THE OHIO STATE UNIVERSITY

Regional Rocket Launch Competition

Final Report

Scarlet and Grey Rocket

Table of Contents

Table of Figures

Executive Summary

The Scarlet and Grey Rocket was designed and built by a small team of undergraduate students at The Ohio State University between January and April of 2014. The rocket was designed to carry a sensing payload and reach an altitude of exactly three thousand feet per the design requirements of the Great Midwestern Regional Rocket Launch competition. The design process centered upon structural design, aerodynamics, and avionics. From the motors available for the propulsion system an I540 rocket motor was selected. The final rocket was 79.75 inches in height with a four inch body diameter.

The exterior of the rocket was constructed primarily from wound fiberglass with a commercially purchased plastic nosecone. Plywood was used for the construction of centering rings and bulkheads inside the rocket. The strong exterior materials protect the rocket from shock and impact damage during launch and recovery of the vehicle. A motor tube was fabricated which secures the commercially purchased motor casing to the inside of the rocket. The motor casing was held in place by metal retaining disks.

The rocket features an electronic dual-deploy recovery system with motor ejection charge backup per the requirements of the competition. The dual-deployment setup splits the rocket into two sections at apogee and ejects two drogue streamers allowing the rocket to enter a stabilized free fall. After reaching a low altitude, a second charge in the upper body is ignited which deploys the main parachute, allowing the rocket to return to the ground at a safe impact velocity.

The avionics system controls the electronic deployment system from within a coupler which connects the upper and lower portions of the rocket. The coupler was fabricated by the design team from fiberglass and designed to facilitate the dual-deploy recovery system and safely store the avionics system.

Simulations of the rocket in flight were performed using RockSim9 software and physics based modeling in MATLAB. The rocket is anticipated to achieve a maximum altitude of 3024 feet with a peak acceleration of 16.27 g’s. The rocket cost of construction of the rocket was $1174.

Design Features of Rocket

The final design of the rocket is 79.75 inches in total height and weighs 135.2 ounces at launch. The outside diameter of the body tube is four inches. The breakdown of the rocket is as follows:

1. Fins: The fins have a 9 inch root chord and a 4 inch tip chord. The leading edge of the tip is swept back 4 inches from the leading edge of the root. The semi-span is 3.7 inches. The fins are located 1.25 inches from the back of the rocket. The fins are 0.093 inch thick fiberglass. There are 3 fins, spread evenly 120 degrees apart around the base of the rocket.The fins have the following shape shown by Figure 1.

Figure 1: Fin Design

2. Motor Assembly: The I540 motor casing is secured in a fiberglass motor tube. The motor tube was centered in the body tube with two ½ inch thick plywood centering rings. The motor tube is thirteen inches long and includes metal retaining plate to secure the motor casing in for the back kick of motor. The motor assembly was shown below in Figure 2.

Figure 2: Motor Assembly

3. Lower Body Section: The motor assembly and fins are all secured to the bottom body tube section. The tube is 27 inches long and made of fiberglass. The rocket

will separate between the upper and lower sections at apogee and streamers will be deployed from the lower section. The streamers are intended to provide high visibility of the rocket for visual tracking as well as partially stabilize the rocket during free fall. The lower body section was shown below in Figure 3.

Figure 3: Lower Body

4. Coupler: The coupler housed the electronics payload and holds the charges for the dual deploy recovery system. The coupler was made from fiberglass with plywood bulkheads that provide an air tight seal for the electronics. The coupler is 8 inches long and will be set 4 inches in on the top and bottom body tubes. There are brass pipe fittings on either end of the coupler to hold black powder which functions as ejection charges. More details on the electronic payload can be found in the design features of payload system section. An image of the coupler was included below as Figure 4.

Figure 4: Coupler

5. Upper Body Section: The upper body section is anchored to the coupler to allow and remains attached to it after separation from the lower section. The parachute is stored in this section of the rocket which is deployed at lower altitude by the second ejection charge located in the top of the coupler. An image of the upper section was included below as Figure 5.

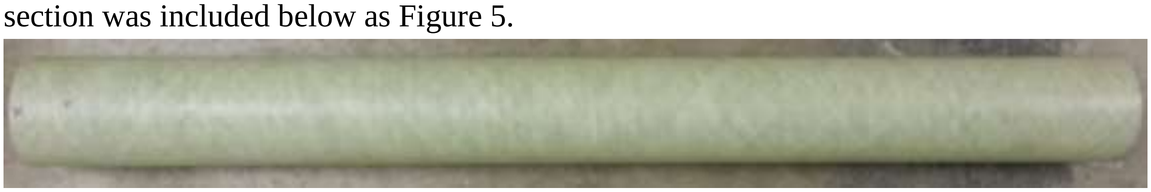


Figure 5: Upper Body

6. Parachute: The Iris Ultra 48 inch parachute was chosen as the main chute. The choice was made based on the size, weight and drag characteristics of the parachute. This parachute compacts into a 2.6 inch diameter, 7.8 inch long cylinder and only weighs 7.5 ounces. The drag coefficient of this parachute is 2.2. An image of the parachute was included below as Figure 6.

Figure 6: Parachute

7. Nose Cone: The length of the nose cone is 16.75 inches. There is a 4 inch insertion section making the effective length of the nose cone 12.75 inches. The bottom of the nose cone was cut off and a plywood bulkhead was inserted into the bottom to create a strong anchor point for the parachute. An image of the nosecone was included below as Figure 7.

Figure 7: Nosecone

Design Features of Payload System

The Scarlet and Gray rocket was equipped with two separate onboard computer systems. The primary computer system was constructed from a combination of independent microcontrollers and sensors interfaced on a single circuit prototype board.

The avionics system was based around an Arduino Fio microcontroller. The Fio is based upon an Atmel ATmega328 microprocessor which runs at a clock speed of eight megahertz. The Fio features 22 general purposes input/output pins, eight of which feature built in analog-to-digital converters (ADCs). The microcontroller also features a socket to connect an Xbee radio modem and connection points for the power source which includes onboard power regulation for up to twelve volt inputs.

Unlike many popular microcontroller systems, the Arduino Fio does not include an onboard FTDI interface. This saved on total weight and bulk of the microcontroller. A separate FTDI chip was used in order to interface the microcontroller with a PC workstation for programming. An image of an Arduino Fio microcontroller was placed below in Figure 8.

Figure 8: Arduino Fio[1]

The avionics system was fully powered by a two cell lithium ion polymer battery with a capacity of 1000 mAh. This battery has a nominal voltage level of 7.4 volts and is capable of 25 amps of continuous discharge current. The entire avionics system draws a 26.9 milliamps of current, giving the system a total operating time of approximately 37 hours neglecting the large temporary current draws for charge ignition. This allows the system to be used in multiple flights without replacing or recharging the battery. The high capacity of the battery and low parasitic resistance also allow for long storage times of the system without requiring recharging.

[1] Stock Photo, from http://arduino.cc/en/Main/ArduinoBoardFio

Component	*Current* μA
Atmel ATmega328	300
Bosch BMP180	1000
Analog Devices ADXL377	300
MediaTek MT3339 GPS	25000
Sparkfun SD Card Logger	300
Total	**26900**

The primary means of tracking the altitude of the rocket was accomplished via a Bosch BMP180 barometric pressure sensor. This sensor is equipped with an I2C digital interface capable of relaying pressure and temperature data to the microcontroller at up to 128 hertz. The BMP180 features analog internal sensors with an integrated ADC which sends data to the control unit. The control unit communicates with the master device via I2C. An image of the BMP180 on the utilized breakout board was placed below in Figure 9.

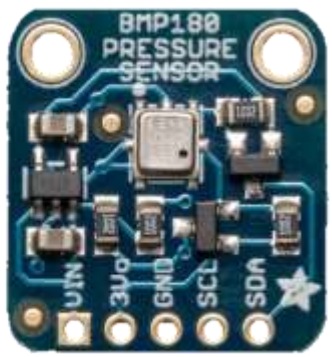


Figure 9: Bosch BMP180[2]

I2C is a half-duplex synchronous digital communication protocol. The Arduino Fio acts as the master device and generates a clock signal on the serial clock (SDA) connection. Data is transmitted via the serial data (SDA) connection by the sensor after being called by the master. The suggested wiring diagram for the BMP180 was included below as Figure 10.

[2] Stock Photo, from http://www.adafruit.com/products/1603

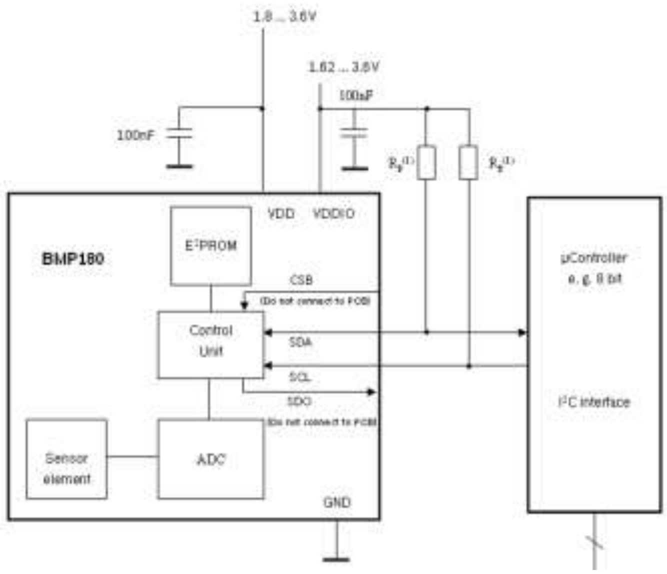


Figure 10: BMP180 Diagram[3]

A MediaTek MT3339 GPS module was also included in the avionics system. This module features sixty-six channels with a ten hertz refresh rate. The module was setup to communicate with the Arduino using a UART connection with data transmitted in the National Marine Electronics Association (NMEA) 0183 standard. The MT3339 features an advertised positional accuracy of 1.8 meters at altitudes up to 40 kilometers. An image of the MT3339 on the utilized breakout board was included below as Figure 11.

Figure 11: MediaTek MT3339[4]

The final sensor of the avionics computer system was an Analog Devices ADXL377 accelerometer. This sensor is capable of three-axis measurement of acceleration in up to +/- 200 g's. The sensor provides three analog output signals which linearly scale +/-200 g's to an electrical signal between zero and 3.3 volts. This correlates to 8.25millivolts per g in difference from the nominal zero g voltage of 1.65 volts. An operational diagram of the ADXL377 was placed below in Figure 12.

[3] From BMP180 Data Sheet, https://ae-bst.resource.bosch.com/media/products/dokumente/bmp180/BST-BMP180-DS000-09.pdf
[4] Stock Photo, from http://www.adafruit.com/products/746

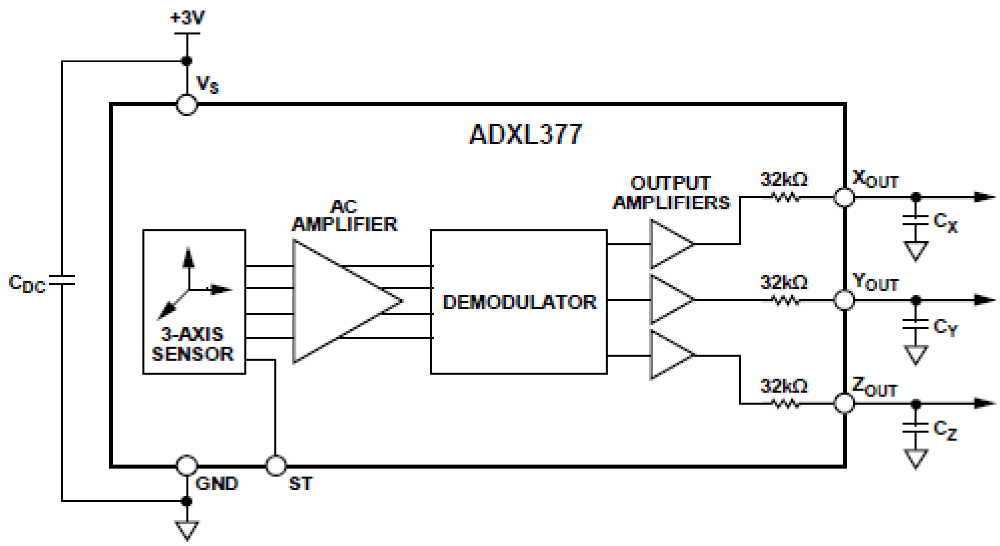


Figure 12: Analog Devices ADXL377 Diagram[5]

The Arduino Fio's ADCs scale an analog input signal from zero to five volts to a ten bit binary number which gives a range of zero to 1023 in decimal. This correlates to a resolution of 4.89 millivolts per decimal integer. Together, this gives the sensor system a resolution of 0.593 g's per decimal digit difference from the nominal. Due to this relatively low sensor resolution, the accelerometer was not used as a direct measurement of the rocket's positional displacement. Rather, the accelerometer was used to detect major flight events during which the rocket undergoes extreme levels of acceleration.

In future revisions of this avionics system, a differential operational amplification circuit may be introduced between the output of the ADXL377 and the ADCs of the Arduino Fio. This circuit would include logic level converters to move the nominal voltage to the 2.5 volt center of the range of the Arduino ADCs to maximize the operational range of the system. It will additionally include signal buffers for circuit isolation.

An image of the ADXL377 on the utilized breakout board was placed below in Figure 13.

Figure 13: Analog Devices ADXL377[6]

[5] From ADXL377 Datasheet, http://www.analog.com/static/imported-files/data_sheets/ADXL377.pdf

The Arduino Fio features an integrated connector for an Xbee radio modem. An Xbee Pro 900 module was included on the system for radio communication with a ground station. The radio relays real time data to the ground station which allows tracking of the rocket in the event of a recovery systems failure. The radio operates at frequency of 900MHz and has an advertised line of sight range of six miles. The modem was coupled with a 900MHz tuned 2dBi RPSMA antenna. The ground station was provided with a matching setup with the modem installed into an Xbee Explorer chip which includes an integrated FTDI interface such that the radio can communicate with the ground station via USB. An image of the radio setup for the ground station was included below as Figure 14.

Figure 14: Ground Station Radio

The avionics system also was designed with onboard nonvolatile data storage in the form of a Secure Digital (SD) card logger. The SD card logger features an Atmel ATmega328 microprocessor which communicates with the Arduino Fio via a UART connection. The logger's onboard processing writes all incoming serial data to a file on the SD card in American Standard Code II (ASCII). An image of the SD card logger was shown below in Figure15X.

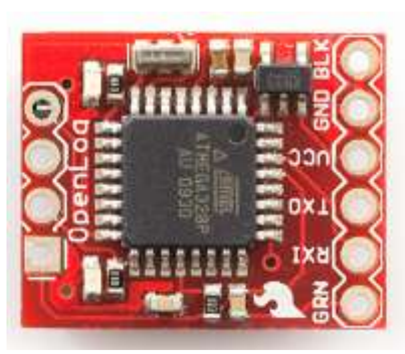


Figure 15: SD Card Logger[7]

The power supply from the 7.4 volt battery was brought down to five volts via a five volt regulator in the avionics circuitry. All individual components were purchased on breakout

[6] Stock Photo, from https://www.adafruit.com/products/1413
[7] Stock Photo, from https://www.sparkfun.com/products/9530

boards with onboard voltage regulation systems such that all were five volt tolerant. A piezoelectric buzzer was also included as part of the system in order to provide audible feedback to control system events. An image of the assembled avionics system was placed below in Figure 16.

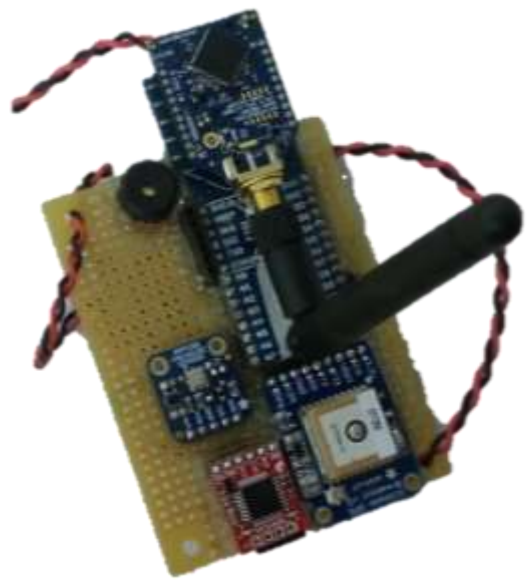


Figure 16: Primary Avionics System

Control software for the primary avionics system was programmed using Arduino C in the Arduino Integrated Development Environment (IDE). Upon power on, the Arduino Fio starts and all sensors are initialized. During the startup procedure, the system provides diagnostic feedback via radio to the ground station. Following this, the system waits for an arm command to be sent via radio from the ground station. After receiving this command, the system will radio confirmation of armament to the ground station and wait for detection of the launch event. The data input from the accelerometer is monitored for launch detection.

During flight, the avionics system logs all sensor data to the onboard SD card and also sends relevant real time data to the ground control station via radio in real time. The microcontroller uses the real time determination of the altitude and velocity of the rocket in order to determine the optimal time to ignite the drogue ejection charge. Ejection charges are electrically ignited using nichrome attached to the avionics battery. The microcontroller sends a high signal to a metal oxide semiconducting field effect transistor which allows the higher voltage and current from the battery to flow through the nichrome, thus igniting the black powder charge.

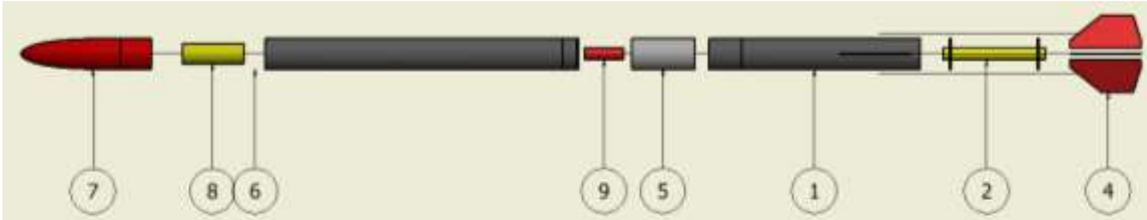
The charge is triggered slightly in advance of the three thousand foot target altitude in order to slow the rocket which is designed to climb slightly passed the target altitude in the event of electronic drogue deployment failure. In the event of a computer failure, there is a motor ejection charge backup which will cause separation and deployment of the drogue streamer. The rocket then is designed to go into a stabilized fall until it reaches low altitude when the computer triggers the ejection charge for the main parachute. This allows the rocket to slow to a safe landing velocity without risking extreme travel due to slow decent from high altitude.

The rocket additionally features a second onboard computer system in the form of a Raven3 commercial altimeter. The system additional features a built-in FTDI interface to allow direct communication to a PC workstation via a standard USB connection. An image of the Raven3 system was included below as Figure 17. The Raven3 utilizes onboard accelerometers and a barometer in order to track the rocket's altitude during flight. The Raven3 therefore provided a benchmarking tool for the primary avionics system.

Figure 17: Raven3 Altimeter[8]

[8] Stock Photo, from http://www.featherweightaltimeters.com/The_Raven.php

Diagram of Rocket



PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	Bottom Body Tube
2	1	Motor Tube
3	2	Centering Ring
4	3	Fin
5	1	Coupler
6	1	Top Body Tube
7	1	Nose Cone
8	1	Main Chute
9	1	Streamer

Figure 18: Exploded View

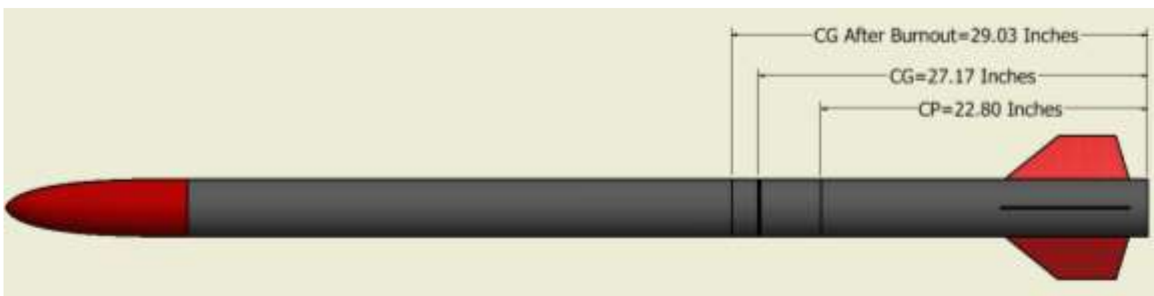


Figure 19: Key Locations

Analysis of Anticipated Performance

A numerical simulation was conducted using MATLAB to solve the differential equations of motion associated with the physical model of the rocket during flight. The simulation was used as check point against the RockSim9 simulation results which were used as the primary design tool for the rocket.

The MATLAB simulation used MATLAB's built in differential equation solver, ode45. A function file was defined to represent the physical model of the rocket which determined the forces and acceleration of the rocket at any point in the flight path given the time, altitude, and velocity of the rocket.

The model was programmed to determine the overall force acting upon the rocket in the vertical direction as the summation of thrust, drag, and weight was defined as a negative force and drag always acts in the direction opposite the vertical velocity of the rocket. The forces were then divided by the mass of the rocket to determine the instantaneous acceleration. The acceleration of the rocket was calculated via the following equation:

$$a_y = \frac{T(t) - D(y,V)\left(\frac{V}{|V|}\right)}{m(t)} - g$$

Where T was defined as thrust as a function of time, D was defined as drag as a function of altitude and velocity, m was defined as mass as a function of time, g was gravitational acceleration, and V was the velocity of the rocket. The force of drag on the rocket was calculated by the following equation:

$$D = \frac{1}{2}\rho(y)V^2 S C_D$$

Where rho was defined as the air density as a function of altitude, S was the frontal area of the rocket, and C_D was the estimated drag coefficient.

The change in weight of the rocket was modeled throughout the motor burn via linear interpolation of the starting rocket weight and the final weight after exhaustion of the propellant. After the motor burnout, the weight of the rocket was considered constant as the final post-burnout value.

Motor thrust data was collected for the I540 motor used in the rocket. This data was then used to determine the thrust at any time during the motor burn period of the flight. MATLAB's built in interpolation procedure was used to piecewise cubic spline interpolation between the data points in order to simulate the launch with higher time fidelity than was available for the thrust data. The thrust data with the interpolated function was shown below in Figure 20.

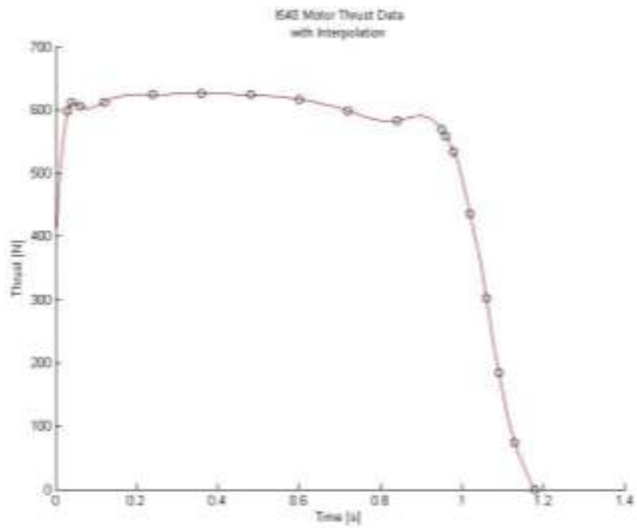


Figure 20: I540 Thrust

The air density change with altitude was determined based upon a curve fit of atmospheric air density from the 1976 US Standard Atmosphere model. Data points were used in increments of every kilometer from sea level to five kilometers and Microsoft Excel was used to produce a quadratic curve fit of the data. The equation had a coefficient of determination of 100% indicating a very accurate data fit for the points used in its determination. The air density data was included below in Figure 21.

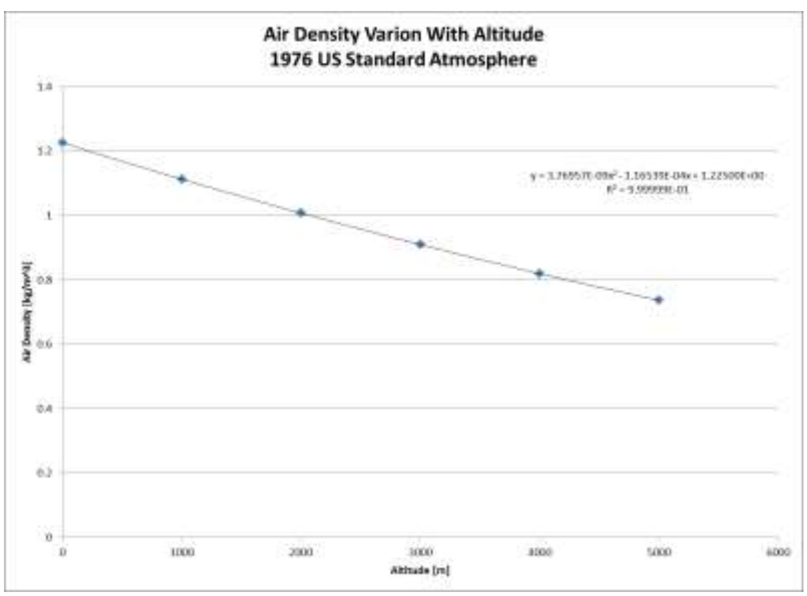


Figure 21: Density Variation with Altitude

The launch simulation was conducted for a fifteen second interval with time stepping of 500 microseconds. The simulation resulted in a predicted maximum altitude of 3017.4 feet and a peak acceleration of 16.53 g's at 0.54 seconds. This matched closely with the RockSim9 simulation results which predicted a maximum altitude of 3030.9 feet with only 0.45 percent between the two simulations. The RockSim9 simulation additionally predicted a maximum acceleration of 16.01 g's, also matching closely with 3.2% relative error between the results. The predicted altitude of the rocket was plotted against time in Figure 22 below, and the acceleration of the rocket over the first three seconds of the flight was shown in Figure 23 below.

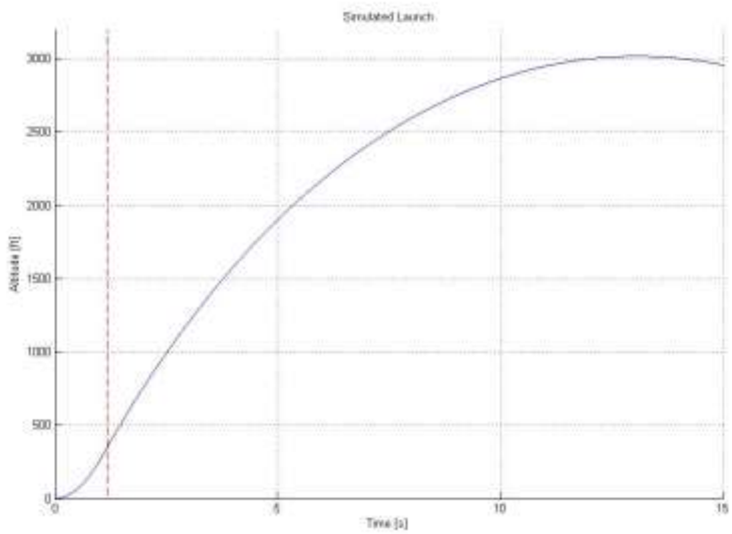


Figure 22: Launch Simulation Results

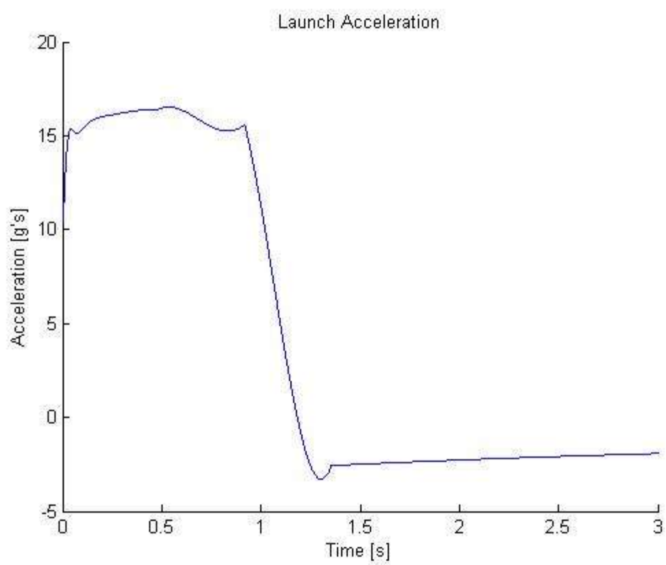


Figure 23: Launch Acceleration

Rocket Competition - Simulation results

Engine selection

[I540WT-*]

Simulation control parameters

- Flight resolution: 800.000000 samples/second
- Descent resolution: 1.000000 samples/second
- Method: Explicit Euler
- End the simulation when the rocket reaches the ground.

Launch conditions

- Altitude: 1000.00000 Ft.
- Relative humidity: 50.000 %
- Temperature: 59.000 Deg. F
- Pressure: 29.9139 In.

Wind speed model: Calm (0-2 MPH)

- Low wind speed: 0.0000 MPH
- High wind speed: 2.0000 MPH

Wind turbulence: Fairly constant speed (0.01)

- Frequency: 0.010000 rad/second
- Wind starts at altitude: 0.00000 Ft.
- Launch guide angle: 0.000 Deg.
- Latitude: 0.000 Degrees

Launch guide data:

- Launch guide length: 72.0000 In.
- Velocity at launch guide departure: 76.8579 ft/s
- The launch guide was cleared at : 0.171 Seconds
- User specified minimum velocity for stable flight: 43.9993 ft/s
- Minimum velocity for stable flight reached at: 24.6722 In.

Max data values:

- Maximum acceleration: Vertical (y): 515.264 Ft./s/s Horizontal (x): 0.262 Ft./s/s Magnitude: 515.267 Ft./s/s
- Maximum velocity: Vertical (y): 513.4899 ft/s, Horizontal (x): 2.0858 ft/s, Magnitude: 513.5023 ft/s
- Maximum range from launch site: 31.20570 Ft.

- Maximum altitude: 3031.07453 Ft.

Recovery system data

- S: Streamer Deployed at : 13.305 Seconds
- Velocity at deployment: 2.4098 ft/s
- Altitude at deployment: 3031.07448 Ft.
- Range at deployment: -31.20570 Ft.

Time data

- Time to burnout: 1.181 Sec.
- Time to apogee: 13.305 Sec.
- Optimal ejection delay: 12.124 Sec.

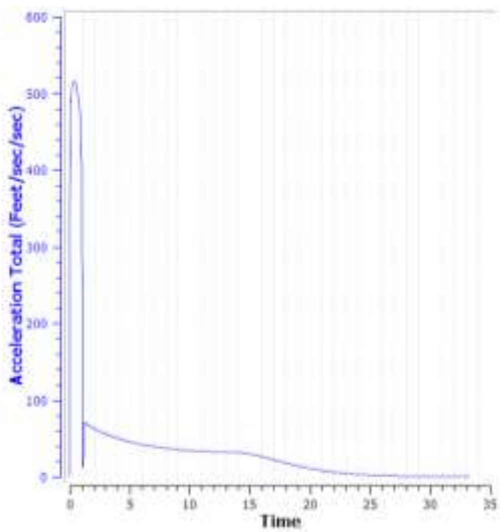


Figure 24: RockSim Acceleration Data

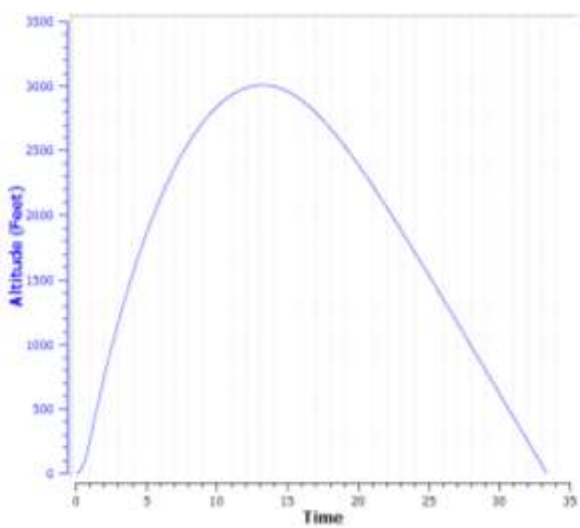


Figure 25: RockSim Flight Simulation

Construction of Rocket

The first design decision made for the construction of the rocket was the diameter of the body tube. Based upon rough estimation of the electronics requirements, it was decided that a four inch body tube would be used. This diameter tube allowed a minimally sized avionics compartment to be inserted from the perspective of total vertical space consumption. The decision to use a four inch tube was reinforced by the fact that four inch tubes are commonly available and therefore have better availability of parts and supporting equipment.

Cardboard was originally intended as the construction material of the body tube. The design team conducted small scale tests on coating cardboard tubes with fiberglass in order to strengthen the construction. These tests resulted in a very rough surface finish which was deemed undesirable from an aerodynamic perspective.

Following cardboard, commercial product called 'Blue Tube' was investigated as an alternative. An image of a 'Blue Tube' body tube was included below as Figure 26. This tube was advertised as cable of withstanding dramatic shock and impact. After testing of the material by the design team, it was determined to be structurally over elastic. Commercial fiberglass body tube was purchased as the final design decision due to the combination of superior structural strength and relatively low weight. The fiberglass tube was included previously in Figure 5.

Figure 26: Blue Tube

The overall length of the rocket was the second determined design parameter. The rocket was designed with 67 inches of total length without the nosecone. The long length of the body tube allowed internal components to be moved large distances to adjust the center of gravity positioning for the rocket. This would later aid in ensuring stable flight for the rocket. A single six foot tube was used in order to cut both the upper and lower body sections.

The nosecone was chosen from a limited number of commercially available options. A commercially manufactured nosecone was desired in order to ensure aerodynamic symmetric to avoid pitching the rocket during flight. A nosecone of 16.75 inches in length was selected which included a four inch insertion section. This added 12.75 inches to the total height of the rocket. The nosecone was constructed from plastic. In order to strengthen the cone, the plastic bottom was removed and a plywood bulkhead was inserted to provide a higher strength anchor point for the main parachute. An image of the modified nosecone was included below as Figure 27.

Figure 27: Nose Cone

A coupler was required in order to join the upper and lower sections of the rocket. The coupler was designed eight inches in length in order to have the capacity to hold the rocket's avionics system. A mold for the coupler was created from insulating foam that was then used in order to produce a fiberglass part. The coupler was intentionally made slightly oversized and then sanded to a precise fit for the rocket. Bulkheads were installed on both ends of the coupler which protect the electronics and provide anchor points. The two bulkheads were mechanically linked through the center of the coupler such that load was transmitted directly rather than through epoxy joints between the bulkheads and fiberglass. Copper fitting were installed on each side to hold ejection charges.

Figure 28: Coupler Bulkhead

Figure 29: Coupler Placement

It was decided that no parachute would be deployed at apogee during the flight of the rocket. This was done in order to avoid allowing the rocket to drift far from the launch site during recovery. Instead, streamers were included in the lower body section which deploy at apogee. This provided visual aid for tracking the rocket, increase drag, and help to stabilize the rocket in free fall. An image of one of the streamers was included below as Figure 30.

The primary parachute is electronically deployed by a second ejection charge when the rocket is close to ground. The Iris Ultra 48 inch parachute was selected as the main chute. This parachute features a drag coefficient that is significantly higher than typical parachutes due to its parabolic design. The parachute weighs 7.5 ounces and can be compacted into a 2.6 inch diameter, 7.8 inch long cylinder. The parachute is commercially rated to slow 12.5 pounds to a terminal velocity of 20 feet per second at sea level. An image of the parachute was included as Figure 6 above.

Figure 30: Streamer

The motor tube construction was performed through a simple methology. The motor casing was coated in vasoline and then layered with fiberglass. Once the resin had set, fiberglass tube was removed from the motor casing. The tube was then cut down to the exact required size and sanded in order to provide a smooth finish. The centering rings were laser cut from ¼ inch plywood before using epoxy to secure them to the motor tube. An image of the motor tube was included above as Figure 2.

The fins of the rocket were one of the last majors componets to be designed. Accurate weights and positions of all other components of the rocket were well established before completing the final design of the fins to ensure stability of the rocket. The fins of the rocket were cut from sheets of commercially purchased high strength fiberglass. The design of the fin was included above in Figure 1.

All of the physical joints were sealed with epoxy. This allowed for strong bonds and fillets on all joints.

Figure 31: Resin and Hardener

Photos of Completed Rocket

Figure 32: Rocket - Exploded View

Figure 33: Completed Rocket

Conclusion

The Scarlet and Gray Rocket was designed to carry a payload of sensing instrumentation to an altitude of exactly three thousand feet above ground level and then return safely to the ground with minimal distance from the launch site. The rocket recovery system features an electronic dual deploy system with motor ejection charge backup. The rocket will descend with a pair of streamers from apogee and will deploy a parachute when close to the ground. The total cost of the project and the development of the rocket was $1,173.50. The rocket will use a Cesaroni I540W rocket motor. The perfect scenario computer simulation averaged an apogee of 3024 feet with a peak acceleration of 16.3 g's. The first deploy of the system will deploy based on the real time data collection of altitude and velocity in order to achieve an apogee as close as possible to three thousand feet. The onboard avionics system will record all relevant data to an onboard SD card and also provide real time GPS tracking via radio to a ground station.

Budget

Item	Price Per U	Qty	Total
Cesaroni 38 mm 5-Grain Case	$ 53.14	1	$ 53.14
5" X 50" Red Ripstop Nylon Streamer	$ 6.99	2	$ 13.98
RockSim v9 – TARC Temporary License	$ 20.00	4	$ 80.00
¼ x 12 x 24 lite ply	$ 4.57	4	$ 18.28
FTEX2-3.91 Airframe Tubing (3.91" X 4.03") (3.91" X 72")	$ 142.08	1	$ 142.08
G-10 Fiberglass Raw Sheet Stock (.125" (1/8") 12" x 48")	$ 93.99	1	$ 93.99
Iris Ultra 48" Parachute - 12.5lbs @ 20fps	$ 110.00	1	$ 110.00
Jeffco Epoxy 1 Gal. Kit, Medium (Kit)	$ 87.90	1	$ 87.90
Barometric Pressure Sensor	$ 9.95	1	$ 9.95
1/8X12X24 balsa sheet	$ 9.52	4	$ 38.08
ADXL377 High G Triple Axis Accelerometer	$ 24.95	1	$ 24.95
Piezo Buzzer PS1240	$ 1.50	2	$ 3.00
98mm Blue Tube	$ 38.95	2	$ 77.90
3.9in (98mm) LOC Body Tube	$ 10.45	4	$ 41.80
XBee Explorer USB	$ 24.95	1	$ 24.95
XBee Explorer Regulated	$ 9.95	1	$ 9.95
900MHz Duck Antenna RP-SMA	$ 7.95	2	$ 15.90
XBee Pro 900 RPSMA	$ 37.95	2	$ 75.90
OpenLog	$ 24.95	1	$ 24.95
Arduino Fio	$ 24.95	1	$ 24.95
Polymer Lithium Ion Battery - 1000mAh 7.4v	$ 5.95	1	$ 5.95
Jumper Wire - JST Black Red	$ 0.95	1	$ 0.95
Adafruit Ultimate GPS Breakout - 66 channel w/10 Hz updates - Version 3	$ 39.95	1	$ 39.95
Featherweight Raven Flight Computer 3	$ 155.00	1	$ 155.00
TOTAL			$ 1,173.50