CORE SUBJECTS: PHYSICS, MATHEMATICS

IF YOU'VE EVER STRUGGLED TO WALK UP stairs with a heavy suitcase or grocery bags, or get up from your chair after a full holiday meal, you've experienced a key concept about flying: It takes more energy to move a larger mass than it does a smaller one. Similarly, it takes more energy to make a large, heavy airplane fly versus a small, light one. A Boeing 747 has the thrust to move way more mass than its little Cessna or Piper brethren. But, if you overload any airplane, you can roll down the length of the runway and never leave the ground—the airplane just can't generate enough lift to overcome the heavy weight.

Aircraft engineers set design limits on airplanes before they leave the factory, and these specifications tell the pilot how much weight the aircraft can handle—whether that weight is represented by people, bags, or fuel. Pilots carefully calculate the weight that they put on the airplane before they take off. Because if they don't, the results can be grim.

Not only does the total weight have to be less than certain absolute limits, it can't be put in the wrong place either. Ever try to jam a heavy load into the trunk of a car, only to watch the rear end sink to the axle? That's no good for the car, to be sure, but a similarly out-of-kilter condition bodes even worse for an airplane.

An airplane balances on two points as it flies through the air, its *center of gravity (CG)* and its *center of pressure* or *center of lift*. The center of pressure is determined by where the total lift created by the wings is concentrated, an average of all the lift vectors emanating from the wing's upper surface. Likewise, the CG is the fulcrum point of balance for all the weight on board the airplane, and the airplane itself (including the wings, the engine, and the fuel).

The center of pressure and the CG work in conjunction to determine the airplane's longitudinal or *pitch stability*. An airplane is typically designed so that its center of pressure is located aft of the CG. This creates a situation in which, if the airplane's nose is abruptly pitched downward, the aerodynamic forces on the airplane will cause it to pitch back up, returning it to level flight.

The CG of the empty airplane is usually located somewhere along the airplane's fuselage near the intersection of the cabin and wings; in most cases this empty CG is close to an optimum CG for the airplane. The farther a weight is placed from the CG, the more it can move the CG away from the optimal position. This is why the fuel tanks are often located near the empty CG of the airplane, so they can be filled without adversely affecting the CG. Consequently, as the airplane uses up the fuel, the change in weight doesn't affect the airplane adversely in flight.

Airplanes have a CG range in which normal operations are possible. If you put a heavy weight near the tail of the airplane, and thus take the airplane out of its operational CG range, the airplane may be too nose-high and therefore difficult or impossible to control. On the other hand, if you move weight too far forward, and ahead of the operational CG range, you may make the airplane so nose heavy that you cannot pull back on the controls hard enough to lift off the runway on takeoff.

Either way, too much weight or too much weight in the wrong place can be hazardous to flying an airplane.

The weight of the pilot and any passengers affect the aerodynamics and handling of an airplane.

ACTIVITY: Weight and gravity

Photocopy this activity for classroom use.
Go to www.aopa.org/path for student worksheets.

TEACHERS:

From this activity, students will learn how to determine the Center of Gravity of an object. They'll also learn how the Center of Gravity can shift when weight is placed in different locations on the same object.

MATERIALS:

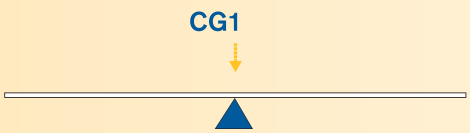
Yardstick or ruler
Two rolls of masking tape
Stickers to label different points on the yardstick (tape will work too)

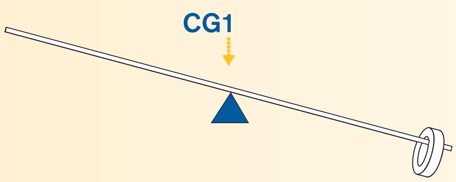
TO DO IT:

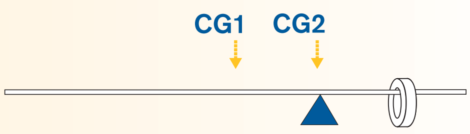
If an object weighs anything, it has a Center of Gravity or CG. As a reminder, this is the fulcrum point at which all the weight in an object balances. It is harder to find the CG on an irregular-shaped object like an airplane, but pilots must be aware of where the CG is during flight and exactly how changes in where weight is placed can affect the CG.

Engineers provide an optimal CG that provides the best overall performance of the airplane. While the placement of fuel is held constant by the location of the fuel tanks, engineers also provide pilots with the best options for placing weight, such as passengers and cargo, so that the CG does not move too far from its optimal position. See for yourself the effect of weight movement on the CG.

- Balance the yardstick on your finger until it hangs evenly. Mark this point on the yardstick with masking tape and label it CG1.
- Tear off a long enough piece of masking tape from one roll to affix the other roll of tape to the yardstick. Pick any point.
- Try and balance the yardstick on your finger at CG1. What happens? Now find the new CG for the yardstick. Mark it CG2.
- Take the same roll of tape and move it somewhere else along the yardstick away from CG1. Find the CG and mark it CG3. The yardstick with one roll of tape attached weighs exactly the same. Is the CG in the same place now that the weight has shifted? If it has moved, how far has it moved, relative to how far the weight moved?
- Have students take other common objects around the classroom and balance them to determine the CG.







ACTIVITY: Center of gravity

Can you guess where the Center of Gravity is on these airplanes?