2015

# Flight Readiness Report

## Saturn V from UW – Washington County

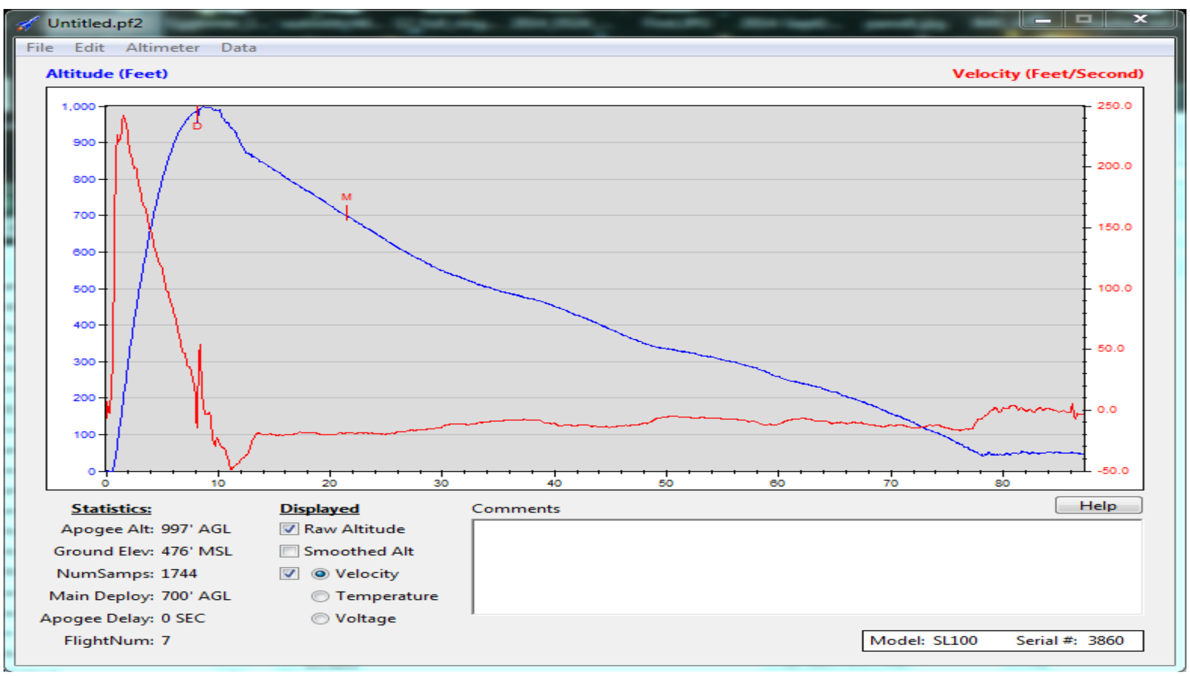
Zachary Young (Captain), Rusty Tillman (Student Member), Randy Lutz (Advisor), Carol Lutz (Advisor), Swapnil Tripathi (Advisor), Mohan Thapa (Advisor)

Zach Young
Saturn V
5/19/2015

## Executive Summary

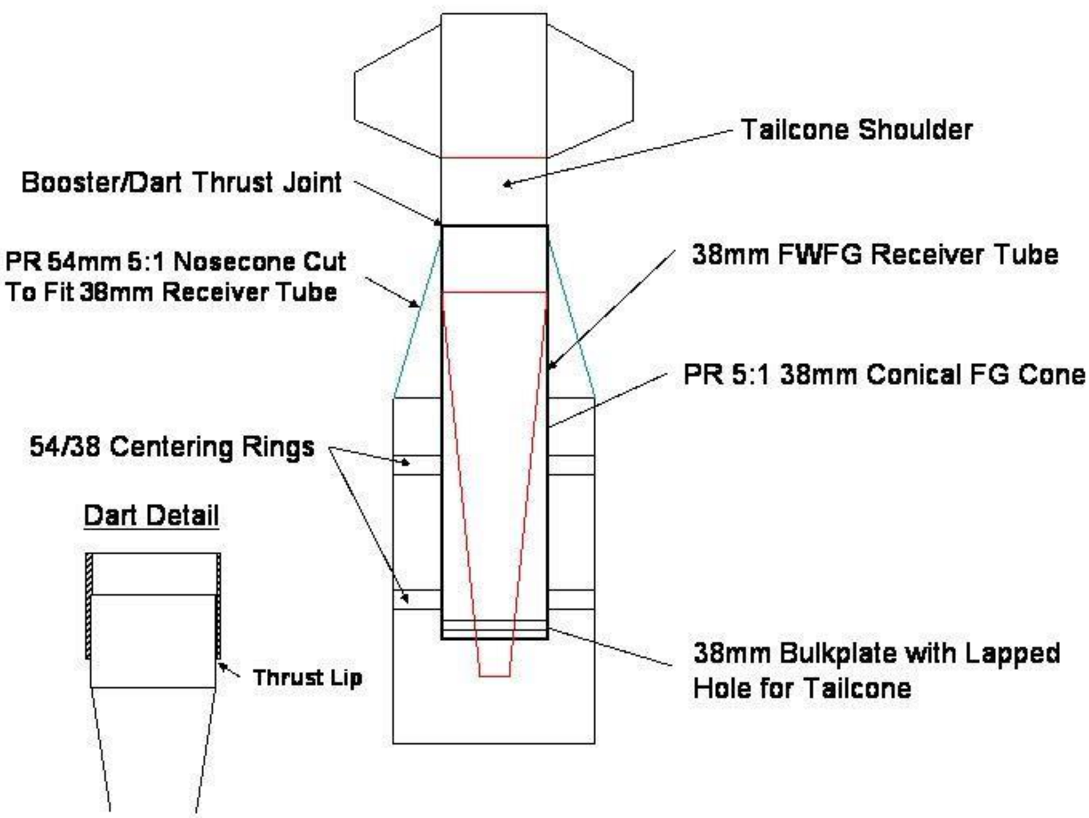
The DARTagnan is not only an 88.5 inch, dual stage, boosted dart, it is one of the (conveniently named) Three Musketeers. We will be launching this basketball-player-sized warrior roughly 2500 feet into the air, boosting our dart far into the atmosphere and leaving our booster behind. Our main objective is to get DARTagnan's dart component to reach as high an altitude as possible, with a benefit in achieving a large booster-dart separation distance. Included in our objectives is our recording of the roll, pitch, and yaw with our programmed Arduino, and every instance a calculation is done the data will be written to a storage device.

DARTagnan combated the brutal winds and fought its way into the sky on April 4th, being launched at Richard Bong Recreational Area on an H motor – which was done to limit the distance the wind would carry it during its decent. Upon arriving and installing the motor and watching Chris Thompson successfully earn her Level 1 certification, DARTagnan lined up on the launch pad with its sabre held upward, standing firm against the relentless wind. With successful launch and deployment of the parachutes, but unsuccessful separation, we went out to find the stages. The booster was found easily, but the dart was a greater challenge. After tracking, it was found safely nestled 50 feet up in a tree. Over an hour of sitting high up in a tree later, attempting to hook the dart with our pole rigging, we successfully retrieved the dart. Data from the dart showed it hit apogee at 997 feet, landing at roughly 50 feet above ground.

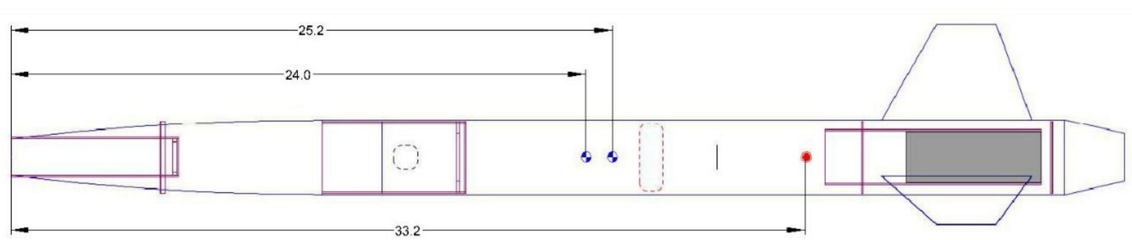


## Rocket Design

The biggest design challenge for our rocket was the inter-stage coupler. In order to couple our dart and booster, it was necessary to install two centering rings - please see the picture below - in order to hold the dart laterally.

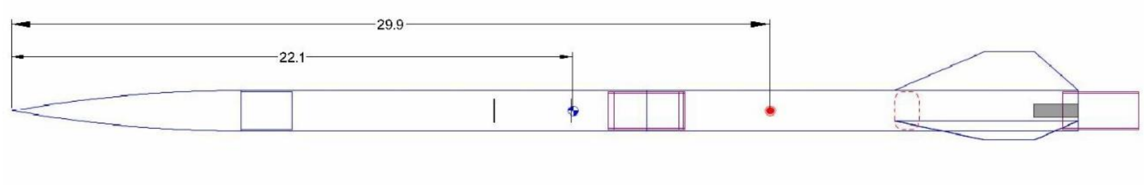



**BOOSTER**

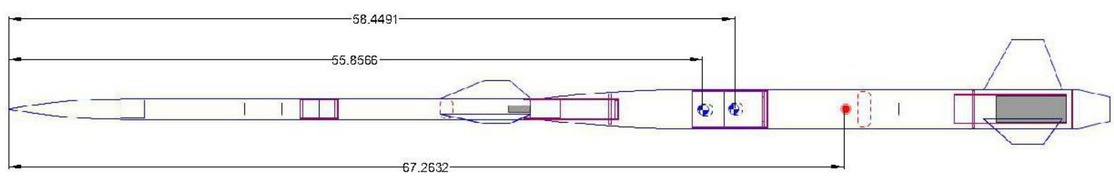



- Diameter – 3.13”
- CP location – 33.2” from front of booster
- $CG_1$ – 25.2” from front of booster
- $CG_2$ – 24.0” from front of booster (after motor burns out)

**DART**




- Diameter – 1.50”
- CP location – 29.9” from front of dart
- CG – 22.1” from front of dart




Our final design is shown above. Critical design parameters are as follows:

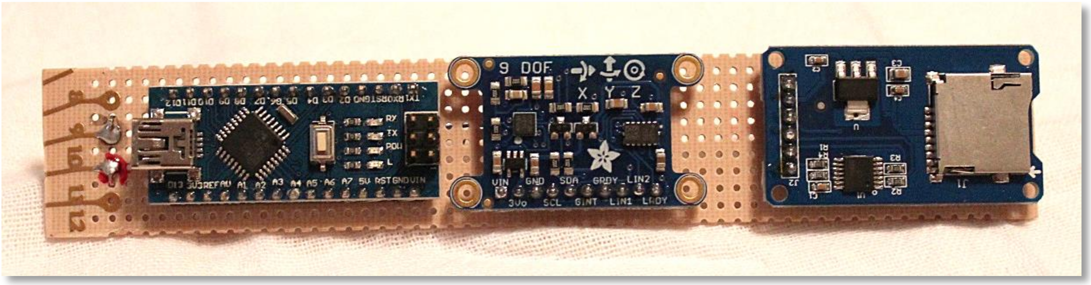
- Overall Length – 88.5”
- CP location – 67.3” from front of rocket
- $CG_1$ – 55.9” from front of rocket
- $CG_2$ – 58.4” from front of rocket (after motor burns out)
- Stability – 4.83 caliper with I445-VM motor

## Payload Design

Video Recording System

The video recording system uses a very popular keychain spy DVR to record the dart's rotation during the flight. The keychain DVR was disassembled and fitted into a 38mm couple tube to allow installation in the payload bay. The particular camera we chose allows the use of an extension cable to optimally position the camera module. A 3D printed shroud and first surface mirror is mounted on the exterior on the airframe to facilitate the down looking view.

Rotation Sensor System




The rotation sensor system consists of the following electronic modules:

1. A generic Arduino Nano micro computer
2. An Adafruit 9 degrees of freedom (DOF) inertial measurement unit (IMU)
3. An Adafruit MicroSD breakout board

The heart of the system is the 9 DOF IMU board. It contains a 3-axis gyroscope, 3-axis magnetometer and a 3 axis accelerometer. Data from these sensors is access by the Arduino computer over an $I^2C$ data bus. The ensemble will be powered using a 130mah LiPo battery.

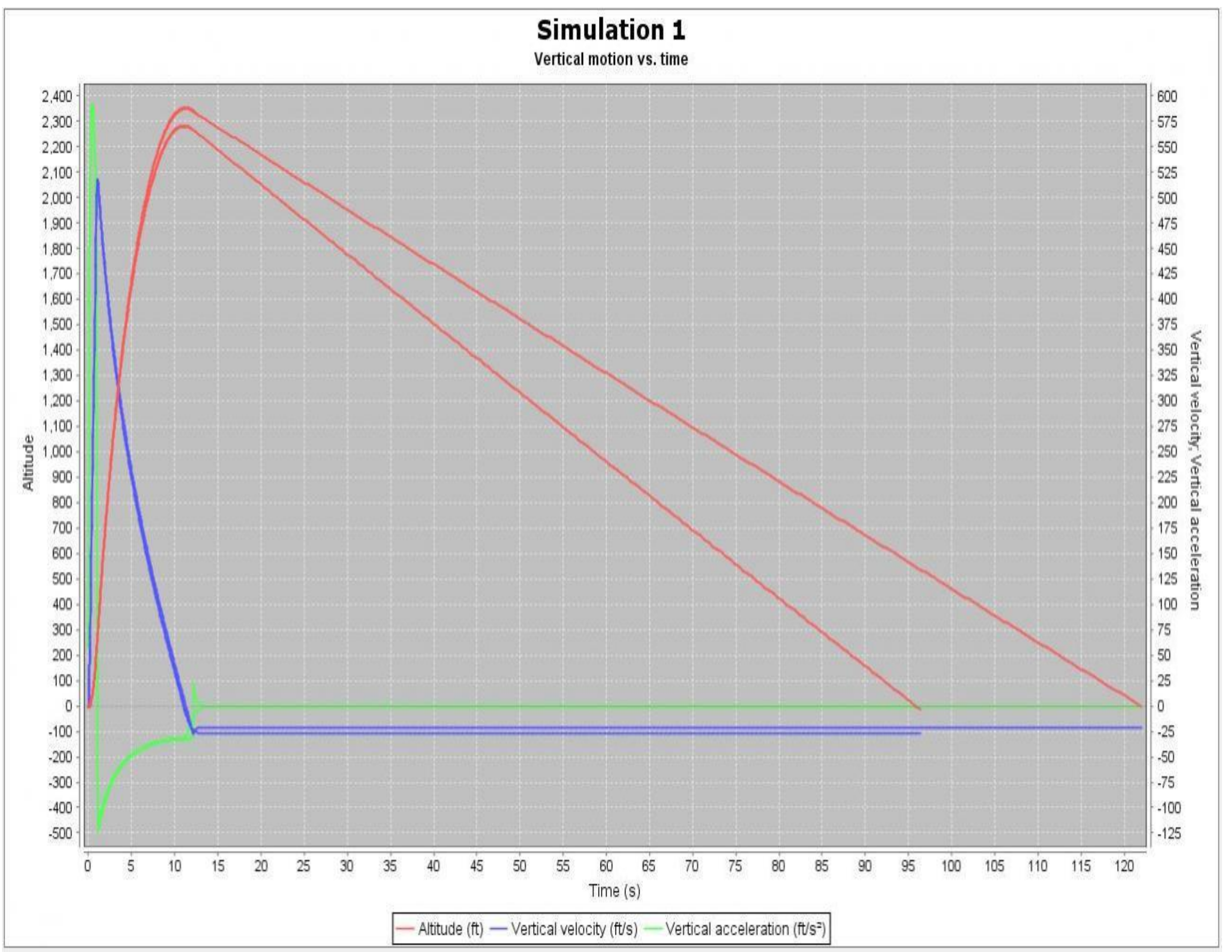
Software for the system was adapted from an open source UAV Attitude and heading reference system (AHRS) developed by camelsoft.com. The software is a quaternion based AHRS which was written for the Arduino Nano and an Altimu-10 IMU manufactured by Polulu. Modification to the software was made to support the Adafruit IMU. Also added was code to log the rotational data to the MicroSD card.

Still to be developed is the visualization software to animate the data collected during the flight.

## Projected Flight Performance

After our practice launch and our rocket was finalized, we took our official measurements and added them into the RockSim simulator to determine our projected flight performance. The projection is as follows:

- Dart
  - Velocity off rod: 55.7 ft/s
  - Apogee: 2588 ft
  - Max Velocity: 517 ft/s
  - Max Acceleration: 590 ft/s^2
  - Flight time: 97.1 s
- Booster
  - Velocity off rod: 55.7 ft/s
  - Apogee: 2107 ft
  - Max Velocity: 517 ft/s
  - Max Acceleration: 590 ft/s^2
  - Flight time: 74.6 s



## Rocket Construction

We began with two phenolic cardboard tubes for the booster and the dart. The first step was to build the motor mount which we did by inserting a centering ring to secure the motor mount within the booster. Next, we inserted our booster fins through the booster airframe and epoxied them to the motor mount. In order to hold everything together snugly, we used 2-part expandable foam to keep everything in place.

With the building of the booster altimeter bay, we had to wire the altimeter up. Instead of soldering the wires to the board we used the wire wrap technique. This is just an effective method as soldering and allows for error – which we definitely occurred on the way. After this the last thing to do was create the interstage coupler, which is listed above in great detail. Something to add is that we needed two centering rings to hold the tail cone laterally because the initial ring was placed too far down that the support was not suitable. Once the second centering ring was added we had complete support.

Finally, we had to build the dart. This was much easier because of the lack of a motor. Instead, we had the tail cone that fit into the interstage coupler and that was as simple as sliding it into the bottom of the dart tube. We needed the altimeter and experiment bay, the same as the booster. One difference was the camera bay and shroud that was needed to visually see the roll, pitch, and yaw. Just like the experiment bay, we took a similar-sized tube (small enough to fit snugly into the tube, but not too snug to get stuck) and epoxied the spy camera and extender into it. We cut a circular hole into the camera and an equally sized hole into the dart airframe so that they camera could see out. In order to get the camera to view downward, we 3D-printed a shroud with a 45˚ edge and epoxied it to the side of the dart tube. Adding a ½ inch first surface mirror to the shroud allowed for the camera to reflect off of it and see downward.

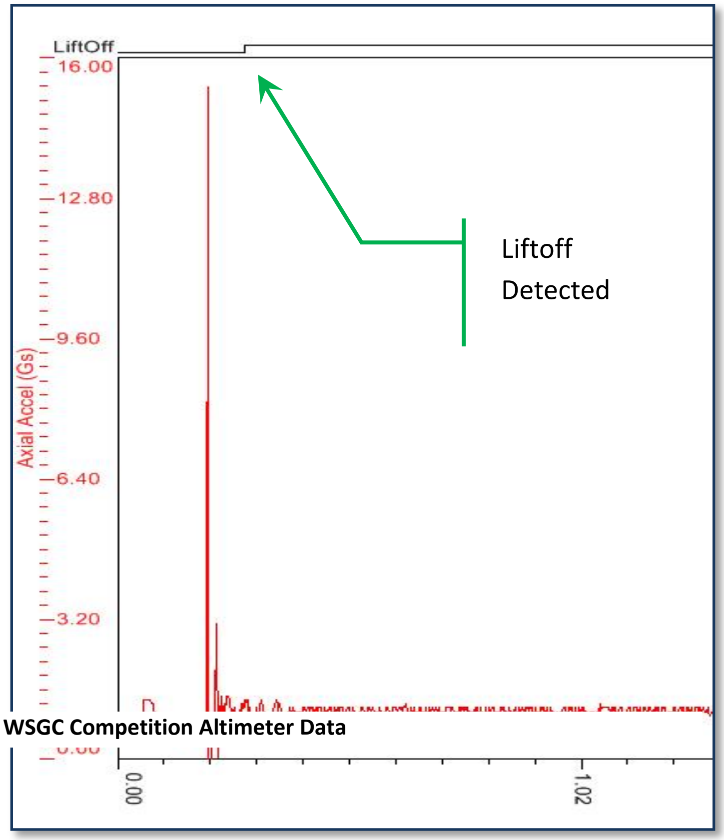
Once the design was complete we launched our rocket and an issue occurred (lack of separation) that required us to drill two holes into the interstage coupler. We had to do this because the precision of the tail cone fit into the coupler created a vacuum seal when attempting to drag separate. The holes prevent the vacuum to occur and allow separation to go smoothly.

On the next page we show some more pictures of construction.


Zach

## Post Flight Failure Analysis

<u>Competition Altimeter Failure</u>



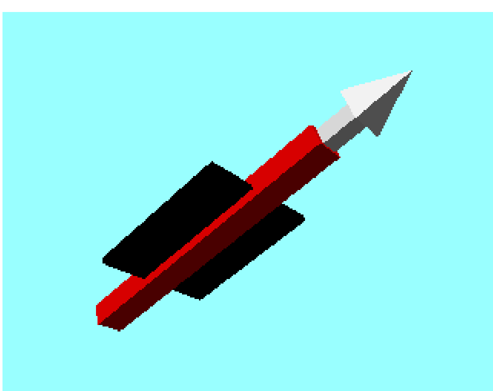
**WSGC Competition Altimeter Data**

The post flight data download of the WSGC competition altimeter only provided approximately five seconds of data for the flight. Analysis of the data reveals that the Raven 3 altimeter recorded a 15.3G transient shortly after it was powered up. Eighty milliseconds after the transient, the altimeter indicated it detected liftoff. The Raven's manual indicates that liftoff is detected when "accelerometer readings in excess of 3 Gs integrate to a 3 mph upward velocity".

The raven altimeter stops logging data at the end of the flight as signaled by a stable 1G reading. As shown on the chart to the left, the accelerometer settles at a reading of 1G just after the transient which caused the Raven to top logging data at the 5 sec mark.

Clearly, the loss of data on the competition altimeter was a result of an unknown disturbance imparting a 15.3G axial acceleration to the dart. This resulted in the premature detection of liftoff and landing.

<u>Off Vertical Flight Path and Dart Booster "Zipper"</u>


**Rocket Attitude at T+1.5 sec.**

As the rocket cleared the launch rail, it quickly deviated from vertical flight. The image at the left is a visualization of the IMU data at T+1.5 seconds and clearly shows the rocket flying nearly 45 degrees from vertical. Since the rocket flew downwind we can rule out severe weather cocking.

The probable cause of the flight path deviation was a slight off axis tilt of the dart when compared to the booster. The tilt was slight, possibly 2 – 3 degrees, but a review of the flight path visualization using the IMU data seemed to indicate that the dart tended to steer the rocket in the direction of the tilt. This resulted in a near horizontal

**Zippered Airframe**

attitude when the ejection charge fired to deploy the chute.

While flying horizontally, the rockets vertical velocity dropped to zero and the altimeter fired the ejection charge. When the parachute ejected at this high horizontal velocity, the shock cord ripped through the airframe causing a classic “zipper” along the body tube.

Dart Separation Failure

The failure of the dart to separate was due to a horizontal component of the aerodynamic forces on the rocket because of the off axis dart. This force perpendicular to the airframe of the dart caused the tail cone to wedge in the interstage coupler and it did not drag separate at motor burnout. The dart stayed attached to the booster until the ejection charges fired which jolted the dart free. However, our expected booster apogee was 2107 feet and the actual booster reached 2169.77 feet – while the dart was still attached.

Although we had separation failure, our actual booster apogee exceeded our expected apogee even including the extra drag and weight of the dart. We can assume, then, that the booster would have reached an even higher apogee had separation been successful. The same can be said for the dart. With our values for the booster being lesser than the actual values, the trend can be shown to affect the dart. Having an estimate of 2588 feet for the dart, we should have reached that height or higher had separation gone as planned.

Camera Failure

For our video camera we chose one of the keychain spy cameras. These have become very popular with rocketeers due to their small size, good video and low cost. Our camera was powered up at the pad just before we launched. When we retrieved our rocket after the flight we only found 3 minutes of video stored in the camera. It was charged for 6 hours the night before the launch so should have had fully charge batteries.

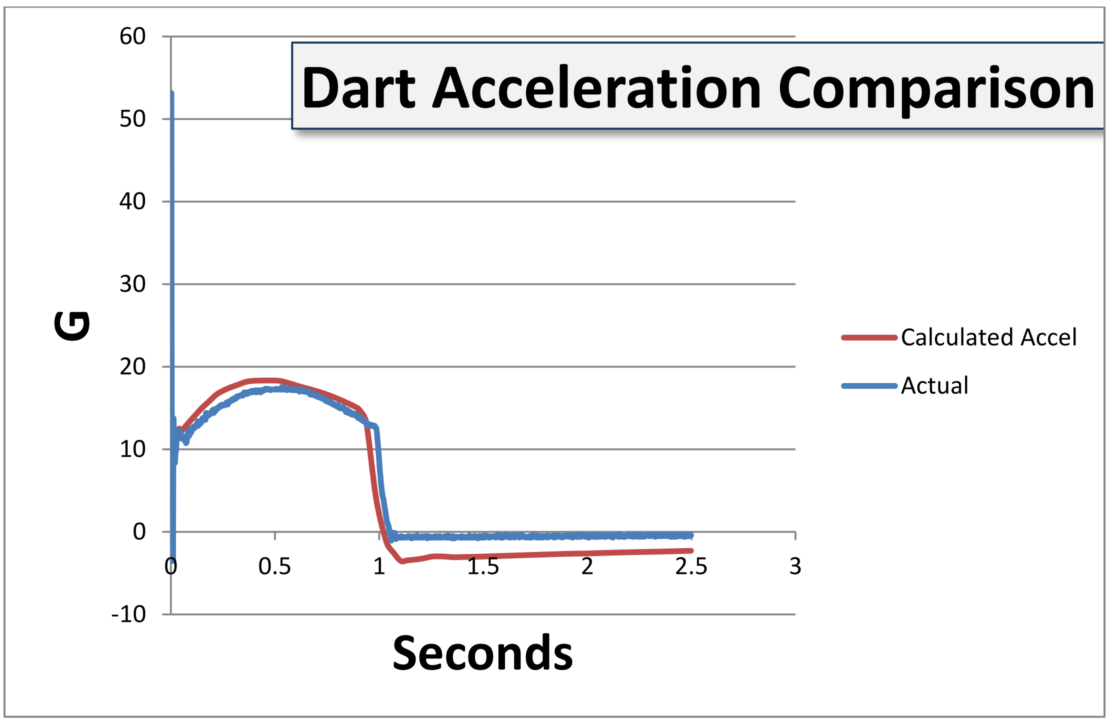
To troubleshoot this failure, the camera was charged for 12 hours overnight and a test recording was started. After an hour or so, the video file was downloaded from the camera and this time there was only 1:55 minutes of video recorded. Clearly the charging circuit in the camera is faulty. When we originally received the camera, we recorded video in excess of 20 minutes to get familiar with the unit. Apparently our testing ran the barriers down and, with the charging circuit inoperable, there was only a few minutes of power left to record our flight. The low cost of these camera is very attractive for use in rockets since they can be destroyed should the rocket experience a problem but this low cost also means their reliability is poor.

Corrective Action

Another attempt to fly our rocket will be made sometime this summer. To increase our chances of success the following changes will be made:

1. The zippered airframe on the dart will be replaced.
2. The dart's tail cone and interstage couple will be modified to ensure the dart is in line with the booster's axial axis.
3. The dart will be shortened to lessen and lateral forces that might cause the dart to bind in the interstage coupler and fail to separate.
4. The keychain camera will be repaired or replaced to ensure we get video during this flight

Acceleration Comparison




**Acceleration Comparison**

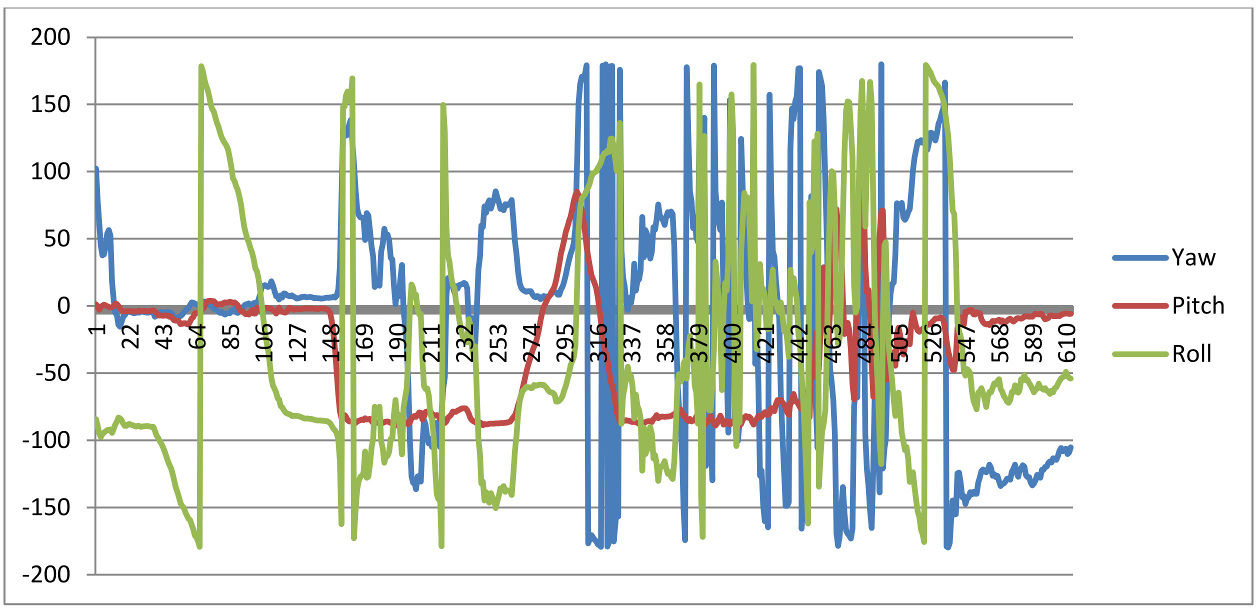
Through comparison of accelerations both predicted and actual, we can see that both were extraordinarily close together. Our measurements were precise and accurate, and therefore the software prediction was nearly exact to the actual acceleration that our rocket experienced.

Flight Performance Reporting Sheet

| Operation | | Yes/No |
|---|---|---|
| | Launch | Yes |
| | Separation of Dart From Booster | No |
| | Recovery Deployment Booster | Yes |
| | Recovery Deployment Dart | Yes |
| | Recovered | Yes |
| | Determined to Be in Flyable Condition | No |

| Maximum Altitude (ft) | | |
|---|---|---|
| | Predicted | 2588 |
| | Actual | 2169.77 |
| **Peak Acceleration (ft/s^2)** | | |
| | Predicted | 589 |
| | Actual | 560.43 |

Rotation Sensor System Data




**X,Y,Z Rotational Data**

It can be shown through the roll data that our dart rotated once around before the parachute deployed. The yaw and the pitch remained very stable up until parachute deployment. We had an extremely stable rocket in each axial component, and had the camera worked we could have visually shown that. Regardless, our data logger worked perfectly and allowed this graph to give us just as good of an insight.

## Conclusion

Team Saturn V began with an adventurous group of students ready to learn new skills and possibly gain a new hobby on the way. After only a few meetings, the stress of the work became too much and the team eventually whittled away to only two – two very studious, knowledge hungry students with much desire to succeed. Rusty and I buckled down and enjoyed the learning experience. Neither of us had ever worked on a rocket, hardly even an Estes rocket, but we learned and grew as time went on. We watched as something that started as parts began to form into a workable, flyable, two-stage rocket. The experience of this rocket competition brought forth from us a knowledge we may have never learned before, and it has left an everlasting impact on what we deem as hard work and dedication. This competition not only taught us how to build rockets, it taught us how to work as a team, how to be leaders, to take initiative, and to accomplish tasks that otherwise seemed impossible. This will not be our last time competing in a high-powered rocket competition – that can be assured.

As much as all of us learned, this event could not have occurred without the reassuring confidence from our mentor and friend, Randy Lutz. His love for this hobby radiated from every pore of his body, and his infectiously warm demeanor kept spirits high and pessimism low. But, a love for the sport does not mean knowledge for it. Randy, however, had a vast knowledge that he was willing to share with us when times got hard. He worked beside us along the entire journey, and without him we could not have accomplished such a wonderful rocket. We thank him greatly for his sacrifice. We would also like to thank Randy's wife Carol for keeping each and every one of us on the right track. Like the guide rail does for the direction of the rocket, Carol does for the direction of the entire group. We would also like to thank both advisors Dr. Swapnil Tripathi and Dr. Mohan Thapa. They allowed for us the environment to work and the reassurance needed to keep our head in the game. Their time does not go unnoticed, and their influence can be seen in each and every one of us. Lastly, we must thank the Wisconsin Space Grant Consortium and NASA for the opportunity to broaden our horizons and to learn that hard work will always pay off. Without them this event will have never have happened, and for that we are grateful.