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Team Air Mail

Flight Readiness Review

2014-2015 Space Grant Midwest High-Power Rocket Competition

UAH Space Hardware Club Huntsville, AL

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Not pictured: Chris Thackston, Thushananth Rajendra

I. Rocket Design Review

A. Design Overview

The rocket consists of two sections, the dart and the booster. The dart is broken up into five subsystems—tracking, recovery, IMU payload, camera payload, and structures and aerodynamics. The booster is broken down into three subsystems— motor integration, recovery, and structures and aerodynamics. Each subsystem dictates what size, shape, and weight the other subsystems must accommodate. The preliminary design of the dart has a three layer carbon fiber airframe with an inner diameter of 1.250 inches. The preliminary design of the booster also has a three layer carbon fiber airframe with an inner diameter of 2.138 inches. Fig. 1 depicts the entire rocket airframe.

Figure 1. Dart and Booster . *The dart is the part on the left and ends with the set of fins furthest left. The booster is on the right. Everything black represents carbon fiber while everything blue is printed ABS plastic.*

B. Dart Subsystems

1. Tracking

Since the dart's body is constructed out of carbon fiber composites which would block the radio frequency (RF) signals needed for the tracker, a tracking system could not be implemented in the dart. Instead, the team has decided to place the tracker in the dart's nosecone, as the nosecone will be constructed out of ABS plastic, which will allow for RF signals to be received and transmitted. A compact battery must be used, but a form fitting battery of sufficient energy must be installed. The solution was found by selecting a cylindrical lithium-ion polymer battery that has the diameter of 0.7 inches. The length of the nosecone is dictated by the lengths of the radio antenna and the battery. Fig. 2 depicts the organization of the components in the nosecone.

Figure 2. Nosecone Tracker. *Shown is the organization of the tracker components that fit within the dart's nosecone. The red cylinder represents the antenna while the silver cylinder represents the lithium-ion battery.*

2. Recovery

The dart will descend under a 28 inch custom sewn rip-stop nylon parasheet. This will be ejected out of the dart using a black powder charge controlled by a PerfectFlite Stratologger altimeter. Kevlar cord will be used as shock cord because of its smaller form factor. It will be attached to eye-bolts screwed into the nosecone and below the black powder charges. The parachute bay will be just below the nosecone and is 7.1 inches long. It will house the parasheet, Kevlar shock cord, nomex to protect the parasheet, and the black powder charges. Fig. 3 shows the recovery bay of the dart.

As a measure of redundancy, there will be two black powder charges packed in the recovery bay, each having an E-match wired to different PerfectFlite Stratologger altimeters. Each Stratologger will be capable of igniting either black powder charge and will have an independent power system.

Figure 3. **Dart Recovery System Bay** *The bay is 7.1 inches long and contains the parasheet,*

3. IMU Payload

To characterize the roll rate of the dart, an inertial measurement unit (IMU) MPU-9250 will be used. This particular IMU was selected because it has nine degrees of freedom, and because of its compact size, it will fit within the body of the dart. The IMU's data will be saved to a flash memory module. The IMU and flash memory module will be controlled by an ATxmega32E5 microcontroller unit (MCU). All components will be able to fit in the body of the dart by using a custom printed circuit board (PCB). The PCB will be powered by a lithium-ion flat pack battery.

The smallest components were found for the IMU, MCU, flash memory module, and lithium-ion battery because of the size constraint created by the dart's inner diameter. The dart's inner diameter had to be large enough to house the IMU payload, conversely, the IMU payload needed to be designed as small as possible to allow for the dart to have a smaller inner diameter.

4. Camera Payload

A camera sensor must be placed so that it can see the ground with the booster still attached. The team chose to place it at the back of one of the fins of the dart as seen in Fig. 4. This was a decision made by the structure and aerodynamics subsystem team to reduce the distance the camera would offset the center of pressure of the rocket. The team chose a hubsan quadcopter replacement camera to take the video. This camera was chosen for its small form factor and because its camera sensor is attached to its circuit board with a ribbon cable. This allows us to house the circuit board inside the dart while running the ribbon cable to the sensor that is outside the airframe.

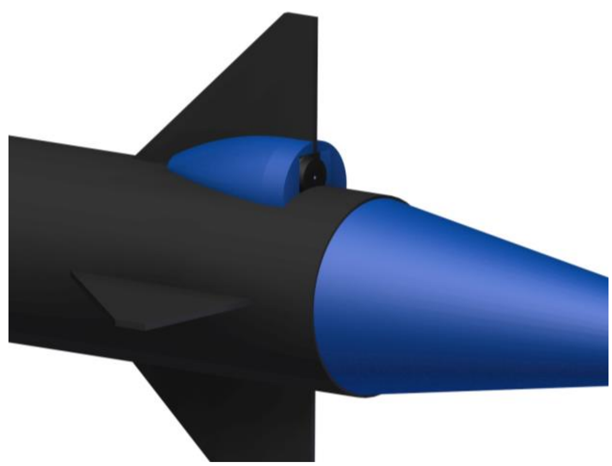

Figure 4. **Camera Protection System** *The camera protection system is made of printed ABS plastic and serves to provide an aerodynamic shell for the camera sensor.*

5. Structures and Aerodynamics

The design of the dart can be found in Fig. 5. The nose cone will house the tracking system for the dart. It will be two halves that are screwed together made of rapid prototyped ABS plastic. Following the nosecone is the recovery bay. Aft of the recovery bay is a sled made of 3D printed ABS plastic that houses the recovery electronics. The last section is the electronics section which houses the altimeter two, the IMU board, and the camera. The two sleds encompass all space in between the recovery bay and the boat-tail. The boat tail is the aft bulkhead of the electronics bay. At the top of the recovery sled is a bulk head that black powder charges will blow against. This can be seen at the aft end of the dart recovery system bay in Fig. 3. Aft of the bulk head is where the recovery electronics are housed. The two 9V batteries will be first and will be sandwiched in. Next will be the two PerfectFlite StatoLogger altimeters. At the very end of the sled will be the boat-tail for the dart. The boat-tail serves to greatly increase the apogee of the rocket along with being the contact surface between the dart and the booster. The boat tail is curved at the end for safety and does not come to a point.

Figure 5. **Dart Post Separation** *Dart configuration after it separates from the booster.*

C. Booster Subsystems

1. Motor Integration

The booster stage will be a 54 mm minimum diameter. 2.138 is what the inner diameter measures out to be. The team has a 2.125 inch mandrel the layup is done on and the added diameter comes from the release material used in between the mandrel and the layup. This allows the one grain motor case to slide in and out with ease. The motor will be packed and inserted. The motor retention system will be a 54 mm Aero Pack retainer as seen in figure 7.

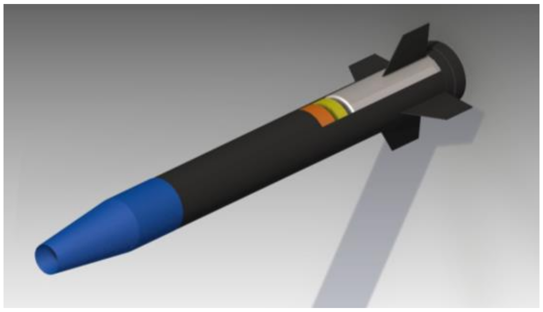

Figure 6. **Minimum Diameter Motor Housing.** *The booster's inner diameter is flush with the outer diameter of the motor.*

2. Recovery

The booster's recovery system will be similar to that of the dart. However, the booster's mass (2.5lb) is roughly twice that of the dart so the parasheet will be larger. It will be ejected from the rocket using black powder charges controlled by a PerfectFlite Stratologger altimeter. The motor eject will be left intact as a backup and will be set to ignite 1-2 seconds after the booster's apogee. It will be contained in a section of the booster directly above the motor and under the transition piece between the dart and booster. The parasheet used for the booster will also be made of rip-stop nylon with a Kevlar shock cord. The Stratologgers and 9V batteries that power them will add mass to the front of the booster, improving

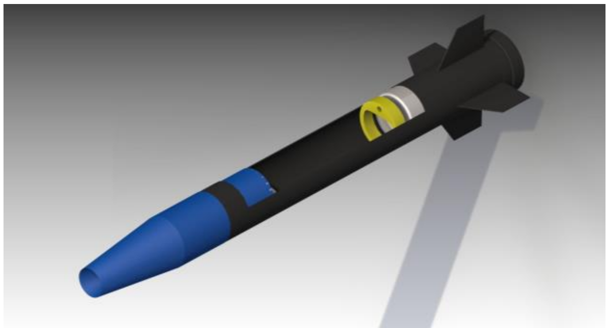

Figure 7. **Booster Recovery Placement.** *The booster's recovery system is placed directly under the transition piece, which houses deployment electronics.*

the stability to drive the dart in a straight path.

3. Structures and Aerodynamics

The booster will be fabricated from pre-impregnated carbon fiber and 3D printed parts. Carbon fiber reduces the mass and provides substantial structure for the booster, which will be the driving variable behind its performance. By adding mass to the transition piece in the form of dense 3D printed parts and altimeters, the team will be able to move the center of mass forward, maintaining a safe stability. By moving the center of mass of the booster forward, the stability of both stages together will be optimized. To move the center of pressure forward, the fins are reduced in size which minimizes the frontal area and reduces drag, allowing the rocket to achieve a greater speed thus pushing the dart to a higher altitude.

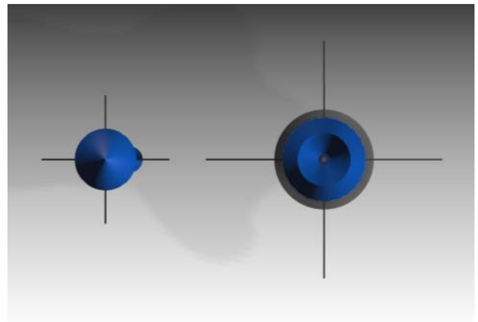

Figure 8. Frontal Profile of the Dart and Booster. *The frontal area of both the dart and booster is as small as possible to reduce drag and drive both higher.*

4. Transition and Booster/Payload Integration

The payload's boat-tail will sit into the transition on the booster as seen in Fig. 9. UAH SLI teams in the past have used a similar system effectively before. The team will be extensively testing this system in compression to ensure its safety and reliability. The size of the transition on the booster is thus dictated by the length the boat-tail will need to be to ensure a reliable seating in the transition along with the electronics in the booster.

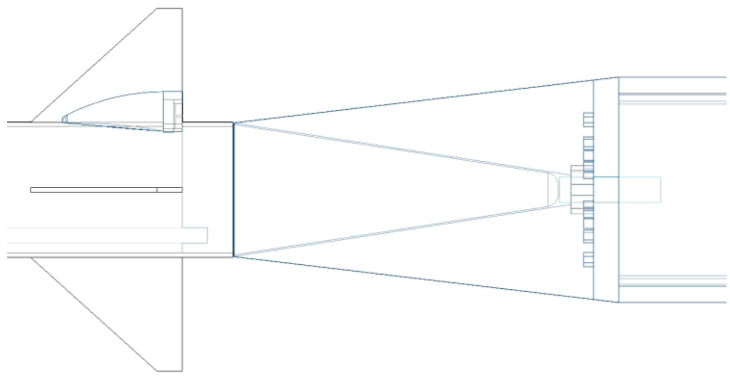

Figure 9. Booster/Payload Integration. *Solid Edge generated image of the boat-tail of the dart resting in the transition of the booster. The transition is broken into two pieces for printing purposes.*

D. Changes Since Preliminary Design

One of the main changes to the design since the Preliminary Design Review is the length of the body tubs. The estimations for size needed to house the electronics and recovery hardware in dart was underestimated. In the test flight, there was no factor of safety for the amount of room required to pack the parachutes, so both chutes were very tightly packed and compressed by the rapid acceleration. The new design has room for all of the electronics and extra space for the parachute as well. This led to a 54% increase in dart body tube length and a 22% increase in that of the booster.

The fins have also been changed from a swept design to a more stable and secure design that protrudes directly from the body tube and is not hanging at all. They have also been greatly reduced in size because they center of gravity is moved further forward due to the increased length.

The last major change from the Preliminary design is the new camera choice. After reoccurring failure of the Eco FlyCam V2, we have switched to the Hubsan 107C, an HD quadcopter camera that is much smaller and more reliable.

II. Building techniques

A. Carbon Fiber

We chose to use carbon fiber for the airframe and fins of the rocket because of its strength to weight ratio. Each tube and fin is three layers of simple weave pre-impregnated carbon fiber at a [0-90/0-90/0-90] ply layout. While using a 45-45 degree ply would be stronger for the needs of the body tube, it was not worth the weight to reduce one layer to cut out 45-45 degree layers. The team found that a three layer tube had the strength needed while still being very light. The test dart body tube and fin set up has a mass of only 100 ± 5 grams and the test booster body tube and fins have a mass of 117 ± 5 grams. The carbon fiber is cut to size and rolled onto a mandrel which has been cleaned, waxed, and sprayed with polyvinyl alcohol, a water soluble release agent. After the carbon fiber is on the mandrel, it is shrink-taped to hold pressure in all locations except where the fins attach. The shrink tape has a release agent on one side so it doesn't stick to the carbon fiber. The fins are made using a tip to tip layup technique. A single piece of carbon fiber runs from the tip of one fin, down to the body tube, over the section of body tube in between two fins and up to the tip of the next fin. There are also one layer inserts added to make the fins from two layers to three for added stability. While carbon fiber is strong, it is not the best at bending and fin flutter could tear it apart. The fins are added to the body tube and compressed using fin molds and large clamps for pressure. The whole assembly, body tube and fins, is then put into a 90 – 100 °C oven for 3 hours. After the layup comes out of the oven, it is cleaned and the fins and body tube are cut to size using a wet saw and Dremel.

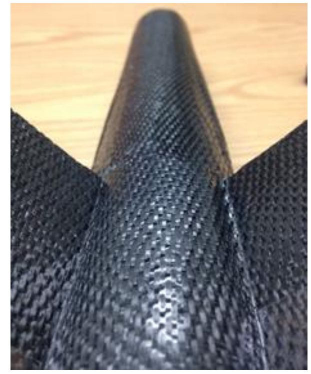

Figure 10. Booster Prototype . *This is an early prototype of the booster stage composed of carbon fiber*

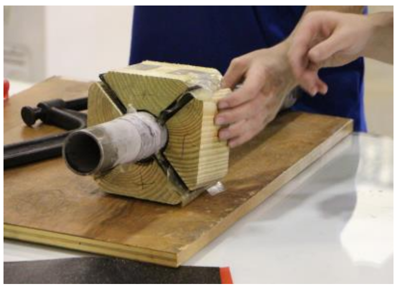

Figure 11. Booster fin Layup. *We used CNC machined wood blocks to compress the fins while curing.*

B. ABS

The transition, boat-tail, mounting bay for electronics, and nose cone tracker all include complex geometry that would be hard to machine or make out of composites so they are 3d printed out of ABS plastic. While this adds mass, it allows geometries that wouldn't otherwise be possible without increasing the diameter of either body tubes.

C. Polycarbonate

Some internal bulkheads can be machined and so were machined out of polycarbonate plastic. The team chose polycarbonate plastic due to its high shock resistance, machinability, and extensive previous use. As an added side benefit, it is translucent. This allows the team to see into areas otherwise hidden by a typically opaque bulkhead. The polycarbonate was machined using a HAAS 3 axis CNC mill.

D. Constructed for safe flight and recovery

A specific change that has been made for the sake of safety is related to the failure the team saw during the test flight. The preliminary design called for a ¼ - 20 all thread rod to run from the bulkhead at the bottom of the transition to the top of the transition through a single nut epoxied to the transition. This proved too easy to fail in tension. In the new design, the bulkhead is connected to the transition using two screws into the transition directly eliminating the need for epoxy. The other job the ¼ - 20 rod, constraining the boat tail in the negative z direction, will now be filled with a screw. The new design can be found in Fig. 9.

E. Pictures

Figure 12. Body Tube Rolling. *We rolled the carbon fiber onto the mandrel to make the body tube before using wood fin molds to compress the fins as well.*

Figure 13. Curing the Layup. *The composites oven to maintain a constant temperature high enough to cure the epoxy.*

Figure 14. Removing the Layup. *Using heat gloves, we removed the layup, which was about 100^{0}C.*

Figure 15. CNC Machining. *The CNC machines were used to make the wood fin molds as well as polycarbonate bulkheads for the booster's transition piece.*

III. Test Flight Report

Figure 16. Rocket Ready to Fly. *The team available for the launch posing just before launch.*
Left to right: Andrew Miller, Davis Hunter, Geoff Suiter, Jordan Teats, Evan Tingley

A. Pre-launch Procedures

The pre-launch procedures went well. The team had specific duties, and each member had a checklist to follow. There was more than one pair of hands working with the booster and dart, so members were able to double-check each other's work.

B. Boost Phase Performance

The boost phase of the launch was successful. The booster itself demonstrated a few technologies the team was testing during this flight. The rail buttons were 3D printed out of ABS plastic. They successfully guided the rocket off of the rails and were not damaged during the flight. Both dart and booster ascended together stably until motor burnout.

C. Separation Performance

Through drag separation, the dart smoothly left the transition piece that was attached to the booster. The booster fell away towards the Earth as the dart continued to ascend. The dart's tail cone and the booster's transition piece performed well together. The dart's path was unchanged by the separation event, so the transition between the stages worked perfectly.

D. Coast Phase Performance

After separation, the booster achieved apogee, and motor eject properly deployed the parachute. However, the apogee was not recorded due to a failure with the JollyLogic altimeter. The dart continued to coast upward after the separation from the booster until apogee, and due to a failure in the recovery system, continued to coast downward.

Figure 17. Unrecovered Booster. *The booster landed in the tree line, but it was not difficult to locate or recover.*

E. Recovery Performance

The dart's recovery system involved redundant PerfectFlite StratoLoggers which ignited two black powder charges to eject the parachute at apogee. However, both of the charges were on the "Main" parachute instead of the "Drogue." This led to the parachutes being deployed at 1,000 ft. after apogee, rather than at apogee. After the rocket fell 3,730 ft. it had a significant velocity. This caused the Kevlar attached to the parachute to snap, which ultimately buried the rocket about a foot underground. This only damaged the nosecone, which is a different design than the final configuration. However, it briefly disconnected the altimeters from power, causing a complete loss of flight data.

Figure 18. Pre-Recovery Dart. *The dart was buried in a nice crater due to recovery failure. The tail cone is missing because it was ejected with the parachute.*

The booster's recovery was deployed unsuccessfully. The parachute still deployed, and the rocket descended safely in a visible and recoverable location, but the transition piece attached to the other end of the shock cord was lost upon deployment. We have since redesigned the failure point on the transition piece so that this failure will not occur again. The JollyLogic was inside the booster transition piece, but it was still recovered intact. However, we were unable to recover any data about the flight.

F. Post-launch Procedures

The post-launch procedures went well. Both the dart and the booster were recovered successfully, and the team was able to identify the successes and failures of the day and the sources of the failures.

Flight Characteristics

Booster Length (in)	22.74
Booster Stability (cal.)	1.43
Booster Weight (g)	668
Max Booster Diameter (in)	2.60
Dart Length (in)	41
Dart Stability (cal.)	1.91
Dart Weight (g)	663
Max Dart Diameter (in)	1.334
Overall Length (in)	59.74
Overall stability (cal.)	1.99
Overall Weight (g)	1195
Thrust to Mass Ratio	25.6

IV. Discussion of Results

A. Apogee Comparison

Using rocket simulation software, we had a predicted apogee of 4,745 ft. The actual apogee was only measured by the tracking system inside the dart, which gave a reading of 4,730 ft. Despite the accuracy of the simulation, there are a number of sources of error in both the simulation and the rocket itself. The rocket that we flew was an imperfect layup, so the carbon fiber composing the body tube around the fins bulged outward, and it was much rougher than the rest of the rocket. The layup was also imperfect on the dart because we had to use packing tape to apply compression while curing, which made the carbon fiber rough. For the booster, we used release/shrink tape, which applied much better compression, but it stuck to the epoxy despite supposedly being able to release. This made the surface of the booster rough as well, which lowered the apogee. We were also unable to properly simulate the motor retention system, which added frontal area and increased drag.

B. Peak Velocity and Acceleration Comparisons

As stated in the previous section, due to a number of failures with altimeters, we were not able to recover any data about velocity or acceleration. However, we are able to infer that since the apogee was extremely close to the simulation, the peak velocity and acceleration were very close as well. The simulated values were 856 ft/s and 983 ft/s^2.

C. Video and Rotation Data

At the time of this flight, the data rotation board was not ready, so we flew a ballast mass at the same position in the body that the system will be in the final configuration. For this flight, we also chose to eject the tail-cone from the dart instead of the nosecone. This interfered with the placement of the camera, which will be placed at the back of the dart under a fin. So, we flew the rocket with the housing that will shield the camera sensor from the air during flight. We found that the increase in frontal area on one side was not significant enough to affect the flight of the dart.

Figure 19. Completed Rocket. *The rocket went from being prepped to launching very quickly, and the only pictures are of it on the rail.*

V. Planned Design Improvements

A. Nosecone Shape

The nosecone flown during this test flight was made to house a tracker that was wider than our dart's body tube which made the nosecone a fairing. In our final configuration, the nosecone will be a diameter continuous with the body tube.

B. Ejection Direction

During this test flight, we chose to use a rear-eject to move mass forward to correct the difference in stability created by the wider nosecone. In our final design, the recovery system will be ejected out the front of the dart. This will allow us to place the camera in the aft end of the rocket and in there is a failure in the parachute deployment, the rocket will tumble without a nosecone, rather than falling stably without a tail cone.

C. Body Tube Length

One thing we found was a problem was fitting the parachutes in the body tube length allotted for each. So, in the final design, the body tubes will be extended with a factor of safety to fit the parachutes safely and not be compressed by anything during ascent.

D. Transition Design

A significant point of failure on this flight was the design of the booster transition, which was lost upon motor ejection. The final design will secure the transition to the shock much better by attaching it with two ¼-20 bolts rather than relying on epoxy.

VI. Budget

System	Item	Amount	Total
Management	Registration	$400.00	$400.00
Testing	Rocket	$453.57	
	Electronics	$471.77	$925.34
Hardware	Rocket	$438.94	
	Electronics	$643.81	$1,082.75
Travel	Meals	$4,380.00	
	Hotel Rooms	$2,038.54	
	Van Rentals	$1,400.00	$7,818.54
Total			**$10,226.63**

The actual budget above differs in two ways from the planned budget, which totaled $12,711.00. Rocket and Electronics Hardware totaled $1,623.00 in the planned budget but have now been decreased to $1,082.75. Also, fewer team members are traveling to competition than had originally been budgeted. This reduces the planned travel budget from $9,760.00 to the actual travel budget, $7,818.54.