Experimental Sounding Rocket: *Sonic Eagle*

8th Intercollegiate Rocket Engineering Competition, Green River, UT, June 22, 2013

Experimental Sounding Rocket Association, Logan, UT

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Objective: Win the advanced category at the 8th IREC

Abstract

Rocket science has progressed greatly from its early development in the 1200's. Our research consists of the design, fabrication, launch, and recovery of a supersonic experimental sounding rocket with a target apogee of 25,000 feet above ground level. The configuration of the rocket will consist of a booster stage with a second stage, designed to carry a ten pound payload. Research has been conducted to mitigate trajectory failures, prevent structural damage, and locate the system after impact using BeeLine GPS. An onboard data acquisition computer will acquire data including; altitude, velocity, acceleration, and other important statistics. Data measured will be used to validate computational models that are designed to predict the rocket's trajectory. These models are based on Newton's Laws in two dimensions which include velocity, mass, and altitude as a function of time. A test rocket has been used to begin the validation of the computational programs and to also verify design specifications of the final rocket.

Background

The Experimental Sounding Rocket Association(ESRA) is dedicated to advancing aerospace engineering education. They sponsor the Intercollegiate Rocket Engineering Competitions (IREC) in which all competitors build and fly sounding rockets. The emphasis of the competition is student design and construction of as many parts of rocket as possible. The objective is design, build and launch a rocket with 10-lbs minimum payload closes to 25,000 ft above ground level. Rocket must reach at least 12,500 ft but not exceed 27,000 feet, must carry an altimeter to record apogee, mst be recoverable and descent velocity shall be between 75 and 150 ft/s. Testing of recovery system, avionics, GPS and trajectory simulation validation shall be conducted prior to competition.

Design

The rocket consists of a booster and a second stage. Many constraints and parameters must be considered to successfully satisfy these requirements. The controlling factor of the booster stage design dimensions is the rocket motor. In order to reach our target apogee of 25,000 feet, the rocket will be propelled by rocket motor of impulse class O-3400, where its total impulse is 4734.92 lbs*sec. Similarly, many constraints must be considered when designing the second stage inside and outside diameters. Minimizing the outside diameter will reduce drag, but the inside diameter must be adequate to house the electronic components and parachute. An impulse class I-242 motor was chosen for the second stage, and its total impulse is 123.24 lbs.*sec. During its trajectory the rocket undergoes heavy acceleration loads; therefore the airframe will need to have longerons. During burn time damage is induced on the airframe, so a thermal shield has been designed to protect the airframe during burn time at the interstage. The Converging portion of the interstage also allows for optimized stress distribution to prevent stress concentrations on the airframe.

Once an appropriate design was established the separation criteria was analyzed. The separation of the first and second stage occurs solely on drag variation. The drag/ mass ratio for each stage were analyzed to confirm the occurrence of separation. Figures 1 and 2 show the complete inboard profile of the first and second stage, with a description of what is in each bay. The weight budget is shown on Table 1.

The nose cone of the second stage was designed in order to fulfill the aerodynamic requirements, the drag separation criteria, and the payload requirement of ten pounds. The Sears-Haack geometry was chosen for its ideal design for a "Mach-breaking" nose cone.

Once the design of the rocket was completed, the rocket's total weight and drag was calculated and a simulation of the rocket's flight trajectory was generated to confirm the design. Figures 3-6 show the resulting ideal trajectory simulation for the *Sonic Eagle*. In order to obtain a stable trajectory of the rocket during flight, an appropriate static margin was ensured. A rocket can stray away from its intended vertical path during flight if the static margin is not adequate. Table 2 shows the calculated static margin for the *Sonic Eagle*

Inboard Profiles of the Booster Stage and Second Stage

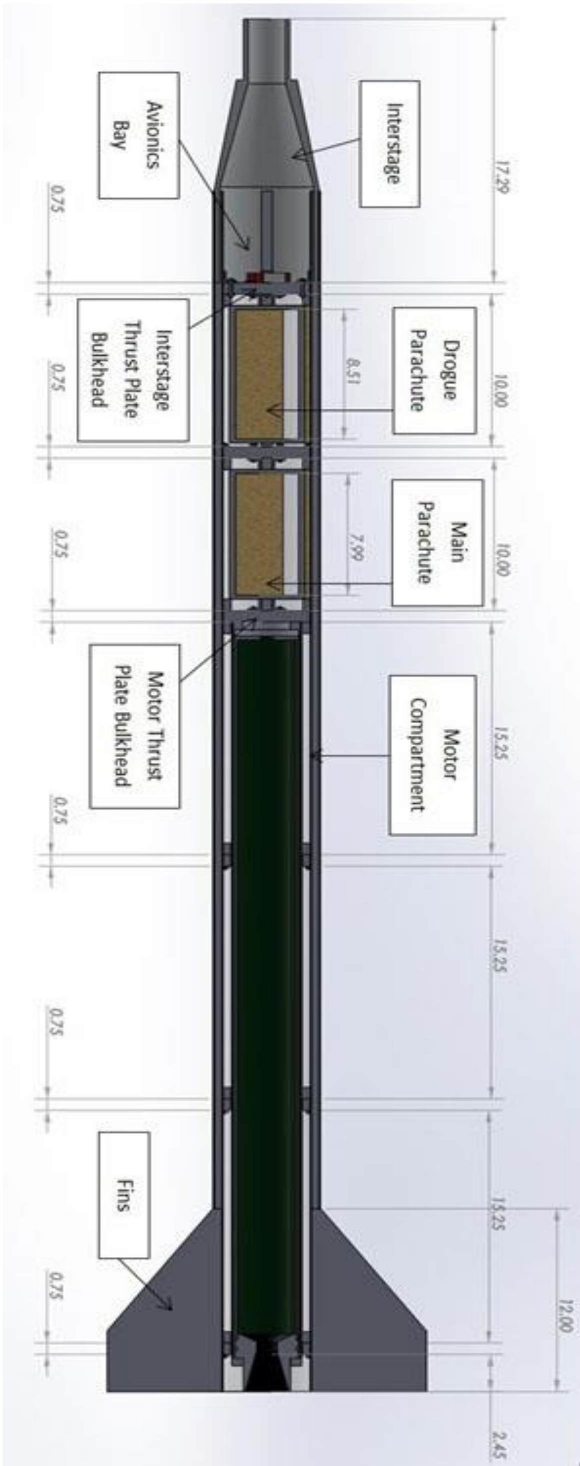

Figure 1: Booster Stage

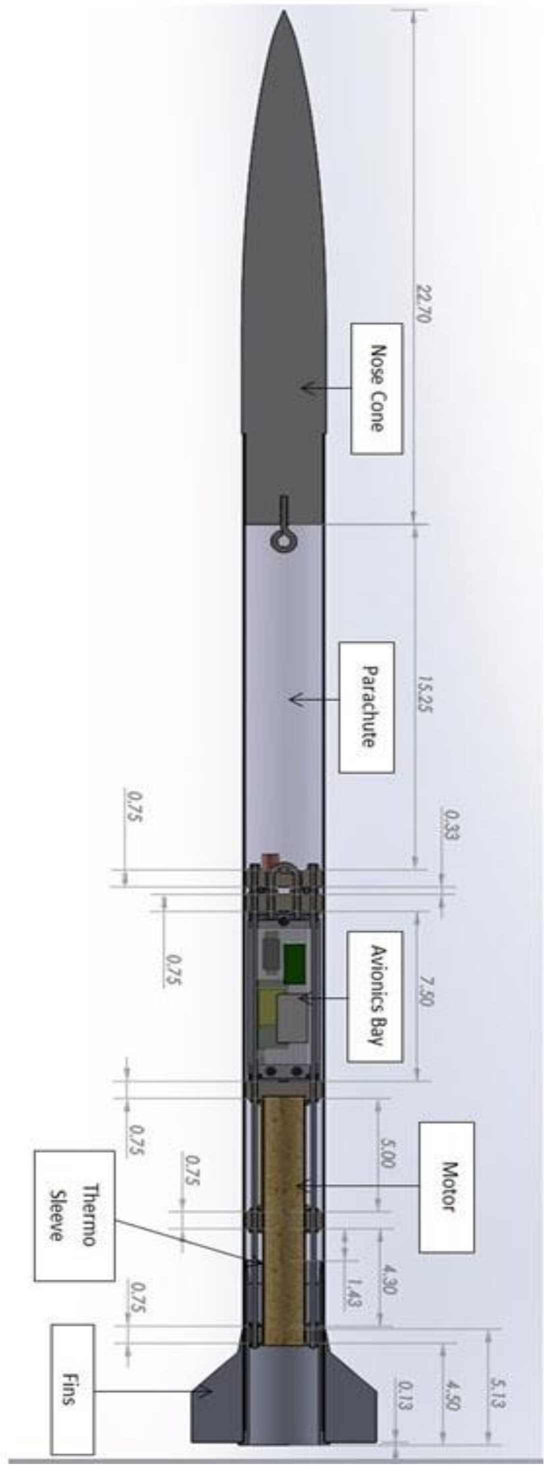

Figure 2: Second Stage

Trajectory Simulation
A simulation of the trajectory has been done to show the local altitude, range, Mach number and dynamic pressure versus time for the Sonic Eagle.

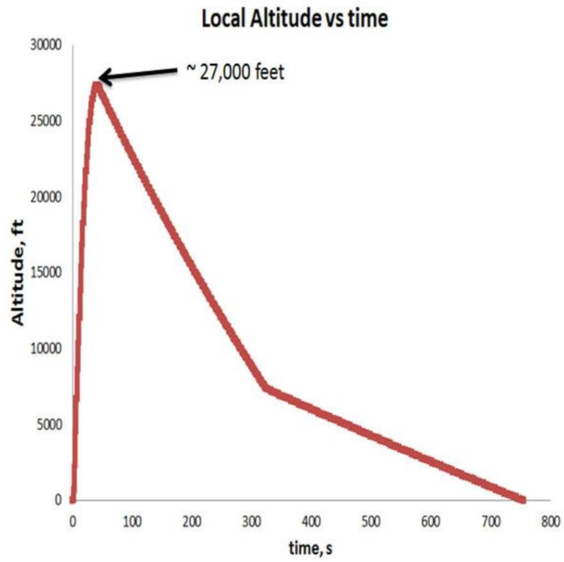

Figure 3: Local Altidude vs. Time

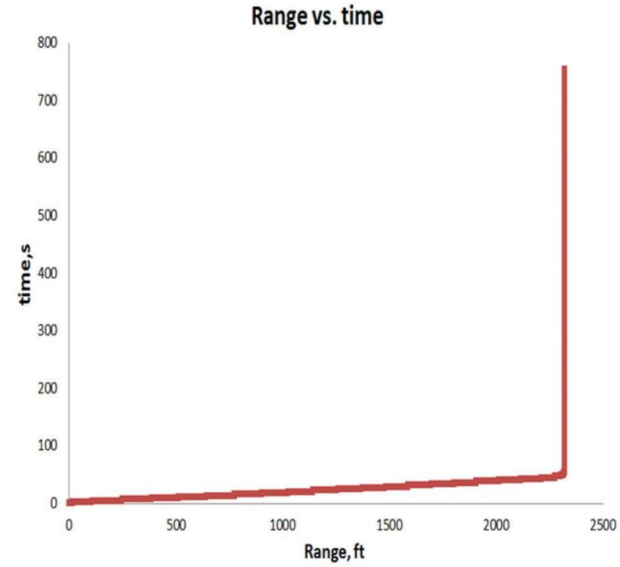

Figure 4: Time vs. Range

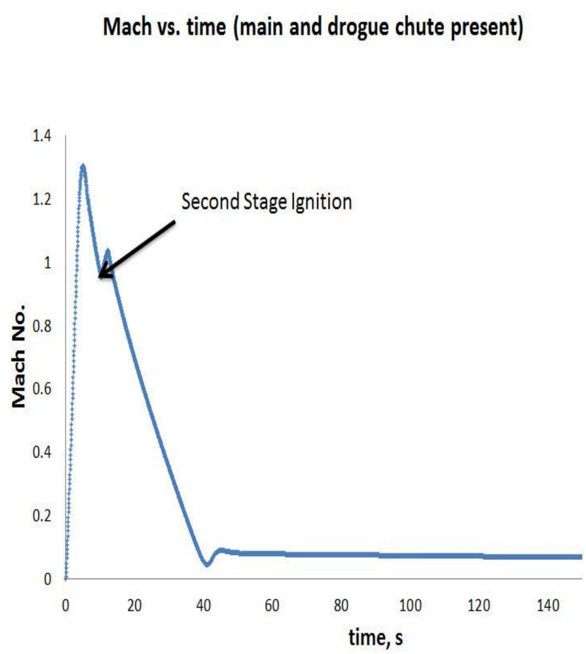

Figure 5: Mach number vs. time

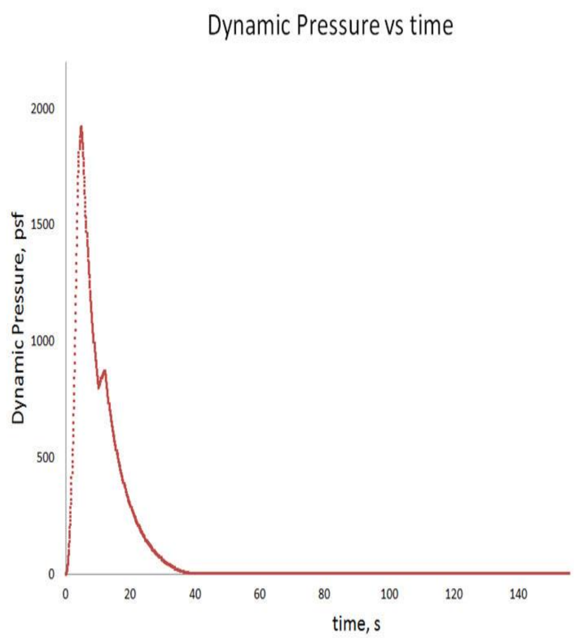

Figure 6: Dynamic Pressure vs. time

Table 1: Weight Budget

	Stage 2 (lbs)	Stage 1 (lbs)	Composite lbs (both stages)
Payload	13.4	0	13.4
Parachutes	1.41	6.72	8.13
Avionics	1.25	1.15	2.40
Structure with fins	1.13	11.18	12.31
Motor Case	0.54	12.34	12.88
Propellant	0.67	24.09	24.76
Total	18.40	55.48	73.88

Table 2: Static Margin

Event	Location during Flight in feet	calibers	inches
Stage 1 at near the ground	400	2.8	17.24
Stage 1 at burn out	6000	5.032	30.59
Stage 2 after Stage 1 burnout	6100	5.3	18.5
Stage 2 at Stage 2 Burn out	16870	5.75	20.15
Stage 2 near apogee	26100	5.5	19.25

Electronics

The Raven3 flight computer has been chosen for this rocket. It contains 4 pyro outputs that start different events, shown in figure 8. One of the events will be parachute deployment. Parachute deployment will use black powder ignited by a Raven3 flight computer system interfaced to a barometric sensor that approximates altitude. The ejection charge will be triggered by a predetermined altitude from our analysis using our trajectory program SKYAERO. Figure 7 shows the rocket without the casing, where the GPS, barometric sensor and Raven3 flight computer will be located at, the blasting caps will contain black powder that will be ignited to eject parachute, and finally the motor housing encloses the motor casing.

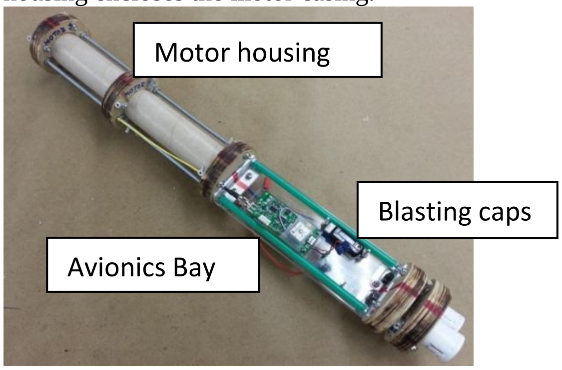

Figure 7: Second Stage rocket without skin

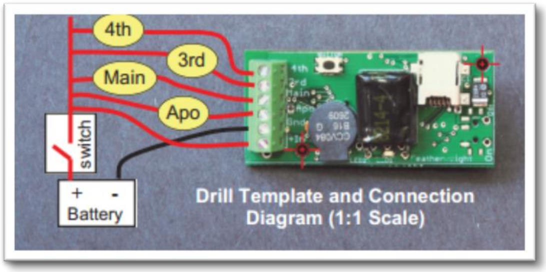

Figure 8: Raven Flight Computer

Recovery Approach

Booster Stage Parachutes:

The booster stage uses a two parachute recovery system. Shortly after apogee, a pyrotechnic charge will be ignited, via the onboard flight computer, to deploy the drogue parachute. This parachute is designed to maintain a descent velocity of approximately 70-100 ft/s. A fast descent velocity is desired as it will minimize lateral drifting and prevent the booster from being blown far down range. At about 1,000 ft. above ground level, another charge will be set off releasing the main parachute. The drogue parachute will act as a pilot parachute and pull the main parachute from its compartment. The main parachute is designed to decrease the rate of descent to around 20 ft/s. giving the booster a lower impact velocity to minimize risk of impact damage to the airframe.

Second Stage Parachute:

The second stage utilizes a single parachute; however, this parachute will serve a dual purpose. In addition to controlling descent, the parachute may also be used to control apogee. Should on-board telemetry indicate that the dart will surpass its desired 25,000 ft. apogee, the parachute will be deployed on ascent to reduce its climb velocity to achieve the desired target apogee as precisely as possible. Similar to the booster stage, this parachute will also use a two-event system to control rate of descent. A reef cord will be used to restrict the maximum inflation of the parachute under its initial descent such that the rate of descent is nearly 100 ft/s. At a predetermined low altitude, a second pyrotechnic charge will be ignited to sever the reef cord allowing the parachute to fully inflate and reduce the rate of descent to approximately 20 ft/s., which will allow for a safe landing, minimizing the risk of damage to the vehicle.

GPS system:

The BeeLine GPS utilize the 70cm amateur radio band at 420-450 MHz HAM radio with a power output of 100mw. The expected range is about 40 miles. Because of the frequencies the tracker uses a HAM license was required to operate the system. We were able to obtain an amateur radio license with a call sign of KK6BQS. This is then programed into the BeeLine GPS, which will transmit an industry standard Automatic Packet Reporting System (APRS) packets. The APRS packet contains position/object/item which contains the latitude and longitude of the rocket. A sound card in a laptop will then be used to decode the data packet using the AGW Tracker. A cable to connect the stereo output of a handheld radio to a mono input of a microphone in a computer was then created to receive the packets from the radio to the computer. Once the packet is decoded the call sign with latitude and longitude of the rocket location will be displayed.

Figure 9: BeeLine GPS

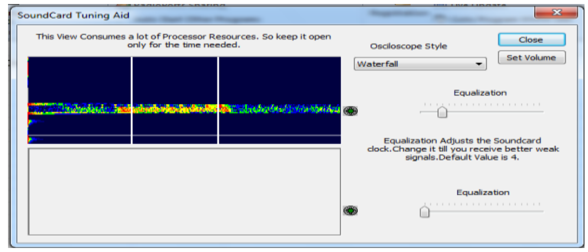

Figure 10: Sound card decodes data

Wind Compensation

The primary focus for implementation of the wind measurement system is for the reduction of risk. Knowing the wind speed and direction will allow for a more accurate prediction of trajectory throughout the duration of flight and the impact location, making recovery of the rocket easier. The wind measurement system consists of a 3 foot diameter tether pilot balloon (pibal), a winch system to retain, retract and measure tether length, and sensor optics, shown on figure 11. A balloon template is used to control balloon dimensions so that measurements will be accurate and consistent with calculations. The balloon drag increases monotonically with wind speed in the rocket operating regime, from about 0 to 25 ft/s. Using the winch, pibal altitude can be calculated. The weights of the empty balloon can be measured and the weight of the gas enclosed as well as the weight of the tether line can be calculated. Lastly the elevation angle and azimuth angle can be measured by using the sensor optics. Once all these values are known, the wind velocity can then be determined. The wind velocity will be calculated at low and high altitudes, and then will be broken into in-plane and cross-plane winds. A wind profile will then be generated using this data and input into the trajectory simulation program SKYAERO. The impact point displacement caused by in-plane and cross-plane winds can then be found, and the proper launcher elevation angle and azimuth angle will be calculated to compensate for the displacements caused by the wind.

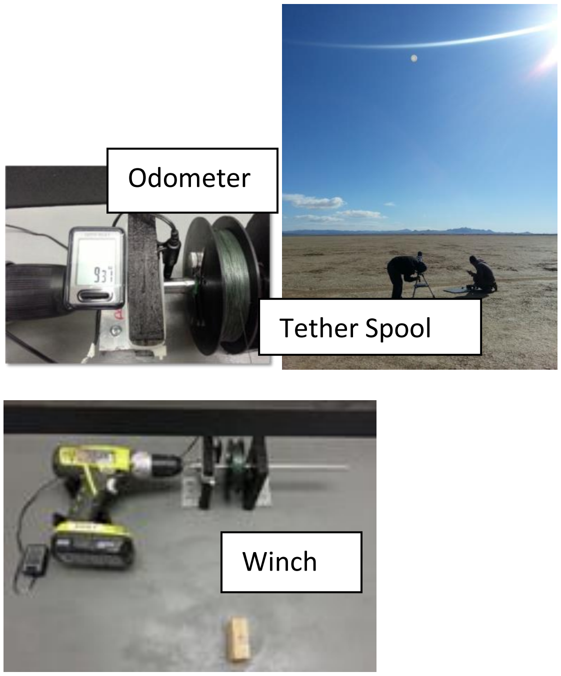

Figure 11: Wind Compensation System

Testing

In order to have a succesful flight in the competition testing was done to verify every design aspect prior to its implementation. These tests include both ground tests and flight tests. Before starting the design of the rocket, testing was done on a test and training (T&T) rocket. The T&T rocket was launched with an altimeter on board and the actual results were compared to the simulation software results. After multiple flights the simulation software was validated to work and ready to use for the actual rocket. Other tests that were done on the T&T rocket included venting, stability, avionices tests and field rehearsal. These tests prepared the team to begin the actual design of the rocket and its different componets.

Tests were also done for the full scale second stage rocket. These tests included avionics, ejection/deployment, full functionality of the rocket, and procedures. One test was the flight computer system ground test. The logic and conductivity was tested, and ground simulation was used to validate the e-match functionality. An e-match igniter was inserted inside a smoke trail, and if the flight computer is working it will send a signal to the e-match and ignite the smoke trail. The test was succesful. The ejection of the second stage parachute was also tested. There were some testing failures in this realm, involving the parachute burning up as well as no parachute ejection at all. These failures lead to a stronger design of the parachute ejection mechanism, and better parachute packing for smoother ejection and to protect it against getting burned. After several modifications the parachute ejection was succesful and the design was finalized. The dis-reefing mechanism was also ground tested to ensure that it will cut the line and dis-reef the second stage parachute, a successful test. Full functionality of the second stage was performed when an actual flight test was performed. The outcomes of the test were that the second stage design was verified, safe launch operations were performed, and field preparedness was enhanced. The GPS system has also been tested on the ground, the the T&T rocket and on the second stage rocket and has proved succesful.

Conclusion

The *Sonic Eagle* is ready to win in the 8th Intercollegiate Rocket Engineering Competition this June. The design has been fully finalized and manufactured after many analyses, including: stress analysis, trajectory simulations, drag analysis, trade studies between different designs, and testing. After multiple test launches it has been concluded that the actual apogee is always less than the simulated one because real conditions are never ideal. Motors have been chosen accordingly to achieve a higher apogee than desired, with the current simulated apogee at 27,000 feet. The actual apogee is expected to be less than this number, and closer to the desired apogee of 25,000 feet.

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