Team Rocket Power:

Flight Readiness Report

Team members:

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1. Aerodynamics

Proper aerodynamic performance was ensured by the construction technique detailed and the large static margin of stability. Care was taken to ensure that the Cd was kept to a minimum during the construction of the rocket to promote better aerodynamic behavior during flight. All rough spots and stray epoxy were sanded smooth and the fins were properly aligned and epoxied to decrease fin flutter in high velocity flight.

2. Rocket Build

2.1 Overview

The rocket kit chosen for this project is the D-Region Tomahawk kit, made by Public Missle, Ltd. It is 71 inches long, has a 3 inch diameter, and weighs 55 ounces without added parts. To incorporate dual electronic deployment, the kit was modified to remove the piston deployment. The coupler made for the original kit was engineered into an avionics bay for the dual deployment system. The kit contains a pre-slotted Quantum tube airframe which was chosen due to its strength compared to cardboard tubing, and its forgiving and easy to use nature. Quantum tubing is made from a blended polymer and appears as a medium grey with a smooth surface finish. The motor mount and coupler are both made from Phenolic material for added strength and rigidity.

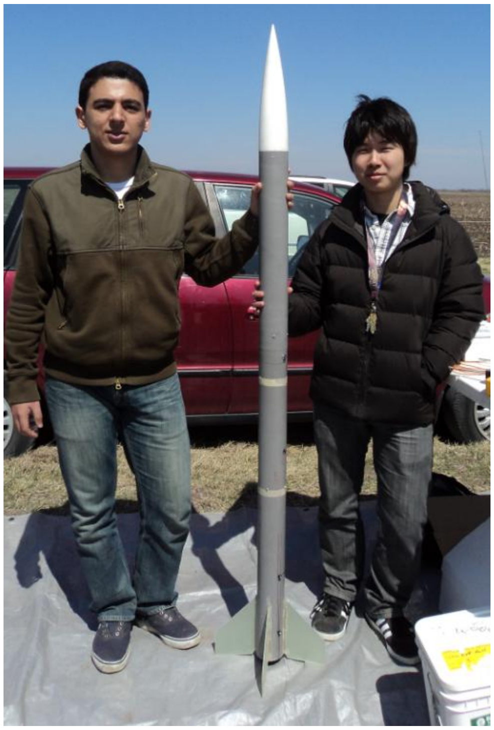

Figure 1: Overall rocket design

2.2 Nose Cone Analysis

The nose cone intended to fly with this kit was modified for this project to allow for bulkhead attachment. The original Ogive nose cone was hollow molded plastic closed at the shoulder. To allow for secure attachment of the main parachute, the closed off portion of the nose cone was cut off and a fiberglass bulkhead was epoxied in place with a centered eyebolt for fast attachment of a quick link and main chute. A picture of the modified nose cone and eyebolt can be seen in figure 2 below.

Figure 2: Ogive nose cone with bulkhead modification

2.3 Upper Airframe Analysis

The upper airframe serves as the housing for the main parachute. The parachute will be attached via tubular nylon shock cord to the nose cone eyebolt and the coupler U-bolt using quick links. Protective recovery wadding will separate the black powder ejection charges from the parachute to prevent damage to the parachute. The upper airframe is connected to the nose cone via three 2-56 nylon shear pins, and to the coupler by four 6-32 bolts attached to nuts on the inside of the coupler. The ejection charges are placed between the top bulkhead plate of the coupler and the main parachute. This setup ensures that the ejection charge pushes out the main parachute, so if there is a deployment issue with the drogue chute in the lower airframe, the main has a higher chance of succeeding in slowing the descent rate. Figure 3 shows the upper airframe with attachment holes

Figure 3: Upper airframe

2.4 Coupler Analysis

The coupler is made of Phenolic material and was engineered into the avionics bay for this project. The coupler will contain the electronics and will also serve as the mounting connection points for the black powder charges. Bulkhead end caps were made from fiberglass and fitted with U-bolts for the shock cord and chute attachment. The charges will be wired to terminal blocks that are epoxied onto the top of each bulkhead. The coupler also houses the switch band with two keyed arming switches on the outside. The switch band ensures that the electronics can be armed separately while on the launch pad. The bay will house a StratoLogger SL100 flight altimeter and an Altus Metrum Telemetrum for telemetry. The avionics sled is located inside the coupler and is made from aircraft grade plywood and will be secured using threaded nut and washer to the coupler. Aluminum rod spacers were epoxied to the surface of the sled to ensure that the sled is securely seated in the electronics bay. The sled will slide over a threaded rod that spans the entire length of the a

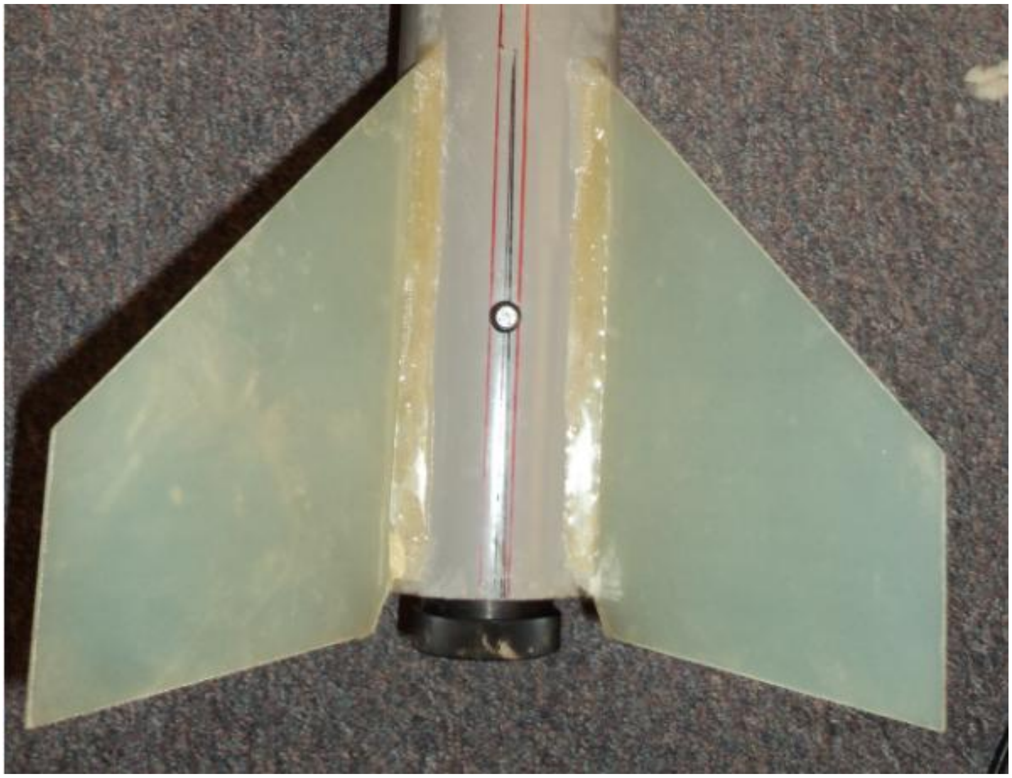

Figure 5: Fin assembly

The motor subassembly consists of a phenolic motor mount, wood centering rings, the Aeropack 38mm retainer, and a motor casing. During initial assembly, only the forward centering ring was epoxied to the motor mount to ensure that the interior fillets and aft rail button could still be mounted easily. The rocket's shock cord was securely anchored to the motor mount using epoxy through a notch in the inner diameter of the forward centering ring. The motor mount assembly was centered and epoxied to pre-sanded surfaces in the booster airframe.

Figure 6: Motor mount during assembly

The launch rail interface for the rocket is two 1010 standard size rail buttons attached to the side of the booster airframe. The rail buttons attach via screw to a flanged nut that passes through the airframe body. This ensures that the rail buttons are securely attached to the airframe. The aft rail button flanged nut was also epoxied and attached during the same time as the interior fillets were completed for the fin assembly. This system allows for replacements of rail buttons in the case of any breaking off. The forward rail button was also placed at the center of pressure location of the rocket for easy identification of the Cp prior to flight.

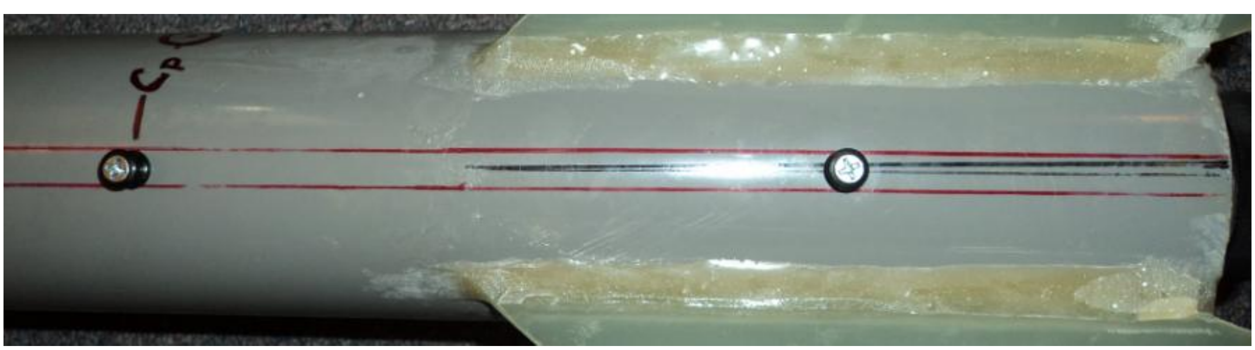

Figure 7: launch rail assembly

The motor retention used is the 38 mm Aeropack Motor Retainer. This retention system was chosen because it is reloadable so it can be used for multiple flights. It provides a quick way to mount the motor, and it is easily installed on the rocket. The retainer was installed on the exposed section of the motor mount after the aft centering ring was installed using epoxy on pre-sanded surfaces. Care was taken to ensure that no epoxy entered the interior of the motor mount. The Aeropack system uses interlocking, threaded machined aluminum parts, and is highly resistant to damage and motor forces during flight.

Figure 8: Aeropack retainer and aft centering ring

The booster airframe also houses the variable ballast system for the rocket. The ballast is constructed from extra phenolic coupler material and is filled with copper BBs for the adjustment of weight to reach the ideal altitude. The ballast was placed at the rocket's original center of gravity to ensure that the margin of stability intended for the rocket remained the same. The shock cord is passed through slits cut into the ballast container and is knotted before and after the ballast to ensure that it does not shift around during the rocket's flight. The ballast container rests on four 6-32 bolts installed radially inwards on the booster airframe. This ensures that the ballast remains in the correct location during the ascent of the rocket. This system also minimizes the volume the drogue ejection charges are required to pressurize, therefore minimizing the amount of black powder required.

Figure 9: Variable ballast system

The drogue parachute will also be located inside the booster airframe along with the drogue ejection charge and protective recovery wadding. The drogue chute will be attach to the booster airframe and the coupler via two quick links. The drogue ejection charges will be placed below the chute to help push the chute out of the booster airframe. This system aids to ensure the recovery system performs as expected to minimize the chance of damage to property and harm done to people.

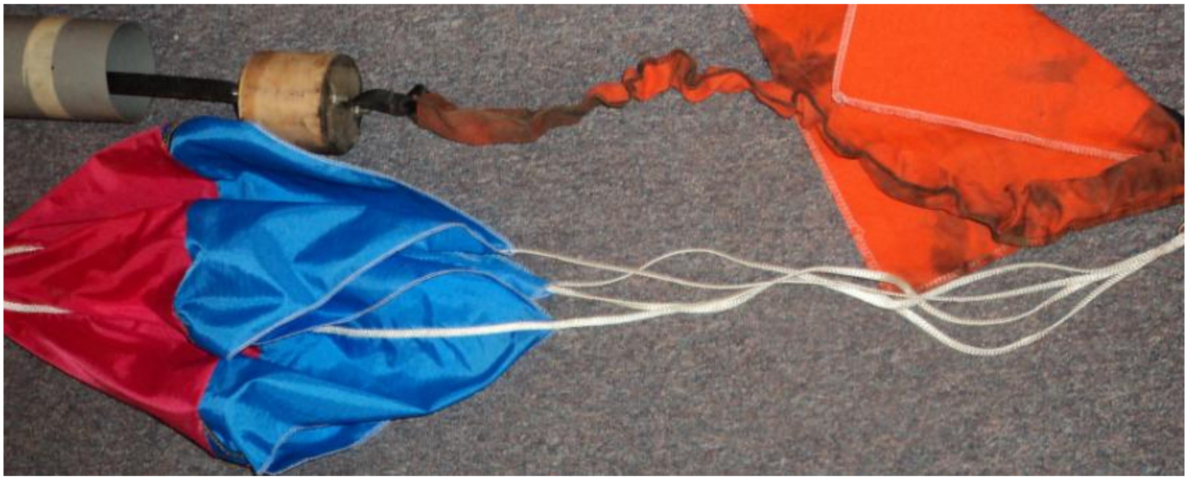

Figure 10: Drogue chute attachment

3. Safety Plan

The safety officer for this project is Stephanie Camello and she is a Junior in Aerospace Engineering. She is fully aware of the responsibilities necessary for this position. Team mentor Mark Joseph also plays a big role in safety precautions by loading the motor and all the black powder charges. To ensure personal safety while building the rocket, work is only conducted in mentor designated work areas with up to date equipment. This includes gloves that are worn when working with epoxy, goggles that are worn when cutting and drilling material, and a well ventilated area. All members a required to wear proper attire during construction including close toed shoes and non-baggy clothing. All inexperienced team members only operate equipment under the supervision of an experienced team member. All team members were notified of all MSDS locations prior to the start of the project.

At the launch site, several more safety precautions besides those mentioned above will be taken. Throughout the rocket assembly, continuity checks will be done frequently to ensure the avionics are wired and functioning correctly. This ensures the avionics play their role in deploying the parachutes and hence makes for a safe landing. Furthermore, any hazardous or explosive materials such as the ejection charges or the motor will only be handled by the team mentor or under his direct supervision. The team mentor will also be responsible for ensuring the rocket is in a safe condition to fly once team personnel are finished with the assembly.

Once the rocket is ready for launch, it will be taken out to the launchpad only after team members are given the all clear from launch coordinators. The motor ignition wiring will be done by launchpad personnel only after it is confirmed that the rocket is securely on the guide rails. Team members and all other personnel on the launch field will retreat to a safe distance away from the launchpad and the motor will be ignited once the launch field is clear. Once the rocket is in the air, all personnel will keep a watchful eye on it to avoid harm done to people. If there is such a risk, people will be warned and evacuated immediately from the rocket's landing zone. Finally, once the rocket is on the ground, retrieval will not be commenced unless the launch field is clear and team members are given the OK from launch operators.

The rocket will also undergo ground testing prior to flight to ensure safe and proper performance of the electronics and rocket parts. Ground charge testing was completed prior to the test launch on 4/07/2013 to confirm the amount of black powder that was required to separate the sections of the rocket and pull out the parachutes. The amount of black powder that was determined to be required for the rocket was 1.5 grams and 2.0 grams for the drogue and main chutes, respectively. Continuity checks were also performed on the electronics to ensure that they had a better chance of performing as expected.

4. Test flight

On Sunday, 4/07/2013 the first full test flight was completed for the rocket. The team participated in Thunderstruck, a high powered rocketry event held near Lafayette, Indiana where individuals and teams alike come to fly their rockets.

Figure 11: Rocket on launch rail

Preliminary launch preparations included setting up a team station and removing all rocket parts from the car and to the station. Once everything had been moved and all parts were present, rocket assembly began. The team assembled all systems for the interior of the rocket first, ensuring all proper steps were taken.

Assembly began with the payload bay. This was a sensitive and critical part of the assembly as the payload bay housed all the avionics and wiring that were responsible for monitoring the flight and deploying the parachutes. Work on the payload bay consisted of the necessary wiring to establish a connection between the avionics and the ejection charges and, mounting the payload sled into the payload bay and sealing the bay at both ends. Several continuity tests were performed throughout the wiring process to ensure all flight avionics were performing as planned. Once the payload sled was ready and the charges wired, the main tube assembly began.

The ballast container was first slid into the booster airframe of the rocket and secured. Then the drogue parachute was encased in protective insulation, connected via shock cords to the ballast container from the bottom and the payload sled from the top and slid into the lower half of the rocket. Chute blast protectors and shock cord protectors were used to help ensure the ejection charges did not damage the chute. The payload bay was then mounted on top of the lower airframe of the rocket and the ejection charges were placed with the drogue chute such that they would push it out at detonation. Next, the main chute was encased in insulation, connected via shock cord to the nose cone and coupler section, then inserted into the upper half of the rocket together with its ejection charges. A total of five 2-56 nylon shear pins were used to connect the separable sections of the rocket together after all chutes, shock cord, recovery wadding, and ejection charges were loaded into the rocket.

Once the rocket was assembled, it was checked for safety purposes by Mark Joseph the team safety supervisor and mentor. Upon the safety check completion, the motor was prepared for insertion into the motor mount. The motor ejection charge was removed and not used, as the dual-deploy system helped to ensure proper deployment of the recovery system. The motor retainer was removed and the motor was slid into the motor compartment from the lower end of the rocket. The retainer was then placed back in its original position. Continuity checks were also done throughout the motor placement process. Once the rocket was sealed, a laptop was set up with an antenna connected to the Teledongle to establish connection to the onboard telemetrum.

Once team was given the OK from Mark Joseph and the launch field controllers, the rocket was taken out and placed onto one of the several present launchpads and slid onto the guide rails. More continuity checks were performed and once it was confirmed that the avionics were functioning, the motor was wired for ignition and all personnel evacuated the launch field.

The rocket launched successfully and the recovery system performed as expected. Once the rocket was at apogee, the drogue chute was deployed successfully and the rocket started to descend. At an altitude of 600 feet, the main chute was successfully deployed and the rocket landed safely on the field. Once it was safe to do so,the rocket was collected from the field at the touchdown location.

The pre-flight weight without the motor installed was 7.2 lbs.

Figure 12: Rocket safely landed

5. Flight characteristics

The flight characteristics for the test flight as reported by the telemetrum and altimeter are as follows.

Max Altitude	2486 ft AGL
Range	1214.4 ft from launch pad
Landing Velocity	14 ft/sec

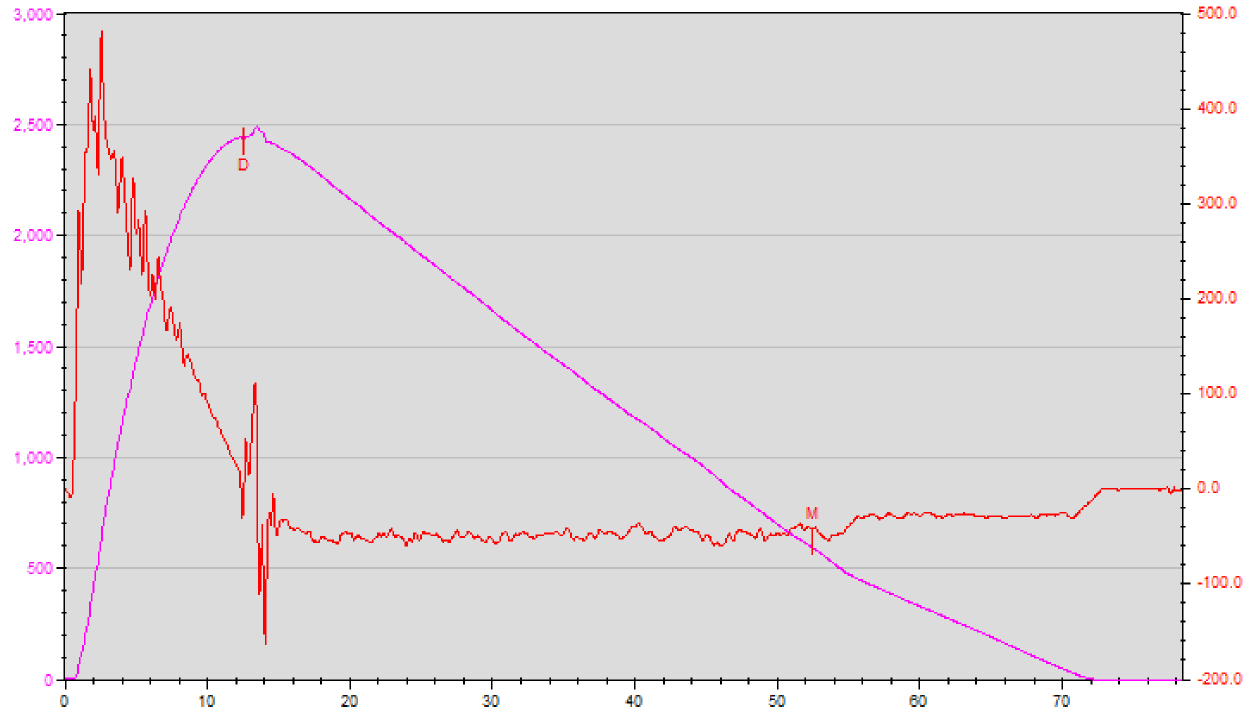

Figure 13: Test flight plotted using Altimeter software

The drogue chute opened as expected at apogee and the descent rate under the drogue was 17 ft/sec. The descent rate under the main chute was 14 ft/sec, which is well under the limit of 20 ft/sec landing velocity. The test flight provided valuable data on the actual amount of ballast required by the rocket to better approach the target altitude and proved that the recovery system and rocket could perform safely and to expectations.

6. Launch Check off list

The launch check off list includes everything that must be done before flight can occur and the safety officer is responsible for going through all the steps. The launch check off list is as follows:

1. Ensure all components are present and working
2. Assemble electronic bay
    a. Insert and secure a new battery for the altimeter and TeleMetrum
    b. Check that all wires are securely connected
    c. Make sure the altimeter turns on and a signal from the TeleMetrum is detected
3. Attach the eyebolt to threaded closure
4. The mentor will measure and load the black powder and electronic matches and place them in the necessary positions
5. Attach the main and drogue parachutes to their shock chords and cover them with a safety blanket to protect them from the charges
6. Load parachute and attach shock cord to nose cone
7. Attach booster section to coupler using shear pins
8. Attach nose cone using shear pins
9. Rocket is ready for safety inspection

7. Stability

To ensure the rocket enjoyed a stable flight, several measures were taken during construction. They were mainly concerned with two aspect of stability, the first was to maintain the center of gravity above the center of pressure, and second was to keep the sections of rocket tubing and fins as rigid as possible during flight. The static margin of stability was 3.54 cal when the rocket was simulated in the OpenRocket software. To maintain this margin of stability, the ballast was added such that the location of the center of gravity did not change.

The alignment of the rockets different sections was put at jeopardy by the many different cuts and attachments that had to be done during construction. To keep the rocket as straight as possible, all body tube cuts were made with a straight tape guideline to ensure the saw did not veer off and cut into unwanted areas. furthermore, team members were very adamant on measuring several times before cutting or drilling.

The center of pressure of the rocket was specified by the manufacturer at 60” from the tip of the nose cone. A rail button was placed at the specified center of pressure to ensure quick locating of it prior to flight.

Stability | Drag characteristics | Roll dynamics

Component	CG / in	Mass / oz	CP / in	$C_{N\alpha}$
Nose cone	9.0	5.6	6.156	2.0
Payload section airframe	23.75	6.94	23.75	0
Airframe	52.25	11.9	52.25	0
Fin set	67.941	6.43	66.69	19.2
Total	**52.152**	**136**	**60.969**	**21.2**

Figure 14: Stability data from OpenRocket

8. Simulations

The rocket was modeled and simulated in OpenRocket. The margin of stability was found from the model and was determined to be 2.82cal with the motor installed. Given this margin of stability, the rocket is expected to perform safely and as expected. The rocket was simulated by OpenRocket to reach an apogee at 2962 ft AGL and land with a vertical velocity of 24.7 ft/sec. The total coefficient of drag was estimated at .58. The simulations will be refined with the flight data received from the test flight on 4/07/2013 and the ballast and Cd will be optimized to reach the goal altitude.

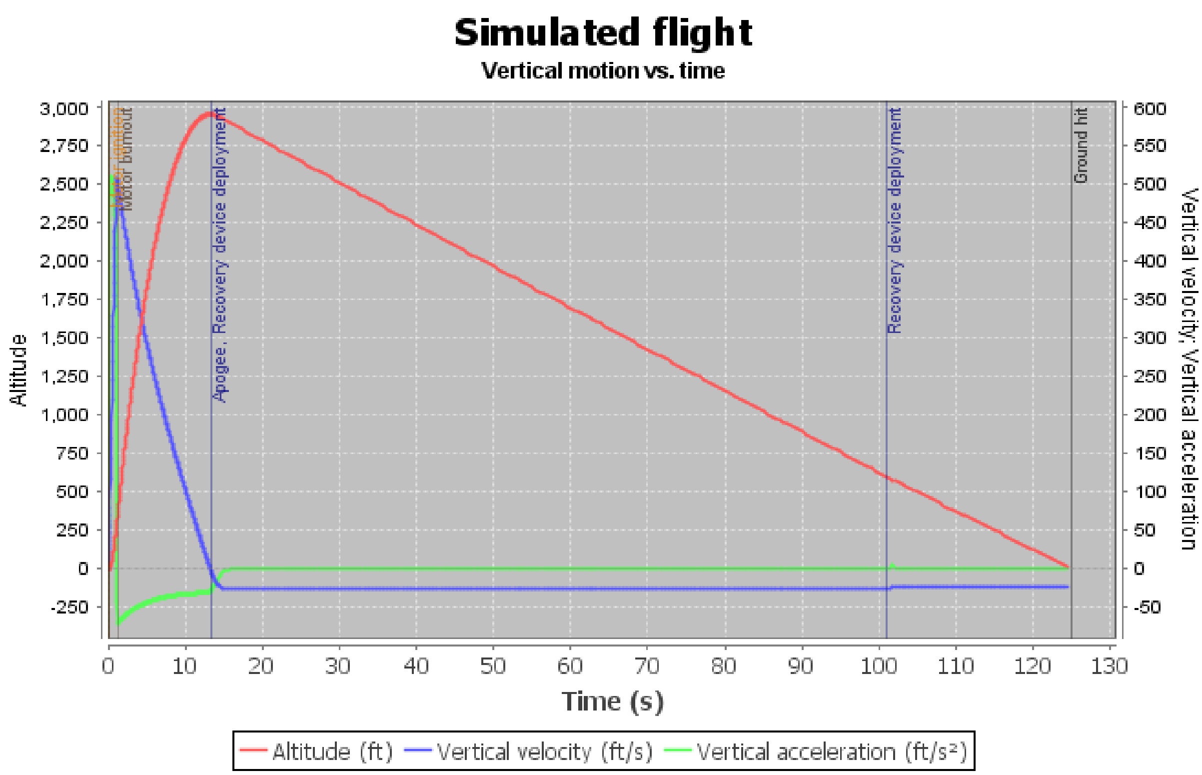

Figure 15: Predicted flight from OpenRocket

Stability | Drag characteristics | Roll dynamics

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Nose cone	0.00 (0%)	0.00 (0%)	0.04 (6%)	**0.04 (7%)**
Payload section airframe	0.00 (0%)	0.00 (0%)	0.09 (15%)	**0.09 (15%)**
Airframe	0.00 (0%)	0.13 (23%)	0.15 (26%)	**0.28 (49%)**
Fin set	0.09 (16%)	0.00 (0%)	0.08 (14%)	**0.17 (30%)**
Total	**0.09 (16%)**	**0.13 (23%)**	**0.36 (61%)**	**0.58 (100%)**

Figure 16: Predicted Cd from OpenRocket

9. Epoxy

The main adhesive used in the rocket's parts together was epoxy. The epoxy chosen for the project was the Aeropoxy ES6209 Liquid High Strength Adhesive for it's strength and reliability. Since the locations requiring epoxy were ones that would undergo large loading, a high strength adhesive was required. Epoxy is an adhesive substance made by mixing resin and hardener fluids together in a specific ratio and stirring vigorously for a period of around 5 minutes. If the resulting paste is of desired consistency it is taken from the mixing container and applied to the rocket such that the paste is in contact with the surfaces needing to be glued together. All surfaces were pre-sanded with 80 grit sandpaper prior to epoxy application to ensure that the epoxy would adhere firmly. Especially for the Quantum tubing, which has a high surface finish, sanding is of high importance to ensure proper bonding. After its application, the epoxy was left to harden overnight. Any epoxy that was in the incorrect location after drying would be sanded off using sandpaper. The result was surfaces glued together firmly and securely. Care was taken to ensure that direct skin contact with epoxy was minimized to prevent harm done to personnel.

Epoxy was the adhesive substance of choice for several reasons. It provided strong enough bonds needed to overcome the large forces the rocket would experience. It was also easily and quickly prepared all while being within the project's allotted budget plan.

The use of epoxy came with several hazards as well. Unhardened epoxy glue is a toxic substance and hence had to be handled with care. Several safety measures were taken to avoid coming in contact with wet epoxy, such as wearing gloves whenever handling epoxy, using tools to apply it rather than hands/fingers and immediately disposing of mixing containers once all the needed epoxy had been taken out and applied.

10. Payload

The coupler houses the rocket avionics payload. Since there was no other required payload for the project, only the necessary flight avionics were implemented for this mission to keep costs, form factor, and weight to a minimum.

The coupler’s outer diameter is 3.00 in and the inner diameter is 2.878in. The switch band is a 1.5 in section cut from the lower airframe. Keyed switches that are able to be locked in the on position serve as the arming controls for the rocket’s electronics.

In order to relieve the differential pressure between the atmosphere and the internal payload bay a 1/4 in hole was drilled into the payload bay. The payload’s end bulkheads are made from 1/4 in G-10 fiberglass material to ensure strength in the presence of black powder ejection charges.

Figure 17: Bulkhead lids for the payload bay

Inside the coupler, there is a payload bay which houses the avionics. The board that holds the electronics together is created from aircraft grade plywood that is held into place by a threaded rod as shown in

11. Avionics

The rocket’s payload bay houses two pieces of avionic equipment: a Stratologger SL100 with a 9V battery to power it and an Altus Metrum Telemetrum with the 850 mAh 3.7V Lipo battery to power it. These components were all secured to the payload sled as described in the payload section using stand offs and screws.

The SL100 is an onboard altimeter whose main purpose is to measure and record the altitude of the rocket during its flight. This information was invaluable to the team during the rocket's flight test as the collected altitude data was the main guideline around which post-testing modifications were built. The SL100 was also selected as the altimeter for the main ejection charges for the main and drogue chute.

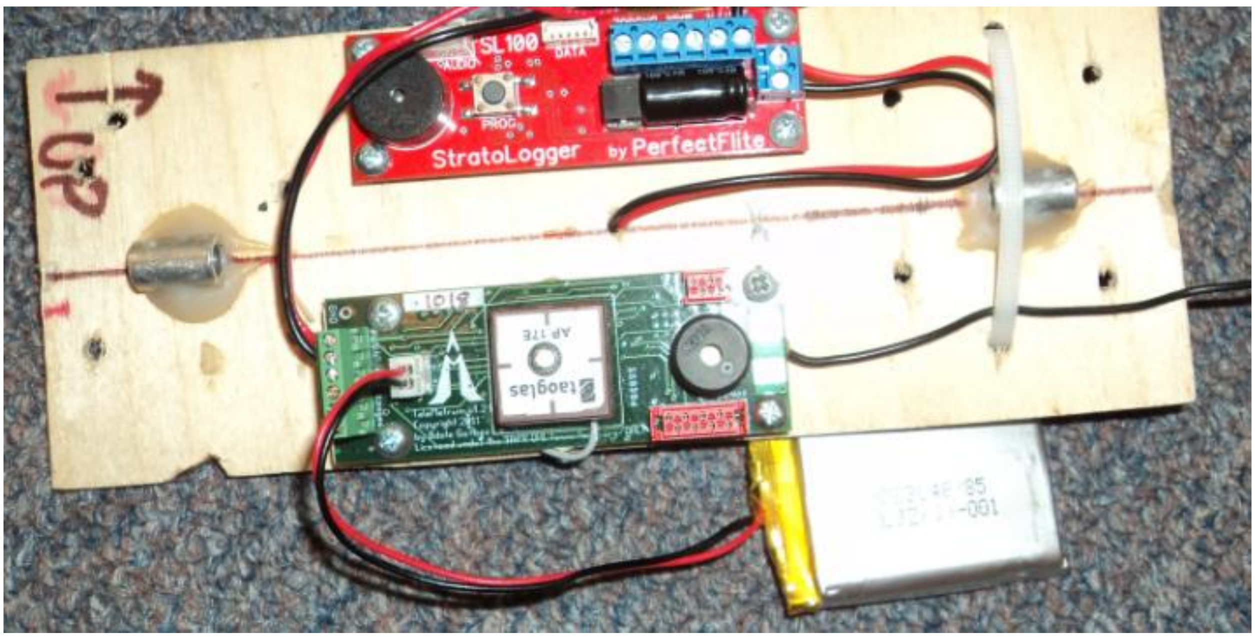

Figure18: Flight avionics

The Telemetrum is more advanced than the SL100; as its functions are not solely centered around the rocket's altitude. Rather, the Telemetrum houses a set of sensors that enable it to measure several other aspects of the rocket's flight such as speed and orientation: The accuracy of which are enhanced by an on-board GPS system. Furthermore, the Telemetrum has the ability to relay information back to computers on the ground that is connected to the necessary peripherals (antenna and Teledongle). This feature of the Telemetrum gives team members access to live telemetry data while the rocket is in the air. The Telemetrum was chosen as part of the flight avionics for the telemetry feed and as the altimeter for the backup charges for the parachutes. The Telemetrum also offers live feedback on the status of the ejection charges during flight and provides instant feedback when the charges are set off. Since it provides GPS data, a Ham radio license is required to operate it. The team mentor's callsign was used to operate the Telemetrum during the test flight. The team leader will also be obtaining a Ham radio license prior to the competition launch to operate this piece of equipment.

12. Motor

The motor required, as per the competition guidelines, is the Cesaroni Technology Inc. I-540WT motor. The motor has the characteristics shown below.

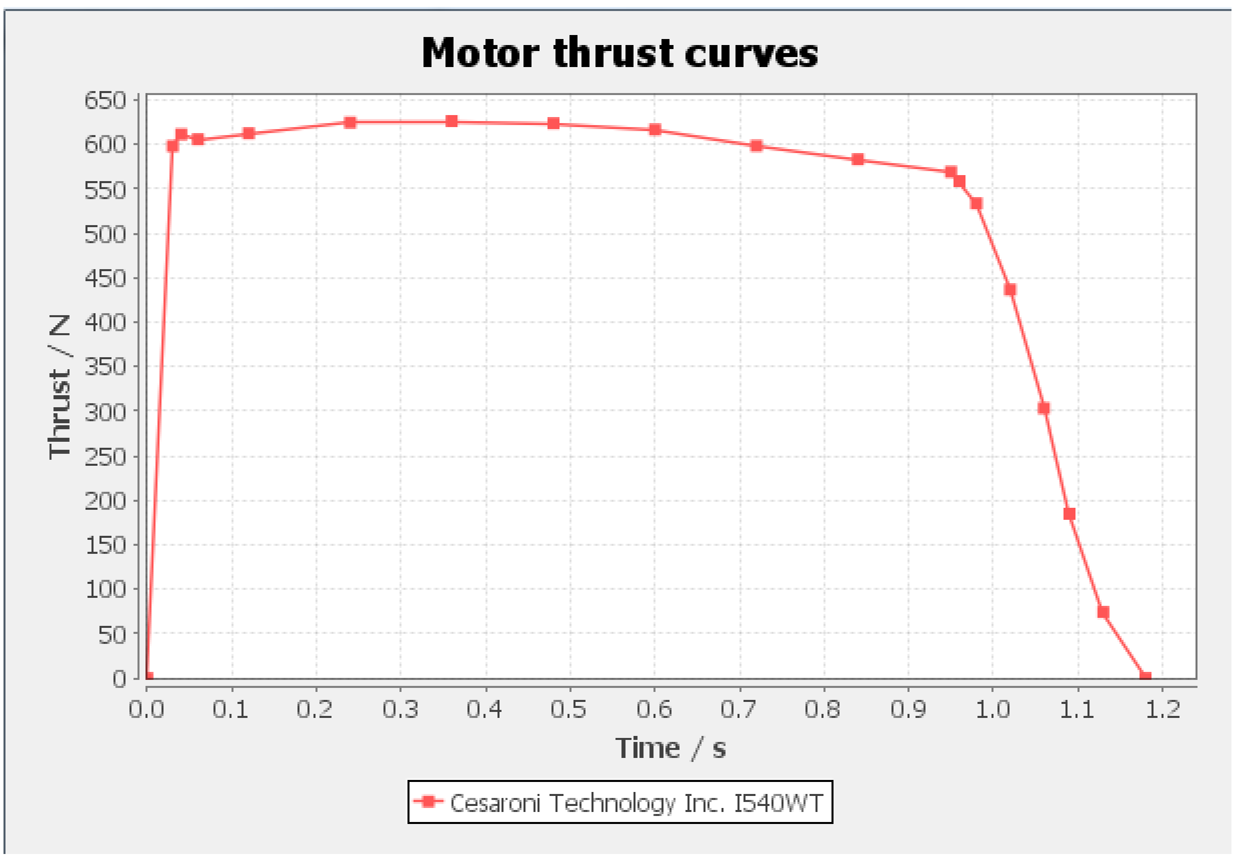

Figure 19: CTI I-540WT motor characteristics

13. Design Constraints

The construction efforts on the rocket were both bounded and guided by several constraints posed by the competition. The rocket had a maximum length limit of 72 inches, a maximum radius limit of 4 inches and a maximum mass limit of 7.5 pounds (not including the motor). Component wise, the rocket was required to have an electronically deployed parachute with a motor based backup system. Furthermore, the competition's objective of achieving an altitude of 3,000 feet as accurately as possible provided some restraints on construction and design.

These constraints had a major influence in the design phase of the project. For example, the team personnel decided on using the PML D-region Tomahawk rocket kit because it fell comfortably within the competition restraints and allowed ample room for structural modification and creative ideas all while remaining within the set limits. The kit was modified to accommodate electronic dual deployment and a variable ballast system was designed for adjust the altitude of the rocket. The coefficient of drag for the rocket was relatively low compared to 4 in rockets, thus the ballast system was required to reach the altitude goal. The small form factor of the avionics was also a design constraint, as all of the flight electronics and power sources needed to be housed in a small volume.

14. Recovery system

The recovery system included the main and drogue parachutes, chute insulators, shock cords, ejection charges, shear pins and an on-board-telemetrum and altimeter. The 5 ft Rocketman chute was selected as the main chute for their reliability and the team members' previous experience with them.

The recovery system functioned as follows. The altimeter and telemetrum kept track of the rocket's altitude as they both ascended; once the rocket was at apogee, the altimeter signaled to set off the ejection charges via preconnected wires. The explosion from the charges forced the shear pins that were keeping the nose cone and the upper section of the rocket connected to break and allow the rocket to separate. The drogue parachute, previously tucked in an insulating patch to protect it from the blast, became free to break out of the rocket and deploy. The drogue parachute is a small sized parachute meant to prevent the rocket from falling freely yet allowing falling quickly enough so as to not have it drift too far away. After the drogue was deployed, the rocket descended fairly quickly at 17 ft/sec all while its separated sections were kept together via the shock cords. Once the rocket descended to an altitude of 600 feet the altimeter sent another signal to set off a second set of charges, this time to break shear pins connecting the lower and mid sections of the rocket to free the main chute from its insulating cover and deploy it. Again, shock cords kept the separated rocket sections connected. Unlike the drogue, the main parachute was large enough to decelerate the parachute to a slow enough descending speed to allow it to land safely. During the entire flight, the Telemetrum provided GPS coordinates and telemetry data in real time. Once the rocket had landed, team members awaited an all-clear signal from the launch operators and then proceeded to walk to the landed rocket and collect it. The Telemetrum is also designed to emit a radio beacon to aid in the finding and retrieval of the rocket. As proved in the test flight, the recovery sub system performed as expected and worked well for the mission requirements.

Figure 20: Main parachute assembly