, Raziq, Gavin

NAR Section #534: Livermore Unit NAR (aka LUNAR).

NAR Mentor: David Raimondi, President of LUNAR

1.4 Facilities/Equipment

- The Lab (Thimann Labs 372)
    - The team has a dedicated lab space on campus to serve as a workbench and general storage space. 24/7 access has been granted to team members. Entry to the lab space requires a keyholder to be present, thus at least one of the two co-captains must be present during the use of this space.

- Also as a part of the on campus Sustainability Lab program, the team has access to numerous machines including a bandsaw, CNC router, 3D printer and soldering station. Refer to section 4.1 for safety details regarding this lab space
- Idea Fab Labs
  - When the team requires specialty parts that need heavier machinery, the local makerspace offers numerous services. Student Pro Membership can be purchased at a rate of $60 per month which includes 8am to midnight access to a variety of tools including a laser cutter/engraver, 4ft by 14ft CNC bed router, 3D printers and numerous other hand tools. The makerspace offers training course to uses these machines, which a member will complete if necessary.
- Materials
  - Material to make the rocket can largely be sources from online stores. Companies such as McMaster-Carr, Apogee Rocketry, and Amazon offer an extensive online store of rocket parts and equipment.
  - Special material such as high powered rocket motors require a more extensive purchasing procedure which will be handled on a case-by-case basis.
- Software
  - Vehicle design and modification will be done using the educational version of Solidworks CAD software
  - Modeling of the rocket's flight and other characteristics will be done in python using the open source Anaconda distribution.
  - RocketSim will also be used to verify our own custom scripts and models

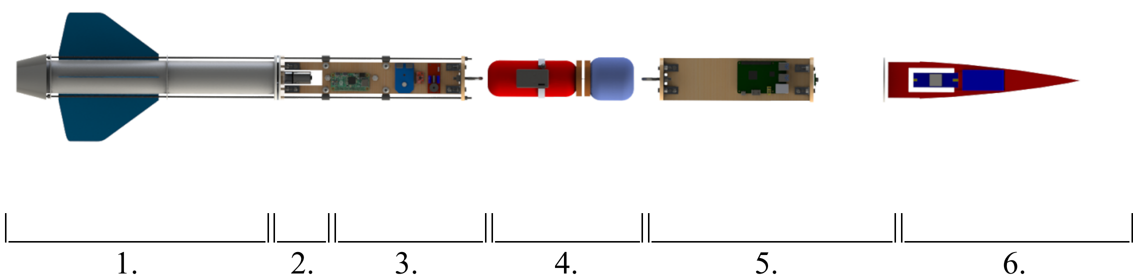
2. Technical Design:

EFFECTIVE-1 Technical Design

The rocket is optimized to be lightweight and highly durable, with a minimal drag coefficient. The competition rocket will consist of five segments. Each one is described in detail in this section.

Exterior

Interior



1. Motor mount, Fins
2. Adaptive Drag Aerobraking System (ADAS)
3. Lower Avionics Bay
4. Recovery
5. Payload Bay
6. Nosecone, GPS Recovery

General Rocket Properties

Rocket Mass	Rocket Length	Rocket Outer Diameter	CG, Wet	Wet Motor Mass	Dry Motor Mass	Rocket with Wet Motor
2.65kg	182 cm	7.88cm (3.1 in)	73.48 cm	840g	424g	3.06kg

Rocket Aerodynamic Properties

C_d	C_d , ADAS 100%	A	A, ADAS 100%	Static CP	Static Margin of Stability, Wet Motor	Dynamic Margin of Stability at 20 m/s (Rail exit velocity)	Dynamic Margin of Stability at 100 m/s, ADAS 100%
0.28	0.49	48.7 cm^2	63.2 cm^2	505.5mm	2.9 calibers	2.5 calibers	1.8 calibers

2.1 Airframe, Motor Mount, Fins, and Nose Cone

The majority of the rocket's body and sections of its interior will be constructed from fiberglass. The G12 filament wound fiberglass airframe is 107 cm (42") in length and has a 7.62 cm (3") inner diameter. We choose fiberglass as our main airframe material due to its lightweight and high-strength properties. This diameter is selected to fit a Raspberry Pi 3, while minimizing the cross sectional area—and thus the drag—of the rocket. The cross sectional area varies as the radius of the rocket's body squared, so slight changes in the diameter yield large differences in the rocket's drag.

The 40 cm length of the motor tube was selected to accommodate J- and K-class motors for adaptability in motor selection. The fiberglass motor tube transfers the thrust generated by the motor to the primary rocket structure through a series of bulkheads. In addition to the fiberglass body and motor housing, two ¼"-20 all-threads extend from the base of the rocket and through the support bulkheads, serving as additional structural supports. They also act as rails for the mounting of the lower avionics and the ADAS. A clear section of the rocket body is mounted atop the main body tube for our camera payload, which is described in a later section.

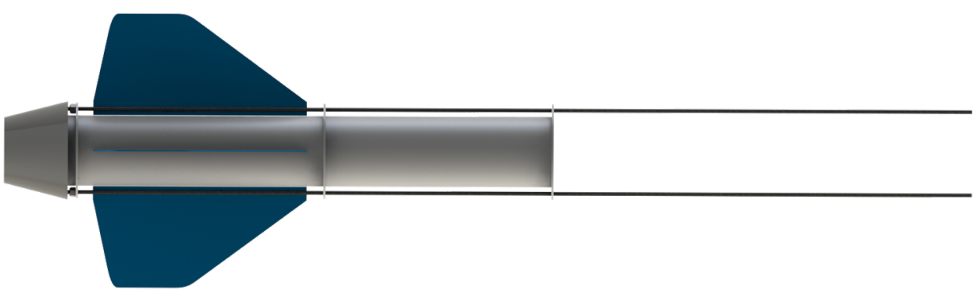
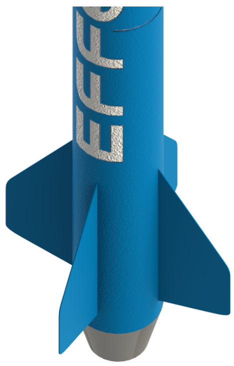


Figure 1: The motor bay is an integral part of the rocket's substructure. It contains three bulkheads, and steel all-thread that extends through the majority of the airframe. The motor housing is 40 cm in length, meaning that it can accommodate a mid-range K-class motor.

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 handbook regulation 2.16.



The fiberglass nose cone is a 25 cm 4:1 LD-Haack (also known as the Von-Kármán), one of the most aerodynamically efficient shapes for a streamlined body, as revealed by our comparison test of different shapes.

2.2 Adaptive Drag Aerobraking System (ADAS)

The total impulse of any given rocket motor (the mean thrust multiplied by the total burn time) can vary by approximately ±10%. 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 test flights have shown that composite motors are more likely to underperform than overperform. Similar apogee differences are seen as a result of weathercocking, which can angle the rocket significantly. We consider these disparities unacceptable for the competition flight, and strive to achieve an arbitrary level of accuracy in reaching an apogee of 1609.34 meters. To precisely reach pre-specified apogees, we introduce Corrective Envelope (CE) and Corrective Fineness (CF) as two concepts that best summarize our efforts in the design process. CE refers to the maximum reduction in apogee that can be achieved assuming full 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, ideally within a meter. 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 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 major gusts of wind and small turbulence-related uncertainties alike. We also aim to minimize turbulence, which could affect the rocket's overall aerodynamics. The result is a streamlined pair of drag fins mounted perpendicularly to the rocket's velocity vector, which are controlled 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 is above our threshold value. We find that the drag coefficient of the rocket with ADAS fully deployed increases by 75% to 0.49. 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 (0.92 N m) and high speed (142 RPM), which are both necessary to deploy ADAS precisely. ADAS communicates with the avionics bay, and is situated flush against the aft motor bay bulkhead to lower the

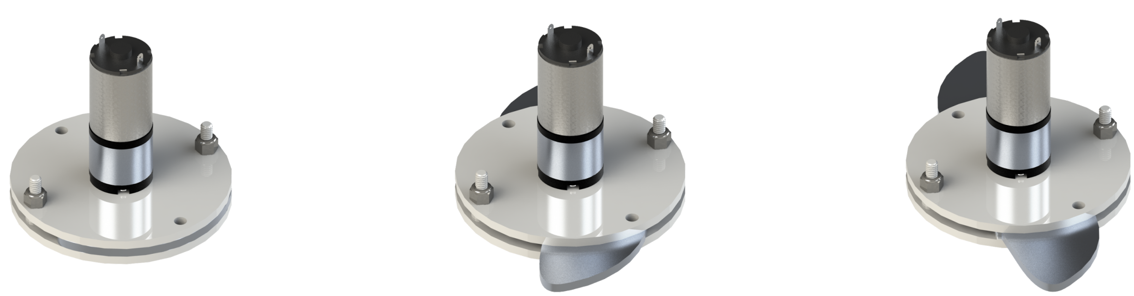


Figure 2: SolidWorks model of ADAS, at 0%, 50%, and 100% deployment.

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.

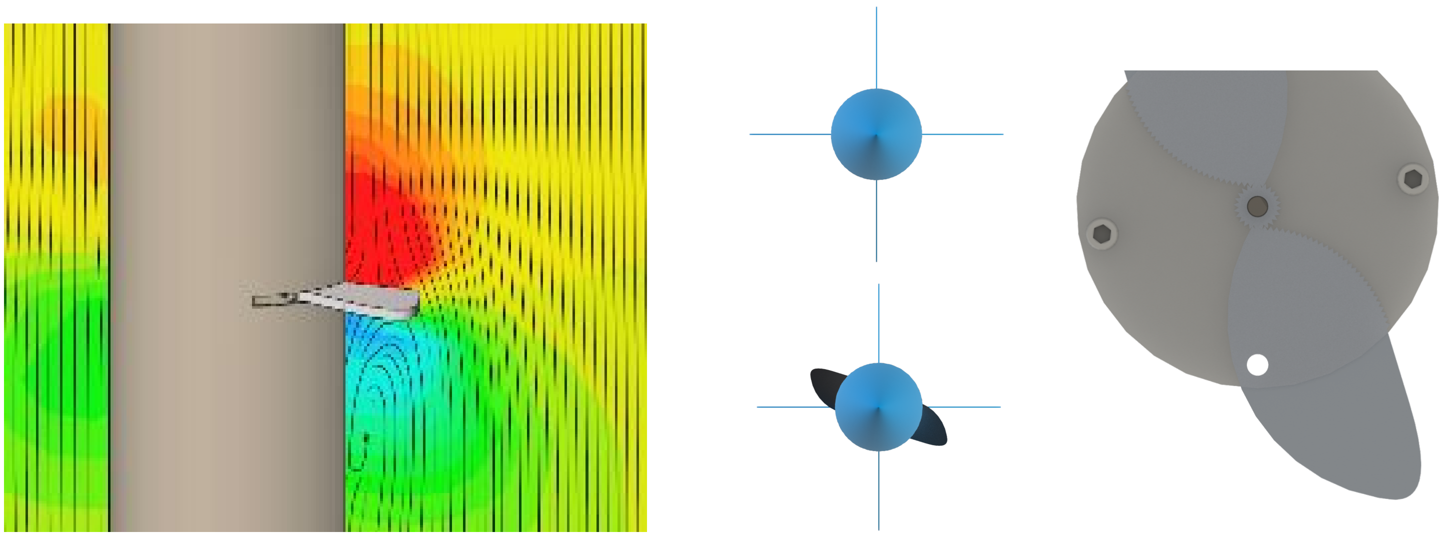


Figure 3: A fluid simulation of the flow pattern around ADAS at full deployment. A view of the vertical cross section at full deployment. The C_d of the rocket at full fin deployment is 0.49, and the total aerobrake area is 14.5 cm^2.

2.3 Lower Avionics Bay

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 (θ) 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. ADAS may also need to run flight simulations in real time as a point of redundancy.

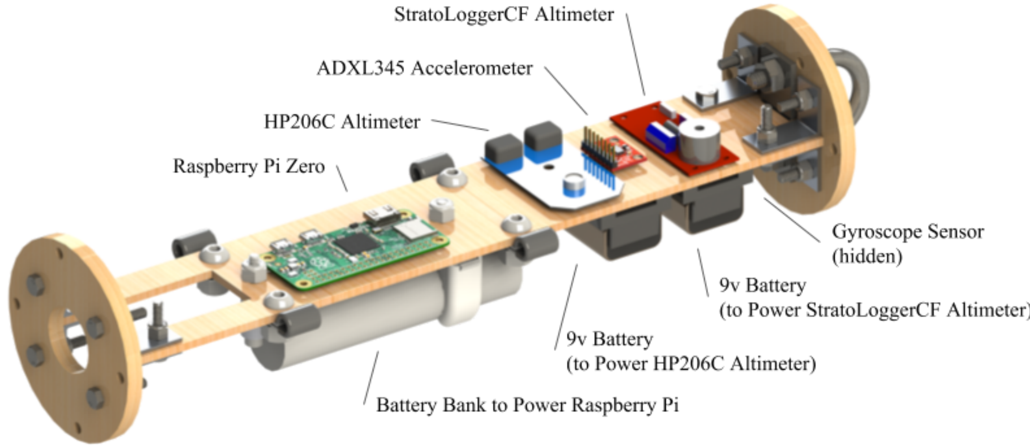


Figure 4: The lower payload bay consists of the avionics system mounted onto a sled. Not pictured are the two ¼”-20 steel all-threads that secure the top bulkhead to the airframe. Wires and zip-ties are also not pictured.

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.

2.4 Recovery

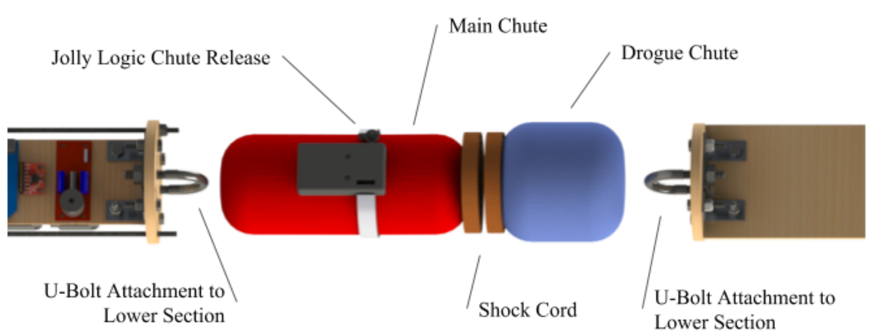


Figure 5: The recovery payload is sandwiched between the two avionics payloads, held in place with a strong shock cord and two U-bolts.

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.

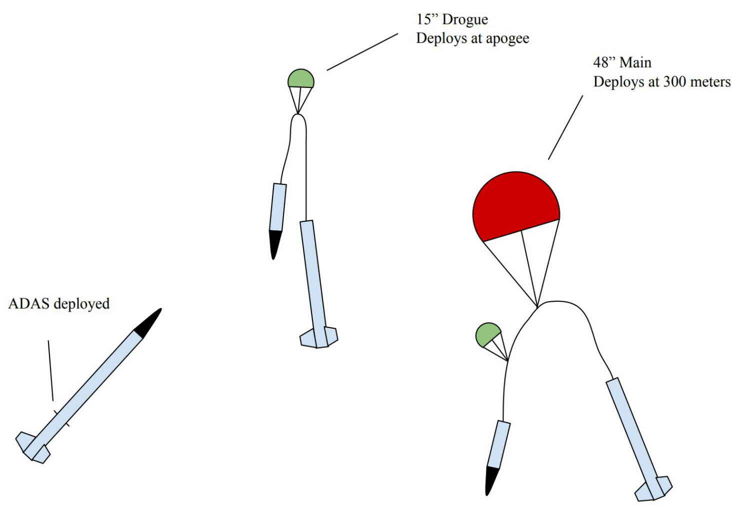


Figure 6: The parachute system deployment scheme for **E-1**. A chute release mechanism will trigger the deployment of the main chute at a specific altitude, as read by a dedicated altimeter. ADAS retracts after apogee to minimize the risk of tangling.

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:

$$v_{terminal} = \sqrt{\frac{2mg}{\rho_{air} C_d A_{parachute}}}$$

The kinetic energy of a mass moving at velocity *v* is given by the equation:

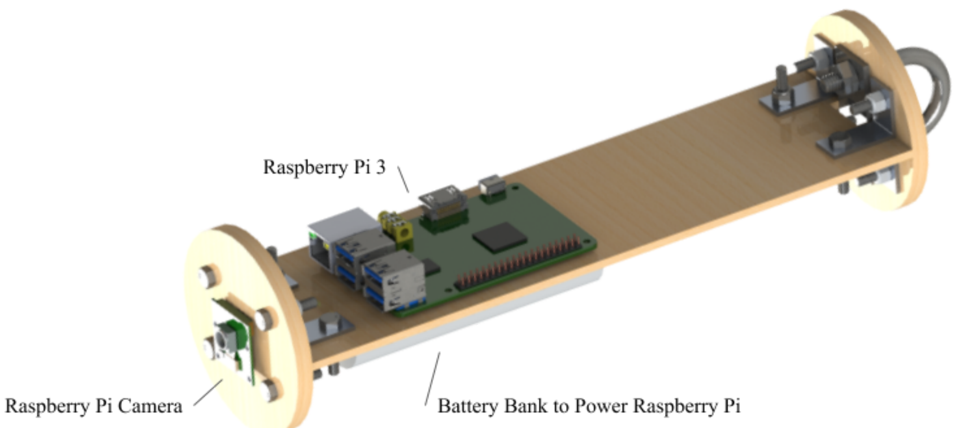
$$KE = \frac{1}{2}mv^2$$

Rule 3.3 in the Student Launch handbook stipulates that our rocket does not exceed a descent kinetic energy of 75 ft-lbf, which corresponds to 101.7 J. The maximum descent velocity for a 3 kg rocket to satisfy this energy requirement is 8.23 m/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 0.47 m^2, corresponding to a diameter of 30.6”. We therefore select a 48” parachute to account for the risk of partial deployment and tangling.

To ensure a safe main chute deployment and a contingency for main chute failure, we stipulate that the drogue chute have a terminal velocity of ~20 m/s. Performing a similar calculation as above, we find that the drogue chute should have a surface area of 0.08 m^2, corresponding to a diameter of 12.6”. We use a 15” nylon parachute.

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

2.5 TARS Payload



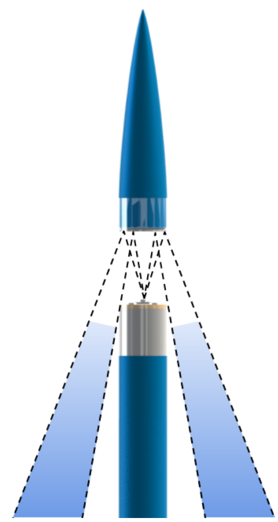


Figure 7: TARS, the Target Recognition System, is designed to track objects of different colors in real time with a powerful Raspberry Pi 3 computer. The Pi camera is pointed at a mirror fixed to the base of the nose cone, reflecting light from the field below the rocket. Empty space is left on the instrument board for future additional avionics payloads.

E-1’s payload will satisfy this year’s target detection experiment requirement with TARS, the TArget Recognition System. It consists of an upward-facing video camera mounted inside of a clear tube with a rear-facing mirror to allow for a wider field of view closer to the launch pad. The camera will be controlled and its video feed analyzed by a Raspberry Pi 3, 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. The payload bay will also house a speaker to make a startup indicator sound.

2.6 Manufacturing Methods

The construction of **E-1** will employ a variety of manufacturing techniques. The airframe and motor housing are composed of fiberglass and will be attached to other fiberglass components using a bonding epoxy. The wooden portions of the rocket such as the avionics sleds and bulkheads will be laser cut, drilled, and hand-refined. These wooden parts generally fasten to the rocket with traditional bolt and nut fasteners, which will be secured by hand. The manufacturing of custom electronics will be avoided for cost efficiency. Specialty parts such as the nose cone GPS mount will be 3D printed. The metallic fins of the ADAS system will be manufactured using a CNC router with fine enough resolution to create the custom gear teeth.

3. EFFECTIVE-1 Software and Flight Control

3.1 Flight Parameters and Control Loops

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.

3.2 ADAS Control Software

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.

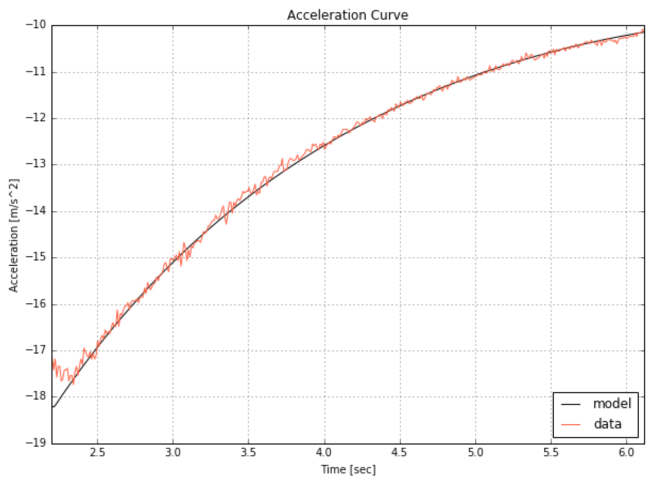


Figure 8: Coast phase deceleration data, as measured aboard **E-0.25**. The model was fitted to the data, but **E-1** will be actively fitting its acceleration to a model with ADAS.

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.

3.3 Test Rockets:

Miniature test rocket: EFFECTIVE-0.25

Our final rocket will largely employ the designs and techniques learned from our miniature test rocket, Effective-0.25. The rocket was launched with G-class motors and had an onboard payload that included an accelerometer, an altimeter, a servo, and storage, all of which were operated automatically by a Raspberry Pi Zero-W. We had three nominal flights, and high resolution flight data for two of those. Each flight had an apogee of ~1100 feet, approximately a fifth of the nominal competition apogee.

In addition to being an exercise in compliance with safety rules and regulations, this rocket served as a proving ground for the onboard computer and sensor systems, practice using relevant tools and parts, validation of our custom-written python-based computer model, and an excellent


opportunity to analyze flight data. The rocket's drag coefficient, parachute descent rate, acceleration, velocity, and altitude profiles were all determined with the data collected.

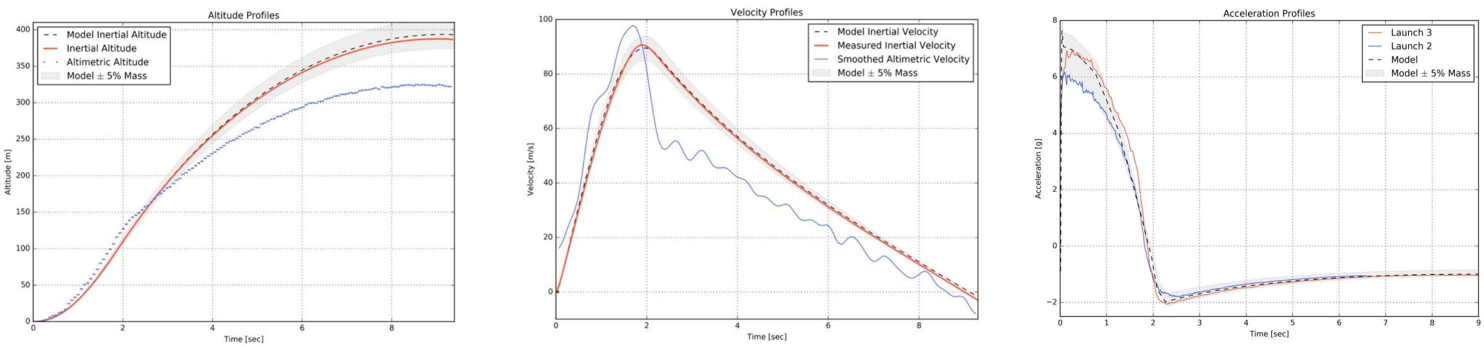


Figure 9: Data collected by two flights of the miniature rocket, **E-0.25**. The altitude data in the first plot displays inertial altitude as measured by the accelerometer, altimetric altitude as measured by the altimeter, and the model inertial altitude. Altimetric altitude is significantly lower than inertial altitude due to significant weathercocking. Altimetry also displays wind-related pressure effects that skew altitude measurement (most evident at 2 seconds). The acceleration profiles in the right panel show that motors can vary significantly in their thrust curves. Our code, `Rocketscript.py`, shows excellent agreement with flight data.

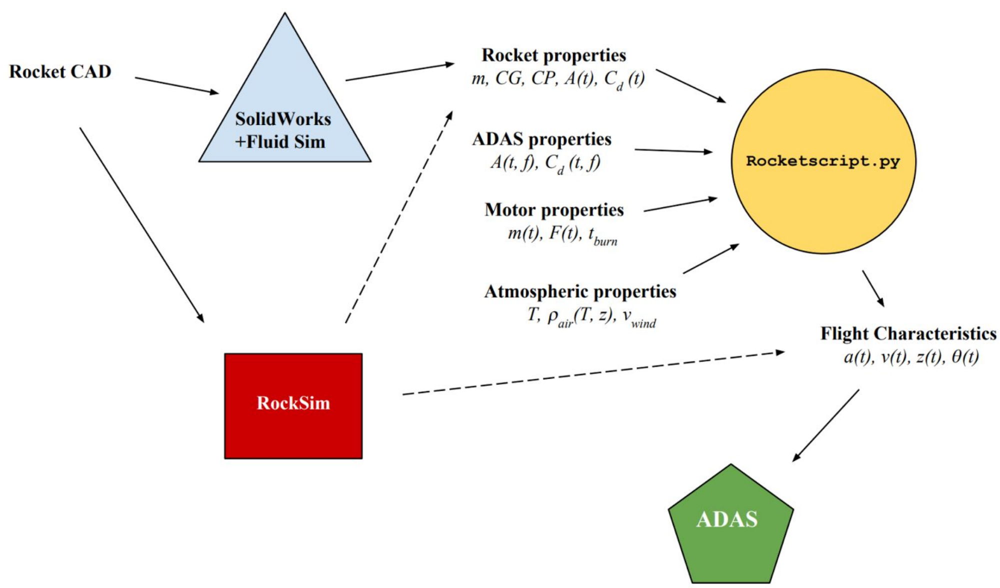
This test run allowed us to determine our priorities for future designs. Specifically, we found that the rocket's drag coefficient of ~0.4 was sub-nominal, and effort will be placed in improving its aerodynamics by polishing the body, choosing a more efficient nosecone shape, and adding a tailcone to minimize skin friction drag and base drag. Fins will have more rounded shapes to minimize fin tip vortices. The data acquisition rate also appeared to be sub-nominal, reaching 33 Hz instead of the intended 50 Hz. This is attributable to error in the programming of the onboard control loop, which has since been corrected. It was found that the rocket was strongly buffeted by ~20 mph winds, resulting in a sub-nominal apogee. We have updated our models to accommodate wind effects, and a gyroscope will be added to future iterations to measure the rocket's absolute angle relative to an ideal vertical flight. Lastly, the rocket's descent rate was variable due to parachute tangling. This will be mitigated with a ball bearing snap swivel for our final recovery design.

Subscale rocket: EFFECTIVE-0.5:

To prepare for the competition launch, we will build a prototype rocket with the same structure, payload, and avionics as those intended for the competition rocket. **E-0.5** will have a 38mm motor mount instead of a 54mm motor mount, allowing us to do several economically-efficient low-altitude I-class flights. This will serve as a proving ground for the rocket structure and avionics systems, and will give us the opportunity to gain a Level-1 NAR/TRA certification. Additionally, having an identical airframe to the competition rocket allows us to make several measurements of the drag coefficient of the aerobraking system, and will let us calibrate our models to the data. We plan to use the Cesaroni I303 motor, which will yield apogees of ~1,000 meters and a slightly higher peak acceleration than that projected for **E-1**.

3.4 EFFECTIVE-1 Computer Modeling

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 RockSim as a sanity check for our CAD designs and our rocket code.



3.5 EFFECTIVE-1 Motor Selection: J293

Our solidworks model of **E-1** indicates that the rocket's total mass, without adhesives, paint, or ballast, is 2.65 kg. We round this mass up to 2.85 kg to account for extra materials, potential ballast, and mass overruns. An exhaustive search of motors turned up that the 831.6 Ns **Cesaroni J293** motor would most closely reach the intended apogee. Without ADAS correction or ballast, this motor will carry the rocket to a projected altitude of 1,730 meters. Adding a 10% (as per regulation 2.21.8) ballast mass of 0.26 kg reduces the projected altitude to 1,660 meters, which is well within our corrective envelope.

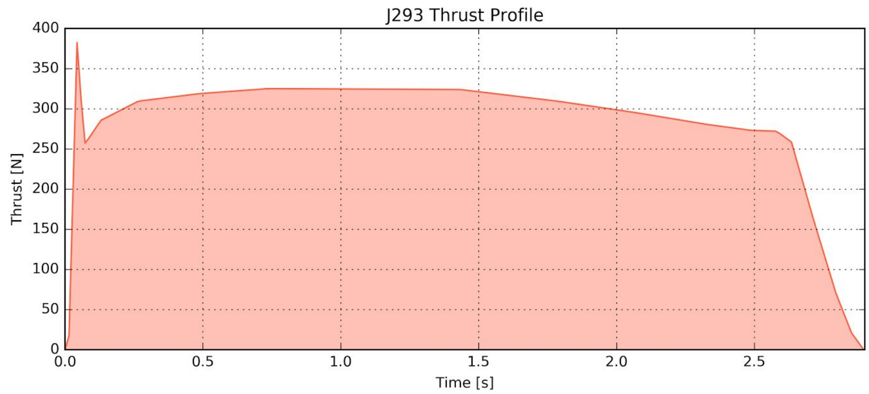


Figure 10: The thrust curve of the Cesaroni J293 motor is fairly flat, with a peak thrust of ~380 N. Short motor burns are preferable to longer ones, as the relative duration of coast phase is larger. This allows for more time for inflight computation and correction. Unlike the color of this plot, the motor burns blue.

Having the extra ~50 meters of buffer space leaves room for uncertainties in wind, mass, and temperature, and will allow us to successfully correct the rocket's deceleration curve without too severe of an ADAS deployment. This motor meets the handbook requirements, including regulation 2.21.3. 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.

3.6 EFFECTIVE-1 FLIGHT REQUIREMENTS

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

- ❖ Meet all safety criteria for pre-launch activities, and all SL flight requirements and restrictions
- ❖ Record precise altimeter, accelerometer, and gyroscope measurements throughout the duration of the flight, and use those measurements to find the rocket's altitude, angle, and velocity at each time step
- ❖ Deploy ADAS and have it make fine and coarse adjustments to the rocket's acceleration at a rate of 10 Hz

- Achieve pre-specified apogees to within 2%
- Successfully deploy parachute recovery system at apogee, and subsequently at a given altitude
- Activate TARS and have it differentiate between and locate tarps of different colors, even at high rotational velocities
- Achieve nominal motor burn to within 10% of projected total impulse
- Achieve pre-specified apogees to within 0.1%
- Pair TARS with the gyroscope to correct the video feed for angular velocity
- Perform a successful flight with full ADAS correction (100% deployment starting at motor burnout)
- Repurpose TARS to track and observe topographical and atmospheric features

4. Safety

First and foremost, our team's top priority is safety. We emphasize the importance of taking necessary precautions to avoid physical harm and breaching of safety regulations. The team's safety officer, Nick, will oversee all team activities to ensure compliance with safety codes.

4.1 Facilities

Team members have access to the workspace in Thimann Labs 372. This 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.

4.2 Risk Assessment

Below is a table of risks the team feels most concerned about:

Hazard	**Cause**	**Effect**	**Likelihood and Severity (RAC)**	**Mitigation**

Improper use of tools and machinery	Lack of proper training or experience	Injury of team member(s)	3C	Ensure proper training before a member is allowed to use a tool. Ensure first aid kits containing adequate supplies are accessible.
Improper handling of hazardous materials	Lack of proper training, accidental spillage	Injury of team member(s)	2D	Ensure proper training before a member is allowed to enter spaces containing hazardous materials. Ensure proper safety equipment is being used and is within the vicinity of work, such as safety goggles and an emergency eye wash station. A list of hazardous materials will be keep for each of the team's facilities, complete with MSDS documentation for all material requiring such documents.
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 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, 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	Direct impact with rocket; property	4D	Preflight inspection to ensure rocket structural integrity.

	stability margin	damage		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.
Sunburn	Solar UV exposure	Sunburn	3D	Provide sunscreen to team members during outdoor event.
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.
Failure to meet funding requirements	Inadequate planning; insufficient membership and engagement	Unable to purchase necessary goods and services	1D	Pointed fundraising campaigns, proper budgeting, economical expenditures, recruiting a non-STEM major
Failure to meet deadline	Inadequate planning; insufficient membership and engagement	Potential disqualification from the competition	1D	Proper time management, continuous comparisons of current situation to the project timeline. Reduction of project scope if necessary.

4.3 Student Briefing

Members will be briefed on hazard recognition and accidental avoidance prior to participating in any club activities in which they may be exposed to such hazards. In order to operate within our lab space, all students must complete the school mandated lab safety training program, which will ensure students are familiar with the risk involved in working in an active lab space. New students will receive an additional brief during their introduction to the lab space including guidelines on how to handle unique and the most frequently encountered hazards in the rocket lab space.

Pre-launch briefings will be carried out with the guidance and supervision of our NAR mentor, David, and conducted by the team's safety officer, Nick. The pre-launch briefing will serve to remind participants of the hazards, regulations, and proper procedures relevant to the launch and launch conditions.

4.4 Caution Statements and Documents

Caution statements will be included in build plans and procedures, as well as other relevant documents. These statements will include a list of Personal Protective Equipment (PPE) accompanied by a description of the proper procedures for the task. Task which shall require a clear, written caution statement include but is not limited to the handling of chemicals, assembly of the airframe, and machine use. The MSDS for all material acquired by the team will be printed in the lab and will be on the team's website.

4.5 NAR Mentor Responsibilities

David Raimondi, our NAR mentor, will be responsible for the handling and assembly of rocket motors and black powder charges. He will also purchase the latter items. All hazardous operations will be delegated to him. David will also oversee launch safety, including the launch pad assembly and the ignition mechanisms, making sure that these strictly follow the NAR high power safety code as well as NFPA 1127, "Code for High Power Rocket Motors".

4.6 Federal, State, and Local Laws

Team members shall abide by all applicable laws and regulations when participating in team related events. Each team member shall be held accountable to this with the completion of the Membership Form.

The team will comply with the regulations specified within Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets when the team operates any high powered rocket. The team seeks to remain within these laws by limiting the team's scope to traditional amatuer rocketry.

The team will comply with Code of Federal Regulation 27 Part 55: Commerce in Explosives by observing all requirements necessary for the sale, storage and transport of explosive material within the US.

The team shall comply with NFPA 1127 during all design, construction, and operation of model rockets.

The team shall comply with all local laws during all activities. Local fire code shall be observed at all times, and launches shall be conducted at designated locations. The team has selected to launch from Snow Ranch in Farmington, CA.

4.7 Plan for NRA/TRA mentor handling of energetic devices

The team's NRA/TRA mentor shall purchase rocket motors and other required devices through well established vendors when requested to 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.

4.8 Membership Form

All members shall be required to sign the following form before admission into the team, and prior to engaging in team activities (See Appendix A for a collection of completed forms) :

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)

5. Challenges Summary

UC Santa Cruz has neither a mechanical engineering department nor a pedigree in rocketry. The biggest challenge for this year will be establishing a presence and collecting a group of people who are equally driven and similarly passionate about rocketry. Our solution is to approach our rocketry endeavors with passion and excitement, a contagious aspect of our personalities.

The primary technical challenges are addressed in above sections, but we summarize them here. The highest technical priority of our competition rocket is achieving a precise apogee. This is initially a hardware challenge, but then becomes a data analysis and software challenge once the hardware meets our threshold requirements. Our solution to this is ADAS, a flexible and easily programmable hardware-software module that has both large-scale and small-scale corrective capabilities. Lastly, a major challenge is coordinating and orchestrating an entire team logistically between the two of us. We overcome this challenge with a synergistic approach to work, and plan to recruit members to take over the more time-consuming aspects.

6. Educational Engagement

In order to promote STEM education and contribute to the further inspiration of the developing youth, the UC Santa Cruz Rocket Team will host numerous educational engagement activities targeted at a broad range of students. The team has plans to contact the local high school (Santa Cruz High School), elementary school (Bay View Elementary), and the local chapter of the Boys and Girls Club (Boys & Girls Clubs of Santa Cruz County). In addition to presenting a general introduction lesson to rocket science, the team has constructed a bottle rocket launcher which will engage all students involved.

The team also intends to participate in the annual MESA (Math, Engineering, Science Achievement) day hosted on the UC Santa Cruz campus. MESA day involves a variety of STEM competitions for students 6 to 12 grade which spans everything from model bridge building to balsa wood glider contests. However, as this event falls on March 3rd which is outside of the date specified requirement 1.5 (FRR Due date of February 2018), the competition will not contribute to the 200 participants required. Therefore, the team seeks to help students prepare for the competition, in addition to helping host the competition itself. Additionally, the team will continue to engage heavily with the UCSC Society of Physics Students club, which was there for the team's inception. This includes launch competition days, where students build small model rockets and compete in a tournament while learning about rocket physics. We project that two dozen STEM and non-STEM students would be interested in participating in such an event.

Educational Engagement Activity	Projected Number of Participants
UC Santa Cruz OPERS Club Fest	40
UCSC Physics Club Launch Competitions	20
Santa Cruz High School Outreach	90
Bay View Elementary Outreach	50
Boys & Girls Clubs of Santa Cruz County Outreach	50
MESA Day help student team preparations	50
MESA Day 2018 (after February 2018)	(100)
Total before February 2018:	300

As per handbook regulation, we will fill out an educational engagement report after each educational event we host. Our main evaluation criteria for a successful educational engagement are as follows:

- ❖ Participants reported that they learned about the science behind rocketry
- ❖ Participants were intrigued or inspired by the engagement
- ❖ Participants enjoyed the event, and would come again
- ❖ Participants had some hands-on experience with a rocket

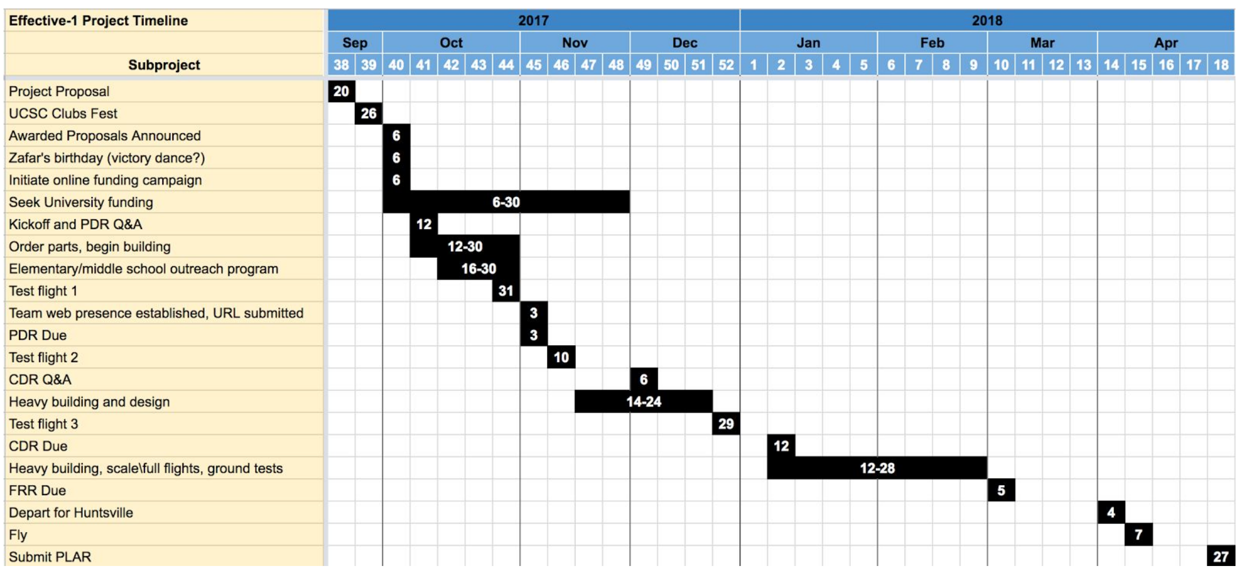
7. Website

Per General Requirement 1.6 the team shall establish a website by November 2017 in order to host competition documents in addition to serving as a platform to communicate with the public. The team's webmaster, Connick, is leading the effort to compose the website and establish a URL for the team. We have reserved UCSCRocketry.org. This website will host our documentation, photos, contact information, events calendar, and outreach information.

8. Project Plan

8.1 Timeline

Our projected timeline involves a rapid and aggressive funding strategy, and intensive build/design weeks. Much like a rocket goes higher if given a short but intense burn, our team will thrive on an initial burst of productivity, and use the latter months to refine and tune ADAS and other sensitive systems on a software level. We do not specify what our focus is during the build sessions, as our workflow is best when fluid.



8.2 Recruitment

Our recruitment campaign will be multi-pronged. Our first outreach attempt will be at the UCSC Clubs Fest, where we will attract new and returning students with a bottle rocketry competition, an information packet about the club, and a NASA meatball sticker. The next phase of our outreach will be through social media; we will establish a more visible media presence on Facebook, and we will announce our club at Physics Club meetings and at various large lectures. In all of our recruitment efforts, we will be enthusiastic and excited about meeting new people and sharing the fun of high power rocketry with them.

8.3 Detailed Mass and Cost Budget

This budget is not finalized, and is subject to change. There are some components that are missing from the list.

Airframe					
Item	**weight per (g)**	**price per**	**quantity**	**weight (g)**	**price**
Body tube 3"x48" Fiberglass	658	92.15	1	658	92.15
3" FIBERGLASS 4:1 OGIVE NOSE CONE	143.3	30.95	1	143.3	30.95
AERO PACK 38P/3" TAILCONE RETAINER	65.7	43.87	1	65.7	43.87
54MMX48" G12 THIN-WALL FIBERGLASS FW AIRFRAME TUBE	139	65.77	1	139	65.77
Centering Ring G10 FIBERGLASS CR 54MM/3"	8.2	13.18	2	16.4	26.36
3" Fiberglass Bulkhead	19	5.41	1	19	5.41
Class 8.8 Medium-Strength Steel Threaded Rod	50	9.52	2	100	19.04
Fiberglass Resin	20	20	1	20	20
Fin Material	24	27	1	24	27
Fasteners	10	10	1	10	10
Manufacturing		50	1	0	50
Airframe Subtotal				**1161.4g**	**$303.55**

Adaptive Drag Aerobraking System					
Item	**weight per (g)**	**price per**	**quantity**	**weight (g)**	**price**
142 RPM Premium Planetary Gear Motor w/Encoder	109	50	1	109	50
Fin raw material	30	16.64	1	30	16.64
Slide plate raw material	30	16	1	30	16
Manufacturing		50	1	0	50
Fasteners	10	10	1	10	10
Adaptive Drag Aerobraking System (ADAS) Subtotal				**179g**	**$142.64**

Lower Avionics Bay					
Item	**weight per (g)**	**price per**	**quantity**	**weight (g)**	**price**
Raspberry Pi Zero W	9	40	1	9	40
Altimeter HP206C	5	26.95	1	5	26.95
Accelerometer ADXL345	0.33	15	1	0.33	15
PERFECTFLITE STRATOLOGGER ALTIMETER CF	10.77	58.8	1	10.77	58.8
Raspberry Pi Battery Pack	61	10	1	61	10
9v Batteries	45	3	2	90	6
9v Battery holders	1	5	2	2	10
Sled Material	21	3.72	1	21	3.72
Bulkhead material	28	5.95	1	28	5.95
Sled Clips	4	5.56	1	4	5.56
U-bolt Parachute Fastener	45.3	1	1	45.3	1
Manufacturing (laser cutter, 3D printing)		50	1	0	50
Fasteners	46	10	1	46	10
Lower Avionics Bay Subtotal				**322.4g**	**$242.98**

Recovery					
Item	**weight per (g)**	**price per**	**quantity**	**weight (g)**	**price**
Drogue Chute 15" NYLON ROUND PARACHUTE	20	8	1	20	8
Main Chute 48" NYLON PARACHUTE	67	22	1	67	22
Kevlar Cord #1500	-	1	2	-	2
Eggfinder GPS Tracking System	20	100	1	20	100
Jolly Logic Chute Release	17.5	130	1	17.5	130
2 Cell 7.4V Lipo Battery for GPS	32	8	1	32	8
3D Printed GPS Housing	11	50	1	11	50
Fasteners	10	10	1	10	10
Recovery Subtotal				**177.5g**	**$330**

UCSC Rocket Team

Payload Bay					
Item	**weight per (g)**	**price per**	**quantity**	**weight (g)**	**price**
Sled Material	31.5		1	31.5	0
Bulkhead material	28		1	28	0
U-bolt Parachute Fastener	45.3	1	1	45.3	1
Raspberry Pi B	45	48.99	1	45	48.99
Raspberry Pi Battery Pack	61	10	1	61	10
Raspberry Pi Camera	6	35	1	6	35
Clear Cast Acrylic Tube	111	42	1	111	42
Fasteners	46	10	1	46	10
Payload Bay Subtotal				**373.8g**	**$146.99**
E-1 Flights				(motor and casing mass not added to total mass)	
Item	**weight per (g)**	**price per**	**quantity**	**weight (g)**	**price**
Cesaroni 54mm 2-grain case	-	55.27	1	-	55.27
Cesaroni J293 Motor	-	72.95	3	-	218.85
Wadding	-	-	-	-	-
Black powder charges	-	-	-	-	-
Ejection charge canisters	-	10.	1	-	10.
Ignitors	-	-	-	-	-
Gas, travel	-	20	3	-	60
E-1 Flights Total					**$344.12**
E-1 Total				2214.1g	$1510.28
E-0.5					
Item	**weight per (g)**	**price per**	**quantity**	**weight (g)**	**price**
Body tube 3"x48" Fiberglass	658	92.15	1	-	92.15
AERO PACK 38P/3" TAILCONE RETAINER	65.7	43.87	1	-	43.87
54MMX48" G12 THIN-WALL FIBERGLASS FW AIRFRAME TUBE	139	65.77	1	-	65.77

Centering Ring G10 FIBERGLASS CR 54MM/3"	8.2	13.18	2	-	26.36
3" Fiberglass Bulkhead	19	5.41	1	-	5.41
Class 8.8 Medium-Strength Steel Threaded Rod	50	9.52	2	-	19.04
Fiberglass Resin	20	20	1	-	20
Fin Material	24	27	1	-	27
E-0.5 Subtotal					**$299.60**
E-0.5 Flights					
Item	**weight per (g)**	**price per**	**quantity**	**weight (g)**	**price**
Cesaroni 38mm 4-grain case	-	47.77	1	-	47.77
Cesaroni I303 Motor	-	49.63	3	-	148.90
Wadding	-	-	-	-	-
Black powder charges	-	-	-	-	
Ejection charge cannister	-	10.	1	-	10.
Ignitors	-	-	-	-	
Gas, travel	-	20	3	-	60
E-0.5 Flights Subtotal					**$266.67**
E-0.5 Total					**$566.27**
SLI Travel and Lodging					
Item		**price per person**	**quantity**	**number of nights**	**price**
Roundtrip flight		700	~3	-	**2100**
Hotel/motel stay		100	~1	4	**400**
Rental car		50	1	4	**250**
Travel Total					**$2750**
Grand Total					**$4826**

8.4 Funding

Funding will be largely acquired through a GoFundMe campaign, the UCSC-sponsored Giving Day on March 8th, and club funding through the Student Organization Advising & Resources program (SOAR). Other potential sources of funding will include college-specific club donors, departmental donations, and corporate avionics sponsors. Given the cost efficiency of our rocket and the small size of our team, we are confident in our ability to acquire sufficient funding both for building the rocket and for travel to the competition.

8.5 Sustainability and Partnerships

As this is the team's rookie year, the partnerships it establishes with educational organization and corporate sponsors will serve as a solid foundation for the coming years. Additionally, all of the documentation that the team creates during the design process, or otherwise shall be available on the team's google drive, such that any student current or future may access the work completed and build on the lessons that the team has learned in the past. Moreover, we plan to meet with some of the theoretical fluid dynamicists on campus (professors and graduate students) to learn about their methods, and integrate our work with theirs. This would be a fantastic opportunity to learn about the detailed computational aspects of fluid flow, and attempt to share our experience in rocketry. This will potentially build a curricular tie between a computational fluid dynamics course and the rocket team. Lastly, and most importantly, the UCSC Rocket Team will give back to the community that fostered our early ambitions: the Society of Physics Students club. The club had an outing where we launched small Estes model rockets and enjoyed food together. We received great praise and students were interested in our efforts. We aim to preserve this culture by doing monthly rocket launches near campus. This will add to the culture of the club, which is similarly preserved by our artistic logos and flyers. We plan to have launch competition days, where students build small model rockets and compete for various flight parameters such as maximum apogee, velocity, or minimum descent rate. *Effectivus ad astra.*

Appendix A

I, Nicholas Hammond , 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.

Nicholas Hammond
(Name Print)

Nicholas Hammond
(Signature)

9/20/17
(Date)

I, Kent Roberts, 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.

Kent Roberts
(Name Print)

(Signature)

9/20/17
(Date)

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)

9/20/17

(Signature) (Date)