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ROCKET STABILITY

by Vernon Estes

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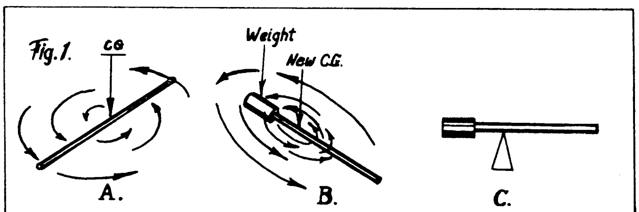
One of the first principles any rocket designer must learn is that unless a rocket has a complex electro/mechanical guidance system, it will fly only if its center of gravity (also known as center of mass) is far enough ahead of the center of pressure to allow air currents to act against the rocket causing a stabilizing effect.

From your science class or other scientific studies you have probably learned that if a rotating force is applied to a free body in space it will cause it to rotate around its center of gravity. As an example of this, you could take a wooden dowel or uniform stick about two feet long and toss it into the air so that it will rotate end over end (see Fig. 1, example A). You will notice that regardless of how you throw the stick, vertically or horizontally, hard or easy, it will always rotate about its center. If a weight is attached to one end of the stick and it is again thrown into the air it will rotate about a new location (Fig. 1, example B). This time the point about which it rotates will be closer to the weighted end. If you take the weighted stick and balance it across a sharp edge you will find that the point at which it balances (its center of gravity) is the same point about which it rotated when tossed into the air (Fig. 1, example C).

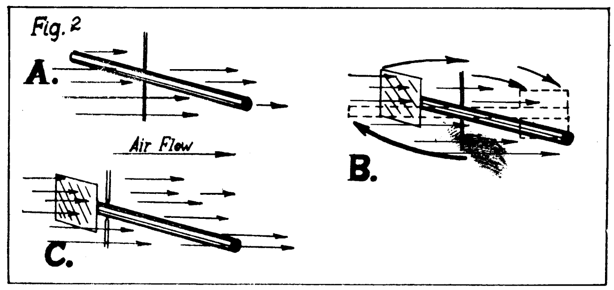


This simple explanation should aid you in understanding how a free body in space rotates around its center of gravity. A model rocket in flight is a free body in "space." If, for any reason, a force is applied to the flying rocket to cause it to rotate, it will always do so about its center of gravity.

Rotating forces applied to rockets in flight can result from lateral winds, air drag on nose cones, weights off-center, air drag on launch lugs, crooked fins, engine mounted off-center or at an angle, unbalanced drag on fins, unequal streamlining, etc. Obviously, some of these factors are going to be present in all rockets. Therefore, since rotating forces will be present, your rocket must be designed to overcome them. If your rocket is not so designed it will loop around and go "everywhere," but end up going nowhere. Nearly all model rockets are stabilized by air currents. By stabilized, we mean that all rotating forces are counteracted or overcome. This means that for each force trying to make the rocket rotate we must set up an equal and opposite force to counteract it.

How is this accomplished? Ask any rocket expert and he will simply say to design the rocket so the center of gravity is ahead of the center of pressure. From studying our first experiment it is easy to see how we could find the center of gravity by simply balancing the rocket on a knife edge as shown in example A of Fig. 3. But what and where is the center of pressure? The following experiment should aid you in understanding more about the center of pressure of a rocket.

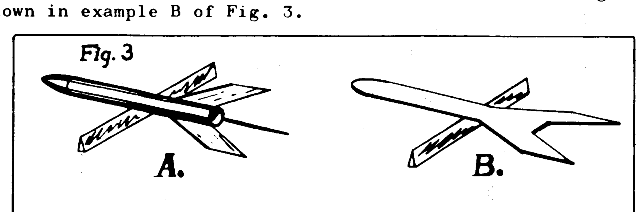
Suppose we take the same 2 foot long piece of dowel used in our first experiment and place it on a low friction pivot as shown in example A of Fig. 2. (The low friction pivot consists of two needle points held rigidly in place on opposite sides of the object by a heavy wire or board frame-work. The needle points are placed against the object just tightly enough to hold it, without interfering with its rotating on the axis created between the two points.) Then suppose the dowel is held in a uniform air current (wind) of 10 to 15 miles per hour. If the pivot has been placed in the center of the dowel and if the dowel is uniform in size (area) the forces exerted by the air pressure will be equal on both sides of the pivot and the air current will produce no rotating effect. In this condition the center of gravity and the center of pressure will be at the same point.



If, however, a vane of 3" x 3" cardboard is glued to one end of the dowel and it is again put into the air stream with the pivot in the same position, the moving air current will exert the greatest force against the end of the dowel which has the vane attached to it as in example B of Fig. 2. This will cause the dowel to rotate until the end away from the vane points into the wind. If we now move the pivot closer to the vane end of the dowel we will be able to locate a point along the dowel where equal air pressure will be applied to both ends. The air current will no longer cause any part of the dowel to point into the wind. This point is called the lateral center of pressure. Remember, the lateral center of pressure has to do only with the forces applied to the surface directly by air currents, and the larger the surface the greater the forces will be.

The ideal way to find the lateral center of pressure of a model rocket is to suspend the rocket between pivots as was done with the 2 foot dowel in Fig. 2, and hold the rocket in a uniform lateral air current. This can be accomplished to some degree of accuracy by holding the suspended rocket in a breeze of 10 to 15 m.p.h. The same effect can be accomplished very accurately by the use of a low velocity wind tunnel. However, since most model rocket builders and designers do not have wind tunnels and low friction pivots as described above, other methods must be provided for determining the center of pressure.

Keeping in mind the fact that the air pressure applied to a surface is proportional to the area of the surface, it then becomes possible to approximate the rotating effect of the action of the air pressure by making a uniform area cutout of your rocket and locating the balancing point of this cutout. To make this cutout, simply lay your rocket over a piece of cardboard and mark around the edges. Next, cut around the lines and balance the cutout on a knife edge as shown in example B of Fig. 3.



This method will determine the lateral center of pressure (the center of pressure with the air currents hitting the rocket broadside). If the rocket is designed so the lateral center of pressure is 1/2 the body diameter (1/2 caliber) behind the center of gravity it will have ample stability under all reasonable conditions. If, however, the rocket's fins are very crooked, set at opposing angles, or if the rocket uses a disc or cone for stabilizing, the lateral center of pressure should be set at least one diameter behind the center of gravity.

In flight, of course, the rocket will not be traveling sidewards, but with its nose pointed into the wind. With the model's nose pointed into the wind, the location of the effective center of pressure will be affected by the shape of the fins, the thickness of the fins, the shape of the nose cone, location of the launching lug, etc. With most designs this shift is to the rear, adding to the stability of the rocket.

Suppose a model rocket starts to rotate in flight. It will rotate around its center of gravity. When it turns the air rushing past it will then hit the rocket at an angle. If the center of pressure is behind the center of gravity on the model, the air pressure will exert the greatest force against the fins. This will counteract the rotating forces and the model will continue to fly straight. If, on the other hand, the center of pressure is ahead of the center of gravity the air currents will exert a greater force against the nose end of the rocket. This will cause it to rotate even farther, and once it has begun rotating it will go head over heels in the air.

It is easy to see from this why it is best to build the rocket with its fins as far as possible to the rear. The farther behind the center of gravity the center of pressure is placed, the stronger and more precise will be the restoring forces on the model, and it will fly straighter with less wobbling and power-robbing side-to-side motion. Under no circumstances should fins be placed forward of the center of gravity on a model, as they will add to its unstability tendencies rather than help stabilize it.

When building high performance, light weight rockets, quite often a more precise method of determining the stability margin of the rocket is desired. While the experienced rocketeer will develop an ability to tell, by looking, approximately how stable a rocket will be, any rocket, once constructed, should be checked to determine whether or not it has sufficient stability to be safe in flight. The simplest, least expensive method of doing this requires only a string and some tape.

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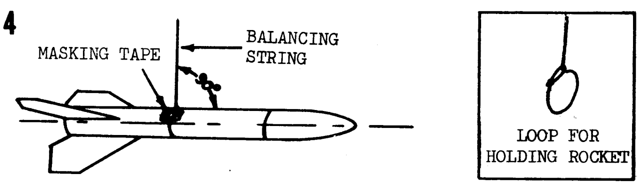

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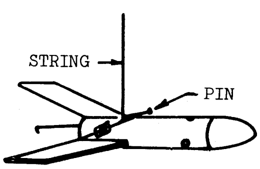
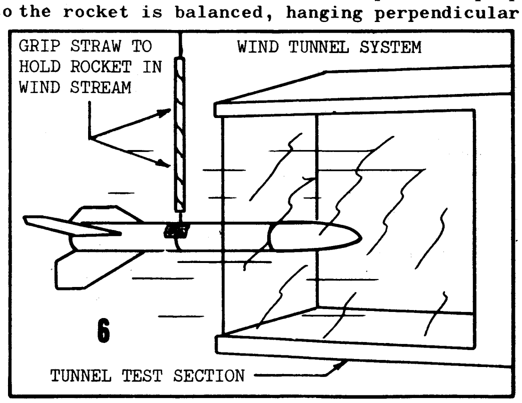


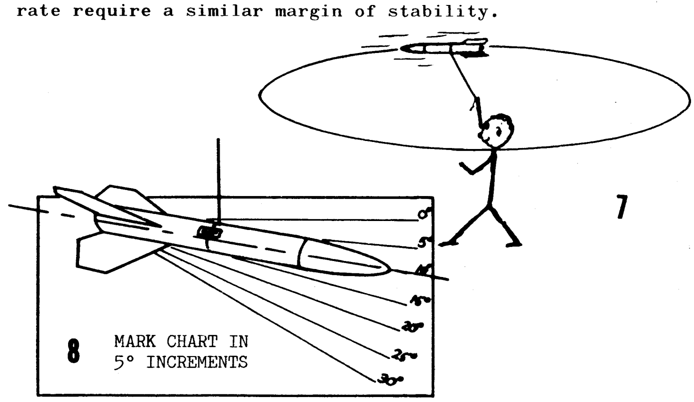
The rocket to be tested (with an engine in flight position: The center of gravity is always determined with an engine in place.) is suspended from a string as illustrated in Fig. 4. The string is attached around the rocket body using a loop as shown. Slide the loop to the proper position so the rocket is balanced, hanging perpendicular to the string. Apply a small piece of tape to hold the string in place. If the rocket's center of gravity (balance point) falls in the fin area, it may be balanced by hooking the string diagonally around the fins and body tube as shown in Fig. 5. A common straight pin may be necessary at the forward edge of one of the fins to hold the string in place. This string mounting system provides a very effective low friction pivot about which the rocket can rotate freely.



For the first system slide a soda straw along the string to a position just above the rocket. Then suspend the rocket in a low velocity air stream (wind tunnel or gentle breeze), with the nose of the rocket pointing into the wind, and then turn the rocket approximately 10° out of the wind to see if it recovers. If so, the rocket is stable enough for flight.

The second method involves swinging the suspended rocket overhead in a circular path around the individual, as shown in Fig. 7. If the rocket is stable, it will point forward into the wind created by its own motion. If the center of pressure is extremely close to the center of gravity, the rocket will not point itself into the wind unless it is pointing directly forward at the time the circular motion is started. This is accomplished by holding the rocket in one hand, with the arm extended, and then pivoting the entire body as the rocket is started in the circular path. Sometimes several attempts are required in order to achieve a perfect start. If it is necessary to hold the rocket to start it, additional checks should be made to determine if the rocket is flight-worthy.

Small wind gusts or engine misalignment can cause a rocket that checks out stable when started by hand as described above to be unstable in flight. To be sure that the rocket's stability is sufficient to overcome these problems, the rocket is swung overhead in a state of slight imbalance. Experiments indicate that a single engined rocket will have adequate stability for a safe flight if it remains stable when the above test is made with the rocket rebalanced so the nose drops below the tail with the rocket body at an angle of 10° from the horizontal (see Fig. 8). With cluster powered rockets a greater degree of stability is needed since the engines are mounted off center. The cluster powered rocket should be stable when imbalanced to hang at 15° from the horizontal. Heavier rockets which accelerate at a lower rate require a similar margin of stability.



Caution should be exercised when swinging rockets overhead to avoid collision with objects or persons nearby. Velocities in excess of 100 miles per hour are possible. This is sufficient to cause injury.

Suppose you construct a rocket and find that it will not be stable. Do not try to fly it. Corrections must be made. Tests have been made where the stability of the rocket was in question. If it was completely unstable it would loop around and around in the air, seldom reaching over 30 feet in height and never reaching a velocity in excess of 20 or 30 miles per hour. However, occasionally one of these rockets would make a couple of loops, suddenly become stable due to the lessening of the fuel load, and make a bee line straight into the ground. Had anyone been standing in the wrong place a serious injury could have resulted.

If a rocket does not show the degree of stability required for safety it can be easily altered to conform either by moving the center of gravity forward or by moving the center of pressure rearward. To move the center of gravity forward, a heavier nose cone is used or a weight is added to the nose of the rocket. To move the center of pressure rearward, the fins may be made larger or moved farther back on the body tube. With the Astron Scout rocket and many other designs, greater stability is obtained by constructing it so that a large portion of the fins project beyond the rear of the rocket body.