Rocket Anatomy 101

By Mark Newton

Most rockets are composed of sections or parts, carefully chosen and arranged to create a flight-worthy vessel. Understanding the name and purpose of each part is one of the first steps into the hobby of model rocketry. Let's examine these and how they contribute to the flight of a rocket.

Nose Cone

The nose cone is usually the part that first interacts with the air in flight. The nose cone parts the air as the rocket moves through the atmosphere. Pushing the air out of the rocket's way creates friction. The friction pushes the nose cone downward, transferring the air's force to the airframe. The rocket's passage through the air creates heat of friction; for most model rockets, this heat is trivial, because it lasts only for a few seconds. However, for a slender high-powered rocket that flies several miles high at twice the speed of sound, the heat of friction can melt the paint off the nose cone.

Nose cones come in many shapes: rounded, elliptical, parabolic, ogive, and conical, to name a few. The nose cone usually has a shoulder Ñ a section that fits inside the airframe to keep it centered on the rocket Ñ and a place on the bottom where the recovery system can be attached. This attachment varies in size with the rocket: model rockets have a plastic slot or small screw eye, while mid-sized rockets often have eyebolts, and large rockets have massive U-bolts or welded eyebolts. Once the recovery system has been attached, the nose cone stays joined to the rocket throughout the flight.

Nose cones are made from many different materials as well: small ones are often molded plastic or wood (balsa wood, basswood); high power manufacturers frequently use fiberglass, carbon fiber, or other composite materials. Composite provide greater strength and less weight, but cost more to purchase. Some people make their own nose cones from wood turned in a drill chuck or wood lathe. Frequently, nose cones on large home-built rockets are constructed by stacking and gluing sheets of foam, shaping the stack with a hot wire cutter, then covering the foam with a fiberglass/carbon fiber skin. The variations are endless.

Regardless of their shape, rockets are all constructed with a nose cone, and airframe and fins.

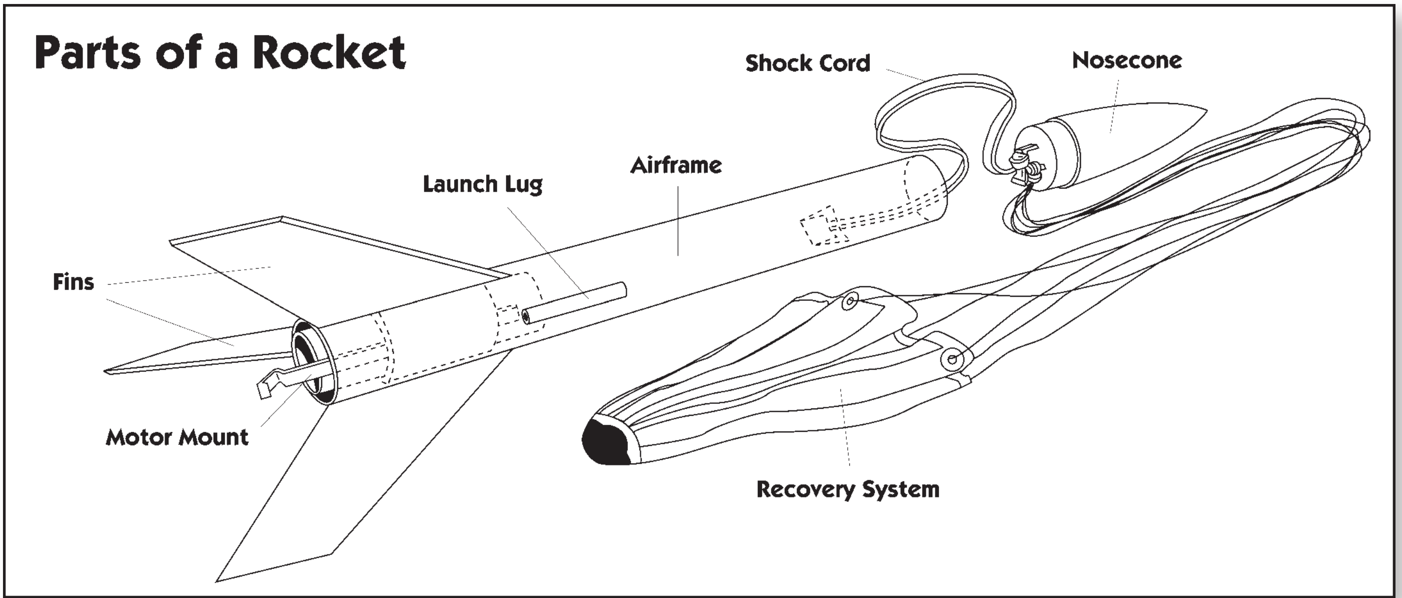
Airframe

Sometimes called the body tube, the airframe provides the main structure of the rocket, supporting the nose cone and fins. During flight, the airframe is compressed from two directions: the motor pushes up from the bottom during thrust, and the nose cone pushes down as it parts the air. If the rocket veers to one side during flight, the airframe can be hit with air resistance from the side as well. The airframe must be able to withstand these forces, or the rocket will buckle or break. On the inside, the airframe holds the recovery system – the parachute, streamer, etc – as well as other parts, such as centering rings or motor tubes, some of which can also strengthen the airframe.

Rolled paper tubes are the most common form of airframe. They are relatively lightweight, and they crush during a crash to absorb the impact force – a desirable safety characteristic. In high power rocketry, airframes shift to heavy-walled paper, phenolic tubing (paper soaked in a high-temperature phenolic resin), plastic tubing, fiberglass, carbon fiber and other materials. These advanced materials handle the greater forces imposed by high-thrust motors and greater weights. Some builders reinforce their airframes by covering them with epoxy and fiberglass or other materials. For scratch-built rockets, paper tubes of all sizes, from paper towel rolls to oatmeal containers to concrete forming tubes, have been employed as airframes. Most airframe tubes can be purchased in lengths of 2-5 feet. When longer airframes are needed, a coupler is placed between two tubes to join them into one long tube. The coupler is usually made of the same material as the airframe. No matter the material, the goal is to create a structure that will not fold under the stresses of flight.

Fins

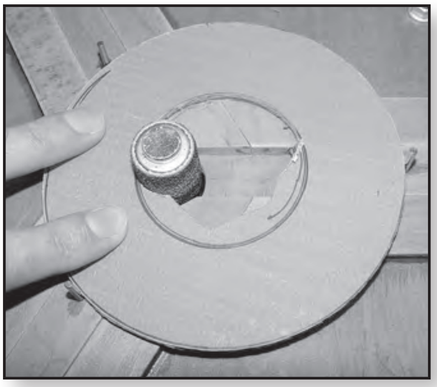
Fins provide the rocket's guidance. In flight, air flows over the fins, beginning at the leading edges and ending at the trailing edges. When a rocket is flying in a straight path, it encounters less air resistance (drag) than if it flies at an angle. If the rocket attempts to turn, the fins opposite the direction of turning are moved into the airflow, and the air pushes more on the exposed fin surfaces than on the other fins, until the rocket rights itself, just as a weather



vane always points into the wind. Fins are usually the first part of a rocket to fail during powered flight, because they have air flowing around them on every side, and they are made of thin material to reduce their air resistance and weight. Fins can fail because they literally flutter apart, or can simply separate from the rocket because they are not properly attached. In either case, failure of one fin usually dooms the flight, as its guidance system is now unbalanced, and there is less air resistance near the tail once the fin is gone, moving the center of pressure (CP) forward, perhaps even ahead of the center of gravity (CG). At this point, the rocket often does a few quick loops to celebrate the loss, likely tearing the airframe apart in the process.

Because thin fins have less air resistance than thick ones, rigid materials are used to provide stiffness with minimum thickness. For model rockets, balsa wood or basswood are favorites. Competition models may use waferglass, a thin material made from plastics and fiberglass called G-10 (garolite). High power rockets use aircraft-grade birch plywood or thicker sheets of G-10. These materials are strong, but they become very heavy as their size and thickness increases. To reduce the weight of large fins, some builders use lighter materials for the center (core) such as foam or balsa wood, add hardwood strips for the fin edges, then reinforce the core with a skin of thin hardwood or composites, such as fiberglass/epoxy. If built properly, these reinforced fins can perform as well as solid fins, but with a fraction of the weight.

Whatever material is chosen, the fins must be secured to the rocket at their root edges, so they will not separate from the airframe during the most stressful part of the flight (usually at motor burnout), sometimes at speeds beyond 1000 miles per hour. Model rocket fins are usually just glued to the airframe surface, while high power rockets often have fins with tabs that fit through slots cut in the airframe; the tabs are glued to the motor tube. These are known as through-the-wall fins; they gain strength by being glued both to the motor tube and to the airframe. There are many other techniques to strengthen fin attachment that you will find as you progress in the hobby. No matter the technique, the goal is to keep the fins attached to the rocket throughout the flight.



Motor Tube

The motor tube contains the motor and is attached to the airframe in some manner, usually with centering rings. The motor tube is often made of the same material as the airframe. A model-rocket motor tube often has a thrust ring inside and the motor pushes against the ring during thrust. High power rockets have no thrust ring inside – the thrust ring is at the aft end of the motor. This lets you insert motors of different lengths without spacers. The motor tube transfers the thrust of the motor to the centering rings, which transfer it to the airframe. Therefore, the motor tube and centering rings must be able to withstand the highest impulse produced by the motor. In addition, the motor tube must be able to handle the heat produced by the motor, where surface temperatures can go beyond 200F.

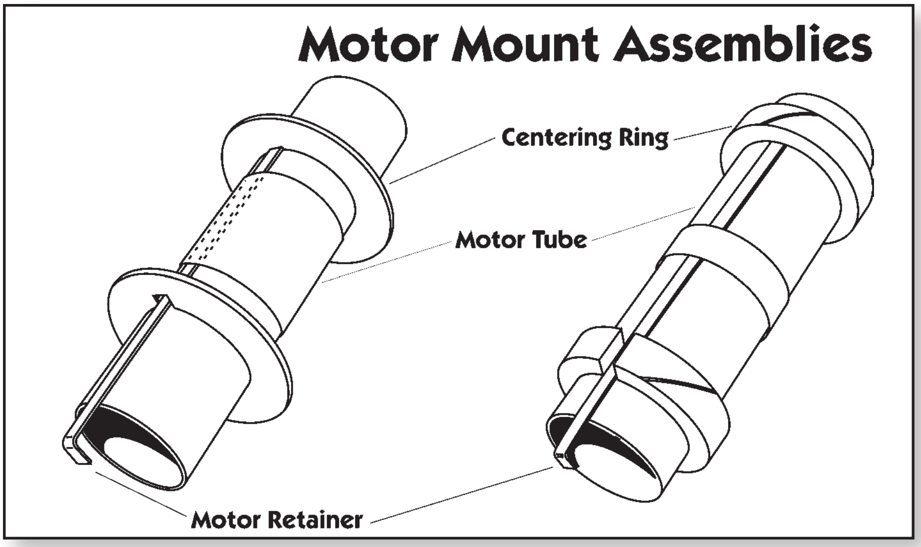
Centering Rings

The centering rings center the motor tube inside the airframe and transfer the thrust of the motor to the airframe. Model-rocket centering rings are made of cardboard or balsa wood. For high power rockets, aircraft-grade plywood or G-10 is the material of choice. A rocket weighing up to 3 pound would probably have 1/8"-thick plywood centering rings; a 30-pound rocket might use 3/4" plywood. Just like fins, centering rings get very heavy as they get larger and thicker. As with fins, centering rings can be made from lighter materials, reinforced with composites like epoxy/fiberglass to give the same strength as wood but with less weight.

In larger rockets, it is common for the forward centering ring to do double duty: a U-bolt or forged eyebolt in the centering ring provides a solid attachment point for the recovery system. Likewise, the aft centering ring often holds the motor-retention hardware.

Motor Retention

Once a model-rocket motor’s propellant has burned out, its delay charge gives the rocket time to coast to maximum altitude. Once this



delay burns through, the charge pressurizes the interior of the rocket, forcing it apart and deploying the recovery system; however, when the interior is pressurized, the rocket motor will be blown out the aft end of the rocket unless something restrains it. The motor-retention system secures the motor, so it cannot leave the motor tube in flight. An engine holder, a lightweight metal clip, is frequently used for small motors. The clip snaps over the motor to restrain it, then the clip can be pulled back to release the burned-out motor. This style of clip is found in most kits in the hobby shop.

Such a clip is inadequate for high power rocket motors: most large rocket kits do not include motor retention, allowing the builder to choose a suitable method. As a result, other retention devices have been developed for larger motors. A common homemade design is the “Kaplow clip”, in which a bolt is threaded into a blind T-nut set in the centering ring. The bolt and T-nut secure a metal tab that hooks over the aft ring of the motor. Several commercial retainers are available, including variations of the Kaplow clip (e.g. PML), retainers with snap rings (e.g. Giant Leap Rocketry) and threaded retainers (e.g. Aeropack). All these devices have different benefits and costs, but all accomplish the primary job: keep the motor in the rocket.

Recovery System

The recovery system consists of several parts that work together to reduce the airspeed of the rocket, so it can be recovered and flown again. The NAR safety code requires every rocket to have a recovery system. A typical recovery system consists of shock-cord attachment point(s), a length of shock cord, flame protection, and the recovery device itself, which is usually a parachute.

If everything goes perfectly, the recovery system is deployed precisely at apogee, the peak of flight, when the rocket is moving very slowly. Things do not always happen perfectly. If the recovery system is deployed a few seconds before (or after) apogee, the rocket may be moving upward (or downward) at high speed. Ejecting a parachute, while moving at 300 feet per second(fps), puts a great strain on the chute, the shock cord, the attachment points, and the airframe itself. Recovery systems must be able to handle forces 40-60 times the rocket’s total weight. Model rockets are relatively lightweight, so a folded-over piece of paper, glued to the shock cord and to the inside of the airframe, is adequate. Some models use a piece of Kevlar around the motor tube for the attachment point.

However, the attachment point must be much stronger for bigger, heavier rockets. Large rockets use one or more U-bolts or forged eyebolts through the centering rings to absorb the large stresses of deploying the recovery system. Large rockets may also use a Nomex deployment bag or some similar technique to delay the opening of the parachute. A delayed opening has advantages: when the rocket deploys its recovery system, it separates into pieces connected by the shock cord, usually (a) the nose cone, (b) the chute, and (c) the airframe, motor, and fins. While the assembled rocket is highly streamlined, so that it can move through the air with minimal drag, its individual components are not. Once the nose cone and airframe separate, the increased drag will quickly slow down the rocket, even before the parachute opens. Delaying the parachute opening for a second or two can mean the difference between opening at 300 fps or 100 fps – a large difference in stress on the recovery system.

Rockets can be recovered by many techniques, including parachute, streamer, glider, helicopter, featherweight, tumble, and nose blow for starters. The most common recovery method is the parachute or streamer for model rockets, with parachutes being the rule for high power rockets. Parachutes also change as rockets change, from inexpensive plastic sheets in model rockets to the more expensive, bulkier, and heavier nylon fabric for large rockets. Plastic parachutes, even well constructed ones, cannot handle the stresses imposed by large, heavy rockets. Streamers work well for small rockets, but are not effective for safe recovery of heavy rockets.

Commercial motors typically use black powder (BP) to pressurize and separate the rocket for recovery. BP burns at temperatures near 2000F, which can destroy nylon or plastic. To protect heat-sensitive rocket parts, flameproof wadding is placed between the motor and the recovery system. As rockets get larger, the wadding may be replaced with a cloth made of flameproof aramid fibers, such as Kevlar or Nomex. Another approach is to cool ejection gas before it contacts the sensitive parts, by making the gas pass through a series of offset baffles or a mass of heat-resistant material such as coarse stainless steel wool.

Launch Lug/Rail Buttons

The launch lug is a small but important part of the model rocket. The lug fits over the launch rod, so that the rocket is guided along the rod for the first few feet of flight, while it is still moving too slowly to be stabilized by fins. The launch rod may be 1/8" in diameter for small model rockets, up to 1" for large rockets. It is important to select a rod that is proper for the weight and length of the rocket: a 1/8" rod works fine for small rockets, but it is inadequate for, say, a 1-pound rocket, where a 1/4" rod is a better choice. Most flyers use a rod between 3 and 6 feet long. One disadvantage of a launch rod is “rod whip”: as the rocket leaves, the rod whips, sometimes throwing the rocket off its flight path.

Since rails are stiffer than rods, they are a good choice for high power rockets. Rail buttons or guides are then used on the rocket instead of lugs. Seen from the top, a rail appears like the letter C. The button or guide slides down the gap in the rail. The rocket moves up the gap during flight. A rail can be reinforced with guy wires, and it can handle large rockets without rod whip. In spite of the greater cost of rails, they are increasing in popularity. Launch buttons and rail guides differ only slightly: a button looks like a miniature sewing spool, while a guide is a longer piece with a slot on each side, to fit down the rail.

Building a Rocket

By Mark Newton

Yes, it is the always the first rule in construction: read and follow the directions. But now you want to build a rocket using your own parts, or you want to modify a manufacturer's kit for more radical flights. What can you do to keep it together with that F motor, when the kit was really designed for a D motor? Simple: use your bag of building tricks to reinforce key parts of the rocket so it can "return alive" from that flight you've planned.

The Fundamental Rule of Building

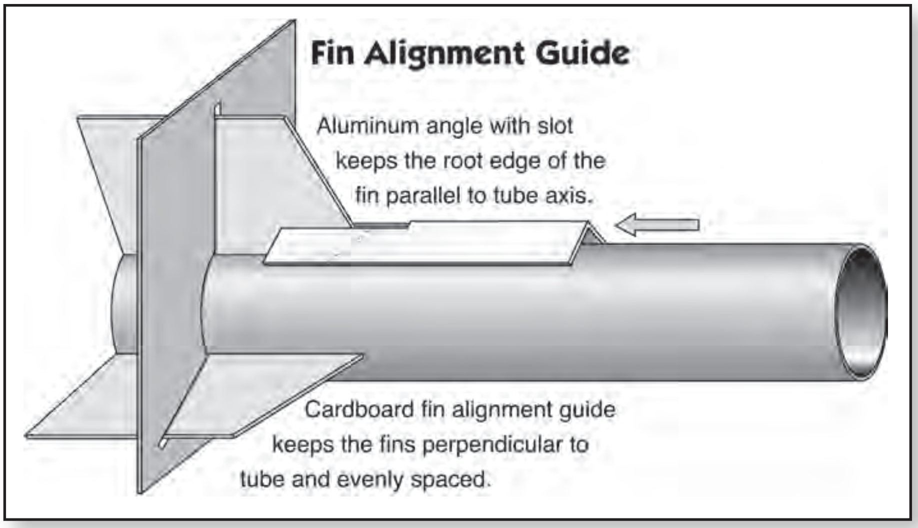
All right, maybe there are more rules than one to remember. But over time this rule keeps moving to the top of the list: MORE ATTACHMENT SURFACE AREA IS BETTER. You will notice how much the surface area impacts the various components when the rocket is assembled, for example, sanding a surface before gluing cuts micro-ridges in the surface. These ridges provide more surface area for the glue to bond to, increasing the strength of the bond. You will build stronger rockets if you do things to increase surface area as you build.

Choose Your Adhesive Wisely

Rocket parts come in a variety of materials: molded plastic, paper, cardboard, plywood, balsa wood/basswood, phenolic tubing, Quantum tubing, fiberglass, and aluminum are some of the materials in your rocket. No single glue has the ideal properties to bond all these materials together. To achieve the greatest strength with the least weight, you must choose adhesives with the best properties for the materials you want to bond. For example, two-part epoxy gives a strong bond to hold wood fins on a paper body tube, but it adds more weight to the rocket than yellow (aliphatic) glue does. For bonding paper and wood products together, yellow glue is your best choice. It is stronger than the materials you will bond. Once glued, the parts will strip away from the glue before the glue itself fails, and yellow glue is much easier to handle than epoxy: no mixing, no gloves, less expense, and water clean-up. Outside of wood and paper, most other materials adhere best with epoxy, including phenolic tubes, G-10 fins, Quantum tubing, plastic nose cones, and aluminum. Epoxy is the rocketeer's friend when bonding two items made from different materials.

NOTE: You will become hypersensitive (allergic) to epoxy over time if you work with it without wearing protective equipment such as nitrile gloves. Latex gloves do not protect you from epoxy. Also, use epoxy cement only in areas with good ventilation.

Now, having talked up epoxy for most materials, let's look at the exceptions. When building many of the new ready-to-fly kits, you can use modeling cement to bond plastic to plastic. Also, most epoxies do not hold up under high temperatures. For bonding metal motor mounts or retainers to motor tubes, special high-temperature epoxies are recommended. For field repairs, nothing beats cyanoacrylate (CA), also known as "super glue." It will repair broken fins and launch lugs. It is wonderful stuff to have in your field box. CA also has another feature: when soaked into paper or wood, it acts like an instant sealer, making the fibers stiff. CA-soaked items sand easily, without the "fuzz" that normally accompanies sanded wood or paper. You have to pick the right CA for the job, as it comes in thin, medium, and thick viscosities. Thin CA is best for soaking into wood/paper, while medium or thick CA is best for bonding materials in construction or field repair. Some rocket manufacturers recommend CA for constructing their kits.

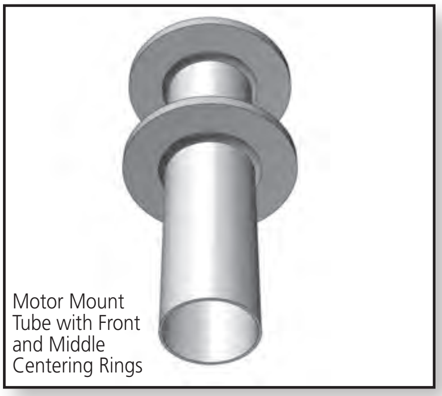


Fins

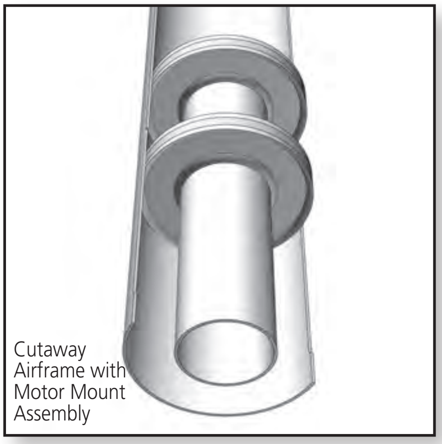
For the typical rocket, fins and motor mounts are the parts that receive the most stress in flight. Motor thrust and wind shear both attempt to shred fins from the airframe. The fins usually also receive a beating when the rocket hits the ground. Reinforcement and building techniques can increase the strength of fins. Let's discuss some techniques for wringing more performance from your fins:

Reinforce your fin stock. Balsa or plywood fins can be reinforced with a layer of typing paper. Coat the fins on both sides with a thin coat of yellow glue, cover each side with typing paper, then put a layer of wax paper over the typing paper. Press the whole setup under books, bricks, or something else flat and heavy for several hours while the glue dries. After the glue has dried, remove the fins, peel off the wax paper, and carefully coat the typing paper with CA. The CA will stiffen the paper and wood so that it sands easily. From this point, the fin can be sanded, cut, or treated like any other balsa fin. This technique also eliminates the need for sealing balsa fins prior to painting.

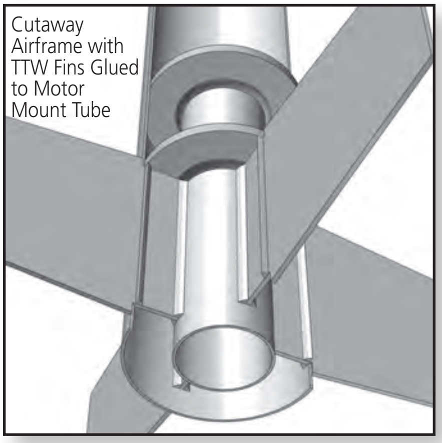
Reinforce your fin joints. Increasing the surface area of your fin joint will keep fins attached through those high-performance flights, especially if your fins are attached directly to the airframe (surface mounted). The simplest reinforcement is a glue fillet, which forms a smooth joint between airframe and fin surfaces. Proper fillet technique is discussed in most basic rocket kits. For more strength, use reinforcement materials. Tissue paper and yellow glue work great for model rockets. Cut a rectangle of tissue paper as long as the fin joint to be reinforced, and about two inches in width. Cover the tissue with a thin coat of yellow glue and gently push it into the joint-a Popsicle stick helps. You can increase the strength further with a second layer of tissue. After you've done several, you will be able to create a smooth reinforcement that keeps



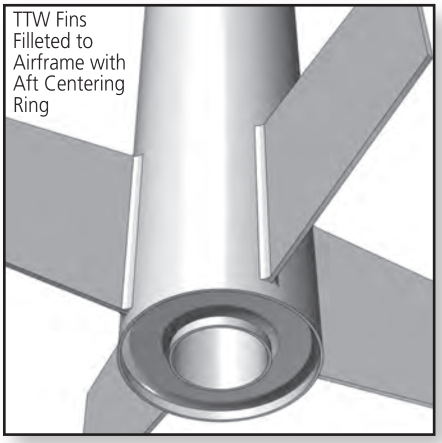
Motor Mount Tube with Front and Middle Centering Rings



Cutaway Airframe with Motor Mount Assembly



Cutaway Airframe with TTW Fins Glued to Motor Mount Tube



TTW Fins Filleted to Airframe with Aft Centering Ring

those fins attached. This technique also works for high-power rockets-substitute fiberglass cloth and epoxy as reinforcement materials.

Use through-the-wall (TTW) fins. Through-the-wall fins have tabs that go through the airframe and bond directly to the motor tube. This requires fin slots to be cut through the airframe. TTW fins achieve greater strength by providing multiple locations (that's surface area) to bond the fins to the airframe and motor tube: fillets can be placed on the inside and outside of the airframe and on the motor tube, especially if the aft centering ring is removed to permit access to the interior of the rocket. To get this access, slide in the motor mount and centering rings, but glue only the forward centering ring to the motor tube—do not put any glue on the aft centering ring. Once the forward ring has dried, carefully remove the aft ring, using a hobby knife. Once the aft ring is removed, you will have access to the TTW fins, and can now put glue fillets or reinforcements on every fin/airframe joint. This makes an incredibly strong fin joint. Once all glue is set, the aft centering ring can be glued into place. Another way to create a TTW setup is to glue centering rings, fins, and recovery attachment to the motor tube, then slide the whole unit into the airframe. This is a great way to build a strong structure, but requires the rocket's fin slots to extend to the rear of the airframe.

Your choice of technique may be limited by your rocket choice: for example, a kit with surface-mounted fins will eliminate the TTW technique, but you could reinforce the fin and the fin joint. In addition, these techniques can be combined: paper-reinforced balsa fins can be designed for through-the-wall mounting, with tissue paper reinforcements at the joint.

Airframe and Coupler

It is pretty rare to have a rocket fail in flight due to collapse of the airframe if the airframe is commercially available tubing intended for the size motor used. Your chance of failure becomes greater with long, slender rockets such as SuperRoc competition models. To strengthen airframes, two general techniques are reinforcement with composite materials like fiberglass (or carbon fiber) and epoxy, or using a smaller tube inside the airframe-a "tube in a tube" design. The tube in a tube is a simple technique to add considerable strength to the airframe. A set of centering rings keeps the inner tube correctly located inside the airframe. This technique can be even more effective when two-part foam is poured between the two tubes and permitted to harden. Another variation is a ring of wooden strips glued around the inside (or outside) of a tube. You have to be careful about wood choice here: stay with lightweight woods like balsa, basswood, or spruce. Consider a combination: a tube within a tube, centered with a series of balsa wood strips. This can turn a model rocket airframe into a mid-power (or even high power) airframe. If you have enough couplers, gluing them inside the airframe is a simple way to double the airframe's thickness.

One more trick: the ends of a body tube can be hardened by adding a few drops of thin cyanoacrylate (CA) and giving it several minutes to cure. Once cured, the hardened ends can be sanded to a smooth finish-a great way to permit nose cones and transitions to slide easily on/off the tubing. Do this in a well-ventilated area because of the strong CA fumes.

When a long rocket has an airframe failure, it almost always occurs at a coupler joint. As a rule, couplers are made to be the same thickness as the airframe tubing. If your coupler appears to be thin, you might want to strengthen it. Think of a coupler as an airframe, and use the same techniques to stiffen the inner wall of the coupler.

Nose Cone

Really, there is not much you should do to increase the performance of your nose cone. One area that you can improve is the attachment point of the nose cone to the recovery system. Some nose cones provide no attachment point, and some provide a point that is probably too weak. In general, you want an attachment point that is able to handle loads that are fifty times the weight of the nose cone. For example, a 6-ounce nose cone needs an attachment point that can handle loads of 6 ounces x 50 = 300 ounces.

There are several ways to get this type of attachment point. Some nose cones have a spot in their base to permit a quarter-inch eye to be screwed into the base. If an eye is used, always try to use one that does not have any break where the circle closes. Solid eyes, whether welded, cast, or forged, can handle 2–3 times the working load of an open eye, and will not open up under high loads. If your nose cone has no attachment point, then create one: invert the nose cone and pour a small amount of epoxy into the nose tip. Use a stick to push a piece of tubular nylon or Kevlar string into the epoxy, and permit it to cure. Another simple attachment point can be made by placing a piece of Kevlar or tubular nylon under a small square of fiberglass, saturated with epoxy glue. Press the square inside the nose cone, and permit it to cure. The larger the fiberglass square, the less likely that it will be pulled from the nose cone.

If your nose cone is made of balsa wood, you can seal the nose cone and give it a hard shell by dripping thin cyanoacrylate (CA) over the nose cone. This will harden the wood's fibers, making it easy to sand. Next, fill in deep groves with Elmer's Fill-N-Finish Lite, sand again, and you're ready for final finishing.

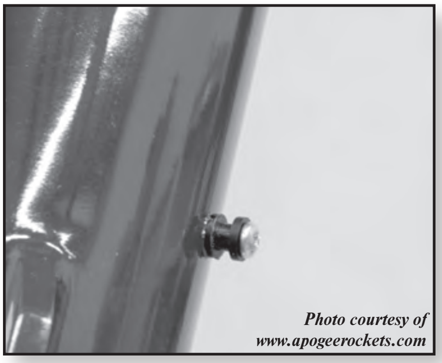


Photo courtesy of www.apogeerockets.com

Launch Lugs/ Rail Buttons

Among fliers of mid and high-power rockets, there is a move away from launch lugs toward rail buttons/guides. Rails are more rigid than rods, making them a better choice for those long and heavy rockets. Whether you use launch lugs or rail buttons, the biggest concern is always getting a good attachment to the airframe. For launch lugs, it is easier to use paper launch lugs on paper airframes, and brass or aluminum lugs on phenolic, fiberglass, or Quantum tubing. Paper lugs on paper airframes bond firmly if both surfaces are sanded before applying yellow glue. A little more work is required for brass or aluminum launch lugs, as they have a much smoother surface. To prepare metallic lugs, first sand the lug and the airframe with extra-fine sandpaper to increase the bonding surface, then clean both surfaces thoroughly (alcohol is recommended as a cleaning solvent). The surfaces can then be bonded with epoxy or, for more strength, cover the lug with a piece of epoxy-soaked fiberglass, extending over onto the body tube an inch on each side. This increases the bonded surface area, decreasing the chance that the lug will pull off during flight.

Rail buttons and rail guides vary. Some rail guides are designed for a surface mount, using an adhesive strip. These are simple to attach, but great care has to be given to assure a good fit to the airframe and a clean surface for the adhesive. Before applying the adhesive, lay a piece of sandpaper, rough side up, on the airframe. Slide the rail guide back and forth on the sandpaper, keeping it firmly against the airframe. This sanding will gradually make the base of the guide conform to the curvature of the airframe. Once the sanding is complete, sand the area on the airframe, clean both surfaces, place the adhesive strip on the rail guide, and place the guide on the airframe. It is important that these surface-mounted rails be kept under pressure for several hours. Pressure can be applied with clamps (spring, rope, woodworking clamps, etc.). Traditional rail buttons are not surface mounted-they must be attached through the airframe, and ideally, also through a small piece of wooden reinforcement inside the airframe. An extra piece of wood adds significant strength to the button. It's a good thing. Retrofitting rail buttons to an existing rocket is more problematic, since you cannot get inside the rocket to get a good attachment point for each button. In this case, think about hanging a picture at home: use drywall anchors. Find a screw that fits the rail button, and buy the matching plastic expansion piece. Drill the hole, insert the plastic expansion piece, then screw the button down on the airframe. This trick also works well for retrofitting motor-retention tabs.

Photo courtesy of www.aeropack.net

Motor Retention

Nothing ruins your day like losing your hundred-dollar reload case and driving your beautiful rocket into the earth because the recovery system did not deploy because the motor casing was ejected. It's almost enough to make you want to go back to the office-almost. This need not happen to you. A little time and effort spent on motor retention will pay rewards in recovering your rocket to fly again. Most model-rocket kits provide motor retention in the form of a clip, but as you move into larger rockets, you are left to provide your own retention system. In general, retention systems are designed to work with motor casings that have a thrust ring built into the aft end of the motor. A retention system works best when it is built into the rocket during construction. If you are new to retention systems, start with a purchased one. They are available from a number of vendors, such as Aeropack, Public Missiles, Giant Leap Rocketry, Rocketman, Bourne Again Rocketry, to name a few. Once you've seen a few homebrew setups and asked some questions, you will be ready to make your own system. For a time-tested design, look at "Kaplow clip" below. There are dozens of designs that all function well. Attend a club launch and just look around-you'll see for yourself. A personal favorite is a piece of quarter-inch all-thread, attached to the side of the motor tube with a wrap or two of glue-soaked paper and positioned so the threads protrude about half an inch beyond the aft end of the motor tube. On the field, slide in your motor, place a washer and quarter-inch nut on the all-thread, and snug it down: simple, cheap, and effective.

Recovery System

Nowhere does focusing on surface area pay more dividends than in recovery-system construction. An adequate system has to handle about fifty times the rocket's weight as it slows the rocket to a safe descent rate. The ideal situation is to spread this load out over a large area. Attaching the recovery system in two or three places or bonding the recovery strap down the side of the motor tube or along the edge of two or three through-the-wall fins are some ways to spread that recovery load across the rocket. Many model rocket kits advise you to glue a shock cord in a paper tab, and then attach the tab to the airframe sidewall. This technique works well for small, light rockets but generally not on large, heavy ones. Another place to beef up your recovery system is the parachute. You can replace plastic 'chutes with nylon ones for extended durability; however, you can also strengthen that plastic 'chute for a few pennies. Remove the shroud lines that came with the 'chute, and make your own with upholstery thread from a fabric store. Better yet, cut the thread long enough to go across the center of the parachute canopy and down two opposite sides to form two shroud lines. Tape the thread down to the canopy with a good quality tape, such as 3M. This will produce a parachute that is much tougher and more resistant to shroud-line failure.

Elastic shock cords are a source of contention in rocket circles. Your rocket will be more reliable if you discard the elastic shock cord that comes with the kit and replace it with one that is the same diameter but 4-5 times the length of the rocket. Longer is good, as it provides more shock cord to absorb opening loads. Longer cords also lessen the chance that two separated rocket parts will snap together and hit each other. Elastic is available at fabric stores. In larger rockets, avoid elastic and use to tubular nylon or Kevlar.

For flight prep, abandon the wadding in favor of Nomex cloth available from vendors, or install an ejection baffle system. Although they cost money up front, they simplify your flight prep every time you use them.

Centering Rings

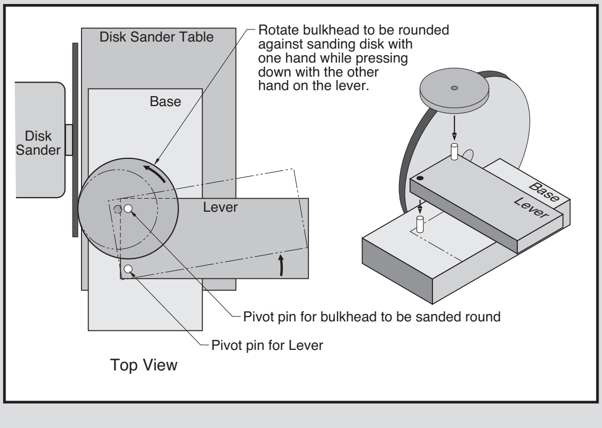
The lowly centering ring is a hidden part that performs an essential duty. At liftoff, your rocket motor pushes against the thrust ring, which pushes against the motor tube, which pushes against the centering rings, which finally pushes the airframe. Centering rings therefore transfer the motor's thrust to the airframe. In most large rockets, they are also the attachment point for the recovery system. They must be able to withstand more force than your motor can produce. Model rockets typically use cardboard or balsa wood for centering rings, while mid and high-power rockets use plywood, G-10 phenolic, or composite materials for strength. The problem with materials like plywood and phenolic is their weight-a pair of rings can add significant weight to the rocket. You have to challenge yourself to build strength, not weight. For example, a rocket with through-the-wall (TTW) fins needs centering rings mainly just to center the airframe and contain the ejection charge-the fins carry most of the flight stresses, since they are attached to both the motor tube and the airframe. In this situation, the rings could be made of foam core (foam with a layer of poster board on each side), available at hobby and graphics stores. This can cut several ounces of weight from your kit. Lacking TTW fins, another approach to reduce weight is to choose one ring and build it to handle both motor thrust and recovery loads. This permits the other ring to be made of lightweight materials. The forward centering ring is often the best one to build up, as it moves the center of gravity forward, making the rocket more stable in flight.

Homemade Sanding Jig

Perfectly round bulkheads and centering rings for rockets can be made with the simple, homemade fixture. The fixture is clamped to the work table of a small inexpensive disk sander. Dimensions are not shown here, as they will vary with the size of the disk sander used. The drawing provides enough detail to build this fixture.

Make a 3/4-inch thick plywood lever with two 1/4-inch dia. holes located generally as shown. Make a 3/4-inch thick plywood base with one 1/4-inch dia. hole and glue a 1/4-inch dia. dowel rod with 3/4-inch extending up. Glue another 1/4-inch dia. dowel rod in the lever, also extending up. Mount the lever on the dowel rod protruding from the base.

To make a disk, use a compass to draw the disk diameter on a piece of thin plywood, such as 3/16-inch. Saw out the disk, being careful to saw outside the line drawn by with the compass. Slip the roughly sawn disk onto the dowel rod protruding from the lever. With the base securely clamped to your disk sander work table, slowly rotate the lever until the sawn disk engages the sanding disk. Hold the lever down tightly with one hand to keep it from moving in relation to the disk sander. And at the same time, slowly rotate the sawn disk against the spinning sandpaper disk until you have made a full revolution. Now, move the lever a little to remove more of the circumference of the disk, and continue the process. It works best to remove a little at a time and to stop after two or three passes to check the diameter of the disk with the tube into which it will be ultimately inserted.



Another approach to stiff centering rings is to build them up from lightweight materials, much like an I-beam in skyscraper construction. For example, two flat rings become very stiff when separated with spacers. Centering rings like this are easy to build from materials like foam core, balsa, or thin plywood. They also have the advantage of greater surface area when glued into the airframe. You can even fill the void in the structure with a two-part expanding foam to add stiffness.

Given these options, there simply is no reason to slap heavy centering rings in a rocket. Remember, the lighter your rocket, the higher it flies on a given motor and the less robust your recovery needs to be for safe recovery.

Conclusion

There is simply no substitute for looking at the ways that other people build their rockets. Building stock kits is enjoyable, but after you complete a few of them, it is time to start modifying them for less weight, more airspeed, and greater durability. The tips and tricks above will keep you busy for a while, and by the time you've tried them, you will have seen enough variations that you'll never run out of tricks to try on your next project.

Rocket Stability

By Rick Weber

This article covers the basic concepts of model rocket stability. For those readers wishing to learn more about this subject, there are several excellent books listed at the end.

A stable model rocket will fly straight and true. An unstable rocket will fly erratically–posing unwanted danger to spectators and probably ending up a pile of wreckage. You might think that building a stable rocket is easy. With a pointed nose in front and fins at the rear, it should fly like an arrow, right? Not always. As a rocket designer, it is your job to ensure that the rocket you build will remain stable in flight, flying wobble-free in a vertical or near-vertical path.

To understand how to make your rocket stable, you first need to know the ways that a rocket can move about in flight. Figure 1 shows that a rocket can roll around its center axis and pitch about its center of gravity. Aside from its forward motion, rolling and pitching are the rocket's two basic degrees of freedom. A rocket can be designed to purposely make it roll, which can actually add to its stability. However, for most model rockets, and especially for beginners, it is best not to design them to roll. So, that leaves one motion–pitch–for us to deal with. To make your rocket fly stable, your job boils down to controlling its pitching motion.

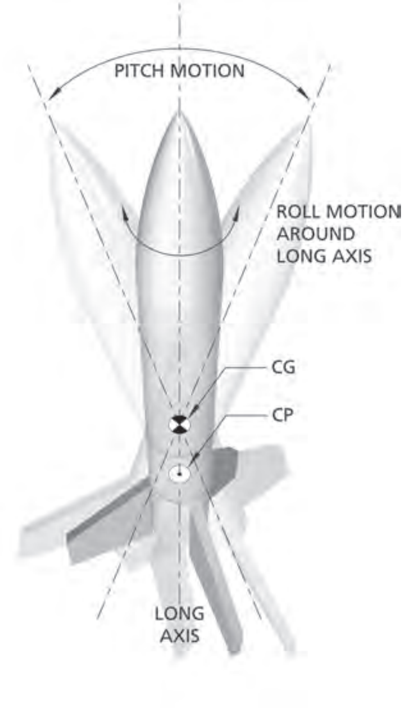
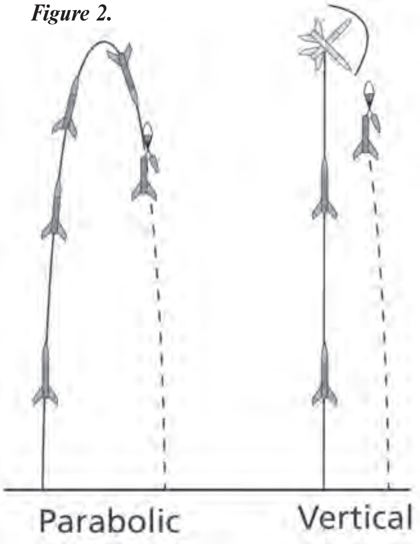


Figure 1.

It is perfectly natural for a rocket to pitch during a normal flight. Most rocket flights follow one of the two flight paths shown in Figure 2. They can follow a parabolic path, in which the rocket gradually pitches during its time aloft, or they can go straight up, perfectly vertically. At the very top of a vertical flight, a rocket will abruptly pitch over 180 degrees as it begins its return to earth.

Figure 2.



What we don't want is uncontrolled pitch, which can cause the rocket to wobble, and in the worse case, deviate off course so as to be dangerous to spectators or to fly so far away as to be irretrievable.

Here are those conditions that can cause uncontrolled pitch in a model rocket:

1. Basic instability in the design.
2. Imperfections in construction.
3. Flying in excessive wind.

Let's take these points one at a time:

1. Basic Instability in the design–For you to understand why a rocket is stable or unstable, it is necessary to understand two terms: the center of gravity and the center of pressure.

Every object, including your model rocket, has a center of gravity (CG). The CG is a single point where all the mass of the object can be considered to be concentrated.

It is relatively easy to find the CG of a model rocket. You merely balance the fully loaded, ready-to-fly rocket on an edge, such as a ruler's, as shown in Figure 3a. When it balances evenly, imagine that the knife slices through the rocket at this location. (Just imagine this; don't guillotine your model!) The CG lies at the center of the circle that would be formed by the stroke of our imaginary knife.

Besides having a CG, every object that flies through the air also has a center of pressure (CP). The CP is the point on a rocket where all the aerodynamic forces acting on it balance out. To understand what that means, let's break it down. Aero means air. Dynamic means moving. In simple terms, aerodynamics explains how an object, such as a model rocket, moves through air. When you stick your hand out of a car window, you can feel the aerodynamic forces at work.

Unlike the easy way we have to find the CG of a rocket, finding the CP is more involved. There are two methods generally used to locate the CP. One is the cardboard-cutout method, and the other is the calculation method. The cardboard-cutout method has been used by model rocket builders for many years and is relatively simple. Although the calculation method provides a more accurate CP location, it does involve some rather lengthy, tedious math. Fortunately, in recent years, solving this math has been greatly simplified by computer programs designed specifically to do this task. Two popular programs are RockSim and SpaceCAD. Because this article will be read by people new to rocketry and because of limitations of space, we will present only the cutout method here. Those readers who wish to delve into the math and computer programs will find links to sources of this information at the end of this article.

To create a cardboard cutout of your model rocket, you simply draw the rocket's profile on a piece of stiff cardboard of uniform thickness, as shown in Figure 3b. Place the cardboard cutout on the edge of a ruler, and mark the point along the center axis where the cutout perfectly balances; this point is the CP of the cutout. The corresponding point on your model is the approximate CP of the model. Mark this location with the CP symbol.

Now that you have located the CG and the CP, here is the most important rule for creating a stable rocket: The CG must be located forward of the CP, as shown in Figure 3c. Ideally, the CG must not be any closer to the CP than 1.5 times the diameter of the body tube.

So what do you do if you find that the CG of your rocket is too close to or even to the rear of the CP? You can either move the CG forward or move the CP aft.

To move the CG forward you can:
a. Increase weight forward of original CG.

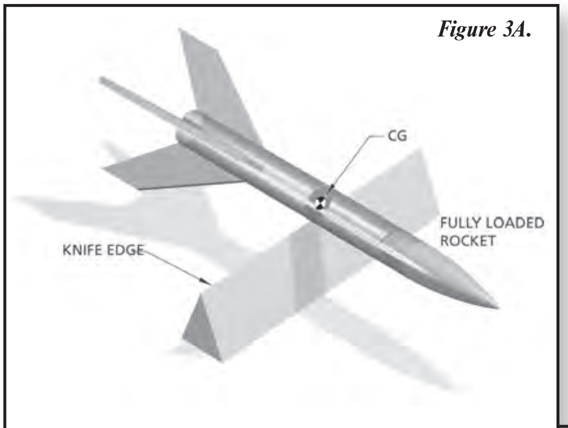


Figure 3A.

b. Decrease weight rearward of original CG.

To move the CP rearward, you can:
a. Increase the area of each fin.
b. Increase the number of fins.
c. Move the fins rearward.

2. Imperfections in Construction– How many ways can a model rocket builder goof up the rocket's construction? More ways than we have space for here. But let's look at some of the more common ones.

a. Adhesives that are not intended for assembling model rocket components or adhesives that are applied incorrectly account for a lot of rockets coming apart in flight. When a fin comes off, your rocket will probably fly erratically until it crashes. Epoxy, cyanoacrylate (CA, also known as Super Glue), and white or yellow glue are strong when applied according to the directions on the containers. Make sure the materials you are joining are compatible with the adhesive you are using. For example, white glue works well attaching wood fins to a cardboard body tube, but not well in attaching plastic fins to a cardboard body tube. When mixing epoxy, be careful to mix the two parts in their correct proportions. Insufficient amounts of even the best adhesives will leave a weak bond. Be sure to "test" your finished rocket by wiggling the parts that have been joined by adhesives. Better to break it here than to watch it catastrophically disassemble in flight.

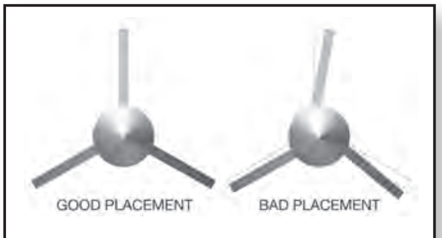


Figure 4.

b. It is especially important to make sure the fins are all the same size and are aligned parallel to the tube and are equally spaced around the body tube. See Figure 4. One crookedly mounted fin can cause a rocket to fly radically off course. Skilled model rocket builders often use a fixture to hold the fins in perfect alignment while they are being glued to the body tube.

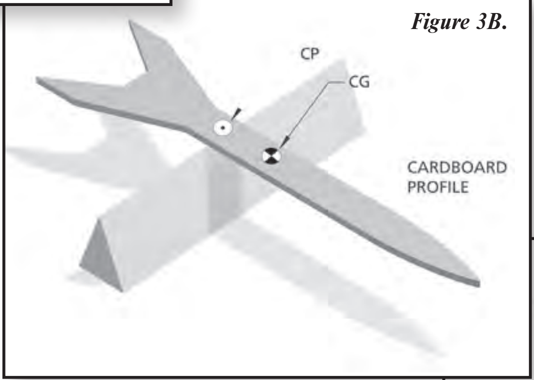


Figure 3B.

c. It is also important to be sure the motor mounts are attached so that they are aligned parallel to the body tube, so that the motor will not thrust off center. Off-center thrust can cause a rocket to pitch away from a proper flight path (Figure 2) and crash.

d. The rocket's guides for a launch rod or rail must be attached firmly to the body tube and parallel to it. If a guide were to break off before the rocket gained enough speed to keep it stable, the rocket could pitch away from its intended flight path.

3. Flying in Excessive Wind–Flying your model rocket in winds above 15 miles per hour can cause it to fly far off course. Weathercocking can cause your rocket to turn and head into the direction of the wind. Figure 5 shows how wind can push on a rocket, much as it does on a weathervane, so as to turn the nose into the wind, just as it turns the arrow of the weathervane. If the launch rod is not set at the correct angle for the prevailing wind and for your rocket, weathercocking can cause the rocket to pitch over and fly a long way–into the wind. Fortunately, the same wind can grab your rocket's deployed parachute and return it downwind to you. The trick is to set the launch angle correctly. This can be done by trial and error until you figure out the best angle for your particular rocket for various wind speeds. Under no circumstances should you launch a model rocket in a wind that exceeds 20 mph or at a launch angle greater than 30 degrees from vertical. These are two cardinal NAR safety rules.

That is model rocket stability in a nutshell. For those of you wishing to learn more about this subject, check into these sources:

"Model Rocket Design and Construction",
Timothy S. Van Milligan,
http://www.apogeerockets.com

"Handbook of Model Rocketry",
G. Harry Stine, John Wiley & Sons, Inc.
605 Third Ave., NY, NY 10158-0012

"Advanced Model Rocketry",
Michael Banks and Tim Van Milligan,
http://www.kalmbach.com

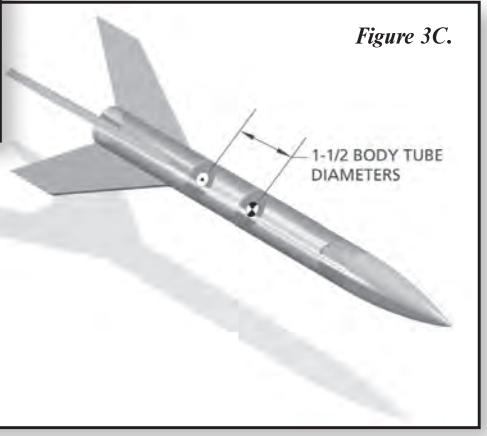


Figure 3C.

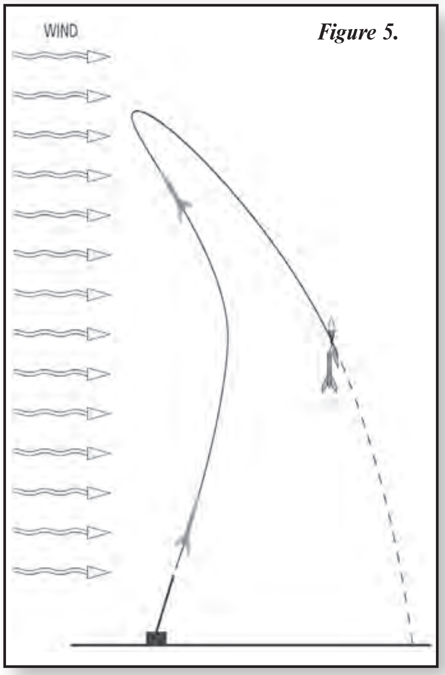


Figure 5.

What's in a Rocket Motor

By Greg May

Introduction

Building your rocket is just the first step toward a successful flight; you need a motor to make it fly. Motors come in a wide variety of sizes and power. Understanding the differences in the various motors is key to deciding which motor to use.

Your motor needs to have the right amount of power. Too much power, and your rocket could literally come apart; not enough, and the rocket could just sit on the pad. Your motor also needs to have the correct delay for deploying the recovery system. Too short a delay, and the recovery system can be torn from the rocket; too long, and the rocket may impact the ground before the recovery system is deployed. This article will help you learn how to choose the correct motor for your rocket.

How Does it Work?

A model rocket motor is a miniature version of solid-propellant motors used by professionals. They are commercially made and tested for reliability. Figure 1 shows a cross-section of a typical model rocket motor:

The paper casing to holds everything inside and protects your rocket from the hot gases produced when the motor burns.

The clay nozzle concentrates and directs the flow of the gases to produce usable thrust.

The propellant, a mixture of fuel and an oxidizer, is pressed or molded into a solid grain that burns to produce a large amount of gas.

The delay burns slowly after the propellant is used. It produces smoke to aid in tracking your rocket and allows the rocket to slow before the ejection charge is fired.

An ejection charge is provided to activate the recovery system. In a typical model rocket the ejection charge blows the nose cone off the top of the body tube and deploys the recovery system. Flameproof recovery wadding is used to protect the recovery system from the ejection gases.

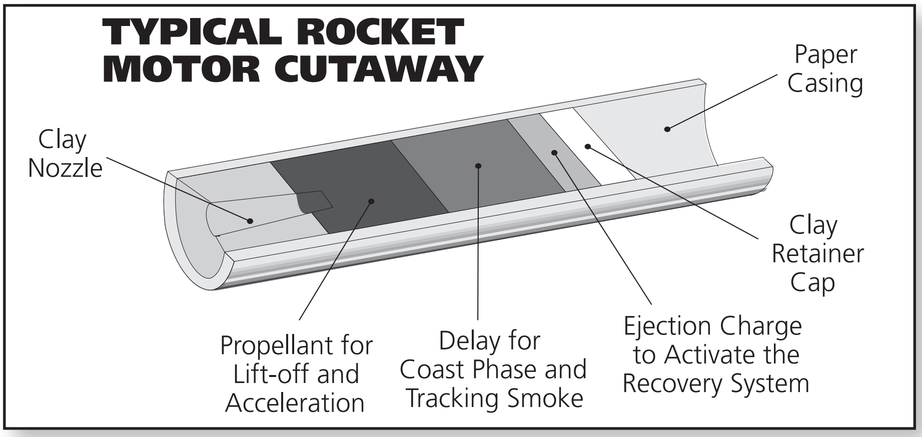
Standard Motor Sizes

Rocket Motor Sizes

Size (mm)	**Type**
13 mm	Mini Motor
18 mm	Standard Motor
24 mm	D Motor
Mid- and High-Power	
29 mm	Mid-Power to Level 1
38 mm	Mid-Power to Level 2
54 mm	Level 1 to Level 2
75 mm	Level 2
98 mm	Level 3

Size is also important. Your model rocket has been designed to hold a certain size motor. Both diameter and length are important here. The table above shows the more common motor diameters.

The length depends on the amount of thrust in the motor. For the smaller motors (13 mm, 18 mm, and 24 mm), the length is usually fixed (1.75", 2.75", and 2.75" or 3.75" respectively).



TYPICAL ROCKET MOTOR CUTAWAY

Types of Motors

Let's start off with what various motors are made of. Today's motors fall into three basic types: black powder, ammonium perchlorate, and hybrid. The smaller motors are usually black powder (BP), while the larger motors are usually ammonium perchlorate and hybrids.

Since BP motors are the most widely used by model rocketeers, we will start here. The first thing to understand is the engine-identification system, printed on the motor casings. The markings consist of a letter and a number followed by another number or letter.

What Do the Motor Codes Mean?

For an example, let's start with a common BP motor, a B6-4. This breaks down into three parts, the B, the 6, and the 4. Let's see what they mean.

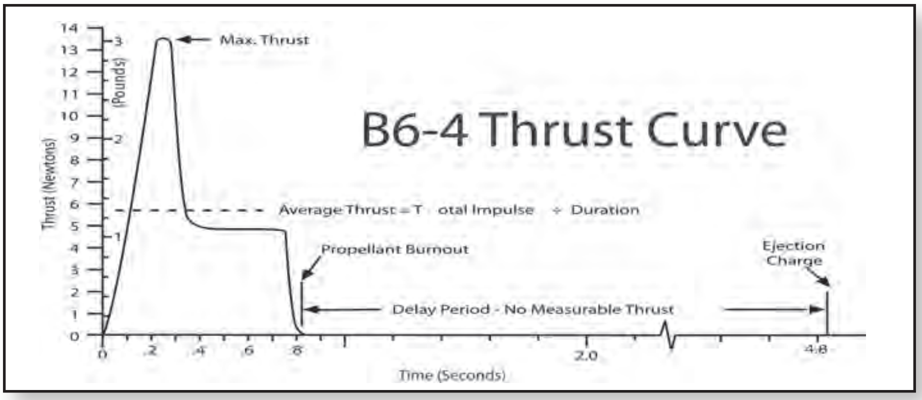
B The letter indicates the total impulse, or total power, produced by the engine. Each letter indicates twice the power of the previous letter. Letters for motors range from A to O. Note that the letter indicates a range for the total impulse of the motor, not an exact value. For instance; a B motor has a total impulse between 2.501 newton-seconds and 5.000 newton-seconds. The ranges are listed below:

Model and High-Power Motors

Code	**Impulse Range**
1/2A	0.625–1.250
A	1.251–2.500
B	2.501–5.000
C	5.001–10.000
D	10.001–20.000
E	20.001–40.000
F	40.001–80.000
G	80.001–160.000
H	160.001–320.000
I	320.001–640.000
J	640.001–1280.000
K	1280.001–2560.000
L	2560.001–5120.000
M	5120.001–10240.000
N	10240.001–20480.000
O	20480.001–40960.000

As you can see, when the power doubles with each letter, it doesn't take long to reach powerful motors; a G motor averages 64 times the power of an A motor. Motors ranging from H to O require special certification from either NAR or Tripoli to purchase and fly.

6 The first number shows the engine's average thrust in newtons, or the average push exerted by the engine. (4.45 newtons = 1 lb.)



Average thrust = total thrust in newton-seconds divided by thrust duration in seconds

The thrust curve for the B6-4 motor is above.

As you can see, the average thrust is roughly 6 newtons over the burn duration, while the maximum thrust is about 12 newtons for a very short time. This sort of pattern is typical of rocket motors. To find out about the thrust curve for a particular motor, contact the manufacturer or search for the motor at http://www.thrustcurve.org. All rocket-motor manufacturers publish thrust curves for their motors. The total thrust will fall inside the range of the letter classification of the motor. From the graph above, the average impulse is 6 newtons, and burnout occurs at about 0.8 seconds. The total impulse is about 4.8 newton-seconds, which falls inside the range of 2.51 to 5.00 newton-seconds. This same calculation can be derived from most manufacturers' thrust curves.

4 The second number tells you the time in seconds between the end of the thrust and the firing of the ejection charge.

This number is placed on the motor for the rocket flyer to use to determine the delay desired for deployment of the recovery system (streamer, parachute, etc.). This usually depends on the weight of the rocket. A lighter rocket may need a longer delay than a heavier one, because the lighter rocket will coast higher before slowing to a safe ejection speed, while a heavier rocket will slow more quickly and so will need a shorter delay. Some motors, known as boosters, have a 0 for the delay time, indicating that they have no delay. These motors are used for the lower stages of multistage rockets; as soon as the lower-stage motor burns out, it immediately ignites the next stage. Be careful not to use a booster motor in a single-stage rocket, since the recovery system will deploy immediately upon burnout.

The motor code provides this information – total thrust range, average thrust, and delay – so rocket flyers can determine how best to fly their rockets in the safest possible manner.

Now, more about the various types of propellant. As mentioned, black powder is the most common and is typically used from 1/4A up to D motors. There are some BP motors that have a higher impulse, but these are not common. For motors higher than D, the usual propellant is ammonium perchlorate. This is the same propellant that is used in the solid-rocket boosters on NASA's space shuttle.

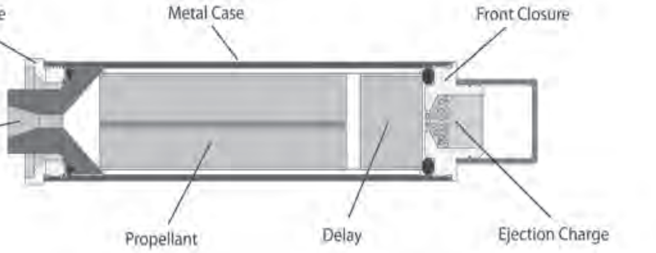
Most BP motors are single-use motors. This means that you purchase and use the motor as a complete unit and then throw away the used casing. Most medium and high-power motors are reloadable. These motors employ a reusable casing (typically aluminum alloy) and a separate propellant. Reloadable motors are more complicated to use than single-use, since the motor must be assembled before each use. The advantage is that the propellant is less expensive than the single-use motor. If you fly your rocket many times, the reloadable motor can save you money.

Model rockets usually use BP motors; this includes rockets from Estes, Quest, and others. Medium-size rockets use the larger BP motors, usually D motors, or the ammonium perchlorate composite propellant (APCP) motors. Large rockets, i.e. high-power rockets, mostly use APCP motors.

Reloadable Motors

Reloadable motors are a way to reduce motor expenses. The initial costs are high because you need to purchase a motor casing and end closures. This casing and closures are reusable and should last for a very long time when properly maintained. Once the casing is obtained, the cost per reload is less than for the comparable single-use motor. The reloadable motor takes some skill to assemble, so it's important to follow the manufacturer's instructions carefully. Below is an example of a 29mm reloadable motor.

Reloadable motors come in a wide variety of diameters and lengths: the more or less standard diameters are 18mm, 24mm, 29mm, 38mm, 54mm, 75mm, and 98mm. The lengths vary from as short as 3 inches to as long as 49 inches. Each casing has a limited number of propellant variants. For instance, an Aerotech 29mm/240 casing can be loaded with H97, H180, H210, and H220 reloads. For this reason, you may want to purchase various case sizes so that you can fly a large variety of reloads. The end hardware remains the same for a given diameter. Be aware that some case lengths may need larger nozzles and/or seal discs.



RELOADABLE ROCKET MOTOR CUTAWAY

Hybrid Motors

The third type of motor is known as a hybrid motor. The hybrid motor does not use either black powder or APCP. As fuel, the hybrid uses ordinary flammable solid materials, such as plastic or even cardboard, which burn when ignited in the presence of a compressed-gas oxidizer, usually nitrous oxide. The fuel and oxidizer remain separate until the oxidizer is introduced into the combustion chamber. These motors are exempt from federal regulation because their components are not highly combustible until combined.

Hybrid motors for the rocket hobbyist are not new and are gaining popularity because of the lower costs per flight and their easily accessible components. However, there is a high initial investment in the ground equipment used to prepare the motor. Also, hybrid motors are more complicated to assemble, first, because there are more parts than with a solid-propellant motor and, second, because compressed gases require special handling. More information about hybrids can be found at http://www.pratthobbies.com/info_pages/hybrids.htm.".

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