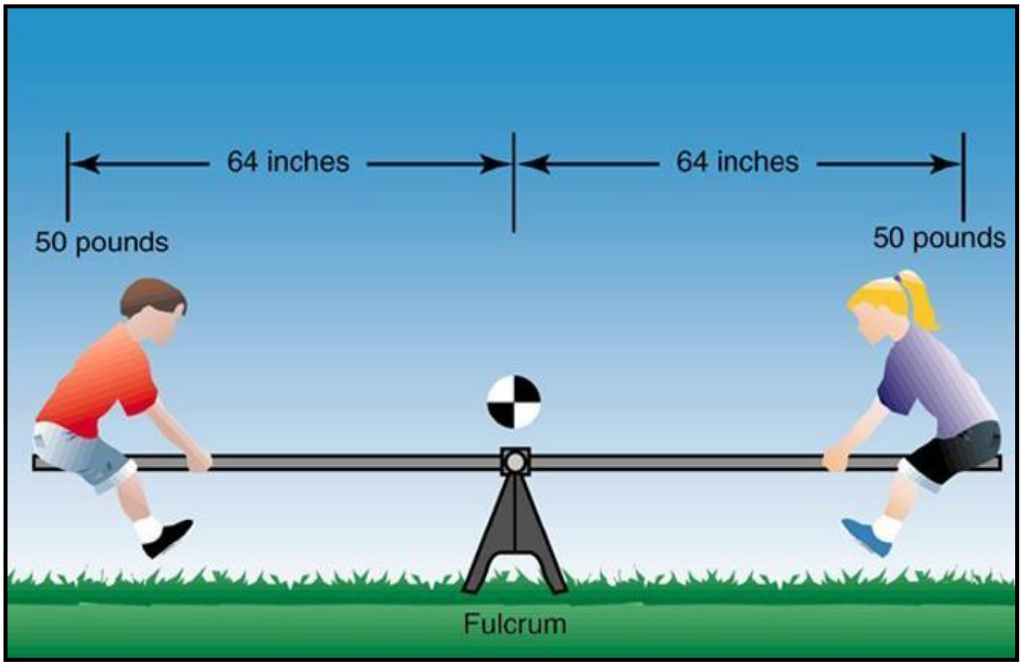
The Trailing Edge

May 2024

My Teetertotter is Broken

There are a number of myths that we learn about airplanes as we learn to fly. I'd like to address one of them. Let's talk about weight and balance. Engineers like to call this 'mass properties,' but it has nothing to do with going to church. Do you remember the teetertotter on the school playground? If you put the big kid on one end and the little kid on the other end, it doesn't work. They can't go up and down until the big kid scooches toward the middle and the whole thing comes into balance. Sometimes, you can put two little kids on one end to balance out the big kid. During pilot training, they used the teetertotter to explain weights, arms, and moments. In order for the thing to work, the moments have to be balanced even if the weights aren't. The center of gravity (CG) needs to be at the fulcrum of the teetertotter.

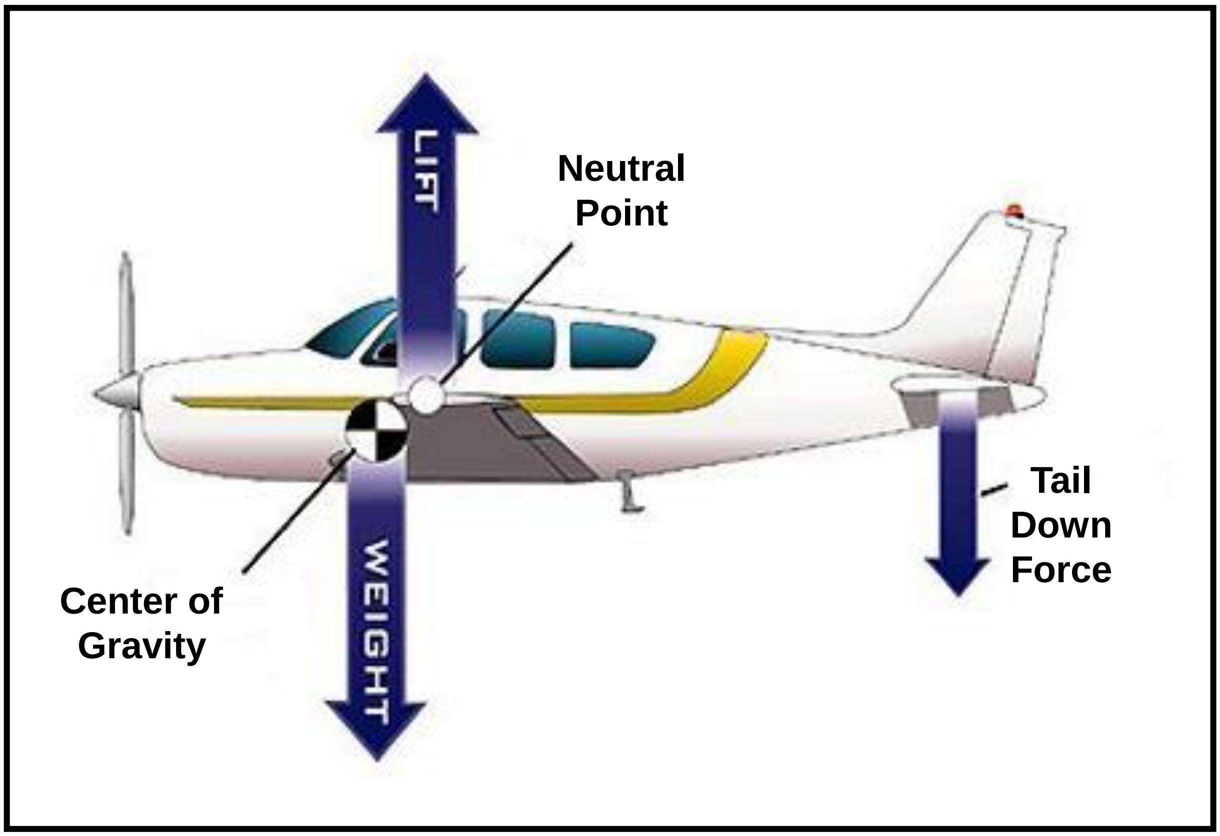


Armed with that concept, we learned to add the weights of everything on the plane: fuel, oil, bags, people, even the empty weight of the airplane to get the gross weight. The purpose was to ensure the gross weight was less than or equal to the maximum allowable gross weight. With that exercise complete, we learned to determine the moment of each of those weights by multiplying the weight times the arm, or distance from the datum. When we added all the moments and divided by the gross weight, we got the CG of the loaded airplane. There is a forward limit and an aft limit to where the CG is allowed to be. We checked the result to ensure the CG was "in the envelope." That envelope is really an area on a graph that defines the acceptable combinations of weight and CG. For some airplanes, the CG limits change as the weight changes. Next, you needed to ensure that the CG would remain in the envelope for the duration of the flight. For many training aircraft, this is a no brainer. If the CG is in the box at takeoff, it will remain in the box all day. However, there are some more complex aircraft where the movement of the CG throughout the mission is not so intuitive.

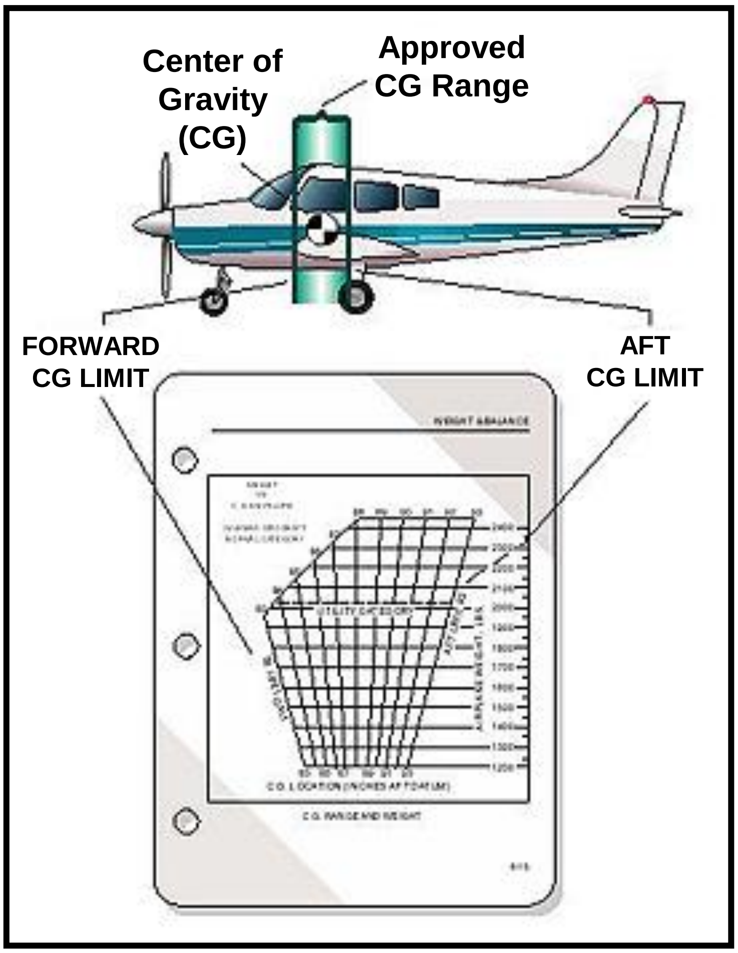
For some military aircraft, consideration must be made for what happens when the airplane fires or releases weapons, or "stores." The release of a bomb or an external fuel tank results in an immediate change in weight and CG. For this reason, the military operators must compute the weight and CG at takeoff, at landing (typically at 'zero fuel'), and at the 'worst-case condition.' That may impose operational restrictions on what weapons can be employed and when. That can all lead to a fascinating application of some fifth-grade math. Nevertheless, we seldom have to address such complexities in our calculations for our little airplanes. We never release or fire anything in flight – at least not on purpose. Moreover, in most general aviation aircraft, the CG moves either forward or aft with the consumption of fuel. Still, the next time you do a weight and balance computation, take a moment (no pun intended) and determine the CG in the zero-fuel condition. I'll bet it will still be between the forward and aft limits, but will it be where you expected it to be? Some electronic flight bags (EFB), such as Foreflight, will calculate your weight and CG at landing. However, for some aircraft, it might make sense to calculate the CG with zero fuel. If any fuel is required to maintain the CG in the envelope, it is serving as ballast and cannot be considered as useable fuel.

What happens if you find yourself in command of an aircraft in flight with a CG that is not within the prescribed limits? To paraphrase John King in one of the King School videos on the subject, "Congratulations! You are a test pilot, whether you want to be or not." After deciding where on your flight suit you're going to put the applicable patch, you are going to have to figure out how to fly the airplane in its current configuration. This is where the teetertotter myth fails us. Too many aviators and maintainers believe that an airplane with an out-of-range CG will simply tend to tilt in the applicable direction, like the teetertotter: An aft CG will make the airplane tilt nose up, and a forward CG will make the airplane tilt nose down. However, that is not how it works in flight. To be sure, those CG limits are real and should be respected with due reverence, but let's take a look at what makes them so pertinent. To begin, let me introduce a term that is not often thrown around in the bar at the officers' club, the "neutral point." You already know that the CG is a point on the aircraft where the moments of the weights in each direction are equal, so the aircraft effectively pivots about the CG as if suspended at that point. The neutral point is similar but has to do with the planform area of the aircraft. To better understand this, let's look at an example.

Go back to the bar in the O club and look at one of the darts in the dart board. The only significant areas on the dart are the tail feathers. That means the neutral point of the dart is very near the tail end. Now, consider the location of the CG of the dart. It is easy to determine that the weight attached to the front, along with that pointy thing, makes the CG very near the front of the dart. A dart wants to do nothing but hurl through the air in a straight line because the CG is well ahead of the neutral point. The tail feathers keep the pointy end at the front, ready to impale the bullseye on the dart board. You want the pointy end of your airplane to always point into the relative wind, but you also hope to be able to maneuver as you see fit. You won't be able to wheel and soar high in the sunlit silence if you can't pitch or turn or deviate from a straight line. The forward limit is important.



What would happen to that dart if some foolhardy drunkard put the tail feathers on the wrong end? What if the weight is not way up at the front? In short, what happens if the CG ends up behind the neutral point? The pointy end will no longer want to point into the wind. However, before you reach that extreme condition in your airplane, there is another more subtle but still less than desirable effect that will become discernable. Notably, your airplane is blessed with speed stability. If perturbed from a state of equilibrium where your aircraft is at a particular pitch attitude and steady airspeed, the aircraft will find its way back to that state. This is no happy accident. There are unseen forces at work to achieve this wonderful characteristic. There is a downward ‘lift’ on the horizontal stabilizer trying to pitch the nose up. At the same time, there is a comparable force trying to pitch the nose down, namely the CG is forward of the lift vector of the wing. A change in airspeed results in a change in the load on the horizontal stabilizer. It decreases if the airspeed decreases. That allows the nose to drop and the airspeed to increase. If the speed increases, the load on the horizontal stab increases, raising the nose and decreasing the airspeed. As the CG moves aft, the balancing load on the horizontal stab must be decreased to keep everything trimmed out. With a lighter load on the stab, changes in airspeed will have less effect. Therefore, as the CG moves aft, the speed stability becomes less stable. The aircraft becomes less inclined to return to the trimmed condition. With further aft movement, the speed can become unstable. A perturbation in pitch causes the aircraft to want to fall off in the direction of the perturbation. It may still be controllable but will require some skills to keep it where you want it to be. Think of balancing a yard stick on your nose. It can be done, but it requires active concentration, not to mention a degree of agility.



The forward and aft limits of the CG envelope are important. We all learned that concept in ground school, along with the procedures for determining the location of the CG. Armed with a better understanding of why they are important, perhaps you will look at the depiction of the CG envelope in your Pilot’s Operating Handbook with deeper appreciation for what machinations and mastications were involved in the creation of that particular piece of sausage.

- Scott “Stormy” Weathers