How to Successfully Build and Test Fire a KNSU Based Rocket Motor

John Miller

3/4/2011

Read everything before doing anything!

Warning: Attempting any work with rocket motors and fuels without the proper knowledge, tools, workspaces, or sense is INCREDIBLY DANGEROUS AND STUPID. Do not attempt any these steps under any circumstances unless you are willing to face serious injury, property loss, and possible death.

Introduction:

I have been interested in rocketry for as long as I can remember. When I was much younger, I loved building and flying model rockets. Simple ones, those that can be purchased from hobby ships then easily assembled at home with scissors and a bottle of white glue. These kits are inexpensive and incredibly fun. If all you want to do is build a rocket and push the button to make it fly, these are exactly what you want. The rockets are properly balanced and fly very well, and they incorporate parachute recovery systems. The motors used are proven to work and very rarely fail. These motors will not catastrophically fail [CATO] or cause any irreparable damage to your rocket. They can be cheaply purchased and the same rocket can be flown hundreds of times. The motors have electric ignition systems which are safe and not flame based and allow the individual launching the rocket to be a safe distance from the launch pad.

I can not make any of these claims with my rockets.

My rockets are dangerous, prone to failure, and hard to ignite. Likewise, I currently have no plans to write instructions for using my motors in commercial rocket bodies. It is possible, but not easy in any way whatsoever. My motors have no recovery systems and will probably destroy a perfectly good commercial rocket body. The motors I have designed are probably illegal where you live and if you're caught with them you'll be deemed a felon and thrown in jail. Maybe not, but who wants to take the chance? People can make bombs with the materials involved in making these motors.

Before you buy any materials or ready any workspaces, read through this document in its entirety. Then go take a nap or read a book, come back, and read it again. If you are uncomfortable with or have trouble understanding any of the concepts and methods described below, do not do any of it. Commercially tested, regulated, and known safe rockets are inexpensive and lots of fun. I do not recommend any individual build their own rocket motors unless they are seriously interested in amateur rocketry and are capable of dealing with the potential ramifications. If you follow the instructions listed below, be entirely prepared to have the FBI knocking on your door, asking what on earth you're doing building rockets.

If you're reading this and thinking "Geez, why did this guy even bother writing all this?" it's because I don't want people to hurt themselves or get arrested. If you want to build a rocket to hear the "fwoosh" and see it fly a few hundred feet into the sky then I'll tell you again: buy commercial rocket systems. $50 and a weekend is all you need for lots of fun. If, on the other hand, you want to see a rocket launch and know deep down that you facilitated the means that allowed the rocket to fly, you may be interested in doing what myself and many other amateur rocketeers have done. This guide is not about making rockets, this guide is about making the motors that make rockets fly.

You will greatly benefit from this guide if you already have an interest in chemistry and physics. I don't go into much detail regarding the fundamentals of rocketry, as this guide is intended for basic construction and troubleshooting, but understanding combustion reactions and specific impulses in relation to rocketry will help you *immensely*. Without this knowledge you may as well be baking a cake or tying your shoes. Don't just do what I tell you - think about why I told you what to do and *then* do it. Even better, if you think you can do a step better than me, do it! This is merely a set of guidelines, not a rigid configuration of rules. What I've written is what works best for me, not necessarily what works best for you. I'm going to go ahead and assume that most individuals interested in amateur rocketry are going to be capable of modifying my instructions to fit their needs. In fact, all of these instructions and all my my knowledge is a culmination of information that I have collected from various books and websites and them proceeded to modify. There is no one "right" way to do this. There are lots and lots of wrong ways, but no one right way. This is rocket science - make a design, preform an experiment, study the results, and redesign until you've got it right.

Abstract:

This guide is intended for instructing individuals on making very simple rocket motors as an introduction to amateur rocketry. As the experimenter gets more adept with the techniques, they may move on to more complex designs and processes as necessary. This guide is intended for beginners and those interested in building simple motors that function properly and consistently.

Step One: Gather the Materials

The list of materials and ingredients needed to build these motors is not a long one. A list showing everything required, as well as their purposes, is below.

Expendable Materials:

- Potassium Nitrate, or KNO_3. This acts as the motor's oxidizer, providing the fuel with very fast access to oxygen. This is absolutely vital and luckily, not too hard to get. In the United States it can be purchased in small quantities [450g] for about six dollars from hardware and gardening stores as "stump remover." The brands Spectracide and Grant's work well, and are 99%+ KNO_3. One bottle should be enough for many motors.

- Sucrose, $C_{12}H_{22}O_{11}$. This is the fuel for the reaction, providing the much needed carbon. I've found that any types of plain table sugar work fine, though I would *not* use any sort of imitation sugars or brown sugar. A plain, cheap, granular sugar works best. Don't bother buying powdered confectioners' sugar as you'll be pulverizing it yourself. Keep the sugar in a dry place after purchase as it tends to absorb moisture.
- Plain cat litter, typically bentonite clay. This will be ground and used for the cap at the top of the motor as well as the nozzle at the bottom.
- Craft paper. This is often sold at office supply stores as well as many drug stores and just about anywhere craft supplies can be purchased. The rolls are very inexpensive and you'll probably end up wanting to have a lot. It will be used for making the cast in which the motor is formed.

Tools:

- A hot glue gun and plenty of extra glue sticks. This will be used to seal the ends of the motor when necessary, especially during the formation of the nozzle.
- Scissors, for cutting the paper strips for the cast and trimming excess.
- A dowel, preferably 3/4" in diameter. This is incredibly important for both shaping the cast and packing the fuel.
- Tape, for holding the rolled cast together.
- A hammer, for packing the fuel
- A drill and 1/4" bit, used to drill out the cores of motors.
- A coffee grinder. Some use a ball mill, but I find that to be incredibly difficult and tedious. Coffee grinders quickly pulverize small amounts of material into very workable consistencies. There is almost no risk of accidental ignition of KNSU within the grinder.
- A scale, preferably one that can operate with the precision of one gram. Digital greatly preferred over analog kitchen scales, though sliding balances work very well.

Other:

- Trays for weighing materials on the scale.
- A small table vise to hold the motors for static testing.
- A well lit and spacious work space in which tools can be set up and used without disruption. An easily cleaned surface is preferable.

Step Two: Mix the Fuel

Most KNSU motors are comprised of a ratio of 65% KNO_3 to 35% Sucrose. For our purposes, this easily translates down to 20g KNO_3 and 11g Sucrose. Carefully weigh out those amounts into a tray [this is assuming you know how to properly use your scale, including tareing]. Try and keep the amounts within one gram of what they are supposed to be. Set up your coffee grinder and make sure it is clean and dry inside and out. Pour the KNSU mix into the grinder and grind it until it is the consistency of confectioners' sugar. Allow the dust to settle before taking the lid off, you do not want to inhale the fine particles. Set this aside or keep it in the grinder. If you do remove it, I advise that you put it into a sealable container as to keep as much moisture as possible from making contact and being absorbed - KNSU is incredibly hygroscopic and will quickly absorb water.

Step Three: Prepare the Cast

The cast is one of the most important parts of any rocket motor. It holds the fuel and provides the motor with its shape. For our purposes, the cast will be made of tightly rolled paper. This is for several reasons. One, it's cheap and easy to get. Two, it's easy to work with. Three, it's not particularly strong. This is very important - in the event of a CATO [catastrophic failure] paper can be easily blown apart in such a way that pressure from the explosion is quickly dispersed. If plastic or metal casts are used, and the motor experiences a CATO, it's possible that sharp and deadly shrapnel will be involved.

To make the paper cast, first cut a piece of dowel that is about six inches long. This will be the form for the cast as well as your tool for packing the cast. It is vital that the form and packing tool are the same size exactly, to insure the best possible compression of the fuel. Next, cut a strip of paper around sixteen inches long and three inches wide. If you do not have brown paper, it is possible to layer two pieces of 20lb printer paper, though these are not as easy to work with. Wrap the paper tightly around the dowel. The end result will be a three inch long tube with an inner diameter of 3/4". If the paper is constantly sliding and telescoping out, you haven't wrapped it tight enough. Once you're certain it's tight enough and the top and bottom are both flat, tape the free end down to the body of the tube, holding it all together. Move the dowel in and out of both sides of the cast, pay close attention to not catch the inner edge and to watch where it can most easily be inserted without catching any edges. Making the cast takes some practice to get good at but is very important in the long run.

At this point what you have is the cast, the tube that will hold the fuel. Before you can load it, however, you need to cap it. I typically cap my motors with ground up cat litter [bentonite clay] and keep them in place with a simple friction fit. This way, in the case of a CATO, the top plug will be blown out, hopefully preventing the entire casing from getting shredded, throwing burning paper everywhere. To do this, set up the cast on a flat surface, preferably with a piece of paper underneath. Pour in a small amount of ground clay, maybe two or three grams. Take special care not to knock over the cast at this point! Carefully insert the dowel straight down and hammer it down, making sure to pack the clay into a solid slab. Do not hammer too hard or else you'll blow out the end of the cast, which causes all sorts of problems. A few solid hits should do the trick.

Now remove the dowel and inspect the cast, inside and out. It should look like a grey wafer is stuck on one end of the cast. If you tap it with your finger it should not crack, chip, flake, or fall apart. If it does, remake the cap. If there is any excess powder on the inside of the cast, pour it back with the rest of the clay. Now is a very good time to weigh your cast, so that you can know how much fuel you're loading into it.

Step Four: Loading the Fuel

The KNSU mixture is loaded in the same way the clay for the end cap was loaded. It may be helpful to make a funnel out of paper in order to keep from making a mess. To achieve the most compression, it's a good idea to pour in small amounts at a time, and then pack them, versus pouring in a lot and packing it all at once. You want the KNSU to be in as solid as possible, but be careful not to disturb it or you might dislodge some. If you can invert the tube without it all pouring out, it's packed well. You'll want to leave some space at the top for the nozzle, a little less than half an inch, or around two centimeters, works well. Once it's all packed, weigh the motor and compare that number with the number from the empty cast to determine how much fuel was loaded. For this size I've found it to often be around 28 to 30 grams, though it varies depending on method.

Step Five: Packing and Drilling the Nozzle

The nozzle is what makes or breaks a rocket. Without it, the fuel is absolutely useless. If the mouth is too wide, the exhaust gasses from the fuel will disperse too quickly and provide very little thrust; whereas if the mouth is to narrow the motor could back pressure due to exhaust gasses not escaping fast enough. This scenario is the leading cause in CATOs. Picking the right diameter and shape nozzle is very tricky and there are a variety of schools of thought on the subject. Straight through [not angled] nozzles of 1/4" have worked well for me for this type of motor. I have tried choking it down as far as 1/8", which results in a near instant CATO, and up as far as 1/3", which results in a very pretty and very static motor. Somewhere between 1/8" and 1/4" works well - you'll have to do your own experiments to find what you think works best.

To make the nozzle, pack clay on top of the fuel leaving a paper rim about an eighth of an inch deep. Make sure the clay is packed very well, but don't pack it to the extent that the shape of the motor is deformed. Blow away any excess clay to make sure the surface is clean and clear of cracks or obvious deformations. It should be rock hard like the cap on the top of the motor.

Using the hot glue gun, fill the last bit of space up to the edge of the paper. While it is cooling it may be beneficial to use a pen to create a dimple in the center of the pool. This will act as a guide for the drill bit, as drilling through solid hot glue can be very tricky sometimes. Allow the hot glue to set and cool completely. During this time I weigh the motor another time so that I can determine how much mass will be lost during drilling. My motors are often around 50g at this point.

In drilling, you create two very important things at once - the nozzle and the core of the motor. As previously stated, the nozzle directs the exhaust gasses out of the rocket to provide thrust. The core of the motor provides a sort of channel for the exhaust to expand into, giving it direction. If you make and light a rocket with no core, it will very quickly burn out or have much trouble burning. This is because all of the crud from the end of the motor burning didn't get moved out of the way because of the lack of thrust, and because of that there is no space for the unburned fuel to burn into, thus extinguishing the rocket. You want to core of the motor to go almost all the way to the cap, but not quite. I try and get it within a quarter of an inch of the cap. If the core does extend through the length of the motor when the fuel is burned to the top of the core it will likely blow out the top cap because there is less work involved in doing that than there is in escaping out of the rear nozzle. Remember: nature is inherently lazy.

To start drilling, first attach a small bit to the drill, 1/8" works well. Make sure the bit is centered and the motor is aimed straight onto the bit. Stab the now cool pool of hot glue onto the bit and it should be able to drill all the way through to the end within a few seconds. With the drill still spinning, pull the motor straight off. Pour out all the excess powder dislodged from drilling. Swap out that bit with the 1/4" and, using the pilot hole, drill out the core. Be sure to compare the length of the bit with the side of the motor so that you don't drill too far! Back the drill out as before and pour out any and all lose fuel. There will be quite a bit, but don't worry - this is unavoidable and having that lose powder wouldn't help the rocket at all anyway. If all the fuel pours out, it's because you didn't pack it well enough and your motor is now doomed to failure. Start over at this point. Provided everything has gone well up to this point, your motor is now ready for ignition. If you're not going to use it right away, wrap it in cling wrap and store it in a plastic bag to keep it free from moisture.

Step Five [Alternate]: Using Pre-Formed Nozzles

I have been recently toying with the concept of using pre-formed nozzles instead of packing then drilling clay, with mixed success. So far one of the quickest and most rewarding methods I have found is to create and pack the cast as normal, except stopping before packing the end with clay to be drilled as the nozzle. At this point I take the dowel and insert it into the hole and mark the depth. I cut along this mark to create a slab of wood that perfectly fits into the end of the motor. I drill out the center of the slab to create a preformed nozzle. Once drilled, it can be fitted to the back of the motor with a variety of types of adhesives, though it should be noted that it will experience incredible pressure and should be secured as well as possible. When the adhesive is set, the the hole that is the nozzle can be used to guide the drill bit in forming the core.

There are a variety of potential advantages to using pre-formed nozzles, and the greatest of them all is erosion resistance. Erosion of the inner walls of the nozzle is inevitable, and often causes the motor to decrease performance or veer wildly mid-flight. The longer the burn lasts, the more erosion the nozzle will experience. Stronger nozzles allow for longer casts which in turn allow for more fuel, and finally a longer burn time. Wood nozzles will burn, but they will not crack and chip apart like clay nozzles. Pre-formed nozzles also are easier to make and more reliable in their creation. They are not without their downsides, however. Mounting them tightly is the biggest problem I have come across. If they are not well secure the initial stages of the burn will be incredibly successful, but the farther up the core the motor burns the more pressure there is exerted against the nozzle. This can mean amazing performance for your motor, or it can lead to a CATO wherein the amount of energy needed to blow your rocket to bits is less than the amount of energy needed to expand solely through the nozzle.

I have had some good runs and some bad runs with pre-formed wood nozzles. Most of the failures have be the result of overpressure blowing the nozzle out of the motor, one resulted in the front cap being blown off. I see the advantages of using nozzles that are less prone to erosion and plan on using them more often as possible. It is worth noting, though, that an additional danger associated with using wood nozzles is the fact that the nozzle may continue to burn long after the fuel has been exhausted. This means that if the empty cast were to land in a dry field or area with dead grass, the embers or flames from the wood nozzle burning can easily ignite the surrounding area. Be prepared to track down the casing as quickly as possible to prevent any fires.

Step Six: Fuses

While I would prefer to use pre made visco fuse, I don't have any. As such, I make simple fuses out of the KNSU mixture and tissue or wax paper. They burn consistently and ignite the motors without fail. If you have access to proper visco fuse, ignore this section. If not, you can easily make fuses yourself.

The fuses I make tend to be three or four inches long and use a very small amount of KNSU; the scrapings out of your coffee grinder should be plenty. Tear, or cut, a piece of wax or tissue paper three inches by two inches. Fold up [along the longer side] a lip of paper around a quarter inch long. It's not vital to be precise here. Into that tray pour a bit of KNSU. It is important to not use too much, or it will be hard to roll, but make sure you have a consistent line or else your fuse may not work. Roll it as tightly as possible and twist it so it stays together. Make sure not to tear it, it is fragile. This is another part that will require lots of practice to get good at.

Step Seven: Test Firing

Now that your motor is complete and you have a fuse ready, you can set up your test platform. It is imperative that you perform your tests outdoors away from anything that can be even slightly perceived as flammable. KNSU burns incredibly quickly so even in the event of a CATO it's unlikely that any major fires would be started, but it also burns very hot and could easily burn through the side of a cheap gas can. Common sense is important here, and if you're not sure of something, relocate. Keep a large bucket of water on hand as well, and a fire extinguisher if possible.

To hold the motor in place I use a small four pound bench vise. It's nothing special, but works very well for the purpose. If I ever make a motor powerful enough to move it, I'll be thrilled. When you position your testing area think about where the business end of the motor will be facing - flames, hot glasses, and smoke will be spraying out as far as twenty feet, so make sure everything within that area is safe. It's also often a good idea to have the rear of the motor pointing straight up, through be sure there is no potential whatsoever for it to fall over.

Once you have your testing area set up and cleared, you can mount the motor on your stand and insert the fuse. If using a home made fuse, be sure not to insert it too far, yet insert it far enough that the fuel will be ignited. If too much fuse is in the core, the burn will be impeded - you want the fuse to be blown out the instant the fuel is lit.

At this point you're going to want to make sure that you are fully protected from the worst possible scenario. Protective glasses, or even better, a face mask, are highly recommended. Gloves and a heavy shirt and pants will keep you safe from many smaller embers, if you think something horrible is going to happen dig a bunker or set up a piece of plate steel between you and the motor. Stand at least 50 feet back when you fire it. This is also a good time to set up your camera to record the burn.

Preferably with a long lighter, light the fuse. Now run away. A four inch home made fuse takes about five seconds to ignite the motor, depending on how far it was inserted. You should be able to move back 50ft in that time. The fuse will appear to go out when it's inside the motor, and after a moment the fuel will ignite. Bask in the glory of the culmination of your efforts. It will last about two seconds.

When it's all over, and the smoke has cleared, go inspect the motor. Look at what shape it's in - if it's pretty good you can probably re-pack it and use it over again. There are some casts I've reused more than five times! Make note of the end cap especially - does it look like it was stressed exceptionally? Is it going to blow out if you reuse it? If in doubt, you can probably get away with packing a bit of new clay on top of it.

Step Eight: Uninhibited Launching

If you have the space, doing an "uninhibited launch" is definitely worth attempting. A static, or inhibited, firing will tell you if your motors can burn without CATO, whereas an actual launch will tell you if your rockets are both stable enough and producing enough thrust to fly. There is very little work required in making these motors capable of simple flight. Prepare, pack, and drill the cast using the same methods as your static tests. Using either heavy wire, like from a straightened clothes hanger, or a smaller wood dowel, create a tail for the motor. Secure it perfectly parallel with the body, then attempt to balance the rocket on your finger. Place your finger directly behind the rear end of the rocket and hold it up. If it topples forward, your tail is not heavy enough. You can replace your tail with something longer, or you can try wrapping tape around it in order to add weight. If you do the latter, be sure to evenly spread out the application of tape. Should the rocket topple backward when you try to balance it, trim the tail until it works, though be careful to only remove a small amount at a time.

The tail is vital to the flight of the rocket. It provides the much needed stabilization usually offered by fins, yet is provided by a much simpler design. Should the tail be improperly balanced with the body of the rocket, one of two things will happen: either the rocket will accelerate rapidly and have an unstable trajectory, or the rocket will fly very slowly or have trouble flying at all. These scenarios express what happens when the motor is heavier than the tail and when the tail is heavier than the motor, respectively. You want to prevent either of them from ever happening if at all possible. An unstable rocket is incredibly dangerous and can lead to accidental fires or serious injuries.

When performing flight tests, it is imperative that you have a huge amount of space to work in. In my experience 50g motors can easily fly a few hundred meters - meaning you will be propelling a decent amount of incredibly volatile material an unknown distance, at an unknown but typically high speed. If the rocket CATOs mid air, burning and unburned fuel will likely be blown in all directions, potentially starting fires and injuring yourself and any bystanders. If recovery of the materials is not required, launching over a large body of water (free of boaters and swimmers) is recommended. Any results of a CATO will fall into the water and be immediately extinguished. Likewise, the possibly smoldering cast will fall in and be extinguished. The obvious downside to this is that you will be unable to recover the cast and tail once they fall in; though even if you can, they're probably ruined.

What if something goes wrong?

Unfortunately, there are many opportunities for problems to arise when building, testing, and flying homebuilt rockets. Below I will attempt to list the most common problems I have had, as well as their potential causes and methods of prevention or repair. Building rockets is very tricky, and many things have to go just right in order for them to fly or even burn successfully. Even I sometimes make motors that end in CATO or fail to produce enough thrust to fly. More practice in construction and testing leads to higher quality motors and more consistent construction.

- I can't get the paper roll tightly around the dowel.

Try putting a small piece of tape on the underside of the edge of paper that you're rolling onto the dowel. This way when you roll the paper it will stick onto itself and hopefully allow you to roll it tighter.

- When I remove the dowel, the tube pulls out and won't go back in.

Turn the dowel in the direction you rolled the paper while pulling it out. This prevents the paper from catching it so easily.

- When I put the dowel back into the tube to pack the clay or fuel it gets stuck. (or the dowel catches an inner flap of paper.)

It often helps to twist the dowel in the direction in which the paper was rolled so that it can act as a simple screw and can move past the inner edges. If the edge did get caught, and was pushed down, try and flatten it out with a pencil or apply a small piece of tape to hold it down.

- When I was compressing the fuel (or clay) the cast split and the contents spilled out.

There are two potential causes of this: either the cast was rolled too thin and was too weak, or during compression you hit it too hard and split the cast. Depending on the severity of the damage you can try to patch the cast with tape, though it is recommended that you do not do this. If fuel has been poured, try and recover as much as you can then discard the cast and make a new one.

- During drilling the nozzle cracked and broke apart.

If you used a pilot hole, it is possible that your larger bit was not sharp enough and because of your pressing the motor onto the bit, it cracked instead of was drilled. Sharpen your bit or try to ease down the motor much more slowly. If you did not use a pilot hole, the larger bit had nothing to catch on and cracked the nozzle because there was nothing for it to go into. Regardless of the situation, remove all the clay and repack the nozzle, taking care to drill it slowly and with a pilot hole.

- When I lit the fuse, nothing happened, it just went out.

You probably underestimated the depth of the nozzle and didn't push the fuse in far enough to light the fuel. Wait a few minutes before approaching the motor before doing anything with it. Something could be still burning, if only slightly, and if it's moved the embers could dislodge and ignite the fuel in your hands. Wait for it to go out, then use the drill to clear out any residue left from the fuse. Roll another fuse and place it further into the core than the previous one.

- The motor lit, then very quickly both ends blew out.

This is the most common type of CATO experienced in static testing. For one reason or another the core was over pressured. Either the nozzle was too small or somewhere in the core burn residue got stuck, preventing exhaust from exiting in the way that it should. The fact that both nozzles blew out is the inherent safety feature in this type of motor - in the case of over pressurization the ends are blown out at a low velocity and the motor can rapidly vent. This is what happens if, mid-combustion, you see a bright flash of orange or violet light and a large cloud of smoke. All the fuel burned rapidly in a low pressure environment. This equates to zero thrust and will not lift a rocket.

- In a flight test the rocket failed to leave the ground.

Either there as not enough thrust to overcome gravity, or the friction between the stick and the ground was so high that the rocket was being held back. The most common errors associated with not having enough thrust are associated with the nozzle. A nozzle that's too big will not release the exhaust under enough pressure to achieve launch. Other problems here could be fuel that's not well enough packed, a core that is clogged with burn residue, or simply a rocket that's too heavy.

- The rocket flew fine initially, but then started spinning out of control.

Your nozzle was probably not thick enough and thus eroded very quickly. This means early in the flight exhaust gasses will be directed straight back as intended, but after a short while the clay will erode and the direction of force will change, causing the rocket to flip or spin out of control. Try packing the nozzle thicker or drilling it straighter.