PEAK OF FLIGHT NEWSLETTER

Issue 606 / August 15th 2023

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Zephyr Repair After a Motor CATO

By David Anisman

What Can Go Wrong, Will

On a chilly May morning earlier this year, just south of Salt Lake City, my Zephyr sat perched on the launch pad for its first flight…. and my first L1 certification attempt. I'd run through my check list twice and was feeling confident, as I'd followed the advice of many of my Utah Rocket Club colleagues and kept the flight as simple as possible. I was flying on a Cesaroni H120 for an estimated altitude of 1800 feet. I considered using a Jolly Logic Chute Release, but decided not to in order to keep things really simple; if it drifted, I'd be happy to walk!

Figure 1: Zephyr at crash site

Finally, it was my turn! The LCO announced the launch and the countdown commenced: 5, 4, 3, 2, 1…… DISASTER!! After a rather slow start off the pad, the rocket clawed its way to about 75 feet and - to my horror - started cartwheeling before nose-planting into the desert soil (https://www.youtube.com/shorts/6X4sHP9paac). As the rocket sat aft end up and burning, someone started singing "Happy Birthday to You!" (you can actually hear it in the video) Then came that all too humiliating ejection charge, propelling the body tube backward. That got a big laugh from the crowd (it always does!), but I will confess, I found it hard to join in.

As bummed as I was, I was also determined to learn from whatever happened and recover from it to fly again. At this point, there can be a real desire to go grab the rocket and take it back to your prep area to do a postmortem. But the first step should be a thorough inspection of the crash site (Fig 1) as it may provide some key clues to what transpired. At the crash site, the only obvious damage I could see was that the aft end of the motor mount tube, with its attached Aeropack retainer, had separated from the rocket and was lying next to it. Otherwise, the body tube appeared to have survived without buckling and the all important fin can seemed fine. Certainly a lot better than I'd expected!

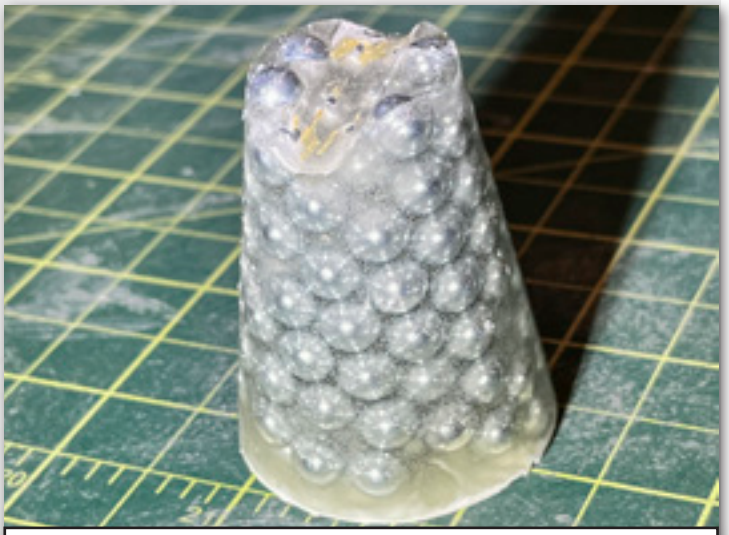

Figure 2: Broken nose weight from the crashed Zephyr

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Back at the prep area, I confirmed that the rocket framework - body tube, fins/fin can and nose cone - were entirely intact (!)…. .a tribute to the engineering Apogee put into this rocket and, I must say, me - for following directions! The two areas of major damage were the nose cone weight and the motor mount tube. I had put in nose weight using a dowel through the nose cone tip and pouring a slurry of epoxy and BBs to surround the dowel (Apogee Advanced Construction Video #84, https://www.apogeerockets.com/Advanced_Construction_Videos/Rocketry_Video_84). The weight broke just aft of the dowel, leaving the dowel and the forward portion of the weight place and allowing the aft portion to rattle around freely in the nose cone (Fig 2). This loose weight would no longer serve its purpose, but more concerningly would also be a destabilizing factor during flight. That would need to be removed before the rocket would be safe to fly.

Figure 3: The damaged motor mount tube

Sadly, the motor mount tube was severely damaged. There was molten remains of the motor liner inside it; it had been perforated and had also collapsed over about half its length. It was clearly beyond repair (Fig 3). It would need to be removed and replaced if this rocket would ever fly again.

Analysis

So what exactly happened? As best I can put it together, the primary cause of the CATO (catastrophic failure) was a defect in the motor liner, just forward of the

Figure 4: A defect in the motor liner likely leading to the CATO

aft closure (Figs 4 & 5). As a result, instead of all the thrust being directed out axially through the nozzle, the defect allowed thrust to be vented sideways. This super hot thrust burned through the casing and motor mount tube and resulted in vectored thrust. The summed vector of (weakened) axial thrust and quite powerful lateral thrust was probably at a 60 degree angle to vertical, which caused the rocket to cartwheel. It also caused the aft end of the motor mount tube with its Aeropack retainer to

Figure 5: Another view of a defect in the motor liner likely leading to the CATO

come off on impact (the retainer can be seen just to the right of the body tube in Fig 1). With nothing to hold the motor and motor casing in place, the motor "flew through" on impact, coming to rest in the forward end of the motor mount tube, with the forward half of the casing extending beyond the motor mount tube. As a result, the still-burning aft end of the motor with its casing lodged inside the motor mount tube just aft of the forward centering ring, causing a breach of the motor mount tube

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Figure 6: The resulting motor tube after being removed

wall and collapse of the middle half of the motor mount tube. I was actually able to pass a long dowel from the aft end of what remained of the motor mount tube, through the breach in the tube and into the body tube cavity forward of the forward centering ring, without going out the forward end of the tube! I did attempt to use the dowel to re-expand the motor mount tube, but it was sealed in the collapsed state by the molten motor liner that had extruded through the breach in the casing. Clearly, the motor mount tube could not be salvaged or repaired and had to be replaced. I was able to reach in for the forward end of the body tube and pull out the motor mount tube as the epoxied joints had largely burned away (Fig 6).

Motor Mount Tube Repair

The best news of all was that the fins were not only intact, but seemed to be solidly attached to the airframe. As I'd already extracted the damaged motor mount tube, this had to be due to the robustness of the internal and external fin fillets with the body tube. So it seemed that I wouldn't have to do any fin repair! The next step in the repair was to determine if the interior of the fin can (fin tabs and centering rings) was in good repair, as well as cleaning it up to allow a new motor mount tube to be placed. Unfortunately, the only way to do this was to remove the aft centering ring, which was epoxied to both the inside of the body tube and the aft surfaces of the fin tabs. I'd have to be very careful to avoid adding more damage that might prevent an adequate repair!

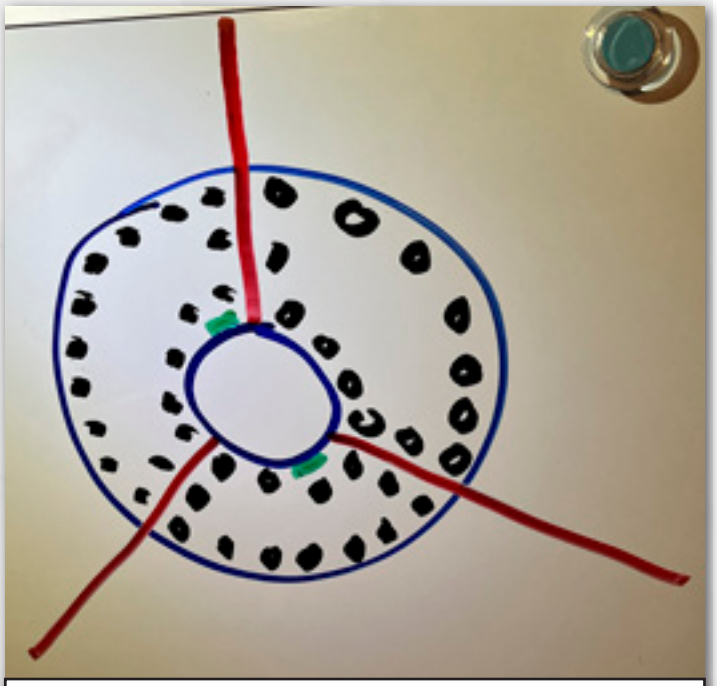

Figure 7: Zephyr schematic to determine where to safely drill

I took time to review Apogee's Zephyr construction instructions to refresh my memory on the internal anatomy of the rocket (is this starting to sound like surgery?) as I wanted to be abso-

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lutely certain that I knew what was behind that aft centering ring, and where everything was, so that in removing it, I could be as precise as possible. I drew a schematic (Fig 7) showing where I could safely drill (black circles) and where I could not drill (green squares). The green squares were the alignment rails, whose original purpose was to make sure the fin tab slots on the aft centering ring were perfectly aligned with the corresponding slots on the forward centering ring. It seemed to me I wouldn't need the rails any longer since the fins were already in place. But as the figure shows, the alignment rails sit very close to a fin tab, and I elected not to try to drill into the rails in order to be sure I wouldn't inadvertently damage a fin tab.

After drilling the holes, I used a keyhole saw to cut out the wedges of centering ring (Figs 8-10). This wasn't easy, as the saw, which was the finest one I could find (14 teeth per inch) tended to grab the wood; a light touch, short strokes and patience were the key to cutting through with control. I then ground down what was left of the aft centering ring (Fig 11) with a Dremel and several different bits. A one inch diamond cutting disc was small enough to use inside the fin can opening without damaging neighboring surfaces, but I had to go very slowly (and use two hands!) to keep it under control. A coarse (60 grit) sanding drum was also great, but required care to keep under control and was limited in that it couldn't get into sharp corners, like

Figure 8: Step 1 of holes being drilled to remove the aft centering ring

Figure 9: Step 2 of holes being drilled to remove the aft centering ring

Figure 10: Step 3 of holes being drilled to remove the aft centering ring

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Figure 11: Aft centering ring fully removed

between a fin tab and the body tube. This last problem was solved by using a 1/8" drill bit - carefully! - using the side of the bit as a grinder. The aft edge of the fin tabs had a tab which fit into notches in the original aft centering ring, (Fig 12) to preserve the correct orientation of the centering ring with the fin tabs. As this orientation was no longer relevant (the fins were already glued in place), I decided not to keep the tabs, as cutting a new set of centering ring notches would be difficult (and I was determined to do this without ordering a replacement centering ring….which Apogee does sell).

Figure 12: Closeup of the fin tab for aft centering ring alignment

Figure 13: Replacement tube for motor mount

The next step was to test fit a thick-walled 38mm tube to see if the channel for a new motor mount tube was the right size. Here, I proved lucky: the new tube fit in smoothly all the way past the forward centering ring, and fit snugly as well. This meant that no additional major work would be necessary other than routine clean up to get the new motor mount tube in place (Figs 13 & 14). This was a real stroke of luck, as further reconstruction deep inside the fin can would have proved quite difficult.

Figure 14: Closeup of replacement tube for motor mount

The most challenging part of the clean up inside the fin can was removing the alignment rails, which at this point were still

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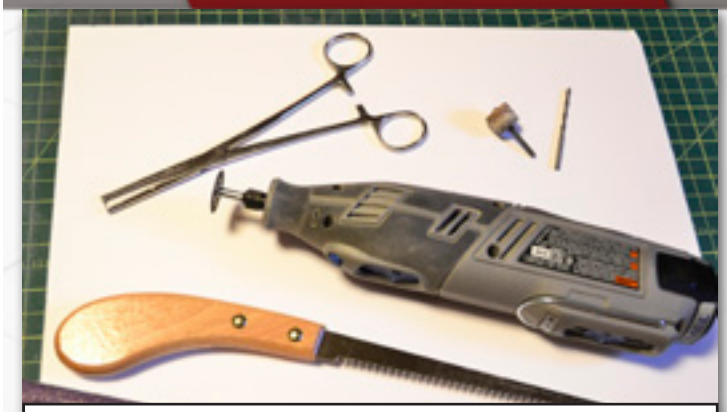

Figure 15: Hemostat on top left

glued into the forward centering ring, and I definitely didn't want to damage that ring! I could grind down some of the rails with Dremel attachments, but ultimately I had to reach into the fin can with a hemostat (the silver clamp thingy in Fig 15) and pry away the rails until most of them were gone. I did have the option to just snip off the aft end of the rails with a diagonal cutter tool, as the rails really wouldn't be in the way when replacing the motor mount tube. But this would leave unnecessary weight in the fin can, so I decided to remove them…..carefully!

The rest of the clean up required working deep inside the fin can, which was a challenge. One invaluable tool was the hemostat mentioned earlier. They come in a variety of lengths and shapes (straight vs curved) and have a locking mechanism that allows you to grab something with less effort as you manipulate the tool. (Hemostats are readily available on Amazon for from $5 to $15) I was able to reach into the fin can to remove bits of motor mount tube and overhanging epoxy with the hemostat, nibbling away a little at a time. Another very helpful tool is every rocketeer's favorite: 60 grit sandpaper glued on a wood dowel. This helped clean things up, preparing the fin tab surfaces for a new motor mount tube. But I had to be very careful not to enlarge the channel for the new motor mount tube. Had this happened, however, I would have considered using some FixIt Epoxy clay (available at Apogee - https://www.apogeerockets.com/Building-Supplies/Adhesives/FIXIT-Epoxy-Clay) on the fin tab edges to narrow the channel. Once hardened, the clay could be sanded to a precise diameter to receive the new motor mount tube; it also will bind to epoxy applied as a fillet.

Figure 16: Circular cutting bit used to cut new aft centering ring

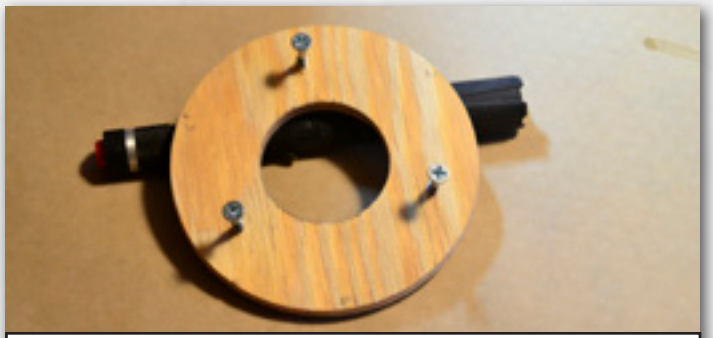

Figure 17: New aft centering ring

To create a new aft centering ring, I used 3-ply 1/8" plywood. My first attempt was to cut one on my jig saw, but the result wasn't a very true circle and required a lot of sanding; even then, it didn't really fit properly. A better option was to use a circle cutting bit on my drill press (Figs 16 & 17); since I'm always looking for an excuse to buy a new tool, this seemed the ideal solution! (Amazon, MIBRO Heavy Duty Circle Hole Cutter, $12). This tool is adjustable to allow cutting holes from one to six inches and has a reversible chisel blade to allow cutting both inside and outside cir-

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cles. One important safety caveat: it should not be used on a hand-held drill, and the drill press speed should be less than 500 RPM. Only a very small amount of sanding was required to get a perfect internal and outer diameter fit. As I wanted to be able to dry fit the new aft centering ring on the motor mount tube for initial glue up, then remove it for epoxying inside the fin can, I installed three wood screws so I could remove the ring after the initial glue up.

Figure 18: New motor mount tube installed

I had some spare 38mm thick walled MMT (38mm LOC Body Tube purchased from Apogee - https://www.apogeerockets.com/Building_Supplies/Body_Tubes/High_Power_Tubes/38mm_LOC_Body_Tube) from a scratch build; I cut an 11" piece (ensuring I had enough to attach a new Aeropack retainer) and it fit perfectly (Fig 18). To glue the new motor mount tube in place, I used a similar two-step procedure as in the original instructions, but with slight modifications as the fins were already in place. First, I drew lines on the motor mount tube corresponding to the fin locations using an aluminum angle; I made sure these lines extended all the way to the aft edge of the tube so they'd be visible during the initial motor mount tube glue in. Next, I ran a bead of epoxy on the motor mount tube

Figure 19: Centering ring glued into place

just forward to the line where the forward centering ring would sit, as well as beads of epoxy along the 3 fin lines, being sure to stop short of where the aft centering ring will sit so that this ring wouldn't be glued in prematurely. With the aft centering ring dry fit into place on the motor mount tube, I slid the tube into the correct depth with the fin lines NOT aligned with the fin tabs. At that point, I rotated the motor mount tube - without advancing it - so the fin lines aligned with fin tabs to "draw" some epoxy

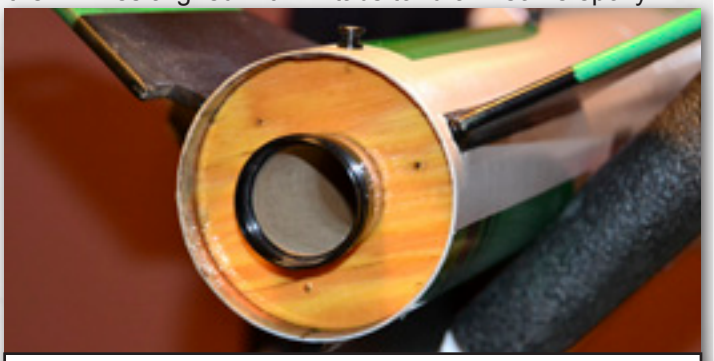

Figure 20: Completed replacement of centering ring and motor mount

between the root edge of the fin tab and the motor mount tube. Once this was dry, I removed the aft centering ring and applied some epoxy where needed to the motor mount tube - centering ring and motor mount tube - fin tab joints (Fig 19). I then epoxied the aft centering ring into place. Lastly, I epoxied on a new Aeropack retainer and put a thin coat of epoxy over everything (except the retainer), followed by a final coat of paint (aesthetics!). Fini! (Fig 20)

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Nose Cone Repair

Here I had an easy out: buy a new nose cone! (Apogee PNC-98 - https://www.apogeerockets.com/Building-Supplies/Nose-Cones/For-56mm-to-98mm-4in-Body-Tubes/PNC-98-4in-X-19-8in) But part of the fun of doing the repair was to see what solutions I could come up with. I knew that I'd have to first cut a hole in the base of the nose cone to extract the loose fragment. Then I'd have to seal up the hole.

But how to seal up the hole? The Zephyr nose cone is made of polypropylene, which makes it really sturdy. This is great for a high power rocket, but it makes repairs tricky. There are two categories of plastics: polystyrenes and olefins (polypropylene and polyethylene). Most cyanoacrylate glues and epoxies don't bond well to the olefins; they do okay with the styrenes. I did a lot of research to find an adhesive that would adhere to polypropylene and found Loctite Plastics Bonder (Fig 21), a 2-part set up with an activator that is applied just prior to the actual glue. (Note: I subsequently spoke to other rocketeers who said that most epoxies will work fine to glue a plywood bulkhead into the nose cone if you rough up the surfaces to be bonded and have a good, snug fit; this can be reinforced with small wood screws. But by that time, I'd already completed my repair)

Figure 21: Loctite Plastics Bonder

The base of the Zephyr nose cone has two surfaces: a larger flat one and a smaller slanted one. If I cut the hole for extracting the epoxy/BB nose weight on the slanted surface, it wouldn't be large enough to remove the fragment, so I initially cut a hole on the larger surface. Either way, I also had to cut off the attachment bar for securing the shock cord and parachute shroud lines. Thus, my repair also needed to include a new attachment point.

Figure 22: Nose weight is larger than the hole

In the end, I had to cut a larger hole to get the epoxy/BB weight fragment out (Figs 22 & 23). I decided to fill the hole using two shaped pieces of 1/8" plywood, one of which would hold the eye bolt to replace the shock cord/shroud line attachment point (Fig 24). The position of the hole was chosen so I could have the new shock cord attachment point on the flat area of the repair (rather than on the sloping shoulder). The two pieces of plywood were beveled slightly (using a jigsaw) to get a better fit, but the small area in which I had to work meant that it was hard to maneuver the pieces into the hole. I also wanted to be able to compress the pieces against the inside of the nose cone plastic while the adhesive grabbed. To do that, I relied on the eye bolt for the semi-circular piece and

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Figure 23: Hole was enlarged to remove the weight

put in two small wood screws to the rectangular piece, ensuring that they were positioned inside the perimeter of the hole. I also needed some way to support the NC while my two hands were busy gluing in the plywood pieces. I crafted a simple support out of some spare furring strips, gluing them into a grid that rested on top of a 5 gallon bucket. The square hole in the middle was sized to fit the nose cone securely (Fig 25). Before attempting to glue the pieces in place, I did several dry fit rehearsals so I knew exactly how to manipulate each piece into the proper position.

Figure 24: Replacement attachment point

Figure 25: Nose cone suspended for fixing

Gluing in the pieces had one other tricky part: the glue is a thick liquid that was easy to apply on the surface of the plywood piece before maneuvering it into position. But the activator tube is like a felt tip marker and has to be applied to both surfaces before applying the glue; getting it on the inside of the nose cone plastic was awkward. I glued in one piece at a time, applying upward pressure (on the eye bolt and screws, respectively). Once the two pieces were glued in using the Loctite, I drilled pilot holes and used 3/4" screws around the perimeter of the repair to reinforce the entire thing. Gaps in the mid-line plywood joint were filled with thick CA (Figs 26, 27 & 28).

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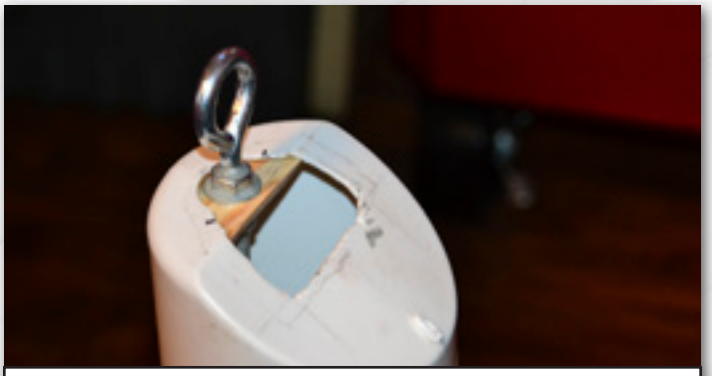

Figure 26: Step 1, the main attachment point was installed

Figure 27: Step 2, a filler piece was added to close the hole

Figure 28: Step 3, both added pieces are secured

Final Thoughts and Lessons Learned

As anyone who's been around rocketry a while can tell you, unexpected things can happen when you launch a rocket. This was my third CATO (all motor issues), and I've learned that while CATOs are miserable, it helps to laugh at them; it makes them easier to deal with! Once the dust settles, take the time to analyze what happened so you can apply what you learn and avoid problems in the future. As this scenario demonstrates, though, some problems can't be anticipated. All you can do is pick up the pieces - quite literally! - and move forward. I found the repair to be almost more satisfying than the original build since it required me to be innovative. It also gave me an excuse to buy a circle cutting bit, which I plan to use a lot in the future to create my own centering rings and bulkheads. One thing I would have done differently (had I realized I could) would have been to simply cut off the bottom of the nose cone in a flush circle and epoxy in a slightly recessed bulkhead with an eye bolt. One thing this episode definitely taught me is that a robustly engineered and well built rocket can withstand a ton of abuse and still be flyable.

About the Author

I am a recently retired Family Physician and Colonel (ret), USAF, MC. In 2019, I decided to rekindle my fondly remembered exploits with model rockets as a kid in the late 1960s. Since then, I have enjoyed progressing through low and mid power rockets until finally getting my L1 Certification this year with the Utah Rocket Club. I especially look forward to working with kids to get them excited in rocketry. I must give credit to my wife, Pam, who has both tolerated and encouraged my growing love of rocketry, and who flew her first rocket this year (an egg-lofter and the egg survived)!

David Anisman