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APOGEE PEAK OF FLIGHT NEWSLETTER

The Cardboard Cut-out CP Method

By Tim Van Milligan

Many modelers have heard about the cardboard cut-out method for approximating the location of a model's Center-of-Pressure (CP). But why does this method work, what are it's limitations, and how does it compare to the Barrowman method of calculating stability? In this article, I'd like to explore all of these questions, so that we can design better models which will be safe when launched.

First, what is the Center-of-Pressure? By definition, it is the point on the rocket where all the aerodynamic forces balance. As shown in Figure 1, when a fin is placed in an airflow, a lift force is created along the entire surface of the fin. Since it would be a nightmare to try to determine the lift force at each point on the surface of the fin, we just combine them all into one 'big' force. But where do we put the location of this force. That is what the CP of the fin is: the location where we can place this force.

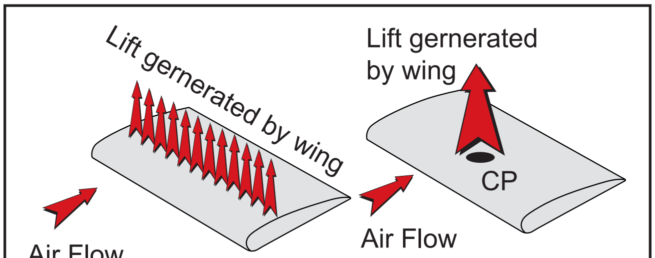

Fig. 1

As you know, the location of the CP is very critical when it comes to the stability of the rocket. So we need a method to find out where it is. Without a location, we can't compare the relationship of the CP to the CG, and we won't know if the rocket will be stable prior to launch.

To keep the discussion simple, lets assume our rocket has straight rectangular fins. For starters, lets ignore everything on the model; except one fin. Lets mount this fin on a thin dowel running along the span, so that it is free to pitch up or down. Now lets assume the fin is in an airflow, so the wind is blowing toward the leading edge of the fin. When air flows over the fin, it creates forces (lift and drag) that act on the fin. Because our fin is free to rotate, it will pitch up or down in response to the forces.

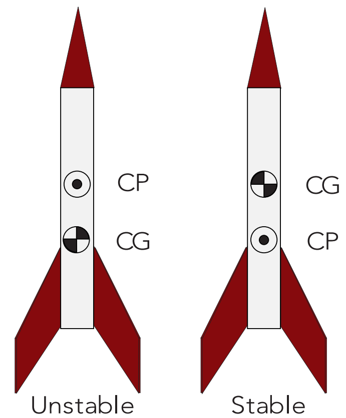

Fig. 2

First, lets position the dowel at the midpoint of the fin as shown in Figure 3. This location is the 1/2 chord line. Now we can do mind exercises and see what happens when we move the location of the CP (the point where we assume all the forces act). If the CP is behind the 1/2 chord line, the fin will pitch up in response to the forces acting on the fin. If it is in front of the line, it will pitch downward. And if the CP is on the 1/2 chord line, the fin will not rotate either up or down.

The same situation occurs no matter where we place the location of the dowel along the chord of the fin; as shown in Figure 4. What is most important for us to recognize is that when the CP is positioned on the dowel line, the fin will not rotate either up or down in response to a force. This is the location we will be looking for.

You might have heard that the "Cardboard Cut-out

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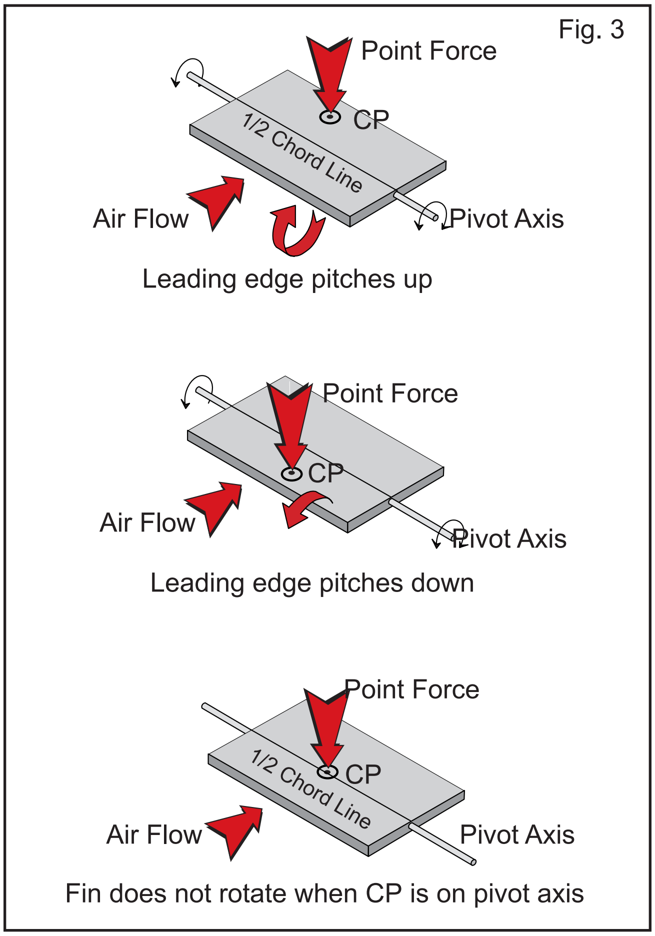
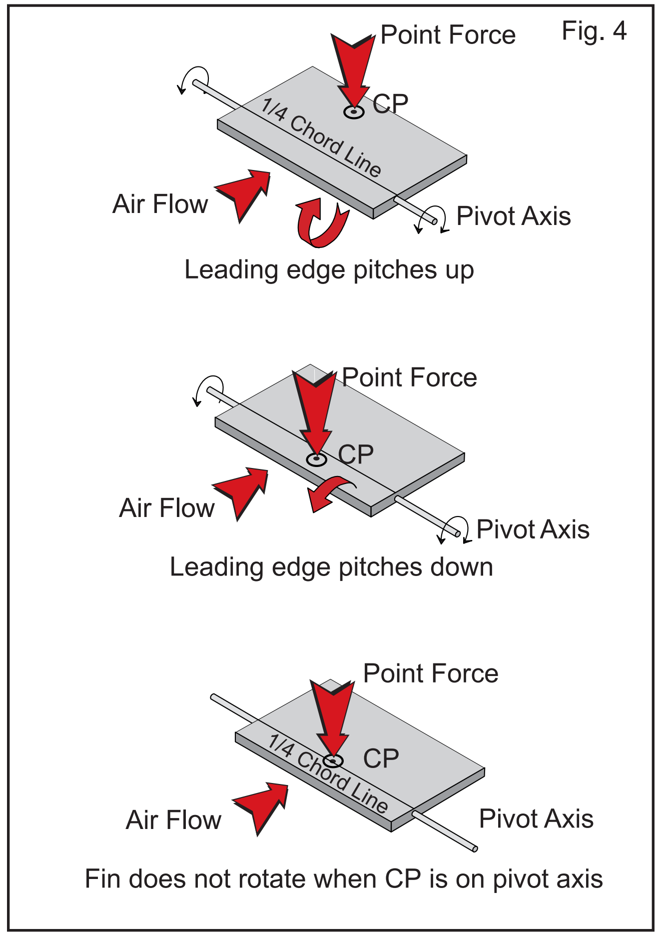


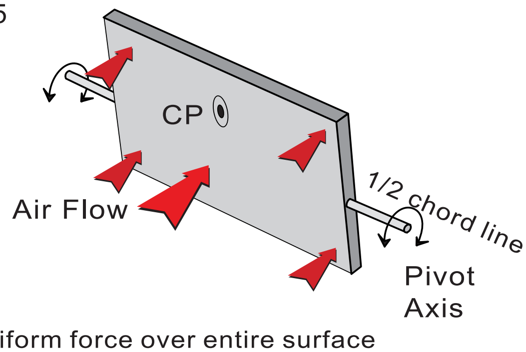


Method" assumes that the model is at a 90° angle of attack to the airflow. For our fin, this is shown in Figure 5. The full face of the fin is being blasted by the airflow. As each air particle hits the surface of the fin, it creates a tiny force that is trying to push the fin backward. By simple intuition, we can combine all the tiny forces and substitute one big force acting in the exact center of the fin area. So now we know where the location of a fin's CP is for

You also remember that a model will rotate around its Center-of-Gravity (CG). As long as the CG location is in front of the CP, the model will be stable. From this we can define "stability" by which direction the rocket pitches when a force is applied. Going back to our single rectangular fin, the CG will be along the 1/2 chord line; which is also the CP location from the cut-out method. This is the same situation as shown in Figure 3. Since we want the fin to be stable, the CG must be moved ahead of the CP, similar to what is shown if Figure 4. By looking at Figure 3, we can define a stable rocket as one that will pitch upward when a downward force is applied to the CP of the fin. If we change the direction of the force to "up" (like a LIFT force), then the fin will pitch down. I mention this as a definition of stability only.

How does this cardboard cut-out CP location compare to the location calculated by the Barrowman equations? If you look at the Barrowman equations, you can do a quick calculation for a single rectangular fin. Lets assume the chord length

Fig. 5



Uniform force over entire surface

is 3 inches.

The equation for the location (X_f) of the CP as measured from the leading edge is:

X_f = Xr/3 * ((C_r + 2C_t)/(C_r + C_t)) + 1/6((C_r + C_t) - ((C_r*C_t)/(C_r+C_t)))

Where:

X_r = Leading edge sweep
C_t = Tip chord length
C_r = Root chord length

For our fin, X_r= 0, and C_r = C_t = 3 inches.

The equation now becomes:

X_f = 0 + 1/6((C_r + C_t) - ((C_r*C_t)/(C_r+C_t)))
X_f = 1/6(2*C_r) - C_r2/2*C_r)
X_f = 1/6(2*3 - 32/2*3)
X_f = 1/6(6 - 9/6)
X_f = 1/6(6 - 1.5)
X_f = 1/6(4.5)
X_f = .75 inches

To find the chord percentage that X_f is, we just divide by the chord length (3 inches). This tells us that the CP for a rectangular fin as measured by the Barrowman equation is on the 1/4 chord line.

Therefore, the Barrowman method predicts the CP will be at the 1/4 chord line, while the cardboard cutout method predicts it will be further back at the 1/2 chord line. Based on this, you'd think that the cut-out method overestimates the model's stability, because the CP is further back (which we think is a good thing).

But things really start to change when you add a body tube to the simulation. In the Barrowman method, the body tube does not affect the CP position of the rocket at all. The only thing the body tube does is to move the CG forward. But in the cut-out method, the extra area greatly changes the CP location; moving it too far forward. The longer the tube, the further forward the CP moves.

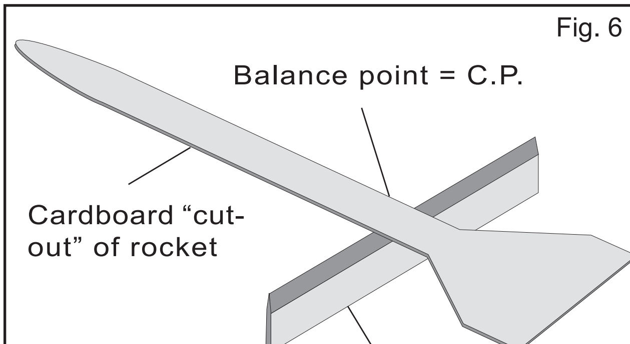
So because the cut-out method's CP has moved so far forward of the fins, when a comparison is made between the locations of the CP and CG, we may find that the model is "unstable!" So to compensate, we add an even longer tube or more nose weight to move the CG forward. Because of this, we say that the cut-out method is "overly conservative."

Being conservative in stability is not a bad thing. We want our models to fly stable, but you can take it too far. When a model is "too stable," it weathercocks into the wind. This can be a dangerous situation; particularly if you assumed the model will go straight up and have selected a long delay rocket motor. In this case, the model will arc over and eject the recovery device on a downward trajectory; or even impact the ground without ejecting the parachute. That is not good.

The best situation is to use the Barrowman equations to design your rocket and check its stability. It is more reliable in predicting the location of the CP. But the equations can be tedious if you had to do them long-hand, and fortunately there are computer programs that use them. The "RockSim" program from Apogee Components (for Windows95) is particularly nice for designing rockets. It not only calculates the CP, but it also calculates the CG of the rocket and checks for stability. The newest version of RockSim also has both the Barrowman equations and the cardboard cut-out method for CP location determination. This lets you check both methods at the same time, and you can see the differences in the CP locations.

There are limitations to the Barrowman equations. For example, you are limited to rockets with the "classical" shape. As soon as you make one fin bigger than the other, or strap on

Fig. 6



Locating the rocket’s approximate
“center-of-pressure”

side pods, the method can't be used. That is why the cardboard cut-out method is still around; because you can still use it to design odd shaped rockets.

I hope this article answered some of your questions about the cardboard cut-out method for calculating rocket stability

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Tim Van Milligan is the owner of Apogee Components (http://www.apogeerockets.com) and the curator of the rocketry education web site: http://www.apogeerockets.com/education. He is also the author of the books: "*Model Rocket Design and Construction," "69 Simple Science Fair Projects with Model Rockets: Aeronautics"* and publisher of the FREE e-zine newsletter about model rockets. You can subscribe to the e-zine at the Apogee Components web site, or sending an email to: ezine@apogeerockets.com with "SUBSCRIBE" as the subject line of the message.