

ESRA 30k Aerodynamics & Recovery

Team # 2.4



Technical Portfolio Revision 4

March 20th, 2020

Team members:

Annalise Daul
Mikayla Farr
Hayden Ferrell

Project Sponsor:

Oregon State AIAA

MIME Advisor:

Dr. Nancy Squires

Supervising Instructor:

Dr. Nancy Squires

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Project Management



Team Charter

Team Purpose

The Aerodynamics & Recovery sub-team is responsible for researching, designing, and manufacturing the dual deployment recovery system; designing the nose cone; performing simulations and calculating aerodynamic performance characteristics. This sub-team will meticulously record and ensure proper component weights, determine drag and lift coefficients of the rocket, manufacture both parachutes, research and design the fins and nose cone, perform simulations to successfully predict flight path, apogee altitude, touchdown velocity, lift and drag coefficients and flight characteristics, and ensure overall mission success. The team will also be working closely with the Structures and Integration, Payload, and Propulsion subteams to discuss rocket design parameters to facilitate simulations, ensure accessibility to the avionics bay, and create a functional and reliable recovery system for the rocket. Furthermore, Aerodynamics & Recovery will work with Avionics for TeleMega communication, accurate altimeter readings, and overall mechatronics. Stakeholders of our team are Dr. Nancy Squires, the American Institute of Aeronautics and Astronautics, Oregon State University, and all of the team members themselves. It is expected that our team prioritizes safety and the success of the ESRA 30K Rocket Team as a whole.

Team Goals

Aerodynamics & Recovery strives to design and implement a successful recovery system, perform accurate simulations, and ensure favorable aerodynamics for our rocket. All of these goals will support mission assurance and success. The team also has specific goals:

- Place at the 2020 Spaceport America Cup competition.
- Integrate all components of the recovery system successfully. Ensure ease of access to the avionics bay.
- Successfully deployment of both the drogue and main parachutes. Safely land the rocket with a touchdown velocity less than the maximum allowable velocity.
- Earn and receive an “A” in MIME 497 and MIME 498.
- Test all parameters to ensure the highest degree of mission success.
- Research, design, and test an alternative deployment method (specifically, compressed carbon dioxide) to black powder charge. If feasible, use this charge method for dual deployment at competition.
- Make this team and this mission our top priority.

Team Member Roles/Responsibilities

Mikayla Farr	Subteam Lead	Fin Design, Simulations, Safety Point of Contact
Hayden Ferrell	Weight & Status Lead	Nose Cone Design, Ejection System, TeleMegas
Annalise Daul	PDM/CAD Lead	Recovery System Design, Parachutes

Ground Rules

Regular team meeting schedule and location:	Tuesday at 2PM, Rogers 340
Regular advisor meeting schedule and location:	Wednesday at 6PM, Rogers 226
Primary method of communication:	Text/Phone Call
Secondary method of communication:	Email

All team members must also adhere to the following ground rules:

1. There shall be no unexcused absences from meetings. If an emergency arises and members cannot attend a meeting, team members must communicate their absence to the subteam or team lead.
2. In case of tardiness, communicate with team lead as soon as possible and arrive as soon as possible.
3. Prioritize team and overall mission above all else.
4. Hold yourself responsible and perform the work to which you committed. Team members will contribute equal parts and assist other members with their responsibilities.
5. Complete tasks in a timely manner.
6. Communicate all questions, struggles, and concerns. Do not hesitate to ask clarifying questions, to challenge team members, and keep communication open and honest.
7. Design within and around the budget. Allocate funds to the most significant parameters prior to further allocation.
8. Conflicts will be dealt with as soon as possible. If necessary, a mediator may be used to help with conflict resolution.
9. Do not, under any circumstances, sacrifice the safety of others.
10. By signing this team charter, team members are fully committing to ESRA 2019-2020 and the completion of MIME 497 and MIME 498.

Potential Barriers and Coping Strategies

Potential barriers to our success are related to the overall budget, weight restrictions, and design complications of parachute manufacturing, nose cone design, and the architecture of the recovery system. Specific obstacles are detailed below:

- Budget Concerns
 - The material used for the parachutes can be very expensive. To reduce cost, our team will collaborate with other rocketry teams to order bulk material.
 - The use of compressed carbon dioxide for parachute deployment will certainly be more expensive than black powder. Compressed carbon dioxide canisters can be purchased commercially but are expensive.
 - If the outer diameter of our rocket changes from the previous year, Aerodynamics & Recovery will be responsible for recreating a nose cone mold. This will be time-consuming as well as expensive.
- Weight and Size Concerns
 - The compressed carbon dioxide system will be heavier than a black powder system. Since the team will attempt to minimize the weight of the rocket as much as possible, Aerodynamics & Recovery must be prepared to design with strict weight restrictions.

- The parachutes will be very heavy. However, reducing the size of the parachute could compromise the safety of the rocket upon descent.
- The parachutes will take up a lot of space. The team must be able to determine the most compact method for packing the parachutes. The team must also be able to fit all protective bags (for example, parachute protection blankets or bags) within the allotted space.
- Workload Concerns
 - Team members are students and will have responsibilities outside of ESRA. Thus, the team must be able to balance the workload appropriately. In some cases, exams or assignments could be barriers to progress.
 - All team members will be busy, and, as a result, the scheduling of meetings, deadlines, assignment work times, and so on will be dependent on each team member's availability.
- Limited Time
 - Developing all components for the recovery system, performing simulations, computing fluid dynamics of the rocket, determining drag and lift coefficients, and researching will take a lot of time. All aspects of the work require methodical designing and testing, both of which could extend our timeline.
 - The competition date is set in stone. If we are behind schedule, we cannot push out the date of the competition; the team must deliver on time.

In addition, the team will likely be under extreme pressure and high-stress situations. In order to balance stress and responsibilities, the team must stay on top of work, eliminate procrastination, and establish a personal routine or method to cope with stress.

Aerodynamics & Recovery Subsystem Responsibilities

Components/Sub-systems

- Fins
 - Fin Research: Mikayla Farr
 - Fin Design: Mikayla Farr
 - Fin Flutter Analysis: Hayden Ferrell
- Nose Cone
 - Nose Cone Research: Hayden Ferrell
 - Nose Cone Design: Hayden Ferrell
- Recovery System
 - Drogue and Main Parachute Research: Annalise Daul
 - Drogue Parachute Design: Annalise Daul
 - Verify Main Parachute Design: Annalise Daul
 - Recovery System Research: Annalise Daul, Mikayla Farr
 - Recovery Harness Design: Mikayla Farr, Hayden Ferrell
 - Shock Cord Length
 - Swivels
 - Quick Links
 - Manufacturing Drogue Parachute: Annalise Daul, Mikayla Farr, Hayden Ferrell
 - Test of Main Parachute on MATLAB: Annalise Daul
 - Test of Drogue Parachute on MATLAB: Annalise Daul
- Ejection System
 - Black Powder Ejection System Research: Annalise Daul, Hayden Ferrell
 - Black Powder Calculation: Hayden Ferrell
 - Ejection System Design: Annalise Daul, Mikayla Farr, Hayden Ferrell
 - TeleMegas/Avionics Point of Contact: Hayden Ferrell
- Simulations
 - OpenRocket: Mikayla Farr
 - RAS Aero II: Mikayla Farr

Persons & Roles

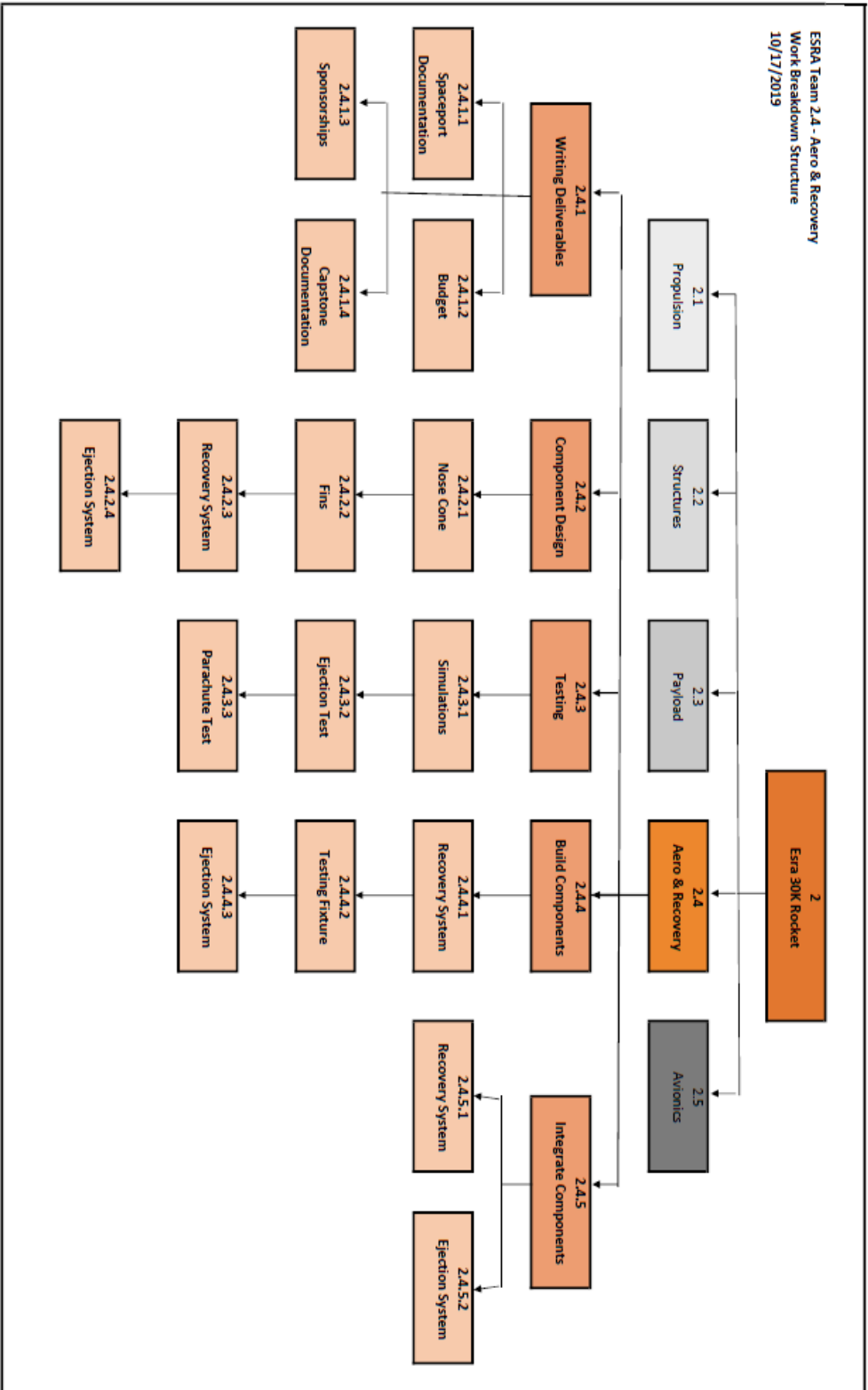
- Mikayla Farr
 - *Team Lead*: The main point of contact for the Aero and Recovery sub-team. Also responsible for scheduling meetings (both with sub-team members and with other sub-teams), organizing the sub-team drive, and verifying all due dates are met.
 - *Team Budget*: Responsible for verifying the Aero and Recovery sub-team stays within budget.
 - *Spaceport America Documents*: Responsible for proofreading all Spaceport America documents and turning them in.
 - *Safety Point of Contact*: Responsible for all safety documentation and ensuring all members on the sub-team abide by safety regulations.
- Annalise Daul
 - *PDM Lead*: Responsible for managing CAD parts and assemblies numbering system.

- *Team Inventory*: Responsible for taking inventory and maintaining status on the inventory.
- Hayden Ferrell
 - *Weight and Status Lead*: Responsible for creating, updating and maintaining a digital ledger of all current and past component weights for use in simulations and rocket stability.
 - *Team Sponsor*: Responsible for carrying out sub-team sponsor requests through required paperwork and communicating with the overall team sponsorship point of contact.

Certifications

- Ply Cutter Certification
- Propulsion Lab Certification
- Black Powder Seminar
- Sewing Education

Work Breakdown Structure



Project Schedule

ID	Task Name	Duration	Start	Finish	Amount	Separator	October	November	December	January	February	March	April	May	June	July
1	ESPA 30K Aero and Recovery	270 days	Wed 9/25/19	Sat 6/20/20												
2	Documentation	232 days	Fri 9/27/19	Fri 5/15/20												
3	Scope and Research Statement	35 days	Fri 9/27/19	Thu 10/31/19												
4	Design Proposal	22 days	Thu 11/14/19	Thu 12/5/19												
5	Design Proposal Revision	8 days	Fri 1/24/20	Fri 1/31/20												
6	Evaluation 1	1 day	Mon 2/10/20	Mon 2/10/20												
7	Final Presentations	1 day	Mon 3/9/20	Mon 3/9/20												
8	Evaluation 2	1 day	Tue 3/17/20	Tue 3/17/20												
9	Final Report	25 days	Fri 4/17/20	Mon 5/11/20												
10	Engineering Expo	1 day	Fri 5/15/20	Fri 5/15/20												
11	Design	116 days	Wed 9/25/19	Sat 1/18/20												
12	Research	52 days	Wed 9/25/19	Fri 11/15/19												
13	Design Drogue Parachute	85 days	Thu 10/17/19	Thu 1/9/20												
14	Verify Last Years Main Parachute	60 days	Thu 10/17/19	Sun 12/15/19												
15	Design Fins	35 days	Tue 10/22/19	Mon 11/25/19												
16	Design Nose Cone	35 days	Tue 10/22/19	Mon 11/25/19												
17	Simulations Round 1	55 days	Tue 10/29/19	Sun 12/22/19												
18	Optimize Fins Round 1	35 days	Mon 11/18/19	Sun 12/22/19												
19	Design Recovery System	10 days	Thu 1/9/20	Sat 1/18/20												
20	Test	120 days	Sat 1/11/20	Sat 5/9/20												
21	Simulations Round 2	4 days	Sat 1/11/20	Tue 1/14/20												
22	Optimize Fins Round 2	4 days	Sat 1/11/20	Tue 1/14/20												
23	Test Drag Coefficient of Nose Cone	20 days	Mon 1/13/20	Sat 2/1/20												
24	Upper Body Integration Test	1 day	Sat 1/25/20	Sat 1/25/20												
25	First Full Scale Integration Test	1 day	Sat 2/1/20	Sat 2/1/20												
26	Simulations Round 3	4 days	Sun 2/9/20	Wed 2/12/20												
27	Optimize Fins Round 3	6 days	Sun 2/9/20	Fri 2/14/20												
28	Second Full Scale Integration Test	1 day	Sat 2/15/20	Sat 2/15/20												
29	Ejection Tests	14 days	Fri 2/28/20	Thu 3/12/20												
30	Third Full Scale Integration Test	1 day	Sun 3/1/20	Sun 3/1/20												
31	Telemeter Flight Mode Test	1 day	Mon 3/2/20	Mon 3/2/20												
32	Fourth Full Scale Integration Test	1 day	Sun 3/8/20	Sun 3/8/20												
33	First Full Scale Launch	1 day	Sat 4/11/20	Sat 4/11/20												
34	Second Full Scale Launch	1 day	Sat 5/9/20	Sat 5/9/20												
35	Build	164 days	Thu 1/9/20	Sat 6/20/20												
36	Build Recovery System	17 days	Thu 1/9/20	Sat 1/25/20												
37	Manufacture Shock Cords	7 days	Sat 1/25/20	Fri 1/31/20												
38	Manufacture Drogue Parachute	17 days	Wed 1/29/20	Fri 2/14/20												
39	Ballast Entire Rocket	28 days	Fri 2/28/20	Thu 3/28/20												
40	Completion	5 days	Tue 6/16/20	Sat 6/20/20												

Project: Aero and Recovery Sch
Date: Thu 4/2/20

Task: Sprint Milestone Summary

Project Summary: Inactive Task Inactive Milestone Inactive Summary

Manual Task: Manual Summary Rollup Manual Summary

Start only: Finish only: Done

Progress: Manual Progress

Page 1

Global CRs/ESs



Global Customer Requirements and Engineering Specifications

Table 1. Global customer requirements.

Number	Customer Requirement	Weight
1	The rocket must follow all IREC safety requirements.	30
2	The rocket must be designed and manufactured on budget.	20
3	The rocket must meet 30,000 feet, through simulation.	25
4	The rocket must be lightweight.	25
5	The rocket must comply with SA and ESRA rules.	25
6	The rocket must be integrated by the first launch window.	25

Table 2. Global engineering specifications.

Number	Engineering Specifications	Upper Limit	Lower Limit	Target
1	Total number of incidents that do not meet safety requirements.	--	--	0
2	Total amount project goes over budget.	--	--	< \$9,000
3	Altitude of rocket.	39,000 ft	21,000 ft	30,000 ft
4	Combined weight of rocket.	150	--	< 100
5	Total number of competition rules not followed.	--	--	0
6	Time necessary to complete full integration.	--	--	< 7 hr

Global Engineering Specifications Justification

Engineering Specification #1: Total number of incidents that do not meet safety requirements

Justification: The Experimental Science Rocketry Association (ESRA) requires adherence to all safety requirements designated by the Intercollegiate Rocket Engineering Competition (IREC). Failure to meet all rules and regulations may result in disqualification from the competition. It is imperative to ensure the total number of incidents that do not meet the safety requirements is zero.

Engineering Specification #2: Total amount project goes over budget

Justification: At the beginning of the term, ESRA is allotted a fixed budget (approximately \$10,000) through the College of Engineering and American Institute of Aeronautics and Astronautics. Exceeding this budget will require alternative fundraising and sponsorships.

Engineering Specification #3: The altitude of the rocket

Justification: The OSU ESRA team is in the 30,000 ft AGL apogee with SRAD solid rocket propulsion system category, so the goal is 30,000 ft. Points will be awarded for $\pm 30\%$ of the goal apogee, so the upper and lower specification limits are 39,000 ft and 21,000 ft respectively.

Engineering Specification #4: Combined weight of rocket

Justification: The weight of the fully integrated rocket will affect the aerodynamics of the flight, the amount of propellant needed, and the recovery system. Based on the recommendations given by Oregon Rocketry (OROC) mentors, the combined weight of the rocket must be below 150 lbs, with a goal of achieving a weight less than 100 lbs.

Engineering Specification #5: Total number of competition rules not followed

Justification: Failing to adhere to all competition rules and regulations may result in disqualification of the ESRA team. Therefore, it is of utmost importance to ensure the total number of competition rules not followed will be zero.

Engineering Specification #6: Time necessary to complete full integration

Justification: At the competition, the time necessary to fully integrate the rocket will be limited. If the rocket is not rail-ready by our designated launch time frame, we will lose the opportunity to compete at Spaceport America.

Aero and Recovery CRs/ESs



Customer Requirements and Engineering Specifications that Aero and Recovery are Responsible for

Table 3. Global customer requirement that Aero and Recovery is responsible for.

Number	Customer Requirement	Weight
3	The rocket must meet 30,000 feet, through simulation.	25

Table 4. Aero and Recovery specific customer requirements.

Number	Customer Requirement	Weight
7	The rocket must be stable.	25
8	The drogue and main parachutes must provide sufficient descent speeds.	50
9	The rocket must have backup deployment charges.	5
10	The rocket must have successful pre-flight separation and parachute deployments.	20

Table 5. Global engineering specification that Aero and Recovery is responsible for.

Number	Engineering Specifications	Units	Lower Limit	Target	Upper Limit
3	Altitude of Rocket.	ft	21,000	30,000	39,000

Table 6. Aero and Recovery specific engineering specifications.

Number	Engineering Specifications	Units	Lower Limit	Target	Upper Limit
7.1	The center of pressure must be aft of the center of gravity by the specified stability margin on the launch rail.	Calibers	1.5	1.75	2
7.2	The center of pressure must be aft of the center of gravity by the specified stability margin during the flight profile.	Calibers	1.5	-	6
8.1	The drogue parachute must provide an appropriate descent velocity for the rocket from apogee.	ft/s	75	100	150
8.2	The main parachute must provide an appropriate descent velocity to safely land the rocket on the ground.	ft/s	-	≤ 30	-
9	The number of backup deployment charges that detonate for the entire recovery system.	#	0	2	2
10	The number of successful parachute deployment tests per parachute.	#	--	3	--

Aero and Recovery Engineering Specifications Justification

In addition to ESRA's Universal Engineering Specifications, there are seven Aerodynamics & Recovery Engineering Specifications that can be found on tables 3 and 4. This document explains and supports the engineering specifications (ES) values and tolerances for all Aerodynamics & Recovery engineering specifications for the overall mission.

ES 3: The altitude of the rocket.

- Lower Limit: 21,000 ft
- Target: 30,000 ft
- Upper Limit: 39,000 ft

Justification: The OSU ESRA team is in the 30,000 ft AGL apogee with SRAD solid rocket propulsion system category, so the goal is 30,000 ft. Points will be awarded for $\pm 30\%$ of the goal apogee, so the upper and lower specification limits are 39,000 ft and 21,000 ft respectively.

ES 7.1: The center of pressure must be aft of the center of gravity by the specified stability margin on the launch rail.

- Lower Limit: 1.5 calibers
- Target: 1.75 calibers
- Upper Limit: 2.0 calibers

Justification: Spaceport America Cup IREC Design, Test, & Evaluation Guide [1] states, "Launch vehicles shall remain 'stable' for the entire ascent. Stable is defined as maintaining a static margin of at least 1.5 to 2 body calibers, regardless of CG movement due to depleting consumables and shifting center of pressure." Aerodynamics & Recovery will design for the center of pressure (CP) to be 1.75 calibers aft of the center of gravity (CG) to ensure stability of the rocket and comply with IREC rules.

ES 7.2: The center of pressure must be aft of the center of gravity by the specified stability margin during the flight profile.

- Lower Limit: 1.5 calibers
- Upper Limit: 6.0 calibers

Justification: Spaceport America Cup IREC Design, Test, & Evaluation Guide [1] states, "Launch vehicles shall remain 'stable' for the entire ascent. Stable is defined as maintaining a static margin of at least 1.5 to 2 body calibers, regardless of CG movement due to depleting consumables and shifting center of pressure. All launch vehicles should avoid becoming "over-stable" during their ascent. A launch vehicle may be considered over-stable with a static margin significantly greater than 2 body calibers (eg greater than 6 body calibers)." Aerodynamics & Recovery will design for the center of pressure (CP) to be aft of the center of gravity (CG) by the stability criteria allowed by IREC rules for the entire flight profile.

ES 8.1: The drogue parachute must provide an appropriate descent velocity for the rocket from apogee.

- Lower Limit: 75 ft/s
- Target: 100 ft/s
- Upper Limit: 150 ft/s

Justification: Spaceport America Cup IREC Design, Test, & Evaluation Guide [1] states that the drogue parachute must deploy at or near apogee with a descent velocity recommended between 75 ft/s and 150 ft/s. Thus, Aerodynamics & Recovery decided to design the drogue to obtain a target descent velocity of 100 ft/s. The purpose of the drogue is to slow and orientate the rocket for the main parachute deployment, and, as such, the team decided that a value between the recommended velocities was sufficient.

ES 8.2: The main parachute must provide an appropriate descent velocity to safely land the rocket on the ground.

- Target: Less than 30 ft/s

Justification: As with ES 8.1, IREC recommends a descent velocity no greater than 30 ft/s for the main parachute [1]. The target descent velocity will be less than or equal to 30 ft/s to ensure a safe rocket landing.

ES 9: There must be successful backup deployment charge detonations for the entire recovery system.

- Lower Limit: 0
- Target: 2
- Upper Limit: 2

Justification: The backup deployment charges must be tested on the ground prior to the competition launch. There must be a sufficient number of successful detonations of the backup charges to ensure the rocket has a reliable redundant backup system. The team will perform at least four ground tests on the recovery system and there must be at least one successful backup detonation for the rocket as a whole per test. This gives rise to the target value of this engineering specification: four successful detonations of the backup deployment charges.

ES 10: There must be a sufficient number of successful deployment tests per parachute.

- Target: 3

Justification: The recovery system will be tested on the ground as well as during test flights. The team will perform ground tests on the recovery system until each parachute has successfully deployed three times. This number of successful deployments is one less than the number from the 2018-2019 ESRA Aero and Recovery sub-team in hopes to diminish the amount of soot left on the Telemegas from each ejection charge.

[1] 2019, “Spaceport America Cup Intercollegiate Rocket Engineering Competition Design, Test, & Evaluation Guide.”

Codes and Standards

Code or Standard Name: Spaceport America Cup IREC Rules and Requirements

Description: This document defines the rules and requirements in order to participate in the Spaceport America Cup.

Reference: [1] Experimental Sounding Rocket Association, *Spaceport America Cup Intercollegiate Rocket Engineering Competition Rules and Requirements Document*, ESRA (online) available: <http://www.soundingrocket.org/sa-cup-documents--forms.html> (Accessed 10/3/19)

Implications to this project: In order to participate at IREC, the entire ESRA 30k Team must abide by the rules and requirements listed by ESRA and IREC in this document. It is the responsibility of the sub-team to ensure that all components for the recovery system obey the rules outlined in the documentation.

Code or Standard Name: NFPA 1127-Code for High Power Rocketry

Code Description/ Summary: This code outlines the proper procedures for safe operation of high power rockets.

Reference: [2] *Code for High Power Rocketry*, NFPA Standard 1127-2008 (online) available: <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1127> (Accessed 11/7/19)

Implications to this project: The NFPA code outlines how to properly operate a high power rocket which is the same rocket classification that the ESRA 30k Team is intending to manufacture and fly at IREC. The Aero & Recovery sub-team must understand how to safely operate a high powered rocket in order to launch at IREC.

Code or Standard Name: ATF Title 18, United States Code, Sec. 1102, Chapter 40

Code Description/ Summary: This code explains how to handle, store, and classify certain explosives.

Reference: [3] U.S. Department of Justice Bureau of Alcohol, Tobacco, Firearms and Explosives, *Federal Explosives Law and Regulation*, ATF (online) available: <https://www.atf.gov/explosives/docs/publication-federal-explosives-laws-and-regulations-atf-p-54007/download> (Accessed 11/7/19)

Implications to this project: The Aero & Recovery sub-team will be using black powder charges to deploy the drogue and main parachutes. This will involve frequent storage, handling, and packing of black powder for detonation. The sub-team must review and comply with the US Code to ensure the safe use and storage of all black powder charges both in and out of competition.

Design Specifications



Design Specifications for the Overall Rocket

Summary

Fully integrated, the rocket is 145 in. from the tip of the nose cone to the end of the boat tail and with an outer diameter of 6.339 in. This gives us an aspect ratio of 1:22.87. The rocket currently weighs 136 lbs with the propellant and approximately 93.8 lbs without.

The main parachute is positioned between the nose cone assembly and the avionics bay, and will be attached to each with an eyebolt. The drogue will additionally be attached to the avionics bay on one end, as well as the bulkhead above the forward enclosure on the other. The payload will be situated in the nose cone assembly of the rocket, as it is non-deployable and will stay in the nose cone for the duration of the flight. It will be secured with a removable bulkhead, while the motor will be retained with a permanent bulkhead adhered to the lower body tube. The avionics bay will have a permanent bulkhead adhered to the inner walls of the upper body tube, while the other bulkhead will be removable and attached with a threaded rod through the assembly.

As it stands now, our rocket has an acceptable stability margin range. Simulations in OpenRocket show that the current static stability is 1.71 calibers, with center of gravity and center of pressure 92.005 in. and 103in. from the tip of the nose cone, respectively. A simulation in RASAero II yielded a stability margin range of 1.68 calibers to 4.17 calibers which is within the 1.5 to 6.0 caliber range allowed by IREC.

Spaceport America recently released drawings for a ballistics tracker that will be required in all rockets at the competition. The team is currently in the process of finding ways to attach the tracker to the rocket without adding any length.

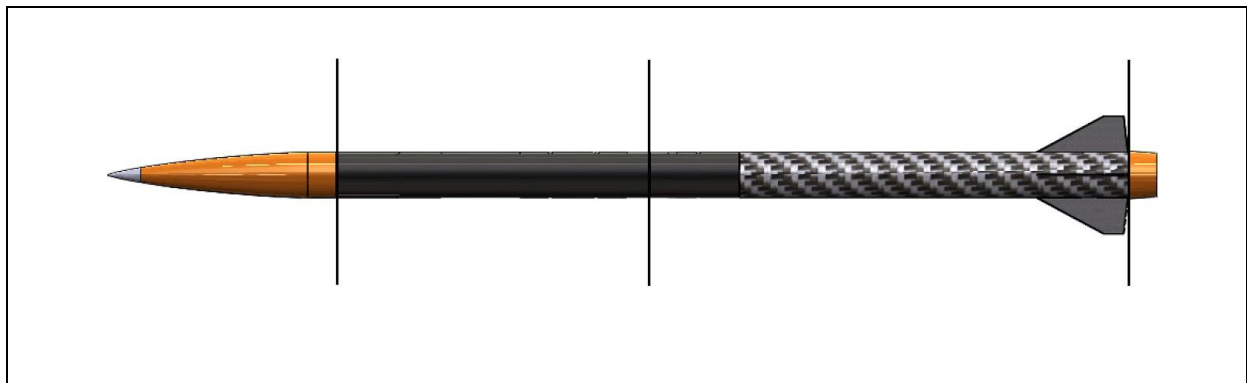


Figure 1. Overview of the entire rocket with breakpoints.

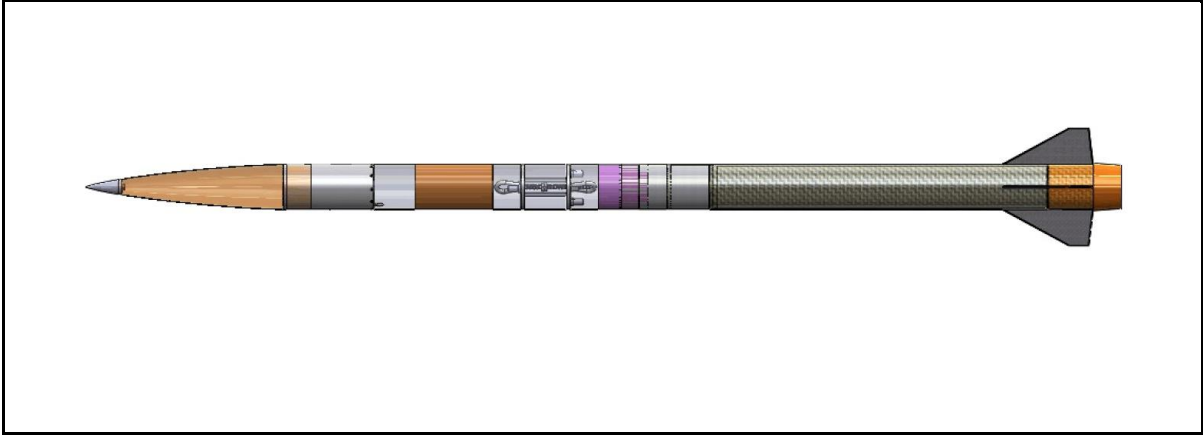


Figure 2. Transparent view of the entire 2019-2020 ESRA rocket.

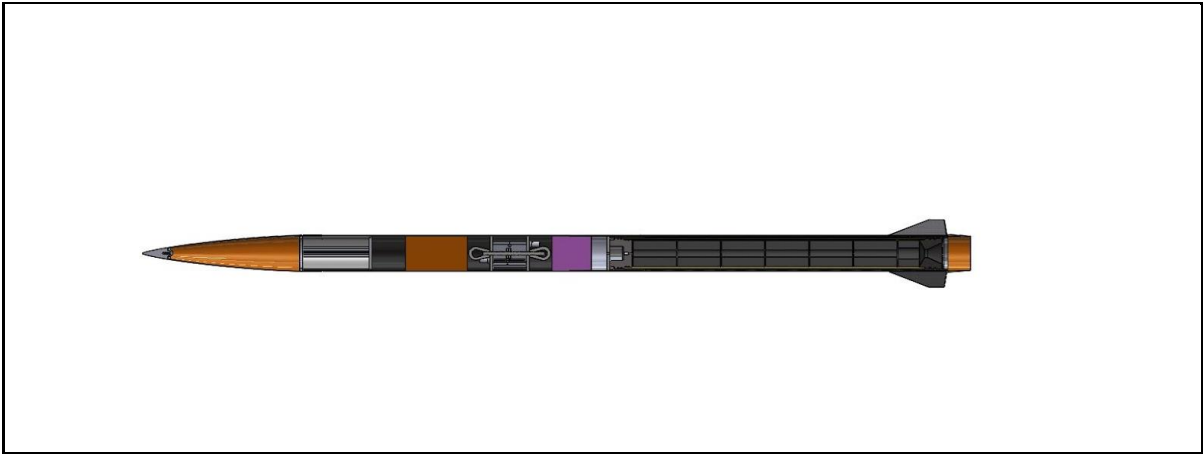


Figure 3. Section view of the entire 2019-2020 ESRA rocket.

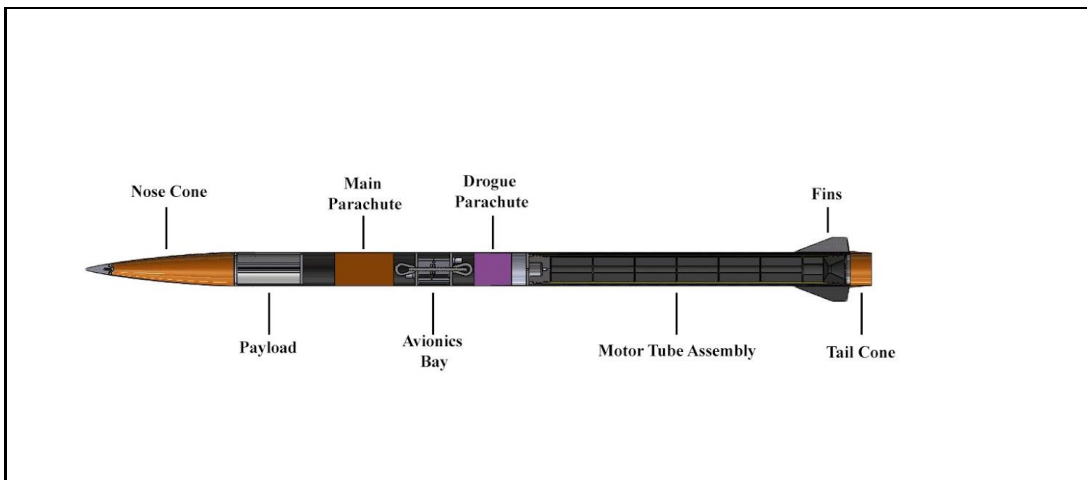


Figure 4. Section view with labels of the entire 2019-2020 ESRA rocket.

Design Specifications for Aerodynamics & Recovery

Ejection System

The current ejection system for the rocket is a black powder system that requires the powder to be packed in surgical tubing and then taped to the bulkhead inside the rocket. The current amounts of black powder needed for the primary and redundant charges for both the main and drogue parachutes are listed in Table 7 and the lengths of surgical tubing required for each charge are listed in Table 8. Each charge has two rubber end stoppers on either end of the surgical tubing. These rubber stoppers are to be cut to 0.75 in. and get three wraps of duct tape to make the fit tighter around the surgical tubing. An extensive procedure on how to pack the charges is included in Appendix A.

Table 7. The mass of primary and redundant ejection charges for both the main and drogue parachutes.

	Main Parachute (Mass, g)	Drogue Parachute (Mass, g)
Primary Charge	6.50	5.50
Redundant Charge	9.75	8.25

Table 8. The length of surgical tubing for the primary and redundant ejection charges for both the main and drogue parachutes.

	Main Parachute (Length, in.)	Drogue Parachute (Length, in.)
Primary Charge	3.500	2.750
Redundant Charge	3.875	3.125

The mass of black powder for each parachute compartment was determined by an initial calculation and then validated/adjusted by completing extensive full-scale ejection tests. First, a calculation was performed to determine the amount of black powder that would pressurize the system to 20 PSI. This enabled a good starting point for black powder mass to be used for testing. This calculated value for each compartment was the first charge size tested. Based on these results, the charge was then increased by 0.5 to 1.0 grams. Once an amount was obtained that fully separated each compartment of the rocket and cleared the recovery system, two additional tests were performed to verify the first was not an anomaly. A more extensive analysis of how these numbers were obtained can be found in the Testing Procedure 3.

There are a total of four ejection charges in the finalized rocket design, two primary charges and two redundant charges. There is also a redundant TeleMega that is used for the redundant charges. Figure 5 is a figure of the finalized OpenRocket design with each ejection charge pointed out and Figure 6 is a schematic of each packed ejection charge.

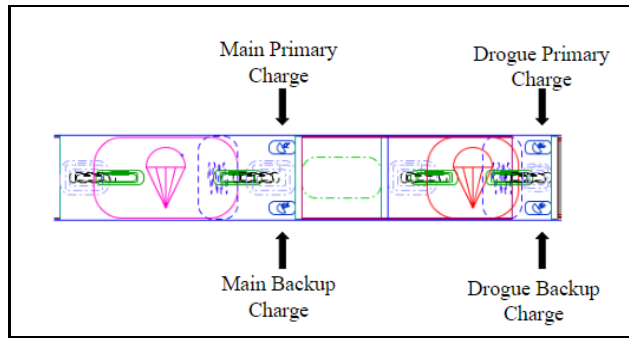


Figure 5. A screen capture of the OpenRocket design showcasing the recovery packing areas with the designated charges.

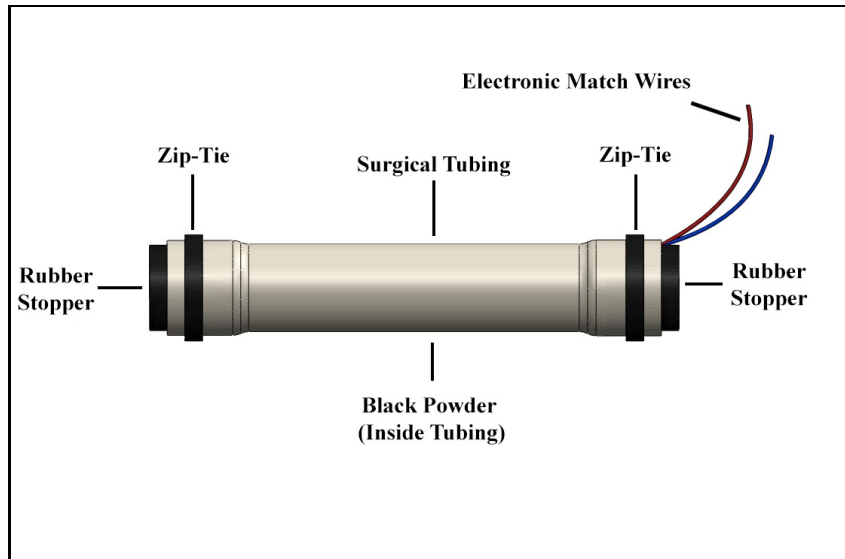


Figure 6. A schematic of a packed black powder charge.

Fin Design and Justification

Research was conducted to determine the optimal fin design for the ESRA 2019-2020 rocket. Although an elliptical fin is the most aerodynamic, it is hard to manufacture [1]. Therefore, more practical shaped fins are trapezoid or clipped deltas. Trapezoid fins are similar to clipped delta fins, except clipped deltas have a swept leading edge, which increases the stability of the rocket [1]. A more important factor than the overall fin shape is the cross-section of the fin. At subsonic speeds, a tapered airfoil cross-section is ideal, while at transonic and supersonic speeds a tapered diamond cross-section is ideal [1]. Another important factor in fin design is the material of the fin. By using multiple materials, such as a composite sandwich, fin flutter is mitigated since each material has a different resonance value [2]. The last design parameter of fin design is the number of fins to use on the rocket. Research concluded that three fins yield slightly better performance than four, but it is a lot harder to ensure proper alignment of three fins [1]. Often, the increase of performance for three fins is negligible.

After conducting this research a fin design was created. The current fin design for the ESRA 2019-2020 rocket is a clipped delta fin with a tapered rectangular cross-section as shown in Figure 7. Chamfers of 0.125 in. at 30° angles were added to the leading and trailing edges to decrease the surface area at the fin's tip chord and create a cross-section similar to a diamond shape. The taper in the fin decreases by 20% of the thickness of the root chord. The current dimensions were determined through the optimization feature in OpenRocket and are shown in Table 9 [3].

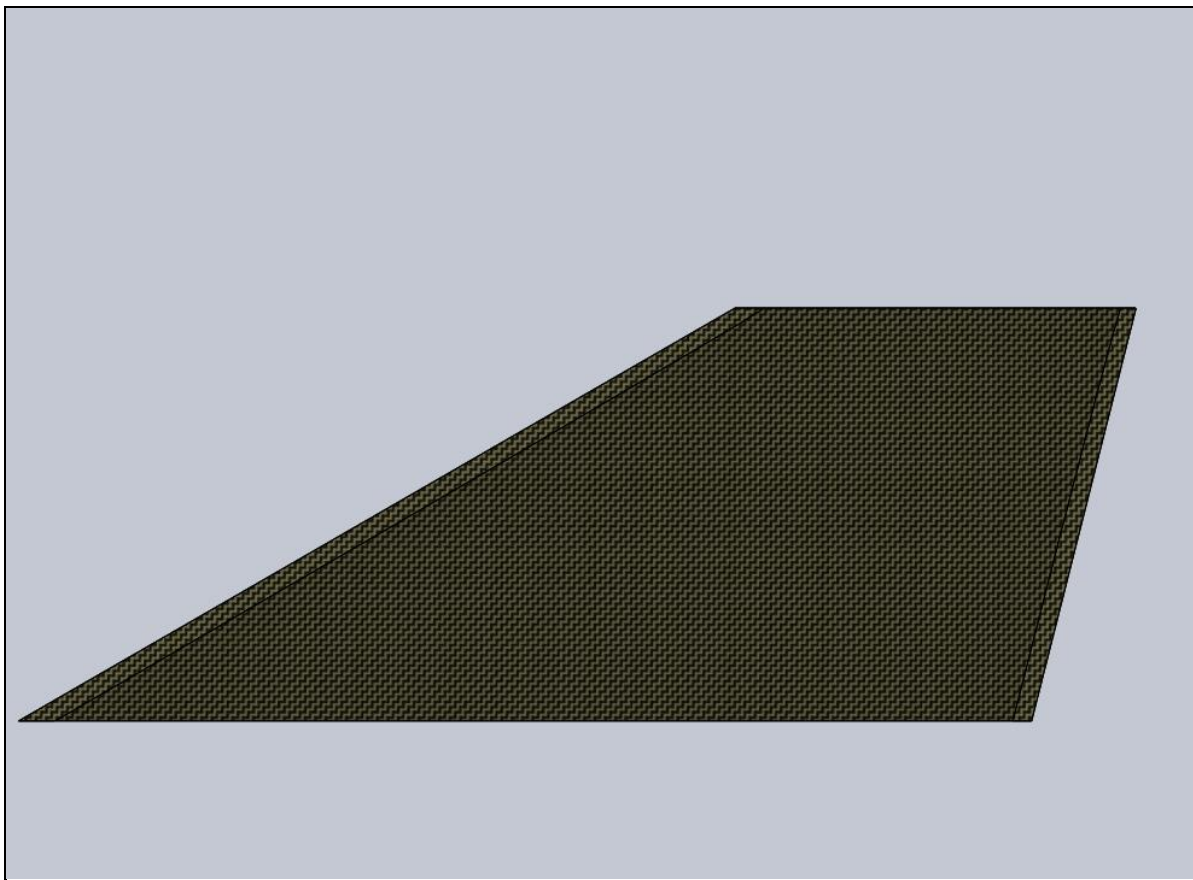


Figure 7. A solid model for the current fin design for the 2019-2020 ESRA team.

Table 9. Current fin dimensions for the 2019-2020 ESRA team.

Name	Dimension
Root Chord	12.00 in.
Span	4.90 in.
Tip Chord	4.75 in.
Sweep Length	8.49 in
Sweep Angle	60°
Root Thickness	0.25 in
Tip Thickness	0.20 in
Cross-Section	0.125 chamfer at 30°

Nose Cone Design and Justifications

Research was conducted to determine the optimal nose cone profile for the 2019-2020 ESRA rocket. This research was conducted using information from Gary Crowell's "A Descriptive Geometry of Nose Cones" [4], Stoney's NACA Research Memorandum [5], and OpenRocket flight simulations. The research concluded that the Von Karman profile, a variation of the Haack Series profile, was the optimal profile for the transonic flight characteristics of the ESRA rocket. The diameter of the nose cone for the 2019-2020 ESRA rocket is determined by the diameter of the airframe, which the Structures and Integration sub-team has confirmed to be 6.4 inches. The length is determined by the fineness ratio, which according to Crowell should be 5:1 [4]. This makes the optimal nose cone length 32 inches. The nose cone body is to be manufactured out of fiberglass, as it is RF transparent and will provide the rigidity needed to be structurally sound during the flight. The nose cone tip is to be manufactured out of 6061 aluminum, as it does not need to be RF transparent and aluminum provides superior performance in regards to aerodynamic heating. Aluminum is additionally readily available and easily machined by the Structures and Integration sub-team. The design derived and optimized for the 2019-2020 ESRA rocket nose cone was nearly identical to that of the 2018-2019 nose cone, therefore the Structures and Integration sub-team opted to utilize the existing 2018-2019 nose cone for the 2019-2020 ESRA rocket. Solid models and overall dimensions for the nose cone body and tip can be seen below in Figure 8 and Table 10 and Figure 9 and Table 11 respectively [3].

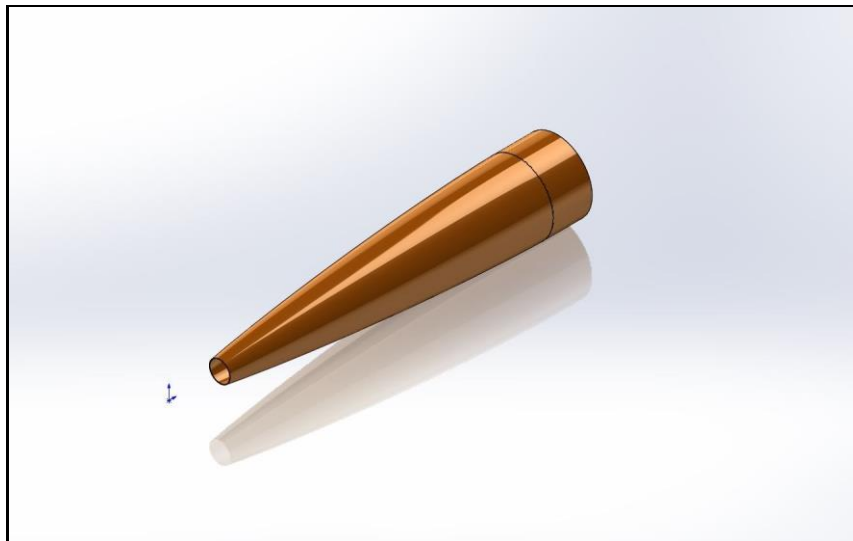


Figure 8. Solidworks model of nose cone body. [3]

Table 10. Current nose cone body dimensions for the 2019-2020 ESRA rocket. [3]

Dimension	Value	Units
Overall Length	31.4	in.
Shoulder Length	4.0	in.
Body Length	27.4	in.
Outer Diameter	6.39	in.
Inner Diameter	6.29	in.
Thickness	0.05	in.

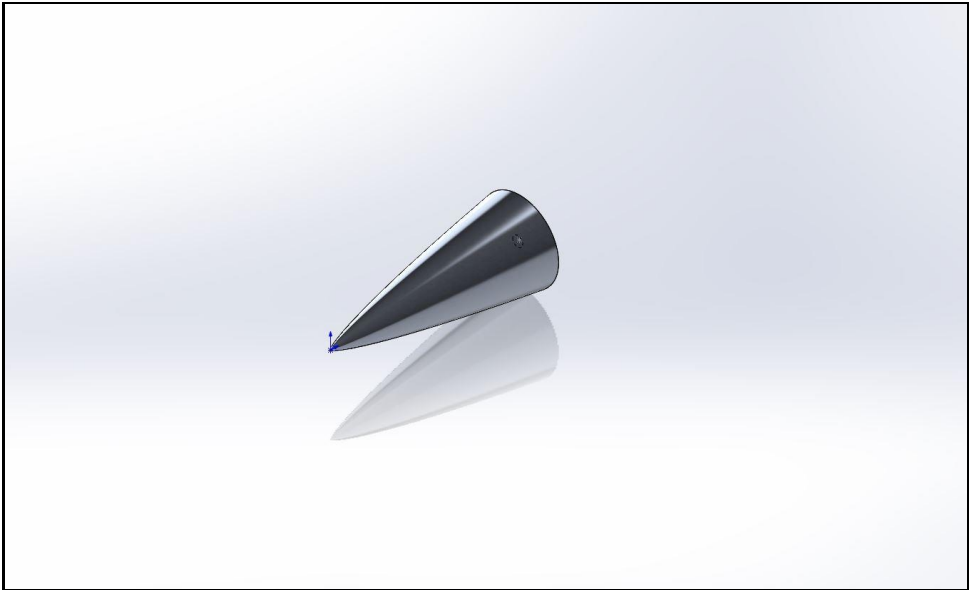


Figure 9. Solidworks model of nose cone tip. [3]

Table 11. Current nose cone tip dimensions for the 2019-2020 ESRA rocket. [3]

Dimension	Value	Units
Length	4.98	in.
Outer Diameter	2.09	in.
Thickness	Filled	N/A
Tap	½-20	UNF

Parachutes Design and Justification

The main and drogue parachutes were designed as parachutes of annular, or toroidal, shape with relatively large spill holes. Annular parachutes have the highest coefficient of drag with the smallest total surface area [6]. Since annular parachutes have less surface area as compared to hemispherical or flat circular shapes, annular parachutes also have the highest drag per canopy weight [6]. Tables 12 and 13 provide the overall dimensions for the drogue and main parachutes, respectively.

Table 12. Drogue Parachute Dimensions.

Dimension	Value	Units
Surface Area	4.39	ft ²
Outer Diameter	28.96	in.
Spill Hole Diameter	5.79	in.
Shroud Line Length	36.20	in.
Packed Length	0.25	in.
Canopy Weight	0.63	oz
Number of Gores	12	-
Gore Base Width	7.89	in.
Gore Vent Width	1.52	in.
Gore Height	19.56	in.
Gore Apex Height	6.13	in.

Table 13. Main Parachute Dimensions, Re-Used from ESRA 2018-2019 Team [3].

Dimension	Value	Units
Outer Diameter	138.9	in.
Spill Hole Diameter	27.8	in.
Shroud Line Length	180	in.
Packed Length	8.72	in.
Canopy Weight	14.37	oz
Number of Gores	12	-

Note that the packing lengths of the parachutes were calculated from the surface area of the canopy, the rolled parachute and an approximate diameter to represent this, and the known packing density for manual packing of parachutes. See Appendices E and F from the Technical Analysis to see the calculations for the drogue and main parachutes, respectively. See Figures 10 and 11 show the gore layout for the drogue parachute and main parachute, respectively.

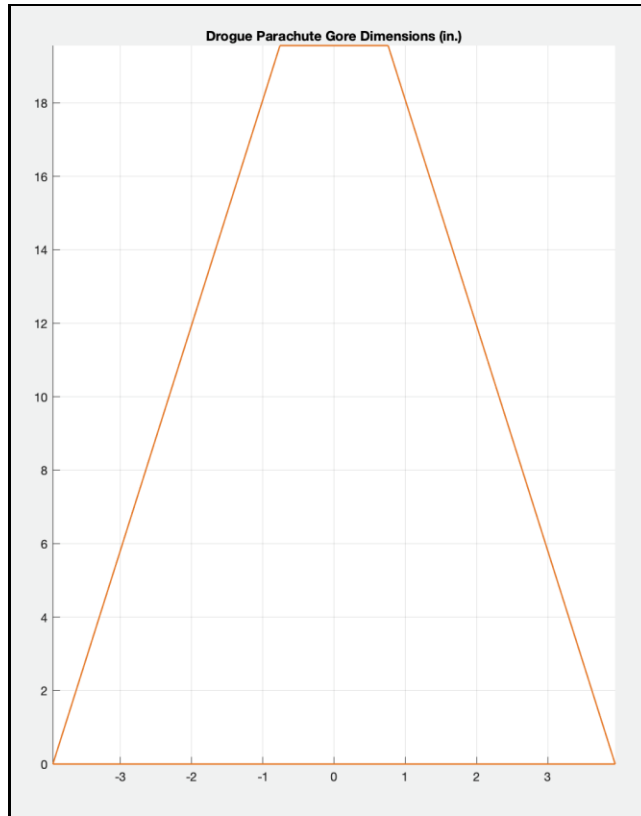


Figure 10. Drogue Parachute Gore Design.

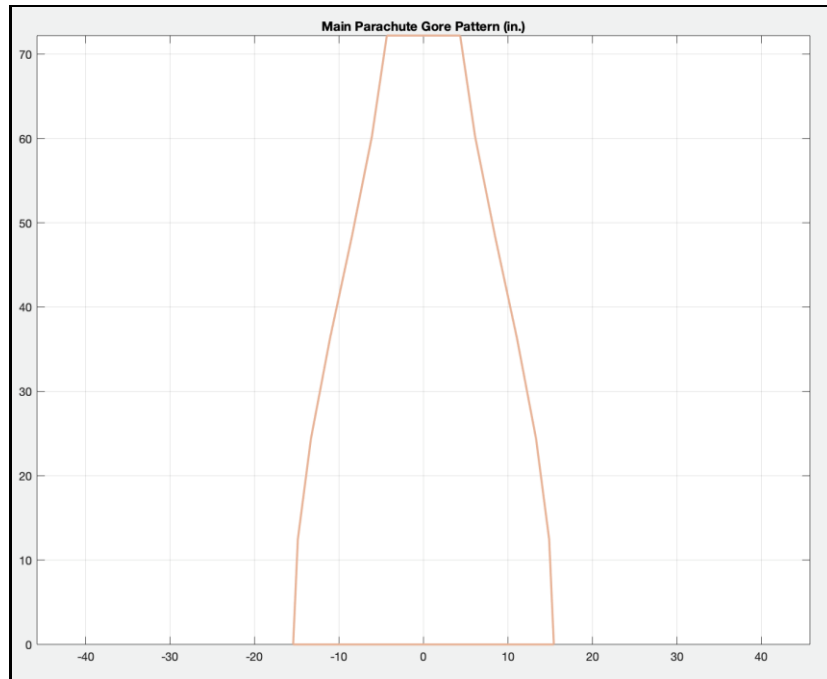


Figure 11. Main Parachute Gore Design from ESRA 2018-2019 Team.

The main parachute will be stored within a deployment bag. The main parachute deployment bag was purchased from Fruity Chutes, a commercial parachute and rocketry products. The main parachute deployment bag has a length of 11 in. and the parachute will be packed to this length and added to the lower body airframe. The CAD model for the main parachute reflects this set length. The drogue parachute will not be contained within a deployment bag; the parachute will be folded and rolled properly. It will be wrapped in a Nomex blanket and added to the upper body frame. From practice, the team measured an approximate packed length of 7 in., and the CAD model reflects this length. This accounts for the discrepancies between the CAD models for the packed parachutes, Figures 12 and 13, and the calculated packed lengths, Tables 12 and 13.

The parachutes will be made from nylon fabric. Nylon provides high strength, toughness, high capacity of energy absorption, and has a relatively low weight [7]; all of the material properties of Nylon are desirable for parachutes. The previous team, 2081-2019 ESRA 30k Rocketry Team, used ripstop nylon as the parachute canopy material [3]. Other Oregon State University AIAA Capstone teams have historically used the ripstop nylon as well. As such, the material chosen for the parachute was 1.1 oz/yd² ripstop nylon. Figures 14 and 15 show the MATLAB plots of the main and drogue parachute canopies, respectively.

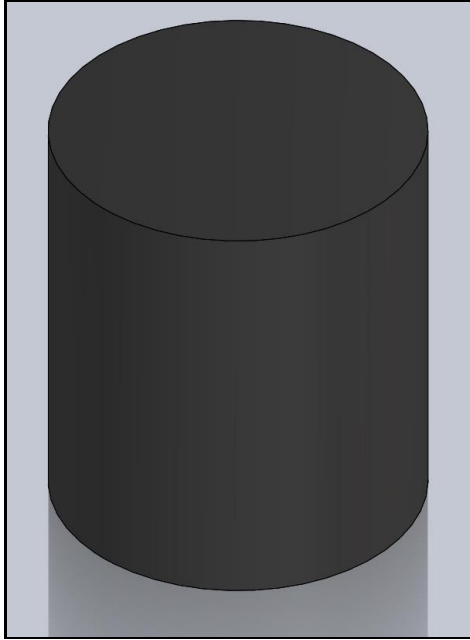


Figure 12. CAD Model of the Packed Drogue Parachute.

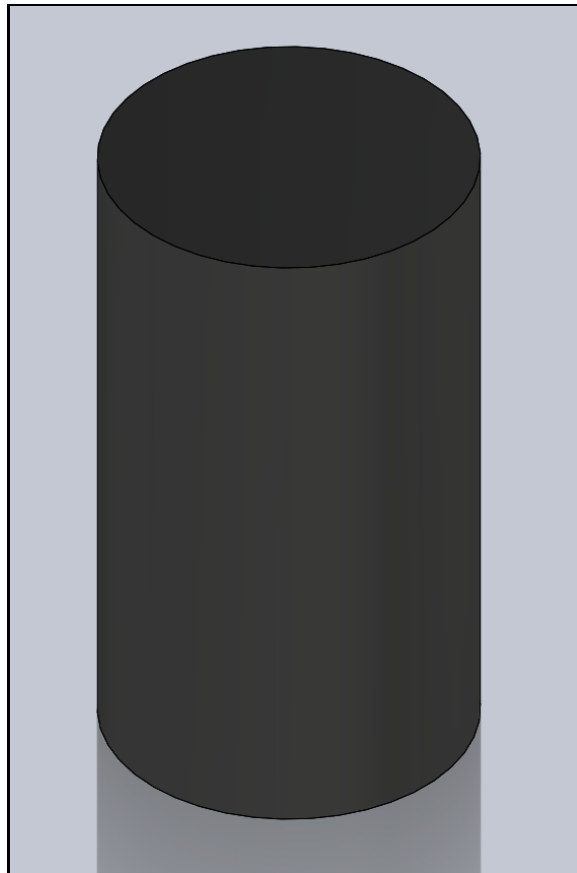


Figure 13. CAD Model of the Packed Main Parachute.

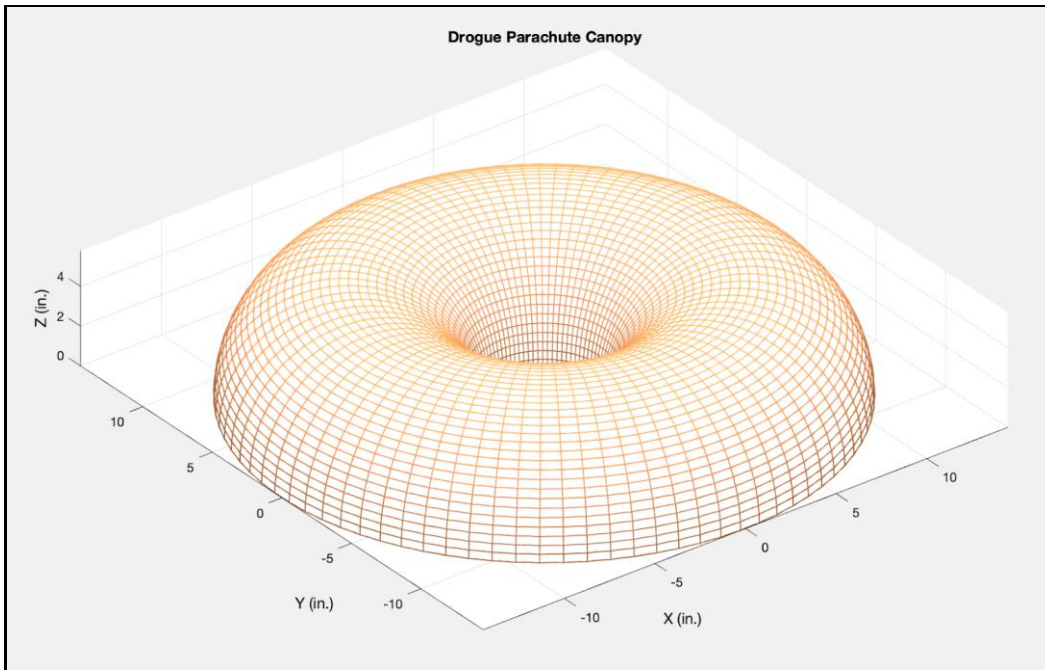


Figure 14. MATLAB Plot of Drogue Parachute Canopy.

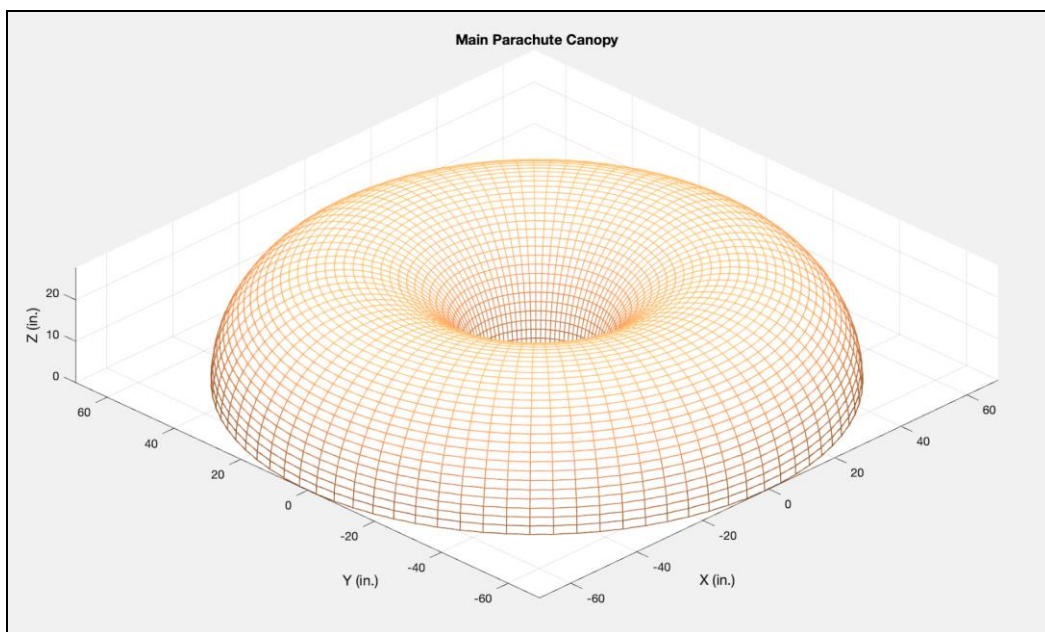


Figure 15. MATLAB Plot of Main Parachute Canopy.

Recovery System

The recovery system consists of the shock cord, quick links, swivels, nomex blankets, and kevlar covers for the shock cord as shown in Figure 16. Each shock chord (for the drogue and main parachutes) is 36 ft long. On either end, it has a figure 8 knot to which a swivel and quick link are attached to. This quick link allows for easy attachment to each eyebolt on the bulkheads. Then located along the shock cord is a butterfly knot to which a swivel is attached to. The parachute for this section then attached to this swivel.



Figure 16. The drogue parachute recovery system components with labels.

Figure 17 shows the recovery layout for when the drogue is deployed and Figure 18 shows the layout for once the main parachute is deployed. The location of the parachute on the shock cord was determined by ensuring that no rocket components, the nose cone and body tubes, could collide with each other. It was also determined by verifying that the drogue parachute would not be in the way of the main parachute as it was deployed. Each shock cord has a nomex blanket to help protect the shock cord and parachutes from gas of the black powder. Kevlar covers are placed over the nylon shock cord near the bulkhead where the black powder charges are placed. This helps protect the nylon from melting or getting burned when the black powder charge goes off.

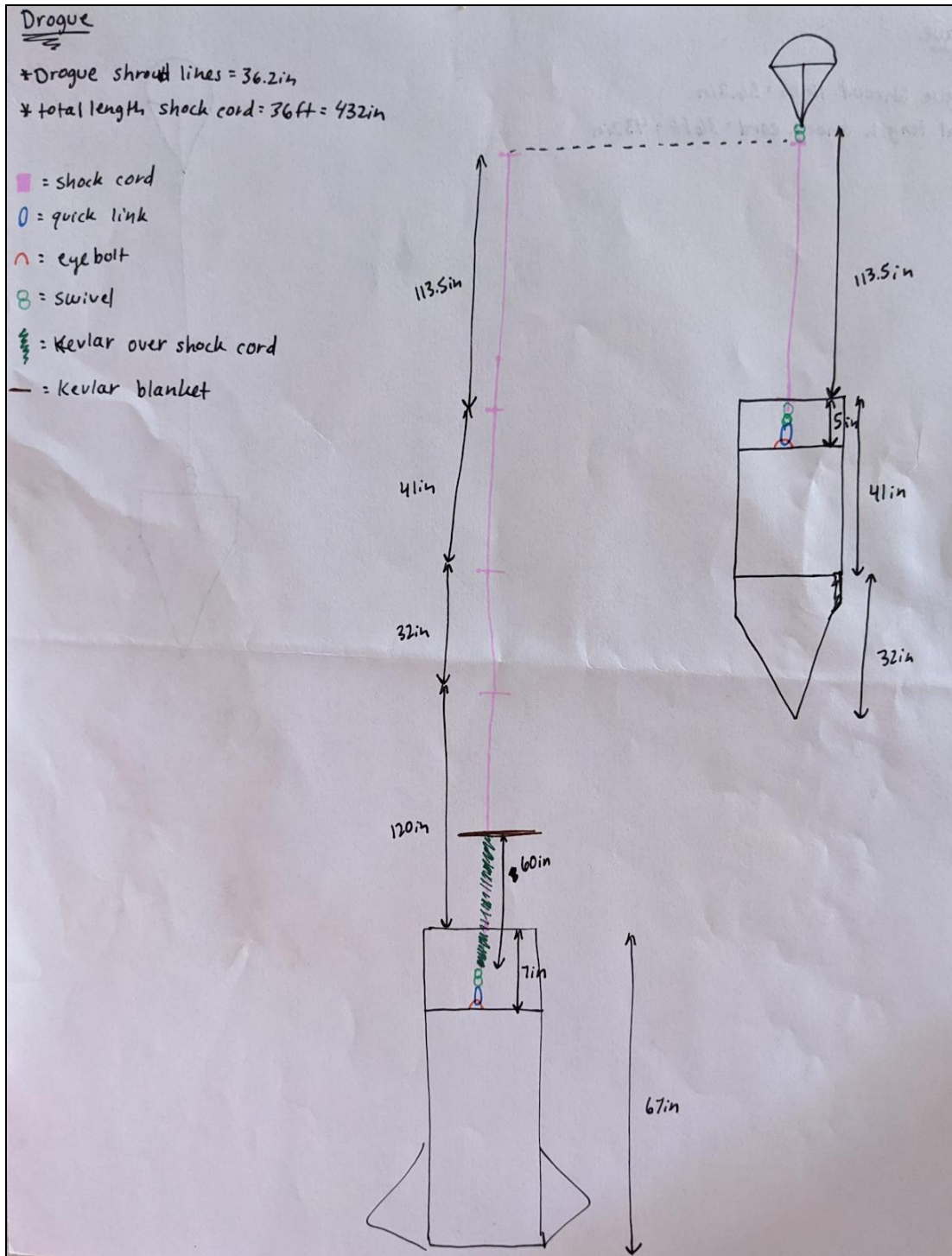


Figure 17. Recovery system when the drogue parachute is deployed.

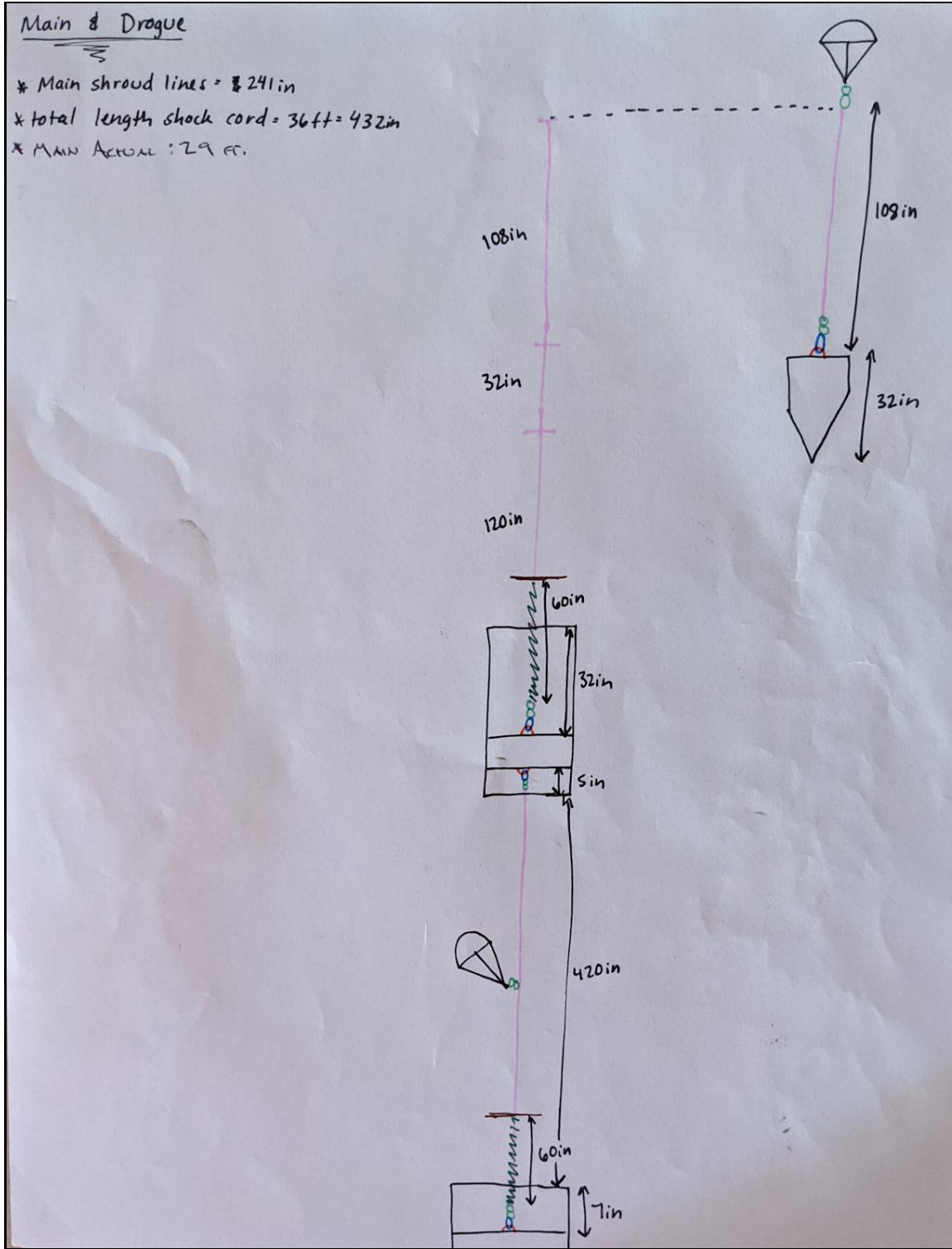


Figure 18. Recovery system after the main parachute is deployed.

References

- [1] T. Milligan, 2017, "What is the Best Fin Shape for a Model Rocket?" Peak of Flight, (422), pp. 1-10, from <https://www.apogeerockets.com/education/downloads/Newsletter442.pdf>
- [2] E. Fraley, 2018, "Design, Manufacturing, and Integration of fins for the 2017-2018 OSU ESRA 30K Rocket." honors thesis, Oregon State University.
- [3] K. Badger, M. Khine, M. Levy, 2019, "ESRA 30K Rocket: Final Design Report." Capstone design report, School of Mechanical, Industrial, and Manufacturing Engineering, Oregon State University, Corvallis, OR.
- [4] G. Crowell, "The Descriptive Geometry of Nose Cones", April 2011. [Online]. [the descriptive geometry of nose cones - The RocketryForumhttps://www.rocketryforum.com › attachments › nosecone_eqn2-pdf.336812](https://www.rocketryforum.com › attachments › nosecone_eqn2-pdf.336812) [Accessed Oct. 19, 2019]
- [5] W. Stoney Jr. , "Transonic Drag Measurements of Eight Body-Nose Shapes," NACA Research Memorandum L53K17, 1954.
- [6] Knacke, T., 1992, "Parachute Recovery Systems Design Manual," AD A247-666, Para Publishing, Santa Barbara, California.
- [7] 1971, "NASA Space Vehicle Design Criteria (Structures): Deployable Aerodynamic Deceleration Systems," NASA SP-8066, National Aeronautics and Space Administration.

Appendix A

Packing Procedures for the Black Powder Ejection Charges

Safety Consideration: Restricted area, authorized personnel only.

Safety Consideration: Safety glasses must be worn at all times.

Safety Considerations: Gloves must be worn at all times.

Safety Consideration: Clear area of all power sources.

1. Cut and label surgical tubing with Sharpie.
2. Cut rubber stoppers. To get a tight fit, wrap 3 layers of duct tape around the stopper that are the length of the width of the tape.
3. Wedge rubber stopper into one end of surgical tubing.
4. Place a zip tie on the end of the surgical tubing with a rubber stopper. Ensure the zip tie covers both the surgical tube and rubber stopper.
5. Pull the zip tie as tight as possible.
6. Cut off extra material from the end of the zip tie.
7. Take covers off E-match.
8. Check the continuity of every E-match that will go inside a charge.
9. Twist the ends together to avoid triggers from static discharge.
10. Label the end of each E-match. The drogue primary: black, 1 dot. The drogue redundant: black, 2 dots. The main primary: red, 1 dot. The main redundant: red, 2 dots.
11. Measure the correct amount of black powder for the charge that is being packed.
12. Place E-match in the center of the surgical tubing, hold it here.
13. Grab the open end of the surgical tubing, and slowly and carefully pour the black powder into the surgical tubing while keeping the E-match in the middle of the tubing.
14. Cut rubber stoppers. To get a tight fit, wrap 3 layers of duct tape around the stopper that are the length of the width of the tape.
15. Wedge rubber stopper into one end of surgical tubing.
16. Place a zip tie on the end of the surgical tubing with a rubber stopper. Ensure the zip tie covers both the surgical tube and rubber stopper.
17. Pull the zip tie as tight as possible.
18. Cut off extra material from the end of the zip tie.
19. Repeat these steps for the 3 remaining charges.
20. Place completed charges in a safe area to store.

Bill of Materials

Item Number	Name	Vendor	Aero and Recovery Bill of Materials		Material	Size	Qty	Unit Cost	Shipping Cost	Total Cost
			Part Number	Material						
Overall Section & Recovery Assembly										
Exhaust System										
1	Lower Structural Thimble	McAuler Car	5234826	Rubber	1.2" I.D., 5.8" O.D., 1.16" Wall, 25 #	1	\$44.50	\$0.00	\$44.50	
2	MCJ Primer Lubricant	MGI	-	Copper Plastic	3# 80 ct	1	\$80.00	\$13.73	\$93.73	
3	Weather Chemical Resistant Saumgwa Rubber Fock, Black	McAuler Car	6289E14	Rubber	1.2" Diameter	10	\$2.54	\$0.00	\$25.40	
4	FFFG Black Powder	The Gun Works, Store Pickup in Eugene	-	Black Powder	1 lb.	1	\$27.00	\$0.00	\$27.00	
5	Wadding	ebicosk	EB9073	Cellulose Fiber	1 lb.	1	\$4.99	\$0.00	\$4.99	
6	Threadlocker Blue	Home Depot	20972800	-	0.20 fl. oz	1	\$6.95	\$0.00	\$6.95	
7	Nylon Sheet Screens	McAuler Car	97265A117	Plastic, Nylon	4-40 Thread, 1.2" Long	2	\$6.98	\$0.00	\$13.96	
8	Delicate Painters Tape	Home Depot	-	Adhesive	0.94 in by 60 yds	3	\$5.38	\$0.00	\$16.74	
9	Gentle Tape	Cellula	60035	Adhesive	1.88 in x 35 yd	1	\$8.48	\$0.00	\$8.48	
10	Homody Battery Operated Electronic Scale	Amazon	050106	Stainless Steel Plastic	8 x 7 x 2 in.	1	\$39.20	\$0.00	\$39.20	
11	8" Long Zip-Ties	Home Depot	-	Plastic	8", 100 count	1	\$8.22	\$0.00	\$8.22	
12	PPE Face Shield	Majed	10078371827837	Plastic	NA	3	\$25.20	\$0.00	\$75.60	
13	PPE Nitrile Gloves	Amazon	GENE-AD-K	Nitrile Rubber	Medium	1	\$9.95	\$0.00	\$9.95	
14	PPE Hearing Protection	Majed	1009594597261	Plastic	NA	3	\$28.75	\$0.00	\$86.25	
Penetrant Assembly										
15	Nexus Blaster	Frury Clanes	NA	Kerlar	21" for 6" Airframe	2	\$27.00	\$0.00	\$54.00	
16	Main Deployment Bag	Frury Clanes	CDB-55	Kerlar	6 in. x 13 in. L.	1	\$51.60	\$0.00	\$51.60	
17	1.1 oz Ripstop Nylon, Black, Calandered	Ripstop By the Roll	Black	Ripstop Nylon	1 yd x 60 in.	5	\$5.95	\$7.95	\$37.70	
18	1.1 oz Ripstop Nylon, Blaze Orange, Calandered	Ripstop By the Roll	Blaze Orange	Ripstop Nylon	1 yd x 60 in.	5	\$5.95	\$0.00	\$29.75	
19	International Orange 550 Paracord	The Paracord Store	550C-10R250	Paracord	250ft	1	\$15.88	\$13.49	\$29.37	
20	Shock Cord 1 inch Tubular Nylon Hot Orange	Stringworks.com	NA	Nylon	1ft	73	\$0.42	\$7.99	\$38.65	
21	Seam Binding	Amazon	-	Polyester	1" by 50 yards	1	\$12.49	\$0.00	\$12.49	
22	Main Penetrant (use one from last year)	Left over from ESRA 2018-2019	-	Ripstop Nylon/Reinforced Paracord	3.527 m	1	\$390.93	\$0.00	\$390.93	
23	Certhuler, mixed to 3300 lb	Left over from ESRA 2018-2019	-	Stainless Steel	1/2 in.	4	\$15.99	\$0.00	\$63.96	
24	Certhuler, mixed to 2400 lb	Left over from ESRA 2018-2019	-	Stainless Steel	5/16 in.	7	\$10.99	\$0.00	\$76.93	
25	Certhuler, mixed to 2200 lb	Left over from ESRA 2018-2019	-	Stainless Steel	9 mm	1	\$10.99	\$0.00	\$10.99	
26	Large Steel (316 Stamples)	Left over from ESRA 2018-2019	-	Stainless Steel	-	3	\$10.99	\$0.00	\$32.97	
27	5/16" Stainless Steel Jaw & Jaw Survival	E-Rigging	51607110	Stainless Steel	5/16"	5	\$9.52	\$8.74	\$56.54	
28	Ripstop Repair Tape, Yellow	Sultrix	100090	Ripstop	2" X 25' roll	1	\$7.95	\$8.70	\$16.65	
29	Ripstop Repair Tape, Black	Sultrix	100086	Ripstop	2" X 25' roll	1	\$7.95	\$0.00	\$7.95	
30	Seam Grip Sealer and Adhesive	Ripstop By the Roll	-	Adhesive	1 oz	2	\$7.50	\$3.55	\$18.95	
31	Size E Nylon Thread	Pan Gear	T1012	Nylon	4#E	1	\$30.25	\$0.00	\$30.25	
Total Cost								\$1,420.45		

Design Specifications for Purchased Components

This document lists the components that are to be purchased by the Aerodynamics and Recovery sub-team for use on the 2019-2020 ESRA rocket, and their relevant specifications as provided by the manufacturer.

Surgical Tubing:

- Outer Diameter: 0.625 in
- Inner Diameter: 0.500 in
- Weight: 1.1 lbs
- Length: 300 in
- Material: Natural Rubber (Latex), Polyisoprene Rubber

E-Matches:

- Maximum No-Fire Current: 300 mA
- Minimum All-Fire Current: 705 mA
- Resistance: 0.8-1.3 Ohms

Rubber Stoppers for Ejection Charges:

- Outer Diameter: 0.500 in
- Finish: Smooth
- Length: 120 in
- Material: Santoprene, Weather and Chemical Resistant Rubber Rod

Black Powder:

- Refer to codes and standards section in technical portfolio 2
- FFFFg Black Powder, Goex Brand

Blue Loctite for Parachute Swivels:

- Size: 0.20 fl. Oz.
- Temperature Resistant: 300°F
- Non-Permanent

Nylon Sheer Screws

- Size: 4-40 Thread
- Length: 0.50 in.
- Material: Nylon Plastic
- Breaking Strength: 37 lb each

Ripstop Nylon:

- Weight: 1.1 oz/yd²
- Thickness: 20D
- Calendered

550 Paracord:

- 7 strand nylon core
- 32 Strand Nylon Sheath
- Approx. Diameter: 0.16 in
- Tensile Strength: 550 lbs

Shock Cord:

- Tensile strength: 4000 lbs
- Outer Diameter: 0.94 in.
- Melting Temperature: 380°F
- Tubular Nylon

Seam Binding:

- Width: 1 in
- Length: 50 yds
- Polyester Ribbon, Black

Stainless Steel Swivels:

- Size: 5/16 in.
- Weight: 0.38 lb
- Working Load Limit: 1200 lbs
- Style: Jaw by Jaw

Ripstop Nylon Tape for Parachute Patches:

- Size: 2 in. by 25 ft.
- Weight 0.75 Oz ripstop nylon

Wadding:

- Fire Resistant
- Biodegradable

Nomex Blanket:

- Weight: 6 oz
- Edges: Double Sewn

Main Parachute Deployment Bag:

- Packed Length: 13 in.

Size E Nylon Thread:

- Weight Per Spool: 8 oz
- Tensile Strength: 8.5 lbs

Testing and Results



Testing Procedures for Aerodynamics & Recovery

Testing Procedure 1: Simulate the flight trajectory.

Purpose: To verify the rocket will reach an altitude of 30,000 ft, through simulation.

ES Addressed: The engineering specification addressed is ES 3: The rocket must meet 30,000 ft, through simulation.

Test Equipment: BurnSim, OpenRocket, Computer.

Testing Procedure:

1. Model full-scale rocket motor in BurnSim.
2. Input correct grain lengths, diameters, and propellant characteristics.
3. Input nozzle geometry.
4. Input weight of motor hardware.
5. Save BurnSim file as “.eng” file.
6. Open the OpenRocket software.
7. Click on the Edit tab and then the Preferences button.
8. In the General tab navigate to the User-Defined Thrust Curves option and click Add.
9. Navigate to the proper location of the desired thrust data.
10. Close the OpenRocket Software.
11. Reopen the OpenRocket Software.
12. Open the file for the rocket that contains the proper rocket design.
13. Click on the Motors and Configuration tab, click on New Configuration, and find the uploaded thrust curve.
14. Click on the Flight Simulations tab.
15. Click on the New Simulation tab.
16. Enter the correct launch conditions for the predicted launch.
17. Click the Simulate and Plot button on the lower right of the pop-up window.
18. Navigate to the Present Plot Configurations bar and select the Vertical Motion vs. Time plot.
19. Click the Plot button on the lower right of the pop-up window.
20. To zoom in, click an outer corner of the area you want and drag the mouse until the proper window is selected.

Passing Condition: The rocket reaches an altitude of at least 30,000 ft. through simulation.

Test Result: The test was passed with an apogee altitude of 33,936 ft. AGL from the OpenRocket simulation.

Test Validation: Below is the Altitude vs. Time plot from the OpenRocket simulation.

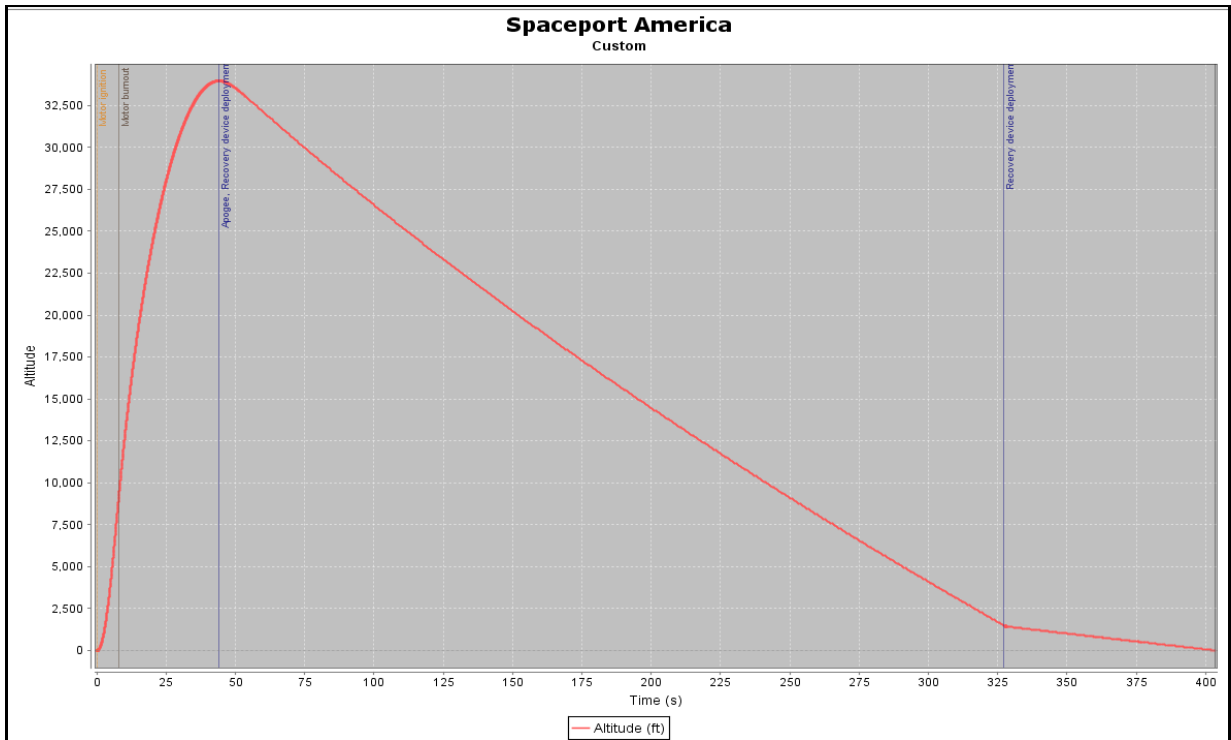


Figure 19. OpenRocket Altitude vs. Time plot for ESRA 2019-2020 rocket.

Testing Procedure 2: Simulate the stability margin of the rocket.

Purpose: To determine the launch rail stability margin of the rocket.

ES(s) Addressed: The engineering specification addressed is ES 7.1. Engineering specification 7.1 states the center of pressure must be aft of the center of gravity by the specified stability margin on the launch rail.

Test Equipment: A computer with Java and OpenRocket software.

Testing Procedure:

1. Open the OpenRocket software.
2. Open the file for the rocket that contains the proper thrust data.
3. Click on the Flight Simulations tab.
4. Click on the New Simulation tab.
5. Enter the correct launch conditions for the predicted launch.
6. Click the Simulate and Plot button on the lower right of the pop-up window.
7. Navigate to the Present Plot Configurations bar and select the Stability vs. Time plot.
8. Click the Plot button on the lower right of the pop-up window.
9. To zoom in, click an outer corner of the area you want and drag the mouse until the proper window is selected.
10. For the launch rail stability, use the stability margin in the simulation display window at Mach 0.1.

Passing Condition: The stability margin on the launch rail must be between 1.5 and 2 calibers.

Test Result: The test was passed with a launch rail stability margin of 1.71 calibers from the OpenRocket display window at Mach 0.1.

Test Validation: Below is a screen capture of the OpenRocket display window, with the stability margin of 1.71 calibers in the upper right.

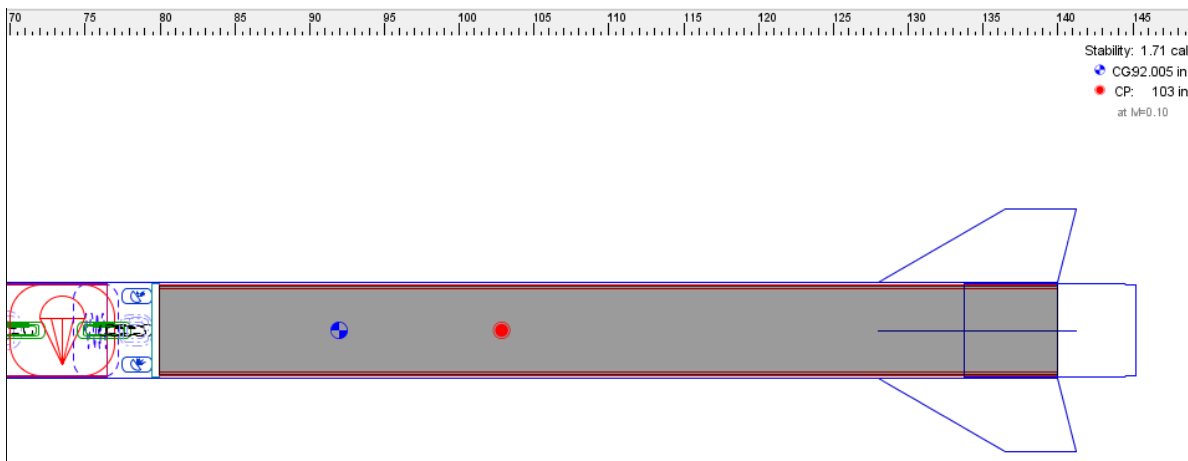


Figure 20. OpenRocket display window of the launch rail stability margin in the upper right.

Testing Procedure 3: Ejection Tests.

Purpose: The purpose of the full scale ejection test is to verify that the black powder charges will provide sufficient pressurization to cause launch vehicle separation.

ES(s) Addressed: The engineering specifications addressed are ES 9 and ES 10. ES 9 states that the number of backup deployment charges that must detonate for the entire recovery system while ES 10 states the number of successful parachute deployment tests per parachute.

Test Equipment:

- Protective face shield
- Safety Glasses
- Hearing protection
- Nitrile Gloves
- Power supply with adequately long lead wires
- Electronic matches
- 4444FG black powder
- Surgical tubing
- Scale
- Zip-Ties
- Gorilla Tape
- Complete airframe sections
- Complete nose cone
- Ballast to simulate payload
- Drogue and Main parachutes
- Test stand
- Ratchet straps

Optional for Remote Detonation via Telemega:

- TeleMega Flight Computer
- Teledongle USB
- Phone/laptop with AltOS UI installed
- Lipo battery
- Lead Wire (~50ft.)
- Yagi antenna

Testing Procedure:

1. Ensure all individuals are wearing proper personal protection equipment, then assemble black powder ejection charges using the following procedure (schematics are shown in Figures 21 and 22.):

Safety Consideration: Restricted area, authorized personnel only.

Safety Consideration: Safety glasses must be worn at all times.

Safety Considerations: Gloves must be worn at all times.

Safety Consideration: Clear area of all power sources.

- A. Gather the following materials: surgical tubing, tubing plugs, gorilla tape, zip ties, and electronic matches. (exact materials are specified in the Design Specification for Purchased Components under the Design Specs tab of the Technical Portfolio).
- B. Cut and label surgical tubing with Sharpie.
- C. Cut rubber stoppers. To get a tight fit, wrap 3 layers of duct tape around the stopper that are the length of the width of the tape.

- D. Wedge rubber stopper into one end of surgical tubing.
- E. Place a zip tie on the end of the surgical tubing with a rubber stopper. Ensure the zip tie covers both the surgical tube and rubber stopper.
- F. Pull the zip tie as tight as possible.
- G. Cut off extra material from the end of the zip tie.
- H. Take covers off E-match.
- I. Check the continuity of every E-match that will go inside a charge.
- J. Twist the ends together to avoid trigger from static discharge.
- K. Label the end of each E-match. The drogue primary: black, 1 dot. The drogue redundant: black, 2 dots. The main primary: red, 1 dot. The main redundant: red, 2 dots.
- L. Measure the correct amount of black powder for the charge that is being packed.
- M. Place E-match in the center of the surgical tubing, hold it here.
- N. Grab the open end of the surgical tubing, and slowly and carefully pour the black powder into the surgical tubing while keeping the E-match in the middle of the tubing.
- O. Cut rubber stoppers. To get a tight fit, wrap 3 layers of duct tape around the stopper that are the length of the width of the tape.
- P. Wedge rubber stopper into one end of surgical tubing.
- Q. Place a zip tie on the end of the surgical tubing with a rubber stopper. Ensure the zip tie covers both the surgical tube and rubber stopper.
- R. Pull the zip tie as tight as possible.
- S. Cut off extra material from the end of the zip tie.
- T. Repeat these steps for the 3 remaining charges.
- U. Place completed charges in a safe area to store.

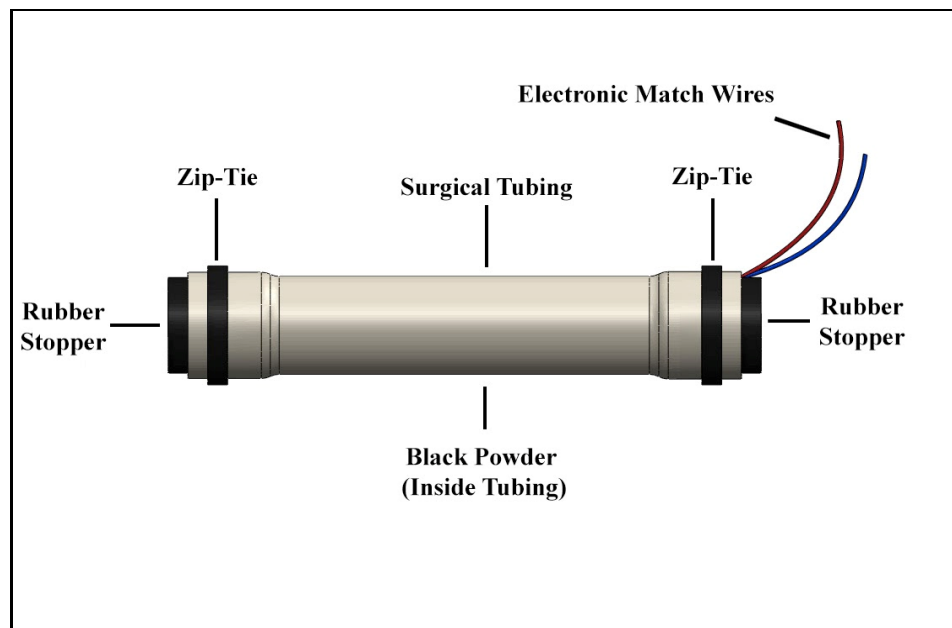


Figure 21. A labeled schematic of the packed black powder charge.

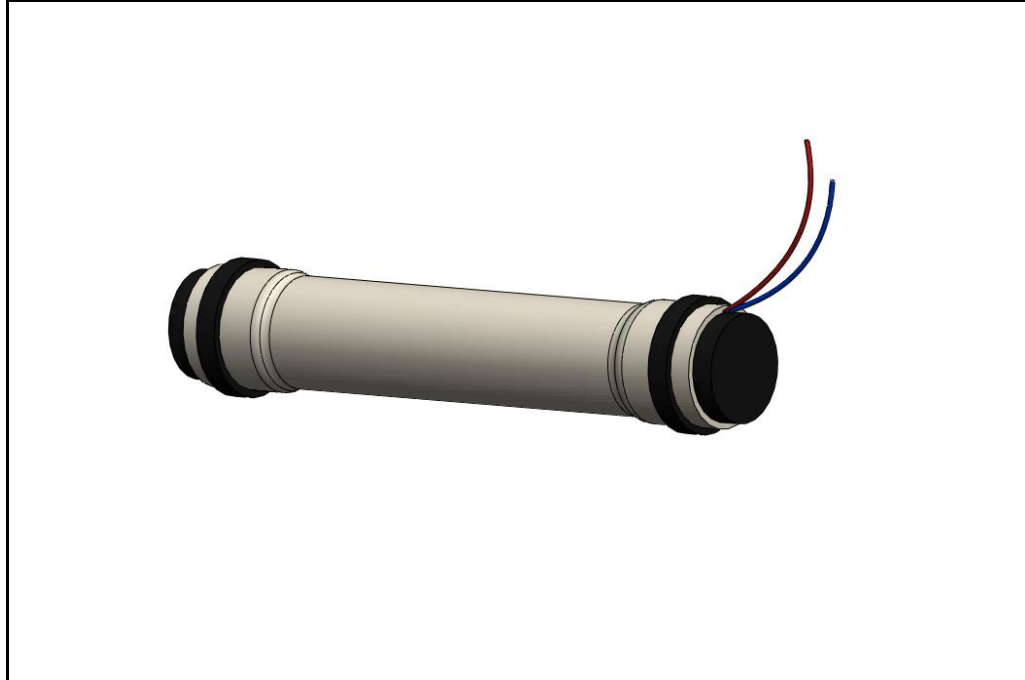


Figure 22. A screen capture of the schematic of the packed black powder charge.

2. Connect both wires of electronic match to each lead wire, ensuring no power sources are nearby.
3. Install and secure the charge assembly into the airframe.
4. Secure airframe to test stand in horizontal position (or with a slight positive angle from tail to tip).
5. Secure stand and rocket to weighted object with ratchet straps to mitigate motion of rocket backward when ejection occurs.
6. Install parachutes into their respective airframe with protection mechanisms such as Nomex blankets and dog barf. You may also install payload ballast if testing the upper airframe ejection mechanism.
7. Fasten sections of airframe together using shear pins.
8. Stand a distance of at least 10 ft away from the testing station and ensure all observers are wearing appropriate personal safety protection equipment (i.e., safety glasses, hearing protection, closed toed shoes, etc.).
9. Alert everyone in the area that the charge is going to be detonated, and provide adequate and audible countdown sequence.
10. If performing manual ejection, send a signal to e-match by holding one wire from the lead wire to the ground terminal of the 9V battery and contact the other wire to the positive terminal. If TeleMegas are used, connect the lead wires to their respective terminals on the TeleMega, then insert the Lipo battery into the TeleMega and wait for the beeping sequence to finish. Once completed, step at least 10 ft away and send the signal to the electronic match through the phone or laptop from AltOS using “Fire Igniter”.

Passing Condition: Parachute and all applicable components fully clear the end of airframe.

Test Result: The test was passed after increasing the black powder mass of the drogue primary charge by 1 gram. Each charge produced three successful ejections, bringing the final black powder masses for the charges to 6.5 grams for the main primary and 5.5 for the drogue primary.

Table 14. Ejection testing information and results.

Results of Successful Deployment Charges				
Date	Charge	Size	Shear Pins	TeleMega/Battery
2/28/2020	Main Primary	6.5 g	4	Battery
2/29/2020	Main Primary	6.48 g	4	Battery
2/29/2020	Main Primary	6.53 g	4	Battery
3/10/2020	Drogue Primary	5.54 g	5	TeleMega
3/10/2020	Drogue Primary	5.55 g	5	TeleMega
3/10/2020	Drogue Primary	5.56 g	5	TeleMega

Test Validation: Below are photos of a successful drogue parachute ejection and main parachute ejection as well as links to a video representation of each.



Figure 23. Successful drogue parachute ejection.



Figure 24. Successful main parachute ejection.

Link to drogue ejection video:

<https://drive.google.com/open?id=1yIHClnJt9NfS1YjWjrbsYw3M7O4UWxxc>

Link to main ejection video: <https://drive.google.com/open?id=19foTp3mh-NjcTNdpI6GfwVTL0h5lm2YR>

Testing Procedure 4: Descent velocity of the drogue parachute.

Purpose: This testing procedure verifies the parachute sizing calculations for the drogue parachute. The drogue parachute deployed at an apogee of 30,000 ft prepares the rocket for the main parachute deployment at 1,500 ft. The drogue must slow the rocket to a descent velocity between 75 and 150 ft/s. Thus, the drogue parachute should provide the rocket a descent velocity of approximately 100 ft/s when the main parachute deploys.

ES Addressed: The engineering specification addressed is ES 8.1: The drogue parachute must provide an appropriate descent velocity for the rocket from apogee.

Test Equipment: MATLAB, OpenRocket.

Testing Procedure:

1. Write MATLAB code to calculate the parachute surface area to provide the appropriate descent velocity. See Appendix E in the Technical Analysis for the drogue parachute design.
2. Use OpenRocket to simulate the flight path and descent velocities of the rocket for the drogue and main deployment events.
 - a. Open the OpenRocket software.
 - b. Open the file for the rocket that contains the proper thrust data.
 - c. Click on the Flight Simulations tab.
 - d. Click on the New Simulation tab.
 - e. Enter the correct launch conditions for the predicted launch.
 - f. Click the Simulate and Plot button on the lower right of the pop-up window.
 - g. Navigate to the Present Plot Configurations bar and select the Total Velocity vs. Time plot.
 - h. Click the Plot button on the lower right of the pop-up window.
 - i. To zoom in, click an outer corner of the area you want and drag the mouse until the proper window is selected.
3. Determine the descent velocity provided by the drogue parachute prior to the main parachute deployment from the simulated velocity profile of the rocket. See Appendices G, H, and I from the Technical Analysis for the drogue parachute descent analysis.

Passing Condition: The OpenRocket simulation shows that the drogue parachute slows the rocket to a velocity between 75 and 150 ft/s prior to main parachute deployment.

Test Result: The MATLAB analysis shows that the drogue parachute slows the rocket to a descent rate of 83.2 ft/s, which passes the test. The OpenRocket simulation shows the rocket has been slowed by the drogue parachute to a velocity of 94.2 ft/s, which also counts as passing.

Test Validation: MATLAB Command Window Output:

```
Terminal Velocity of Drogue:  -25.4 m/s  
                             -83.2 ft/s
```

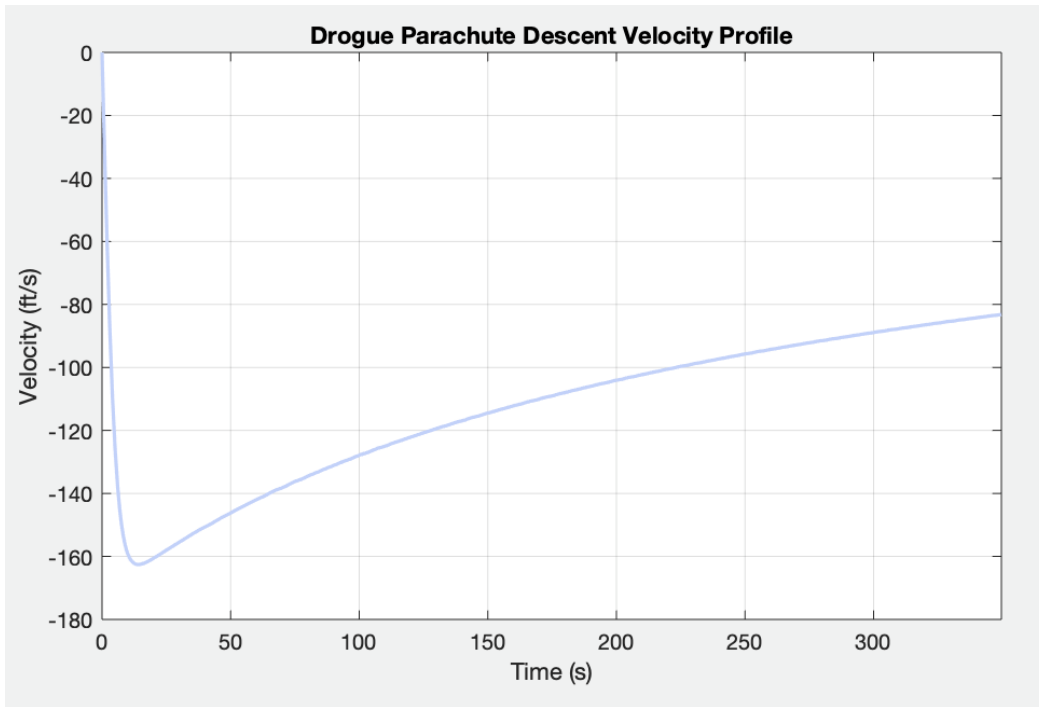


Figure 25. MATLAB Descent Velocity Profile for Drogue Parachute

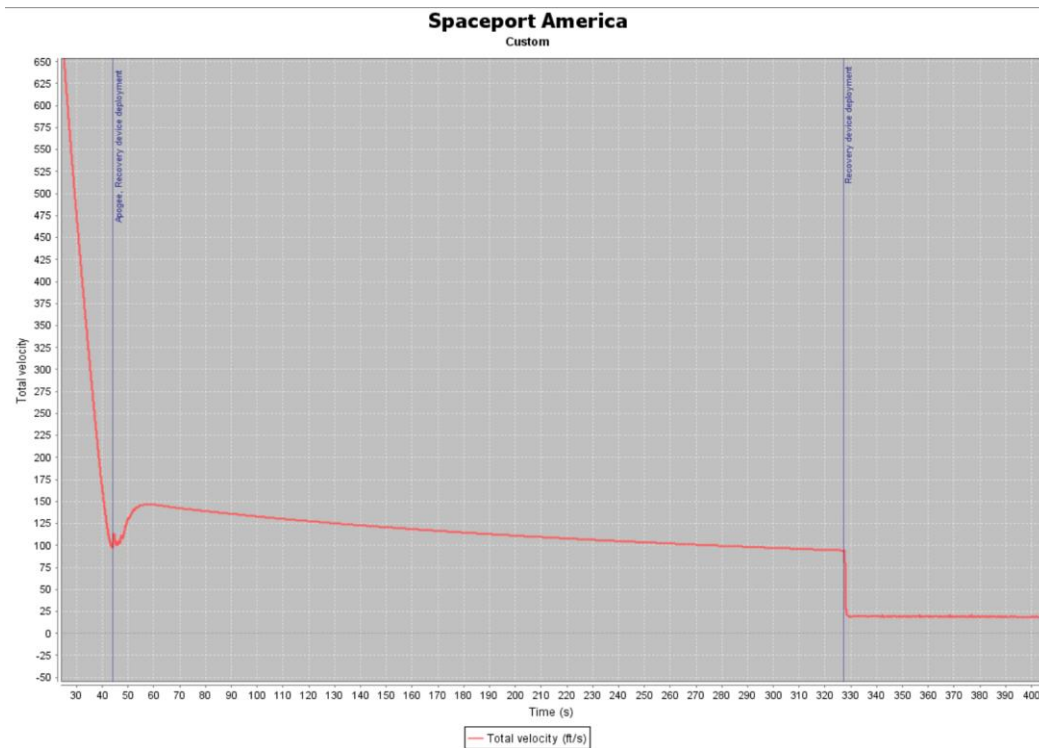


Figure 26. OpenRocket Simulation of Flight Velocity Profile. See Velocity at ~325 s.

Testing Procedure 5: Descent velocity of the main parachute.

Purpose: This testing procedure verifies the parachute sizing calculations for the main parachute. The main parachute deploys at an altitude of 1,500 ft above ground level. The main parachute must slow the rocket to a touchdown velocity no greater than 30 ft/s.

ES Addressed: The engineering specification addressed is ES 8.2: The main parachute must provide an appropriate descent velocity to safely land the rocket on the ground.

Test Equipment: MATLAB, OpenRocket.

Testing Procedure:

1. Write MATLAB code to calculate the parachute surface area to provide the appropriate descent velocity. See Appendix F in the Technical Analysis for the main parachute design calculations.
2. Use OpenRocket to simulate the flight path and descent velocities of the rocket for the drogue and main deployment events.
 - a. Open the OpenRocket software.
 - b. Open the file for the rocket that contains the proper thrust data.
 - c. Click on the Flight Simulations tab.
 - d. Click on the New Simulation tab.
 - e. Enter the correct launch conditions for the predicted launch.
 - f. Click the Simulate and Plot button on the lower right of the pop-up window.
 - g. Navigate to the Present Plot Configurations bar and select the Total Velocity vs. Time plot.
 - h. Click the Plot button on the lower right of the pop-up window.
 - i. To zoom in, click an outer corner of the area you want and drag the mouse until the proper window is selected.
3. Determine the touchdown velocity provided by the main parachute from the simulated velocity profile of the rocket. See Appendices G, H, and J from the Technical Analysis document for the main parachute descent analysis.

Passing Condition: The OpenRocket simulation shows that the main parachute slows the rocket to a touchdown velocity of less than or equal to 30 ft/s with a target rate of descent at 20 ft/s.

Test Result: The MATLAB analysis verifies that the rocket will land on the ground at a touchdown velocity of 21.3 ft/s. Though not less than 20 ft/s, the touchdown velocity of the rocket under the main parachute still falls within the acceptable range and, thus, passes this test. The OpenRocket simulation yields a touchdown velocity of 19 ft/s, which is also a passing condition.

Test Validation: MATLAB Command Window Output:

```
Terminal Velocity of Main:      -6.5 m/s  
                              -21.3 ft/s
```

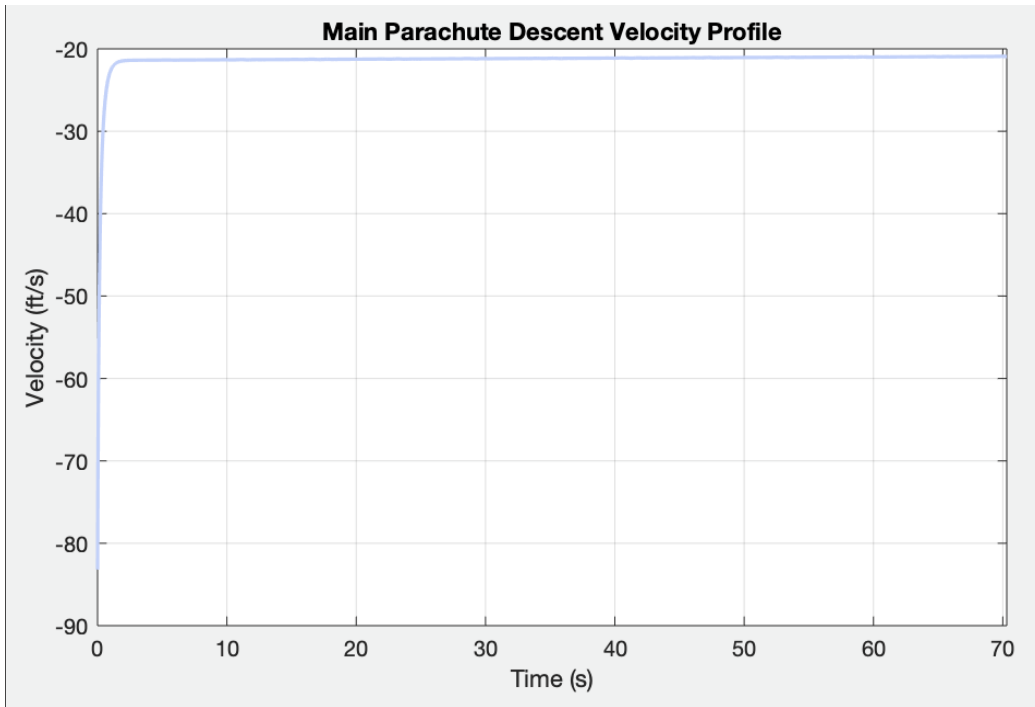


Figure 27. MATLAB Descent Velocity Profile for Main Parachute.

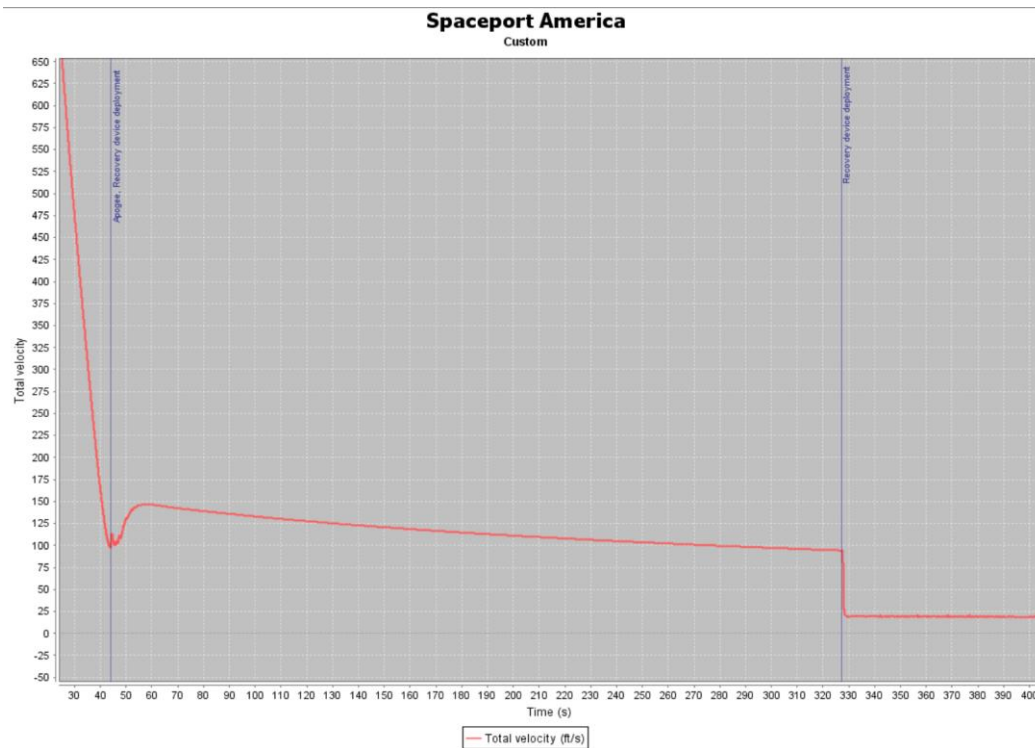


Figure 28. OpenRocket Simulation of Flight Velocity Profile. See Velocity at ~400 s.

Testing Procedure 6: Simulate the stability margin of the rocket.

Purpose: To determine the stability margin for the entire flight profile of the rocket.

ES(s) Addressed: The engineering specification addressed is ES 7.2. Engineering specification 7.2 states the center of pressure must be aft of the center of gravity by the specified stability margin during the flight profile.

Test Equipment: A computer with RASAero II software.

Testing Procedure:

1. Open the RASAero II software.
2. Open the file for the rocket that contains the proper aerodynamic traits.
3. Select the proper motor file.
4. Double click on the Motor Loaded tab and verify the nozzle exit diameter, Cg, and weight values are correct.
5. Click Save.
6. In the flight simulation window, scroll to the far right and click on the View Data tab. It may take several moments to load.
7. Once loaded, it will automatically display the Altitude vs. Time plot. To change this, click on the drop down menu located at the top of the screen and select Stability Margin plot.
8. To zoom in, click an outer corner of the area you want and drag the mouse until the proper window is selected.
9. Verify the minimum value is larger than 1.5 calibers and the maximum value is less than 6 calibers.
10. When exiting the window, click Save.

Passing Condition: The stability margin for the entire flight profile must be 1.5 to 6 calibers.

Test Result: The test was passed with a minimum stability margin of 1.68 calibers and a maximum stability margin of 4.17 calibers over the entire flight profile of the rocket. This result was obtained from the Stability Margin plot in RASAero II.

Test Validation: Below is a screen capture of the Stability Margin vs. Time plot from the RASAero II simulation. This plot shows a minimum stability of 1.68 calibers and a maximum of 4.17 calibers.

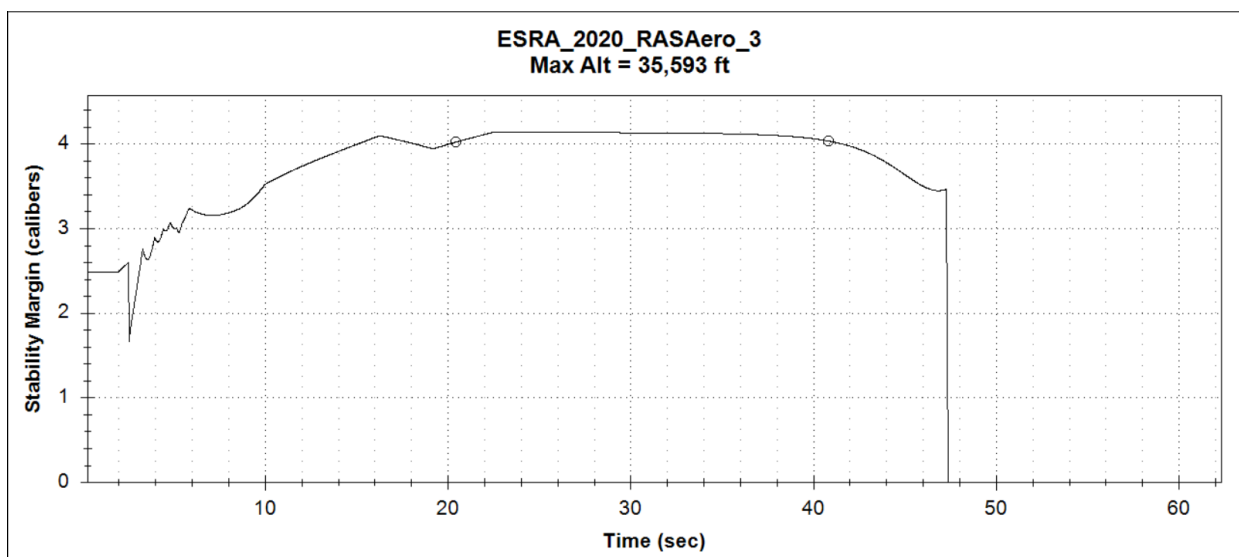


Figure 29. The Stability Margin vs. Time plot in RASAero II.

Technical Analysis



Technical Analysis

Experimental Sounding Rocket Association (ESRA) 30k Rocketry Team

Aerodynamics & Recovery Sub-Team

Oregon State University

2019-2020

Annalise Daul

Mikayla Far

Hayden Ferrell

Disclaimer for Simulations: A two-dimensional layout of the current rocket was created in OpenRocket for the 2019-2020 ESRA 30k rocketry team. The simulation used the current thrust data from the Propulsion Mixing sub-team and a motor configuration was selected. This simulation includes details of the rocket during its projected flight. The total weight of the rocket used for this simulation was 136 lb. Of the total weight, the propellant weighed 42.2 lb. Appendix A displays the printout of the propellant data and key flight parameters of the rocket. This is the finalized data from the Propulsion Mixing sub-team, but it may change based on the results from our first test launch. Therefore, the technical analyses were performed with the current weights and status of the rocket.

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Analysis 1

Analyst: Mikayla Farr

Date: 12/6/2019

Corresponding Engineering Specification: NA

Given: The problem is to determine the number of fins that yields the best performance parameters for the current rocket design. The recommended dimensions for a clipped delta fin are known and will be the initial dimensions for the fin optimization performed in OpenRocket. It is also known that it is easier to properly align four fins than three fins. This is because it is harder to place fins at even increments of 120° with minimal angle of attacks.

To Do: The goal of this analysis is to determine the optimal number of fins for the current rocket design by using the fin optimization tool in OpenRocket and comparing the maximum apogee altitude results.

Solution: Throughout the design process the number of fins were heavily considered. Fins play an important role in helping the rocket achieve its targeted altitude and proper stability margin. Therefore, it was critical to come up with a solution to this design problem. To determine if three or four fins was optimal, fin optimizations for each were performed with the current design of the rocket. To maintain the amount to variables in the fin optimizations, each optimization began with the same fin dimensions and their parameters had the same parameter ranges. The starting fin dimensions and parameter ranges are shown in Table 15. After completing the fin optimizations for each, it was shown that four fins yielded a slightly higher altitude than the three-fin configuration. The results of each optimization are shown in Table 16.

Table 15. Initial fin dimensions and each design parameter's minimum and maximum value.

Specification	Root Chord (in.)	Tip Chord (in.)	Span (in.)	Stability (calibers)
Starting Dimensions	12.70	6.33	12.70	-
Minimum	10.00	3.00	4.00	1.50
Maximum	15.00	9.00	12.70	2.00

Table 16. Results for the number of fins.

Number of Fins (#)	Stability Margin (calibers)	Predicted Altitude (ft)
3	1.5	37,759
4	1.5	37,878

Analyst: Mikayla Farr

Date: 12/6/2019

Answer: Since both fin configurations yielded the same stability margin, the predicted altitude and the ease of alignment were the two factors that were considered to determine if the use of three or four fins was optimal. As seen in Table 16, the altitude of the three-fin configuration was slightly lower than the altitude of the four-fin configuration. Therefore, since it is much easier to align four fins and it yielded a higher altitude, the current rocket design will use the four-fin configuration. Our sub-team is confident that the four-fin configuration can be implemented correctly. To clarify, this test does use older numbers, but the results are still accurate to show that four fins should be used instead of three fins.

Analysis 2

Analyst: Mikayla Farr

Date: 2/14/2020

Corresponding Engineering Specification: NA

Given: The problem is to determine the fin dimensions that yield a stability margin of 1.7 calibers. The general weight of the rocket is known as well as the current location of its center of pressure and center of gravity.

To Do: The goal of this analysis is to determine the correct fin dimensions for the rocket using the fin optimization tool in OpenRocket.

Solution: After conducting extensive research, it was concluded that a clipped delta fin would be the best fin shape for the rocket. The last step in designing the fins was to optimize their dimensions to yield the best performance parameters for the rocket. The initial dimensions were determined by using the recommendations from Richard Nakka's Experimental Rocketry Website [1]. It recommended the Root Chord and Span were two times the outer diameter and the Tip Chord was one outer diameter [1]. It also suggested the sweep angle was less than 70 degrees for a four-fin configuration [1]. The number of fins on the rocket will remain constant at four since it was proven in Analysis 1 to be optimal. The optimization of the fin dimensions was performed in OpenRocket using the optimization tool where a minimum and maximum dimension was specified for several fin dimension parameters. The optimization was selected to determine the dimensions that yielded a stability margin of 1.7 calibers. OpenRocket iterated 39 times before it yielded the optimal dimensions. The optimization window is shown in Figure 30, while the initial dimensions, minimum and maximum dimension parameters, and optimized dimensions are shown in Table 17. The dimensions shown in Table 17 vary slightly from those in the optimization window to improve ease of manufacturing. The dimensions were changed so slightly that they did not greatly change the stability or altitude of the rocket.

Analyst: Mikayla Farr
Date: 2/14/2020

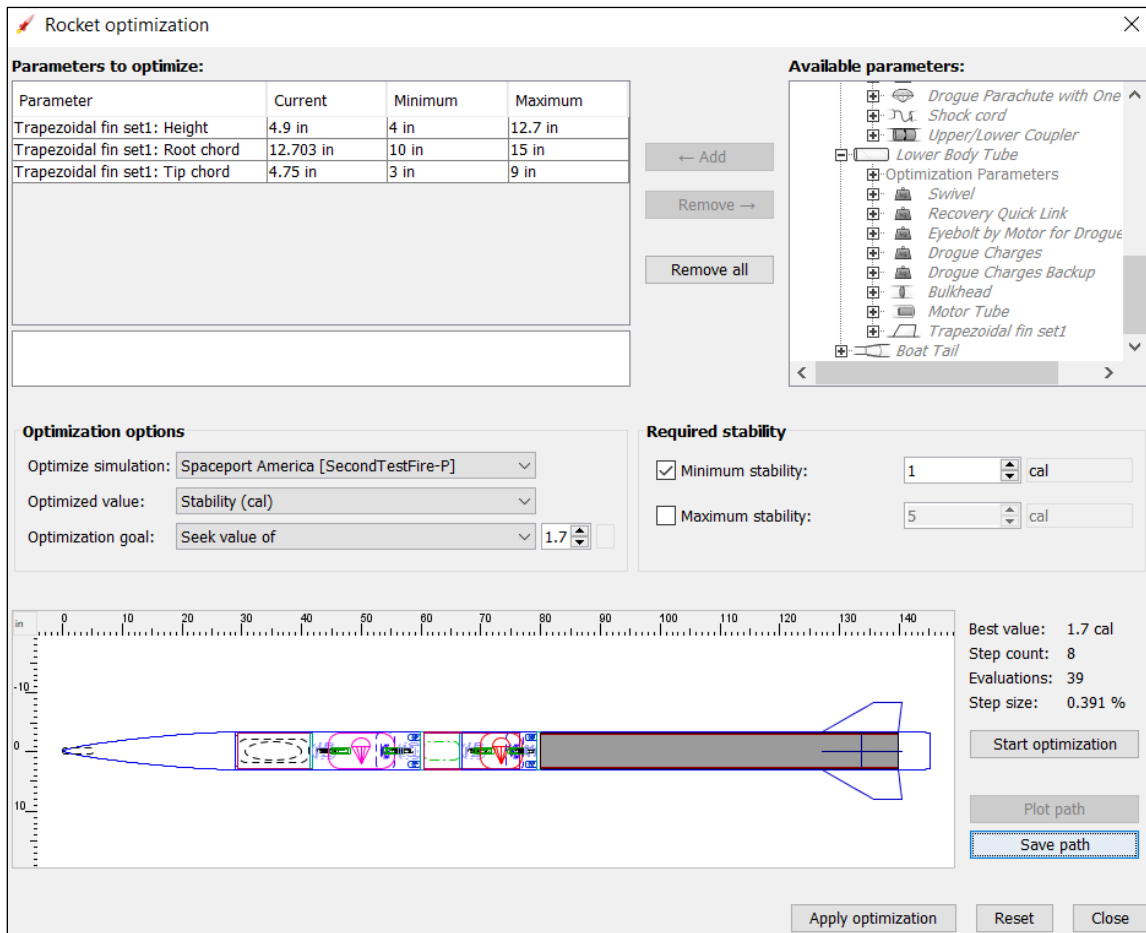


Figure 30. The optimization window to determine optimal fin dimensions.

Table 17. Initial fin dimensions, minimum and maximum dimensions, and optimized dimensions.

Specification	Root Chord (in)	Tip Chord (in)	Span (in)	Sweep Angle (°)	Altitude (ft)	Stability (calibers)
Initial Dimensions	12.700	6.330	12.700	40.0	-	-
Minimum	10.000	3.000	4.000	70.0	-	1.00
Maximum	15.000	9.000	12.700	40.0	-	-
Optimized	12.000	4.750	4.900	60.0	33,428	1.71

Answer: The fins will have the optimized dimensions shown in Table 17. Our sub-team is confident that these fin dimensions will yield the altitude and stability the rocket needs for its flight. These dimensions were also checked for fin flutter in Analysis 14 and given to Structures and Integration so the fins could be manufactured.

Analysis 3

Analyst: Mikayla Farr

Date: 2/11/2020

Corresponding Engineering Specification: ES 3: The altitude of the rocket.

Given: The problem is to determine the altitude at apogee and where this occurs in the duration of the flight. The motor data from the Propulsion Mixing sub-team is known and their thrust curve is uploaded into OpenRocket. The launch conditions have been set to the latitude and longitude of Spaceport America and a wind speed for the location has been set. A display window of the launch conditions is shown in Appendix B.

To Do: The goal of this analysis is to use the current layout of the rocket and data from the Propulsion Mixing sub-team to determine the time apogee takes place and its predicted altitude.

Solution: Once the two-dimensional layout of the rocket was completed, a motor configuration using the current data from the Propulsion Mixing sub-team was created, and the flight simulation was run. The flight simulation yielded a value in the display bar as well as an Altitude vs. Time plot of the results. This plot is shown in Figure 31. It is important to note that a wind speed of 10 mph with a standard deviation of 1.8 mph was assumed for the purpose of this simulation.

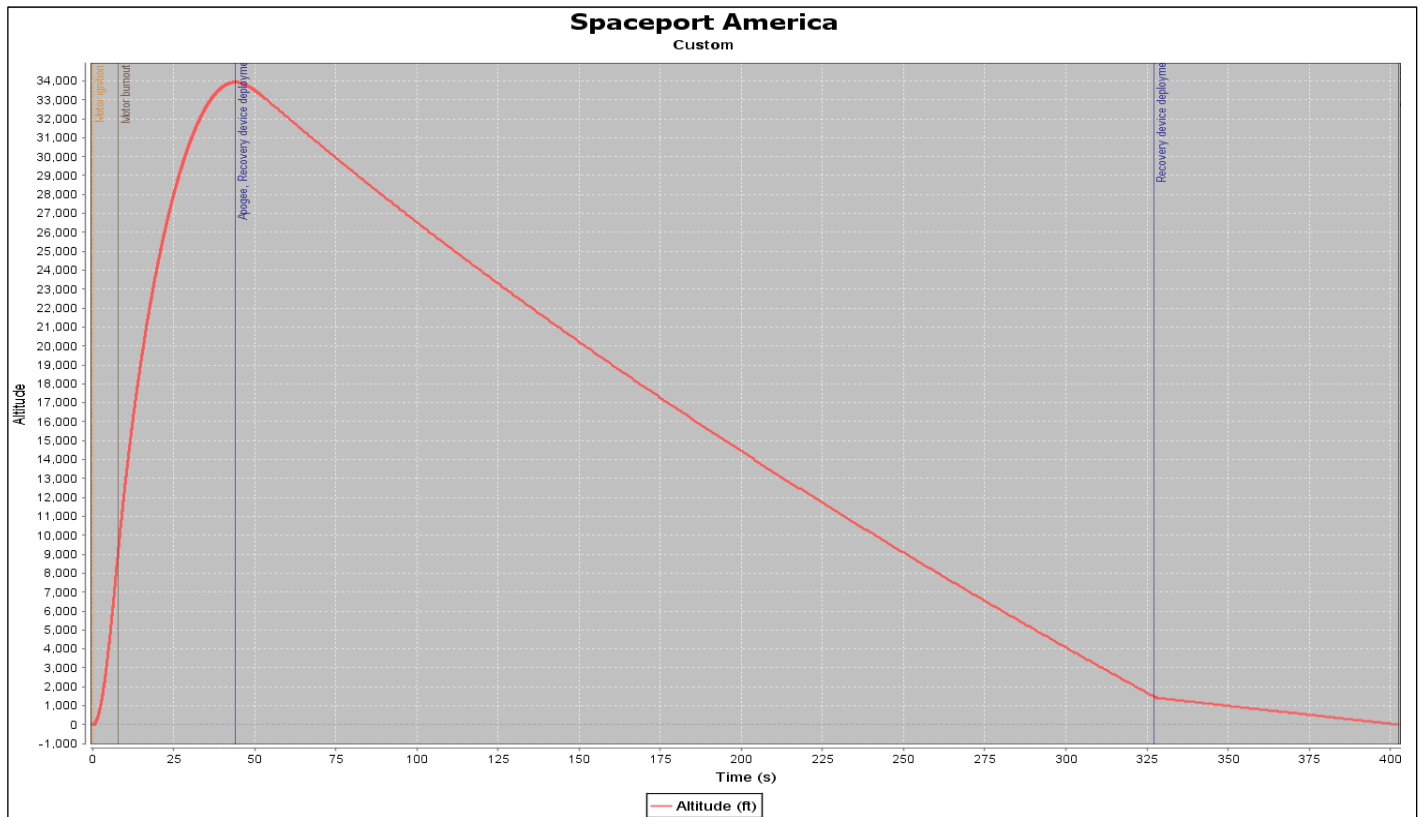


Figure 31. OpenRocket Altitude vs. Time plot for ESRA 2019-2020 rocket.

Analyst: Mikayla Farr

Date: 2/11/2020

Answer: From this analysis it was concluded that the current rocket design will reach an apogee of 33,932 ft at a time of 44 seconds. The target altitude of the rocket is 30,000 ft. Therefore, this altitude will be compared to the altitude in the RASAero II simulation as well as the actual altitude obtained from a test launch. From here, changes will be made to the propellant's grain geometry until the target altitude is obtained.

Analysis 4

Analyst: Mikayla Farr

Date: 2/13/2020

Corresponding Engineering Specification: ES 3: The altitude of the rocket.

Given: The problem is to determine the altitude at apogee and where this occurs in the duration of the flight. The motor data from the Propulsion Mixing sub-team is known and their thrust curve is uploaded into RASAero II. The launch conditions have been set to the latitude and longitude of Spaceport America and a wind speed for the location has been set. A display window of the launch conditions is shown in Appendix C.

To Do: The goal of this analysis is to use the current layout of the rocket and data from the Propulsion Mixing sub-team to determine the time apogee takes place and its predicted altitude.

Solution: Once the two-dimensional layout of the rocket was completed, a motor configuration using the current data from the Propulsion Mixing sub-team was created, and the flight simulation was run. The flight simulation yielded a value in the display bar as well as an Altitude vs. Time plot of the results. This plot is shown in Figure 32. It is important to note that a wind speed of 10 mph was assumed for the purpose of this simulation.

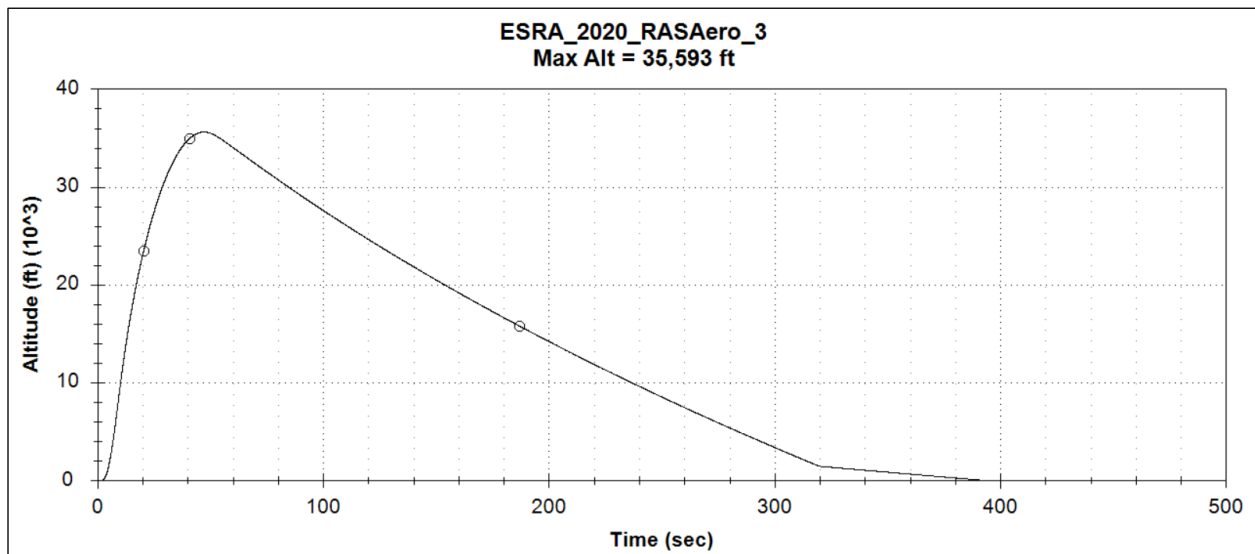


Figure 32. RASAero II Altitude vs. Time plot for ESRA 2019-2020 rocket.

Answer: From this analysis it was concluded that the current rocket design will reach an apogee of 35,593 ft at a time of 47 seconds. The target altitude of the rocket is 30,000 ft. Therefore, this altitude will be compared to the altitude in the OpenRocket simulation as well as the actual altitude obtained from a test launch. From here, changes will be made to the propellant's grain geometry until the target altitude is obtained.

Analysis 5

Analyst: Mikayla Farr

Date: 2/12/2020

Corresponding Engineering Specification: ES 7.1 and ES 7.2: The center of pressure must be aft of the center of gravity by the specified stability margin on the launch rail and the center of pressure must be aft of the center of gravity by the specified stability margin during the flight profile.

Given: The problem is to determine the stability margin of the rocket throughout its entire flight. The data from the Propulsion Mixing sub-team is known and their thrust curve was uploaded into OpenRocket. The launch conditions are set to the proper conditions for Spaceport America and are displayed in Appendix B.

To Do: The goal of this analysis is to determine the stability margin for the rocket throughout its entire flight, using the thrust data from the Propulsion Mixing sub-team.

Solution: Once the two-dimensional layout of the rocket was completed, a motor configuration using the current data from the Propulsion Mixing sub-team was created, and the flight simulation was run. The flight simulation yielded a Stability Margin vs. Time plot of the results. This plot is shown in Figure 33. It is important to note that a wind speed of 10 mph with a standard deviation of 1.8 mph was assumed for the purpose of this simulation. The launch rail stability is determined by using the stability margin displayed in the display window at Mach 0.1 and can be seen in Figure 34.

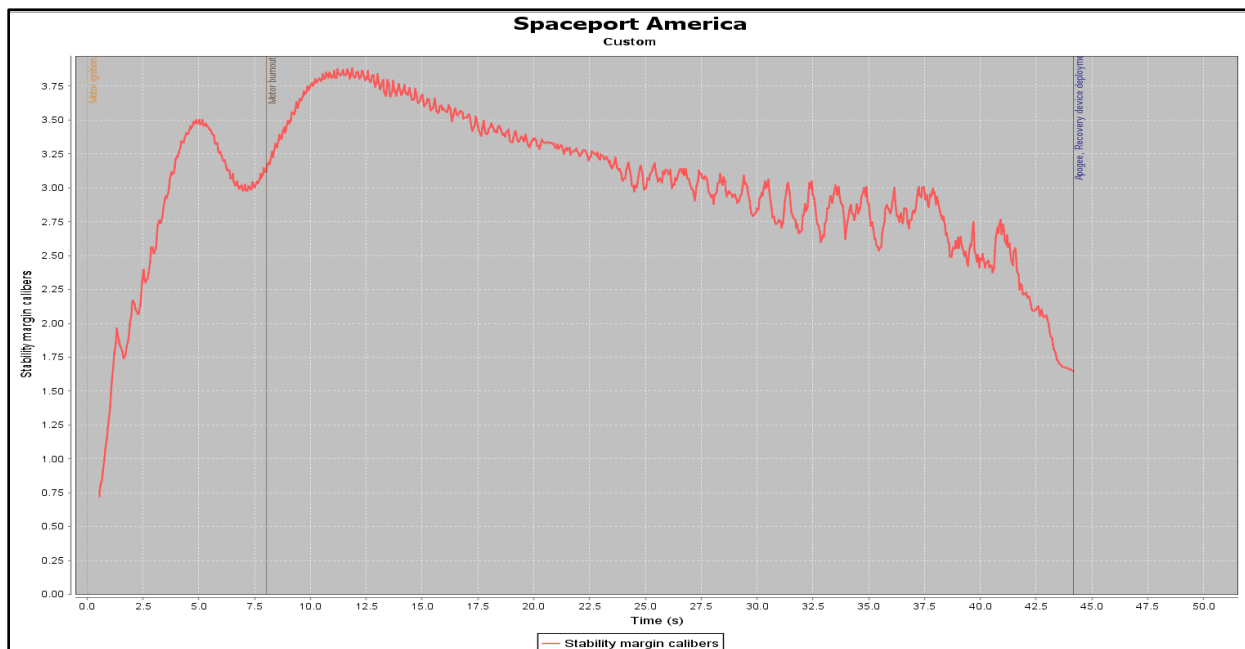


Figure 33. OpenRocket Stability Margin vs. Time plot for ESRA 2019-2020 rocket.

Analyst: Mikayla Farr
Date: 2/12/2020

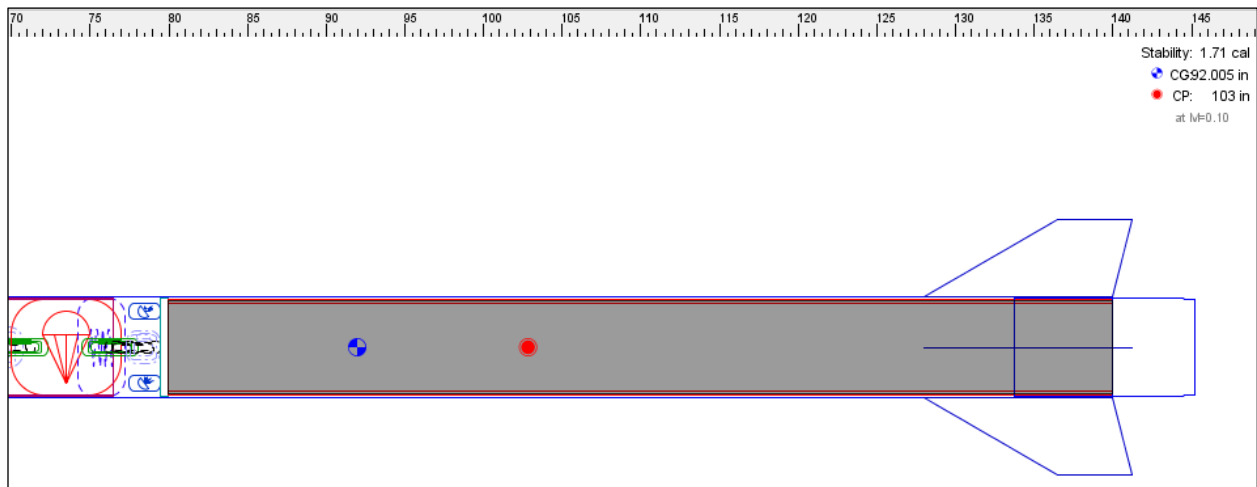


Figure 34. OpenRocket Stability Margin Displayed in the Rocket Display Window.

Answer: From this analysis it is concluded that OpenRocket does not yield an accurate stability margin for transonic and supersonic speeds. Therefore, the stability plot from the RASAero II simulation will be used to satisfy the stability margin for the entire flight profile. Since OpenRocket is accurate for subsonic speeds, the value in the display window will be accurate. Therefore, the launch rail stability is 1.71 calibers. This value is within the range allowed by IREC which requires a stability margin 1.5 to 2.0 calibers on the launch rail.

Analysis 6

Analyst: Mikayla Farr

Date: 2/12/2020

Corresponding Engineering Specification: ES 7.2: The center of pressure must be aft of the center of gravity by the specified stability margin during the flight profile.

Given: The problem is to determine the stability margin of the rocket throughout its entire flight. The data from the Propulsion Mixing sub-team is known and their thrust curve was uploaded into RASAero II. The launch conditions are set to the proper conditions for Spaceport America and are displayed in Appendix C.

To Do: The goal of this analysis is to determine the stability margin for the rocket throughout its entire flight, using the thrust data from the Propulsion Mixing sub-team.

Solution: Once the two-dimensional layout of the rocket was completed, a motor configuration using the current data from the Propulsion Mixing sub-team was created, and the flight simulation was run. The flight simulation yielded a Stability Margin vs. Time plot of the results. This plot is shown in Figure 35. It is important to note that a wind speed of 10 mph was assumed for the purpose of this simulation.

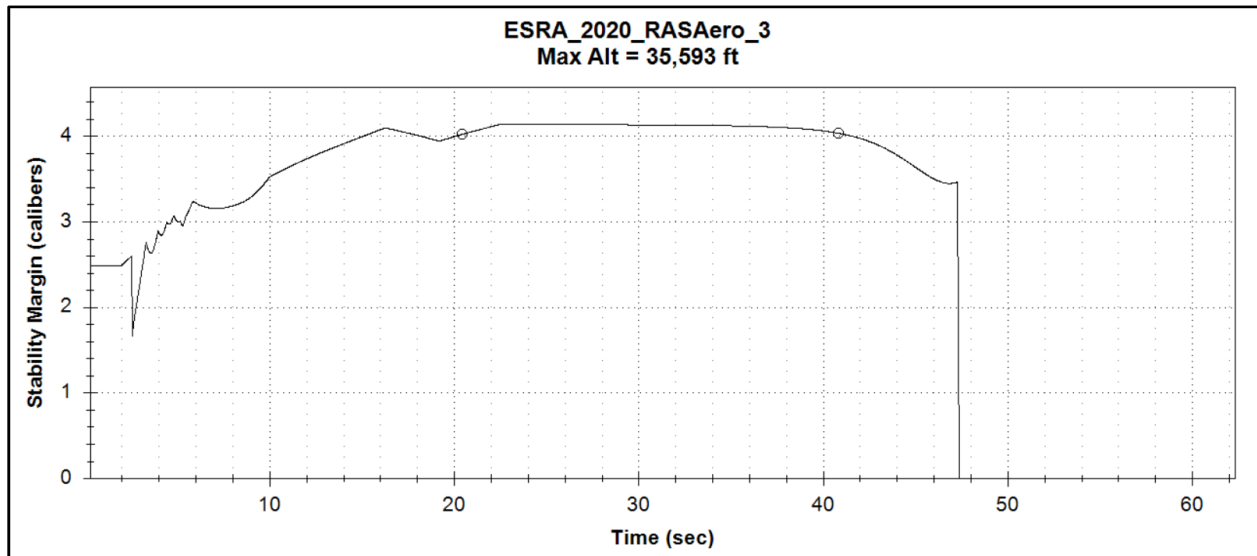


Figure 35. RASAero II Stability Margin vs. Time plot for ESRA 2019-2020 rocket.

Answer: From this analysis it is concluded that the minimum stability margin is 1.68 calibers and the maximum stability margin is 4.17 calibers. These values are within the 1.5 to 6.0 caliber range that is required by IREC rules. The launch rail stability is 2.5 calibers, which varies from the 1.71 calibers found in OpenRocket. The decrease in stability shortly after motor ignition is due to the response of the nose cone and fins' aerodynamic traits as the rocket passes through transonic speed.

Analysis 7

Analyst: Mikayla Farr

Date: 2/12/2020

Corresponding Engineering Specification: NA

Given: The problem is to determine the Mach numbers the rocket sees during specific times of its flight. The data from the Propulsion Mixing sub-team is known and their thrust curve was uploaded into OpenRocket. The launch conditions have been set to the latitude and longitude of Spaceport America and a wind speed for the location has been chosen. A display window of the launch conditions is shown in Appendix B.

To Do: The goal of this analysis is to determine the Mach numbers the rocket encounters during the duration of its flight.

Solution: Once the two-dimensional layout of the rocket was completed, a motor configuration using the current data from the Propulsion Mixing sub-team was created, and the flight simulation was run. The flight simulation yielded a maximum Mach number value in the display bar as well as a Mach Number vs. Time plot of the results. This plot is shown in Figure 36. It is important to note that a wind speed of 10 mph with a standard deviation of 1.8 mph was assumed for the purpose of this simulation.

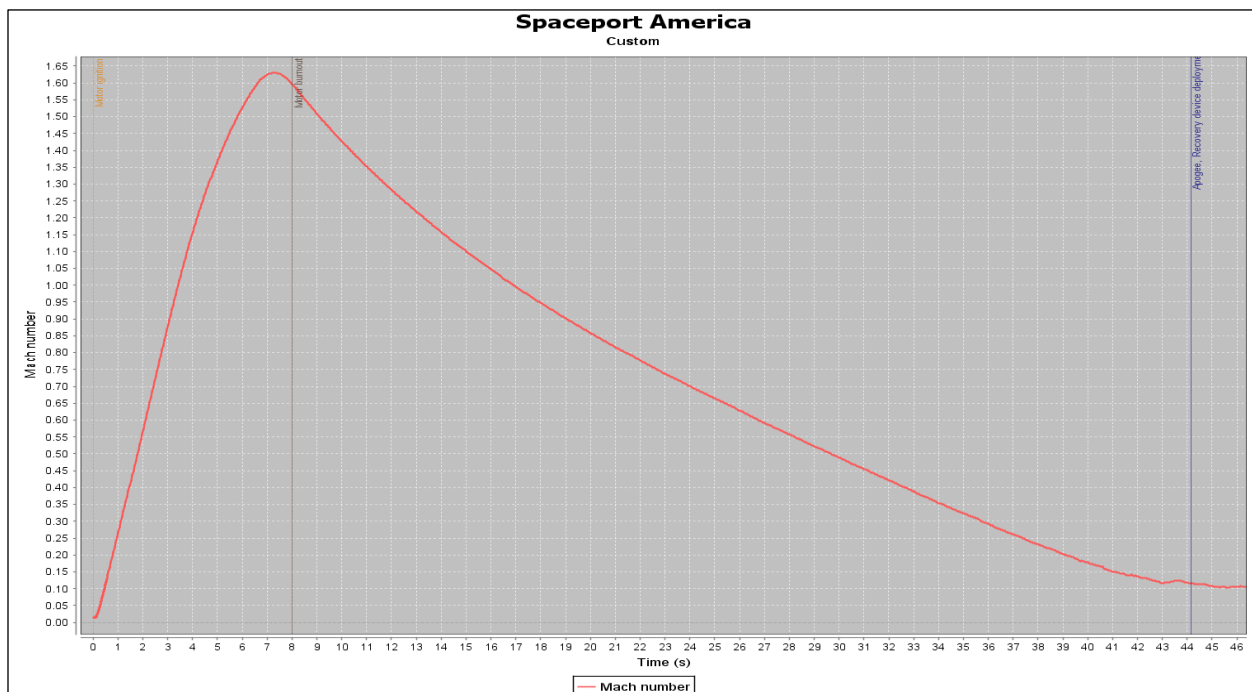


Figure 36. OpenRocket Mach Number vs. Time plot for ESRA 2019-2020 rocket.

Analyst: Mikayla Farr

Date: 2/12/2020

Answer: From this analysis it was concluded that the maximum Mach number the rocket will see is 1.63 at a time of 7.3 seconds after motor ignition. Therefore, the maximum speed of the rocket is classified as supersonic. Subsonic flight is classified as a Mach number less than 0.8 [2]. Transonic flight are Mach numbers between 0.8 and 1.2 and supersonic flight is classified as a Mach number larger than 1.2 [2]. Therefore, the rocket is in subsonic flight from motor ignition to 2.75 seconds after, transonic flight from 2.75 seconds to 4.3 seconds after motor ignition, and supersonic flight from 4.3 seconds to motor burnout at 8 seconds. This analysis yielded the maximum velocity of the rocket, which was used to determine characteristics such as the nosecone shape and evaluate the fin flutter shown in Analysis 14.

Analysis 8

Analyst: Mikayla Farr

Date: 2/12/2020

Corresponding Engineering Specification: NA

Given: The problem is to determine the Mach numbers the rocket sees during specific times of its flight. The data from the Propulsion Mixing sub-team is known and their thrust curve was uploaded into RASAero II. The launch conditions have been set to the latitude and longitude of Spaceport America and a wind speed for the location has been chosen. A display window of the launch conditions is shown in Appendix C.

To Do: The goal of this analysis is to determine the Mach numbers the rocket encounters during the duration of its flight.

Solution: Once the two-dimensional layout of the rocket was completed, a motor configuration using the current data from the Propulsion Mixing sub-team was created, and the flight simulation was run. The flight simulation yielded a maximum Mach number value in the display bar as well as a Mach Number vs. Time plot of the results. This plot is shown in Figure 37. It is important to note that a wind speed of 10 mph was assumed for the purpose of this simulation.

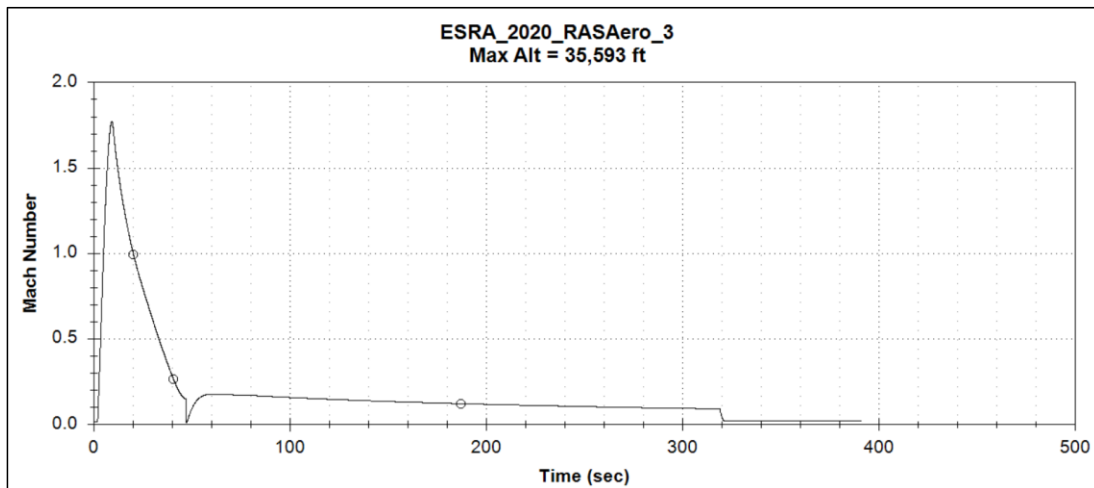


Figure 37. RASAero II Mach Number vs. Time plot for ESRA 2019-2020 rocket.

Answer: From this analysis it was concluded that the maximum Mach number the rocket will see is 1.77 at a time of 9 seconds after motor ignition. Therefore, the maximum speed of the rocket is classified as supersonic. The rocket is in subsonic flight from motor ignition to 4.5 seconds after, transonic flight from 4.5 seconds to 5.8 seconds after motor ignition, and supersonic flight from 5.8 seconds to motor burnout at 9 seconds. This analysis yielded the maximum velocity of the rocket, which was used to determine characteristics such as the nosecone shape and evaluate the fin flutter shown in Analysis 14.

Analysis 9

Analyst: Mikayla Farr

Date: 2/12/2020

Corresponding Engineering Specification: This was an ES for Structures and Integration

Given: The problem is to determine the drag coefficient of the rocket at various Mach numbers during its flight. The data from the Propulsion Mixing sub-team is known and their thrust curve was uploaded into OpenRocket. The launch conditions are set to the proper conditions for Spaceport America and are displayed in Appendix B.

To Do: The goal of this analysis is to determine the coefficient of drag for key rocket components at various Mach numbers.

Solution: Once the two-dimensional layout of the rocket was completed, a motor configuration using the current data from the Propulsion Mixing sub-team was created, and the flight simulation was run. The flight simulation yielded a Coefficient of Drag vs. Mach Number plot of the results. This plot is shown in Figure 38. The coefficient of drag of the nose cone, upper body tube, lower body tube, fins, and boat tail at various Mach numbers are displayed in Table 18 through Table 22. The Mach numbers of these tables were chosen based on the Mach number ranges for subsonic, transonic, and supersonic flight. A Mach of 1.0 was chosen because it had the largest drag other than at motor ignition. It is important to note that a wind speed of 10 mph with a standard deviation of 1.8 mph was assumed for the purpose of this simulation.

Analyst: Mikayla Farr
Date: 2/12/2020

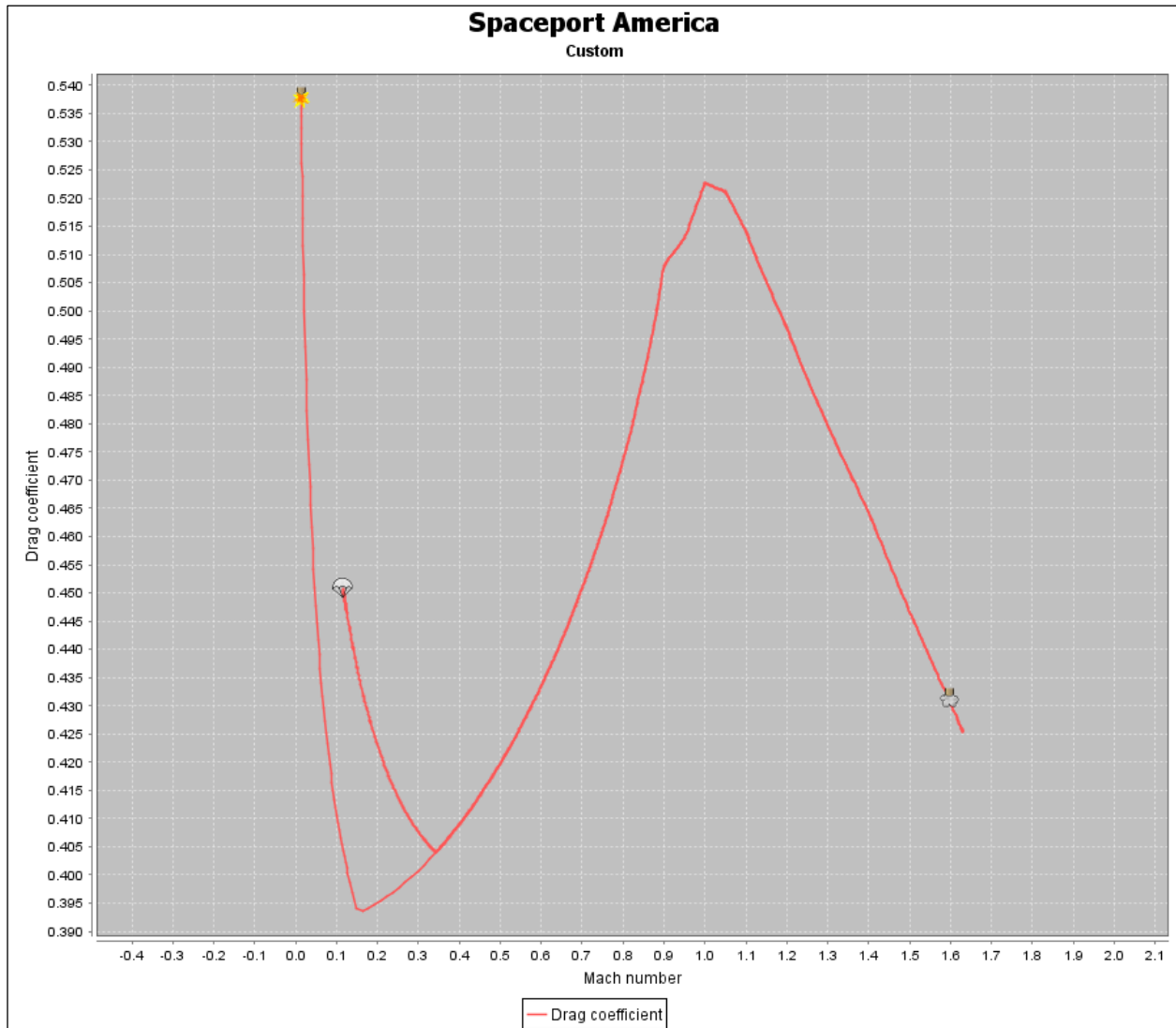


Figure 38. OpenRocket Drag Coefficient vs. Mach Number plot for ESRA 2019-2020 rocket.

Table 18. OpenRocket Coefficient of Drag at Mach 0.3.

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Nose Cone	0.00 (0%)	0.00 (0%)	0.03 (8%)	0.03 (8%)
Upper Body Tube	0.00 (0%)	0.00 (0%)	0.07 (17%)	0.07 (17%)
Lower Body Tube	0.00 (0%)	0.00 (1%)	0.13 (33%)	0.13 (34%)
Trapezoidal fin set1	0.00 (0%)	0.00 (0%)	0.03 (8%)	0.03 (8%)
Boat Tail	0.00 (0%)	0.12 (31%)	0.01 (2%)	0.13 (33%)
Total	0.00 (0%)	0.13 (32%)	0.27 (68%)	0.40 (100%)

Analyst: Mikayla Farr

Date: 2/12/2020

Table 19. OpenRocket Coefficient of Drag at Mach 0.8.

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Nose Cone	0.00 (0%)	0.00 (0%)	0.03 (7%)	0.03 (7%)
Upper Body Tube	0.00 (0%)	0.00 (0%)	0.06 (14%)	0.06 (14%)
Lower Body Tube	0.00 (0%)	0.01 (1%)	0.12 (26%)	0.13 (27%)
Trapezoidal fin set1	0.02 (4%)	0.00 (0%)	0.03 (6%)	0.05 (11%)
Boat Tail	0.00 (0%)	0.19 (40%)	0.01 (2%)	0.20 (42%)
Total	0.02 (4%)	0.20 (41%)	0.26 (54%)	0.47 (100%)

Table 20. OpenRocket Coefficient of Drag at Mach 1.0.

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Nose Cone	0.01 (3%)	0.00 (0%)	0.03 (6%)	0.04 (8%)
Upper Body Tube	0.00 (0%)	0.00 (0%)	0.06 (11%)	0.06 (11%)
Lower Body Tube	0.00 (0%)	0.01 (1%)	0.11 (22%)	0.12 (23%)
Trapezoidal fin set1	0.03 (6%)	0.00 (0%)	0.03 (5%)	0.06 (11%)
Boat Tail	0.00 (0%)	0.23 (44%)	0.01 (2%)	0.24 (46%)
Total	0.05 (9%)	0.24 (46%)	0.24 (46%)	0.52 (100%)

Table 21. OpenRocket Coefficient of Drag at Mach 1.2.

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Nose Cone	0.04 (9%)	0.00 (0%)	0.03 (5%)	0.07 (14%)
Upper Body Tube	0.00 (0%)	0.00 (0%)	0.05 (11%)	0.05 (11%)
Lower Body Tube	0.00 (0%)	0.01 (1%)	0.10 (21%)	0.11 (22%)
Trapezoidal fin set1	0.04 (7%)	0.00 (0%)	0.02 (5%)	0.06 (12%)
Boat Tail	0.00 (0%)	0.19 (39%)	0.01 (1%)	0.20 (41%)
Total	0.08 (16%)	0.20 (40%)	0.22 (44%)	0.50 (100%)

Table 22. OpenRocket at Coefficient of Drag at Mach 1.77.

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Nose Cone	0.05 (12%)	0.00 (0%)	0.02 (5%)	0.07 (18%)
Upper Body Tube	0.00 (0%)	0.00 (0%)	0.04 (11%)	0.04 (11%)
Lower Body Tube	0.00 (0%)	0.00 (1%)	0.08 (21%)	0.09 (22%)
Trapezoidal fin set1	0.04 (10%)	0.00 (0%)	0.02 (5%)	0.06 (15%)
Boat Tail	0.00 (0%)	0.13 (33%)	0.01 (1%)	0.14 (34%)
Total	0.09 (22%)	0.14 (34%)	0.18 (44%)	0.41 (100%)

Answer: From this analysis it was concluded that the coefficient of drag of the entire rocket begins at a value of 0.537, which is the largest coefficient of drag the rocket experiences. The drag coefficient then decreases to a value of 0.40 at Mach 0.3. It then begins to increase and experiences another maximum coefficient of drag of 0.52 at Mach 1.0. After reaching this maximum, it continues to decrease, and the rocket experiences a coefficient of drag of 0.41 at its maximum velocity.

Analysis 10

Analyst: Mikayla Farr

Date: 2/12/2020

Corresponding Engineering Specification: This was an ES for Structures and Integration

Given: The problem is to determine the drag coefficient of the rocket at various Mach numbers during its flight. The data from the Propulsion Mixing sub-team is known and their thrust curve was uploaded into RASAero II. The launch conditions are set to the proper conditions for Spaceport America and are displayed in Appendix C.

To Do: The goal of this analysis is to determine the coefficient of drag for key rocket components at various Mach numbers.

Solution: Once the two-dimensional layout of the rocket was completed, a motor configuration using the current data from the Propulsion Mixing sub-team was created, and the flight simulation was run. The flight simulation yielded a Coefficient of Drag vs. Mach Number plot of the results. This plot is shown in Figure 39. It is important to note that a wind speed of 10 mph was assumed for the purpose of this simulation.

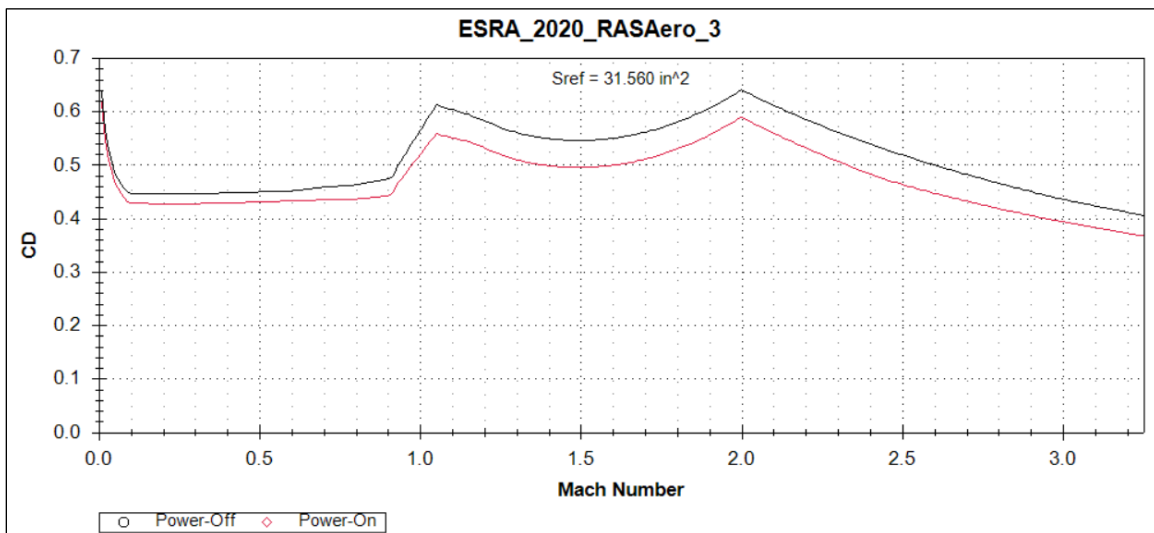


Figure 39. RASAero II Drag Coefficient vs. Mach Number plot for ESRA 2019-2020 rocket.

Answer: From this analysis it was concluded that the coefficient of drag of the entire rocket begins at a value of 0.618, which is the largest coefficient of drag the rocket experiences. The drag coefficient then decreases to a value of 0.427 from Mach 0.16 to 0.32. It then begins to increase and experiences another maximum coefficient of drag of 0.612 at Mach 1.05. After reaching this maximum, it continues to decrease, and the rocket experiences a coefficient of drag of 0.523 at its maximum velocity of 1.77 Mach. Any Mach number above 1.77 can be ignored in the above plot since the ESRA rocket will not reach speeds faster than that.

Analysis 11

Analyst: Mikayla Farr

Date: 2/12/2020

Corresponding Engineering Specification: ES 8.1 and ES 8.2: The drogue and main parachutes must provide the rocket with appropriate descent velocities.

Given: The problem is to determine the velocity of rocket right before the main parachute deployment event and its predicted ground hit velocity. The data from the Propulsion Mixing sub-team is known and their thrust curve was uploaded into OpenRocket. The launch conditions are set to the proper conditions for Spaceport America and are displayed in Appendix B.

To Do: The goal of this analysis is to determine the descent velocity of the current rocket design just prior to the main parachute deployment and touchdown velocity.

Solution: Once the two-dimensional layout of the rocket was completed, a motor configuration using the current data from the Propulsion Mixing sub-team was created, and the flight simulation was run. The flight simulation yielded exact values in the display bar as well as a Total Velocity vs. Time plot of the results. This plot is shown in Figure 40. It is important to note that a wind speed of 10 mph with a standard deviation of 1.8 mph was assumed for the purpose of this simulation.

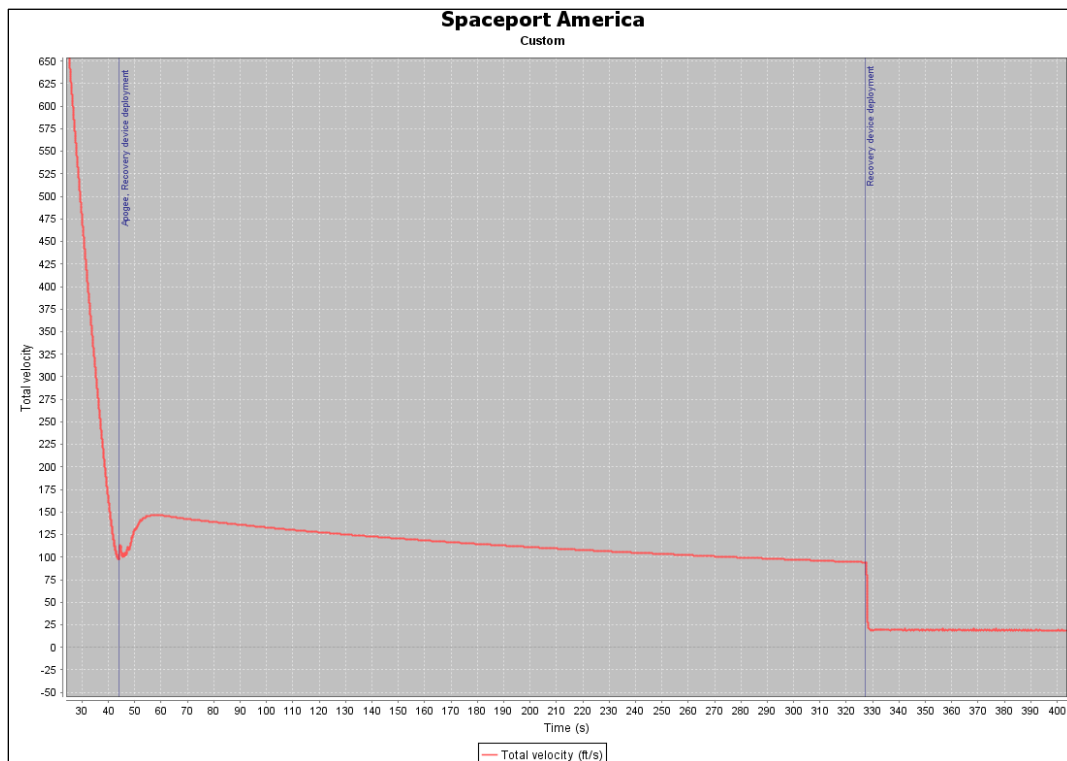


Figure 40. OpenRocket Total Velocity vs. Time plot for ESRA 2019-2020 rocket.

Analyst: Mikayla Farr

Date: 2/12/2020

Answer: From this analysis it is concluded that the descent velocity of the drogue parachute just prior to the main parachute deployment event is 94.2 ft/s and the ground hit velocity is 19 ft/s. Currently, both of these velocities are within the range of the competition rules. The error of this function in OpenRocket is unknown and therefore these values should be used only for rough estimates of the descent velocities. The actual method for finding the descent velocities should be validated via MATLAB.

Analysis 12

Analyst: Mikayla Farr

Date: 2/12/2020

Corresponding Engineering Specification: ES 8.1 and ES 8.2: The drogue parachute must provide an appropriate descent velocity for the rocket from apogee and the main parachute must provide an appropriate descent velocity to safely land the rocket on the ground.

Given: The problem is to determine the velocity of rocket right before the main parachute deployment event and its predicted ground hit velocity. The data from the Propulsion Mixing sub-team is known and their thrust curve was uploaded into RASAero II. The launch conditions are set to the proper conditions for Spaceport America and are displayed in Appendix C.

To Do: The goal of this analysis is to determine the descent velocity of the current rocket design just prior to the main parachute deployment and its ground hit velocity.

Solution: Once the two-dimensional layout of the rocket was completed, a motor configuration using the current data from the Propulsion Mixing sub-team was created, and the flight simulation was run. The flight simulation yielded exact values in the display bar as well as a Total Velocity vs. Time plot of the results. This plot is shown in Figure 41. It is important to note that a wind speed of 10 mph was assumed for the purpose of this simulation.

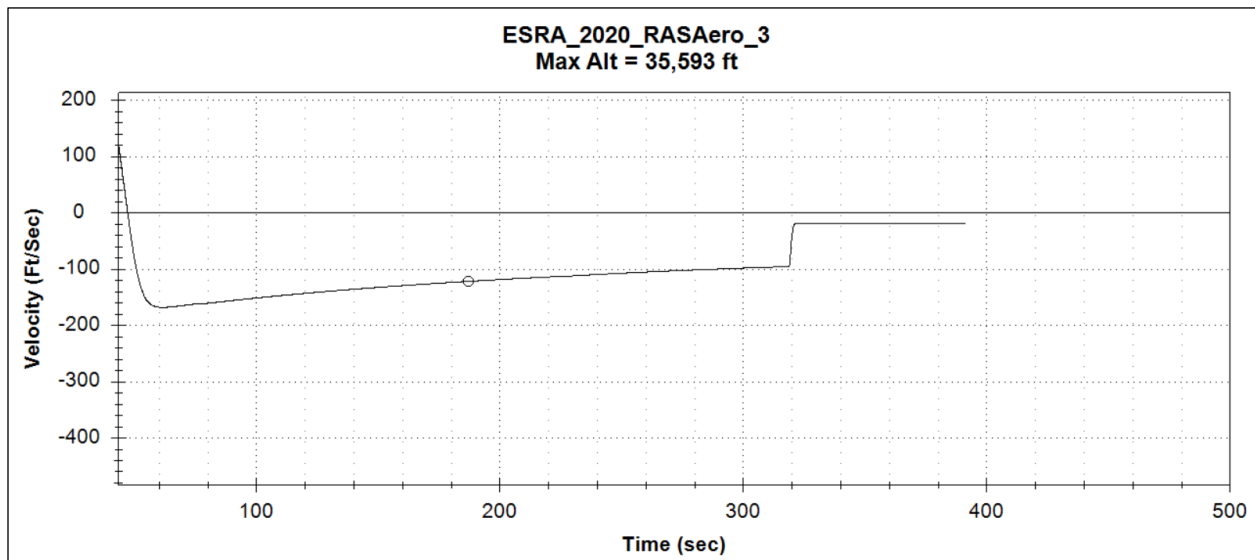


Figure 41. RASAero II Total Velocity vs. Time plot for ESRA 2019-2020 rocket.

Answer: From this analysis it is concluded that the descent velocity of the drogue parachute just prior to the main parachute deployment event is 96.1 ft/s and the ground hit velocity is 19.8 ft/s. Currently, both of these velocities are within the range of the competition rules.

Analysis 13

Analyst: Hayden Ferrell

Date: 2/15/2020

Corresponding Engineering Specification: NA

Given: The problem is to determine if the nose cone from the 2018-2019 ESRA rocket is viable for use on the 2019-2020 ESRA rocket and how it may perform in comparison to alternate nose cone profile designs. Preliminary research was conducted using Stoney's NACA Research Memorandum [3] and suggested that the ½ Power Series profile may perform as good or better than the Von Karman profile for a transonic flight. The 2018-2019 nose cone is a Von Karman profile, with a diameter of 6.35 inches and a length of 31.75 inches, giving it a fineness ratio of 5:1, which is described as ideal [2]. The diameter of the nose cone matches that of the 2019-2020 ESRA rocket airframe diameter, therefore it can be concluded that this nose cone will be able to integrate with the 2019-2020 rocket. The body is made of fiberglass, which has the necessary RF transparency characteristics for the payload and avionics equipment, and the tip is manufactured from 6061 aluminum [4].

To Do: In order to determine if the 2018-2019 nose cone is viable for use on the 2019-2020 ESRA rocket, a performance analysis must be conducted to compare the 2018-2019 Von Karman profile with an equivalent ½ Power Series profile. If the Von Karman profile performs superiorly to the ½ Power Series profile, calculations must be made to confirm the 6061-aluminum tip will be able to withstand the temperatures associated with aerodynamic heating.

Solution: OpenRocket flight simulations of the 2019-2020 ESRA rocket in which all parameters were kept constant except for the nose cone profile were conducted, yielding the results in Figures 42 and 43 below. This uses an older simulation but is still viable to determine if last year's nose cone can be used.

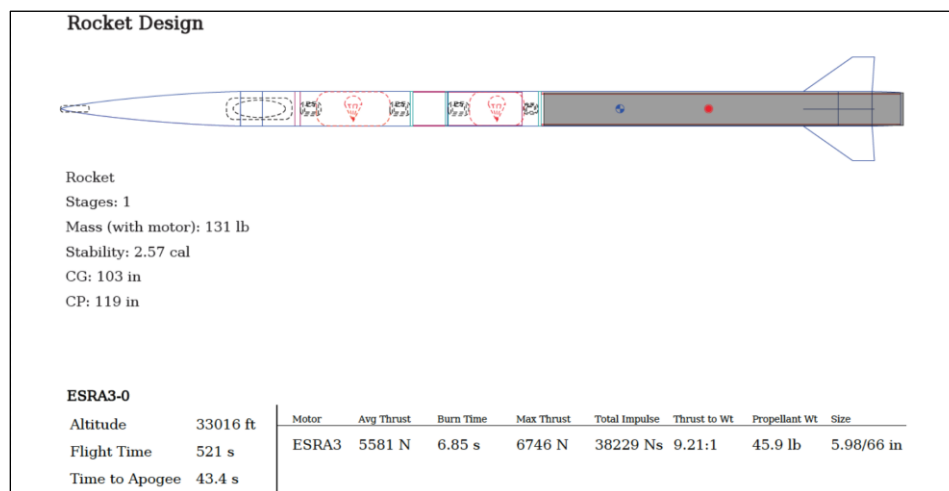


Figure 42. ESRA flight simulation using Von Karman nose cone profile.

Analyst: Hayden Ferrell
Date: 2/15/2020

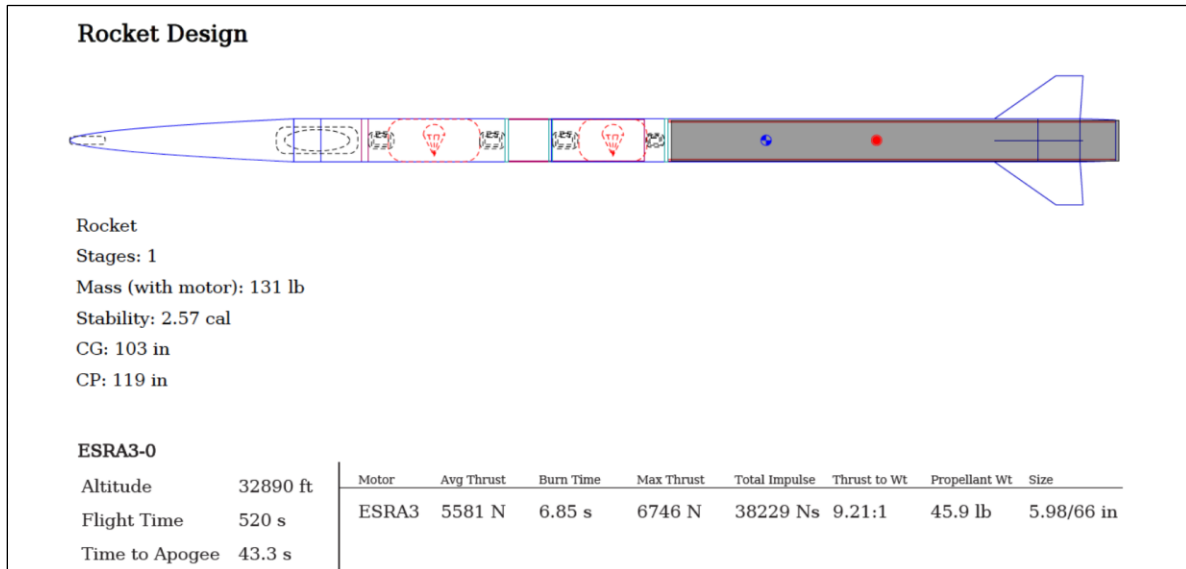


Figure 43. ESRA flight simulation using ½ Power Series nose cone profile.

The simulations conclude that the Von Karman nose cone profile performs superiorly to the ½ Power Series profile. To confirm that the 6061-aluminum tip of the 2018-2019 nose cone will be able to withstand the aerodynamic heating during flight, the stagnation temperature at max speed will be calculated.

Known Values:

Static Temperature along the Stagnation Streamline (T) = 268.8 K

Mach Number at the Point of Interest along the Stagnation Streamline (M) = 1.77

Ratio of Specific Heats of Air (γ) = 1.4

Find stagnation temperature using Equation (1) [5]

$$T_0 = \left(1 + \frac{\gamma-1}{2} * M^2\right) * T \quad (1)$$

Answer: The 2018-2019 nose cone can be integrated into the 2019-2020 ESRA airframe, and its Von Karman profile was shown to be superior to that of the ½ Power Series. The stagnation temperature was calculated to be 437.2 K at an altitude of 10,000 ft. An aluminum tip like that of the 2018-2019 nose cone can withstand up to 855.15 K before failing [6], therefore the nose cone tip will not fail during flight. This analysis therefore proves that the 2018-2019 nose cone can be used on the 2019-2020 ESRA rocket.

Analysis 14

Analyst: Hayden Ferrell

Date: 2/15/2020

Corresponding Engineering Specification: NA

Given: The problem is to determine the flutter velocity of the current fin design to ensure the fins will not be structurally compromised during flight. If at any given altitude, the velocity of the rocket surpasses the flutter velocity, the fins will be compromised and may shear off during flight.

To Do: The goal of this analysis is to determine the flutter velocity profile throughout the flight of the rocket and compare it to OpenRocket flight data to ensure that flutter velocity is not surpassed during flight.

Solution:

Known Values:

Effective Shear Modulus (G) = 10^6 psi

Fin Aspect Ratio (AR) = 0.5851

Fin Taper Ratio (λ) = 0.3958

Fin Normalized Thickness (T) = 0.0208 inches

Atmospheric Scale Height (H) = 26,500 feet

Height at sea level (h_0) = 0 feet

Find the atmospheric temperature in degrees Fahrenheit at sea level using Equation (2)[7]

$$T_0 = 59 - 0.00356 * h_0 \quad (2)$$

Find the atmospheric pressure in psi at sea level using Equation (3)[7]

$$P_0 = 2116 * \left(\frac{T_0 + 459.7}{518.6} \right)^{5.256} \quad (3)$$

Find the speed of sound in feet per second at the sea level temperature using Equation (4) [7]

$$C_{s0} = \sqrt{1.4 * 1716.59 * (T_0 + 4660)} \quad (4)$$

Find the flutter velocity in feet per second for a given altitude in feet, “h”, using Equation (5)[7]

$$V_f = 1.223 * C_{s0} * e^{(0.4 * \frac{h}{H})} * \sqrt{\frac{G}{P_0}} * \sqrt{\frac{(2+AR)}{(1+\lambda)}} * \left(\frac{T}{AR} \right)^{\frac{3}{2}} \quad (5)$$

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Use MATLAB to plot calculated flutter velocity vs. altitude, shown in Figure 44.

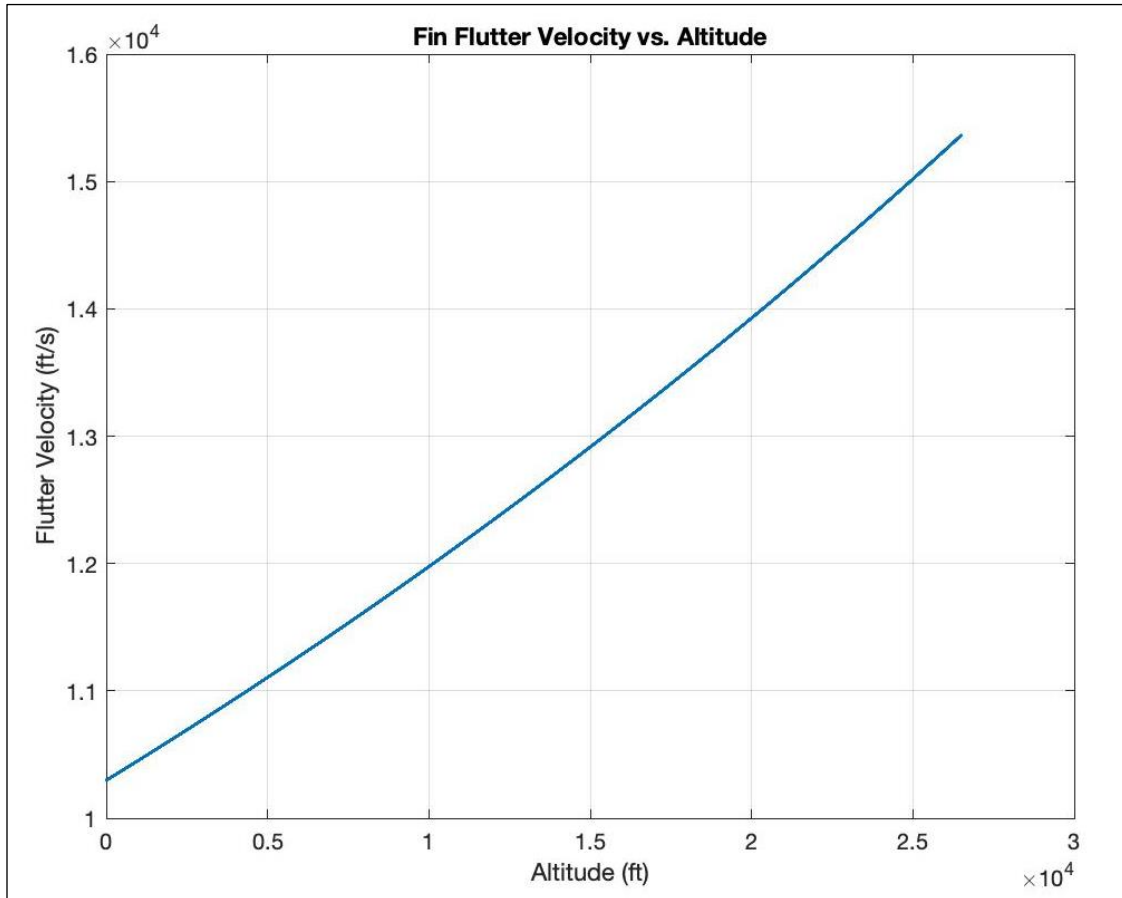


Figure 44. Plot of flutter velocity vs. rocket altitude for 2019-2020 ESRA rocket.

Answer: From this analysis we can see that the minimum flutter velocity is approximately 10,290 ft/s, and with the rocket reaching a max speed of Mach 1.77, or approximately 1,880.7 ft/s, we can conclude that flutter velocity will not be surpassed at any point during flight and that the current fin design will be structurally sound. The MATLAB code used to create the flutter velocity plot can be found in Appendix D.

Analysis 15

Analyst: Hayden Ferrell

Date: 2/15/2020

Corresponding Engineering Specification: ES 10: The number of successful parachute deployment tests per parachute.

Given: The problem is to determine the amount of black powder needed to successfully separate the launch vehicle at apogee and at 1500 ft. In order to ensure that the proper air frame pressurization of 20 psi is reached, and the drogue and main parachutes are successfully ejected from the launch vehicle, the correct amount of 4444FG black powder to use for the ejection charges must be determined.

To Do: The goal of this analysis is to determine the mass of black powder needed for the upper and lower body tube ejection charges.

Solution:

Known Values:

$$P = 20 \text{ psi}$$

$$1 \text{ lbm} = 454 \text{ g}$$

$$L_{\text{Upper}} = 21 \text{ in}$$

$$L_{\text{Lower}} = 13.75 \text{ in}$$

$$D = 6.25 \text{ in}$$

$$T_{\text{BP}} = 3307 \text{ R}$$

$$R = 265.9$$

Find the volume of the upper and lower body tube sections in cubic inches using Equation (6)

$$V = \frac{\pi}{4} * D^2 * L \quad (6)$$

Find the necessary mass of black powder in grams to provide the pressure, P, to the upper and lower body tubes using Equation (7)

$$m = \frac{P*V}{R*T} * \frac{454 \text{ g}}{1 \text{ lbm}} \quad (7)$$

Answer: From this analysis, the ejection charges for the upper body tube must ignite 6.5 g of black powder for adequate pressurization, and the charges for the lower body tube must ignite 4.5 g of black powder (rounding to nearest half gram). In order to ensure separation, a safety factor of 1.5 will be used when making the backup charges. This brings the final masses of black powder to 9.75 g for the upper body tube and 6.75 g for the lower body tube.

Analysis 16

Analyst: Annalise Daul

Date: 1/8/2020

Corresponding Engineering Specification: ES 8.1: The drogue parachute must provide an appropriate descent velocity for the rocket from apogee.

Given: To follow the 2020 Spaceport America Cup recommendations, the drogue parachute should slow the rocket to a descent velocity between 75 and 150 ft/s to prepare the rocket for the main parachute deployment [8]. The drogue parachute will be deployed at an apogee of approximately 30,000 ft and serve as the sole decelerator for the rocket until the main parachute deploys at 1,500 ft. The shape of the drogue parachute was chosen to be annular or, equivalently, toroidal.

To Do: Determine the proper size of the drogue parachute to slow the rocket to approximately 100 ft/s for the main parachute deployment event. Find the required surface area, outer diameter, vent diameter, length of suspension lines, and gore parameters of the drogue parachute.

Solution: This analysis approach was based upon the work of Theodore W. Knacke [9].

The nominal surface area of the drogue parachute canopy was calculated from Equation 8 for the desired rate of descent provided by the drogue.

$$V = \sqrt{\frac{2 \cdot W}{S_O \cdot C_D \cdot \rho}} \quad (8)$$

The nominal surface area, S_O , was solved for by rearranging Equation 8. Rate of descent, V , was set to the desired descent velocity achieved by the drogue parachute. The coefficient of drag, C_D , for the parachute was set to an optimal value of 2.2. The density, ρ , was set to the density of air corresponding to the altitude of drogue parachute deployment. The dry weight of the rocket, W_d , was used as the approximate weight upon drogue deployment.

The nominal parachute diameter, or outer diameter, was solved for using Equation 9 for the surface area of a circle.

$$S_O = \frac{\pi}{4} \cdot D_O^2 \quad (9)$$

Annular parachutes have relatively large venting holes as compared to other parachutes. The vent diameter, D_V , of an annular parachute was calculated as 20% of the parachute outer diameter. See Equation 10. This rule of thumb comes Fruity Chutes, a commercial parachute manufacturer often used by Oregon State University rocketry teams.

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Date: 1/8/2020

$$D_V = 0.2 \cdot D_O \quad (10)$$

Then, the venting and outer diameters are used with Equation 11 to solve for the actual surface area of the parachute.

$$S = \frac{\pi}{4} \cdot (D_O^2 - D_V^2) \quad (11)$$

In addition to the parachute dimensions, the length of the suspension lines was calculated. Suspension lines, also known as shroud or extension lines L_e , are dimensioned for annular parachutes by the ratio of line length to nominal diameter, equal to some value that optimizes the drag coefficient [9]. Equation 12 was used to solve for the length of the suspension lines for the annular drogue parachutes.

$$\frac{L_e}{D_O} = 1.25 \quad (12)$$

Once the overall dimensions of the drogue parachute were calculated, the gore dimensions were calculated. The number of gores, N_g , was set to 12. Then, the gore parameters were determined using the ratios and equations from Figure 45.

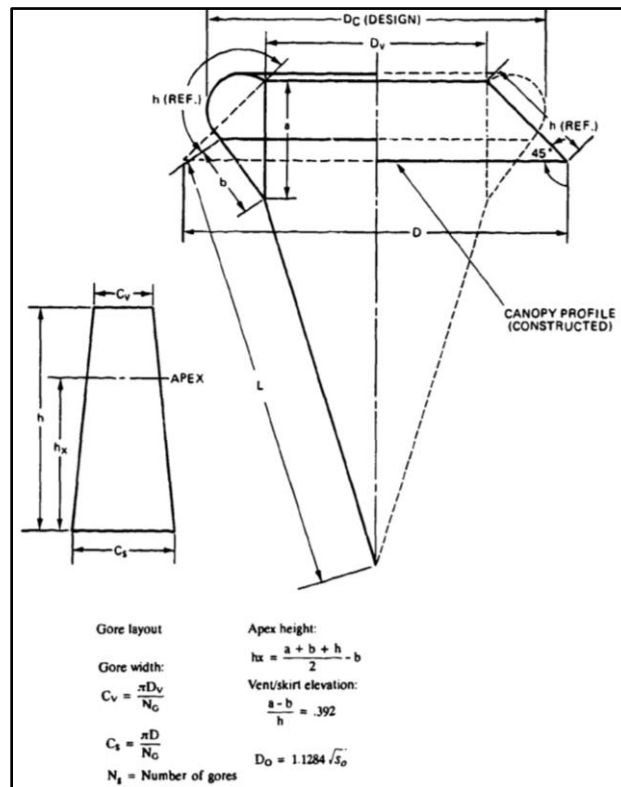


Figure 45. Gore Dimensions for Typical Annular Parachute Design [9].

Analyst: Annalise Daul

Date: 1/8/2020

Answer: To ensure the rocket attains a descent rate of approximately 100 ft/s for the main parachute deployment, the drogue parachute will have the following dimensions. The MATLAB code for the drogue parachute calculations can be found under Appendix E.

$$S = 4.39 \text{ ft}^2$$

$$D_O = 28.96 \text{ in.}$$

$$D_V = 5.79 \text{ in.}$$

$$L_e = 36.20 \text{ in.}$$

$$h = 19.56 \text{ in.}$$

$$h_x = 6.13 \text{ in.}$$

$$C_V = 1.52 \text{ in.}$$

$$C_S = 7.89 \text{ in.}$$

Analysis 17

Analyst: Annalise Daul

Date: 1/8/2020

Corresponding Engineering Specification: ES 8.2: The main parachute must provide an appropriate descent velocity to safely land the rocket on the ground.

Given: The Intercollegiate Rocket Engineering Competition (IREC) requires that the rocket has a touchdown velocity no greater than 30 ft/s at the 2020 Spaceport America Cup [8]. This means the main parachute must slow the rocket to this specified descent rate after deployment at 1,500 ft. The shape of the main parachute was chosen to be annular or, equivalently, toroidal.

To Do: Determine the proper size of the main parachute to ensure the rocket lands at a descent rate of approximately 20 ft/s. Find the required surface area, outer diameter, vent diameter, length of suspension lines, and gore parameters of the annular shaped main parachute.

Solution: Sizing the main parachute followed the same approach as Analysis 16. However, Equation 9 was multiplied by a factor of safety, FS , equal to 1.5 to yield a more conservative size for the main parachute, as recommended by Knacke [9].

Answer: To ensure the rocket attains a touchdown velocity of 20 ft/s, the main parachute would have the following dimensions. The MATLAB code for the main parachute calculations can be found under Appendix F. Below are the calculated values of the main parachute with a factor of safety.

$$\begin{aligned}S &= 194.29 \text{ ft}^2 \\D_O &= 192.63 \text{ in.} \\D_V &= 38.53 \text{ in.} \\L_e &= 240.78 \text{ in.} \\h &= 130.08 \text{ in.} \\h_x &= 40.74 \text{ in.} \\C_V &= 10.09 \text{ in.} \\C_S &= 52.45 \text{ in.}\end{aligned}$$

Though the above dimensions are appropriate for the ESRA 2019-2020 rocket named Pisces Volantes, the Aerodynamics & Recovery team decided to reuse the main parachute manufactured by the ESRA 2018-2019 team. This parachute has an outer diameter, D_O , of 138.86 in. Analysis 18, the MATLAB Parachute Descent Analysis, verifies the main parachute of the aforementioned outer diameter provides a descent rate that falls within the acceptable range for Engineering Specification 8.2.

Analysis 18

Analyst: Annalise Daul

Date: 2/8/2020

Corresponding Engineering Specification: ES 8.1 & ES 8.2: The drogue parachute must provide an appropriate descent velocity for the rocket from apogee and the main parachute must provide an appropriate descent velocity to safely land the rocket on the ground.

Given: The rocket must be slowed to appropriate descent velocities as required by IREC rules. The descent rate of the rocket depends on the amount of drag force provided by both the drogue and the main parachutes. These drag forces depend on the surface area of the parachutes. In addition, the air density affects the drag produced by the parachute canopies. The drogue parachute will deploy at the apogee of approximately 30,000 ft AGL. This altitude has a much lower density than the density at 1,500 ft, the height at which the main parachute will deploy. In all, this analysis serves to support that the design of the parachutes will sufficiently slow the rocket to an appropriate velocity at the main parachute deployment event and upon touchdown.

To Do: Determine the descent velocity the drogue parachute slows the rocket to for the main parachute deployment event and the touchdown velocity under the main parachute.

Solution: The descent analysis developed depends heavily on the drag coefficients of the rocket components and parachute canopies, the altitude, pressure, temperature, and density of the Earth's atmosphere, and the overall mass of the entire system. The descent analysis uses the barometric formula [10] to simulate how the velocity profile of the rocket will change as a function of descending altitude. The velocity profile was solved using MATLAB's ordinary differential equation solver function for the equation of motion.

This analysis uses the launchpad altitude above ground level, the predicted height of apogee, temperature lapse rate, gravitational acceleration on Earth, the molar mass of air, and predicted drag coefficients of the rocket and its components to predict, as accurately as possible, the velocities obtained throughout descent. This will serve to validate the parachute designs and confirm that the rocket will comply with IREC rules.

The analysis was developed on MATLAB. Refer to Appendices E through J for the codes corresponding to different aspects of the descent analysis. Figure 46 shows the output verifying that the parachutes do provide the rocket with the appropriate descent rates: the drogue slows the rocket to a velocity between 75 and 150 ft/s and the main provides the rocket with a landing velocity less than 30 ft/s.

```

Terminal Velocity of Drogue: -25.4 m/s
                             -83.2 ft/s

Terminal Velocity of Main:   -6.5 m/s
                             -21.3 ft/s

Total Descent Time:  420.0 s

```

Figure 46. MATLAB Command Window Output for Descent Analysis Code.

Figures 47 and 48 show the plots of the altitude profiles above ground level as a function of time after parachute deployment and the corresponding velocity profiles.

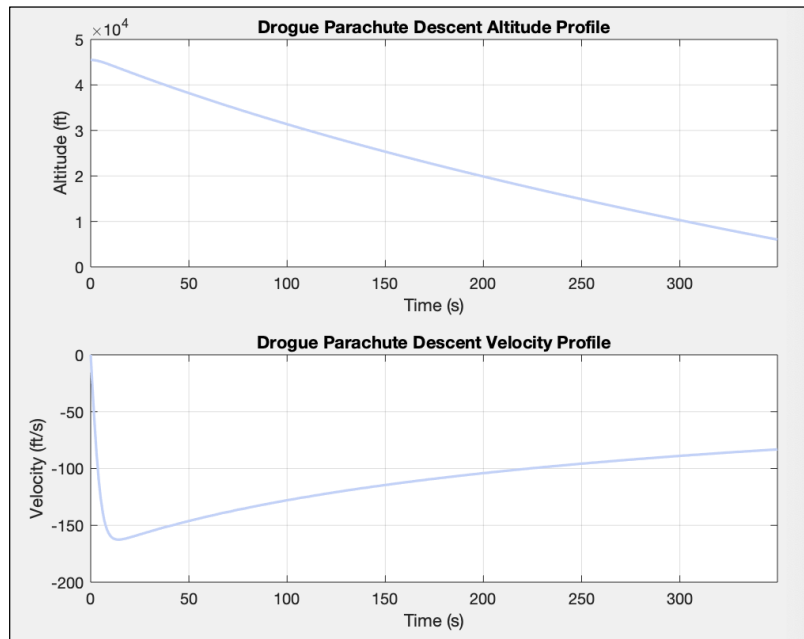


Figure 47. Rocket Descent Under Drogue Parachute.

Analyst: Annalise Daul
Date: 2/8/2020

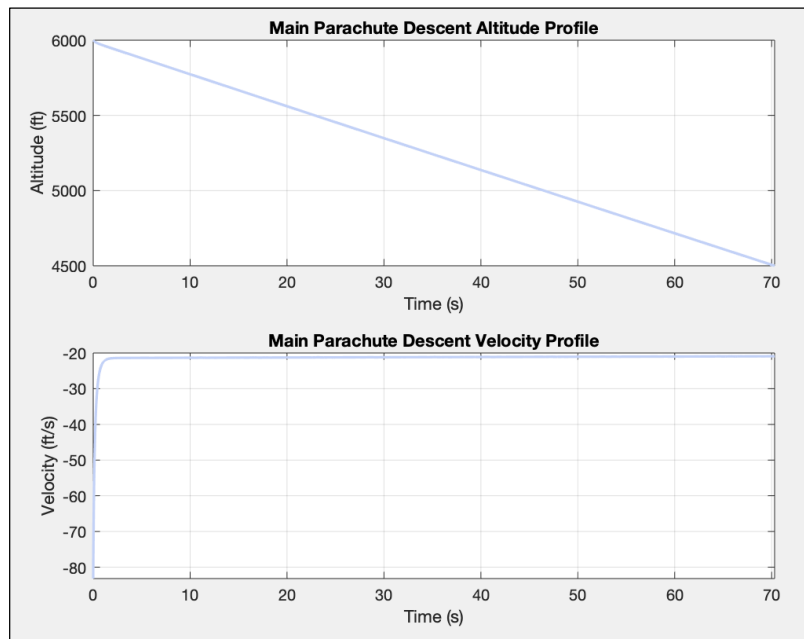


Figure 48. Rocket Descent Under Main Parachute.

References

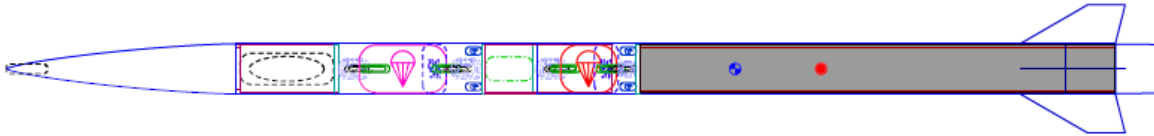
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Appendices

Appendix A

OpenRocket Motor and Key Flight Parameters for ESRA 2019-2020 Rocket

Rocket Design



Rocket

Stages: 1

Mass (with motor): 136 lb

Stability: 1.71 cal

CG: 92.005 in

CP: 103 in

SecondTestFire-P

		Motor	Avg Thrust	Burn Time	Max Thrust	Total Impulse	Thrust to Wt	Propellant Wt	Size
Altitude	33927 ft	Second	4937 N	7.8 s	7053 N	38554 Ns	8.14:1	42.2 lb	5.98/60 in
Flight Time	403 s	TestFire							
Time to Apogee	44 s								
Optimum Delay	36.1 s								
Velocity off Pad	147 ft/s								
Max Velocity	1822 ft/s								
Velocity at Deployment	94.3 ft/s								
Landing Velocity	18.8 ft/s								

Appendix B

Display Window of the Launch Conditions for OpenRocket

The screenshot shows the 'Edit simulation' window with the following settings:

- Simulation name: Spaceport America
- Flight configuration: [SecondTestFire-P]
- Launch conditions (selected tab):
 - Wind:
 - Average windspeed: 10 mph
 - Standard deviation: 1.8 mph
 - Turbulence intensity: 18 % High
 - Wind direction: 90 °
 - Atmospheric conditions:
 - Use International Standard Atmosphere
 - Temperature: 105 °F
 - Pressure: 1016 mbar
 - Launch site:
 - Latitude: 28.6 ° N
 - Longitude: -80.6 ° E
 - Altitude: 4595 ft
 - Launch rod:
 - Length: 384 in
 - Always launch directly up-wind or down-wind
 - Angle: 3 °
 - Direction: 90 °
- Buttons: Reset to default, Save as default, Plot >>, Simulate & Plot, Close

Appendix C
Display Window of the Launch Conditions for RASAero II

Launch Site

Launch Site Elevation (ft)	4595
Temperature (deg F)	105.00
Launch Site Barometric Pressure (in-hg)	30.00
Wind Speed (mph)	10
Launch Rail Length (ft)	32
Launch Angle - degrees from Vertical	3

OK Cancel

Appendix D

MATLAB Code for Fin Flutter Analysis

```
%MIME Capstone
%Fin Flutter Analysis
%Hayden Ferrell

clear
clc

%% Fin Characteristics

Ge = (10E6); %effective shear modulus in psi
t = 0.25; %fin thickness (in)
Cr = 12; %root chord (in)
Ct = 4.75; %tip chord (in)
b = 4.9; %fin semi-span (in)

%% Derived Fin Characteristics

S = ((Cr+Ct)/2)*b; %fin area (in^2)
AR = (b^2)/S; %fin aspect ratio
lamda = Ct/Cr; %fin taper ratio
T = t/Cr; %normalized thickness

%% Atmospheric Characteristics

h0 = 0;
TF0 = 59 - .00356*h0; %temp in degrees F at sea level
P0 = (2116*((TF0 + 459.7)/(518.6))^5.256)*.00694444; % psi Pressure at temp
Cs0 = sqrt(1.4*1716.59*(59 + 460)); %ft per s speed of sound at temp

h = 0:1:26500; %ft altitude of max velocity, taken from OpenRocket sim

%% Flutter Velocity Calculation

H = 26500; %Atmospheric Scale Height

Vf = 1.223*Cs0*exp(0.4*h/H)*sqrt(Ge/P0)*sqrt((2+AR)/(1+lamda))*(T/AR)^(3/2);
%(ft/s)
Vfms = Vf*0.3048; %(m/s)

plot(h,Vf,'.')
grid on
title('Fin Flutter Velocity vs. Altitude')
xlabel('Altitude (ft)')
ylabel('Flutter Velocity (ft/s)')
```

Appendix E

MATLAB Code for Drogue Parachute Design

```

clc
clear
clf

% Drogue Parachute
% Annalise Daul
% Revision 4
    % Corrected Gore Parameters.
    % Created New Plot of Gore Shape.
    % Changed Weight from 90lb to 100lb.
    % Deleted the FS for the Drogue Parachute.

% % Specifications
% %
g = 9.80665;          % Gravitational Acceleration, m/s^2
m = 100 / 2.205;     % Mass of Rocket, lb to kg
W = m * g;           % Mass of Rocket, kg to N
V = 100 / 3.281;     % Desired Descent Velocity, ft/s to m/s
Alt = 6e3 / 3.281;   % Altitude at Terminal Vel, ft to m
                    % Alt = Spaceport Alt (5.3e3 ft) + Alt Main Parachute
                    % Deployment (1.5e3 ft)
Dens = ESRA2020_BarometricFormula(Alt); % Density at End of Drogue Descent,
kg/m^3
rocketID = 6.25 / 39.37008; % Rocket Inner Diameter, in to m
Cd = 2.2;            % Drag Coefficient from Fruity Chutes
%FS = 1.2;           % Factor of Safety for Drogue Parachute

% % Parachute Calculations
% %
So = (2*W)/(V^2*Cd*Dens); % Canopy Reference Area, m^2
Do = sqrt((4*So)/(pi));   % Outer Diameter, m
Dv = 0.2*Do;             % Fruity Chutes Website for Toroidal (Annular) Shape
                        % for Spill Hole or Vent Diameter.
                        % From https://fruitychutes.com/help\_for\_parachutes/how\_to\_
                        % make\_a\_parachute.htm
S = (pi/4)*(Do^2-Dv^2); % Canopy Surface Area, m^2
L = 1.25 * Do;           % Suspension Line or Shroud Line Length, m
                        % From T. Knacke

% % Other Calculations
% %
ripstop = 1.1 / 35.274; % Mass per Unit Area of Ripstop Nylon, oz/yd^2 to
                        % kg/yd^2
rsL = 1 / 1.094;        % Ripstop Length, yd to m
rsW = 60 / 39.37;      % Ripstop Unit Width, in to m
rsA = rsL*rsW;         % Unit Area of Ripstop, m^2
rs = ripstop*rsA;      % Mass of Material, kg
MP = S*rs;             % Parachute Mass, kg
WP = MP*9.807;        % Parachute Weight, N

```

```

PackDens = 350;           % Manual Packing Density, kg/m^3
PackVol = MP/PackDens;   % Parachute Packing Volume, m^3
PackL = (4*PackVol)/(pi*rocketID^2); % Packing Length

fprintf('Surface Area:  %0.2f m^2\n', S)
fprintf('                %0.2f ft^2\n\n', S*3.28084^2)
fprintf('Outer Diameter: %0.2f m\n', Do)
% fprintf('                %0.2f ft\n', Do*3.28084)
fprintf('                %0.2f in\n\n', Do*39.37008)
fprintf('Inner Diameter:  %0.2f m\n', Dv)
% fprintf('                %0.2f ft\n', Dv*3.28084)
fprintf('                %0.2f in\n\n', Dv*39.37008)
fprintf('Parachute Weight:  %0.2f N\n', WP)
% fprintf('                %0.2f lbf\n', WP*0.22481)
fprintf('                %0.2f oz\n\n', WP*0.22481*16)
% fprintf('Packed Volume: %0.2f in^3\n', PackVol*39.37008^3)
% fprintf('Packed Length: %0.2f in\n\n', PackL*39.37008)
fprintf('Shroud Line Length:  %0.2f m\n', L)
fprintf('                %0.2f ft\n', L*3.28084)
fprintf('                %0.2f in\n\n', L*39.37008)

% % Gore Calculations
% %
D = 1.04 * Do;           % Ratio of Gore Diameter to Parachute Diameter from
                        % Knacke
NG = 12;                % Number of Gores
Cv = (pi*Dv)/NG;        % Width of Gore at Vent Diameter, m (Gore Vent Width)
Cs = (pi*D)/NG;         % Width of Gore at Outer Diameter, m (Gore Base Width)
a = 0.319 * Do;
b = 0.2 * Do;
h = 0.304 * Do;         % Gore Reference Height, m
hx = (a+b+h)/2 - b;     % Gore Apex Height, m
GoreH = h*sind(45);     % Drogue Inflated Height, m
GoreH = pi*GoreH;      % Gore Height, m

fprintf('Gore Height:  %0.2f m\n', GoreH)
fprintf('Gore Height:  %0.2f in\n', GoreH*39.37008)
fprintf('Gore Base Width: %0.2f m\n', Cs)
% fprintf('                %0.2f ft\n', Cs*3.28084)
fprintf('                %0.2f in\n\n', Cs*39.37008)
fprintf('Gore Vent Width:  %0.2f m\n', Cv)
% fprintf('                %0.2f ft\n', Cv*3.28084)
fprintf('                %0.2f in\n\n', Cv*39.37008)

% % % Gore Plot
% % %
yCv = GoreH*39.37008;
Cvx1 = (-Cv/2)*39.37008;
Cvx2 = (Cv/2)*39.37008;
line([Cvx1, Cvx2], [yCv, yCv], 'color', ' [.89 .47 .2]', 'linewidth', 1.2)
ylim([0 yCv])
xlim([(-Cs*39.37008)/2, (Cs*39.37008)/2])
hold on

```

```
Csx1 = (-Cs*39.37008)/2;
Csx2 = (Cs*39.37008)/2;
line([Csx1, Csx2], [0,0], 'color', ' [.89 .47 .2]', 'linewidth', 1.2)

delta = Csx2-Cvx2;
slope = yCv/delta;
xrange = linspace(0, delta);
xval = xrange + Cvx2;
yval = yCv - slope.*xrange;
yval = yval';

plot(xval, yval, 'color', ' [.89 .47 .2]', 'linewidth', 1.2)
hold on
plot(-xval, yval, 'color', ' [.89 .47 .2]', 'linewidth', 1.2)
grid on
title('Drogue Parachute Gore Dimensions (in.)')
```

Appendix F

MATLAB Code for Main Parachute Design

```

clc
clear
clf

% Main Parachute
% Annalise Daul
% Revision 5
    % Corrected Gore Parameters.
    % Created New Plot of Gore Shape.
    % Changed Weight from 90lb to 100lb.

% % Specifications
% %
g = 9.80665;          % Gravitational Acceleration, m/s^2
m = 100 / 2.205;     % Mass of Rocket, lb to kg
W = m * g;           % Mass of Rocket, kg to N [kgm/s^2]
V = 18 * 0.3048;     % Desired Descent Velocity, ft/s to m/s
rocketID = 6.25 / 39.37008; % Rocket Inner Diameter, in to m
Cd = 2.2;             % Drag Coefficient from Fruity Chutes Website
                    % Use as Reference for Approximate Drag
                    % Coefficient for Annular = Toroidal Parachute

FS = 1.5;             % Factor of Safety for Main Parachute
                    % FS from T. Knacke

% % Landing Kinetic Energy
% %
KE = 1/2*m*V^2 ;     % Units: kgm^2/s^2 = J
fprintf('Impact Kinetic Energy: %0.1f J\n\n', KE)

% % Air Density (kg/m^3) at Deployment Altitude (m)
% %
Alt = 4.5e3 / 3.281; % Altitude at Landing, ft to m
                    % Alt = Zero (Ground) + Alt @ Competition = 4.5e3
Dens = ESRA2020_BarometricFormula(Alt); % kg/m^3

% % Parachute Calculations
% %
So = (2*W)/(V^2*Cd*Dens)*FS; % Total Canopy Surface Area, m^2
Do = sqrt((4*So)/(pi)); % Nominal Diameter, m
% Do = 3.527; % ESRA '19 OD
Dv = 0.2*Do; % Fruity Chutes Website for Toroidal (Annular) Shape
            % for Spill Hole or Vent Diameter.
            % From https://fruitychutes.com/help_for_parachutes/how_to_
            % make_a_parachute.htm
S = (pi/4)*(Do^2-Dv^2); % Canopy Surface Area, m^2
L = 1.25 * Do; % Suspension/Shroud Line Length, m

% % Other Calculations
% %

```

```

ripstop = 1.1 / 35.274; % Mass per Unit Area of Ripstop Nylon, oz/yd^2 to
                        % kg/yd^2
rsL = 1 / 1.094;      % Ripstop Length, yd to m
rsW = 60 / 39.37;    % Ripstop Unit Width, in to m
rsA = rsL*rsW;       % Unit Area of Ripstop, m^2
rs = ripstop*rsA;    % Mass of Material, kg
MP = S*rs;           % Parachute Mass, kg
WP = MP*9.807;      % Parachute Weight, N
PackDens = 350;      % Manual Packing Density, kg/m^3
PackVol = MP/PackDens; % Parachute Packing Volume, m^3
PackL = (4*PackVol)/(pi*rocketID^2); % Packing Length

fprintf('Surface Area:  %0.2f m^2\n\n', S)
% fprintf('              %0.2f ft^2\n\n', S*3.28084^2)
fprintf('Outer Diameter: %0.2f m\n', Do)
% fprintf('              %0.2f ft\n', Do*3.28084)
fprintf('              %0.2f in\n\n', Do*39.37008)
fprintf('Inner Diameter:  %0.2f m\n', Dv)
% fprintf('              %0.2f ft\n', Dv*3.28084)
fprintf('              %0.2f in\n\n', Dv*39.37008)
fprintf('Parachute Weight:  %0.2f N\n', WP)
% fprintf('              %0.2f lbf\n', WP*0.22481)
fprintf('              %0.2f oz\n\n', WP*0.22481*16)
% fprintf('Packed Volume:  %0.3f m^3\n', PackVol)
% fprintf('              %0.3f ft^3\n', PackVol*3.28084^3)
% fprintf('Packed Volume: %0.2f in^3\n', PackVol*39.37008^3)
% fprintf('Packed Length:  %0.2f m\n', PackL)
% fprintf('              %0.2f ft\n', PackL*3.28084)
fprintf('Packed Length:  %0.2f in\n\n', PackL*39.37008)
fprintf('Shroud Line Length:  %0.2f m\n', L)
fprintf('              %0.2f ft\n', L*3.28084)
fprintf('              %0.2f in\n\n', L*39.37008)

% % Gore Calculations
% %
D = 1.04 * Do;      % Ratio of Gore Diameter to Parachute Diameter from T.
                    % Knacke
NG = 12;           % Number of Gores
Cv = (pi*Dv)/NG;   % Width of Gore at Vent Diameter, m (Gore Vent Width)
Cs = (pi*D)/NG;    % Width of Gore at Outer Diameter, m (Gore Skirt Width)
a = 0.319 * Do;
b = 0.2 * Do;
h = 0.304 * Do;    % Gore Reference Height, m
hx = (a+b+h)/2 - b; % Gore Apex Height, m
GoreH = h*sind(45); % Main Inflated Height, m
GoreH = pi*GoreH;  % Gore Height, m

fprintf('Gore Height:  %0.2f m\n', GoreH)
fprintf('Gore Height:  %0.2f in\n\n', GoreH*39.37008)
fprintf('Gore Apex Height: %0.2f m\n', hx)
fprintf('              %0.2f ft\n', hx*3.28084)
fprintf('              %0.2f in\n\n', hx*39.37008)
fprintf('Gore Base Width:  %0.2f m\n', Cs)

```

```

% fprintf('                %0.2f ft\n', Cs*3.28084)
fprintf('                %0.2f in\n\n', Cs*39.37008)
fprintf('Gore Vent Width:  %0.2f m\n', Cv)
% fprintf('                %0.2f ft\n', Cv*3.28084)
fprintf('                %0.2f in\n\n', Cv*39.37008)

% % Gore Plot
% %
yCv = GoreH*39.37008;
Cvx1 = (-Cv/2)*39.37008;
Cvx2 = (Cv/2)*39.37008;
line([Cvx1, Cvx2], [yCv,yCv], 'color', ' [.9 .7 .6]', 'linewidth', 1.2)
ylim([0 yCv])
xlim([(-Cs*39.37008)/2, (Cs*39.37008)/2])
hold on
Csx1 = (-Cs*39.37008)/2;
Csx2 = (Cs*39.37008)/2;
line([Csx1, Csx2], [0,0], 'color', ' [.9 .7 .6]', 'linewidth', 1.2)

delta = Csx2-Cvx2;
slope = yCv/delta;
xrange = linspace(0, delta);
xval = xrange + Cvx2;
yval = yCv - slope.*xrange;
yval = yval';

plot(xval, yval, 'color', ' [.9 .7 .6]', 'linewidth', 1.2)
hold on
plot(-xval, yval, 'color', ' [.9 .7 .6]', 'linewidth', 1.2)
grid on
title('Main Parachute Gore Dimensions (in.)')

```

Appendix G

MATLAB Code for Descent Analysis

```

clc
clear

% Parachute Performance
% Descent Analysis Rev 1
% Annalise Daul

% % Initial Descent
% % Drogue Parachute Deployment

% % Analysis
% %
Alt = 4.5e3/3.281; % Spaceport America ~Altitude at GL, ft to m
                    % Essentially the "Zero" Point (Landing Alt)
h1 = 4.1e4/3.281; % Altitude at [Simulated] Apogee, ft to m
h01 = Alt + h1; % I.C. Height of Drogue Parachute Deployment, m
v01 = 0; % I.C. Velocity at Drogue Deployment, m/s
t = 2e3; % Time Range
hDeploy2 = 1.5e3/3.281 + Alt; % Altitude of Main Deployment Event, m
                    % Deployment Event 2

[T, Z] = ode45('ESRA2020_DescentDrogue', [0 t], [h01 v01]); % Solve
tDeploy2 = interp1(Z(:,1), T, hDeploy2); % Time to Altitude at which the
                    % Main Parachute Deploys

t1 = [ 0 tDeploy2 ]; % Change Run Time from Zero to Drogue Time Interval
[T1, Z1] = ode45('ESRA2020_DescentDrogue', t1, [h01 v01]); % Data Points,
Drogue
                    % Descent Time Interval
v1 = Z1(end,2); % Velocity at Main Deployment = Terminal Velocity, Drogue

% % Drogue Plots
% %
figure(1);
grid on
subplot(2,1,1) % Plot Altitude vs Time for Initial Descent
plot( T1, Z1(:,1), 'color','[.4 .7 .6]','linewidth',1.2);
title('Drogue Parachute Descent')
ylabel('Altitude (m)')
xlabel('Time (s)')
grid on
xlim( t1 )

subplot(2,1,2) % Plot Velocity Profile for Initial Descent
grid on
plot( T1, Z1(:,2), 'color','[.4 .7 .6]','linewidth',1.2 );
ylabel('Velocity (m/s)')
xlabel('Time (s)')
grid on

```



```

xlim( t1 )

% % Final Descent
% % Main Parachute Deployment

% % Analysis
% %
h2 = 1.5e3/3.281; % Main Deployment Altitude ASL, m
ho2 = Alt + h2; % Height of Main Parachute Deployment, m
vo2 = v1; % Velocity at Main Deployment = Terminal Velocity Under
% Droque, m/s
[ T2, Z2 ] = ode45('ESRA2020_DescentMain', [0 t1], [ho2 vo2]);
t2 = interp1( Z2(:,1), T2, Alt );
v2 = interp1( Z2(:,2), t2 );

% % Main Plots
% %
figure(2);
subplot(3,1,1) % Plot Altitude vs Time for Final Descent
plot( T2, Z2(:,1), 'color','[.4 .7 .6]','linewidth',1.2);
title('Main Parachute Descent')
ylabel('Altitude (m)')
xlabel('Time (s)')
grid on
xlim([ 0 t2 ])
yline( Alt );

subplot(3,1,2) % Plot Velocity Profile for Final Descent
plot( T2, Z2(:,2), 'color','[.4 .7 .6]','linewidth',1.2);
ylabel('Velocity (m/s)')
xlabel('Time (s)')
grid on
xlim([ 0 t2 ])
yline( v2 );

subplot(3,1,3) % Plot First 2s of Velocity Profile for Final Descent
plot( T2, Z2(:,2), 'color','[.4 .7 .6]','linewidth',1.2 );
ylabel('Velocity (m/s)')
xlabel('Time (s)')
grid on
xlim([ 0 2 ])

% % Printing All Values
% %
fprintf('Terminal Velocity of Droque: %.1f m/s\n', v1 )
fprintf(' %.1f ft/s\n\n', v1*3.281 )
fprintf('Terminal Velocity of Main: %.1f m/s\n', v2 )
fprintf(' %.1f ft/s\n\n', v2*3.281 )
% fprintf('Droque Descent Time: %.1f s\n', t1(2))
% fprintf('Main Descent Time: %.1f s\n', t2)
fprintf('Total Descent Time: %.1f s\n', t1(2)+t2)

% % Plots, English Units

```

```

% % For Final Presentation Slides

% % Drogue Parachute Plot
% %
figure(3)
% %
subplot(2,1,1)
plot( T1, Z1(:,1)*3.281, 'color','[.76 .82 .97]','linewidth',1.6 );
title('Drogue Parachute Descent Altitude Profile')
ylabel('Altitude (ft)')
xlabel('Time (s)')
grid on
xlim( t1 )
% %
subplot(2,1,2)
grid on
plot( T1, Z1(:,2)*3.281, 'color','[.76 .82 .97]','linewidth',1.6 );
% '[.73 .85 .8]'
title('Drogue Parachute Descent Velocity Profile')
ylabel('Velocity (ft/s)')
xlabel('Time (s)')
grid on
xlim( t1 )
% % Main Parachute Plot with English Units
% %
figure(4);
% %
subplot(2,1,1)
plot( T2, Z2(:,1)*3.281, 'color','[.76 .82 .97]','linewidth',1.6 );
title('Main Parachute Descent Altitude Profile')
ylabel('Altitude (ft)')
xlabel('Time (s)')
grid on
xlim([ 0 t2 ])
% %
subplot(2,1,2)
plot( T2, Z2(:,2)*3.281, 'color','[.76 .82 .97]','linewidth',1.6 );
title('Main Parachute Descent Velocity Profile')
ylabel('Velocity (ft/s)')
xlabel('Time (s)')
grid on
xlim([ 0 t2 ])

```

Appendix H
MATLAB Function File for Descent Analysis
Barometric Formula

```
function [ Dens ] = ESRA2020_BarometricFormula( h, ~ )

% Calculates the Air Density at a Given Altitude Above Sea Level

% Uses Barometric Formula for Air Density
% Applicable to Troposphere or Altitudes ~< 36k ft

G = 9.80665;           % Gravitational Acceleration on Earth, m/s^2
M = 0.0289644;       % Molar Mass of Earth's Air, kg/mol
R = 8.3144598;       % Universal Gas Constant, J/mol.K

rhoo = 1.225;        % Air Density at Sea Level, kg/m^3
To = 288.15;         % Temperature of Air at Apogee, K
Lapse = -0.0065;     % Temperature Lapse Rate, K/m
hb = 0;              % Base Altitude for Barometric Formula, m

Dens = rhoo.*(To./(To+Lapse.*(h-hb))).^(1+(G*M)./(R*Lapse)); % Density,
                                                                % kg/m^3

end
```

Appendix I

MATLAB Function File for Descent Analysis Drogue Parachute

```

function [ zder ] = ESRA2020_DescentDrogue( ~, z )

% Function to Solve for Altitude and Velocity of Rocket When Drogue
% Parachute Deploys at Apogee

m = 110/2.205;           % Mass of Rocket, kg
g = 9.80665;           % Gravitational Acceleration, m/s^2
RocketOD = 6.339 / 39.37; % Outer Diameter of Rocket, in. to m

L1 = 67/39.37;         % Length of Lower Body Tube, in to m
L2 = 41/39.37;         % Length of Upper Body Tube, in to m
A1 = RocketOD*L1;      % Reference Area of Lower Body Tube, m^2
A2 = RocketOD*L2;      % Reference Area of Upper Body Tube, m^2
CD1 = 1.2;             % Drag Coefficient of Body Tubes
CD2 = CD1;

L3 = 32/39.37;         % Length of Nose Cone, in to m
CD3 = .4;              % Drag Coefficient
A3 = 1/2*RocketOD*L3; % Reference Area, m^2

D4 = .7357;           % Outer Diameter of Drogue Parachute, m
                        % Comes from "ParachuteDrogue_4.m" File
A4 = pi/4*D4^2;       % Reference Area of Drogue Parachute, m^2
CD4 = 2.2;            % Approximate Drag Coefficient for Drogue

h = z(1);             % Altitude Used For "BarometricFormula.m" Function File
v = z(2);
Dens = ESRA2020_BarometricFormula(h); % Density Values, kg/m^3

FD1 = 1/2*Dens*v^2*CD1*A1;
FD2 = 1/2*Dens*v^2*CD2*A2;
FD3 = 1/2*Dens*v^2*CD3*A3;
FD4 = 1/2*Dens*v^2*CD4*A4;

zder(1) = z(2);
zder(2) = (FD1+FD2+FD3+FD4)/m - g;
zder = zder';

end

```

Appendix J
MATLAB Function File for Descent Analysis
Main Parachute

```
function [ zder ] = ESRA2020_DescentMain( ~, z )

% Function to Solve for Altitude and Velocity of Rocket Once Main Parachute
% Deploys

m = 110/2.205;           % Mass of Rocket, lb to kg
g = 9.80665;            % Gravitational Acceleration, m/s^2
RocketOD = 6.339 / 39.37; % Outer Diameter of Rocket, in to m

A1 = pi/4*RocketOD^2;   % Reference Area of Both Body Tubes, m^2
A2 = A1;
CD1 = .82;              % Drag Coefficient of Both Body Tubes
CD2 = CD1;

A3 = A1;                % Reference Area of Nose Cone, m^2
CD3 = .2;               % Drag Coefficient of Nose Cone

D4 = .7357;
A4 = pi/4*D4^2; % Reference Area of Drogue Parachute, m^2
CD4 = 2.2;          % Approximate Drag Coefficient Desired for Drogue

D5 = 3.527;          % Re-Using Main Parachute from ESRA '19
A5 = pi/4*D5^2;     % Reference Area of Main
CD5 = 2.2;          % Main Parachute Drag Coefficient
                    % ESRA 19: Main OD as 3.527 m
                    %           Main ID as .705 m
                    %           Reference Area of 9.771 m^2

h = z(1);           % Altitude for BarometricFormula.m Function File
v = z(2);           % Velocity
Dens = ESRA2020_BarometricFormula(h); % Density Values, kg/m^3

zder(1) = z(2);
FD1 = 1/2*Dens*v^2*CD1*A1;
FD2 = 1/2*Dens*v^2*CD2*A2;
FD3 = 1/2*Dens*v^2*CD3*A3;
FD4 = 1/2*Dens*v^2*CD4*A4;
FD5 = 1/2*Dens*v^2*CD5*A5;
zder(2) = (FD1+FD2+FD3+FD4+FD5)/m - g;
zder = zder';

end
```

Appendix K

MATLAB Code for Drogue Parachute Plot

```
clear
clc
clf

% Drogue Parachute Plot
% Annalise Daul
% Plot for ParachuteDrogue_4.m File

Do = .7357*39.37008;    % Outer Diameter of Main, m to in.
Dv = Do * .2;         % Inner or Vent Diameter of Main, m to in.
r = ( Do-Dv )/4;      % Internal Radius, in.
R = ( Do/2 )-r;       % Centroidal Radius, in.

u = linspace( 0, 720, 88 );
v = linspace( 0, 720, 88 );
[ u,v ] = meshgrid( u,v );
x = (R+r*cosd(v)).*cosd(u);
y = (R+r*cosd(v)).*sind(u);
z = r.*sind(v);

% Plot Toroidal Parachute

figure(1)
mesh( x,y,z, 'linewidth', .8 )
colormap(copper(88))
axis equal
axis([-inf inf -inf inf 0 inf])
xlabel('X (in.)', 'FontSize', 12 );
ylabel('Y (in.)', 'FontSize', 12 );
zlabel('Z (in.)', 'FontSize', 12 );
title('Drogue Parachute Canopy', 'FontSize', 12 );
```

Appendix L

MATLAB Code for Main Parachute Plot

```
clear
clc
clf

% Main Parachute Plot
% Annalise Daul
% Plot for ParachuteMain_6.m File

Do = 3.527*39.37008;    % Outer Diameter of Main, in.
Dv = Do * .2;          % Inner or Vent Diameter of Main, in.
r = ( Do-Dv )/4;       % Internal Radius, in.
R = ( Do/2 )-r;        % Centroidal Radius, in.

u = linspace( 0, 720, 88 );
v = linspace( 0, 720, 88 );
[ u,v ] = meshgrid( u,v );
x = (R+r*cosd(v)).*cosd(u);
y = (R+r*cosd(v)).*sind(u);
z = r.*sind(v);

% Plot Toroidal Parachute

figure(1)
mesh( x,y,z, 'linewidth', .8 )
colormap(copper(22))
axis equal
axis([-inf inf -inf inf 0 inf])
xlabel('X (in.)', 'FontSize', 12 );
ylabel('Y (in.)', 'FontSize', 12 );
zlabel('Z (in.)', 'FontSize', 12 );
title('Main Parachute Canopy', 'FontSize', 12 );
```

Appendix M

MATLAB Code for Main Parachute Gore Design from ESRA 2018-2019 Team

```

clear
clc
clf
%define the parameters
OD=3.527*39.37008;%inches
ID=0.2*OD;%inches
r = (OD-ID)/4; % Internal Radius
R = (OD/2)-r; % Centroidal Radius
SA = 0.5; % Seam Allowance (in inches)

u=linspace(0,720,30);
v=linspace(0,720,30);
[u,v]=meshgrid(u,v);
x=(R+r*cosd(v)).*cosd(u);
y=(R+r*cosd(v)).*sind(u);
z=r.*sind(v);

%plot the figure of toroidal
figure(1)
mesh(x,y,z);
axis equal
axis([-inf inf -inf inf 0 inf])
xlabel('X (in)', 'fontsize',14);
ylabel('Y (in)', 'fontsize',14);
zlabel('Z (in)', 'fontsize',14);
title('Main Parachute', 'fontsize',14);
colormap hsv;

% Find data points
X = x(1:7,1:2);
Y = y(1:7,1:2);
Z = z(1:7,1);
dx = X(:,1) - X(:,2);
dy = Y(:,2) - Y(:,1);

for i = 1:length(Z)-1
    dz(i) = Z(i) - Z(i+1);
    DX(i) = X(i,1) - X(i+1,1);
end

dz = dz';
DX = DX';

% Define Gore subsection width (L) and gore subsection Height (h)
L = sqrt(dx.^2+dy.^2);
H = sqrt(dz.^2+DX.^2);

for j = 1:length(H)+1

```



```

    if j ==1
        H0 = SA;
    else
        h(j) = H0 + H(j-1);
        H0 = h(j);
    end
end

h=h'; % Gore subsection height
W_sa = L./2+SA; % Factor seam allowance into width
WIDTH = [-W_sa;W_sa];% Gore subsection Width
HEIGHT = [h;h]; %
M = [WIDTH,HEIGHT]; % MATRIX FOR HEMISPHERICAL
% Plot the Hemispherical Pattern
figure(2)
plot(W_sa,h,'color','[.9 .7 .6]','linewidth',1.8)
hold on
plot(-W_sa,h,'color','[.9 .7 .6]','linewidth',1.8)
axis equal
grid on
title('Main Parachute Gore Pattern (in.)')
line([-W_sa, W_sa], [0,0], 'color','[.9 .7 .6]','linewidth',1.8)
line([-W_sa(7), W_sa(7)], [H0,H0], 'color','[.9 .7 .6]','linewidth',1.8)

```

Recommendations for Future Teams



ESRA Aero & Recovery Recommendations

ESRA 2020-2021 Team

The Aerodynamics and Recovery sub-team has several recommendations for the 2020-2021 ESRA Aerodynamics and Recovery sub-team. All of these recommendations come from the experience of previous years, research, guidance by mentors or GTAs, or trial and error by our sub-team. It is recommended that you look through our research, simulation, parachute, and Technical Revision 4 folders on Google Drive early on to get a starting point for this project. Other recommendations can be seen below.

Project Management/Communication

1. **Document all of your work.** Always document your work and never save over anything. Create an archive folder to place an outdated document into, that way if you ever wanted to go back to the original idea, you can.
2. **Collaborate and communicate with other sub-teams.** Communication and collaboration are both essential to team cohesiveness and success. Note that communications with the Avionics, Propulsion, and Structures and Integration sub teams are especially crucial.
3. **The person who is responsible for the simulations should also be the Weight and Status Officer.** This will make updating the simulations easier and less likely for updates to the sheet to be missed in the simulations. Also, the person doing the simulations will use it the most and this allows them to format the sheet as they desire.
4. **The sub-team lead should have a lighter course load, leadership experience, and be detail-oriented.** As the sub-team lead, you do a lot of paperwork and bookkeeping tasks for the sub-team. It can be overwhelming at times so the sub-team lead should be organized and detail-oriented. The sub-team lead should also have outstanding communication and listening skills to help this project run smoothly.
5. **Schedule large tasks out in the beginning and make due dates for these tasks weekly.** Many components of this project are large and overwhelming. By enforcing weekly checkpoints or due dates the project will stay on track and the project will not seem as large. Time-management is huge for this project to be successful.
6. **Make a detailed Roles and Responsibilities document early and try to change these responsibilities as little as possible.** To avoid one person taking on too many items, try and determine the roles and responsibilities of the sub-team early on. By sticking to these, you avoid one person not holding up to their end of the bargain. It is okay to change these as you learn which ones take more time, but each sub-team member should be solely responsible for at least one subsystem/component of the project.

Parachutes

1. **Research and reach out early.** There are many resources for parachute designs, but the best resource was T. Knacke's "Parachute Recovery Systems Design Manual," which can be found by going to ESRA 2019-2020 > Sub Team Folders > 2.4 Aero & Recovery > Research > Recovery System > Parachutes. There are other helpful documents on parachute and recovery system designs. In addition, reach out to OROC mentor Joe Bevier and graduate student Trevor Rose.

2. **Refer to our MATLAB codes for designing the parachutes.** These codes, though not perfect nor the be-all and end-all, provide very good starting points for designing the parachutes.
3. **Use ripstop nylon patching tape for parachute patches.** This method of patching parachutes is quick and easy but also effective. The adhesiveness of the tape allows the force of the hole to act on the entire patch whereas a sewn patch will only have forces applied to the seams. Since tape allows for the force to be spread across a larger area, the force directly on the hole with nylon tape will be less than that of a sewn patch.
4. **Learn how to sew early on and practice extensively.** Ripstop nylon is a very challenging fabric to sew since it is so thin and slick. Order extra ripstop to practice sewing to determine the stitch desired and to get used to the thin fabric coupled with the use of course, nylon thread.
5. **Use the ply cutter to cut the parachute gores.** The orientation is very quick and the ply cutter is easy to use. This allows you to take the gore from the MATLAB file, make a .dxf file in SolidWorks (or your preferred CAD software) by plotting the points given from MATLAB, and then tracing the lines you want cut/drawn using Pattern Smith. This ensures that the gores are all the same size, that they are the correct size, and it only takes minutes to cut them out. However, at least one member must be certified to use the ply cutter. Thus, be sure to get your certification.
6. **If using the ply cutter to cut the gores, you should replace the blade before you cut the ripstop nylon.** Most of the time, the roller blade is left very dull from use. To ensure you get a proper and clean cut, replace the blade before use.
7. **If using the ply cutter, draw a seam allowance using the pen feature.** This will outline the actual gore with a marker and make the process of attaching gores to one another and sewing the hems much easier.

Ejection System

1. **Start with the calculated black powder charge.** Then, test the black powder charges. Size up by half of a gram for each unsuccessful separation of the body tubes. You do not want to oversize the charges and run the risk of burning the deployment bag, blankets, shock cord, or parachutes. Repeat the process until sufficient charge size has been reached.
2. **Make sure all pins shear and separation occurs.** The worst case scenario would be to shear all of the pins but not have separation. As long as separation occurs, then the size of black powder charge was good, regardless of how far the body section “flew” or if the parachute came out.
3. **Use old parachutes if possible.** You will often hear about teams ruining their parachutes through black powder testing. Utilizing existing parachutes from previous teams is a great way to mitigate this risk during the testing phase while determining the appropriate size of black powder charge. As of next year there will be two existing drogue parachutes and one existing main parachute at your disposal.
4. **Use a battery to determine the size of the charge or the Telemega with it outside of the rocket.** The Telemegas are very powerful computers, but not very robust. The antenna and other components are extremely delicate and should be handled with care at all times. Due to this, using the Telemega for ejection testing inside the airframe can cause a great deal of wear-and-tear over several ejection tests and create a high risk for damage/malfunction. We recommend using the Telemega for remote ejection from *outside*

the airframe by running a lead wire from the charge to the Telemega in a safe and protected location until an appropriate charge mass is determined. Once this mass is determined, an ejection test can be conducted with the Telemega inside the airframe to ensure communications and RF transparency.

5. **Use the vacuum chamber in Graf to test the TeleMegas in Flight Mode.** In order to validate that the Telemega's barometric pressure sensor is functioning properly, we recommend using the vacuum chamber in Graf hall in combination with common christmas lights. Wire two bulbs into the respective apogee and main charge terminals on the Telemega, power on the device in flight mode, and place it in the vacuum chamber. As you pull the air out of the chamber, this will simulate flight and you should see the Telemega respond accordingly via your AltOS ground station. Once a desired altitude has been reached, slowly let air back into the chamber and observe the lights. They will illuminate when power is sent to the charge terminal, indicating a successful altitude reading and subsequent parachute deployment.
6. **Although weight is not in the calculation for the size of the black powder charge, it does affect the charge's ability to shear the pins and separate the rocket components.** Therefore, all ejection testing should be done in the same order that the events will happen in the air, the drogue parachute first and then the main parachute. When doing ejection testing for the drogue parachute, ensure that all weight is in the rocket that will be there when the actual event occurs (i.e. the payload, nose cone, motor tube without propellant, etc.). Avoid setting up the ejection tests where the rocket is acting as a cantilever beam. Try your best to make it as flat and supported as possible. The main parachute ejection tests can be done using the upper only, replicating that the drogue would have already deployed.

Recovery System

1. **Use a shock cord length that is 2 to 3 times the entire rocket length for each section.** Essentially, the longer the shock cord, the better, specifically when the length is within this range of 2 to 3 times the body length. However, you need to verify that having a longer shock cord will not substantially increase the weight of the rocket and all the recovery components will still fit.
2. **Place the parachute about two-thirds and one-third along the shock cord.** This allows your parachute plenty of room to open up but also prevents any rocket components from colliding with each other once separation occurs. An analysis of the exact lengths should be determined by drawing a schematic of the recovery system and allowing at least five feet from the bottom of one component to the top of the other. Our schematic of our recovery system should be referenced and can be found at the end of our design specifications document in the MIME 498 Tech Rev 4 folder.
3. **Use a swivel at every connection point.** This will add weight to the rocket, but if you have weight to spare then these swivels will help prevent the shock cords from getting tangled. If you cannot have one at every connection point then it is crucial to have at least one attached to the shock cord for each parachute.
4. **Make kevlar covers for the nylon shock cord.** This protects the shock cord from the black powder charge once it is ignited. We have leftover kevlar in a bin, so no need to order any. The kevlar cover should be slightly larger than the width of the shock cord so you can change out the cover if it gets burned.

5. **Use one Nomex blanket for each recovery harness.** This helps protect the parachutes and shock cord from the black powder charges. It is important to place these blankets close to the bulkhead where the charge will go off and sew it in place or tie a knot so it cannot move up the shock cord. Oftentimes, these blankets can act as a parachute themselves and can actually bound up the shroud lines if they move up the shock cord; be sure they stay in place.
6. **Make your own shock cord.** It is super easy and much cheaper. I would refer to our BOM and order the same tubular nylon we ordered for our shock cord. It was cheap and easy to sew with the Size E nylon thread.
7. **Use figure 8 knots by the bulkhead attachment points and a butterfly knot for the parachute connection point.** If desired, you can sew in permanent loops where it is recommended to have more longitudinal stitches than transverse stitches. If knots are used, verify that the knot is tied correctly and get rid of any folds or kinks in it, since these make knots less strong. Also, if you are using knots, it is important to note that the knots take up a decent amount of the shock cord. We wanted 36 ft originally and ordered that exact amount, but once the knots were tied the shock cord was about 26 ft. So order extra shock cord if you plan to use knots.

Nose Cone

1. **Use research to understand how nose cone shape affects flight dynamics.** To begin designing a nose cone, it is important to understand the various effects the shape has on flight characteristics. Gary Crowell's "The Descriptive Geometry of the Nose Cone" is a great piece of literature for gaining this understanding and establishing a design baseline. For the flight characteristics of ESRA rockets in the past, the Von Karman profile and $\frac{1}{2}$ Power Series profiles are most applicable.
2. **Use a composite body and metal tip.** When manufacturing the nose cone, the best structure combination is to utilize a composite body that allows for RF transparency, such as fiberglass, and a metal tip to negate aerodynamic heating, such as aluminum. Having RF transparency helps maintain telemetry connection with the rocket and minimizes weight, while the metal tip will ensure structural rigidity during flight.
3. **Use OpenRocket to verify your nose cone design.** Once you have zeroed in on a nose cone design, you can use OpenRocket to conduct flight simulations and verify it or make adjustments as needed. Other components of the rocket may not be finished yet, however you can use the previous teams rocket as a good starting point for weight/dimensions and insert your propulsion teams BurnSim file as well as your nose cone design to get an idea of how the design will perform.

Fins

1. **Optimize the fins in OpenRocket, but then change the dimensions so they are easier to manufacture.** The fin optimization tool in OpenRocket is a great starting point for the fin dimensions. Sometimes it can be a little difficult and output dimensions that are impossible to manufacture. Therefore, once the optimization has occurred, try messing with the dimensions slightly to see how it impacts stability and altitude. I would recommend modifying the dimensions slightly so they are easier to manufacture for the Structures and Integration sub-team.

2. **Optimize the fins to a desired stability margin.** Although altitude is important, the main point of the fins are to ensure the rocket has proper stability both on the launch rail and throughout its entire flight profile. I would recommend that the fins are optimized to the stability margin of 1.75 calibers or greater, since Spaceport likes to see rockets of our size with a larger stability margin.
3. **Go with a trapezoidal or clipped-delta fin shape.** This fin shape is easy for our Structures and Integration sub-team to manufacture and offers good performance for the rocket's altitude and stability margin.
4. **Use a rectangular cross-section but chamfer the leading and trailing edges to reduce induced drag.** Since the Structures and Integration sub-team manufactures our fins, any cross-section other than rectangular would be extremely hard to manufacture. Adding the chamfer on the leading and trailing edges helps the rocket's aerodynamics. It improves the fins performance greatly but is easy to manufacture.
5. **Add a small taper on the fin to decrease induced drag on the tip chord.** Adding a taper as small as 0.05 in. greatly increases the fin's performance and is also easy to do from a manufacturing standpoint.
6. **Use four fins.** Although three fins increase the performance of the rocket, this increase is often so small it can be considered to be negligible. Four fins are much easier to manufacture than three fins, because it is easier to align fins at 90 degrees than at 120 degrees. Also, with three fins, if misalignment were to occur, it has a much greater impact on the rocket's overall angle of attack than if a four fin arrangement is misaligned. Also the ESRA team already has a fin jig for manufacturing four fins.

Simulations

1. **Use OpenRocket and RASAero II.** RasAero II is much more accurate with supersonic speeds but OpenRocket is easier to navigate. Also, you must have a complete model in OpenRocket because RASAero II does not allow you to calculate the center of gravity. Therefore, the center of gravity calculated in OpenRocket will be used as an input into RASAero II. I recommend that RASAero II is used for the stability margin for the entire rocket's flight profile. This will yield more accurate stability margin measurements.
2. **RASAero II must be done by a sub-team member who has a PC.** Our sub-team ran into issues when it came to downloading the RASAero II software onto a MAC computer. No issues occurred once a member with a PC tried to download the software. If no sub-team member has a PC then a lab computer or Citrix should be used.
3. **The sub-team member who does OpenRocket simulations should also do the simulations for RASAero II.** This made doing the simulations very easy since RASAero II needs a lot of its inputs from OpenRocket. Also, having a single person do the simulations allows them to know the exact numbers at all times and makes it very easy to compare the two.
4. **I recommend that the following launch conditions are used as a starting point for the Spaceport America simulation in OpenRocket.**
 - a. Average windspeed: 10 mph
 - b. Standard deviation: 1.8 mph
 - c. Turbulence intensity: 18%
 - d. Wind direction: 90°
 - e. Temperature: 105 °F

- f. Pressure: 1016 mbar
 - g. Latitude: 28.6° N
 - h. Longitude: -80.6° E
 - i. Altitude: 4595 ft
 - j. Launch rail length: 384 in.
 - k. Angle: 3°
5. **I recommend that the following launch conditions are used as a starting point for the Brothers, Oregon simulation in OpenRocket.**
- a. Average windspeed: 10 mph
 - b. Standard deviation: 1.8 mph
 - c. Turbulence intensity: 18%
 - d. Wind direction: 90°
 - e. Temperature: 40 °F
 - f. Pressure: 1016 mbar
 - g. Latitude: 43.8° N
 - h. Longitude: -121° E
 - i. Altitude: 4345 ft
 - j. Launch rail length: 384 in.
 - k. Angle: 3°
6. **I recommend that the following launch conditions are used as a starting point for the Spaceport America simulation in RASAero II.**
- a. Launch site elevation (ft): 4595
 - b. Temperature (°F): 105
 - c. Launch site barometric pressure (in-hg): 30.00
 - d. Wind speed (mph): 10
 - e. Launch rail length (ft): 32
 - f. Launch angle (°): 3
7. **I recommend that the following launch conditions are used as a starting point for the Brothers, Oregon simulation in RASAero II.**
- a. Launch site elevation (ft): 4345
 - b. Temperature (°F): 40
 - c. Launch site barometric pressure (in-hg): 30.00
 - d. Wind speed (mph): 10
 - e. Launch rail length (ft): 32
 - f. Launch angle (°): 3
8. **I recommend that the additional settings in RASAero II are used to help increase the accuracy of the simulations.** The nozzle exit diameter, center of gravity, and weight of the rocket greatly impact the accuracy of the simulation. Make sure the additional options are also as follows:
- a. All Turbulent Flow is checked.
 - b. Rogers Modified Barrowman is checked.
 - c. Surface Finish is Rough Camouflage Paint.
 - d. The proper launch conditions above are used in the simulation.

General Recommendations

1. **Get Level 1 and Level 2 certified.** Do this early. The sooner you get your certification, the better your understanding of rocketry and recovery.
2. **Dual Deployment.** One person should get their Level 2 certification by doing a dual deployment. It will significantly enhance your understanding of the separation events and the overall recovery process. If you plan to do a Level 2 with dual deployment, make sure to use shear pins to retain the nose cone so it does not pop off when the drogue is deployed.
3. **Begin designing as soon as possible.** The sooner your team determines a design for the parachutes and overall recovery system, the sooner you can begin your analyses. Then follows testing. By getting this done early, you will be able to launch sooner. As fall and winter terms progress, the weather only gets worse. Thus, be prepared for any launch window opportunities as early as possible.
4. **Use Joe Bevier as a mentor.** He has a lot of experience in high power rocketry and was a big help when it came to questions regarding parachute packing, recovery system design, ejection system design and testing, and simulations.
5. **Be safe.** Always.