

Final Report for NAR Level 3 Certification Project



“Impulse Control”

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1. Introduction

A. Overview

The Level 3 certification project is an implementation of an Ultimate Wildman kit-built rocket, 144 123 inches in length and 6 inches in diameter. The airframe and fins are fiberglass, with a Von Karman 5:1 aluminum tipped filament wound fiberglass nosecone and 98 mm fiberglass motor mount with aluminum motor retainer (Aeropack). Any test launches requiring smaller motors than the MMT, Aeropack reducer will also be utilized. The rocket weighs ~~(in-simulation) 29 lbs.~~ 42 lbs. without motors and flying with a planned Aerotech M1780NT-PS (New Blue Thunder propellant) it weighs ~~(in-simulation) 40 52 lbs.~~ on the pad.

The selection of a motor for Cert flight is being driven by a goal of launching this project on a field with a maximum altitude waiver of 9,500' AGL. This limiting factor is being done to maximize the choices of locations for the certification flight.

B. Flight operation

With the proposed motor, a simulated launch shows an altitude of 7,100' AGL is achieved. The project uses a traditional dual deployment recovery system (drogue chute deployed at apogee and main chute at 1,000'). The rocket design is augmented to include 2 GPS trackers (one in the E-bay and the other in the nose cone), a flight video recording camera that is mounted to the side of the rocket and covered with a shroud.

For this project, 2 test flights are performed to test the airframe, new altimeters, and the recovery system. Plus, the ability to make adjustments in techniques or equipment.

	Motor	Total Impulse (Ns)	Combined weight (Lbs)	Ave Thrust to Weight ratio	Max Velocity (mph)	Max Acceleration (g)	Apogee (ft)
Test Flight 1	AT L1256 WS	3,785	~~38~~ 48	7	406	55	4,515
~~Test Flight 2~~	~~AT L2200G~~	~~5,104~~	~~40~~	~~12~~	~~564~~	~~55~~	~~6,548~~
Test Flight 2	CTI L995R	3,618	50	12	365	55	4,120
Cert Flight	AT M1780NT	5,783	~~40~~ 52	10	570	55	5,445

C. Risk assessment and mitigation

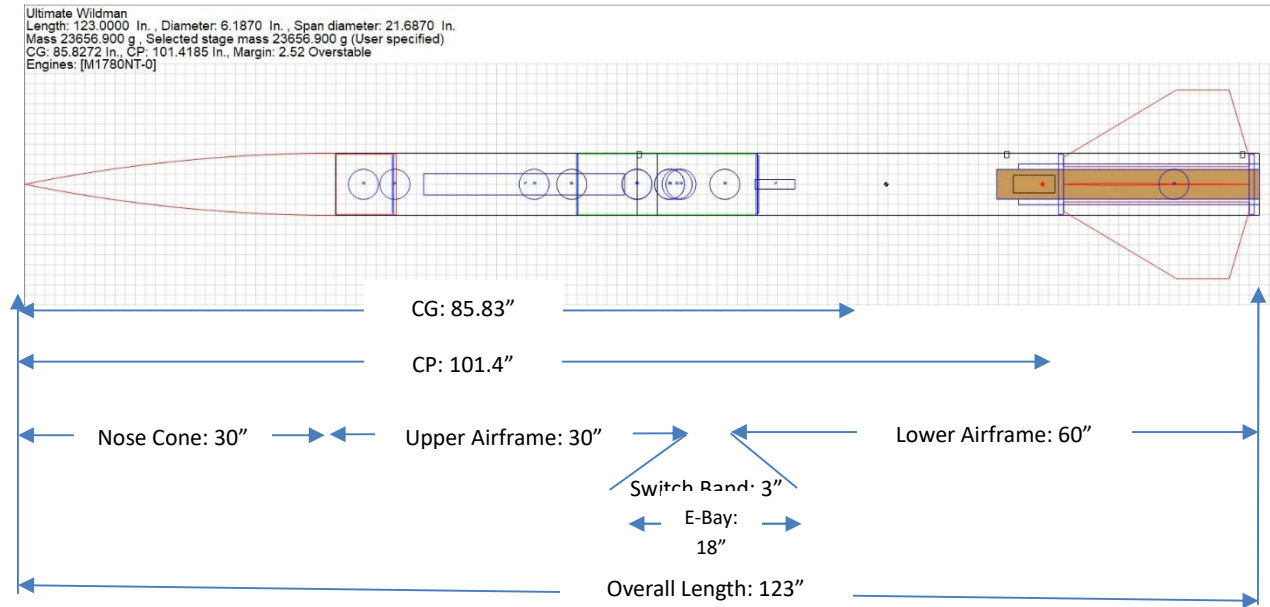
The design and building techniques incorporate those techniques that have been used in my previous flights and those that have survived high gees and Mach speed. In this project there are 3 characteristics that will expand my experience and skills:

1. Greater stress on airframe due to a new impulse class of motors and the increased likelihood of speeds near or over Mach,
2. Stress on the recovery system due to greater weight of the rocket, and
3. Experience in assembly and use of Aerotech motors vice my go to CTI motors, which are in short supply.

Reducing the risk of airframe failure (risk #1), additional reinforcement is planned for fin attachment. Reducing the risk of recovery system failure (risk #2), stronger components are used in the entire recovery system and a rocket design that includes utilizing U-bolt & eye-nuts directly connected to the all-threads in the E-Bay vice my traditional method of transferring recovery force from the eye-bolts to bulkheads and then to all-threads. Additionally, the inclusion of a deployment bag to better manage and soften the deployment of the main chute. Reducing the possibility of a CATO due to inexperience with assembling and launching Aerotech motors (risk #3), inclusion of additional test flights with Aerotech motors are included.

2. System Drawings

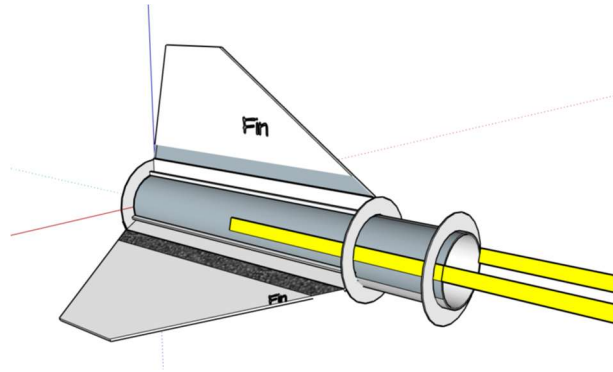
A. Overview Scale drawing (1 sq = 1")



B. Lower Airframe Drawing

1. Harness attachment and to MMT:

1" flat Kevlar webbing is attached to the MMT by forming a loop with the two ends attached to the MMT. The two centering rings are notched to the size of the Kevlar strap, and the webbing is run between the centering rings and the MMT. A knot is added to the Kevlar webbing just after the 2nd centering ring as a redundancy should the epoxied end come loose.

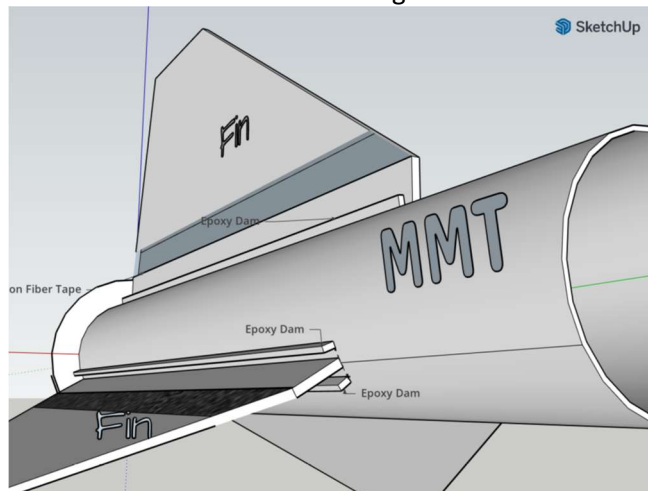


2. Attaching the 2 forward centering rings:

The two forward centering rings are attached to MMT with epoxy and the CF tape added for extra reinforcement.

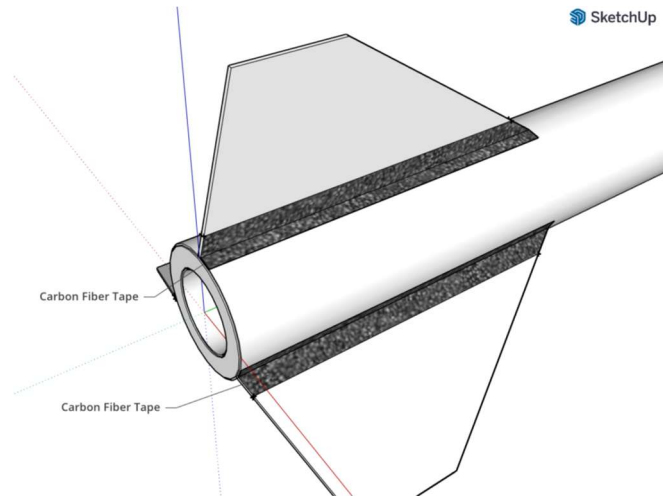
3. Fin root attachment to MMT:

Each Fin is surrounded by two wood strips (one on each side) between the CRs and adjacent to each fin (distance equivalent to thickness of the fin). These wood strips are sealed with CA glue to create an epoxy dam. First complete attaching all items (but the fins) to the MMT. Then the MMT is epoxied into the lower airframe. Each epoxy dam will be filled through the fin slot with T-88 structural epoxy to a depth of ¼". Then a fin will be inserted into the pool of epoxy and secured into proper alignment and allowed to cure before moving to the next fin.



4. Fin attachment to body tube:

After fins have been epoxied to MMT, Carbon Fiber Tape (2") will be applied to each side of the fins to provide reinforcement and attachment between the fins and the lower airframe. Half of the CF tape will be applied to the fin and the other half applied to the outside of the body tube as shown.



5. Rail & Unistrut Buttons:

3 rail buttons are used on the airframe. Both types of buttons use ¼-20 bolts which allows them to be swappable at the field from a single set of holes. The two lower buttons are installed above the lower most centering ring and just above the upper most centering ring. The third button is installed just below the E-Bay, in the switch band, or just above the E-bay (TBR). Each rail button is screwed into a locking hex nut that has been embedded in a conformal wooden backer and epoxied inside the airframe.

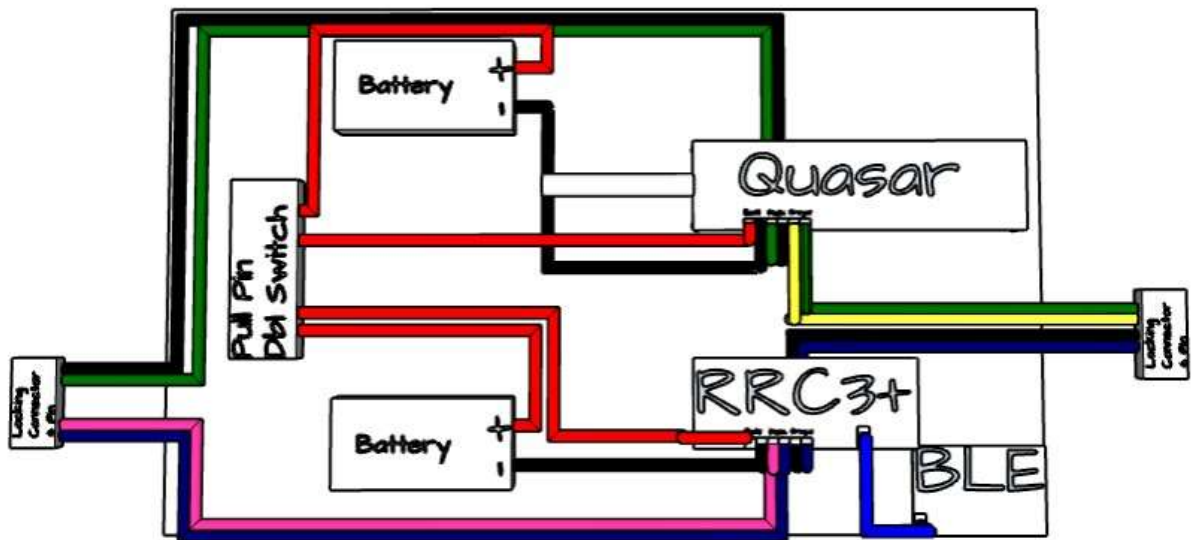
6. Vent holes:

A 1/8" vent hole is placed in the top of both the upper and lower airframes. Additionally, a 1/8" vent hole will be added to the nose cone bulkhead.

C. E-bay Sled Drawing

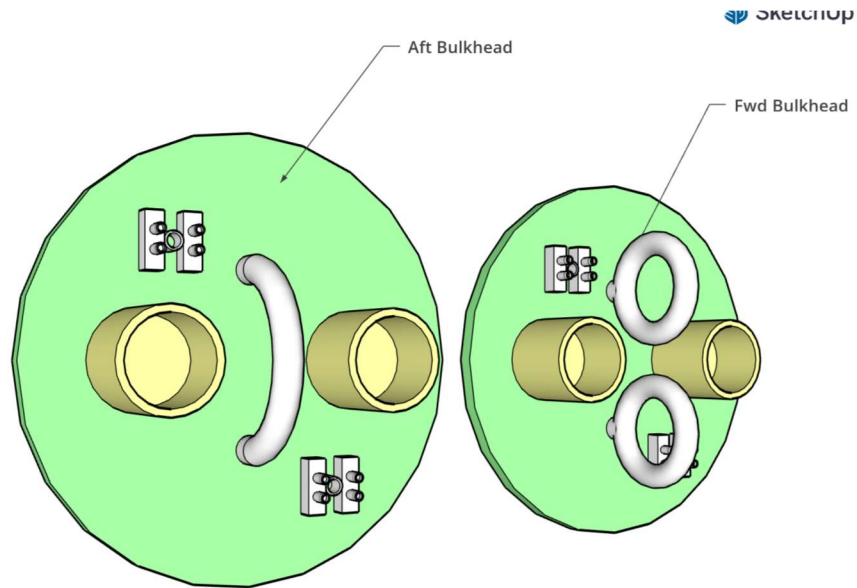
The components on the sled are shown as a logical placement to demonstrate connectivity between components. The physical placement of components will be different than shown. Specifically, the battery will be attached to the back of the sled with wires passing through the sled to its underside. Wires will be routed on both sides of the sled.

Two flight computers are being used to manage the deployment of the Drogue and Main chutes. The Eggtimer Quasar is the primary flight computer (plus GPS tracking and telemetry downlink) and the Missileworks RRC3+ is the backup flight computer. Both computers will be fully disconnected from the batteries by a dual pull-pin switch. When a pin is inserted through one of the vent holes and into the switch both computers are inert.



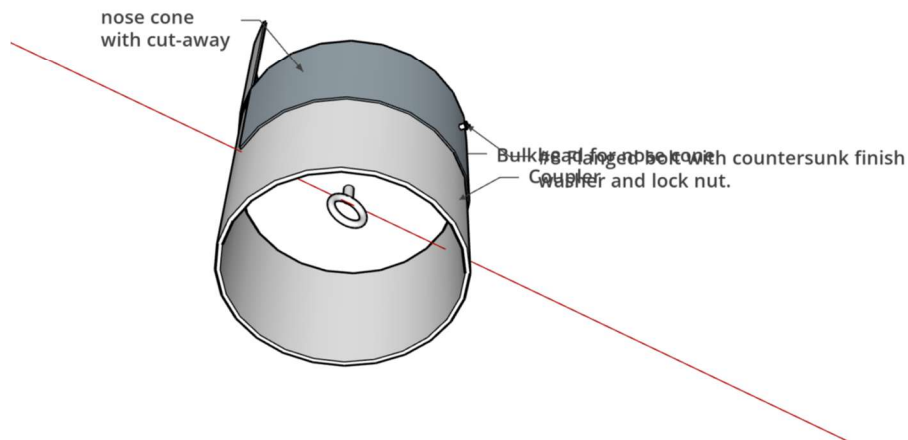
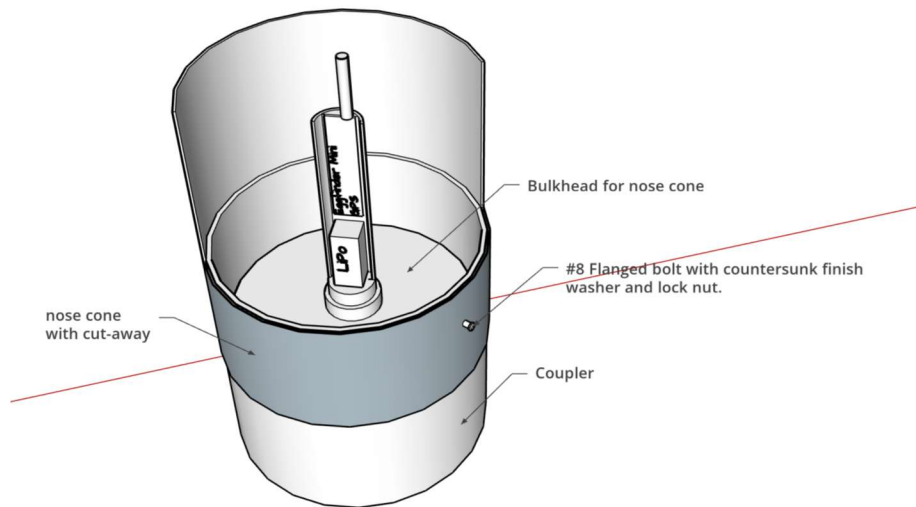
D. Bulkhead Drawing

Each Bulkhead has two ejection charge wells (one primary attached to the primary flight computer and one backup attached to the backup flight computer). The charge wells are 1" CPVC end caps (9 grams 4f BP capacity) and bolted and epoxied to the bulkhead. Each charge well is mated to the terminal block assigned to it. Wires run from a 4-pin connector on the backside of the bulkhead and pass through a small hole and then screwed into the terminal block. The wire holes are filled with epoxy to prevent ejection charge gases from entering the E-Bay. The 4-pin connector has a mating connector that runs wires to the appropriate flight computer. In the center of the Aft bulkhead is a 3/8" U-bolt that is tied to 3/8" all-threads rod via long coupling nut. The Fwd bulkhead has two 3/8" oval eye-nuts that are attached to all-thread rods in the E-Bay.



E. Nose Cone Drawing

The nosecone holds a 2nd GPS unit (Eggtimer's EggFinder mini). The GPS board will be attached to Labrat's sled and secured to the nosecone bulkhead by a 1/4" welded eyebolt. The bulkhead is attached to the nose cone coupler with epoxy. The coupler is removable from the nosecone via 3 #8 flanged head bolts. Each bolt will be inserted through a countersunk finish washer, which was epoxied to the outside of the nosecone, and then screwed into a locknut that is epoxied to the inside of the mating surface of the coupler.



3. Construction materials and techniques (Construction Package)

A. Airframe (General) materials including

1. Fiberglass – Filament wound & 0.063" Thickness
 - Upper Airframe, lower airframe, switch band, e-bay, nose cone
2. Fiberglass – G10 & Thickness 0.125"
 - Fins, centering rings, coupler bulkheads,
3. Launch pad interface
 - ¼-20 weld nuts with conformal spacer will be installed in 3 locations inside the lower airframe tube. Depending on launch site, either a 1515 rail button or a Unistrut rail button will be screwed into these nuts.
4. Fin Reinforcement materials
 - 2" Carbon Fiber Tape (For use between external body tube, centering rings, and fins)
5. Adhesives
 - CA Glue (temporarily attaching components,
 - West Systems Epoxy (for items not attached to MMT),
 - Aeropoxy(external Fin fillets if needed),
 - JB Weld Epoxy,
 - System 3 T-88 Structural Epoxy (Fin Roots within epoxy dams)
6. Misc Hardware
 - Aeropack 98MM motor retainer assembly with universal flange mount.
 - 3 - 1515 Rail buttons with ¼-20 flanged bolts and lock nuts (Swapable)
 - 3 – Unistrut buttons with ¼-20 flanged bolts and lock nuts (Swapable)
 - RunCam 6 (4K video camera) and Shroud
 - #4-40 nylon sheer-pins. 3 pins are installed on the upper airframe / nose cone and 2 on the lower airframe / Ebay.
7. Black Powder
 - Goex FFFFg Black Powder

B. Photographs (See Appendix B)

1. Show construction of areas hidden after assembly
2. Show details of construction

2. Description of recovery system components and operation (Recovery Systems Package)

A. Recovery Hardware

1. Products used:
 - 3/8" Quick links load limit 2,200#
 - One Bad Hawk Ultimate Harness (1/2" tubular kevlar 40' long 3 loop and 1/2" tubular kevlar 30' long 2 loops) est load limit 5,300#
 - 1" flat Kevlar webbing (load limit 4,000#)
 - 3/8" Ubolts load limit 1,075#
 - ¼" Eyebolt on Nosecone load limit 500#
 - 3/8" Eye-nuts load limit 1,800#
 - 3/8" All-threads load limit 2,400#
 - 3/8" Coupling nuts load limit 8,800#
 - SkyAngle Cert-3 Extra Large Parachute attached to the payload and booster sections (The Main Chute)

- SkyAngle DROGUE 32" (The Drogue Chute)
- SkyAngle Classic Chute II 44" (The Nosecone's Chute)
- 2 CHUTE PROTECTOR 24X24
- SkyAngle Deployment Free Bag X-Large

2. Concept of recovery deployment

- The rocket is designed to separate into two independent pieces.
- At apogee, the rocket separates between booster section and E-bay. Primary and backup drogue charges will fire at apogee and 1 second after apogee respectively causing the 4 4-40 nylon screws to shear and deploy the 32" drogue chute.
- The rocket will descend at a rate just under 70 ft/sec with payload section kept 35' above the booster section.
- At 1,000' altitude, the primary main charge will fire and shear its 4 4-40 shear pins, separating the nose cone from the payload section and push out the nosecone's 44" chute. Should this not happen, the backup flight computer will fire its backup drogue charge at 900'.
- Nosecone is not coupled to the remainder of the rocket airframe. Instead, it is attached to its own chute and the deployment bag, which is holding the main chute.
- As the nosecone's chute inflates, the nosecone will descend slower than the rest of the airframe and will pull the deployment bag off the main chute and drift away from the remainder of the rocket. The nosecone chute is sized to have a descent rate (17 ft/sec) that closely matches the descent rate of the rest of the airframe under the main chute.
- Once the deployment bag releases the main chute, the 10' chute will fill and slow the remainder of the rocket down to 18 ft/sec.
- Should the rocket ever fall faster and 120 ft/sec, a failsafe protocol will fire all charges and release all chutes on board the rocket. And hope for the best.

3. Vent holes for flight computers:

$$\text{E-Bay volume} = \pi * (6''/2)^2 * 18'' = 509 \text{ in}^3$$

$$\text{Single port Diameter} = 2 * \text{SQRT}(509/6397.71) = .5564''$$

Using 4 vent holes:

$$\text{Multi Port Diameter} = 2 * \text{SQRT}((.5564/4)/\pi) = .421'' \text{ or } 27/64 \text{ drill bit Round to } 7/16'' \text{ drill bit.}$$

4. Black Powder (BP) Calculations:

Using the Ejection Charge Calculator in Rocksim, I came up with the following charge recommendations:

Size of 4F Black Powder Charge		
Section	Primary (g)	Backup (g)
Booster	6.5	7.0
Payload	4.0	4.5

Ejection Charge Calculator

Inputs:

Desired Internal Pressure: 9 psi

No. of Shear Pins: 4

Shear Pin Diameter: #4 Nylon Screws

Show Help Text

The drawn rectangle depicts the volume to be pressurized. Now, grab either end of the rectangle to change its dimensions.

Calculated Parameters:

BP Required: 6.446 g

Force on Bulkhead: 1131.93 N

Length to be Pressurized: 30.2111 in

Body Tube Diameter: 6 in

Volume to be Pressurized: 854.198 cubic in

Ejection Charge Calculator

Inputs:

Desired Internal Pressure: 9 psi

No. of Shear Pins: 4

Shear Pin Diameter: #4 Nylon Screws

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The drawn rectangle depicts the volume to be pressurized. Now, grab either end of the rectangle to change its dimensions.

Calculated Parameters:

BP Required: 3.924 g

Force on Bulkhead: 1131.93 N

Length to be Pressurized: 18.3906 in

Body Tube Diameter: 6 in

Volume to be Pressurized: 519.983 cubic in

Ground tests verified these charge amounts with a 17' separation between booster and payload sections, and a 7' separation between payload section and the nose cone.



Appendix A - Test Flight results

Test Flight #1 – Impulse Control was launched on an Aerotech L1256-WS. The rocket flew straight and stable to an apogee of 4,097'. The Drogue was successfully deployed at apogee and had a decent rate under 70 ft/sec. At 1,000', the main charges fired and separated the nosecone and released the deployment bag from the payload section. Unfortunately, the SkyAngle deployment bag had suffered a failure in that its 2' nylon strap pulled free from the seam it was sewed into on the bottom edge of the deployment bag and the bag remained on the main chute – preventing it from inflating. The purpose of the strap was to allow the nosecone (under a separate chute) to pull the deployment bag from the main chute and allowing the main chute to inflate. Luckily the rocket landed in a soft patch of earth and no damage was found.

In discussion with the vendor (b2 Rocketry Company), they felt there may have been a manufacturing step missed during production. The bag is being returned to the vendor for inspection.



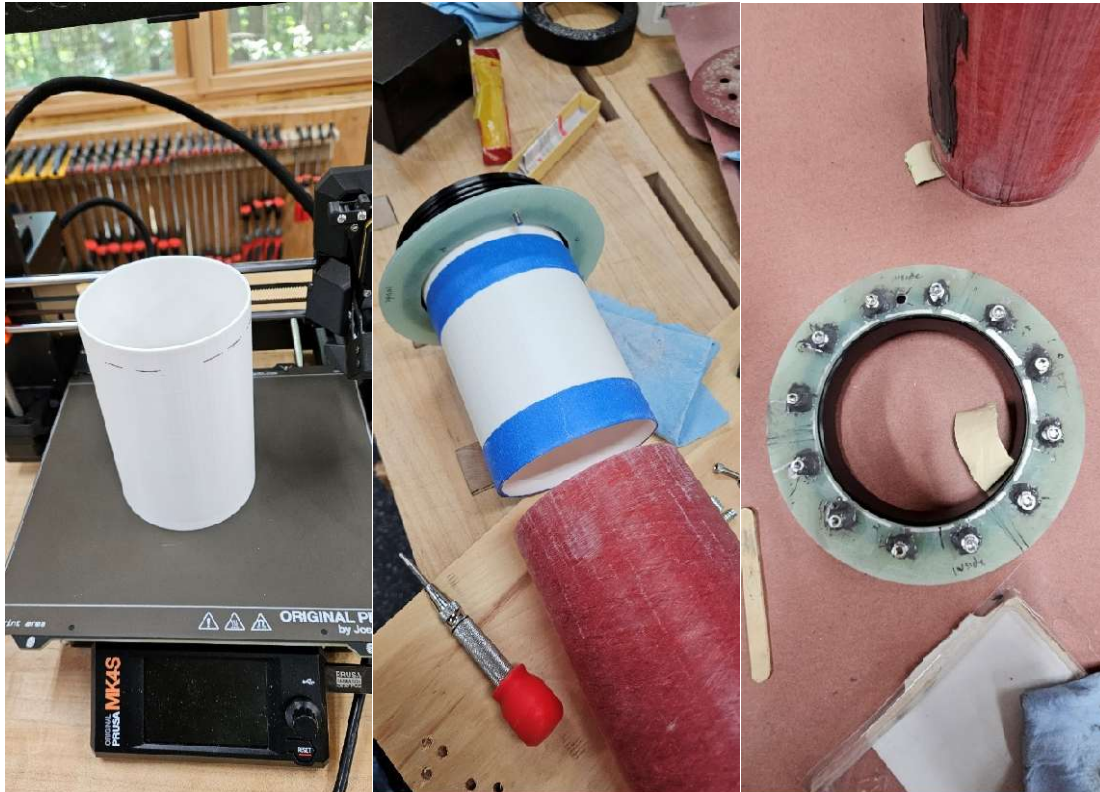
Test Flight #2 – Impulse Control was relaunched using a custom-built deployment bag (loaned to me by Howard Druckerman) and flown with a CTI L995R. The rocket flew straight and stable to an apogee of 3,221'. The Drogue was successfully deployed at apogee and had a decent rate under 70' per second. At 1,000', the main charge fired and separated the nosecone. This time the new deployment bag held up and separated properly allowing the main chute to fully deploy and slowed the main airframe to under 18 ft/sec. The nosecone came down as designed under its own chute at 17 ft/sec.

Appendix B – Build Photos

Step 1) Wash Everything, inside and outside.



Step 2) Attach Motor retainer to rear CR. To center the retainer, a 98mm cylinder was 3D printed to model the motor. The holes of the centering ring were marked on the aft CR. Then one hole was drilled on a drill press, and alignment was verified by inserting the supplied bolt. Then the remaining holes were drilled. All the bolts were inserted, and the threaded inserts were installed as nuts on the back side of the CR. These nuts were then epoxied with J-B Weld.



Step 3) The 1" wide Kevlar strapping was epoxied using J-B Weld to each side of the MMT (between fins).



Step 4) Both centering rings were epoxied in place with J-B Weld. Then epoxy dams were built on either side of where the fins will go and between the two centering rings. Each dam was $\frac{1}{2}$ " tall and $\frac{3}{8}$ " standoff from the fin. These dams were then sealed by applying epoxy where the dam walls attached to the MMT and centering rings. Each dam was tested with water for leaks. I also noted how much water could be placed in an epoxy dam along with the fin before it would overflow the dam. This was recorded and used when installing the fins.

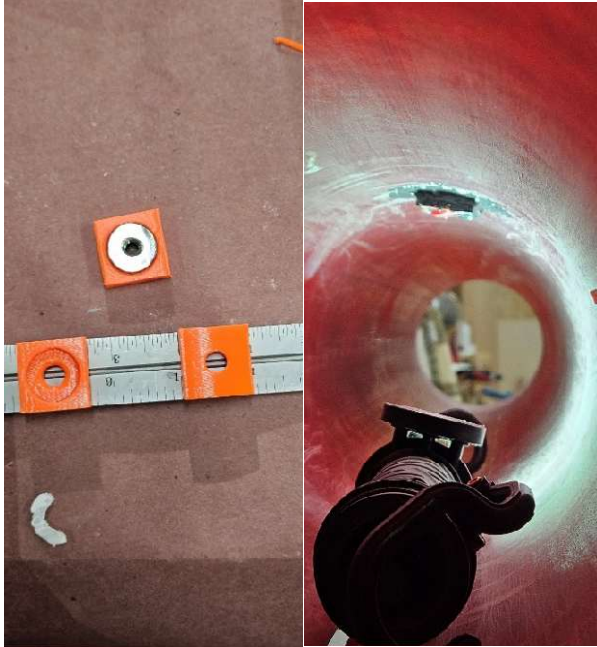




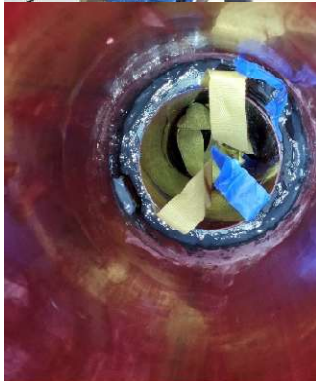
Step 5) The booster body tube was roughed up with 80 grit sandpaper and cleaned with acetone.



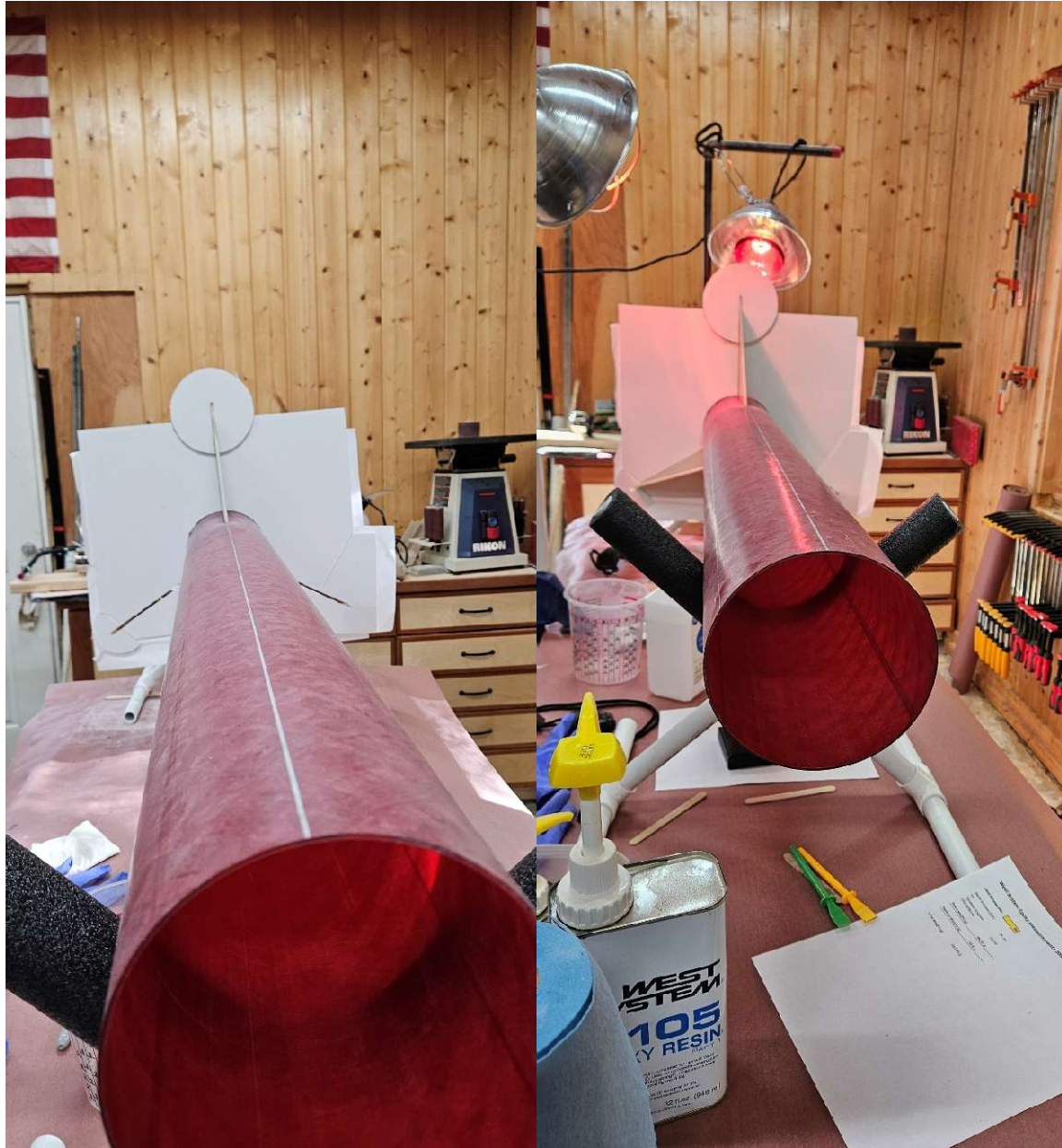
Step 6) Backing blocks were 3D printed with PETG (40% infill) for the t-nuts that hold the rail buttons. I selected 1515 rail buttons and Unistrut rail buttons that both use ¼-20 bolts so that they can be swapped in the field. 3 t-nuts for the rail buttons were installed along the same line. Each nut was epoxied to the inside of the body tube. 1 button was placed above the aft most CR. A 2nd button was placed just above the 2nd CR. The 3rd button was placed on the Ebay switch band between and below the two vent holes to avoid disturbing the air that is moving into the Ebay.



Step 7) The MMT was epoxied into the BT with J-B Weld. Epoxy was slathered in front of both CR before inserting the MMT into the BT. A second coat of J-B weld epoxy was applied to the top CR with the use of a long dowel rod. The aft most CR was also coated with J-B Weld Epoxy. Once the epoxy was dried, I used a fiber scope to inspect the coverage of epoxy on the forward most CR. One mistake, I failed to remove the blue tape that was holding the Kevlar straps out of the way. While I have managed to remove most of the blue tape, some still hides in this space.



Step 8) Installing the fins. I created a jig to hold the fins by printing out a template and gluing it to the foam board. Holes were cut out of the foam board where the body tube and the fins will go. From step 4, I prepared enough West Systems Epoxy to fill #1 fin epoxy dam. Then I squirted that epoxy into the dam followed by inserting the fin. I placed the fin alignment jig in place to hold the fin in proper orientation. These steps were performed on the other two fins.



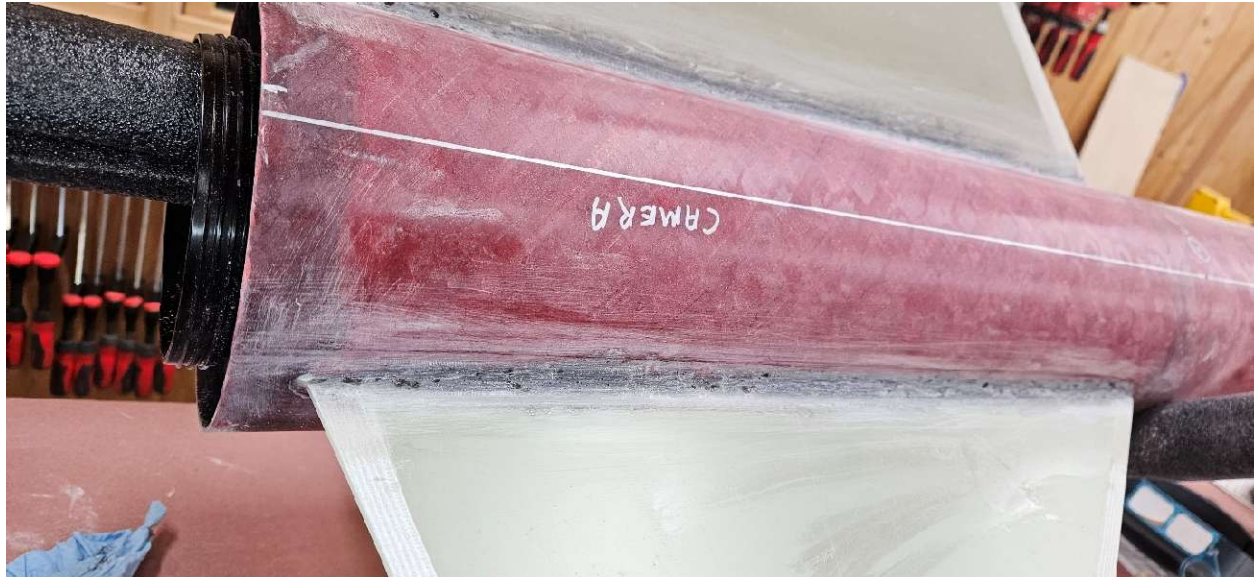
Step 9) placed a fillet on each fin with rocketpoxy. I also did this to seal the fin to the BT for the next step.



Step 10) To place an upper fillet on the inside of the BT where the fin intersected with the BT, I drilled a small hole near the center of the fin. Then I oriented the fin to be pointed down and squirted West Systems epoxy with a syringe through the hole and allowed the epoxy to run down to the intersection and tilted the rocket to get the flow to run to both the back and front of the fin along to the BT. I used a bright light to illuminate the shadow from the epoxy to verify the coverage.



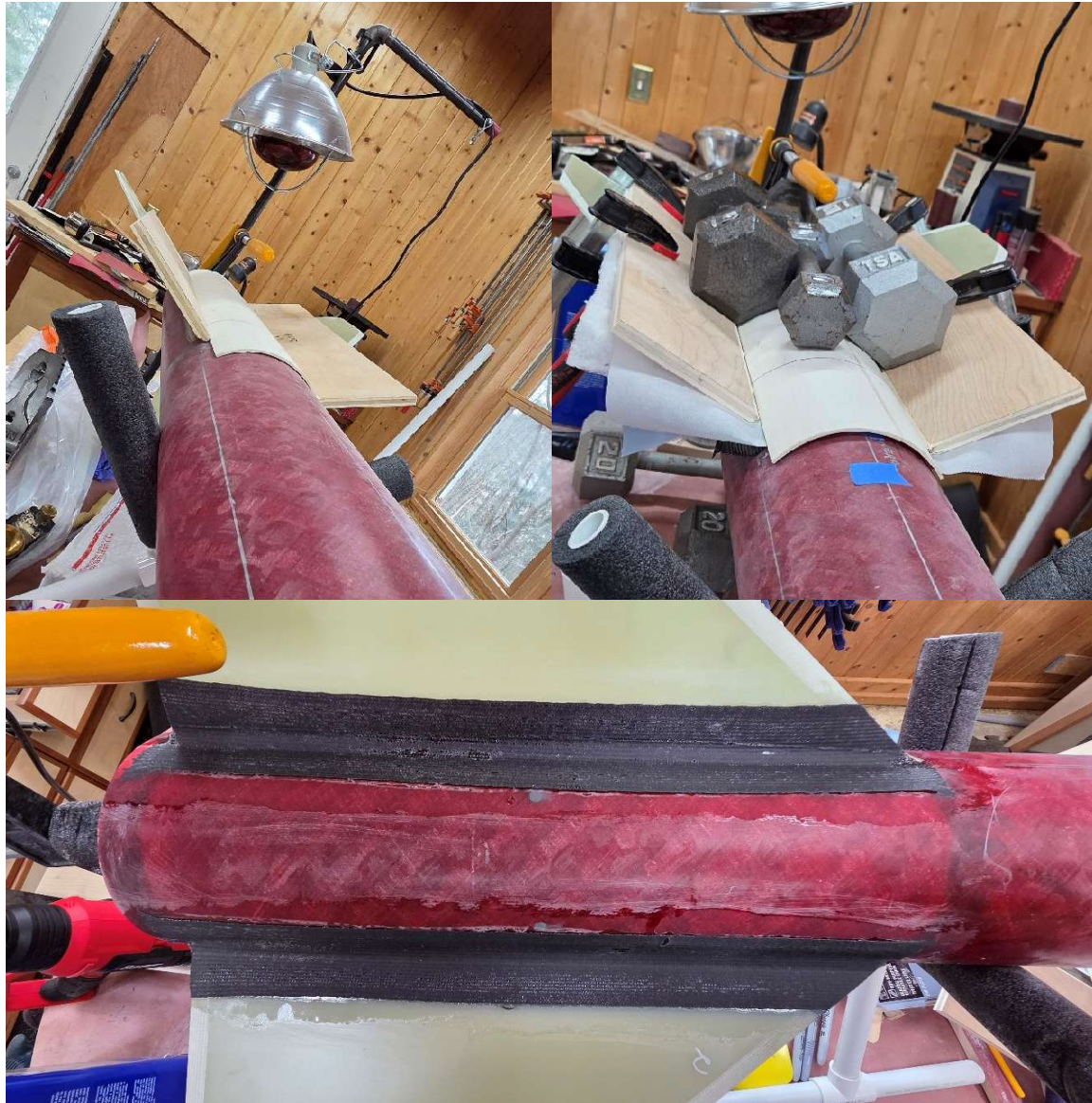
Step 11) I decided the fillet was too small for laying the carbon fiber tape on the fins to BT. Therefore, I roughened up the previous fillets and placed larger fillets on the rocket with West Systems epoxy mixed with carbon fiber. When it was dried, I sanded the area with 80 grit sandpaper.



Step 12) To apply the carbon fiber tape, I created a jig to press the tape into the fillets. The jig was built with a piece of 6" PVC pipe cut to fit the BT between the fins. Then I shaped the ends of two pieces of plywood to match the fillet shape.

Then when ready, I applied epoxy to the area where I was applying the carbon fiber tape. I then laid down the tape, smoothed it out, added more epoxy to fully wet it, then placed release fabric, batting, followed parchment paper.

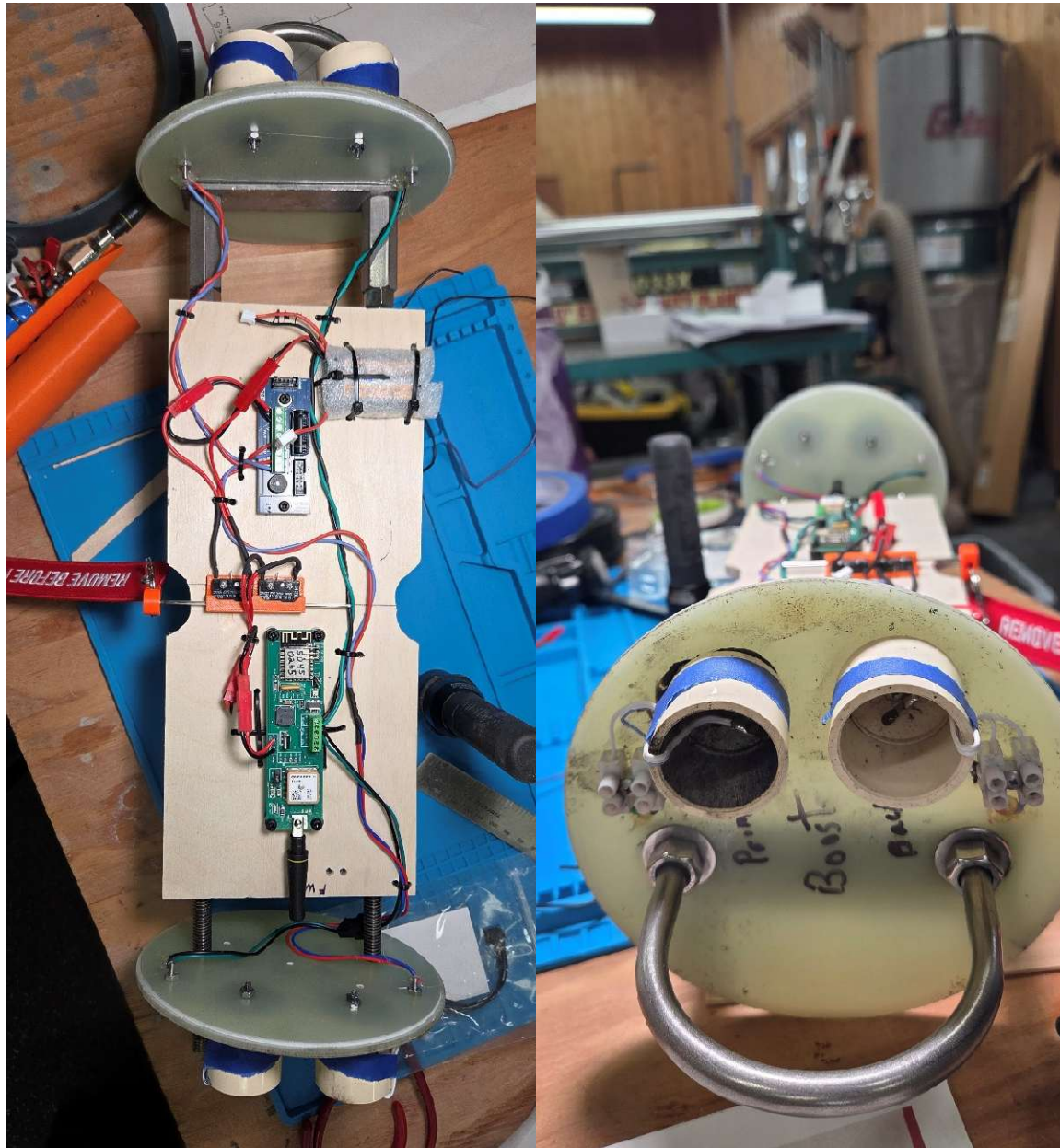
Then I added the jig pieces and then weights and clamps. Added heat to help with the curing process.



Step 13) Reducing the E-Bay diameter. The E-Bay was way to big to fit inside the Booster BT and Payload sections. I spent a day sanding the tube by spinning it on my wood lathe and sanding it with 60 grit sandpaper.



Step 14) Building the E-Bay. I built a sled for the electronic out of 1/4 " plywood. I secured the sled to the 3/8" all thread by epoxying 4 pieces of aluminum tubing to the back of the sled. All wires were tied to the sled with cable ties. The LiPo batteries were wrapped in foam padding and secured with 3 cable ties. 1" CPVC end caps were used as ejection charge wells. These wells are able to hold 8g of BP each. Each flight computer is fully independent from the other by having separate power switches, batteries, and wires.



Step 15) I have placed an E-Bay in the nose cone for a 2nd GPS unit. The nosecone coupler is secured with 3 #6 bolts and lock nuts. The GPS sled is attached to the post of the eyebolt and held in place with a lock nut.



Step 16) Aligning the third rail button. Before adding the 4 #4-40 nylon shear pins, I installed a 1515 rail on the rail buttons and adjusted the rotation of the E-Bay until the 3rd button allowed the rail to slide without binding. Locking the BT sections and installing the sheer pins.



Step 17) The assembly is complete for Impulse Control.

