

PEAK OF FLIGHT

NEWSLETTER

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PEAK OF FLIGHT

Model Rocket Stability

By Timothy Van Milligan

The definition for model rocket stability is when the Center-of-Gravity (CG) is in front of the Center-of-Pressure (CP). The further distance the CG is in front of the CP, the more stable the rocket will be.

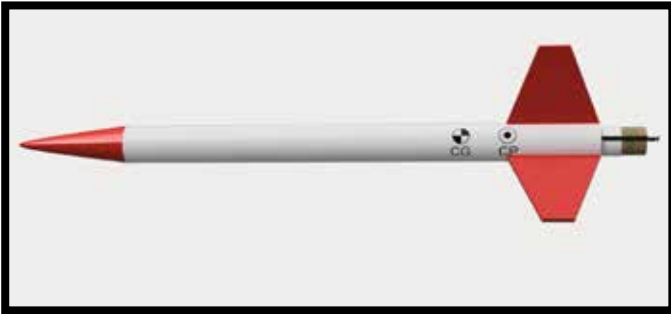


Figure 1: A stable rocket is defined as one where the Center-of-Gravity is forward of the Center-of-Pressure.

“Stability” for us essentially means to fly a predictable flight path. We desire the nose of the rocket to point forward and the model to fly in a predictable trajectory so that the launch is safe. You can equate stability with safety.

In an unstable rocket, where the Center-of-Pressure is in front of the Center-of-Gravity, the rocket will tumble end-over-end and fly an erratic path. It is always bad and should be avoided.

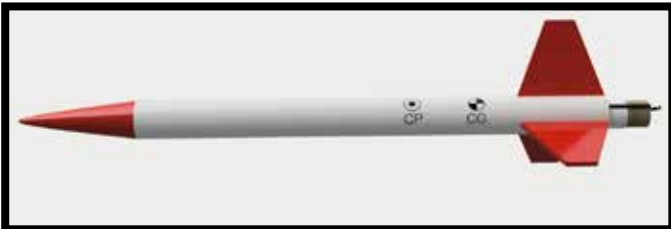


Figure 2. In an unstable rocket, the center-of-pressure is forward of the center-of-gravity.

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Locating the Center-of-Gravity

Finding the center-of-gravity is easy because all you have to do is balance the rocket on your finger or the edge of a ruler. It is the balance point of the rocket.

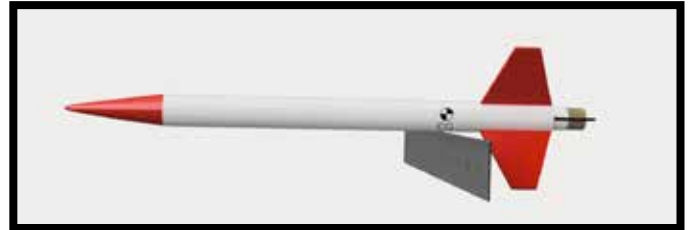


Figure 3: The Center-of-Gravity is the point where the rocket balances. Half of the weight of the rocket is on either side of the balance point.

When you perform a balance check to find the Center-of-Gravity, always put a new rocket motor in the back end. This will give you the worst case situation, which is the furthest back the CG of the rocket will be during the flight. As the rocket engine burns, the back end of the rocket gets lighter, and the CG position moves forward. If you locate the CG of the rocket after the flight, you will notice that the balance point has moved towards the nose cone.

Locating the Center-of-Pressure

Finding the Center-of-Pressure of the rocket is a lot harder. To understand why this is, you have to understand what the Center-of-Pressure is.

The definition of Center-of-Pressure is the point on the rocket where all the aerodynamic forces balance. There are two aerodynamic forces that act on a rocket. They are the forces of Lift and Drag. These forces are only present when the rocket is moving through the air. If there is no movement, there are no forces. This is why we can't easily find the CP point like we can find the CG location.

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You can feel the aerodynamic forces by sticking your hand out the window of a moving car. If you have your palm facing into the air, you can feel the pressure trying to push it back. This is the Drag force. If you hold your hand palm facing downward in the air stream, and then you slightly twist it so your palm starts to face into the oncoming wind, you'll feel your whole hand rise upwards. This is the Lift force.



Figure 4: You can feel the aerodynamic forces of lift and drag on your hand as you stick it out the window of a moving car.

The same aerodynamic forces of Lift and Drag are acting on a rocket too. In fact, every part of the rocket feels a small force of Lift and Drag. There are lift and drag on the nose cone, the tube, and the fins. It isn't really just one force. It is distributed over the entire surface.

But we engineers want to simplify things. We want to combine all those individual forces and say they are pushing on just one single point on the rocket. In essence, we'd like to balance all the forces, so that we can say that half of the forces are in front of the balance point and the other half are behind it.

This balance point is called the "Center of Pressure." It can also be called the "Aerodynamic Center," but that is more common when talking about airplanes. In rocketry, we just call it the Center of Pressure.

Figure 5 shows the lift forces on the rocket

(the blue arrows). Each component contributes to the overall lift force on the rocket. The spring and the pink arrow represents the downward force necessary to prevent the rocket from moving. The position of the spring is the important thing here. If it is located at the center of pressure location, then the rocket will be perfectly stable and won't move up or down, nor will it tilt up (called "pitch") nor rotate side-to-side (called "yaw"). If you pull down on the spring, the rocket will maintain its stable orientation with respect to the wind (the green arrows).

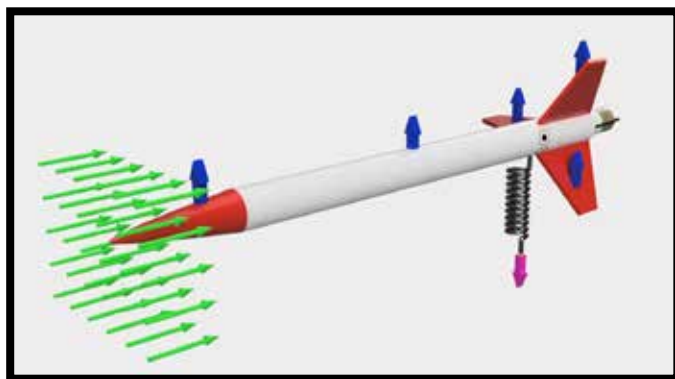


Figure 5: The Center-of-Pressure is where the lift and drag forces on a rocket balance. The blue arrows indicate lift forces trying to pull the rocket upward. The pink arrow is the force you'd have to apply to balance against the lift forces. If the spring is right at the Center-of-Pressure location, the rocket will not tilt, rotate, or move up/down. It will stay steady in the airflow.

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The best and most accurate way to find the Center-of-Pressure point is to balance the rocket in a wind tunnel that is blowing air over the rocket.



Figure 6: Here the girl is holding the rocket on a caliper to find the balance point.

Actually, instead of pointing the nose into the airstream, the rocket should be held sideways to the airflow like in **Figure 7**. If you put the balance point at the right location on the rocket, the rocket should stay oriented sideways to the airflow. That balance point, where it stays sideways without rotating, is the Center-of-Pressure location. If the rocket doesn't spin on the pivot, this means that the forces on the front part of the rocket balance out the forces on the rear of the rocket.

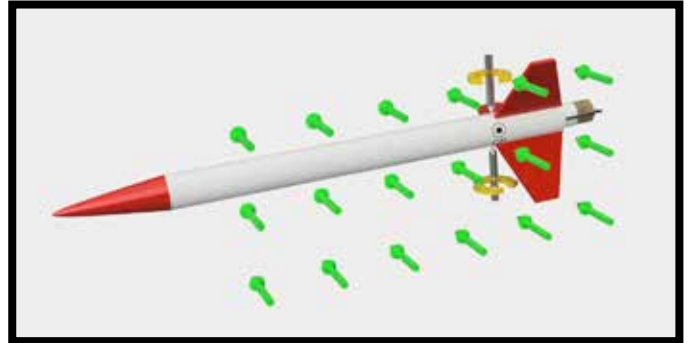


Figure 7: The CP point is that location where the rocket won't rotate because the forces one side of the rocket balance out with the forces on the other.

The downside of the wind tunnel is that you rarely have one that is big enough that the entire rocket will easily fit inside of it. So we look for other ways to estimate the CP point on the rocket. The next best thing is to use a software program like RockSim (https://www.apogeerockets.com/RockSim/RockSim_Information). RockSim calculates the CP position on the rocket using the Barrowman Equations. You can download the original Barrowman report from the Apogee Components web site at: https://www.apogeerockets.com/downloads/barrowman_report.pdf. You can do the calculations long-hand, but after you do it once, you'll realize that it is a chore and you'll be happy to let a computer do the calculations for you. It does it instantaneously so you can see the results as you make changes to the rocket.

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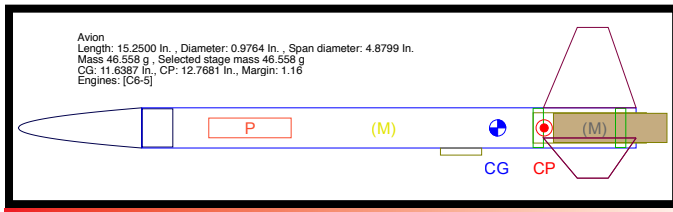


Figure 8: RockSim uses the Barrowman Equations to find the CP location of the rocket, as well as the CG so that the stability can be estimated.

The downside to the Barrowman Equations is that they assume some things, like that the shape of the rocket is long and skinny, and that the rocket is flying at a low angle-of-attack. Because of these limitations, there is a little bit of uncertainty as to the exact position of the CP. We're pretty confident it is where the equations estimate it at, but not 100% certain. Because of this, we need to build in a little factor-of-safety into the rocket.

The factor-of-safety is called the "Stability Margin." It is a number that tells us the relative distance the CG is in front of the CP. By definition, it is the actual distance they are apart, divided by the body tube diameter. Therefore, it is a number that doesn't have any units. But if it is a number of 1.0, that means the CG is 1.0 body tube diameters in front of the CP. In **Figure 8**, the Margin is 1.16, which indicates the CG is 1.16 times the body diameter in front of the CP.

The factor of safety we use in model rocketry is that we want the CG at least 1.0 body tube diameters in front of the CP; which tells us the static margin is 1.0. Greater than 1.0 is okay. It's when the Static Margin is less than 1.0 that you should be concerned.

Conclusion

This article is the basics of rocket stability. From this point, you can go a lot deeper into the subject and additional links and resources are listed below. If you found this information useful, we hope you'll share this page with your friends and link to it on your own website.

Additional Resources:

Build your own wind tunnel - Peak-of-Flight Newsletter #252 (<https://www.apogeerockets.com/education/downloads/Newsletter252.pdf>)

Peak-of-Flight Newsletter articles dealing with rocket stability: https://www.apogeerockets.com/Peak-of-Flight?pdf_list=topics&#Rocket_Stability

Model Rocket Design and Construction (https://www.apogeerockets.com/Rocket_Books_Videos/Books/Model_Rocket_Design_And_Construction)

Avion rocket kit - <https://www.apogeerockets.com/Rocket-Kits/Skill-Level-1-Model-Rocket-Kits/Avion>

About The Author:

Tim Van Milligan (a.k.a. "Mr. Rocket") is a real rocket scientist who likes helping out other rocketeers. He is an avid rocketry competitor and is Level 3 high power certified. He is often asked what is the biggest rocket he's ever launched. His answer is that before he started writing articles and books about rocketry, he worked on the Delta II rocket that launched satellites into orbit. He has a B.S. in Aeronautical Engineering from Embry-Riddle Aeronautical University in Daytona Beach, Florida, and has worked toward an M.S. in Space Technology from the Florida Institute of Technology in Melbourne, Florida. Currently, he is the owner of Apogee Components (<http://www.apogeerockets.com>) and also the author of the books: *Model Rocket Design and Construction*, *69 Simple Science Fair Projects with Model Rockets*: Aeronautics and publisher of the "Peak-of-Flight" newsletter, a FREE e-zine newsletter about model rockets. You can email him by using the contact form at <https://www.apogeerockets.com/Contact>.

