PEAK OF FLIGHT NEWSLETTER

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Fabricating A Composite Transition For Boosted Darts

By Clay Reynolds

Some Background in Boosted Darts

Boosted darts are essentially a traditional two-stage rocket, except in place of a powered second stage they have a "dart", which is a small profile, high-density coast vehicle. Contrary to what you may think gravity is actually not your greatest enemy when it comes to altitude of a rocket flight, it's actually air resistance (except in a few special situations). The idea of a boosted dart is to simply minimize drag while maximizing your momentum. Exploiting this principal leads to some pretty cool results. For example, the Loki sounding rocket was a 76mm diameter N class rocket that boosted a dart to just over 180,000ft. The slightly upscaled version, the Super Loki sounding rocket was a 98mm (4in) diameter rocket that boosted a 1.625" diameter 13.5lb dart to over 372,000ft, well within the current definitions of space on a hobby O class rocket.

Importance of a Specialty Transition

A boosted dart is actually fairly simple and not much more complicated than a regular single stage high performance rocket; that is, if you don't want it to be. The most challenging and head scratching part for making a boosted dart for me was designing the interstage transition. The dart by nature has a nearly full boat tail in order to minimize drag and this makes creating an interstage transition somewhat problematic (**Figure 1**). Another important factor into this design is simplicity. There are multiple ways you could release the dart: drag separation, timed charges, and even some kind of spring-loaded locking system. I'm a firm believer in the KISS (keep it simple stupid) methodology when it comes down to these decisions and I ultimately decided on the drag separation method. By making a cavity that would "lock" the dart in place under boost and easily detach after burnout, the dart could automatically detach on its own. The dart in this case measured 29mm and weighed 5lbs. A dart even this size would easily detach from the transition at motor burnout simply because the dart will not be slowing down nearly as fast as the booster. Using this method eliminates any need for complex staging or charges.

Figure 1: Booster and dart stages of the Boosted Dart rocket. The dart has a nearly full boat tail.

Lets Make a Transition!

There are a few things you will need to gather before making a transition for a boosted dart. It is first assumed that you have access to basic tools and have the knowledge to build basic composite parts as well as a basic understanding of epoxy resins systems and building techniques. Make sure you prep your BONDING surfaces! I always prep my surfaces by sanding with rough sand paper (~120 grit down to the first layer of fibers) and wiping down with acetone to remove any residues. ALWAYS wear gloves to protect yourself from harmful epoxy resins, but also to decrease the chances you could contaminate your bonding surfaces. Your transition cone takes the brunt of much of the in-flight G forces, so making sure you have good bond strength is one of the many ways to make sure you have a successful flight. (On a side note, I have tested this transition to Mach 2.8 and 40+Gs)

Ok, first of all lets make a list of materials needed. Again, I'm assuming you have the basics already available to you.

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Parts Needed

- ☐ Filament wound nosecone: Filament wound nosecones have the superior strength needed to take the G forces. Sold by Apogee Components and a few other vendors
- ☐ Coupler tube: I.D. same as the O.D. for your dart, I made mine
- ☐ Laminating/pourable epoxy: I've used HTR-212 and U.S. Composites 635 with success
- ☐ Plastic Saran Wrap
- ☐ Centering ring*
- ☐ Dart Tailcone: Optional, but very helpful
- ☐ 5 minute Epoxy
- ☐ Thick Epoxy resin: JB weld and/or Rocketpoxy works well
- ☐ Chopped carbon/fiberglass/kevlar, improves overall strength and reduces weight
- ☐ Hot glue gun

** Very crucial in making sure your transition stays straight. You may be able to purchase a centering ring or make one yourself. Make sure the O.D. of your centering ring fits inside your nosecone and make sure the I.D. of the ring is the same as the O.D. of your coupler tube. If you're lost don't worry, you'll see more of how this works later.*

Basic Design

Figure 2 is a cross section of what you'll be making; hopefully this clarifies the process somewhat. The nosecone for this transition did continue back to the right farther until it fit a 3" airframe

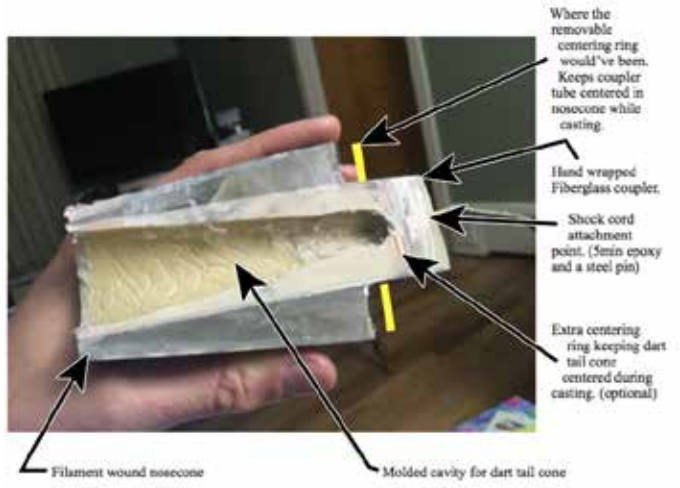

Figure 2: Cross section of a composite transition

like on **Figure 3 on page 6.** However, this particular transition in the image above came from a failed boosted dart attempt. (Motor CATO, due to liner issues. You really think I'd cut a perfectly good transition in half?) Even after taking the brunt of a CATO and falling from ~5,000ft the only major damage was sustained on the unsupported part of the transition and a minor crack in the epoxy in the upper end of the photo. The unsupported portion is missing, which is the reason this particular piece looks so short. A transition "step" was machined out of aluminum and placed at the beginning of this transition, which is also not shown in this particular cross section.

So you still want to make a composite transition? No? Fine, well I'm going to talk about how you could make one anyway.

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First things first, you'll need to make or buy a composite coupler tube the same I.D. as the O.D. of your dart. I was unable to find something that fit the size I needed, but maybe you'll have better luck. So instead I just wrapped a fiberglass tube around a section of airframe on my dart. (If making composite tubes is new to you I suggest reading the **Peak of Flight Newsletters:** 370- https://www.apogeerockets.com/education/downloads/Newsletter370.pdf and 371- https://www.apogeerockets.com/education/downloads/Newsletter371.pdf, "Fabricating Carbon Fiber Airframes" by Alex Laraway) Most of you likely know the basics of composites or have already made a number of tubes before so I'll leave this portion for you to figure out on your own. Once you make or buy a coupler tube we'll be able to continue on with the build process!

Building The Transition

Now that all the materials and parts are on hand we can begin the build process.

1. Remove the upper section of the nosecone so your coupler tube fits nicely inside. Keep in mind not all nosecones have a uniform wall thickness, so take your time and remember it's better to go slow and make a few cuts progressively down the nosecone than to buy another nosecone. If a lathe is available, that makes easy work of this process. If you don't have a lathe, cut the nosecone with a hand saw or band saw, then true up the end on a belt sander. If you've built rockets before I'm sure you've got your own method to true up ends.

2. Then cut down your coupler tube section to the length required. My coupler tube length was 5-1/4", but yours will almost certainly differ; it all depends on the length of tailcone on your dart. I like to leave about 1" or so extra for shock cord attachment on the bottom end, and I also like to have the transition accept more than just the tailcone on the dart. (It helps keep the dart centered when casting and provides a slightly better fit.)

3. Now onto bonding. You will first need to prep your surfaces! First, we will be bonding a plug into the inside of your coupler tube. Once you have sanded and used acetone to wipe down the bonding surfaces we can begin. I like to use 5min epoxy for this step. I find it bonds well to composites and decreases the time to move onto the next step. Just be careful, mixing large amounts of 5min epoxy can be dangerous. (Epoxy forms an exothermic reaction, I have recorded temperatures of over 250F with 5min epoxy!) The plugged end will be the inside your transition, so now would be the time to attach a shock cord if you plan on it. I generally make a few knots in my shock cord, cover the end with duct tape or masking tape and then fill the tube to about 3/4" with

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5min epoxy. Pour the epoxy from the other end, being very careful to pour straight to the bottom of the tube to avoid getting any epoxy on the inside surfaces of the tube. This creates a plug so you'll be able to fill the upper section with epoxy to mold your dart tailcone, but this also provides an attachment point for recovery system. If you don't feel comfortable placing the full force of recovery on a 5min epoxy bond joint then attach a steel pin through the coupler tube, tie off your shock cord there and then continue with making the plug. (I'd highly recommend using a pin of some sort for extra strength.) Again, you don't have to use 5min epoxy, it's just what I personally like to use and allows you to quickly move to the next step.

4. As of now you should have a plug and shock cord bonded into your coupler tube. Prep the top inside of the nosecone and O.D. of your coupler tube. Then place your centering ring and coupler tube inside the nosecone until you are happy with the fit. Make sure to have a section of coupler tube protruding out the top of your nosecone. This will give space to form a transition ring. At this point I like to hot glue the coupler tube in place at the top of the nosecone (don't worry, the hot glue will be removed later). The point of this is to lightly secure the coupler tube into the nosecone while also sealing off the front end. Use the centering ring to center the coupler tube while the glue cools. The centering ring I used had two holes drilled opposite of one another where a single piece of string was tied to either side. This allows one to easily remove the centering ring later. Once cooled, pull out the centering ring and visually inspect. If you need to repeat this step do so or until you feel comfortable with how centered the coupler tube is. This needs to be perfect, as you have very little room for any adjustments later on.

5. I like to use 10 or so grams of 5min epoxy to secure the coupler tube in before mixing a larger batch of epoxy. Mix the epoxy then pour into the bottom of the transition. You will need to remove the centering ring carefully to do this. Make sure to not accidentally pull the coupler tube out of alignment. After pulling out the centering ring, be very careful and double check the alignment. When you're happy with it mix your epoxy and pour, making sure not to get any epoxy on the upper inside surfaces of the nosecone. Once this fully cures you can move onto the next step.

6. Now the coupler tube should be bonded and centered into the nosecone. Of course, a few grams of 5min epoxy is not going to be enough, and you may have already guessed that we need to fill this cavity with a bit more epoxy. I filled my transition with 3.5" of epoxy but this number will vary, just remember you want enough bond strength to take the weight of your dart under maximum acceleration. This is where you'd need to mix up some laminating epoxy/thin epoxy resin. I

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recommend using laminating epoxy because it is easier to pour. Also make sure you DO NOT use 5min or another fast setting resin. You may find this much epoxy may lead to a thermal runaway reaction. I'd also recommend some additives for the epoxy like chopped carbon/kevlar/glass to improve strength and reduce weight. Add very small amounts of these additives at a time until you get a nice consistency, you'd be surprised how little it takes. Once mixed pour the epoxy into the nose just like in **Step 5**, being careful not to get any epoxy on the top inside sides of your nosecone. Let this sit the required cure time of your resin system and move onto the next step.

7. Now we get to the fun part! Prep the inside surface of the coupler tube and make sure to have the tailcone for the dart and some Saran Wrap ready. Also if you want to use a centering ring for your tailcone make one now and place it in the bottom of your coupler tube. Then mix up some thick epoxy resin (I've used Rocket-poxy and JB weld just fine). You may be able to use a thin resin system or perhaps even add chopped carbon/kevlar/glass, but I have not tried this. This decision is entirely up to you and what you have available. Once these materials are ready wrap the entire outside of the nosecone in tape. This will make any mess made by the epoxy easier to clean up. Then mix up enough epoxy to nearly fill the inside of your coupler tube. Once mixed, pack the epoxy into your coupler tube as best as possible, then take two sheets of Saran Warp and as best you can pull over the tailcone on your dart. Yes, you will have wrinkles, but that's just fine. Then slowly slide your dart's tailcone into the uncured epoxy pushing out any extra epoxy as you go. I like to push the dart in a half-inch or so past the tailcone. Because the dart has the same O.D. as the I.D. of the coupler tube it should self center if you have a good fit. If you placed a centering ring at the bottom you can feel your way around until you feel the back end of your dart push through. Once this is done place the whole assembly on a flat surface and eyeball with a carpenter square (**Figure 3**), or if you have any less rudimentary ideas to test straightness then try one of those.

Figure 3: Using a carpenters square to check alignment of the dart in the transition

Sometimes it's helpful to cast this piece by using the entire dart to help eyeball its straightness. If there was a tight fit on the coupler you should have nothing to worry about, but it doesn't hurt to double

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check. Once you feel comfortable, leave everything to be and wait to remove the dart until your epoxy is fully cured.

8. Almost done! Now that your epoxy has cured you can remove your dart from the transition. It should come out with little to no effort, but the Saran Wrap will stay in the transition. Note: you will not be able to remove all of the Saran Wrap from the transition, but this does not pose any problems later on.

Figure 4: I machined an aluminum piece to go on the top of the transition piece.

9. Now as you've probably noticed you have a really nice non-aerodynamic square edge on the leading edge of your transition. I machined an aluminum transition piece to fit this area (**Figure 4**) and bonded it in with JB Weld; if you don't have access to a lathe you may be able to cast one out of epoxy. By using tape on the back end of this flat edge it is possible to cast an epoxy slug in this area then fashion a cone with a file and some sandpaper, this will take some time though.

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Finishing

Your transition should now be finished. You may have already noticed that if you press your dart into the transition with force it can be very hard to remove. I like to place a small piece of cotton in the bottom of my transition keeping the dart from wedging itself in so tight it will not drag separate; this is a crucial step when you go to fly. If your dart doesn't separate, then your entire flight was virtually pointless. As far as finishing goes I like to sand and spray a few layers of high temp ceramic paint for looks **(Figure 5)**, but the rest is up to you!

Testing

It's always a good idea to stress test your transition before flight. I added weight to the top of the dart while in the transition until it equaled out to the expected G forces of the flight. After doing this, make sure your dart can easily be removed from the transition otherwise it may not drag separate or just as bad it may remove your transition from the booster while it separates. Pinning in the transition or having other modes of attachment can greatly reduce the chances of your transition pulling up with the dart. If the recovery for your booster is stored in the transition make sure the dart will also not force the transition on so tight that your recovery fails to deploy. Remember, it's always the little things that dictate success or failure in rocketry, and I wish you good luck!

Figure 5: Finished model painted and prepped.

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