PEAK OF FLIGHT NEWSLETTER

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PEAK OF FLIGHT

Converting a Rocket into Two-Stage Rear Ejection

By Tim Van Milligan

I got this question a while back, and I thought it would be a good topic for a newsletter article. Glen Doggett asks: "Is there a kit or conversion plans for this Nike Apache rear-eject-gap-stage rocket (**Figure 1)** featured in Advanced Construction Video #82 (https://www.apogeerockets.com/Advanced_Construction_Videos/Rocketry_Video_82). The rocket is visible at that 2 minute, 41 second mark.

Figure 1: The single-stage Estes Nike Apache kit that was converted to a two-stage rocket.

First off, this rocket kit has long since been discontinued. So you may have to search the auction web sites to find one if you wish to build the rocket I did. Because of this issue, I'll try to be as generic as possible with the description here of the modification of the rocket to a two-stage rocket. You may find some other rocket that you can use these techniques with.

I also have to say that this is a pretty complex modification, because it involves taking the Estes Nike Apache rocket, which was intended to be a single stage rocket, and converting it to a two-stage rocket. My friend Chris Michielssen, whose Odd'l Rockets kits we sell at Apogee (https://www.apogeerockets.com/Oddl_Rockets), has a building block where he goes through the construction of the rocket without modification at: http://modelrocketbuilding.blogspot.com/2014/04/estes-nike-apache-old-unfinished-build.html

The two things that make this a difficult conversion are the blow-mold transition section that holds the two parts of the rocket together, and adding gap-staging to the rocket.

The transition, since it is blow-molded, is fairly easy to modify. It only needs to be made hollow by cutting off the ends. If it was made from a solid balsa wood part, it would be much more difficult to modify.

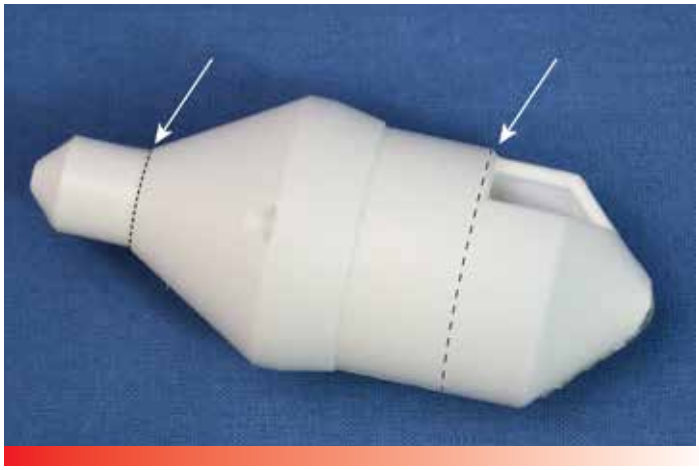

Figure 2: The cut lines on the blow-molded transition. This will make it into a hollow part.

The rear part is easy to modify, and you can see where to make the cut in **Figure 2**. The para-

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chute loop was cut off, because it would interfere with the engine tube of the booster as it slides up into the transition.

The front part is cut off right at the top of the transition. These two cuts open up the transition. The transition is glued directly into the top of the booster tube. It is permanently attached, but it is hollow, so the engine mount tube can pass through it. But before you glue it in, you have to anchor the front end of the shock cord for the booster tube into the tube. I prefer to wedge it under the shoulder of the plastic transition. You need to use Kevlar® here, because it needs to be really strong and you won't have a chance to replace it later.

The engine mount tube for the booster stage runs through the entire length of the lower section. So you'll measure from the front of the transition to the rear end of the large body tube. That will be the length of the engine mount tube you'll need to cut for the rocket.

The motor tube will need two centering rings for it to slide inside the larger diameter booster stage tube. These are shown in **Figure 3**. They are a little mangled because I made them out of thin cardstock material, and this rocket has flown numerous times. In hindsight, I should have made them out of more durable cardboard or switched to thin plywood. But I recall that the reason we built this rocket was for the NAR's "Scale Altitude" competition, where weight is critical to the performance of the rocket.

You can also see in **Figure 3** that there is a streamer attached between the two rings. Again in hindsight, I should have moved the location of the streamer closer to the rear centering ring. The reason is that with these rear ejection rockets, it is possible for the engine mount to start rotating sideways as it slides rearward out of the rocket. If it cants over too much, it can wedge in the tube and get stuck. So by putting the streamer as far back on the engine mount tube as practical, it is possible for the streamer to unfurl even though the tube might not fully eject. That will save your booster stage from streamlining into the ground and becoming smashed up.

Figure 3: Centering rings are added to the ends of the booster engine mount tube. A streamer is taped to the tube as the recovery device for the lower stage.

However, by moving the streamer further aft in the rocket, you are also moving the center-of-gravity rearward on the rocket. This is destabilizing. So you really need to check your stability software to make sure

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the rocket will still have enough stability margin to be safe. I like to use RockSim (https://www.apogeerockets.com/Rocket_Software/RockSim) for this task, but you may use something else.

The placement of the forward centering ring can also be important. The engine mount tube may slide too far through the forward hole in the transition section. Ideally, the hole that was made when you cut the forward shoulder off the transition section will just barely allow the bottom of the rocket motor to slide through. But it will not fit the tube, which is the engine mount of the booster stage. If you get lucky, the tube will stop sliding forward when it hits the inside edge of the narrow part of the transition.

But because it is made from blow mold plastic, the inside diameter will never be perfectly circular after you cut the shoulder off. The blow mold process does not usually leave a constant wall thickness of plastic inside the part. In some areas it will be thicker than others, so your hole will be a bit lopsided. Because of that, you'll need to sand out the hole to try to make it more circular. It is possible to sand away too much material, which would allow the engine mount tube to slide all the way through the hole.

In that case, the position of the forward centering ring is more important. You'd then want to glue it on the tube so that when inside the rocket, it butts up against the rear edge of the aft shoulder of the transition (see **Figure 4**). This is the part that you glued into the booster tube earlier. Now that aft shoulder will become a stop, preventing the centering ring and the motor tube from sliding forward through the booster section.

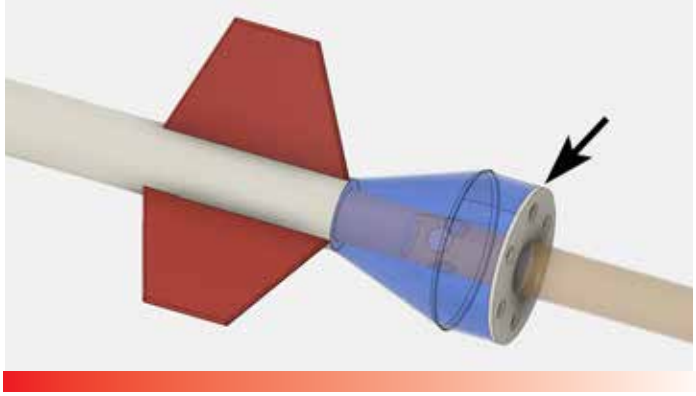

Figure 4: The position of the forward centering ring on the engine mount tube should butt right up against the shoulder of the transition piece.

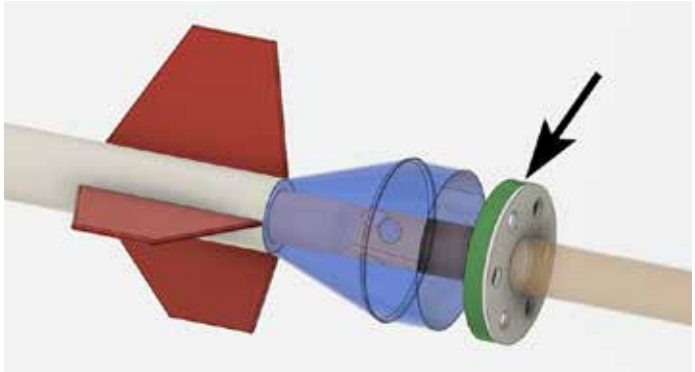

Figure 5: If the ring doesn't contact the shoulder piece, then you'll need to add a short tube (the green piece) in front of the centering ring.

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If you glue it too far aft along the engine tube, you may have to create a little ring and glue it in the larger booster tube to prevent the ring from sliding forward into the tube, as shown in **Figure 5 (Page 4)**. The point that I'm making here is that if you make a mistake in positioning the ring, you can always fix the problem. That is the fun part of engineering.

The other thing that you should do on both centering rings in the booster is to cut in some vent holes as shown in **Figures 4** and **5 (Page 4)**. This is another thing that I should have done to the model that you don't see in **Figure 3 (Page 3)**. I learned a lot from the flight of the rocket to know that I should have cut some holes in the centering rings. The reason for the holes is to make sure that your gap-staging works properly.

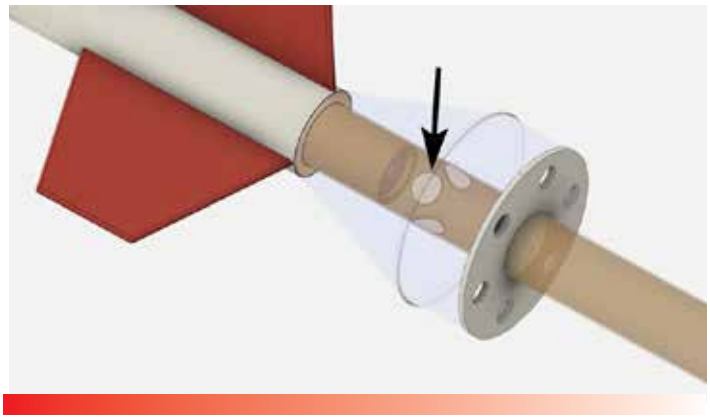

Figure 6: Vent holes in the front of the engine mount tube are located just aft of the nozzle of the upper stage.

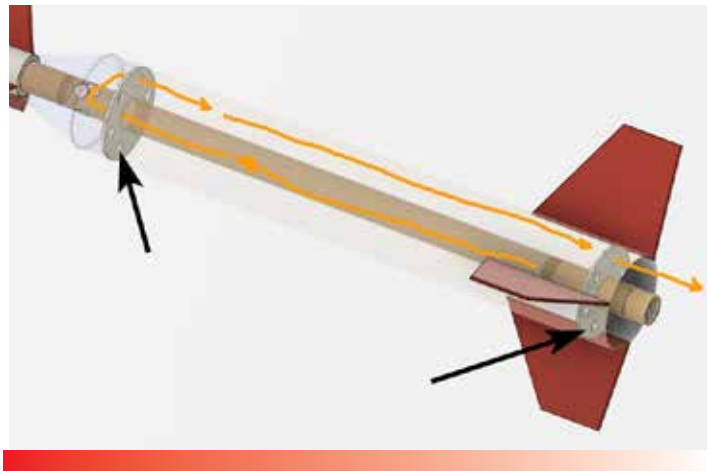

Figure 7: Vent holes are also cut into the centering rings of the booster. This allows the ejection charge gasses to pass out the rear of the stage during the flight.

How Gap Staging Works

The process of gap-staging was described in ***Peak-of-Flight Newsletters #98*** and ***#99*** (https://www.apogeerockets.com/education/downloads/Newsletter98.pdf and https://www.apogeerockets.com/education/downloads/Newsletter99.pdf).

The important part to remember in gap-staging is that you have to vent the cooler air in the engine mount tube of the booster. This allows the hot exhaust gasses to pass through and go directly into the nozzle of the upper stage. If you don't vent the cooler air in the tube, the inside of engine mount tube gets pressurized, and the two sections of the rocket will separate before any of the hot exhaust gasses from the booster motor get into the upper stage to ignite it. What will happen is that the upper stage won't ignite, and will come down ballistically. This is exactly what happened with the model shown in **Figure 3 (Page3)**. The nose cone got crushed, which is why you don't see it in any of the photos.

These vent holes are shown in **Figure 6**. There are three holes just below the nozzle of the upper stage rocket motor. Ideally, you want the vent holes to go directly out the side of the rocket

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near the nozzle, which was shown on page 5 of ***Peak-of-Flight Newsletter #99***. But since this is a scale model, I couldn't have holes in the middle of the transition section.

The solution was to vent the air out the rear of the rocket. That is the reason for the holes cut in both of the centering rings in the booster section, which you can see in **Figure 7 (Page 5)**. The way it works is that when the booster's ejection charge goes off during the flight, the hot air travels up the tube as shown by the orange arrow. As it moves forward, it pushes the cold air in front of it. That cold air exits the motor tube just below the nozzle. It then turns and flows rearward through the centering rings and out the rear of the booster stage tube.

At the same time, hot gas and burning chunks of propellant hit the nozzle end of the upper stage motor. The heat is so intense, that the propellant of the upper stage ignites.

Here is where it gets complicated

Once the upper stage ignites, its sends a jet of hot exhaust and burning gasses back down into the motor tube of the booster stage. As far as I can surmise, the amount of exhaust gases coming out the nozzle of the upper stage overwhelms the hot ejection charge gasses from the booster stage. The two gasses collide in the motor mount tube, and pressurize it. The pressure is so intense, that the whole motor tube assembly starts to slide rearward. This releases it from the core of rocket and the streamer comes out the back of the tube.

You're probably asking why the motor tube in the booster section doesn't separate from the upper stage motor without igniting the propellant in the stage. That certainly is possible, as I've found out from experience. I've launched several rockets of this configuration where the upper stage did not ignite. I think the reason is that I didn't have enough holes in the centering rings to vent the cooler air quick enough from the booster stage.

But most times, it works. And it is spectacular when it does. The upper stage ignites and quickly accelerates at a very fast speed. Meanwhile, the motor tube and the streamer are ejected rearward out of the booster section. The streamer unwinds from the tube and fully unfurls. It whips around, slowing the booster section down as it descends to a safe landing.

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Other Considerations

I want to point out two other considerations to making this work successfully. First, you have to use a Kevlar® shock cord (https://www.apogeerockets.com/Building_Supplies/Parachutes_Recovery_Equipment/Shock_Cord). The shock cord it going to get scorched by the heat of the ejection charge, so it has to be of a material that can take the heat. That is why you'd choose Kevlar® over elastic in this situation. And make it longer than normal shock cord. I've found that rear ejection seems to put a lot more stress on the shock cord than standard ejection.

As mentioned previously, one end of the shock cord is anchored at the forward end of the booster's body tube. You can't anchor it along the wall with an Estes style paper anchor. The reason is that the centering ring wouldn't be able to slide past it when the motor tube was being ejected out the back. This is another reason my centering rings are so beat up as shown in **Figure 3 (Page 3)**. The wrong kind of anchor was used inside the tube. Fortunately, the rings were flexible enough to pass over the shock cord anchor. But they got really bent up in the process.

The other end of the shock cord is attached to the forward engine mount tube. In **Figure 8** you can see that I had tied the cord around the tube behind the centering ring.

I've had problems with this type of "around-the-tube" anchor coming loose from the tube. It can tear out the cord as well as the entire centering ring.

Figure 8: The shock cord is attached to the engine mount tube behind the forward centering ring. It is wound around the tube in preparation for launch.

I've since changed to gluing the shock cord long-ways on the tube, as shown in **Figure 9 (Page 8)**. This gives more surface area in the direction of the tugging force on the cord. I'd also reinforce the cord on the tube with a piece of fiberglass cloth over the top to increase the bonding surface of the glue.

In **Figure 8**, you'll see how the shock cord is wrapped around the forward part of the engine mount tube. This works really well for storing the cord during launch. Just wrap it around the tube and shove the whole thing into the booster tube. At ejection, the cord simply slides off the tube nice and easy without any tangling. The only caveat is that you shouldn't allow the shock cord to wrap over the vent holes in the forward part of the tube. I've had thin Kevlar® burn through at this

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point during the flight because of the hot gasses being concentrated in one section of the cord.

The last thing is the fit of the upper stage motor into the forward part of the engine mount tube of the booster section. That motor simply extends out the rear of the rocket, and into the motor tube that runs the length of the booster stage. This is the only bond that holds the two stages together.

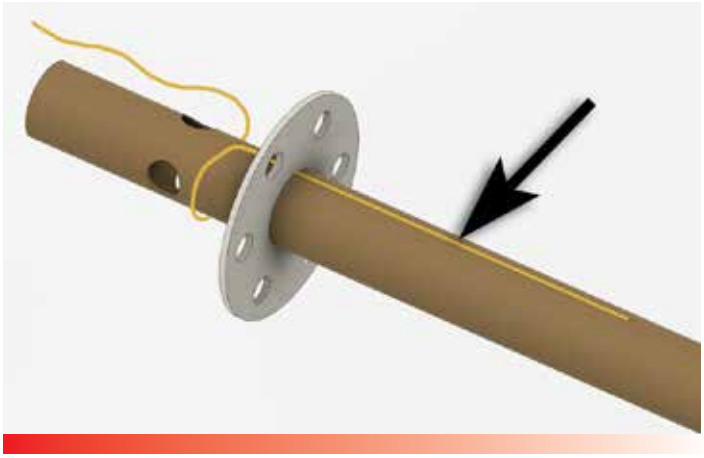

Figure 9: A better way to attach the shock cord is to glue it along the length of the motor mount tube. This is stronger than going around the tube.

This isn't my favorite way of connecting stages together, because the fit of the motor into the top of the booster stage is critical. If it is too tight, there is the risk of the stages not separating correctly during the flight. If it is too loose, the two parts of the rocket could be joined crooked, and the rocket could tip off when it is flown. I'd describe the fit as "snug" but not "tight."

In this particular rocket, the upper stage motor is held in the stage by using the friction-fit technique **(Figure 10)**. This is not my favorite way of holding motors in the rocket either, as they tend to kick out at ejection. In this particular rocket, you have no choice, because the upper stage is a minimum diameter tube. The motor just barely fits into the tube. Some day we'll find a better way of holding the motors in the tubes of minimum diameter rockets like this one. If you have an idea, please send it to me.

Figure 10: The upper stage motor is friction fitted into the top stage. The exposed portion of the motor holds the two stages together during launch.

Conclusion

I hope that this article gave you some ideas and techniques that you can use in your own projects. Gap-stage rear-ejection is a fun rocket if you ever have chance to build one. It is complicated during the construction phase, but they are simple to prep for flight.

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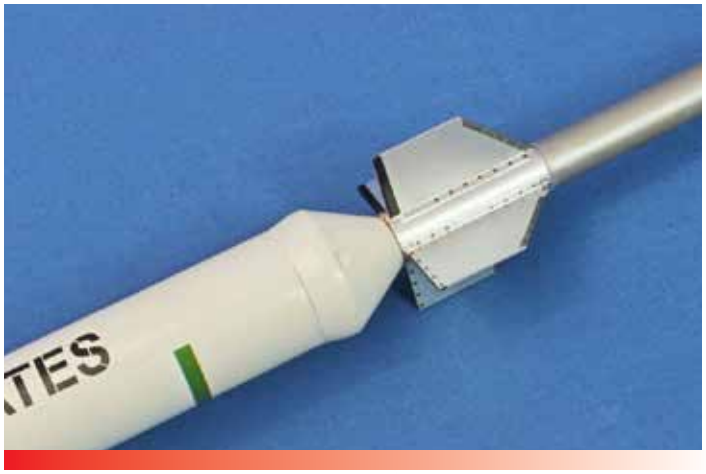

Figure 11: The two stages joined for flight.

About The Author:

Tim Van Milligan (a.k.a. "Mr. Rocket") is a real rocket scientist who likes helping out other rocketeers. He is an avid rocketry competitor, and is Level 3 high power certified. He is often asked what is the biggest rocket he's ever launched. His answer is that before he started writing articles and books about rocketry, he worked on the Delta II rocket that launched satellites into orbit. He has a B.S. in Aeronautical Engineering from Embry-Riddle Aeronautical University in Daytona Beach, Florida, and has worked toward a M.S. in Space Technology from the Florida Institute of Technology in Melbourne, Florida. Currently, he is the owner of Apogee Components (http://www.apogeerockets.com) and also the author of the books: "Model Rocket Design and Construction," "69 Simple Science Fair Projects with Model Rockets: Aeronautics" and publisher of the "Peak-of-Flight" newsletter, a FREE e-zine newsletter about model rockets. You can email him by using the contact form at: https://www.apogeerockets.com/Contact.