# Reducing Catos in Pyrotechnic rockets

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The purpose of this article is to attempt to explain a relatively new discovery I made while experimenting with black powder rockets. There are various types of black powder rockets. My focus at the time was high-powered nozzle-less rockets made with ball-milled black powder propellant.

The propellant was regular 75-15-10, made with good BP charcoal, such as willow or stag horn sumac. Since I first started making these, my propellant was granulated by moistening the mill dust with 2% of its weight of paraffin wax dissolved in naphtha. Enough naphtha was used to bring the propellant mixture to a consistency where it could be made into a ball and grated through a screen. The mesh of the screen was about like window screen or perhaps a bit finer. The propellant was then dried in a thin layer outdoors. This method was suggested by a gentleman named Gary Smith. After the first time trying it, I never looked back.

This background is just as important as the discovery, in my opinion. Historically, black powder rockets have been made with screen-mixed powders, and with nozzles. The propellant is quite weak from a lifting point of view. However, the extra-coarse charcoal makes for a very nice display as the rocket ascends. The general advice with these rockets has been that, if they ascend too slowly, add more saltpetre. If they explode, add more charcoal. This is good advice, and has been in use since forever. The rockets I am referring to here are nozzled core burners, not end burners. Using straight 75-15-10 is not usually done with this kind of rocket for aesthetic reasons, and because of the increased likelihood of CATOs.

In my early experiments with rockets, I wanted to lift as much as I could. At that time, nozzle-less rockets made with hot BP were becoming popular. They had way more lift than traditional rockets, but lacked the graceful charcoal tail. Putting charcoal or ferro-titanium in the increments above the spindle tip gave a mediocre-to-satisfactory tail, but without sacrificing lifting power.

To put this into perspective -- I could lift 4" ball shells on 1-pound nozzle-less black powder rockets made with standard black powder tooling. The person who promoted this method was Donald Josar, known as DJ. He has now passed on, but his web pages live on. They can be found at: http://www.pyrosystems.com/mirrors/dj/bp/index.html. Nozzle-less core burners are the kind of rockets I have most experience with.

As my experience and fascination with rockets grew, I wanted to achieve more power. Who wouldn't? So, I made different charcoals and improved my milling methods and media in many incremental stages. Then I started to get the idea that if I could just keep on making improvements, eventually I could harness enough power from a 1-pound nozzle-less black powder rocket to lift a 6-inch ball shell. My propellants got hotter and hotter, and my Acme test stand showed the improvements as I went along.

But, lifting that shell did not seem to be in the cards. As a side note, the Acme test stand is used to create thrust curves by sacrificially testing rocket motors on it. It is a recent invention by a fellow named Pete Hand. This unit has software that can be used to predict how big and heavy an object can be lifted to a certain altitude. Without it, I would have never have made the discovery. I will *finally* explain --

I was running out of options to increase the power of my propellant. The naysayers were rolling their eyes at my foolishness, already. I had one thing yet to try. I could make my propellant without adding the 2% wax to granulate it. As much as I liked the wax as an aid to consolidation and as a reducer of dust while pressing, I had to take it out.

Ned Gorski of Fireworking.com was touting the advantage of using alcohol as an aid to granulating black powder at that time. With no residual binder the black powder would be as powerful as it could be. So I did it. Well, in a word- BOOM! (And again, and again)

Then I stepped down a 'power level' to Steve LaDuke's universal tooling, which has a shorter, fatter spindle. This tooling makes a rocket with a little better than half the power of a rocket made on standard black powder tooling, all other things being equal. Again, BOOM! The motor was blown to smithereens! Now I was really scratching my head. There was *no way* taking out the 2% wax caused that much of an increase in power that the rocket would CATO. So if it wasn't the power, what could it be? I announced my intention to give up, and deemed alcohol-granulated black powder unsuitable for use in rockets.

Suddenly I awoke in the middle of the night with an idea -- wax the rocket tube! The logic is really quite simple. With wax in the hot BP propellant, I had no CATOs after hundreds of rockets. Removing it instantly caused CATOs even on weaker tooling. So, the wax performs a function. If the function is not related to power, it must be something else. My feeling was that the wax must somehow improve the relationship between the fuel grain and the inner wall of the tube.

As soon as I got up that morning, I made up a solution of wax in warm naphtha and applied it to the inner wall of the tube, with a dauber I fashioned from some jute twine wrapped around a threaded rod. I pressed a motor on the weaker universal tooling.

Presto -- no CATO! I was using the same alcohol-granulated black powder that CATO'd all my rockets just days before. So, I tried it with the standard black powder tooling. Wow! I had way more thrust now! I had just *doubled* the peak thrust Ned was getting out of his rockets.

I announced my results immediately, in case I got hit by lightning before I got to brag. Like any new thing, there is always doubt. As soon as I reported my findings though, Lloyd Sponenburgh rushed to the fore as a proponent of this new method. A flurry of discussion ensued, and suddenly my dream of lifting a 6 inch ball shell on a 1 pound rocket became a possibility again! My original method of using a wax solution was immediately replaced by using melted wax. Naphtha is highly flammable, so it was great to be able to do without it. When I explained this breakthrough to my friend, Ray, who always had time to listen to my rocket stories, he paused for a few moments. Then he said this: "Sounds like you've taken your rocket motors from being two-stroke and made them four-stroke."

In my simple way of looking at it, the wax was a glue or filler that stuck the propellant grain to the tube wall so that fire could not work its way between the two and cause a CATO due to overpressure. As it turns out, there's more to it than that.

Lloyd was instrumental in explaining my idea to me. The wax is being pressed into the outer surface of the fuel grain. This has an inhibiting effect on flame propagation, rendering the black powder on the outside of the fuel grain non-flammable on its surface. So, even if fire sneaks in-between the fuel grain and the tube wall, it's not likely to get far. That's not all, though.

Waxing the tube has a lubricating effect, allowing the pressing force to be delivered more fully to the propellant, and less to the friction between the propellant and the inner tube wall. So, you can actually get more propellant in the tube than in an unwaxed tube that is pressed at the same pressure on the ram.

Pressing black powder in an unwaxed tube can make quite a bit of noise, but in a waxed tube, it's practically silent.  Another very important benefit of waxing the tube is that of preventing the tube from compressing under high pressing forces. If you press 'dry' black powder propellant to a high pressure (like 9000psi), the motor tube will be shorter after pressing. This is because the propellant is grabbing the tube with every increment and pulling it down.

Later, it is theorized, the tube 'relaxes' and returns partially to its original length. This 'stretching' causes cracks to develop in the fuel grain. Each crack increases the surface area of burning propellant, and leads to CATOs. This phenomenon is called 'the relaxation theory' and was originally advanced by Steve LaDuke in regard to rockets.

This would explain why black powder motors that have been stored for a long time have an increased tendency to CATO.  It has been confirmed by Edwin Brown, previously of Estes Corporation (model rocket engine manufacturer).  Takeo Shimizu mentions using paraffin to coat the inside of pyrotechnic tubes to prevent compression and re-expansion of the tube in his book F.A.S.T.  If a rocket motor is pressed in a waxed tube, the initial tube compression does not occur. Ned Gorski has done extensive testing on this and other aspects of tube waxing, and confirms many of these findings.

In the U.S., and here in Canada, we use NEPT tubes for rockets. They are made of virgin kraft paper and are very strong and smooth.

Before the tubes are waxed, they should be prepared. I like to de-burr the cut ends inside and out.  A rolled-up strip of medium sandpaper works well when twisted in the tube ends.  After cleaning up the ends I also blow the dust out of the tubes. It is not a good idea to use high pressure air to blow them out because this can cause delamination of the inner paper layers. Sanding dust will not affect the performance but it will leave an ugly-looking coating.

On the next page is a picture of some 3 pound (1" ID) tubes I waxed. The second-from-right tube on the bottom had dust in it when it was waxed.

There are two main methods of applying the wax, as currently in use.  Both methods have advantages.

The first method is to apply the hot wax with a dauber, like a shotgun swab. The wax is melted and kept hot on a hotplate with the dauber in it while the tubes are being waxed one by one.

The second method is to melt the wax in an electric hot-pot and put a metal cone into the hot wax. The wax is carefully poured into the tube while it rests on the hot cone. When the tube is almost full (and not overflowing) it is lifted off the cone, and the hot wax returns to the pot.

Another method posted on YouTube takes a different approach to the 'pour' method. The poster makes some pretty cool rockets. Here is a short mini-tutorial on his way of waxing tubes: https://www.youtube.com/watch?v=N3vSHaJlgUM.

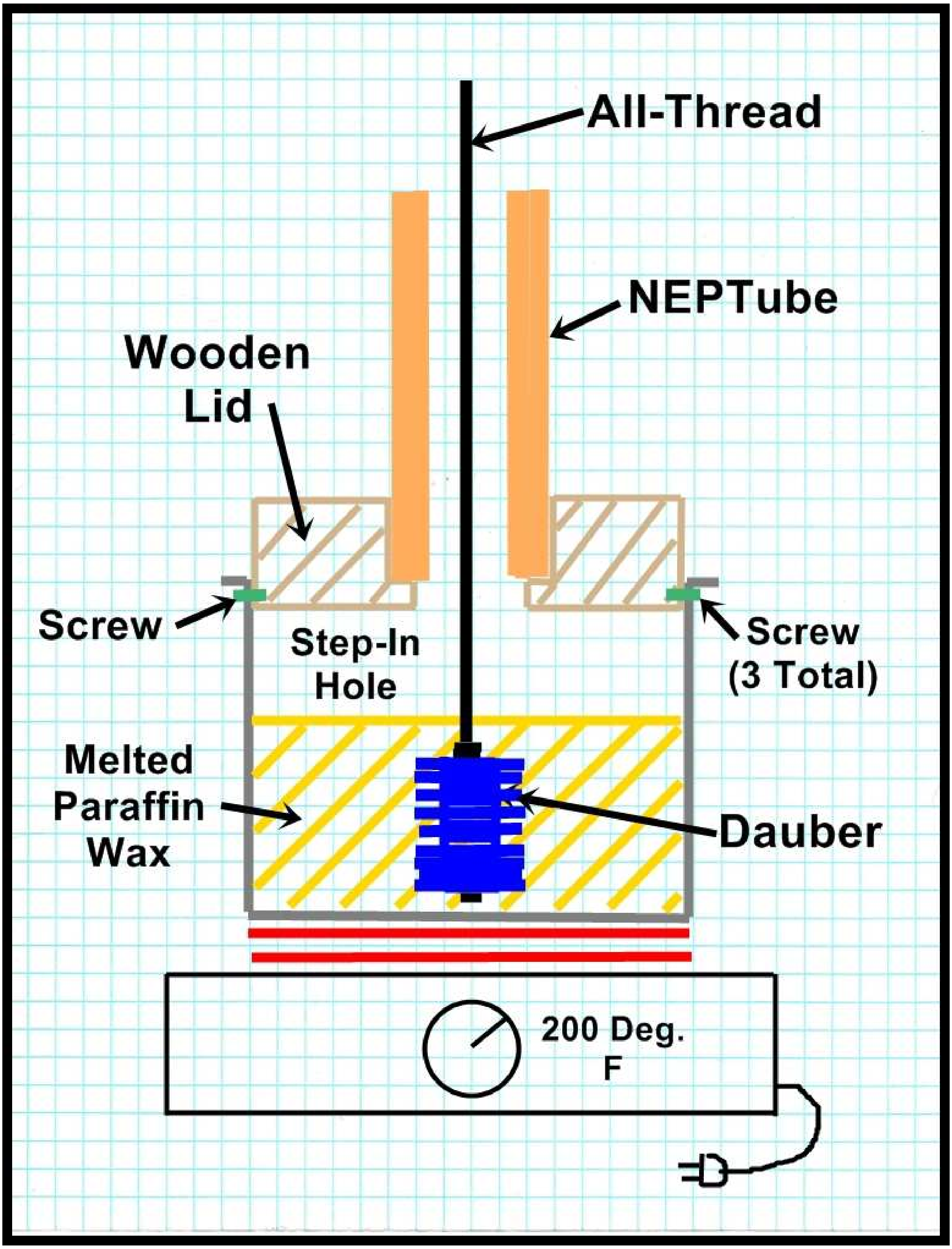
The way I have waxed most of my tubes is with a dauber. So let's look at that method first. Here is a picture of some waxed tubes and the daubers used to apply the wax:


The numbers on the tubes indicate the weights of the tube before and after waxing, and the difference in grams. There is not much difference in the amount of wax applied with the different daubers. For a 1-pound tube 7 ½" long, about half a gram of paraffin is applied. The dauber on the upper left is my original one, made by wrapping jute around a threaded rod and putting nuts on the ends.

On the lower left is a 12-gauge shotgun swab. The one on the upper-right is made from soft ScotchBrite scrubber pads punched out with arch punches and stacked tightly.

The aluminum applicator on the lower-right was a gift sent to me to try, by a generous rocket maker. I like the shotgun swab the best, but they all work.

Here is a simple diagram of my original tube waxing apparatus:



200 degrees Fahrenheit works, but I have since found that 225 or 250 are more-suitable temperatures.

Ned Gorski devised a different method that involves pouring the hot wax into the tubes. He uses two electrically heated pots with an aluminum cone sitting in one of them. Here is a picture of one of them:

Please note, however, that these cheap pots don't stand up to the melted wax for very long. Better-quality pots are needed. I used red high-temperature silicone to try to delay the inevitable, since I had already purchased these before I found out that they would leak. Ned has since stepped up to Presto Brand pots made of aluminum.

The wax is melted and heated to 250 degrees Fahrenheit in two pots. A tube to be waxed is held with the bottom pressed against the aluminum cone, which prevents the wax from pouring through. The other pot is used to slowly pour the wax into the tube to the desired level (more on that later). When the tube is full enough, it is lifted off of the cone and the wax pours down the cone into the pot with no splashing. Touching the emptied tube against the hot cone a couple of times cleans any excess wax that accumulated on the edges of the inner-most tube edge by re-melting it.

As the pot with the cone is used repeatedly, it gets fuller, and it is necessary to pour some of the wax back into the 'pouring' pot. Obviously, the cone must be attached to the pot, so it doesn't move when pouring the hot wax. Some folks bolt them in and others attach strips of aluminum to the sides and friction-fit them in.

I used a strong magnet, epoxied into the cone. Another idea is to drill a small hole horizontally through the cone near the tip. The cone could be lifted out with a wire hook and transferred back and forth between pots, instead of pouring the hot wax as one pot fills up.

Now that the common methods of applying the wax to the tube interior have been shown, I will share a few thoughts about them. The dauber is my preferred method. I like it because it is cheap and easy to try and because it limits the amount of wax applied to the tube.

I also like it because it was my idea, and the pouring method isn't. But seriously folks, if you apply too much wax to the tube interior you will be 'cursing a blue streak', for sure. The drifts will be almost impossible to insert and withdraw. They will become coated with wax and be a royal pain to clean off. I have never over-applied the wax using a dauber. With the pour method, I have.

Luckily, I was able to heat up the aluminum applicator shown in my picture of daubers, and slowly lower it down into the over-waxed tubes to melt out the excess.

The pour method is expensive to set up. It can work perfectly though. The wax has to be really hot and the tubes cannot be cold. Ideally, they might be warmed prior to the waxing.

The pour method does have the advantage of being able to fill the tubes to a precise level, especially if a colorant is added to the wax to show the level better. Also, if a person is using a pulpy tube rather than a nice, hard, impervious tube like NEPT manufactures, the pour method is the better way. This is because the pulpy tube absorbs the wax, so that hardly any is left on the surface, if you use a dauber.

The pour method will apply 2-4 times as much wax as a dauber on a pulpy tube. Eger tubes (Albert Eger, GmbH) are a good example of pulpy tubes. The video I linked to previously that shows the pour method was done using Eger tubes. So, in that case, the choice to pour was a good one.

The reason why a person might want to fill the tubes to a specific level is two-fold. First, some folks have had concerns that the nozzle might blow out if the nozzle area of the tube is waxed. So, not waxing that area is thought to avoid that problem. I have not had that problem personally, and I wax my tubes top-to-bottom.

Second, somebody might want to use a spindle puller to remove the spindle from the core. In a large nozzled rocket with a completely waxed tube, you can pull the entire fuel grain out of the tube if it is waxed! I've done it folks!

I've used spindle pullers and the 'twist-off method' both. I like the twist-off method better. I press my rockets to high pressure and the nozzle clay (no matter what kind I've used) grabs the spindle like a dog on a slipper. A good general rule-of-thumb might be to not count on using a spindle puller on a large rocket, if the tube is waxed.

## Why wax tubes at all?

The simple answer is: if you don't have problems with CATOs, don't bother waxing your tubes. People have made rockets for hundreds of years without waxing the tubes. The only reason I resorted to it was because I was attempting to do the impossible. I was attempting to lift a 6 inch ball shell on a 1 pound nozzle-less rocket on *standard* BP tooling. This was the fantasy that drove the quest.

Well, I had to add a nozzle- but I did it! Yes, it was a low flyer, but that rocket took off with authority. Here it is: https://www.youtube.com/watch?v=x5yPbp4tlw0

And here's a straight-salicylate whistle rocket on BP tooling:

https://www.youtube.com/watch?v=60amK83KxxQ

If you want to use extra-long tooling and use 3 pound nozzle-less BP rockets to send 6" ball shells WAY up there, you can count on waxed tubes to get the job done without fear of CATO.

An example: https://www.youtube.com/watch?v=aBSWfsuZikM

That rocket motor was 12 inches long, and the propellant was double-component milled BP with 2% wax.

## Conclusion

Let's go back to the beginning for a moment. "If rockets ascend too slowly, add more saltpetre. If they explode, add more charcoal." This rule can now be all but ignored, except for posterity. Waxing the rocket tubes allows one to make an almost infinite variety of black powder rockets of varying power levels without fear of CATO.

Let's also keep in mind that this idea sprang forth from the idea of using 2% wax in the propellant to help consolidate the fuel. I have stored nozzle-less rocket motors made with straight ball-milled 75-15-10 and 2% wax for over 3 years. Each year I test one.

So far, so good. In almost all cases (with black powder rockets) waxing the propellant will achieve the same thing as waxing the tube. But, waxing the propellant uses naphtha. Waxing the tubes doesn't.

A straight, hot 75-15-10 BP propellant with 2% wax in it will lift a 4" ball shell to a respectable height. A straight, hot 75-15-10 BP propellant *without* wax and pressed into a waxed tube will lift the same shell to a 10% greater height.

In short, waxing my rocket tubes gives me the confidence to do pretty much anything I want with BP rockets, and that's why I do it. I have flown hundreds of rockets with waxed tubes in front of audiences and never had one CATO. Many of my experiments and rockets can be found on my YouTube channel.

Thank you all for your interest. https://www.youtube.com/user/imastrangerhere/videos.