Flight Readiness Report

Rocket Team

University of Minnesota - Twin Cities

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Table of Contents:

Design Summary

To meet the "active drag" design challenge and objective of the Space Grant Midwest High-Power Rocketry Competition, the Rocket Team at the University of Minnesota has developed a concept in which the surface of our rocket changes to vary its coefficient of drag. The rocket was designed considering all competition parameters. It attempts to test an experimental design while maintaining a safe and stable flight.

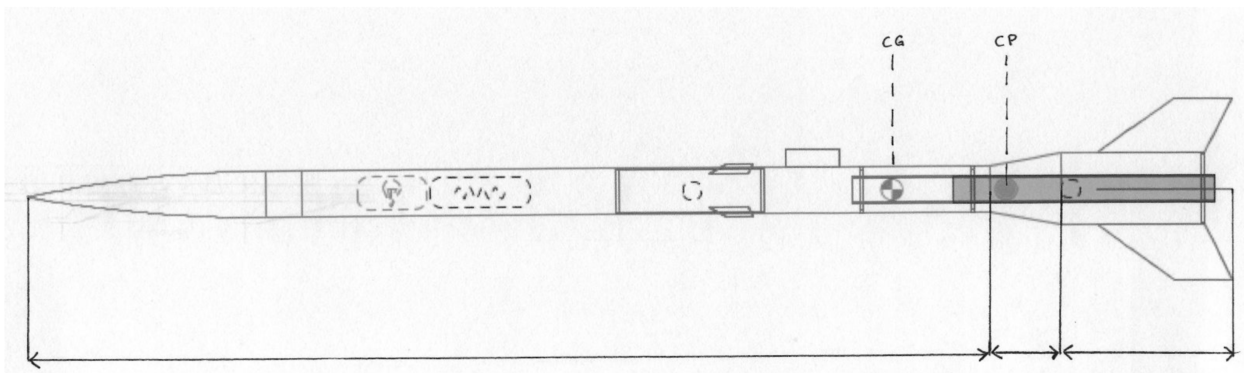
Initial airframe plans call for a 2.56-inch diameter, 3-foot long forward tube which transitions conically over a 5-inch length into a 4-inch diameter, 7-inch long "shroud" tube. The drag mechanism is a unique "salt-shaker" design in which two slotted transition pieces (each with four, evenly spaced 45-degree slots) overlap in either an open or closed state (activated by one small, high-torque servo motor) to control the flow of air through the "shroud." At the aft end of the shroud there are four slots in the airframe corresponding to the slots in the transition above, as well as a flat centering ring (referred to as "redirect plate"). It was designed so that when the transition slots are open, the rocket has a higher coefficient of drag than when the slots are closed. The rocket features a single-deploy recovery system with a 4-foot diameter parachute. It is deployed by a pyrodex charge activated at apogee by a Stratologger altimeter. To simulate the rocket's flight, OpenRocket, SolidWorks modeling, and ANSYS simulation software have been used.

The team is organized into four sub-teams which specialize in four different areas of this project. They are the Drag System, Simulation, Drag Mechanism, and Build subteams. Each is responsible for its respective area of the project, with the Build subteam being responsible for assembling all the physical parts into the completed rocket.

Airframe Design

Stability

One condition of the challenge of the Midwest competition is to maintain stability throughout flight, both with the drag system disengaged and engaged. The center of mass and center of pressure of the disengaged system are displayed in Figure 1 below. The center of mass is 46.26 inches from the tip of the nosecone and the center of pressure is 55.52 inches from the same reference point. The static margin of this state is 2.32, which is within the stated competition stability limits of 1 to 5. In the open state, the rocket becomes more stable as the center of pressure moves further from the reference point at the top of the nose cone. The static margin with the drag system engaged is approximately 2.5 (this value is limited because of the shape of the engaged drag system).



Main Body **Transition** **Shroud**

Figure 1 - Airframe Sections

Main Body Segment

The forward section of the rocket, referred to as the main body, consists of an ogive, plastic nosecone (13 inches exposed) and two 2.56-inch diameter sections of blue tube body tube (23 inches and 17 inches in length, respectively). The main body houses the parachute, avionics bay, video camera, and forward section of the motor mount tube.

The hollow nosecone fits into the forward two inches of the main body (23-inch length) and has a forged eyebolt glued to its base. The nosecone serves as the separation point for parachute deployment. It houses the recovery system in the form of a Stratologger altimeter mounted to a fiberglass sled, screw switch, nine-volt battery, and a one inch PVC endcap (ejection charges). The sled is centered by a threaded rod (permanently in the nose cone) and is secured by a removable bulkhead which screws into place at the base of the nosecone. The parachute takes up a 17-inch section of tubing and includes tubular, nylon shock cord (18 feet) and a fire retardant parachute protector (12-inch diameter).

The avionics bay (8 inches long) is made of 2.56-inch blue tube coupler tubing and contains two wooden bulkheads (¼-inch thick), two threaded rods (¼-inch diameter), a removable fiberglass sled, the drag computer, and a phenolic tube (1-inch diameter, 8 inches long). The avionics bay serves as a coupler that links the main body's two sections together. A single canard fin (0.72-inch span) is surface mounted to the body tube over the avionics bay section. It is necessary in order to mount the rocket on the launch rail because of the transitional nature of the rocket (a launch lug will be mounted to one of them).

The next section of the main body is a 5-inch section where the downward-facing camera is mounted externally to the rocket. It is housed in a 3D-printed, plastic case that screws through the main body wall into a wooden backing. The remaining length of the main body is filled by the front of the motor mount assembly (8 inches long). This section of the motor mount is supported by two centering rings: the upper is located ⅜-inch from the top of the motor mount tube, and the lower is flush with the aft end of the main body (17-inch length). Refer to Figure 2 below for detailed orientation specifics.

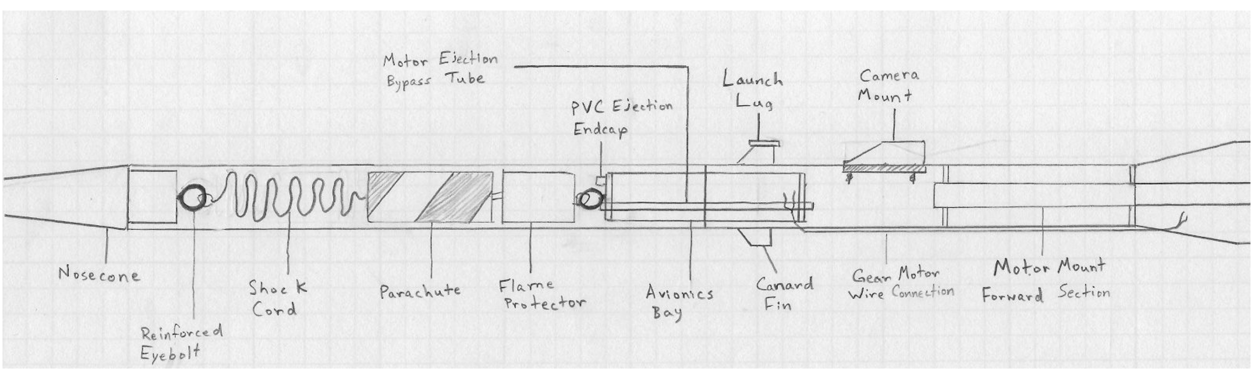


Figure 2 - Main Body Components

Transition Segment

The exposed transition section of the airframe is a conical, hollow, fiberglass, part that connects the 2.56-inch diameter airframe to the 4-inch diameter shroud. The outer transition remains stationary throughout flight and houses the moving part of the drag mechanism, the inner transition. When it reaches its 4-inch diameter, the outer transition continues for one inch, allowing a coupler connection of the transition to the shroud. The outer transition is removable to allow access to the drag mechanism between flights. During flight it is riveted in place to the shroud coupler. Four slots, each equally spaced at 45 degrees (radially) are cut ⅛-inch from its forward opening and ⅛-inch from its 4-inch base. The inner and outer transition pieces are identically slotted. The inner transition is designed so that it begins at a 2.56 inch diameter and transitions to the inner diameter of the outer transition. At this point, the inner transition is attached to an aluminum ring gear (see Figure 3) with the same outer diameter. The inner transition-gear assembly is contained by the outer transition and the rests on the shroud coupler at its base.

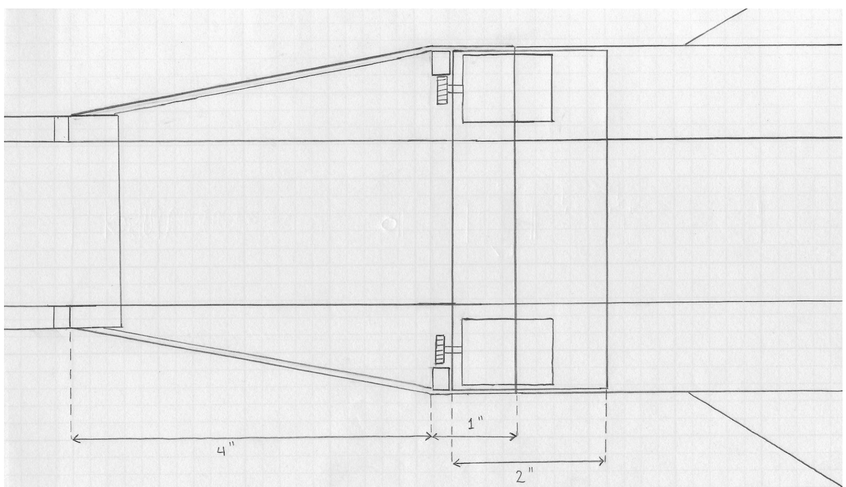


Figure 3 - Transition Schematic

Shroud Segment

The 7-inch length of shroud tube (4-inch diameter) surrounds the gear motors of the drag mechanism, the aft section of the motor mount tube, the four fins, and the "redirect plate" (a uniquely shaped rear centering ring). The shroud coupler is permanently attached to the upper first inch of the shroud. The gear motor is mounted to the inside of the shroud coupler. It fits in the 0.72 inches between the shroud coupler and motor mount.

The shroud has four 1-inch slots that run from its base up to one inch from its top. The four fins are mounted through these slots to the motor mount tube. The fins are designed so that they form four channels for air inside the shroud. At its base, the shroud has four holes cut into its side, each evenly spaced at 45 degrees and cut from the base to one inch from the base. These holes allow for air entering the shroud to escape, while the drag mechanism is engaged. The final component of the shroud section is the redirect plate, a wooden centering ring at the base of the rocket. The role of this part is to cause turbulence and increase the drag force when the mechanism is engaged relative to the drag when disengaged. This component is the most structurally critical and is described thoroughly in the Drag Mechanism Design Features section.

Avionics Bay Design

The avionics bay for this rocket is made of 2.56-inch blue tube coupler (8 inches long) and is designed so that on its aft end there is a permanent bulkhead, at its forward end has a removable bulkhead, and has two threaded rods running its length which support a fiberglass sled. The avionics bay also has a ¼-inch pvc tube running its length, which connects the section below and above the avionics bay. Holes are cut in the bulkheads for the tube, and it is permanently attached to the aft bulkhead. The purpose of this tube is to transfer the motor ejection charge gasses through the avionics bay and to the parachute section without damaging the electronic components. In the event that our Stratologger-triggered ejection charges fail, the motor ejection blast will bypass the avionics bay and eject the parachute at the nosecone separation point.

The sled houses all drag computer components in the rocket with a few exceptions. The required AltimeterTwo, siren, Stratologger altimeter, ejection charges, and radio transmitter are all stowed above the avionics bay in the parachute and nose cone sections. The gear motor, located in the drag mechanism transition piece, and the external Mobius camera are the other exceptions. The dimensions of the sled are approximately 2.3 inches by 7.75 inches. Within this area, the drag computer components (Intel Edison, accelerometer, pressure sensor, battery), Stratologger, screw switch (with wooden backing), and 9V battery will be contained.

Budget

Item	Price	Mass	Quantity	Total Cost	Total Mass
Airframe Components					
Blue Tube (2.56 inch)	$26	500 g	1	$26	500 g
Blue Tube Coupler (2.56 inch)	$9	60 g	1	$9	60 g
Blue Tube Motor Mount (38 mm)	$16	100 g	1	$16	100 g
Nose Cone (2.56" Ogive)	$11	100 g	1	$11	100 g
Shock Cord 1/2"	$25	20 g	1	$25	20 g
G-10 Fiberglass Sheet (1/8")	$20	20 g	1	$20	20 g
HAMR Motor Retainer (38 mm)	$31.95	22.7 g.	1	$32	22.7 g
Drag Computer					
Intel® Edison	$119.95	5 g	1	$120	5 g
Barometric Pressure Sensor - BMP180	$9.95	5 g	1	$10	5 g
Triple Axis Accelerometer - ADXL362	$14.95	5 g	1	$15	5 g
Break Away Headers - Straight	$1.50	2.5 g	2	$3	5 g
Snappable Protoboard	$7.95	10 g	1	$8	10 g
Jumper Wires	$1.95	5 g	1	$2	5 g
Breadboard	$5.95	20 g	1	$6	20 g
Hook-Up Wire (Stranded, 22 AWG)	$16.95	5 g	1	$17	5 g
Drag Mechanism					
Fiberglass Transition (4" to 54mm)	$59.99	200 g	2	$120.00	400 g
Gear Motor	$15	20 g	2	$30	40 g
Borrowed Parts/Already In Possession					
Fiberglass Shroud Tube (4 inch)	$0	120 g	1	$0	120 g
Main Parachute (48")	$0	65 g	1	$0	65 g
Parachute Protector	$0	25 g	1	$0	25 g
Mobius Camera	$0	39 g	1	$0	39 g
Camera Casing	$0	20 g	1	$0	20 g
Fiberglass Cloth	$0	100 g	1	$0	100 g
Cesaroni Reload Pro38 I540	$0	598.2 g	2	$0	1196.4 g
Five Grain Motor Casing	$0	163.9 g	1	$0	163.9 g
Acrylic Sheet (5 mm)	$0	50 g	1	$0	50 g
Eye Bolts	$0	22 g	2	$0	44 g
Shear Pins	$0	0.02 g	2	$0	0.04 g
Siren	$0	30 g	1	$0	30 g
Radio	$0	30 g	1	$0	30 g
Plywood	$0	60 g	1	$0	60 g
Epoxy	$0	300 g	1	$0	300 g
Stratologger Altimeter	$0	13 g	1	$0	13 g

Jolly Logic AltimeterTwo	$0	6.7 g	1	$0	6.7 g
Igniters	$0	1 g	3	$0	3 g
PVC Endcap	$0	5 g	1	$0	5 g
G-10 Fiberglass (1/8")	$0	10 g	1	$0	10 g
Threaded Rod (20")	$0	25 g	2	$0	50 g
Plastic Rivets	$0	1 g	6	$0	6 g
Launch Lug	$0	2 g	1	$0	2 g
Rail Button	$0	2.7 g	1	$0	2.7 g
Total Rocket Build Cost					$470
Total Mass					3619.44 g
Competition Fees					
Competition Attendance	$400	N/A	1	$400	N/A
Travel (estimate - TBA)	$75	N/A	2	$150	N/A
Hotel	TBA	N/A	1	TBA	N/A
Total Competition Cost					$1020

Drag System

Drag Mechanism Design

To meet the challenge of the competition, a slotted transition concept was conceived in which two motors are activated and turn a gear (attached to the inner transition) that changes the slotted transition between open and closed states. In the initial closed state, the four slots are closed and the air experiences the rocket as if it were a normal transition. In the open state, the turbulence experienced from air bouncing around within the shroud and off of the flat redirect plate cause enough difference in velocity to inspire a significant decrease in altitude.

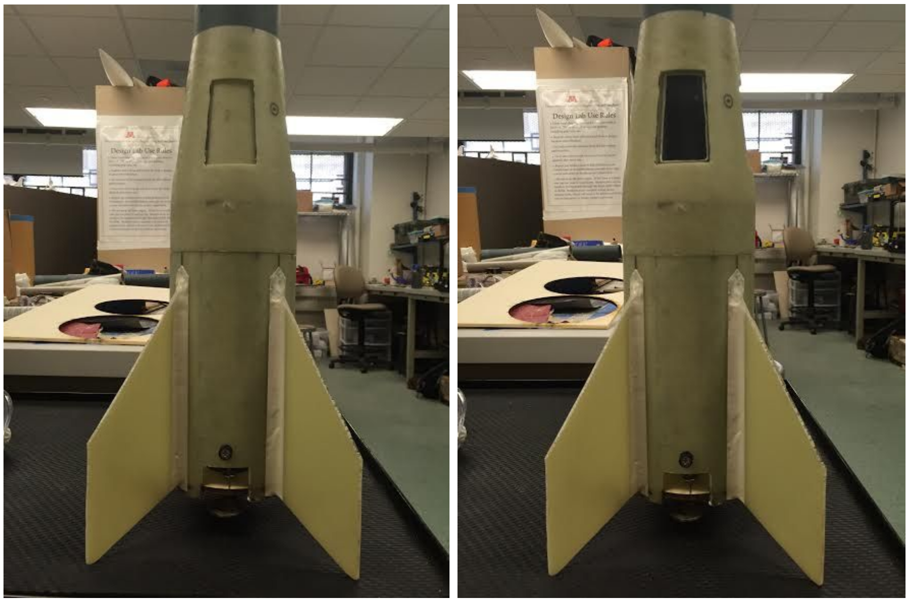


Figure - Drag system in closed (left) and open (right) states

The drag mechanism is effective because in its open (engaged) state, the coefficient of drag is significantly higher than in the closed (disengaged) state. The drag computer, housed in the avionics bay, controls this variation between the open and closed state. It utilizes a pressure sensor and accelerometer to identify airspeed and predict the rocket's apogee altitude. Based on these predictions, the drag computer will activate the drag mechanism (a small gear motor which turns a ring gear attached to the inner transition piece) until the rocket is on course for apogee at 75 percent of the initial flight's peak altitude.

To communicate between the drag computer in the avionics bay and the gear motors in the shroud coupler, wires run externally on the rocket out of a small hole in the side of the avionics bay and down through a small hole in the transition. The need for this communication was crucial in the decision that the rocket should have a single deployment system. The avionics that control the drag system could not separate without severing this connection.

Drag Computer

The drag computer will be connected to a pressure sensor and an accelerometer. SparkFun breakout boards will be used for both. The data from the pressure sensor will be used to calculate altitude, and the accelerometer will measure the acceleration of the rocket. These parameters, along with known aerodynamic properties of the rocket, will be used to calculate when the drag mechanism should be engaged and to what degree it should be open. The computer we will be using is an Intel Edison. It features the Intel Atom system on a chip, which includes a dual core CPU and a built in microcontroller. Its dimensions are $1.4 \times 1.0 \times 0.15$ inches.

The Intel Edison was chosen because it runs an embedded linux operating system, and has a small form factor. This provides multitasking, interprocess communication, a command line interface, and gives team members experience using an embedded OS. On the rocket, several tasks need to be running simultaneously. Data must be collected from each of the sensors, the drag calculation must run on each set of input data, control signals must be sent to the motor articulating the drag system, and flight data must be recorded. With a multitasking operating system, each of these tasks can be represented as concurrent separate processes. Each process can communicate using the predefined standard library for interprocess communication. This library makes use of resources provided and managed by the operating system to manage the exchange of data between processes. The operating system also provides a command line interface for interacting with the computer during tests and after flights for data retrieval. The drag computer is able to be accessed with a USB cable, and will open a terminal connected to it on another computer. Tests can then be run on the software interactively and data files can be transferred between the Edison and the computer it is connected to.

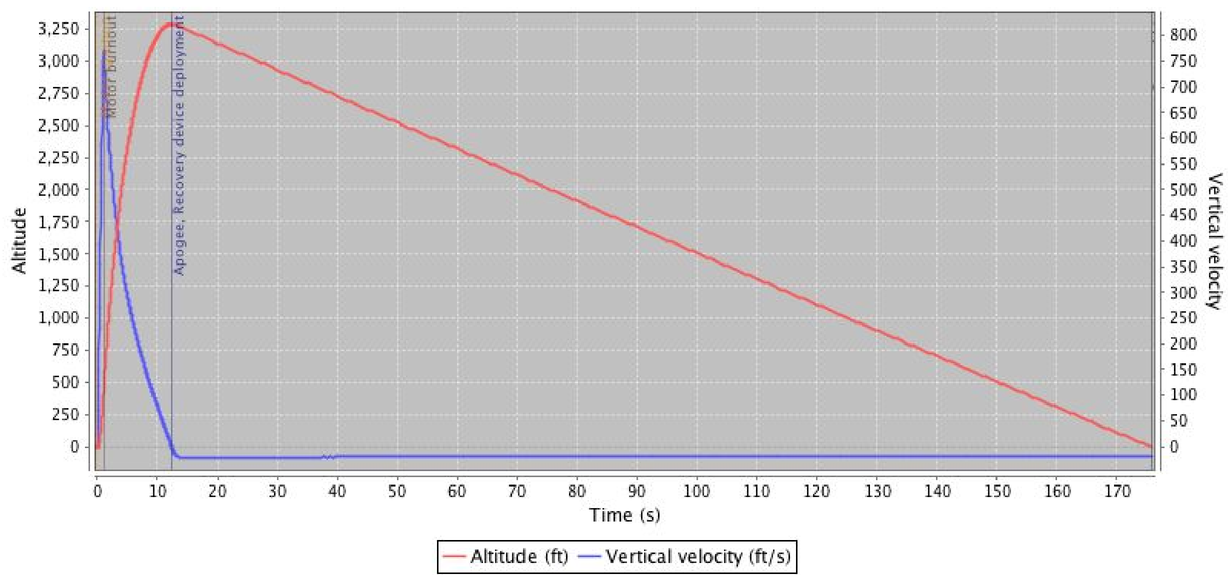
The version of linux selected is Yocto Linux, which is used in industry for embedded systems. Team members will gain experience writing multithreaded programs and using the services provided by an OS. The Intel Edison was selected as opposed to other boards running embedded linux due to its small size. The avionics bay will be a small space to build a computer, so boards such as the Raspberry Pi were ruled out based on size. The Edison also provides sufficient input and output to interact with the sensors and motors used in this project, making it an excellent choice.

Test Flight Report

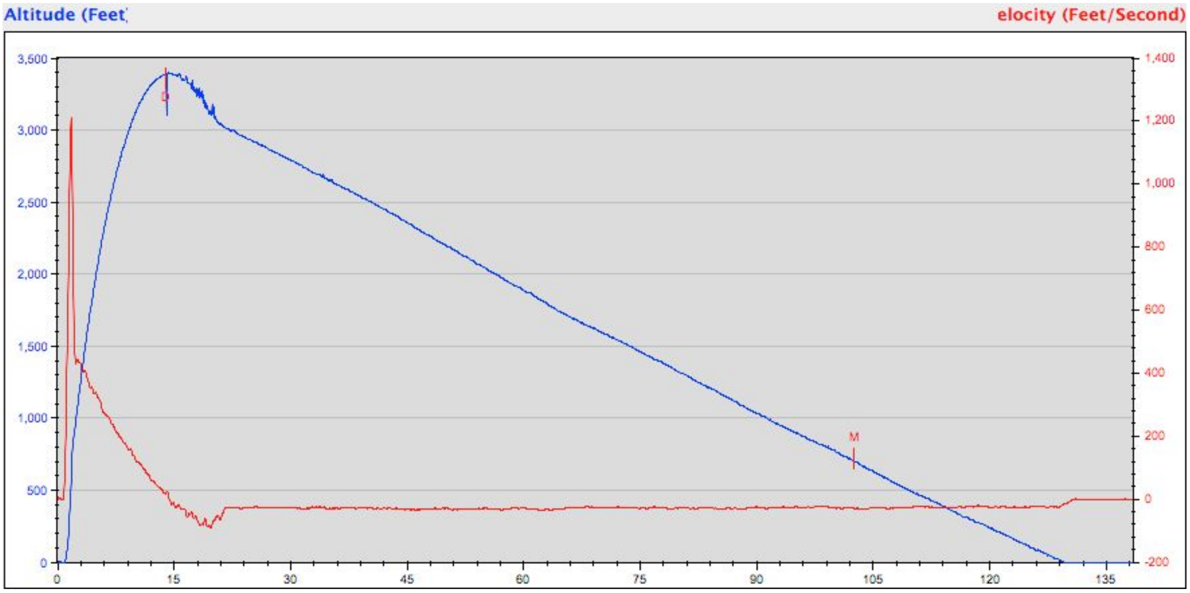
Flight Performance

The two test flights were successful and upon both recoveries the rocket was in flyable condition. For the first launch the rocket was in its closed state and reached an apogee higher than was anticipated. There was some concern that the predicted point of apogee was optimistic and that the actual point would be much lower, but the actual apogee was actually around 100 ft higher than expected.

Closed State (Predicted)
Vertical Motion vs. Time



Closed State (Actual)



In the predicted closed state, the rocket would have reached apogee at 3287 ft, cleared the launch rail at a velocity of 76 ft/s, had a maximum velocity of 794 ft/s, and descended at a velocity of 19 ft/s. The real apogee was 3394 ft and had a maximum velocity of 1200 ft/s. The error encountered is described in further detail in the discussion of results section. These values meet the requirements outlined in the competition handbook of a deactivated flight apogee of at least 3000 ft, a 6 foot long launch rail clearance of at least 45 ft/s, and a descent velocity of less than 24 ft/s.

Open State (Predicted)

Vertical Motion vs. Time

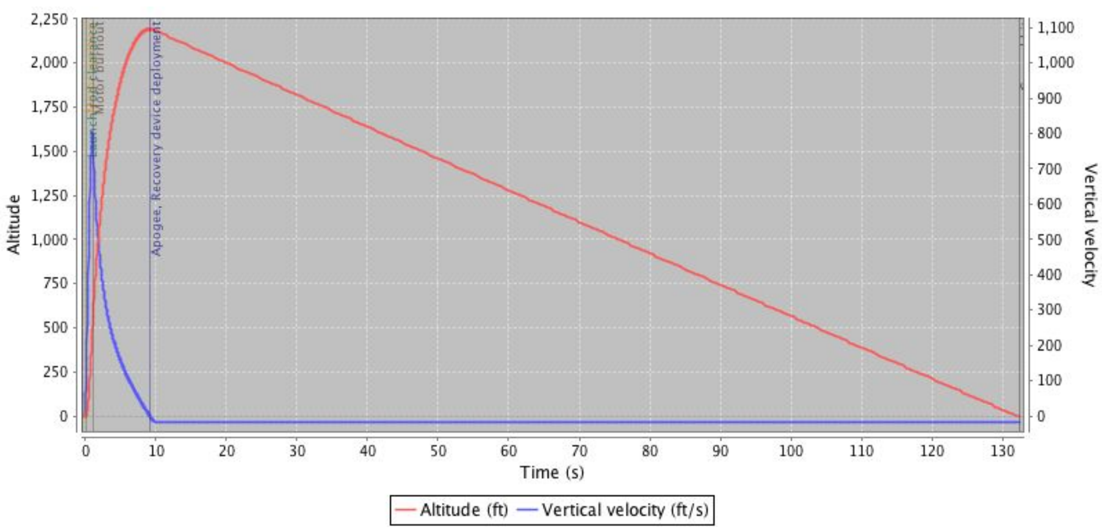
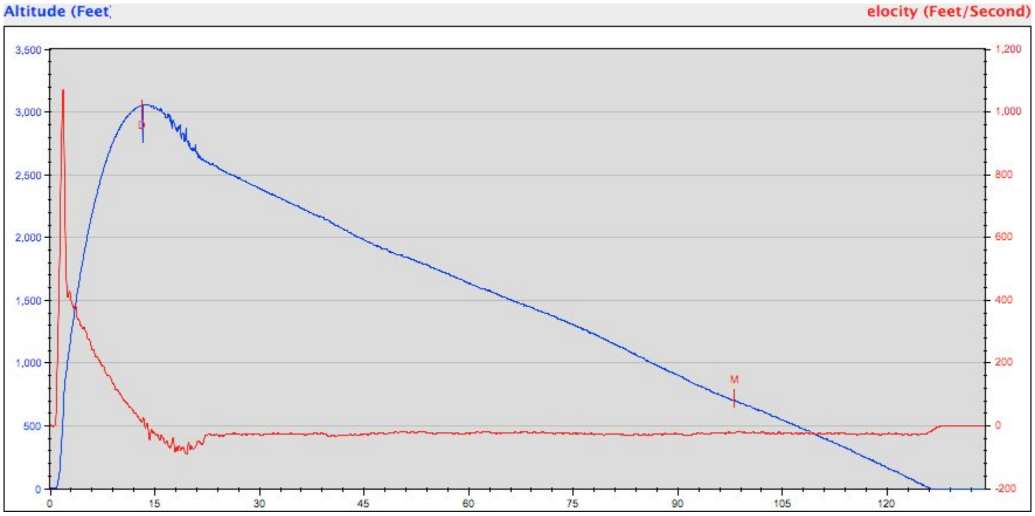


Figure 6 - Open State Flight

Open State (Actual)



The above two figures display data for the drag system engaged for the entire flight (through the boost and descent states). The predicted apogee reached in this state would be 2001 ft, the maximum velocity would be 656 ft/s, the rocket would leave the launch rail at 72 ft/s and would descend at 20 ft/s. The actual values for the open flight are an apogee of 3057 ft and a maximum velocity of 1080 ft. These values fall within the constraints laid out in the competition handbook.

Flight Characteristics

State	Mass	Motor	Apogee	Max Velocity	Descent Velocity
Closed	3266 g	I-540	3394 ft	1200 ft/s	25 ft/s
Open	3266 g	I-540	3057 ft	1080 ft/s	25 ft/s

Drag System Performance

The drag system in its completely engaged state was much less effective than expected and desired. Instead of the second flight resulting with 61 percent of the initial flights apogee as was modeled, the actual drag induced altitude reduction was to 90 percent on the second flight. This difference in result can be attributed to the limited ability of the OpenRocket simulation program to model our unique and unconventional design. Some steps are being taken before the competition launch to increase the effectiveness of the engaged state and give the rocket a better chance of hitting 75 percent of its initial apogee on its second flight (these include expanding the size of the intake slots and are described in further detail in the improvements section below). However, considering the high probability that the performance of the drag mechanism will be insufficient in achieving the desired amount of drag, the computer will be programmed to deploy the mechanism after motor burnout and retract upon apogee. This approach will give the mechanism the best shot at hitting 75 percent of the initial flight's peak altitude.

Given the availability of a third launch (our team owns an additional I-540 motor) we may choose to attempt a more practical percentage of our peak altitude. Targeting 90 percent of the initial apogee for instance, would give our drag mechanism a chance to be active as it was designed to be. Though this would not help our competition score, it would prove our design is capable of being an "active" drag system.

Recovery System Performance

As mentioned earlier, choosing a single deploy configuration for the rocket was necessary for the connection of electronic components and the drag mechanism. It also simplified mounting the video camera, but complicated accessing the avionics bay and passing the commercial motor's ejection charges through the avionics bay. To solve the problem of accessing the avionics bay, the main body was split into two sections and linked using the avionics bay coupler tube. This solution also made it easier to epoxy the motor mount to the main body and allowed for easier attachment of the camera mount's backing. The solution to the motor ejection charge problem was to install a tube that sends the pressure from the gasses to the upper parachute section. From simulations with the rocket's given mass, it was determined that a 48-inch diameter parachute would recover our rocket at a safe descent speed of approximately 20 ft/s, which is below the maximum allowable descent velocity of 24 ft/s.

Both recoveries of our rocket were deemed successful and the rocket was perfectly intact after its first launch and able to launch a second time. Descent velocity of both launches was roughly 25 ft/s, slightly above the 24 ft/s velocity stated in the competition handbook. To reduce the descent velocity the parachute size (currently 48 in) can be increased or the rocket mass can be decreased. As a significant reduction in rocket mass is unlikely, the parachute size will need to be increased slightly (the rocket's paint job will add significant mass). As can be observed from the altitude and velocity data in the “actual” launches above and as was seen in the camera footage, the rocket separated at apogee from the Stratologger triggered ejection charge, but both times, did not deploy its recovery system completely until the motor’s ejection charge ignited (at approximately 16 seconds after ignition.

Video Monitoring Performance

The downward-facing video footage was capable of recording the difference between the open and closed states of the drag system. Though the drag system did not engage during the test flight, the footage will be able to record the activation and retraction of the drag mechanism in the competition flight. The onboard video recording system also made it possible to detect the time of apogee and recovery systems.

Downward facing video from the closed state test launch.

Completed Rocket/Test Flight Photos

Left - The launching of the rocket in its open state. From the ground the rocket looked stable off of the launch rail and had a successful ignition for both of its flights.

Above - The closed state launch upon recovery. Having only descended under a main parachute, the rocket drifted nearly half a mile.

Right - An image of the drag mechanism in its open state. From this orientation the ring gear that attaches to the inner transition is visible. This prototype of the ring gear is wooden whereas the gear used for the competition flight will be made from ⅛ inch thick aluminum.

Left - Motor retention system consisting of bolts, washers, t-nuts and wingnuts.

Below - Single canard fin on the upper section of the Main Body on which is mounted the upper rail button. The span of the fin is 0.72 inches, exactly the difference in radius between the main tube and shroud tube.

Left - Prepping the closed state rocket on the launch pad by inserting the igniter into the motor.

Simulation

Flight Predictions

Flight simulations were modeled using OpenRocket. In the closed state, the rocket has a closed transition section (slots are closed). The open state was modeled using an estimate of the actual model. This is an estimate because the program is unable to model a transition piece with holes in it. Instead, four solid tubes and a flat centering ring were used to modeled the open state. This rough prediction may account for the variance of the actual difference in apogee from the predicted.

Construction

Below are the guidelines Rocket Team followed when constructing the rocket. For the sake of length, dimensions and some detailed steps are left out of this document.

- Cut body tubing to indicated lengths
- Laser cut wooden centering rings and bulkheads
- Laser cut fiberglass fins and AV bay sled
- Waterjet cut aluminum planetary gear
- Slot the transition pieces with Dremel tool
- Cut the inner transition until it fits inside the outer transition
- Slot the shroud tube for fins
- Construct motor assembly from motor mount tube and two forward centering rings
- Insert and epoxy motor assembly into the aft tube of the main body until the rear centering ring is flush with the rear body base
- Epoxy the four fins to the motor mount assembly
- Attach the shroud coupler through the first inch of the shroud
- Epoxy the shroud tube in place (to fins)
- Attach the inner transition to the planetary gear
- Seal the aft end of the shroud with the rear centering ring
- Attach the motor retention system to the aft end of the motor mount tube (taking care to not drip epoxy on the inside of the tube

- Mount the gear motor on the inside of the shroud coupler to the specified dimensions

*The remaining steps are all standard kit build procedure (involve drilling holes and sanding)

Project Deadlines

- October 1 - Notice of Intent to Compete and Space Grant "sponsorship"
- January 29 - Team Registration
- February 12 - Declaration of Competition Attendance
- March 1 - Part Order Deadline
- March 18 - Preliminary Design Review
- March 21 - Begin Building
- April 8 - Complete Building
- April 11-15 - Paint Rocket
- April 19 - College of Science and Engineering Expo
- April 24 - Practice Launch
- April 2016 - Practice Launch Deadline
- May 6 - Flight Readiness Report, Educational Outreach Form
- May 15 - Competition Day 1: Oral Presentations and Safety Checks
- May 16 - Competition Day 2: Competition Launch
- May 17 - Alternate Launch Date
- May 27 - Post-Flight Performance Evaluation and Data Collection Report

Pre-flight Checklist

- ❏ 1. Inspect all shock cord connection points.
- ❏ 2. Inspect wiring connections in the altimeter bay.
- ❏ 3. Inspect drag system wiring.
- ❏ 4. Test all battery voltages.
- ❏ 5. Insert batteries into their respective housings.

- ❏ 6. Turn on and mount Mobius camera in camera housing.
- ❏ 7. Attach PVC blast cap to the top of the altimeter bay. Ensure cap is full of black powder and is properly secured with a latex seal and electrical tape.
- ❏ 8. Connect and secure the body sections to the altimeter bay.
- ❏ 9. Ensure alignment of the top and bottom launch lugs.
- ❏ 10. Fold and insert parachute (with flame protector) into the top section of the body tube.
- ❏ 11. Activate the AltimeterTwo inside the nose cone.
- ❏ 12. Insert and secure nose cone to body tube.
- ❏ 13. Check rotation of the active drag transition section.
- ❏ 14. Install motor.
- ❏ 15. Double check CG with loaded motor.
- ❏ 16. Place rocket on the launch rod.
- ❏ 17. Arm Stratologger altimeter.
- ❏ 18. Arm AltimeterTwo.
- ❏ 19. Listen to correct beep sequence:
    - ❏ 9 short beeps (Preset 9)
    - ❏ First flight: Beep sequence for 3200 ft. (3_2_10_10)
    - ❏ Second flight: Beep sequence for 2400 ft. (2_4_10_10)
    - ❏ Long pause.
    - ❏ Beeps describing altitude of previous flight:
        - ❏ First flight altitude: ___________________
        - ❏ Second flight altitude: _________________
    - ❏ Long pause.
    - ❏ Beeps describing battery voltage as __.__ Volts.
    - ❏ Long Pause
    - ❏ A pulse of three beeps, indicating correct chute attachment.
- ❏ 20. Final visual inspection.
- ❏ 21. Pre-launch photographs.
- ❏ 22. Ready for launch.

- ❑ **Post-Flight Checklist**
- ❑ 1. Locate rocket.
- ❑ 2. Carefully inspect for structural damage.
- ❑ 3. Take a picture of the rocket.
- ❑ 4. Turn off Mobius camera.
- ❑ 5. Disassemble rocket, removing the motor.
- ❑ 6. Inspect wiring and circuitry for damage.
- ❑ 7. Retrieve and record information from the altimeters.
- ❑ For second launch:
    - ❑ Revisit the Pre-Flight Checklist.
- ❑ For final launch:
    - ❑ 1. Disarm altimeters.
    - ❑ 2. Remove camera.
    - ❑ 3. Disconnect the battery.

Outreach

Rocket Team at the University of Minnesota is not only committed to educating its members on the details of high-powered rocketry but also makes efforts to promote rocketry in general to elementary school students and all members of the community. The main outreach event of the year is the University of Minnesota College of Science and Engineering Expo. The CSE Expo is a single day event at which Rocket Team creates a promotional display booth and talks to middle school children about rockets, the physics behind them, and how they might become involved in a project of their own. This event took place on April 19th this year, and team members were be present throughout the day, showcasing the completed rocket.