Design, Construction, and Testing of West Virginia University's *Wild & Wonderful II* Sounding Rocket

Team 85 Project Technical Report for the 2018 Spaceport America Cup

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The *Wild & Wonderful II* launch vehicle is designed to carry an 8.8-lb payload to a target altitude of 10,000 ft above ground level (AGL) using a student researched and developed (SRAD) solid rocket motor. It is 7 inches in diameter, 141 inches long, and weighs 69 lbs on the launch pad. Nearly the entire rocket is student-built, with the exceptions of the parachutes and electronics. Launching and recovering *Wild & Wonderful II* at the 2018 SAC will be the culmination of months of work of a small but dedicated group of West Virginia University (WVU) engineering students and their sponsors. *Wild & Wonderful II borrows much of its design and structures from the 2017 SAC winning rocket, Wild & Wonderful.*

Nomenclature

AGL	=	above ground level
APCP	=	ammonium perchlorate composite propellant
BATES	=	BAllistic Test and Evaluation System
CG	=	center of gravity
CONOPS	=	concept of operations
HTPB	=	hydroxyl-terminated polybutadiene
MEOP	=	maximum expected operating pressure
NASSA	=	Nevada Aerospace and Science Association
SAC	=	Spaceport America Cup
SRAD	=	student research and developed
WVU	=	West Virginia University
WVUER	=	West Virginia University Experimental Rocketry

I. Introduction

WEST Virginia University Experimental Rocketry (WVUER) is proud to present the *Wild & Wonderful II* project for competition in the 2018 Spaceport America Cup (SAC). *Wild & Wonderful II* is carefully designed to carry an 8.8-lb payload to a target altitude of 10,000 ft above ground level (AGL) using a student researched and developed (SRAD) solid rocket motor. WVUER is a student organization at West Virginia University (WVU) that is dedicated promoting the advancement of amateur high-power rocketry by educating and uniting like-minded individuals who

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are passionate about rocketry. This will mark WVU's forth entry in IREC since being formed in 2013 and the first year our team is entering two teams into the competition (in conjunction with team 86). This year's team is comprised of 13 undergraduate WVU students, 3 of which will be attending the competition, led by Vice President Cameron Hale, a WVU Junior, and Secretary Matt Hines, a WVU junior. The primary sponsors of this project are the WVU Statler College of Engineering & Mineral Resources, the WVU Department of Mechanical & Aerospace Engineering, the West Virginia Space Grant Consortium, and NASA Independent Verification and Validation. The team's technical advisor, Joe Pscolka, who is a longtime Tripoli Rocketry Association level 3 member contributed greatly to the success of the project.

II. System Architecture Overview

Wild & Wonderful II is composed of 6 major sections. The nose cone is located at the forward end of the rocket and includes two BigRedBee 900 MHz GPS trackers. The payload bay houses the 8.8-lb aluminum payload in a 3U CubeSat form factor and is bolted to the nose cone to prevent the two sections from separating at any point during flight. The main parachute bay carries the main parachute, deployment bag, pilot parachute, and the main recovery harness as well as a NOMEX blankets to protect heat-sensitive materials. The avionics bay houses the two Perfectflite StratologgerCF altimeters which provide the official altitude scoring and parachute deployment capabilities. The drogue parachute bay carries the drogue parachute and its associated recovery harness as well as a NOMEX blanket. Finally, the booster section includes the fins, boat tail, and solid rocket motor. A schematic of these sections is shown below in Fig. 2. Dotted lines represent where the launch vehicle separates, first at apogee to deploy the drogue parachute (event #1), and later at 1500 ft to deploy the main parachute (event #2). Code 1515 rail buttons are located on the avionics bay and at the base of the booster, just above the boat tail.

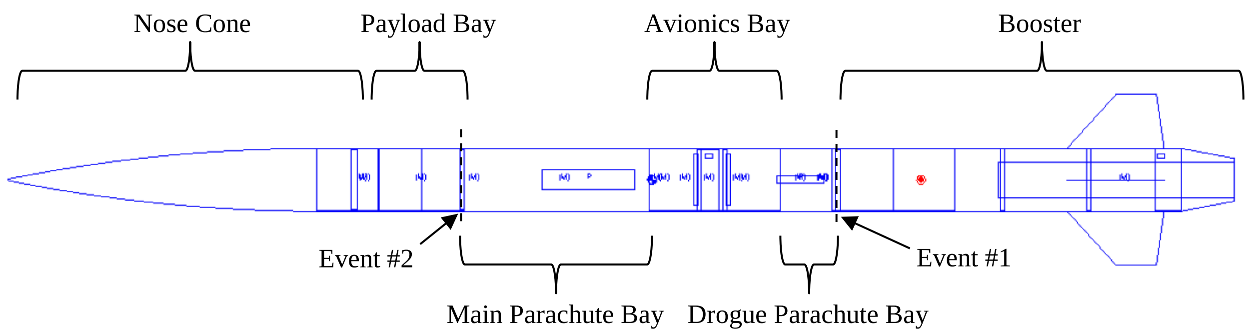

Figure 1. *Wild & Wonderful II* System Architecture.

A. Propulsion Subsystem

The propulsion subsystem features an SRAD solid rocket motor. Our internal nomenclature for the motor is FPS (flight propulsion system) 42. This is the second iteration of our club's fourth major solid rocket motor design. Both the propellant and motor hardware are student-built. The motor casing is a standard 98mm diameter and 36 inches long, constructed of 6061-T6 aluminum alloy. This case has been hydraulically pressure tested to 1600 psi, which is more than double the maximum expected operating pressure (MEOP) of 441 psi. The forward closure is also constructed of 6061-T6 aluminum alloy, has two O-rings, and is retained by an internal snap ring. This alloy was chosen for both parts because of its high strength, low cost, and excellent machinability. It also has a threaded hole in the center which allows a pressure transducer to be connected for static firings. For the competition flight, this hole will be sealed by a threaded plug and Teflon tape. Exhaust gases flow out the nozzle, which is made from superfine isomolded graphite and has two O-rings for sealing purposes. The nozzle is retained by a stainless-steel washer and an internal snap ring. The stainless-steel washer helps to evenly distribute the load across the base of the nozzle to avoid creating pressure points which could fracture the brittle graphite. The nozzle has a throat diameter of 0.938 inches and an exit diameter of 1.875 inches. These dimensions are critical to ensure a safe chamber pressure and an optimally-expanded exhaust.

This motor utilizes a Nevada Aerospace and Science Association (NASSA) Yellow propellant, which is an ammonium perchlorate composite propellant (APCP) that contains ammonium perchlorate, aluminum, and hydroxyl-terminated polybutadiene (HTPB), as well as other trace additives. Regretfully, the team cannot disclose the exact formulation due to its proprietary nature. Approximately 10 pounds of this propellant is loaded into the motor, separated into 5 BATES grains. Each propellant grain has a length of 5.313 inches, an outer diameter of 3.245 inches, and a core diameter of 1.375 inches. From static test data, it produces an average of 420 pounds of thrust for about 5.7 seconds, making it an N1841 designation. The casing wall is thermally insulated by a phenolic liner, which prevents damage from the hot combustion gases during motor operation. Several critical internal joints such as the interfaces between the nozzle and thermal liner, and the forward bulkhead and thermal liner are sealed with high-temperature automotive RTV sealant.

The design process for this motor was iterative. The starting point for this this year's process was last year's motor. The motor last year propelled *Wild & Wonderful* to 9,600 ft of the 10,000 ft goal in the 2017 SAC. Knowing that last year's rocket simulated between 11,000 ft and 12,000 ft in RockSim, we aspired to design the motor to achieve an apogee of just over 12,000 ft. From last year's design, producing a total impulse of roughly 10,000 Ns, we decided that an increase of roughly 10% would make up for the reduced overall altitude. This corresponded to altitude simulations of just over 12,000 ft which was deemed ideal. In the history of WVUER, the team had always designed such that simulations achieved apogees close to 10,000 ft, but the flights had always fallen short.

As a first iteration of the design, we decided to reduce the core diameter of some or all of the BATES grains used in the 2017 motor. Although we have had some marginal success in the past with other core geometries, we decided to make modifications to the 5-grain BATES geometry used in FPS 41 (SAC 2017). The limiting parameter for reducing the core geometry is mass flux at the bottom of the last grain, which we showed would still be within the regime to prevent severe erosivity and burn rate acceleration.

Simple geometric analysis showed that a length of 5.313 inches produced a neutral-burning grain. The NASSA Yellow propellant was used in last year's motor and was chosen again for this motor. It is a basic propellant formula that is well-tested, stable, and simple to make. With this starting point, all other motor parameters were designed by iteratively changing values in a student-written MATLAB motor simulation code. The goal was to design a motor which operated near a chamber pressure of 500 psia and had about 10,000 Ns of total impulse but remained within team-established erosive burning criteria.

B. Aero-structures Subsystem

Wild & Wonderful II has a relatively standard aerodynamic configuration for a vehicle of its size, including an ogive nose cone, four fins, and a boat tail. Its general configuration is identical to the team's previous SAC entry. Although it is more difficult to construct an ogive nose cone than a conical nose cone, the ogive shape typically has lower drag in subsonic conditions since it smoothly transitions into the body tube, while a conical nose cone creates a sharp corner that can cause flow separation and increased drag. The team chose to equip the base of the rocket with a boat tail, rather than leaving the end of the rocket flat like in previous years, further reducing drag by decreasing the size of the low-pressure region in the wake of the vehicle.

Previous WVUER rockets have had their payload bays located in the center of the rocket, between the drogue and main parachute bays. This configuration made it difficult to keep the payload separate from essential structure, in accordance with IREC rules. For this reason, the payload bay is now located above the main parachute bay and under the nose cone. This new arrangement makes the payload much more accessible, and shifts the center of gravity (CG) forward significantly. This foreward CG position is advantageous because the rocket now requires smaller fins to maintain a favorable stability margin. From team member and advisor personal experience, it was decided that four fins should be used rather than a three-fin design to keep the vehicle stable during flight. The fins were sized to achieve a stability margin between two and three, which is appropriate for a rocket this size from team and advisor experience. At liftoff, *Wild & Wonderful II* has a stability margin of 2.1. These fins also feature a "double-diamond" hexagonal airfoil, which promotes lower drag and turbulence when compared to square airfoils, but is much easier to construct than an airfoil, such as a NACA 0012. All aerodynamic analysis was conducted using RockSim software.

The primary load-bearing structures on the vehicle are the body tubes themselves. These body tubes are hand-made by the students using 5-6 wraps of 6 oz/yd^2 8-harness satin weave fiberglass and U.S. Composites 635 Thin Epoxy Resin System. These specific materials were chosen because the team has extensive experience with them, developed over the past several years of rocket construction. Internal bulkheads separate the sections of the rocket and are constructed of ½ inch plywood, held in place by 30-minute epoxy hardened by colloidal silica. The nose cone is constructed of 2-inch insulation foam board, wrapped with 5 layers of fiberglass, and the boat tail is constructed of solid wood, bored out to fit the fiberglass motor mount tube.

C. Recovery Subsystem

The recovery subsystem is a standard dual-deployment configuration, which utilizes a drogue and a main parachute. At apogee, the drogue parachute deploys, allowing the rocket to descend quickly to minimize drift. At an altitude of 1500 feet, the much larger main parachute deploys to slow the vehicle to a safe landing speed of approximately 20 ft/s.

The control portion of the recovery system features two Perfectflite StratologgerCF barometric altimeters and four black powder ejection charges which are fired by MJG electric matches. Each altimeter has a charge for deploying the drogue parachute and a charge for deploying the main parachute, as well as its own switch and 9V battery. This makes the system have double-redundantcy, as any single battery, switch, altimeter, or e-match failure will not result in system failure. Fig. 2 shows a block diagram of the configuration of the recovery electronics and event architecture. The altimeters are programmed such that the primary and secondary charges never fire at the same time. At apogee, the primary altimeter fires its drogue charge, and the secondary altimeter fires its drogue charge after a one-second delay. At 1500 ft, the primary altimeter fires its main charge, while the secondary altimeter does not fire its main charge until the rocket has descended to 1300 ft.

The booster section of the rocket is secured to the drogue parachute bay by two 2-56 nylon screws, which serve as shear pins. These shear pins prevent premature aerodynamic separation and prevent the two sections from rotating relative to each other, preventing rail button misalignment. The payload section and nosecone of the rocket is secured to the main parachute bay by four 2-56 nylon screws which also serve as shear pins. These shear pins prevent the jolt generated by drogue parachute deployment from causing the main parachute to also deploy at apogee, which could cause the rocket to drift much farther during descent. For this section, four shear pins are used instead of just two due to the significant mass and inertia of the payload section and nose cone. Flight testing in April of 2017 and the competition flight at the 2017 SAC have proven that the main will not prematurely deploy under normal circumstances.

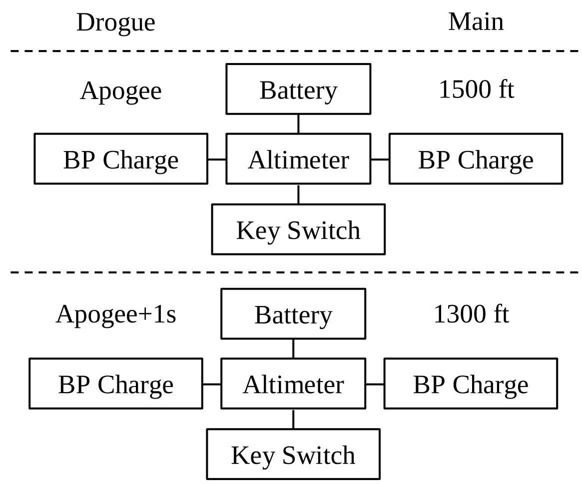

Figure 2. Configuration of Recovery Electronics.

From ground testing, it was found that three grams of black powder was sufficient to deploy the drogue parachute and six grams was sufficient to deploy the main parachute. The main charge is much larger than the drogue charge primarily due to the increased number of shear pins in the main parachute bay.

A SkyAngle Cert-3 Drogue parachute, contained in a deployment bag, is used to slow the rocket's descent after reaching apogee. The integrated flight test in April confirmed the expected descent rate of approximately 80-100 ft/s, which is within the ESRA suggested range of 75-150 ft/s. A SkyAngle Cert-3 XL parachute slows the rocket for a safe landing at approximately 20-25 ft/s. Both parachutes were chosen for their rugged construction, as well as team members' favorable experiences with SkyAngle parachutes in their own rockets. The proper sizing was determined by the rocket's unloaded weight (weight with no propellant). The deployment bag is used to prevent the large main parachute from getting tangled during assembly and also to create a slower, smoother deployment rather than a large jerk. A 24-in parachute from Top Flight Recovery serves as the pilot chute, which inflates and pulls the deployment bag off the main parachute, allowing it to inflate. Both the drogue and main parachutes are protected from ejection charge hot gas by a 24x24-in Nomex chute protector.

D. Payload Subsystem

The payload subsystem is composed of 9.2 lbs of ballast, in a 3U CubeSat form factor (10x10x30 cm). A single, solid block of aluminum with dimensions 5"x4"x4" was welded to a 1/8" thick square aluminum tube of dimensions 7"x4"x4". This is secured to a ¼" thick aluminum bulkhead by three ¼"-20 steel screws. This bulkhead is held into the payload bay with two, 1/4"-20 allthread rods that run to an epoxied wooden bulkhead towards the top of the section. A 1/8" aluminum "washer" matching the shape of the wooden bulkhead acts as a pressure distributor, allowing stresses encountered during recovery events to be more evenly distributed across the epoxied joint. The payload by was designed so that the payload could be fully removed without affecting the structural integrity of the system. The payload bay is attached to the nosecone with four 8-36 steel screws and to the main parachute body tube with four 2-56 nylon screws.

III. Mission Concept of Operations Overview

Wild & Wonderful II follows a standard dual-deployment flight profile. After ignition, powered, and unpowered ascent, a small drogue parachute is deployed at apogee, which allows the vehicle to fall quickly, minimizing wind drift. At 1500 ft, a larger main parachute deploys to slow the vehicle to a safe landing speed. Fig. 3 depicts the full flight profile.

A. Ignition

The first phase of flight is the ignition sequence. This phase begins when the FIRE command is sent from the launch controller to the igniter in the solid rocket motor. The igniter, made of a proprietary material, burns, transferring sufficient heat to the solid propellant to ignite it. Motor chamber pressure will rise as the flame front spreads to all exposed propellant surfaces. The end of this phase will be signified by the motor reaching steady-state chamber pressure. The duration of this phase is typically a few seconds or less.

B. Liftoff

The liftoff phase of the flight is signified by the first motion of the launch vehicle along the launch rail. Guided by its two rail buttons, one on the booster section and one on the avionics bay, the rocket accelerates to the end of the launch rail. The liftoff phase concludes at the instant the bottom rail button, located just above the boat tail of the rocket, leaves the launch rail. At this time, the velocity of the rocket will be approximately 90-100 ft/s -- sufficient to ensure stable flight. This phase has been flight-verified twice. This event signifies the beginning of powered flight. The entire liftoff phase lasts only a fraction of a second.

C. Powered Ascent

During the powered portion of the flight, the solid rocket motor operates at steady-state chamber pressure, producing a relatively constant thrust force. The launch vehicle continues to accelerate, reaching its maximum velocity at motor burnout. The four fins located at the base of the vehicle ensure that it remains stable as it encounters aerodynamic disturbances. During ascent, as the motor burns, the center of gravity (CG) shifts forward as the distribution of rocket mass changes in accordance with mass leaving the motor. This further stabilizes the rocket, meaning the period of minimum static margin is during liftoff. When the motor chamber pressure falls below 10% of steady-state, the powered portion of the flight ends and the unpowered portion, or coasting portion, begins. The powered ascent phase lasts approximately six seconds.

D. Unpowered Ascent

During the unpowered ascent phase, the launch vehicle continues to gain altitude but its velocity is rapidly reduced by gravity and aerodynamic drag. The remaining combustion gases in the solid rocket motor drain, returning it to atmospheric pressure. After approximately 20 seconds, the rocket reaches its maximum altitude, which concludes this phase of the flight.

E. Drogue Parachute Deployment

At the instant that the primary altimeter detects the launch vehicle is no longer ascending but rather is descending (no vertical velocity), it initiates the first event. An electronic match ignites a black powder charge, which pressurizes the drogue parachute bay above atmospheric pressure. This pressure breaks the 2-56 shear screws and forces the booster section away, pulling out the drogue parachute. Once second after the primary altimeter fires its charge, the secondary altimeter fires its own drogue deployment charge, providing redundancy in the event that the primary altimeter fails to deploy the drogue parachute. Full inflation of the drogue parachute marks the end of this phase.

F. Descent Under Drogue Parachute

Once the drogue parachute is fully inflated, the launch vehicle descends at approximately 80-100 ft/s. The conclusion of this phase occurs at 1500 feet above ground level, when the primary altimeter fires its main parachute deployment charge.

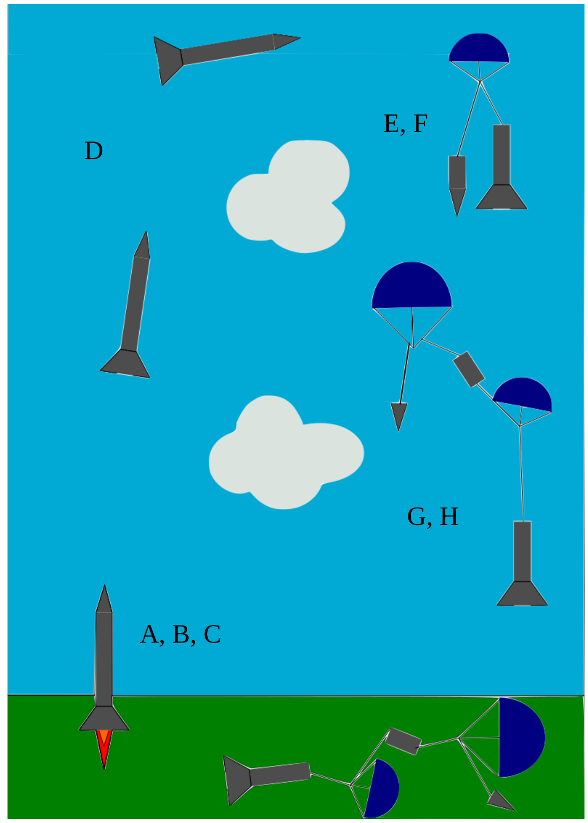

Figure 3. Concept of Operations (CONOPS).

G. Main Parachute Deployment

Upon descending to 1500 feet above ground level, the primary altimeter will initiate the second event, firing its second electronic match, which ignites a small black powder charge in the main parachute bay. The charge pressurizes the bay, forcing the payload bay and nose cone (bolted together) from the top of the vehicle, thereby pulling the main parachute, deployment bag, and pilot parachute free of the rocket body. Next, the pilot parachute inflates, pulling the deployment bag free of the main parachute and allowing it to fully inflate. For redundancy, the secondary altimeter will fire its main deployment charge at an altitude of 1300 feet above ground level. The main parachute deployment phase concludes once the main parachute reaches full inflation, which begins the final mission phase.

H. Descent Under Main Parachute

In the final phase of the mission, the launch vehicle descends at approximately 25 ft/s until contacting the ground. Nominal end of mission is marked by soft touchdown of all sections of the launch vehicle.

IV. Conclusions and Lessons Learned

Regardless of the outcome of the flight at IREC, it will cap off a highly successful year for the team. On the technical side, the team adopted better procedures to create more consistent propellant. Early on, the team struggled with low propellant density, which hinders performance but can also cause other major issues. This issue was solved by adjusting mixing and degassing steps and times. The team gained valuable knowledge about the likely performance of *Wild & Wonderful II* from the flight of *Wild & Wonderful* in SAC 2017. Analysis of last year's flight data indicated a necessity for approximately 10% higher delivered impulse, so this year's team worked towards that end. Propulsion design culminated with a hot firing confirming the increase in total impulse. The team also worked to improve the integration of the larger 3U-sized payload. Both of these improvements make *Wild & Wonderful II* an evolution of the *Wild & Wonderful* flight vehicle.

Experimental rocketry and propulsion is a unique subject not typically taught at most universities. Keeping a team like this running requires a high level of corporate knowledge transfer in a short amount of time, which has always been a high priority for the team. That is why new members are recruited as freshman and sophomores, which gets them involved early enough to gain the necessary experience by their junior and senior years. Also, every club meeting is typically followed by an optional lesson, led by different senior members of the group depending on the subject matter. This year, one series of lessons focused on rocketry fundamentals, like stability, good construction practices, safety, and more. Another lesson series covered solid rocket propulsion and how to design a safe motor, and a third lesson series taught team members how to create a spreadsheet to simulate motor performance.

The main lesson learned this year is that project success hinges on good scheduling, setting deadlines, and keeping margin available.

Having two teams preparing two separate launch vehicles meant that it was particularly important to keep to a tight schedule, since delays in the completion of elements of one rocket could set production of similar components on the other vehicle behind schedule. Equally important; however, was effective communication between both teams to share information and give updates that could affect progress of the other vehicle, especially regarding club supplies of materials, chemicals, and budget usage.

This year was also the first that our club, in conjunction with several faculty members at WVU, designed and administered a formal Experimental Rocketry course. The course was taught by our club faculty advisor and was taught to mainly juniors and seniors. This was the case because much of the material covered in the course was deemed "above the level that an underclassman could reasonably complete." In this regard, our clubs internal learning – that which younger members benefit from – goes above and beyond a standard college engineering curriculum.

Appendix

The following documents are attached at the end of this report: System Weights, Measures, and Performance Data, Project Test Reports, Hazard Analysis, Risk Assessment, Assembly, Preflight, and Launch Checklists, and Engineering Drawings.

Acknowledgments

The team would like to thank the following sponsors for their generous financial and material support of our project. None of what we accomplished this year would be possible without them.

- Statler College of Engineering & Mineral Resources
- WVU Department of Mechanical & Aerospace Engineering
- WVU Student Government Association
- NASA West Virginia Space Grant Consortium
- NASA Independent Validation & Verification Facility
- Aurora Flight Sciences
- Pscolka Woodworks
- Touchtone Research Laboratory
- Graphite Store

Also, we would like to extend special thanks to the following individuals for their particularly dedicated contribution to our project's success this year.

- Joe Pscolka
- Tripoli Pittsburgh
- Pam Gelet
- Kelsey Crawford
- Candy Cordwell
- Dr. Majid Jaridi

Spaceport America Cup

Intercollegiate Rocket Engineering Competition

Entry Form & Progress Update

Color Key — SRAD = Student Researched and Designed — v18.1

Must be completed accurately at all time. These fields mostly pertain to team identifying information and the highest-level technical information.

Should always be completed "to the team's best knowledge" , but is expected to vary with increasing accuracy / fidelity throughout the project.

May not be known until later in the project but should be completed ASAP, and must be completed accurately in the final progress report.

Date Submitted: 12/10/2017

Team ID: 85

* You will receive your Team ID after you submit your 1st project entry form.

Country: United States

State or Province: West Virginia

State or Province is for US and Canada

Team Information

Rocket/Project Name:	Wild & Wonderful II
Student Organization Name	WVU Experimental Rocketry
College or University Name:	West Virginia University
Preferred Informal Name:	WVU
Organization Type:	Club/Group
Project Start Date	8/16/2017
Category:	10k – SRAD – Solid Motors

Projects are not limited on how many years they take

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Faculty Advisor	Dr. Patrick Browning	patrick.browning@mail.wvu.edu	304-293-3601
Alt. Faculty Adviser	Pam Gelet	pamela.gelet@mail.wvu.edu	304-293-4314

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Address Line 2:	P.O. Box 6106
Address Line 3:	Morgantown, WV 26506-6106
Address Line 4:	
Address Line 5:	

Demographic Data

This is all members working with your project including those not attending the event. This will help ESRA and Spaceport America promote the event and get more sponsorships and grants to help the teams and improve the event.

Number of team members

High School		Male	13
Undergrad	13	Female	
Masters		Veterans	
PhD		NAR or Tripoli	2

Just a reminder the you are not required to have a NAR, Tripoli member on your team. If your country has an equivelant organization to NAR or Tripoli, you can cant them in the NAR or Tripoli box. CAR from Canada is an example.

STEM Outreach Events

We often seek out and engage in college-organized and external venues for STEM outreach. We focus on spreading education of rocketry for under-represented students in the Mountain State, especially those in rural areas.

Rocket Information

Overall rocket parameters:

	Measurement	Additional Comments (Optional)
Airframe Length (inches):	141	
Airframe Diameter (inches):	7.12	
Fin-span (inches):	19.37	
Vehicle weight (pounds):	49	
Propellent weight (pounds):	11	
Payload weight (pounds):	9	
Liftoff weight (pounds):	69	
Number of stages:	1	
Strap-on Booster Cluster:	No	
Propulsion Type:	Solid	
Propulsion Manufacturer:	Student-built	
Kinetic Energy Dart:	No	

Propulsion Systems: (Stage: Manufacturer, Motor, Letter Class, Total Impulse)

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1st Stage: SRAD Solid, 10 pounds of aluminum-HTPB-AP composite propellant, N Class, 10511 Ns
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Total Impulse of all Motors: 10551 (Ns)

Predicted Flight Data and Analysis

The following stats should be calculated using rocket trajectory software or by hand.

Pro Tip: Reference the Barrowman Equations, know what they are, and know how to use them.

	Measurement	Additional Comments (Optional)
Launch Rail:	ESRA Provide Rail	
Rail Length (feet):	17	
Liftoff Thrust-Weight Ratio:	6.37	
Launch Rail Departure Velocity (feet/second):	72	
Minimum Static Margin During Boost:	16 inches	*Between rail departure and burnout
Maximum Acceleration (G):	6.5	
Maximum Velocity (feet/second):	936	
Target Apogee (feet AGL):	10K	
Predicted Apogee (feet AGL):	12060	

Payload Information

Payload Description:

Our payload is an inert mass in a cubesat form factor that is mounted between two aluminum bulkheads. This constitutes the section of airframe located just below the nosecone, but is not a structural component of the nosecone. The inert mass is 4"x4"x5" solid aluminum stock welded to 4"x4"x7" aluminum tube for a final dimension of 4"x4"x12". The solid stock of the payload is secured to the bottom bulkhead by three 1/4-20 bolts. The aluminum bulkheads on the bottom and top of the payload pay are held together in tension with two 1/4-20 allthread rods. The approximate weight of the removable ballast is 4.1kg (9lbs).

Recovery Information

Our recovery system is a dual-deployement scheme that utilizes three parachutes, redundant altimeters, and 4F black powder ejection charges. The main parachute is a Skyangle Cert-3 Large. The main parachute is contained by a deployment bag and nomex fabric. The drogue parachute is a Sky Angle Cert-3 drogue and is contained with nomex fabric. The pilot parachute is contained with nomex fabric. The altimeters are Perfect Flight Stratologgers, each capable of initiating two events for a total of four events. There are four PVC canisters of 4F black powder for each of the events in dual, redundant recovery. The main parachute bay canisters will contain 6 grams of black powder while the drogue parachute bay canisters will contain 2 grams. These numbers are subject to change per the evaluation of recovery testing. Chronological, critical recovery steps: On the pad the altimeters are armed with the use of key switches. During ascent, the altimeters will detect a threshold change in barometric pressue (holes will be drilled into the airframe). Because this rocket's speed will exceed Mach 1, the altimeters chosen are specified to have on-board sensory feedback to mitigate the possibility of a premature deployment. The altimeters will recognize apogee by determining that the time rate of change of barometric pressure has come to 0. The presets on the altimeters will initiate 2 events using e-matches in contact with the black powder canisters. These presets are at 1 and 2 seconds following apogee. At this time, either of the charges will seperate the airframe below the recovery bay. The airframe is held together by 4, #2 nylon shear screws. The drogue parachute will then deploy and maintain the descent rate at 80ft/sec. At 1500ft and 1250ft the altimeters will initiate the final events, seperating the airframe above the recovery bay. The airframe is held together by 4, #2 nylon shear screws. At this point, a pilot chute will deploy. The pilot chute will then pull the main parachute from the delpoyment bag. At this point, the main chute will inflate. The main chute will maintain a rocket decent rate of 20-25ft/sec until the rocket lands. Secondary recovery systems include GPS tracking and amateur radio equipment. It should also be noted that a WVUER engineer is developing a custom parachute comparable in size to the Sky Angle Cert-3. We will be testing this chute in the coming months to determine its feasability as an SRAD sustitution to the Sky Angle Cert-3.

Planned Tests

* Please keep brief

Date	Type	Description	Status	Comments
11/11/17	Ground	Propellant characterization (validity check)	Minor Issues	Could not determine steady-state burn time.
12/28/17	Ground	Propellant characterization (validity check)	Minor Issues	Use of larger nozzles to prevent slag build up
2/11/18	Ground	Recovery testing	Successful	
2/18/18	In-Flight	SRAD parachute testing (did not happen)	TBD	
3/11/18	In-Flight	Flight Test (did not happen)	TBD	Kloudbusters, KS
5/17/18	Ground	Motor Test	Successful	

Any other pertinent information:

Following WVU Experimental Rocketry Team's 1st place finish in the 10K SRAD category at the 1st annual Spaceport America Cup, our organization has gone through a period accelerated growth. Our main sponsors have pledged more support than ever before in hopes to facillitate not only another win, but the continuing education of young engineers excited to learn about experimental rocketry. As a side effect of the inter-collegiate publicity that our team has attracted, the number of incoming freshman interested in our club has increased and we are in a position where teaching the next generation of rocket engineers at WVU is an exigent task. To do so, we have organized several out-of-class lectures to teach new-comers theory and practical applications of solid motor design, fundamentals of rocket performance, and construction. Another side affect of the attention our club has recieved is a new upper-level technical course outlining much of the work we do in the club; this is allowing for more junior and senior engineering students to become involved with our team. With the influx of support and personell, our desire to teach young students about experimental rocketry, and the need to give experience to those inheriting the club, we decided to support a 10K SRAD project. This project is a means by which new members can cut their teeth on a high-powered rocket while learning from members of the team who are veterans of previous SACs (and IRECs). For the past four months, our younger members have been working to design the payload, parachute, motor and recovery systems for a rocket that will take 1st in the 10K SRAD category at the 2nd annual Spaceport America Cup.

End of File

Project Test Reports Appendix

A. Recovery System Testing

Wild & Wonderful II's recovery system was ground tested on April 30, 2017. The primary goal of the test was to determine proper sizing of the black powder ejection charges needed to reliably break the shear pins in each section and deploy the parachutes with an appropriate but not excessive amount of force. First, the electronics bay and booster section packed as they would be for flight. Both were placed on the ground and the electronics bay was secured to prevent recoil. A single ejection charge was fired, breaking the two shear pins in the booster and propelling the booster section a short distance, pulling out the recovery harness and drogue parachute in the process. After repeated testing, it was found that three grams of black powder was the desired amount.

Next, the other half of the rocket was tested in a similar manner. Once again, the electronics bay was secured to prevent recoil and a charge was fired to break the shear pins and push away the nose cone and payload bay sections, deploying the main parachute in the process. After repeated testing, it was found that six grams of black powder reliably broke the four shear pins in the forward section of the vehicle but did not produce excessive force that could cause damage.

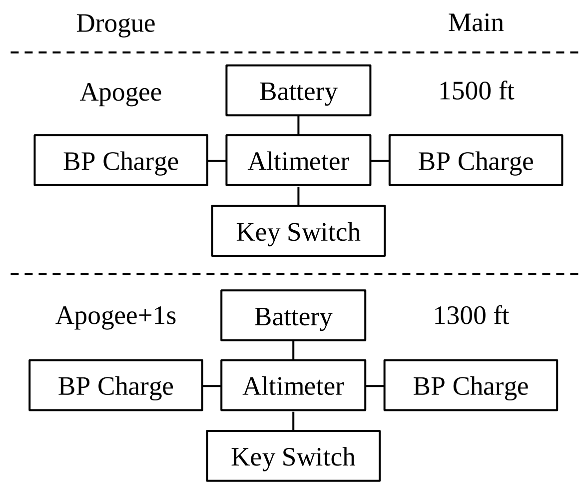


Figure 4. Configuration of Recovery Electronics.

The heart of the recovery system features two Perfectflite StratologgerCF barometric altimeters and four small black powder ejection charges which are fired by electric matches. Each altimeter has a charge for deploying the drogue parachute and a charge for deploying the main parachute, as well as its own switch and battery. This makes the entire system fully redundant, as any single battery, switch, altimeter, or e-match failure will not result in system failure. Fig. 4 shows a block diagram of the configuration of the recovery electronics. The altimeters are programmed such that the primary and secondary charges never fire at the same time. At apogee, the primary altimeter fires its drogue charge, and the secondary altimeter fires its drogue charge after a one-second delay. At 1500 ft, the primary altimeter fires its main charge, while the secondary altimeter does not fire its main charge until the rocket has descended to 1300 ft.

B. SRAD Propulsion System Testing

Figure 5. ***Wild & Wonderful II propulsion system hotfire on May 17th, 2018***

The propulsion system of *Wild & Wonderful II* is a student researched and designed (SRAD) solid rocket motor. On May 17th, 2018, the final test motor was placed on the team's test stand. The stand holds the motor vertically, with the exhaust pointed straight up into the air, as shown in Fig. 5. The forward bulkhead of the motor presses down on a load cell, which is connected to a student-built data logging system. Ultimately, this system allows the thrust curve of the motor to be recorded.

The test was successful as the motor performed just as expected, producing an average thrust of 420 pounds for 5.7 seconds. Following standard motor code definitions, the designation of this motor is N1840. No damage to the motor hardware, including the nozzle, was observed during post-test inspection.

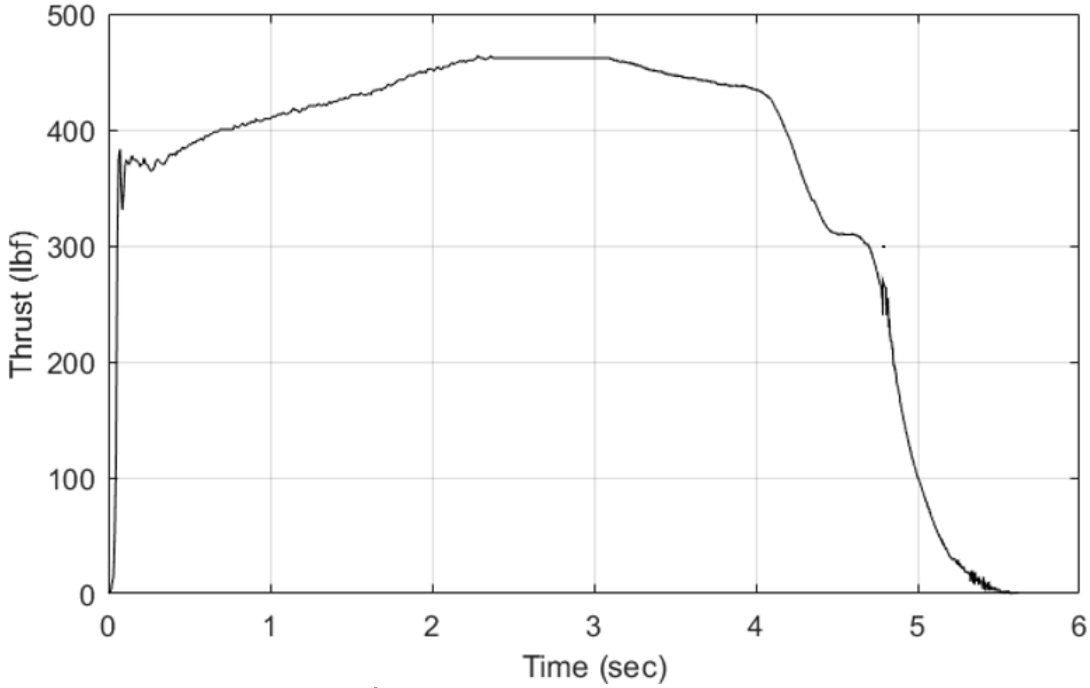


Figure 6. Thrust Curve from May 17th Static Test, Final Flight Motor Configuration.

C. SRAD Pressure Vessel Testing

The motor casing used in the *Wild & Wonderful II* propulsion system is machined by students on a metal lathe from 6061-T6 aluminum stock. As such, it is hydraulically pressure tested in accordance with IREC rules. The motor casing used this year is the same article used in last year's competition, so it was not retested this year. The data included in this report was recorded last year.

Pressure testing of the 98mm motor casing was conducted using a hydraulic pump rated to 8,000 psi. A TC Logger system with a connected pressure transducer was used to obtain and log accurate pressure readings. Bulkhead 98B1 was connected to the pressure transducer using a 2" long @ 1/8x27 NPT brass nipple. Bulkhead 98B2 was connected to the hydraulic pump using 2" long @ 1/8x27 NPT brass with a ¼x20 NPT to 1/8" adapter. Two lubricated O-rings were placed on each bulkhead in their respective grooves. Bulkhead 98B1 was slid in one end of the casing that was being tested and secured using a standard 98mm snap-ring. The casing was then filled with standard weight hydraulic fluid. Bulkhead 98B2 was then slid into the open end of the case without the pump connected to allow air and excess fluid to bleed out and secured in place with a standard 98mm snap-ring. The pump was then connected to the tubing on 98B2. The casing was placed into a large diameter tube acting as safety shield. The TC Logger system was connected to a computer and data recording was started. The pressure was then gradually raised using the pump. Once the predetermined pressure of 1600psi was reached, well over double the calculated max operating pressure, the pressure was held for 1-2 seconds as shown in Fig. 7. When the pressure was released the pump was disconnected and bulkhead 98B2 is removed; the fluid was removed. Bulkhead 98B1 was then removed and the casing was cleaned.

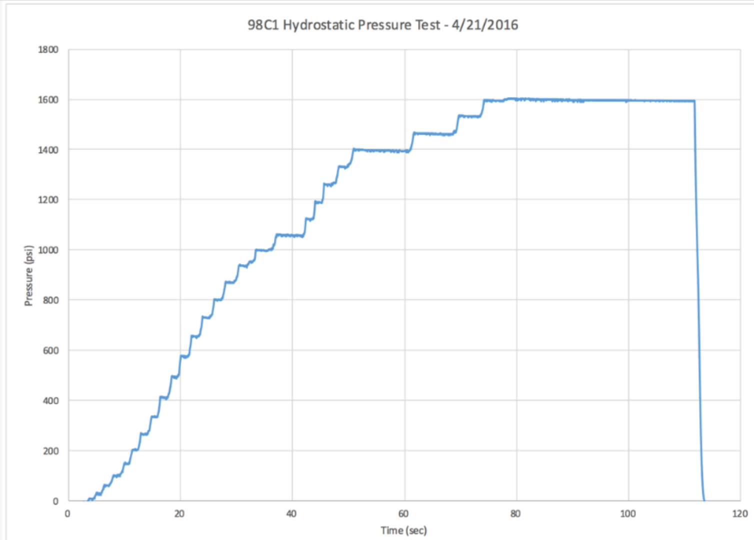


Figure 7. Hydrostatic Pressure Testing of SRAD Motor Casing Conducted on April 21st, 2016.

Hazard Analysis Appendix

A. Propellant Storage and Handling

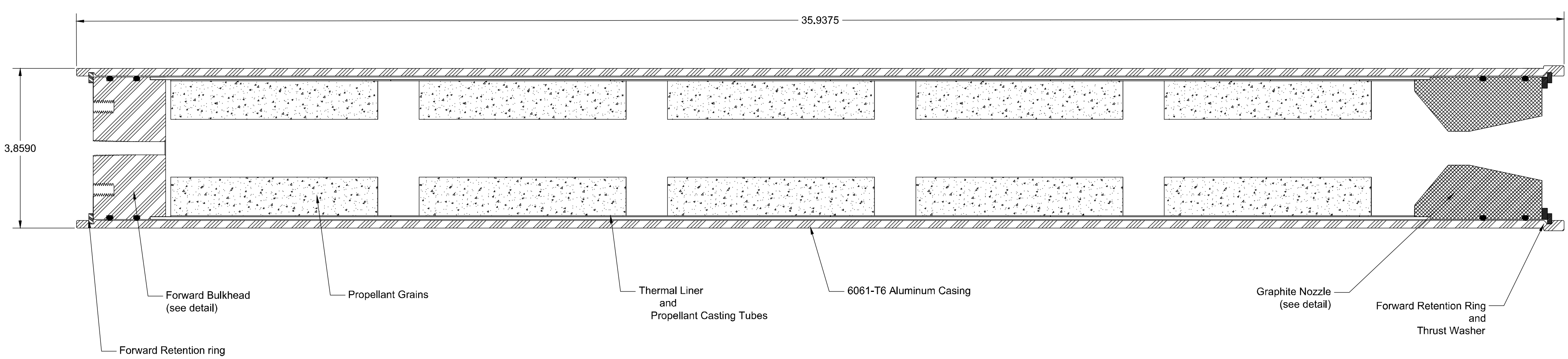
The solid rocket propellant used in *Wild & Wonderful II's* SRAD solid rocket motor is stored and transported in sealed plastic to prevent moisture or other damage from occurring. For safety, it is always stored separately from any type of ignition source and never inserted into the motor casing or any other type of pressure vessel until immediately before flight.

Team: West Virginia University (85)		Project Name: Wild & Wonderful II	Date: 5/25/2018	
Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury After Mitigation**
Injury during arming of recovery system	Falling from ladder/platform	Medium; tall rockets may have arming devices high above ground	Design rocket such that arming switches can be easily reached using no more than a 4-foot ladder/platform	Low
Recovery initiator activates prematurely during assembly/preparation	Faulty avionics wiring	Medium	Load ejection charges last, use arming switches in series with batteries, never point rocket at personnel once charges are loaded, even when unarmed	Low
Motor fails to pressurize on ignition ("hang fire")	Initiator fails to fire or fails to transfer sufficient heat to start combustion	Medium	Do not approach rocket for at least 2 minutes, do not approach rocket if any smoke is spotted, only 2 crewmembers approach rocket wearing faceshields to quickly remove and unhook initiator	Low
Fire on launch pad	Catastrophic motor failure	Medium; fire is very likely to follow any catastrophic motor failure	Make no attempt to extinguish fire, wait for it to fully burn out before approaching, extinguish any secondary fires started	Low
Catastrophic failure of solid-fuel motor during boost with flying debris	Structural failure of aluminum motor casing	Medium; student-machined motor hardware	Use ductile material for motor casing, hydrostatically test motor casing to much higher pressure than expected (successfully tested to 1,600 psi), perform full static firing of flight motor	Low

	Structural failure of forward closure or nozzle		Visually inspect nozzle for cracks, visually inspect all O-rings for damage, grease all O-rings to reduce chance of damage during assembly	
	Cracks in propellant grain	Medium; student-formulated and student-manufactured propellant grains	Visually inspect propellant grains before motor assembly	
	Propellant debonding from casting tube			
	Structural failure of propellant grain		Use bonding agents and polymer crosslinkers in propellant formula to increase tensile strength, static test flight motor to characterize erosive burning behavior	
	Debris such as casting tube clogs nozzle during motor operation	Medium	Securely glue propellant grains into thermal liner to prevent casting tube from being ripped out	
Rocket experiences significantly non-vertical flight path	Aerodynamically unstable vehicle	Medium; always a concern for all rockets	Ensure that CG is located well forward of CP when in flight configuration, simulate aerodynamic properties using RockSim and RASAero	Low
	Insufficient velocity when leaving rail		Use single motor instead of cluster, ensure rocket has suitable thrust-to-weight ratio (at least 5:1)	
Recovery initiator activates prematurely during rocket flight	Improper use of barometric altimeters	High; air pressure increases in transonic region may cause some altimeters to detect	Use only proven barometric altimeters designed for Mach 1+ flights	Low

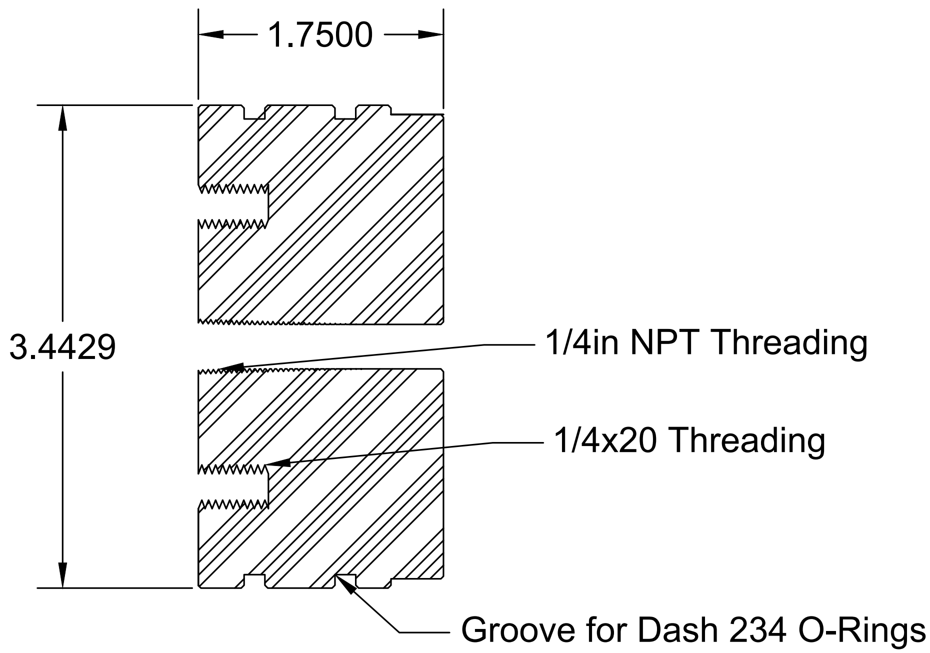
		apogee conditions and fire ejection charges		
	Interference from other electronic payloads	High; electronic sensors for payload experiments have not been flown on a rocket before	Completely isolate recovery system and power supply from other payloads	
Structural failure of fins during flight, resulting in rapid disassembly of vehicle and falling debris	Fins lack required structural integrity	High; high aerodynamic forces will be experienced	Fabricate fins from high-strength fiberglass with supporting wooden spars	Low
	Fins improperly secured to rocket		Secure fins to rocket using heavily reinforced fiberglass and high-strength epoxy	
Recovery system fails to activate, rocket falls at high speed	Wiring connection breaks	Medium; recovery system must survive extreme forces during launch	Use only locking connectors or terminal blocks	Low
	Battery is too weak to properly fire ejection charge	Medium; battery may deteriorate during storage	Use only fresh batteries, test batteries before assembly, record battery voltage reported by altimeter prior to launch	
	Ejection charges not strong enough to separate rocket	Medium; tolerances in shear pins and friction may cause components to snag during deployment	Ground test all recovery components multiple times before flight	
	General failure of recovery initiator	Medium	Ground test all recovery components before flight, redundant recovery initiation systems, fully isolated from each other, including redundant altimeters, wiring, initiators, and ejection charges	

Main parachute deploys at apogee	Recovery harness inadvertently frees main parachute from its compartment	Medium; drogue deployment often imparts a large jerk on the rest of the vehicle	Use shear pins to secure nose cone and main parachute compartment	Low
High-speed deployment of recovery system causing damage to airframe, harnesses, and/or parachute	Non-vertical, arcing flight path	Medium; even the straightest flight will have some residual velocity at apogee	Double thickness of fiberglass airframe at all separation points, use nylon harnesses that offer slightly more elasticity than Kevlar, use deployment bag to slow parachute deployment	Low
	High upper-altitude winds	Medium; ground-level winds may be drastically different than those at 10,000'AGL		



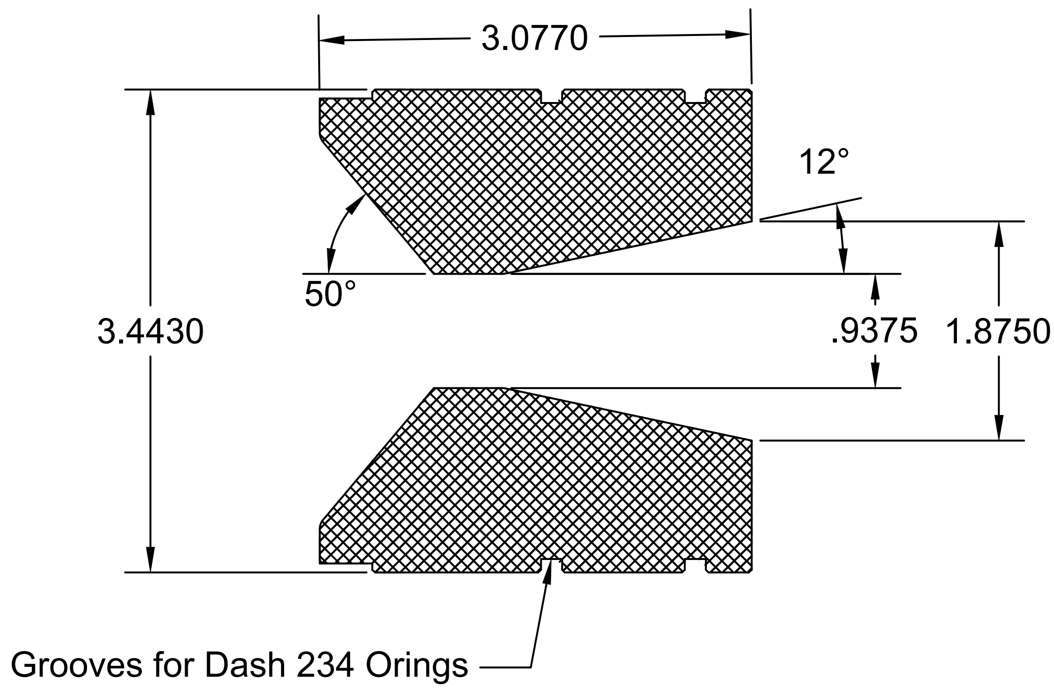
Motor Overview Drawing

Drawn on 29 May 2017 by Ryan R. Maurer



Foreward Bulkhead Drawing

Drawn on 29 May 2017 by Ryan R. Maurer



Nozzle Drawing

Drawn on 29 May 2017 by Ryan R. Maurer