Pegasus II

Tripoli Level 3 Project Documentation

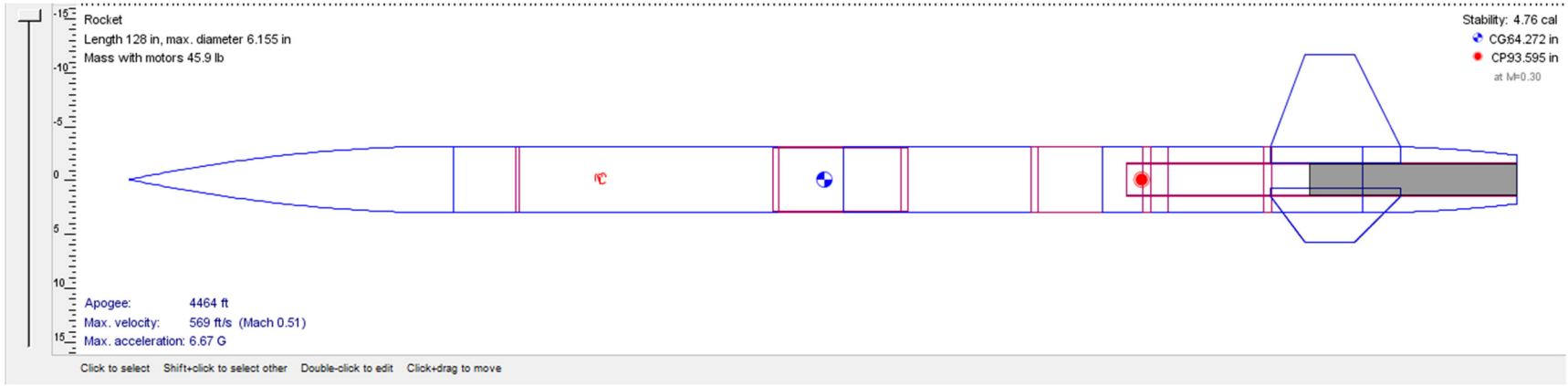
Brian Wheeler

Contents:

A. Design Overview

Pegasus II is a 38lb, 6” diameter rocket constructed with filament wound fiberglass components from Rocketry Warehouse. It will generally achieve around 8,000 ft on M motors and 5,000 ft on L motors. The test flight and Level 3 certification flight will take place at Washington Aerospace Club’s Fire in the Sky launch on May 28 + 29, 2016

The rocket’s center of pressure is calculated to be 34.4” from the base. This is marked with a small hole in between the booster’s rail buttons to confirm stability before flight.

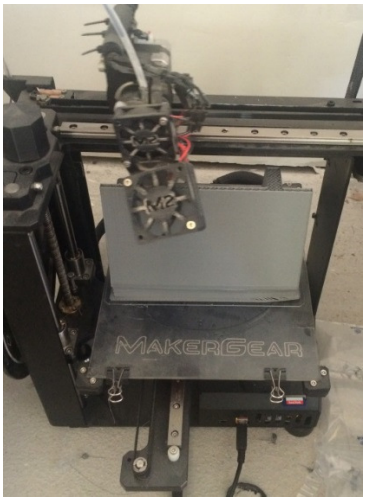

Rocket
Length 128 in, max. diameter 6.155 in
Mass with motors 45.9 lb
Stability: 4.76 cal
CG64.272 in
CP93.595 in
at M=0.30
Apogee: 4464 ft
Max. velocity: 569 ft/s (Mach 0.51)
Max. acceleration: 6.67 G
Click to select
Shift+click to select other
Double-click to edit
Click+drag to move

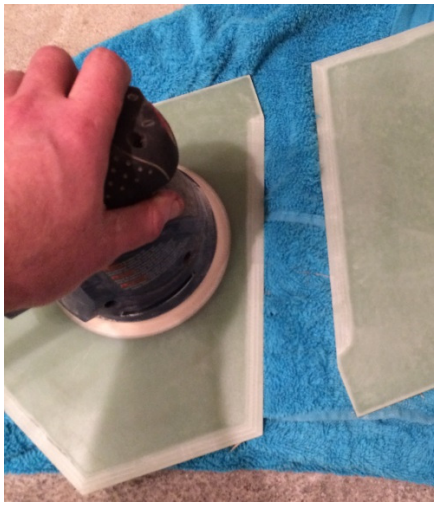
B. Booster Construction

Three 0.1875” fin slots were cut through the body tube and tail cone using a router on a plate with 4 cam rollers.

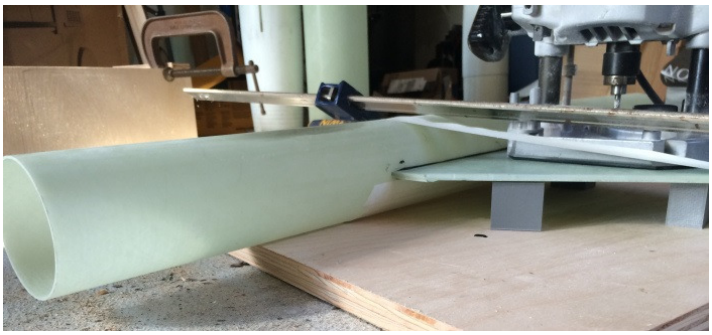
Fins were first rough cut from 0.1875″ G10 fiberglass, then trimmed straight using a router with a straight-cutting jig and a composite cutting bit

Using a 3D printer, a jig was created to bevel the fins at 10 degrees while leaving 0.100″ thickness at the tips. This Jig was clamped onto the router base, and each fin was moved by hand against the router to create the bevel. The fins and the motor tube were then sanded to create a rough surface for epoxy adhesion.



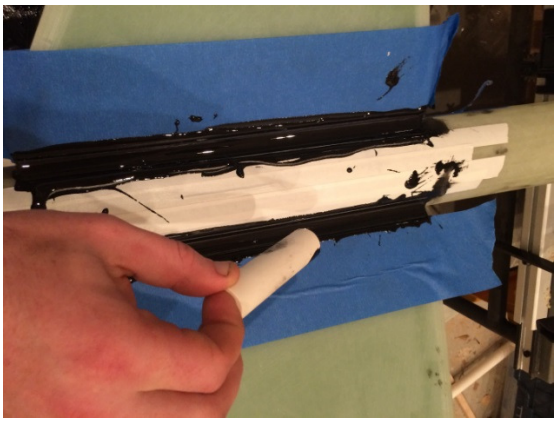


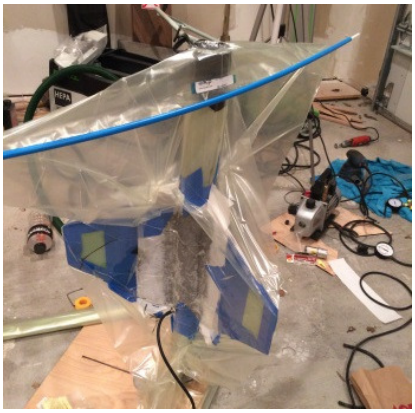
To attach the first fin, 3 blocks were 3D printed to present the fin at precisely the correct elevation relative to the motor tube. High temperature Proline 4500 epoxy was used for fin tacking and fillets. For the remaining 2 fins, two alignment guides were used, cut with a laser cutter from thin plywood.



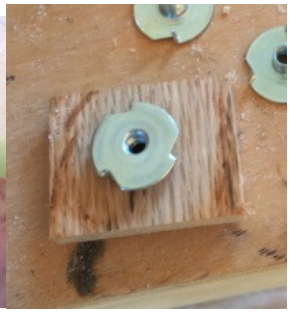
Proline 4500 epoxy fillets were created using a 1″ diameter PVC section. To apply masking tape for the excess epoxy, permanent marker was applied repeatedly to the PVC and rubbed along the joint to create a mark at the edge of the desired fillet. Tape was then applied at this line

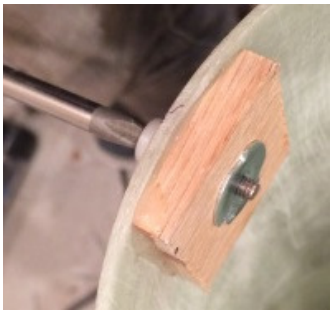
Around 20 minutes after each fillet was created, the masking tape was removed. 3 layers of 5.7 oz 2×2 twill carbon fiber was then applied using Aeropoxy to the fin joint area. This will ensure the fin tabs remain attached to the motor tube.



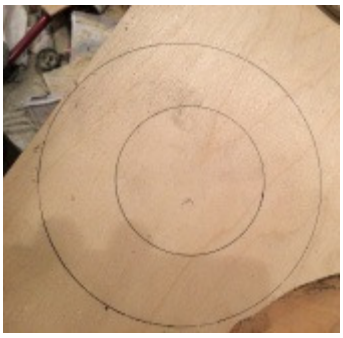



Rail Button mounts were created using oak with a 3 pronged #8x32 threaded insert which is mechanically prevented from escaping. Grease was applied to the rail button and machine screw, epoxy was spread over the rail button support piece, and then the rail button was screwed into place, forcing the support against the airframe ID. These three 1010 buttons are spaced at 2 ft intervals starting at 15” from the base of the rocket.



Centering rings were made out of 7-ply plywood. These were rough cut with a scroll saw, then trimmed to size using an aluminum template with a router and a flush-trim bit. A bulkhead was created with a 5/16” U-bolt to connect to the recovery harness and to provide motor retention via an aluminum threaded rod connected to the forward closure.




A thrust plate was machined from 7075 aluminum to transfer the motor’s thrust to both the motor tube and the tail cone simultaneously. Grooves were cut to ensure mechanical bond, then the plate was

attached to the motor tube and the tail cone with ProLine 4500 Epoxy. The motor is retained using a 3/8” Aluminum threaded rod that connects the forward closure to the bulkhead at the top of the booster.



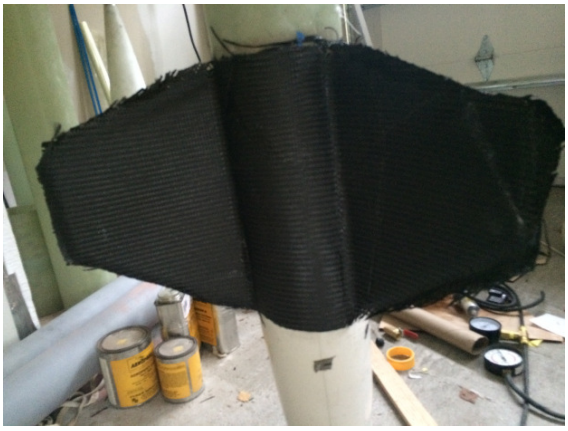


Once the rail button mounts and centering rings were installed, the fin can assembly, airframe, and tail cone were epoxied together. Then external fillets were created.



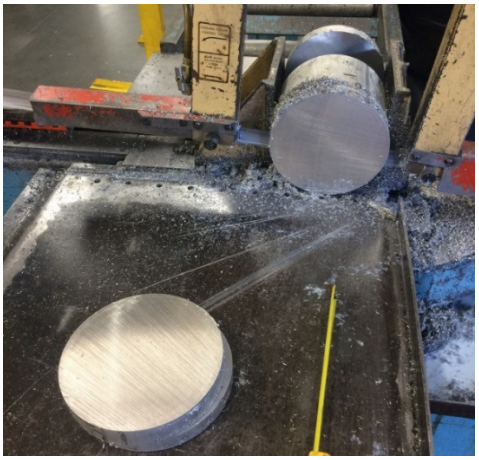
Two layers of 2×2 carbon were laid tip to tip on the fins, and the setup was vacuum bagged.

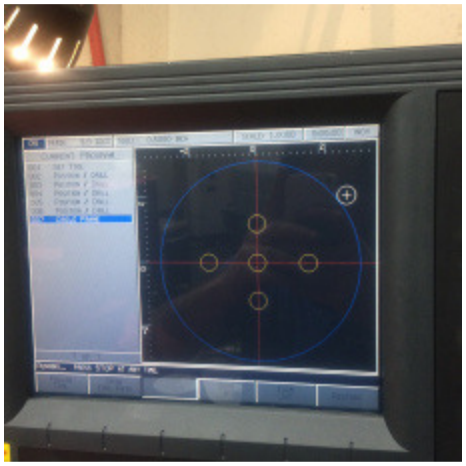
The final construction step for the booster was to coat the carbon with Aeropoxy Light and sand.



C. Electronics Bay (Mechanical) Construction

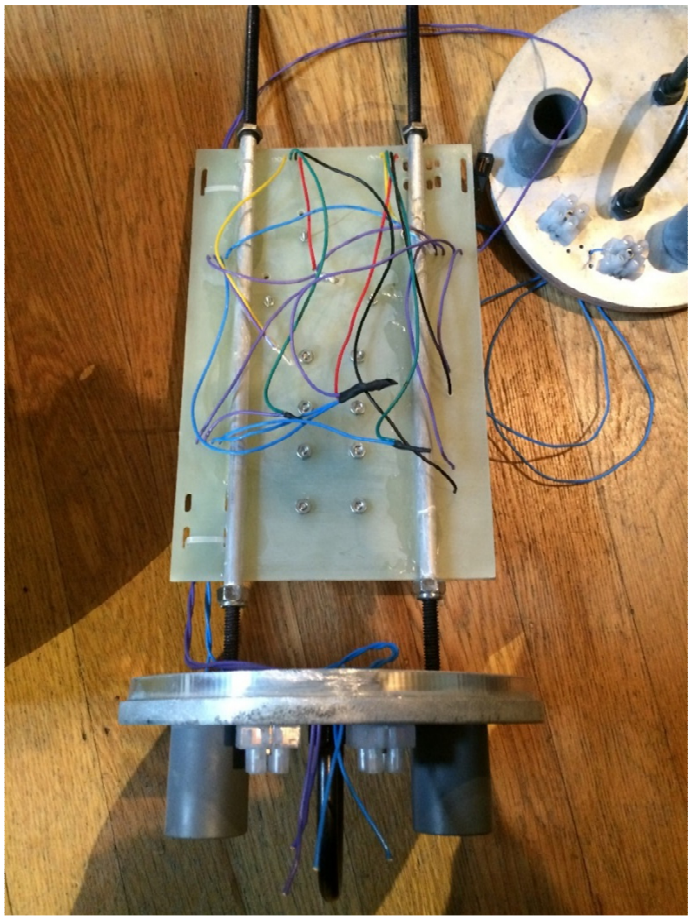
The electronics bay bulkheads are milled from 6061 Aluminum. They are 0.3″ thick, with an additional 0.3″ thick shoulder to center the bulkhead in the coupler. A 1/16″ Thick, 5.875” Diameter O-ring seals the joint between the end of the coupler tube and the bulkhead.





A switch band was epoxied in the center of the coupler which houses the electronics bay. Three ¼” vent holes were drilled around the ring, and two holes were drilled for the Missileworks switches. An additional hole was drilled for the 3rd rail button.

Running the length of the electronics bay are two ¼”x20, 13” long high strength steel threaded rods, which hold the two bulkheads together and act as rails for the electronics sled. The electronics sled is created with a 0.125″ thick G10 fiberglass sheet, with thin walled aluminum tubing that slides over the threaded rods.

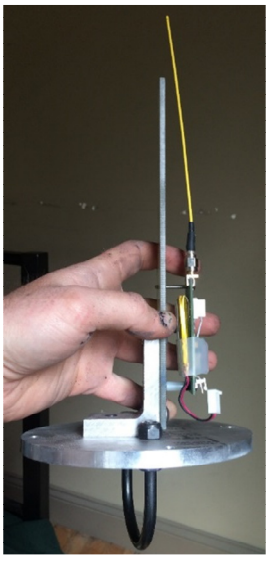


5/16” x 2” U-Bolts are attached with nylon insert nuts and o-rings to create a seal. Doghouse rocketry charge wells were attached to each bulkhead, as well as 2 pairs of screw terminals for attaching the electric matches.

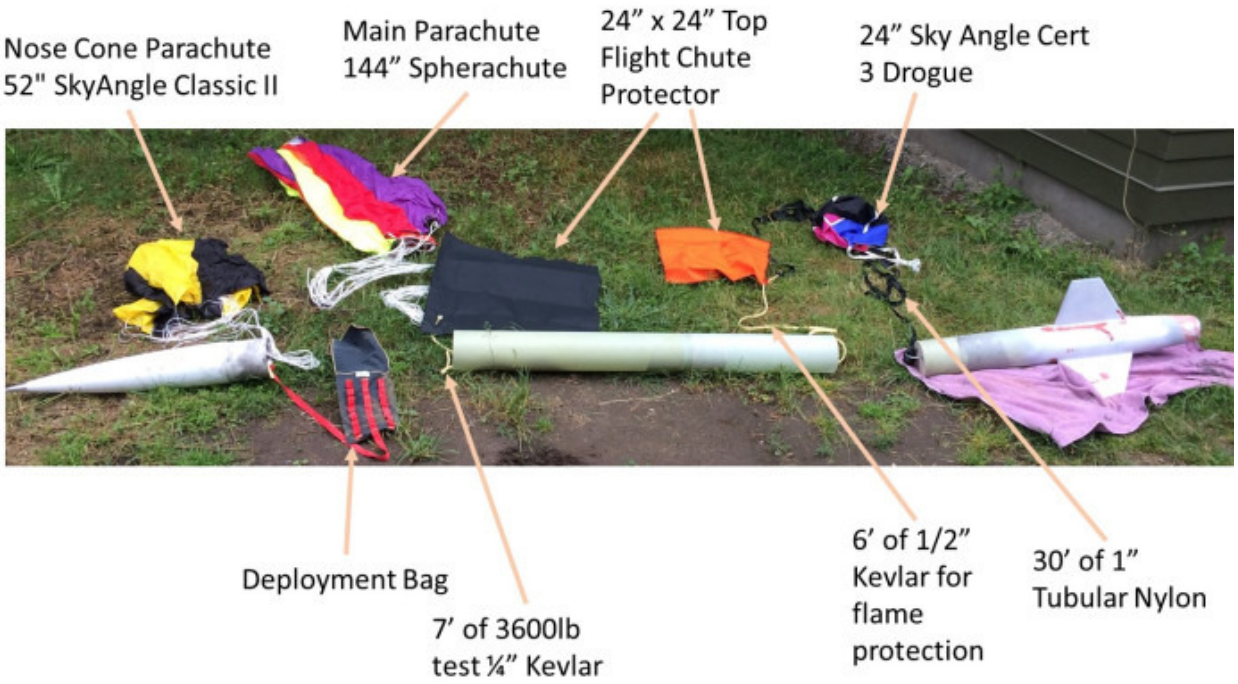
D. Nose Cone Construction

The Nose Cone is a Rocketry Warehouse 6″ filament wound cone. The shoulder was attached using Aeropoxy Structural Adhesive

A ring was machined with 4 x 1/4-20 mounting holes to mount the bulkplate, which attaches to the recovery harness. This ring was epoxied in place using Proline epoxy after cutting grooves into the exterior aluminum surface for adhesion. On the bulkhead, an L-bracket was machined to connect a small fiberglass board which holds the GPS transmitter



E. Recovery System Components



1. **Drogue Chute Configuration**
    1. Based on the failure of the first certification attempt, the drogue in subsequent flights will be placed 1/3 of the way along the shock chord from the upper section to the booster. This should keep the two sections relatively horizontal, and at worst should keep the upper section above the booster, reducing the chance for the main to tangle when it deploys from the upper section of the rocket.
    2. The Drogue Parachute is a SkyAngle 24" L3 Drogue
    3. The forward and aft rocket sections are held together with 6 ft. of 1/2 " tubular Kevlar for flame protection, and then 30 ft of 1" tubular nylon. The nylon was chosen because it can stretch slightly during an energetic deployment, allowing a longer deceleration for the rocket components. A 24″x24″ flame protector protects the drogue.
2. **Main Chute Configuration**
    1. The main parachute for the rocket (minus the nose cone) is a 144" Spherachute, which is rated for 30 to 54 lbs. This parachute will be stored in a deployment bag. This parachute is attached to the rocket with 6 ft. of 1/4" tubular Kevlar.Descent rate of the 32 lb airframe is 15 ft/s
    2. The Nose Cone has its own 52″ SkyAngle Classic II which will pull the nose cone and deployment bag away from the rocket's main parachute. Descent rate of the 6.2 lb nose is 15 ft/s
3. **Black Powder Charges**

    Based on online calculators, the ejection charges were estimated and then tested. The charges will be 4 grams for the drogue (with a 5 gram backup at a 1 second delay) and 6 grams for the main (with a 6 gram backup 100 feet delayed)

4. **Shear Pins**

   Three #4x40 shear pins are used to secure the booster and nose cone to the central section.

5. **Rivets**

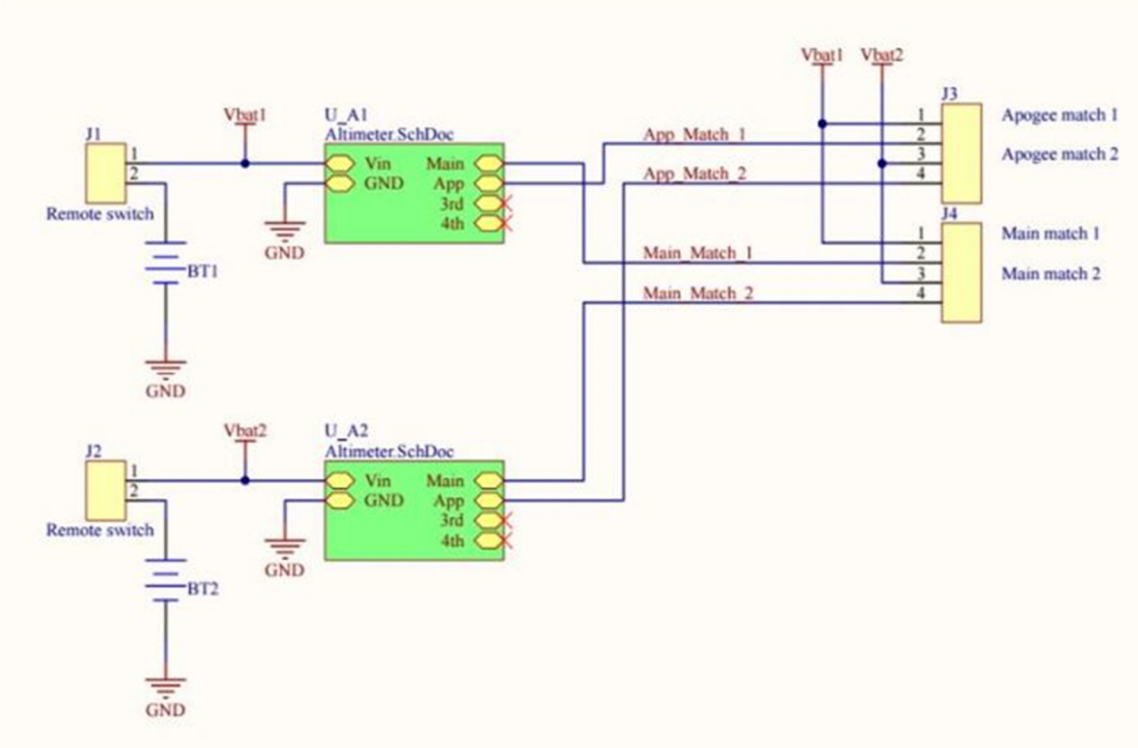
   Six 0.242” diameter click-lock shank rivets are used to secure the two middle airframe sections to the electronics bay for the duration of the flight. These are designed to be several times stronger than the shear pins. This setup functioned successfully during testing.

Making a black powder ejection charge with an e-match, tape, and cling wrap.

Testing the charges (video at wheelerl3.wordpress.com)

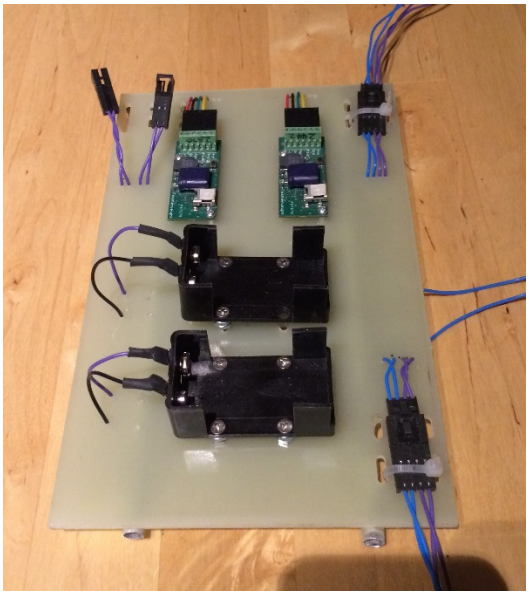
F. Electronics (Electrical)

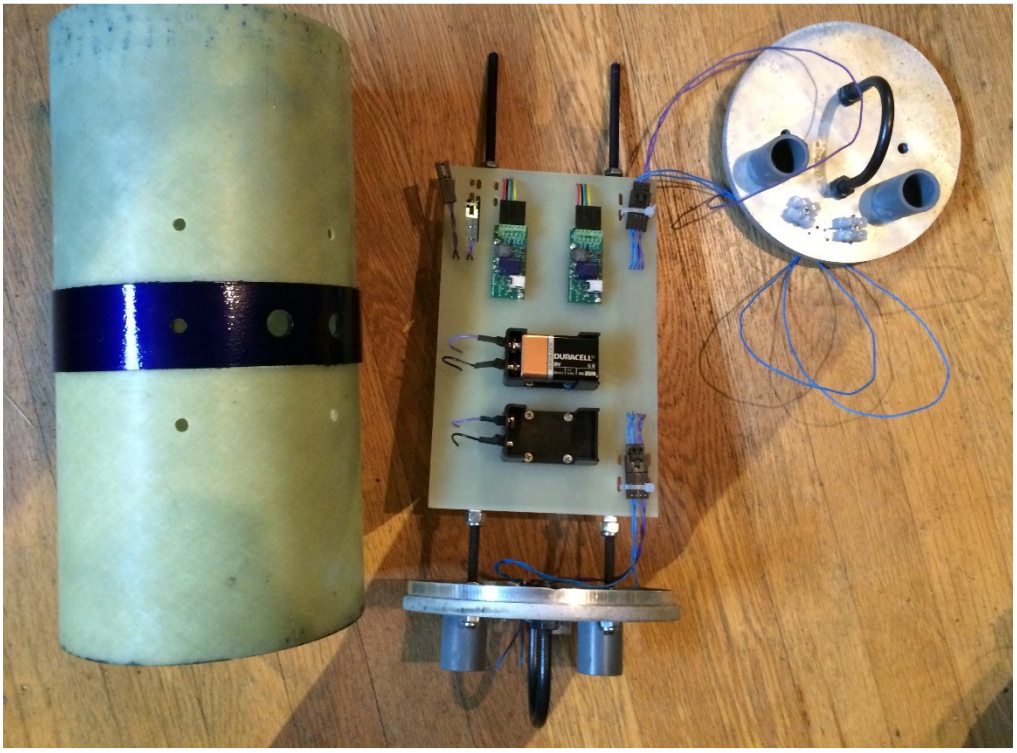
The rocket's electronics consist of redundant Raven Accelerometers/Altimeters each powered by a 9V battery. Doghouse Rocketry wire connectors are used to connect the sled to the bulkheads and the two Missileworks rotary switches. All 4 charges are activated with "General Electric ignitors" from Amazon, which have been tested in the flight configuration. A schematic is shown below:

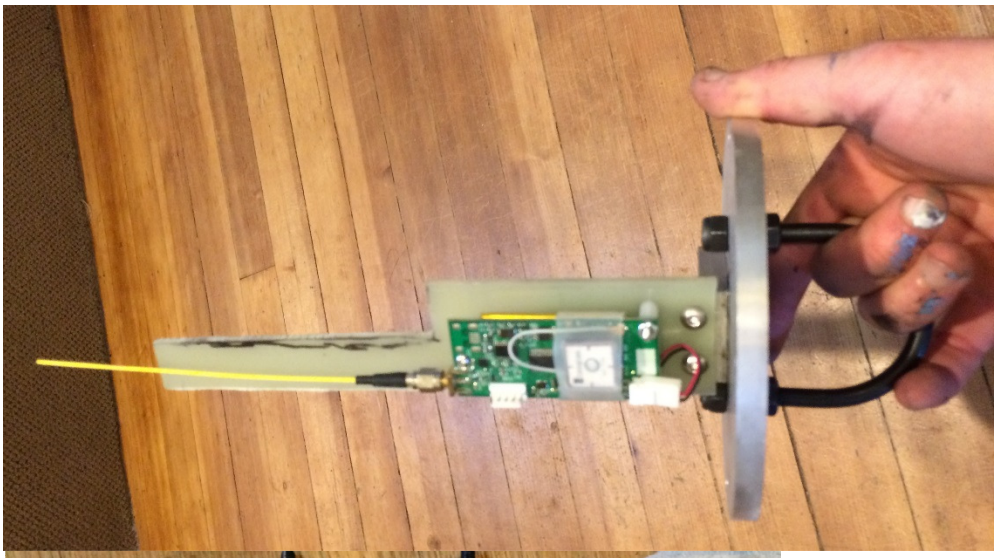


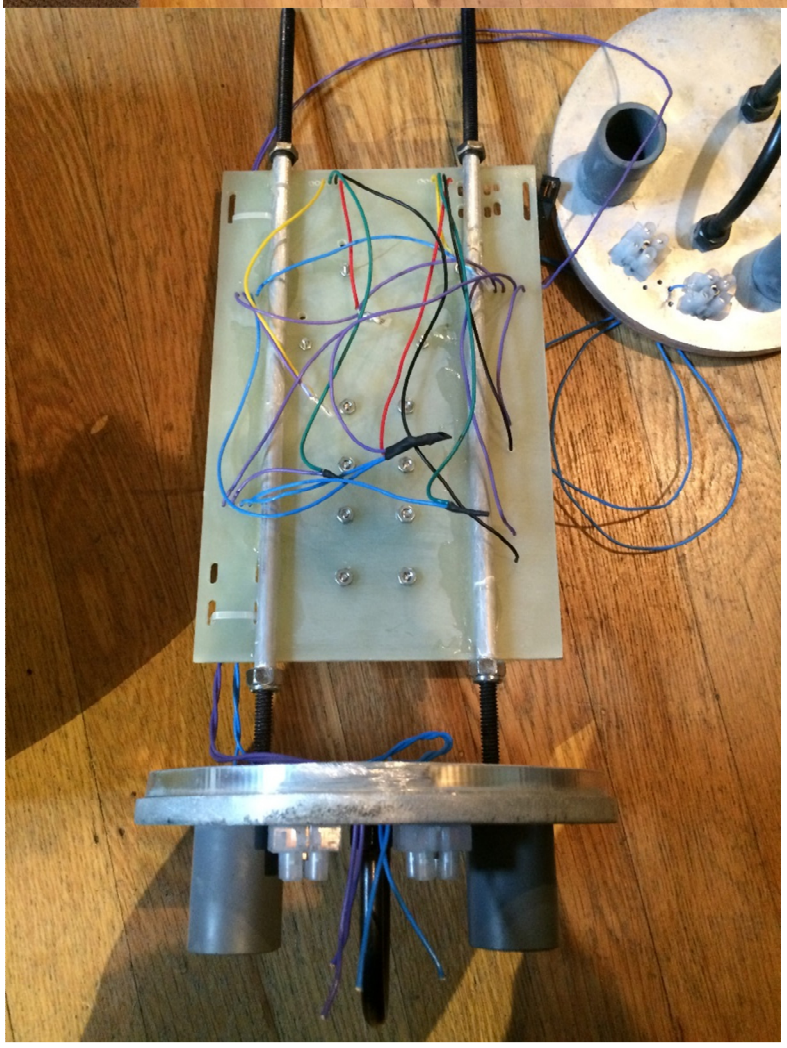
All wire connections were soldered and then covered in heat shrink using a heat gun. All electrical connectors are latching and are cable tied to the board before launch. A fresh 9V battery will be used for each flight. Screw terminals are used to connect the electric matches to the system on the face of the bulkhead.

A Big Red Bee 70cm GPS tracking unit is housed by itself in the nose cone, and is simply plugged into its onboard power supply before flight



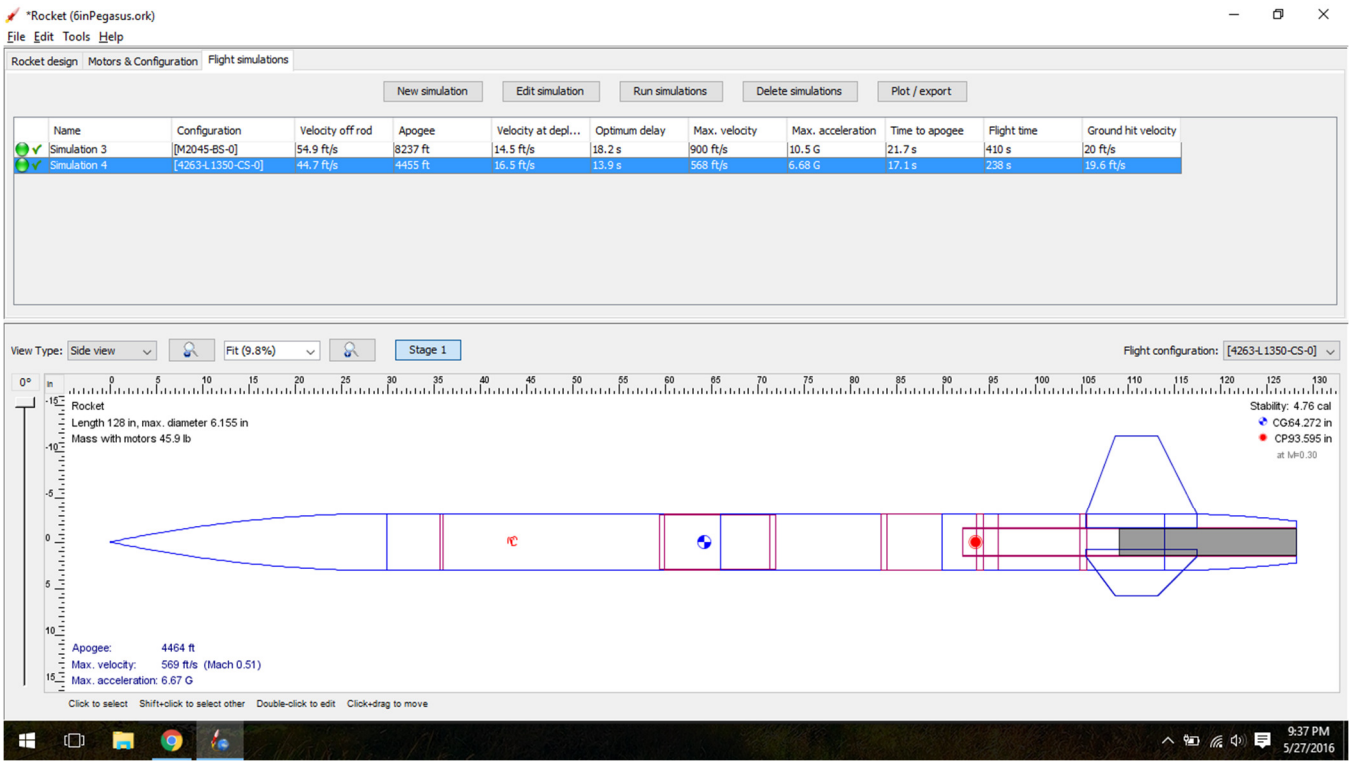

DURACELL





G. Simulation

Flight simulations were run with the two flight motors, a CTI Pro75 L1350 for the test flight, and a CTI Pro75 M2045 for the certification flight. The actual measured weight of 38 lb, and the measured empty CG of 53” from the rocket’s base are used for the simulation. The rod length is set to be 96” – 38.4” = 57.6”, which is the length of the rod remaining above the central rail button. The simulation results are listed in the table below



	L1350	M2045
Velocity of Rail	44.7 ft/s	54.9 ft/s
Apogee	4455 ft	8237 ft
Max Velocity	568 ft/s	900 ft/s
Max Accel	6.68 G	10.5G

H. Parts List

	Part No	Qty	Description	Vendor
A. Booster				
	A1	1	24" Long 6" G12 airframe	Rocketry Warehouse
	A2	1	12" long 6" G12 Coupler	Rocketry Warehouse
	A3	1	6" Nose Cone cut to 14.25" Length and slotted for 3 fins to create a 6" to 4.2" Tail Cone	Public Missiles / Custom Slots
	A4	1	Aluminum 4.1" to 3" thrust plate	Custom
	A5	1	7 ply, 3/8" thick 3" to 6" Birch Centering Ring	Custom
	A6	1	7 ply, 3/8" Thick 3" to 6" Coupler Birch Centering Ring	Custom
	A7	1	14 ply, 3/4" Thick 6" Coupler Bulkplate with 1/2" hole for motor retention and drilled for U-Bolt	Custom
	A8	1	5/16" Diam by 2" ID Black Oxide U-Bolt rated at 600 lb, secured with nylon insert nuts permanently attached with JB-Weld	ACE Hardware
	A9	3	Fins cut from 0.1875" G12 12"x12" blanks	Custom
			Composites	
	A10		3 layers 5.7 oz Carbon from fin root to fin root across motor mount tube	US Composites
	A11		1 Layer of 10 oz Carbon from fin tip to fin tip	US Composites
	A12		1 Layer 5.7 oz carbon from fin tip to fin tip	US Composites
			Rail Buttons	
	A13	2	#8 x 32, 1" Long Flat head machine screw	Doghouse Rocketry
	A14	2	1010 delrin rail buttons	Doghouse Rocketry
	A15	2	#8 x 32 three pronged wooden threaded insert	ACE hardware
	A16	2	Pine carriers for rail button threads	Custom
			Motor Retention	
	A17	1	3/8" x 16 Aluminum threaded rod, 25" L or 10" L depending on motor	McMaster
	A18	1	3/8" x 16 Hex Nut	McMaster
B. Middle Section				
	B1	1	24" Long 6" G12 airframe	Rocketry Warehouse
	B2	1	36" Long 6" G12 airfram	Rocketry Warehouse
	B3	1	12" Long 6" G12 coupler	Rocketry Warehouse

	B4	1	1.5" Long 6" Switch Band	Rocketry Warehouse
			E-Bay Bulkhead Assy	
	B5	2	Electronics Bay Bulkhead - Aluminum Milled Part	Custom
	B6	2	5/16" Diam by 2" ID Black Oxide U-Bolt rated at 600 lb, secured with nylon insert nuts	McMaster
	B7	2	Large Charge Wells	Doghouse Rocketry
	B8		#10x24 Flat head socket cap screw	Mcmaster
	B9	4	Terminal Strip, 2 wire	Doghouse Rocketry / Cut to size
	B10	4	#4x40 Socket Head Cap Screw, 7/16" Length	McMaster
			Electronics Bay Internals	
	B11	2	13" Long 1/4x20 High Strength Threaded Rod	McMaster
	B12	6	1/4x20 Nylon Insert Nut	McMaster
	B13	4	1/4x20 Thin Nut	McMaster
	B14	1	5" x 10" Electronics Bay Board, cut from 0.125" G10 Fiberglass	Custom
	B15	2	Raven Altimeter Unit	Featherweight
	B16	4	#2x56 x 0.5" machine screw	McMaster
	B17	4	#2 x 0.125L nylon spacer	McMaster
	B18	4	#2x56 Hex Nut	McMaster
	B19	2	4 terminal connector	Dog House Rocketry
	B20	2	2 terminal connector	Dog House Rocketry
	B21	2	9V battery holder	Dog House Rocketry
	B22	8	#4x40 flat head machine screw, 0.5" Lenngth	ACE Hardware
	B23	8	#4 ID Nylon spacer, 7/32 length	Mcmaster
	B24	2	Rotary switches	Missileworks
			Third Rail Button	
	B25	2	#8 x 32, 1" Long Flat head machine screw	Doghouse Rocketry
	B26	2	1010 delrin rail buttons	Doghouse Rocketry
	B27	2	#8 x 32 three pronged wooden threaded insert	ACE hardware
	B28	2	Pine carriers for rail button threads	Custom
			Section Connectors	
	B29	12	.242” diameter click-lock shank rivets	Mcmaster
	B30	*6*	*#4x40, 5/16 Length Nylon Screws (REPLACE EACH FLIGHT)*	Mcmaster
			Seals	
	B31	8	6.5mm ID x 1.5mm thickness O-ring (Seals 1/4" rods)	McMaster
	B32	8	8mm ID x 1mm thickness O-ring (Seals 5/16" threads for U-bolt)	Mcmaster

			Electronics Bay Expendables	
	B33	*4*	*"General Electric Igniter" (REPLACE EACH FLIGHT)*	*Amazon*
	B34	*1 ft*	*Saran Wrap for making ejection charges (REPLACE EACH FLIGHT)*	*-*
	B35	*2*	*9V Duracell battery (REPLACE EACH FLIGHT)*	*-*
	B36	*20 g*	*FFFFG Black Powder for ejection charges (REPLACE EACH FLIGHT)*	*Muzzle Loader Supply*
C. Nose Cone				
	C1	1	30" Long FWFG Nose Cone	Rocketry Warehouse
	C2	1	Nose Cone Bulkplate Carrier Ring, 4.5" ID	Custom
	C3	1	Nose Cone Bulkplate, 0.3" Thick, Aluminum	Custom
	C4	1	5/16" Diam by 2" ID Black Oxide U-Bolt rated at 600 lb, secured with nylon insert nuts	McMaster
	C5	1	Bulkplate to Electronics Plate L-Bracket, Aluminum	Custom
	C6	1	Electronics Plate, 0.125" G10 Fiberglass	Custom
	C7	4	1/4 x 20 Button Head Socket Head Cap Screws, 3/4" Length	McMaster
	C8	1	3/8" Button Head Socket Head Cap Screw, 3/4" Length	McMaster
	C9	2	#4x40 Button Head Machine Screws, 1" length	McMaster
	C10	2	#4 screw x 0.5" Length Nylon Spacer	McMaster
	C11	2	#4x40 hex nut	McMaster
	C12	1	Big Red Bee 70cm GPS Transmitter	Big Red Bee
D. Recovery				
			Drogue	
	D1	1	SkyAngle Cert 3 Drogue (24")	SkyAngle/ Wildman
	D2	6 ft	1/2" tubular Kevlar	Top Flight Recovery

	D3	2	1400 lb capacity quick link	McMaster
	D4	1	Nomex Blanket for <=8" Rockets	Top Flight Recovery
	D5	30 ft	Tubular Nylon	Top Flight Recovery
			Main	
	D6	6 ft	1/4" tubular Kevlar	Top Flight Recovery
	D7	1	144" Spherachutes Main Parachute	Spherachutes
	D8	1	XXL Deployment Bag,	SkyAngle
	D9	1	52" Classic II Parachute	Skyangle
	D10	2	1400 lb capacity quick link	McMaster
E. Adhesives				
			Proline 4500 Epoxy	
			Fin attachment, fillets, centering ring attachment, thrust plate attachment, coupler attachment, Nose Cone bulkplate carrier attachment	
			Aeropoxy Structural Adhesive	
			Booster Bulkhead attachment, switch band attachment, rail button mounts	
			Aeropoxy Laminating Resin	
			Used with Carbon Fiber in fin can.	
			JB Weld	
			Permanently secure U-bolt in inaccessable booster bulkhead	
			Aeropoxy Light	
			Filling rough surface of carbon and seam lines between tail cone and booster tube	

I. Pre-Flight Checklist

A. At Home

Charge

i. Camera
ii. Radio
iii. GPS Bluetooth Converter
iv. Tablet
v. Iphone
vi. Hand Drill

B. Motor Assembly

1. Build motor according to Cesaroni instructions. Use SuperLube for grease.

C. Electronics Bay Prep

1. Measure the voltage of 2 new 9V batteries to confirm voltage >=9V.

2. Insert two batteries into holders, and apply 2 cable ties to each to hold in position

3. Connect the two switch connectors, the drogue charges connector (top, 4 wire), and the main charges connector (bottom, 4 wire). Use Cable ties to secure each of the 4 wire connectors

4. Ensure each of the 4 left-most screw terminals on each raven is secured to the 6-lead male terminal. The red wire should be on the LEFT.

5. Create 2 ejection charges with 4 grams of black powder and 2 ejection charges with 6 grams of black powder using saran wrap, masking tape, and an electric match.

6. On the **drogue** side (lower) bulkhead, screw the 4 gram black powder charges into the screw terminals and insert the charge ends into the charge wells. Tape shut

7. On the “MAIN” side bulkhead, screw the 6 gram black powder charges into the screw terminals and insert the charge ends into the charge wells. Tape shut.

8. Place the two large o-rings onto the e-bay bulkhead shoulders.

9. Double check that the top of the electronics sled is aligned with the “up” arrow on the electronics bay coupler. Slide the electronics sled, threaded rods, and lower bulkhead into the bottom of the electronics bay coupler, ensuring no wires snag.

10. Place the MAIN bulkhead with the 6 gram charges on the “up” end of the electronics bay coupler. Place 2 o-rings to seal the bay. Now complete the assembly by tightening 2 thin 1/4x20 hex nuts on the MAIN bulkhead side of the threaded rods, tightening the first pair against the bulkhead and the second pair against the first.

11. In a non-confined space, carefully turn on the switches, one at a time. Listen for a pair of high beeps. If OK, turn back off the switch and move on. Otherwise, disassemble and troubleshoot.

D. Nose Cone
    1. Ensure the L-Bracket and U-bolt are tightly attached to the nose cone bulkhead. Ensure the Big Red Bee is securely attached to the carrier fiberglass panel, and that this panel is attached to the L-Bracket.

    2. Connect the wire connector to power on the transmitter.

    3. Secure the bulkhead to the nose cone's bulkhead carrier ring with 4 ¼" Button Head Socket Cap Screws.

E. Recovery Prep

    1. Booster U-Bolt: The 30' length of Tubular Nylon should be attached with a figure eight knot. The 24" Cert 3 Drogue should be attached with a quick-link, tightened sharply. Pull test the knot and inspect for 10 strands.
    2. Drogue Central Connection (Quick-Link): The opposite end of the 30' of Tubular Nylon should be attached with a figure eight knot. The 6' of ½" Kevlar, with the parachute protector somewhere along the length, should also be attached with a figure eight knot. The quick-link should be tightened sharply. Pull test both knots and inspect for 10 strands.
    3. Drogue Electronics Bay U-Bolt: The 6' of ½" Kevlar should be attached with a figure eight knot. Pull test the knot and inspect for 10 strands.

    4. Main Electronics Bay U-Bolt: The 6' of ¼" Kevlar should be attached with a figure eight knot. Pull test the knot and inspect for 10 strands. Place the main chute protector along this Kevlar.

    5. Main Chute Connect: At the far end of the 6' of ¼" Kevlar, the main parachute's shroud line loop should be attached with a figure eight knot. Pull test the knot and inspect for 10 strands. Place the main chute protector along this Kevlar.

    6. Nose Cone U-Bolt: The deployment bag's nylon "tail" should be attached with a quick-link. The Sky Angle 52" Classic II parachute should be attached with a second quick-link. The 2 quick link should be tightened sharply.

F. Rocket Assembly

    1. Install motor with the threaded rod extending from the forward closure. Use a 3/8" nut at the forward bulkhead to secure the motor from the front, and use a second nut to prevent loosening.

    2. Center Section: Double check e-match connections and shock chord connections with figure 8 knots. Then slide the 2 mating tubing sections onto the electronics bay assembly. Secure each with 6 black plastic rivets. Sorry again about the flames being upside-down… A small hole can be used to align to the rail button for proper clocking.

    3. Booster Section: Double check the kevlar to nylon knots, the drogue to kevlar knot, and the kevlar to booster knot. Slide center section onto booster and secure with 3 #4 shear pins

4. Nose Cone: Double check the drogue to nose cone connection, and Nose Cone chute to Nose Cone connection. Slide the nose cone onto the rocket and secure with 3 #4 shear pins

G. Last Checks

1. Measure the center of gravity of the rocket. If this is not >6" forward of the CP marking hole, DO NOT FLY.

2. Turn on the Nexus Tablet and check the radio link with the rocket. Turn on the navigation app on the Iphone.
3. Fill out flight card. Calm down. Double Check that the rocket electronics are OFF

4. Strip igniter leads. Twist lightly together and tape to rocket

5. Bring these items along with the rocket
    i. Camera
    ii. Igniter
    iii. Masking Tape
    iv. Flat Head Screw Driver for Electronics Switch.
    v. Phillips Head Screw Driver to adjust 3rd Rail Button
    vi. Hand Held Radio with Bluetooth Converter
    vii. Tablet
    viii. Iphone
    ix. Flight Card

H. At Pad
1. Load rocket and raise rail

2. Insert igniter into motor and tape into place

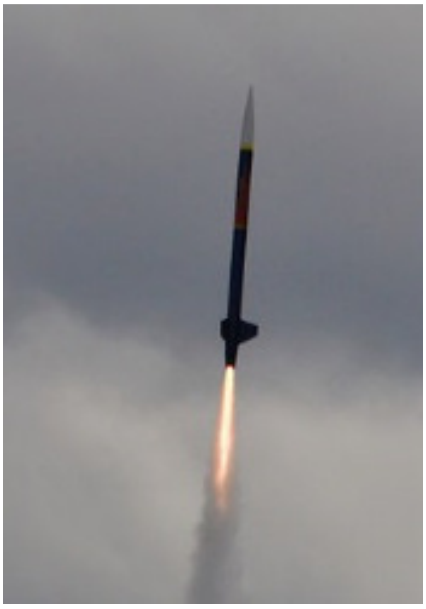
3. **TURN ON ELECTRONICS**. Listen for 2 high pitched beeps on each. If not the case, **DO NOT FLY.**

4. Test control system leads for sparking. If OK, attach to igniter leads.

J. Flight Summaries

First flight: CTI L1350 C-Star

This was a flawless flight to 4794 ft, according to the Raven altimeter. Max velocity was 537 ft/s and max acceleration was 8.4 g's.



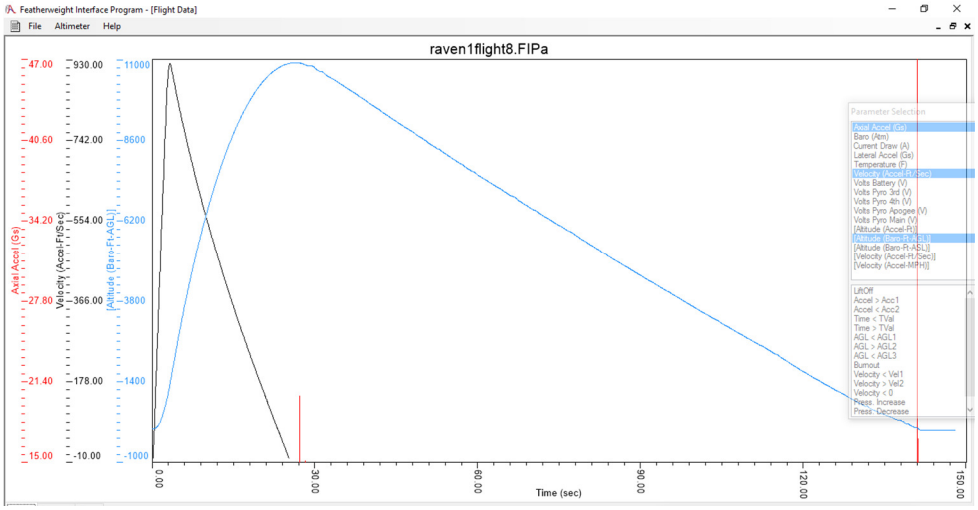
The second picture illustrates the configuration that caused the next flight to fail: With the drogue attached to the booster, the upper assembly hangs below. When the main deploys, it's possible for it to become tangled in the shock chord and the booster itself

Second Flight: CTI M2045 Blue Streak

According to the surviving Raven altimeter, this flight flew much higher than the simulation to 10,889 ft. Max Velocity was 921 ft/s (Mach 0.82) and max acceleration was 14 g's.

The flight was nominal until the main parachute deployment. The chute tangled as it rose up through the shock chord, and never inflated. The rocket hit the ground hard, but the only damage was in the electronics bay, where the electronics sled broke off its "rails" and one of the Ravens was damaged. For subsequent flights, the drogue will be moved to 1/3 of the way along the shock chord from the upper section to the booster.


Photos by Jim Wilkerson



Raven altimeter data plot showing 10,889 ft max altitude.

Third Flight: CTI M1675 Pink

This flight was completely successful, achieving 8100 ft in altitude and recovering without issue. As a result of this flight, I earned my Tripoli Level 3 Certification!