

NAR Level 3 Certification Project

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Member: Champlain Region Model Rocket Club

Overview

One of my main interests in High Power Rocketry is the construction and flying of scale models. When searching for a rocket to build, I stumbled upon a scale drawing of the Thiokol Chemical Corporation's D-Region Tomahawk missile (page 3). After studying this design and the availability of the various components required to construct this rocket, I decided on a 5/9 scale version.

The main body tubes will be made from Performance Rocketry's G12 fiberglass tubing, 3:1 Ogive fiberglass nosecone, and ¼" birch plywood fins reinforced with carbon fiber surfaces. It will use an Aerotech RMS-75mm 5120 Motor Case, which allow for the use of an "L" sized engine for a test flight, as well as an "M" sized motor for the certification flight. The estimated weight loaded is 31.5 lbs, and when launched with an M1500G motor, the rocket should achieve an altitude of ~10500feet.

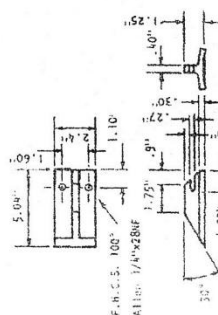
Recovery will use a dual set of PerfectFlite miniAlt/WD logging dual event altimeters. The main chute will be Sky Angel Cert 3 - XLarge, and will provide a rate of decent of ~27 ft/sec.

Design Specification

CHEMICAL CORPORATION
ASTRO-MET DIVISION

100

UNBIBLICAL



DATA SOURCE: Thiokol Chemical Corporation Drawings:

000763, 000764, 000765, 000788, 80C528, 80C529,

R00548, R00750, C00746.

Photographs:
Color: V68-1A, V68-19, V68-20, V68-21, V68-22.

W68-23, W68-24, W68-39, W68-40, W68-44, W68-45.

Black and White: W68-10, W68-11, W68-12, W68-13,

W68-14, W68-15, W68-16, W68-17, W68-30, W68-31,
W68-32, W68-33, W68-34, W68-35, W68-38

W00-32, W00-33, W00-34, W00-35, W00-36.

52.00"

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29.25"

1

1

3:1 Ogive Nose Silica Ceramic

1

1

1

1997

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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20

2.

4

251 F.H.C.S.

9" 1'-0" 1'-0"

DE
2-

Female 1

Canon

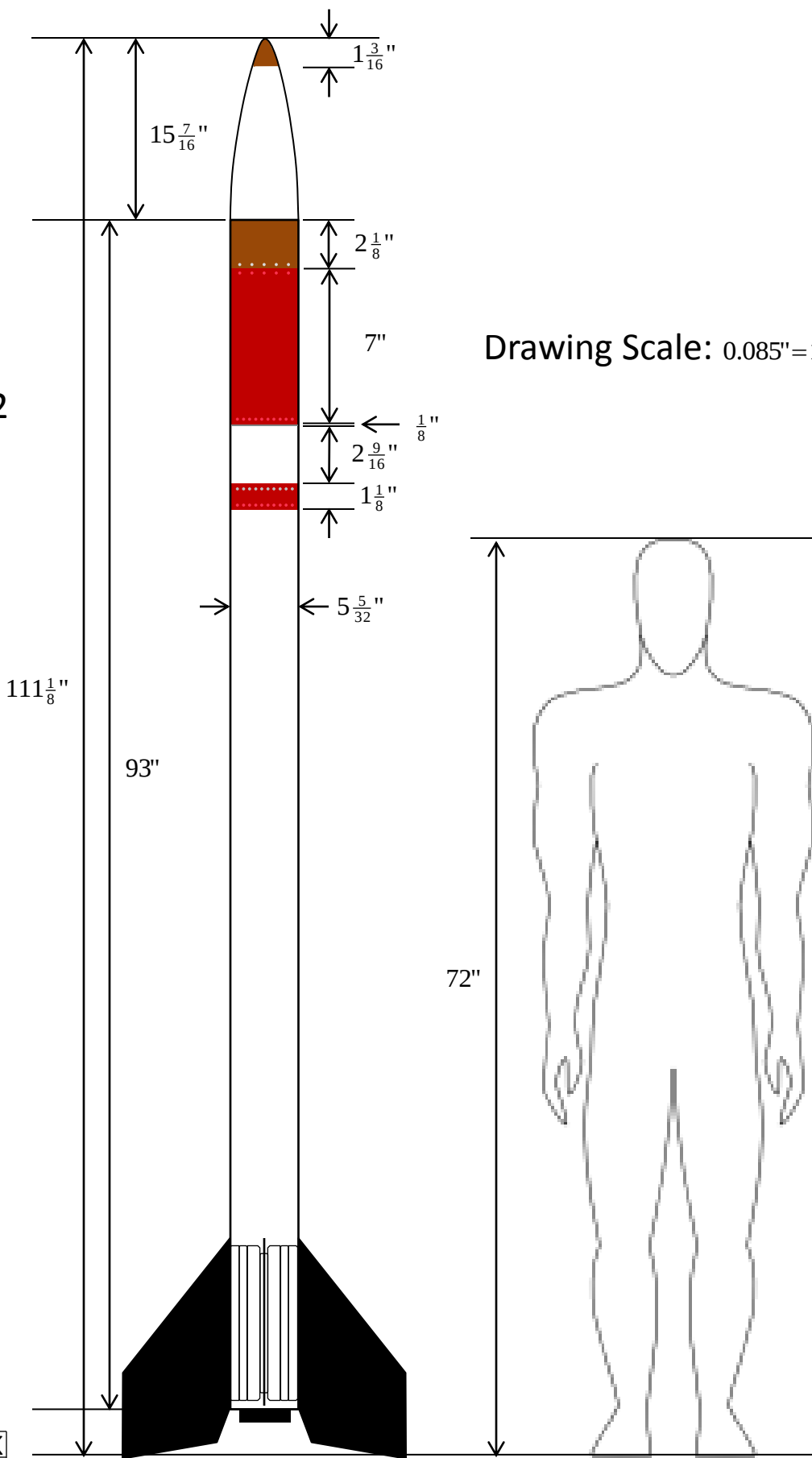
— — — — —

100

△

Scale = 0.57222

Drawing Scale: 0.085"=1"

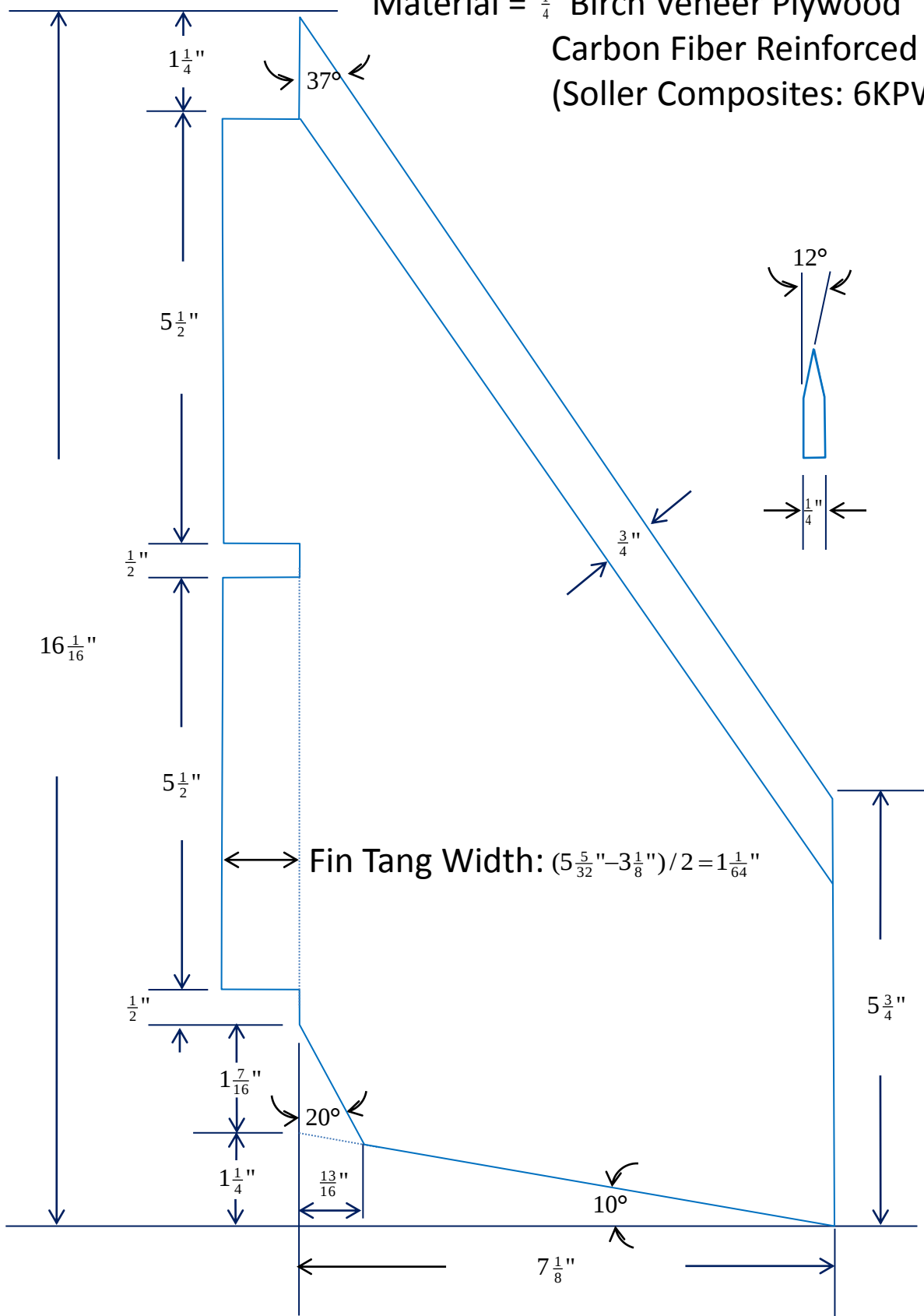


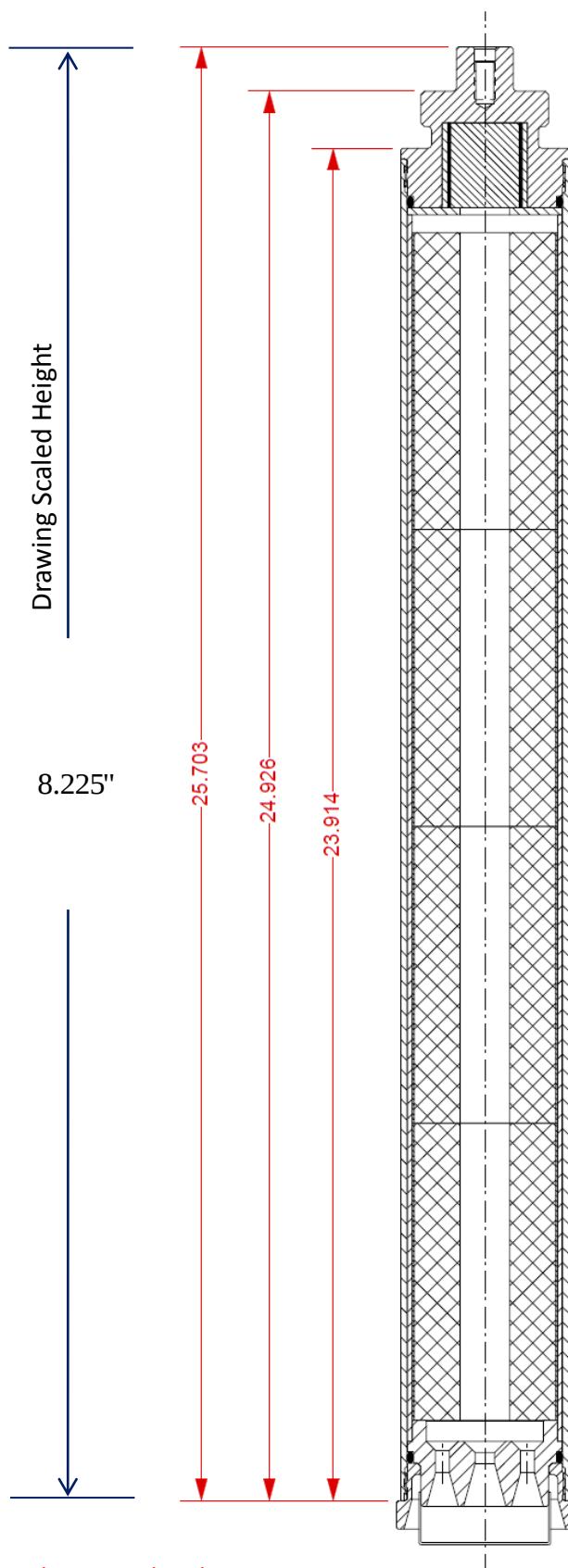
D-REGION TOMAHAWK

Scaled Blueprint

Jeffery H. Oppold 2/25/2012

Material = $\frac{1}{4}$ " Birch Veneer Plywood
Carbon Fiber Reinforced
(Soller Composites: 6KPW50)

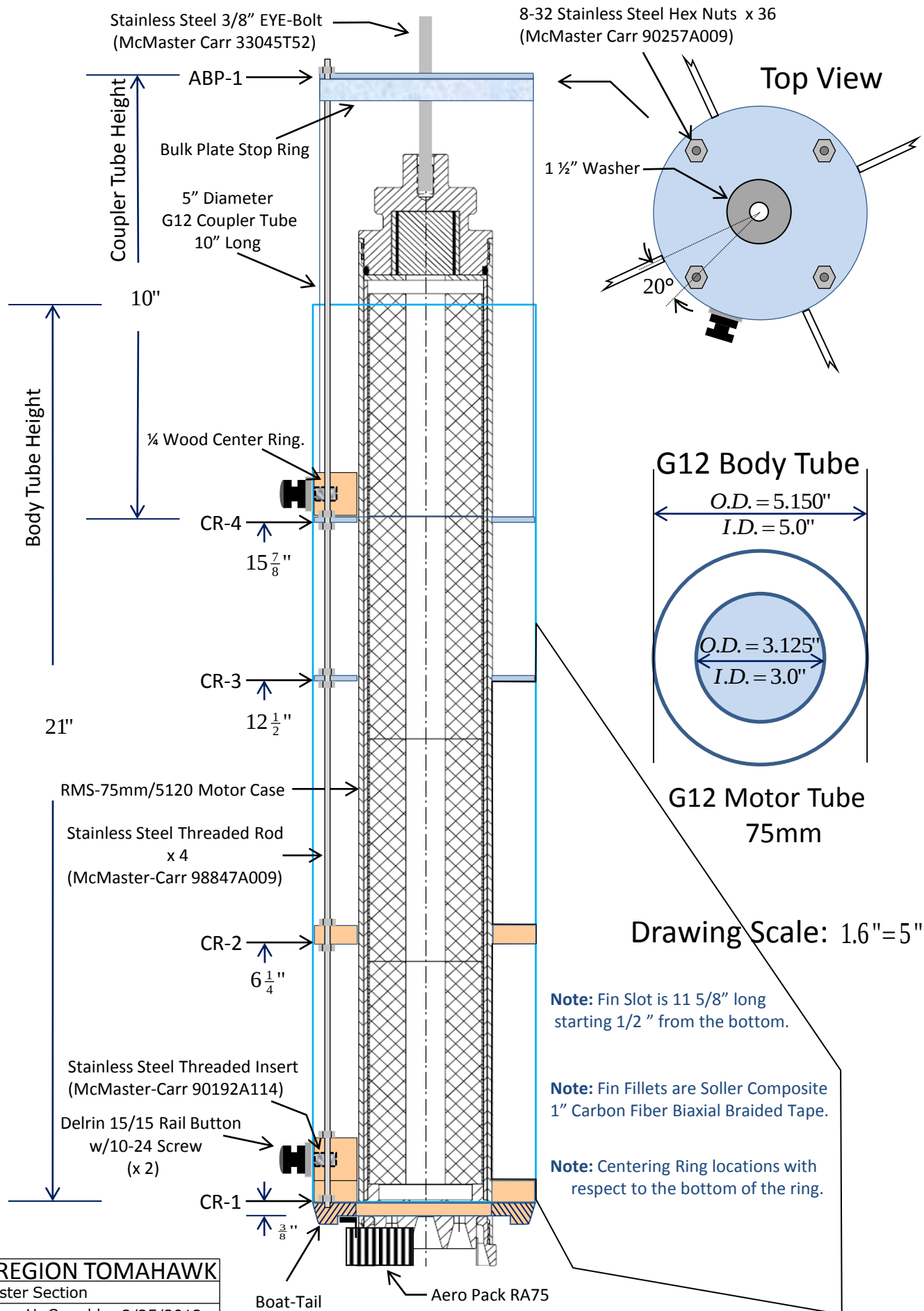




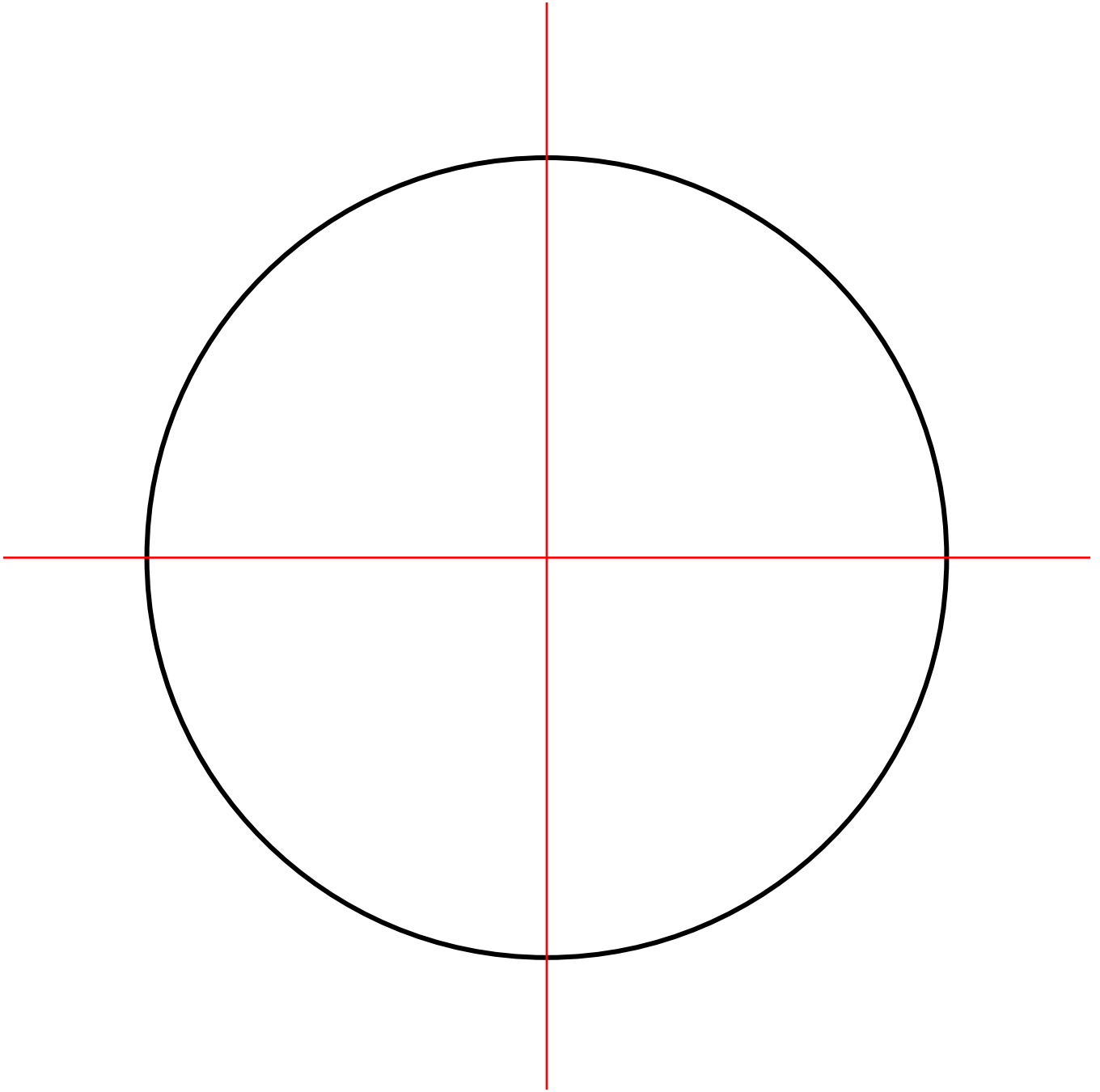
Aerotech RMS-75mm
5120 Motor Case

Note: Taken from the Aerotech web site:

http://www.aerotech-rocketry.com/customersite/resource_library/aerotech_rms_ext_dim_dwgs/75mm_hp_rms/hp_75-5120.pdf

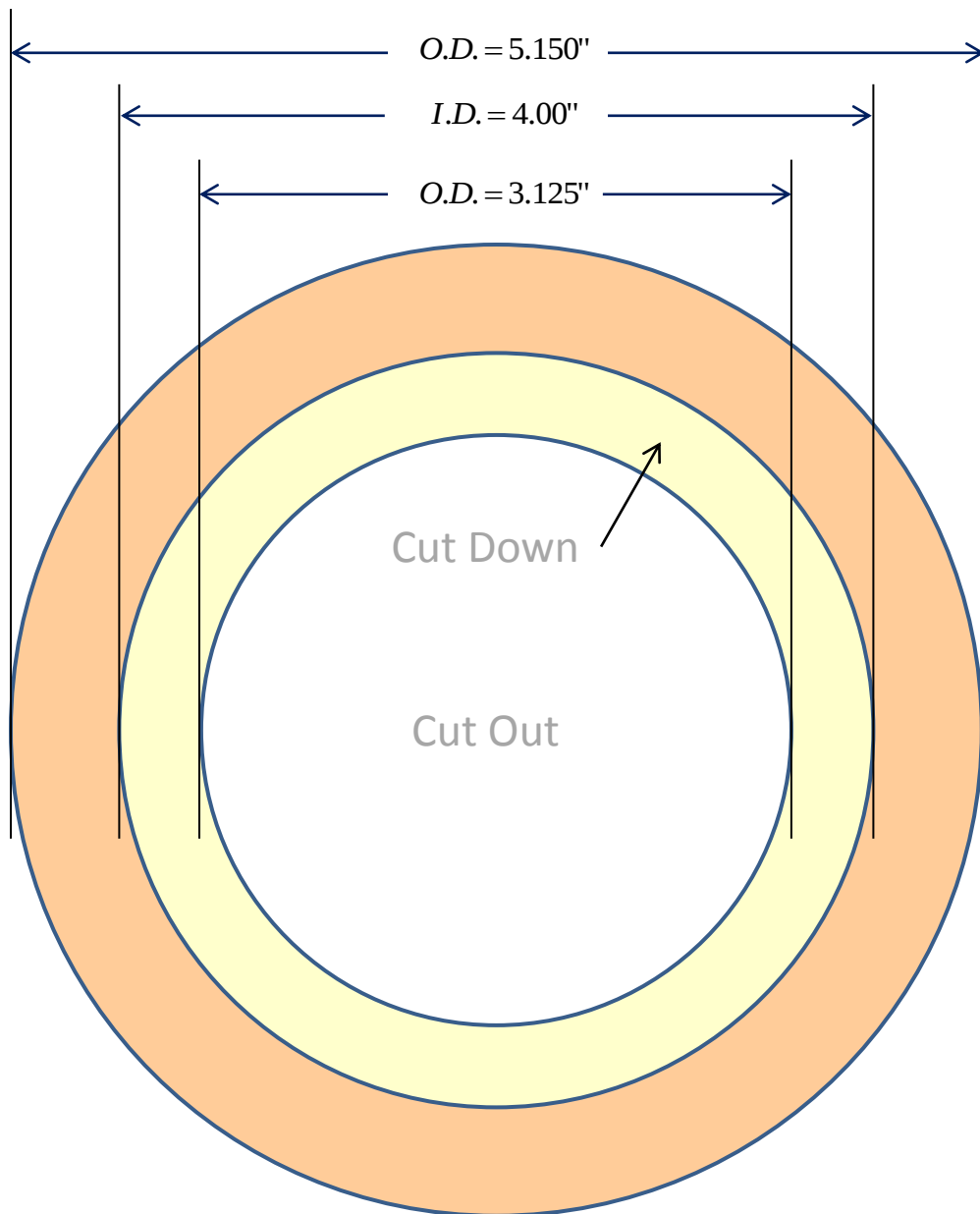


Print out and place tube on top, marking slot location on outside of tube.

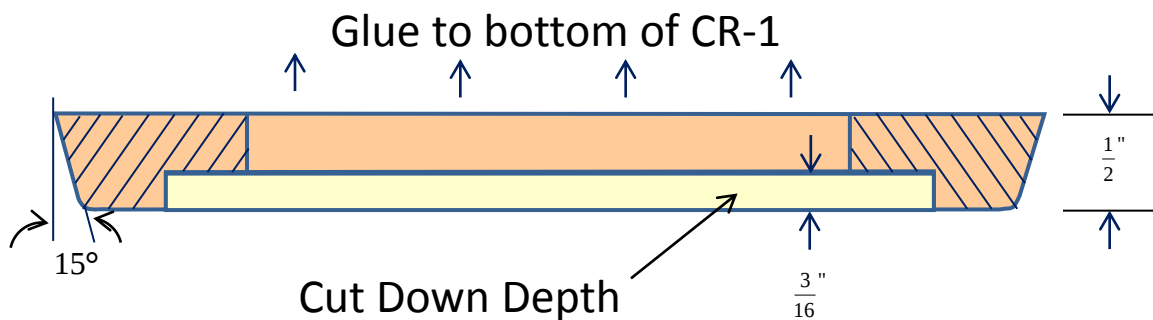


Fin Slot is 11 5/8" long starting 1/2 " from the bottom and is 1/4" in width.

Top View



Side View

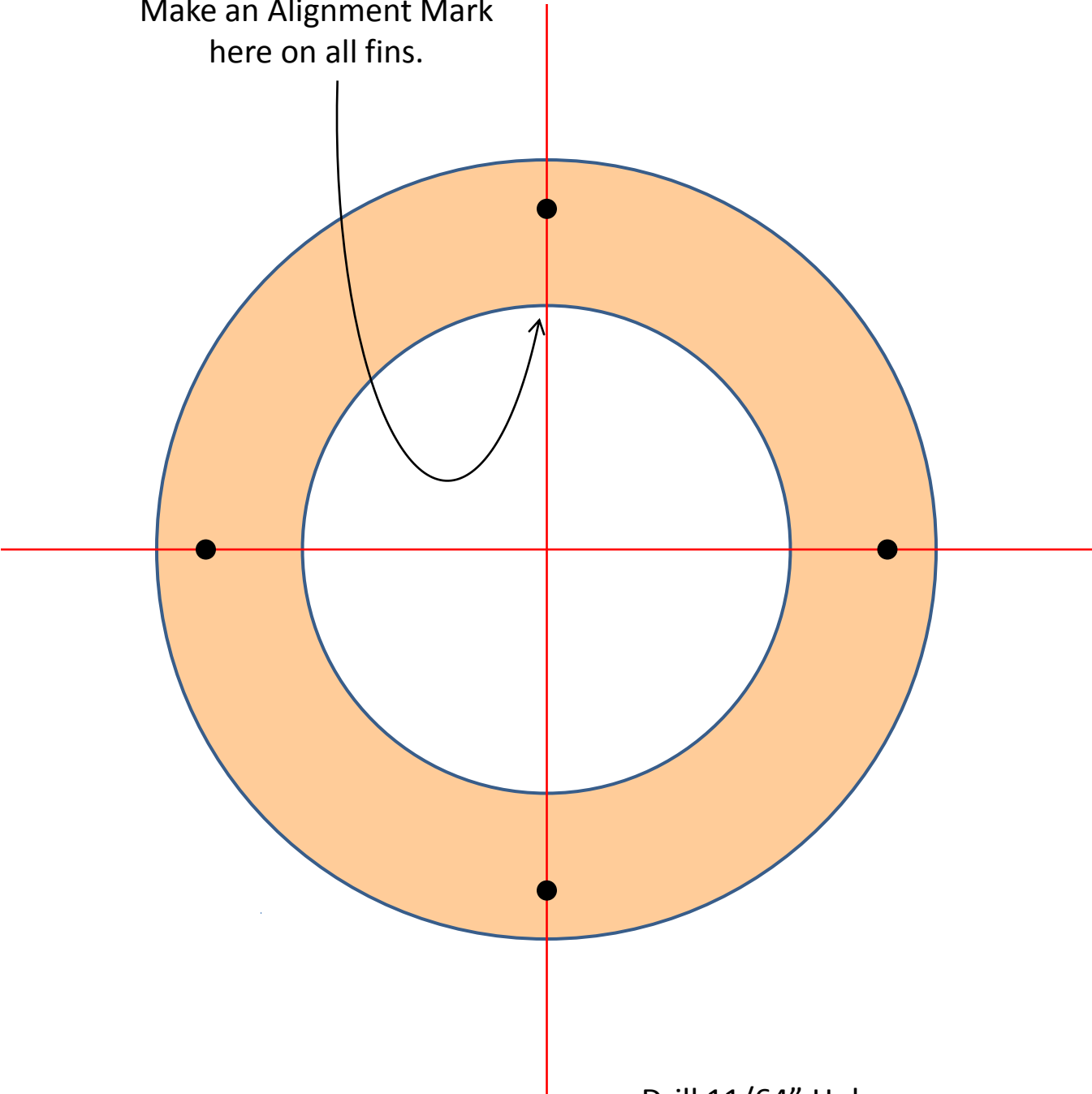


Material = $\frac{1}{2}$ " Birch Veneer Plywood

Drawing Scale: 1.0"=1.0"

Top View

Make an Alignment Mark
here on all fins.

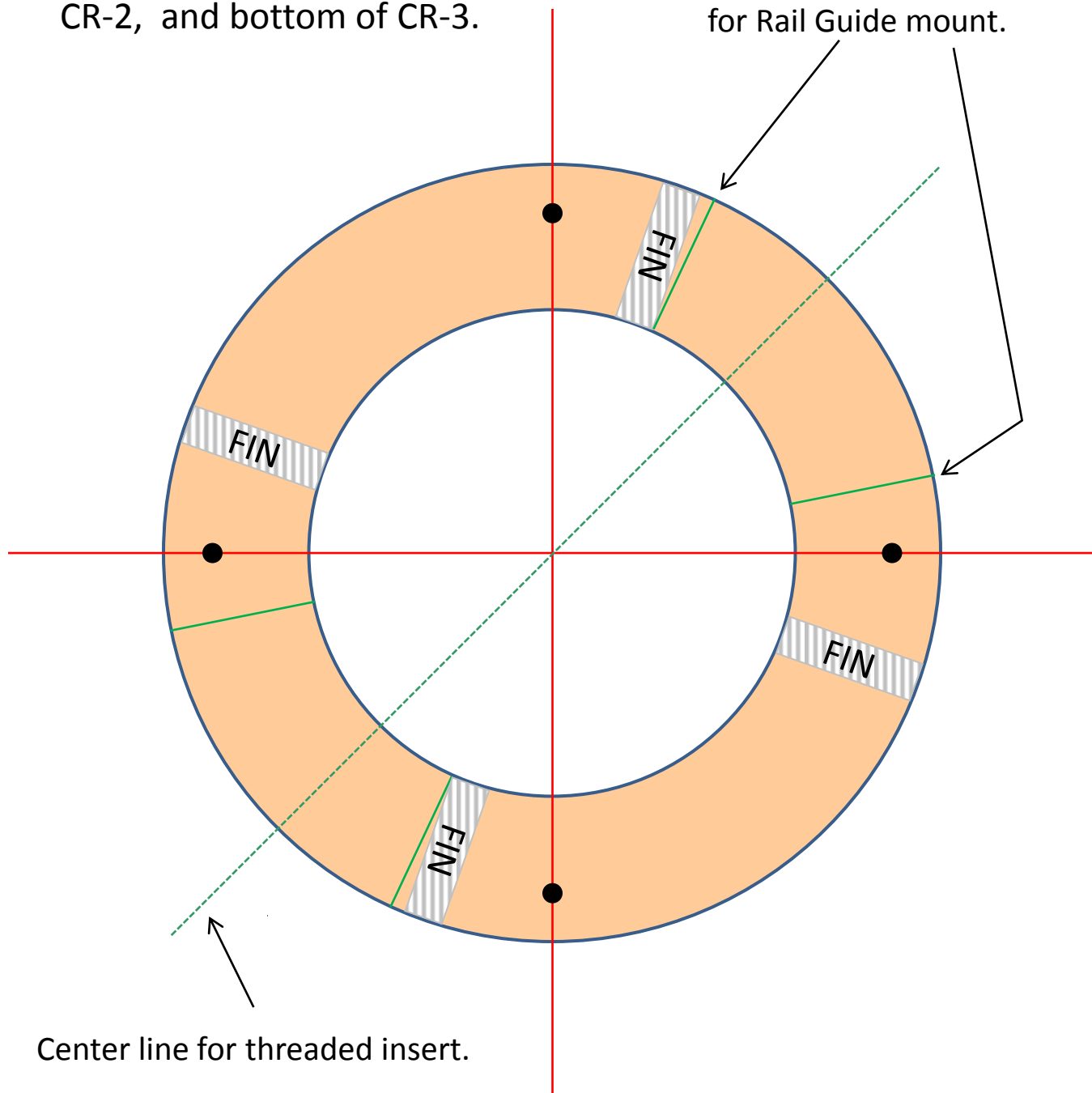


Drill 11/64" Holes

Top View

Transfer to Top of CR-1,
CR-2, and bottom of CR-3.

Placement of 1/6 circle ring used
for Rail Guide mount.



Booster Assembly Procedure

Fins/Centering Rings

- ✓ Cut the fins out of the Birch Plywood. Weight/Fin: 7.50oz
- ✓ Carbon Fiber the fins. (Use West System Epoxy/Bondo Filler) Weight/Fin: 10.65oz
- ✓ Cut four holes for the 8-32 Threaded Rod in each Centering Ring & Top Bulk Plate.
Install the threaded inserts for the Aero Pack into CR-1. ¹Total Weight: 15.0oz
- ✓ Cut the Motor Tube to the correct height. Motor Tube Weight: 16.0oz
- ✓ Dry fit in place CR-1, CR-2 , & CR-3 on to the motor tube.
- ✓ Using the template on page 10, mark the fin locations on CR-1, CR-2 & CR-3.
- ✓ Epoxy CR-1 to bottom of the motor tube making sure its location is correct w/r to the Aero Pack.
- ✓ Using the 8-32 Threaded Rod as an alignment aid, epoxy in place CR-2 & CR-3.
- ✓ Using the fin guides, "tack" epoxy the fins (4-Minute JB-Weld) to the motor tube.
- ✓ Verify that each fin is 90° w/r to each fin on its left and right & is 90° w/r to the body tube.
- ✓ Drill the correct size hole in the center of each rail guide ⅓ ring and screw in the threaded inserts.
- ✓ Using Elmer's Carpenter's Glue, glue the rail guide ⅓ rings to CR-1 & 4. Clamp until dry.
- ✓ Using Loctite Hysol epoxy, put a good size fillet along each fin/body tube seam.
- ✓ Form the internal fin fillets by using the carbon fiber tape & WS epoxy.
- ✓ Epoxy in place CR-4 but omit the top fillet as the coupler tube needs to fit flush against this ring.
- ✓ Install the threaded rod and nuts. Secure nuts with Loctite Blue 242 Threadlocker.
- ✓ Weigh the final assembly. Weight: 86.0oz
- ✓ Subtract 4 x weight/fin and total weight of the rings from the above measurement.
(This is the motor tube/epoxy/carbon fiber/rods/rail guides weight). Updated Motor Tube Weight: 28.4oz

Body Tube

- ✓ Cut the body tube to length from 5" G10 Fiber Glass Tubing.
- ✓ Cut the 4:11 $\frac{5}{8}$ " slots for the fins.
- ✓ Fit the final Fin Can assembly inside the booster tube.
- ✓ Mark the rail guide locations on the outside of the body tube.
- ✓ Remove the Fin Can and drill the holes for the retention screws. Weight: 27.00oz

¹) Boat Tail, CR-1 & CR-2 weigh 4oz each and CR-3 & CR-4 Weigh 1.5oz each.

Booster Assembly Procedure - Continued

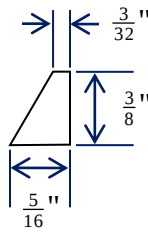
Final Assembly

- ☒ Epoxy the Fin Can into the Body Tube. Use small C-clamps at the body tube/CR-1 joint.
- ☒ Fill the booster/fin joint with epoxy. Sand smooth.
- ☒ Cut the Bulkhead Stop Ring from scrap 5" tubing and epoxy to the inside top of the coupler ring.
- ☒ Weigh the couple tube and bulk plate. Weight: 20oz
- ☒ Insert the Coupler into the Body tube but do not epoxy at this time. Mount the Bulk Plate and temporary secure with nuts. Insert RMS-75mm/5120 Motor Case. Test fit the motor retention bolt.
- ☒ Remove the Bulk Plate and Motor Case. Epoxy the coupler tube to the body tube. Add a generous fillet of West System Epoxy to the topside of CR-4.
- ☒ Re-attach the Top bulk plate. Epoxy the 1 1/2" washer to the top of the bulk plate.

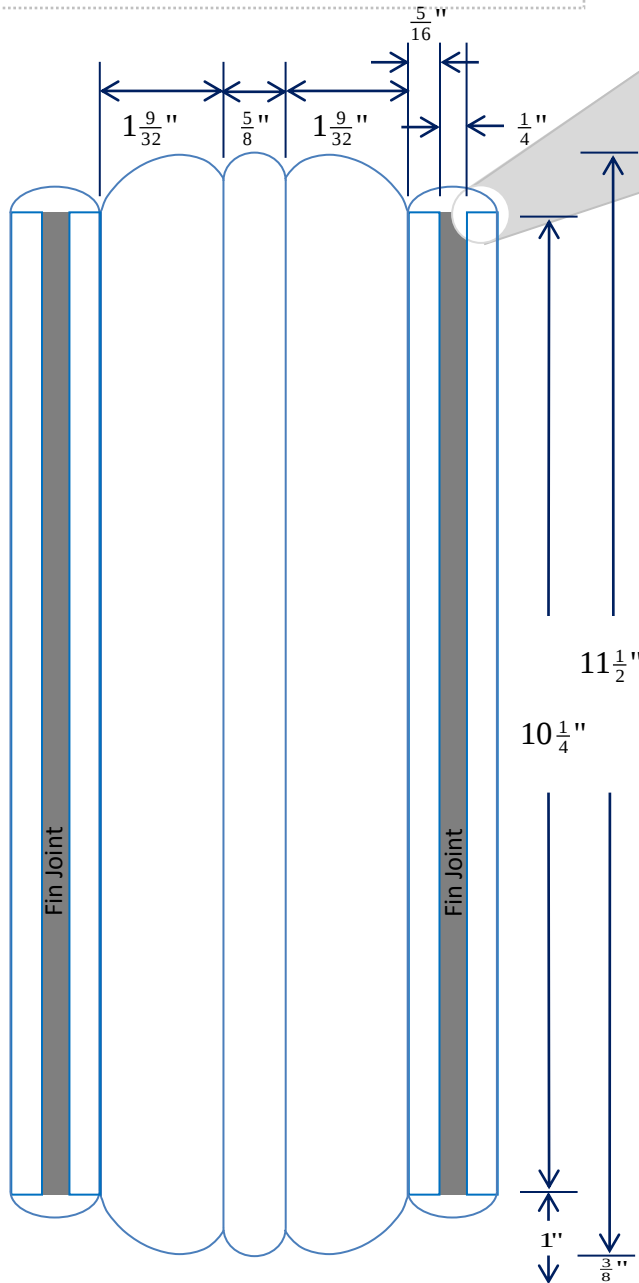
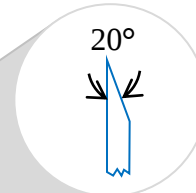
Scale Raised Detail

- ☒ Cut the Fin Fillet from hard wood stock and epoxy in place.
- ☒ Cut the body tubing raised details from PML Quantum tubing and epoxy in place.
- ☒ Finish Sanding all surfaces and spray a coat of Krylon Grey Primer.
- ☒ Weigh the final Booster. Weight:144.5oz

Fin Fillet Cross-sectional Detail
Drawing Scale: 1"=1"



Fin Fillet End detail



Fin shown for reference.

Calculations for Raised Detail Widths:

Tube Circumference = $5.15 * 3.14159 = 16.18"$

Less Fins Width: $(0.25" * 4) = 15.18"$

Final Detail Area: $/ 4 = 3.795"$

Less Fin Fillets: $(2 * 0.3125") = 3.17"$

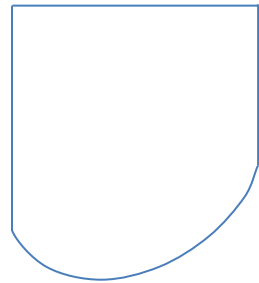
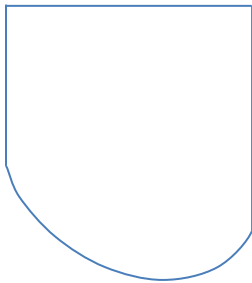
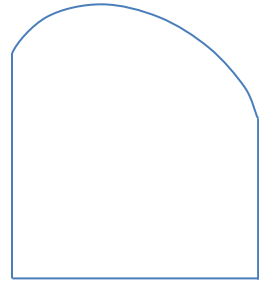
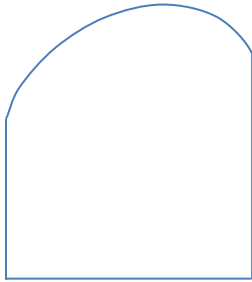
Want 2:1:2 Detail Width Ratio: $/ 5 = 0.634"$

Outside Detail Width $(0.634 * 2) = 1.268"$

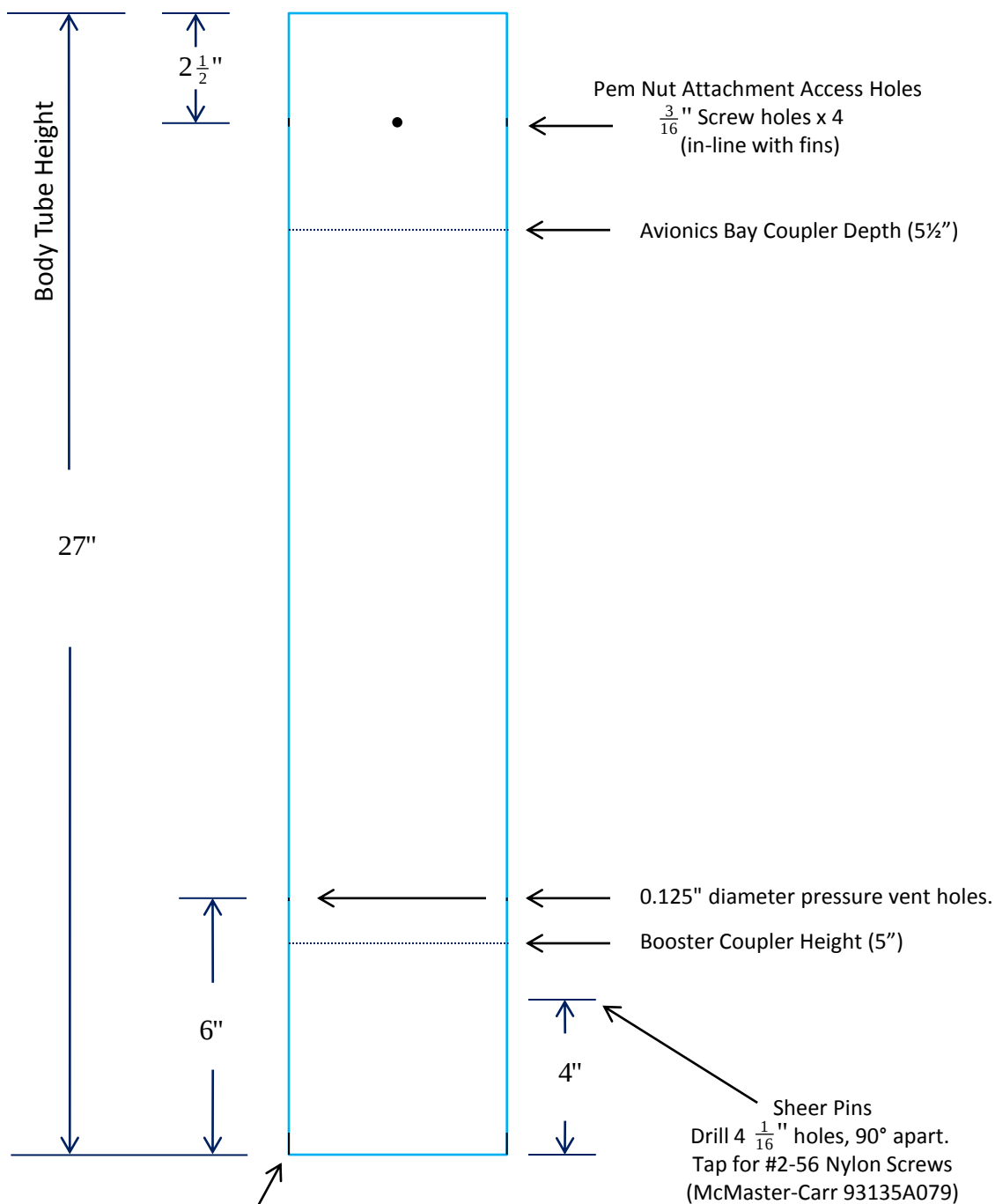
Inside Detail Width = $0.634"$

Bottom of Body Tube

Raised Detail Templates

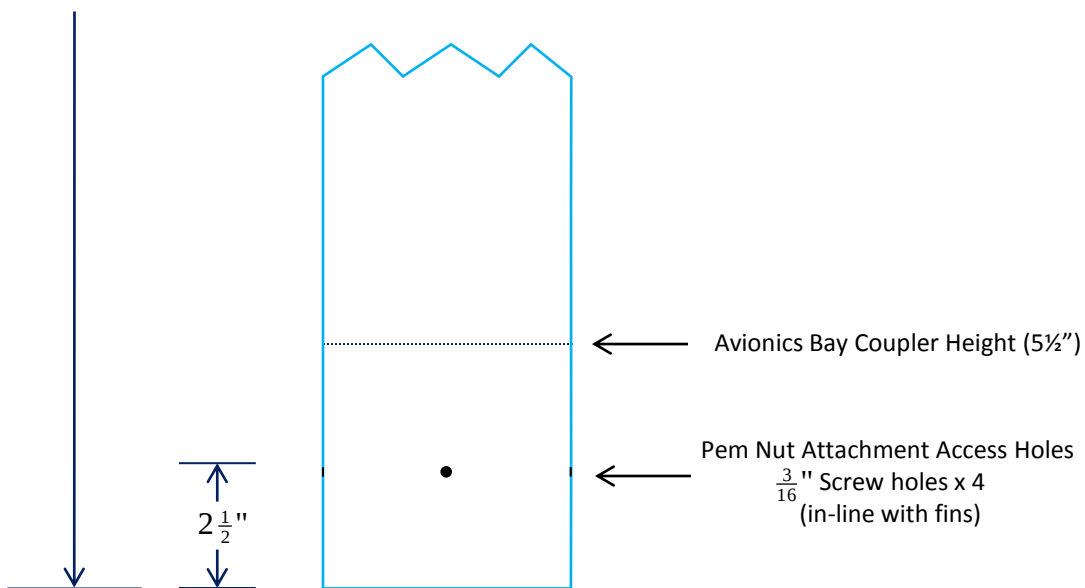
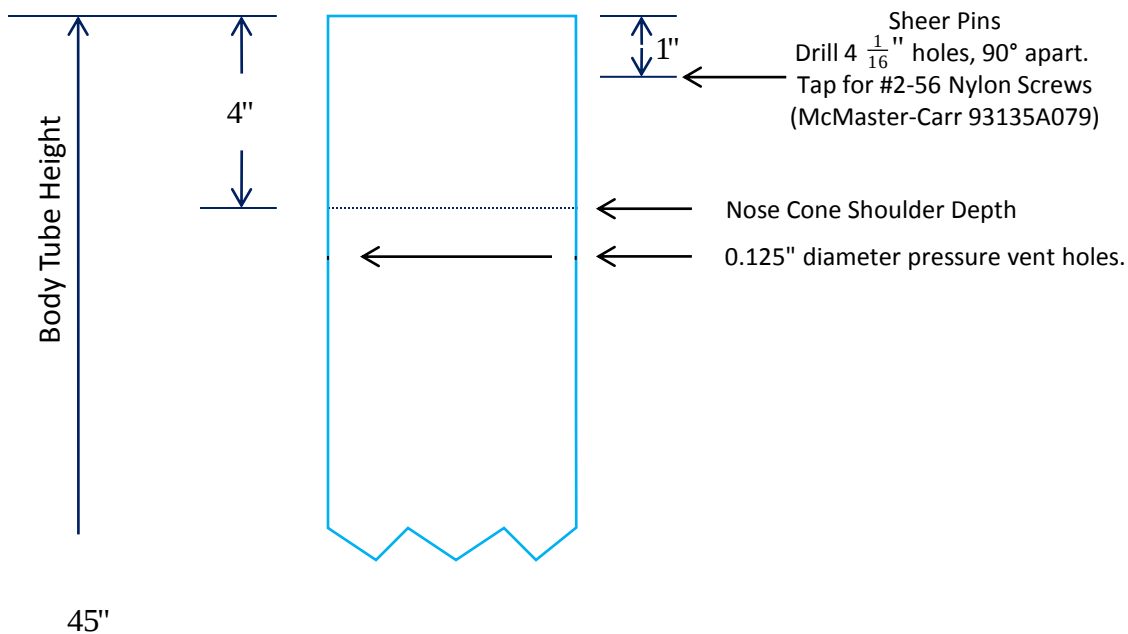


Print on Card Stock and Cut Out.



Anti-zipper steel band embedded
flush with fiberglass surface.
Band is 0.500" wide and 0.025" thick.
(Hose clamp band.)

Note: With the Booster Section attached, drill the
sheer pin holes all the way through the airframe and
the booster's coupler tube. Increase the size of the
coupler's hole to $\frac{7}{64}$ ".



Note: With the Nose Cone attached, drill the shear pin holes all the way through the airframe and the Nose Cone's Shoulder. Increase the size of the shoulder hole to $\frac{3}{32}$ ".

Air Frame Assembly Procedure

Pem Nuts Holes

- ☒ Use the fin alignment guide on page 7 to mark the fin locations at the top of the Mid-Section Air Frame.
- ☒ Extend the marks down 2 ½" from the top of the body tube.
- ☒ Secure the Avionics Bay's Coupler inside the body tube up to the half way point.
- ☒ Drill the 4 holes for the Pem Nuts through both tubes.
- ☒ Use the fin alignment guide on page 7 to mark the fin locations at the bottom of the Upper-Section Air Frame.
- ☒ Extend the marks up 2 ½" from the bottom of the body tube.
- ☒ Secure the Avionics Bay's Coupler inside the body tube up to the half way point, taking care to align the fin locations with those on the Mid-Section Air Frame.
- ☒ Drill the 4 holes for the Pem Nuts.

Mid-Section Shear Pins/Pressure Vents

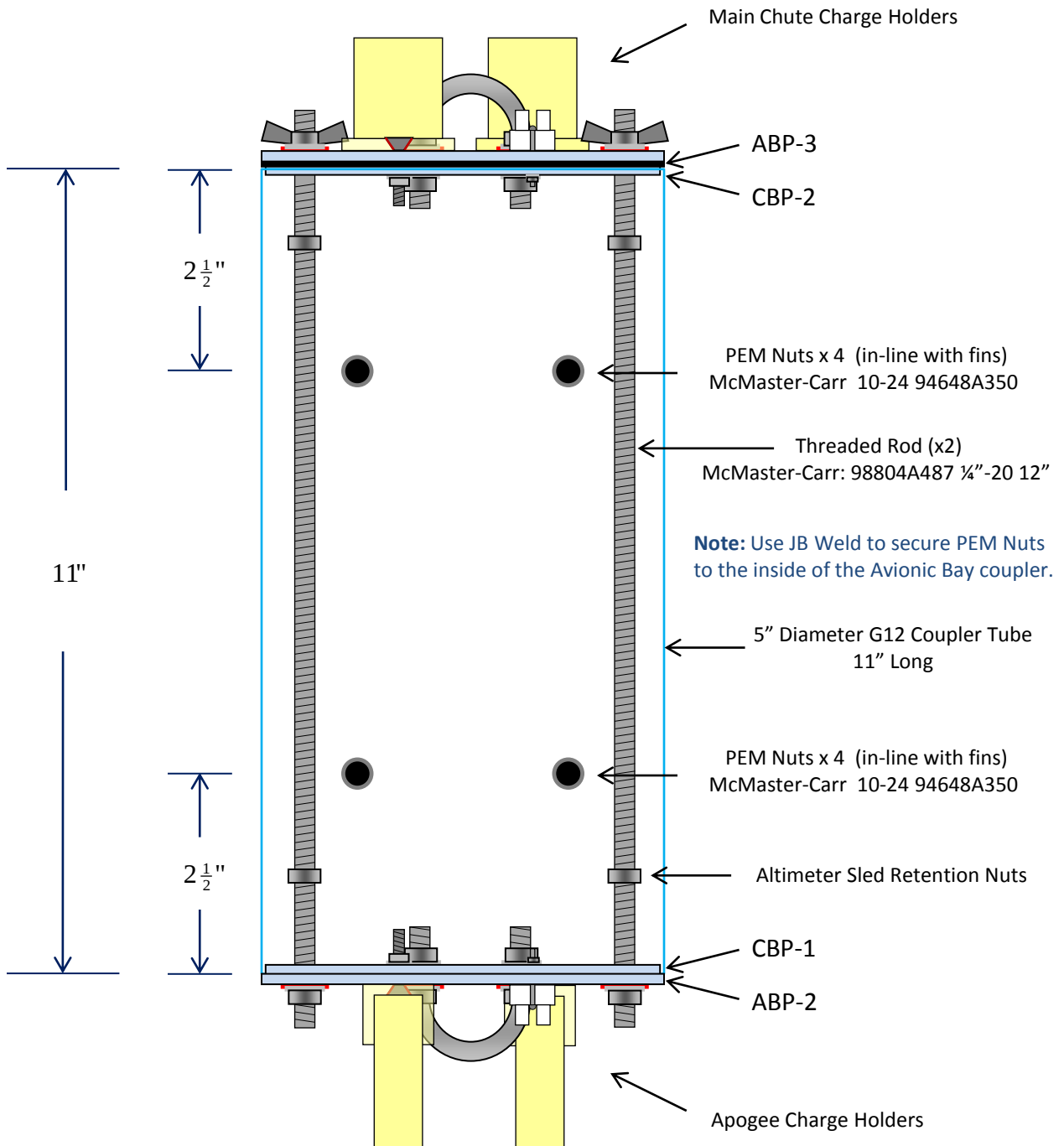
- ☒ Draw an alignment mark directly centered between each fin, and make a mark 4" up from the bottom.
- ☒ Drill a shear pin hole and tap, screwing in a shear pin before drilling the next hole. Drill all 4 holes in this sequence.
- ☒ Drill the pressure vent holes.
- ☒ Weigh the final Mid-Section Air Frame

Weight: 35.0oz

Upper-Section Shear Pins/Pressure Vents

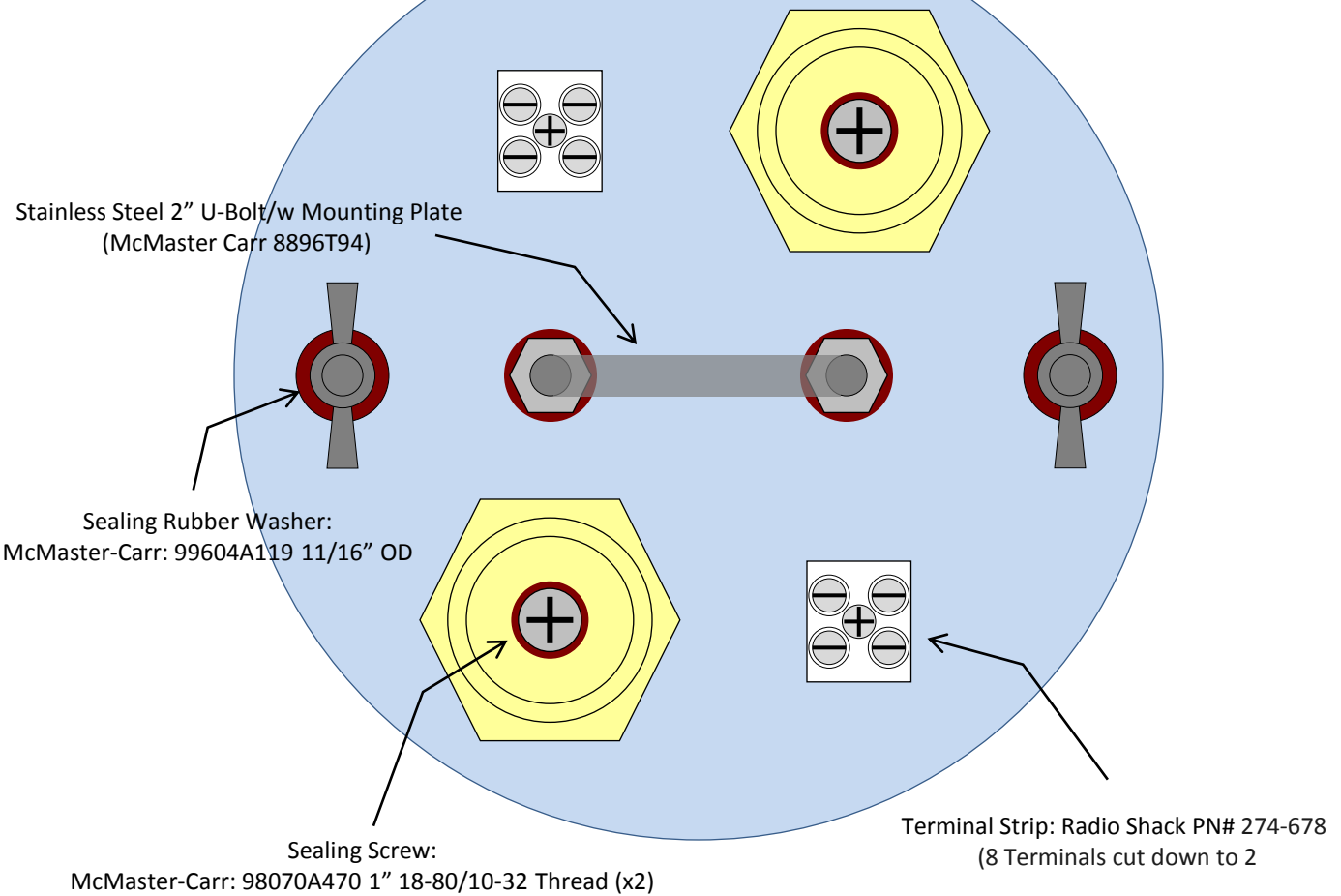
- ☒ Extend the fin alignment marks, drawn in the Pem Nut assembly procedure, down the full length of the tube.
- ☒ Find and mark the center point between each of these marks, 1" down from the top.
- ☒ Drill a shear pin hole and tap, screwing in a shear pin before drilling the next hole. Drill all 4 holes in this sequence.
- ☒ Drill the pressure vent holes.
- ☒ Weigh the final Mid-Section Air Frame

Weight: 59.0oz

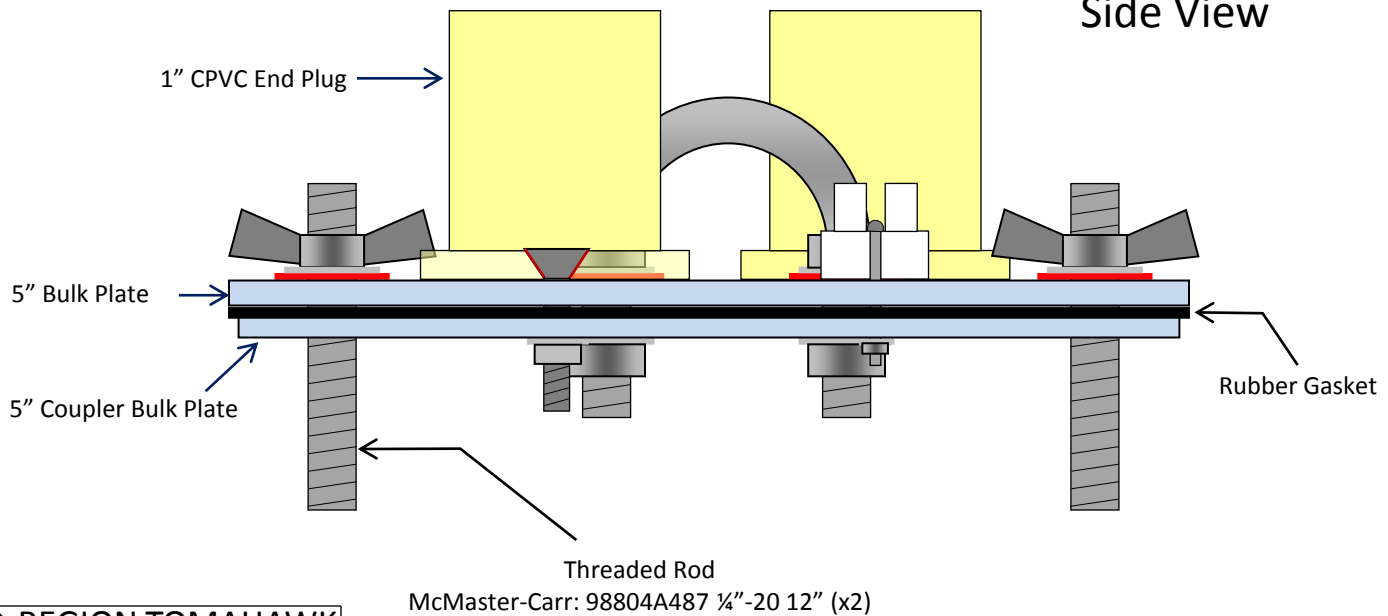


Top and Bottom Charge Holder details are on next two pages.

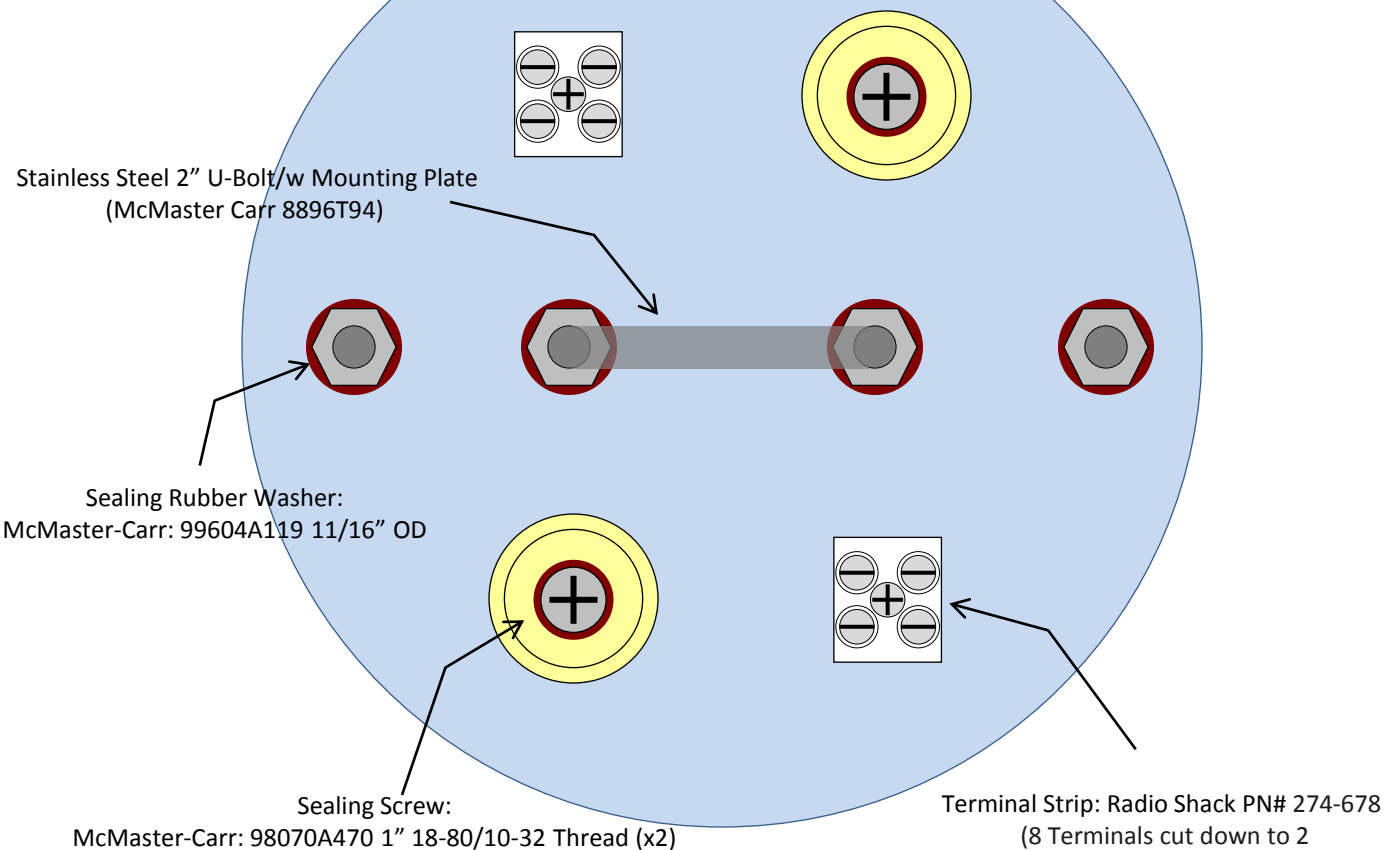
Top View



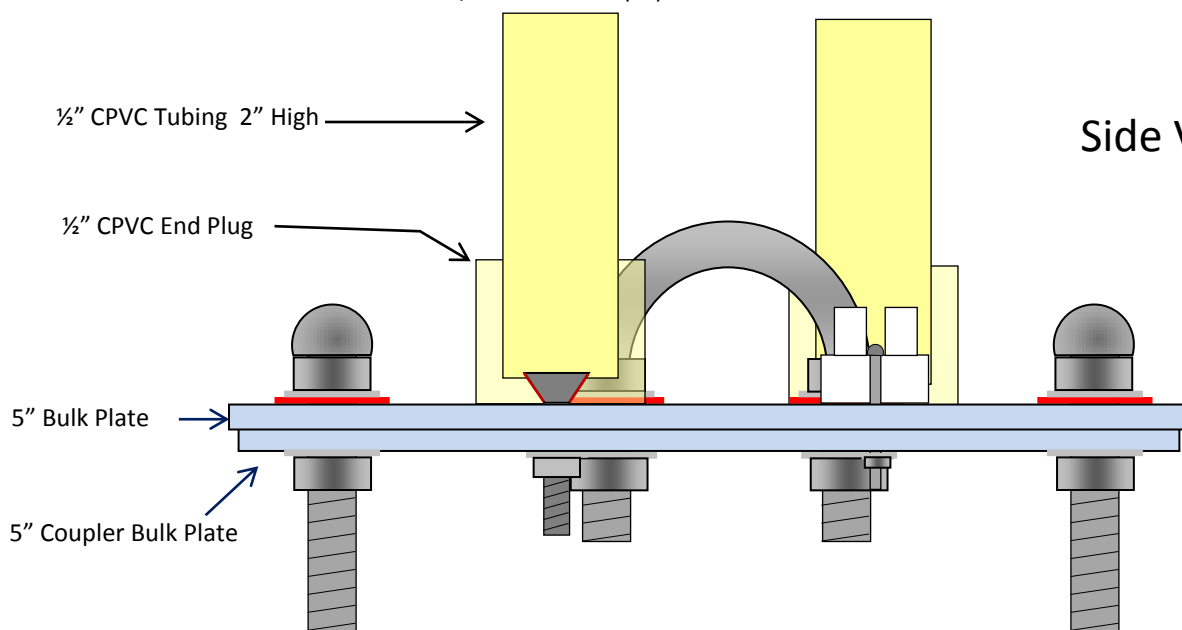
Side View



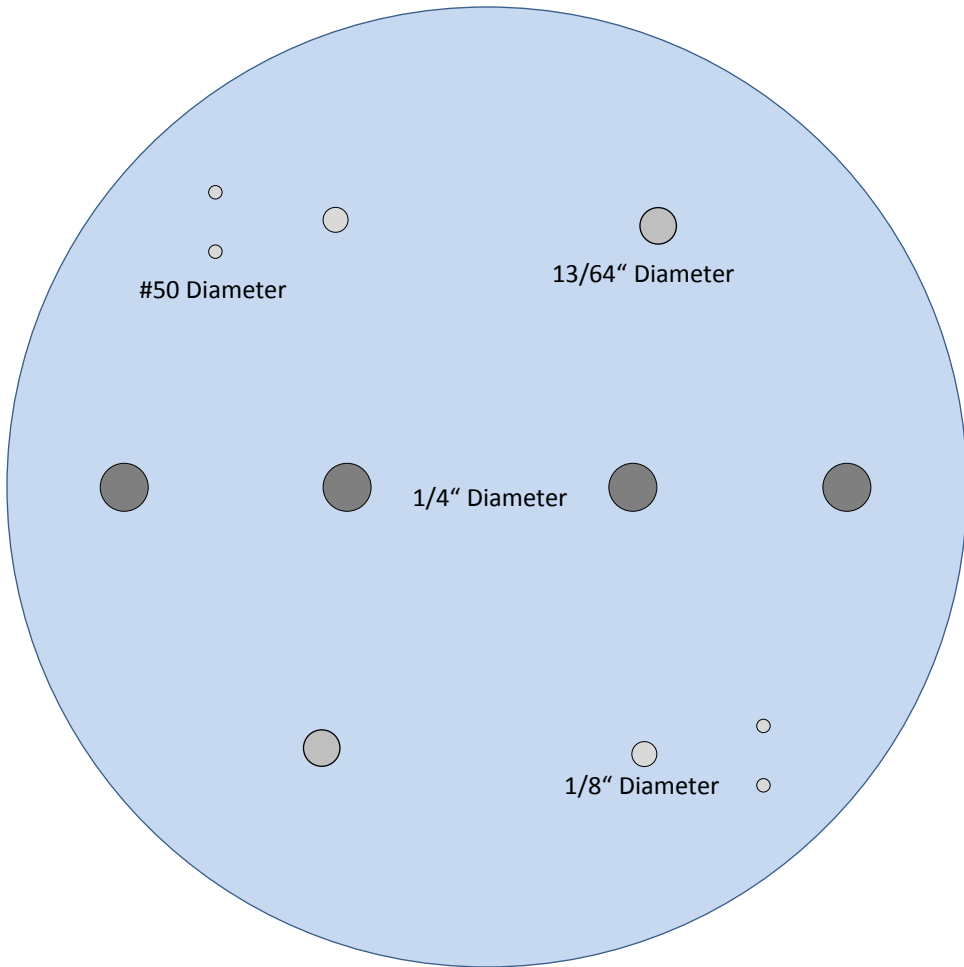
Top View



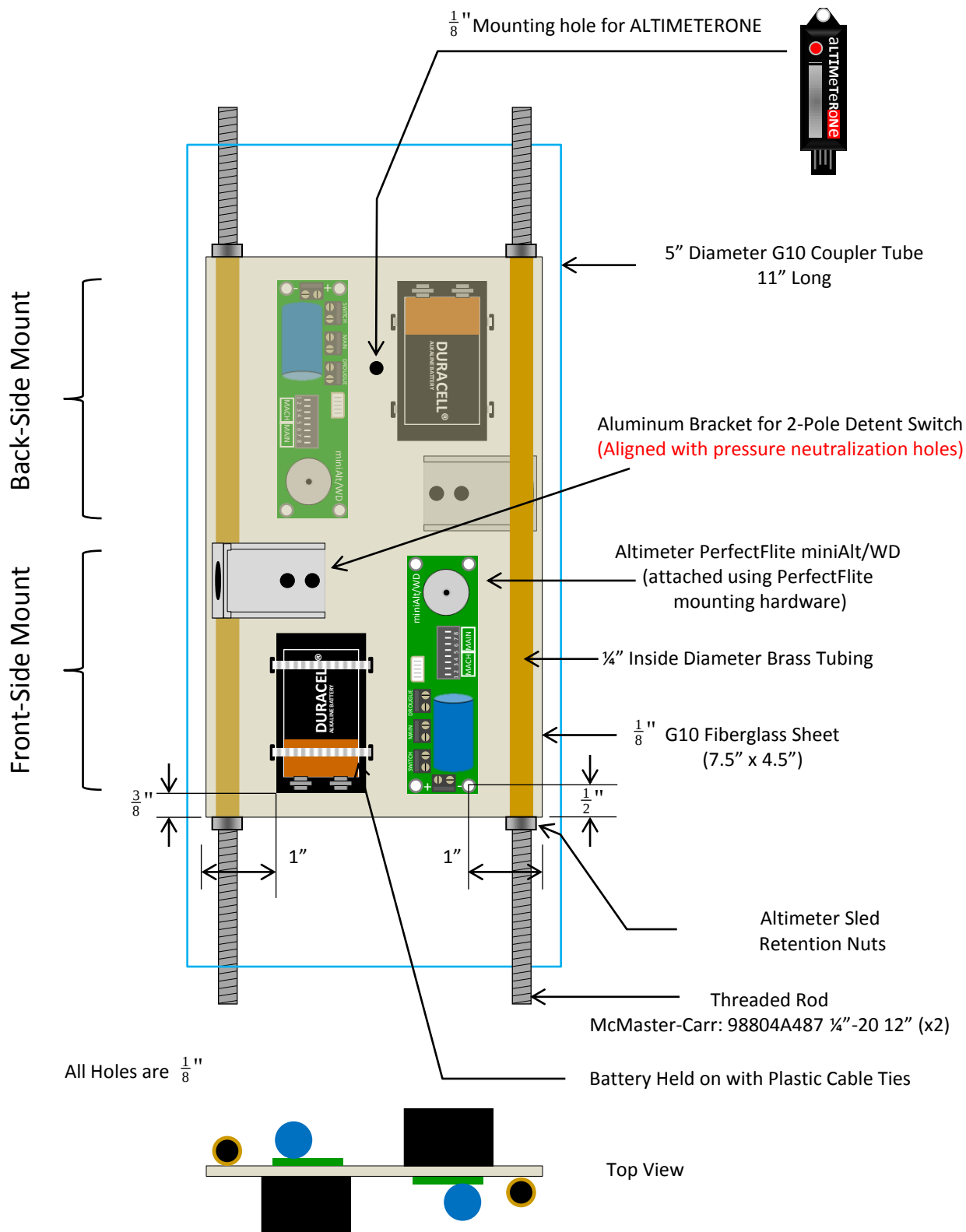
Side View



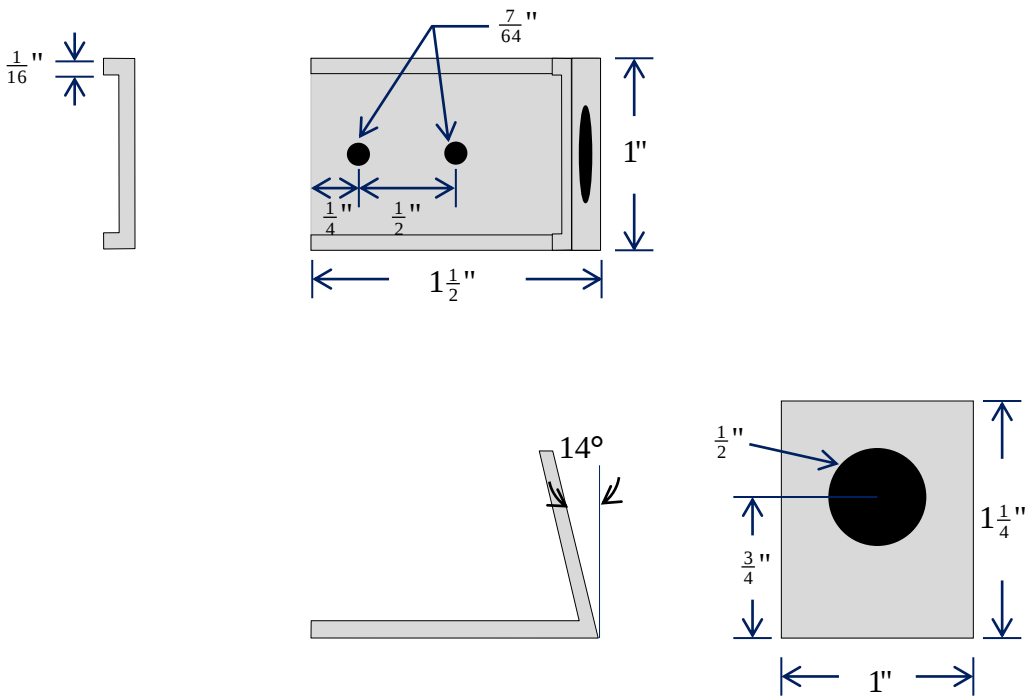
Drilling Template



Altimeter Sled



Aluminum Bracket Detail



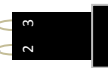
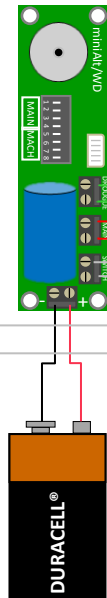
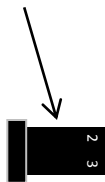
Primary (1100FT) Main Charge

Backup (900FT) Main Charge

Avionics' Top Bulkhead

Missile Works
2-Pole Detent Switch

110 = OFF
220 = ON



Avionics' Bottom Bulkhead

Primary Circuits Wires
are Solid Colors

Secondary Circuits Wires
are Solid Colors w/Black Stripe

Primary Drogue Charge

Backup (+1 Second) Drogue Charge

Avionics Bay Assembly Procedure

Bulk Plates

- ✓ Using the outside edge of the Body Tube Bulk Plate, cut out two gaskets from the gasket material.
- ✓ Using a 4" tube, cutout the center of the gasket.
- ✓ Using CA glue, glue the gaskets to the bulk plates.
- ✓ Epoxy the Coupler Bulk Plates to the Body Tube Bulk Plates, using a bolt through the center holes of the two plates, center the plates and compress the epoxy.
- ✓ Cut out 2 hole drilling templates on page 21.
- ✓ Tape the templates in place over the assembled Bulk Plates and drill the various holes.
- ✓ Assemble and attach the various U-Bolts, wire terminals, and charge holders.

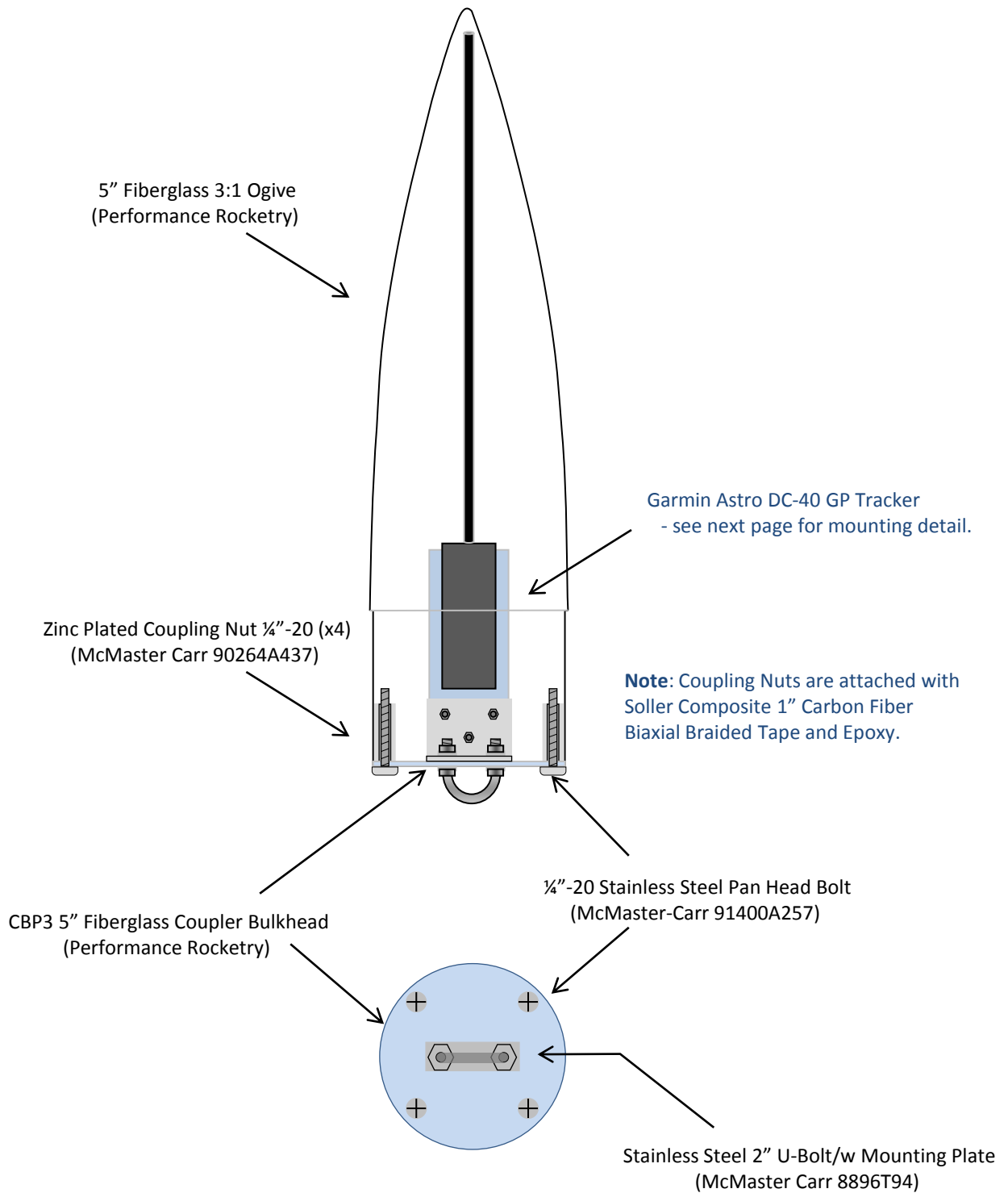
Pem Nuts

- ✓ Using a large C Clamp, compress the Pem Nuts in to the Avionics' Coupler Tube.
- ✓ Using JB Weld, epoxy, on the inside of the tube, the Pem Nuts in place.

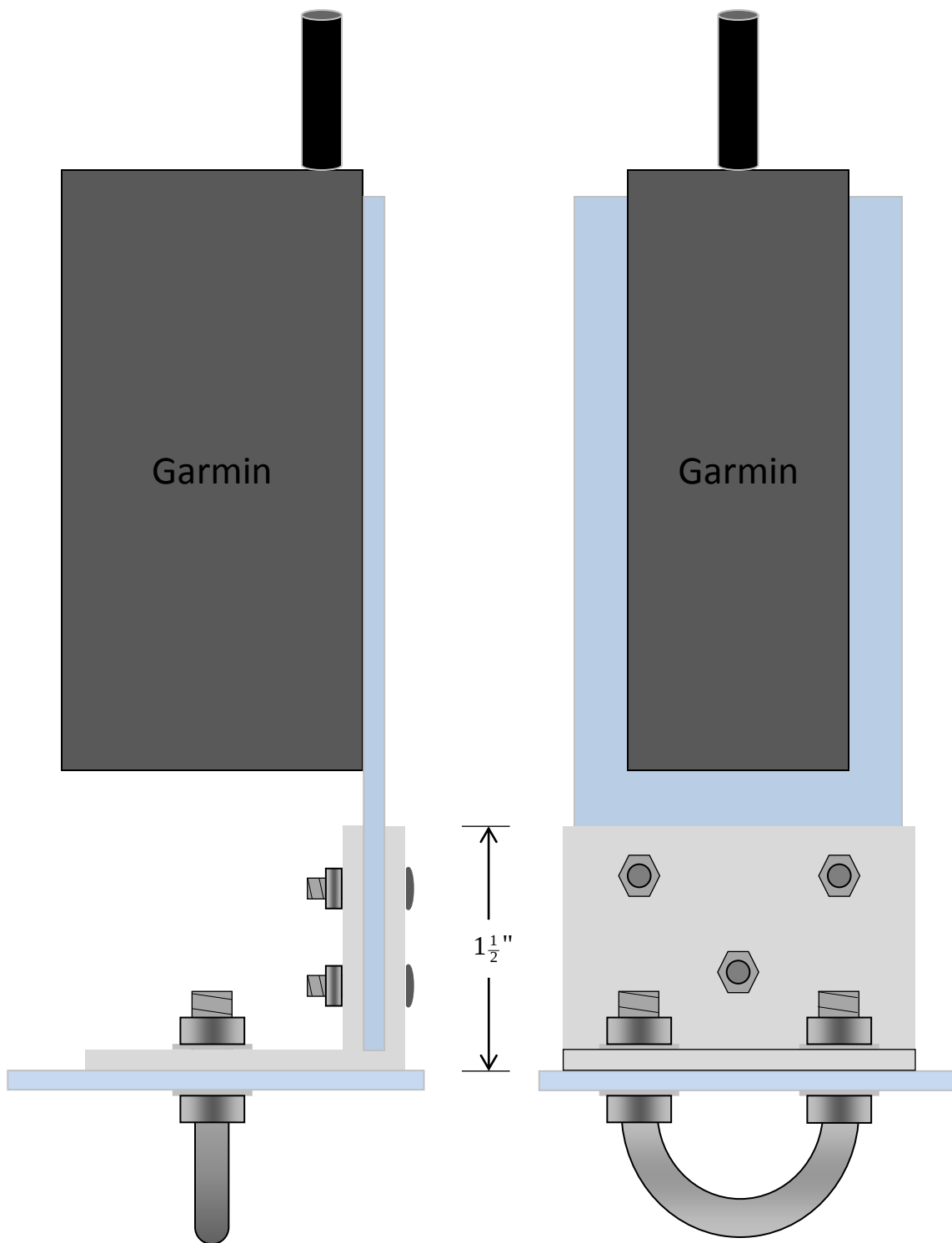
Altimeter Sled

- ✓ Cut the G10 material to the specified dimensions.
- ✓ Using the drilling template supplied with the altimeters, as well as the battery pack and switch bracket, drill the required holes.
- ✓ Cut two pieces of the brass tubing to specified length.
- ✓ Temporarily assemble the two threaded rods through the bulk plates to be used as an alignment aid for attaching the brass tubes to the G10 sled material.
- ✓ Using JB Weld, epoxy the brass tubes to the sled. Note that one tube is on the front, while the other is on the back of sled material. Apply a generous fillet to the joints.
- ✓ Assemble all components onto the Sled and wire per the schematic on page 24.
- ✓ Weigh the assembled Avionics Bay.

Weight: 59.0oz

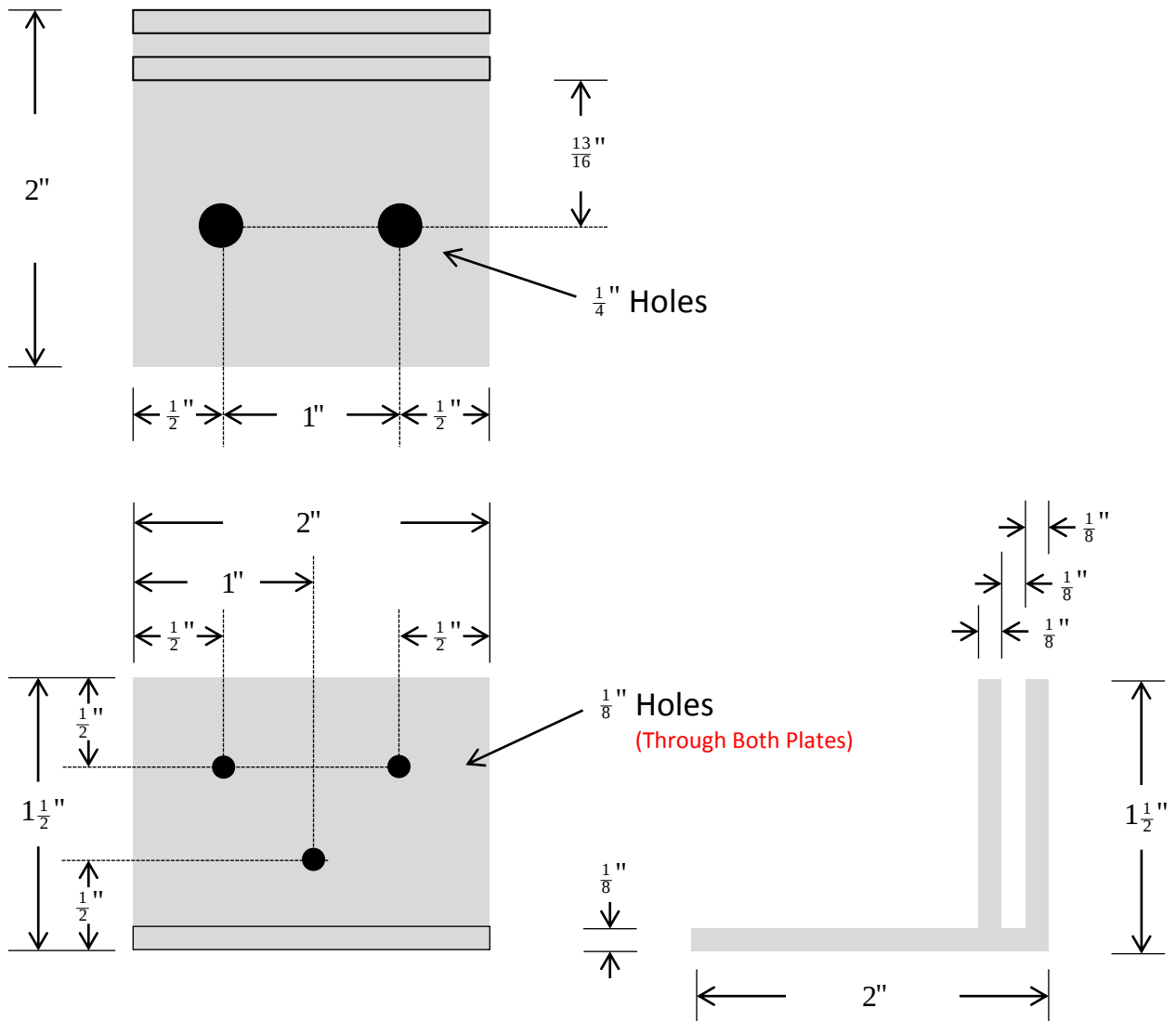


Bottom View



Retention Bolt: M3x16mm 0.50 Pitch

Garmin Astro DC-40 Aluminum Mounting Bracket



Nose Cone Assembly Procedure

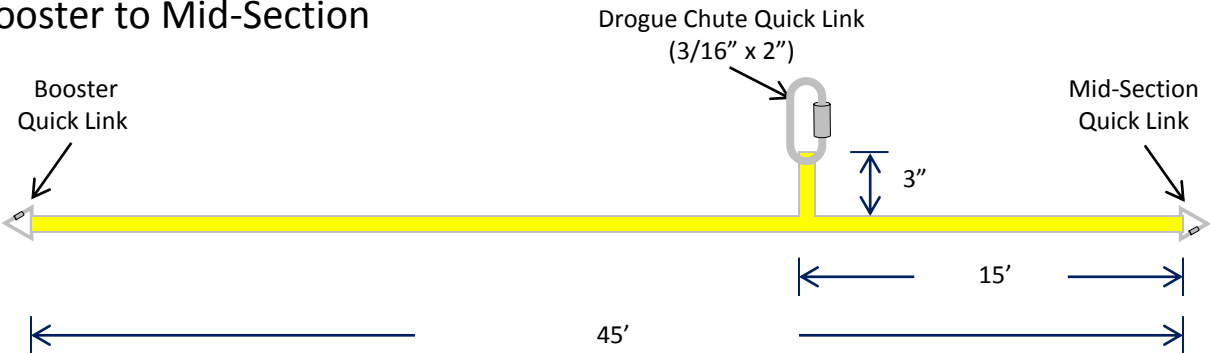
Bulk Plates

- ☒ Drill the four holes in the bulk plate. Use the inside of the shoulder for alignment.
- ☒ Temporary attached the bolts and coupler nuts to the back side of the bulk plate.
- ☒ For each coupler nut, align a flat edge to the outside, flush with the edge of the bulk plate.
- ☒ Using JB Weld epoxy (quick cure), place a small amount on the edge of the coupler nut that is flush with the bulk head outer edge.
- ☒ Slide the assembly inside the nose cone shoulder and allow the epoxy to cure.
- ☒ Carefully remove the bolts and bulk head. The coupler nuts should be perfectly aligned.
- ☒ Using the carbon fiber tape and West System Epoxy thicken to mayonnaise consistency, carefully wrap the tape around the inside of the shoulder covering the coupler nuts. Take care not to the get epoxy on the inside threads of the nuts.
- ☒ Drill the two holes for the U-Bolt.
- ☒ Cut a piece of G10 for the GPS mounting plate.
- ☒ Place the G10 sheet inside the mounting bracket and mark the location of the holes and drill.
- ☒ Using the back piece of the GPS unit, mark where the holes for the attachment screws go and drill.
- ☒ Assemble all components to test for fit and function.
- ☒ Weigh the assembled Nose Cone.

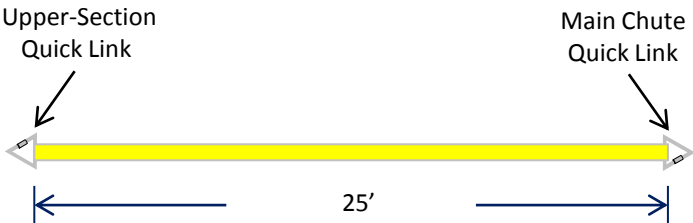
Weight: 29.6oz

Recovery Harness

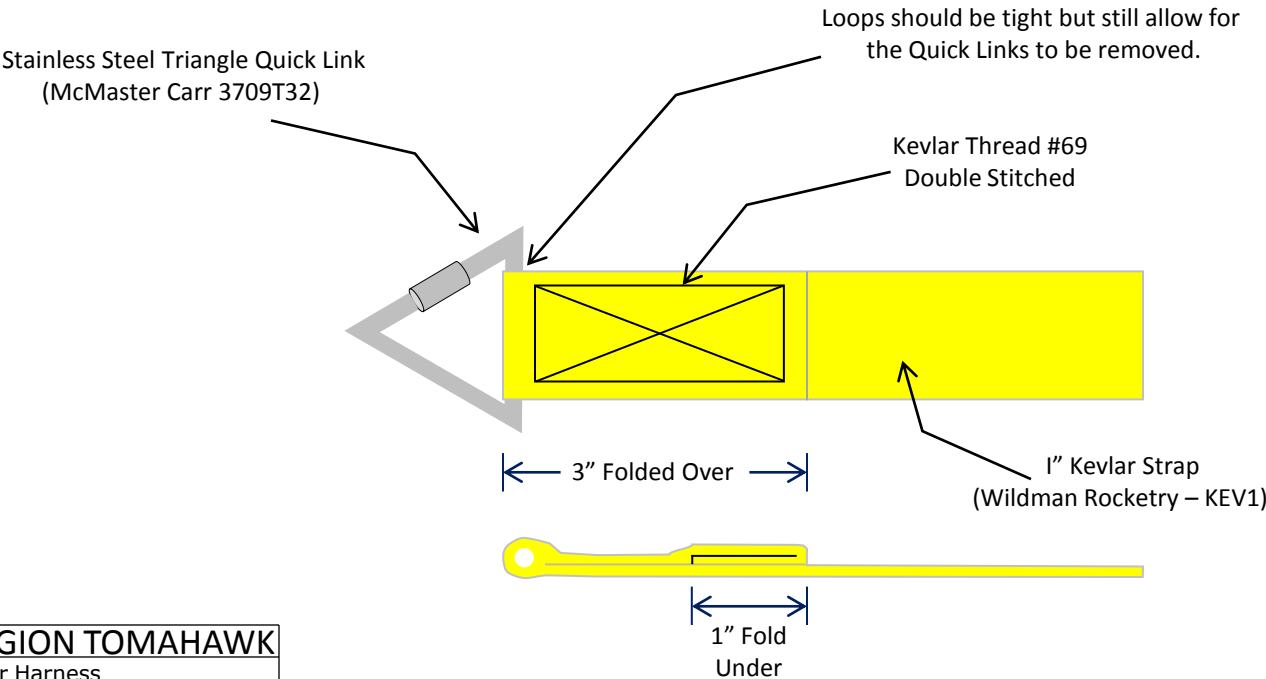
Booster to Mid-Section



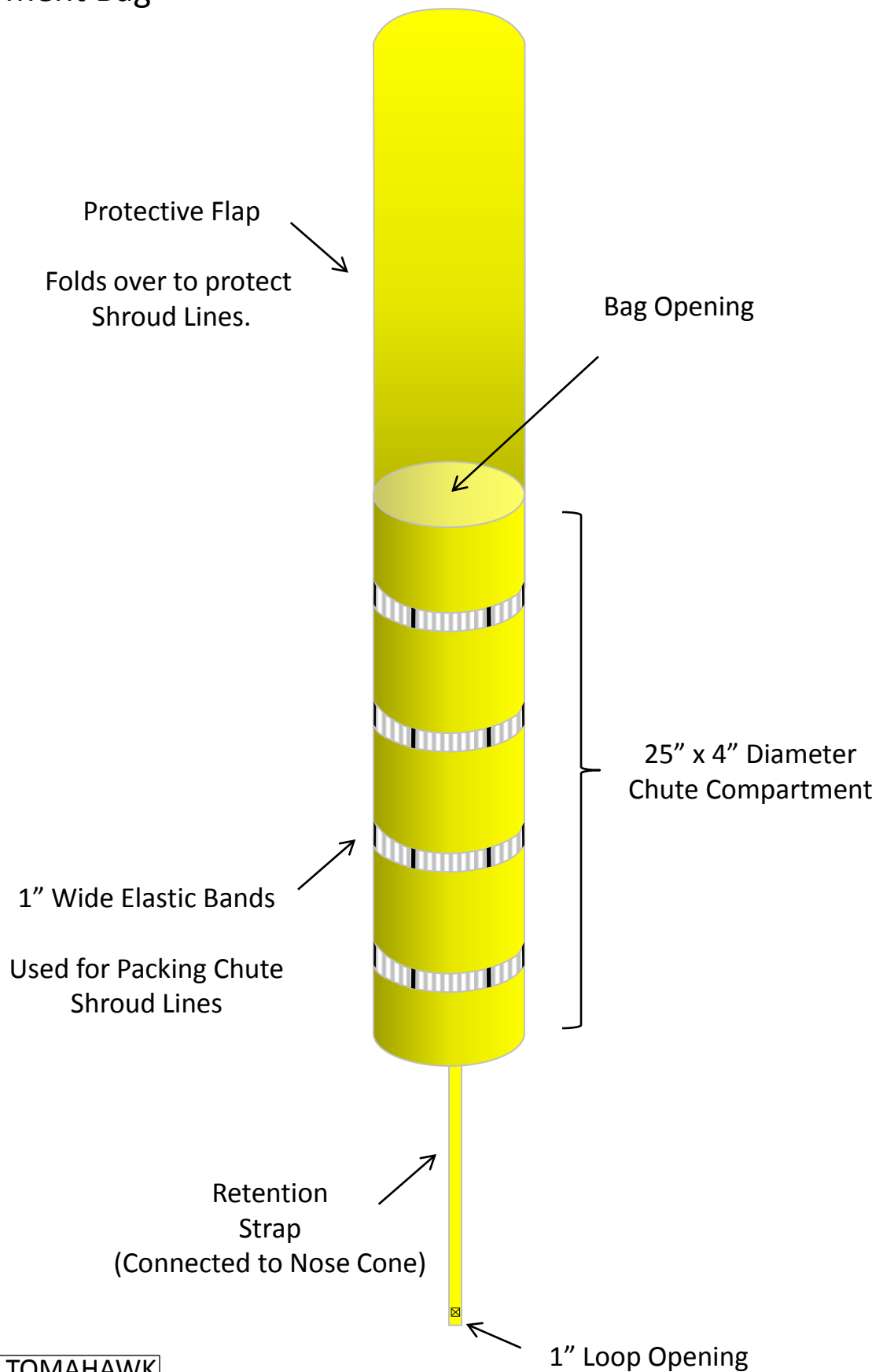
Upper-Section to Main Chute



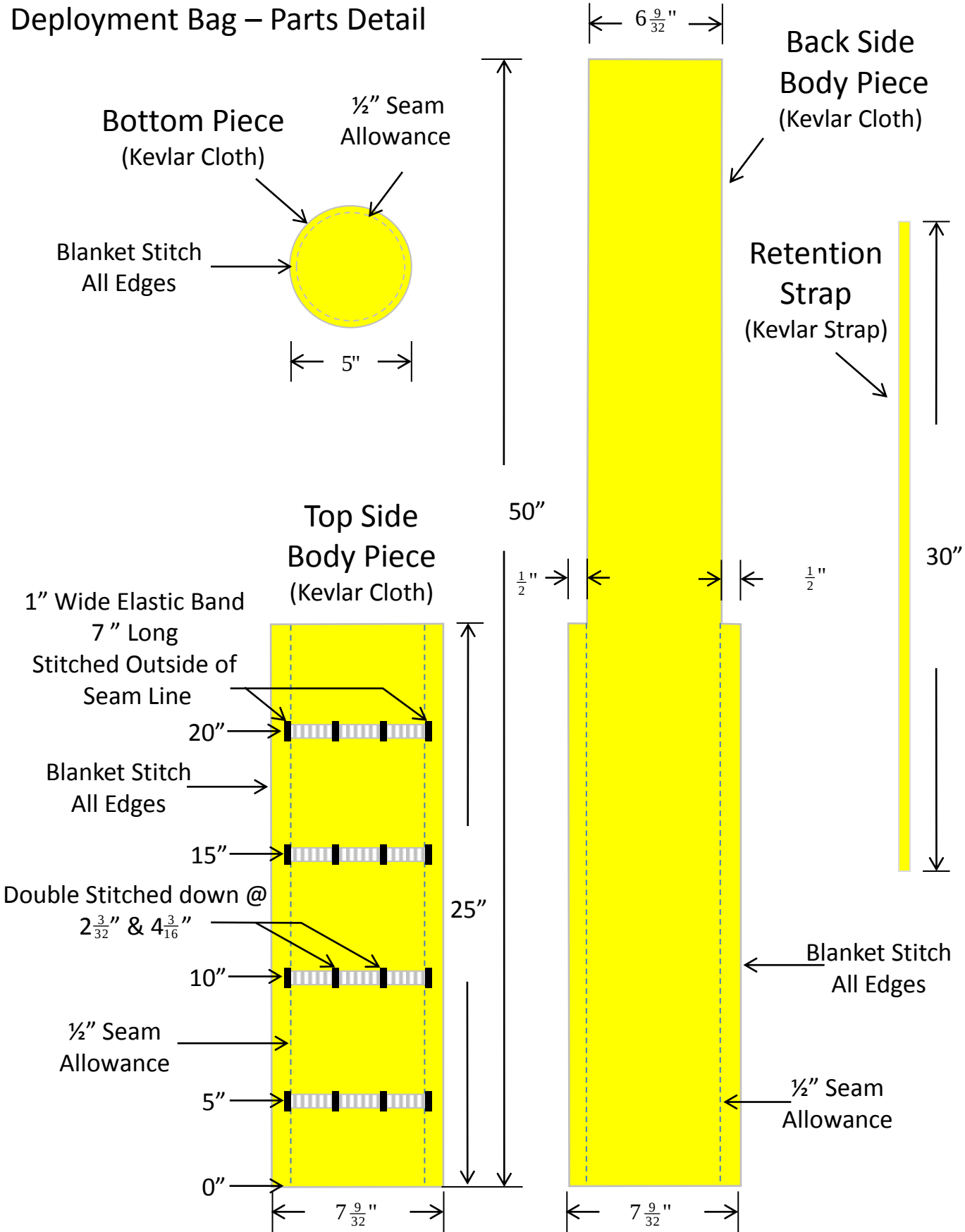
Quick Link/Loop Detail



Deployment Bag

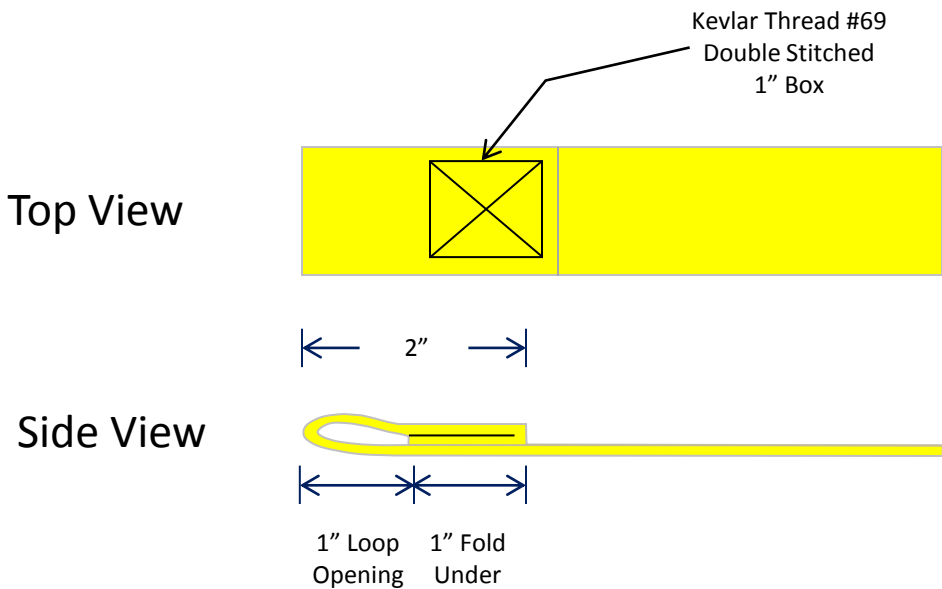


Deployment Bag – Parts Detail



Deployment Bag – Retention Strap

Retention Strap – Loop Detail



Loops are sewn on BOTH ENDS.

Strap is sewn so that one loop is just inside the bag, with the other loop and the majority of strap is outside of the bag – see next page.

Deployment Bag

Retention Strap should exit between the bottom and back-side pieces' seam, centered on the back-side piece with one loop just inside the bag.

1" Wide Elastic Band
6 ⁹/₃₂" Long
Double Stitched down @
0", 2 ³/₃₂", 4 ³/₁₆" & 6 ⁹/₃₂"

20" →

Double Stitched

15" →

Bottom View

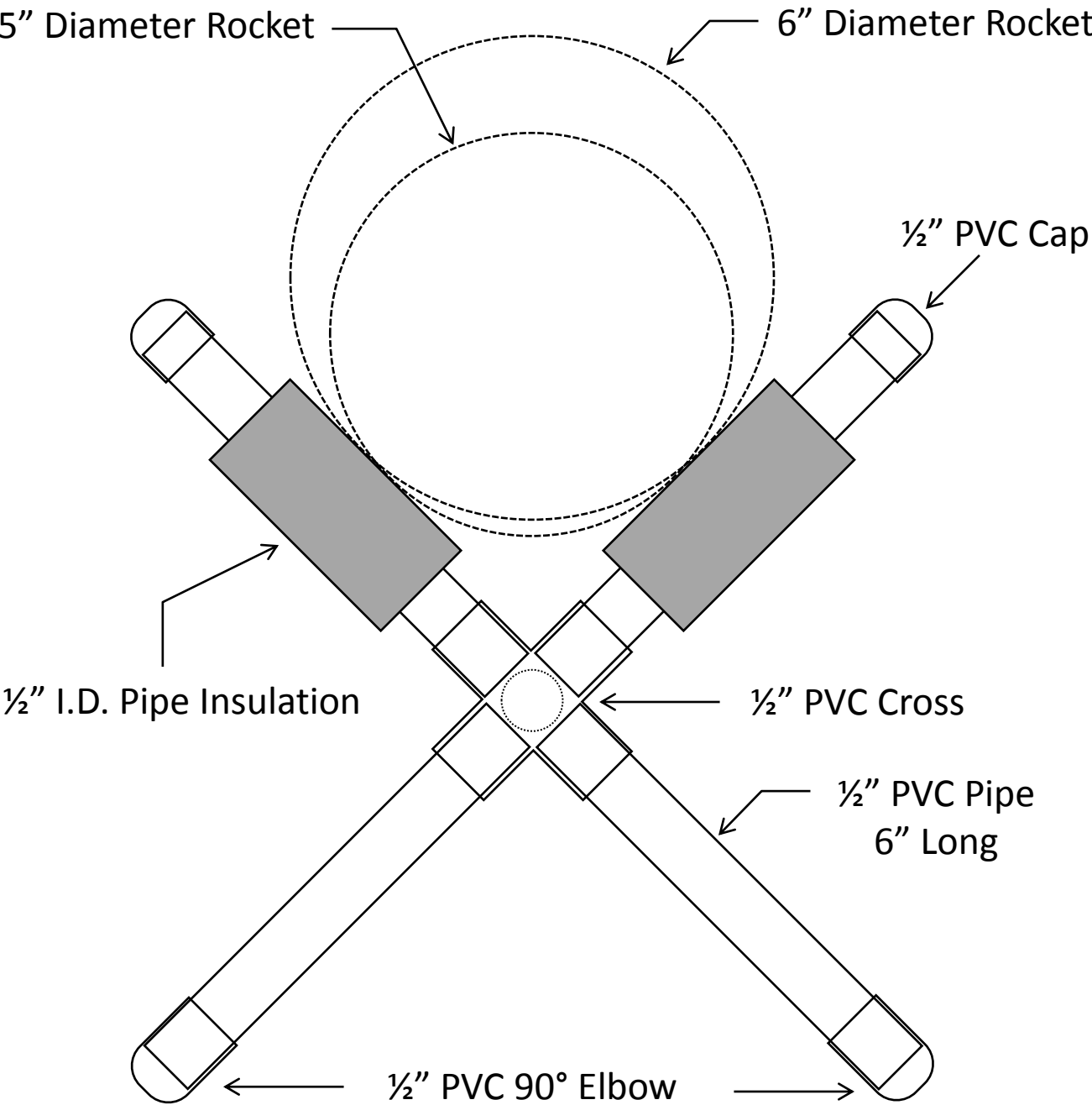
10" →

5" →

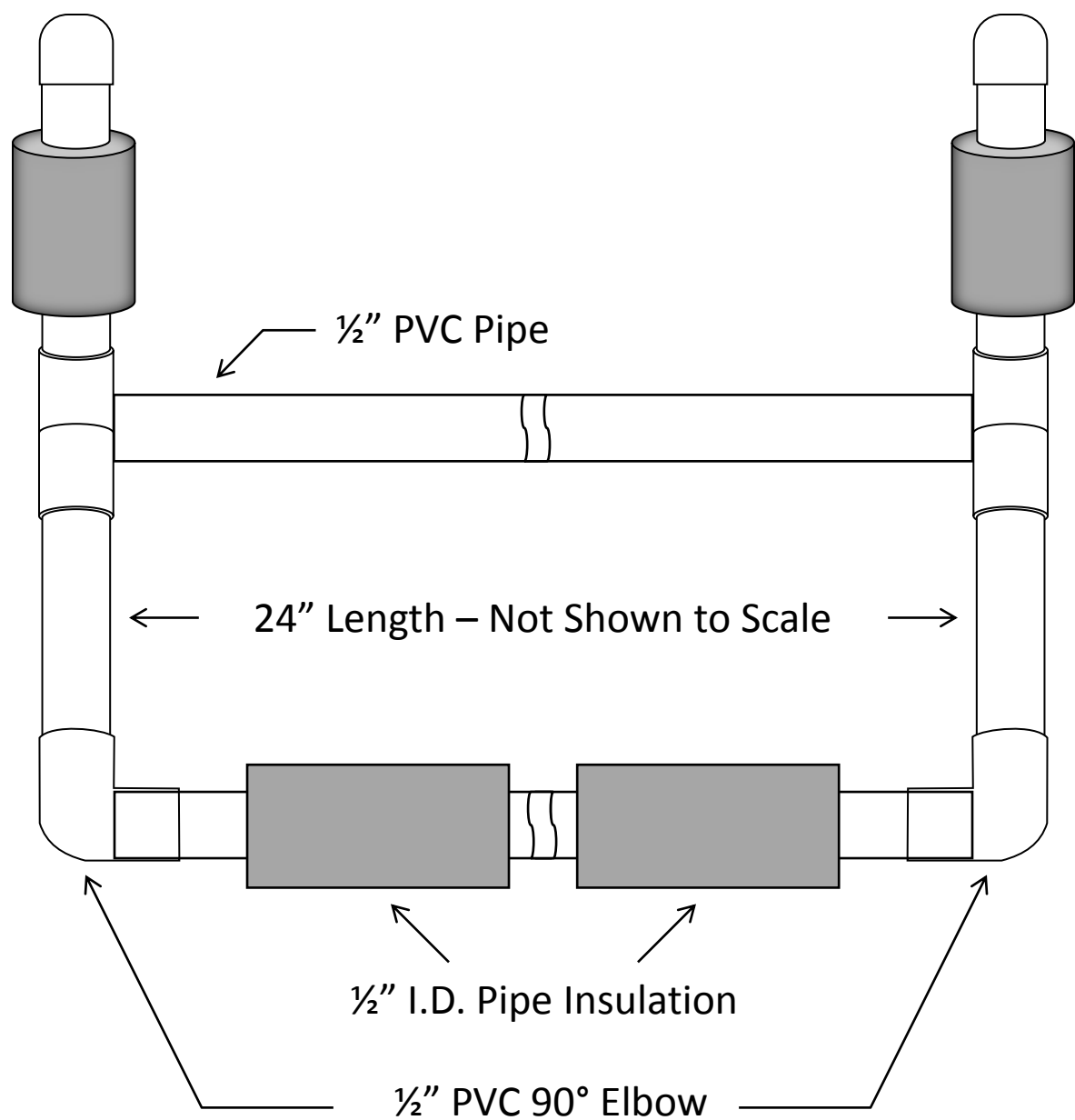
25"

4"

Preparation Stand – Side View



Preparation Stand – Front View



Parts List:

1/2" PVC Cross	x 2
1/2" PVC Round Cap	x 4
1/2" PVC 90° Elbow	x 4
1/2" PVC Pipe	x 10 ft.
1/2" I.D. Pipe Insulation	x 3 ft.

Drawing Scale: 1/2" = 1"

Body (Performance Hobby)

Airframe:	5.0" Glass Tube – 48"	G12-5.0-48	(\$108 x 2)	\$216
Motor Tube:	3.0" Glass Tube – 48"	G12-3.0-48	(\$68 x 1)	\$ 68
Booster/AVbay Couplers:	5.0" Glass Coupler – 10"	G12CT-5.0	(\$40 x 2)	\$ 80
Airframe Bulk Plates:	5.0" Airframe Bulk Plate	FBP5.0	(\$6 x 3)	\$ 18
Coupler Bulk Plates:	5.0" Coupler Bulk Plate	FCBP5.0	(\$6 x 3)	\$ 18
Centering Rings:	5.0" to 3.0" CR	FCR45.0-3.0	(\$7 x 2)	\$ 10
Nose Cone:	5.0" Ogive 3:1	FNC5.0-3-10	(\$70 x 1)	\$ 70

Aeropack

75mm Retainer:	75mm ASSEMBLY – Flange RA75	(\$52 x 1)	\$ 52
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SkyAngle

Parachute:	CERT-3/Xlarge	C3/X	(\$189 x 1)	\$189
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Kevlar

Shock Cord:	50' 1" Kevlar Strap	KEV1	(\$1/ft)	\$ 50
Shock Cord:	In Stock 25' 1" Kevlar Strap	KEV1	(\$1/ft)	\$ 25

Rouse-Tech (Discount Hobby Center)

Motor Case:	RMS-75mm 5120	RT-070	(\$399)	\$399
Forward Seal Disc	RMS-75mm 5120	RT-081	(\$ 27)	\$ 27

Carbon Fiber (Soller Composites)

Tape:	Biaxial Braided Tape 1" x 10'	(\$0.94/ft)	\$9.40
Fabric	In Stock 6KPW50 50" x 1 yard	(\$31/yard)	\$ 31

Northern Hardwoods

Birch Veneer Plywood	¼" Sheet 5' x 5'	\$41.73
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PerfectFlite

Altimeters	In Stock(1) miniAlt/WD	MAWD	(\$100 x 2)	\$200
Hardware	Mounting Stand-offs	MH44	(\$1.5 x 2)	\$ 3

Launch Lugs

Unistrut:	Rail Buttons (x2)	(\$12/pair)	\$ 12
Extreme:	In Stock 1515 Delron Rail Buttons (x2)	(\$10/pair)	\$ 10

Stainless Steel (McMaster-Carr)

Threaded Rod:	8-32 Thread Size – 36"	98847A009	(\$2.59 x 4)	\$10.36
Hex Nuts:	8-32 Hex Nuts	90257A009	(\$8.39 x 100)	\$ 8.39
U-Bolt:	2"/Mounting Plate	8896T94	(\$4.16 x 4)	\$16.64
Sheer Pins:	2-56 Nylon Screws	93135A079	(\$4.99 x 100)	\$ 4.99
Threaded Rod:	¼" – 20 12"	98804A487	(\$2.41 x 2)	\$ 4.82
PEM Nuts	10-24 Captive Nut	94648A350	(\$6.34 x 10)	\$ 6.34
Sealing Washer	Silicon 11/16" OD	99604A119	(\$11.84 x 50)	\$11.84
Sealing Screw	1" 18-80/10-32 Thread	98070A470	(\$8.30 x 10)	\$ 8.30
Coupling Nut (Zinc)	¼"-20 1 ½" Length	90264A437	(\$1.80 x 4)	\$ 7.20
Pan Head Bolt	¼"-20 2"Length	91400A257	(\$5.46 x 10)	\$ 5.46
Quick Link	Triangle	3709T32	(\$7.50 x 4)	\$30.00
Eye Bolt	3/8" - 16	33045T52	(\$21.66 x 1)	\$21.66

Epoxy (McMaster-Carr)

High Strength Epoxy:	Loctite Hysol E-20hp	6430A19	(\$12.16 x 2)	\$24.32
Applicator Gun:		74695A71	(\$27.74 x 1)	\$27.74
Bayonet Mixer Nozzle:	5.9" L with 1/4" Taper Tip	74695A12	(\$0.91 x 12)	\$10.92
Threadlocker:	Loctite® 242, 0.34 oz	91458A112	(\$12.39x 1)	\$12.39

Giant Leap

Chute Swivel: In Stock	½" Eyelet – 1500 lb test		(\$6.00 x 1)	\$ 6.00
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Custom Made

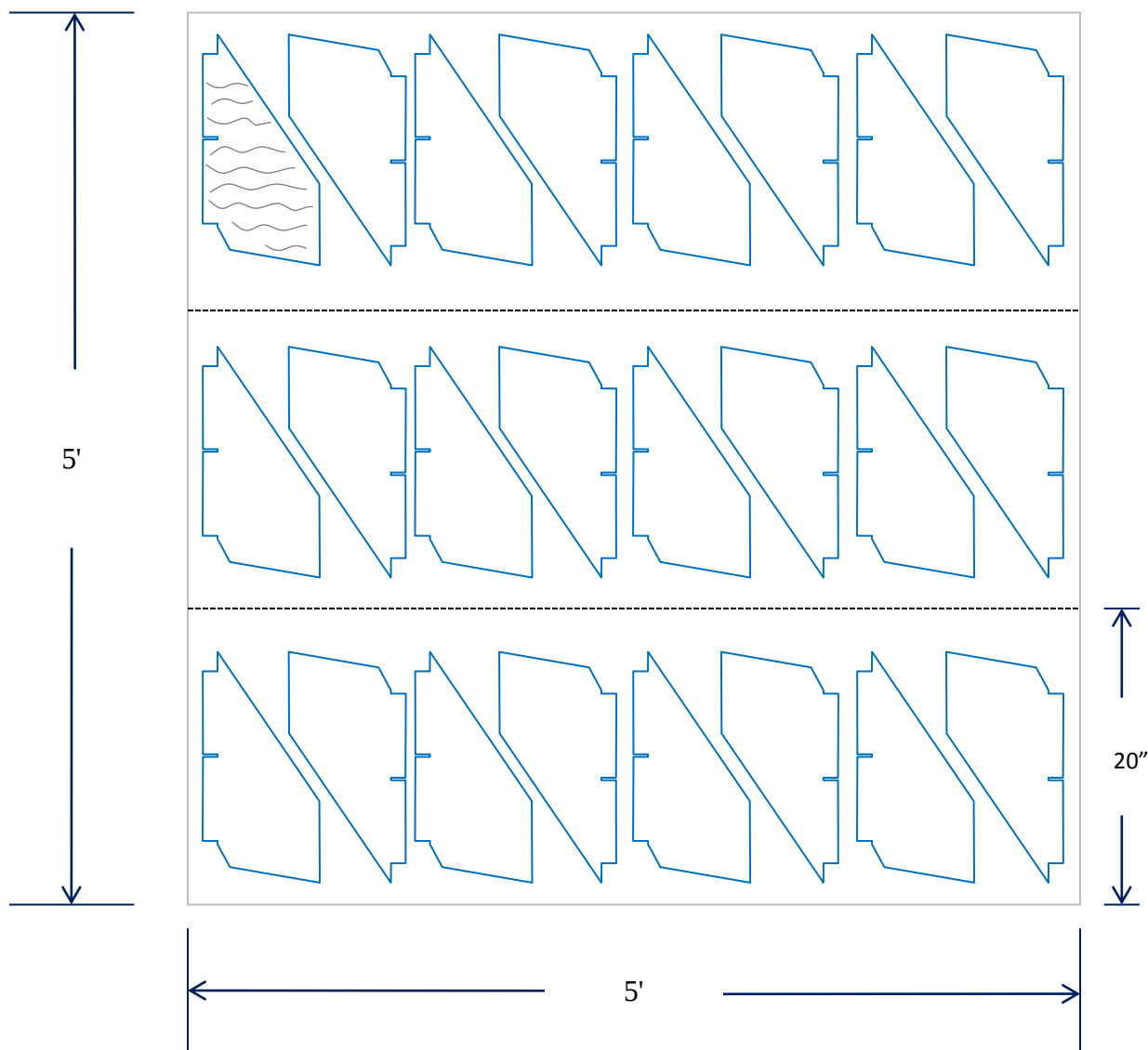
Center Rings:	5.0" to 3.0" ½" Birch Ply		(\$10.00 x 2)	\$20.00
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Construction

D-REGION TOMAHAWK
Construction
Jeffery H. Oppold

Fin Construction

$\frac{1}{4}$ " Birch Plywood 5' x 5' Sheet

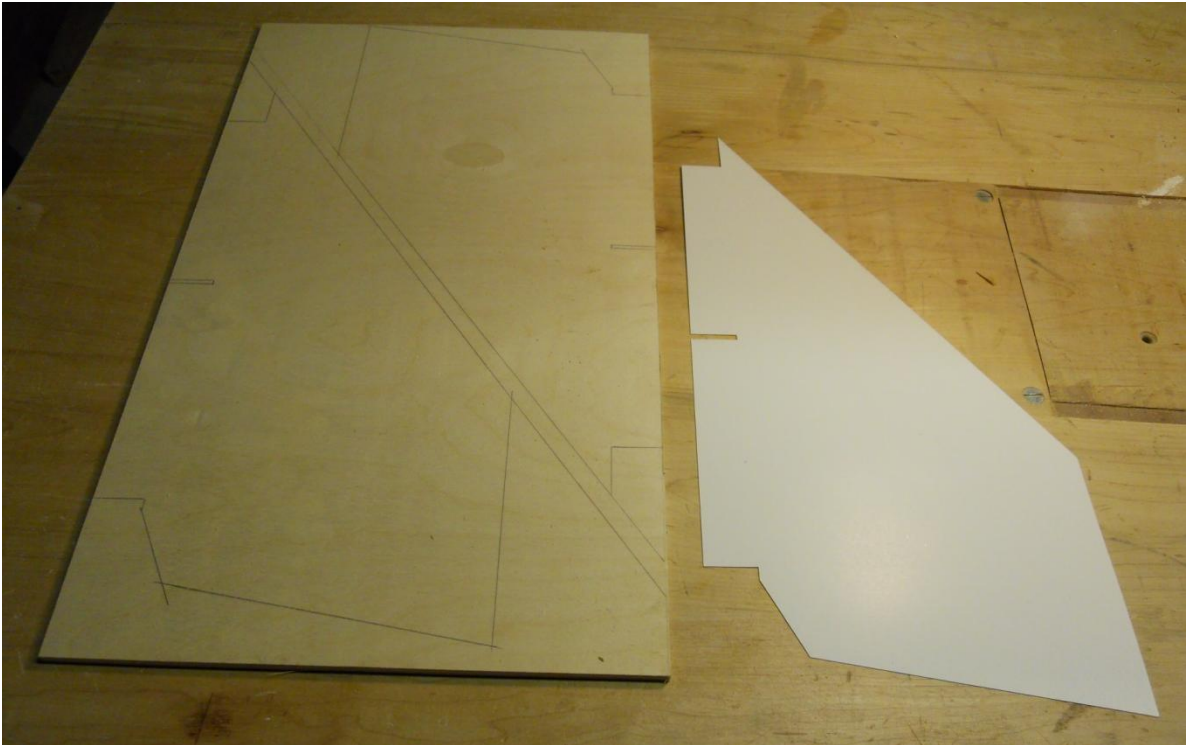


I had the lumber dealer cut the sheet into 3 20" wide pieces so that I could get it home in my car. My plan is to cut 5 or 6 fins and pick the best of 4 out of them.

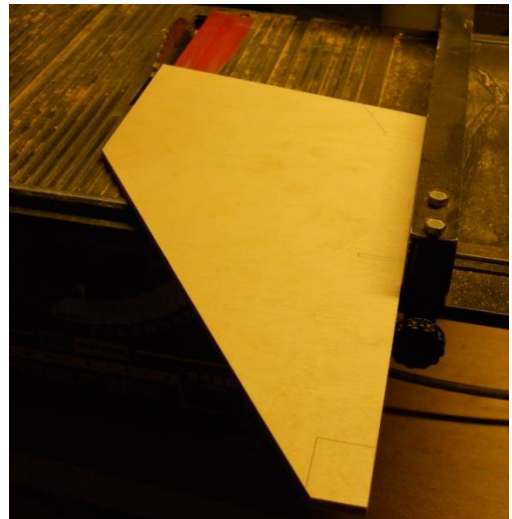
Note the direction of the wood grain as I'll want the outside ply's grain to be perpendicular to the root edge.

Fin Construction – Layout and Rough Cut

I cut out a template of the fins from poster board. This allowed for an easy transfer of the fin pattern to the plywood surface. It turned out that I could lay out 2 fins within the 20" height as shown below and saved a lot of material.

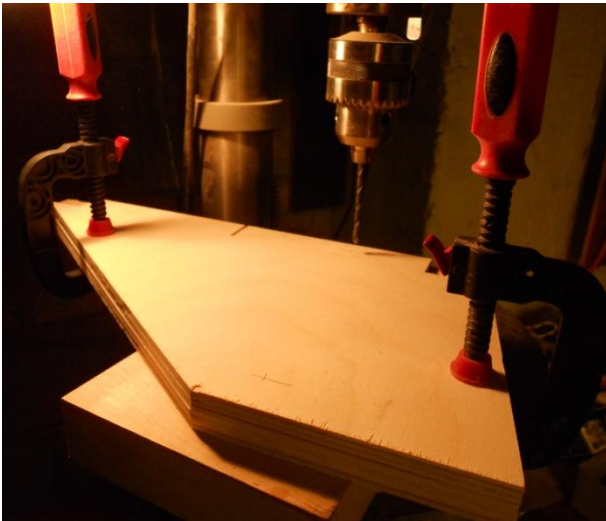


Cutting was done on a table saw. I don't own a table saw so I had a friend help me.



Fin Construction – Sanding and Cutting Centering Ring Slots

It is most important that all four fins be identical so we aligned the root edges, clamped the 4 fins together, then drilled 3 holes and bolted the fins together. This kept them tightly together when the edges were sanded and the centering rings cut. We decided we needed the holes anyway so that each individual fin could be attached to a guide for cutting the 12° knife edge on the leading edge (see next page).



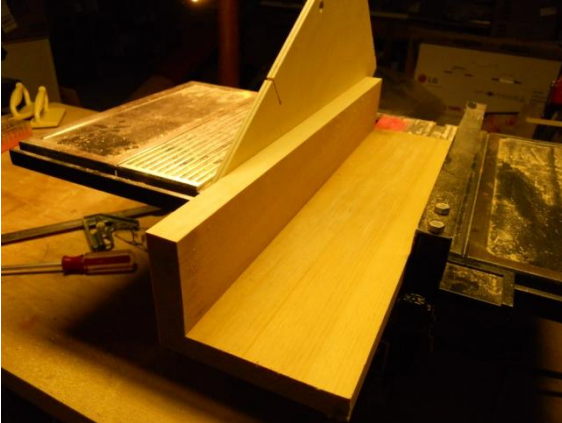
Clamped and on the drill press.

After sanding the edges and cutting the slots for the centering rings.



Fin Construction – Cutting the Knife Edge

My friend came up with a really good idea on how to hold the fins so that we would get a perfect knife edge. We built a half box as a guide so that we could attach the fins to it, then used the ripping fence to align the box and fin to the blade.

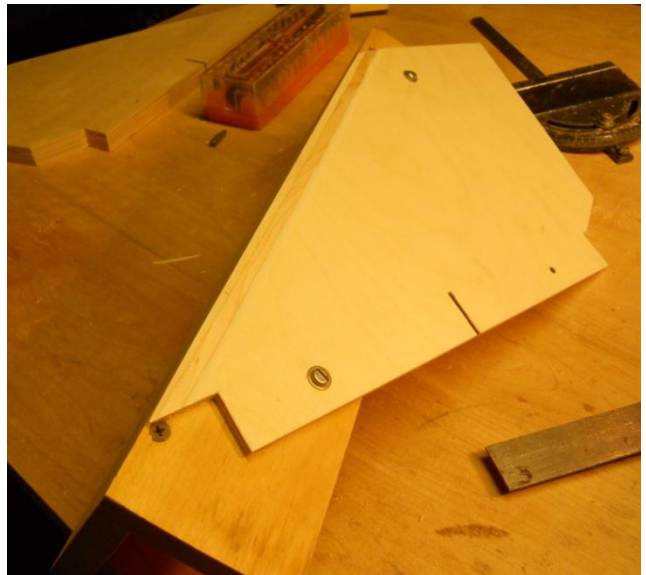


Blade side view.

Guide box with the fin attached and aligned to the ripping fence.

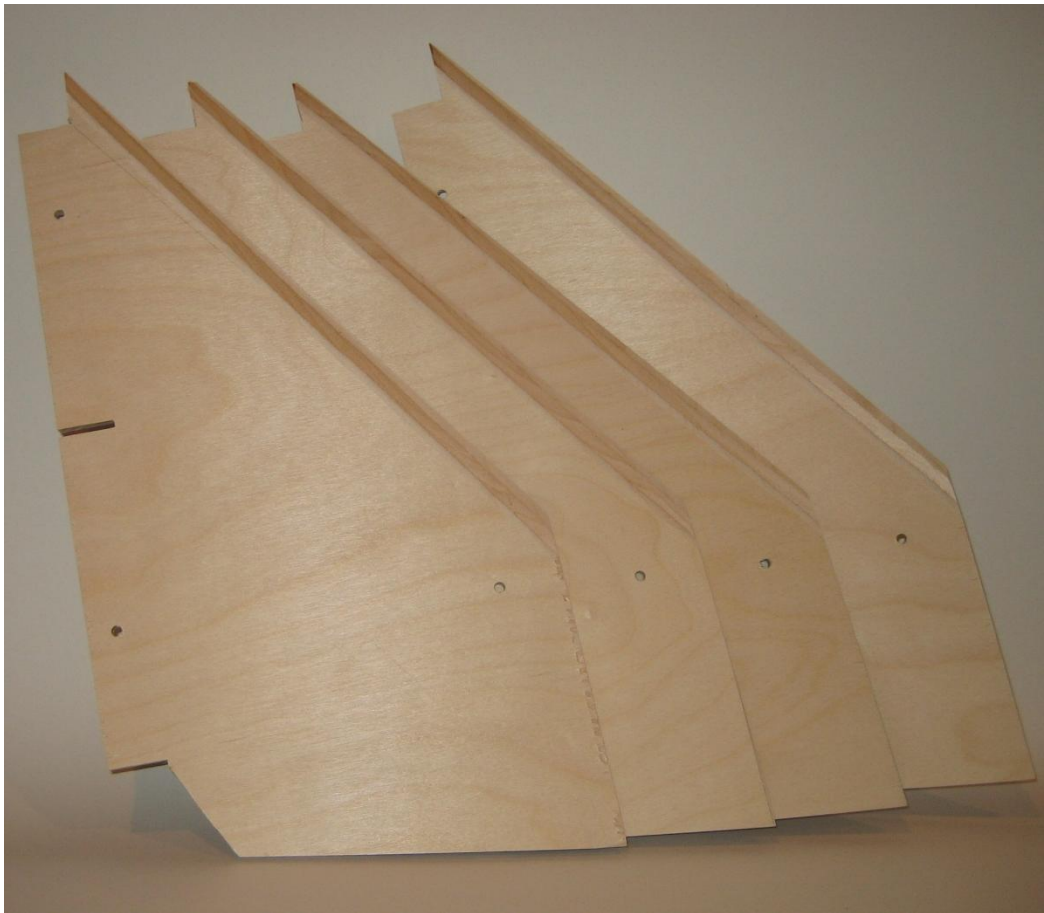


A perfect 12° edge!



Fin Construction – Plywood cuts are Done

Here's a look at the fins after all of plywood cuts have been completed. They each weigh 7.5 ounces. Next step is to fill in the drilled holes, rough edges, and any other imperfections; I'll use JB Weld for this as I want them good and strong.



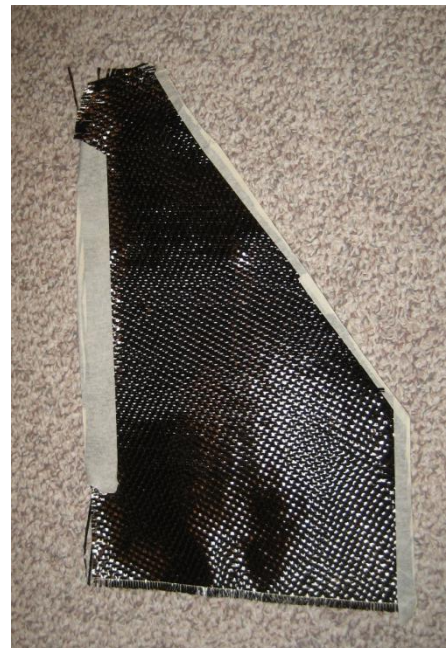
Fin Construction – Carbon Fiber Overlay

The first step in the carbon fiber process is to cut the carbon fiber cloth into the pattern of the fins. Nice scissors are a must, but it's actually pretty easy to cut. However, it unravels real easy so I cut the cloth about 1" bigger on each edge and then use masking tape to hold it.



That's me on the floor cutting the carbon fiber cloth. The bolt is 60" wide and expensive so I want to minimize waste.

Here's what the patterned carbon fiber looks like after it's been cut and the edges taped. I had to cut 8 pieces.



Fin Construction – Carbon Fiber Overlay

The second step is to cut the release fabric and batting. The release fabric is placed right on top of the epoxied carbon fiber so that when compressed, the excess epoxy passes through it and is absorbed by the batting, which is placed over the release fabric. Once the epoxy cures, the release fabric is easily peeled off, leaving a smooth a surface.



The release fabric is actually harder to cut than the carbon fiber. Experience tells me to iron out the wrinkles because they'll end up ruining the surface if I don't.



The batting is ½" inch thick and was purchased at a local fabric store.

In both pictures I'm using a fin as a guide.

Fin Construction – Carbon Fiber Overlay

The third step is to epoxy the carbon fiber cloth to the plywood fins. I use West System 105 Resin and 205 Hardener.



I mixed the epoxy in pudding cups and use cheap sponge paint brushes to apply.

Notice that I have rubber gloves on as well.

A club member recently redid his kitchen counter tops in granite and let me borrow two slabs to use as a press. I have them covered in waxed paper.



Once the carbon fiber is saturated in epoxy, I cover it with the release fabric and gently smooth it out.

The slabs were big enough for me to do two fin surfaces at a Time.

Fin Construction – Carbon Fiber Overlay



These two pieces of plywood have a 12° angle on them acting as a press on the knife edges. They're covered with waxed paper.

Notice how excess epoxy is oozing through the release fabric.



The batting is placed over the release fabric, which is then covered with waxed paper.

I put the second slab over the fins, which weighed about 50 pounds. The tool box then added another 20 pounds. That should provide sufficient compression to make sure the fins cure flat.



Fin Construction – Surface Finishing



Here's a fin after the epoxy has cured and I've cut and sanded the edges smooth. This task is awful: the dust gets into everything so wearing a good mask and safety glasses is a must. The 12° leading edges came out great.

They look really good. They're flat and hard as a rock. All that's left is to fill the cloth grain with filler to get a super smooth surface.



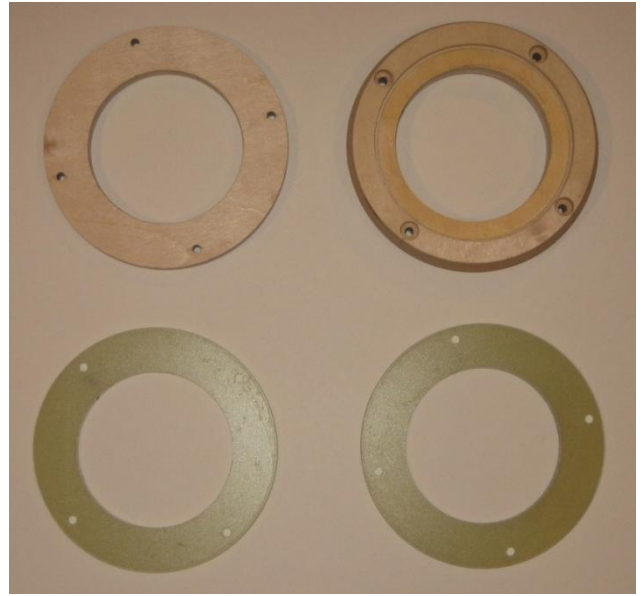
I like auto body filler (Bondo) as it's easy to apply, cures quickly, and sands to a super smooth finish.

Fin Construction – Surface Finishing



Here's a fin after two passes of Bondo and sanding. It's been primed and sanded with 400 grit paper. Noticed that I left the tang raw so that the epoxy joint to the body tube has a rougher surface to adhere to.

Centering Rings



I cut out the centering hole guide on page 9 and marked CR-1. I wanted all the holes to precisely line up so I placed CR-2, CR-3, CR-4, and ABP-1 inside a small piece of body tube and held them in place with a smaller body tube. Using a drill press I drilled the four holes through all rings at the same time. I also placed alignment marks on the rings so that I can place them on the body tube in the same orientation as they were when the holes were drilled – just in case my drilling was slightly off – however, it wasn't!

Next, using the Aero Pack retainer as a guide, I drilled the 12 holes for the threaded inserts into CR-1.



Motor Tube Assembly & Fin Attachment

I cut the motor to the correct length using a hack saw and sanded the ends square.

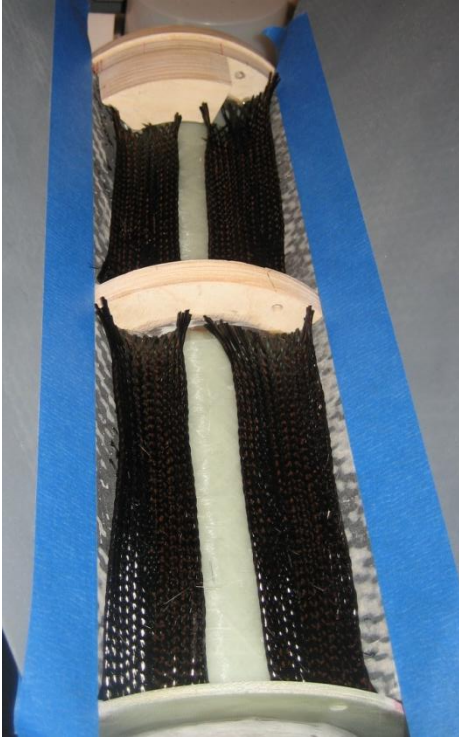
Using the template on page 10, I marked the fin locations (with respect to the holes drilled for the threaded rods) on CR-1, CR-2, and CR-3. Using JB Weld epoxy, I then glued CR-1 to the bottom of the motor tube making sure the fit and location was compatible with the Aero pack. Then using a fin for alignment, I marked the locations for CR-2 and CR-3, and then glued them in place using a threaded rod to make sure the holes were aligned, as well as a square to align the fin location markers. I then added fillets of epoxy to each ring/tube joint.



Here's the fins mounted on the motor tube. It took a bit of doing to get them square but in the end they are right on the money. Using the 4 minute JB-Weld to "tack" the fins in place worked out well as I only had to hold them for a short time and if the alignment wasn't perfect, they snapped right off and I tried it again. I then used the Loctite Hysol epoxy to permanently attach the fins. This stuff is great - the applicator gun makes it easy and the epoxy is as tough as nails!

Internal Fin Fillets

Here's a close-up of the Loctite Hysol epoxy fillets. We're going to cover these with carbon fiber tape and West System epoxy to form a incredibly strong and light weight joint.



I first cut the carbon fiber tape to the right size and covered the fins with masking tape to keep any unwanted epoxy off them.



Here I'm mixing the West System epoxy. I save all my apple sauce containers as they make great mixing bowls. Also, check out the rubber gloves – my wife said it looks like I have Mickey Mouse hands!



Internal Fin Fillets

Each of the four pieces of tape are the same length so I carefully poured about a quarter of the epoxy on them length wise. Using my fingers, I worked the epoxy into the tape until it is evenly saturated. I also adjusted the tape so that it had equal coverage on the fin and body tube.



Here's what the final joint looks like. The West System Epoxy is unbelievably strong when used with the carbon fiber tape. I've used this type of fin joint on three level two class rockets and have never had a fin joint failure – not even on the flight where I had a partial chute failure.

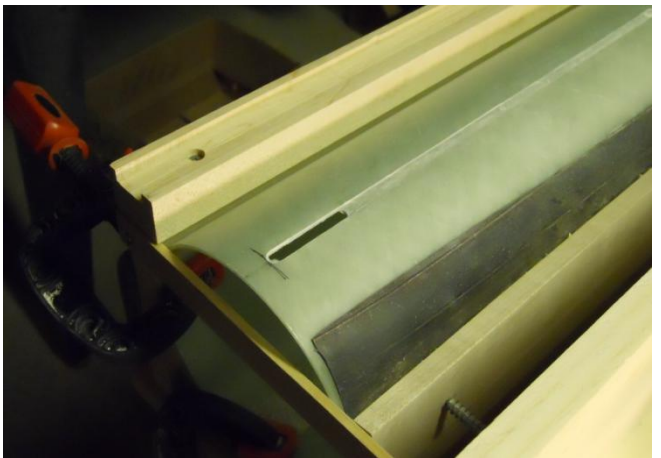
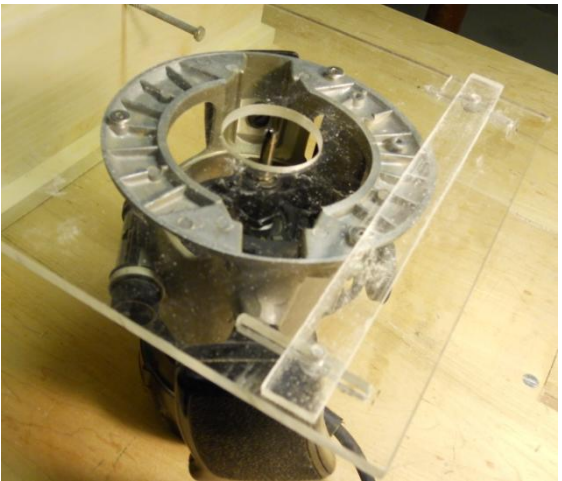


Fin Slots

Here's the box that my friend and I designed and built to router the fin slots. We made it adjustable up to 6 inches so that it can be used multiple times. Notice the grooved slot on the upper left – this will hold the router sled.

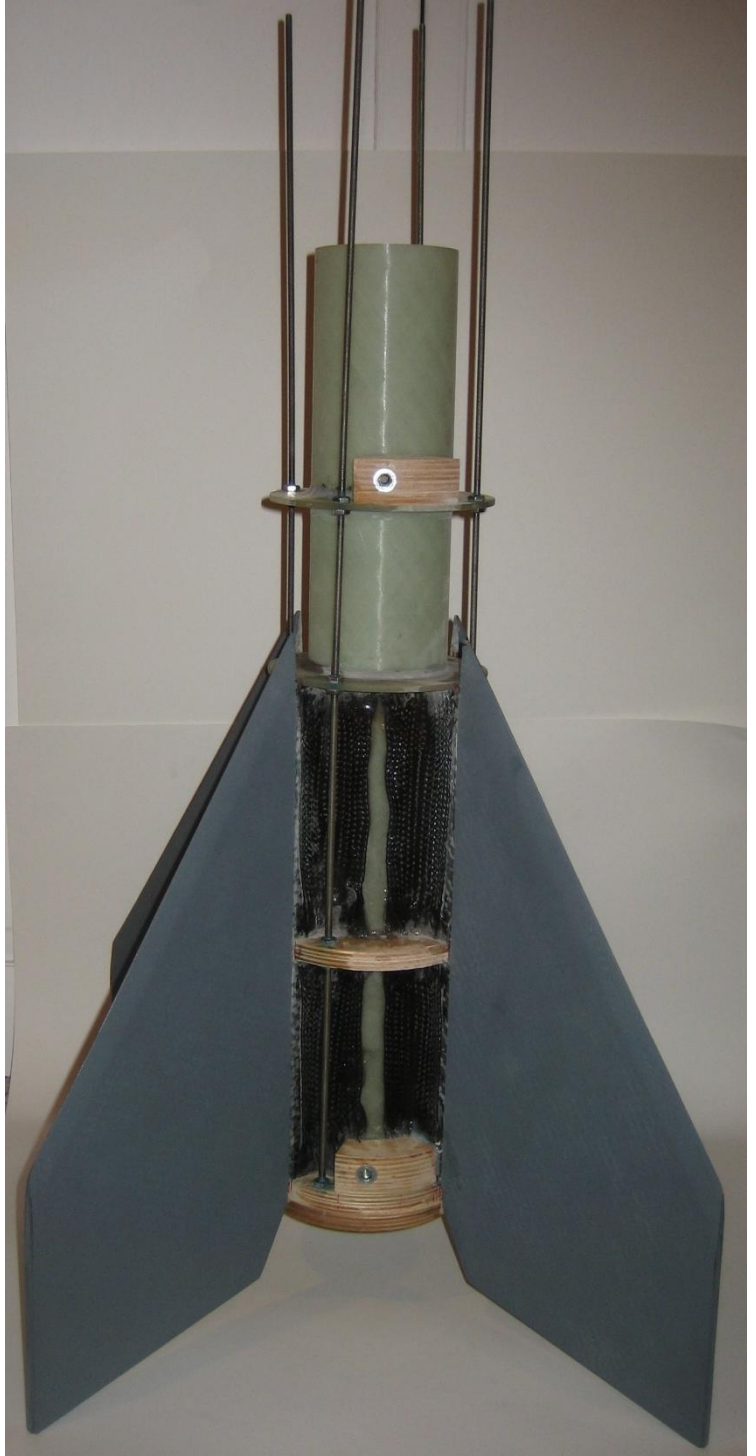
We built the sled out of plexiglass so that it would allow for viewing of the cut as it is being made. Note the rail guide on the right. It fits and slides in the groove slot shown above.

Here's an action shot and a quick look at the start of the second pass on the router. Two passes because the G12 is a tough material to route.



Rail Guides & Threaded Rods

I used a ½" plywood center ring cut into 6 pieces for the rail guide anchors. I placed the booster body tube over the fin can and drilled the holes through the fiber glass body and into the plywood ring so that I would have perfect alignment. I then removed the body tube and enlarged the holes to accommodate the threaded inserts and installed them. I then installed the threaded rods being careful not to stress the fiber glass rings (thumb tightened top and bottom nuts and then alternately tightened the top and bottom nuts to maintain a systematical torque). This was a rather long and tedious task but when finished I could tell this results in an incredibly solid fin can construction.



Booster Coupler

I cut a ½” piece of fiberglass from a scrap piece of 5” G12 tubing, cut it to fit the inside diameter of the coupler tube, and secured it to the top, recessed down the thickness of the bulk plate, with epoxy.

This provides a stop ring for the bulk plate to rest on, flush to the top of the coupler tube. I used epoxy again to secure the bulk plate to the ring via a generous fillet .

I then attached the slotted booster body tube to the fin can, using epoxy at CR-1, and around the fins. To attach the booster coupler, I put generous amount of epoxy on top of CR-4, forming a fillet where the coupler will rest on top of it. I then simply slid the coupler over the threaded rods and held it in place with some weight until cured. I bolted down the threaded rods with two nuts, and secured with epoxy (High Temp JB-Weld).

The next page show the competed booster without the body panel detail.



Fin Slots

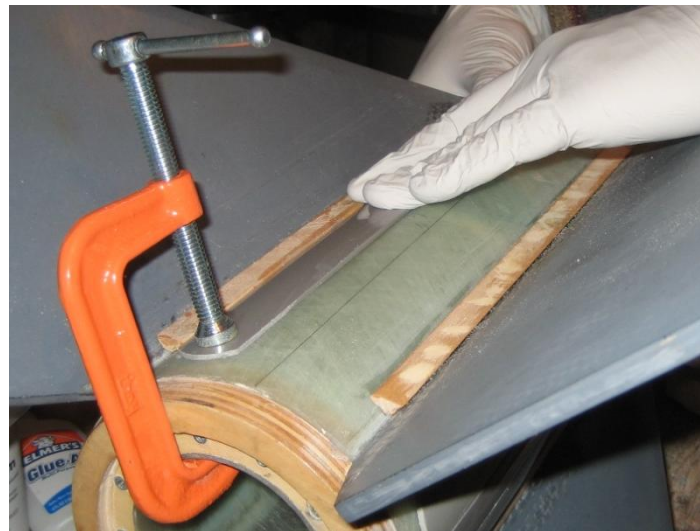
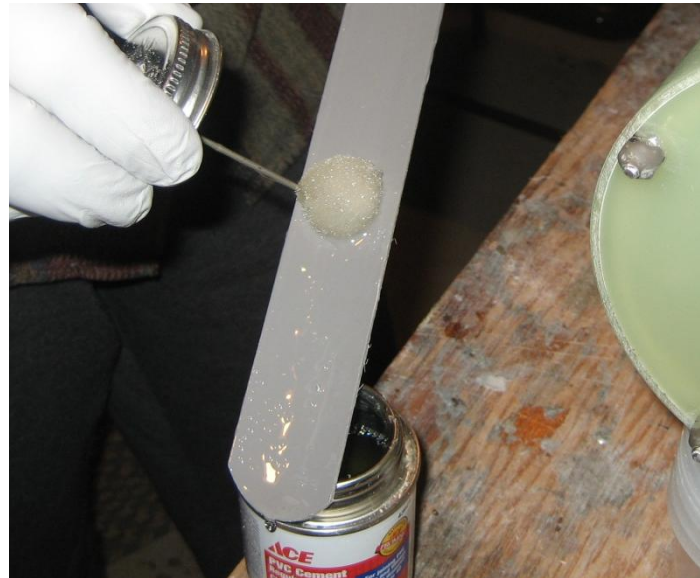
On the left is the booster body tube with the fin slots, and on the right is the completed booster without the body detail.



Body Tube Raised Detail

I cut the fin fillets out of maple and used Loctite Hysol epoxy to secure them in place. This was actually a pretty difficult step as the fillets were quite small to cut on a table saw, resulting in rough surfaces with lots of a blade marks that I filled with Elmers wood putty (seen as white blotches on the fillets). Since I couldn't get clamp on these I used masking tape to hold them place, checking them often to make sure they hadn't moved.

I cut the raised detail pieces and used the templates to round the ends to the correct contours using a dremel tool with a sanding disk. I tested several glues and found that PVC cement worked best for attaching the plastic details to the fiberglass body tube. Once again I had to use my hands on the far end to hold the pieces in place, but the PVC cement dries pretty quick so this wasn't a big deal.



Body Tube Raised Detail

Once all the pieces were in place and the cement had dried, I sanded the details to cleanup any stray cement. I then used a plastic model panel line scribe tool to widen and cleanup the lines between each of the raised detail panels. Below is the raised detail ready for primer and paint.



Pem Nuts/AirFrames/Avionics Bay

I started work on the avionics bay by installing the eight PEM nuts in its coupler tube – see page 16 for drawing. I used the fin alignment guide on page 7 to mark the vertical lines shown, and used a heavy paper wrap to draw the circumferential line 2 ½” down from the top of the mid-airframe tube. I then placed the coupler tube half way inside the mid-airframe tube, taping it in place while I drilled the four holes for the PEM nuts.

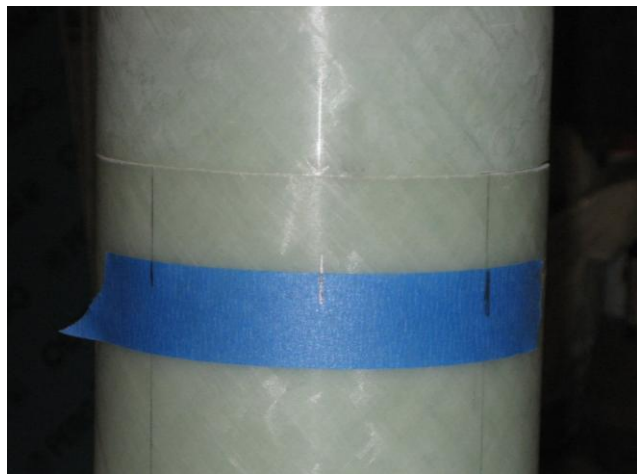
I then marked the lower part of upper-airframe tube in the same manner as I did the mid-airframe tube. I secured the coupler tube to the mid-airframe with several nuts and bolts, placed the upper-airframe tube on the top portion of the coupler tube, and once again drilled the four holes for the PEM nuts.

I then placed an alignment mark to aid in final assembly.



Air Frame

I placed the Mid Section Air-Frame over the booster coupler and aligned it so that the avionics port holes are 90° out of phase from the rail guides (very important as I need to be able to access the switches inside when on the pad). With that alignment intact, I then drew fin alignment marks up the side. I placed tape across these marks and marked the tape, removed the tape, measured for the center point, and then placed the tape back on the body tube and transferred the center mark to body tube. I then used this mark as the vertical alignment for the shear pin locations. I then measured 1" up from the bottom on each shear pin vertical alignment line and drew a mark for the shear pin hole. Then in sequence, I drilled a hole for the 2-256 tap, tapped the hole, and then screwed in a shear pin. I then repeated this sequence at each shear pin location. This resulted in perfect alignment of the 4 pins. I then increased the hole in the coupler to 7/64". Finally, I drilled the 1/8" pressure relief holes. The Upper Air-Frame is assembled in a similar manner.



Avionics Bay

I then compressed the PEM nuts into the coupler tube using a large C-clamp. Using JB-Weld epoxy, I permanently secured the nuts to the coupler tube. You can see in the picture that I roughed up the inside of the tube around each nut so that epoxy would have more surface area to adhere to. Also, it's important to use something like JB-Weld because it works so well with metal.

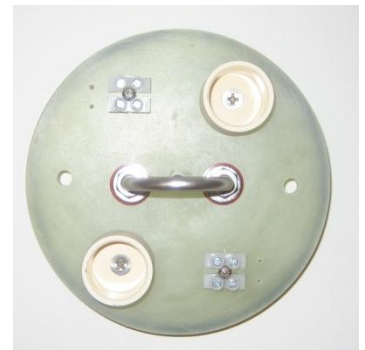
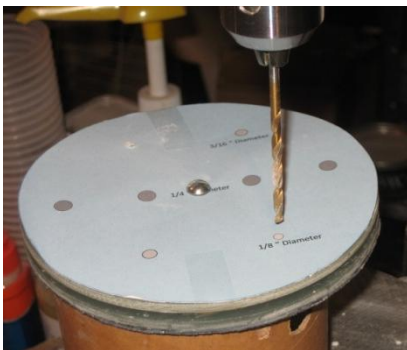


In the sequence of pictures at the bottom, I show how I cut the sealing gaskets that are placed between the Avionics bay's coupler bulkheads. I found the gasket material at ACE Hardware – it looks like nylon but is very compressible – its normal use is for lining the bottom of drawers. I used the coupler bulkhead for the outside guide, and a 4" PML tube for the inside.



Avionics Bay

Using epoxy I attached the bulkhead gasket to the bottom of the top bulkhead pieces (x2), then attached the bottom bulkhead pieces to the gasket side of the top bulkheads. I bolted the two bulkhead assemblies together and then cut out the bulkhead drilling template on page 16 and taped it to the top bulkhead. Using the specified drill bit sizes, I drilled all the required holes on my drill press (Left picture below). I removed the bolt and filled the center holes with JB-Weld and then sanded them smooth when it had dried. The center picture below shows the under-side of one of the bulkheads – highlighting the sealing gasket. The picture on the right shows a completed bulkhead sans the wiring.



From the PerfectFlite User's Manual, the recommended atmospheric pressure sampling port hole size for the miniAlt/WD is calculated as follows:

$$\begin{aligned}\text{Hole Diameter} &= \text{Tube Diameter} \times \text{Tube Length} \times 0.006 \\ &= 5.0'' \times 10.5'' \times 0.006 \\ &= 0.315'' \text{ Diameter or } 0.078 \text{ in}^2 \text{ Area}\end{aligned}$$

I need two holes to access each of the altimeter power switches, so given I know the area, the minimum diameter of these two holes is calculates as follows:

Avionics Bay

$$\begin{aligned}\text{Hole Diameter} &= 2 \times \sqrt{\frac{\frac{1}{2}A}{\pi}} \\ &= 2 \times \sqrt{\frac{\frac{1}{2}(0.078")}{3.14159}} = 2 \times \sqrt{\frac{0.039"}{3.14159}} = 2 \times \sqrt{0.012414"} = 2 \times 0.11142" = 0.22284" \\ &= \frac{15}{64}''\end{aligned}$$

To get these port holes aligned with the switches mounted on the altimeter sled, I reused the 90° alignment marks used for the PEM nut alignment. I ran a piece of masking tape between these marks and marked the tape. I then removed the tape and found the center point between these marks, placed the tape back on the body tube and placed a mark ½" down from the top of the airframe mid-section. With the Avionics Bay inserted into the airframe, I drilled the port hole. I then repeated the above for the airframe upper-section, placing the port hole 180° from the mid-section's port hole, and ½" from the bottom. That completed the construction of the Avionics Bay.



Altimeter Sled

After cutting the G10 material to the specified dimensions, I used JB-Weld epoxy to attach the ¼" brass tubing to opposite sides of the G10 base. To get the proper alignment of the tubing, I attached the top and bottom bulk plates of the avionics bay with the ¼" threaded rod and used it to hold the brass rods in place while the epoxy cured.

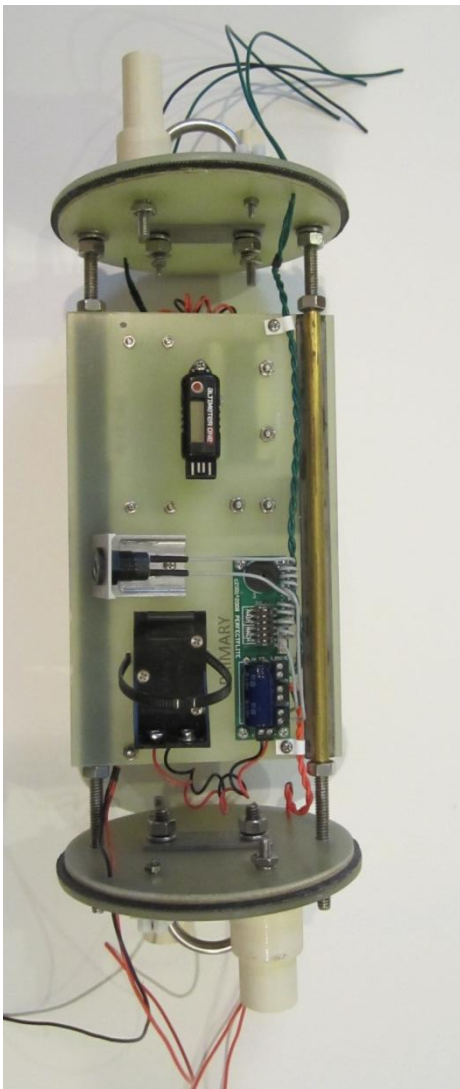
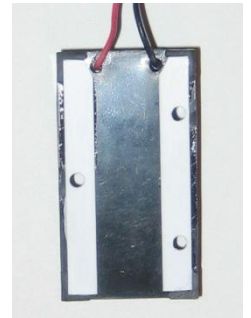
The layout of the altimeter sled consists of a primary and backup circuit, with each circuit mounted on opposite sides of the G10 sled. The PerfectFlite User's Manual had a hole template for the altimeter so I used that. For the switch mounting bracket and battery holder, I simply used them as a template. For the battery cable ties, I first drilled the battery holder holes and attached it temporarily to the sled. I then marked the place for the ties, removed the holder and drilled the end holes of slot, filing out the rest of the slot with a hobby files.

The last thing was to affix labels to aid in the identification of the circuit and various wires.



Altimeter Sled

When I attached the battery holder, I noticed that it was sagging from the tension of the bolts because the stand-offs are only in the corners. To fix this, I cut out two strips of plastic with the proper thickness, glued them in place and drilled the holes.



Here's the assembled Sled sans the battery. In hind sight I wish I would have swap the locations of the bottom wire exit holes at it would have provided a much more clean exit path thru the bulkheads. Not a big deal but something to think about.

Nose Cone

The nose cone arrived with a very warped shoulder and would not fit into the body, so I had to come up with a way to fix the warp. With a lot of force, I was able to get a scrap piece of body tube around the shoulder – which forced the shoulder round. To hold the now round shoulder in place I used auto body filler (Bondo). I built an inside trowel out of popsicle sticks, and keeping it tight against the outside, I was able to mold a pretty decent band of filler, keeping the inside round so that the nose cone bulk head could rest against it.



I had to use a hack saw blade to get the scrap piece off, but with a little sanding I was finally able to get the shoulder to fit.



Nose Cone

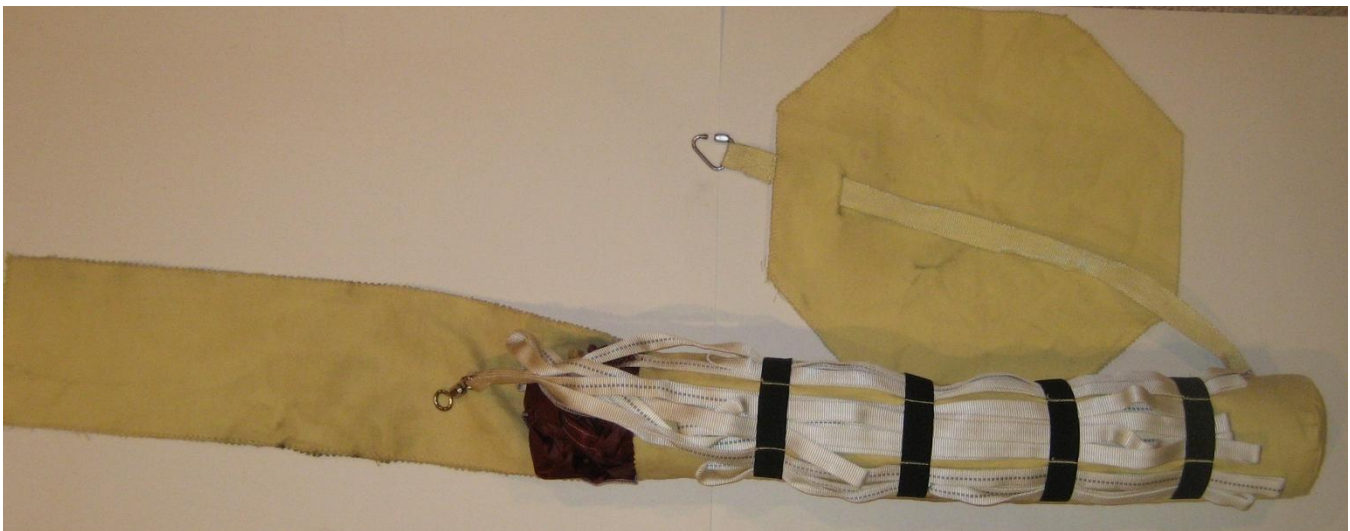
I drilled the 4 holes in the nose cone bulk plate and temporarily bolted the coupler nuts to the bulk head. To get the coupler nuts aligned properly, I used a small bit of JB Weld Quick epoxy on each outside edge of the nuts, inserted the bulk plate into the nose cone and let the epoxy cure. I then removed the bolts and bulk head and checked that the alignment was what I wanted. Then using the carbon fiber 1" tape and West System epoxy thicken to mayonnaise consistency, I wrapped the nuts in the tape, working it tight and into the crevices.

I cut the G10 fiber glass sheet and drilled the holes to mount the GPS unit to the aluminum bracket. I then mounted the bracket and tested the fit. I'll wrap plastic ties around the GPS unit through the holes when I get ready to launch. This really came out nice!



Recovery Harness/Deployment Bag

A local leather repair shop sewed the Kevlar recovery harness and made my deployment bag. Both came out perfect. The bag, when stuffed full with the main chute, slides right out of the tube. I also had him make me 3 hexagon chute protectors – one for the bag, one for the drogue chute, and one for the nose cone chute.





D-REGION TOMAHAWK
Painted
Jeffery H. Oppold 2/25/2012

Simulation & Ground Testing



Tomahawk_level3 - Simulation results

Engine selection

[M1500G]

Launch guide data:

Launch guide length: 120.0000 In.

Velocity at launch guide departure: 78.5265 ft/s

The launch guide was cleared at : 0.260 Seconds

Max data values:

Maximum acceleration:Vertical (y): 662.587 Ft./s/s

Maximum velocity:Vertical (y): 995.0146 ft/s

Maximum altitude: 10559.50304 Ft.

Recovery system data

Parachute-Main Deployed at : 96.039 Seconds

Velocity at deployment: 129.6941 ft/s

Altitude at deployment: 1099.88214 Ft.

Parachute-Drogue Deployed at : 24.815 Seconds

Velocity at deployment: 4.1780 ft/s

Altitude at deployment: 10559.50303 Ft.

Time data

Time to burnout: 3.600 Sec.

Time to apogee: 24.815 Sec.

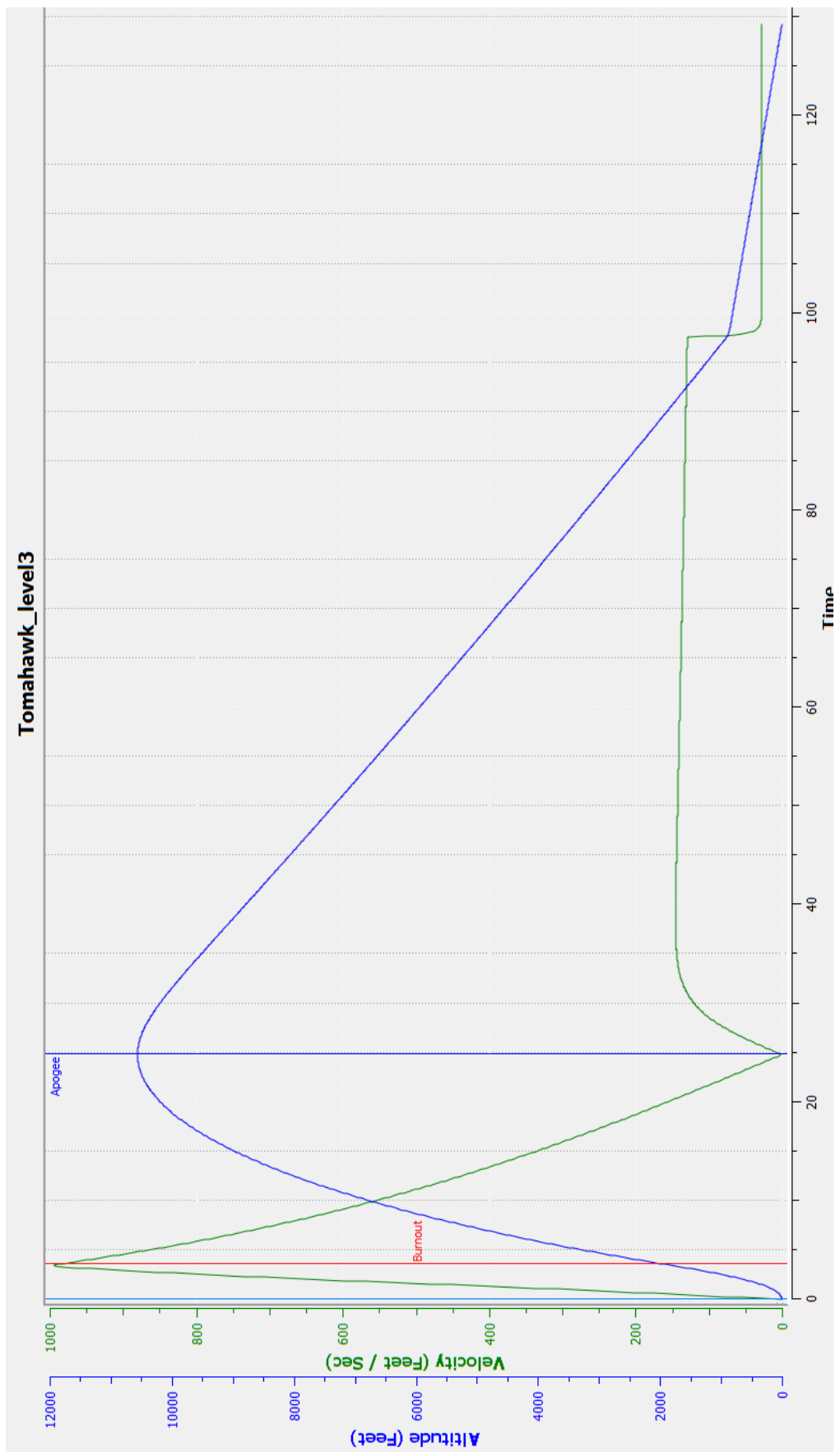
Optimal ejection delay: 21.215 Sec.

Landing data

Time to landing: 134.925 Sec.

Velocity at landing: Vertical: -27.4282 ft/s

RockSim Plot M1500G w/ Dual Deploy Rate of Descents



Drogue Deploy @ 24.8 sec
Apogee Altitude = 10560 ft.
Velocity = 4.0 ft/s

Main Deploy @ 96.0 sec
Altitude = 1100 ft.
Velocity = 129.7 ft/s

Coast 21.2 sec

Boost 3.6 sec
Velocity_{max} = 995.0 ft/sec

Touch Down @ 135 sec
Velocity = 27.4 ft/s

Launch 0 sec

D-REGION TOMAHAWK

Flight Sequence

Jeffery H. Oppold 2/25/2012

Stability Considerations

I found this safety report¹ on-line at the NAR website and used it as a reference for determining my required take-off velocity. In it, the report recommends a simple rule of thumb that the take-off velocity should be at least 4 times the wind speed. A 4:1 ratio limits the angle of attack to 14 degrees, which Dahlquist² found to give ~1 caliber of CP shift (where one body tube diameter is referred to as one caliber). This ratio can be achieved using more thrust, lighter weight, or a longer rod.

RockSim divides the wind speed into several ranges and I've calculated the minimum take-off speed for each range using the above ratio of 4:1.

RockSim Setting	Wind Speed (mph)	Wind Speed (ft/sec)	Take-off Velocity (ft/sec)
Calm	0- 2.9	4.2533	17.0132
Light	3- 7.9	11.5867	46.3468
Slightly Breezy	8-14.9	21.8533	87.4132

On the following three pages are the RockSims results for the above wind conditions. I've assumed a Uni-strut rod length of 10 feet (120 inches).

- 1) **Launching Safely in the 21st Century** *Final Report of the Special Committee on Range Operation and Procedure to the National Association of Rocketry*, <http://www.nar.org/pdf/launchsafe.pdf>
- 2) B. Dahlquist, *Wind Caused Instability, High Power Rocketry*, March 1998. Updated version available at <http://www.apogeerockets.com/education/instability.asp>.

Stability Considerations

Launch conditions

Altitude: 0.00000 Ft.

Relative humidity: 50.000 %

Temperature: 59.000 Deg. F

Pressure: 29.9139 In.

Wind speed model: Calm (0-2.9 MPH)

Low wind speed: 0.0000 MPH

High wind speed: 2.9000 MPH

Wind turbulence: Fairly constant speed (0.01)

Frequency: 0.010000 rad/second

Wind starts at altitude: 0.00000 Ft.

Launch guide angle: 0.000 Deg.

Launch guide data:

Launch guide length: 120.0000 In.

Velocity at launch guide departure: 78.5266 ft/s

The launch guide was cleared at : 0.260 Seconds

User specified minimum velocity for stable flight: 17.0132 ft/s

Minimum velocity for stable flight reached at: 5.6892 In.

Lots of margin with these conditions (~4.6X) – no surprise.

Stability Considerations

Launch conditions

Altitude: 0.00000 Ft.

Relative humidity: 50.000 %

Temperature: 59.000 Deg. F

Pressure: 29.9139 In.

Wind speed model: Light (3-7.9 MPH)

Low wind speed: 3.0000 MPH

High wind speed: 7.9000 MPH

Wind turbulence: Fairly constant speed (0.01)

Frequency: 0.010000 rad/second

Wind starts at altitude: 0.00000 Ft.

Launch guide angle: 0.000 Deg.

Launch guide data:

Launch guide length: 120.0000 In.

Velocity at launch guide departure: 78.5266 ft/s

The launch guide was cleared at : 0.260 Seconds

User specified minimum velocity for stable flight: 46.3468 ft/s

Minimum velocity for stable flight reached at: 40.8599 In.

Here the take-off velocity is about 1.7X – pretty safe. The stable flight velocity is attained about a third of the way up the launch rail.

Stability Considerations

Launch conditions

Altitude: 0.00000 Ft.

Relative humidity: 50.000 %

Temperature: 59.000 Deg. F

Pressure: 29.9139 In.

Wind speed model: **Slightly breezy (8-14.9 MPH)**

Low wind speed: 8.0000 MPH

High wind speed: 14.9000 MPH

Wind turbulence: **Fairly constant speed (0.01)**

Frequency: 0.010000 rad/second

Wind starts at altitude: 0.00000 Ft.

Launch guide angle: 0.000 Deg.

Launch guide data:

Launch guide length: 120.0000 In.

Velocity at launch guide departure: **78.5266 ft/s**

The launch guide was cleared at : 0.260 Seconds

User specified minimum velocity for stable flight: **87.4132 ft/s**

Minimum velocity for stable flight reached at: 151.6107 In.

Here we might have a problem as the rocket does not reach the stable flight velocity until about 2.5ft after it has left the rail. So I would either need a longer rail or lighter winds since I can't change this motor. However, since the Tomahawk has a 3.5 margin of stability, I can safely assume that it would still be stable in these conditions as it would lose about ~1 caliber of margin leaving 2.5.

Booster Separation Charge Test



Above is a series of time lapse frames from the charge test for the booster. I had calculated that I needed a little over 1.5 grams of powder – which appears to be correct. Check out the explosion in the top frame.

Nosecone Separation Charge Test



Above is a series of time lapse frames from the charge test for the nosecone. I had calculated that I needed a little under 3.5 grams of powder – which appears to be correct for 2 shear pins. I was happy to see the deployment bag shoot out and not have to completely rely on the nose cone chute.

Altimeter Test

I tested my dual PerfectFlite Altimeters in my ¼ scale Patriot using the exact altimeter settings that I'll be using on my Level 3 certification flight. All charges occurred as planned and the flight was a complete success. "SET" are the initials of the Scott Turnbull, a CRMRC member and acting RSO for the launch. Below is a scan of the flight card for that launch.

CRMRC LAUNCH RECORD				
Pilot Please Complete	Name	JEFF OPPOLD		
	NAR/Tripoli #			
	Cert. Level (Circle)	None	1	(2)
	Rocket Name	PML - Custom -		
	Manufacturer	PATRIOT		
	Motor(s)	T460T.L		
	Payload			
	Electronics	Dual Perfect Flight		
	Recovery Device	Chute		
	Rocket Weight	9 lbs 10 oz oz		
	Previously Flown	Yes	No	
	Rod Requirement	1/8	3/16	1/4
	(Circle one)	7/16	1/2	3/4
		1"	(Rail)	Other
Predicted Altitude	3400 - Actual ft			
Notes:	LEVEL III Cert Electronics Test.			
RSO Only	RSO Name	SET		
	Successful Flight	Yes	No	
	RSO Comments:	All charges as planned. SET		

Pre-Flight Checklist

(not complete yet)

Shop Pre-Flight

Advance Planning

- ☐ Schedule a launch date with Mike Dutch.
- ☐ Verify availability and type of launch rail (1515 or Unistrut).
- ☐ Verify launch site waiver is above 10,500 feet.
- ☐ Assemble all required paperwork for certification.

Deployment Charges

- ☐ Select 8 e-matches (4 primary/4 Backup). Verify continuity with ohm meter - ~1 ohm.
- ☐ Construct 4 charge holders using Micro-Centrifuge tubes and JBWeld epoxy.
- ☐ Verify that I have enough 4F black powder in my powder can (12oz.)

Altimeter Sled

- ☐ Assemble Altimeter Sled.
- ☐ Install fresh batteries.
- ☐ Check Altimeter deployment settings. Make sure backup drogue is programmed to apogee +1 second.
- ☐ Test Altimeters for proper “Beep” sequences. If all good, remove batteries and pack.
- ☐ Install AltimeterOne.
- ☐ Pack instructions for both the Perfectfite and AltimeterOne altimeters.

Packing

- ☐ Assemble Shock Cords and Quick Links.
- ☐ Pack Main, Drogue, and Nose Cone Parachutes, as well as deployment bag.
- ☐ Secure GPS Transmitter and Receiver from CRMRC Club. Charge batteries.
- ☐ Assemble Tool Box, tapes, tie-down cables, grease, paper towels, table, and chair.
- ☐ Place motor casing inside body tube. Include forward seal ring.
- ☐ Pack unassembled motor and liner tube. Don’t forget assembly instructions.
- ☐ Pack at least four (4) Igniters.
- ☐ Pack cooler with Gator Aid and snacks.
- ☐ READING GLASSES!

Launch Site Pre-Flight

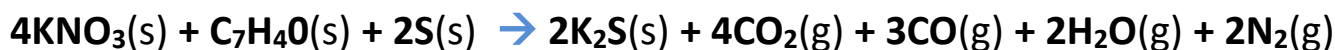
Advance Planning

- ☐ Schedule a launch date with Mike Dutch.
- ☐ Verify availability and type of launch rail (1515 or Unistrut).
- ☐ Verify launch site waiver is above 10,500 feet.
- ☐ Assemble all required paperwork for certification.

Appendix

Black Powder Calculator

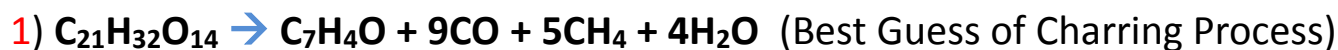
Chemical Reaction of Black Powder:



Where:

KNO₃	-- Potassium Nitrate (Saltpeter)
C₇H₄O	-- Charcoal ¹
S	-- Sulfur
K₂S	-- Potassium Sulfide
CO₂	-- Carbon Dioxide
CO	-- Carbon Monoxide
H₂O	-- Water Vapor (Steam)
N₂	-- Nitrogen

After much research, I decided that the above chemical reaction for the combustion of black powder made the most sense. There are many similar equations found in text books and on the internet for this reaction, most are simplified by treating charcoal as pure carbon, which isn't correct. However, the chemical reaction that occurs during the manufacturing of charcoal is not well known either, but I did find the following:



Where:

C₂₁H₃₂O₁₄	-- Wood (cellulose + lignin)
C₇H₄O	-- Charcoal
CH₄	-- Methane

Molar Weight of the Combustion Products (Right Side):



$$= 2(110.3) + 4(44.01) + 3(28.01) + 2(18.01) + 2(28.01) = 572.71 \text{ g/mole}$$

So, 1 gram of Black Powder produces 572.71 g/mole of gas and solid products.

Now we need to calculate the weight of just the gas products:

Weight of each gas product:

$$4\text{CO}_2: \quad 176.04/572.71 = 0.3074 \text{ g}$$

$$3\text{CO}: \quad 84.03/572.71 = 0.1467 \text{ g}$$

$$2\text{H}_2\text{O}: \quad 36.02/572.71 = 0.0629 \text{ g}$$

$$2\text{N}_2: \quad 56.02/572.71 = 0.0978 \text{ g}$$

Which allows us to calculate the gram moles of the gas products:

Moles of each gas product:

$$4\text{CO}_2: \quad 0.3074/44.01 = 0.006985 \text{ gram-moles}$$

$$3\text{CO}: \quad 0.1467/28.01 = 0.005237 \text{ gram-moles}$$

$$2\text{H}_2\text{O}: \quad 0.0629/18.01 = 0.003493 \text{ gram-moles}$$

$$2\text{N}_2: \quad 0.0978/28.01 = 0.003492 \text{ gram-moles}$$

$$\text{-----}$$
$$= 0.019207 \text{ gram-mole of gas product}$$

The point of the calculations on the previous page were so that we can now use the Universal Gas Law to develop an equation that has pressure, and thus force, as a function of the amount of Black Powder used. First a definition of the Universal Gas Law is in order.

Using the Universal Gas Law:

$$PV = nRT$$

where: **P** = Pressure in lbs/in²

V = Volume in in³ = $\pi (D/2)^2 L$, where **D**=BT Diameter, **L** = BT Length

n = number of gram-moles of powder = 0.019207

R = Universal Gas Constant = 1545.4 ft-lb_f/lb-mol °R

T = Gas Combustion Temperature

= 1300 °C for 10% Sulfur(=2832°R)

Breaking up the variable “n” into two part such that:

$$n = G_{BP}n$$

where: **G_{BP}** = grams of black powder

n = number of moles of gas

and substituting into the universal gas law yields:

$$PV = G_{BP}nRT$$

Solving for **G_{BP}** yields:

$$G_{BP} = PV/nRT$$

(Charge Calculating Equation)

Using the **Charge Calculating Equation:**

$$G_p = PV/nRT$$

and substituting real values and correcting for units yields our ultimate equation for the number of grams of black powder as a function of the pressure and the internal tube volume:

$$\begin{aligned} G_{BP} &= (P \times 3.14159 \times D^2 \times L \times 0.25 \times 454) / (1545.4 \times 12 \times 2832 \times 0.019207) \\ &= (P \times 356.5716 \times D^2 \times L) / (1008730.005) \\ &= 0.0003535 \times P \times D^2 \times L \end{aligned}$$

Finally, we'll need to determine just how much pressure is required to generate the needed force to sever the shear pins and pop out the nose cone:

Pressure Calculator:

$$\text{Pressure (lbs/in}^2\text{)} \times \text{Area (in}^2\text{)} = \text{Force (lbs)}$$

solving for pressure:

$$\text{Pressure} = \text{Force/Area}$$

We now have all the equations that we need to calculate the amount of black powder for both the apogee separation ejection charge (air frame mid-section) and the main chute separation ejection charge (air frame upper-section). Using an on-line force calculator I determined that 200lbs of force would provide enough margin to assure a clean separation.

Tomahawk Calculations:

$$\text{Tube Diameter} = 5'' \text{ (Radius} = 2.5'')$$

$$\text{Area} = \pi R^2 = 3.14159 \times 2.5^2 = 19.635 \text{ in}^2$$

$$\text{Pressure} = 200 \text{ lbs}^2 / 19.635 \text{ in}^2 = 10.20 \text{ lbs/in}^2$$

$$G_{BP} = 0.0003535 \times P \times D^2 \times L$$

Air Frame Mid-Section (L = 17 in)

$$\begin{aligned} G_{BP} &= 0.0003535 \times 10.20 \times 5^2 \times 17 \\ &= 1.53 \text{ grams} \quad \rightarrow \text{Design for 2 grams} \end{aligned}$$

Air Frame Upper-Section (L = 35 in)

$$\begin{aligned} G_{BP} &= 0.0003535 \times 10.20 \times 5^2 \times 35 \\ &= 3.2 \text{ grams} \quad \rightarrow \text{Design for 4 grams} \end{aligned}$$

2) Rocketry Online/Info-Center *Black Powder Usage*: <http://www.info-central.org/?article=303>