19-March-2016

Preliminary Design Report
University of Wisconsin – River Falls
High Powered Rocketry: ORCA

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1. Executive Summary

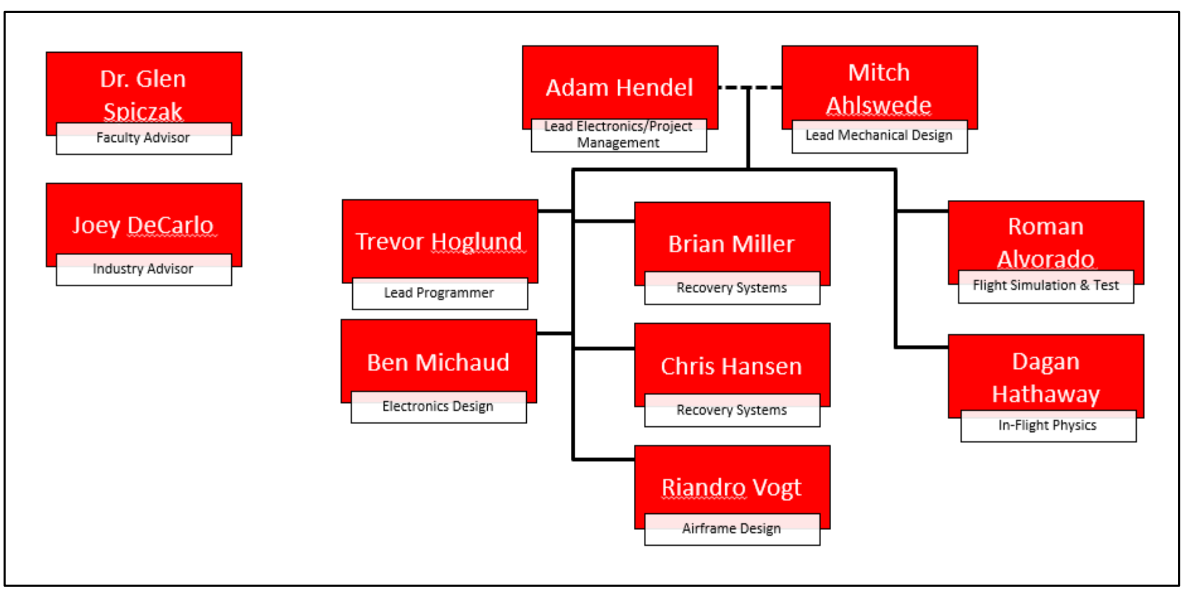
The 2016 Space Grant Midwest High-Powered Rocket Competition calls for competitive teams to design and construct a high-power rocket with an active drag system that will reach an apogee of at least 3,000 feet above ground level and be recovered safely and in flyable condition, predict its flight performance with the drag system both inactive and active, and construct a non-commercial on-board data collection package that will be capable of characterizing the rocket's coefficient of drag over time and capture on-board video to document the operation of the drag system. The main specified objectives are as follows:

1. Design and build a high powered rocket capable of reaching a minimum altitude of 3,000 ft.
2. Construct a non-commercial data collection system to characterize the rockets coefficient of drag over time.
3. Design and Construct an active drag system capable of decreasing the max apogee by 25%.
4. Conduct two high powered launches within 1 hour of each other.

The 2016 UW-River Falls High Powered Rocketry (UWRF-HPR) team rocket stands at 69 inches tall with a 4 inch diameter and adopts a traditional, low risk profile. The active-drag package developed for this competition is the Outward Reaching Cam Apparatus (ORCA). The rocket is expected to reach an apogee of approximately 5,000 feet on the first launch, max velocity of 570ft/sec, max acceleration of 220ft/sec^2. Second launch will reach an apogee of 3,750 feet by engaging the ORCA.

2. Planning and Organization

The UWRF-HPR team officially began development for the 2016 Midwest Rocket Competition once funding was secured in December 2015. The team utilized a modified hierarchal structure to manage personnel and lead the development process (see below). Each team member is given a primary area of responsibility though world loads were shared amongst the team.

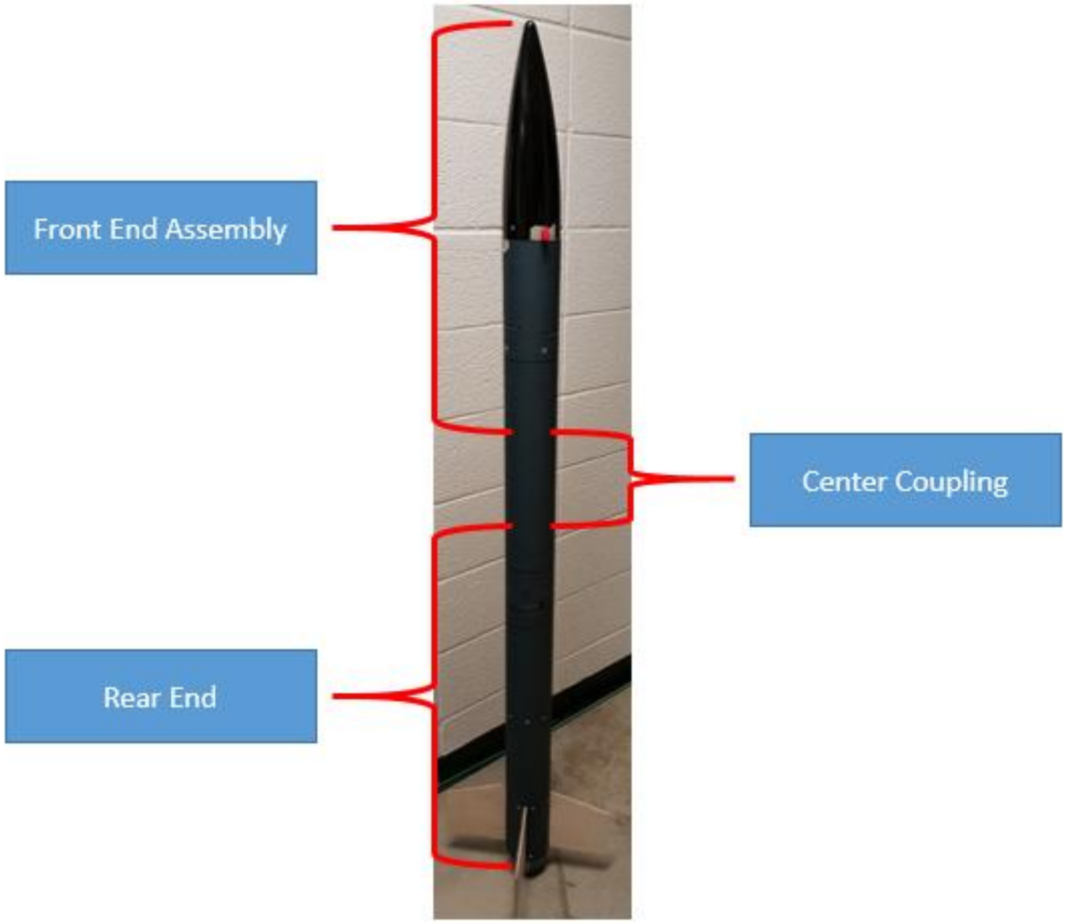


At the onset of development, a tentative schedule of key project milestones was outlined in order to ensure deadlines were met. This tentative schedule was continuously modified as requirement and priorities shifted. Refer to Appendix A for the initial schedule of tasks.

3. Rocket Design, Specifications and Components

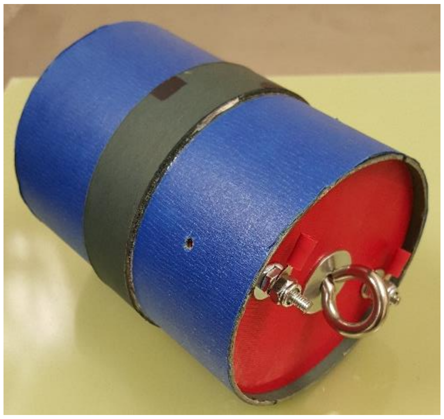
a. Airframe Design

The airframe consists of three sections; the rear end, center coupling, front end assembly. All outer frame material is constructed with Blue Tube 2.0.



Rear End: The rear end consists of the motor housing, fin attachments and drogue chute bay. The motor housing is a 16 inch long Blue Tube of 54mm diameter that accepts the p/n P54-4G High-Power Reloadable Rocket Motor form that also contains a Pro54 case spacer. The fin attachments are made from ¼ inch 5 ply maple wood constructed into a channel design and attached to the motor housing using epoxy. The channels in the fin attachment are designed for four ¼ inch 5 ply maple wood fins to be secured to the airframe. The drogue chute bay is separated from the motor housing by a bulk head with an attached eye-bolt and is 8 inches long, and has two 3/16" vent holes drilled in it. Complete length of the rear end is 28.5 inches.

Center Coupling: The center coupling's main purpose is to be the attachment point between the rear end and front end assembly and be capable of separating during recovery. It is 5 inches long with a centered 1 inch externally exposed point. The fore end has 4 holes to accept nylon sheer pins while the aft is secured by friction. Inside the coupling are two 3D printed frame to secure the turn buckle which connects to both the drogue and main parachutes. There are also two electrical communication rods which connect to the drogue deployment charge.



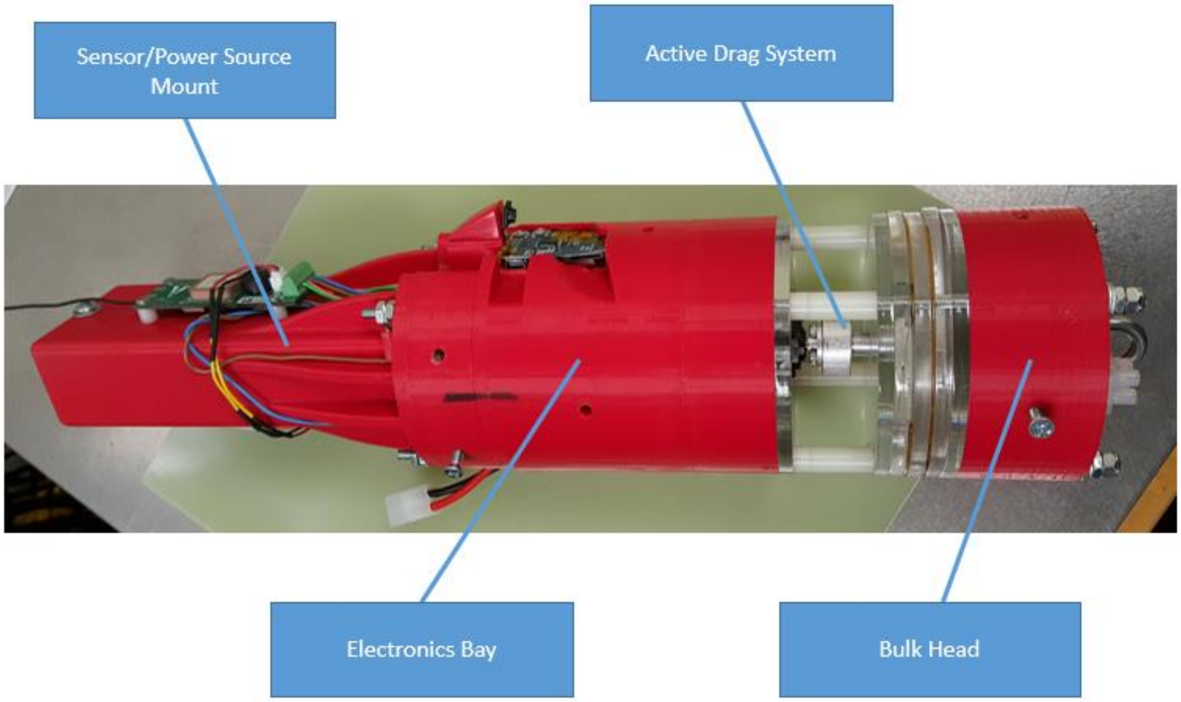
Center coupling

Front end Assembly: The front end assembly consists of the main parachute bay, the ORCA active drag system, electronics bay, and nose cone. The main parachute bay is 16 inches long, has four 3/16 inch vent holes drilled and is separated from the active drag system by a 3D printed bulk head. This bulk head has a centered eye bolt for main parachute attachment, four electrical communication nodes for both main and drogue parachute deployments, and in-wall nylon nuts used to attach the bulk head to the main blue tube frame of the rocket. The electrical communication nodes are dual purpose for communication and also securing the bulk head, drag system, and electronics bay assembly. The active drag system is positioned directly between the bulk head and the electronics bay. The electronics bay and sensor mount houses the flight computer and sensors, GPS unit, and power supply and fits inside the nosecone. The nosecone is a commercially available product procured from Apogee Rockets (PNC 3.9") and is constructed of Poly-propylene Plastic and is 12.75 inches long.

b. **Electronics & Payload**

The active drag system is controlled by an on board microcontroller breakout board (Flight Computer) equipped with a fully supported Atmel ATMEGA 328P and programmed using the Arduino IDE. Onboard sensors include a low power motion processing unit and barometric pressure sensor. Sensor data is logged to micro SD via an integrated breakout board. The drag system is mechanically controlled through a high-torque MG996R servo, which is directly controlled by the flight computer.

The ORCA drag system is situated directly between the bulk head and the electronics bay, and consists of four fins that extend out perpendicular to the direction of flight, and are made of ¼ inch Optix Acrylic Sheets. These fins are maneuvered by a rotational cam driven by a MG996R High Torque Servo with a max torque rating of 10kg/cm. Fins are controlled by rotating the servo, which is connected to a drive shaft on the cam.

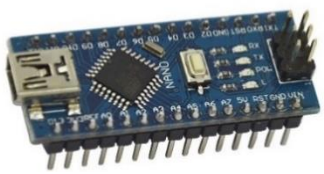


The top of the sensor mount has a channel specific for the competition AltimeterTwo, which make convenient access to the sensor between and after flights.

Also on the sensor mount is the Altus Metrum TeleMetrum v2.0 which will provide ground control with GPS position and also control the dual deployment recovery system.

The flight computer and high-torque servo are powered by a 7.2V / 1500mAh battery. On-board video is powered by an individual battery.

Altitude data is collected via an MPL3115A2 i2C barometric pressure and temperature sensor. There is also an onboard MPU6050, consisting of an integrated gyroscope and accelerometer to calculate in-flight angular acceleration and yaw, pitch and roll position, which will be used in post-flight analysis. All data is logged to Micro-SD via an Adafruit ADA254 SD breakout board.

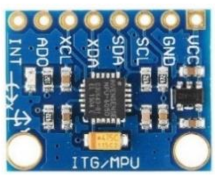


The ATMEGA328P breakout board has an onboard 5V voltage regulator which allows it to be powered by the rocket's main battery. It is flashed with the Arduino bootloader, which enables compatibility with programming via Arduino IDE.

ATMEGA 328P Breakout Board

Pressure data is converted to altitude by way of the Sparkfun.com MPL311A2 library. This data is the most crucial piece of information in the drag system control program.

MPL311A2 Breakout Board



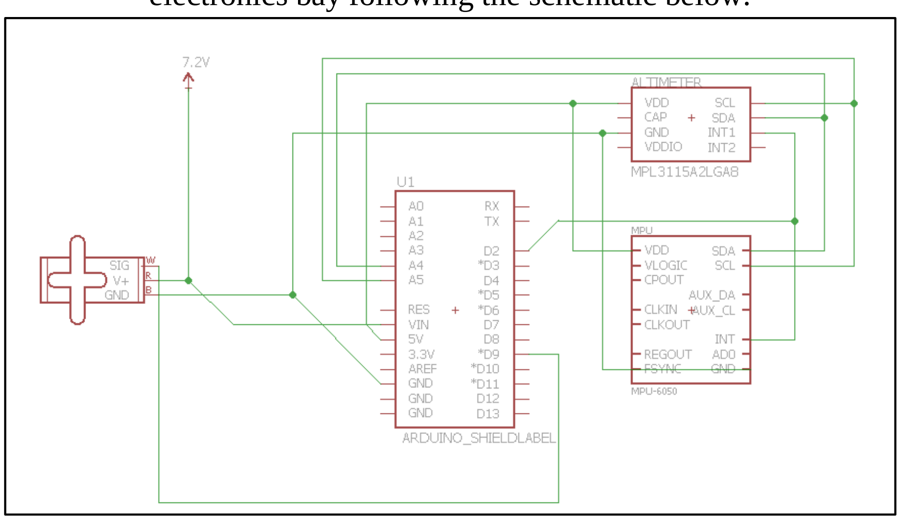
Angular acceleration and yaw, pitch, roll data will be collected on all flights and used for post-flight analysis.

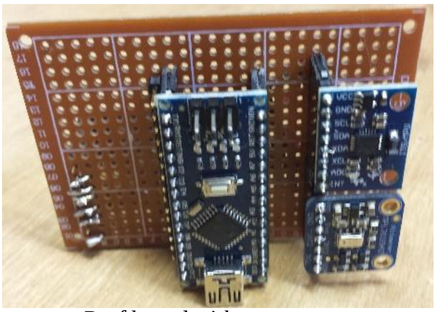
MPU6050 Motion Processing Unit

Altitude, acceleration, yaw, pitch, roll data are logged to micro SD via the ADA254 breakout board. The flight computer utilizes Arduino SD card library.

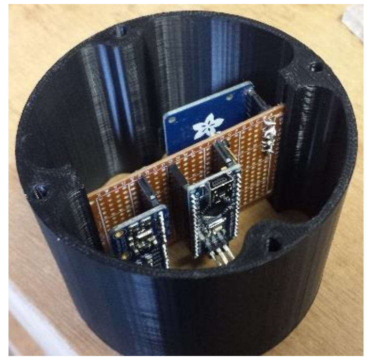
ADA254

All components are soldered onto a perf-board and mounted inside a custom 3D printed electronics bay following the schematic below.





Perf board with components



Flight computer mounted

Video capture is conducted utilizing a modified “808 keychain camera”. The internal circuit board and camera is removed from the factory key fob case and integrated into the frame of the rocket body. The 808 camera provides is powered by its own lithium-polymer battery and will provide up to 90 minutes of continuous video capture at 480p resolution at full charge. The camera system will be removed in order to retrieve the video footage post-flight.

808 Keychain Camera

808 integrated with airframe

c. **Programming**

The ATMEGA328P is flashed with the Arduino bootloader in order to be programmed using the Arduino IDE. The program reads in altitude data provided by the MPL311A2 barometric pressure sensor and calculates change in altitude and change in time clocked by the processor to determine vertical velocity and current altitude of the rocket. A combination of these two values are used to determine when and how long the drag system should be engaged, disengaged or redeployed.

d. **Recovery Systems**

The rocket utilizes a dual deployment system, controlled by the TeleMetrum, consisting of a drogue and main parachute. The drogue’s purpose is to decrease the amount of drift the rocket experiences between apogee and landing while also reducing the descent speed of the rocket prior to deployment of the main parachute. All research indicates a safe main chute deployment speed of less than 50 mph. In order to reach this speed, we used the following formula to calculate a diameter of 30 inches, at a coefficient of drag of 1.5, would be necessary for the drogue parachute:

$$D = \sqrt{\frac{2gm}{\rho C_d v^2 \pi}}$$

The commercially available parachute selected is the 30 inch elliptical from Fruity Chutes and weighs 3.1oz, has a 15.9 cubic inch packing volume. This will provide a 25 mph main chute deployment speed.

To meet the competition landing velocity requirement of 24 ft/sec, we utilized the same formula as above to calculate a diameter of 48 inches at a 2.4 coefficient of drag. The main parachute, 48 inch Iris Ultra Compact, was also procured form Fruity Chutes. This parachute weighs 4.3 oz and has a packed volume of 26 cubic inches. Both parachutes will be secured 1500 lb test Kevlar cord.

e. **Risk Mitigation Analysis**

Risk analysis was conducted as a team function using the following four step process.

1. Identify hazards.
2. Analyze hazards to determine risk.
   a. Risk is defined at the cross section of the probability of the hazard occurring and the severity of the event taking place.
3. Develop and implement controls and procedure to mitigate the risk.
4. Continuously evaluate risks during design and construction.

Operational risks were mitigated by implementing pre and post-flight checklists which are contained in Appendix B and C, respectively.

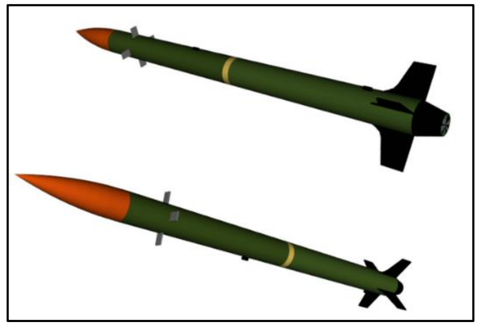
f. **Structural Analysis of Custom-Built Components**

Custom build components consist of 3D printed and wood crafted parts. 3D printed materials were tested using the physical properties of ABS plastic. Infill ratios were increased for components at higher stress portions of rocket. Institutional knowledge of design and performance of both 3D printed and wood constructed parts were leveraged during the design process.

g. **Construction Solutions and Techniques**

All 3D design files, laser cut patterns and wood forms are retained in the University of Wisconsin-River Falls Physics Department.

The rocket will be constructed by dividing assembly tasks amongst the three portions of the rocket: front end assembly, center coupling, and rear end. The electronics bay and payload will be assembled and mounted in to the front end. The motor housing will be mounted to the rear end and the coupling will secure the rear end to the front end assembly.



Render of initial concept

h. **Additional Safety and Material Handling Procedures**

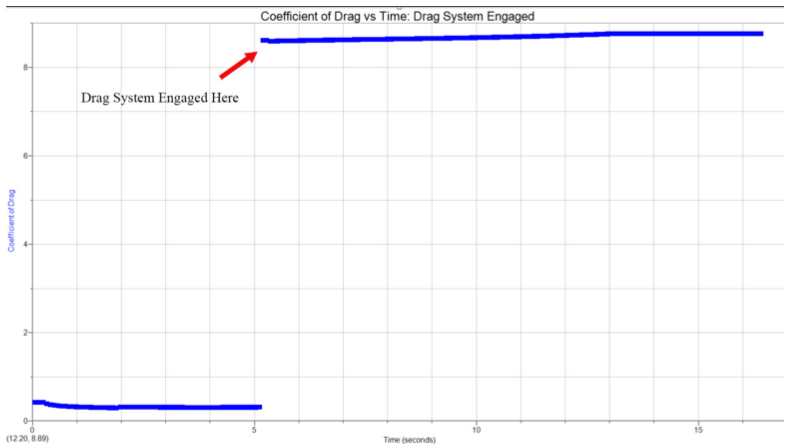
- Materials must be stored and handled with care at all times.
- Materials such as paint epoxy, ejection charges can be hazardous and must only be handled in well ventilated areas.
- Electronics present risk of shock during test.
- Proper personal protective equipment (PPE) must be worn at all times.

4. Flight Simulation, Performance and Analysis

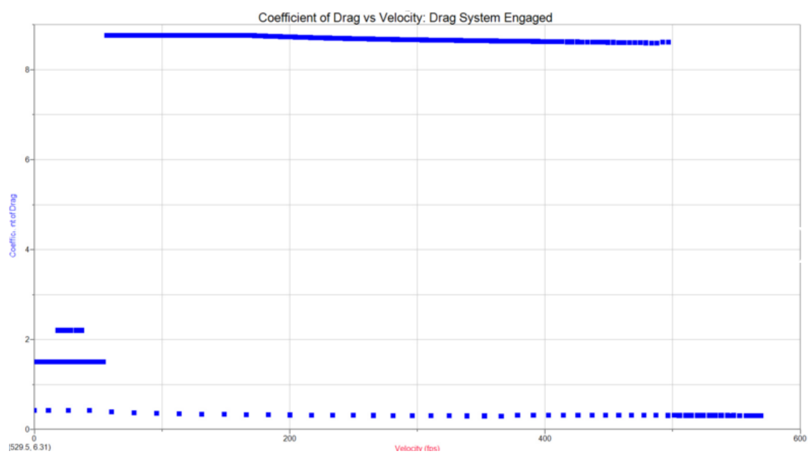
Estimation of the flight performance was conducted using both OpenRocket and Rocksim. Drag system “fins” were simulated as proportionally accurate static fins. Simulations were conducted separately assuming both a deployment for the full duration of the flight, and fully stowed. Environmental conditioned were estimated based on the geographic location and seasonal average conditions. Temperature was assumed to be 50F with a relative humidity of 41%. To simulate the drag system being activated post motor burnout, data from the aforementioned simulations was compiled and analyzed.

Based on simulation, engine burnout is expected to occur ~4 seconds after launch. The rocket will then engage the drag system (on 2nd launch) and reach apogee ~14 seconds later. Based on the selected recovery system, the rocket will be under drogue chute from apogee to 500 feet, then under main chute for the remainder of the descent. Total descent time is expected to be 147 seconds. Assuming 15-25 mph winds, drift is expected to be less than 2500 feet.

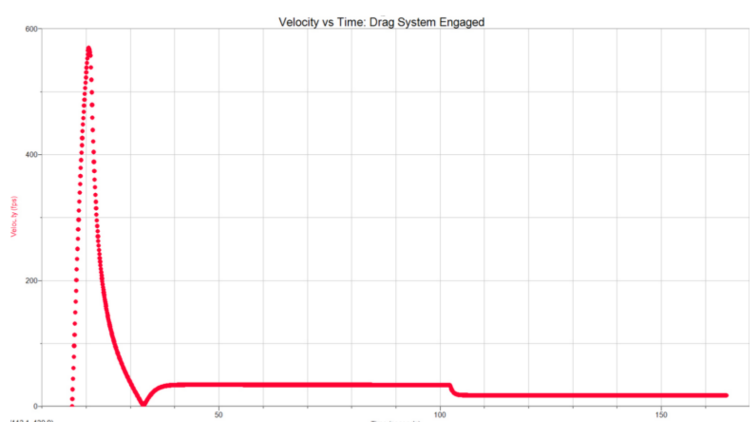
Coefficient of Drag vs Time (drag system engaged)



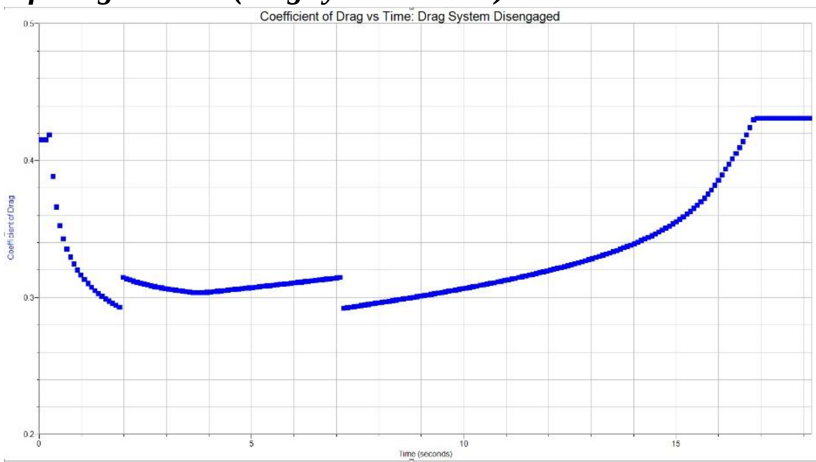
Coefficient of Drag vs Velocity (drag system engaged)



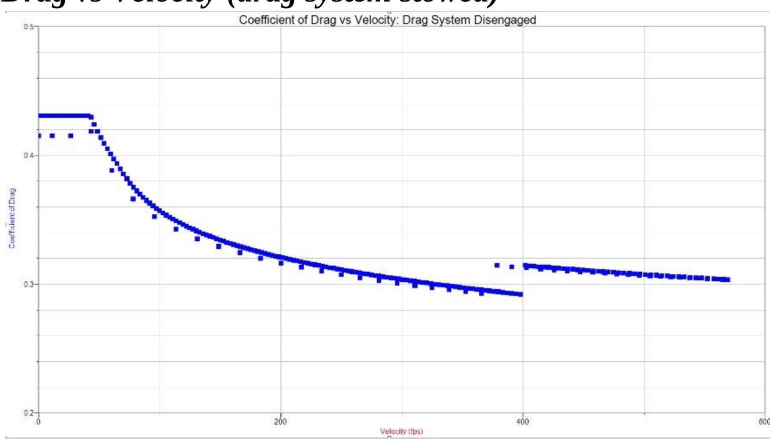
Velocity vs Time (drag system engaged)



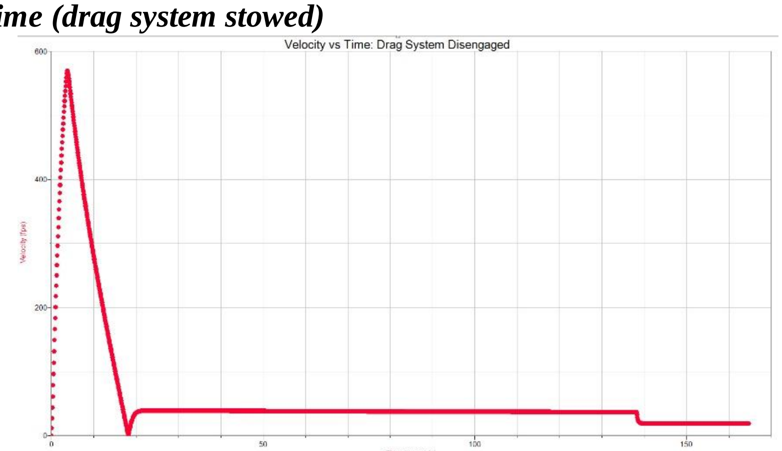
Coefficient of Drag vs Time (drag system stowed)



Coefficient of Drag vs Velocity (drag system stowed)



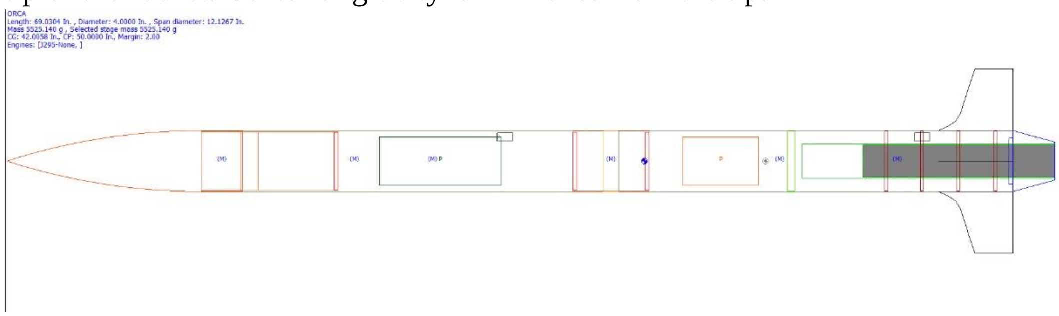
Velocity vs Time (drag system stowed)



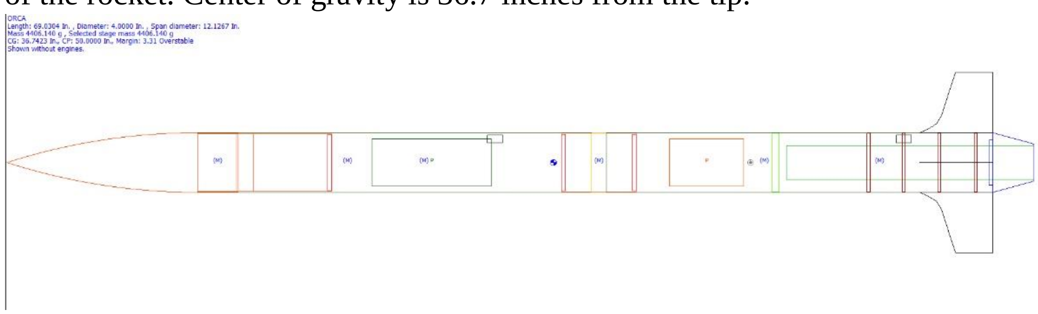
5. Center of Pressure & Center of Gravity Analysis

Knowing that the simulation software is not made to accurately calculate dynamic fins such as on the drag system, all static margins in each possible scenario in motor/drag system combinations will be no less than 2 to ensure maximum risk mitigation is rocket instability.

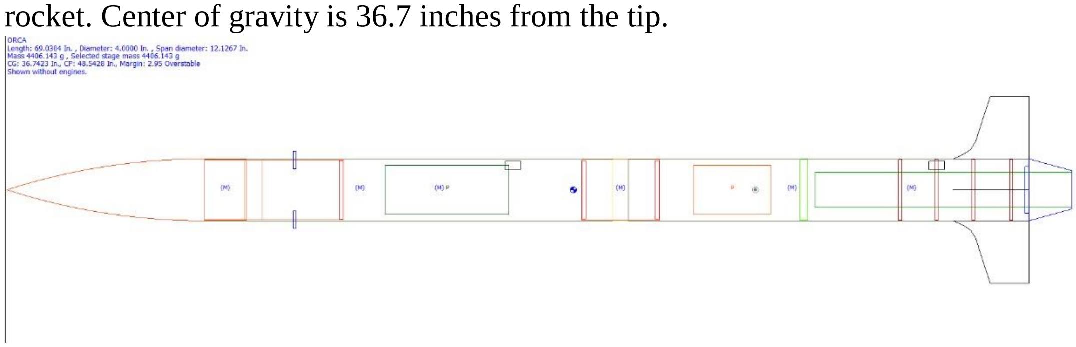
Center of pressure with motor and drag system disengaged is located 50 inches from the tip of the rocket. Center of gravity is 42 inches from the tip.



Center of pressure without motor, drag system disengaged remains 50 inches from the tip of the rocket. Center of gravity is 36.7 inches from the tip.



Center of pressure without motor, drag system engaged is 48.5 inches from the tip of the rocket. Center of gravity is 36.7 inches from the tip.



6. Funding and Budget

Funding for the 2016 High Powered Rocket Team was acquired via the University of Wisconsin-River Falls Undergraduate Research, Scholarly and Creative Activity (URSCA) Grant and the Falcon Travel Grant. Funding via URSCA was the secondary funding option, which was pursued when the team's application for funding from the Wisconsin Space Grant Consortium was denied.

Refer to Appendix D for a line-by-line account of the anticipated cost of the UW-River Falls High Powered Rocket Team's participation in the 2016 Space Grant Midwest High-Powered Rocket Competition.

Appendix A: Project Task Tracker

Task Tracker				
2016 Midwest Rocket Competition				
University of Wisconsin - River Falls				
Main Task Category	**Subtask**	**Responsibility**	**Notes**	**Due Date**
Registration	Submit/Email	Mitch	Submit Regration and fee	29-Jan
Declaration of Competition Attendance	Submit/Email	Mitch	Submit List to Midwest Rocket Competition	12-Feb
Declaration of Competition Attendance	Finalize Team Members	Mitch/Adam	Complete at 1st Meeting	9-Feb
Submit Photos to Competition	Submit/Email	Mitch	Email photos of model rocket launch	
Submit Photos to Competition	Launch Model Rocket	All	Launch model rockets at 2nd meeting	4-Feb
Preliminary Design Report	Submit/Email Report	Mitch		18-Mar
Preliminary Design Report	Final Draft	Adam	Final Draft Complete	16-Mar
Preliminary Design Report	Rough Draft	Adam	Rough Draft Complete	9-Mar
Preliminary Design Report	First Draft	Adam	First Draft Complete	2-Mar
Preliminary Design Report	Motor Selection/Design	Mitch/Roman	Select Motor and Design Housing	29-Feb
Preliminary Design Report	Electronics/Circuit Board	Adam/Trevor	Design Circuit Board and housing	29-Feb
Preliminary Design Report	Drag System	Mitch	Complete Design and Mechanism	29-Feb
Preliminary Design Report	Air Frame	Mark/Riando	Complete design of tube, fins and nosecone	29-Feb
Preliminary Design Report	Chutes	Brian	Complete design of parachutes	29-Feb
Preliminary Design Report	Programming	Adam/Trevor	Complete arduino program for controlling drag and chute sy	29-Feb
Test Launch	Conduct Test Launch	All	Test Rocket at North Branch Site	26-Mar
Test Launch	Schedule/Confirm Launch	Mitch	Schedule or Confirm launch availability near 15-Apr	29-Jan
Test Launch - Assembly	Rocket Completely Assembled	All	Assemble all rocket components, then begin painting	18-Mar
Test Launch - Assembly	Motor Assembly Complete	Mitch/Roman	Motor complete and fixed to airframe	18-Mar
Test Launch - Assembly	Electronics/Circuit Board Assembly Com	Adam/Trevor	Elecronics installed in airframe	18-Mar
Test Launch - Assembly	Drag System Assembly Complete	Mitch	drag system installed in airframe	18-Mar
Test Launch - Assembly	Air Frame Assembly Complete	Mark/Riando	air frame assembled and ready for component installation	15-Mar
Test Launch - Assembly	Parachute Assembly Complete	Brian	parachute installed in air frame	18-Mar
Test Launch - Assembly	Programming Assembly Complete	Adam/Trevor	program loaded to microcontroler	18-Mar
Outreach Event	Conduct Outreach Event	All	Event at High School or SPS meeting	22-Apr
Outreach Event	Schedule Outreach Event	Trevor	Event should be the week after test launch, to present the r	25-Mar
Outreach Event	Submit Outreach Form to Competition	Mitch	Email/submit form	22-Apr
Flight Readiness Report	Submit Readiness Report to Competitio	Adam/Mitch	Email/submit form	6-May
Flight Readiness Report	Final Draft Complete	Adam	Prepare for submission	4-May
Flight Readiness Report	Rough Draft Complete	Adam	Prepare for review	29-Apr
Competition Weekend	PowerPoint Slides	Adam	Prepare/inform team on presenation responsibilities	1-May
Competition Weekend	Launch Tasks	All	TBD, pending test launch	
Competition Weekend	Admin/Logistics	Mitch	Hotels, Transportation, etc.	

Appendix B: Pre-Flight Checklist

			1st Flight	2nd Flight
Category	**Task**	**Notes**	**Initials**	**Initials**
Recovery Systems				
[ ]	Visually inspect all cords and connection points			
[ ]	Ensure parachute properly loaded			
[ ]	Visually inspect ejection charges			
Electronic Systems				
[ ]	Confirm 7.2V main battery			
[ ]	Confirm 3.3V camera battery			
[ ]	Visual confirmation of SD card on flight computer			
[ ]	Disconnect servo (flight 1 only)			
[ ]	Power on main switch in nosecone			
[ ]	Visually observe servo initialization (flight 2 only)			
[ ]	Confirm "ready" LED on main computer			
[ ]	Confirm loaded position of competition altimeter			
[ ]	Power on GPS/recovery system controls			
[ ]	Turn on video capture, visually confirm power up sequence (Two-man confirmation required)			
Propulsion System				
[ ]	Record motor type and mass			
[ ]	Model/Type:________			
[ ]	Mass:________g			
[ ]	Install Motor			
[ ]	Ensure motor retainer fully secured			
Airframe				
[ ]	Visual inspection of nosecone			
[ ]	Visual inspection of sheer pins			
[ ]	Visual inspection of fins			
Operational Items				
[ ]	Secure nosecone on rocket			
[ ]	Capture photograph of rocket on launch pad			
[ ]	Launch Rocket			
[ ]	Begin in flight checklist			

Appendix C: Post-Flight Checklist

			1st Flight	2nd Flight
Operations	**Task**	**Notes**	**Initials**	**Initials**
[ ]	Locate rocket			
[ ]	Pack parachutes			
[ ]	Recovery telemetry file from SD card			
[ ]	Flash max altitude data to memory			
[ ]	Recovery altimeter 2 altitude			
[ ]	Recover and remove video file from camera			
[ ]	Begin charging video camera for 2nd flight			
[ ]	Start pre-flight checklist (after first flight only)			

Appendix D: Budget

2016 Space Grant Midwest High-Powered Rocket Competition							
UWRF High Powered Rocktry: ORCA							
Budget							
Components and Materials	**Unit Price**	**Qty**	**Total**	**Components and Materials**	**Unit Price**	**Qty**	**Total**
Plywood 1/4" 2'x4'	9.92	1	9.92	Racer's Edge 7.2V 1500mAh 6 cell NiCd	10.98	2	21.96
shelf pin 1/4" brass	1.97	1	1.97	ARR Blue AC-98x48" FLC	39.95	1	39.95
1" metal spring clamp	0.99	2	1.98	Blue Tube 98/48	38.95	2	77.90
Sheet Metal Screw Zinc #6x1/2"	1.18	1	1.18	Blue Tube 54/48	23.95	2	47.90
Sheet Metal Screw Zinc #8x1/2"	1.18	1	1.18	LOC PNC-3.90 (98mm)	23.05	1	23.05
Mini Spring Clamp	0.37	2	0.74	Jolly Logic Snap Mount	10.65	1	10.65
8"x10" Non Glare Picture Glazing	1.98	2	3.96	Jolly Logic AltimeterTwo	69.95	1	69.95
Thrded Rod 12x8-32	0.98	1	0.98	Jolly Logic AltimeterThree	99.95	1	99.95
Trnbckle Eye 1/4"x5-1/4"	5.24	1	5.24	Kevlar Shock Cord 1500#	0.92	30	27.60
Paint, Spray Black	7.37	1	7.37	Hatchbox 1.75mm ABS Filament	21.98	1	21.98
Insulating Pipe 3/4C Gray	2.79	1	2.79	Kootek GY-521 MPU-6050	5.99	2	11.98
PVC 3/4"	2.99	2	5.98	Adafruit Altimeter MPL311A2	10.99	2	21.98
CAP 3/4" SCH40	0.69	8	5.52	Adafruit ADA254 SD	14.99	2	29.98
3/4" TEE SXSXS SCH40	0.69	4	2.76	MG996R Metal Gear High Torque Servo	11.99	4	47.96
PIPE SCH40 3/4"/x10 END	2.79	2	5.58	LDO 3.3v 0.8A Voltage Reg	2.00	2	4.00
1/4" Oak Panel	4.39	2	8.78	Ribbon Set	7.29	1	7.29
.22"x24x18" Acrylic Sheet	19.98	2	39.96	Metal Servo Horn	7.99	1	7.99
4x20mm Machine Screws	2.97	3	8.91	5x7cm Protoboards	2.10	1	2.10
Machine Screws Rnd 1/4"	1.18	3	3.54	Osoyoo USB Nano Atmega328p module	7.50	3	22.50
Eye bolt 1/4" x 4	0.48	2	0.96	Tenergy Universal Smart Charger	15.99	1	15.99
Threaded rod 24x10/24	1.46	2	2.92	GPS/altimeter control	458.57	1	458.57
Threaded rod 12x8-32	0.98	4	3.92	Test Motors	85.95	3	257.85
Eye bolt 1/4" x 2-1/2" Zinc	1.18	1	1.18	Micro SD Cards	10.00	2	20.00
Rocker Switch	3.99	1	3.99	Competition Motors	85.95	2	171.90
808 Keychain Camera	7.90	2	15.80	Cesaroni Pro54 4G Casing	84.69	1	84.69
Subtotal			147.11	Subtotal			1,605.67
Components and Materials Total			1,752.78				
Logistics and Administrative							
Competition Registration			400.00				
Shipping			300.00				
Hotels			400.00				
Sustainment			200.00				
Logistics and Admin Total			1,300.00				
Total Costs			**3,052.78**				