2015-2016 NASA Student Launch

Alabama Rocket Engineering Systems (ARES) Team

Critical Design Review: Subscale Flight Test Results

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1. Subscale Flight Results

1.1 Subscale Design and Analysis

The ARES Team's subscale launch vehicle was designed to be geometrically similar to the full scale rocket, and so all components of the vehicle maintained the same shape as their full scale counterparts. The subscale vehicle dimensions were scaled down by 72.7%. This scaling factor was based on a decision to attempt to match the predicted Mach number (0.65) of the subscale vehicle to the full scale vehicle. The team used a graph showing the change in coefficient of drag with change in Reynolds number and found that the estimated change between the full scale and subscale Reynolds numbers at the same velocity would produce a negligible change in drag. This meant that matching the Reynolds numbers was not necessary and in order for the subscale to experience similar aerodynamic forces, the expected Mach number should be matched. To do this, the subscale launch vehicle had to remain fairly large, so the team decided on a 4 inch diameter airframe. This decision produced a 4:5.5, or 72.7%, scaling ratio.

The team decided to use a "dummy weight" to model the payload, as the full payload has not been built yet. This model payload was also scaled using the scaling factor. The model payload consisted of a fiberglass canister filled with steel BBs and resembled the shape of the real payload, but with bulkheads on either side with eye bolts for the attachment of shock cords. Steel BBs were used to create the extra weight because of their high density and low cost. The model payload would be tethered by a shock cord to the drogue parachute on one side, and to the nose cone on the other side.

The airframe of the subscale rocket was built from fiberglass body tubes purchased from Madcow Rocketry. The nosecone, motor mount tube, centering rings, and bulkheads were also purchased from Madcow Rocketry. The team cut custom fins for the rocket out of ⅛ inch fiberglass sheet. The electronics bay was built from material that the ARES Team already had, and contained four StratologgerCF altimeters and four 9V batteries. A 42 inch drogue parachute and an 84 inch main parachute were used for recovery. The subscale rocket was 70.5 inches in total length. The OpenRocket layout of the subscale launch vehicle is shown below in *Figure 1*. The OpenRocket simulation results for the subscale flight with expected weather conditions are listed in *Table 1*.

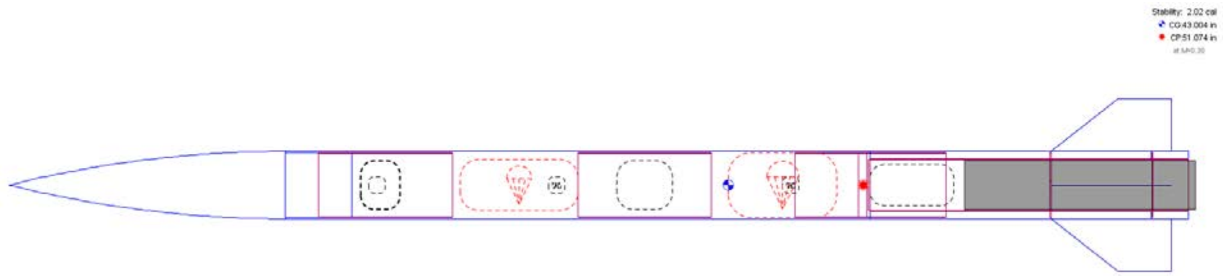

Figure 1. OpenRocket Subscale Diagram

Apogee Altitude[ft]	Average Windspeed [mph]	Gusts Expected [mph]	Wind Direction
6766	9.0	14.0	WNW

Table 1. Max Altitude Result from Expected Weather Conditions

1.2 Test Description

The ARES Team traveled to the Phoenix Missile Works launch site in Talladega, Alabama on January 16th to launch their subscale rocket. Tests performed included a ground ejection test and a flight test.

The ground ejection test was conducted to prove that the ejection charges were adequate for separating the sections of the rocket and ejecting the necessary objects. Two 2-56 nylon shear pins were screwed into the nose cone shoulder and the aft body tube. The ejection charge had to be able to shear these pins and push out the model payload and the drogue parachute at least 3 ft from the forward body tube. The ejection charge cap was filled with 2.5 grams of black powder by the team's mentor, Lee Brock. Black powder was placed in the cup, then an electronic match, "e-match", was placed in the cup, and the empty space in the cap was packed with "dog barf". The cap was then closed with painter's tape. A 15 ft wire was run to the electronic match, and forward section of the vehicle was placed on the ground, elevated by a support to incline the nose cone toward the sky. With all spectators 25 ft away from the charge, the circuit was completed with a 9V battery, and the charge was ignited. The test was successful based on a 3 ft clearance of all ejected objects from the body tube. However, the fiberglass canister modeling the payload was broken during the ejection. The team was determined to launch the subscale rocket, so to account for the weight of the payload and maintain an acceptable stability margin, a hole was drilled into the nosecone and the ballast weight was inserted. The hole was then sealed with putty. The nosecone was then tethered directly to the drogue parachute by a 20 ft shock cord.

For the subscale flight test, the launch vehicle was launched on a 10 ft 1515 launch rail. After assembly of the rocket, the vehicle was brought to the Range Safety Officer (RSO) for inspection. Once the RSO declared the rocket safe and ready for launch, the team brought the subscale launch vehicle to the launch rail. The launch box was disarmed, and the rocket was placed on the rail. The subscale vehicle is shown on the launch rail in *Figure 2* below.

Figure 2. Subscale Launch Vehicle on the Launch Rail

The electronics bay was armed and gave the signal for continuity with all e-matches. Lee Brock then connected the igniter to the launch box and inserted the igniter into the motor. The team retreated to a safe distance behind the RSO and proceeded to watch the launch. The subscale flight test was deemed successful after observation of a stable flight and recovery of all sections of the rocket in a reusable condition. The mass of the main subscale components, as well as the total mass obtained from the OpenRocket file, are included below in *Table 2*.

Component	**Mass (lb)**	**Length (in)**	**Width or Diameter (in)**
Nose Cone	0.75	16	4.0
Forward Body Tube	1.825	35	4.0

Aft Body Tube	0.988	19	4.0
Payload	4.75	8	3.97
Electronics Bay	2.4	7.7	3.97
Main Parachute (Packed)	1.2	9.0	3
Drogue Parachute (Packed)	0.948	6.6	3
Motor w/ Propellant	6.14	13.8	2.95
Motor Propellant	3.36	13.8	2.95
Total Mass	23.4		

Table 2. Subscale Launch Vehicle Component Information

1.3 Results and Analysis

From the ground ejection test, the team proved that an ejection charge of 2.5 grams was able to shear two 2-56 nylon shear pins and push out the drogue parachute and model payload. The team had planned on using more black powder, but Lee Brock advised the team that more would be unnecessary, which was confirmed through the test. The ARES Team will reconsider the amount of powder that must be used in the full scale, but overall this gives the team confidence that the full scale payload will be able to be ejected cleanly from the body of the vehicle.

The flight of the subscale launch vehicle was observed by the team to be stable and without issue. The ARES Team was extremely pleased with the performance of the rocket in flight, bolstering the team's confidence in their ability to build a full scale vehicle that will perform to their expectations. All sections of the rocket were recovered in a reusable condition, after drifting about ¾ of a mile. The recovered launch vehicle is shown in *Figure 3*.

Figure 3. Recovered Launch Vehicle

Once recovered, the team was able to learn the apogee altitude of the vehicle from the StratologgerCF altimeters. The reported altitudes from each altimeter are listed in *Table 3.*

Altimeters	Altitude Reported [ft]
#1 (Forward)	7915
#2 (Forward)	7912
#3 (Aft)	7914
#4 (Aft)	7914

Table 3. Reported altitude from all four altimeters

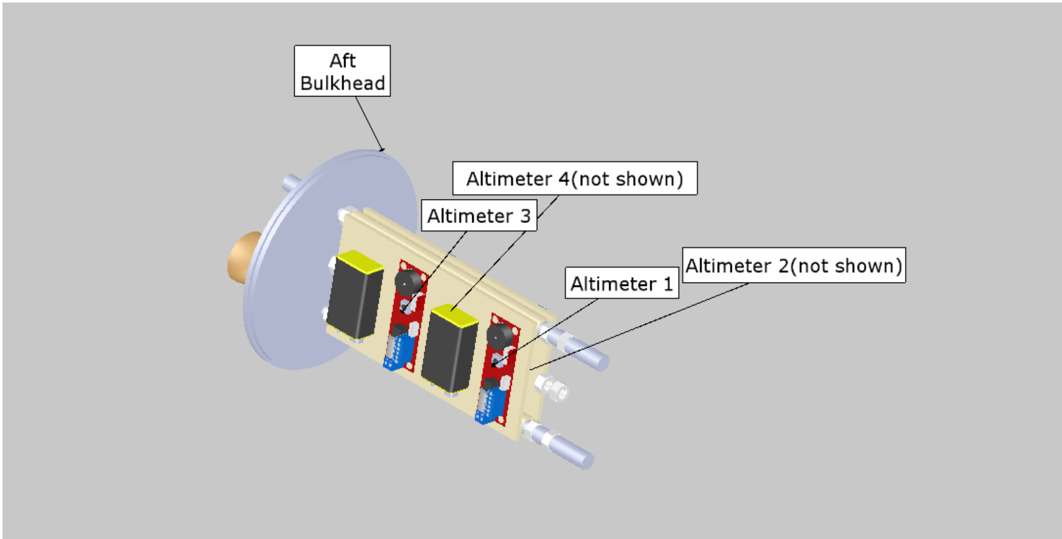

Figure 4. Shows the placement and numbering of all four altimeters

The average from the four altimeter readings was 7913.75 ft. The team then used the average altitude, projected altitude and equation (1) below to calculate the percent error between the OpenRocket simulation and the actual flight. The results are tabulated in *Table 4.*

$$Error = \left|\frac{Projected\ Altitude - Achieved\ Altitude}{Projected\ Altitude}\right| \times 100\% \qquad (1)$$

Achieved Altitude [ft]	Projected Altitude [ft]	Percent Error [%]
7914	6766	14.50

Table 4. The error in ARES' simulation

ARES is extremely concerned by these results. An error of 6.06 % over the expected altitude of 5280 ft would mean a loss of all points for the altitude portion of the competition. To ensure that this does not happen, ARES plans to look into the addition of ballast weight pending the results of our full scale test launch. The team will also be investigating the accuracy of OpenRocket by using RockSim, another rocket simulation program, to model the flight of the subscale. By doing this, the validity of the simulations can be evaluated. In addition, the team will look into the likeliness that the motor produced more thrust than the simulations assume. This will be done by contacting the manufacturer for information on the confidence of the stated average thrust, and if the motor may have provided more thrust than predicted.

1.4 Conclusion

Despite the failure of the payload model during the ground ejection test, the test was deemed successful, and solutions were made to be able to continue with the subscale flight test. The rocket launched successfully, and was recovered in a reusable condition. The subscale rocket reached a significantly higher altitude than what was predicted by OpenRocket and the team will look into solutions to this, pending the results of the first full scale launch. Overall, flight test demonstrated the structural integrity and stability of the rocket, and that the recovery system was functional and adequate. Therefore the flight test was deemed a success. With the successful completion of both the ground ejection test and the subscale flight test, the team will use the knowledge acquired from the results, as well as the testing process itself, to improve the design and construction of the full scale rocket.

Appendix - Completed Launch Preparation Checklist and Procedures Checklist

Ejection Charge Test:

- ☑ Build the rocket as if it were to launch. Dummy weights for the payload can be used, and only the motor casing should be in place.
- ☑ Build the squibs (see Electronics Bay Prep Checklist) for deployment of the parachute and separation of the payload bay. Instead wiring the squibs to the electronics bay run them through the switch holes in the electronics body tube.
- ☑ Receive permission from the RSO to perform the test and go to the designated area for such a test.
- ☑ Attach 10 feet of wire to each e-match wire. The person running the test will stand at the end of the wire, all spectators should stand another 10 feet back.
- ☑ After announcing the test, a countdown from 10 should be completed for each charge.
- ☑ If the parachute is pulled out between the electronics and booster bay, approximately three feet, then it was a successful test. The three feet rule will be used to deem the payload separation successful.

Electronics Bay Preparation Checklist:

- ☑ Using the multi-meter, test the voltage from the batteries for a voltage of at least 9.1 V.
- ☑ Using the multi-meter, test the resistance of the two e-matches to be at least 1 Ω.
- ☑ Connect a battery to the holder and wire the switch and battery to the altimeter.
- ☑ Turn the altimeter on and listen for the beeps to ensure that the drogue and main charge are set to the specified altitudes.
  Drogue/Payload:_____, Main:_______
- ☑ Turn the altimeters off
- ☑ Connect a fresh battery and zip tie it to the sled
- ☑ Use the cup attached to the electronics bay and place the head of the e-match just inside the bottom of the cup. Pour in the required amount of black powder around the e-match and seal the top. Be sure to mark each cup as the drogue or main.
- ☑ Run the main e-match through the hole in the bulk plate.
- ☑ Tape the e-match down and seal the hole using putty.
- ☑ Cut the e-matches so that they are 1 inch longer than is required.
- ☑ Allow no exposed wiring to show.
- ☑ Connect the e-match to the altimeters in the main port.
- ☑ Put the coupler/body tube between the drogue bulk plate and the electronics in the bay.
- ☑ Use the cup attached to the electronics bay and place the head of the e-match just inside the bottom of the cup. Pour in the required amount of black powder around the e-match and seal the top. Be sure to mark each cup as the drogue or main.
- ☑ Run the main e-match through the hole in the bulk plate.

- ☑ Tape the e-match down and seal the hole using putty.
- ☑ Cut the e-matches so that they are 1 inch longer than is required.
- ☑ Allow no exposed wiring to show.
- ☑ Connect the e-match to the altimeters in the drogue port.
- ☑ Place the drogue bulk plate on the threaded rods and begin to work it into place. Ensure the belt is aligned with the switch holes in the body tube.
- ☑ Place the bulk plate on the coupler and bolt it together.

Motor Loading Procedures Checklist:

- ☑ Check for dents in the motor casing.
- ☑ Open reloadable motor reload package.
- ☑ Push motor into the casing, forward end first.
- ☑ Screw on the aft enclosure.

Recovery Prep Checklist:

- ☑ Fold the drogue parachute and wrap it leaving enough of the shroud line to connect to the quick link.
- ☑ Prepare electronics bay as outlined; ensure it is secure on both ends.
- ☑ Attach the parachute shroud lines and parachute protector using a quick link to the desired point on the shock cord.
- ☑ Connect the parachute shock cord to the coupler eye-bolt using a quick link.
- ☑ Fold the shock cords to the point just below the parachute quick link, tape together using one layer of painters tape.
- ☑ Put dog barf in the parachute bay before sliding the drogue parachute and shock cord into the parachute bay, then place more dog barf in the bay prior to sliding the electronics coupler in place.
- ☑ Bolt the forward electronics bay bulk plate in place.
- ☑ Fold the main parachute and wrap it leaving enough of the shroud line to connect to the quick link.
- ☑ Prepare electronics bay as outlined; ensure it is secure on both ends.
- ☑ Attach the parachute shroud lines and parachute protector using a quick link to the desired point on the shock cord.
- ☑ Connect the parachute shock cord to the coupler eye-bolt using a quick link.
- ☑ Fold the shock cords to the point just below the parachute quick link, tape together using one layer of painters tape.
- ☑ Put dog barf in the parachute bay before sliding the main parachute and shock cord into the parachute bay, then place more dog barf in the bay prior to sliding the electronics coupler in place.

- ☑ Bolt the aft electronics bay bulk plate in place.
- ☑ Connect the two body tubes with shear pins.

Motor Installment Procedures:

- ☑ Once all rivets and shear pins are in place, place the rocket on the ground. Ensure the nose cone is pointed in a direction opposite of any crowds or vehicles.
- ☑ Push the motor into place.
- ☑ Screw on the motor retainer.
- ☑ Ensure everything is tight and secure.

Setup on Launcher and Igniter Installation Procedures:

- ☑ Arrive at the selected launch site.
- ☑ Speak with the RSO to determine where to set up the launch pad.
- ☑ Place the pad in the specified location.
- ☑ Have the rocket inspected by the RSO.
- ☑ Once approved by the RSO, take the rocket to the pad.
- ☑ Disarm the launch box.
- ☑ Carefully load the rocket onto the launch rail and check to make sure it slides smoothly down the length of the rail.
- ☑ Adjust the pad if necessary.
- ☑ Arm the electronics bay. Wait to hear chirping from both altimeters.
- ☑ Place the igniter inside the motor. Push the igniter into the motor till it hits the top and then secure it in place using the motor cap.
- ☑ Attach the igniter leads to the launch controller.

Launch and Post-Flight Inspection Procedures:

- ☑ Retreat to the necessary safe distance.
- ☑ Launch.
- ☑ Recover the rocket, nose cone, and payload. **Caution: MOTOR CASING WILL BE HOT.**
- ☑ Any or all of these may not be recovered in the event of a hazardous landing (water landing, power lines, etc.).
- ☑ Inspect for damage.
- ☑ Wait until the motor casing has cooled. Remove it and then clean it thoroughly.
- ☑ Go to the competition tent to have the altimeter read and determine the rocket apogee. For the subscale and full scale launches, the altimeter will be read by team members.
- ☑ Recover the payload data for analysis.

Troubleshooting Procedures:

- ☑ Follow instructions of the RSO at all times during troubleshooting.
- ☑ If vehicle is on the launch pad, ensure the igniter and launch box are disarmed before approaching.
- ☑ Once vehicle is safely removed from the launchpad and taken back to the team's onsite workspace, proceed as necessary.
- ☑ If vehicle is not on the launchpad, ensure all black powder charges and other explosives are not armed before handling.
- ☑ Determine the cause of the error or failure mode (i.e. faulty wiring, incorrect packing of payload or parachute, etc.).
- ☑ Isolate the associated part of the payload or launch vehicle for examination.
- ☑ Consult appropriate safety and preparation checklists to ensure preparations were done correctly and completely.
- ☑ If failure cannot be corrected with checklists, consult available resources, including part manuals, NAR mentor, etc., for further information.
- ☑ Repeat as necessary to fix all issues.
- ☑ Once troubleshooting is complete, reassemble rocket and continue with launch prep and launch procedures.

Safety Officer Signature for Checklists and Procedures:

X____________________________________