Development of a Multistage High-Power Rocket

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In five years of rocketry projects, the Space Hardware Club at the University of Alabama in Huntsville has been primarily focused on university competitions. However, with the introduction of Project URSA, this focus turns solely to expanding students' knowledge and capabilities. The unique challenges posed by designing, building, and flying a multistage rocket further many aspects of the Club's rocketry experience, including simulation, design, and manufacturing techniques. In order to break both altitude and speed records for the University, Ursa flies two stages on high-impulse, solid propellant motors. While this is not the Space Hardware Club's first multistage rocket, this marks the first attempt to fly two powered stages. With Project URSA, the few experienced Club members are given an opportunity to pass their knowledge to a team primarily composed of freshmen. Much like the project itself, the team represents the bedrock and future of the Space Hardware Club's Sounding Rocket Program.

Nomenclature

UAH	= University of Alabama in Huntsville
SHC	= Space Hardware Club
CG	= Center of Gravity
AGL	= Above Ground Level
CNC	= Computer Numerical Control
GPS	= Global Positioning System
ABS	= Acrylonitrile Butadiene Styrene
CONOPS	= Concept of Operations
FEA	= Finite Element Analysis
EDPF	= Engineering Design and Prototyping Facility

I. Introduction

THE Space Hardware Club (SHC) at the University of Alabama Huntsville is a student-run organization that provides undergraduate and graduate students with access to valuable real-world design and fabrication experience. To create guidelines for projects, SHC primarily uses college level design competitions such as the International CanSat competition or the Battle of the Rockets. Additionally, upperclassmen with the club participate

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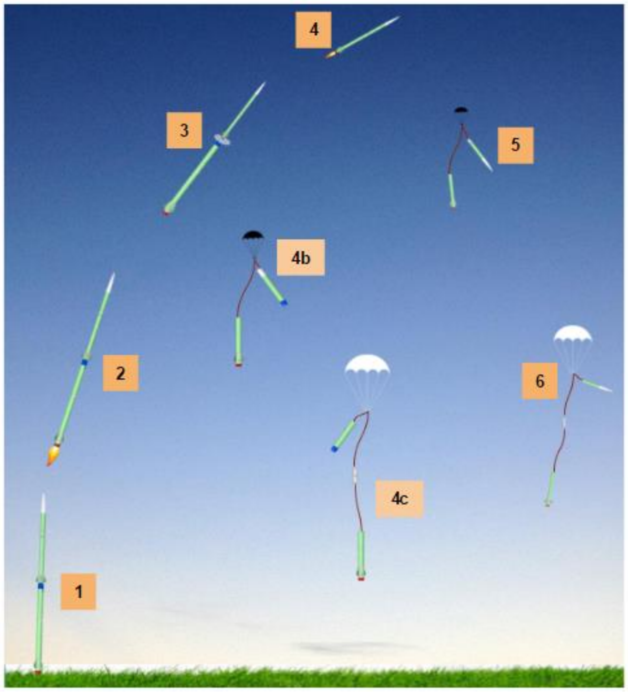
in advanced projects such as building CubeSats or working on NASA's USIP. With Project URSA, SHC seeks to design, build, and fly a multistage high-power rocket without the restrictions imposed by competition requirements. SHC believes that this shift towards independent project development and execution will lead to more applicable experiences for all members of the Club, better preparing them for future work in the field of engineering and for future projects with the Club.

A. Project Overview

The primary objective of Project URSA is to design, build, and fly a high-power multistage rocket capable of reaching a club record apogee of 30,000 feet above ground level (AGL) using 2 powered stages. To achieve this goal, Ursa's motors produce a combined total impulse of 8454 Ns; greater than any rocket the club has flown before. The secondary purpose of Project URSA is to serve as an educational tool to new members of the club. To this end, the project team contains only three upperclassmen: Davis Hunter, systems engineer; James Biaglow, avionics liaison; and Kyle Renfroe, manufacturing consultant. The team lead Marcus Shelton, the subsystem leads, Aaron Hunt and McKynzie Perry, and all other members are underclassmen. This distribution of members allows for all underclassmen involved in the project to gain significant amounts of hands-on experience in the design and actualization of a complex rocketry project, which is paramount to the club as it seeks to continue the development of its Sounding Rocket Program.

B. Concept of Operations

With respect to other high-power multistage rockets, Ursa's concept of operations (CONOPS) is conventional in nature. After launch, the booster motor will fire until burnout. One second after booster burnout, stage separation will occur. After a coast time that will be determined on the day of the launch (reliant on atmospheric conditions at the launch site), the sustainer will ignite and burn. When both the booster and the sustainer reach their respective apogees, each stage will deploy its drogue parachute to begin controlling descent. After descending under drogue, both stages deploy their main parachutes at specified altitudes: 700 feet for the booster, 500 feet for the sustainer.



1	Launch
2	Powered Ascent
3	Separation (2909 ft)
4	Sustainer Ascent
4b	Booster Drogue Deploy (4760 ft)
4c	Booster Main Deploy (500 ft)
5	Sustainer Drogue Deploy (31,232ft)
6	Sustainer Main Deploy (700 ft)

Figure 1. CONOPS *A graphic display of the Concept of Operations for Ursa.*

II. Airframe Design

There are many components of this rocket that are common to all high power rockets. However, airframe design must still take into consideration the unique needs and restrictions of Project Ursa. These considerations include mass, budget, aerodynamic efficiency, and feasibility. To reflect this, trade studies are completed for each component, with the advantages and disadvantages of each possibility analysed.

A. Nose Cone

In the high-power rocketry community, there are three primary nose cone profiles used for supersonic flight. These profiles are the tangent ogive, the Von Karman ogive, and the $x^{1/2}$ profile. The tangent ogive is the most commonly used profile due to its relatively efficient performance at all velocities. While the Von Karman and $x^{1/2}$ both work well below Mach 3, they are each optimized for different velocity ranges. The Von Karman profile derives its performance from its use of a segment of a Sears-Haack body. The Sears-Haack body is a unique shape that has been mathematically derived to produce the lowest pressure drag at supersonic velocities, giving it the lowest drag coefficient in the Mach 1.2 to 3.0 range. The $x^{1/2}$ nose cone, with its blunt tip, has the lowest drag coefficient in the subsonic and transonic regions but quickly gains drag in supersonic flight. Ursa will utilize a Von Karman profile due to its higher predicted altitudes and velocities in simulations, as seen in Table 1. Instead of scratch building a nose cone, the team opted to purchase a commercially available fiberglass Von Karman nose cone and to make modifications to it as required; one of these modifications is the removal of the stock composite tip and the installation of a machined aluminum tip. The custom tip will be threaded to allow for the insertion of a ¼-20 aluminum rod. The threaded rod shall extend to the other end of the nose cone where it will constrain a machined aluminum bulkhead and an eye nut. This eye nut shall be used as a mounting point for the upper stage main parachute shock cord.

Table 1: Nose Cone Performance

Profile	Apogee (ft)	Mach
Ogive	30,538	1.74
Von Kármán	31,232	1.75
x^1/2	30,238	1.74

B. Body Tubes

Due to large motors, each stage of Ursa individually is the size of a typical high-power rocket; the sustainer's body tubes are collectively 60 in long, the booster's body tubes are 72 in long. With the nose cone and boat tail, the total length of the rocket is 12feet. The upper stage has a diameter of 3 in, and the lower has a diameter of 4 in, making the separation event much easier due to the drag differential. With long and skinny rockets, a rule of thumb exists that says stability calculations become accurate when the length to diameter ratio is greater than 30. Because the combined rocket surpasses this mark, the simulation must be adjusted to account for the accuracy. Luckily, this can be easily accounted for by simply increasing the stability of the combined rocket.

When considering material options for an airframe, the main three choices are carbon fiber, G12 fiberglass, and cardboard. Cardboard can immediately be ruled out because it typically disintegrates at transonic speeds, so the choices are fiberglass and carbon fiber. Carbon fiber is significantly stronger, but it is not radiolucent, meaning radio signals can't pass through it. Tracking avionics would be rendered useless by the carbon fiber, so G12 fiberglass was chosen for the airframe. G12 fiberglass is filament wound with weaves varying from 30° to 45°. This material has also been used widely in high-power rocketry and is certainly strong enough to withstand the forces of the flight.

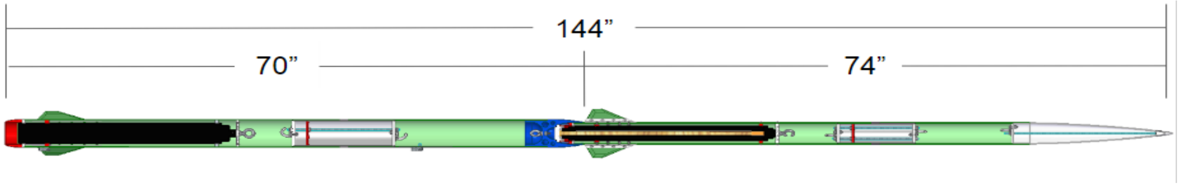


Figure 2. Cross-sectional diagram[1] *The individual stages are both roughly 6 feet long, for a total combined length of 12 feet.*

C. Couplers

Each stage of the rocket has one coupler designed to properly connect the adjoining body tube sections. In addition to joining the body tubes together, the couplers also serve as the area in which trackers and avionics are housed in the rocket. Consistent with the composition of the body tubes, the couplers are made from filament wound G12 fiberglass. For the upper stage of the rocket, the coupler has a total length of 9 inches, an outer diameter of

2.998 inches, and an inner diameter of 2.875 inches. For the lower stage of the rocket, the coupler will have a total length of 12 inches, an outer diameter of 3.998 inches, and an inner diameter of 3.900 inches. The end of each coupler is capped with aluminum bulkheads. The bulkheads serve as the attachment point for the recovery system's shock cords as well as the attachment point for the two ¼-20 rods which run through each coupler. Inside each coupler, an acrylonitrile butadiene styrene (ABS) avionics sled is mounted along the threaded rods. The avionics sled is the direct mounting point for recovery, staging, and tracking electronics. Epoxied along the center of each coupler, there is a switch band which will allows for arming and disarming of the rocket's avionics.

D. Fins

As can be seen in Fig. 3 both the booster and sustainer fins have a clipped delta shape. The fins will have a 1/16th inch thickness square profile. Previously, a 1/8th inch thick hexagonal profile fin was considered; however, through simulations, it was found that the decreased fin thickness increased the apogee just over 3,000 feet. The holes seen in the fins are for the insertion of binding posts, which are the mounting points of the fins to the brackets.

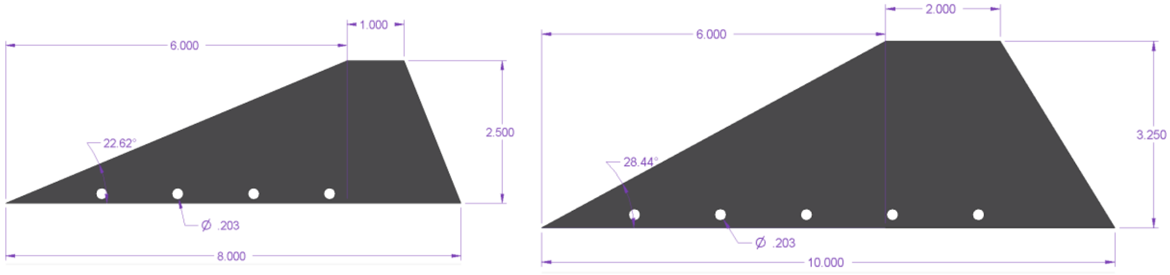


Figure 3. Fin dimensions[1] *The sustainer (left) and booster (right). Fin dimensions are both displayed in inches.*

1. *Flutter*

One of the primary concerns for supersonic high-power rocket flight is the possibility of harmonic resonance causing fin flutter. The consequences of flutter can be catastrophic, resulting in a stability loss and failure of the entire system; therefore maximum velocity must remain below flutter velocity. The speed at which flutter occurs is calculated using Eq. (1)[3]. Equation (1) shows that flutter velocity (V_f) is primarily a function of the speed of sound (a), material shear modulus (G), and the aspect ratio (AR). The aspect ratio of a fin is defined as the span squared divided by wing area.

$$V_f = a\sqrt{\frac{\frac{G}{1.337AR^3P(\lambda+1)}}{2(AR+2)\left(\frac{t}{c}\right)^3}} \tag{1}$$

In addition to the variables mentioned above, the flutter velocity is also a function of atmospheric pressure (P), taper ratio (λ), thickness (t), and tip chord (c).Using this equation, the calculated flutter velocity was about 3690 ft/s (Mach 3.36), which is well above Ursa's maximum velocity 1922 ft/s (Mach 1.75). These calculations also do not account for the bracing effect that the fin brackets have on the fins. Aside from the obvious mechanical advantage provided by the fin brackets, the change in material from carbon fiber to ABS increases the flutter velocity, placing it well above the calculated value.

2. *Aerodynamic Heating*

While it is not a major concern at Ursa's expected velocities, the effects of aerodynamic heating must still be taken into consideration. After determining the maximum velocity of the rocket and the altitude at which it occurs, the heating was calculated using Eq. (2)[4], which is a function of only the specific heat ratio for air (γ) and Mach number (M).

$$\frac{T_1}{T_0} = \frac{\left[2\gamma M^2-(\gamma-1)\right]\left[(\gamma-1)M^2+2\right]}{(\gamma+1)^2M^2} \tag{2}$$

It was found that under the worst case scenario, the increase in temperature achieved would be 260ºF (total temperature of 310ºF), which would occur only at the tip of the nose cone and the leading edges of the fins. This is well within the safe bounds of the aluminum nose tip and carbon fiber fins.

Figure 4[1]. Sustainer fin bracket *The booster and sustainer fin brackets are very similar and will both be 3D printed from ABS.*

3. Fin Assembly

Typically, fins are epoxied onto the rocket with six fillets per fin: two on the outside of the body tube, two on the inside surface of the body tube, and two on the outside of the motor tube. However, to reduce mass, Ursa uses precision machined centering rings rather than a motor tube. This eliminates a possible surface for fillets, making the design weak and infeasible. Accordingly, Ursa has a mechanical fin attachment, which is custom to the rocket.

The materials considered for fin attachment include aluminum, ABS, and nylon. The aluminum is roughly eight times stronger than ABS, but it would also require days of machining on a computer numerically controlled (CNC) mill, threatening the project's timeline. Subsequently, only 3D printed ABS and nylon were compared. Because ABS can be 3D printed on campus, the manufacturing process becomes much cheaper and faster. Additionally, the nylon is only 12.5% stronger than ABS, so ABS was chosen to attach the fins to the rocket.

E. Motor Selection

While choosing motors, there are several factors that must be considered. The first and most obvious consideration is the range of acceptable altitudes; the project goal is reaching an apogee of 30,000 feet AGL, but the FAA waiver at the Kloudbusters Airfest only extends to 50,000 feet, with a max simulated altitude of 40,000 feet. Initially, Ursa was going to fly on the largest motors possible of the given diameters, meaning a six grain 75 mm motor in the booster paired with a six grain 54 mm motor in the sustainer. However, the initial simulations violated both the waiver and the team's budget. The sustainer motor remained the same, but the booster motor was reduced to a four grain 75 mm, which reduces the budget by over $1,000 and remains within the acceptable altitude range. After comparing various options, the motors selected are the Aerotech L1090 for the sustainer and the Aerotech M1780 for the booster. The booster motor is in the Tripoli Rocketry Association Level 3 range[2], and the sustainer is in the Level 2 range[2]. However, with staged rockets, the total impulse for the flight is calculated as the sum of all motors. This necessitates the need for a Level 3 certification for a team member, a first for the Space Hardware Club.

Table 2: Sustainer Motor Choices

Motor	Apogee	Top Speed	Price
L1090	31,232 ft	1932.4 ft/s	$200
K1050	29,494 ft	1857.1 ft/s	$185

Table 3: Booster Motor Choices

Motor	Apogee	Top Speed	Price
M1850	41,313 ft	2093.1 ft/s	$395
M1500	30,979 ft	1916 ft/s	$260
M1780	31,232 ft	1932.4 ft/s	$260

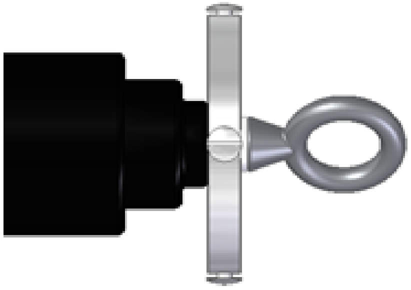


Figure 5. Motor Retention System[1] *The eyebolt is inserted through the retaining bulkhead, which is bolted to the body tube and threaded into the motor.*

F. Motor Retention

There are two primary methods of motor retention after burnout: a forward retention system or an aft retention system, each with their own advantages. Aft retention systems are typically much easier to install, with most consisting of a cap that threads into the back of the rocket. The use of an aft retention system also allows for the use of motor delay ejection charges, which makes it very popular for rockets with a time to apogee lower than thirty seconds. A forward retention system forgoes this ejection charge capability, instead placing a bolt into the forward closure of the motor, where the ejection charge would typically be located. Forward retention systems are typically used on larger, more complex rockets and require the installation of an additional bulkhead for the retaining bolt to thread through. Additionally, this provides a smaller combustion chamber for deployment charges, allowing for more efficient pressurization. For Ursa, the standard bolt in the forward closure is replaced by an eyebolt. This provides a much better mount for recovery shock than the standard method of drilling a hole into a centering ring and mounting the eye bolt there.

III. Staging

The transition piece is at the core of Ursa, both literally and metaphorically. Should it fail, Ursa is no longer a multistage rocket. Because of its unique function and high risk, it is one of the most complex components of the rocket. Components must fit the specific needs of a multistage rocket while also staying within the limits of budget and manufacturing capabilities. Because of this, almost all parts of the transition section are manufactured using 3D printing.

A. Transition

As seen in Fig. 6, the interface between the two stages consists of a transition shell (blue), piston cup (white), and boat tail (red). The piston is secured to the boat tail using 4 nylon screws, which are intended to shear upon ignition of the sustainer. The boat tail is secured to the upper stage through vertical steel bolts running to the centering rings. A similar nylon screw system is used to secure the shell to the aft body tube of the sustainer. Steel bolts are then used to secure the shell to the forward body tube of the booster. There is an O-ring on an inner face of the shell where the piston is inserted to create a pressure chamber for charge separation. All components are 3D printed out of ABS, due to complex geometries and precision fitting. The machining operations that would be required to manufacture these items are far too complex and time consuming given the resources available to the team.

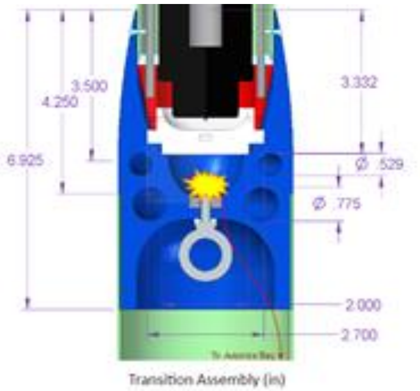


Figure 6. Staging mechanism[1] *Model of the transition piece between the two stages. (All dimensions in inches)*

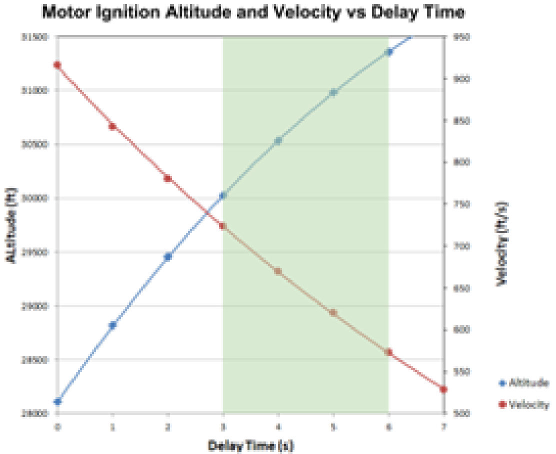


Figure 7. Motor Ignition Delay Graph *The 2nd stage motor ignition delay must balance between altitude gained by extra delay and drift caused by reduced velocity during coast.*

B. Separation and Ignition Delay

There are three distinct phases of staging in any multistage rocket. Phase 1 is the separation of the stages. This is initiated by a charge placed in the pressure chamber of the transition section, colored yellow in Fig. 6. An electronic component in the booster ignites a black powder charge, creating a high enough pressure to shear the nylon screws securing the transition shell to the sustainer. In phase 2, the sustainer, with piston still attached, coasts for a predetermined amount of time. After coasting, electronics in the sustainer ignite the second stage motor, beginning phase 3. An ignition wire runs through the piston, and is designed to break away upon motor ignition. When the motor ignites, the nylon screws holding the piston onto the boat tail shear, allowing the piston with ignition wires attached to fall away from the sustainer. This breakaway system allows for unimpeded motor burn without the additional drag of trailing wires.

Because the sustainer coasts for the duration of phase 2, it is important to time the sustainer ignition so that adequate velocity is maintained for a strictly vertical flight. Ignition at too low of a velocity will cause the sustainer to drift and ignite the motor in a non-vertical direction. Velocity starts decreasing upon stage separation; therefore, the sooner phase 3 begins, the straighter the sustainer will fly. However, if phase 2 is prolonged, the sustainer is able to reach higher altitudes (assuming vertical flight). In order to find the highest possible altitude where the sustainer maintains a velocity above 550 ft/s during coast, simulations were run in RASAero II. The graph of the simulations is shown in Fig. 7, with the acceptable range of delays highlighted in green. Current projections have the delay set conservatively at 5 seconds, but it is subject to change with atmospheric conditions on launch day.

IV. Recovery

The recovery system of Ursa is a dual deploy system similar to most high-power rocket recovery configurations. Each stage contains this typical configuration, resulting in twice the amount of the parachutes and events; this presents challenges when examining flight electronics configurations and recovery bay space. Additionally, the sustainer drogue deployment occurs at a high altitude, necessitating the pressurization of the bay containing the drogue parachute.

A. Descent Control

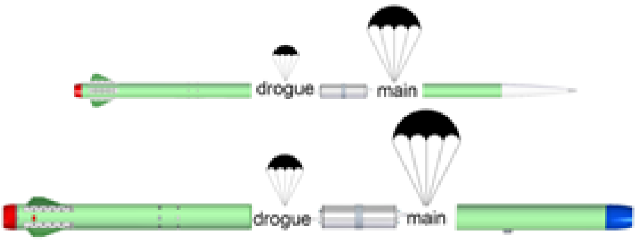


Figure 8. Recovery Placement Diagram *Following typical high-power rocketry procedure, the drogue parachute is placed aft of the main parachute in both stages.*

Each stage of Ursa has two parachutes, a main and drogue, for a total of four recovery deployments. The recovery deployments mirror one another across the stages, only the sustainer has a nose cone and the booster has the transition piece. The respective drogue chutes deploys from the aft body tubes at the coupler. The main chutes deploy from the forward body tube at the coupler. This is illustrated in Fig. 8. The main difference between the sustainer and booster is the sealing of the drogue bay in the sustainer. Because the sustainer is projected to deploy its drogue above 30,000 feet, and black powder does not fully combust at such high altitudes, the drogue bay is sealed with O-rings. The sustainer deploys a 12 in drogue at its apogee (~31, 123 feet), then deploys a 6 foot main chute 500 feet from the ground; the booster deploys an 18 inch drogue at its apogee (~4,637 feet), then its 9 foot main chute 500 feet AGL. These deployments are triggered by altimeters. Chutes are secured to the rocket with 25 foot Kevlar shock cords and connect either at tie-down rings or eye bolts, depending on the bay. Any separating parts of Ursa are pinned together using various quantities and sizes of nylon screws. This is to ensure stages don't accidentally separate during another event. Drogue bays are secured with fewer, weaker screws than the main chute bay, so that when the charge is ignited only the coupler and aft tube separate. Shear pins are placed between the aft tube and coupler for redundancy and safety.

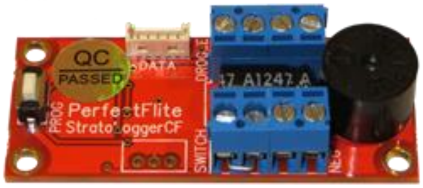


Figure 9. PerfectFlite Stratologger CF *Each stage will use 2 Stratologgers for recovery deployment.*

B. Avionics

Within each coupler, there will be an avionics sled mounted to the coupler's ¼-20 threaded rods. For the upper stage of the rocket, the avionics sled serves as an attachment point for two redundant staging electronics systems, two redundant recovery electronics systems, and a tracking system. For the lower stage of the rocket, the avionics sled serves as an attachment point for two redundant recovery electronics systems and a tracking system. Since the avionics sleds are customizable for multiple configurations, Project URSA is capable of operating with many different avionics systems. For this project, the upper stage avionics sled is equipped to hold two PerfectFlite StratologgerCFs two MissileWorks PET2+ Timers, and one SPOT trace global positioning system (GPS) tracker. The lower stage avionics sled is equipped to hold two PerfectFlite StratologgerCFs and one SPOT trace GPS tracker.

The PerfectFlite Stratologger CF is a compact altimeter capable of working to an altitude of 100,000 feet above sea level. As applied to Project Ursa, the main purpose of the Stratologger is to deploy the recovery system at predefined points throughout the flight. For the upper and lower stage, the Stratologger shall detect the apogee of the rocket's flight, where it will deploy the drogue parachute initiating the first portion of the rocket's controlled descent. At respective altitudes, the Stratologger shall deploy the upper and lower stage's main parachutes. Deployment of the parachutes is achieved by an electrical current from the Stratologger which ignites a black powder charge within the rocket. Since there are two redundant Stratologgers within each rocket stage, there are two charges ignited for each parachute ensuring successful deployment and recovery.

Figure 10. PET2+ Timer *The Pet2+ Timer made by Missile Works will control second stage ignition.*

Figure 11. SPOT Trace *The Spot Trace tracker has been used extensively in SHC high-power rocketry.*

For Project URSA, The MissileWorks PET2+ timer is used to ignite the upper stage motor. To ensure proper ignition of the upper stage motor and to decrease failure modes, there are two redundant MissileWorks PET2+ timers attached to the upper stage avionics sled. The MissileWorks PET2+ timer is equipped with an accelerometer, which is programmed to detect initial motor ignition and burnout. The PET2+ is programmed by the user to ignite the upper stage motor after a certain time delay has passed after the lower stage motor burnout. To ensure that the motor is only ignited when the rocket is in a safe orientation, the PET2+ timer is equipped with a breakwire circuit, as well as a programmable dead band. The purpose of the breakwire circuit is to measure whether or not the upper stage has properly disconnected from the lower stage. The purpose of the programmable dead band is to ensure that the upper stage is pointed at an acceptable angle prior to firing the motor.

The SPOT Trace GPS Tracker is intended for use in harsh conditions such as those found aboard a high powered rocket. Capable of transmitting GPS coordinates every 5, 10, 30, or 60 minutes, the SPOT Trace is vital to successfully finding and recovering the rocket after flight. The SPOT Trace is a self-contained unit which is powered by 4 AAA batteries. With the push of a button, the SPOT begins transmitting location data to satellites which then relay the location data to the internet. From there, the location of the rocket can be viewed from any phone, laptop, or similar device. After Ursa's flight, the landing coordinates provided by the SPOT Trace will be used to find and recover the upper and lower stages of the rocket.

V. Simulation

Due to the high risk present in high-power rocket launches utilizing untested hardware, simulations must be conducted in order to ensure the basic viability of any design. Additionaly, the cost of producing test articles for every component on the rocket would be prohibitively expensive. Instead, Finite Element Analysis (FEA) using Siemens SolidEdge ST8 was used on components deemed non mission critical in order to guarantee their ability to withstand flight loading.

A. OpenRocket and RASAero II

Project URSA used two means of simulation for flight predictions: OpenRocket and RASAero II. Each of these programs has their own set of advantages and disadvantages. The main advantage of OpenRocket is that it allows for the placement of individual components and input of their masses to determine the rocket's center of gravity (CG). The major flaw of OpenRocket is that it uses the Barrowman equations and assumes a constant velocity of Mach 0.3 for stability calculations. However, RASAero II uses a modification of these equations which allows for accurate simulation data in the transonic and supersonic regions. RASAero II also offers many additional forms of aerodynamic data that OpenRocket fails to provide. Because of the strengths and weaknesses of each program, both were integrated into the final simulation procedure. The model was built in OpenRocket, and then the calculated total mass and CG were transferred into RASAero II. After the manufacturing of Ursa is complete, the actual mass and CG of the rocket will be measured and input into RASAero II to ensure that the data is as accurate as possible.

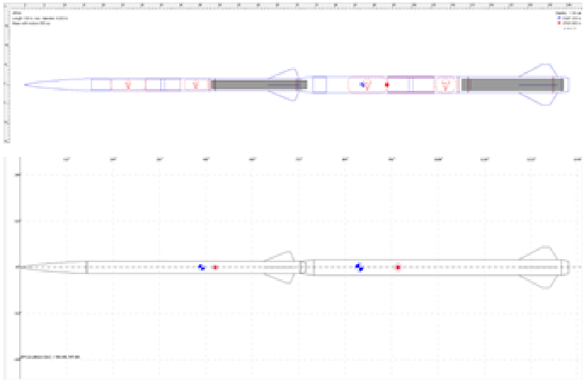


Figure 12. Simulation Examples *This OpenRocket (above) allows for input of individual components, unlike RASAero II (below).*

B. Siemens SolidEdge ST8 FEA[1]

When choosing materials for components in the load path, it is paramount to consider the loads those components will undergo. The calculated loads can then be applied to the component, either mathematically or through simulation software. Components were tested using the linear static finite element analysis feature in Solid Edge ST8. This eliminates the need for multiple subscale tests for each trade study. Rather, the part is modeled, the material is set, and the calculated load is applied to the proper face. Solid Edge then outputs a colored map of the part with a scale of loading so that the user can visualize the particular features under the most stress. The scale of loading also gave the stress values in ksi (1,000 pounds per square inch), so that they could be compared to the yield strength of the material. Figure 13 features an example output of finite element analysis on the aluminum thrust plate of the sustainer. Based on this simulation, it can be seen that the yield strength of the aluminum is over 10 times greater than the max load undertaken by this part. Multiple analyses like Fig. 13 were used to quickly ensure material choices could handle the forces of flight. Components tested with FEA include the thrust plates, bulkheads, and staging mechanism.

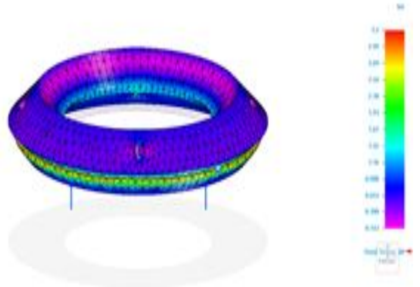


Figure 13. Thrust Plate FEA[1] *SolidEdge FEA was used to analyze any components taking significant load from the motor or drag.*

VI. Manufacturing

In order to properly meet the requirements for Project URSA, much of the rocket's parts will be custom designed, manufactured, and assembled by the members of the team. As the rocket is currently designed, the majority of its parts are not commercially available within the high-powered rocketry community. Many of the unique pieces such as the motor retention system and the stage transition contain complex geometries and functions which make the parts difficult to produce. In order to manufacture the parts required for Ursa, the team shall take advantage of UAH's facilities which allow for students to partake in CNC machining and additive manufacturing.

Figure 15. Haas VF-1 *The Haas VF-1 in the UAH MAE EDFP is used to manufacture all CNC milled parts for Project URSA.*

A. CNC Machining

The majority of the machining for Project URSA will take place within The UAH MAE Engineering Design and Prototyping Facility (EDPF). The EDPF is home to numerous lathes, mills, band saws and drill presses, as well as Computer Numerical Control (CNC) machining systems and 3D printers. Due to the complex geometries required for some parts of the rocket, much of the machining will take place on the CNC mill and lathe available in the EDPF. The mill being used for a majority of the machined parts is a Haas VF-1. The VF-1 will be used to manufacture the thrust plates, bulkheads, centering rings, and forward motor retainers. The aluminum nose cone tip will be machined and tapped using the CNC lathe.

B. Additive Manufacturing

The remainder of the rocket's custom parts will be additively manufactured rather than machined. The UAH EDPF is equipped with a Stratasys Fortus 360mc/400mc which is a fused deposition modeling 3D printer capable of printing with a variety of materials including ABS and polycarbonate. The printer is capable of printing within a 14 in x 10 in x 10 in build volume with a minimum build resolution of 0.005 in. The rocket parts which will be 3D printed include the avionics sleds, transition section, upper and lower fin brackets, and upper and lower boat tails.

C. Assembly

Due to the magnitude of the forces during flight, all components are assembled mechanically, rather than friction fitted or epoxied. This begins in the nose cone, where a threaded rod connects the nose tip to the bulkhead. The couplers operate by the same principal, with two threaded rods running from bulkhead to bulkhead. Fin brackets are secured to the body tube using 10 binding posts per bracket for the booster and 8 for the sustainer. The fins are then secured into the brackets with 5 binding posts per fin for the booster and 4 binding posts per fin for the sustainer. Centering rings and retention bulkheads have threaded holes with bolts inserted through the body tubes. Boat tails and thrust plates are connected by vertical bolts running downward from the aft centering ring into threaded holes in the boat tail. The motors use a forward retention system, with an eye bolt running through the retention bulkhead into the threaded forward motor closure. This allows each motor to slide into the back of its respective stage without removing any components. Body tube sections are connected to the coupler by nylon screws, varying in strength based on ejection charges and order of separation.

Figure 14. Stratasys 3D Printer *The UAH MAE EDFP is equipped with this 3D printer, which will be used for all additive manufacturing.*

VII. Future

Project URSA began in November 2016 and will continue through September 2017. However, due to airspace restrictions, the project will be on hiatus from April 2017 to the final flight in September, having finished all construction and testing. Additionally, after the project ends, all team members plan to use the experience gained in Project URSA to advance Space Hardware Club rocketry through more innovative projects.

A. Testing

Before reaching the flight line, the rocket will undergo rigorous testing on the ground. One of the most high risk failure points is the connection point between the fins and body tubes. This part, along with couplers and staging mechanism will be tested under the loads that will be applied during flight with a factor of safety between 1.5 and 2.5. Additionally, because the sustainer drogue bay must maintain atmospheric pressure until its apogee at approximately 30,000 feet, the pressure differential may cause premature separation. To mitigate this risk, the rocket will be tested in the pressure chamber at the UAH Propulsion Research Center. Finally, the last ground tests will involve black powder charge testing. All four recovery bays will be tested using the same black powder charges that will be used during flight. However, the most important charge test will be in the staging mechanism. Using a mass to simulate the forces exerted by the upper stage during separation, a black powder charge will be ignited in the transition piece to ensure it will not be damaged during flight.

In addition to the ground testing, both stages of Ursa will be tested individually. First, the sustainer will be flown alone because it uses the lowest impulse motor, so it is the lowest risk in case of failure. Furthermore, in the second flight, the rocket will be flown as a boosted dart, so the sustainer must be in flyable condition. For this second test, the booster will fly with the same motor that will be used in the final flight, validating the lower stage completely. However, the motor in the upper stage will be replaced with ballast, allowing for separation testing while staying within the range of the FAA waiver.

B. Flight

Flight testing will occur in March and April in Talladega, Alabama, where the FAA flight waiver limits rockets to apogees below 18,000 feet. The final flight will occur on September 3rd, 2017 at the Kloudbusters Airfest in Argonia, Kansas, where a 50,000 feet AGL flight waiver will be in effect.

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