# Level 3 Certification Project
# Nate Lowrie – TRA 10518

**Completed Picture here**

Project Name: “Experiencing A Significant Gravitas Shortfall”

Advisors: Robert DeHate and Fred Wallace

# 1 INTRODUCTION

My level 3 project will be done using a Madcow (formerly Rocket Warehouse) Formula 200 kit. The rocket will be 8in diameter x 127in long and have 3 slightly swept clipped delta fins. The projected weight without the motor is 58 lbs with a launch weight of 68lbs. A custom machined aluminum thrust plate will be added to the rear of the airframe to transfer the motor load directly to the body tube.

| | |
|---|---|
| Planned certification motor: | **CTI M1560** |
| Projected Altitude: | **4252 ft** |
| Drogue deployment: | **At apogee** |
| Main deployment: | **700 ft. AGL** |
| Backup main deployment: | **500 ft. AGL** |

My current 3-5 year goal is to send a 1kg payload to over 100,000 ft. and recover it. This L3 Certification project is the next step in that goal. The goals of this project and how they relate to my overall mission:

1. First and foremost, obtain my L3 cert. The L3 is required for a flight that high and I can re-acquaint myself with this level of complexity.
2. Create a robust airframe that can be used a test bed for the larger 75mm and 98mm experimental motors I will be developing. My plan for the 100,000 ft. flight calls for using experimental motors and this airframe will serve as an eventual test bed for the larger motors.
3. Gain experience with the ARRD recovery configuration in a larger rocket where the recovery forces likely to be large. I have used the recovery setup on my Level 2 cert. It is also the recovery method I would like to use on the sustainer for the 100k.
4. Machine a custom designed aluminum thrust ring for the rocket. I expect to make custom bulkheads for the 100k project and the thrust plate is a nice, easy start.
5. Develop the tools, ground support, and processes necessary to support a large complex launch. Off the top of my head I would like to use this project to:
    - Develop a better transport rack setup
    - Develop better work cradles for holding the rocket during assembly and prep.
    - Build a proper case for the LCD recievers for the TRS units.
    - Develop a better prep system in regards to a 2 person team. Need to develop a process of running through the checklist better with double confirmations.

My goal is to have the project done and ready for launch by the end of October 2016. I am not really doing anything I haven't done before so this shouldn't be a problem. If we have Red Glare in November 2016 I will launch then if ready, else it will have to be at LDRS in April.

**Complete build details can be found at: Link TRF Build Thread Here.**

# 2 DESIGN OVERVIEW AND FLIGHT SIMULATIONS

Rocksim 9 has been used to determine flight parameters such as C/P, C/G, weights and performance.
Prior to flight, the actual C/G and weight will be measured to verify that the predicted flight parameters (flight track, altitude, descent rate, drift) will be acceptable. During construction components will be weighed to keep an accurate estimate of weight and CG. The Rocksim 9 simulation summary is presented in Figure 3 below.

The planned altitude is 4252 feet AGL with a CTI M1560 motor. Figure 1 and 2 are scale drawing of the project:

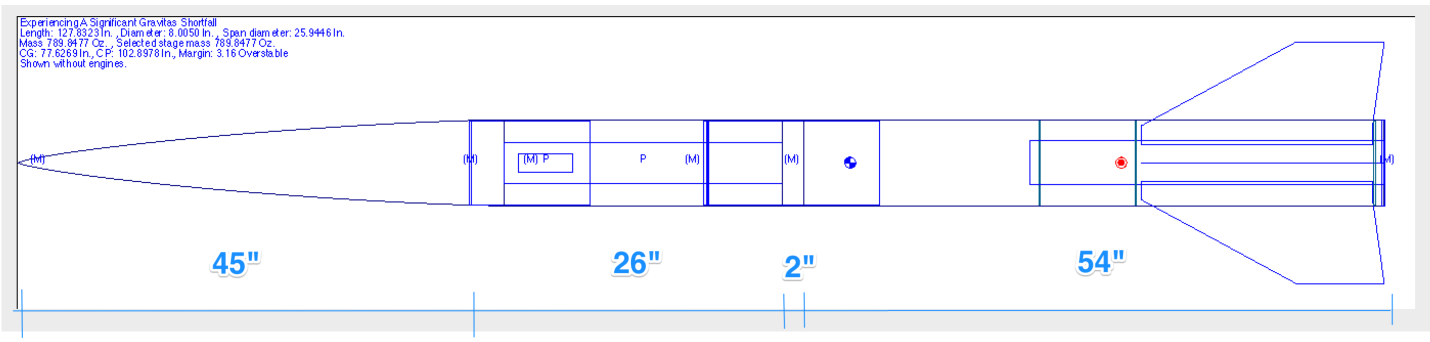


**Figure 1.** Scale drawing without motor.

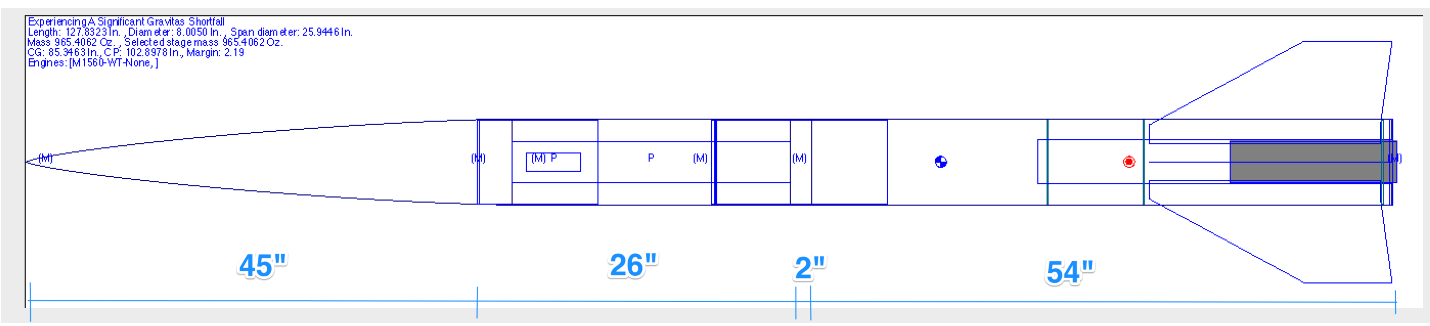


**Figure 2.** Scale drawing showing the CTI M1560 motor installed.

The calculated center of pressure is 102.9" aft of the nose cone tip and is shown in the drawing as a red C/P symbol, just in front of the leading edge of the fins. Using Rocksim v9, and the measured "no motor" CG of 77.6", the aft C/G limit using the M1560 motor was calculated at 85.3" employing Rocksim's stability equations. This yields an acceptable stability margin of 2.19 calibers.

## *Preliminary flight simulation with CTI 98mm M1560 load*

| | |
|---|---|
| Center of pressure | **102.9 inches from nose (Rocksim V9)** |
| Center of gravity | **85.3 inches from nose (Rocksim V9)** |
| Mass at liftoff | **966 oz (60.3 lbs) (Rocksim V9)** |
| Total impulse | **5322 N-sec.** |
| Burn time | **3.5 sec** |
| Estimated Drag Coefficient | **0.4 at takeoff (Rocksim analysis)** |
| Velocity at End of Rail | **60 ft/sec** |

| | |
|---|---|
| Maximum Expected Velocity | **535 feet/sc** |
| Maximum expected acceleration | **562 feet/sec** |

1. Simulations performed in Slightly Breezy (8-14 mph), steady 15 mph and Breezy (15-25 mph) conditions. Rocket trajectory is acceptable in all conditions.
2. All calculations performed using Rocksim v9

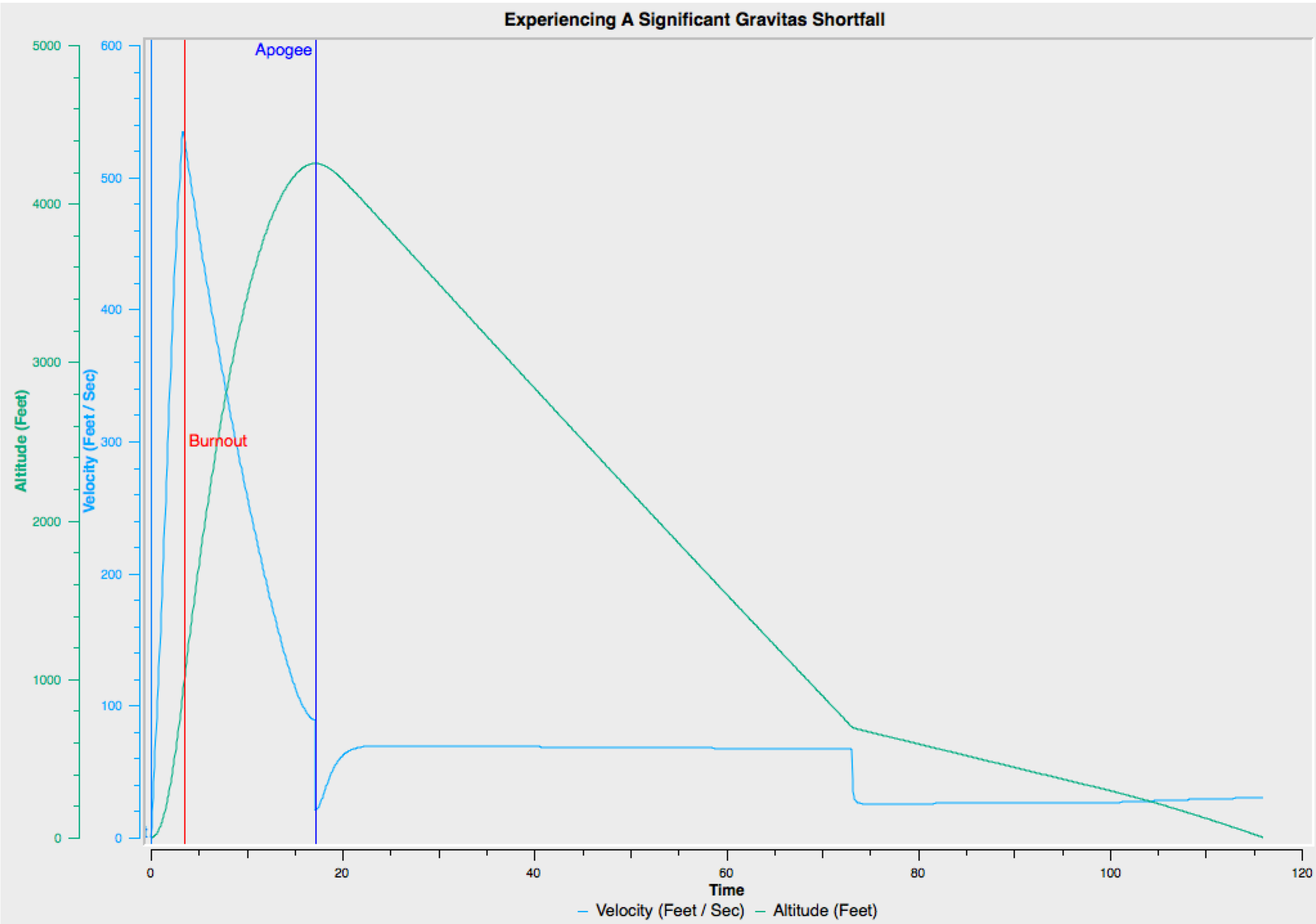


**Figure 2.** Flight simulation graph and a printout of the data (following page).

# Experiencing A Significant Gravitas Shortfall - Simulation results

## Engine selection

[M1560-WT-None]

## Simulation control parameters

- Flight resolution: 800.000000 samples/second
- Descent resolution: 1.000000 samples/second
- Method: Explicit Euler
- End the simulation when the rocket reaches the ground.

## Launch conditions

- Altitude: 100.00000 Ft.
- Relative humidity: 50.000 %
- Temperature: 85.000 Deg. F
- Pressure: 29.9139 In.

### Wind speed model: Custom speed range

- Low wind speed: 14.0000 MPH
- High wind speed: 14.9000 MPH

### Wind turbulence: Some variablility (0.04)

- Frequency: 0.040000 rad/second

- Wind starts at altitude: 0.00000 Ft.
- Launch guide angle: 0.000 Deg.
- Latitude: 0.000 Degrees

## Launch guide data:

- Launch guide length: 120.0000 In.
- Velocity at launch guide departure: 54.3386 ft/s
- The launch guide was cleared at : 0.395 Seconds
- User specified minimum velocity for stable flight: 43.9993 ft/s
- Minimum velocity for stable flight reached at: 80.5724 In.

## Max data values:

- Maximum acceleration:Vertical (y): 562.435 Ft./s/sHorizontal (x): 4.047 Ft./s/sMagnitude: 562.436 Ft./s/s
- Maximum velocity:Vertical (y): 518.9269 ft/s, Horizontal (x): 21.8533 ft/s, Magnitude: 530.8920 ft/s
- Maximum range from launch site: 1347.92628 Ft.
- Maximum altitude: 4214.25485 Ft.

## Recovery system data

- P: Parachute Deployed at : 72.264 Seconds
- Velocity at deployment: 67.3736 ft/s
- Altitude at deployment: 699.93224 Ft.
- Range at deployment: -199.71092 Ft.
- P: Drogue Chute Deployed at : 17.126 Seconds
- Velocity at deployment: 87.3103 ft/s
- Altitude at deployment: 4214.25485 Ft.
- Range at deployment: -1347.92628 Ft.

## Time data

- Time to burnout: 3.500 Sec.
- Time to apogee: 17.126 Sec.
- Optimal ejection delay: 13.626 Sec.

## Landing data

- Successful landing
- Time to landing: 114.194 Sec.
- Range at landing: 711.61189
- Velocity at landing: Vertical: -20.8503 ft/s , Horizontal: 21.7885 ft/s , Magnitude: 30.1575 ft/s

## Competition settings

Competition conditions are not in use for this simulation.

# *Novel/Unique Construction Features*

There are no novel or unique construction features.

# *Major Risk Items*

The major risk item is considered to be recovery. Risk will be mitigated through the following features:

1. Proven, fully redundant flight altimeters, ematches and 4F black powder charges (backups will be 150% of required charges as determined by ground testing)
2. Use of a single screw switch to connect and disconnect the battery from each altimeter stack.
3. A single stainless steel 1 3/8" in eyebolt for the main chute and nose cone attachment points. The deployment forces are low enough that the 800lb rating on the bolt should be more than enough. The ARRD pin will handle the bulk of the stress and is rated to 2000 lbs.
4. All quick links are 5/16" stainless steel (1950 lbs working strength)
5. All recovery harnesses are 7/16" tubular sewn Kevlar main harnesses (5300 lb breaking strength).
6. Use of (6) #8-32 screws backed with epoxied PEM nuts to connect the AV-Bay to the booster. Use of (3) #8-32 screws backed with epoxied PEM nuts to connect the Av-Bay to the Payload bay.
7. Use of (3) #4-40 shear pins for the recovery compartment to help ensure the nose cone does not separate from payload tube before the drogue deployment at apogee.
8. Use of a large main chute (15 ft Surplus Military from Always Ready Rocketry) deployed at 700' and designed to bring the empty rocket back at approximately 16 ft/sec (rocksim V9 calculation)
9. Use of proven ARRD method of dual deployment. The ARRD method of deployment minimizes the chances of tangles or un-inflated parachutes during deployment.

# 3 AIRFRAME DESIGN

The fin can will utilize the following conventional fiberglass construction techniques:

- All epoxy with follow proper preparation an application procedures. Mold release will be properly removed, part surfaces will be prepped properly, and gloves will be used to prevent body oils from affecting the joints. All epoxy will be weighed out to the proper ratios.
- There are no special reinforcing materials applied. Internal Fillets are constructed from US Composites 635 Epoxy with the Fast Hardener, 1/32in milled fiberglass, and 1/4in Chopped Fiberglass in the approximate volumetric proportions of 1:1:0.15.
- The internal fin fillets will be done by epoxy syringe injection.
- External Fillets are constructed from US Composites 635 Epoxy with the Fast Hardener and glass microballoons in the approximate volumetric proportions of 1:1. I look for the consistency of peanut butter. The microballoons help prevent sag and running of the fillets and create a smooth fillet surface.
- Three (3) T-Nuts will be epoxied into the back centering ring and will be used to secure the back of the thrust plate to the back of the airframe
- Due to the thrust plate, motor forces on the centering rings and fins are minimized or eliminated.
- The only hidden area is the space between the two forward centering rings, which has nothing in it.
- There are no frangible or breakaway components in the design.

The Avionics bay will utilize the following attachment and construction techniques:

- The avionics bay will be removable from both the sustainer and booster.
- It will have a 2" switch band to aid in the alignment of the rocket pieces during prep and facilitate the mounting of arming switches.
- It will be secured to the booster using six (6) #8-32 button cap screws attached to PEM nuts that have been epoxied into the coupler. The recovery forces will be transmitted through those screws.
- It will be secured to the payload bay using three (3) #8-32 button head cap screws attached to PEM nuts that have been epoxied into the coupler. These screws don't see any recovery forces so less are required in the design.

The nosecone will utilize the following attachment and construction techniques:

- The nosecone coupler will be secured by four (4) #8-32 button head cap screws attached to PEM nuts that have been epoxied into the coupler.
- The coupler will be removable should we desire to add weight or a payload to the large empty nosecone cavity (none are planned at this point)
- Four (4) #4-40 shear pins are employed for the nose cone (see recovery section for calculations).
- 1 3/8in Stainless Steel forged eyebolts are used for all harness attachment points.
- Four (4) 1/4-20 threaded rods are used to secure the AV bulkheads.
- 1515 rail buttons will be used attached to the airframe by ¼-20 bolts backed-up by an epoxied-in PEM nut

Fin flutter velocity was estimated using the equations in the Apogee Peak of Flight Newsletter 291. A fin flutter velocity of 1316 ft/sec was calculated. The estimated maximum speed on the certification flight is approximately 550 ft/sec so fin flutter is not expected to occur.

Figure 3 provides a list of the airframe materials.

### Nose cone - Custom, Material: G10 Spiral Wound Tube

- Nose shape: Hollow Sears-Haack series (L-V), Len: 45.3323 In., Dia: 8.0050 In. Wall thickness: 0.0825 In. Body insert: OD: 7.8115 In., Len: 0.0100 In.

### Nosecone Bulk Plate - Custom, Material: G10 fiberglass

- OD: 7.8115 In. , ID: 0.0000 In. , Len: 0.2500 In.

### NC coupler - Custom, Material: G10 Spiral Wound Tube

- OD: 7.8115 In. , ID: 7.5500 In. , Len: 11.0000 In.

### Payload tube - Custom, Material: G10 Spiral Wound Tube

- OD: 8.0050 In. , ID: 7.8150 In. , Len: 26.0000 In.

### Switch Band - Custom, Material: G10 Spiral Wound Tube

- OD: 8.0050 In. , ID: 7.8150 In. , Len: 2.0000 In.

### AV Bay Coupler - Custom, Material: G10 Spiral Wound Tube Coupler

- OD: 7.8115 In., ID: 7.5500 In., Len: 16.0000 In. Location: -7.0000 In. From the base of Switch Band

### Airframe Bulk Plate - Custom, Material: G10 fiberglass

- OD: 7.8115 In. , ID: 0.0000 In. , Len: 0.2500 In. Location: 9.1250 In. From the base of Switch Band

### Coupler Bulk Plate - Custom, Material: G10 fiberglass

- OD: 7.6115 In. , ID: 0.0000 In. , Len: 0.2500 In. Location: 8.8750 In. From the base of Switch Band

### Body tube - Custom, Material: G10 Spiral Wound Tube

- OD: 8.0050 In. , ID: 7.8150 In. , Len: 54.0000 In.

### Centering ring - Custom, Material: G10 fiberglass

- Centering ringOD: 7.8150 In., ID: 4.1050 In., Len: 0.1250 In. Location: 32.0000 In. From the base of Body tube

### 98mm MM - Custom, Material: G10 Spiral Wound Tube

- OD: 4.1050 In. , ID: 4.0000 In. , Len: 33.0000 In. Location: 0.0000 In. From the base of Body tube

### Centering ring - Custom, Material: G10 fiberglass

- Centering ringOD: 7.8150 In., ID: 4.1050 In., Len: 0.1250 In. Location: 23.0000 In. From the base of Body tube

### Fin set - Custom, Material: G10 fiberglass

- Planform: trapezoidal, Root chord: 21.5274 In., Tip chord: 8.2522 In., Semi-span: 8.9698 In., Sweep: 14.3544 In., Mid-Chord: 11.8324 In. Misc: Location: 1.0000 In. From the base of Body tube Thickness: 0.1875 In. Profile: square

### Centering ring - Custom, Material: G10 fiberglass

- Centering ringOD: 7.8150 In., ID: 4.1050 In., Len: 0.1250 In. Location: 0.7500 In. From the base of Body tube

### Aluminum Thrust Plate - Custom, Material: Aluminum 7075

- BulkheadOD: 8.0050 In., ID: 4.1000 In., Len: 0.3450 In. Location: -0.1750 In. From the base of Body tube

**Figure 3**. Airframe Materials List. Parts can be referenced to Figure 1 or 2.

# 4 RECOVERY SYSTEMS DESIGN AND OPERATION

Figures 4 through 8 shows the basic recovery system components and function in cutaway picture form. Note that the payload airframe is not shown and the rest of the rocket below the recovery plate is hidden from view. Also note these pictures are to illustrate the general concept of the recovery system and may not be an accurate representation of the final design.

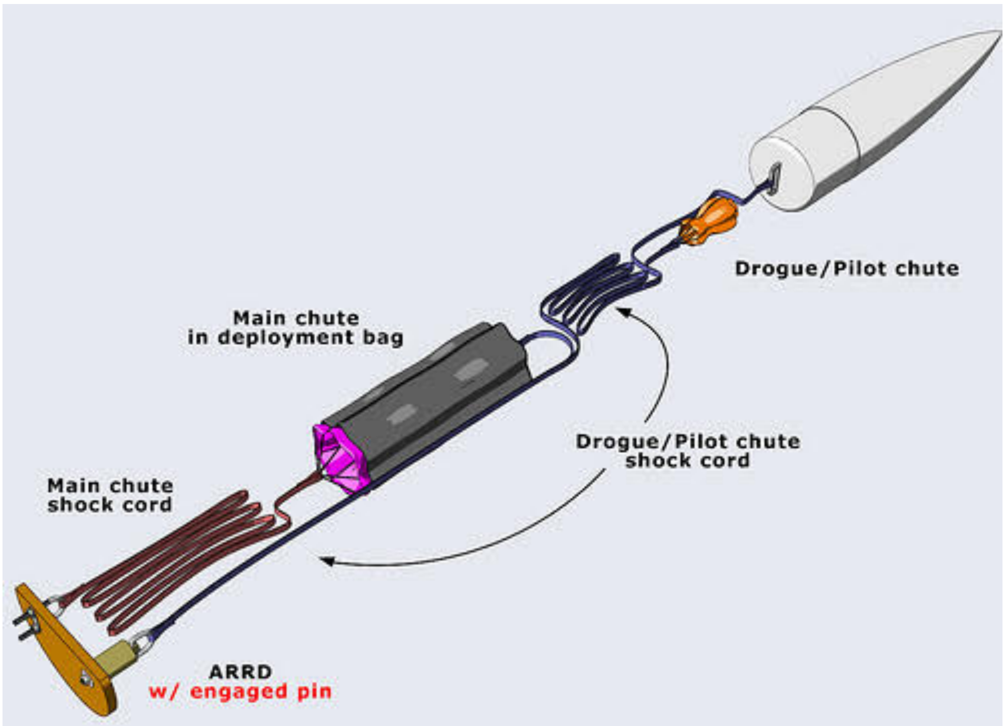


**Figure 4.** Recovery systems package overview. The main shock cord is packed against the av-bay bulkhead. The main chute is packed in a deployment bag and that going in next. A 36in drogue chute is burrito wrapped in nomex cloth and attached 7ft down from a 35ft long 7/16in tubular Kevlar harness. The end of the harness is connected to the ARRD pin and the top of the main deployment bag. The main chute is attached to the end of a 10ft long 7/16in tubular Kevlar harness. The Kevlar harnesses are attached via 5/16in stainless steel quick links to 1 3/8in stainless steel eye bolts on the av-bay bulkhead and main bulkhead.

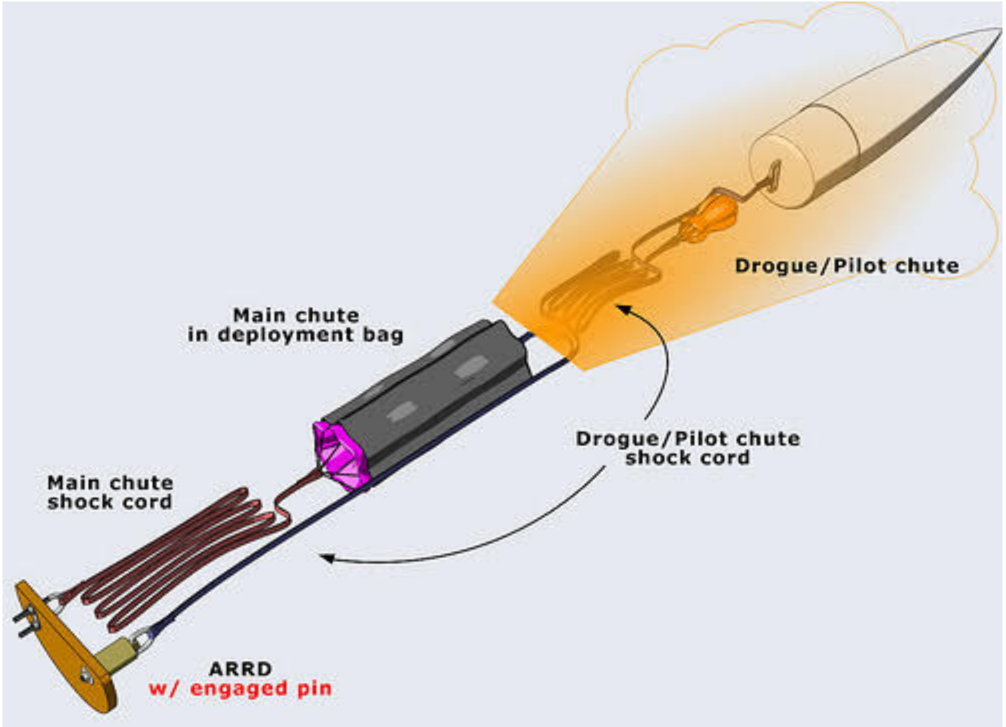


**Figure 5.** At apogee a black powder charge will separate the nosecone from from the payload tube/AV bay. The charge tubes run along the side of the payload bay and exhaust the charge ahead of the main chute bag. The nosecone is held in place with (3) #4-40 shear pins to prevent premature deployment.

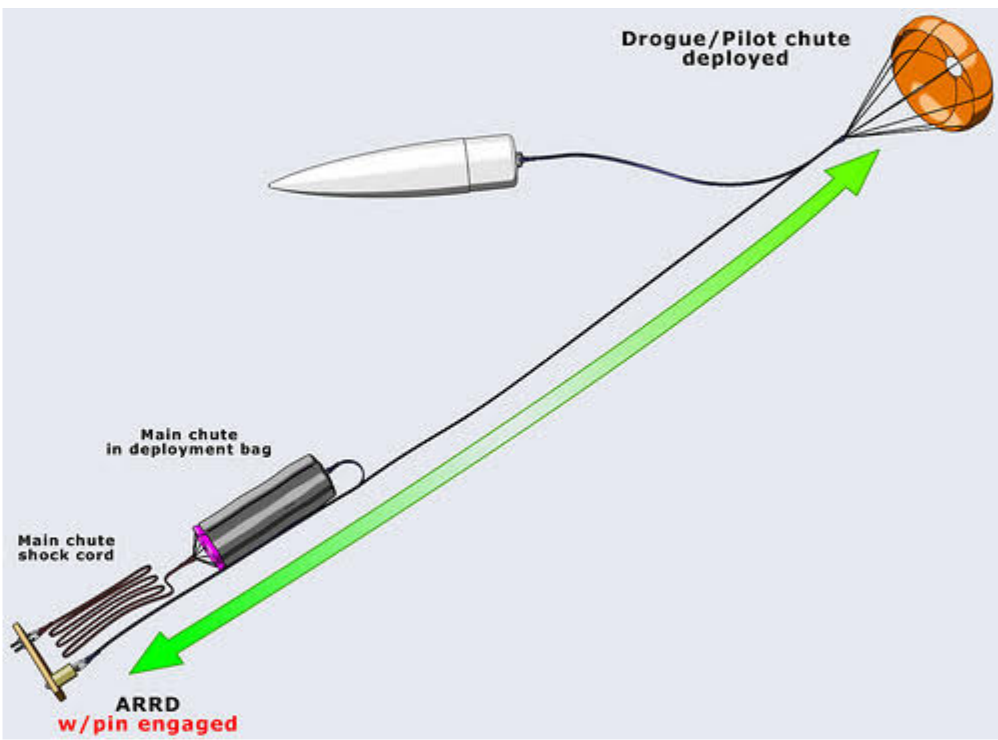


**Figure 6.** The two halves of the rocket will fall at an estimated 60 ft/sec until the barometric altimeter senses 700 ft AGL. The ARRD still has the pin engaged at this time which keeps the drogue from pulling the main out and also keeps the rocket together.

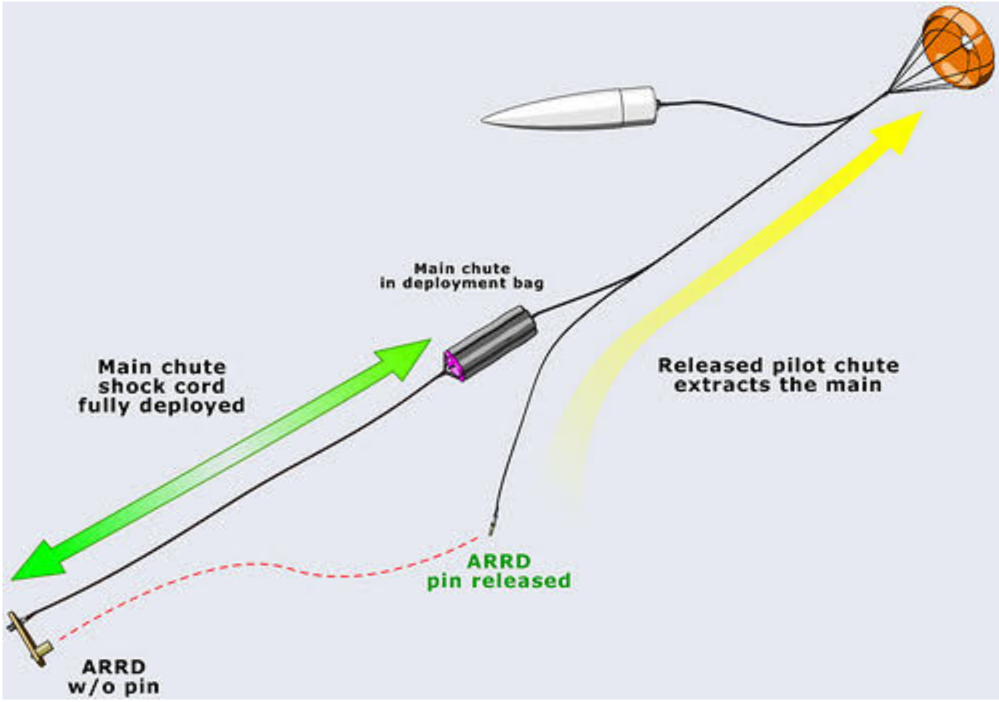


**Figure 7.** At 700ft the altimeter fire an ematch in the base of the ARRD. That ematch ignites a small Pyrodex charge that drives a piston forward which releases the ARRD pin. The drogue chute will pull the 15ft chute in the deployment bag out of the body.

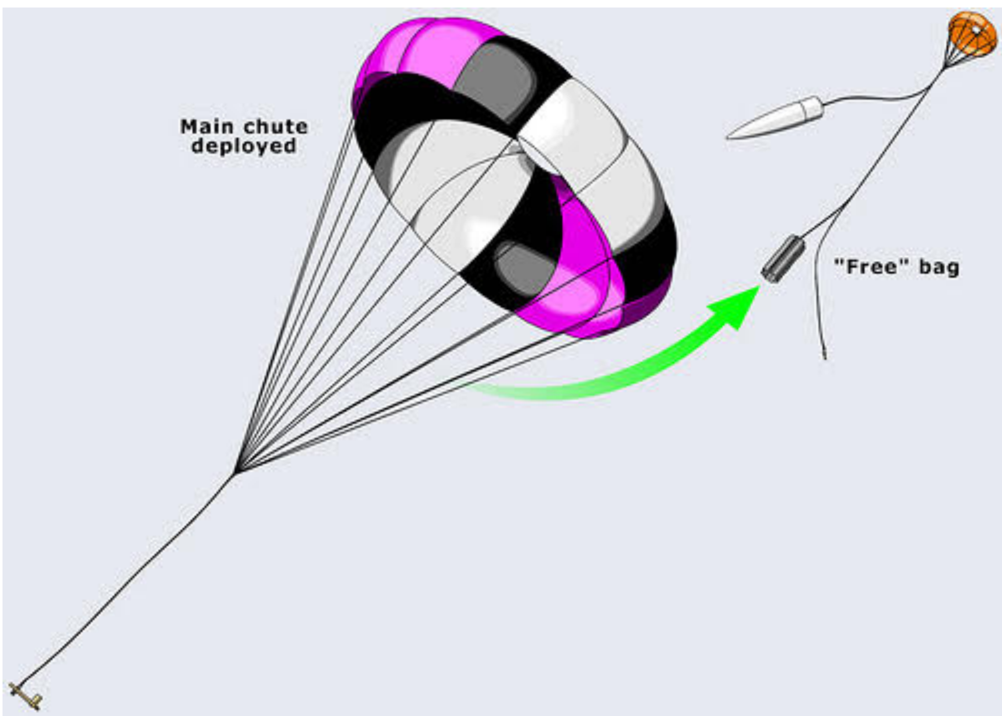


**Figure 8.** The drogue chute continues to pull the deployment bag off of the main chute. The deployment bag allows for a quick gentle deployment. After deployment of the main chute the booster portion rocket should descend as approximately 16 ft/sec (estimated usinig manufacturer's data and Rocksim analysis). The nosecone will descend separately under drogue chute at approximately 20 ft/sec (estimated usinig manufacturer's data and Rocksim analysis).

A few notes about recovery design:

- Three (3) #4-40 shear pins are used to attach the nosecone to the payload tube. Shear pins are used to minimize the chance of premature nose cone separation. No friction fitting is used.
- The Avionics bay and nose cone bulkheads are 1/4in G10 fiberglass.
- Protection from hot ejection gas and particles will be provided via a Nomex deployment bag and blankets. The drogue chute will be burrito wrapped in a 24in blanket. The main chute will be packed in a 7.5in x 16in Nomex deployment bag.
- Four (4) vent holes sized 3/8in are drilled in the AV bay to provide venting for the barometric altimeter units to function correctly. These values were derived assuming a 8" diameter, 18" long payload bay.
- Two (2) 3/16" vent holes are drilled in both the body and payload tube for cavity venting (four holes total). Assuming an equivalent hole diameter of 0.265" shows that the peak pressure differential during the flight can be held back by a single #4-40 shear pin (~40lbs). Thus, the choice of three #4-40 pins, respectively, will be more than sufficient to ensure that pressure difference will not cause premature separation of the rocket components. The pressure differential separation force for the body tube is plotted in Figure 9. For the simulated M1560 flight the burnout deceleration is less than 1G and projected drag separation forces are minimal. Three shear pins will easily restrain the largest anticipated pressure drop from a 6 XL grain 98mm motor (e.g. O3400).

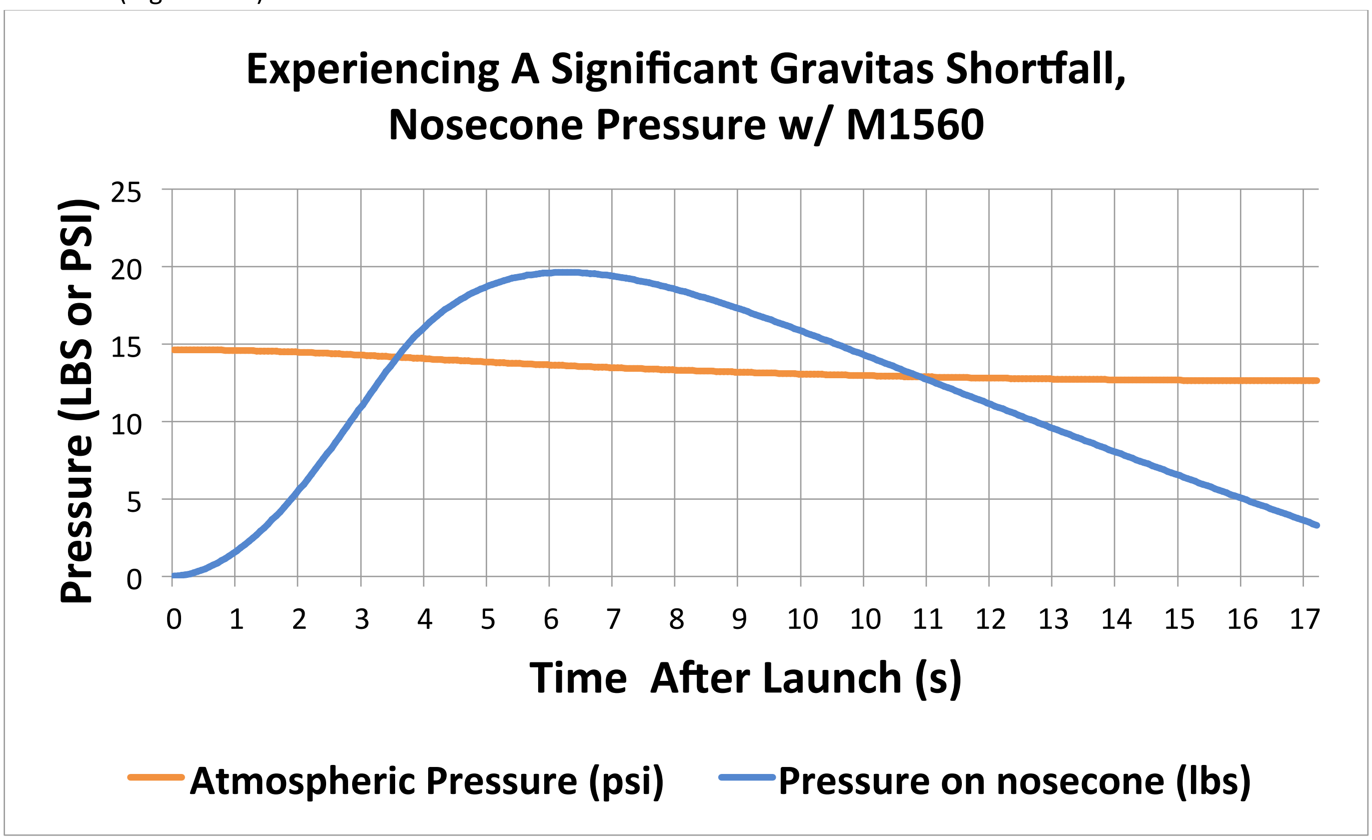


**Figure 9.** External pressure (blue line) and internal pressure separation force (orange line) for the body tube if the net vent hole is 0.265" (equivalent to two 3/16" vent holes). Maximum pressure differential induced force is less than can be held by a single #4-40 nylon shear pin (~40 lbs).

- The main chute was chosen to provide an approximately 16 ft/sec descent rate. According to the manufacturer, a surplus 15 ft. parachute will provide the appropriate descent rate for the projected empty mass of 56 lbs (after burnout minus nosecone).
- The drogue chute was chosen to provide an approximately 20 ft/sec descent rate when bringing down the nosecone and a 60 ft/sec descent rate to bring down the main rocket. According to the manufacturer, a Fruity Chutes 42in classic elliptical parachute will provide the appropriate descent rate for the projected mass of 56 lbs on the drogue portion of the flight and 8 lbs for the nosecone on freebag recovery.

# 5 AVIONICS DESIGN

Overview:

- There are two (2) fully redundant sub-systems
- The primary altimeter will be a Perfectflite Stratologger CF. The Stratologger CF is a barometric dual deployment altimeter that combines a pressure and temperature sensor to determine when the rocket has passed apogee, and when a pre-set altitude has been reached on descent (using a standard model for atmospheric pressure and temperature).
- The secondary altimeter will be an Eggtimer TRS. The TRS is a barometric dual deployment altimeter that combines a pressure and temperature sensor to determine when the rocket has passed apogee, and when a pre-set altitude has been reached on descent (using a standard model for atmospheric pressure and temperature). It also functions as a tracker. The altimeter will relay GPS coordinates and status of recovery channel deployment to a handheld receiver on the ground.
- The primary altimeter will be set to fire the drogue at apogee and the main at 700ft.
- The backup altimeter will be set to delay firing at apogee by 1 second and to fire the main at 500'.
- I have used these backup altimeter settings (+1 sec at apogee and 200 ft differential for mains) on many flights with these altimeters without issue.
- The ematch leads will pass through the bulkhead and the hole will be sealed with a well nut. The ematch leads will connect directly to the altimeter leads.
- 2S 180mah LiPo batteries will be used to power the altimeters and ignite the ematches.
- The drogue charge wells for the brass powder charges will be brass tubing.

Figures 10 and 11 illustrate the schematic for the principal components of the electronic deployment.

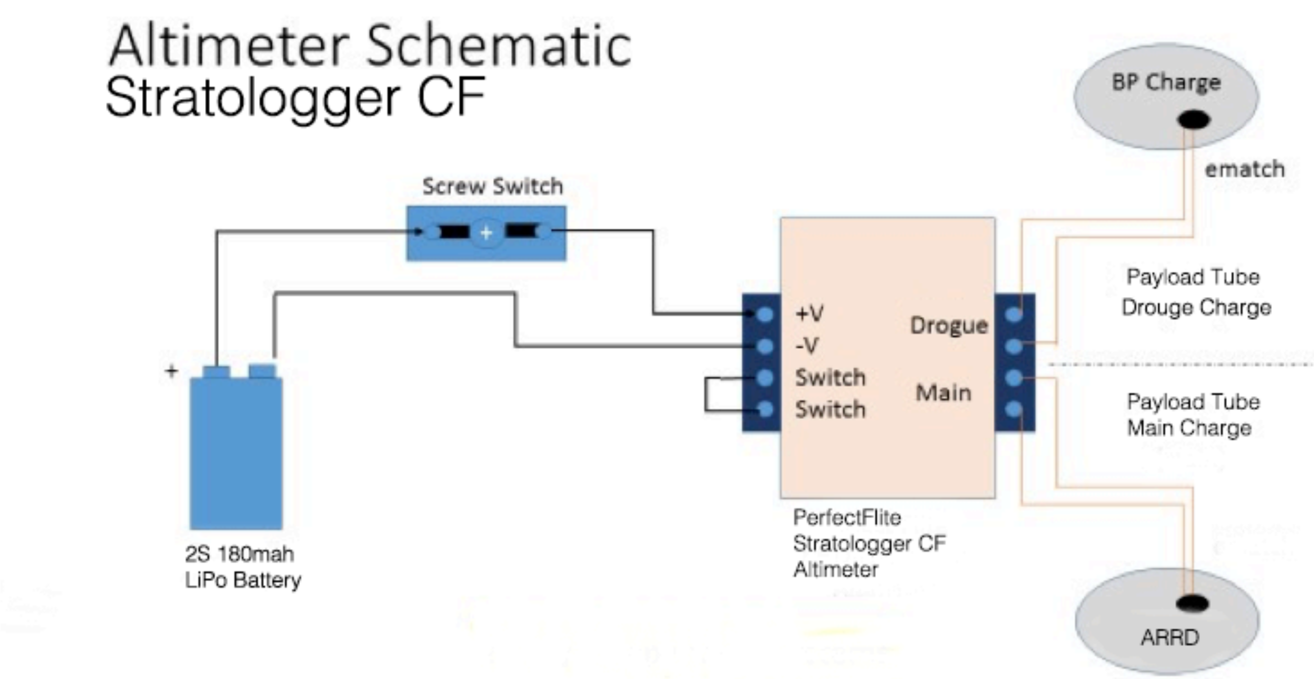

**Figure 10.** Schematic of dual deployment Stratologger CF electronics proposed for Level 3 Flight. Battery current runs directly through the switch so turning off the switch disarms the pyro devices.

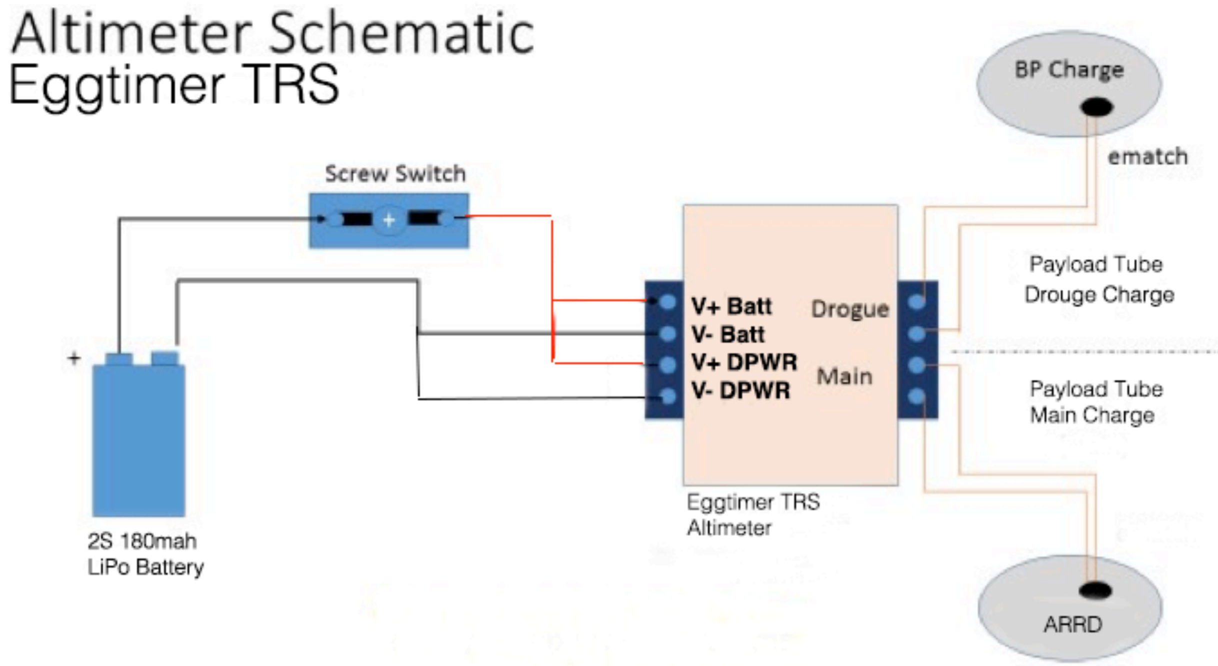


**Figure 11.** Schematic of dual deployment Eggtimer TRS electronics proposed for Level 3 Flight. Battery current runs directly through the switch so turning off the switch disarms the pyro devices.

As shown in Figures 10 and 11, a screw switch is used in series with the battery to disconnect current from the altimeter. When the screw switch is disconnected, no current can flow through the ematches. Components on the avionics sled are mounted using #4-40 steel screws. The batteries are secured through a custom CNC machined holder mounted on the AV to ensure the batteries do not become dislodged in flight or during recovery.

# 6 ROCKET CONSTRUCTION

***To Be completed as rocket is assembled***

# 7 GROUND TESTING

Overview:

- Generic brand ematches will be used.
- One ematch will be used for the primary and secondary drogue charges.
- One ematch will be used for the primary and secondary ARRD charges.
- The starting point for ejection charge testing will be 3.5 grams of 4F black powder for the drogue charges. This is based on breaking 50% more #4-40 nylon shear pins than actually used. This quantity was determined using the equations presented by Vern Knowles, and the shear pin strength published in rocketry online (archival page from the internet). Actual charges will be adjusted based on ground tests. Back-up charges will be 125% of the main charge.

Ground Test Result Details and Pictures

# 8 CHECKLISTS

**See supplemental document “Checklists – Experiencing a Significant Gravitas Shortfall” for all related prep and launch checklists.**

# 9 FLIGHT AND POST FLIGHT RESULTS

To be completed after the flight.