"Buster"

NAR Level 3 Certification Project

Applicant: Dan Crank, NAR 95388

L3CC Advisor: Sather Ranum, NAR 87637

Anticipated Certification Launch: November 4 2016, Princeton IL

Introduction.

The certification rocket, "Buster," is a 5.16" diameter all-fiberglass rocket built from a Rocketry Warehouse Terminator 5 kit. The only modification to the kit as designed is the replacement of the supplied 22" forward airframe tube with a 36" tube, to allow for a larger main parachute compartment. For the certification flight, Buster will fly on a CTI Pro75 M1401 motor of 6268 Ns total impulse.

The rocket will be recovered by a dual deployment system controlled by two redundant altimeters: a Missileworks RRC3 (primary) and a Missileworks RRC2+ (backup). At apogee, a 24" Spherachutes heavy-duty drogue parachute will be deployed, with the backup deployment occurring 1 second after apogee. At 1000 feet AGL, a 48" Fruity Chutes Iris Ultra parachute will be deployed as a pilot chute, which in turn will deploy an 84" Fruity Chutes Iris Ultra parachute as the main. The backup deployment charge will fire at 800 feet AGL. The airframe will descend at a projected rate of 17 ft/sec on the main parachute, while the nose cone will descend separately at a projected rate of 13 ft/sec on the pilot parachute.

In addition to the altimeters, the rocket will carry an Altus Metrum TeleGPS tracker inside the nose cone, a BigRedBee BeeLine tracker in the electronics bay, and a Mobius HD video camera in a plastic shroud attached to the outside of the upper airframe, pointed towards the tail. I hold a current technician class amateur radio license for operation of the trackers on the 70cm band (callsign KD0YPV).

Rocket Specifications:	
Overall length:	117"
Diameter:	5.16"
Weight w/o motor:	27.5 lb.
Weight at launch (est., CTI M1401 motor):	40 lb.
Expected altitude:	9324 ft AGL
Expected maximum velocity:	950 m/s (Mach 0.84)

This rocket is similar in design and operation to the rocket I flew for my Level 2 certification in July 2014 (a 3" diameter all-fiberglass rocket utilizing dual deployment) and on five subsequent flights. The main unknown for me personally is the use of a deployment bag, which I had not attempted before beginning this project. To mitigate the risk of using a new type of deployment, two test flights were planned using the same parachutes to be used as the main recovery apparatus for the certification flight. The first was a low-altitude single-deployment flight of a fiberglassed LOC Doorknob (approximately 16 lb. at launch), which was completed successfully at a launch near Walnut Grove, MO on May 21, 2016. The second was a full dress rehearsal, launching the certification rocket on a CTI L1355 motor at AirFest XXII on September 2, 2016; this flight was also successful. See the testing section (page 18) for details.

Scale Drawings

Prior to assembly, each of the parts was weighed and measured and the rocket was modeled using OpenRocket. As each major assembly was completed, it was re-weighed and its center of gravity re-checked to account for the added weight of adhesives, paint, etc.; the OpenRocket model was updated with these values. Finally, when the rocket was complete, it was weighed and balanced and the model updated again for flight simulation purposes. Therefore, the dimensions and CG / CP values below are calculated by OpenRocket but derived from direct measurements of the parts actually used in construction (i.e., not relying on a kit manufacturer's published values).

OpenRocket indicates a stability margin of 15.9", or 2.3 calibers, with the CTI M1401 motor to be used for the certification flight. A full 6-grain CTI motor, such as the M2020, is the largest motor which will fit into the rocket as built; with a CTI M2020 loaded, OpenRocket indicates a stability margin of 10.3", or 2.0 calibers – still a reasonable value for safe flight.

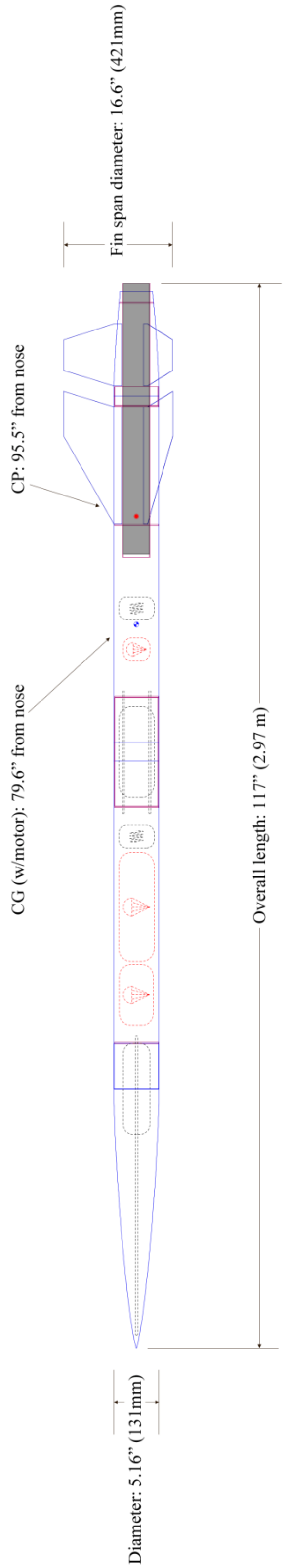


Fig. 1: Physical dimensions.

Construction.

Additional photographs of all assembly steps can be found at http://danno.org/RocketBlog/level3.php.

The airframe is built from the following parts. All parts are the original kit components, with the exception of the forward airframe as noted below.

- Nose cone of filament-wound fiberglass with aluminum tip, 5.17” diameter x 28.5” long (including tip).
- Nose cone shoulder of filament-wound fiberglass, 5.00” dimeter x 8” long (4 7/8” exposed).
- Nose cone bulkhead composed of two fiberglass bulkplates of 4.83” and 5” diameter, total thickness 1/4“.
- Forward airframe of filament-wound fiberglass, 5.17” diameter x 36” long. This is a substitution for the 22” tube supplied with the kit, of the same type and from the same supplier (Rocketry Warehouse) to allow more space for recovery components.
- Coupler tube of filament-wound fiberglass, 5” diameter x 12” long.
- Switch band of filament-wound fiberglass, 5.17” diameter x 2” long.
- 2x Electronics bay bulkheads of 5” diameter, 3/16” thick, with step machined into the edge to fit the coupler tube.
- 2x lengths of ¼” threaded rod, steel, approximately 13” long to serve as electronics bay rails.
- Aft airframe of filament-wound fiberglass, 5.17” diameter x 38” long.
- Tailcone coupler of filament-wound fiberglass, 5” diameter x 2” long.
- Tailcone of filament-wound fiberglass, 11.5” long with an exit diameter of 3.7”
- Six fins of 3/16” thick fiberglass.
- Three centering rings of 1/8” thick fiberglass (two in the aft airframe and one in the tailcone).

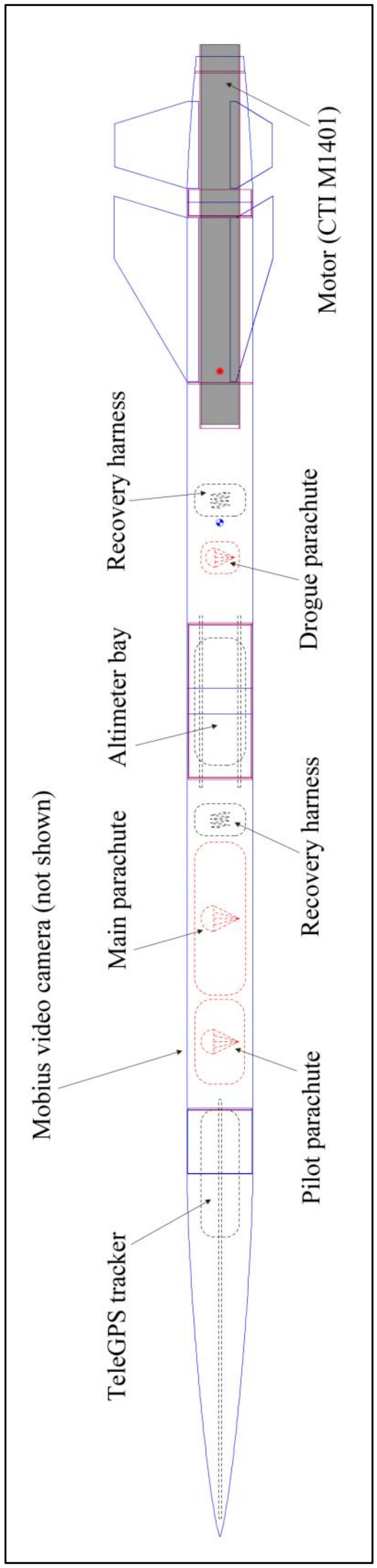
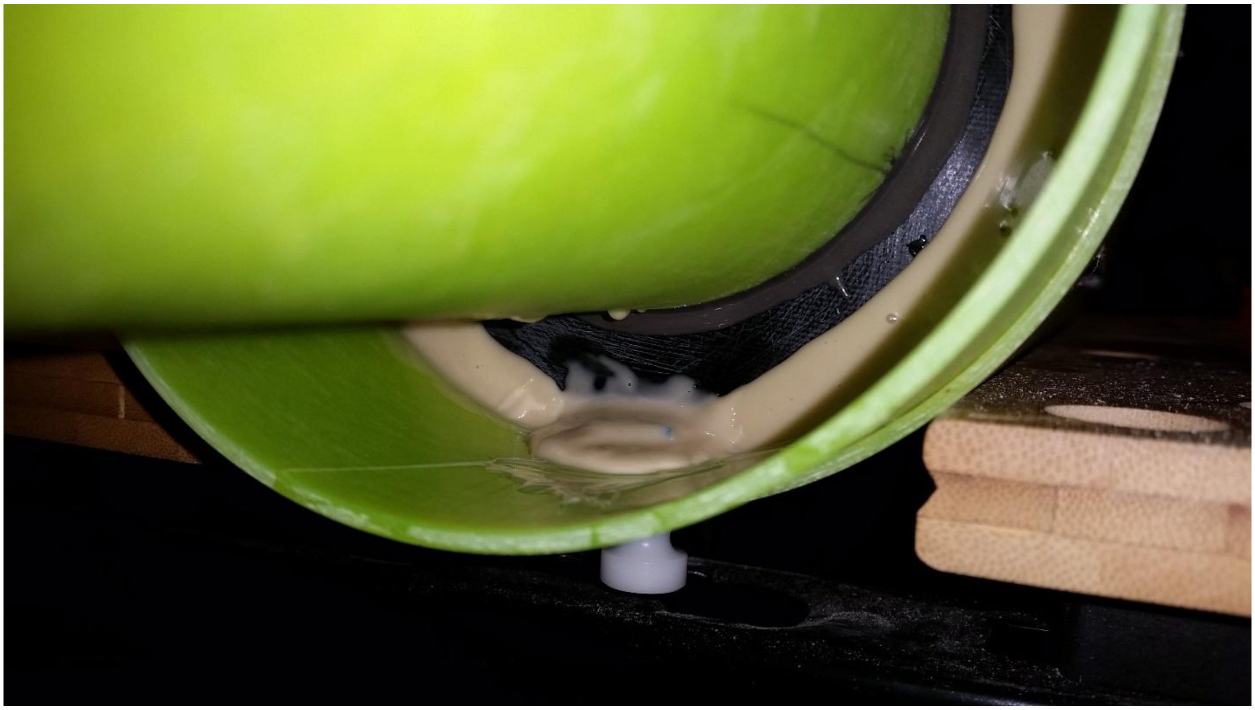


Fig. 2: Layout of components.

Two 1515-sized one-piece Delrin rail buttons are used for launch guidance. They are backed with T-nuts and bonded into the airframe at the location of the forward and middle centering rings, for maximum strength.

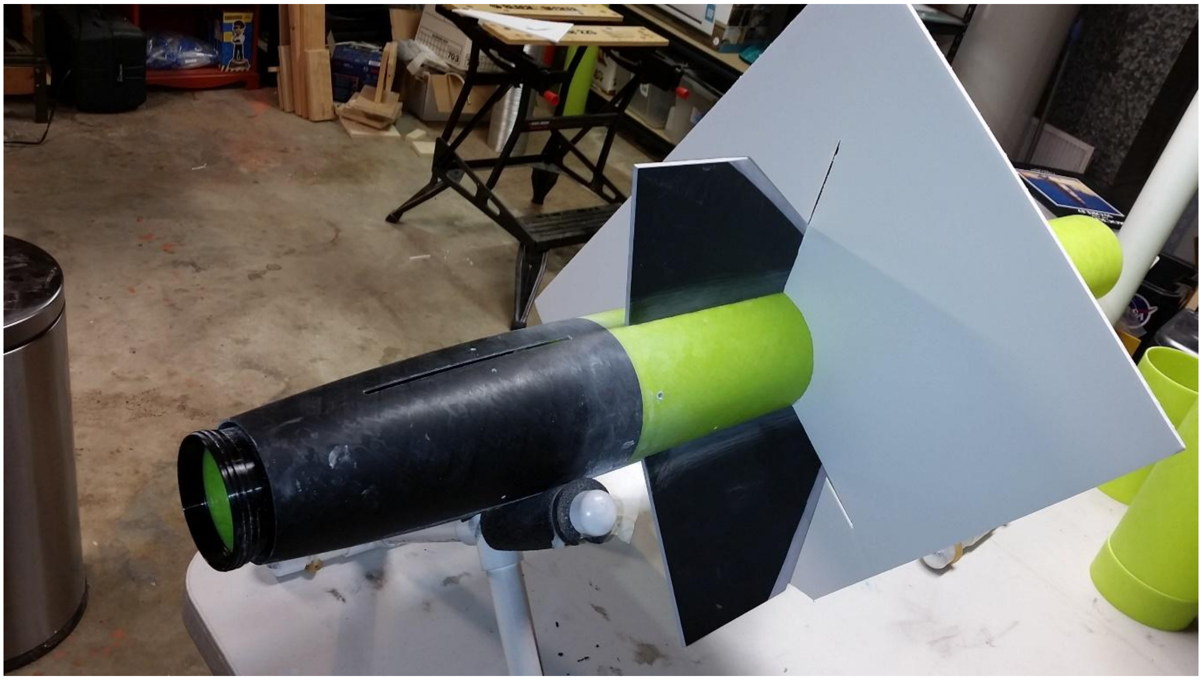


Detail of rail button backing T-nut bonded to airframe and centering ring.

Glenmarc G5000 high strength epoxy ("RocketPoxy") was the primary adhesive used. J-B Weld was used in locations where higher heat resistance was needed (bonding the fins, motor retainer and recovery system anchor to the motor mount tube). Loc-Tite two-hour marine epoxy was used in locations where the adhesive was to be injected via syringe (internal fillets bonding the fins to the motor mount tube and filleting the aft centering ring).

Fins were attached after airframe / motor mount assembly in the following steps:

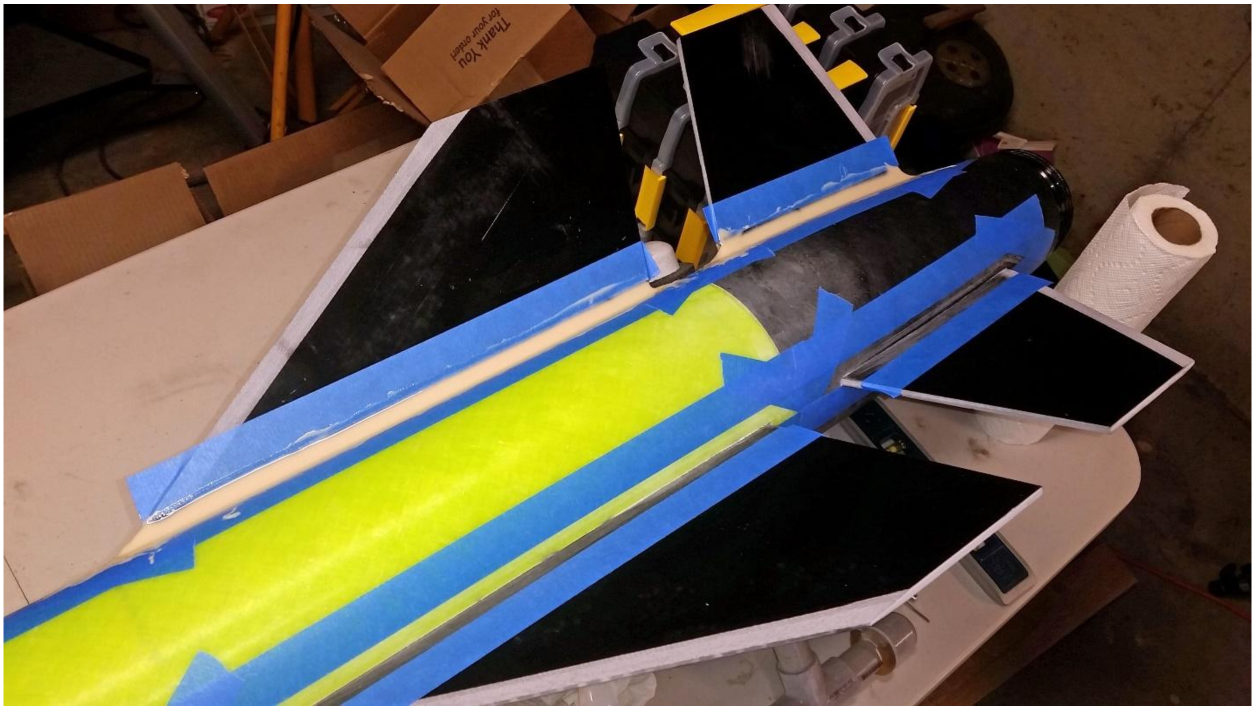
- All bonding surfaces were scuffed with 60 grit sandpaper.
- J-B Weld was liberally applied to the root edge of each fin and the fin inserted into its slot to make firm contact with the motor mount tube.
- The forward fins were aligned using an alignment jig cut from foam board. The rear fins were aligned by clamping each one to the corresponding forward fin with two strips of thin plywood.
- Internal fillets of Loc-Tite two-hour marine epoxy were injected to the fin tab / motor mount joint via syringe.
- External fillets of RocketPoxy were applied with a plastic spoon.



Initial bonding of forward fins; foam board alignment jig shown.

Initial bonding of aft fins; plywood alignment strips shown.

Injection of internal fillets.



Application of external fillets.

After assembly, the rocket was finished with Rustoleum sandable primer and Rustoleum gloss enamel.

Finished product.

Recovery System.

Buster is recovered by means of a dual-stage deployment system. A drogue parachute is deployed at apogee, and two larger parachutes are deployed at an altitude of 800 feet above ground level. Deployment events are commanded by two independent altimeters.

The recovery system is attached to the rocket as follows:

- An aft anchor point consisting of a 3/8” tubular Kevlar strap bonded to the motor mount tube with JB-Weld and then soaked with US Composites thin epoxy. The strap is bonded along opposite sides of the motor mount tube for a length of approximately 16” to provide a strong anchor. (See photo below.)
- A stainless steel quicklink to an aft shock cord of 1/2” tubular Kevlar.
- A stainless steel quicklink to a forged eyebolt attached to the aft electronics bay bulkhead.
- A stainless steel quicklink from a forged eyebolt attached to the forward electronics bay bulkhead to a forward shock cord of 1/2” tubular Kevlar.

Recovery system anchor bonded to motor mount tube. (Also bonded on opposite side of tube.)

The nose cone, designed to descend separately, has its own parachute attached as follows:

- A 1/4” threaded rod threaded into the nose cone tip and secured with Loc-Tite.
- A forged eye nut threaded onto the central rod and secured with a lock washer.
- A stainless steel quicklink attached directly to the nose cone parachute.

(The nose cone is constructed in this way to allow its bulkhead to be removable; the space inside the nose can then be used for a radio tracker or other payload.)

Please refer to Figure 2 on page 5 for location of recovery components inside the airframe.

The airframe is designed to separate at two points during recovery system deployment. At apogee, the aft airframe will separate from the aft end of the electronics bay; the apogee ejection charges are located at the aft end of the electronics bay and separated from the recovery components by a 9" Nomex parachute protector. This point is friction fit and adjusted at launch time by adding small shims of masking tape as necessary. The aft airframe compartment is vented by means of a single 1/4" hole near the top of the compartment on the side facing the launch rail.

At the main deployment altitude, the nose cone will separate from the forward airframe; the main ejection charges are located at the forward end of the electronics bay and separated from the recovery components by a 24" Nomex parachute protector. This separation point is secured by three #4 nylon screws acting as shear pins. The forward airframe compartment is vented by means of a single 1/4" hole near the top of the compartment on the side facing the launch rail.

The approximate weight of the rocket after propellant burnout is 38 pounds, 5 pounds of which is the nose cone. After considering several parachute options (see recovery design, page 16), an 84" Fruity Chutes Iris Ultra was selected as the main parachute, deployed from a deployment bag using the "free bag" technique. When rigged in this way, the nose cone descends separately on its own parachute. To keep the descent rate of the nose cone lower than that of the rest of the rocket (to reduce the possibility of the two parts colliding after deployment), a 48" Fruity Chutes Iris Ultra was selected as the nose / pilot parachute. A 24" Spherachutes heavy-duty parachute was selected as the drogue parachute.

Utilizing Fruity Chutes' online descent rate calculator yields estimated descent rates of 16.5 ft/sec for the main section and 12.5 ft/sec for the nose. Descent rates were intentionally kept lower than typical in an attempt to ensure a successful certification flight.

The deployment plan is illustrated in the diagram on the following page.

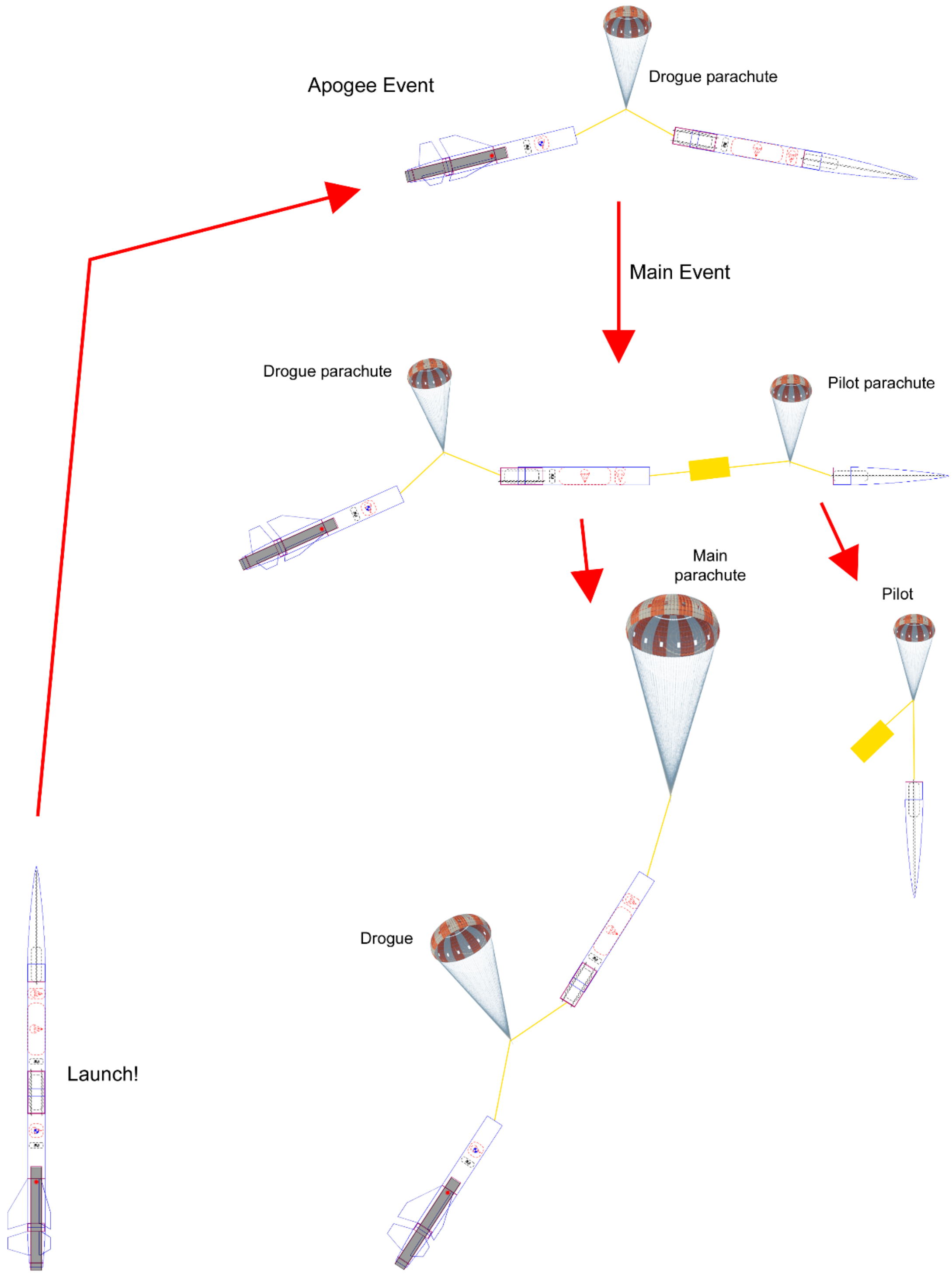


Fig. 5: Recovery plan.

Description of control components.

The altimeters used are a Missileworks RRC3 for the primary deployment events and a Missileworks RRC2+ for the backup deployment events. Each is powered by its own 9 volt battery and armed / disarmed by its own rotary switch. Both altimeters sense altitude by barometric pressure only.

The altimeters are mounted on a fiberglass sled inside the electronics bay using nylon standoffs. The arming switches are mounted to a piece of 3” diameter fiberglass tube cut lengthwise, and aligned with two of the static port holes so they may be easily accessed with a small screwdriver. The batteries are secured with aluminum battery holders and zip-ties so they cannot become dislodged by any forces reasonably expected in normal flight. A small eyebolt (in addition to the main eyebolt used to attach the recovery harnesses) was also added to the bulkhead to provide a means to secure the ejection charge canisters and prevent them from pulling on their wires in flight.

Static port sizing was calculated according to the standard formula posted at http://www.vernk.com/AltimeterPortSizing.htm:

$$D_N = 0.02216 * D_T * \text{sqrt}(L/N) = 0.02216 * 5 * \text{sqrt}(12/3) = 0.2216''$$

This was rounded up to the next drill size available, and three static port holes of 15/64” diameter were drilled to vent the electronics bay.

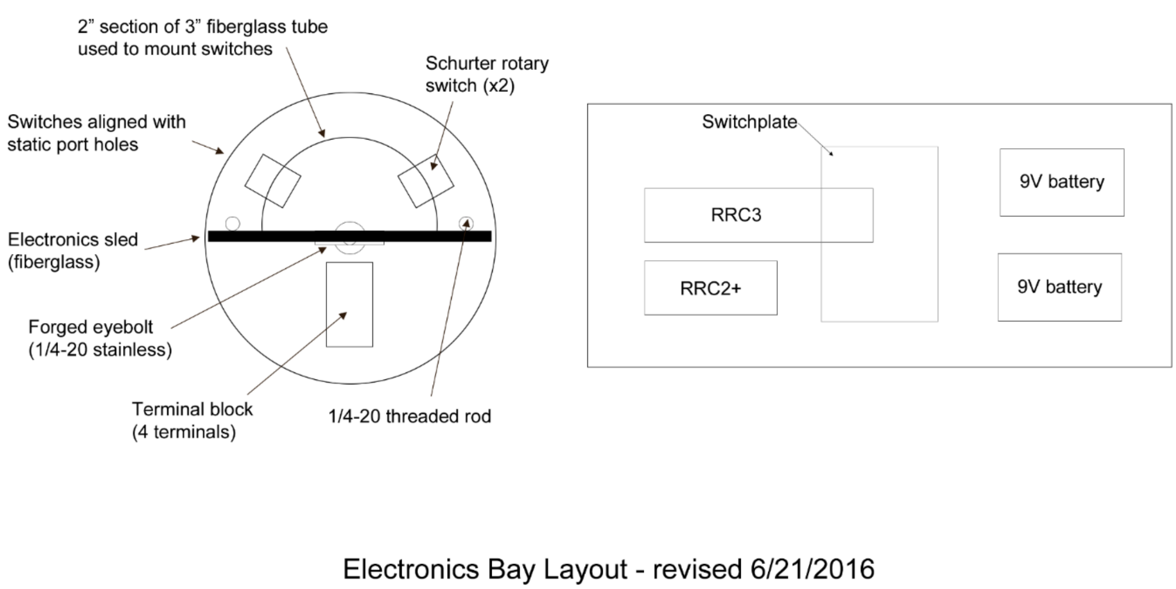
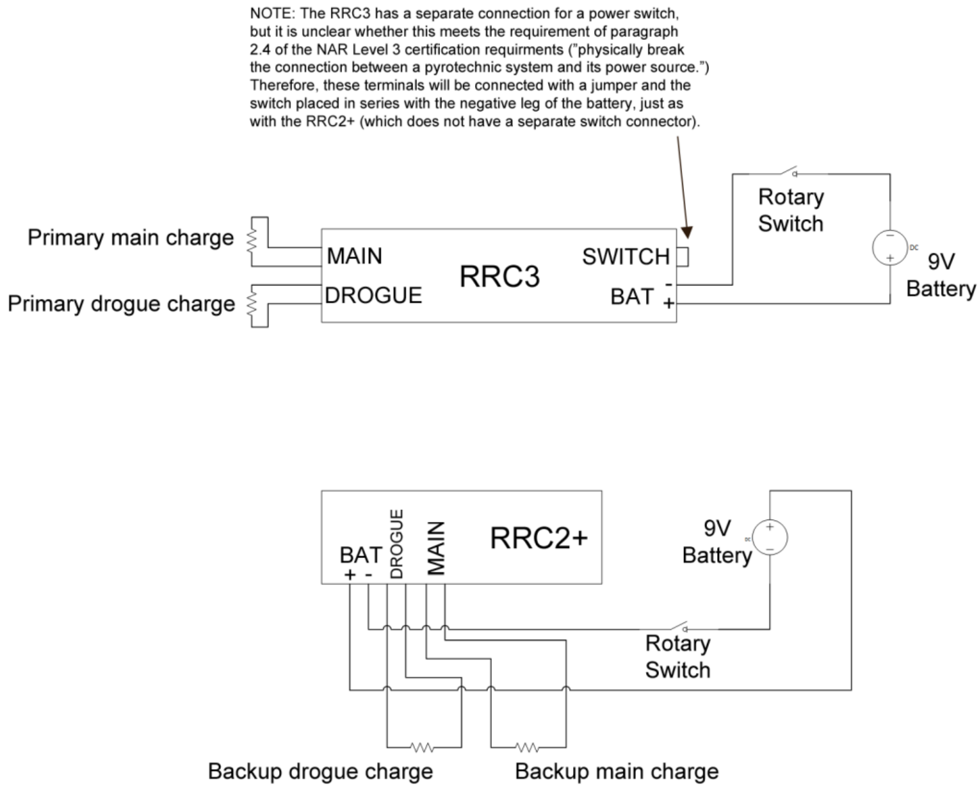
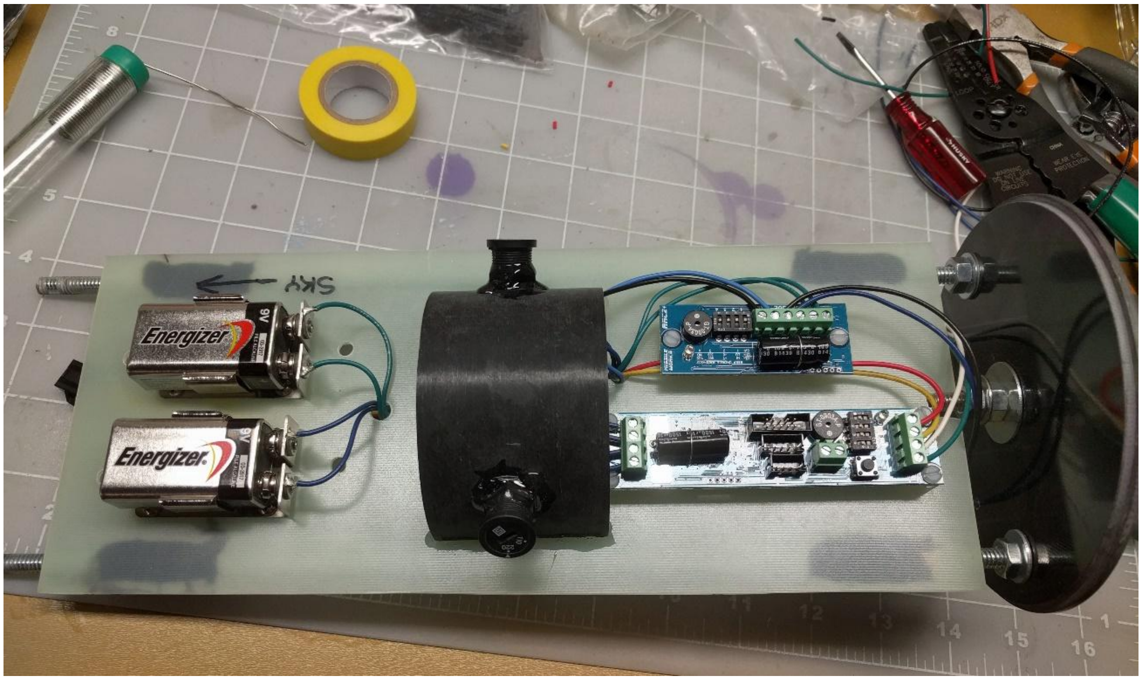


Fig. 3: Electronics bay layout.



Altimeter Wiring - revised 6/21/2016

Fig 4: Altimeter wiring.



Mounting of electronics bay components (reverse of diagram orientation).

Not shown are zip-ties securing the batteries in their holders.

Detail of outside of electronics bay bulkhead, showing terminals for attaching deployment charges and eyebolt for supporting charge canisters.

Description of recovery components and design.

As noted above, several options were considered for recovery of the rocket, with the following factors in mind:

- In my L3CC advisor's experience, large parachutes with fewer gores (e.g., SkyAngle, Crossfire) were more prone to deployment problems than those with more gores (e.g., Spherachute, Fruity Chutes).
- Conventional wisdom is that large parachute deployments are more reliable when rigged with a deployment bag
- Even with the extended forward section, parachute space in a 5" diameter, 38 pound rocket is somewhat limited.

Given these factors, the main parachute options were narrowed down to the Spherachutes hemispherical parachute and the Fruity Chutes Iris Ultra. The decision was also made to use a deployment bag. Given that the expected weight of the rocket, less the propellant weight (which will have burned) and the nose cone weight (which will have separated) is approximately 26 pounds, the following calculations were made to narrow the main parachute selection further:

Manufacturer	Parachute	Weight	Packed Volume	Descent Rate (26 lb. load)
Fruity Chutes	Iris Ultra 84”	19 oz.	105 cu. in.	16.5 ft/sec
Fruity Chutes	Iris Ultra 96”	25 oz.	140 cu. in.	14.5 ft/sec
Spherachutes	Hemispherical 120”	19 oz.	108 cu. in.	21.5 ft/sec
Spherachutes	Hemispherical 144”	29 oz.	198 cu. in.	18 ft/sec
Spherachutes	Hemispherical 168”	39 oz.	252 cu. in.	15.5 ft/sec

Based on this comparison, the Iris Ultra 84" was selected. This parachute can be deployed from a 4"x12" Fruity Chutes deployment bag, which will fit comfortably in the 5" airframe. The 96" Iris Ultra, and all of the Spherachutes options, would have required using a deployment bag designed for a 6" airframe. Gene from Fruity Chutes said that their bags could be hemmed in on the sides to fit the smaller space, but better to avoid this complication.

The next matter was sizing of the pilot parachute. The goal is to bring the nose cone down under the pilot chute at a slower rate than the rest of the rocket (i.e., less than 16 ft/sec) to avoid the possibility that the nose could catch up and collide with the main parachute or anything else. The nose cone by itself will weigh approximately five pounds; therefore, the 48" Iris Ultra was selected as the pilot chute, with a predicted descent rate of 12.5 ft/sec.

A 24" Spherachutes heavy-duty hemispherical drogue was selected. Caution must be exercised in not using too large a drogue parachute, since the drogue's drag is effectively pulling the rocket in the same direction that the pilot chute has to pull in order to remove the deployment bag from the main chute. The greater the lifting force of the drogue, the less effective force the pilot can apply to the deployment bag.

3/8” and 1/2” tubular Kevlar and stainless steel quicklinks rated at 880 pounds capacity were used as attachments throughout the rocket. These should far exceed the strength of the fiberglass components (the breaking strength of which cannot easily calculate).

The ejection charges used are a scaled-up version of a type I have been using successfully since my level 1 certification, based on charge canisters purchased from Pratt Hobbies. The charge container is a centrifuge tube with the pointed tip cut off; an electronic match is placed in the tip of the tube and secured with five-minute epoxy. To prepare the charge, the necessary quantity of Goex FFFFg black powder is added to the tube, completely covering the e-match head, and topped with a small ball of Estes recovery wadding. The tube is then sealed with electrical tape and attached to the electronics bay bulkhead with a zip-tie to keep launch stresses off of the connecting wires, which are connected to a terminal block on the bulkhead.

Ejection charge connected to terminal block for ground test. (Not shown: zip-tie support for charge canister.)

A standard arrangement of three shear pins was selected, since the pins can be aligned with the fins and avoid airflow disturbance over the altimeter bay static ports, which will also number three and be located midway between the fins. The question then was what size shear pin was most appropriate.

Data from five flights of my L2 rocket were examined. The negative axial acceleration associated with the apogee deployment in these flights (the "jerk" when the forward section reaches the end of the shock cord) was typically around 10G and never exceeded 20G. Using this as a guideline, and the fact that the nose cone of this rocket weighs approximately 5 pounds, the total shear force of the pins should therefore be greater than 100 pounds (5 lb. x 20G).

A thorough test of shear pin strengths, documented at https://web.archive.org/web/20110811054310/http://www.rocketmaterials.org/datastore/cord/Shear_Pins/index.php was consulted as a reference. According to this series of tests, three #2 screws sheared at approximately 64 pounds of force, and three #4 screws sheared at approximately 115 pounds of force. Therefore, three 4-40 screws should be (just) sufficient to retain the nose cone under a -20G load.

Calculations documented at http://www.feretich.com/rocketry/Resources/shearPins.html, on the other hand, indicate the shear force of 4-40 nylon screws to be between 50 and 76 pounds of force (per screw). The midpoint of this range (63 pounds force) is used as the starting point for ejection charge calculations. The exact screws available are these: http://www.mcmaster.com/#93135A108.

The black powder calculator at http://www.rockethead.net/black_powder_calculator.htm was used to determine charge size, as follows. The target ejection force was calculated based on 133% of the estimated shear force of the shear pins as a safety margin.

> Ejection force = 3 (number of pins) * 63 (shear force per pin) * 1.33 (safety margin) = 251 lbf
>
> Ejection pressure = 251 (ejection force) / (pi * 2.5 (airframe radius) ^ 2) = 12.8 psi
>
> The main parachute compartment has a diameter of 5” and a length of 26” (the tube length of 36” minus 5” shoulders on both the nose cone and coupler). The online calculator indicates that pressurizing that compartment to 12.8 psi above atmospheric pressure requires 3.33 grams of black powder. This value was used as the charge size for ground testing.

Ground and flight testing.

An initial flight test of the pilot and main parachutes was conducted on May 21, 2016. The purpose of this test was to verify the process of packing and rigging the two parachutes together with the deployment bag. The parachutes were rigged as an “integrated” system (with the pilot chute attached to the crown of the main chute) in a LOC Doorknob flying on a Cesaroni J430 motor. The flight reached 1030 feet above ground level and the parachute deployment worked as expected. A video of this flight test is available at https://youtu.be/LH3ciY9SmmA.

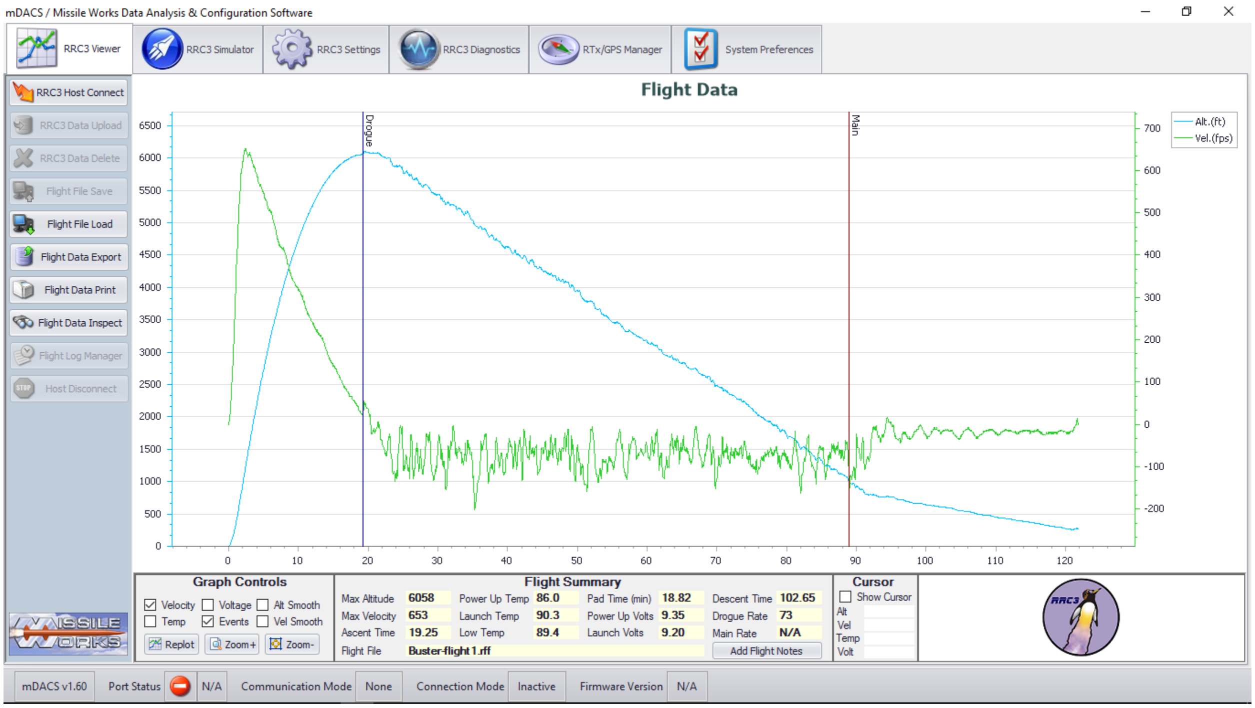
A ground test was conducted on July 4, 2016. The purpose of this test was to verify that the 3.33g charge size was sufficient to shear the shear pins and eject the nose cone from the main parachute compartment, so the parachutes were not loaded. The ejection charge worked as expected and the nose cone was propelled to the end of the shock cord. A video of this test is available at https://youtu.be/rowRF30y2X8.

A bench test of the primary altimeter was conducted on August 14, 2016. The purpose of this test was to verify that the altimeter circuit as designed was capable of igniting the type of electronic matches used for the ejection canisters. The test was conducted using the RRC3's flight simulation mode. The e-matches ignited as expected. A video of this test is available at https://youtu.be/ESkoIR90kyM.

A similar test was attempted for the backup altimeter (which does not have a flight simulation feature) by using a vacuum cleaner to simulate a barometric apogee and trigger the deployment events, but this method was not successful. Another attempt was made using a syringe to draw air out of the electronics bay and reduce the pressure, but this too was unsuccessful.

A second ground test was conducted August 18, 2016. The purpose of this test was to verify that the entire main deployment system would eject cleanly. The ejection worked as expected. A video of this test is available at https://youtu.be/HSnwf1bcCxU.

As a final test, an opportunity to launch Buster presented itself on September 2, 2016 at AirFest XXII in Argonia, Kansas. Everything for this flight was configured as it will be for the certification flight, with the exception of a smaller motor (a Cesaroni L1355). The flight reached an indicated altitude of 6058 feet AGL with a maximum indicated velocity of 653 ft/sec (Mach 0.58). The descent rate under drogue was 73 ft/sec and the descent rate of the airframe under the main parachute was 18 ft/sec (slightly higher than expected). All flight events were as expected, and the rocket was recovered safely less than ¼ mile from the launch pad. A video of the flight is available at https://youtu.be/_m1dxSpdxwA.



RRC3 flight data from Buster's flight at AirFest XXII.

Buster departing Argonia KS on a Cesaroni L1355 Smoky Sam motor.

Safe recovery.

Stability analysis.

Stability of the rocket was analyzed using OpenRocket version 15.03. Prior to assembly, each part was weighed and measured, and from these measurements an OpenRocket simulation file was created and used for planning purposes. After assembly, the rocket was accurately weighed and balanced with all recovery gear and other components loaded (except the motor), and the simulation was updated with the actual values: 27.5 pounds total weight and center of gravity 68.5” from the tip of the nose cone. Buster’s center of pressure, as indicated by OpenRocket, lies at a point 91.5” from the tip of the nose cone, indicating a base stability margin of 23 inches, or 4.6 calibers. The simulation file is available at http://danno.org/RocketBlog/sims/BusterXL_v2.ork.

Weighing and balancing the rocket for refinement of the simulation.

Buster is designed to be launched from a 1515 rail at least 8 feet long. Three motor sizes were simulated using this rail size, and the expected velocity leaving the rail was examined, along with stability at launch. These values were as follows:

Motor	Velocity leaving 8’ launch rail (ft/sec)	Stability margin at launch (cal)
CTI L1355 (test flight motor)	66.3	2.45
CTI M1401 (certification motor)	64.1	2.39
CTI M2020 (largest motor possible)	83.5	2.10

Using the rule of thumb that the velocity of the rocket leaving the rail should be at least four times the speed of the crosswind, the certification flight should be safe in crosswinds up to 16 ft/sec (11 MPH). Higher crosswinds will require a longer launch rail:

Rail length (feet)	Velocity leaving rail (ft/sec)	Maximum safe crosswind (MPH)
10	71.4	12.0
12	78.7	13.5
16	88.4	15.0

For the certification flight, the center of gravity with the motor loaded is expected to be 79” from the nose, or 12.5” ahead of the center of pressure. The center of pressure is clearly indicated with a painted marking on the airframe. As part of the flight preparation checklist, the balance of the rocket will be checked to verify that the CG is approximately 12.5” ahead of the CP.

Certification Flight Profile.

These values are based on OpenRocket simulation and motor data published by Cesaroni at http://www.pro38.com/products/pro75/motor/MotorData.php?prodid=6268M1401-P.

- Launch weight: 40 lbs.
- Recovery weight: 32.5 lbs.
- Motor: Cesaroni Pro75 6268M1401-P
- Total installed impulse: 6268 N-s
- Drag coefficient: 0.590 – 0.695 (calculated by OpenRocket)
- Velocity leaving 8’ launch rail: 64 ft/sec
- Maximum expected velocity: 950 ft/sec (Mach 0.84)
- Maximum expected altitude: 9324 feet
- Maximum expected acceleration: 8.28 G

Launch procedures (checklists).

Materials needed.

- Screwdrivers (flat-blade and Philips head)
- Pliers (needle nose and lineman's pliers)
- Adjustable wrench
- Multimeter
- Wire cutter / stripper
- CTI Pro75 closure tool
- Black powder
- Estes flameproof wadding
- Ejection canisters
- Laptop, USB cables
- Zip ties
- Twist-tie
- Super Lube
- Handheld radio transceiver
- Yagi antenna
- Altus Metrum TeleBT ground station

Pre-flight checklist.

Pre-launch (before leaving town):

- ✓ Clean everything!
- ✓ Assemble motor per manufacturer's directions
- ✓ Charge batteries: TeleGPS, TeleBT, BRB transmitter, Casio camera, JVC camera, Mobius, ham transceiver, drill
- ✓ Clear memory in Casio camera & JVC camera
- ✓ Check TeleGPS config and reset / clear memory
- ✓ Test TeleGPS/TeleBT and leave transmitter battery unplugged
- ✓ Check BRB config
- ✓ Test BRB/Ham transceiver and leave transmitter battery unplugged
- ✓ Check Mobius config (correct video mode; sync clock), test and clear memory
- ✓ Install new Duracell batteries for RRC3 and RRC2+; zip-tie batteries to sled
- ✓ Check RRC3 config via laptop (set main pyro altitude to 1000 feet)
- ✓ Configure RRC2+ via switches (1-ON (high tone), 2-ON (apogee delay), 3-ON 4-OFF (main pyro altitude 800 feet)
- ✓ Check contents of recovery pack

Pre-launch (night before launch):

- ✓ Install motor in rocket

- ✓ Assemble ejection charges (3.33g Goex + wadding) x4
- ✓ Refold / repack main parachute and rig deployment bag as described below:
  - Hold chute by base of shrouds and shake out.
  - Wrap wire or twist-tie around base of shrouds.
  - Lay chute on flat surface and organize panels, six to each side.
  - Fold ⅓ of chute from left to right; fold ⅓ of chute from right to left.
  - Insert top of chute into bag and stuff it in.
  - *Neatly* Z-fold shrouds and place under elastic straps, right to left. First fold will be shorter to keep shrink-wrapped coupler from having to pull through a strap. There will be four folded sections total, two under each set of elastic straps.
  - **REMOVE WIRE OR TWIST TIE FROM SHROUDS!**

At the field:

- ✓ Switch RRC3 on to test; RRC3 should emit a 5 sec beep, 20 sec silence, then repeating long beeps (no continuity). Any other sequence indicates a problem. Switch RRC3 off.
- ✓ Switch RRC2+ on to test; RRC2+ should emit a 1 sec beep (RRC2+ beeps in a higher tone than RRC3), then beep out its last altitude, then pause, then beep out the battery voltage (whole volts, then tenths), then repeating long beeps (no continuity). Any other sequence indicates a problem. Switch RRC2+ off.
- ✓ Connect BRB battery; switch on ham transceiver and verify BRB is transmitting.
- ✓ Check terminal blocks for voltage
- ✓ Connect (4) ejection charges to terminal blocks

Pay special attention to orientation of the sled in the coupler when assembling. The arming switches must be aligned with the designated access hole, and the "up" end of the sled must be aligned with the "up" end of the coupler. There are registration marks on the coupler tube and aft bulkhead which must line up precisely.

- ✓ Insert sled into coupler, attach forward bulkhead plug and assemble coupler with lock washers and hex nuts
- ✓ Attach aft shock cord / nomex between booster & coupler
- ✓ Pack drogue & attach to aft shock cord
- ✓ Check / adjust friction fitting between booster & coupler
- ✓ Attach forward shock cord / nomex to coupler
- ✓ Thread forward shock cord through forward section and attach forward section to coupler with rivets
- ✓ Bundle forward shock cord w/masking tape
- ✓ Attach main parachute to forward shock cord
- ✓ Attach nose shock cord to deployment bag
- ✓ Pack pilot chute and attack to nose shock cord
- ✓ Switch TeleGPS and TeleBT on, check for comm & GPS lock, switch TeleBT off (leave TeleGPS on!)

- ✓ Assemble nose cone with lock washer and eye nut
- ✓ Attach nose shock cord to nose cone
- ✓ Fit nose cone to payload section, install shear pins
- ✓ Check rocket balance - CG should be 12.5” ahead of CP
- ✓ Verify that TeleGPS and BRB are still transmitting
- ✓ Alert certification flight witnesses
- ✓ To pad with rocket, pad camera & recovery pack

At the pad:

- ✓ Place pad camera
- ✓ Switch on-board camera on, REMOVE LENS CAP & start recording
- ✓ Rocket on rail
- ✓ Switch RRC3 on; RRC3 should emit 5 sec beep, 20 sec silence, repeating sequence of three short beeps (drogue and main continuity). Any other sequence indicates a problem.
- ✓ Switch RRC2+ on; RRC2+ should emit 1 sec beep, then beep out last altitude, pause, beep out battery voltage, pause, then repeating sequence of three short beeps (drogue and main continuity). Any other sequence indicates a problem.
- ✓ Start pad camera
- ✓ Insert igniter in motor
- ✓ Connect igniter leads
- ✓ Return to LCO
- ✓ Switch TeleBT on and verify that TeleGPS still has GPS lock and is transmitting - if not, ask LCO to hold launch
- ✓ Switch ham transceiver on and verify that BRB is still transmitting - if not, ask LCO to hold launch
- ✓ Alert certification flight witnesses
- ✓ Go For Launch

Recovery procedures

- In the event of a motor misfire (burned igniter), the rocket can be left in a ready-to-fly state (all electronics powered on) for at least an hour without needing to worry about battery life.
- The nose cone may be tracked via the TeleGPS transmission being received by the TeleBT ground station and then sent to the mobile phone via Bluetooth.
- If the nose cone and airframe become separated after deployment, the main section of the rocket may be tracked separately by the BigRedBee BeeLine tracker in the electronics bay. This is a simple directional signal requiring a Yagi antenna and a handheld receiver with a signal strength meter.
- Disarm both altimeters immediately after approaching the rocket. Even if the deployment appears nominal, there could be a live charge inside the forward airframe.
- Remember to recover the camera from the launch pad area.