High Altitude Deployment Article
By Jim Jarvis – Rockets Magazine, June 2011
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I usually use a CO_2 device for high altitude deployment and it works pretty well. However, in the interest of redundancy, I also use a black powder charge constructed using a piece of latex "surgical" tubing. This method is used by many rocketeers and it seems to solve the problem of incomplete combustion of black powder at high-altitude. I know the method works, as I've used it as the sole deployment method in smaller rockets at altitudes as high as 30,000 feet.

One problem with the latex tube method is that the charges get pretty long when more than about 2 grams of black powder is used. Since I have several high altitude flights planned this year, I decided to experiment with the diameter and wall thickness of the latex tubing with the objective of optimizing the design for my applications. What I learned surprised me, and I ended up developing an alternative approach that I plan to use in my upcoming flights. The results are documented in this article. You're welcome to review the data and draw your own conclusions, and to use the method I've developed on your flights if you want to (with the usual disclaimer "your mileage may vary").

So, Why Won't Black Powder Burn?

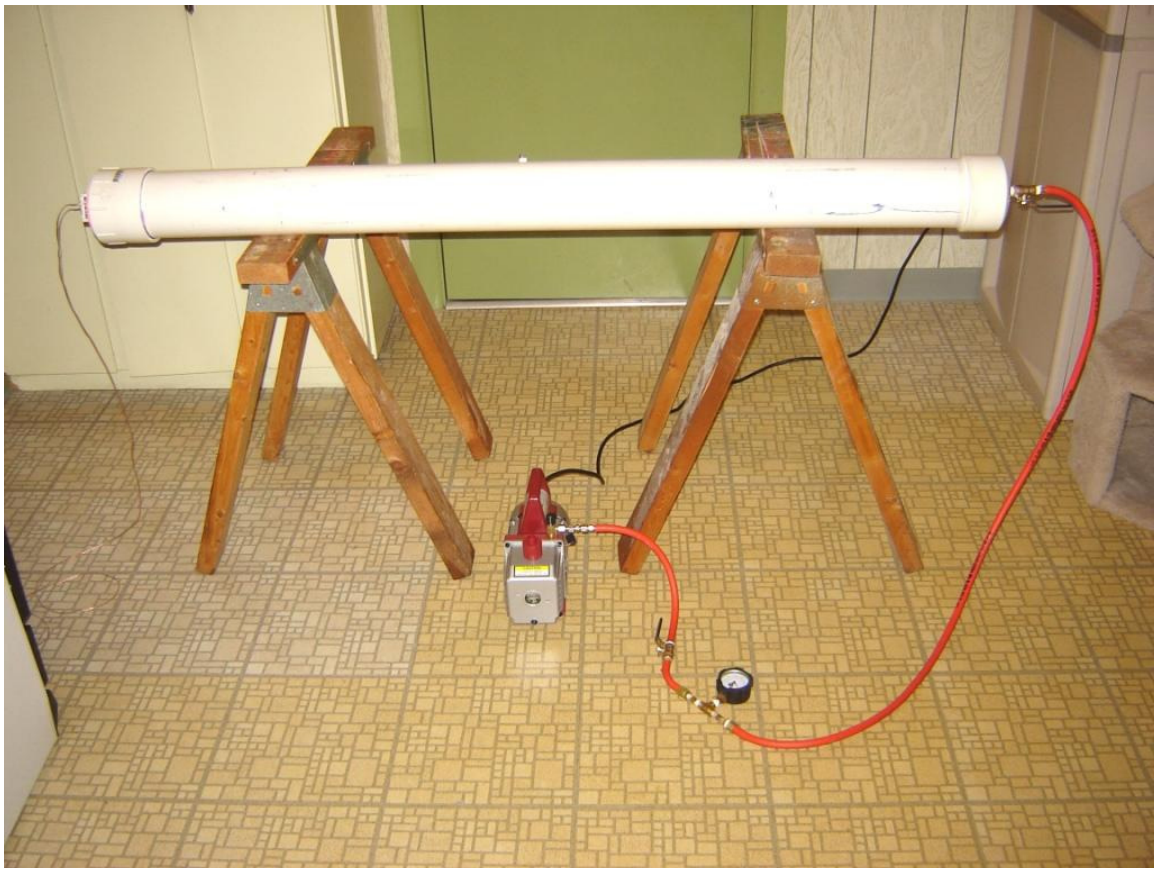
The subject of reliable black powder combustion at high altitude is something of a mystery to many high power flyers. After all, black powder has its own oxygen source, so it should burn even if there's no air. The explanation that makes sense to me is that in a vacuum, there is no media to promote heat transfer between the particles of the black powder. Heat transfer is needed to raise the temperature of the powder to decompose the potassium nitrate, which produces the oxygen that allows the burning process to continue. The particles will burn in a vacuum if they are in contact with each other because heat can be conducted through the solid particles themselves. However, once the particles are dispersed, burning stops if there is no gas present to conduct heat.

The latex tubing approach is intended to contain the black powder particles during the initial part of the burn and to build up some gas pressure inside the tubing (to some extent, the higher the pressure, the faster the black powder burns). As combustion starts, the tubing balloons out. This momentarily keeps the black powder from dispersing and maintains the gas pressure. In theory, this should allow more or all of the black powder to burn. Or so I thought …

Phase 1 – Vacuum Chamber Testing of Latex Tubing Charges

My initial test objective was simply to optimize the latex tubing dimensions for a charge of about 2 grams. So, I constructed the test container from a five-foot piece of four-inch diameter PVC (see Figure 1). One end of the chamber was capped off while the other end had a threaded fitting for changing out the charges. I calculated that a 2-gram charge would momentarily increase the gauge pressure from about -29.9 inches of mercury to about -15 inches if all of the powder burned. Then, the pressure would drop to about -27 inches as the combustion gases cooled. I wanted to do the testing in a relatively large container so that the increase in pressure in the container itself wouldn't promote combustion of the powder. Clearly, the pressure increase in my chamber would be less than what would occur in a packed drogue section of a 3 to 6-inch rocket. However, I wanted a more severe test than the conditions that would be encountered in an actual flight.

Figure 1



I made an assortment of latex tubing charges from tubing with ID's ranging from 1/4 to 3/8 inches and wall thicknesses ranging from 1/16 to 1/8 inches. My initial batch of charges is shown in Figure 2, but I made many more of these charges during the course of the testing. All of the charges were sealed with epoxy on the ends, but some of the charges had a small vent hole to allow the air inside of the charge to escape when the vacuum was applied. The idea here was to avoid the possibility of having the charge balloon out at high altitude, thus reducing the effectiveness of the charge when it fired. I don't know if this would actually occur, but I never observed any differences in the performance of charges with and without a vent hole.

The vacuum pump I used for the testing was designed for servicing air conditioning units. So, it was capable of removing essentially all of the air from the test chamber. I planned to monitor the testing by measuring the initial, peak and final pressure in the test chamber and by determining the weight loss due to combustion (i.e., the weight of the initial charge compared to the weight of the residual material collected after the test). In theory, about half of the weight of the powder should be converted to gas. It was also possible to semi-quantitatively record the "thump" of the charge going off and to determine if any unburned powder remained by lighting the residual material with a match. None of these methods worked perfectly, but it was usually possible to get a pretty good idea how much of the powder burned in any given test.

Figure 2

So, what were the results? To my surprise, none of the tests resulted in more than about 20% of the powder being burned! In most cases, the percentage of the powder that burned was around 10%. I subsequently found an article where another flyer had tested latex tubing charges and also found them ineffective:

http://www.thefintels.com/aer/vacdeploy.htm

My explanation for what is happening is that the initial burning of the powder causes the latex tubing to expand and then rupture. However, as soon as the tubing ruptures, the pressure drops (in my large vacuum chamber) and the remainder of the powder doesn't burn. Basically, the latex tubing isn't strong enough to contain the powder for a long enough period of time. So, if the latex tubing approach doesn't work, why have so many flyers (including me) used it successfully? One obvious factor is that the charges are normally used within the drogue section, which has a much smaller volume than my vacuum chamber. Perhaps the gas produced by the initial burning of the powder produces enough pressure within the smaller volume to support the burning of the remaining powder? In the second phase of my testing, I investigated this hypothesis.

Phase 2 – Charge Effectiveness versus Chamber Volume

Although my initial goal was to conduct testing under worst-case conditions, the evaluation really wasn't complete without some results that more closely simulated what was happening in the drogue section of a rocket. Unfortunately, it's not very easy to put an entire rocket inside of a vacuum chamber for deployment testing. My solution to the problem was to fabricate a weighted cylinder (essentially a piston) that was sized for a snug fit to the inside diameter of my vacuum chamber. The objective of this approach was to use the piston to vary the volume of the portion of the chamber that contained the charge. When the charge fired, the piston itself would be pushed towards the opposite side of the chamber. Conceptually, the test chamber would act as the airframe of a rocket while the piston would act as the departing coupler section (i.e., the zipperless coupler of the fin section of a conventional, dual-deploy design). A successful "event" would be represented by the piston moving vigorously down the length of the test chamber.

I used a spare piece of fiberglass airframe to make the piston, and I cut some bulkheads for each end that had diameters close to that of the inside of the chamber. Then, I put a few pounds of BB's inside the piston giving it a final weight of about 6 pounds. The piston assembly is shown in Figure 3.

I performed a new set of tests with the piston located at different initial positions within the vacuum chamber. The objective was to simulate drogue sections having different volumes. I made a set of latex tubing charges containing 1.5 grams of black powder (I reduced the size of the charge since my test apparatus was starting to resemble an oversized shotgun). I also made a set of 1.5-gram charges from some plastic tubes provided by another flyer (examples of these charges are shown in Figure 4). Similar to the latex tubing charges, these plastic charges did not burn effectively in the full-sized vacuum chamber. However, I wanted to see if their effectiveness would improve as the "drogue section" volume was reduced.

The results of the Phase 2 tests are shown in Figure 5. For each type of charge, the results include the distance between the end of the chamber and the piston, the chamber volume (using a chamber diameter of 3.9 inches), the distance the piston was pushed down the length of the chamber when the charge fired and the approximate percentage of the powder that burned. Note that for the final test for each charge, the volume in the chamber was reduced to only 2.6 cubic inches. This was done by adding a few pieces of plywood to the end cap of the chamber (as shown in Figure 6). For these tests, the piston initially rested against the plywood pieces shown in Figure 6, and the open volume of the chamber was reduced to only the small rectangular area containing the charge itself.

Figure 3

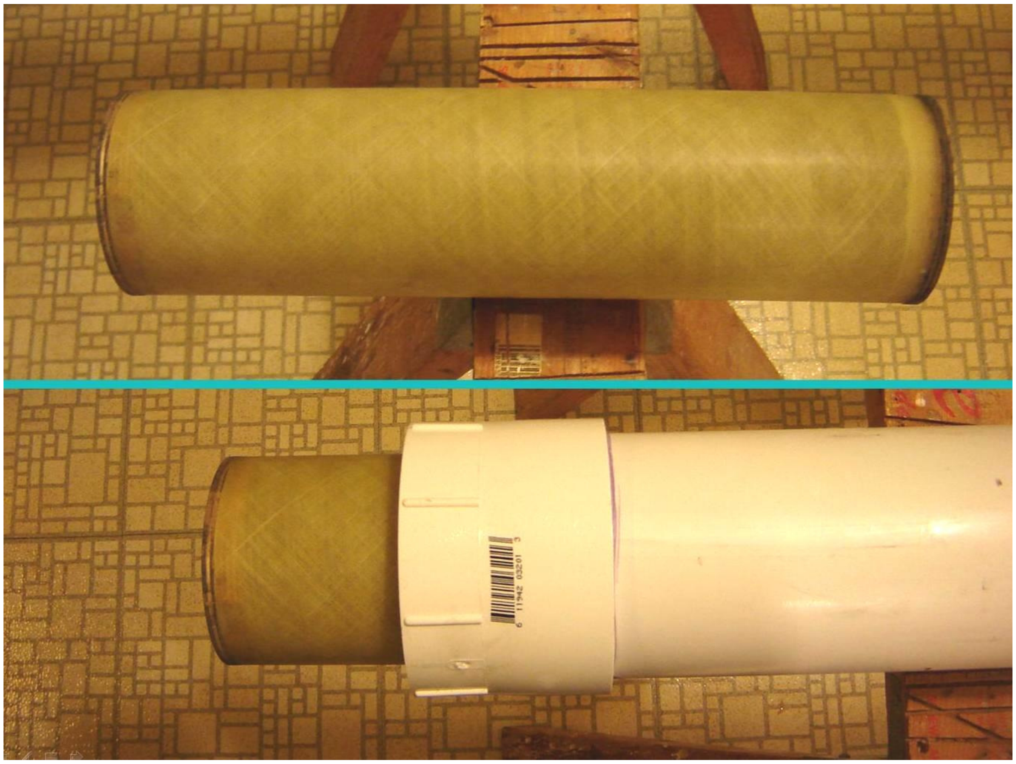


Figure 4

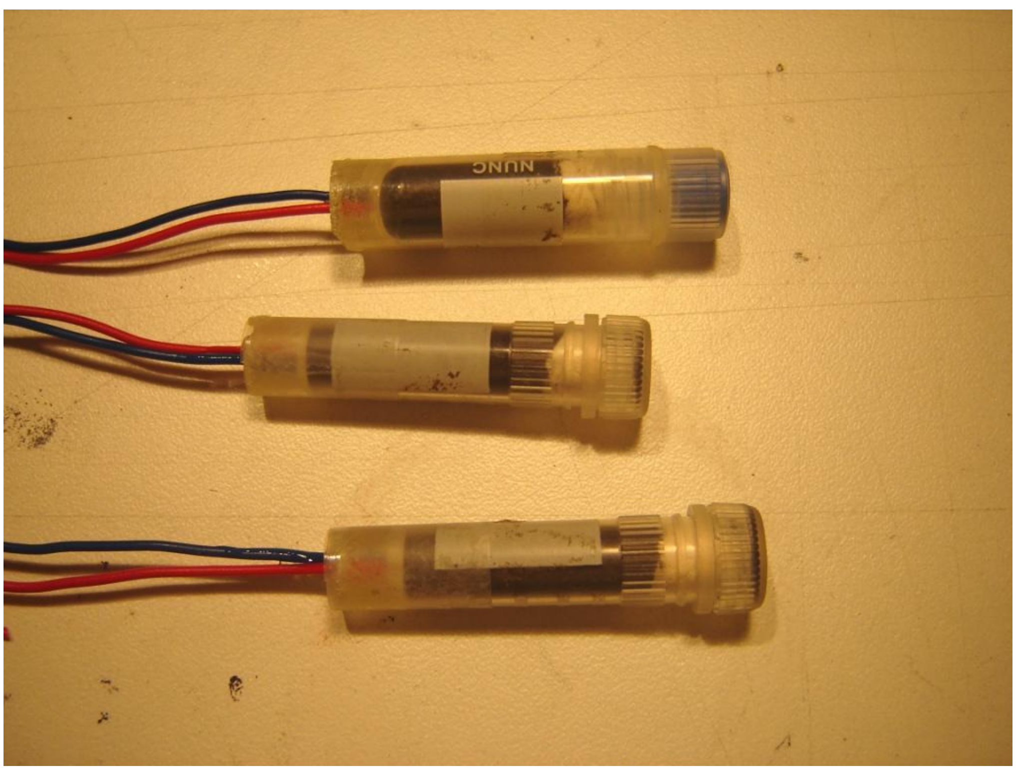
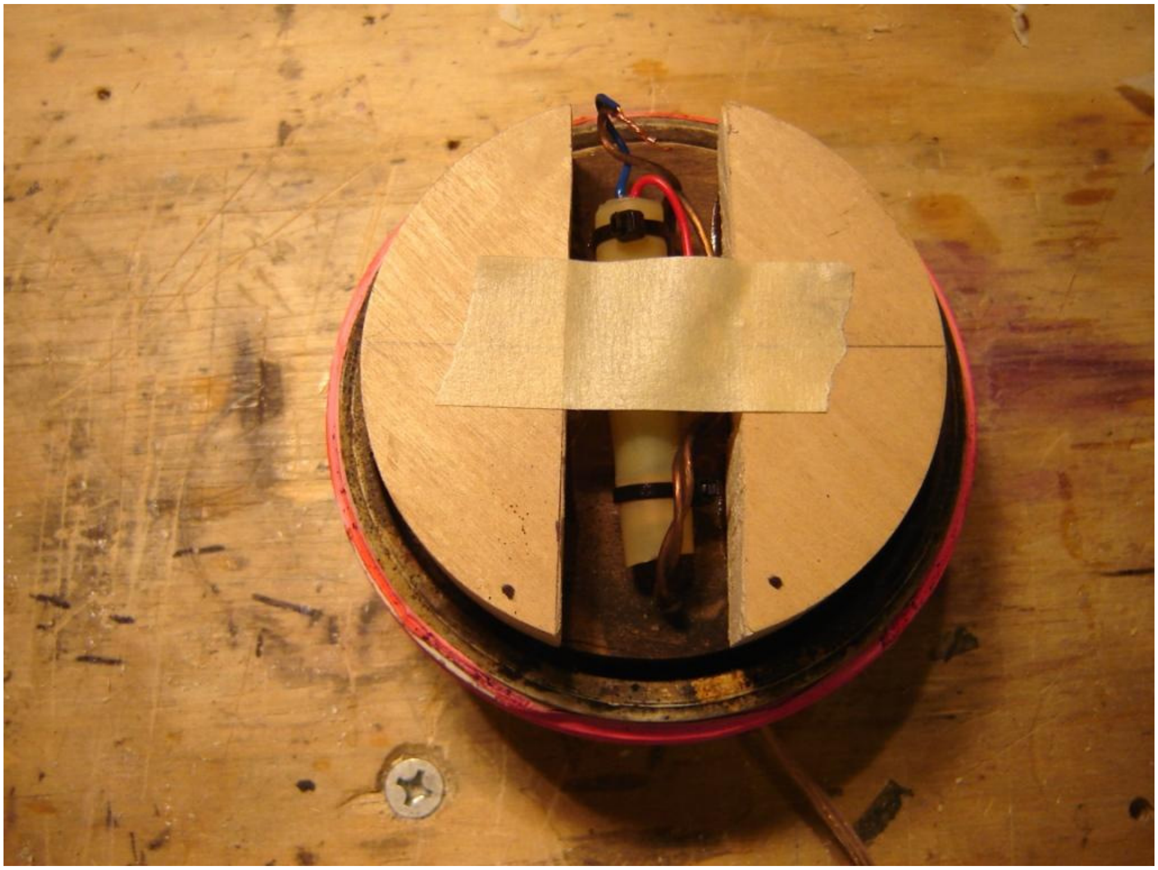


Figure 5

∆ L, in (Note 1)	Open Volume, in^3	Latex Tubing Charges		Plastic Cylinder Charges	
		Movement of Piston, in	% of Powder Burned	Movement of Piston, in	% of Powder Burned
6	72	0.0	10	---	---
3	36	0.5	10	---	---
1	12	12	35	16	50
<1	2.6	11	35	42 (Note 2)	100

Note 1: ∆L is the distance between the end of the chamber and the piston. The charge goes within this volume.
Note 2: This test quickly moved the piston to the opposite end of the chamber.

Figure 6



The Phase II results don't represent the cleanest data set I've ever produced, but they do show that for both types of charges, the effectiveness of the charges improved as the volume of the chamber was reduced. For the latex tubing charges, more piston movement occurred when the chamber volume was low, but the results were not particularly good even at the smallest chamber volume. For small chamber volumes, it appears that enough of the powder burned to perhaps separate a rocket, but it looks advisable to me to increase the amount of powder used by a factor of two at a minimum over what would be used at lower altitudes. Clearly, the latex tubing charges should not be used if the drogue section volume is large. The plastic charges, which didn't burn effectively in the large vacuum chamber, seemed to do a little better than the latex tubing charges. At the smallest chamber volume, all of the powder burned.

Phase 3 – There Must be a Better Way to Separate a Rocket

I know from my own experience and that of others that the latex charge approach can be used to recover rockets at high altitudes. However, the Phase 2 results suggested that there was room for improvement. I was surprised at how small the deployment section volumes needed to be for the charge to be effective, and picking the optimum size for the charge (i.e., the amount of extra powder to use) would be difficult at best. So, my final objective was to find an approach that was subject to less uncertainty.

I started something of a trial-and-error approach, looking at different charge designs. It's not important to document my pathway here, but one experiment was particularly revealing. In this experiment, I tried two different devices made out of the simple 1/4" brass fitting available from Lowes (the two devices are shown in Figure 7). Both devices have a cap on one end with a hole for the ematch wire. The other ends are simply open tubes. I used 2.5 grams of powder in these tests, and the shorter of the two devices was pretty much completely filled. The longer device had Estes wadding filling the space above the powder. Both devices were capped with five layers of electrical tape, which was intended to act as a rupture disk and produce some backpressure.

I conducted the test in the large vacuum chamber, again, looking for a solution that would work reliably under worst-case conditions. The result of the test with the shorter device was that about 50% of the powder burned. However, with the longer device, all of the powder burned. In subsequent experiments with the longer device, I found that the electrical tape was not needed, and it was only necessary to have enough wadding in the tube to hold the powder in place. My conclusion was that the empty part of the tube was the key to the effectiveness of the longer device. It's possible that as the powder starts to burn, this part of the tube provides a restriction to the flow of the combustion gases. This, in turn, causes the pressure to increase, which causes the powder to burn more quickly. In essence, the powder burns before it can be blown out of the tube.

A device like that shown in Figure 7 would work just fine in a rocket at any altitude, even with a large drogue section volume (i.e., if it works on the ground, it will work at altitude). However, this type of charge would have to be fixed to a bulkhead to avoid damaging the rocket. Indeed, during the testing of this charge, the recoil damaged my vacuum chamber. For my applications, I wanted to develop a device that could be attached to the harness in the drogue section with no mounting required. So, I took the concept one step further and developed the "tee" devices shown in Figure 8 (the large one is made from 1/4" parts while the smaller one is made from 1/8" parts). The ematch goes through a hole drilled into a plug that screws into the center part of the tee (note that I

Figure 7

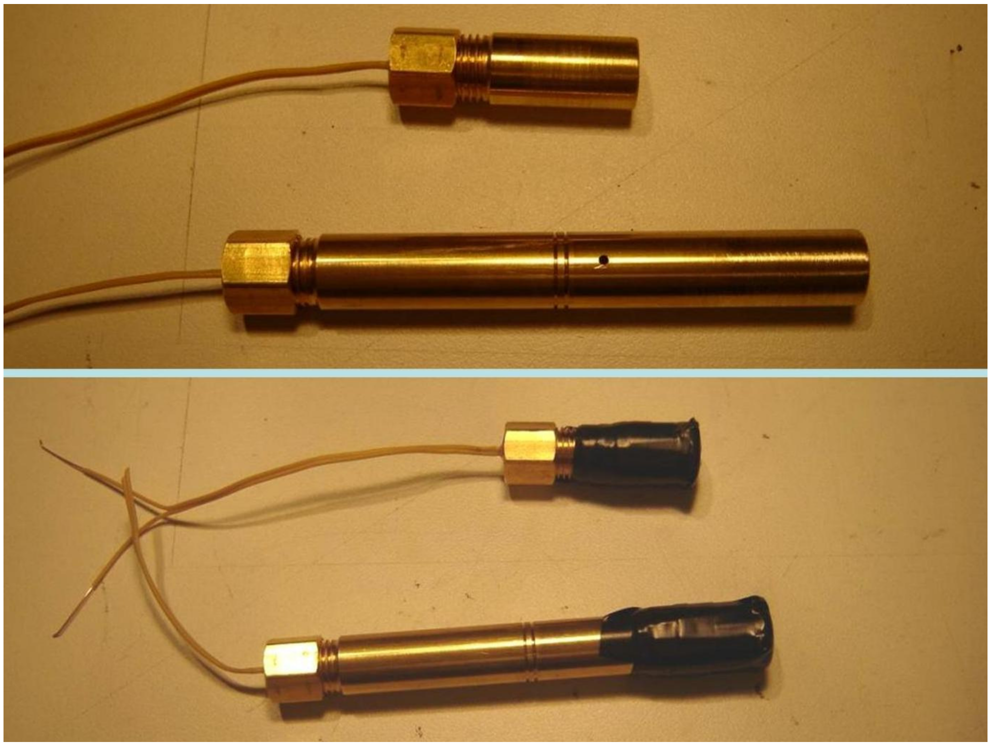
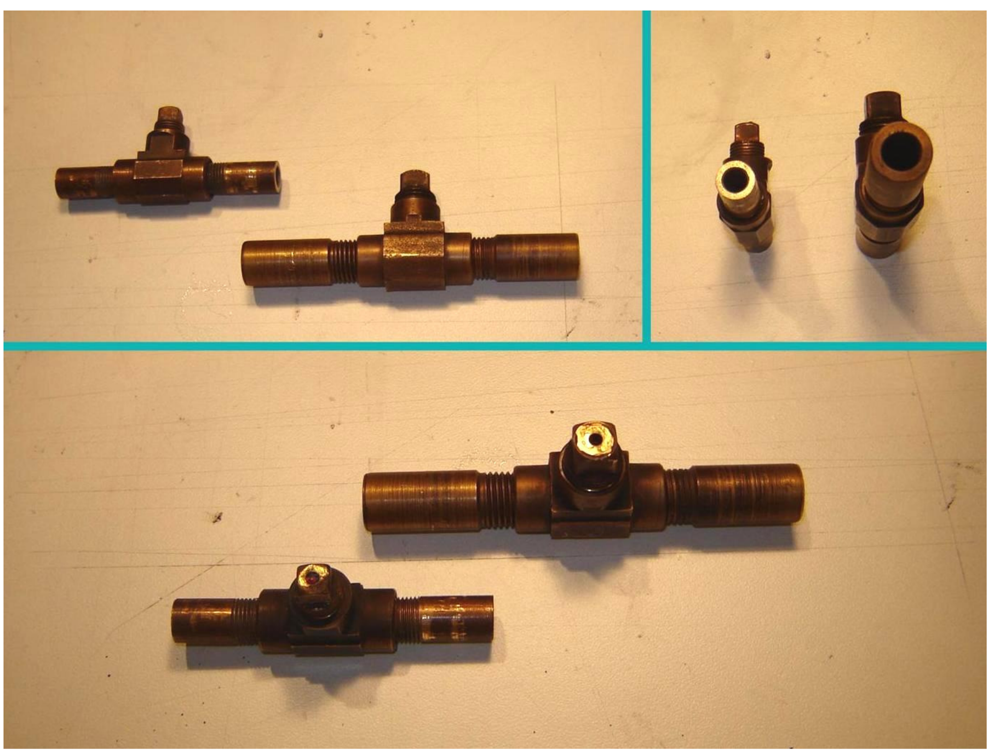


Figure 8



wrap the metal part of the ematch in electrical tape so that it can't short out through contact with the metal plug). The powder goes around the ematch in the center of the tee and then the legs are filled with Estes wadding (actually, wadding is tamped into one leg at the correct position, then the ematch/plug is screwed in, then the powder is added, and finally, the wadding is added to the other leg). The advantage of this approach is that the device stays in place when it fires because the combustion gases exit from both ends. Thus, I believe that the tee approach is a much safer design. I tested the smaller device with charges from 1 to 2 grams and the larger device with charges from 2 to 3 grams. 100% of the powder was burned in all of these tests.

One issue remains, and that is whether or not to seal the charge. I know that some people believe that a high-altitude charge won't work unless there is air in the charge when it fires. In my experience, that is not the case. For example, all of the tee charges I tested were open to the atmosphere (or lack thereof) and they all fired and burned 100% of the powder. However, it is possible that some ematches may not work at all in a vacuum (I tested only J-tech and Oxral ematches), and the initial burning of the ematch and powder would surely be more robust if air was present. This would improve the reliability of the method and is therefore recommended.

Figure 9 shows a diagram of how I intend to construct the charges for my high-altitude flights (I have two planned). For charges of 1.5 and 2 grams, I'm going to use the 1/8" hardware (i.e., the smaller tee device). I'll assemble the threaded fittings with Teflon tape and then I'll seal the ends with a small epoxy plug (these steps should retain the initial air at atmospheric pressure within the tee).

As in the past, I plan to use this device in combination with a CO_2-type deployment system. I think it will prove to be a highly reliable approach. If you want to use the tee approach, simply build it per my design and use the ranges of powder that I tested, and I'm reasonably confident that it will work for you too. Be sure to ground test (safely) whatever approach you choose.

Postscript – May 2013

Although the two-sided "tee" device shown in Figure 9 works just fine, I have found that it is a little more convenient to have a device that is mounted directly to the electronics bay. The approach is shown in Figure 10. This is a one-sided device, and therefore, it has a lot of kick. This approach can only be used with a well-supported base, such as the thick piece of plywood shown in the picture. Also, for the tubing size shown, I would not use any more than 1.5 grams of black powder. However, with this size charge, the ejection charge is VERY ENERGETIC. You must ground test this before flying it.

For the design as shown in Figure 10, the black power goes into the base of the tube. Then, I fill the open part of the tube with wadding, and then cap the top of the tube with a very thin layer of epoxy. It is not necessary to hold atmospheric pressure in the tube, but I believe that if there is pressure in the tube, the e-match itself will burn more reliably.

Figure 9

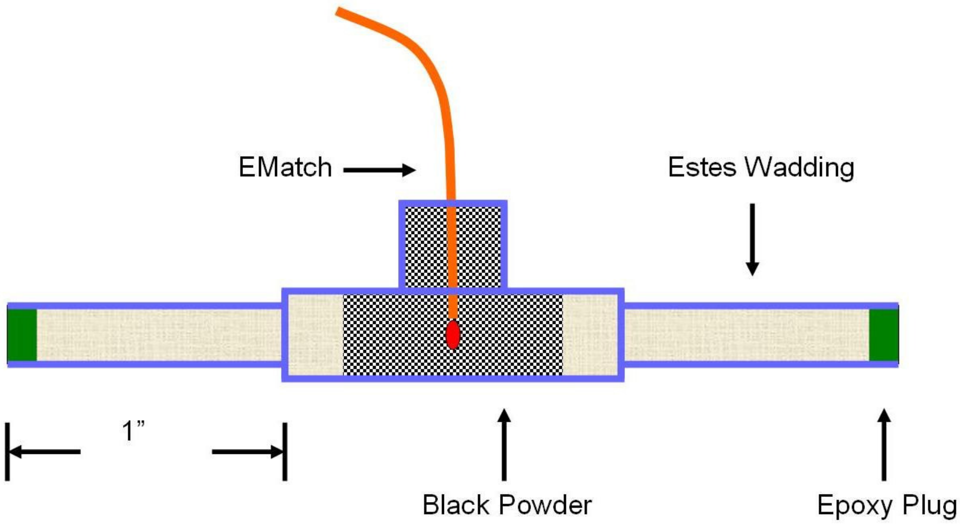


Figure 10