1

Let's Fly Some Rockets!

There are three basic kinds of rockets in hobby rocketry, and we're going to start right off by building small examples of each. Part of the reason is for you to learn some basic concepts before moving on to bigger rockets. Part is just to have some fun with matches, balloons, and projectiles.

The first kind of hobby rocket is the one you may have seen in hobby stores or the local park. Solid propellant rockets burn some sort of chemical, usually black powder in model rocketry. We'll take a look at solid propellant rockets using a match head as rocket fuel.

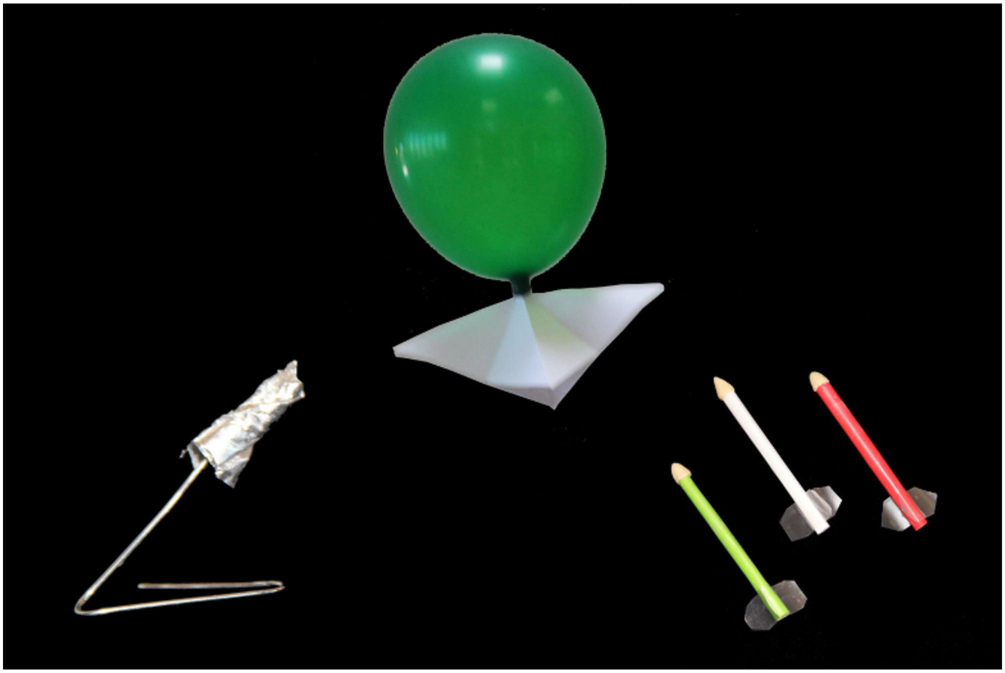

Figure 1-1. *Match head, balloon, and straw rockets are simple examples of the three kinds of hobby rocketry.*

Next most common is the water rocket. Water rockets usually use soda bottles under pressure to force the water out at high speed. We'll use a balloon to get started, forcing air out under pressure instead of water. It's the same idea, though.

Another fun form of rocketry is air rockets. Air rockets use a blast of pressurized air to propel a rocket from the launch pad. Our first air rocket is made from paper, and uses a straw for the launcher.

Shopping List

Table 1-1 lists all of the parts you will need to build the rockets in this chapter. All can be found at your local grocery store or variety store. Some are almost certainly lying around the house, so collect those first.

Tools are pretty basic for this chapter. You will need a pair of scissors or some other way to cut paper, such as a hobby knife. A pair of needle-nose pliers is handy but not absolutely necessary.

Table 1-1. Parts list

Part	Description
Paper matches	We will use a variety of matches. In some cases, the kind doesn't really matter, but this one is important. Get the cheap paper matches that come in a book where the match tears out of the matchbook. Get at least two books of matches, preferably three or four.
Wooden matches	Here you have some choice. You can get by with paper matches, but you will be holding them for a while. Wooden matches work better. I like the long kitchen matches. You could also use a fireplace lighter, one of those long gadgets that create a small flame at the end of a metal rod. They are great if you have one, but the wooden matches are a lot cheaper.
Paper clips	You will need one or two small metal paper clips. Smaller ones are better for our purpose, for reasons we'll see in a moment. Plastic paper clips or paper clips coated in plastic will not work. Thin, stiff metal wire can be used if you have wire cutters and don't mind a little artful bending.
Paper-backed foil	Here's one item you can't find sitting on the store shelf—or can you? It turns out you can, but this one needs some careful repurposing. A good choice is the foil from chewing gum, but be careful: most companies are moving away from foil-wrapped gum. One I found that works well is Wrigley's Extra. I tried lots of foils, and you can, too. One of my favorite failures was the foil used to wrap Hershey's Kisses. The foil was a complete flop, but disposing of the unneeded material wrapped in the foil was quite nice. Remember, experimentation and lab time can be fun. What a great excuse to buy a bag of candy!
Sandpaper	A small piece of fine grit sandpaper. Any old scrap will do.
Straws	Plastic drinking straws are best, but paper will do. Make sure they are fairly large.
Several sheets of paper	Notebook paper, printer paper, or any other thin paper will do. Origami paper is perfect. Construction paper will be too heavy and porous, though—stick with a paper designed for writing or printing that is thin enough to fold.
Transparent tape	You will just need a few inches, so grab a roll from last year's holiday wrapping paper box.
Modeling clay	You won't need much—about enough to form two balls the diameter of the drinking straw.
Balloons	A small variety pack with 25 or so balloons is ideal. If you get individual balloons, try to get both round and long balloons, and get several of each. Avoid the balloons intended for twisting into shapes. They are fun for other reasons, but are not thick enough for our purpose. You're looking for a nice, strong balloon.

Figure 1-2. *Parts and tools for match head rockets include paper matches, wooden matches, paper clips, foil from gum wrappers, sandpaper, a hobby knife, and needle-nose pliers.*

Figure 1-3. *Parts and tools for balloon rockets include balloons, paper, and scissors.*

Figure 1-4. *Parts and tools for straw rockets include straws, tape, perhaps a small amount of clay, paper, and scissors.*

The Match Head Rocket

You'll need these items for your first rocket:

- Paper matches
- Wooden matches or lighter
- Paper clip
- Paper-backed foil
- Sandpaper
- Scissors or hobby knife

Figure 1-5. *An arsenal of match head rockets, waiting for flight.*

Playing with Fire

You are literally playing with fire. As with almost everything else in hobby rocketry, that means you need to exercise a bit of common sense.

This rocket should be built and flown outdoors or in a large room devoid of flammable materials, such as an aircraft hanger or gymnasium. Take a look around. Is there anything within five feet or so that would burn if you held a match under it? If the answer is yes, move it out of the way or pick another location. It's also a good idea to have a hose or fire extinguisher handy.

Our first rocket is a solid propellant rocket capable of flight up to a few feet, but usually traveling only a foot or two. It's made with a single match head from a paper match and a small piece of paper-backed aluminum foil—a gum wrapper or candy wrapper. The launcher is a bent paper clip, and the igniter is another match or fire starter, preferably a wooden match with a long splinter of wood.

Start by bending the paper clip as shown in Figures 1-6 through 1-8. The long, straight part of the wire is the launch rod for the rocket, and the remaining part of the paper clip forms the stand. The angle between the launch rod and the ground should be about 45 degrees (°). Be sure the paper clip is very straight; take out small kinks by very carefully straightening the wire. Needle-nose pliers work well for this.

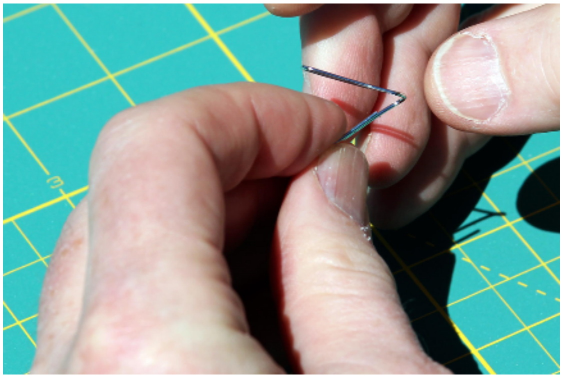

Figure 1-6. *Bend the paper clip up at about a 45-degree angle.*

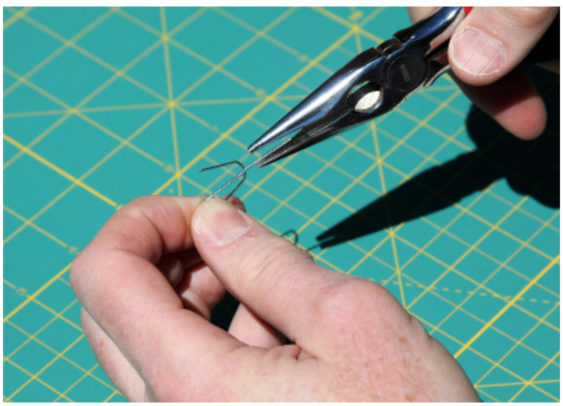

Figure 1-7. *Straighten the end of the wire that sticks up (the launch rail).*

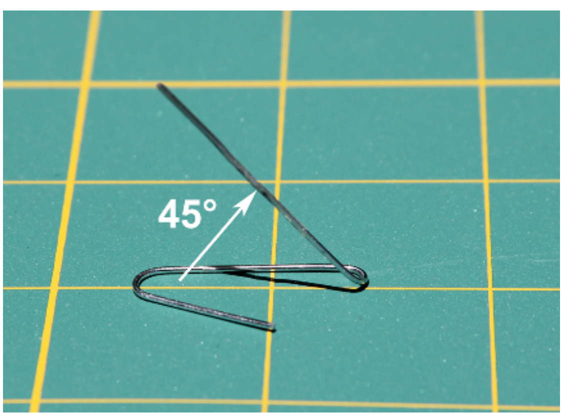

Figure 1-8. *The finished launcher.*

The rocket is made from foil and a match head. Cut one match head from a paper match, keeping as much of the match head and as little of the paper stem as possible. Place this on the paper side of the gum wrapper and fold the foil around the launch rail. Pull it off and use a pair of scissors or a hobby knife to cut all but about a half-inch of the material away. Slide the rocket back onto the launch rail.

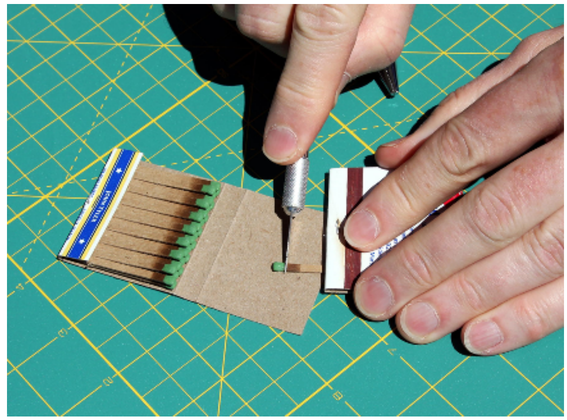

Figure 1-9. *Cut off the match head using a hobby knife or scissors.*

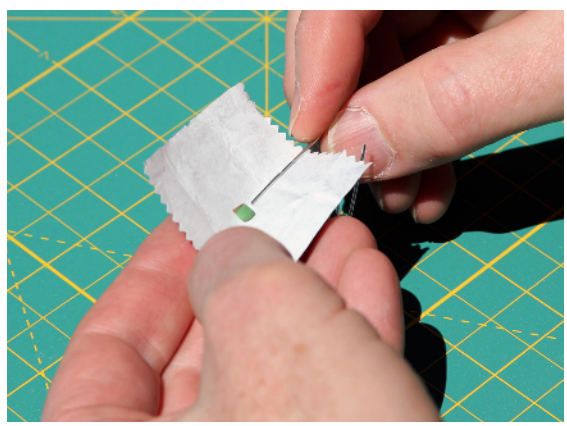

Figure 1-10. *Wrap the foil around the match head.*

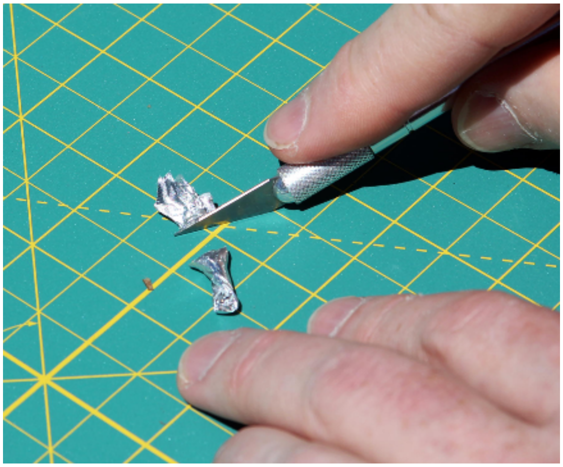

Figure 1-11. *Trim excess foil.*

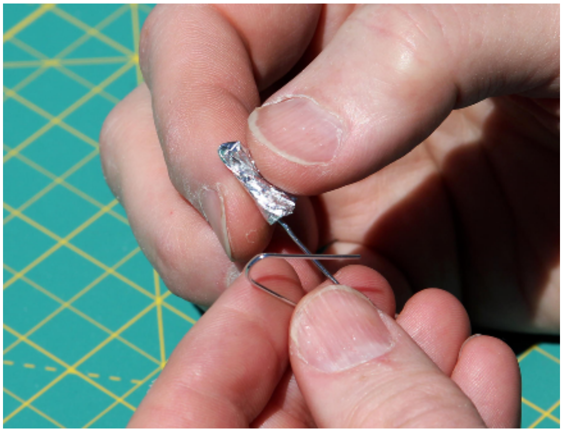

Figure 1-12. *Slip the rocket onto the launch rail, making sure the fit is fairly loose.*

The most critical—and difficult—part of building this rocket is getting the foil just tight enough, but not too tight. The rocket needs to slip off of the launch rail effortlessly. If there is any resistance, especially any snagging, the rocket will sit on the pad, trapped on the launch rail, instead of taking flight. Slip it up and down the launch rail to be sure it moves easily. Sand rough edges on the paper clip if necessary.

When you are satisfied with the fit, hold a long wooden match or lighter directly under the bulge in the rocket where the match head is wrapped in foil. In a moment, the match will ignite and…

Figure 1-13. *Light the rocket by holding the starter under the fuel. Not every try is a success! Here the fuel burned through the side of the rocket.*

What, you got a dud? It happens. (Even NASA has a few mistakes on its record.) If the rocket started to slide but stopped, you likely had a snag on the launcher. Clean the launch rail of any carbon using sandpaper, and check it for rough spots or bends where the rocket might get caught. If the rocket just sat there, it might not have been tight enough on the launch rod. The foil needs to be crimped fairly tightly around the paper clip so there is not a large opening. It can't be too tight, of course—make sure the rocket slides freely—but if it is too loose, the match doesn't provide any thrust. Set up another rocket and try again. Don't expect a high percentage of successes, though. On some days, I do well to get one successful flight out of ten.

Figure 1-14. *A successful launch! The rocket flew about 15,000 mils!*

Newton's Third Law of Motion

Rockets work based on a very simple but often misunderstood principle known as *Newton's Third Law of Motion*. You will see it written many different and equivalent ways. A common way to state it is:

> For every action, there is an equal and opposite reaction.

What does that mean?

Imagine for a moment that you are sitting in a boat on a calm lake. You put a shotgun to your shoulder and fire parallel to the water. Either from experience or from movies, you know the shotgun will push back on your shoulder when it fires. The force will also move the boat. It's a simple example of a rocket-propelled boat. By flinging the shotgun pellets and hot gas in one direction, you move your shoulder and the boat in the other.

Keep in mind that the shotgun boat didn't need air or the water to push against. In fact, it's better off *without* the friction of the air and water. The whole contraption will move even better in the vacuum of space, where there is no friction from air or water to slow it down.

Rockets take this idea to an extreme. They push something—usually, hot gases—very, very fast in one direction. The rocket itself moves in the other direction, but because it is so much heavier, it moves much more slowly than the gases. There is a lot of engineering involved in making all of this work efficiently.

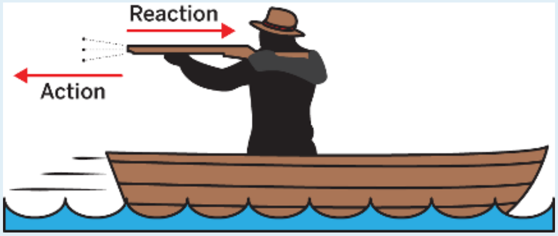

Figure 1-15. *Pellets and gas shot in one direction cause the boat to move in the other.*

One piece of engineering you saw with the match head rocket was nozzle design. The *nozzle* is the small opening that allows the gas, water, or other material to escape out of the back of the rocket. If it is too big, the rocket fuel simply burns, just like a match that isn't enclosed at all. If the opening is too small, the gas cannot escape fast enough, and too much pressure builds up inside the rocket motor, causing the motor to rupture. In extreme cases, we call this an explosion. If the nozzle is just right, the rocket propels itself as efficiently as possible with the available rocket fuel.

Newton's Third Law is a basic principle of physics taught in the first few weeks of pretty much any introductory physics course. Such courses are the perfect place to start if you would like to know more about the science behind rocket propulsion.

Did you try two match heads? In my tests, two match heads were simply too much fuel for a rocket whose combustion chamber was thin foil. The fuel burned through the foil every time.

Keep All Fingers Intact

You might be tempted to take this to the next level. Please don't. Match head rockets are safe and fun, but too many match heads in too strong of a container can create a dangerous explosive.

In particular, do not try to stuff match heads into a CO_2 cylinder like the kind used for pellet guns. It is disturbingly easy to accidentally ignite a match as it is squeezed through the small metal opening, and the result can be an explosion rather than a rocket motor. According to reports, several people lost fingers or eyes attempting to do just this before prepackaged model rocket motors became available.

Stick to one or, at most, two match heads. Use thin foil. Leave the design and construction of larger rocket motors to people with the proper training and facilities.

Balloon Rockets

Figure 1-16. *Up, up, and away!*

Here's what you will need for your second rocket:

- Balloons
- Writing or copying paper
- Scissors or hobby knife

At some point, anyone who plays with balloons blows one up and lets it go. It's a perfect example of a simple rocket. Air is pushed out one end of the balloon, and the balloon itself is pushed in the opposite direction. Go ahead—give it a try.

As you saw, the balloon moves, but there is very little direction to the flight; the balloon twists and twirls around at random. We'd say that the balloon rocket has very little *stability*.

Rocket Stability

Balance a pencil on your finger. The place where it balances is called the *center of gravity*. If the pencil's density is the same along the entire length, the center of gravity is the location on the pencil where there is an equal amount of weight on either side. Finding the center of gravity is a bit more complicated for objects that have some spots that are heavier than others, a topic we'll return to in Chapter 7.

The center of gravity is important because it's also the point the pencil will spin around if you toss it into the air. The same idea applies to the balloon: any spinning object always spins around its center of gravity, unless there is some force throwing it off balance.

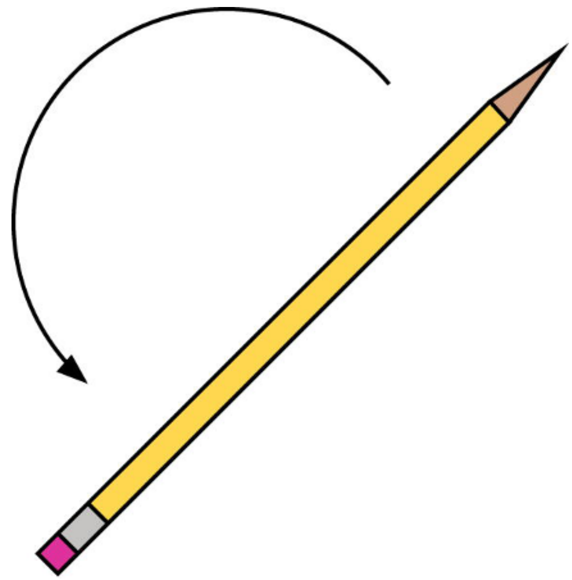

Figure 1-17. *Objects spin around their center of gravity unless there is an outside force.*

Now imagine a weather vane for a moment. You can make one from a pencil by attaching a piece of paper to one end and poking a pin through the center of gravity. When the wind blows from the side, there is more force on the side with the paper vane than the side that just has the pencil, so the pencil spins around until the pencil point is pointing into the wind. You could, of course, move the pin back to a point where the force from the wind was the same on either side of the pin, and the pencil would no longer spin in the wind. That point is called the *center of pressure*.

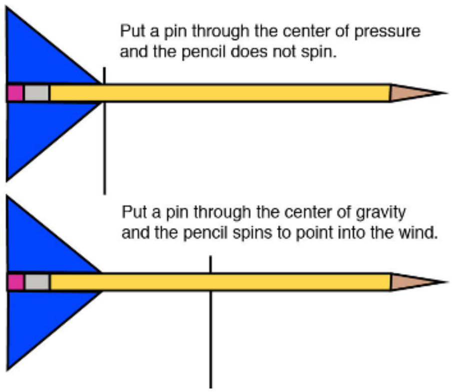

Figure 1-18. *Objects spin in the wind unless they are pinned at the center of pressure.*

Putting these two ideas together gives the classic design for a rocket. The center of gravity is about halfway down the body of the rocket, but the fins near the base of the rocket put the center of pressure well behind the center of gravity. If the rocket starts to spin for some reason—a gust of wind or a slightly off-center thrust from the rocket motor—the fins act to keep it flying straight.

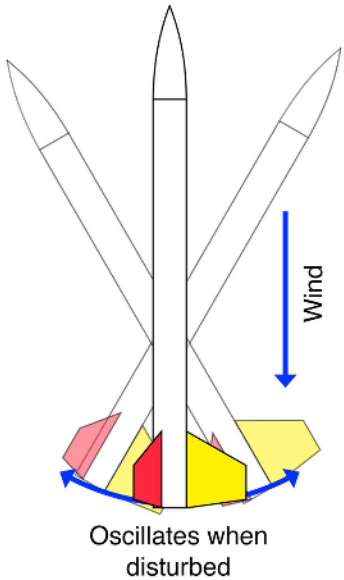

Figure 1-19. *Objects spin in the wind unless the point they turn around is at the center of pressure.*

The skeptics in the crowd may note that NASA's rockets don't all have fins, and they would be right. Some, like the Mercury-Redstone that carried the first American astronaut (Alan Shepherd) into space, did have fins for guidance, but others, like the Mercury-Atlas that carried John Glenn into orbit, did not. Still others, like the Vostok that carried the first human (the Soviet Union's Yuri Gagarin) into space, have tiny fins.

Figure 1-20. *Some rockets don't have fins. They use active guidance instead. From left to right, the Mercury-Redstone has fins, the Mercury-Atlas does not, and the Vostok (Mikhail Olykainen/Shutterstock) has very small fins.*

All of these rockets, though, used active guidance, where computers and gyroscopes monitor the flight of the rocket, redirecting the thrust of the rocket motor to keep the rocket flying straight. Our simpler rockets use fins instead of active guidance.

We'll see later that all of our rockets must have the center of pressure behind the center of gravity by at least the diameter of the body tube, and we'll look at ways to change our rocket designs to make this happen.

Building the Balloon Rocket

We'll need to add something to our balloon to stabilize it. Fins are a little impractical, but a sheet of paper will do nicely. Take a look at Figure 1-21, which shows our balloon rocket with a stabilization system attached.

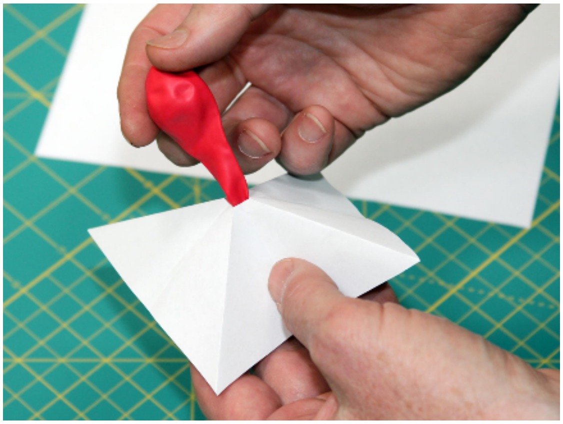

Figure 1-21. *Adding crude fins to a balloon rocket straightens its flight.*

Cut a square piece of paper about the diameter of a long balloon, or 2/3 the diameter of a round balloon. Fold it corner to corner, unfold it, then fold it corner to corner across the other corners. Fold the edges down to form a fin-like shape. Trim out a small opening in the center where the folds intersect. Make the hole just big enough for the neck of the balloon to fit without pinching off the air flow.

Fold the paper as much as possible to form a more fin-like shape. You probably won't be able to make it perfect because you need room to blow up the balloon.

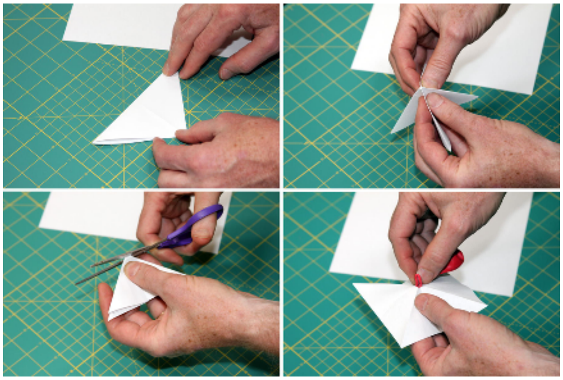

Figure 1-22. *Create a guidance system for the balloon using a piece of paper.*

Finally, blow up the balloon and launch your rocket!

Figure 1-23. *The balloon rocket takes flight.*

If all goes well, the rocket will power across the room flying a lot straighter than before, although definitely not perfectly straight. These are fairly crude fins, after all.

If the rocket is still very unstable, increase the size of the paper. If it is very slow or can't lift itself at all, reduce the size of the paper. The balloon can wear out, too. If the balloon doesn't shrink back to roughly its original size, or if it gets very easy to blow up, it won't have as much power—the balloon's thrust comes from the springiness of the rubber trying to get back into its smallest shape. Switch to a new balloon and try again.

The idea of using a pressurized fluid to power a rocket is something you will see again later in the book. A plastic soda bottle will replace the balloon, a bicycle pump or compressor will replace blowing up the balloon, and we will use water rather than air as a propellant, but the idea is exactly the same.

Exploration

1. Try long and round balloons. Which works better?
2. Try large and small balloons. Again, which works better?
3. How many times can the balloon be used before it loses too much thrust?
4. Can you come up with a design that has better fins?
5. Build a boat from a small piece of wood or Styrofoam and design a rocket propulsion system for it using a balloon for power.
6. Why not use water? Add a small amount of water to the balloon, and then launch it vertically so the water is at the bottom and gets pushed out by the air. Does it work? Why?

Air Rockets

Figure 1-24. *Colorful air rockets.*

You will need these items for an air rocket:

- A straw
- Paper
- Tape
- Clay (optional, but nice)
- Scissors or hobby knife

Air rockets still use Newton's Third Law, but unlike the match head rocket or the balloon rocket, an air rocket doesn't carry the propellant along with it. In this case, the rocket is a projectile, and it is expelled from the launcher with a blast of air.

Theory: Is an Air Rocket Really a Rocket?

A purist might object that an air rocket really isn't a rocket at all, since it doesn't carry along its own fuel or expel something for propulsion.

I tend to get caught in those ivory towers, too. Come down for a moment, and consider that this is a book about rocket science using hobby rocketry. Many of the principles of rocket flight, like stability, apply just as much to air rockets as to chemical or water rockets. Also, not all serious rocket science uses classical rocket propulsion. Consider the *mass driver* as just one example. This NASA concept is a rail gun, generally envisioned as a way to launch material from the Moon for pickup by an orbiting platform. It uses electricity rather than air, but like the air rocket, the energy is provided at launch, not during flight.

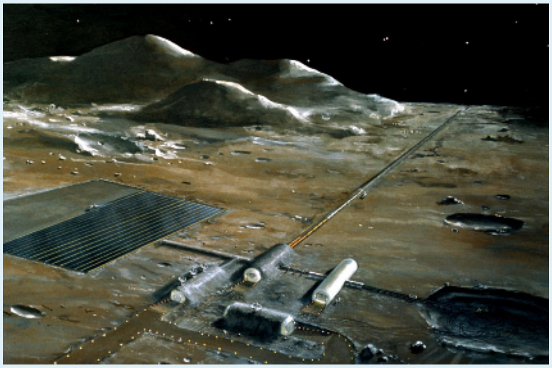

Figure 1-25. *NASA's concept for a mass driver to launch material from the surface of the Moon.*

Besides, air rockets are fun!

The straw is the launcher, and doesn't need any preparation.

Create a *body tube* for the rocket from a strip of paper about four inches long and about as wide as four straw diameters. A sheet of plain paper works well, but origami paper makes a fun and colorful substitute. The straw I used is about 3/16" in diameter, so the width of the paper strip was 12/16", or 3/4". (See, fractions really are useful!)

Wrap the paper around the straw, making it as snug as you can while still letting it slide easily along the straw. Use two small pieces of tape about one inch from each end to secure the paper while you add a final piece of tape along the entire length of the paper tube.

Figure 1-26. *Construct the rocket tube from the paper strip. Tape the ends to hold the paper in place.*

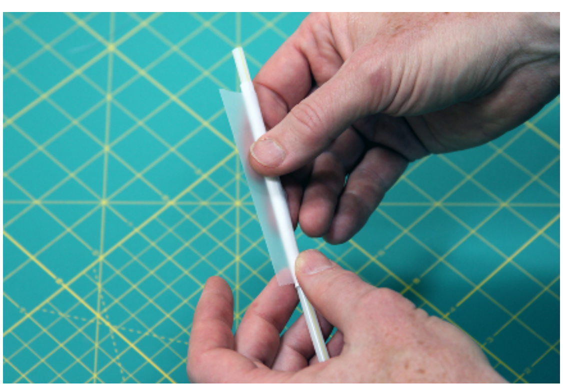

Figure 1-27. *Finish the body of the rocket with a piece of tape along its length.*

Using a long piece of tape, create three or four fins about an inch long at one end of the rocket. Use scissors to trim them to a fun shape. The fins push the center of pressure back toward the base of the rocket. See "Rocket Stability" on page 7 to see why this is important.

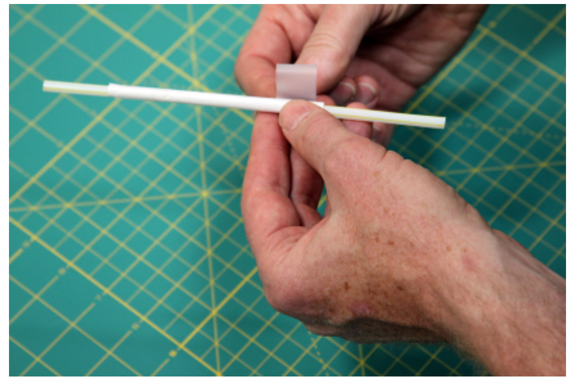

Figure 1-28. *Form three or four fins from tape, evenly spaced around the base of the rocket.*

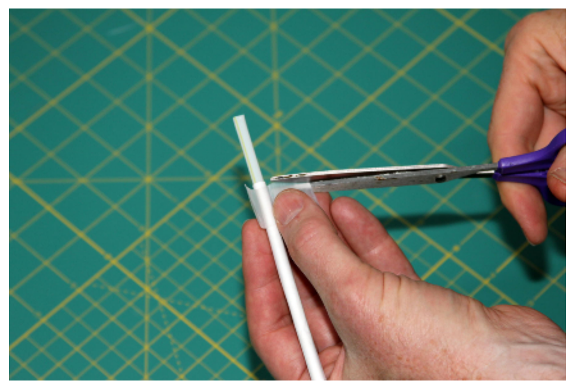

Figure 1-29. *You can trim the fins for a fancy shape.*

Use a small piece of clay to form a nose cone. It needs to block the end of the tube. A nose cone is usually used to reduce drag, which isn't terribly important at this point, but it will definitely add to the coolness factor of the rocket.

If you don't have any clay handy, you can fold the top of the rocket over and tape it shut.

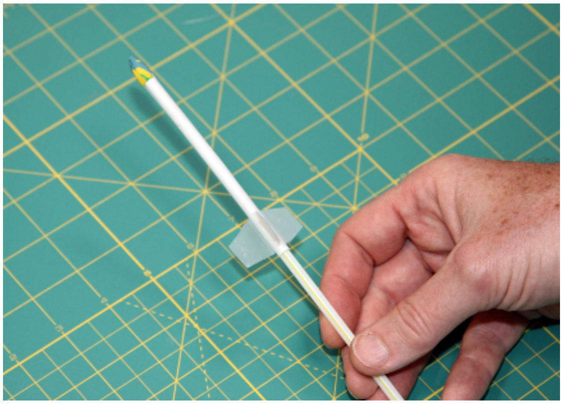

Figure 1-30. *The completed air rocket.*

It's time for the maiden voyage. Despite its simplicity, this air rocket will perform better than the match head or balloon rockets, easily flying 10 to 15 feet. Slip the rocket onto the straw, aim it a little less than 45 degrees from the horizontal for a really long flight, and give a sharp puff into the straw.

Figure 1-31. *A sharp puff into the straw will propel the air rocket 10–15 feet.*

Air rockets are a simple and inexpensive way to explore rocketry. We'll come back to them in Chapter 6. where we build much more powerful versions.