

Bravo Niner Rocket Motor Kit User Manual

“The Rocket Motor Factory in a Box”

October Science Educational Industries, LLC

Green Bay, Wisconsin

www.OctoberScience.com

Welcome!

Congratulations on your purchase of the Bravo Niner rocket motor kit from October Science Educational Industries, LLC. Welcome to the fascinating world of amateur rocketry!

Model rocketry has, for decades, been considered an ideal educational activity for adults to share with teenagers. Rocketry's challenges, fun and excitement motivate young people to learn math, physics and critical problem-solving skills. Rocket projects provide the perfect material for science fairs, scout projects and simple Saturday morning outings with Mom or Dad.

But until now, the typical consumer's involvement with a model rocket launch has revolved almost entirely around the construction of the air-frame and recovery system. The established model rocketry industry discourages curiosity about the business end of rockets – how their motors work and how to make them work better.

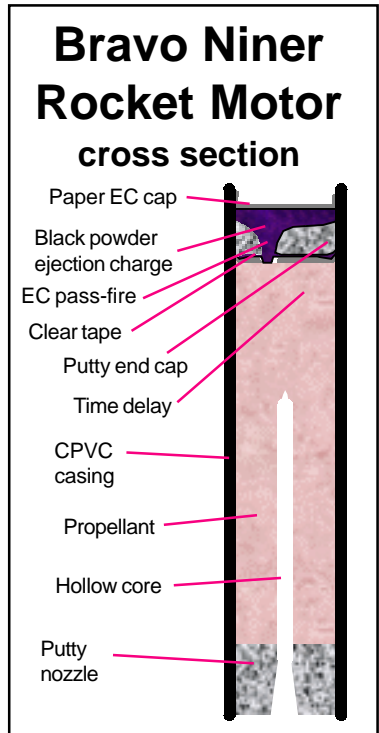
The field of amateur rocketry – as making one's own motors is known – has been around for many years, as reflected in recent Hollywood depictions. Its popularity has grown dramatically in recent years among adults, who often build very complex, ambitious rocket motors. But as strongly as young people are drawn to the field, parents aren't confident they have the skills or tools to safely make motors that perform well.

Now, October Science brings small scale amateur rocketry to the public, providing the tools, materials and specific knowledge to allow young people to make their own rocket motors that *work* — while helping the adults who supervise them to understand and control the inherent risks.

The Bravo Niner kit contains materials to build, from scratch, up to 40 solid fuel model rocket motors, plus other materials to allow you to fly the motors. Depending on your skill in building the motors, you should expect the power of a “B” motor, which means a total impulse of 2.5 to 5 newton-seconds (producing the same amount of energy as a commercially-made B6-4 motor). In any case, your motors, made right, will have plenty of power to produce dramatic launches.

While the directions in this booklet may seem complex at first, we hope you will take your time and enjoy the challenge of building the motors as much as the results. After you make a few motors, you'll see the process is fairly straightforward, and you'll be able to easily turn out a batch of motors with less than an hour of hands-on work. Keep in mind also that of the 30 steps described in this booklet, nine are set-up steps (marked with an asterisk) that need only be done once. Several more are related to testing and can be skipped once you have some experience and confidence with the motors you are building.

Most importantly, a young builder's pride will be tremendous in launching a rocket made with his or her own hands, from top to bottom. His or her understanding of rocket science will be much greater, too.



Rocket motor basics

All rocket motors, whether they use liquid or solid propellant, are powered by fuel and oxidizer. Solid rocket propellant mixtures often contain small amounts of other chemicals to improve their stability during the burn. Your motors will use sucrose as the fuel, potassium nitrate as the oxidizer, and sulfur to improve the burn characteristics.

Rocket motors are designed to produce very large amounts of gas, exhaust gasses, very quickly. In your motors, 63 parts potassium nitrate (KNO_3) and 27 parts sucrose ($\text{C}_6\text{H}_{12}\text{O}_{11}$) combine to produce large volumes of water (H_2O) and carbon dioxide (CO_2) (plus smaller amounts of some other gasses), in about half a second.

A very important part of your rocket motor is the nozzle. Here's why: The rule $E = \frac{M}{2} \times V^2$ (energy equals one half the mass of an object, times its velocity squared) is importantly applied to the exhaust gasses of your motor. For example, if you had something that weighed 10 grams and it were moving at 100 feet per second, its energy would be 50,000 (the units don't matter here). If you ponder the equation $E = \frac{M}{2} \times V^2$, you will realize that doubling the *mass* doubles the energy, while doubling the *velocity* quadruples the energy. In the case of a rocket motor, the thing that has mass is the exhaust gas, and the energy equals the thrust, or lifting power it can produce. The purpose of the nozzle, therefore, is to increase the *velocity* of the exhaust gas. You're pushing a specific amount of gas through a hole in a specific amount of time (the chemical reaction won't wait for the gas to escape!), so the smaller the hole, the greater the velocity.

Why not make the hole as small as possible? Rocket propellants tend to burn faster when they are under more pressure. If you have too much pressure, the reaction of the propellant is to produce more pressure, generally resulting in a blown nozzle or end cap.

There are two basic types of solid rocket motors. Most low-power commercial model rocket motors are end burners. Their propellant starts burning near the nozzle, and burns its way up the grain. The other kind are core burners. The propellant grain is made with a hollow core. The grain is ignited at the same time up and down this core, and the propellant burns from the core outward.

The level of thrust produced by a rocket motor over the time of its burn can be plotted on a graph to produce a thrust curve. The thrust curve of commercially-made end-burning model rocket motor of a "B" size or larger is characterized by a burst of power at the start of the burn, followed by "throttle back" period of several hundred milliseconds. Core burners, on the other hand, throttle up throughout the burn, producing the most thrust just before the time delay begins. The amount of thrust produced at any given instant depends mostly on the surface area inside the motor that is burning at that instant; the surface area burning in a core burner increases as the propellant burns. (The motors you are about to make have one basic characteristic in common with the massive solid rocket boosters on the Space Shuttle: They're both core burners.) It's a great geometry exercise to calculate the amount of propellant surface area burning inside your motor both at the start and at the end of the burn.

A few important questions

One of the most common questions about this kit is, “Isn’t this dangerous?” The answer is yes, it can be. But then, so is riding a bike or boiling water on the stove. You must understand and follow the directions carefully. The lightweight “stick rockets” described in this kit will fly at more than 400 mph. Treat them with the respect due a firearm, and use common sense.

An adult must closely supervise teenage children working with the materials in the kit.

The greatest risk is for the nozzle or end cap at the top of the motor to blow out during firing, shooting out chunks of intensely burning propellant at speeds in excess of 200 mph. While this is rare with proper construction, you must be prepared for it any time you fire a motor. For this reason, **it is critical that the motor be in a vertical position any time it is fired – that is, with the nozzle pointed straight up for a test stand firing, or straight down for a flight.** And obviously, everyone needs to keep their distance, and you must keep the motor away from flammable materials.

Another danger comes from flying a rocket in a way that could allow it to hit someone. The basic stick rockets described in this kit should fly stability when constructed as directed. Using them in kit rocket airframes or original design airframes requires, as always, that you ensure the aerodynamic stability of your rocket before you launch it. The center of gravity must be at least one body tube diameter forward of the center of pressure. (This kit does not cover rocket airframe design issues. Refer to model rocketry handbooks for details.) To be safe, you must **fly these rockets at least 75 yards away** from any bystanders.

The propellant materials in the kit, once mixed (and only then), are highly flammable, and must be kept from any ignition source. (It is a worthwhile (and fun) exercise to take about a teaspoon of the propellant mixture, place it in a small pile on some nonflammable surface, and ignite it electrically as described in this handbook, to get a feel for the flammability of the mixture.) In two years of testing, there was never an incident involving an unintentional explosion or flash fire of rocket propellant prepared as described here.

Users could burn themselves or injure themselves in other ways attempting to ignite a motor with an open flame. **You must use the electric method described in this handbook to ignite your motors.** Bottom line: Read, understand and **follow the directions to the letter**, and use common sense.

What about when they come down?

Stick rockets made from these motors are quite light; the risk of *serious* injury to someone hit by a falling stick rocket is small. However, common courtesy dictates that users take all reasonable steps to launch rockets in an area where there are no bystanders who could be hit by a falling rocket. It *would* be dangerous to put one of your motors in a regular rocket airframe with a hard nose cone and fins, unless you include an ejection charge in your motor. Additionally, as with commercially-made motors, your ejection charge could fail to deploy your recovery system, so again, you’ll want to be sure to launch your rockets in a large, vacant area. (Please don’t litter. Recover all rockets.)

Is this legal?

Every municipality has its own laws regarding fireworks and model rockets. Often, rules for model rockets are less strict than rules for fireworks. It is up to you to determine what rules govern your rockets in your location, and to understand and comply with those rules.

Getting started

What you will need:

Your kit contains everything you need to make about 40 rockets, with the exception of a few items that you probably have readily available. In addition to the items in your kit, you will need:

- Small containers for mixing putty
- Scraps of paperboard of the type used for cereal boxes
- Cellophane tape, e.g. Scotch tape
- A large safety pin or similar sturdy, sharp point
- A scissors
- A knife with a sharp point
- A hammer
- Masking tape
- A double beam balance accurate to 0.1 gram (optional)
- A cardboard tube at least 2 feet long
- A pole or narrow board about 2 feet long
- An empty coffee can
- Some sand or gravel
- A 6v lantern battery or larger battery. (Car battery can be used.)
- A ruler with both metric and English measures
- A 1/4 teaspoon measure

To make a test stand you will also need a sturdy, smooth pole such as a broom handle, some large, thick rubber bands, and a **sturdy** cardboard tube such as the type on which plastic food wrap is wound.

Basic rocket instructions

About the process:

The basic instructions to build a rocket follow. You should read all the directions from start to finish, twice, before you begin.

Start by making a batch of two or three simple motors without ejection charges. Test your first batch on a stable test stand (see page 12) before flying anything, to ensure safety and proper performance. When you're sure you've got it right, fly a few simple rockets using the sticks included in your kit. Do this in a large field away from any people. It's important to be able to find these simple rockets after flight so you can analyze them. Then, make a batch with ejection charges, first firing them on the test stand with a stopwatch, and only then, if you wish, flying them in model rockets with parachutes or streamers – again, away from any bystanders. As with commercial motors, the ejection charges on these motors sometimes fail to do the job, so you're taking a risk. Don't use them in your prized showpiece rocket. Don't use them in any model rocket until you have some experience and confidence they'll work as planned.

The steps:

1* Dry the black powder slurry. Your kit contains a small container of black powder (gunpowder) mixed with water for safety during shipping. To dry, simply open this container and put it in a safe place, away from any possible spark, flame or other intense heat

* Asterisks throughout booklet indicate a set-up step that only has to be done once.

source, away from any breeze, and away from an source of contamination (sawdust, grease, etc.). Several times a day, stir it with a stiff, smooth, nonporous object, such as the butt end of a pen. Always after stirring, do your best to scrape it down off the walls of the container. In a few days it will appear dry but lumpy. Crumble it with your stiff, smooth object, let it dry another 24 hours, then close the container and keep it in a safe place. Do not attempt to hurry drying by using a hair dryer, oven, microwave or any other means. If you simply air dry it, it will be ready when you need it. Note: Do not attempt to increase the power of your propellant by adding black powder. Such motors will not work.

Prepare the motor casing and nozzle

2. Lay out the following materials from the kit for steps 3 through 8:

Up to four (try two for your first batch) plastic tubes (motor casings); the bag of nozzle putty, a knife with a sharp point, the wooden multi-tool, the drill bit, the green dowel and the sandpaper. Get a small

plastic container in which to mix the putty, and a stiff, flat object to mix it (the handle of a teaspoon is fine). Wrap a few layers of masking tape tightly around the chuck end (non-drilling end) of the drill bit.

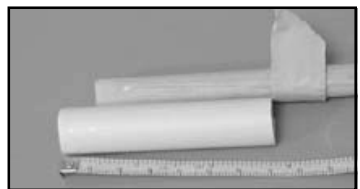
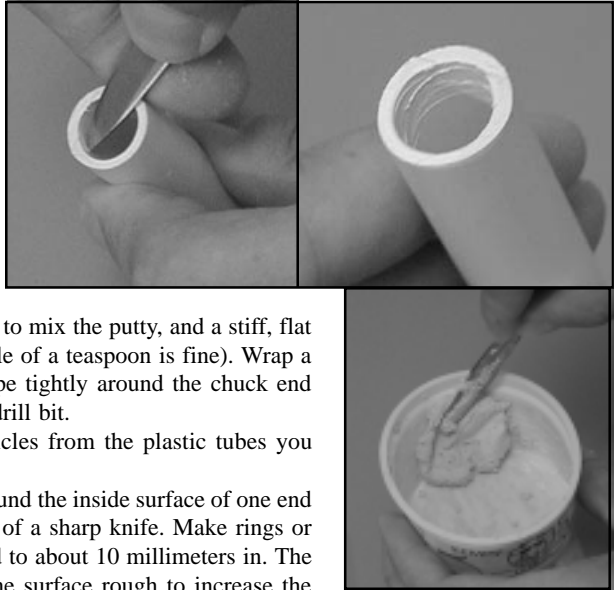
3. Remove any loose particles from the plastic tubes you have selected.

4. Scrape light gouges around the inside surface of one end of the tubes using the tip of a sharp knife. Make rings or hatch marks from one end to about 10 millimeters in. The goal is simply to make the surface rough to increase the strength of the bond with the nozzle putty.

5. Place a small amount (about 1 tablespoon for three or four rockets) of the water putty powder in a small dish. Mix, starting with about five **drops** of water. Add more water **a drop at a time**, as necessary to form a very stiff paste. **Be careful not to add too much water.** (If you do, just start over. Don't try to add more putty powder to save it, or you may find you'll use way too much putty, and you may have to discard it anyway.) The paste must be mixed thoroughly to a consistent, smooth texture.

The putty hardens fast, so you must work quickly. If the putty begins to get crumbly, you must discard it because its strength in its final hardened state will be compromised.

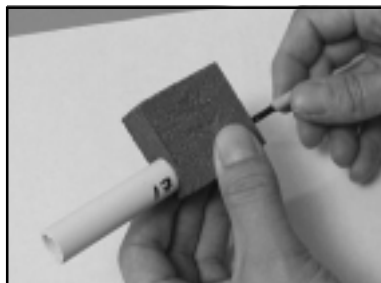
6. Insert the green dowel in the non-gouged end of the motor casing, so that it comes 13 to 15 mm from the other end. Tip: Wind tape around the tube to form a depth guide. Firmly pack the putty into the end of the tube. Try to avoid air pockets and make sure the putty is in firm contact with the wall of the casing all around. Now, slowly



and carefully twist the dowel while holding it at a constant depth inside the tube. While continuing to turn, very gently and slowly pull the dowel out. Wipe the excess putty off the dowel and repeat this process for the other remaining tubes in your batch. Set each tube on end on a smooth, clean surface. Work as quickly as possible so the putty does not harden too much before completing the next step.



7. Form the basis for the nozzle: When the putty is firm to the light touch (not jelly-like) insert the puttied end of the motor casing in the large hole on the green side of the wooden multi tool. Insert the drill bit through the small hole in the multi-tool opposite the motor casing, and press down very gently while spinning the bit clockwise with your fingers. Tip: It's helpful to moisten the end of the drill bit. Drill until you get all the way through the putty. Don't worry if a small chunk of putty drops out the other end when you break through, but if you see an obvious problem, your best bet is to knock out the putty with the green dowel and start over.



8. Cut the sandpaper into four pieces. Forming a piece into a cone which diverges at a 15° angle. Turn the sandpaper cone by hand to widen the aft (exposed) end of the nozzle so that the bottom half of the nozzle diverges at a 15° angle.



9. Label each motor with a serial number. Record serial numbers and any noteworthy aspects of motor assembly in a notebook. Let the nozzle dry for 24 hours. Then **make sure the narrowest part of the nozzle is at least 9/64" in diameter** by checking with the drill bit.

Mix the propellant:

10*. Find a clean area away from any possibility of flame, spark or other ignition source. Massage the bags of sucrose and sulfur **thoroughly** with your fingers to break up **all lumps**. Shake the bottle of potassium nitrate to break up all clumps. For optimum performance, obtain a balance or scale accurate to within 1/100 gram and measure 63 parts potassium nitrate, 27 parts powdered sugar, and 10 parts sulfur.

Discard any excess chemicals by pouring down the drain. Place the measured ingredients together in a clean container, then return them to the plastic bottle that contained containing the potassium nitrate for mixing. The chemicals are pre-measured to a reasonable degree of accuracy, so if you don't have access to a good scale, just empty the contents of the bags of sucrose and sulfur into the bottle containing the potassium nitrate. (Note that the potassium nitrate container contains two small lead balls to improve mixing.) Close the cover of the bottle tightly, take outside, and shake by hand moderately for 15 minutes. **Never** attempt to mix these ingredients mechanically, such as with a blender or coffee

grinder. This mixture is referred to as “propellant.” Hand write on the bottle’s label, “Sucrose-based rocket propellant.”

10 B. Note: It is important to keep this propellant mixture clean. Contamination with small bits of foreign material can cause rockets to behave in unpredictable ways. **Never reuse spilled propellant.** Gather it up and put it in an airtight plastic “slop” container for use later as primer. (See step 23.) Additionally, this mixture will absorb water from the air, so you must keep the lid tightly on the container. It is best not to mix, handle or use it when very high humidity is present.

Pack a basic motor:

11*. Make the core former by pounding one of the coring mandrels (nails) into the small hole on the red side of the multi-tool so that its point extends up through the center of the large hole on the opposite side. You will, obviously, have to support its ends with something, or place it over a hole drilled through the surface of your work bench. Pound the nail in until its head is flush with the red side of the multi-tool.



12. Weigh the casing/nozzle, if possible, and record. Place the multi-tool red side down (nail sticking up) on a sheet of clean paper on solid surface such as a sturdy work bench or the floor.

13. Working on a hard surface such as a cement floor, place the motor casing, nozzle down, over the coring mandrel, and firmly into the multi-tool, so that the nail extends up through the core of the casing. Look straight down into the casing – if the nail is obviously off center, carefully bend it at its base to center it. Make a paper funnel and place it over the open end of the casing. Using approximately 1/4 teaspoon at a time, put the propellant into the casing and bump several times on a hard surface to get the propellant to settle down around the coring mandrel. Never attempt to pack more than 1/4 teaspoon at a time.

14. Insert the red dowel, hole end down, into the motor casing and down over the point of the coring mandrel. Pack the propellant down by striking the top of the dowel several times with a hammer, using moderate force. Angle the red dowel a few degrees this way and that while striking it, to ensure the sides are well packed. It is **absolutely critical** to use the right amount of force during packing. Start by “choking up” about two-thirds of the way on the hammer handle and hammering as hard as you can from the wrist – that is, moving your elbow only 10° to 15°. It’s better to hit it too hard and get it stuck on the multi tool than to not hit it hard enough, in which case the grain will be weak and the motor will blow its end cap or nozzle). Do not place any part of your body over the top of the dowel while packing the propellant.



As you work, propellant will collect in the hole in the center of the red dowel. Remove



it between rounds of packing by tapping it on a clean sheet of paper.

Continue adding the propellant about 1/4 teaspoon at a time, and packing, until the coring mandrel nail is just covered. If you don't want an ejection charge, just add four more 1/4 teaspoon scoops of propellant, packing down after each scoop using the clean end of the **green** dowel (the end not used in step 6). **Pack the last two rounds harder, hammering from the elbow**, and proceed to step 15. If you want an ejection charge, you'll need a time delay. You can vary the time delay of your motors according to your needs. Measure the distance from the top of

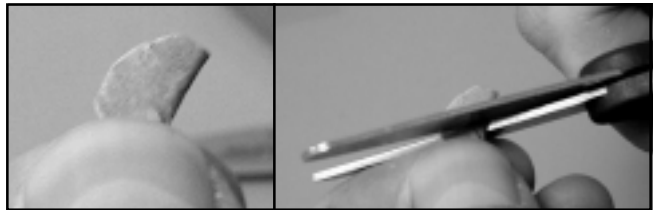
the propellant grain (the top of the coring mandrel) to the top of the casing. It should be around 25mm. We'll call this distance the "potential TD gap" or TD_p . Then continue adding and packing propellant using the green dowel and measure the remaining distance to the top of the casing. This is the "final TD gap," or TD_f . The ejection charge length (TD_L) is the potential TD gap minus the final TD gap. Or, $TD_L = TD_p - TD_f$. Simply put, it's the distance the propellant extends beyond the mandrel.

Vary the TD_f to control the TD_L . Start with a TD_L of 15mm and experiment on your test stand. Again, remember to pack with more force on the last two rounds. The time delay can also be lengthened by moving the opening in the forward closure from the center to the side. See step 15.

Put any spilled propellant that is not significantly contaminated, and whatever you can knock loose from the core of the red dowel, in your slop container. (See step 23.)

15. Forward closure: Cut a paperboard disk about equal to the outside diameter of the motor casing. Note: If you want an ejection charge, follow the directions in *italic and non-italic* type. If not, skip the stuff in italics. *Fold the paperboard disk in half and use a scissors to cut two slits in it to create a diamond-shaped opening 2 - 3 mm across when the disk is unfolded.*

The paperboard cut from the center must be completely removed. No "hanging chads" allowed. You can experiment with cutting the hole in

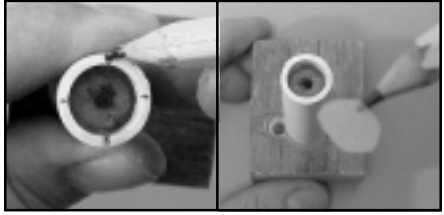


the forward closure so it is off to one side, to increase the ejection delay, but you must ensure the tape can seal off the hole completely.

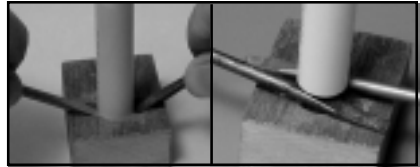
Now place the paperboard disk on top of the motor and pack it down with the green dowel using a few very light hammer blows. The paperboard should form a shallow cup, with material coming slightly up the inside wall of the casing all the way around. If the paperboard comes out when you pull out the dowel, simply stick it back in with a pencil. Reinsert the dowel and "mash down" the edges by hand, forming a firm seal around the casing wall.



Mark the top of the casing at four points, as if forming crosshairs, so you'll know where the hole is after the closure is covered with putty. With a large safety pin or similar point, gently remove a tiny bit of propellant creating a tiny space. Put a bit of black powder in that space. Now cut a circle of cellophane (Scotch-type) tape 5-6 mm in diameter and push it firmly down – sticky side down – over the hole. The goal is to seal the hole so no moisture from the putty you are about to add can get into the hole.



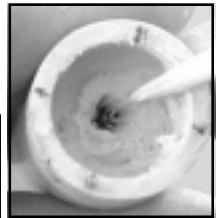
16. Remove the rocket motor from the multi-tool. First gently pry using two screwdriver blades in the side holes as shown. Then pull hard and twist **slowly**. Twisting vigorously could generate enough heat to ignite the motor. You should hear a distinct creaking sound as you pull and twist. If you don't, it means the coring mandril is turning in the wood base. If necessary, pry more: Placing the screwdrivers under the motor as show in the second photo at right (handles come up). Then try pulling and twisting again. (**Do not pound or jam screwdrivers – a spark could result**). Once removed, weigh motor, if possible, and record.



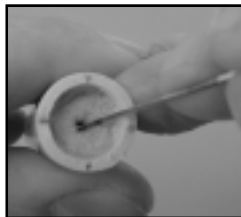
17. Mix a small amount of nozzle putty. Two teaspoons putty powder with three drops water is about right for three motors. Place a plug of putty 4-5 mm thick firmly over the paperboard closure and tape. If no ejection charge is required, allow putty to harden and skip to step 19. Otherwise, proceed without delay to step 18.



18. Use point of one of the small sticks in your kit to gently tease the putty away to expose the taped-over hole. Be careful not to pierce the tape. Allow putty to harden for at least three hours.



19. Using a large safety pin or similar object, break through the tape at the bottom of the putty cap hole, and do your best to remove or obliterate all of the exposed tape.



Crease a small piece of paper and place on it a tenth of a teaspoon (0.5 grams, a bit less than a half of a quarter tsp. measure) of black powder. Make sure the black powder is thoroughly dry. Pulverize it to remove any lumps. Pour a bit of this powder into hole in the putty cap and, using a safety pin, poke some powder down into the hole. Gently but firmly work to ensure some black powder gets packed into the powder that was under the tape.

20. Pour the remaining black powder on top of the plug. Insert another paper cap in the same way as in Step 15 (but without the hole), except this time, instead of packing the cap by driving the dowel with a hammer, you will simply hold the motor in one hand and firmly force the dowel down on the paper cap with the other hand.



21. The propellant mixture is highly hygroscopic – that is, it attracts water out of the air. As such you should close the nozzle opening with a small piece of masking tape. At this point, the motor can be stored for use at any time. Store your motors tightly wrapped in a Ziploc bag, and avoid dropping or any strong impact, which could loosen the propellant grain.

Prepare the motor for firing:

22. Make an igniter: You have two options. Low power igniters are harder to make, but they allow you to bring a smaller battery to your launch site.

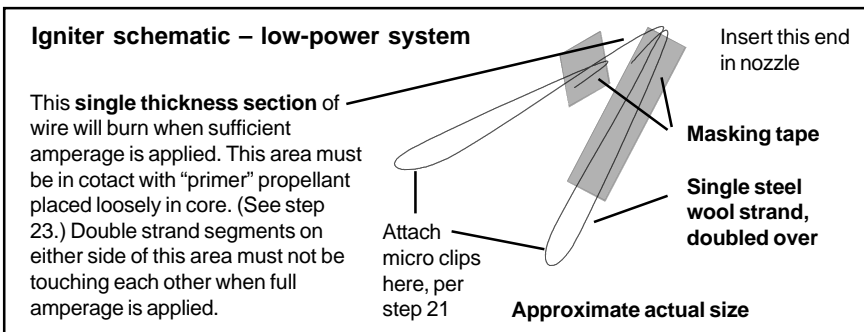
- **For lower power launching systems**, such as those using a single 6 volt lantern battery: Select a thick strand of steel wool, at least 13 cm long. Double over one end at least 3 mm, then loop that end around so that it touches the strand near its center. See illustration below. Use a very thin (3-5mm) strip of masking tape, folded over the long way, to secure the doubled over segment as it touches the strand near its center. Repeat for the other end. The goal is to make the strand double (or triple) along its length except for a portion about 4 mm long in the center. Once you have made a couple igniters, you may want to test them (and your battery) as indicated in steps 29 and 30 (that is, with the igniter alone, no motor), to make sure the wire burns quickly, and **only at the single strand portion** in its center.



Although making igniters in this way can be hard at first, it is well worth the effort to make them correctly. Made with care, these igniters are very reliable.

- **For a higher power system**, such as a car battery:

Your kit contains three segments of steel wire, woven together, about



6 cm long. Pull out one strand of this wire and bend it to the shape shown in the illustration at right. Again, test these igniters with your system to ensure it has the power to burn the wire quickly. **Use caution in testing – this wire burns very fiercely.**

(You can always use igniters like the ones that come with factory motors, with a compatible launch control system.)

23. Prime the motor (not necessary for a high-power launch system). By now you should have a container of “slop” – spilled propellant left over from packing motors. (See step 10 B.) (If not, put a half teaspoon of propellant into your slop container) If your black powder is dry add a bit (1/32 tsp) of it. This is your priming mixture. (If your black powder is not yet dry, the propellant alone works fine as a primer.)

Place a tiny amount of priming mixture on a small, folded piece of paper creased down the middle. Crumble any lumps. Holding the motor nozzle up, use the paper as a guide to pour the priming mixture into the nozzle and down into the hollow core of the motor – about enough to fill 1/3 of the volume of the core. **Critical safety note: this primer must be loose, not packed.**

24. Still holding the motor nozzle up, insert the igniter into the nozzle at least 16 mm, making sure no exposed metal touches from one side to the other. The igniter should slide into the core easily. If it does not, dump out a bit of the primer by tapping lightly. Once inserted, tape the igniter in place by placing masking tape firmly over the bottom of the nozzle, with the igniter leads sticking out on opposite sides. If using a low power igniter, turn the motor right-side-up and lightly tap it against a table edge a few times. This will ensure that the priming mixture comes in contact with the single strand portion of the igniter.

The Rocket motor is now ready for *static* (on an immobile test stand) firing. If your test stand is ready, proceed to step S6.

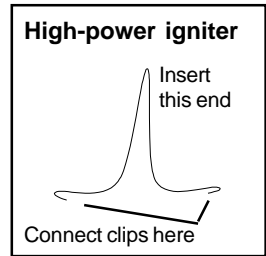
Static test stand

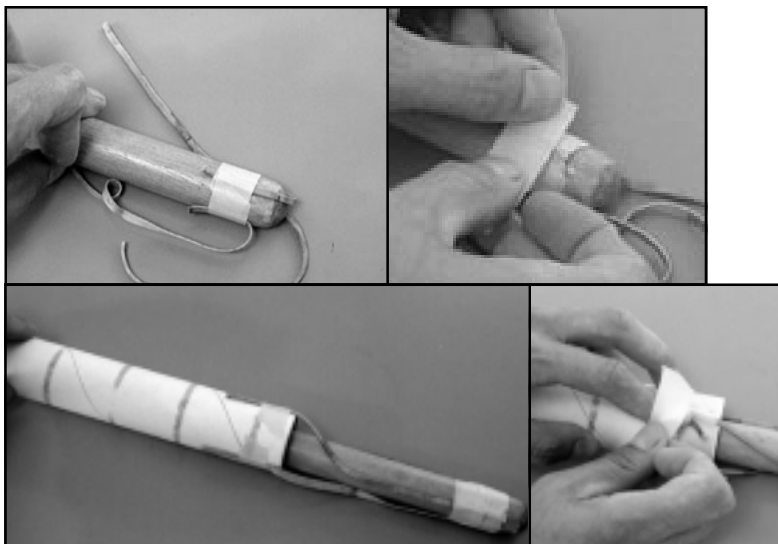
It can be difficult to measure the performance of a rocket motor when it’s flown. A simple but reliable test stand, used in conjunction with a cam-corder, provides a means to do crude but meaningful scientific analysis of the effects of various design variations on motor performance. It won’t be precise, but it will provide a way to compare motors on a consistent basis. **When making your first motors, it is especially important to fire them on a test stand.** If you do not, you may find your motors fly unpredictably, creating an unsafe condition.

Make a simple stand as follows:

S1*. Obtain a wood pole about five feet long, such as a broom handle. Find four thick rubber bands (like the one in your kit that holds the motor casings) and cut them open. Anchor one end of each rubber band to the top end of the pole, spaced evenly around the circumference of the pole. Tape with masking or duct tape, fold, and tape again. Obtain a **strong** paperboard tube such as the core of a roll of plastic food wrap. Slide it on to the pole, and tape the other end of the rubber bands to the tube in the same way you attached them to the pole. Test the strength of the attachments by pulling the paper tube to the end of the pole.

S2*. Secure the test stand vertically by placing in your coffee can and filling the can with sand or gravel.





S3*. Make an S hook with a piece of coat hanger and place one end over the top edge of the paper tube. Get a bucket or similar container and add water to bring the weight of the container plus the water to 204 grams.

S4*. Place the container with the water in it on the other end of the S hook so that it is hanging from the paperboard tube, jiggle the stand so that the paper tube finds a neutral resting place, and mark the position of bottom edge of the paper tube on the pole with a heavy black marker.

Add 204 ml of water to the container and mark again. Repeat, adding 204 ml water at a time, until the container reaches the bottom of the test stand. Each mark represents two Newtons. The peak thrust could be as high as 16 Newtons (about 3.5 pounds). Make sure your stand can handle that.

S5. Go over each mark again, making the mark heavier. Then paint a white stripe under each black mark. The goal is to create as much contrast as possible to make it easier to record the results as viewed on a videotape. Number the marks 2, 4, 6 etc.

To use the test stand:

S6. Tape the motor, primed and with the igniter installed, **securely** to the paper tube with masking tape, nozzle pointing **up**. Use three wraps of masking tape at the top and bottom of the motor, then test by pushing down on the **motor** as far as possible.

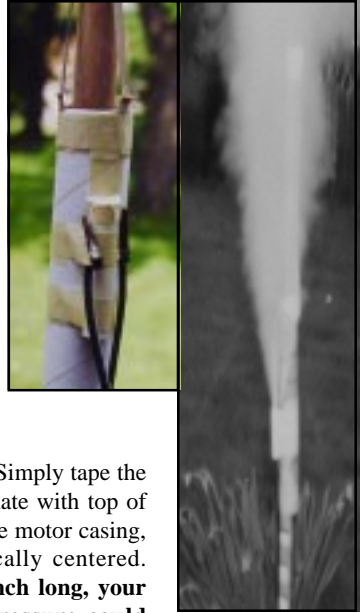
S7. Set up a video camera on a tripod to record. The sun should be at the camera's back.



Looking through the viewfinder, make sure the entire length of the pole is visible, and that you can discern the marks clearly. For best results, set your cam-corder to record images at 30 frames per second, if possible (SP setting).

S8. Roll the video camera, and fire the motor as described in steps 29 and 30 below.

S9. Stop recording. Transfer the tape to a VCR that can play it back frame by frame. Graph the position of the rocket motor on the pole relative to the numbered marks, frame by frame. This will yield the thrust curve for the engine tested, and simple math can be applied to estimate energy output in terms of Newton-seconds.



To launch a basic (stick) rocket:

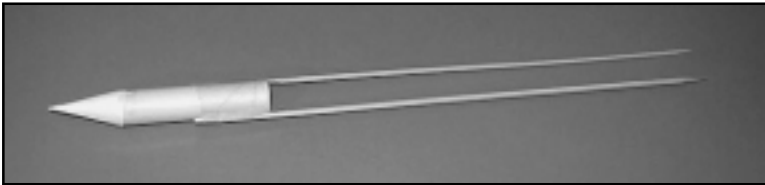
25. Make a paper cone no more than 3/4 inch long. Simply tape the paper into cone shape, trim to the correct size to mate with top of rocket motor, and tape or glue in place directly to the motor casing, taking care to make sure the cone is symmetrically centered.

SAFETY NOTE: If nose cone is more than 1 inch long, your rocket's center of pressure could move forward of center of gravity, causing rocket to fly wildly, like a released balloon. In addition to streamlining, paper nose cone also helps reduce risk to people and property on the ground when the rocket comes down.



26. Take two of the thin wooden sticks included in your kit and flatten one side of each for a length of about 1 1/2" starting

from the blunt end. (Optional: Shave or sand the sticks to about half their normal

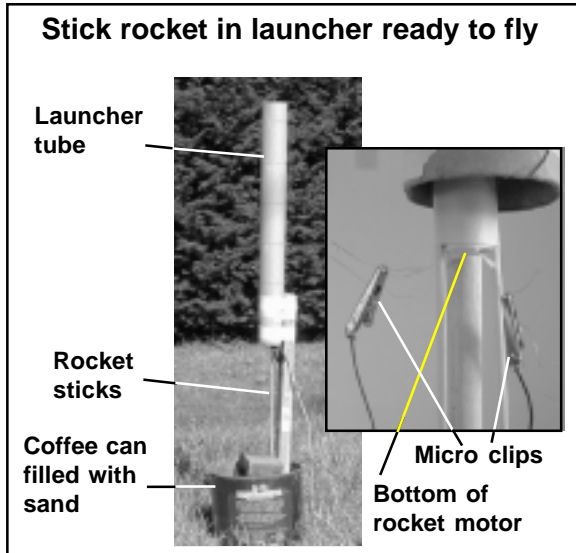


thickness.) Tape or glue the flat side of the stick to opposite sides of the rocket motor. Make sure they are secure and straight. Note: The pointy end of the stick should point in the same direction as the nozzle – down.

27*. Make the launcher: Simply take a cardboard tube at least 18 inches long, such as is used for the core of a roll of gift wrap, and use masking tape to securely attach it to a stick, dowel or narrow board. Make sure the inside of the tube is clear and in good condition. The stick should extend approximately 16 inches beyond the end of the tube. (See photo, facing page.)

28. Go to an open, uninhabited area, such as a vacant athletic field. Erect the launcher by placing the stick or board attached to the tube in a coffee can, and filling the can with sand or gravel on level ground. Point it 5° from vertical AWAY from launch team and observers, and with the wind (wind at the launch team's back as they face rocket). Place a solid, brick

or rock in the can under the launch tube to support the bottom of the rocket (pointy end of the stick). It is important to have a smooth surface that will prevent the bottom of the rocket from becoming stuck in any way. Place rocket up into launcher as shown. No more than a quarter of the rocket motor may extend beyond the bottom of the paper tube. **SAFETY NOTE: It is critical that the launcher be stable.** If a wind gust tips it over at the moment of ignition, the rocket will travel horizontally, creating an extremely unsafe condition.



29*. You may use a commercial ignition system and commercial igniters to ignite these motors, but **do not use your hand-made igniters with a commercial launcher system** – the current from the continuity light may ignite the motor. To make your own ignition system, take the length of wire provided in your kit and remove the insulation from half an inch of each wire, at both ends. Connect the micro clips provided with your kit to each side at one end of this 15-foot wire.

30. Clean the clips with sandpaper if necessary. **Make sure no power is supplied to the wire**, and attach clips to igniter leads extending from the nozzle of the rocket motor. **Critical safety point: Make sure the clips do not touch each other.** Secure the wires so the clips will not touch after the rocket launches. If using low-power (steel wool) igniters: Connect **one side** (polarity is irrelevant) of the wire to a strong battery such as a six volt lantern battery. If using high power igniters, you will need a stronger battery such as a motorcycle or car battery. To use a car battery: First connect jumper cables to the car battery. Then connect **one** wire of your launcher to the other end of one of the jumper cables. Note: Don't be concerned that the wire is much thinner what you would normally attach to a car battery. The system will not draw enough current to overload the wire, as long as the clips or leads to not touch.) Your rocket is now "armed." **You must be at least 15 feet away from the rocket or test stand when firing.**

Make sure the area is clear. Give a loud, clear count down from five, then touch the other side of the wire to the other terminal of the battery (or to the other jumper cable clip). With a strong battery, the rocket motor should fire almost immediately, and the rocket should launch within about half a second. **Immediately remove the wires from the power source upon ignition.** If the motor does not ignite, remove the wires from the power and wait at least 1 minute before approaching it.

* Asterisks throughout booklet indicate a set-up step that only has to be done once.

Critical Safety Points: Always:

- Use remote electric means to ignite motors, whether on test stand or for flight. Never attempt to ignite with a wick or fuse.
- Position the motor with the nozzle pointing straight up for test stand firings, and at the ground for flights. Never ignite a motor that is horizontal or near horizontal.
- Launch rockets in a large vacant area.
- Keep bystanders not directly participating in the launch or motor test at least 75 yards away from a firing motor.

Kit component list

- 40 PCV motor casings
- 120 grams nozzle putty
- 239 g potassium nitrate, for use as propellant oxidizer
- 103 g sucrose, for use as propellant fuel
- 38 g flowers of sulfur, to stabilize propellant burn
- Water slurry of black powder (gun powder) for ejection charge and priming. Dry weight approx. 15 g.
- 1 wooden multi-tool, used in nozzle formation, and to support coring mandrel
- 2 steel coring mandrels (modified nails), one of which will be joined to the multi-tool, plus spare
- 1 9/64-inch drill bit, to form basis for nozzle (to be turned by hand)
- Partial sheet of fine sandpaper
- Red packing dowel with hollow core
- Green packing dowel with solid core
- 40 thin wood sticks suitable for making 20 stick rockets. (Can be reused.)
- 44 strands of thin steel wire for use as high-power igniters
- Wad of steel wool sufficient for making 40 optional low-power igniters
- 2 micro clips to attach wires to igniter for remote ignition
- One length of two-strand wire, for remote ignition

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