2014

Great Midwestern Regional Rocket Competition

April 25th – 26th, 2014

University of Illinois, Urbana-Champaign

Team Celestial Chiefs

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The purpose of the following design report is to evaluate the engineering effort that went into the design of the heavy-lift rocket and how the engineering meets the intent of the competition.

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Executive Summary

The Great Midwestern Space Grant Rocket Competition provides an opportunity for student teams to demonstrate engineering and design skills via a hands on approach. The competition's design goals require a high powered rocket to reach an apogee of 3000ft while building the rocket within specifications noted in the competition rules. Along with the launch goal, there exists aspects such as pre-flight flight properties estimation, completion of a design report, giving a presentation, and post flight data analysis. This report describes and evaluates the rocket design decisions and solutions used in order to achieve the prescribed goals through application of problem solving, analytical engineering, and hands-on skills using the combined skills of a team dedicated to creating a complete high-powered rocket.

Plan of Action

In order to facilitate a fluid and organized process of decision-making, the following plan of action was adopted:

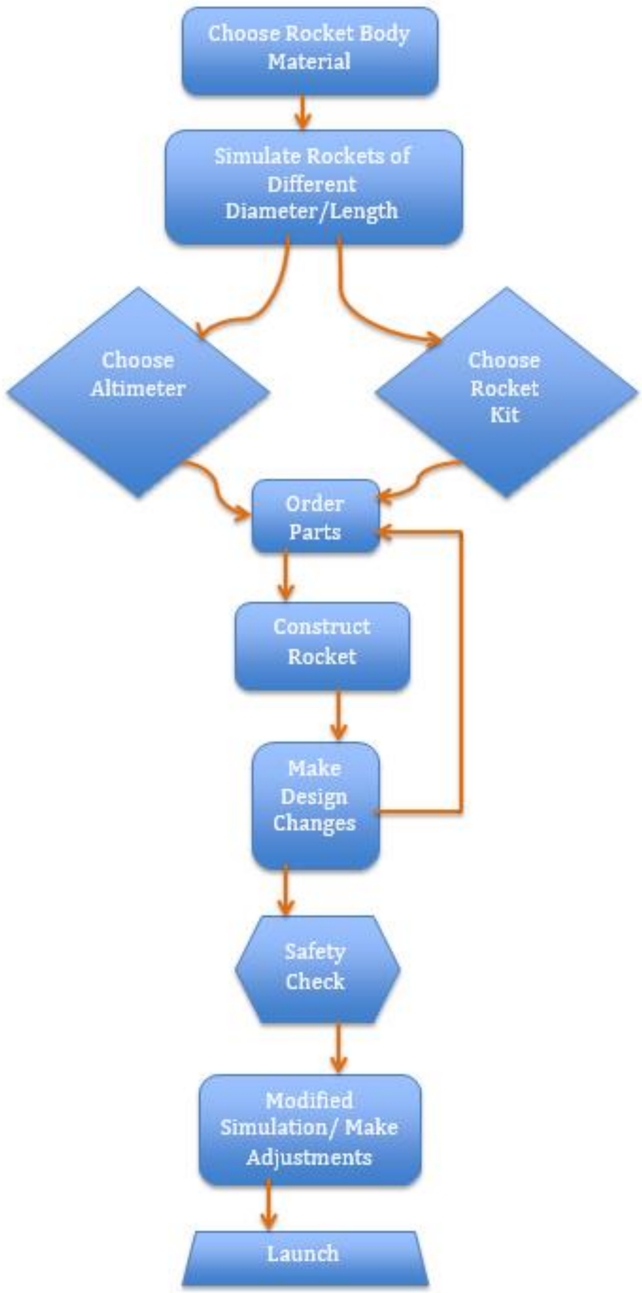

Figure 1

As seen in the flowchart above, the creation of a well-structured plan of action enabled the team to apply a timeline and goal setting scheme for each step of the design process.

Starting with the decisions that dealt with the design of the rocket, the material of the rocket was chosen. Subsequently, the decision about the physical specifications of the rocket was influenced by simulation tests using OpenRocket. Upon determining the suitable rocket specifications, the team researched purchasable kit rockets and electronics. The method of choosing the optimal electronics was based on the requirement for specific post-flight analysis. Following the decision on the various materials and parts, the rocket was purchased and constructed. After full construction, flight simulations and a test launch motivated necessary design changes, including a safety check. Upon test launch, data became available to make suitable alterations required to achieve the goals of competition before launch.

Design Features of Rocket

The first step in choosing the best rocket in order to meet competition requirements was to decide between a cardboard or fiberglass body. Several aspects of both materials factored into the decision, such as ease of use, sturdiness, ease of modification, and builder friendliness. Considering the aforementioned characteristics as well as the time constraint, the team decided to use a cardboard body.

Upon making the decision to use cardboard, the choices of rockets were narrowed down according to dimensions restrictions and optimized deliverables. To do so, using OpenRocket, rockets of various lengths, diameters, and motors were simulated. Based on the results obtained, the bounds of optimality were narrowed down between 5' and 6' with a high J or low K motor. Upon examination of available materials and evaluating the characteristics that would best meet aforementioned goals, the Madcow Torrent was chosen, shown below in Figure 2.


Figure 2

After selecting the rocket to purchase, simulations were further conducted in order to determine potential modifications that may be required, as well as choosing the correct motor. OpenRocket was used to conduct these simulations and testing. Simulations using the list of available motors provided the team the most viable motor for the rocket. One of the defining characteristics was the apogee obtained using each motor. The desired apogee was approximately a 300ft overshoot of the required 3000ft. This height would provide room for adjustments if necessary, and room for error based on the calculated coefficient of drag. Based on the criteria defined, the Cesaroni J357 Blue Streak was chosen.

In order to allow for design changes, an extra body tube section was purchased. This body tube was longer (32'') than the original upper section provided in rocket kit. The longer body tube provided for later adjustments to the height of the rocket and allowed for the main parachute to be housed in the upper section. The optimal overshoot was achieved with the longer body tube's increased drag.

The decision on the size of the parachute was based on the initial OpenRocket simulation, which calculated an estimate for the ground hit velocity. The rule of thumb for high powered rockets is anywhere between a 15-25 ft/s decent rate once the main parachute is deployed. There are pros and cons to being at the maximum or minimum of this range. While a quick descent is favorable in order to keep the rocket from drifting too far from the launch pad, the risk of damaging the rocket upon landing increases. Because of the previous decision to use a cardboard rocket, the choice was made to err on the side of caution and aim for a fairly low rate of approximately 17 ft/s. Based on previous good experience with SkyAngle parachutes, a 44'' was chosen for the rocket's estimated weight according to the rocket weight vs. parachute area tables provided by the company.

Design Features of Payload System

Upon deciding on the rocket specifications, focus was shifted toward flight mission requirements regarding data gathering. In order to successfully capture flight performance using more than one measurement system, the team researched electronics that were easily integrable on the kit rocket payload, spatially efficient, implementable with the time constraint, accurate, and within the budget.

Primary Altimeter:

The Featherweight Raven2 Altimeter was chosen as the primary device for flight performance gathering. The Raven2 is 1.8''long and has 4 outputs. The altimeter has the ability to gather axial and lateral acceleration of +/- 70 Gs and +/- 35 Gs respectively, a high precision temperature sensor and barometric data up to +/- 0.3% accuracy. The Raven2's 4 outputs can be programmed with logic options and can be selected in combination for each output. It is to be used with a 9V input battery, and deployment charges can be wired to the outputs in use. A picture of the Raven2 is shown below in Figure 3.

Figure 3

Through evaluation of competition specifications and deliverables for the selected rocket design, 2 outputs are required (Main and Apogee) with the dual deployment mechanism. The Raven 2 was set to deploy an apogee charge at the point when the velocity was negative, and the main charge was set to deploy at an altitude of 608 ft. With its own interface available to evaluate the stored data, the logged data can be easily outputted in forms of graphs and comma-separated values making it useful for post flight data analysis and flight optimization.

Non-Commercial Altimeter:

Adhering to further instructions, a second non-commercial altimeter was to be designed in order to report the same data (velocity vs time and acceleration vs time). Through research and evaluation of ease, an Arduino Micro, Sparkfun T-5403 Barometric Pressure Sensor, and Sparkfun Breakout SD/MMC Board were to be used in union to communicate with the sensor and SD card, sense pressure data, and store the pressure data respectively, shown below in Figure 4.

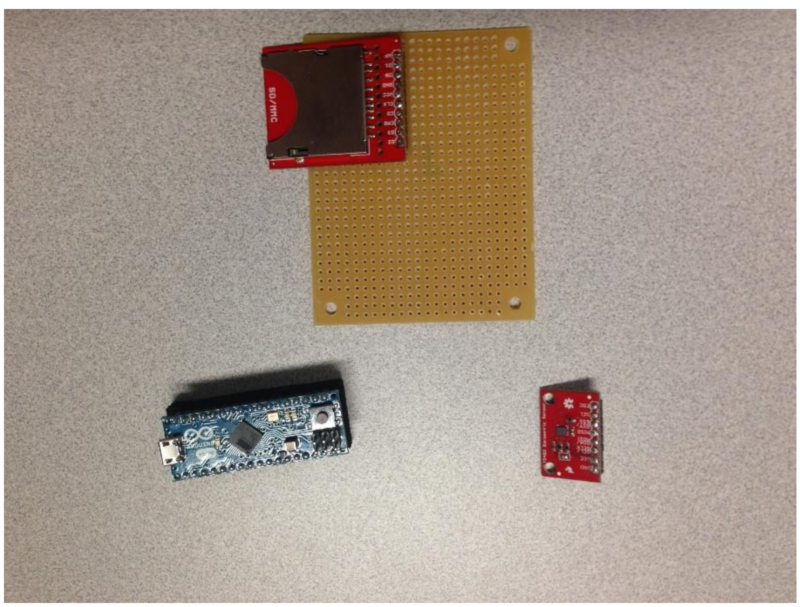

Figure 4

The Arduino Micro is a 20 pin I/0 microcontroller with a USB slot, and measures 4.88 cm x 1.77 cm, making it ideal with respect to compactness and ability. It operates at 5V and can be regulated with a 3.3V or 5V pin on the Arduino. Arduinos have their own IDE that can be used to program the Arduino to read the data required from sensors. The Sparkfun T-5403 Barometric pressure sensor, with dimensions 2.3 cm x 1.7 cm I2C, can be used to measure absolute pressure, and temperature. Pressure data can be used to approximate altitude by using the formula shown below:

$$Altitude = 44330 \cdot (1 - \frac{p}{p_0})^{\frac{1}{5.255}}$$

Where p is the local pressure being measured by the sensor, and p_0 is the baseline pressure defined as the ambient pressure.

In order to store the data for use post-flight, a Sparkfun Breakout SD/MMC board is employed for data storage. The SD card is a Transcend 16GB, 32FAT, with dimensions 1.3'' x 1.5''. During the design process, the Raven altimeter to be added by the competition hosts was also taken into account while analyzing the rocket's weight, available payload area, and power usage. To provide power to the payload and all of these components, three 9V batteries were designated for each functioning electronic piece.

Diagram of Rocket

Shown below in Figure 5 is the OpenRocket diagram from the final completed rocket. The location of the CG and CP were manually overridden in the model to accurately reflect position. The final design of the 4'' rocket ended up being just over 68'' in length with the addition of the extend upper section housing the main parachute (dashed circle) and the same length of lower section with the drogue parachute (dashed ellipse).

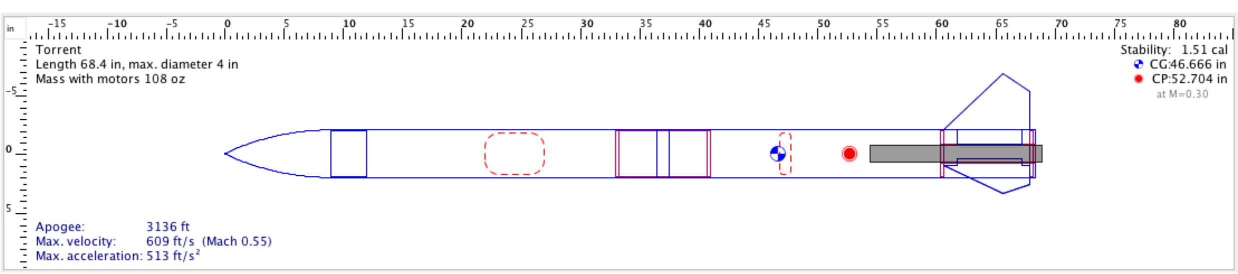

Figure 5

Analysis of Anticipated Performance

To perform the analysis of the predicted performance, several programs were utilized. As stated in the sections above, OpenRocket was used as the main tool to iterate changes and simulations of the rocket. Throughout the design process, the original stock RockSim file provided by the manufacturer was modified to match the specifications of the rocket model. By measuring the precise weight of each component and overriding the weight in OpenRocket, the final weight of the total rocket was matched with what was experimentally measured.

One of the biggest approximations in any aerodynamic software is that of the coefficient of drag (C_D). Because it is largely dependent on surface preparations, such as the types of paint and primer applied, calculating a number is difficult without wind tunnel or experimental testing. Prior to the test launch, the rocket was given one coat of primer, so simulations of the stock surface “Smooth Paint” was applied in OpenRocket. This texture, along with the original smaller upper body tube, gave the rocket a total calculated coefficient of drag of approximately 0.49. With a given launch weight of 2177 g, the predicted altitude was calculated to be 3370 ft. As described in the Test Launch section, this predicted altitude was calculated using the launch conditions on that day with a wind of approximately 10 mph and temperature of 70˚. After the test launch, the C_D was refined by comparing the predicted simulation with that of the actual. In order to do this, Matlab code was written to iterate the C_D value for the rocket until the calculated plot of height vs time matched that of the experimental output from the Raven2 data. After several iterations, it was determined that, for this given simulation, a value of 0.44 could be applied that matched the experimental curve reasonably well, shown in Figure 6 below. Because this secondary calculation only estimates drag based on the given cross section, it was predicted that its value would be slightly less than that of OpenRocket, which uses more rigorous estimations.

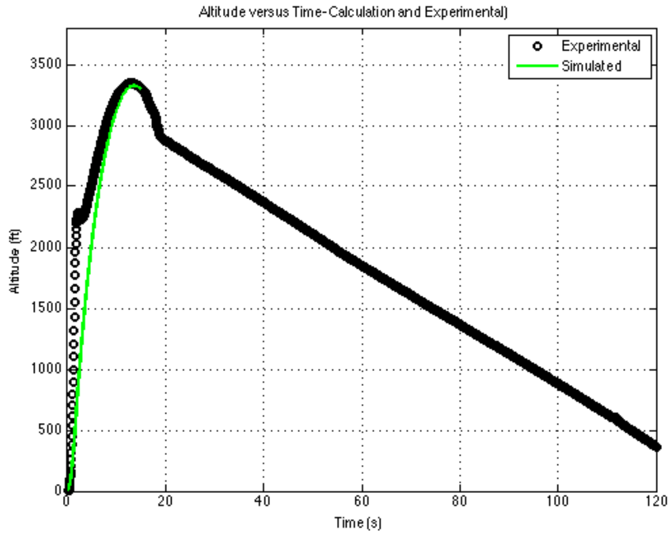

Figure 6

With the validation that OpenRocket's simulation was in the correct ballpark, the decision was made to use OpenRocket to calculate the max altitude and acceleration of the rocket. After updating the model with the increased length of upper section body tube from 12'' to 27.5'', the predicted launch conditions of 50°, 15 mph wind (based on the predicted forecast), and a C_D of 0.55 were used to calculate the values displayed in Figure 7 below. A plot of the predicted altitude vs time, velocity vs time, and acceleration vs time is also displayed in Figure 8.

Predicted Flight Characteristics		
Max Altitude		3059 ft
Peak Acceleration		516 ft/s
Max Velocity		605 ft/s
Time to Apogee		12.7 s
Ground Hit Velocity		16.1 ft/s

Figure 7

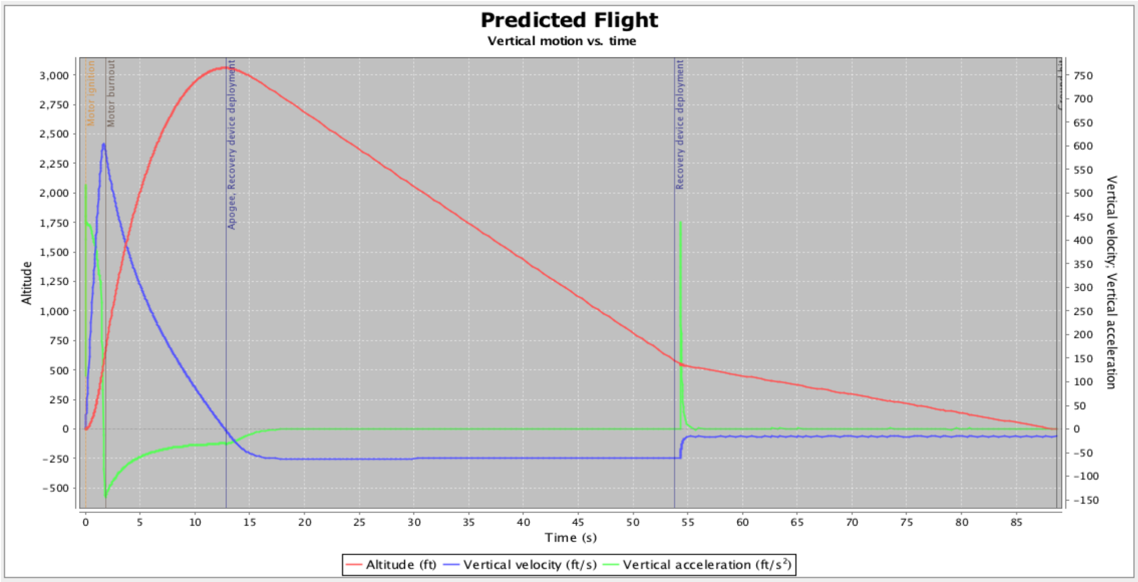

Figure 8

Construction of Rocket

Construction of Body:

In order to construct the rocket purchased, the Madcow Torrent, an already made available assembly manual was used. Out of the box, the rocket appeared to have a glassine finish, so it was sanded down in order to make sure the epoxy to be used had a rougher surface to adhere. The first order of construction dealt with fitting and epoxying the centering rings onto the motor mount. Seeing that this was one of the most essential parts of the rocket, a test fit was conducted in order to make sure that the centering rings could be slid on and would fit snugly. The centering rings were placed approximately 1/2'' away from the front and aft end of the motor tube. Epoxy was applied and the part was allowed to dry before inserting it into the body tube. In order to have an efficient construction process, cool-downs were well managed to ensure there was always a part to be worked on.

After letting the epoxy for the centering rings dry, their alignment was checked and fillets were applied after an eye bolt was inserted on the fore centering ring. After letting epoxy dry, a shock cord was attached using an overhand knot. The motor mount was then test fitted into the body tube to ensure a snug fit. Due to a little uneasiness of making it fit well, the centering rings were sanded to an amount that would increase snugness. In order to make sure the centering rings were positioned correctly, the fins were inserted to mark placement. Upon confirmation of correct placement, the outer edges of the aft centering ring were epoxied and the inside of the body tube were epoxied for the fore centering ring. The motor mount was slid in, and placed appropriately as measured and fit in accordance with the fins. Fillets were then applied at the ends upon drying to ensure rigidity of position and increase the strength to avoid motor mount pull out during the high force events of the launch and parachute deployments. After the centering ring and motor mount were set, the fins were inserted. The fins were sanded down to remove any difficulty when sliding them into the precut slots and were checked to make sure they fit snug. The inner thickness of the fins were then coated with wood glue, and the fins were placed in the slots. The perpendicularity of the fins was check and upon setting, fillets were applied on the outside of the fins and the body tube to increase the structural strength of the joints to prevent breaking a fin off in the event of a hard landing.'

For the rail guides, two 5/64'' holes were drilled on the rail button line previously marked out on the side of the rocket. The aft rail button was screwed directly into the side of the rocket and aft centering ring of the motor tube. The fore rail bottom on the other hand was inserted to a weld nut to hold it in place. In both cases, epoxy was applied to the screw or bolt to prevent it from backing out.

Construction of Payload Section:

Next the payload section of the rocket was assembled. Eyebolts were inserted on the two bulkheads, and epoxy was applied to ensure the nuts did not back off. For the outer surface of the tube, markings were made 4 1/2'' from either ends in order to fit a coupler. After ensuring it was correctly aligned, the thin coupler ring was epoxied to the outside of the 12'' payload section. With the shell created, the next step was to create the payload sled. The Torrent kit came with a precut 4'' electronics sled kit and all the hardware required for assembly. Laser-cut threaded rod guides were positioned and attached along with a small battery support using Gorilla wood glue. The next step was laying out all of the electronics: Arduino perforated board, Raven3, Raven2 and three batteries. It soon became apparent that the 4'' sled lacked enough room for all of the components. To correct this, extra basswood was used to create an extension the same width as the original board in order to extend it by 2'' and then secured to the original sled using two bolts shown in Figure 9. This gave enough room for the Arduino perforated board and also provided an extra support for additional battery on the back side, shown in Figure 10. With the layout determine and penciled, holes and slots were drilled for the needed board attachments as well as zip ties for the batteries.

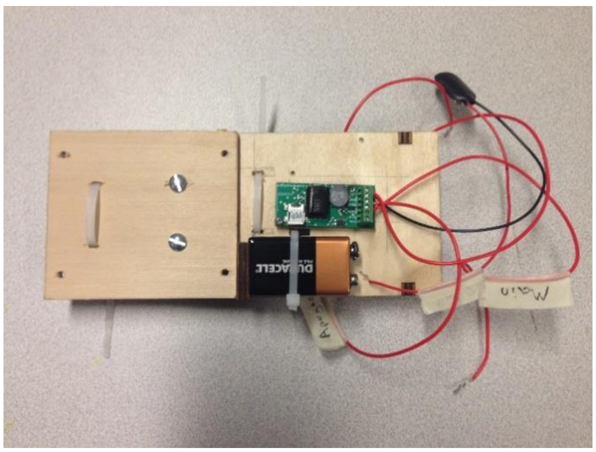

Figure 9

Figure 10

Final Steps:

Upon completion of the body tube and the payload section, final steps were taken in order to make sure the rocket was ready for launch. Primarily, insertion of the nose cone, and ensuring that it fit snug with the upper section. To allow for easier removal, the nose cone was sanded down.

Vent holes were marked and drilled on the side of the coupler in order to allow the pressure sensors in the electronics bay to provide the correct pressure readings. On the lower and upper body tubes, holes were also needed to vent and release the pressure generated from the ejection charges. The size and number of the holes was determined based on the volume of the compartments for both the lower section, upper section and payload bay. Using an online calculator, three 1/8" holes were determined to be needed in order to properly vent each of the bigger sections and the same was applied for the payload bay to allow more than enough space for the pressure to equalize.

A motor retainer was placed on the end of the motor tube which was exposed to allow a quick and easy insertion of the casing and motor. Instead of using regular epoxy attach, JB weld was utilized due to its higher temperature resistance, especially with the retainer's location relative to the exhaust of the engine.

With the main sections completed and hardware attached, the next step was connecting all the pieces together. In order to do this, the nylon shock cord provided in the kit was used. After dividing the cord in half, which was still tied to the fore centering of the motor mount and cutting, cord protectors were slid on each section to prevent the charring of the cord during the ignition of the deployment ejection charges. Overhand knots were utilized to tie both the parachute protector and loop to the quick loop for the each parachute. The knots were placed in such a way that when the rocket was fully deployed, there was enough space sections to prevent contact. The loops for the parachutes ended up being located about ⅓ of the way down the top of each cord section for safe deployment shown in Figures 1 and 2 below which are the upper and lower sections from left to right.

Figure 11

Figure 12

Painting was the last part of construction. Due to the lack of a weight constraint, it was elected to fully prime the rocket before putting on the final coat. To prevent the obstruction of fit up as well as filling the drilled vent holes, tape was used to cover critical areas. Using multiple light coats of spray paint, a smooth surface finish was achieved on all components.

Upon full construction of the rocket, and determined launch-readiness, pre-launch safety measures were taken to check for stability. The center of pressure and center of gravity were marked on the rocket. The center of pressure was found through the use of OpenRocket, giving the value of 52.5'' from the tip of the nose cone. In order to mark the center of gravity a simple finger-balance method was utilized. The method gave a distance of 46'' from the tip of the rocket. By comparing the distance between the CP and CG of the rocket, the stability margin was found to be approximately 1.5, which falls within the rule of thumb stability of 1-2 diameter lengths between the two points.

Test Launch

On the weekend of April 20th, the opportunity was given to test the rocket at a Central Illinois Aerospace located at the Rantoul Airfield in Rantoul, IL. Before preparing the rocket for launch, ejection charge testing was done to ensure that the rocket would separate at deployment and push the parachutes out of the body tubes. The decision was made to use friction fitting instead of shear pins to hold the rocket together during ascent and prevent separation due to pressure drag. This decision was based on the ease of use and previous success of this method with similar cardboard rockets.

In order to calculate the estimated grams of black powder needed based on the volume of each of the compartments and desired force of 12 psi, an online calculator was utilized which suggested a charge of approximately 1 gram for each section. After positioning the rocket, placing the created charges, and clearing the area, the sections were individually tested as shown in Figure 13. In both cases, the rocket separately cleanly and the

parachutes exited without an issue which validated the estimation of the charge size.

Figure 13

With charge testing done, the rocket was fully prepped for launch. Due to a material constraint, it was decided to do just a single deployment at apogee and forego the dual deployment. The purpose of the launch was to collect data from the Raven in order to compare the estimated C_D values with the actual from the test flight. Before launching, the OpenRocket model was fully update with the correct weights and flight condition of 70°, clear skies and a 10 mph wind, which gave a predicted apogee of 3370 ft.

Figure 14

The launch went smoothly with the rocket jumping off the pad without any wobble or instability and ascending almost perpendicularly with very little weather cocking or turning into the wind. At apogee, the main parachute was deployed and the rocket drifted safely down at approximately 24 ft/s before landing softly in the field with no damage to the body. The actual altitude ended up being 3345 ft which came within 25 ft of the predicted.

Adjustments:

In order to decrease the maximum altitude to meet the competition goal, the rocket was adjusted by adding length to the upper section thereby increasing weight and drag. The process is described fully in the previous sections.

Photographs of Rocket

Figure 15: Finished Nose Cone

Figure 16: Finished Electronics Bay

Figure 17: Finished Upper Body Tube Section

Figure 18: Finished Bottom End

Conclusion

By adhering to the action plan created by the team at the beginning of the design process, the Celestial Chiefs successfully created a high-powered rocket that follows the set of design requirements detailed in the Great Midwestern Regional Rocket Competition. The software simulations and flight test predict that the rocket will meet the flight requirements of the competition as well. The ability of the rocket will be tested when the launch occurs at the competition on April 26th, 2014, in Minnesota. Additionally, post-launch analysis will determine if the requirement for multiple types of altitude measurement were met by the rocket. Furthermore, the team was able to build the rocket within, and significantly under, budget by using unused, leftover parts from previous years. Since cost is one of the motivating factors in space vehicle design, being under budget is a commendable accomplishment along with successfully designing and building a functional rocket.

Budget

On the next page in Figure 19, is a table for this year's budget. Included in the table, is the list of all the hardware, electronics and miscellaneous items that were purchased for the construction of the rocket along with the vendor and price of the items. By reusing items from previous competition years, the cost of the putting together the rocket was significantly reduced compared to past years when budgets have pushed $800 to $900. The reused items and the total budget including reused items are highlighted in blue. The budget without reused items is also included.

Rocket Part List	Vendor	Price
Hardware		
Torrent Rocket Kit	Madcow Rocketry	$133.45
38mm Motor Retainer	Aeropack	$31.03
32''- 4'' Body Tube	Madcow Rocketry	$13.95
J357 Motor	Cesaroni	$57.91
Motor Case	Pro-X	$53.46
54'' Parachute	SkyAngle	$82.50
Electronics		
Arduino Micro	Arduino	$25.00
T-5403 Barometric Pressure Sensor	Sparkfun	$15.00
3-Axis Accelerometer Sensor	Sparkfun	$28.00
Raven2 Altimeter	Featherweight	$155.00
Breakout SD/MMC Board	Sparkfun	$10.00
16 gb SD Card	Amazon	$12.00
2- Key Switches	AeroCon Systems	$12.00
Miscellaneous		
Building Supplies	Hardware Store	$50.00
Ejection Lighters with Tube	Wildman Rocketry	$18.00
Engine Igniters	Apogee Rocketry	$12.83
Total (including reused parts)		$710.13
Total		$503.43

Figure 19