THE PHYSICS OF FLIGHT

By Dave Pickenpaugh

Chapter II - Stability and the Center of Gravity

Most of us who build R/C aircraft understand the need to balance an airplane at the recommended "CG" point shown on the plans. This point usually is about one-fourth of the way back from the leading edge of the wing. This longitudinal balance point has a counterpart, the lateral or span-wise balance point. To understand why balancing is so important, we have to take a look at how all the forces act on an airplane when it is in flight.

The CG is the center of gravity, which is the point at which the airplane balances. You can support the airplane at this point and it will not fall off in any direction. We are concerned mostly with the longitudinal balance since it affects the inherent stability of the aircraft. Longitudinal and lateral balances both affect the performance of the airplane.

First, let's discuss the lateral balance point. It is not nearly as critical at the longitudinal balance as it mostly affects the airplane's ability to track straight and level at all speeds and attitudes. If the builder does not remember to balance the airplane laterally, it probably will still fly reasonably well but may have a tendency drop one wing during loops. Most airplanes will have an acceptable lateral balance if built according to the plans and instructions. If you plan to use a side-mounted engine or some other equipment that may make one side heavier than the other, you will need to add weight to one wing to balance the airplane laterally. Otherwise the airplane will not track straight through maneuvers.

Analysis of the effects of the longitudinal balance point are much more complex. An airfoil cannot create lift and remain in equilibrium, as the process of creating lift also creates a pitch-down attitude. Most of the wings we use on R/C airplanes have semi-symmetrical airfoils. Since both the top and bottom of the wing have curved surfaces, each develops a certain amount of lift. The greater curve on the top of the wing generates more lift than the lesser bottom curve, which allows the airplane to remain aloft. The point at which the lifts acts is called the center of pressure. The nose-down pitching action is caused by the fact that the upward lift acts further back on the wing than the downward lift. This makes the wing rotate forward, causing the nose of the airplane to pitch down. The horizontal tail is used to counteract this rotation, as it develops lift in the downward direction.

Remember the see-saw (or teeter-totter) you played on when you were a kid? If you had a bigger kid on one end and a smaller one on the other, you had to move the board off center to make it balance the two kids. Keeping that image in mind, the horizontal tail is the smaller kid, the wing lift is the bigger kid, and the CG is the balance point. A large force with a short lever can be balanced with a small force with a longer lever. A force multiplied by the distance over which it acts is called a "moment." When all of the forces are in balance the airplane is considered to be trimmed.

Stability refers to the airplanes tendency to return to trimmed condition after a disturbance. Airplanes can have varying degrees of stability, or even be unstable and still fly. Many modern fighters are inherently unstable. An airplane operates in a three-dimensional environment, therefore it can rotate about three axes. Movement about the lateral axis is called pitch (nose up or down), rotation about the longitudinal axis is called roll, and motion around the vertical axis is called yaw. It is important to note that all three axes pass through one point -- the center of gravity.

When an aircraft is in flight, any force that tends to rotate the aircraft will result in a rotation about the CG. This is why the CG location is so important. Airplanes are considered for their longitudinal stability (stability in pitch), lateral stability (stability in roll), and directional stability (stability in yaw). It is usually not too difficult to make an airplane stable laterally and directionally. By far, the most important consideration in airplane design and construction is longitudinal stability.

Different airplanes vary in their degrees of stability. We all know that trainer airplanes will return to upright if we let go of the controls and have sufficient altitude for recovery. Most of the time the trainer airplane has the CG moved to a more forward location than a high-performance airplane. The design is extremely stable, but sacrifices performance for ease of flying. In contrast, an aerobatic airplane is still stable, but to a much lesser degree. Most pattern and aerobatic airplanes have a tendency to stay in their current attitude, and will not quickly correct to upright straight and level flight. The extreme limit of stability is called neutral stability, in which the airplane remains in its current attitude until another force causes it to assume a new attitude. The CG in pattern and aerobatic planes usually is further to the rear when compared with the trainers.

A tail is not required to make an airplane stable. There are a number of flying wing designs, and each requires a careful calculation to determine exactly where the CG and the center of pressure need to be located. With the CG located aft of the aerodynamic center, the lift force will give a nose-up pitching moment. The designer has to make sure that the natural downward pitching moment is balanced out by the lift moment.

Most airplanes have a tail of some sort, and it provides the balancing moment needed to counteract the downward pitching moment that results from the generation of lift. As the angle of attack of the wing is changed in flight, the moment from the tail surfaces has to be continually changed to maintain a trimmed condition. The longer the tail, the smaller amount of force that is needed to maintain stable flight. Take a look at a bat airplane with a very short tail, and notice how it has a tendency to quickly to pitch up/down while in flight. Compare this with a pattern airplane with a long fuselage, and its very stable flight characteristics.

You may want to experiment with how the location of the CG affects aircraft performance. Take one of your airplanes and make sure the CG is located where shown on the plans. Fly it several times and take note of its performance and stability characteristics. Now rebalance the aircraft so the CG moves forward a little, maybe a 1/4" or so, and fly it again. You should see a marked increase in its stability, and it should resist any action that attempts to move it about the lateral and vertical axes. You may move the CG even further forward, but be careful not to move it so much that the plane won’t respond.

Now move the CG slightly aft of the designated point. Depending on your airplane, you may want to move the CG in small increments, maybe as small as 1/8" at a time. With each flight you should notice a marked decrease in stability, but a much greater response to control inputs. Be careful not to move the CG so far aft that the airplane become unstable. If that happens, you probably will find yourself needing to build another airplane.

While this brief discussion about center of gravity and stability will not qualify you to be an aerodynamic engineer, you should have a better understanding of how to increase the stability or the agility of your airplane. Next month we will investigate ground effect and tip vortices. Until then check those planes and make sure the CG is where it belongs.