Team Jarts Rocket Design

Alex Folz, Brett Foster, Eric Logisz, Cameron Schulz

Milwaukee School of Engineering

Abstract

The objective of the 2012 Wisconsin Space Grand Consortium collegiate rocket competition was to construct a rocket capable of live video feed through the thrust phase while flying to an exact altitude of 3,000 feet.

The airframe of the rocket was designed utilizing a simplistic, low weight design to provide a properly balanced rocket. The main chute was designed for two separate scenarios of deployment; the first scenario involves a remote controlled manual deployment, and the other is activated by an automatic elevation trigger, which will serve as a failsafe to ensure the rocket makes a safe landing. A numerical simulation, developed in MATLAB, was used to predict the performance of the rocket. The maximum predicted acceleration calculated is **506** $\boldsymbol{ft/s^2}$, and the maximum predicted altitude calculated is **3480.6** $\boldsymbol{feet}$. Further analysis of the rocket design and discrepancies are attached below.

Design Features of the Rocket

General Design. The airframe for the rocket was constructed out of fiberglass wrapped phenolic tubing with a diameter of 3.097 inches. We chose fiberglass wrapped tubing because it provides high strength while weighing less than other options. Another advantage of fiberglass tubing is its resilience in form; it's capability to deform under extreme force while still maintaining the ability to return to its original shape. This has proven to be beneficial with regards to the camera mounted on the exterior. This fiberglass phenolic tubing is also resistant to zippering, a factor considered in the design phase due to the fact we will be deploying a drogue parachute while the rocket is still ascending. The risk or possibility of zippering was reduced not only by the selection of fiberglass wrapped phenolic tubing, but also by the use of 30 feet of half inch nylon shock cord.

This length of cord will reduce impulse forces; a large contributor in zippering. Due to the combination of these characteristics we chose fiberglass wrapped airframe over phenolic or quantum tubing which is less expensive. The rocket was designed to utilize a 3.097 inch diameter in order to properly house the chosen electronics. The total length of the airframe was designed to utilize a total of 49 inches of tubing; this allows enough space to accommodate the internals while placing the CG and CP in proper relation to one another. After the addition of the nose cone the total rocket length equals 62 inches. The launch weight of the rocket (including the airframe, recovery system, motor mount and motor) equals 8.09 pounds.

The rocket incorporates three clipped delta fiberglass fins evenly spaced around the bottom of the rocket's airframe. The specific shape of the fins provide sufficient manipulation of the Center of Pressure in order to eliminate the necessity for a fourth fin. This reduces unnecessary drag on the rocket while maintaining a stable flight with a CP lower than the CG.

Recovery System. The main parachute has a variable diameter of 24, 30, or 48 inches, and a drogue parachute with a diameter of 24 inches, tubular nylon with a diameter of 0.5625 inches, two nomex cloths, and two nomex shock cord sleeves are combined and utilized to act as the recovery system for the rocket. When thrust from the motor has ended, the rocket will continue to gain altitude until approximately 2,850 feet, at which point the first ejection charge will be automatically triggered in order to separate the upper portion of the rocket from the center electronics bay. This will also deploy the drogue parachute; this will bring the rocket into a rapid, controlled descent. The half inch tubular nylon incorporated is rated to 2,000 lbs, 30 feet will be used in order to minimize the risk of zippering.

The drogue parachute will serve as a break parachute in order to bring the rocket to a stop at 3,000 feet. On the day of the competition, we will assess conditions in order to properly program the electronics to deploy the drogue parachute at roughly 2,850 feet allowing the rocket ample time to stop at 3,000 feet. The rocket will then fall under the control of the drogue parachute until within 500 feet of the ground; at this point an altimeter will trigger a second ejection charge which will deploy the main parachute. In order to reduce the risk of parachutes not deploying there will be a second set of ejection charges connected to a separate altimeter. This altimeter will be programmed to deploy the drogue parachute at apogee and the main parachute at 400 feet above the ground. This measure will ensure the rocket the ability to achieve a safe recovery. The d-links and half inch tubular nylon shock cord are shown in *Figure 1*.

Figure 1: Shock cord and d-links used to connect the sections of the rocket

Electronics & Storage. The center section of the rocket is used to house the electronics which deploy the parachutes; this section was constructed using a portion of coupling tubing with a length of 9 inches. A 2 inch section of fiberglass phenolic airframe centered and epoxied around the coupling tubing is displayed in Figure 2.

Figure 2: Electronics bay with the U-bolt connections and threaded rod mounting rails

The approximate 3.5 inches of exposed coupling tube remaining on each end of the center section is to fit into the top and bottom sections of the rocket's airframe connecting all three pieces. The electronic bay is capped on both ends by bulk plates, these bulk plates are attached to the bay by a pair of threaded rods running the full length of the bay. Each bulk plate also has a U-bolt attached through it to allow the d-link on the shock cord to attach to the electronics bay between the upper and lower sections of the rocket.

The primary altimeter used in this rocket is a MARSA4, a programmable parachute deployment system. This particular system was selected because of its four ejection channels. It is also field programmable and provides a plethora of data from each flight. The combination of these characteristics makes this system ideal for the controlled descent system being implemented. The fact that this system satisfies the design by ejecting the drogue parachute while the rocket is still coasting upward, the many sensors possessed by the altimeter, and the accurate data given for a quality post flight assessment makes this piece crucial in our rockets success. This is all accomplished by the small device shown in *Figure 3*.

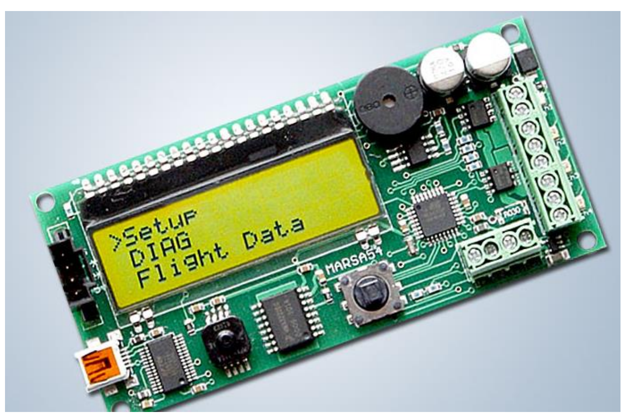

Figure 3: MARSA54 Parachute Deployment System
Source: http://www.rocketryplanet.com/content/view/3541/29/#axzz1KVksSdHZ (4/13/2012)

The second altimeter housed in this electronics bay is a PerfectFlite StratoLogger Altimeter. This altimeter was chosen as a backup altimeter due to its ability to deploy a drogue parachute at apogee and a main parachute ranging from 100 feet to 9,999 feet in 1 foot increments. This altimeter will also record altitude and velocity plots that can be used in the post flight assessments. This altimeter is not as accurate as the primary altimeter but serves the purpose well as a redundant backup system in case there is failure in the primary system.

Both of these electronic components are mounted to a plywood sled using stand offs and screws. The sled has two metal tubes mounted to it to slide onto the threaded rods. This system allows for the electronics to be mounted securely while providing easy access allowing them to be wired and programmed on launch day.

Figure 4: PerfectFlite StratoLogger
Source: http://www.perfectflite.com/sl100.html (4/13/2012)

These systems are joined by the competition R-DAS altimeter used to record flight data. This system will be housed in the nose cone. Our selected nose cone is an intellicone from Public Missiles. The R-DAS will be mounted on the same rail system that is utilized in the main electronics bay. The use of an intellicone saves space in the rocket and allows for a shorter overall rocket length, resulting in a beneficial relationship between the center of gravity and pressure.

Video System. The video system will be housed in a half nose cone epoxied to the fiberglass wrapped phenolic tubing. This capsule was placed at the center of gravity of the rocket to reduce the moment arm of the drag force. The capsule projects off the rocket by one inch. Dr. Matthew Anderson helped determine the boundary layer at the center of gravity is 0.6 inches. The outside 0.4 inches of the capsule will see drag, however this will be minimal due to minimal surface area. The small amount of extra drag will cause a slight amount of instability, but this is taken into account in the center of pressure and center of gravity. The capsule is displayed in *Figure 5* accompanied by the bottom view in *Figure 6*.

Figure 5: Rocket booster depicting the side nose cone

Figure 6: Rocket showing the bottom of the side nose cone

The video system chosen was the BoosterVision GearCam mile high combo. This system uses a 1 inch x 1 inch camera mounted with a 9V battery inside the capsule. The signal will be received using a 14db antenna; this antenna has a range of 5,000 feet vertically. The original system had a range of 3,000 feet but to ensure video throughout the flight the upgraded 14 db antenna was purchased.

Figure 7: Booster Vision GearCam
Source: http://www.boostervision.com/cart/scripts/prodView.asp?idproduct=77 (4/13/2012)

Center of Pressure/ Center of Gravity. The locations for the center of gravity and the center of pressure were determined by constructing a sample model in OpenRocket. The rocket construction analysis found in OpenRocket allowed for the modeling of most components of the design while enabling the designer to make adjustments to calculate the ideal dimensions. The only component that was not modeled in OpenRocket was the half nose cone used to house the video system. The result of the analysis can be seen in figure 8 displaying the layout of the rocket design and the resulting calculations for the placement of the Center of Gravity and the Center of Pressure. The analysis also provides how these two points relate to each in producing a stable rocket. The CP must be located more than 1 airframe diameters below the CG to make the rocket stable. Our rocket's stability margin is 3.52. This margin is considered over stable but due to the fact we are adding instability to the rocket by adding the side nose cone to house the video system the rocket was designed over stable to accommodate the video system's instability. A result of the rocket being over stable would be the rocket would not act optimally in windy conditions causing the rocket to reach a lower maximum altitude. This was accounted for when choosing a motor because our maximum altitude is 3,353 feet. As a result we have extra altitude to spare if conditions are windy.

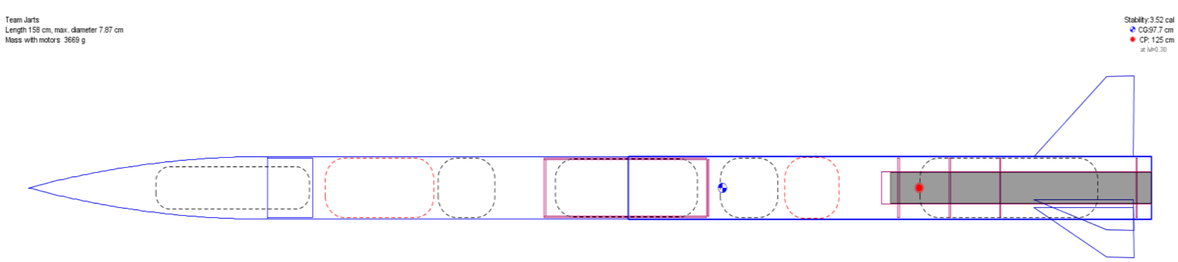

Figure 8: OpenRocket Construction Analysis

CP$_{\textbf{Rocket}}$ =<u>49.2</u>" from top of rocket
CG$_{\textbf{Rocket}}$ = <u>38.5</u>" from top of rocket **with motor**

CG_{Rocket} = 35.2" from top of rocket **after burnout**
Stability Ratio = 3.52

Analysis of the Anticipated Performance

Assumptions

1. Weight was assumed to be constant throughout the flight.
   w_{rocket} = $\mathbf{6.765\ lbs}$

2. The density of air was assumed to be constant throughout the entire portion of the flight.
   = $\mathbf{0.00238\ slug / ft^3}$

3. Gravity was assumed to be constant.
   $g = \mathbf{32.2\ ft/s^2}$

4. The drag force due to air resistance was assumed to be proportional to the square of the velocity. The drag force was calculated using Equation 1:
   $$F_D = \frac{1}{2}\rho C_D A v^2 \qquad (1)$$
   Where: ρ= *density of air*   *A = cross sectional area of the rocket*
   C_D= *coefficient of drag*   *v = instantaneous velocity of the rocket*

5. The coefficient of drag was assumed to be constant.
   C_D = $\mathbf{0.6}$

Linear interpolation was used to extract data points of the thrust of the motor to take in account the variation. (http://www.thrustcurve.org/simfilesearch.jsp?id=1685)

Predicted Velocity History. Two distinct portions of the flight are present. First is the thrust portion of the flight. During this phase, the rocket is accelerated upward from the ground to the point when the thrust ends. Thrust is maintained throughout this entire phase. The second phase of the flight is when the motor finishes providing thrust and the rocket decelerates until apogee. During this portion, the rocket continues to fly as a projectile. There is no thrust during the second phase.

Phase 1: Motor Accelerating Rocket (0 < time < 1.8 seconds)

The velocity can be predicted using Newton's second Law and a numerical algorithm. Newton's second Law says that the sum of the forces is equal to the product of mass and acceleration.

$$\sum F = ma \qquad (2)$$

When applied to the rocket, Equation 2 becomes:

$$-\frac{1}{2}\rho C_D A v^2 - mg + T = ma \qquad (3)$$

A numerical method (Euler's Method) is applied and this becomes:

$$-\frac{1}{2}\rho C_D A v_i^2 - mg + T = m\frac{v_{i+1}-v_i}{\Delta t} \tag{4}$$

Equation 4 can be rearranged as follows:

$$\boxed{v_{i+1} = v_i + \left(\frac{-\frac{1}{2}\rho C_D A v_i^2}{m} - g + \frac{T}{m}\right)\Delta t} \tag{4}$$

Equation 4 was scripted in a MATLAB code (Appendix 1) from the time of launch (t=0 sec) until the thrust ends (t=1.8 sec). A plot of this equation can be seen in Figure 9.

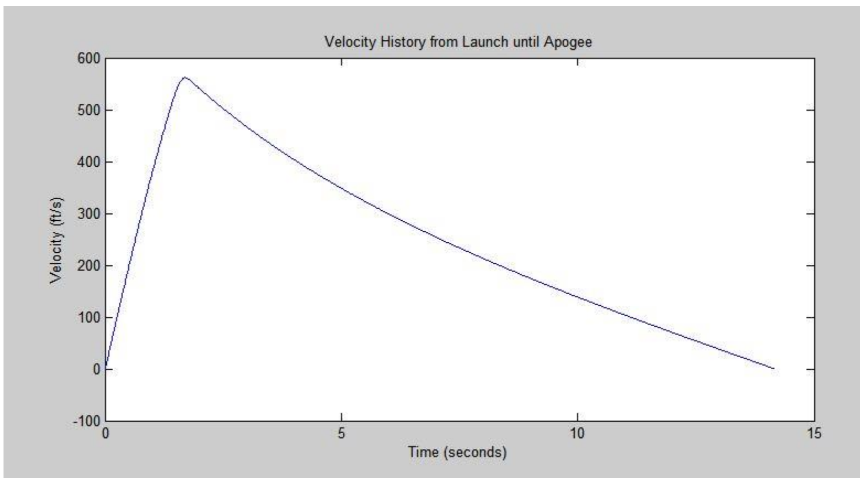

Figure 9: Velocity History Plot of the Rocket Produce by MATLAB

Predicted Acceleration History. The acceleration of the rocket was predicted by applying a numerical differentiation model on the predicted velocity data. The acceleration was calculated as follows:

$$a_i = \frac{v_i - v_{i-1}}{\Delta t} \tag{5}$$

Equation 5 was scripted in a MATLAB code (Appendix 1). This algorithm was applied from the time of launch until apogee was achieved. A plot showing the acceleration data can be seen in Figure 10.

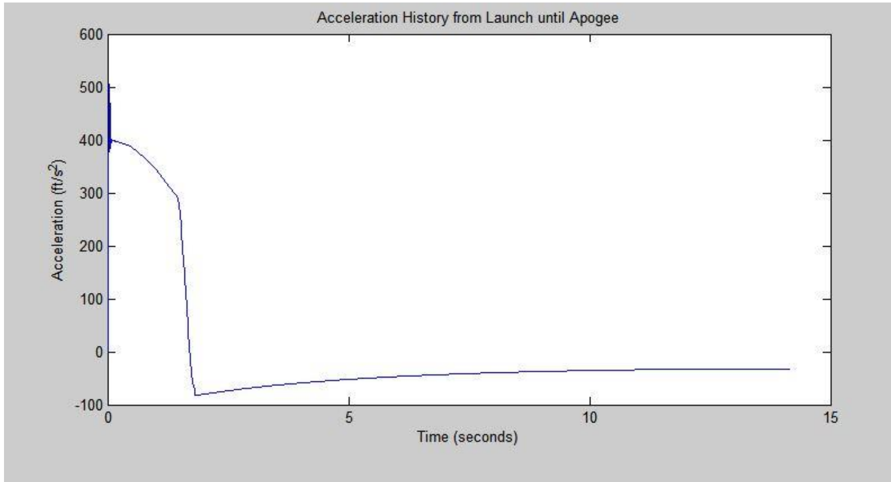

Figure 10: Acceleration History Plot of the Rocket Produce by MATLAB

It is anticipated that acceleration is initially positive since thrust is applied. The acceleration decreases during this phase because the drag force is increasing. Acceleration is negative after thrust ends because the rocket is slowing down. It should be noted that the maximum acceleration achieved in the flight is **506 $\boldsymbol{ft/s^2}$**.

Predicted Altitude History. The altitude history of the flight was also predicted using a numerical model. This was calculated by applying the trapezoid rule to find the area under the velocity curve. The equation used to calculate the height above Earth's surface (altitude) is as follows:

$$h_{i+1} = h_i + \frac{(v_{i+1} - v_i)}{2} \Delta t \tag{6}$$

Equation 6 was scripted in a MATLAB code (Appendix 1). This algorithm was applied from the time of launch until apogee was achieved. A plot showing the predicted altitude history can be seen in Figure 11. The maximum altitude achieved was **3480.6 $\boldsymbol{feet}$**.

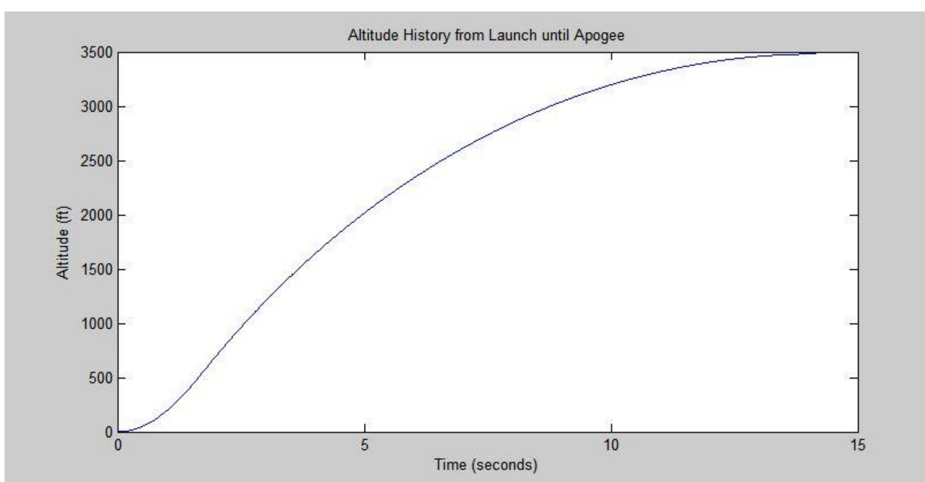

Figure 11: Anticipated Altitude Projection Plot of the Rocket Produce by MATLAB

Summary of Flight Performance

Maximum Acceleration	**506 ft/s^2**
Maximum Altitude	**3480.6 $feet$**
Time at Apogee	**14.17 $seconds$**

Table 1: Pre-Flight Analysis Predictions of Results

Although the maximum altitude is predicted to be 3480.6 ft, the rocket will be stopped at 3000 ft due to a drogue chute. Therefore the time to apogee will also be less.

Post Flight Analysis

Overall Performance. The table below has three distinct columns of values that were obtained from different sources. The "MATLAB Prediction" column contains the values that were determined from the MATLAB model that Team Jarts constructed of the rocket. The "OpenRocket Prediction" column contains the values that were determined from the OpenRocket model with the exact wind conditions from the day of the launch. The "Official" column contains the values that were measured using the equipment provided by the competition officials.

Flight	MATLAB Prediction	OpenRocket Prediction	Official
Maximum Altitude [ft]	3480.6	3135	2680
Peak Acceleration [ft/s^2]	506	413	363.86
Length of Video [s]			6

Table 2: Summary of both predicted and measured results for analytical comparison

The official data was then used in formula 1.1 in order to compute the total score for the flight.

$$\left(10\frac{ascent\,video\,time}{ascent\,time}\right)^2-\left(\frac{ascent\,video\,time}{ascent\,time}\right)^2\left|\frac{apogee-3000}{50}\right|^2 \tag{0.1}$$

Using this formula with the official data a total score for the flight was found to be 15.34.

$$\left(10\frac{6[s]}{11.770[s]}\right)^2-\left(\frac{6[s]}{11.770[s]}\right)^2\left|\frac{2680[ft]-3000[ft]}{50}\right|^2=15.34$$

The primary reason that the rocket did not achieve results closer to the predicted values in OpenRocket was from the rocket having a high stability margin and therefore weather cocked into the wind. In order to achieve better results, the center of gravity would have had to be moved back on the rocket by adding weight to the aft end. This is a tradeoff between weather cocking and weight, both causing a decrease in altitude. If the conditions on the day of launch were less windy, the rocket would have performed closer to what was predicted.

Altitude. When comparing the results of the predicted data to the actual data, one can confirm the analysis method used. There was a relatively small disparity between the predicted altitude and the recorded value for the OpenRocket prediction. The percent difference for this prediction was 14.5%. The predicted value was also known to be high when designing due to the fact that there was no numerical value for the coefficient of drag for the side pod that housed the camera. The MATLAB prediction percent difference is much higher due to the fact this prediction did not take into account launch angle, wind speed, or the added coefficient of drag of the side pod. The percent difference in the MATLAB prediction was 23%. Overall the nontraditional shape of the rocket with a side pod resulted in the larger percent differences. The large differences in the two percent difference values stems from the fact that MATLAB model did not take into account the launch rod angle and wind.

Acceleration. The comparison of the acceleration values yields a larger variation. However this can be due to the fact of the added drag that was produced by the side pod that was not accounted for in the predictions. The percent difference from the OpenRocket prediction was 11.9%. The MATLAB prediction percent difference was 28.1%. Again, the high percent difference in the MATLAB prediction come from the fact that wind and launch angle was not accounted for in this prediction.

Video. The video feed that was received and recorded by the competition produced about 6 seconds of video. This video feed started shortly after ignition and ended about a little over halfway through the ascent phase. The fact that the video feed was not received during ignition could be due to the large acceleration the rocket was undergoing. In order to improve the percent of video feed received another receiver could have been added on the ground so that two people could track the rocket.

Conclusion

Team Jarts' confidence in their rocket to meet the completion performance criteria and its ability to perform in such a way as to be field repairable were validated at competition. Although, the numerical simulations predicted produced a high percent difference, the post-flight analysis was able to identify potential sources for these errors. The rocket was also designed to overshoot the goal altitude of 3,000 feet due to the fact that the team knew the side pod was not accounted in the calculations. Also the team designed the rocket to overshoot the goal altitude because we knew the rocket was over stable and would not act ideally in windy conditions. The successful design, analysis, and execution of this project allowed Team Jarts to view this endeavor as an engineering achievement.

Acknowledgement

Team Jarts' thanks Wisconsin Space Grant Consortium (WSGC) for their contributions to make this project possible.