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 stably, your job boils down to controlling its pitching motion.

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,

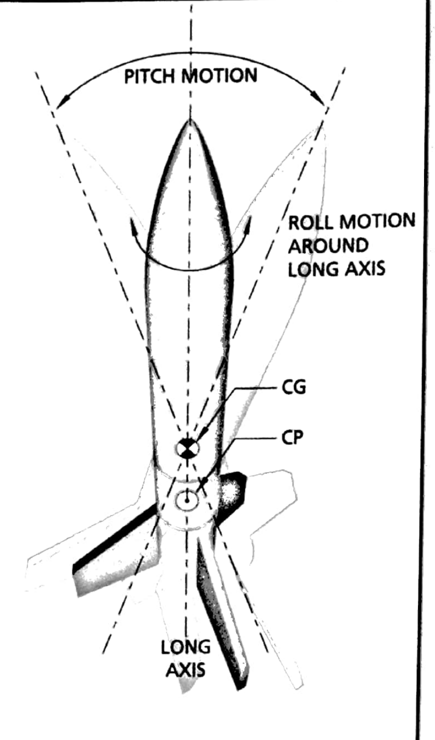

Figure 1.

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.

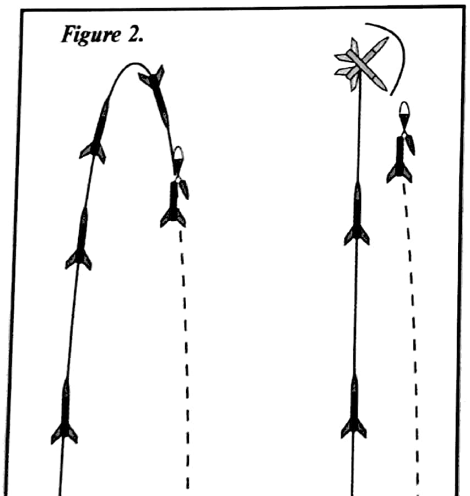

Figure 2.

What we don't want is uncontrolled pitch, which can cause the rocket to wobble, and in the worst 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. Three popular programs are RockSim, SpaceCAD, and OpenRocket. 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. 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.

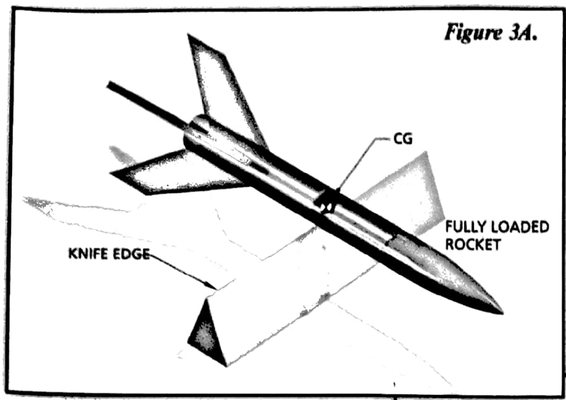

Figure 3A.

To move the CG forward you can:

a. Increase weight forward of original CG.
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.

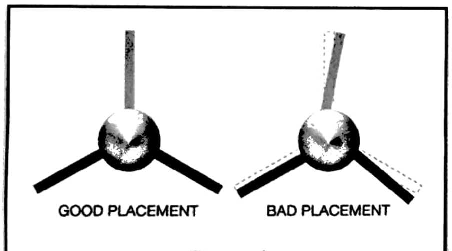

Figure 4.

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.

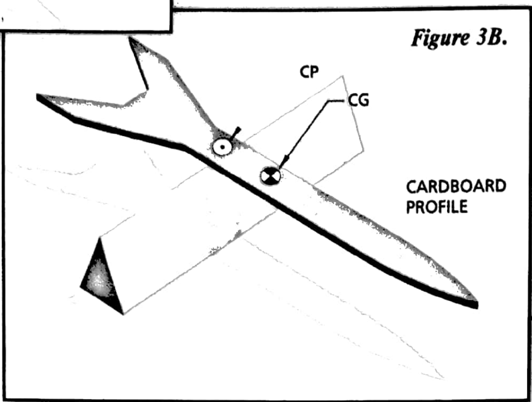

Figure 3B.

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,
www.apogeerockets.com

Handbook of Model Rocketry,
7th ed, G. Harry Stine and Bill Stine

Advanced Model Rocketry,
Michael Banks and Tim Van Milligan,

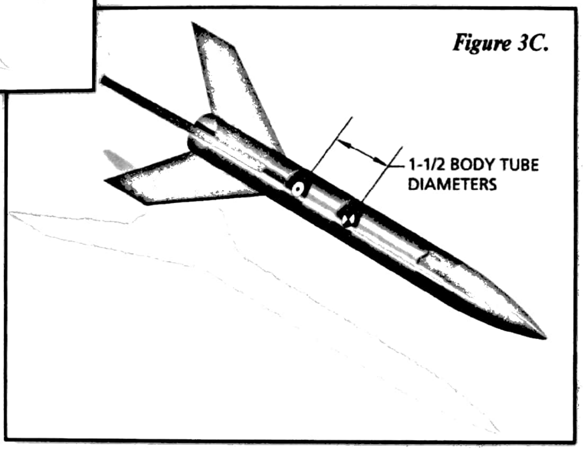

Figure 3C.

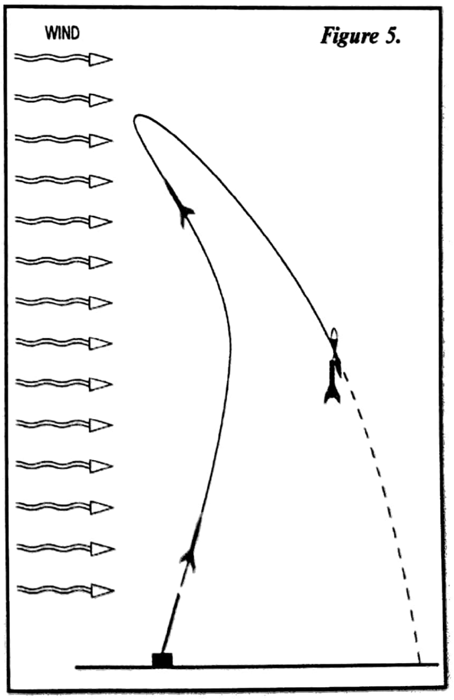

Figure 5.