Rocket Team at UCSC

NASA Student Launch
2018-2019 Proposal
September 19, 2018

1 General Information

1.1 School Information and Project Title

School: University of California, Santa Cruz
Organization: The Rocket Team at UCSC
Location: University of California, Santa Cruz
1156 High St.
Santa Cruz, CA 95064
Project Title: Aeolis
Date: September 19th, 2018

1.2 Team Mentors and Advisors

Mentor -- David Raimondi
Email -- d.raimondi@sbcglobal.net
Phone Number -- (408) 963-8286
Details -- NAR Section #534
President of Livermore Unit NAR (LUNAR)

Faculty Advisor -- Ian Garrick-Bethell
Email -- igarrick@ucsc.edu
Phone Number -- (831) 459-1277

1.3 Team Leadership

Co-Captain -- Duncan Bark
Email -- dabark@ucsc.edu
Phone Number -- (424) 542-3705

Bio-- Duncan is a second year Computer Science student here at UCSC. He participated in many aspects of the team last year and hopes to lead the team to success in Huntsville. He hopes that his experience will help the team be more efficient, successful and enjoyable for everyone!

Co-Captain & Safety Officer -- Richard Alves
Email -- raalves@ucsc.edu
Phone Number -- (831) 917-3030

Bio -- Richard is a senior Electrical Engineering student here at UCSC. This will be his second year on the team, and he hopes to make the most of it by taking on the position of Safety Officer and secondary captain. He has experience working with the Applied Optics labs in the engineering department on campus, and is excited to impart his knowledge and responsibility to an engineering feat of this scale.

Project Lead -- Kent Roberts
Email -- kelrober@ucsc.edu
Phone Number -- (619) 846-6223

Bio -- Kent is a senior Physics student here at UCSC. As a co-founder of the team, Kent hopes to continue leading the team to success and achieve new heights. His experience with FIRST Robotics and an internship at General Atomics solidifies his position and expertise as Project Lead.

1.4 Team Membership and Organization

The Rocket Team at UCSC will consist of approximately 20 students, from a variety of backgrounds and majors. The group responsible for constructing the final vehicle is divided into various sub-teams (known as the Rocket Design Teams), each with their own sub-team lead, as well as team-wide executive leadership known as the Elected Board of Officers. This is done in order to partition and complete required tasks efficiently. An election will be held early in the school year to determine these sub-team leads based on students applicable skills to those respective fields. A look at how the team is composed can be seen in Figure 1.4.1. The sub-teams and their roles in the team are as follows:

- *Payload Team* -- Designs, constructs, and tests the chosen payload (in this case, the rover).
- *Recovery Team* -- Decides necessary procedures and components for recovering the vehicle, including allocation of parachutes, and telemetric devices for locating the rocket upon landing.
- *Vehicle/Airframe Team* -- Responsible for the modeling (design and flight test) and production of the rocket vessel capable of carrying the on-board systems while maintaining aerodynamics.
- *Adaptive Drag Aerobraking System (ADAS) Team* -- This team designs and builds a robust air-braking system for the rocket to better reach its intended apogee.

A treasurer, Alex, who is responsible for the budget and acquisition of funds, will act as another integral part of the team's leadership and mission. Finally, the team has designated an outreach coordinator, Vera, who is responsible for organizing and conducting outreach events along with managing the team's social media aspects, and website lead who is responsible for the development of the team's website.

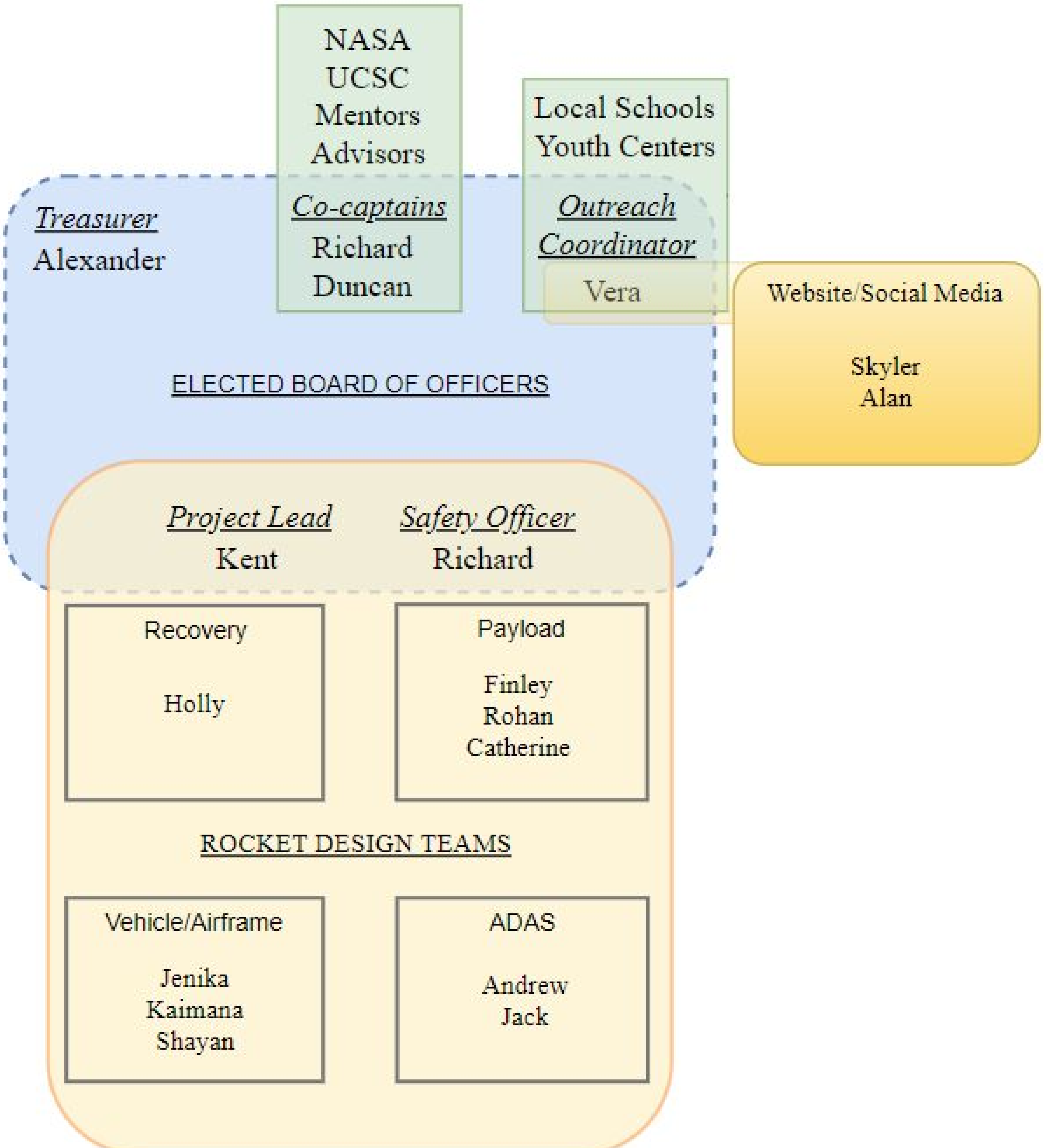


Figure 1.4.1 Overview of the organization of the team for the 2018-2019 SLI Project

2 Facilities and Equipment

2.1 Workspace

2.1.1 Thimann Labs Room 368

The team is involved with the on campus Sustainability Lab program which grants us a dedicated lab space that serves as a workbench and general storage space. Room 368 will be our main fabrication area containing all of our supplies, and small hand tools.

Entry to the lab space requires at least one of the two key-holding co-captains to open the doors, therefore, at least one of the co-captains will be present during the use of the space. This helps to make sure that all operations run smoothly and all members of the team are following the correct, and safe procedures.

To be permitted within the lab space the Sustainability Lab program requires one to complete necessary safety trainings and to provide proof of completion. The team's safety officer will hold a seminar with all unverified members to help them through the trainings before they are allowed to work in the lab space. Refer to section (3.5.3) for more safety information and details regarding use of the lab space.

Figure 2.1.1.1 Thimann Labs Room 368

2.1.2 Thimann Labs Room 343

Room 343 houses all the heavy machinery including routers, band saws, and sanders. This room can only be unlocked by properly authorized Sustainability Lab personnel, but can be used freely by any member with the right training.

2.1.3 Thimann Labs Room 373

Room 373 houses all the 3D printers available for use by team members. It features various printers that each offer different benefits and printing characteristics. This room can only be unlocked by a Co-Captain but team members may use this space should it be required.

Figure 2.1.3.1 Thimann Labs Room 373

2.1.4 Idea Fab Labs

Should the team require any specialty parts that requires machinery not available through the on-campus facilities, a local makerspace offers numerous services. Student Pro Membership can be purchased for $60 a month which includes 8am to midnight access to various machinery and tools including a laser cutter/engraver, 4ft by 14ft CNC bed router, 3D printers and scanners, and numerous other hand tools. Use of the facility is preceded by training courses which a member will complete if necessary.

2.2 Launch Sites

The team will be utilizing the launch site provided by our mentor's NAR chapter, LUNAR. This launch site is located just east of Stockton, takes approximately three hours to travel there and allows for flights up to 15,000 ft with motors no larger than class "M". The launch site also provides numerous launch rails including 1010 and 1515 rails of various lengths. The team will also be able to purchase any necessary motors at the launch site should it be necessary. Due to all of these factors, this launch site will be the primary launch site for the team.

2.3 Materials

The majority of the materials necessary for the rocket will be sourced from online stores including McMaster-Carr for hardware, Apogee Rocketry for general rocketry materials, and Amazon for an extensive inventory of parts and equipment. The team will also be able to purchase materials and equipment from a local hardware store should it be needed immediately.

Motors and other specialized parts will be purchased in-person either from our mentor, David Raimondi, or from a vendor at the LUNAR launch site. This is done so that energetics are not stored on campus, and all rules and regulations are followed.

2.4 Software

The team will be using various programs and resources in the design, construction and testing of the launch vehicle. Vehicle design will be done using the educational version of Solidworks CAD software and the website GrabCAD to better facilitate collaborative work. Modelling of the rocket's flight and other characteristics will be done using the open source Anaconda distribution of python. This code is written by team members and verified through use of the OpenRocket modelling software.

To facilitate communication and collaborative work, the team will be using Slack to discuss, make announcements, and share work. The team will also use Google Drive to store all documents and resources necessary. Along with Google Drive, the team will use GitHub to more easily share, and work on all code necessary for the rocket.

2.5 Website and Remote Conferencing

The team will be utilizing ucscrocketry.org to host documentation, photos, contact information, event calendar, outreach information and any other information about the team. The website will be designed, and built by team members, with modifications being done throughout the school year. We aim for the website to represent the team in a clean, informative, and inspiring manner. We hope for the website to show the public what it is we do, who we are, and what we stand for.

Remote conferencing, necessary for document presentations, will be completed on campus in a reserved room in a library. From there we are able to have knowledgeable members present the documents, explain details, and answer any and all questions. We will be utilizing a team member's laptop with webcam, and cell phone to conduct these conferences.

3 Safety

3.1 Safety Officer's Plan

The Safety Officer position for Rocket Team at UCSC for the 2018-2019 SLI competition will be fulfilled by Richard Alves. He will be responsible for keeping all personnel involved with constructing and launching the rockets safe from injury, ensure laws applicable to rocketry are being followed at all times, as well as preventing unwanted damage to the rocket where possible. Safety is of the utmost importance to the team and will not be treated lightly. In the case where the Safety Officer will be unable to complete their duties due to personal or unforeseen reasons, an immediate replacement must be made to fill the vacancy.

Specific responsibilities of the Safety Officer include the following:

- Be fully competent in the known laws and regulations of NAR/TRA, the FAA, the state of California, and UC Santa Cruz with regards to building and launching the vehicle and payload.
- Ensure the team's compliance with local, state, and federal law.
- Provide the team with safety information, hazard and risk assessment and analysis, failure mode analysis, PPE requirements, materials safety data sheets, and emergency procedures.
- Oversee the design, construction, and testing of the rockets and subsystems.
- Create and enforce checklists for each launch of the vehicle that meet safety and operation standards as per launch needs.
- Attend the following activities such that checklists requirements are met, safety protocol is followed, and guests are educated on the procedures involved:
  -- Building sessions
  -- Launch tests
  -- Ground testing of vehicle and payload
  -- Recovery activities, including design and installation of recovery components
  -- Educational/Outreach events
  -- Logistical meetings with the rest of the Board
- Provide a Safety Manual detailing the necessary steps to gain access to lab workspaces, handle tools and materials, understand the laws and regulations in rocketry, and identify risks.
- Provide a Safety Acknowledgement Form that members must read and sign to certify that they have completed all deliverables in the Safety Manual and have met lab access requirements.
- Maintain a list of all students and their contact information who have signed the Safety Acknowledgement Form.
- Cooperate with the team's NAR mentor, David Raimondi, to safely handle and prepare electric matches, charges, ignitors, and the motors used on the launch vehicles.

3.2 Risk Assessment

3.2.1 Risk Assessment Matrix

In order to quantify the magnitude with which certain hazards may occur for the team during the project, it is necessary to create a risk assessment matrix. This tool can then be used to identify and prioritize issues that could arise, as well as how to mitigate them. Each hazard is studied and analyzed by its impact to human health, environmental damage, and importance to the launch vehicle and payload.

Each risk will have a severity and probability value given to it. Severity is identified as numbers 1 - 4 with 1 being ranked most severe. It is used to gauge how devastating the effects of an incident would emerge on the team's goals. Table 3-1 describes the severity levels and details. The probability, or likelihood, an event will occur is also taken into account, and is designated by capital letters A - E, with A representing the most frequent or likely event to happen. Table 3-2 shows the details on risk probability and its levels. Together, the severity and probability can form a Risk Assessment Code (RAC) which can rank the dangers jeopardizing the team's participation in the competition, from direct physical harm to monetary losses. Table 3-3 and Table 3-4 break down the RAC and each risk level's color legend and the associated penalties.

Description	Value	Properties
Catastrophic	1	May cause life-threatening injury or death, irreversible damage to the environment, and complete loss of onboard systems. Violates at least one major law/regulation, and fails the entirety of the mission.
Critical	2	May result in serious injury, major but reversible environmental damage, and major damage to onboard systems. Violates at least one law/regulation, and most of the mission is severely impacted.
Marginal	3	May result in minor injuries, minor damage to the environment, and minor damage to onboard systems. Does not violate a law/regulation, and the mission is not critically affected by the outcome.
Negligible	4	May result in little to no injuries, minimal damage to the environment, and at most partial damage to a non-critical onboard system. Does not violate any law/regulation, and its impact on the mission is barely noticeable.

Table 3-1 Hazard Severity Levels and Criteria

Description	Code	Properties
Frequent	A	Expected to occur with >90% probability; happens almost immediately or very soon.
Common	B	Expected to occur between 50% - 90% probability; usually happens in the near future, if not more than once over a set period of time.
Occasional	C	Expected to occur between 10% - 50% probability; possible to happen once over a longer period of time.
Unlikely	D	Expected to occur between 1% - 10% probability; a remote chance that it happens at some point much farther in time.
Improbable	E	Expected to occur with <1% probability; almost certainly will never happen and will not be expected at any time.

Table 3-2 Hazard Likelihood Designation and Criteria

Likelihood	**Severity**			
	Catastrophic (1)	**Critical (2)**	**Marginal (3)**	**Negligible (4)**
Frequent (A)	1A	2A	3A	4A
Common (B)	1B	2B	3B	4B
Occasional (C)	1C	2C	3C	4C
Unlikely (D)	1D	2D	3D	4D
Improbably (E)	1E	2E	3E	4E

Table 3-3 Risk Assessment Codes (RAC)

Risk Level	Penalties/Response
Extreme	Unacceptable. Will cause complete project failure. Immediate mitigation required.
Moderate	Undesirable. Will cause major loss in competition points and project status. Mitigation required soon.
Low	Acceptable. Will cause minor loss in points and project completion. Mitigation needed on case by case basis.

Table 3-4 Risk Level Color Codes

3.2.2 Hazard Analysis

Some hazards, including their potential causes, effects and mitigation tactics, known to the team are outlined in Table 3-5 using the RAC designation created above in Section 3.2.1. Note that these hazards do not encompass all possible events down to the minutia, and is expected to encompass more issues in future documentation as time progresses with the project.

Hazard	Cause	Effect	RAC	Mitigation
Machining Equipment and Tools	Improper use of equipment; lack of PPE	Serious bodily injury, death	1B	Team members must prove their training to Safety Officer before being allowed to work with powered devices
Hazardous Materials	Improper handling	Eye/Skin/Respiratory irritation	2C	Team members must pass training to access materials
Ignition of Ejection Charges	Improper handling; faulty ejection charges	Serious injury	2B	Safety Officer and Mentor will verify proper installation of ejection charges
E-match Ignition	Improper handling; faulty hardware	Minor injury	3C	Hardware will be purchased from reputable sources and handled properly
Motor Failure, Catastrophe at Take-Off (CATO)	Improper motor handling; faulty motor	Loss of launch vehicle	1D	Safety Officer will verify motor is handled properly and motors will be purchased from a reputable source
Solid Propellant Motors	Improper motor handling	Serious bodily injury, death	1C	Safety Officer will oversee proper motor handling and storage
Electronics	Exposed higher voltage wires; improperly	Severe electric shock, burns	2D	Team members will follow the correct procedure from

	battery handling			trainings and seminars
Ground Testing	Hardware strikes personnel	Minor injury, possible vehicle damage	3C	Safety Officer will enforce a safe distance and procedure
Launch Events	Failure to follow launch range protocol and NAR Code	Serious injury, death, loss of launch vehicle	1C	Team will adhere to NAR Safety Code, the Range Safety Officer, Range Rules, and team mentor at launch sites
Team prohibited from continuing SLI project	Lack of funds; failure to comply to NASA rules and deadlines	Loss of team morale; integrity of presence on campus diminished	2D	Team will follow all guidelines from NASA and university, and

Table 3-5 Personnel Hazard Analysis

3.3 NAR/TRA Personnel Duties

3.3.1 NAR Code Compliance

The NAR High Powered Rocket Safety Code will be adhered to throughout the project in regards to rocket development and launches. Each requirement laid out in the code has been complied with by the team as seen in Table 3-6.

NAR Code	Team Compliance
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.	David Raimondi, the team mentor, or other certified members will be the only persons allowed to purchase and handle motors.
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.	The rocket and its subsystems will only use the materials allowed, with the only addition to the list potentially being carbon fiber, but it is lightweight and composite.
3. **Motors**. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes	All motors will be purchased from commercially available vendors, with David Raimondi doing the purchase and handling for the majority of the

except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.	time. Other personnel will maintain Safety Manual standards in regards to the motors should they be nearby.
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.	Only on the launchpad at NAR/TRA certified events will the electronic ignition system be installed onto the vehicles. Onboard recovery altimeter systems will be inhibited from activation while the vehicle is on the launch pad. The Range Safety Officer will also communicate any concerns and requirements to safety issues at these events.
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.	The Range Safety Officer and the team's Safety Officer will be responsible for communicating any issues before, during, and after a misfire. In the case where one occurs, the defined procedure will be followed.
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.	All pre-launch procedures will be followed and carried out by the officials at the NAR/TRA events or by the team if necessary. Further requirements set for by the Range Safety Officer or team mentor will also be adhered to.
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	Sufficient testing of the launch vehicle will occur before any launch event. This will ensure the supplied rails at the NAR/TRA launchpad are capable of handling the team's design.

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.	The team will not build a vehicle that surpasses allowed weight, nor will it select motors that exceed the specified threshold.
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.	These guidelines, as well as those determined by the Range Safety Officer and team mentor, will be carried out at the launch events. FAA waivers and other advisory notices will also be checked for by the team mentor.
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).	All launches will occur at events and locations approved by NAR/TRA and the team mentor.
11. **Launcher Location**. My launcher will be 1500 feet from any occupied building or from any	The team will ensure the location being used at any launch site will fulfill this requirement, as well

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.	as any advisement from the Range Safety Officer.
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.	A recovery subsystem will be designed and tested by the Recovery subteam that meets these guidelines. In addition, a recovery checklist will be followed throughout the event to ensure the compliance in preparing the recovery methods is met.
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.	All team members and persons at the event will adhere to this rule. The Range Safety Officer can also declare unsafe conditions for retrieval as necessary, and their guidelines will also be followed. Professional third-parties may be contacted in order to recover the item(s).

Table 3-6 NAR High Power Rocket Safety Code and Rocket Team at UCSC Compliance to the code

3.3.2 Motor and Pyrotechnical Safety

David Raimondi, the team's mentor, will be responsible for the purchase, storage, transportation (by car), and general handling of any and all motors to be used on launch vehicles. Any team members who have achieved a Level 2 High Power Rocketry Certification will also be able to assist in motor responsibility if possible. Other items that Mr. Raimondi will be responsible for include the ignition charges, electric matches, and any other pyrotechnical items necessary to launch and recover the vehicle.

3.4 Law and Regulation Compliance

3.4.1 National Laws

The Safety Officer and all team members who have signed the Safety Acknowledgement Form will be able to understand and abide by the relevant federal laws regarding high-powered rockets, specifically the ones listed here:

- Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets
- Code of Federal Regulation 27 Part 5: Commerce in Explosives; and Fire Prevention
- NFPA 1127 "Code for High Power Rocket Motors"

3.4.2 Launch Sites

All launches will occur at NAR/TRA approved sites, likely around California (Stockton or San Diego) and the surrounding areas (Reno, NV or Phoenix, AZ). Mr. Raimondi will handle correspondence with the coordinators at these locations to arrange for the team to launch from these sites, as well as being present to assist in matters relating to the pyrotechnics and logistics at these events for the team. He will also be capable of informing the FAA (via Notice to All Airmen), United States Air Force, and local airports to notify them of any potential launches in the relative air spaces. Launches will only occur if weather conditions and the FAA permit, with the ultimate choice being left to the Range Safety Officer (RSO). The RSO dictates whether the vehicle may launch or not, and thus communication with the RSO is of critical importance. Pre-launch checklists will be used to ensure the plans and requirements of the rocket and subsystems are met before being placed on the launchpad, and another set of checklists will ensure proper handling while on the launchpad. Any changes to the checklists or plans in flying will be immediately brought to the attention of the RSO.

3.4.3 Written Safety Compliance Agreement

The team is aware of and understands the regulations put forth by NASA in their guidelines and rules. As per requirements, the Rocket Team at UCSC acknowledges the following NASA safety regulations and will incorporate them as part of the Safety Manual and Safety Acknowledgement Form:

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.

3.5 Team Safety Measures

3.5.1 Required Training

All students and team members who wish to help directly build rockets must successfully complete lab safety courses as designated by lab safety training courses. These activities are online and free, with the only stipulation being the student set up a necessary account with the UC Learning Center (http://learningcenter.ucsc.edu/). Once the student has an account, they will take two mandatory courses to gain access to the on-campus labs and workspaces:

- Laboratory Safety for Research Personnel
- Hazardous Waste Management

In addition to the above, should a student need to use power tools and are unfamiliar with them, they will also undergo taking the course "Hand and Power Tool Safety." Some other tasks may be assigned based on the student's need, but the above should be sufficient for any new member of the team who has no previous experience in the laboratory setting.

The Safety Officer will also personally help students on equipment they are not familiar with until they feel comfortable with the devices involved. Briefings will be carried out periodically, usually before launches and at the beginning of the academic year to ensure all team members are aware of their duties when around the rocket and its materials.

3.5.2 Lab Safety Equipment

Any Personal Protective Equipment (PPE) necessary for fabrication will be available in the lab space of Thimann 368 and the Idea Fab Labs. These include safety glasses/goggles, lab coats, and gloves. In addition to PPE, the lab space is outfitted with labeling of potentially hazardous materials using standard lab symbols and labeling as found in the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) Hazard Labels, which students should be able to clearly identify and understand based on their training. Team members will be required to wear appropriate attire going into the lab for work, specifically closed-toed shoes, properly fitted clothing, and no loose hair or accessories.

3.5.3 Lab Space Usage

The rooms allotted to the team in Thimann Labs is only accessible through keys which are designated to the two co-captains, Richard Alves and Duncan Bark. However, since the space is considered part of the Sustainability Lab program, more than just the team leaders will have access to Room 368, where the launch vehicles and payload is stored. It is thus imperative for the specific cabinet and shelving areas designated for the team to be easily seen by other lab visitors, and is thus marked off by yellow tape and labels identifying the team's presence and its equipment (Figure 35.3.1). Outside of this room and down the hall is Room 343 which houses the heavier machinery and tools, such as band saws and routers. This space is also limited to properly authorized Sustainability Lab personnel, but is considered freely to use by any of the program members, so the team will not keep any hardware outside of Room 368 cabinet spaces.

Also on campus that the team may potentially use, though unlikely, is the Arts Department and its facilities. Should the team ever find the need to get access to the equipment there, the proper faculty and administration will be notified in advance and all protocols followed to be allowed entry and usage.

Off campus, the Idea Fab Labs may also prove useful for the team. For this facility, any team members going will be aware of the rules and protocols as needed there, and will not be allowed to leave parts there once finished with their visit. Transportation can be arranged to go from campus to the city with the use of members and their cars, or through the conveniency of the city of Santa Cruz's metro bus system.

It should also be noted that the access to on-campus spaces through the Sustainability Lab is a privilege, and that the team act respectfully and collaborate alongside the other student groups who use the spaces in Thimann Labs. Should members fail to adhere to lab policies, or otherwise disrupt the community, the program may remove access and storage space for the entire team. Therefore, it will be important that all students unfamiliar with the Sustainability Lab be briefed in the Safety Manual and in person when necessary.

Figure 3.5.3.1 Work and storage space for the Rocket Team at UCSC marked off by yellow tape and labels in Thimann Labs 368

3.5.4 Safety Acknowledgement

Once a student has completed all necessary trainings and preparation to begin working in the lab spaces on the rockets, it will be required of them to read and sign a form stating that they understand all the risks associated with the team's work environment and can act responsibly. A copy of this Safety Acknowledgement Form can be found in Appendix A.

If a student cannot comply with the rules and regulations regarding any level of the project, or be the direct cause cause of an accident which results in damage to a person(s) or property, their lab access privileges may be revoked for an indefinite amount of time based on the severity of the incident and at the Safety Officer's discretion.

4 Technical Design

4.1 General Vehicle Dimensions

Figure 4.1.1 The Aeolis Rocket

General Rocket Properties

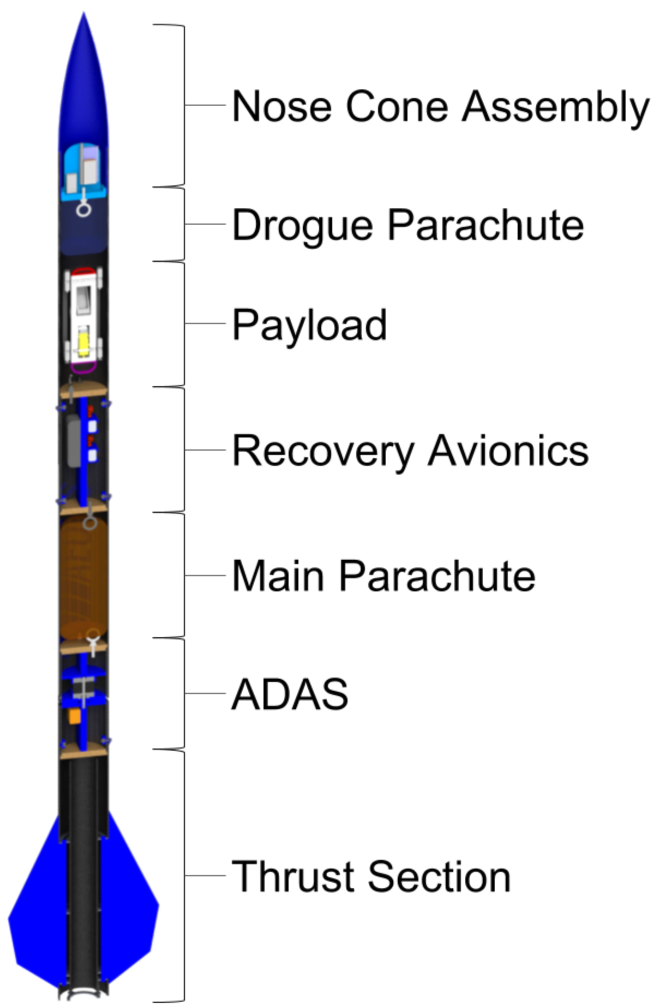
Chosen motor: Aerotech K805G

Apogee Target: 1609.34 meters (One Mile)

Stability Margin: 2.446 (CG - CP / Diameter)

CP: 54 cm

Rocket Mass	Rocket Length	Rocket Outer Diameter	CG, Wet	Wet Motor Mass	Dry Motor Mass	Rocket with Wet Motor
5.447 kg	215.9 cm	10.16 cm (4 in)	78.8543 cm	1540 g	672 g	7.35 kg



Nose cone assembly: 328 g
Drogue parachute: 33g
Payload: 1500g
Recovery avionics + surrounding airframe: 1272g

Main parachute: 212g
ADAS: 835g
Thrust section: 1266g
Total: 5.4kg = 12lb

4.1.1 Material Selections

The primary airframe, couplers, and motor tube will be constructed from carbon fiber. Carbon fiber offers superior strength and rigidity over other comparable airframe materials.

The centering rings which constrain the motor tube to the airframe shall be constructed from 6061 Aluminum. This material is readily available and easily machinable. It's low density and high strength is ideal for aerospace applications. The required thickness of the centering rings, and the bonding agent used to join the material to carbon fiber shall be a focus further investigation.

This rocket includes a removable fin assembly, thus 3D printing the fins from ABS material offers a simplification of manufacturing. While more prone to damage, a replacement can be easily replicated with minimal labor. The proper fin thickness to meet durability requirements shall be the subject of further investigation.

The nose cone shall be a COTS part because manufacturing such a complex composite shape accurately is currently beyond the capabilities of resources available to the team.

Internal bulkheads will be constructed of oak, or a similar hardwood.

The avionics shall be mounted to a custom 3D printed sled constructed of ABS. These sleds shall then slide onto high strength steel all threaded rods which span each avionics bay section.

All material selections are subject to modification pending the results of further trade studies and FEMA results.

4.1.2 Construction Methods

The rocket will be constructed in segments which will couple and be joined by either a semi-permanent fastener, or a shear screws.

Each segment will feature a carbon fiber airframe constructed by the team. The team is currently pursuing a wet-layup approach. The current manufacturing methods includes wrapping the carbon fiber material around a properly shaped and prepared mandrel. Applying pressure to the material via a vacuum bag/pump. Impregnating the material with epoxy resin. Curing the component within an oven. And finally removing the component from the mandrel.

A custom router jig shall be used to slot the airframe gaps for the fins.

The aluminum centering rings shall be manufactured in house on a CNC router. Additional features can be machined on the bridge port mill or machine lathe in the lab.

3D printed components will either be printed on a Flashforge Creator Pro or Ultimaker 3.

Semi-permanent attachments of rocket segments will be fastened during flight preparations and only removed post-recovery. Thus these attachments must remained fixed for the duration of the

rocket's flight. This is accomplished via an embedded nut bonded into place within the coupler section of the attachment point. The joint is then locked by threading two 8-32 bolts into place.
Two 8-32 bolts were found to provide a sufficient 3.2 factor of safety:

Passivated 18-8 Stainless Steel Steel 8-32 Pan Head screw (McMaster 91772A197)
Ultimate Tensile Strength: 70,000 psi
Ultimate Shear Strength: = .6 X UTS = 42,000 psi
Body Shear Area: 0.0124 si
Single Shear Strength: = USS X BSA = 520 lbf

Thus for a rocket mass below 10kg (22lb) experiencing a maximum of 15g's of acceleration the maximum characteristic shear force is expected to be below 1400 Newtons (330 lbf). Accounting for the two bolts included in each attachment point, these semi-permanent joints have a greater than 3.2 factor of safety.

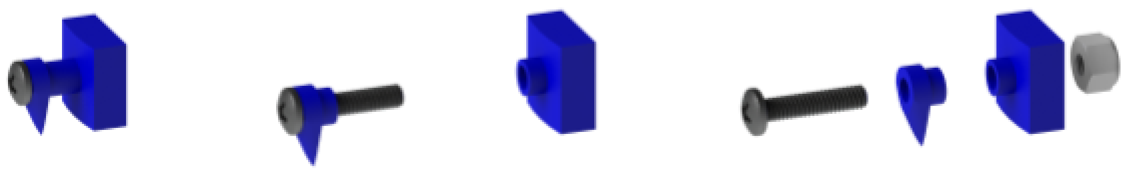


Figure 4.1.2.1 Exploded views of the semi-permanent segment attachment system.

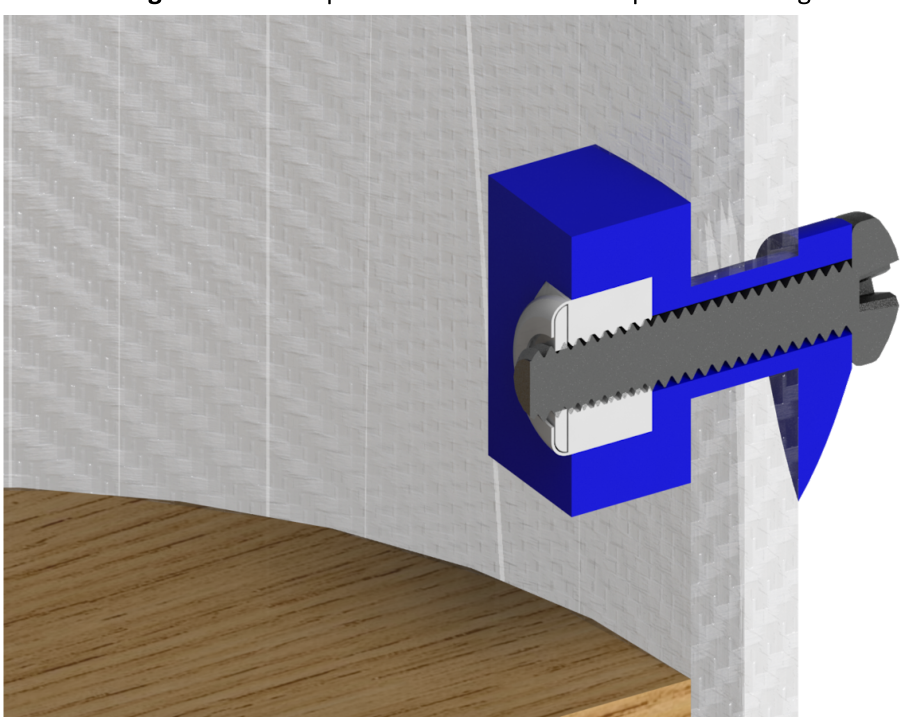


Figure 4.1.2.2 Semi-permanent attachment point in place.

4.2 Projected Altitude

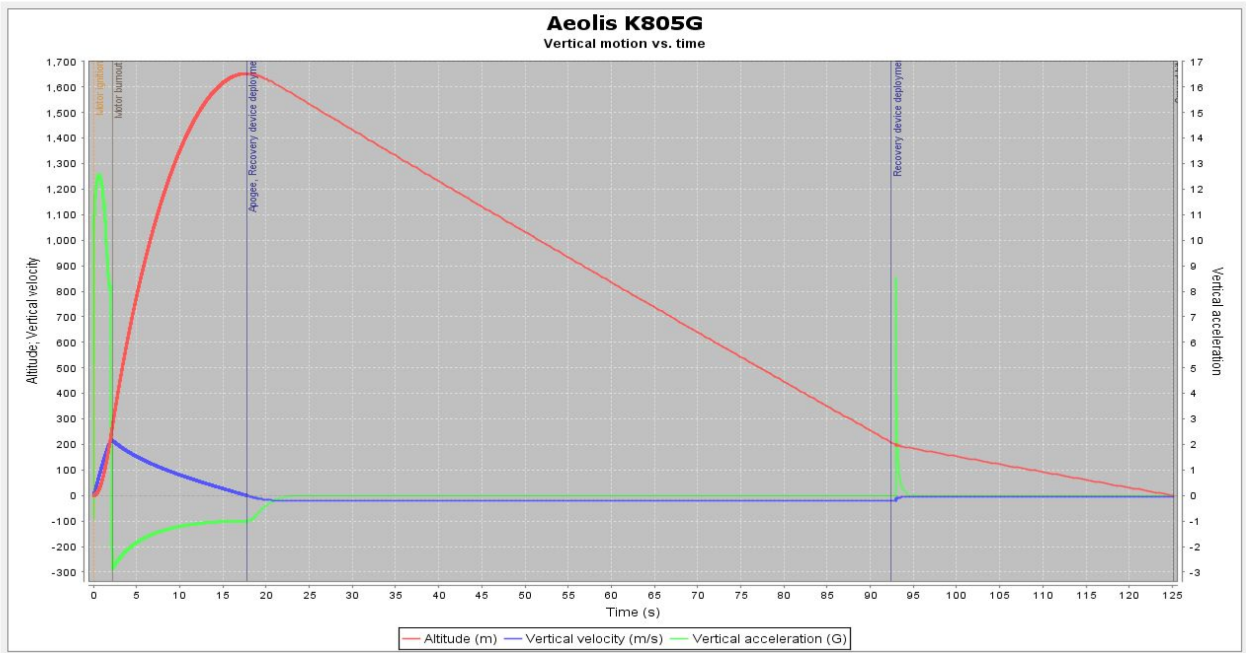


Figure 4.2.1 Altitude, Velocity, and Acceleration graph of the rocket with K805 motor

Using the AeroTech K805 motor, we expect an apogee of 1654 meters under perfect conditions, and an apogee of 1614 meters in 20 mph winds. Since we are aiming for an apogee of 1609.34 meters (one mile), the K805 provides enough additional altitude for ADAS to correct and allow us to reach exactly one mile, even in poor conditions.

4.3 Recovery System

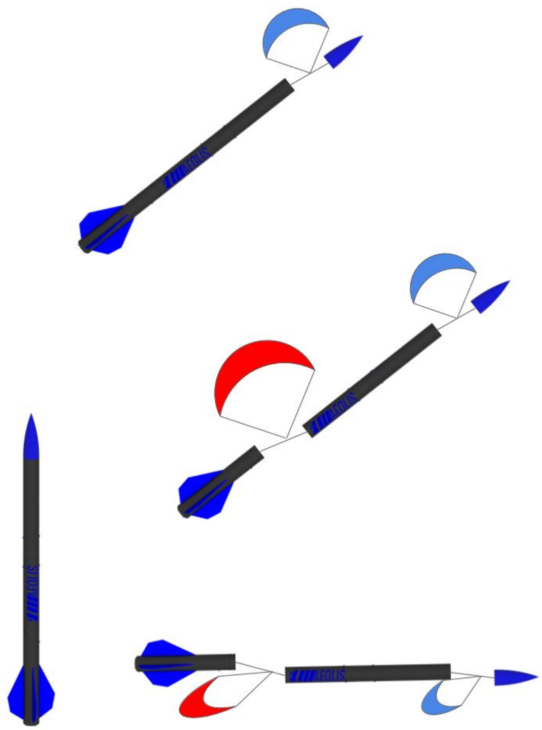


Figure 4.3.1 The stages of recovery

The rocket will perform a two stage recovery, separating into three tethered segments. A 24 in drogue parachute shall be released at apogee and a 64 in main parachute will be deployed at 700 ft. Each parachute deployment shall be redundantly triggered via strattologger devices. Once the rocket has landed, it shall be located via the radio beacon included in the nose cone. Once the rocket is inspected and declared safe, the rover deployment shall be triggered by a radio signal. 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 most massive independent section of the rocket, the thrust section, weighs 1.942 kg, and along with a landing velocity of 6.2 m/s, the landing energy will be 37.33 J, which is well within the energy requirement.

4.4 Motor Designation

Using the AeroTech K805 motor, the rocket is expected to have a velocity off the rod of 23.2 m/s (76.3 ft/s) and a maximum velocity of 216 m/s (710 ft/s). This satisfies requirement 2.18 which states the rocket must have an exit velocity of at least 52 ft/s. With the K805, the rocket has a static stability margin of 2.446 thereby satisfying requirement 2.17.

4.5 Payload

The team has chosen to participate in the deployable rover/soil sample recovery challenge. This decision was based on the following engineering design decision matrix:

		Options			
		UAV / Beacon Delivery		Rover / Soil Sample	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Retainment	-	-	-	-	-
Deployment	2	1	2	4	8
Navigation	5	4	20	3	15
Terrain	4	5	20	3	12
Design Complexity	5	1	5	5	25
Beacon Drop VS Soil Collection Complexity	4	3	12	2	8
Cost	3	2	6	5	15
Mass	3	3	9	4	12
Total Score			**74**		**95**

Weight: 1 (non-concern) - 5 (major concern)
Score: 1 (hard/complex) - 5 (easy/simple)

General notes included:

- The retainment method is similar for the two challenges
- Deployment of a UAV is significantly harder than a rover
- A piloted UAV can have adaptable navigation
- The rover's performance is terrain dependent

- A custom UAV is a significant design challenge
- Dropping a beacon is simpler than collecting and sealing a soil sample
- Rover components are cheap and common
- The rover is predicted to have a larger mass than a UAV alternative

After careful consideration, the team shall pursue the rover challenge, favoring the deployment and design simplification over the adaptable navigation and task simplicity of the UAV challenge.

4.5.1 Design Concepts

Preliminary design concepts have been investigated to inform the team's further progress and design decisions. These concepts shall be further researched, modeled, and prototyped to be incorporated into trade studies.

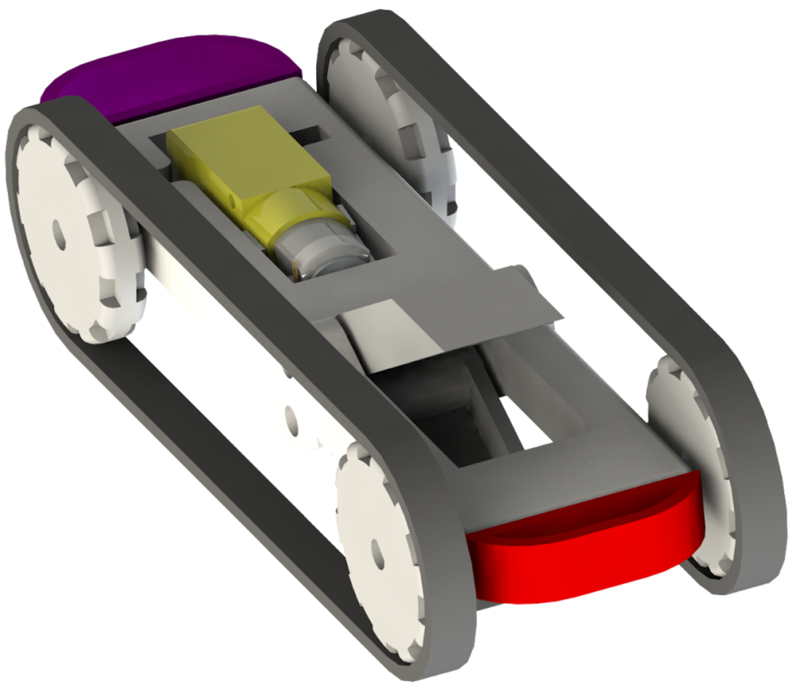


Figure 4.5.1 A rover concept with treads and double scoop soil sample collection device

4.5.1.1 Payload Requirements

NASA SLI Requirements:

- 4.3.1. Teams will design a custom rover that will deploy from the internal structure of the launch vehicle. *(Rover cannot be a part of the airframe)*
- 4.3.2. The rover will be retained within the vehicle utilizing a fail-safe active retention system. The retention system will be robust enough to retain the rover if atypical flight forces are experienced.
    - Spring loaded clamp?
- 4.3.3. At landing, and under the supervision of the Remote Deployment Officer, the team will remotely activate a trigger to deploy the rover from the rocket.
    - Radio receiver to trigger Rover
- 4.3.4. After deployment, the rover will autonomously move at least 10 ft. (in any direction) from the launch vehicle. Once the rover has reached its final destination, it will recover a soil sample.
    - Rover must drive at least 10ft. And collect the soil sample at the **FINAL** destination.
- 4.3.5. The soil sample will be a minimum of 10 milliliters (mL).
    - ~2.65 g
- 4.3.6. The soil sample will be contained in an onboard container or compartment. The container or compartment will be closed or sealed to protect the sample after collection.
- 4.3.7. Teams will ensure the rover's batteries are sufficiently protected from impact with the ground.
- 4.3.8. The batteries powering the rover will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other rover parts

Team Derived Requirements:

- The rover shall undergo extensive ground testing featuring a variety of terrain environments and obstacles, especially terrain similar to that of the landing zone
- The rover will be easily integrated into the rocket during launch preparations and easily removable without powering on the rover.
- The rover will remain securely locked within the rocket during flight
- The rover will land in ideally an upright or upside down orientation
    - Avoid the possibility of a rover-side scenario
        - determined by orientation within internal structure of launch vehicle/possible landing orientation of said structure
- The recovery system shall be designed to give the rover a direct path clear from other rocket components
    - Prevent parachute tangling or blocking to rover with other segments of the rocket airframe
- Rover deployment will be triggered by an external radio signal
    - Carefully note the frequency and avoid other teams using the same frequency

            - Use a direction antenna to avoid being the cause of error for another team
- Upon deployment signal, the rover will sense the orientation of its landing and set the proper drive direction accordingly
    - Doing this prior to the deployment signal would introduce the programmatic challenge of sensing the landing
    - Without establishing orientation, the rover could drive deeper into the rocket.
- Rover will release itself from the retention system
    - Opening a spring loaded clamping
- Rover will perform a pre-programmed drive routine
    - End travel must be greater than 10ft
    - Include multiple obstacle avoidance/recovery maneuvers
- Collect a >10mL soil sample at final location
- Seal the soil sample within the rover
- The rover must have sufficient battery energy storage to survive a 2 hour holding wait time, flight and execute deployment and mission and retrieval

Stretch Goals:
- Return soil samples to a laboratory to conduct analysis
    - Characterising chemical composition
    - Searching for microbial life
    - Keep an active log for each launch site / travel location
        - Sub scale/ Full scale Snow Ranch flight time contrast/comparison

Compare the results from various other sources tie into sustainability mission

4.5.1.2 Drivebase

The rover must be able to navigate a variety of terrains. The rover may encounter rocks, tall grass, mud, and other obstructions. Measures must also be taken to prevent the rover from entangling with parachute chords or other components of the rocket in its landing configuration. Thus the rover must feature a robust drive method. The following table was created to inform the decision:

Treads		Wheels	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
• Traction on a variety of wet/loose surfaces • Ability to navigate rough terrain	• Limited size selection without incurring manufacturing complexity • Difficult repair • Tensioning requirement	• Simplicity • Variety of sizes	• Wheel diameters must be at least twice the height of an obstacle

Treads offer a major advantage when planning for the variety of terrains that the rover may be subject to encounter. Primarily for this reason the rover is planned to propel itself via treads.

4.5.1.3 Soil Collection Method

The soil collection mechanism must obtain at least 10mL of soil and seal it within the rover. Also, the team has selected to abandon controlling the landing orientation of the rover in favor of a soil collection method which operates in both the proper and inverted rover orientations. Current system under investigation include:

- Scoop
- Drill
- Spear

When done selecting these methods, the associated sealing method for each soil collection technique is a major factor. Additional rover components required for each design was also a major factor. It was determined that two clamping scoops offered the greatest simplicity.

The clamping scoop mechanism only requires a driving system to open/close the clamps. When the rover reaches the soil collection location, the clamps shall be commanded to open. The rover shall drive forward, leveraging the torque of the drive system to force soil into the downward facing scoop. The rover will then stop and close the scoops. A rubber seal incorporated into the edges of the scoops shall then seal the soil sample.

4.5.1.4 Navigation Algorithm

The rover will autonomously drive a minimum of 10ft from the rocket landing site. This will be accomplished by the rover running a series of pre-programed routines. A bumper sensor shall be included on the forward face of the rover for obstacle detection.

4.6 Requirements

Each subteam is expected to make a plan to verify that all requirements for their specific subteam will be followed. For example, the outreach team will be responsible for requirement 1.5 and 1.6, and the safety officer is responsible for all safety related requirements. The team's Co-Captains will verify that all subteams are on route to satisfy all the requirements set in the handbook. General plans are in place for the requirements and details of this is in each specific section throughout the proposal. This is done so that the requirements are being followed along with the general design and planning process.

4.7 Major Technical Challenges and Solutions

4.7.1 Removable Fin System

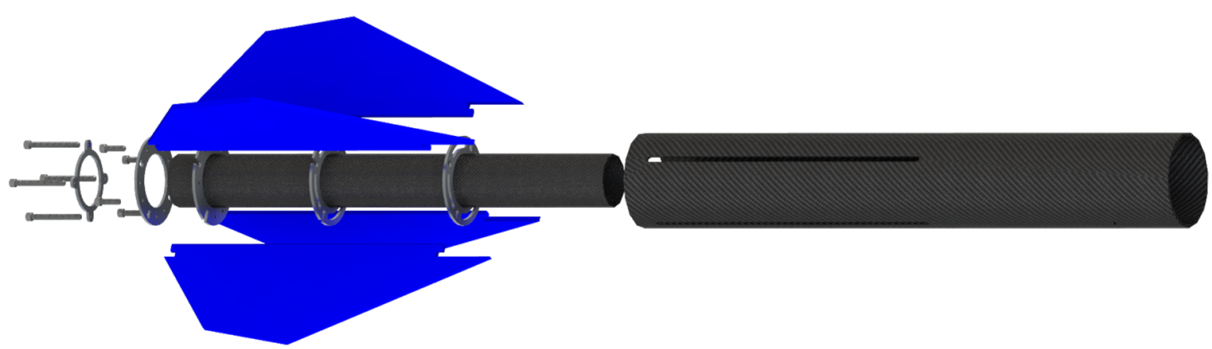
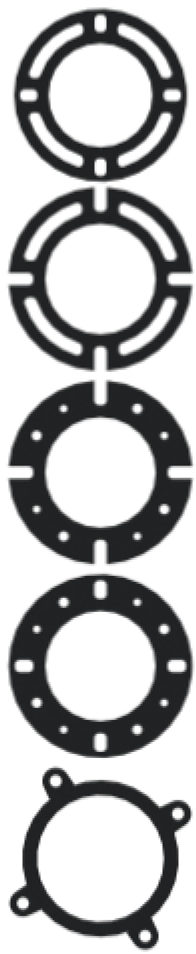


Figure 4.7.1.1 Exploded view of the thrust section

The fins of a rocket are the most commonly damaged components of any design. Events such as ground impact, rocket transport, and display pose high risks to damage fins. Complex and time consuming repairs are often necessary if such damage occurs. This can be avoided by designing and adopting a removable fin architecture. Thus if a fin is damaged the repair is as simple as swapping another one in, rather than undertaking an entire thrust section rebuild.

Removable fins will also reduce the risk of damage in transport in addition to reducing the rocket to a friendlier form factor.



The removable fin assembly is accomplished via a series of meticulously designed centering rings as shown in figure 4.7.1.2. In descending order, the top most centering ring is fixed to the motor tube and within the thrust section airframe. This ring provides a landing for the tops of each fin. Next, the mid ring provides additional structural bridging between the motor tube and thrust section, while the open slots constrain the radial direction of the fins. Third, this centering ring is also bonded to both the thrust section and motor tube. This ring houses the threaded termination of the fin retainment bolts and the motor retention bolts. The fin retainment ring clamps onto the lower fin tabs and locks them in place. The fin retainment ring features closed slots to enclose the lower fin tabs. Finally, the motor retaining ring will lock the motor within the rocket, preventing reverse ejection.

Figure 4.7.1.3 depicts a preliminary fin design. While dimension such as chord lengths may vary, the removable fin design requires the inclusion of tabs on either edge of the fin.

Figure 4.7.1.2 Centering Rings

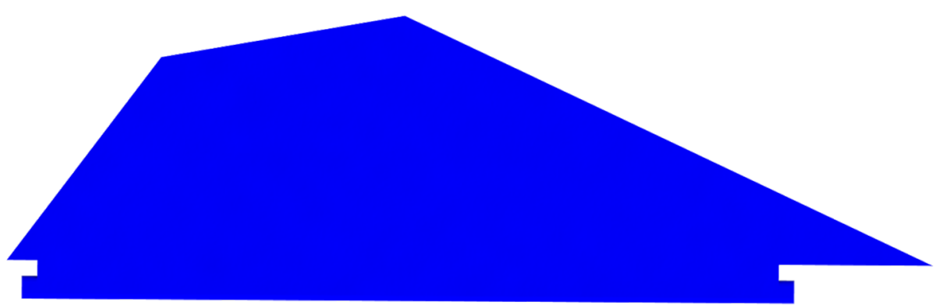


Figure 4.7.1.3 Fin

4.7.2 Adaptive Aerobraking System (ADAS)

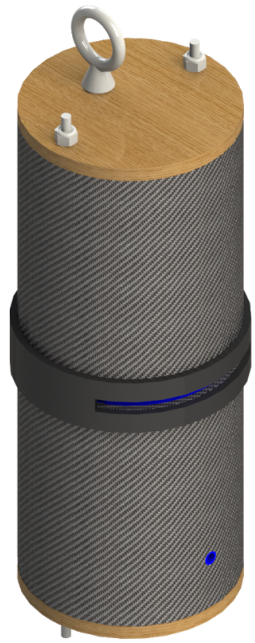


Figure 4.7.2.1 ADAS

ADAS System Properties	
Drive motor	NEMA-17 stepper motor
Battery	Tattu 3s LiPo Battery Pack 45C (11.1V/850mAh)
Max motor current draw	350 mA
System mass	850g
Maximum addition drag force	157 N (no-advisable at max velocity)
Deployment accuracy	3.5 steps / 1% deployment
Closed to full deployment time	2.1 seconds

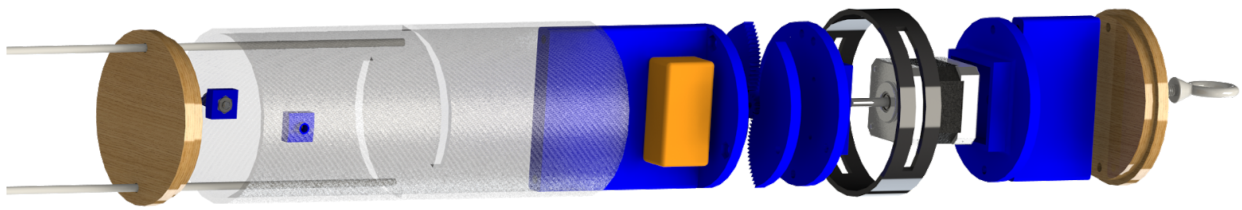


Figure 4.7.2.2 Exploded view of ADAS

The ADaptive Aerobraking System was developed with the intention of reaching our one mile apogee target with arbitrary precision. The system extends two semi-circular aerobraking fins from the interior of the rocket in order to generate addition form drag on the rocket. Implement with the proper PID control algorithm, this device will make course corrections to the rocket's trajectory mid flight.

ADAS is driven by a NEMA-17 stepper motor. This motor was selected based on torque, speed, and accuracy requirements as calculated follows:

The ADAS motor must overcome any friction generated with the mechanism during maximum aerodynamic loading. The following is a calculation of the maximum frictional torque the motor must overcome in a worst case scenario. Ideally, the ADAS fins will never deploy under these conditions, and the mechanism itself designed to reduce frictional losses, but the following gives a sense of the torque output necessary of a motor to drive ADAS.

$$F_D = \frac{1}{2}\rho v^2 C_D A$$

Taking,
The density of air: 1.225 kg/m3
CD: 1.28 (for a flat plate)
A: 0.25*Rocker Interior Area = 2.8 in2 = 1.7e-3 m2

$$F_f = uN$$
$$N = F_D$$

ABS Coefficient of friction maximum: 0.46

$$\tau = F_f \, x \, r$$

The average radius of an ADAS fin ~ 1in = 2.5e-2

$$\tau = 2.5e-2 * 0.46\,(\frac{1}{2} * 1.225 * v^2 * 1.28 * 1.7e-3)$$

Thus for a given velocity, the necessary fin torque can be calculated. Or for a given operating velocity, the matching torque requirement can be found.

Since the motor will drive the fins at an approximate 7:1 ratio, and given the vehicle is required to stay under the speed of sound (343 m/s), the maximum motor torque requirement of the ADAS motor is:

$$\tau = 0.26Nm \ = \ 36.8 \ oz - in$$

Since all flight correction is planned post-MECO and thus below the maximum velocity, ADAS will operate in a velocity regime well below 343 m/s. Thus the readily available NEMA-17 stepper motor, featuring 28 oz-in of torque was declared sufficient.

Another important factor in the selection of a ADAS drive motor is the opening and closing time scale of the drag fins. In order to course correct accurately, a rapid deployment response is critical. The motor spins freely at 50 RPM. Taking into account the 7:1 gearing and the fact that full ADAS fin deployment is approximately a quarter turn of the fin gear, the NEMA-17 motor can open ADAS from 0 to full deployment in 2.1 seconds. Since a proper tuned ADAS system will smoothly open the fins with possibly minor jittering correction, this speed is found to be sufficient.

In order to provide the most possible control of ADAS fin deployment, a sufficient number of motor stepps must be mapped onto the deployment angles of the ADAS fins. Since the NEMA-17 motor features 200 steps per revolution, 350 steps will be mapped from 0 to 100% ADAS deployment. This is sufficiently accurate to drive the motor to any specified deployment angle.

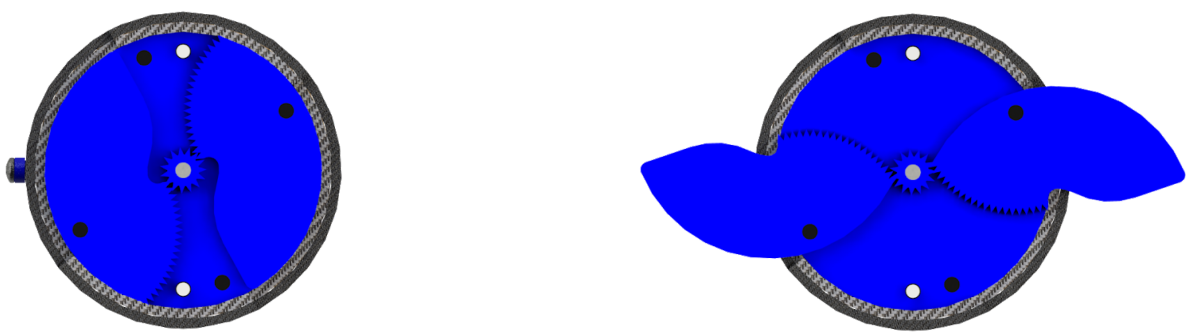


Figure 4.7.2.3 ADAS closed (left) open (right)

Extensive research into the control of ADAS was performed between the completion of last year's competition season and this proposal. The culmination of which is the following paper on the subject authored by team member,
Nitay Ben-Shachar:

ADAS Control Algorithm Improvements

Contents

1 Introduction

The goal of the ADAS mini project is to produce a system that can control the rocket's ascent in order to reach a predetermined desired apogee. In this document I present the proposed idea from the 2017-2018 project and a new idea that could make the process easier and more transferable between rockets. The old idea (detailed in 1.1) is to precalculate the nominal trajectory of the rocket and load it into the rocket computers. Pros include: Since all the difficult calculations are done on the ground, the rocket computers don't have to be particularly powerful but can use data that was calculated using more finely tuned and comprehensive algorithms. Cons are: Every rocket/change to the rocket requires a new trajectory calculation, with some manual tweaking required. As of now, we don't have a very sophisticated simulation program, just OpenRocket and the python simulator [1], so the pro doesn't give much of an edge. The data usually takes a lot of the limited memory in the onboard computers, so for more detailed trajectories, either more memory would have to be added or a better implementation of the trajectory would have to be done. The pros of the new algorithm: It is relatively lightweight, will have comparable calculation speed as last year's method and is much more transferable to new rockets or modifications. The new algorithm would calculate the drag coefficient needed to reach the desired apogee in real time using a few assumptions and a predetermined solution to it's trajectory based on these assumptions. Cons are: assumptions may be less reasonable than expected, affecting the actual apogee of the rocket.

[1] https://github.com/UCSC-Rocket-Club/Modeling

1.1 Previous Algorithm

The algorithm used in the 2017-2018 year had a very preliminary design. No kalman filter was used to filter the input data, the sensors were not attached in the bestest of ways leading to wishy washy measurements and not the best filters were applied, for example to calculate the angular position of the rocket.

A 1d numerical integrator was used to calculate the trajectory of the rocket for selected ADAS deployment profiles, implemented in python [2]. The drag force was calculated using SolidWorks flow simulations and these were loaded into a 2D array that would get interpolated to give the drag force as a function of the current deployment and velocity. The air density was varied in accordance to the altitude, and the mass of the rocket was adjusted throughout the burn time with respect to the thrust generated. The rocket was also assumed to only have a vertically directed trajectory.

The ADAS deployment profile was tweaked until the calculated apogee was the required 1 mile. The corresponding height profile and velocity profile were then saved together. Together they form all the required data to follow the nominal trajectory. A map is formed from the altitude of the rocket to the nominal velocity at that altitude in order to achieve the correct apogee.

Using this idea, at every iteration of the control loop, if the rocket can measure its altitude and velocity, it can figure out how far from the nominal velocity for its current altitude it is traveling at. Using an appropriate PID algorithm the deployment can be controlled in order to remain as close as possible to the nominal velocity at every altitude.

The whole arrays could not be loaded into the arduino as it would take up too much data. Instead, the graphs were partitioned into smaller sections, with a quadratic fit being applied to every section. A quadratic was chosen as C will round floating point numbers to a certain number of significant figures, and so to not lose any information, we must ensure that each term in the chosen polynomial does not exceed this limit of the number of significant figures. by testing extreme cases with examples from the fitted polynomials, quadratic equations were the highest possible order polynomial that had no significant data loss.

Any time a new rocket is designed, every change in mass or change in the desired apogee, means that a new 'nominal trajectory' has to be designed and calculated. Although the majority of the process is automated this takes some time and effort, with slight manual adjustments needed in certain places. Unfortunately the code could never be tested due to mechanical or software failures so we do not know if this idea works, further test should be conducted. In the case that it doesn't, an alternative is presented.

[2] see gitHub repository

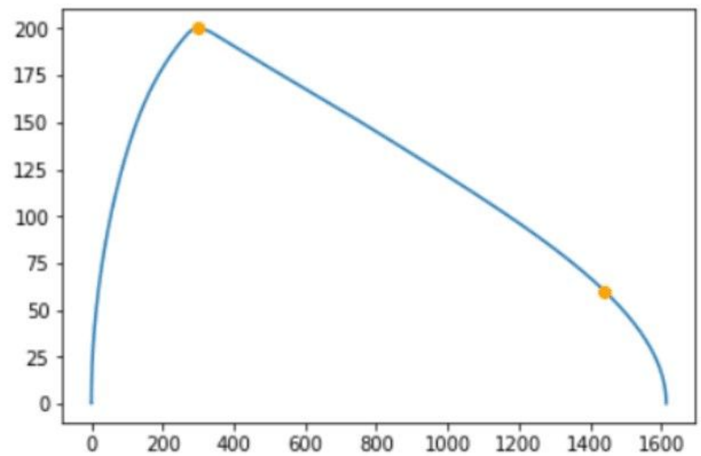


Figure 1: The x-axis is height, the y-axis is the velocity of the rocket. The path illustrated is the calculated nominal trajectory. The code uses PID to follow the curve as best it can.

2 Idea for Alternative Algorithm

2.1 Intro

This new algorithm originates from a solution to a relatively simplified model of the rocket, see 2.2 for a full list of assumptions. Using these assumptions we can calculate precisely what the necessary drag coefficients needed to reach the apogee given the initial conditions (height and velocity) and the target apogee. By constantly calculating the required drag coefficients we can directly get an estimate for the deployments needed at that iteration in order to reach the required apogee.

2.2 Assumptions

We are assuming constant air pressure and gravitational force. The rocket is assumed to be flying straight up. The drag force is proportional to v^2, ie the coefficient of drag is independent of velocity, although this could be accounted for by using a 2 dimensional lookup table rather than a 1 dimensional one for the drag coefficient. No wind is present.

2.3 Formula

At any point after burnout, so during the coasting phase, we wish to calculate the deployment of ADAS needed to reach the desired altitude at apogee. Note that this deployment could be fed directly into the motor or could go through a PID algorithm which will account for offsets and such (especially the P and I components of it at least). We do this by considering the forces acting on the rocket and applying Newton's Second Law.

The forces acting on the rocket are the gravitational force and the drag force.

$$m\left(\frac{d^2x}{dt^2}\right) = -mg - \frac{1}{2}\rho C_d A \left(\frac{dx}{dt}\right)^2$$

$$\frac{d^2x}{dt^2} = -g - \frac{\rho}{2m}(C_d A)\left(\frac{dx}{dt}\right)^2$$

Now define: $\alpha = \frac{\rho}{2m}$ this is a constant

$\Delta = C_d A$ this depends on the deployment of the ADAS fins.

So this problem equates to solving for Δ given the initial conditions and the target. To solve this DE first convert it to a first order equation in terms of $v = \frac{dx}{dt}$

$$\frac{dv}{dt} = -g - \alpha\Delta v^2$$

$$\frac{1}{g + \alpha\Delta v^2}\frac{dv}{dt} = -1$$

$$\frac{1}{1 + \frac{\alpha\Delta}{g}v^2}\frac{dv}{dt} = -g$$

Rescale the velocity variable to be able to integrate, define:

$$\nu = \sqrt{\frac{\alpha\Delta}{g}}v \qquad \frac{dv}{dt} = \sqrt{\frac{g}{\alpha\Delta}}\frac{d\nu}{dt}$$

And so we have that:

$$\frac{1}{1+\nu^2}\sqrt{\frac{g}{\alpha\Delta}}\frac{d\nu}{dt} = -g$$

$$\frac{1}{1+\nu^2}\frac{d\nu}{dt} = -\sqrt{\alpha\Delta g}$$

Now integrating both sides

$$\int \frac{1}{1+\nu^2}\frac{d\nu}{dt}dt = \int -\sqrt{\alpha\Delta g}dt$$

$$tan^{-1}(\nu) = -\sqrt{\alpha\Delta g}t + c$$

Now substituting in the initial condition at $t = 0$ whish is the current time we have $v = v_0$ and so using the above equation $\nu = \nu_0$

$$c = tan^{-1}(\nu_0)$$

Now resubstituting in ν for its definition in terms of x

$$\frac{dx}{dt} = \sqrt{\frac{g}{\alpha\Delta}} tan\left(-\sqrt{\alpha\Delta g}t + c\right)$$

From here we simply integrate with respect to t to get x as a function of t

$$x = \int \sqrt{\frac{g}{\alpha\Delta}} tan\left(-\sqrt{\alpha\Delta g}t + c\right) dt$$

Since $tan(y) \equiv \frac{sin(y)}{cos(y)}$ and making a trig substitution we can get the following:

$$x = \sqrt{\frac{g}{\alpha\Delta}} \left(-\frac{ln\left(cos\left(-\sqrt{\alpha\Delta}t + c\right)\right)}{-\sqrt{\alpha\Delta g}}\right) + X$$

Using the initial condition that $x(0) = x_0$ which is the height measured by the sensors at that instance we get

$$x_0 = \sqrt{\frac{g}{\alpha\Delta}} \left(\frac{ln\left(cos\left(c\right)\right)}{\sqrt{\alpha\Delta g}}\right) + X$$

and hence

$$X = x_0 - \frac{1}{\alpha\Delta} ln\left(cos\left(c\right)\right)$$

We are interested in the height reached at apogee. Apogee occurs when $\frac{dx}{dt} = v = 0$. Solving this equation from the expression given above:

$$\frac{dx}{dt} = \sqrt{\frac{g}{\alpha\Delta}} tan\left(-\sqrt{\alpha\Delta g}t_t + c\right) = 0$$

$$-\sqrt{\alpha\Delta g}t_t + c = tan^{-1}(0) = 0$$

Only taking the first solution

$$t_t = c\sqrt{\frac{1}{\alpha\Delta g}}$$

Now at the top, $t = t_t$ and $x = x_t$ where x_t is the target height. Plugging these into the equation for height

$$x_t = \frac{1}{\alpha\Delta} ln\left(cos\left(-\sqrt{\alpha\Delta g}t_t + c\right)\right) + X$$

$$x_t = \frac{1}{\alpha\Delta} ln\left(cos\left(0\right)\right) + X$$

$$x_t = \frac{1}{\alpha\Delta} ln\left(1\right) + X$$

$$x_t = X = x_0 - \frac{1}{\alpha\Delta} ln\left(cos\left(c\right)\right)$$

$$x_0 - x_t = \frac{1}{\alpha\Delta} ln\left(cos\left(c\right)\right)$$
$$\Delta = \frac{1}{\alpha\left(x_0 - x_t\right)} ln\left(cos\left(c\right)\right)$$

Since c depends on Δ in a non-trivial way this is a transcendental equation for Δ which should be solved numerically? to get the appropriate deployment in order to reach apogee (future) Since $tan(c) = \nu_0$ then $cos(c) = \frac{1}{\sqrt{1+\nu_0^2}}$ and so:

$$\Delta = \frac{1}{\alpha\left(x_0 - x_t\right)} ln\left(\frac{1}{\sqrt{1+\nu_0^2}}\right)$$
$$\Delta = \frac{1}{\alpha\left(x_0 - x_t\right)} ln\left(\frac{1}{\sqrt{1+\frac{\alpha\Delta}{g}v_0^2}}\right)$$
$$\Delta - \frac{1}{\alpha\left(x_0 - x_t\right)} ln\left(\frac{1}{\sqrt{1+\frac{\alpha\Delta}{g}v_0^2}}\right) = 0$$

Newton's method can be used to calculate the roots of this equation. Need to show that newton's method will converge to the root for good enough guesses with constraints of when it will converge and make sure the algorithm only initially guesses a good enough value

$$\Delta\alpha\left(x_0 - x_t\right) = ln\left(\frac{1}{\sqrt{1+\frac{\alpha\Delta}{g}v_0^2}}\right)$$
$$e^{\Delta\alpha\left(x_t - x_0\right)} = \sqrt{1+\frac{\alpha v_0^2}{g}\Delta}$$
$$e^{\Delta\alpha\left(x_t - x_0\right)} - \sqrt{1+\frac{\alpha v_0^2}{g}\Delta} = 0$$

Taking this as the root of a function

$$f(\Delta) = e^{\Delta\alpha\left(x_t - x_0\right)} - \sqrt{1+\frac{\alpha v_0^2}{g}\Delta} = 0 \tag{1}$$

$$f'(\Delta) = \alpha\left(x_t - x_0\right) e^{\Delta\alpha\left(x_t - x_0\right)} - \frac{1}{2}\frac{\frac{\alpha v_0^2}{g}}{\sqrt{1+\frac{\alpha v_0^2}{g}\Delta}}$$

$$f'(\Delta) = \alpha\left(x_t - x_0\right) e^{\Delta\alpha\left(x_t - x_0\right)} - \frac{\alpha v_0^2}{2g\sqrt{1+\frac{\alpha v_0^2}{g}\Delta}} \tag{2}$$

Now this equation can be solved numerically using Newton's Method, guessing the root and applying a first order taylor expansion to get the next guess

2.4 Newton's Method

A simple implementation of Newton's method with these functions (equations 1 2) can be found here [3]. The function takes in the initial guess, how close to zero the function can be for it to count as a root (getting to zero exactly may take an infinite number of steps, so we want to stop when we are close enough) and the maximum number of iterations, this was for testing purposes, in case the root is not converged upon in a reasonable number of steps, indicating that the function is diverging from the root and so a better initial guess has to be made.

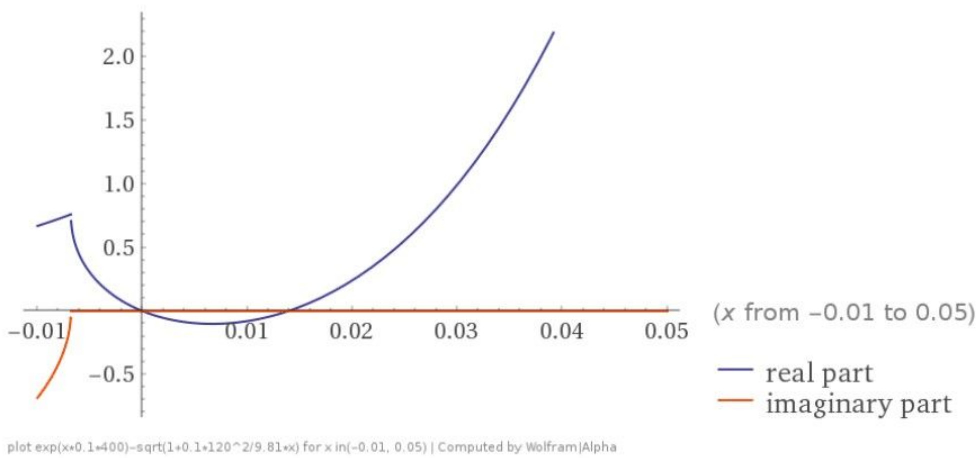


Figure 2: Equation 1 is plotted. As can be seen from equation 1, for all parameters there is a solution at $\Delta = 0$ that we want to avoid, the other solution is the interesting one. If we approach it from the right, Newtons Method will converge to the interesting root, otherwise it will converge to 0.

2.5 Testing

All testing was done using the same parameters as the simulations for the final rocket modifications (ie the mass) for E-1. Initial simulations for the new method have been partially successful, by implementing the code in python as in the gitHub Repository, we can re-run the numerical trajectory calculator with the control algorithm implemented. As can be seen in the jupyter notebook under AA1 in the gitHub repository, the trajectory has an apogee of 1595m which is a tiny bit under the desired apogee of one mile (1609m). The ADAS deployment is shown in figure 3. This suggests that if a PID filter is implemented and some other tweaks the algorithm can performance very well, and may be more adaptable to different situations such as a tipping rocket etc. As we can see the algorithm deploys too much in the beginning and doesn't have enough wiggle room to adjust for that.

[3] https://github.com/UCSC-Rocket-Club/Modeling/tree/master/AA%201

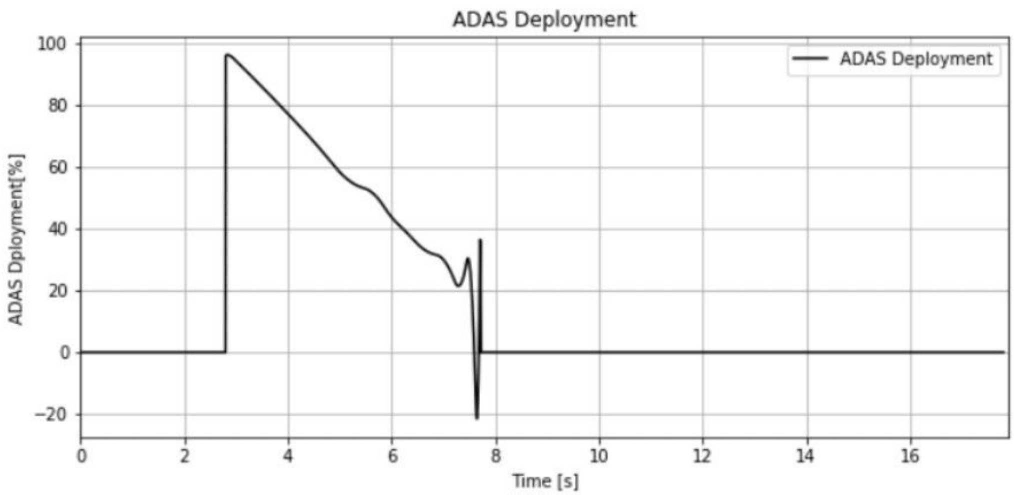


Figure 3: The deployment of ADAS when a preliminary (without PID) design of the new control algorithm was implemented. As seen, it over extends ADAS in the beginning and cannot regain the height it had lost.

3 Implementation Problems

Be sure that when a code is computing any numerical value, rounding cannot be an issue otherwise the result can be orders of magnitude off! This happened with initial c implementations while trying to calculate the nominal velocity given the height of the rocket (and hence if to deploy ADAS or not). Use correct orders of operation (e.g. don't divide first as some numbers will get rounded down to zero and so any further operation on them will be redundant), so use the correct data types

4 Proposed Future Steps

1. Program a Kalman Filter. Kalman filters are some of the most lightweight filters that filter out noise or unnecessary vibrations in the sensor data. This is especially a problem if incoming sensor data is integrated as as was noticed, small systamatic errors build up. This was eradicated by zeroing the integrated position using the altimeter, however the altimeter has a large error so this added to the noise in the data.

2. Carry out Flow Simulations or Wind Tunnel Tests to calculate a lookup table correlating Δ (coefficients of drag) to the deployment of the fins. This could also be done by analysing data from flights with several deployments. Note that the drag coefficient may have a very nontrivial dependence on velocity.

3. Digital tests of the control algorithms as well as any other control algorithms should be carried out to test their accuracy, response and adaptability in different scenarios. Possible scenarios to test could include:

(a) Angled take off, even if the angle is not constantly being adjusted , it'd be good to see how the algorithms react to having a constant underachieving rocket

(b) Incorrect lookup table, probably the most probable of potential problems. This could be due to variability in skin drag, mass distributions affecting the aerodynamics of the rocket or many other sources. A good PID loop should be able to account for this through the I component, noticing that there is a constant/not constant offset and adjusting for it as long as its constant enough.

4.7.3 Radio Transmitter/Receiver and Locator

The team has previously selected to use a COTS GPS transmitter for recovery purposes. The GPS data was inaccurate and unreliable as a real-time recovery method. Thus the team has elected to move to a radio beacon locator which provide better real-time locating information and will reduce vehicle mass. This however requires a member of the team to obtain an ameture radio license. Something that is not necessary technically challenging, but is critical to the success of this subsystem.

4.7.4 Rover Retainment

The development of a rover retainment mechanism poses a real challenge. The mechanism must be easily attached to the rover to simplify payload integration, while sufficient to hold to rover in place. It has been determined by the team that the release of the mechanism must be handled on the rover-side of the contraption. Thus only one radio receiver is required to be on the rover, as opposed to a seperate receiver housed on the rocket and an addition rocket to rover initiation of the drive routine. Current system under investigation are spring loaded locks and a nichrome wire burning technique.

5 Education and Community Engagement

5.1 Past

Last year the team hosted 10+ outreach events in the local community with a total outreach of 100+ kids and community members.

The team's outreach events consisted of a brief introductory lecture style lesson on rockets and then a hands on component in which the students made their own paper rockets and launched them using our modified bike pump launcher. We first visited the ROV Team from Branciforte Middle School, a local alternative school, where we had a more indepth talk about rockets and then we helped them make their own paper rockets to launch (pictured below). Once they finished, we went outside and launched them.

Figure 5.1.1 ROV Team Paper Rocket Launch Activity

Then, every friday for two months the team visited Monarch Elementary School and, with a new group of students each week, made a presentation on rockets, and then helped and launched the student's paper rockets.

Figure 5.1.2 Helping ROV Team make Paper Rockets

The team also participated in a Porter College Night, where we handed out pamphlets and helped UCSC students make paper rockets that we launched across the stage. The team also participated in a Women in Physics and Astrophysics (WiPA)/Women in Stem Education (WiSE) event where a team member gave a talk about astronomy and the middle school aged girls made and launched paper rockets.

Last year's experience with outreach events has inspired us to expand our efforts to reach many more kids, students and community members. We hope to get kids excited about rockets and STEM education as a whole, just as we accomplished last year.

Figure 5.1.3 Students while launching paper rockets

5.2 Planned

In order to promote STEM education and contribute to the further inspiration of the developing youth, the Rocket Team at UCSC will host numerous educational engagement activities targeted at a broad range of students. The team has already contacted all of the local high schools and has concrete plans for outreach events in the near future with Costanoa High School, an alternative high school located in Santa Cruz. We have also reached out to the local elementary and middle schools and have events planned with Monarch and Westlake Elementary, as well as the middle school ROV team from Branciforte Small Schools. In order to reach the widest range of students throughout Santa Cruz, we have also reached out to the local after school groups, including the local chapter of the Boys and Girls Club (Boys & Girls Clubs of Santa Cruz County), the Central Coast YMCA, the Discovery Learning Center of Santa Cruz, the Live Oak Clubhouse in Santa Cruz county, and Santa Cruz Parent. All of the listed places above have already been contacted and we have plans to have at least one rocketry event with them during this upcoming year.

For all of our grade school events we present a general introduction lesson to rocket science, and then assist the students with constructing and launching their very own paper rockets. We are not limited to grade school aged students, and also plan on continuing outreach events at the University of California Santa Cruz through college night events-which include informational pamphlets and an opportunity for students to build and then launch their own paper rockets.

5.3 Social Media Presence

In order to increase our presence in the Santa Cruz community, we plan on avidly using both Facebook and Instagram in order to keep our followers aware of what we are doing, as well as to potentially be easier to be gotten ahold of for the scheduling of our outreach events. The Instagram (ucscrocketry) and Facebook (Rocket Team at UCSC) accounts will be monitored by Vera Umansky, the head of outreach and social media for the team. We aim to post a minimum of once a week once the school year starts, including progress photos of the rocket, information on our team and SLI, and photos or plans of our outreach events.

6 Project Plan

6.1 Timeline

6.1.1 Build Schedule

Activity	Start Date	End Date
PDR Prep	Oct 4	Nov 2
PDR Due	Nov 2	
CDR Prep	Nov 2	Jan 12
Design Rocket	Nov 2	Nov 13
Build Subscale Rocket	Nov 2	Nov 30
Subscale Test Launches	Dec 1	Dec 8
CDR Finalization	Dec 9	Jan 3
CDR Due	Jan 4	
FRR Prep	Jan 5	March 4
Design Full Scale	Jan 5	Jan 17
Full Scale Build	Jan 18	Feb 1
Full Scale Launch	Feb 2	Feb 9
Adjustments/Optimization	Feb 3	Mar 3
FRR Due	March 4	
FINAL LAUNCH	April 3	

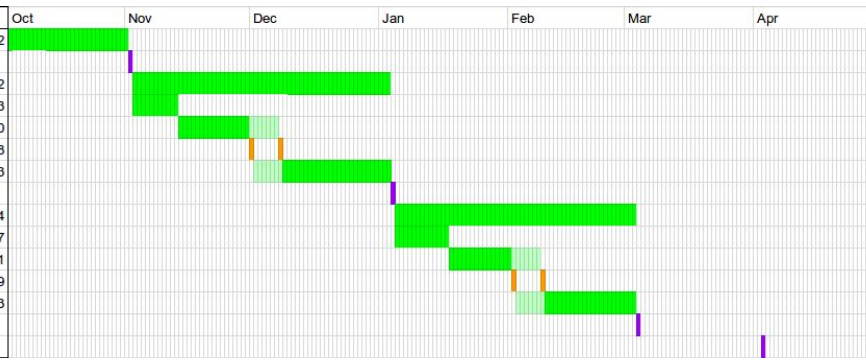


Figure 6.1.1 Team Timeline

Our build schedule revolves around a distinct two-phase construction approach: design, then build. This is followed by two possible launch dates, the second one to be used in the edge case that the first launch is made impossible due to weather, mechanical issue, etc. In the case that neither launch is possible, our team has a list of backup launch dates and locations that are less desirable due to either distance or timing, but they will be acceptable in the case that they are needed.

6.2 Planned Expenditures

This budget has not yet been finalized and is subject to change. Some items are not listed, and generalizations are made based on current observations and past experiences.

Thrust Section			
Item	**Price Per Unit ($)**	**Quantity**	**Total**
3.75in aluminum plate	5	5	25

(.13in)			
ADAS Section			
Item	**Price Per Unit ($)**	**Quantity**	**Total**
Socket head cap screw	.25	10	2.5
3.75in wood disk	1	8	8
Eyebolt	5	4	20
All-thread Material	15	1	15
Hex nuts	.1	20	2
Lock nuts	.2	20	4
NEMA 17 Stepper Motor	15	1	15
ADAS Battery 11v-850mah	16	1	16
Avionics Section			
Item	**Price Per Unit ($)**	**Quantity**	**Total**
Main parachute (60”)	80	1	80
Drogue parachute (24”)	55	1	55
Perfectflite Stratologger	55	2	110
9v battery	2.5	10	25

Nosecone Section			
Item	**Price Per Unit ($)**	**Quantity**	**Total**
3:1 Fiberglass	40	1	40

Nosecone			
Beacon Battery	15	1	15
Beacon	80	1	80
Rover Payload			
Item	**Price Per Unit ($)**	**Quantity**	**Total**
Wheel	5	4	20
Tread	15	2	30
Motor	25	1	25
Scoop	5	2	10
General Hardware (screws, epoxy, etc)	150	1	150
General Travel	100	4	400
Travel	500	8	4000
Grand Total			**5147.5**

Table 6-1 Planned Expenditures including Travel

6.3 Funding

6.3.1 General Funding

Our funding will come mainly from fundraiser projects such as the team's GoFundMe campaign and the University of California Santa Cruz's Giving Day event. This has proven to be an effective funding strategy, as shown by our success last year, when we raised over $5,000 from the two projects alone. This year, we will incorporate a financial outreach program that seeks to establish sponsorships with local, as well as non-local businesses. Due to the efficient and economical operation of our team, we are confident that even without any additional funding, we will accomplish our goals. Still, we will aspire to not only improve on the quality of our work, but to nourish local businesses and establish mutually beneficial relationships with multiple local and non-local companies.

6.4 Sustainability

6.4.1 Partnerships/Funding Sustainability

We have already began discussing partnership opportunities with several local businesses, specifically for the manufacturing of several key components in our planned builds at discounted prices in exchange for promotion of their company. This is part of a widespread effort in our team to further engrain ourselves into the community at our school, surrounding area, and intellectual community. For our funding sustainability, we are aiming to find companies that are willing to provide capital funding in exchange for promotion. We have reached out to several companies and are in the process of establishing an effective relationship with them.

6.4.2 Student Engagement/Recruitment

For recruitment of team members, we have several planned outreach events such as OPERS fest, where we plan to recruit the majority of our members. In addition to planned events, we have had great success with recruiting team members through personal outreach in our classes and extracurricular activities, which serves to be great since people in such areas are inclined to already be interested in STEM enrichment activities.

6.4.3 STEM Engagement

For STEM engagement, we have planned several outreach events at local schools, social clubs, and school-sponsored events. We will engage students at the university level, as well as students in elementary, middle, and high school programs. Our goal is to inspire a diverse group of individuals from a variety of intellectual, ethnic, and economic backgrounds.

7 Conclusion

The Rocket Team at UCSC is excited to participate again in the Student Launch competition after last year's astonishing rookie performance in coming close to a fully capable, and efficient vehicle design. We are quite humbled by the support we received from NASA, our families and friends, and even our own Congressional representative, Jimmy Panetta. Our efforts truly become more impressive in light of the fact that the organization has no mechanical or aerospace engineering departments on campus for support. Instead, the team is able to rely on the tenacity and persistence of its membership to advance our mission. After some tough decisions and meetings, the team has reorganized its leadership and division of labor to overcome the pitfalls of the past year. Since the team's inception, we have garnered the publicity and students willing to carry on the technological progress made thus far. This year, the team also sets it sights on reaching out to more of the local community and schools, as well as securing additional funding. Numerous electronics companies located around Silicon Valley would be capable of sending devices and components for great values towards the team and its non-profit status. Nearby elementary and middle schools we reached out to this past year were grateful for the demonstrations and education we provided and are looking forward to our return. Above all, we are looking to expand our presence on campus by bringing in more students this year, and improve the standards of safety we uphold, both for ourselves and the projects we facilitate. It should prove to be an intense yet rewarding challenge for the team, and one we hope will secure the presence and spirit of the team at UC Santa Cruz and beyond.

8 Appendix

Appendix A - Safety Acknowledgement Form

Rocket Team at UCSC Safety Acknowledgement Form

I, ______________________________, hereby agree to the terms and conditions specified in the following laws and guidelines with which the Rocket Team at UCSC shall abide by. They are as follows:

Federal Laws and Regulations:

1. Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets
2. Code of Federal Regulation 27 Part 5: Commerce in Explosives; and Fire Prevention
3. NFPA 1127 "Code for High Power Rocket Motors"

NASA Safety Guidelines:

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.

In addition to the above, I also certify that I have completed the following courses located on the UC Learning Center website using my own UC Santa Cruz school student account in order to gain access to the on-campus Sustainability Lab program spaces:

1. Laboratory Safety for Research Personnel
2. Hazardous Waste Management

By signing this document, I acknowledge that I have read and understood the information listed above, have read and completed all deliverables in the Rocket Team at UCSC's Safety Manual, and agree to abide by the aforementioned laws, rules, regulations, guidelines, and any future iterations thereof. Failure to satisfy these conditions will result in immediate punishment, or discharge from the team, by the Safety Officer at their discretion.

____

(Print Full Name)

______________________________ ______________

(Signature) (Date)