PEAK OF FLIGHT NEWSLETTER

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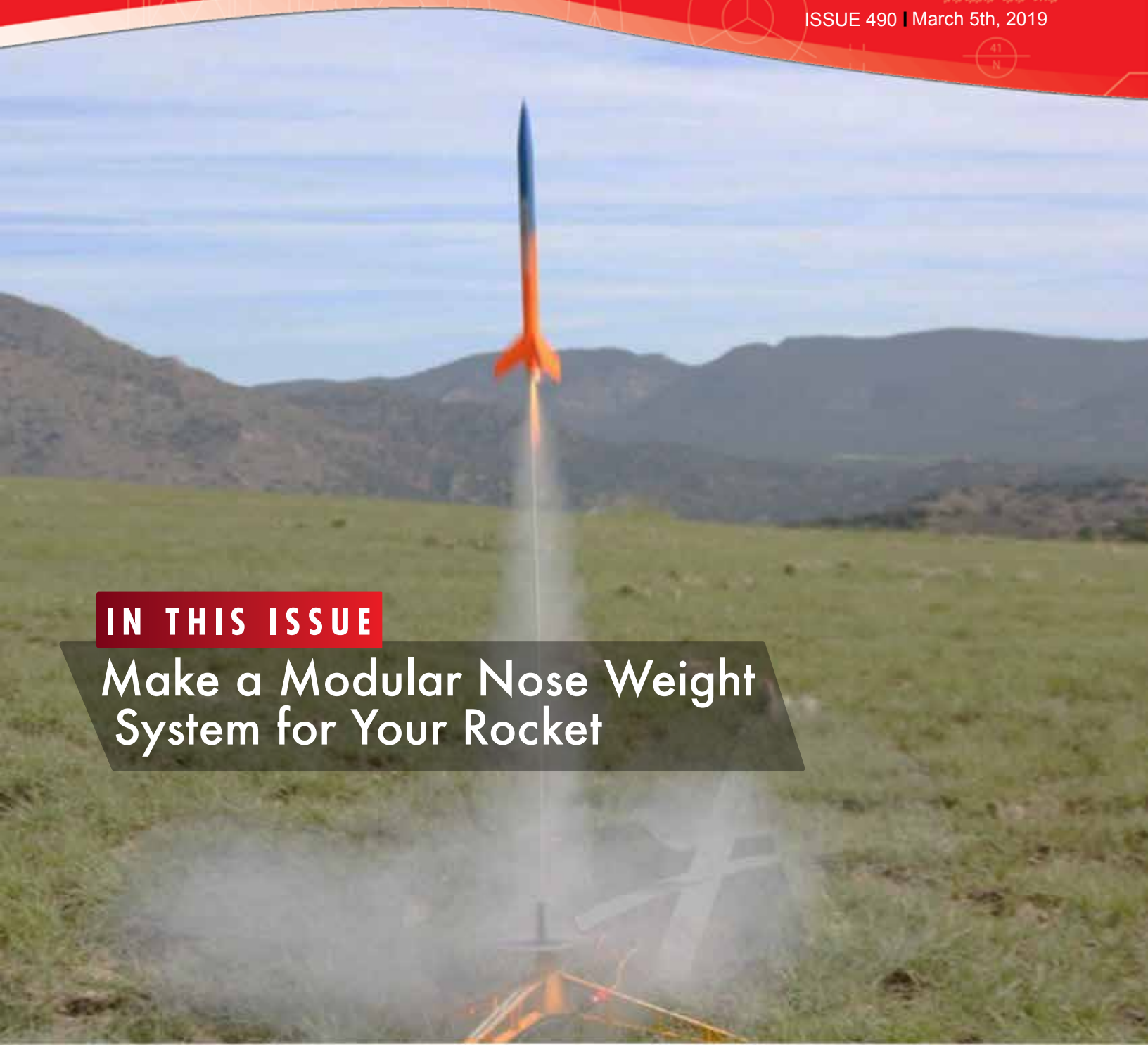

IN THIS ISSUE

Make a Modular Nose Weight System for Your Rocket

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PEAK OF FLIGHT

Make a Modular Nose Weight System for Your Rocket

By Josh Frizzell

Why Build an Adaptive Nose Weight System?

Most low-power rockets are designed such that they will be stable within the range of rocket motors that the rocket can accommodate. For example, a typical rocket fitted with an 18 millimeter (mm) motor mount will usually be stable on motors with A, B, or C (or even D with the now readily-available 18mm composite motors) impulse. However, the story changes as we graduate into mid-power rocketry and changes profoundly as we move into the world of high power.

Take, for instance, a mid-power rocket with a 29mm motor mount, perhaps a typical 2.6 inches in diameter. Many rockets in that class feature plywood fins with through-the-wall fin mounting and, if constructed well, could handle motors that breach the lower range of high power. That rocket will probably fly in a nice, well-behaved manner on a range of mid-power motors, with no modification to the kit, and serve you well as a docile park flyer. That same rocket, though, could handle a lengthier, higher-powered (and more massive) motor and put on an impressive performance. Who doesn't love a big roar that you can feel, a big, bright flame, and a healthy pillar of smoke? The challenge that then arises is that the more massive motor shifts the center of gravity (CG) rearward. That CG shift could result in a configuration that dangerously destabilizes the rocket's flight unless we somehow counteract the shift.

The typical response to a CG that is too far aft is to simply add weight to the nose. Nose weight is a tried-and-true method and is relatively simple. One can add lead shot, steel shot, BBs, fishing sinkers, etc. and epoxy them in place in the tip of the nose cone (that method necessitates a mechanical means of securing the epoxy and mass into the nose cone since epoxy does not adhere well to plastic; instructions on how to securely and permanently add nose weight to a nose can be found here: https://www.youtube.com/watch?v=A8bS6Dbdw9Y. The advantage of this method is that mass is added as far forward in the rocket is possible, which will result in the greatest forward CG shift with the least weight added.

But what if we want to use a particular rocket in a range of flight configurations? If we omit the nose weight, we are limited to the smaller range of motors that the rocket could handle. If we permanently add nose weight, the added weight will decrease the rocket's performance if it is also flown on lower-powered motors and could possibly result in an "over-stable" configuration in which the rocket is overly sensitive to cross winds when relatively low-mass motors are used. Furthermore, the extra weight might rule out motors at the small end of the spectrum that the rocket could otherwise use. More weight means we'll need more thrust to accelerate the rocket to a stable speed before leaving the launch rod, and that could eliminate motors in the smaller end of our potential selection from our list of safe options. Wouldn't it be nice if we could adapt the rocket's nose weight to the motor we want to use? Wouldn't it be great if we could easily change the rocket's balance characteristics quickly, with only basic tools, right there at the range? Then we could get the most possible use out of our rocket, ranging from mid-power park flyer to high-power performance monster.

Consider another scenario that would make adaptable nose weight useful: a cluster-motor rocket that could perform safely on a combination of some or all of its motor mounts. For example, the suped-up 1/100-scale Saturn V build that I'm working on has a 24mm motor mount clustered with four 18mm mounts (a proper Saturn V should have five plumes of flame and exhaust, shouldn't it???). Seriously, though, the model would fly safely (and substantially less expensively) with a single high-thrust composite 24mm motor in the center. But when it's time to really light the fires, the model will need substantial nose weight to counterbalance the four additional 18mm motors.

Continued on page 3

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Make a Modular Nose Weight System for Your Rocket

Continued from page 2

Furthermore, the nose weight required to safely balance full-throttle 5-motor mode will be too heavy for the thrust provided by single-motor mode. The keep the model flexible and safely flyable in a variety of configurations, the nose weight will have to be adaptable (**Figure 1**).

Figure 1: This Saturn V model with a motor mount cluster is an example of a kit that needs extra nose weight to counterbalance the engine weight.

Likewise, a rocket with parallel staging could be used in single core alone mode, OR with the side boosters unpowered, OR with the center core and boosters under power. For instance, my rocket equipped with a strap-on booster pod kit (**Figure 2**, https://www.apogeerockets.com/Rocket-Kits/Skill-Level-2-Model-Rocket-Kits/Strap-on-Booster-Pods) could work in any of those combinations, but adding motors to the boosters also adds significant high-density junk in the rocket's trunk. For the rocket to work in each of those configurations, we'll have to manage the rocket's weight and balance to make it a safe flyer.

Options for adding an adaptable nose weight system to your next rocket build is what we'll discuss in this article.

Option 1: Add a Payload Bay

One of the easiest ways to shift a rocket's CG forward is to simply make the rocket longer. By adding a payload bay, we make a rocket more stable without adding mass to the nose cone. The advantage of this method is that it is easily reversible, especially if you rig your rocket with quick links. Fly the rocket with the payload bay for bigger motors, and leave it off for smaller motors. You can use your stock nose cone in either configuration without the need to buy a second.

Figure 2: Rockets with boosters added would also need varying nose weight in order to work in different flying configurations.

Continued on page 4

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Make a Modular Nose Weight System for Your Rocket

Continued from page 3

A payload bay is simple to build. You won't need much more than a section of body tube and a coupler that fit your rocket. I prefer this method when practical because we don't have to add mass such as metal, which is undesirable in the event of a recovery system deployment failure and resulting lawn-dart-style return to Earth. Another nice advantage of this approach is that if you have more than one rocket with the same diameter you can build one payload bay and use it interchangeably.

We will, however, need to ensure that our nose cone stays with the rocket during recovery. Keep in mind that during deployment the nose cone and payload bay could receive a jolt, and the nose cone will be pointed downward while hanging from the parachute. We don't want a pointy nose cone to make a solo flight, so we should secure the nose cone to the payload bay in a way that's reliable but easy to undo. You can use small, discrete shear pins to hold the nose cone in place while keeping it removable (https://www.apogeerockets.com/Building-Supplies/Misc-Hardware/Nylon-Shear-Pins-20-pack). You'll need to drill small holes through the payload bay and nose cone shoulder for the shear pins, and tapping threads in the nose cone's plastic will make the process easier (https://www.apogeerockets.com/Building_Supplies/Tools). Adding a little bit of cyanoacrylate (CA) glue around the shear pin holes in a cardboard body tube will help make the connection more robust.

Adding an electronics bay (even if empty) shifts the CG forward even more. Even if you're not flying dual deployment and don't include any electronics, building an electronics bay gives you the option for dual deployment if desired later and gives you a more stable rocket NOW. For my latest 4-inch diameter build, the electronics bay hardware alone weighed in at a non-trivial 2.3 ounces (**Figure 3**). You can add additional hardware onto the electronics bay's sled rods (since they're already there anyway) to create even more forward CG shift. Electronics bays are readily available as kits (https://www.apogeerockets.com/Building_Supplies/Electronic_Bays) or are fairly easy to pull together yourself.

Option 2: Multiple Nose Cones

If you rig a rocket's recovery system using a quick link, you can easily swap back and forth between nose cones on a given rocket (https://www.apogeerockets.com/Building_Supplies/Misc_Hardware). Keep one nose cone stock, then have a second nose cone with permanently-installed nose weight as described in the intro section of this article. Again, adding weight to the tip of the nose cone has the advantage of greatest CG shift with the least possible weight added. This approach is feasible for rockets with plastic nose cones up to approximately 4 inches in diameter, but having multiple nose cones in larger rockets could quickly become cost prohibitive.

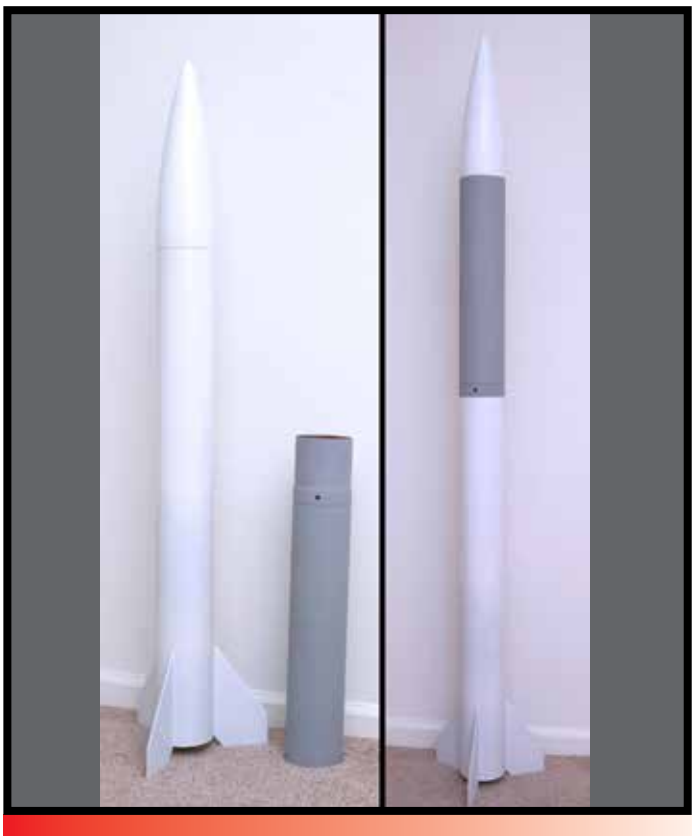

Figure 3: Adding a payload/electronics bay is another way to easily shift the CG forward.

Continued on page 5

Make a Modular Nose Weight System for Your Rocket

Continued from page 4

Option 3: Universal Clevis Pin and Washers

A universal clevis pin is a metal shaft with a flange on one end and several holes drilled in the shaft. Since the pin has several holes, we can change the mass we add to the pin by adding washers to the pin and securing them in place with a cotter pin above and below the washers. Changing the number of washers stacked together on the clevis pin changes the mass of the nose weight, and therefore changes the CG. If desired, you can use the lowest hole in the clevis pin to attach a shock cord.

To mount the clevis pin in the rocket, an option is to cut away the bottom portion of the nose cone where the shock cord attaches, leaving only the straight part of the nose cone's shoulder. Roughen the plastic inside the nose cone (I like to use a rat tail file) to give epoxy a surface that it can adhere to. I also like to drill small holes around the nose cone shoulder's circumference into which epoxy can squeeze out. Then run your clevis pin through a coupler bulkhead sized for your nose cone (https://www.apogeerockets.com/Building_Supplies/Bulkheads/Coupler_Bulkheads) and epoxy the clevis pinhead to the bulkhead on the side of the bulkhead where the clevis pin's flange is located. Use epoxy to install the bulkhead with the clevis pin pointing downward away from the nose cone and the clevis pin's flange inside the nose cone. I prefer J.B. Weld epoxy for this task because it is not runny, doesn't feel sticky, cleans up easily with water (baby wipes work very well to clean away excess from the rocket parts or your hands), and most importantly, is very strong when cured. Use a straight edge (a ruler works well) to squeegee off the epoxy that squeezed through the holes that you drilled before the epoxy sets to save yourself some filing and sanding later. Apply a generous fillet of epoxy around the bulkhead. When the epoxy sets, the bulkhead will be locked in place into the nose cone and you can stack washers onto the clevis pin for almost infinitely adjustable nose weight **(Figure 4)**. Once you've got adequate washers added, bend the cotter pins around the clevis pin shaft. Wrapping some masking tape around the cotter pins will help eliminate potential parachute snags.

The disadvantage of this method is that we are not adding mass as far forward in the rocket as possible. Consequently, we'll need a little bit more mass (and performance-robbing weight) than if we used the permanent weight in the nose cone tip described above. Furthermore, the clevis pin is permanently mounted and becomes a little bit of mass that we can't remove. However, the added mass will still achieve our goal of shifting the CG forward, and we can add or remove mass simply by adding or removing washers from the washer stack.

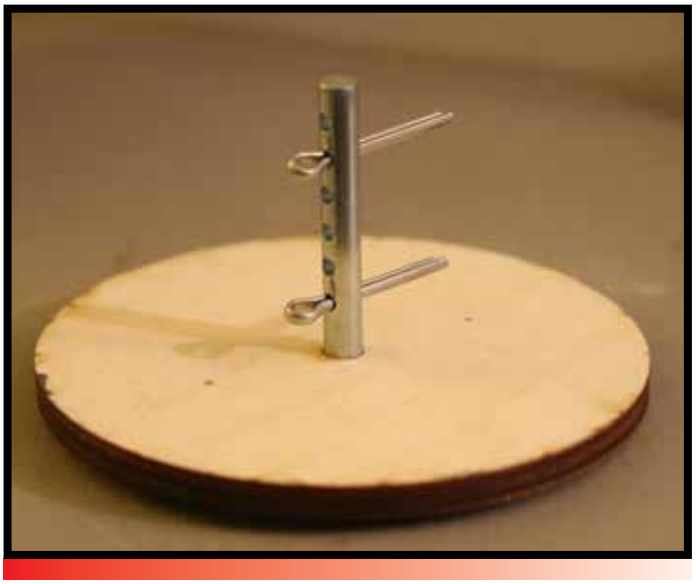

Figure 4: Attaching a clevis to a bulkhead to be epoxied to the base of your nose cone is another way to add variable nose weight.

You'll also need to cater the washers that you use to the pre-drilled holes so the final assembly is snug and solid. Using some thin, small washers in the stack can help you achieve a rattle-free fit.

Continued on page 6

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Make a Modular Nose Weight System for Your Rocket

Continued from page 5

Option 4: Bolt and Washers

We can take the concept of stacking metal washers on a shaft further by using a long bolt mounted to a nose cone in the same way we used a coupler bulkhead to mount the clevis pin in **Option 3**. The bolt option, however will give us a longer piece of hardware on which to stack washers and we can acquire bolts in a huge range of diameters and lengths (and therefore weights) readily and inexpensively. Since we're not limited to the pre-drilled holes of the clevis pin, we have practically infinite flexibility to fine-tune our weights.

We face a few challenges when implementing the bolt method.

- Since we will remove the nose cone's shock cord attachment, we will have to devise a way to attach the shock cord.
- We will have to ensure that any parts threaded on to the bolt (i.e., parts that will hold our washers in place) are immobilized and completely unable to come loose. Should hardware come unthreaded during flight, our washer stack will likely fall to the rear of the rocket resulting in severe instability.

Let's tackle each problem.

4.1 - Shock Cord Attachment

My preferred method is to attach the shock cord to the lower end of the adaptive weight rather than attaching directly to the bulkhead (e.g. with a eye bolt or U-bolt). The reason is that the recovery system won't be next to the weight system, which seems like it would be less likely to result in laundry entanglement problems. Rather, by attaching our shock cord to the end of the weight system bolt, the parachute and shock cord can be packed in a way that they are clear of the weight system at deployment. We have a couple of options to achieve this.

4.1.1 - Hole through Bolt

If you've never drilled through steel hardware, it's not as hard as it sounds. A decent drill bit and a good hand drill (I prefer the corded variety for the consistent torque they provide, but that is certainly not necessary) will make relatively short work of it. Simply drilling a hole through the end of the bolt gives a shock cord attachment. If desired, a file or rotary tool will remove sharp edges and threads that could compromise the shock cord. That's a simple solution to the shock cord attachment, but we'll still need to secure our weight system from working loose. More on that later.

4.1.2 - Eye Bolt and Threaded Coupler

Another solution is to use a threaded coupler to attach an eye bolt to the end of our washer-bearing bolt. The coupler adds substantial additional weight to shift our CG forward and can be easily removed if desired. The eye bolt also adds mass while providing a smooth, snag-free piece of hardware to attach our shock cord. Again, we still need to make the system bombproof so it doesn't come unthreaded.

4.2 - Securing the Weight System

We also have multiple options for ensuring that the hardware keeping out washer weights in place can't come loose. This is a safety-critical step, as failure to keep the washers attached to the nose cone area will result in the washer falling to the rear of the rocket, resulting in a very unstable configuration.

Continued on page 7

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Make a Modular Nose Weight System for Your Rocket

Continued from page 6

4.2.1 - Cotter Pin through Threaded Coupler

We've established that we can drill a hole through the shaft of a bolt. Now let's drill a hole all the way through our threaded coupler and bolt together (**Figure 5**). Then we can use a cotter pin through both components to ensure that the hardware can't unthread in flight. Jamming the threaded coupler up against a regular nut before attempting to drill will help keep the assembly still while you're advancing the hole. Adding a hole through both ends of the threaded coupler, with one through our weight system bolt and the other through our eye bolt, allows us to add two cotter pins and lock the whole assembly together.

Figure 5: Drilling a hole through both your threaded coupler and bolt together is not as difficult as it seems.

4.2.2 - Crown Nut and Cotter Pin

If you opt to attach the shock cord through a hole that you drilled in your weight-bearing bolt, you can drill one additional hole through the bolt that will accommodate a cotter pin. A crown nut can engage with the cotter pin, providing an immobilized lower support for our washer weights (**Figure 6**).

4.3 - Locking it Down

While our main safety concern is ensuring that the washer weights can't fall from the bolt that holds them, we can also lock the washers down so they won't rattle and bounce around. I like to use a Nylon-insert lock nut above the washer stack to achieve this. Thread the lock nut onto your bolt before adding the washers. Then add your washers and lower securing hardware. Once that's done, all that remains is to tighten the lock nut down onto the washers.

Figure 6: Drilling another hole into the bolt to use with a cotter pink and crown nut will help to lock your washers into place.

How Much Weight?

So we now know that we can adapt a rocket's weight and balance to the motor that we want to fly with. Great! But how do we know how much weight to add? What effect will adding a payload bay or electronics bay have? How do we know if we need to add any weight at all? We need to calculate the rocket's stability margin, and that's most easily achieved with a rocket design and flight simulation software such as RockSim (https://www.apogeerockets.com/Rocket_Software/RockSim). Sound intimidating? It's not. The software is user-friendly and

Continued on page 8

Make a Modular Nose Weight System for Your Rocket

Continued from page 7

there are lots of resources out there to guide you. Beyond the scope of this article, getting to know the software opens a huge new horizon of rocketry opportunity to you, since you will be able to knowledgeably create your own rocket designs that are safe and have predictable flight attributes. It's a worthwhile endeavor if you haven't yet explored it.

We calculate the stability margin as a ratio of the rocket's CG versus its center of pressure (CP). Generally, a rocket that is safely stable but not over-stable will have a CP that is between about one to two body tube diameters behind the CG. Rocket simulation software can fairly easily find your rocket's CG, CP, and stability margin. If the software indicates that your stability margin is less than 1, odds are you've got some work to do in order to make your rocket into a safe, stable flyer. The tactics described above can help you bring the stability margin into the safe range.

A small, cheap scale is a great asset in figuring out what hardware types and sizes will get your stability margin where you want it to be. To get you started, I've listed below a few common hardware assets and their weights as measured on my scale:

- One bolt, 6 inches long, 3/8" diameter, plus one nut = 2.8 ounces (oz.)
- 3/8" eye bolt with 1" threaded shaft = 2.1 oz.
- 3/8" threaded coupler = 1.8 oz.
- One washer, 3/8" hole, 1 ½" outer diameter = 0.5 oz.
  - Stacking washers quickly adds up high-density mass!!!
- Universal clevis pin, 5/16" diameter, no washers or pins = 0.4 oz.
- Electronics bay hardware (small)
  - Two threaded rods, 3/16" diameter, 10" long
  - Two washers per rod
  - One lock washer per rod
  - One wing nut per rod
  - Total = 2.3 ounces
- One 3/8" crown nut = 0.2 ounces

Clearly, some basic hardware can quickly add up the ounces to give you the CG shift you need. Once you know how much mass you need (determined using software), you can create a hardware combination that will give the desired effect.

Conclusion

Changing your rocket's stability characteristics can be inexpensive and relatively easy. An adaptive nose weight system can help you add flexibility to your rocket's weight and balance, allowing you to exploit the full range of motors that your rocket can accommodate. If you exploit the building ideas described in this article you can change your rocket's CG literally on the fly. Get the most out of your rockets by installing an adaptive nose weight system.