Preliminary Design Report

University of Iowa

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Midwest High Power Rocketry Competition
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Executive Summary

This report contains information about the University of Iowa's preliminary design for this competitions rocket. Detailed descriptions of all the components of the rocket, such as funs, airframe, propulsion system, and payload, are included. Each description includes any calculations and formulas used as well as the reasoning behind the chosen design. An analysis of the rocket design is included with appropriate figures and plots used to show the rocket simulation data. This analysis is used to predict the flight performance of the rocket as it is designed. There is also a safety analysis included along with all relevant safety procedures necessary. A final section of appendices is included to show a breakdown of all equations as well as any external sources utilized for the design of the rocket.

Rocket Airframe

Rocket Body Specifications

The main body tube of the rocket is approximately 51 in (129.5 cm) long and will be constructed out of G12 fiberglass tubing with a diameter of 4 in (10.2 cm). This length was decided such that the internal space was large enough to accompany all of the subsystems of the rocket that will be operating during the flight. These systems include recovery, electronics, payload and propulsion. G12 fiberglass was the chosen material because it has been proven as a very strong material, highly suitable for high power rocketry. In order to accomplish the assigned task of capturing visual data of successful parachute deployment, a camera will be mounted on the side of the airframe, coincident with the electronics bay. This is done in order to limit the amount of extra wiring or electronics bays needed to fulfill this requirement. The camera will be mounted at an upward angle so that it can be mounted without causing any extra drag force, however minimal, while also still being able to record the parachutes successfully deploy. Simulations also estimate the total mass of the launch vehicle to be 10.258 lbs (4.653 kg).

Nose Cone Specifications

The nose cone, which is also made of fiberglass, adds an additional 15.75 in (40 cm) with a shoulder length of 4.7 in (11 cm). This brings the total length of the rocket to 66.75 in (169.5 cm). The nose cone can be seen below in Figure 1 and has an ogive profile. The length was extended a small amount to account for the payload bay, which is where a mass will be placed during launch with the larger motor. This concept will be further explained in the payload section.

Figure 1: Nose Cone

Fin Specifications

Four fins will be manufactured in-house, comprising of 1/16 in (1.59 mm) thick carbon fiber. This material was chosen since it was surplus from a separate competition, and thus there was no cost to purchase the material. This material has also been proven to be a strong material to use for fins, and has performed excellently in the past. Also, because the fins will be manufactured in-house, that will also not cost the team any additional funds. The fins will be tabbed such that they can be attached to the motor mount via internal filleting for extra strength. This internal filleting will be complemented by external filleting with epoxy resin composite. This will not only provide extra strength on the external airframe, but will also serve to reduce the drag from surface imperfections. Each fin is trapezoidal, with an 8 in base, 4 in free side, and a 5 in height. This shape was chosen to take advantage of the stability of wider wings, and fins will be placed 90 degrees apart from each other in order to achieve symmetry. Figure 2 below shows a model of the fins.

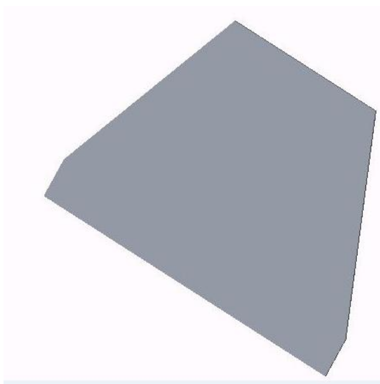

Figure 2: Fin Geometry

Rocket Recovery System

The recovery subsystem is not only comprised of the parachutes that will ensure safe descent, but also the electronics that control the blasting charges. The electronics that control the subsystem are laid out in greater detail in the electronics section. Other than electronics, the recovery subsystem is made up of the drogue parachute, main parachute and blasting caps that will deploy the aforementioned parachutes. The drogue parachute will be 15 in (38.1 cm) in diameter. It will be deployed just after apogee is reached at the start of the descent. The objective of the drogue parachute is to slow the descent of the launch vehicle so that when the main parachute is deployed, the connection points for the parachute are not fractured due to shear stress that is brought on by the immense drag forces. Further into the descent stage (roughly 800 - 1000 ft above ground), the main parachute will be deployed. This parachute will be approximately 36 in (91.45 cm) in diameter. The purpose of this parachute will be to further decrease the descent velocity of the launch vehicle, allowing it to land safely. Although the mass of the launch vehicle is currently an estimation, the estimate was given a comfortable amount of cushion in order to size the drogue and main parachute.

Rocket Propulsion System

For the propulsion subsystem, the two motors chosen are the J449 for the smaller motor, and the K360 for the larger motor. These motors have a very similar specific impulse, so they will be able to launch the rocket to similar heights. Each motor will be enclosed in an appropriate motor casing, which will then be slotted into 2 in (54 mm) fiberglass tubing. Each motor casing is made out of thin-walled 6061-T6 aluminum tubing with an anodized coating for corrosion protection and also includes a rear enclosure. On the end of the tubing towards the tail end of the rocket, the casing will be secured with a retaining ring. Two centering rings will then be adhered to the tube and slotted into the tail end of the main body tube. Slots will have been cut into the body tube to allow the tabs from the fins to fit inside. These tabs will be adhered to the 54 mm tube, lying in between the centering rings, with epoxy and will serve as the base of the internal filleting. The predicted performance of these two motors will be further detailed in the Analysis of Anticipated Performance Section.

Electronics

Dual Deployment and Altimeter

Overview

The device selected for the dual deployment has a built in altimeter to measure the altitude of flight. The device, known as the stratologger, is capable of deploying two parachutes, a main and drogue. After the flight has concluded, the stratologger communicates to the user the flights apogee. The velocity of the flight is then transferred to the computer for further data evaluation.

Setup

The materials needed to assemble the dual deployment and altimeter are listed below in table 1:

Table 1: Dual Deployment and Altimeter Materials List

Description	**Quantity**
9V Battery	1
StratologgerCF Altimeter	1
Switch	1
Electrical Wire	Arranged

The DT4U Transfer Kit and Computer are not listed as materials for the actual build of the electronics recovery system. There are only needed for post flight data transfer and analysis.

The connections for Stratologger and battery can be seen in the wiring diagram below:

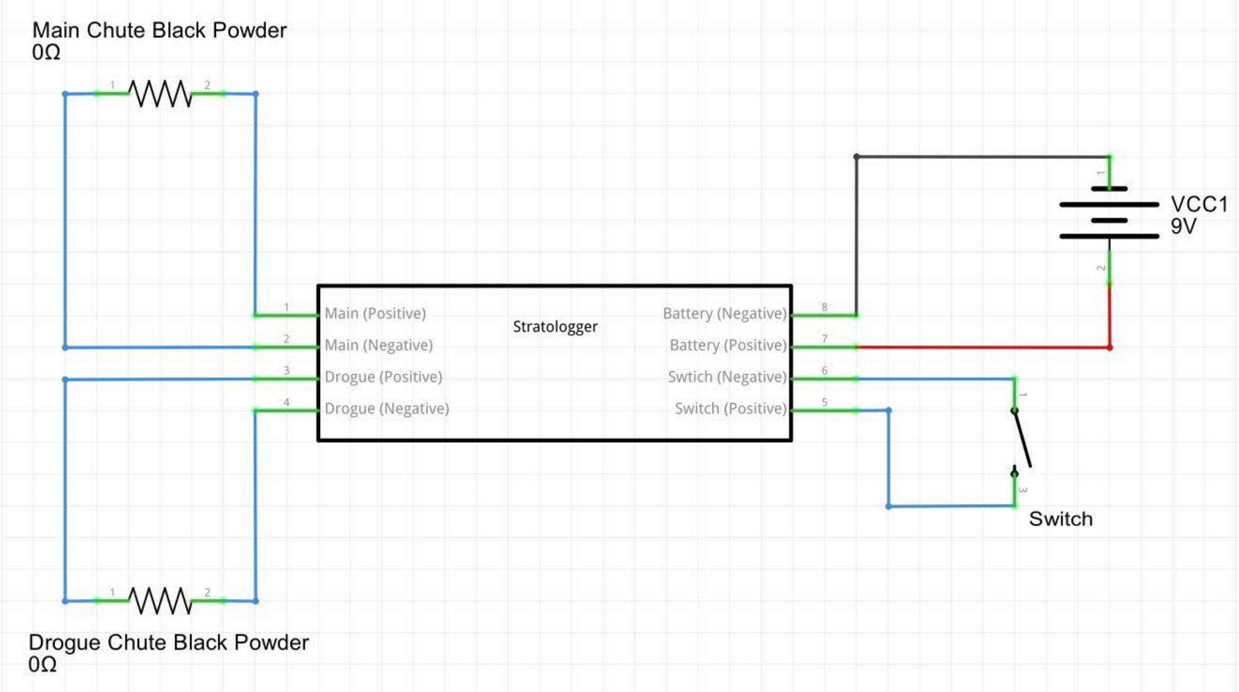

Figure 3: Recovery System Wiring Diagram

Design Features

The Stratologger various features produces a lot of adaptivity in the design of the recovery system. The Stratologger has a set of terminals designated for an external switch. The external switch allows the user to turn on the Stratologger right before launch in order to reduce any possible misfires of the black powder charges. The external switch will be in the off position during mounting on the launch rail. The switch will be activated when the rocket is ready for launch.

When the Stratologger is turned on, the Stratologger will sound a continuous series of beeps to notify the user the current settings. When a steady beeping noise is present from the Stratologger, it is in launch mode and ready to record altitude.

During the flight of the launch vehicle, the stratologger uses pressure readings to determine the altitude. Once the launch vehicles reaches apogee, a current is sent through the drogue terminals on the Stratologger to ignite the black powder that will deploy the drogue parachute. The second charge, the main terminals, will send a current when the predetermined height is reached. The main parachute ignition can be chosen from a pre determined values on the Stratologger or programmed manually.

After the flight, the Stratologger will repeat the max altitude and max velocity using audible beeps until powered down. The Stratologger will also play a high pitched siren in order to find the launch vehicle. Using, the DT4U transfer kit, PNUT and Stratologger software, the altitude and velocity of the flight can be displayed graphically for the user.

Velocity Measurement Device

Overview

The noncommercial velocity measurement device will use software capabilities of the Arduino and Sparkfun accelerometer to determine the velocity of the launch vehicle. The accelerometer will record the acceleration of the launch vehicle and relay that information to the Arduino where it will be processed and saved. Using a USB, the data will be transferred and analyzed to determine the velocity of the launch vehicle.

Setup

The materials needed to assemble the velocity measurement device are listed below in table 2:

Table 2: Velocity Measurement Device Materials List

Description	**Quantity**
9V Battery	1
Arduino	1
ADXL345	1
Switch	1
Electrical Wire	Arranged

The USB and and computer used to interpret and display the data are not listed as they are used post flight.

The connections for the ADXL345, Arduino, and battery can be seen below in figure 4:

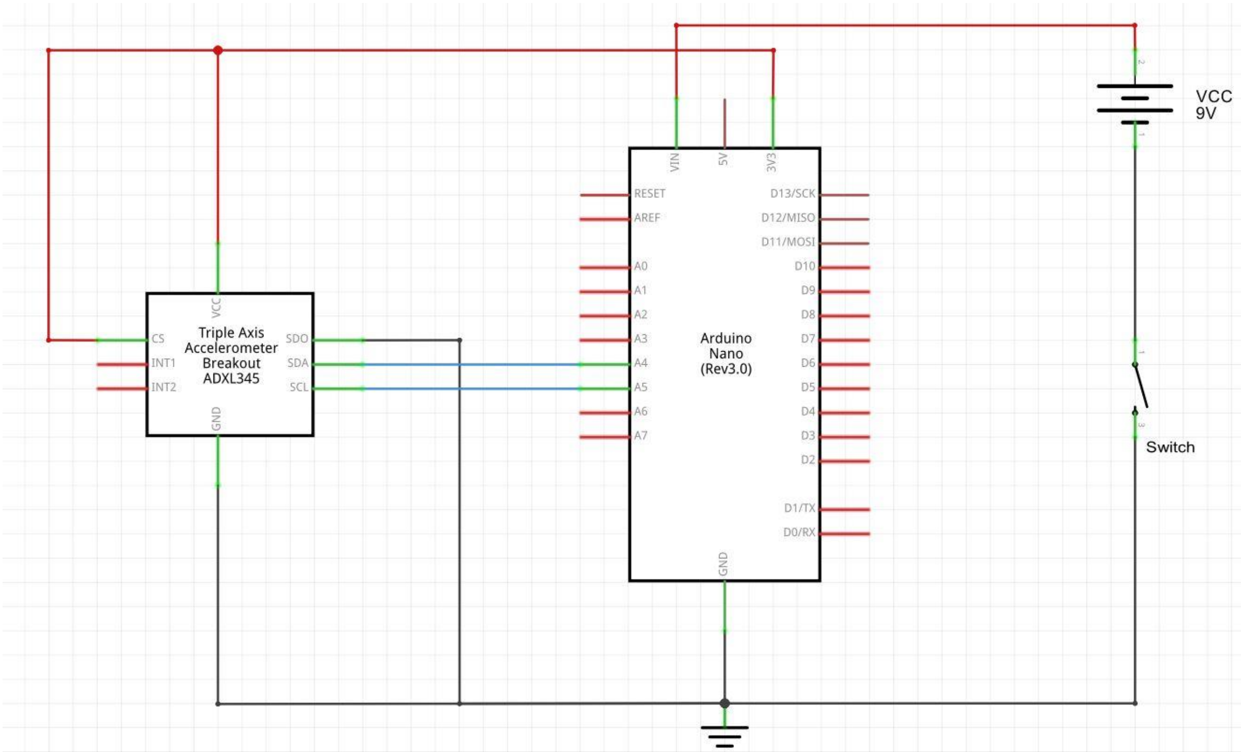

Figure 4: Velocity Measurement Device Wiring Diagram

Design Features

The Arduino is connected to the ADXL345 through serial communication either SP1 or I^2C. The ADXL345 stores the acceleration in registers corresponding to their axis of acceleration and sends the real time acceleration to the Arduino, where the Arduino will store the data for the entire flight. After the flight is over the data will be transmitted serially to the computer through the USB for further data calculation to determine the velocity of the launch vehicle.

The ADXL345 has an inactivity register built into the processor. The register acts as an inactivity threshold in which data will not be collected until the acceleration is higher than user defined value. This allows keeps the ADXL345 from transmitting extraneous values that are unrelated to the flight to the Arduino. A switch will separate the power supply from the two devices in order to keep the Arduino and ADXL345 from reading and recording prior to launch during the assembly of the launch vehicle on launch day.

Payload Design Features

The payload bay subsystem will be entirely mechanical, so no electronics will be required to operate it. This will keep manufacturing costs and weight down to a minimum. The payload bay will be mounted internally inside the body of the launch vehicle. It will be constructed out of the same fiberglass material as the rest of the rocket. This round component will be comprised of internal coupling tubes that will slide into the body. The tube will be capped on both ends with fiberglass bulkheads on either side that will be secured with epoxy. Figure 5 below shows a CAD model of the payload bay.

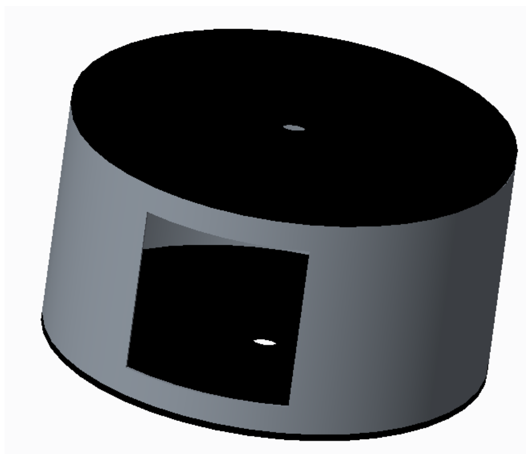

Figure 5: CAD Model of Payload Bay

In order to access the payload bay, there will be a hole cut into the side, and the payload bay will be allowed to freely rotate in order to expose the internal bay to the outside. To achieve this, the coupling tube will be restricted from translational movement by the bulkheads. The bulkheads will be secured and prevented from moving in any way using epoxy and also at least 3 elbow brackets shown in Figure 6.

Figure 6: CAD Model of Elbow Bracket

These brackets will be fastened to the exterior body with the head of the fastener on the outside of the body in order to limit the amount of drag on the exterior. Each fastener will also be further secured with epoxy in order to prevent the fasteners from loosening during flight. Once closed, the door will be locked using a simple system that consists of two I-bolts and a quicklink, or other self-locking carabiner. Both I-bolts will be secured to the airframe in the same fashion as the fasteners for the brackets. An example of the system locked is shown in Figure 7. Please note that Figures are not drawn to scale, and only serve to give visual examples of the design. A simple drag calculation was used to determine the amount of drag the exterior components would create. The following equation was used:

$$F_D = \frac{1}{2} \rho u^2 C_D A \quad (1)$$

In Equation (1), ρ is the fluid density, which would be air. A is the projected area of the object, u is the fluid velocity and C_D is the drag coefficient. With air density being 0.0024 slugs/ft^3, air velocity being 728.3 ft/s, projected area being approximately 0.042 ft^2 and drag coefficient being 1.17, at the maximum velocity the drag force will only be 11.5 lbs. However, this number is a very rough estimate and is mostly dependent on how much of the projected area is exposed to the air stream. The drag force applied to the exposed components will decrease when decreasing exposed area.

Figure 7: CAD Model of Locking System

In order to ensure that the added mass does not affect the stability of the rocket, The payload bay will be placed as close to the center of mass of the rocket as possible, even placing it a small amount closer to the nose cone so the center of gravity stays in the correct spot relative to the center of pressure. The correct amount of mass was estimated using properties of material density. First, a material was chosen. This material is aluminum, because it was readily available, free and was cut into a cylinder for the team (again, for free). Once the density of the material was known, an iterative process was used utilizing the simulation software in order to bring the apogee of the second motor as close to the apogee of the second motor as possible. When the target mass was identified, then it was a simple math problem to find the volume of aluminum that would be required. Given that the diameter was already decided, just the height of the cylinder needed to be determined. The only other problem with this method is the fact that during flight, the mass will be bouncing around during flight which could potentially cause damage. To prevent this, a hole will be drilled in the center of the cylinder so that the mass can be secured to a bolt during flight.

Because the specific impulse of both motors is very similar, a very small amount of mass is required to bring the larger apogee down to the lower apogee. The projected mass required will be approximately 0.33 lbs (150 g). This brings the cylinder height to be about 0.47 in (1.56 cm). This means that the payload bay is quite large compared to the material it will be housing, but this was done for the sake of being on the safe side in case a longer cylinder was used.

Analysis of Anticipated Performance

In order for any rocket to be launched and to fly properly, the center of gravity and center of pressure must be oriented correctly to have a successful, vertical launch. These factors were determined using the OpenRocket software this student organization uses for creating and simulating their rockets. Since the competition requires teams to launch a rocket using two motors, there will be different centers of gravity and centers of pressure at each launch. Table 3 shows these values, and how the static margin falls approximately within the general standard of 2 to 3 Cal.

Table 3 CoG and CoP for J-449 and K-360 Motors

Motor	Center of Gravity (inches from base)	Center of Pressure (inches from base)	Static Margin (cal)
J449	20.47 in	11.81 in	2.06
J449 Burnout	24.88 in	11.81 in	3.06
K360 (weighted)	19.69 in	11.81 in	1.88
K360 Burnout	24.72 in	11.81 in	3.12

Although the static margin falls on the lower end of the standard requirement for rockets, as the rocket launches and burns out, the rocket will become more stable since the mass at the base of the rocket will drop, causing the center of gravity to move closer toward the tip of the rocket. The test flights will be used to determine whether the flight of the rocket is satisfactory. If the flight is not as straight mass will be added towards the tip of the rocket to make the rocket more stable during flight.

Figure 8 below gives a visual depiction of the center of gravity and center of pressure on our competition rocket.

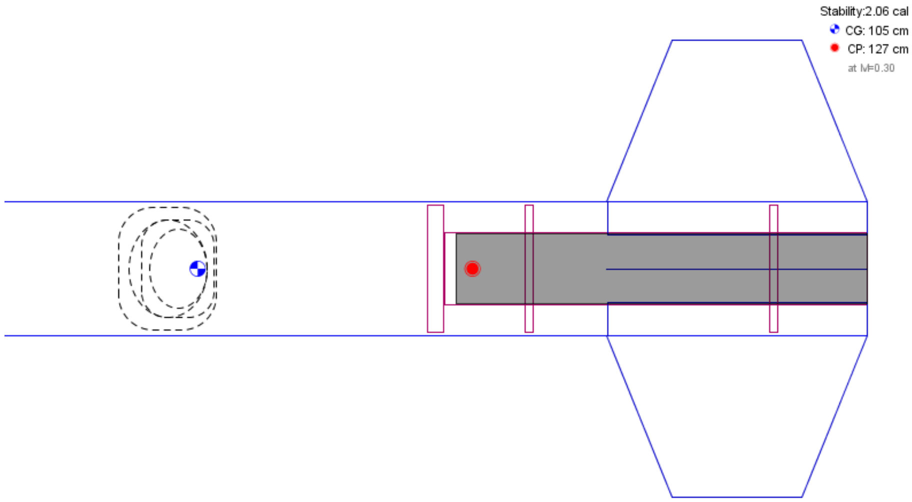

Figure 8: Center of Gravity (blue dot) and Center of Pressure (red dot).

The estimated maximum altitude, peak velocity and peak acceleration, are mostly dependent on the size of the motor used for launch. Table 4 below gives these estimated values using our J-class and K-class motors.

Table 4: Anticipated Performance of J and K-Class motors for Competition

Motor	Max Altitude	Max Velocity	Max Acceleration
J-449	1370 m	222 m/s	107 m/s^2
K(weighted)	1366 m	206 m/s	71.9 m/s^2

Fin Flutter

Our teams beginning design consisted of a shorter body length and larger fins, giving us a rocket just as stable as our current design. The problem that came about with this previous design, however, was the possibility of fin flutter during launch and burnout. The larger fins would be more prone to fluttering at a high velocity, so calculations and design changes were made to prevent this from occurring. Figure 9 includes our current design calculations used to find fin flutter velocity.

Fin Flutter Equation: $Vflutter = a * \sqrt{\frac{G}{\frac{1.337AR^3 * P(\lambda+1)}{2(AR+2)(\frac{t}{cr})^3}}}$

Geometric Equations: Area of Fin: $S = \frac{1}{2}(cr + ct)b$

Equation in Fin Flutter $Ar = \frac{b^2}{s}$

Tip/Root Chord ratio $\lambda = \frac{ct}{cr}$

Temperature variation (°F) $T = 59 - 0.00356H$

Pressure variation(lb/in^2) $P = \frac{2116}{144} * \frac{T+459.7}{518.6}^{5.256}$

Speed of Sound (ft/s) $a = \sqrt{1.4 * 1716.59 * (T + 460)}$

Known Variables:

Properties during flight:

Shear Modulus (G) = 600,000 psi

Max Altitude (H) = 4,432.24 ft

Max Velocity (Vmax) = 216 m/s

Fin Properties:

Root Chord (cr) = 8 in

Tip Chord (ct) = 4 in

Span (b) = 5 in

Thickness (t) = 0.1 in

$$Vflutter = 332.72\frac{m}{s} \;>\; Vmax = 222\frac{m}{s}$$

Figure 9: Fin Flutter Calculations for Current Design

From this data, it can be concluded that this competition rocket will not experience fin flutter since the maximum rocket velocity will not exceed the fin flutter velocity calculated. The flight path of each launch appears quite similar (Figures 12 and 13). However, the K launch achieves a higher apogee compared to the J launch. To achieve roughly the same apogee, a 150-g weight will be placed within the payload bay of the rocket, which is located at the center of gravity of the rocket. This allows the rocket to achieve a slightly smaller apogee, while not jeopardizing the static margin or flight path of the second launch.

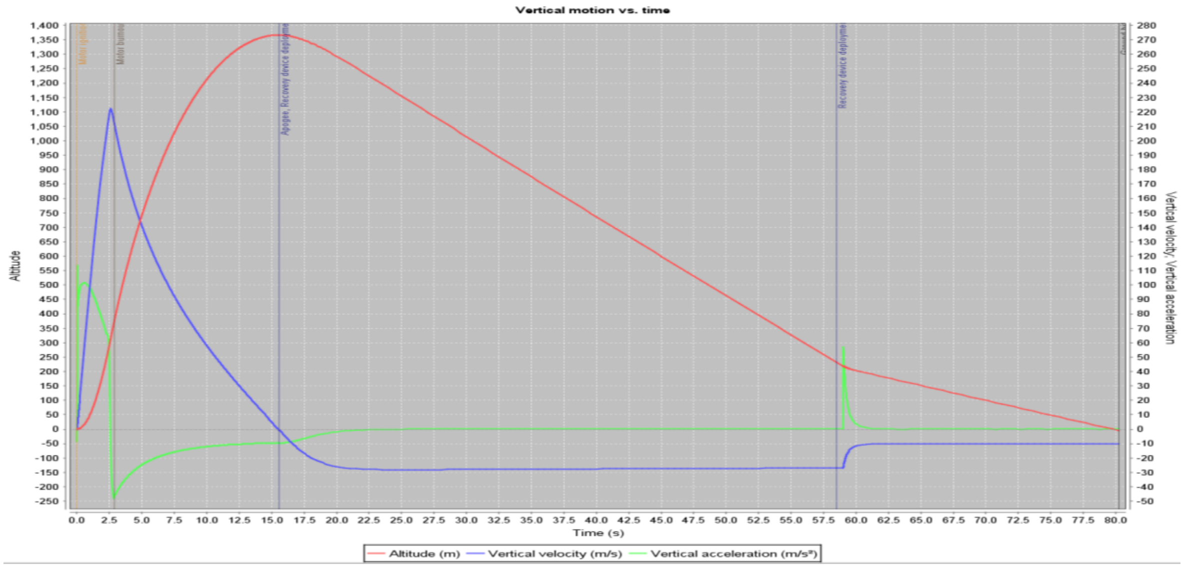

Figure 12: J launch and flight path using J-449 Motor

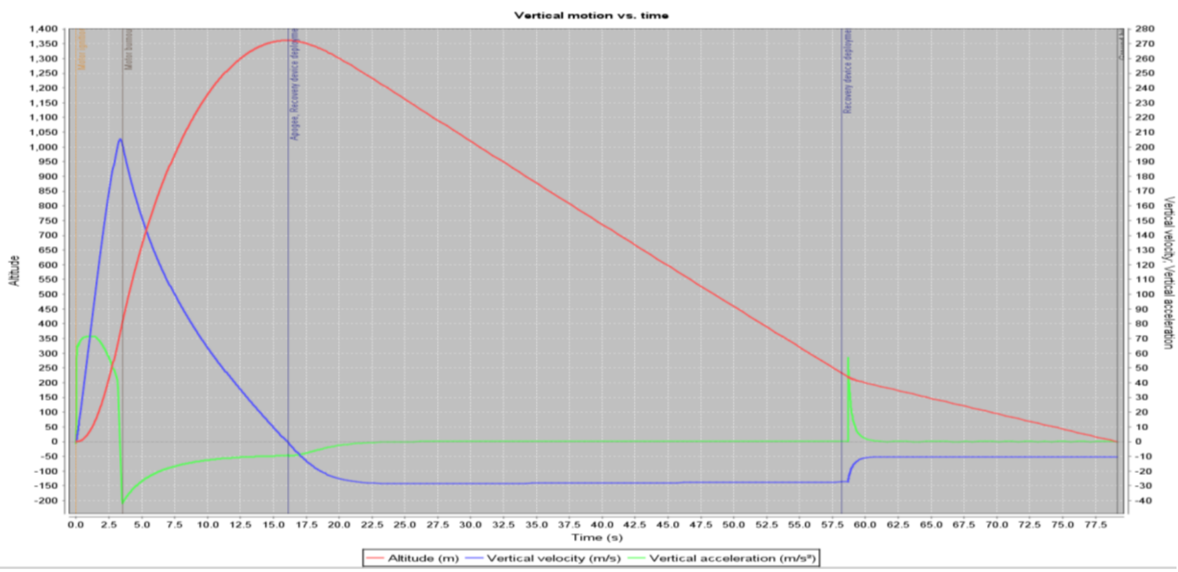

Figure 13: K launch and flight path using K-360 Motor and 150-g weight

Innovation

The innovation with this launch vehicle design is focused on the payload bay. This is because it is entirely mechanical, requiring absolutely no electronics to control it. Another innovation would be the lack of changes that need to be made in order to achieve the goal of reaching a consistent apogee with 2 different class motors. This task may seem rather daunting at first, but the goal can nearly be achieved with the correct selection of motors. The camera system, while not necessarily a complex system, is innovative in how simple it is. Since the camera will not be mounted externally to the body, it will not be creating any additional drag force and will also not be at risk of detachment due to the immense shear force during launch and flight.

Safety

Work on the rocket shall not be permitted unless there are at least two general members and the safety officer present in the work area. The safety officer makes the final determinations on who is allowed to use power tools, and ensures proper supervision during the use of power tools. The safety officer is also responsible for making sure that all members make proper use of personal protective equipment (PPE) while working. The minimum necessary PPE required are safety glasses/goggles, with other protective equipment like gloves, earplugs and respirators used when needed for certain tools and materials. Before the first construction session, the safety officer will ensure that all members have been informed of the health hazards associated with different areas of shop work, have taken all safety quizzes required by the University of Iowa and have signed the required paperwork. The University of Iowa adheres to the guidelines of the Occupational Safety and Health Administration (OSHA). An additional form written by the safety officer will be signed by all members, and details rules specific to the building process, to ensure competition rules are followed.

Materials:

-all epoxies will be handled with proper PPE (safety glasses, gloves, ventilation masks) in a well-ventilated area

-all power tools will be used by people trained in their use, with additional supervision

-no power tools will be used without the approval of the safety officer, and all power tools will be inspected before use to ensure that they are in proper working order

-all tools and materials will be stored in their proper places, with drawers and cabinets being labeled

Risks to Successful Completion

-poor rocket design: Proper design of the rocket is crucial. An unsafe design will be prevented by following NAR guidelines for safe rocket design. These guidelines will be read by all members at the first meeting for design. The team mentor will be involved throughout the process, and will be allowed to have final say on the rocket's design.

-injury to members during construction: This will be mitigated by proper instruction of all members prior to use of power tools and/or hazardous materials, and through the proper use of PPE. All members will take safety quizzes as required by the University of Iowa, and will not be permitted into the workspace without successfully completing these quizzes.

-poor construction quality: Poor quality control during the construction phase could lead to the rocket breaking upon launch or while in the air, posing a threat to spectators. This will be mitigated by quality control throughout the construction process. Supervision will be provided, with more experienced members leading the construction process. Detail-oriented tasks will be performed slowly with proper materials to ensure quality.

-electronics failure: If our electronics package fails to work properly and does not send the correct signals through the circuits, then there are risks that the parachutes don't deploy. To mitigate this risk, we are including a backup altimeter to act as a failsafe option. Proper electronics expertise will be applied in creating the electronics, but sometimes the components and solder do not properly conduct.

-shock cord failure: Our drogue chute is designed to slow the rocket in order to provide an appropriate speed for opening the main chute. The drogue chute must be opened properly, at the point of apogee, in order to provide ample drag and allow the main chute to open without issue.

The NAR/TRA mentor will either perform the preparation of the motor on launch day, or will assist team members in this process. Prior to launch, the safety officer and mentor will coordinate on launch day procedures, with the mentor having final say on who performs specific launch-related tasks.

Prior to construction of the rocket, all participating members will be trained in the use of power tools. Explanation of hazards in the work area, including flammable and hazardous materials, will be given in a mandatory meeting to be conducted by the team leader and safety officer. PPE will be worn by all members working on the construction process. Supervision will be provided when working with hazardous materials to ensure the safety of all members.

The pre-launch briefing will be planned by the safety officer and team mentor. This is to ensure that all important details are mentioned during pre-launch briefings. Pre-launch briefings will be conducted by the team safety officer and team mentor and will go over all important details of the assembly and launch process. These briefings will be mandatory for all members attending the launch, even if they will only be spectating. Only a few members will take the rocket to the launch pad, and they will be accompanied by a NAR/TRA member.

All written plans for the rocket will include pertinent safety information regarding the specific materials. Each member will be responsible for reading the given safety information before handling any hazardous materials. Prior to the first construction session, all participating members will be given a sheet detailing safety procedures and rules within the workspace. Members will be asked to sign these sheets as proof that they have read and understand the safety guidelines for the construction space. These sheets will be written by the safety officer, with input given by the team leader. All submitted materials required for the competition will contain the pertinent safety information as prepared by the safety officer.

Prior to the construction process, laws and regulations regarding flammable materials and fire prevention will be read. This is to ensure that safety is kept in mind throughout the construction process. Prior to launch, all regulations concerning airspace, fire prevention, and motor handling will be read through by all participating members, even if they will not be handling the motor. The NAR/TRA mentor will be consulted during this time to ensure that all members and the mentor are in agreement with launch procedures.

Any and all motors needed will be purchased through the NAR/TRA mentor, and will be kept by the mentor until needed for launch. The NAR/TRA mentor will assist the team in preparing the motor for launch to ensure safe use of the motor. Any other energetic devices that will be used in the rocket will be cleared through the mentor before being added to the rocket itself to ensure proper assembly and safe use. Storage and transport of the energetic devices will be coordinated with the mentor as needed.

All members will be given a written statement detailing safety regulations. This will include basic safety during the construction process, as well as details of safety before and during the launch. All members will be informed of the required safety procedures on launch day during the pre-launch briefing, and will be expected to listen to the RSO throughout the launch process and respect the RSO’s final decision on the launch. The safety officer will coordinate directly with the RSO during the inspection to answer any questions and ensure that the rocket will be able to be safely launched.

Model Rocket Demonstration

In addition to the design of the launch vehicle, the team was successfully able to launch and recover at least one small scale model rocket. This requirement was fulfilled on the weekend of February 4th, and the figures below show the model rocket on the launch pad and when recovered.

Figure 14: Model Rocket on Stand

Figure 15: Recovered Model Rocket

Budget

Below is the planned budget for a single rocket and travel. A second rocket of the same specifications and design has been budgeted into the club's funding to allow for newer members to gain more experience in rocket fabrication as well as safeguard against any damage occurring during testing.

Rocket Costs:	Body Tube (Fiberglass):		$100.00
	Nose Cone:	$50.00	
	Centering Rings (Fiberglass) x2:		$17.52
	BulkHeads (Fiberglass) x5:	$6.53	
	<u>Motors:</u>		
	Cesaroni I100:	$73.00	
	Ceseroni J210:	$68.00	
	<u>Parachutes:</u>		
	36'' Main:	$90.00	
	15'' Drogue:	$53.62	
	<u>Electronics</u>*:		
	ADXL 3-Axis Accelerometer:		$18.00
	Switch x2:	$3.00	
	DT4U Data Transfer Kit:	$25.00	
	9 V Batteries:	$7.00	
	Shock Cord**:	$17.50	
	Fin Manufacturing:	$100.00	
	Sub-Total:	$629.17	
	Sub-Total (2 Rockets):		$1258.34
Travel Costs:	Hotel Costs***:	$1080.00	
	Car Rental + Gas (2 Rentals):	$400.00	
	Sub-Total:	$1480.00	
Total Expenditures:		**$2109.17**	
Total Expenditures (2 Rockets):		**$2738.17**	

* Cost for the Stratologger altimeter and Arduino controller not included since both are already owned.

** Shock cord used is 5 yards of Kevlar 22.

*** Hotel cost based on 3 rooms for 3 nights at $120/night.