BULLDOG ROCKETRY

PRELIMINARY DESIGN REPORT

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EXECUTIVE SUMMARY

The Minnesota Space Grant Consortium conducts the Space Grant Midwest High-Power Rocket Competition for teams from educational institutions across the United States. The University of Minnesota Duluth (UMD) is in its third year of competition at this event, and the Bulldog Rocketry club was founded in the fall of 2014 to ensure its participation in future competitions. Forming an official club gives the team access to additional resources and institutional support, and provides a bank of knowledge, references, and resources that can be passed on from year to year.

The Bulldog Rocketry team is designing a high-powered rocket for competition May 19th and 20th in North Branch, MN. The goals of this competition are to design a high-power, two-stage rocket consisting of an unpowered dart and booster which will drag-separate past motor burn-out and will be recovered safely and in flyable condition. The team will predict the flight performance of the rocket and will construct a non-commercial on-board data collection system to capture three-axis rotation of the dart; the team will also collect video from a downward-looking on-board camera mounted to the dart. The video and three-axis rotation data will be compared to characterize flight performance. The flights will be scored on the dart's maximum altitude and the separation between dart and booster. The team has launched a model rocket, taught 6th-12th grade students about rocketry during Engineering Day to fulfill its community outreach obligation, and will complete a test flight of the fully-functional competition rocket in advance of competition. The team has kept safety, quality, and innovation at the forefront of the design and manufacturing processes.

Bulldog Rocketry's preliminary rocket design has a 4 in. diameter booster 17.5 in. in length coupled by a custom-designed reducer to a 2.5 in. diameter dart 12.4 in. in length. The fully assembled rocket measures 45.5 inches from the tip of the nose cone to the bottom of the booster fins, and its estimated mass is 3.71 lb. The fins on the dart and booster are designed to look like bulldog legs, in honor of the mascot of the University of Minnesota Duluth. Custom parts have been designed to ensure separation of the booster and dart, and to ensure safe recovery of the entire system. The team will continue to refine and improve the design in advance of the test launch and competition.

Bulldog Rocketry has designed an avionics package to meet the requirements of the competition. The on-board data collection system is comprised of an Arduino and an Inertial Measurement Unit (IMU), which are programmed to record the three-axis rotation of the dart. Video will be collected by a small "spy cam" modified by the team; the video data and the IMU data will be compared to characterize the flight.

The team's rocket components, avionics package, and recovery system have been designed to ensure a safe and successful launch of the rocket, separation of the dart and booster, rotational data collection, and recovery of the system.

BULLDOG ROCKETRY TEAM SUMMARY

The Bulldog Rocketry team is a registered student organization comprised of students in the mechanical, industrial, and electrical engineering departments at the University of Minnesota Duluth.

Project Manager: Tyler Carlson
Airframe: Kameron Young (Lead), Amy Enrooth
Simulation: Alec Ashton (Lead)
Avionics Design: Jordan Gaytan (Lead), Chet Peterson (Lead), Tom Stinar, Josh Duellman
Safety: Adam Shearen (Lead), Bret Cuda, Kai Wang
Separation: Wilmar Tropezado (Lead)
Technical Writer: Donna Carpenter

COMPETITION PARAMETERS

Flight Mission

- Capture video and 3-axis rotational data over time from an unpowered boosted dart

Booster Recovery

- Motor ejection required, electronic ejection optional
- Parachute required
- Recovery parachute ejection is prohibited during ascent
- Non-ejection-based braking systems are allowed

Dart Recovery

- Electronic ejection required
- Dual deployment optional

Rocket Constraints

- Mounting location for competition flight recorder required for booster and dart

Model Rocket Demonstration Flight

- Purchase, assemble, fly, and recover a model rocket
- Before and after pictures of the team at the launch site required

Test Flight

- Purchase, assemble, fly, and recover fully-functional rocket prior to competition
- H-class or higher motor required

Rocket Design and Safety Reviews

- Participate in a safety review the day prior to launch.
- Present analysis of non-pre-qualified components at safety review
- Additional safety review recommended
- Rockets must pass Range Safety Officer’s Inspection on launch date

Educational Outreach

- Share information pertinent to aerospace with at least one non-rocketry group.
- Outreach must be completed by May 4th, 2015.

DESIGN CONSTRAINTS

Required Motor

- Cesaroni 475-I455-16A

Required Flight Data Recorders

- Jolly Logic "Altimeter Two"
- Required in dart and booster
- Provided by competition

SUCCESSFUL FLIGHT CHARACTERISTICS

A successful flight consists of the following elements:

- Launch
- Dart and booster separation during ascent
- Deployment of dart and booster recovery systems
- Recovery of dart and booster in flyable condition

DEMONSTRATION FLIGHT

On March 11th, 2015, Bulldog Rocketry launched an Estes Alpha rocket on the UMD campus. To ensure recovery of the rocket, a type A motor was used.

PLANNED TEST FLIGHT

Bulldog Rocketry has a planned a test flight of the fully-functional competition rocket during the competition-provided test launch in late April 2015, in North Branch, MN.

EDUCATIONAL OUTREACH

Members of Bulldog Rocketry took part in Engineering Day on October 25, 2014. Engineering Day is put on by the Swenson College of Science and Engineering at UMD for 6th-12th grade students interested in science and engineering. The team exhibited information about rocketry, displays of rockets from previous competitions, and details of the 2015 competition.

TIMELINE

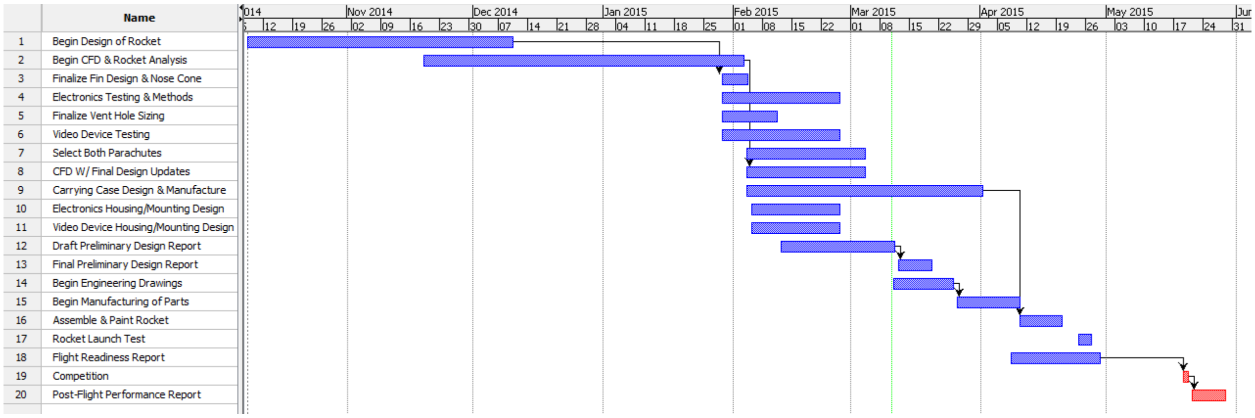


Figure 1: Timeline of major project activities

The timeline of major project activities is shown in Figure 1. Planning and design ran from October2014 – January 2015, and analysis, procurement, manufacturing, and assembly began in February 2015.

BUDGET

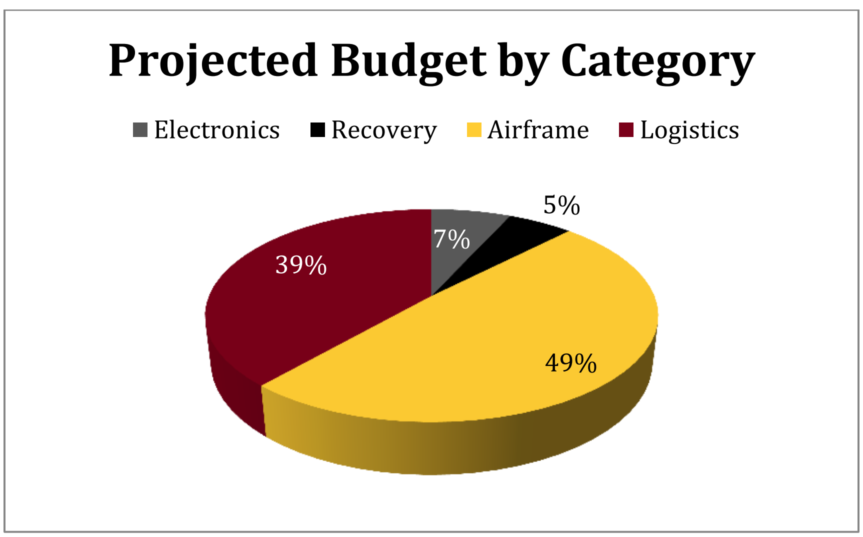


Figure 2: Projected Budget by Category

Figure 2 shows an overview of the team's budget allocation. A detailed breakdown of the budget, as well as the overall projected costs, is given in Table 1. As manufacturing and assembly of the rocket begins, costs will be updated.

Table 1: Projected Budget

Component	Category	Cost
Video Camera	Electronics	$ 9.75
Mirrors	Electronics	$ 1.89
IMU	Electronics	$ 12.95
Arduino	Electronics	$ 19.95
Stratologger	Electronics	$ 79.95
Altimeter Two	Electronics	$ 69.99
Kevlar Cord	Recovery	$ 11.04
Shock Cord	Recovery	$ 25.98
Dart Parachute	Recovery	$ 58.00
Booster Parachute	Recovery	$ 64.00
4" Blue Tube	Airframe	$ 38.95
2.56" Blue Tube	Airframe	$ 26.95
8" Blue Tube coupler	Airframe	$ 9.25
Bulkheads	Airframe	$ 11.40
Tail Cone	Airframe	$ 8.95
Centering Rings	Airframe	$ 13.90
G10 Fiberglass - Fins	Airframe	$ 9.28
Construction Materials (est.)	Airframe	$ 75.00
ABS Plastic - Nose Cone (est.)	Airframe	$ 500.00
PA802CF - Reducer (est.)	Airframe	$ 700.00
Fasteners	Airframe	$ 17.01
Registration	Logistics	$ 400.00
Lodgings	Logistics	$ 600.00
Transportation	Logistics	$ 100.00
Model Rocket Kit	Logistics	$ 7.00
Total Projected Costs		**$ 2,871.19**

ROCKET DIAGRAM

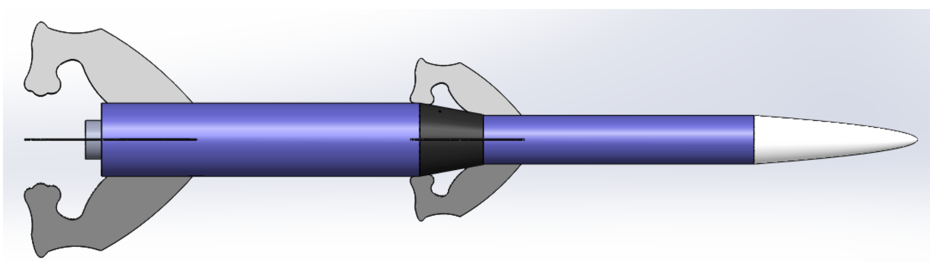


Figure 3: CAD Model of Rocket System

The preliminary rocket design has a 4 in. diameter booster, 17.5 in. long. The booster is coupled, using a custom-designed reducer, to a 2.5 in. diameter, 12.4 in. long dart. The nose cone has a power series curve profile and is 9 in. long. The fully-assembled rocket measures 45.5 in. from bottom of booster fins to nose cone tip. The system weighs 3.71 lb (1.68kg), without manufactured or yet-to-be purchased components considered.

CENTER OF PRESSURE

The center of pressure is the geometrical center of the rocket; if the rocket was translated from 3D to 2D, the center of pressure is the centroid of the 2D image. Locating the centroid of each component and the rocket system is necessary to predict the performance of the rocket. External forces act on bodies at their centroids; if the centroid is not located at the center of mass, forces acting on the rocket will create a moment, which the fins must counteract to stabilize the rocket.

The centers of pressure were located by breaking down the rocket system into components: the booster body, dart body, booster fins, dart fins, reducer, nose cone, and tail cone. The areas and centroids of each component were calculated and combined, using a weighted average calculation, to find the centroid of the entire rocket. Figure 4 shows the locations of the centers of pressure of the rocket system (E), booster (A), and dart (F). The coordinate system assumes the rocket or component is upright on its fins and the ground is Y = 0. The X and Z coordinates are constant at X = 0 and Z = 0, assuming the rocket is symmetric about its central axis.

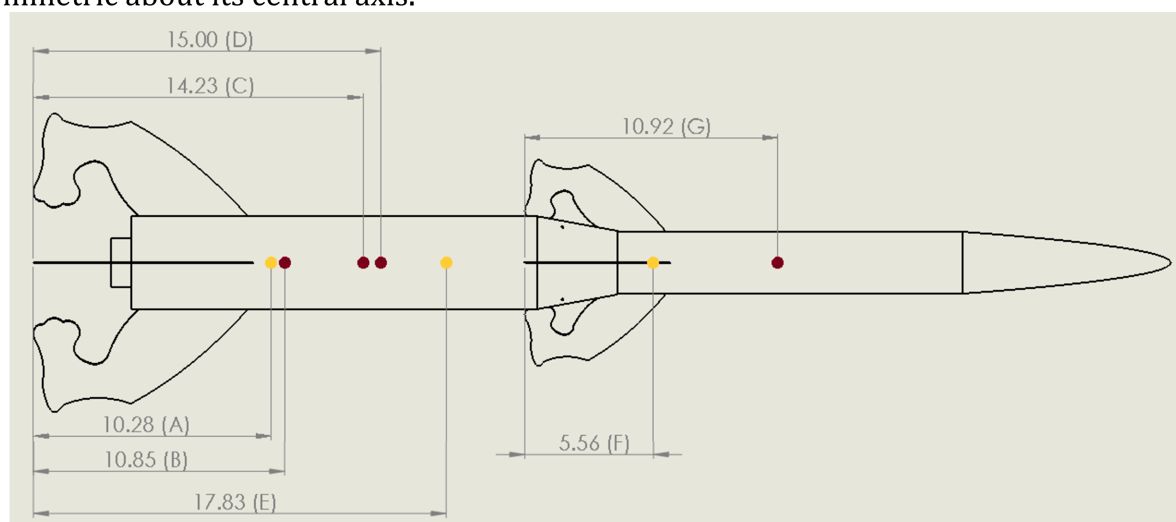


Figure 4: Centers of pressure (gold dots) and centers of gravity (maroon) (units in inches)

CENTER OF GRAVITY

The centers of gravity of the rocket system before burnout (C) and after burnout (D), the booster (B), and the dart (F) are shown in Figure 4. All measurements are referenced from the bottom of the booster fins, excepting the centers of pressure and gravity of the dart, which are referenced from the bottom of the darts fins.

During flight the rocket rotates about its center of gravity, causing the axis of symmetry and flight direction to be offset by a displacement angle. Lift and drag forces of the inclined rocket create a torque about the center of gravity. A stable rocket has its center of pressure behind its center of gravity; the torque will rotate the nose of the rocket back toward the direction of flight. An unstable rocket has its center of pressure ahead of its center of gravity; the torque increases the displacement angle between the rocket's axis of symmetry and direction of flight.

Figure 4 shows the center of pressure of the booster-dart system is ahead of its center of gravity before and after motor burnout. The preliminary design is unstable and will be refined before manufacturing to produce a stable rocket. Redesign will move the center of pressure of the system after burnout at least a booster's diameter behind the center of gravity. Reducing and redistributing the mass of the system will produce a stable rocket.

The centers of pressure of the booster and dart after separation are behind their respective centers of gravity; they will be stable after separation. To improve stability, the design will be refined so the center of pressure of each component after separation is behind its center of gravity by at least its diameter. The location of the centers of pressure and gravity once the rocket is stable will help determine the launch angle. If the final design of the rocket is overstable (where the center of pressure is well behind the center of gravity), then the rocket should be launched straight up regardless of wind; if the rocket is stable but not overstable, the rocket may be launched at an angle depending on the wind conditions.

DESIGN FEATURES OF ROCKET

NOSE AND TAIL CONE

The nose cone profile is a power series equation based off of the outer diameter of the body tube (D), desired nose cone length (L), and (X, Y) coordinates in a standard Cartesian plane.

$$Y(X) = \frac{D}{2} * (1 - \frac{X}{L})^{0.5}$$

The tail cone allows access to the camera mounted inside, while sealing the tail end of the dart during flight. It also creates a slipstream during separation, so the dart will begin separation from the booster immediately after the rocket begins to decelerate. The tail cone will be custom-built to achieve the unique shape. Figure 5 shows the configuration of the tail cone, nose cone, and camera mirror housing.

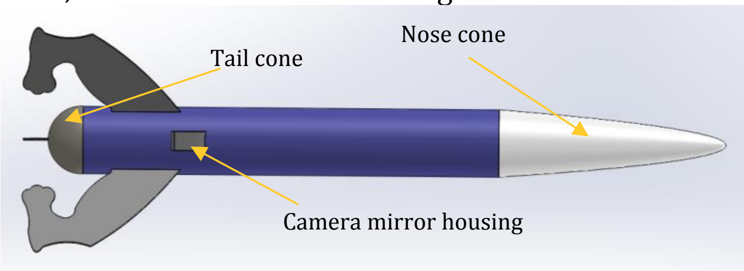


Figure 5: Overview of major features of the dart

The nose and tail cones will be 3-D printed from ABS plastic, using a filament printer. ABS plastic was chosen for its impact resistance and toughness; its MSDS and material properties are readily available. To provide support to the nose cone and to house the electronics, a nose cone insert will be designed and manufactured from the same material.

SEPARATION

A reducer will couple the dart and booster. The reducer will couple the booster's 4.0 in. diameter body tube to the dart's 2.56 in. diameter body tube. Figure 6 shows the reducer and its major features. The reducer's head has a lip, which tapers to a short face with securement holes. The lip rests on the booster's body; screws will be threaded through the body tube to the reducer's securement holes.

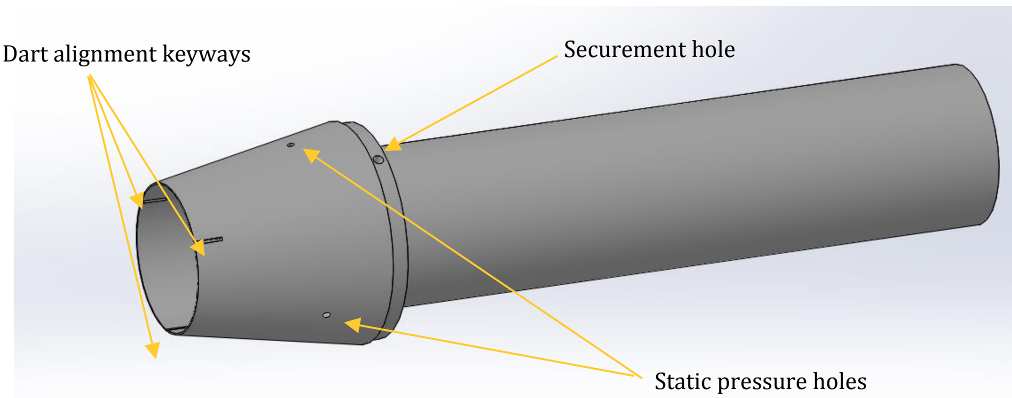


Figure 6: Major features of the reducer

Three static pressure holes on the reducer will prevent negative pressure from building up and prevent separation. The reducer has fin alignment keyways to ensure proper fin placement and prevent the dart from spinning when coupled to the booster.

The reducer will be 3-D printed from PA 802-CF to achieve its unique shape and features. PA 802-CF is a melt-mixed black carbon fiber filled with nylon 11, selected for its flame resistance, stiffness and mechanical properties, and its resistance to warping at elevated temperatures.

The reducer houses the booster's parachute and must be designed to withstand the forces from the motor ejection. Finite Element Analysis (FEA) and a physical buckling test will be conducted using Blue Tube, the material used for the body of the rocket. Once the buckling load of Blue Tube is known, a design study of the reducer will be conducted with the buckling load and the material properties of PA 802-CF. The design study will determine the optimal outer diameter of the reducer; the inner diameter is based on the dart's dimensions. A preliminary physical buckling test was conducted on Blue Tube; the buckling load was 5200 lbf. Additional physical buckling tests will be conducted to further characterize Blue Tube before the PA 802-CF design study is conducted.

FIN DESIGN

The rocket's fins were designed to look like bulldog legs to honor UMD's mascot. The fin profile, shown in Figure 7, is based on a traditional fin. The paw portion is offset from the airframe to prevent damage during motor ignition. The booster fins have a 5 in. flange and the dart fins are scaled-down versions of the booster fins with a 3.5 in. flange.

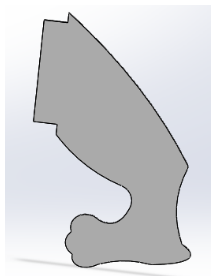
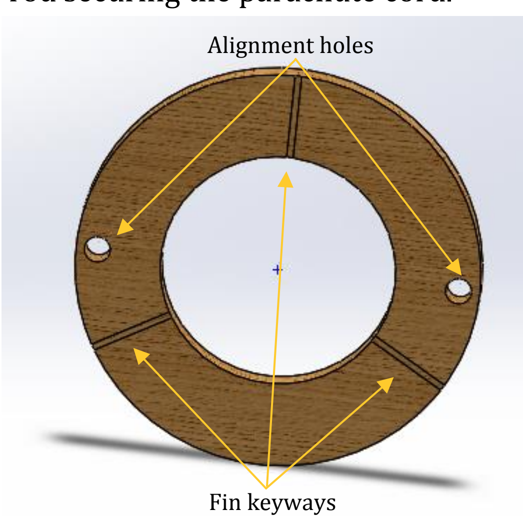


Figure 7: Fin profile

The fins are made from 1.58 mm-thick G-10 fiberglass, chosen for its strength and flame resistance. To ensure uniformity, a .DXF file of the fins was created and the fins were cut with a water jet. To avoid delamination during cutting, a 1 in. lead-in was planned.

The fins will be positioned using centering rings; keyways in the rings will increase the area of the fin epoxied to the ring. The booster's lower centering ring and the dart's centering rings will be purchased and modified as shown in Figure 8. Keyways will be machined and holes will be drilled to accommodate threaded rods used for alignment and support. The upper centering ring of the booster, shown in Figure 9, was custom-designed and will be manufactured from PA 802-CF composite using a 3D printer. The upper centering ring features keyways, a reducer channel, holes for alignment rods, and a hole for the rod securing the parachute cord.



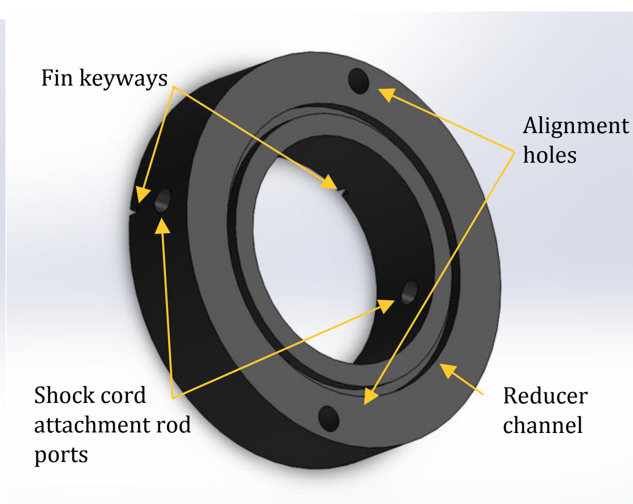


Figure 8 (left): Centering ring for dart and lower booster centering ring
Figure 9 (right): Upper centering ring

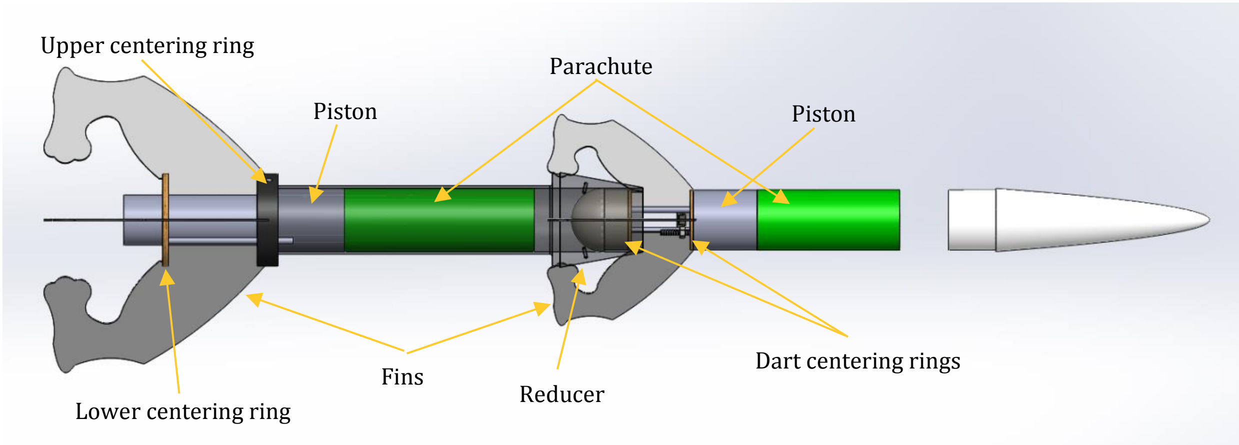


Figure 10: Breakdown of major components to the booster and dart

RECOVERY

The motor will eject the booster's parachute. To minimize the booster's mass, there will not be a secondary ejection system. The ejection blast will force the piston upward, ejecting the parachute. The Stratologger will eject the dart's parachute; the dart will also employ a piston. The pistons protect the parachutes from heat generated during ejection. The layout of the recovery systems is shown in Figure 10.

The booster has a 30 in. elliptical parachute with a descent rate of 20 ft/s for a mass of 3.2 lbm. The dart has a 24 in. elliptical parachute with a descent rating of 20 ft/s for a mass of 2.3 lbm. The slow descent rate protects the components during landing. The booster's and the dart's masses are below the chute ratings, so additional parachute options will be researched to reduce and rebalance mass.

DESIGN FEATURES OF PAYLOAD SYSTEM

AVIONICS DESIGN

The avionics package is an Arduino Pro-Micro microcontroller with an ATmega32U4 processor and a 3-axis gyro Inertial Measurement Unit (IMU). These components collect, process, and output angular rates of rotation about the X, Y, and Z axes.

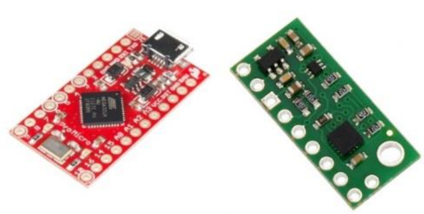


Figure 11 (left): Arduino Pro-Micro
Figure 12 (right): IMU

The Arduino board was chosen for its size and operating specifications. The system voltage is 3.3V running at 8MHz, making it compatible with the IMU, which operates below 3.6V. The IMU was chosen due to its size and compatibility with the Arduino. Its configurable options include three angular rate sensitivities, seven output data rates, and a programmable external interrupt signal. The three angular velocity readings are available through a digital interface (Arduino), which operates in I²C mode. The carrier board includes a low-dropout linear voltage regulator that provides the 3.3V required by the device, allowing the sensor to be powered from 2.5V to 5.5V. The breakout board includes a circuit that shifts the two I²C lines to the same logic voltage level as the supplied VIN, so the board can interface with 5V systems.

The Arduino reads data from the IMU through an I²C connection made by wiring the devices together. Figure 13 shows the carrier board schematic for the IMU. The Arduino is powered by a 5V LiPo battery wired to the RAW pin, which regulates the supplied voltage down to the 3.3V needed to operate the IMU. The battery is wired directly to the VIN pin on the IMU instead of directing voltage from the Arduino to the IMU. This ensures a constant voltage will be supplied to the IMU if the Arduino fails to power the IMU. The IMU and the Arduino are also connected at each GND pin.

The connection between the IMU and the Arduino was established using I²C mode. At least two logic connections are required to use the IMU in I²C mode: SCL and SDA. These pins are connected to built-in level-shifters making them safe to use over the input voltage range of the IMU; they are connected to an I²C bus operating at the same logic level as VIN.

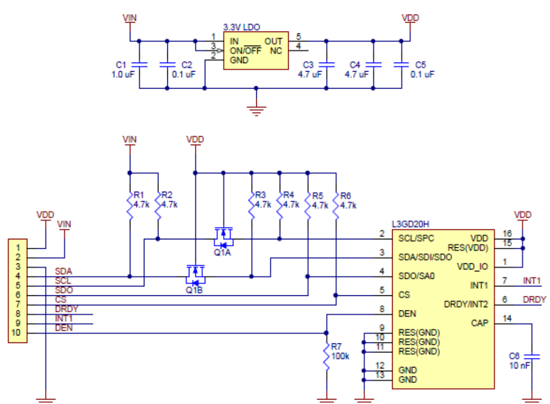


Figure 13: Schematic of Carrier Board on IMU

With the CS pin in its default state (pulled up to VDD), the IMU can be configured and its angular velocity readings can be queried through the I²C bus. In I²C mode, the gyro's 7-bit slave address has its least significant bit determined by the voltage on the SDO pin. The carrier board pulls SDO to VDD through the use of a 4.7kΩ pull-up resistor connecting the I²C lines of the devices, making the least significant bit 1 and setting the slave address to 1101011b by default. The Arduino uses pins 2 and 3 as the SDA and SCL I²C communication lines and the Arduino has its own labeled pins for its SDA and SCL communication lines.

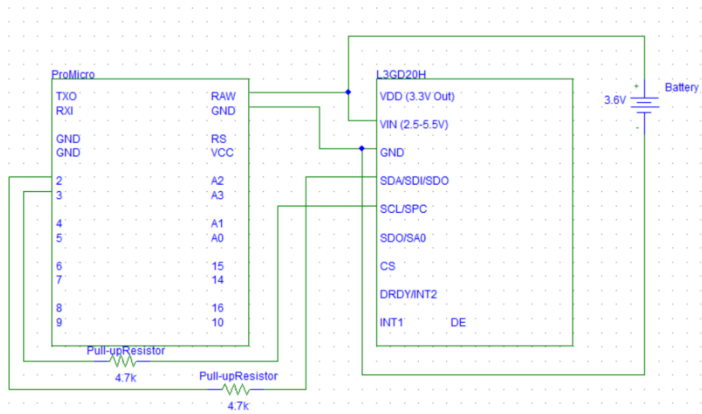


Figure 14: Wiring Diagram of Arduino and IMU

The avionics system will be located in the nose cone of the dart. The system will be secured using strips of Velcro, to make it easy to install and remove.

VIDEO

Video will be taken from a camera inside the dart. A cutout was made in the body of the dart, with a plastic window to prevent airflow into the dart body. The mirror housing will be mounted on the side of the dart (see Figure 5) and the mirror will reflect images of the rocket's ascent through the window into the camera. The mirror housing was 3D printed from ABS plastic and is shown in Figure 15.

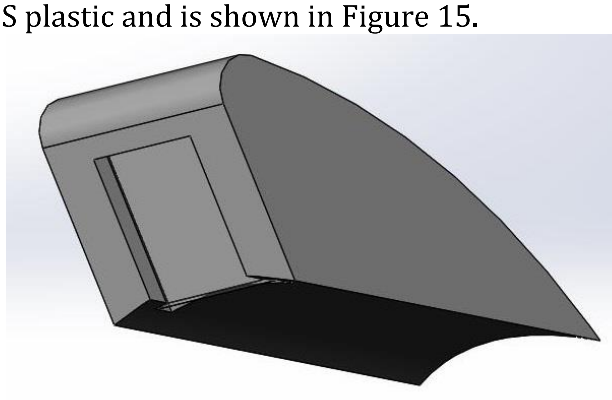
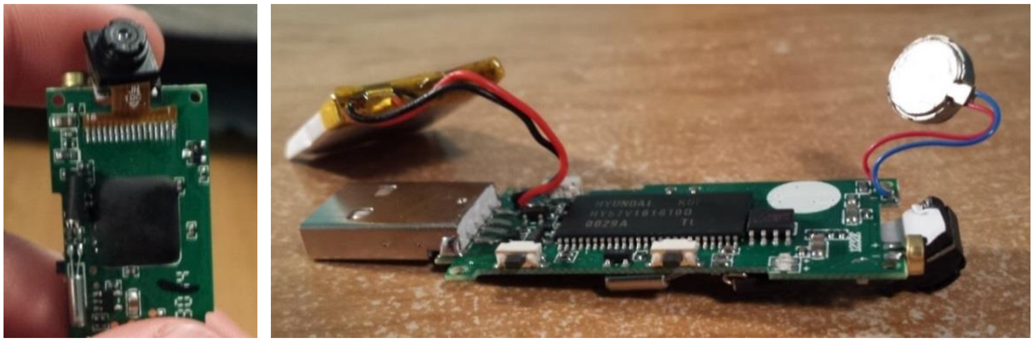


Figure 15 (left): 3-D printed camera mirror housing
Figure 16 (right): Camera as purchased

The camera is a "spy cam" concealed in a USB stick; it is shown in its initial form in Figure 16. It was selected because it is small and lightweight, provides quality video, and has a two-hour run time. The outer casing of the camera was removed to reduce its mass and dimensions and to give more flexibility in lens positioning. The camera post-modifications is shown in Figures 17 and 18. Without the case, it is easier to verify the camera is on, as the vibration of the camera is more apparent and an LED indicator is exposed.



Figures 17 and 18: Camera after modifications

VIDEO AND ROTATIONAL DATA COMPARISON

To compare rotational data from the IMU with rotation seen in the on-board video, the IMU is situated relative to the camera to establish a frame of reference for the change in rotation.

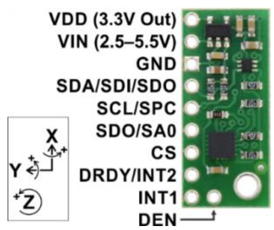


Figure 19: Axis Orientation of the IMU

The video camera will be oriented downward, but due to space constraints in the nose cone the IMU must be orientated vertically, as shown in Figure 19. The coordinates of the IMU data will be translated to a Cartesian coordinate system. X in the IMU coordinate system will be translated to Z in Cartesian coordinates, Y will be translated to X, and Z to Y.

SEPARATION AVIONICS

To fully characterize the flight performance of the dart and the booster and to capture the apogee separation, the dart and booster will each have an altimeter. The dart will have a Stratologger and the booster will have a Jolly Logic Altimeter Two, shown in Figure 20.

Figure 20: Jolly Logic Altimeter Two

The Jolly Logic Altimeter Two was chosen because it is the competition altimeter; using this device will allow the team to become familiar with it prior to competition. The Stratologger will be used in the dart because it is also deploying the recovery system. The altimeters, as well as the competition altimeters, will be mounted with Velcro for easy installation and removal, and will be powered by a 9V battery.

PREDICTED PERFORMANCE

The predicted performance was analyzed assuming an over-designed rocket with a total mass of 6.6 lb and a dart mass of 2.76 lb. The "parachute open" velocity was assumed to be 98.4 ft/s, which will change once the mass of the rocket is finalized. The predicted apogee for the dart is 3445 ft and for the booster is 3215 ft. The estimated separation is 230 ft.

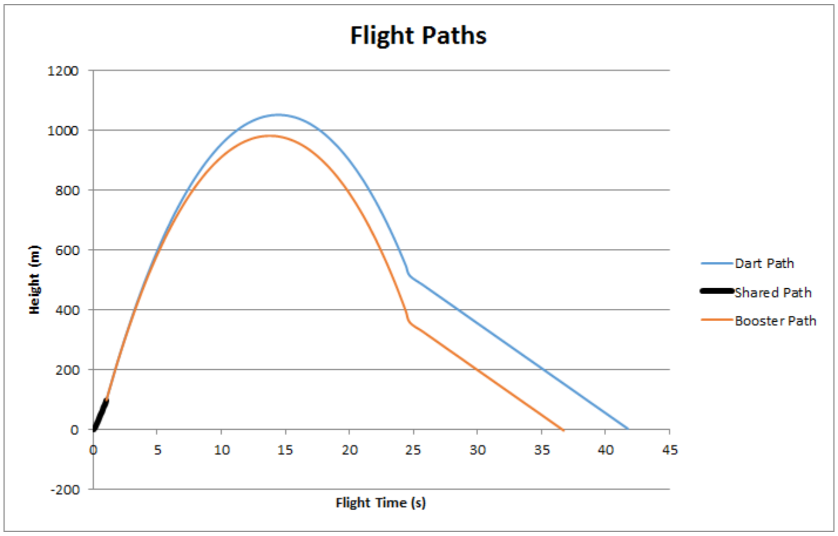


Figure 21: Trajectories for Booster and Dart

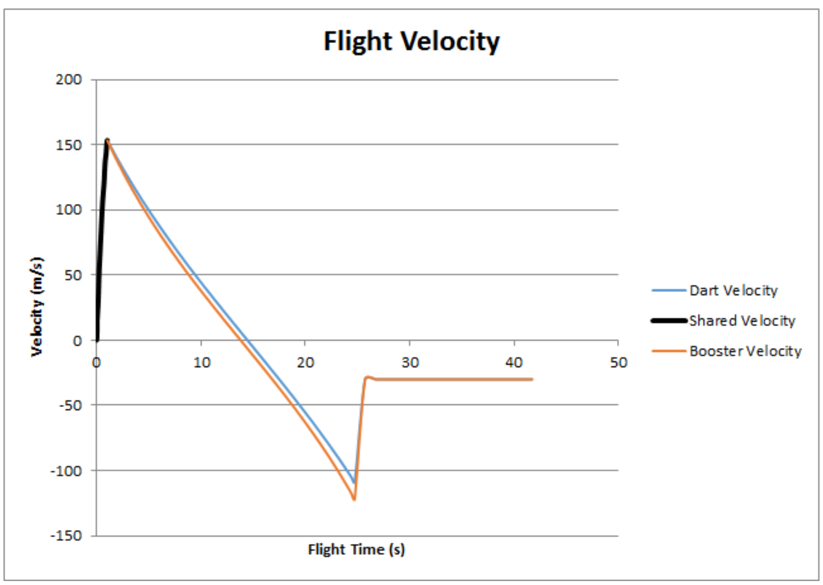


Figure 22: Velocity profile of Booster and Dart through flight

Figures 21 and 22 show the booster and dart trajectories. During the burn stage of the flight, the components are attached, so their trajectories are identical. Upon separation, the differences in apogee and deceleration are due to the difference in drag between the two components. The wider booster section has a higher drag coefficient, so it reaches a lower apogee than the dart. The velocities level off at 20 ft/s once the recovery systems are deployed, so the components will safely descend. Drag coefficients for the components were calculated using computational fluid dynamics (CFD) analysis in ANSYS Fluent.

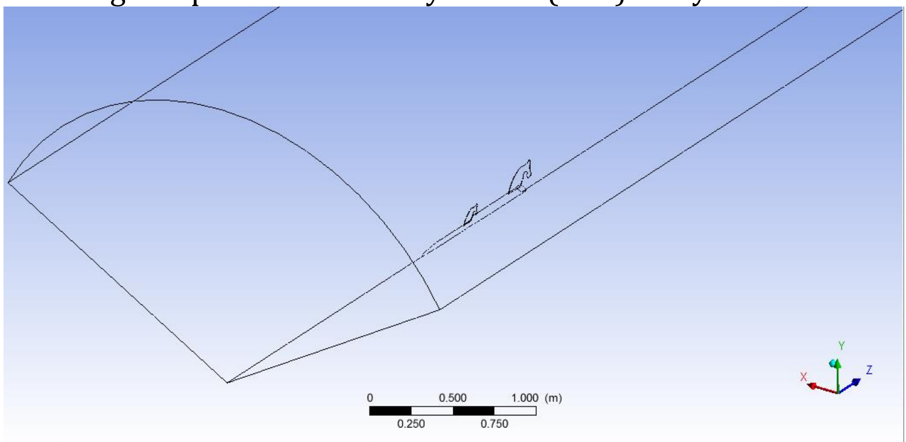


Figure 23: Illustration of Simulation method

The CFD solution method is shown in Figure 23. To reduce solution time, one set of fins was analyzed. The coordinate system in Figure 23 is consistent through the simulations; air-flow is defined in the positive Z-direction. The fins are located on the YZ plane, the plane of air the rocket will disturb the most during flight. The planes of symmetry bounding the simulation domain intersect the rocket body halfway between the two sets of fins; these planes show the most relaxed airflow around the rocket. The simulation was repeated several times, increasing the air speed and comparing calculated drag coefficients.

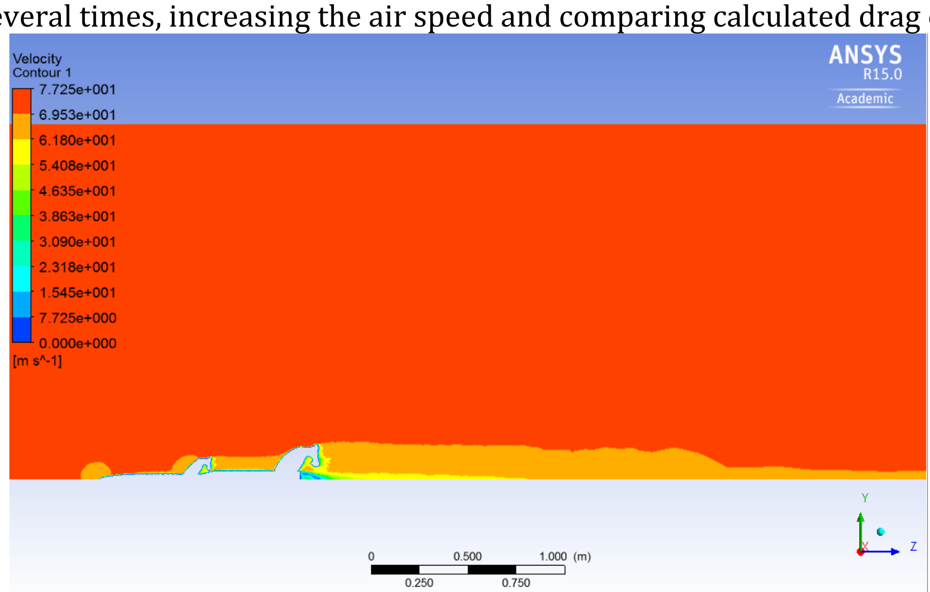


Figure 24: Rocket-booster system velocity profile at 230 ft/s (70 m/s)

Figure 24 summarizes the results of the CFD analysis. The velocity and pressure of the airflow around the rocket are calculated in hundreds of thousands of locations. The red region in Figure 24 is the maximum velocity in the domain and the blue regions are zero velocity. Standard fluid flow problems assume the body of the rocket will be directly surrounded by a stagnant layer of air. A wake region develops directly behind the booster, creating a low pressure zone that will slow the rocket.

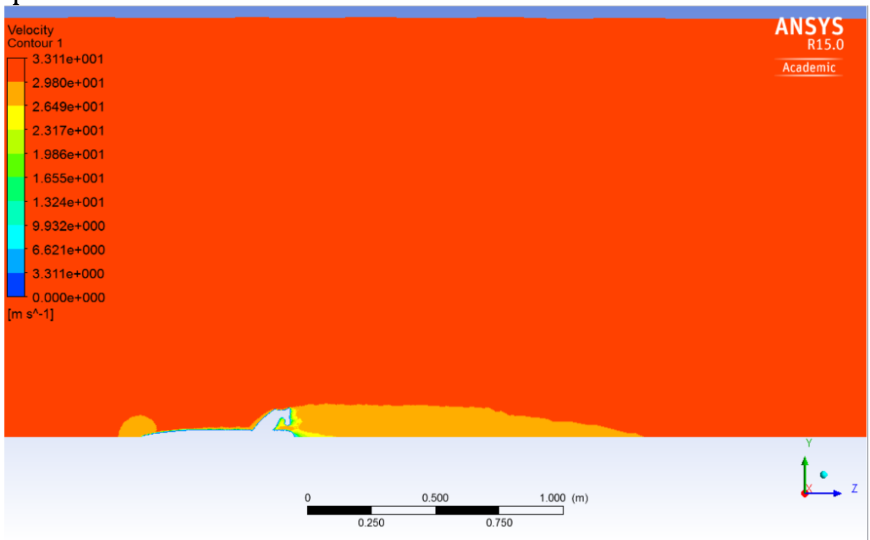


Figure 25: Dart velocity profile at 98.4 ft/s (30 m/s)

Figure 25 shows the velocity profile of the dart. The wake region of the dart is much smaller than the booster-dart system's or the booster's wake regions due to the tail cone.

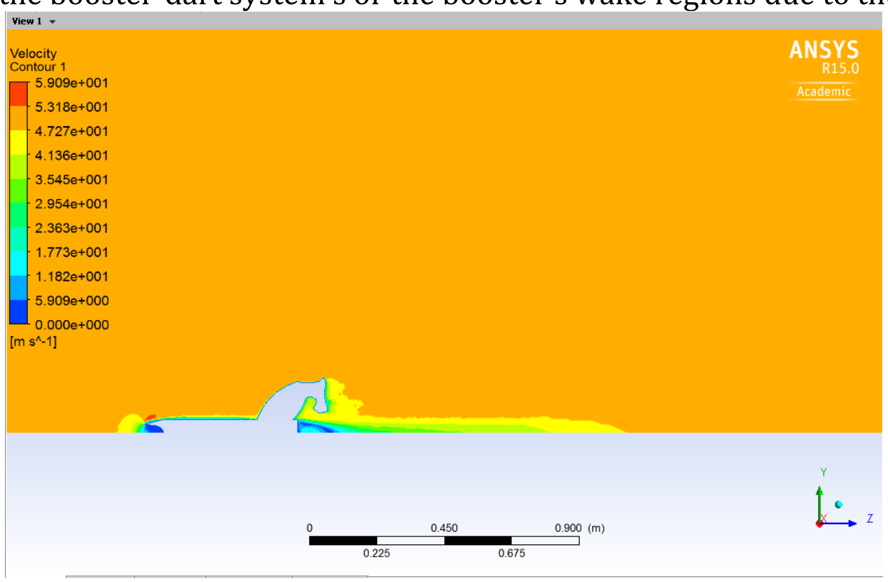


Figure 26: Velocity profile of booster at 164 ft/s (50 m/s)

The CFD analysis of the booster, shown in Figure 26, diverges from the analysis of the booster-dart system and the dart. The cavity at the nose of the booster where the tail cone sat fills with air upon separation and becomes a high pressure zone. Once this pressure equalizes, the booster's flight characteristics mimic that of a section with a full nose cone; the high pressure area acts as a nose cone would, smoothing the incoming airflow.

The simulations produced the drag coefficients for the booster-dart system and for each component individually, which are shown in Table 2.

Table 2: Drag Coefficients

Component	Drag Coefficient
Booster	0.45
Dart	0.33
System	0.42

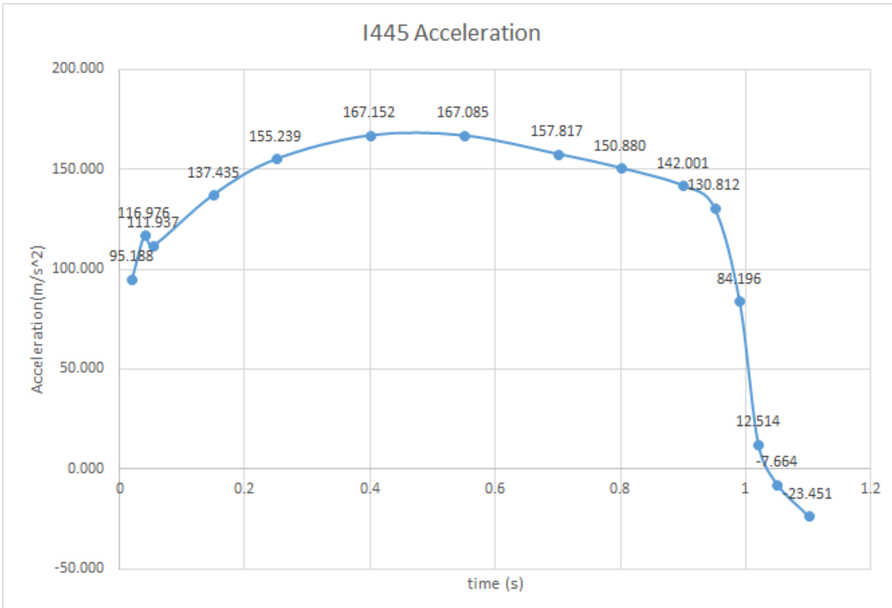


Figure 27: Acceleration plot of motor burnout

Figure 27 shows the acceleration characteristics of the Cesaroni I445 motor assuming a rocket weight of 6.6 lb. The maximum acceleration of the rocket system is 548 ft/s^2 (167 m/s^2). Near the end of the burn, the force of drag becomes greater than the supplied power from the rocket. Separation is predicted to occur just over 1 s into the flight, at the point the plot in Figure 27 intersects the X-axis.

SAFETY FEATURES AND CONSIDERATIONS

The contents of the detailed pre- and post-flight procedures are included in Appendices A and B. Copies of the procedure checklists will be available for the judges to review during the Range Safety Officer's inspection. The procedure checklists will also include spaces to record the temperature, relative humidity, barometric pressure, and wind speed, as determined by the National Weather Service observation station at the Rush City Regional Airport.

A preliminary construction and assembly procedure is included in Appendix C. As design choices are finalized, the procedure will be updated and converted to a checklist format. All construction will occur in a well-ventilated area. Gloves will be required during epoxy procedures. All machining will be done by qualified operators and eye protection will be required. A custom jig will be designed to hold the rocket during assembly to protect it and to ensure construction quality.

To protect the rocket during transit and to display it securely during judging, a carrying case will be constructed. The carrying case will be a 4 ft long by 2 ft wide jointed box and will hold the rocket and supplies needed for assembly and repair. The front of the box will be a door, and the support ribs will be mounted on drawer slides. The ribs and rocket will slide out, making the rocket accessible and safe during judging and the presentation, and will protect the rocket in case of inclement weather. A compartment with lock will secure the black powder during travel and at launch site.

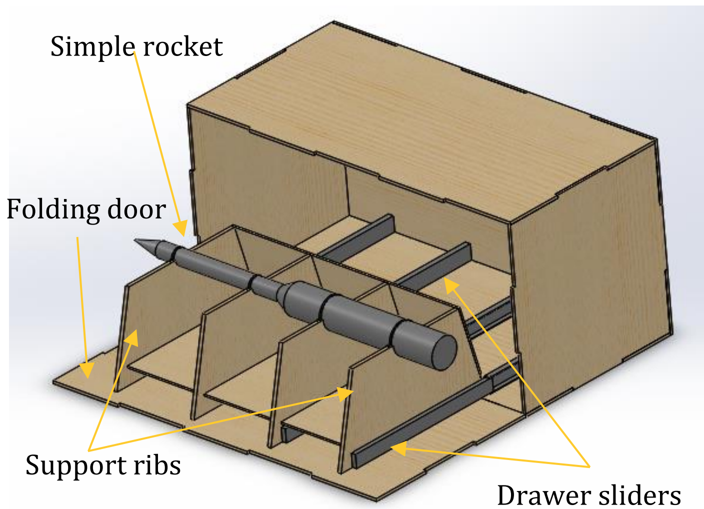


Figure 28: Preliminary case design

A failed test launch for the 2014 Midwest Regional Rocketry Competition required rebuilding of a portion of the rocket. When creating new fins, an old version of the fin .DXF file was used in the water jet cutter. The fins were cut with a too-small flange, which contributed to the failure at the competition. To avoid manufacturing errors, the 2015 team implemented version control for the design CAD files, using the Product Data Management (PDM) feature in SolidWorks. The PDM vault allows all team members access to the files, but only allows one team member at a time to check out the design for revision; if the design is checked out, the rest of the team members have read-only access. The most up-to-date version of the file is stored in the vault, and team members will only modify the current version.

CONCLUSION

Bulldog Rocketry will launch a rocket at competition that meets or exceeds all competition requirements. The team's avionics package, custom-designed components, extensive simulation analysis, and its commitment to safety, quality, and innovation ensure Bulldog Rocketry will have a successful, safe, and competitive entry in the 2015 Space Grant Midwest High-Power Rocket Competition

APPENDIX A: PRE-LAUNCH PROCEDURE

Initial Inspection

1. Inspect all four shock cord connection points.
2. Inspect Velcro attachments in booster payload.
3. Inspect all wiring connections and Velcro attachments in dart and nose cone.
4. Check and record all battery levels: Camera, Altimeter Two (1 – Booster, 2 – Competition Booster, 3 – Competition Nose Cone), Stratologger, Arduino.
5. Ensure the Camera, Altimeter Twos (1-3), Stratologger, and Arduino are OFF.

Dart Inspection

6. Connect the Stratologger and Arduino 9V batteries.
7. Inspect & install nose cone payload assembly. Turn on and arm Altimeter Two (3), will display READY. Arm Arduino and IMU. Inspect static pressure ports on nose cone.
8. Turn on camera and check for GREEN LIGHT
9. Install and secure tail cone into dart
10. ENSURE POWER IS OFF! Install dart chute blast cap inside of piston with ⅓ black powder, ⅔ wadding, secure with electrical tape. DOUBLE CHECK WIRING CONNECTIONS!
11. Inspect and fold dart parachute and attach to shock cord via quick link
12. Install dart piston, shock cord, parachute, and nose cone into the dart

Booster Inspection

13. Run shock cord through the reducer and attach to securement rod inside of booster
14. Arm Altimeter Two (1 & 2), each will display READY
15. Install reducer into booster and secure with 3 screws
16. Inspect and fold booster parachute and attach to shock cord via quick link
17. Install booster piston, shock cord, and parachute into the reducer
18. Inspect booster and reducer static pressure ports
19. Install dart into booster

Launch Pad Inspection

20. Record motor mass.
21. Install motor.
22. Place rocket on launch rail.
23. Arm Stratologger altimeter.
24. Listen for correct beep sequence as follows: 2 short beeps (Preset 2), long pause, 5 short beeps (Describing an altitude of 500 ft. for dart parachute deployment), short pause, 10 short beeps, short pause, 10 short beeps, long pause, a sequence of beeps and short pauses (Describing altitude of last flight), A sequence of beeps and a short pause followed by another sequence of beeps (Describing battery voltage as X.X Volts), long pause, A non-stop pulse of 3 beeps (This indicates that the chute is connected properly. IF A PULSE OF 1 OR 2 BEEPS, THEN THE CHUTE IS NOT CONNECTED. DO NOT LAUNCH!!!)
25. Final visual inspection
26. Photograph rocket on pad and start on-ground video camera
27. Launch

APPENDIX B: POST-LAUNCH PROCEDURE

1. Approach components with **caution**; inspect from afar to verify it is safe to approach

Dart Inspection

2. Record Stratologger altitude and voltage: remove smart nose cone bay, listen to Stratologger. Stratologger will report an extra-long high pitch tone, indicating the start of data reporting. A sequence of beeps and short pauses indicates apogee altitude (outputs numbers left to right). A sequence of beeps and a short pause followed by another sequence of beeps describes the battery voltage as X.X Volts.
3. Turn off nose cone electronics: Stratologger, Altimeter Two (3), Arduino, IMU.
4. Turn off camera.
5. Collect all components of dart
6. Return to Judges' booth and wait for booster recovery team

Booster Inspection

7. Turn off booster electronics: Altimeter Two (1-2)
8. Collect all components of booster
9. Return to Judges' booth and wait for dart recovery team

Judges' Inspection

10. Present booster and dart to judges for inspection of rocket and collection of data
11. Return electronics if not doing another launch: Altimeter Two (2-3)

Bulldog Rocketry Team Inspection

12. Inspect booster and account for condition of motor, reducer, shock cord, parachute, body, fins, piston, and remaining hardware
13. Download/collect data from Altimeter Two (1)
14. Inspect dart and account for condition of nose and tail cone, electronics bay, shock cord, parachute, body, fins, piston, and remaining hardware
15. Download/collect data from, Stratologger, Arduino/IMU, Camera

APPENDIX C: PLANNED CONSTRUCTION PROCEDURES

1.) Assembly Preparations
    a. Cut body, coupler, and motor mount tubes and threaded rods to length with band saw
    b. Cut 3 fins with water-jet
    c. Cut shock cords to length with scissors
    d. Mill fin keyways in centering ring and drill holes for support rods with mill
    e. Drill holes in bulk heads for piston with hand drill
    f. 3-D print electronics chassis, nose cone, and tail cone
2.) Assembly Process of Booster Section
    a. Assemble motor mount chassis by securing centering rings onto threaded rods using hex nuts and Loctite
    b. Install shock cord rod into the top centering ring
    c. Insert motor mount chassis in body tube 1” past the bottom of the body tube.
    d. Insert the fins into the centering ring slots to clock the chassis into position
    e. Epoxy motor mount chassis into lower booster body tube
    f. Epoxy the fins into the centering ring slots and also onto the body tube
    g. Insert the motor mount tube into the chassis and epoxy into position.
    h. Epoxy the aluminum retaining ring to the motor mount tube
    i. Attach shock cord to shock cord rod in top centering ring
    j. Run shock cord through reducer, place reducer in top centering ring
    k. Secure reducer to booster body tube using 3 button screws
    l. To make piston, epoxy a bulk head into a 4 inch section of coupler tube
    m. Run shock cord through piston bulk head leaving enough shock cord for piston to escape reducer. Epoxy shock cord to bulk head hole
    n. Let assembly cure
3.) Assembly Process of Dart Section
    a. Mount electronics to chassis using Velcro strips
    b. Insert electronics chassis into nosecone snugly
    c. Assemble camera mount chassis by securing the 2 dart centering rings onto both threaded rods using hex nuts and Loctite
    d. Install U-bolt into top centering ring and secure using hex bolts and Loctite
    e. Insert the fins into the centering ring slots to clock the chassis into position
    f. Epoxy camera mount chassis into lower dart body tube
    g. Epoxy the fins into the centering ring slots and also onto the body tube
    h. Epoxy camera mirror housing onto outside of dart body tube
    i. To make piston, epoxy a bulk head into 2.5 in. length of coupler Tube, let cure
    j. Run shock cord through piston bulk head leaving enough shock cord for piston to escape reducer. Epoxy shock cord to bulk head hole
    k. Let assembly cure
4.) Assembly of Rocket
    a. Lay sections of rocket in correct order (booster, piston, booster chute, tail cone, dart, piston, dart chute, nosecone)
    b. Slide rocket together and secure