Lt Col Richard Lowe sat toward the back of a commercial flight taking off from Denver International Airport on 20 December 2008 when a powerful gust of wind slammed into the airliner. The plane lurched off the runway and, after several bounces into the air, came to a rough landing that damaged the fuselage and set the aircraft’s right side on fire.

Lowe, a reservist, is a flight instructor with the 340th Flying Training Group. He’s also a pilot with Continental Airlines. With 10,000-plus flying hours, the colonel had the experience needed to remain calm, assess the situation, and jump into action, even though he was simply hopping a ride aboard Continental Flight 1404 just like any other passenger.

With flames licking the aircraft, it was important to get everyone out as soon as possible because the plane would eventually explode. Lowe first helped a couple of passengers off the aircraft, then assisted two injured crew members. Lowe returned to the aircraft several times to aid others and check that no one was still onboard. The colonel later told a fellow Airman that on his last trip into the burning plane he could feel the hair stand up on the back of his neck. The plane exploded seconds after he exited.
For his courage, Colonel Lowe received the Airman’s Medal at a ceremony in 2010 at the Air Force Reserve Command Joint Reserve Base in Fort Worth, Texas. The military awards the medal for “heroism not involving actual conflict with an armed enemy.” It is the highest noncombat-related award granted by the Air Force. Lowe also received a presidential citation from the Air Line Pilots Association for his actions.
The Axes of Rotation and How the Primary Flight Controls Work

Flight takes place in three dimensions. A pilot’s job is to control an aircraft’s attitude in this three-dimensional space. Attitude is an aircraft’s orientation, or angle, in relation to the horizon.

During flight, an aircraft rotates about its center of gravity. This rotation is described by a three-dimensional coordinate system made up of three principal axes. The center of gravity is the central point of this coordinate system, and the three axes starting at the center of gravity are perpendicular to one another (Figure 4.1).

The yaw axis (vertical axis) is a line that starts at the center of gravity, runs perpendicular to the wings, and is directed toward the aircraft’s lower surface. Yaw is the side-to-side motion of an aircraft’s nose. The pitch axis (lateral axis) is a line that starts at the center of gravity and runs from wingtip to wingtip. (You read in Chapter 1, Lesson 1 that pitch is the up-and-down motion of an aircraft’s nose.) The roll axis (longitudinal axis), too, is a line that begins at the center of gravity, is perpendicular to the yaw and pitch axes, and runs from nose to tail. Roll is the up-and-down motion of an aircraft’s wings.

Wing Tips

The terms roll, pitch, and yaw were originally nautical terms. Aircraft and ships have similar motions. Both roll along their longitudinal axis. Both pitch about their lateral axis (in aircraft, wingtip to wingtip). And both yaw about their vertical axis.
A pilot works with control surfaces to direct an aircraft’s yaw, pitch, and roll. You read in the previous lesson about rudders, which control yaw, and elevators, which control pitch. The other control surface is the ailerons. An aileron is a small hinged section on the outboard portion of a wing.

These control systems respond differently, depending on airspeed. Their function is to change airflow and pressure distribution over and around the airfoil. Moving any one of the control surfaces changes the airflow and pressure. The changes in airflow and pressure distribution then affect the lift and drag produced by the combination of airfoil and control surface, and they let a pilot direct the aircraft about the three axes of rotation.

Pilots maneuver ailerons to control their roll about the longitudinal axis. Ailerons usually move in opposite directions. When one deflects up on one wing, the other deflects down on the other wing. For smaller aircraft, pilots move these hinged devices by means of a control stick—a handle attached by cables, pulleys, or some other means to control surfaces for the purpose of controlling them. Many times newer aircraft use advanced computer systems for control.

If a pilot flips the aileron up on his or her right wing, the lift decreases on that wing because the camber has decreased. At the same time, the aileron is deflecting down on the left wing, and the lift on that wing has increased because the camber has increased. The result is the left wing rises, the right wing drops, and the aircraft rolls to the right (Figure 4.2).
Rudders, elevators, and ailerons are an aircraft’s primary control surfaces. They make an aircraft controllable and safe to fly. Aircraft also have secondary control systems composed of flaps, slats, and spoilers. They let a pilot maintain even more control over an aircraft’s performance. As you read in the previous lesson, these secondary devices play a major role during takeoff and landing.

During takeoffs and landings, aircraft velocity is fairly low. Yet lift depends on sufficient velocity as well as airfoil shape and wing area. Takeoffs call for high lift and low drag. Landings require high lift and high drag. Engineers design wings to maintain high lift during such low-speed flight. By increasing wing area and altering wing shape with movable secondary control surfaces, an aircraft can get the lift it needs in challenging speed conditions. One airplane part manufacturers design for takeoffs and landings is the wing flaps, which you read about in the previous lesson.

Flaps, which sit at a wing’s trailing edge, move down via hinges and move aft on metal tracks in the wing. By deploying the flaps down, a pilot increases the airfoil’s camber and this increases lift. By sliding the flaps aft, a pilot increases wing area, which increases the lift surface. Furthermore, moving the flap aft also increases drag, which is important, because pilots need to slow down when landing.

**Types of Flaps**

Wing flaps come in four varieties: plain, split, slotted, and Fowler (Figure 4.3). The *plain flap* is the simplest. It attaches at the trailing edge of the wing and, when deployed, increases camber and lift. It also increases drag because the surface bends into the main airflow, so the plane is subject to a nose-down pitching moment.
Orville Wright and J. M. Jacobs designed the *split flap* in 1920. The flap is hinged under the wing’s trailing edge. It rotates down to generate lift, as the plain flap does, and increases drag. This helped a pilot descend toward the runway at a steeper rate than then-current wings would allow and thus made landing approaches easier.

The most commonly used flap is the *slotted flap*. The slotted flap sits in a groove carved into the underside of a wing’s trailing edge. It generates more lift than plain and split flaps. When pivoted down, a duct forms between the lower surface of the wing’s trailing edge and the flap’s leading edge. High-energy air below the wing pours through this path to the flap’s upper surface. It next accelerates the upper surface boundary layer and slows airflow separation, which gives the pilot more lift. This type of flap also generates needed drag but doesn’t interfere with lift.

The fourth type of flap is the *Fowler flap*, which is a type of slotted flap. However, it doesn’t have hinges, but instead uses metal tracks to slide backward and pivot down. When moderately extended, the Fowler flap increases lift by greater camber and wing area. When fully extended downward, however, the flap increases drag but provides little additional lift.

![Different types of wing flaps](Reproduced from US Department of Transportation/Federal Aviation Administration)
The Effects of Slats on Flight

At the front of the wings on some aircraft are slats that you move like flaps to generate more lift. Sliding slats forward increases the lift surface by increasing wing area. Rotating a slat’s leading edge down increases camber, which also helps with lift. (Note that not all slats increase camber, however.)

Aircraft use four types of slats: fixed slots, movable slats, leading edge flaps, and leading edge cuffs (Figure 4.4). The fixed slot is fixed in place, so it doesn’t move, swivel on hinges, or slide, and it doesn’t increase wing camber. It is also a fixed distance from the airfoil’s leading edge, and so forms a long, thin opening along the wing’s length between the fixed slot and the airfoil. The fixed slot increases lift because, like the slotted flap, it channels airflow to a wing’s upper surface to delay airflow separation at higher angles of attack. In this way it delays stall.

Movable slats slide along tracks. At a low angle of attack, high pressure at the wing’s leading edge pins the slats against the wing’s leading edge. But at a higher angle of attack, the high-pressure area slips under the wing so the slats glide forward. When the slats open, the airflow from beneath the wing moves over the wing’s upper surface and delays airflow separation.
Leading edge flaps are yet another invention. They increase lift and wing camber and decrease the size of the nose-down pitch produced by trailing edge flaps. They extend down and forward from a hinge under the wing’s leading edge. Extended just a bit, they increase lift more than drag. Fully extended, drag increases more than lift.

The fourth type of slat is the leading edge cuff. Manufacturers and pilots slip these fixed devices onto a wing’s leading edge either during or after assembly to increase lift and wing camber. They curve the wing’s leading edge down and forward. The airflow attaches to the wing’s upper surface at higher angles of attack and lowers the stall speed. So with a leading edge cuff installed, an aircraft can assume a higher angle of attack without reaching a critical angle of attack when landing at relatively low speeds. Leading edge cuffs can decrease efficiency at cruising speeds, although improved technology has erased some of this drawback.
The Effects of Spoilers on Flight

Spoilers are small, flat plates that attach to the tops of the wings with hinges. When a pilot deploys a spoiler, it pivots up into the airstream. A spoiler's purpose is to “spoil” the airflow, increasing drag and decreasing lift. Spoilers have a different role than flaps and slats, which pilots use to increase lift. Designers refer to spoilers as high-drag devices.

Spoilers Deployed on Both Wings

Raising spoilers on both wings slows an aircraft in any phase of flight. Pilots also use the spoilers to “dump” lift, which forces an aircraft to descend more rapidly. Once on the runway, pilots raise their spoilers to keep the aircraft on the runway by erasing lift. This also improves the efficiency of the brakes by shifting the aircraft's weight from the wings to the wheels. Friction forms between the wheels and the runway because of the loss of lift and the transfer of weight. In addition, the spoilers continue to slow the plane while rolling to a stop on the ground (Figure 4.5).

Spoiler Deployed on One Wing

Raising spoilers on only one wing causes a rolling motion. Pilots use this method to bank—to roll or tilt sideways—an aircraft in flight. When banking, one wingtip falls and the other climbs. If you deploy a spoiler on the right wing, this decreases...
the lift and raises the drag on the right wing because the spoiler has disturbed
the airflow over that wing. As a result, the right wing dips down, the left wing rises,
and the aircraft banks and yaws right.

Spoilers cause torque, just as rudders, elevators, and ailerons do. Torque results
in rotation. The net torque—the difference in forces—is what causes the aircraft
to rotate about the center of gravity. For instance, after a pilot deploys a spoiler on
the right wing, an aircraft will roll clockwise to the right. But if a pilot tilts a spoiler
on the left wing, the aircraft will roll counterclockwise to the left.

The Elements of Controlled Flight

Flight consists of a number of phases: takeoff, climb, cruise, descent, and landing. Each of these stages of
flight applies the forces and control surfaces you’ve
read about in this and previous lessons.

Takeoff, Climb, Cruise, Descent, and Landing

Pilots taxi their aircraft along a runway or taxiway before and after a flight. To taxi
is to move slowly on the ground before takeoff and after landing. Takeoff begins from a
standstill and accelerates to takeoff speed to get into the air. Landing involves touching
down on the runway at a landing speed and slowing down to zero speed.

Takeoff

During the takeoff phase of flight, engines provide the thrust that gets the aircraft
from zero speed to a speed sufficient for takeoff. The thrust is usually set to a
maximum at this stage. The runway must be long enough for the aircraft to reach
takeoff speed. A safe takeoff speed is comfortably above stall speed and gets an
aircraft into the climb phase with satisfactory aircraft control.

Some other factors affect takeoff. These include aircraft weight, wind, and runway
slope and condition, which all help determine how long a runway an aircraft
needs to take off safely. As weight increases, requirements change: an aircraft must
accelerate to a higher takeoff speed, and it must combat an increase in drag and
friction with the ground.

Wind conditions are also important. Headwinds reduce takeoff distance because
they increase the rate of airflow over the wings from leading to trailing edge and
therefore contribute to lift. Tailwinds increase takeoff distance for just the opposite
reason. (A headwind is wind blowing against the direction of travel. A tailwind is
wind blowing from behind.)

How much a runway slopes and the condition of the surface (wet, icy, etc.) also
affect takeoff and landing distance. The slope influences how long it will take
an aircraft to get off the ground or come to a stop. The runway condition affects
such factors as ground roll and brake efficiency.
Climb

Once an aircraft has accelerated to a sufficient takeoff speed along the runway, the pilot raises its nose and the plane becomes airborne. The aircraft now enters the climb phase (Figure 4.6).
As soon as the aircraft reaches a positive rate of climb, the pilot raises the landing gear and accelerates out to the speed at which he or she retracts the flaps. The pilot raises the flaps and accelerates to climb speed. He or she then sets the engines on climb power, which is usually below full power. Thereafter, the pilot climbs until reaching the assigned level-off altitude.

**Cruise**

Once the pilot gets to cruising altitude, the aircraft remains there until arriving near the destination airport. Sometimes the aircraft must change altitude because of weather or turbulence. The flight crew members now concern themselves with weather conditions, avoiding other aircraft, fuel consumption, and perhaps passenger issues, among other things. When the aircraft gets near the destination, the pilot and crew prepare to descend and land.

**Descent and Landing**

An aircraft descends from its cruising altitude by decreasing thrust and/or engaging the secondary control systems. During the final phases of descent, a pilot will lower the aircraft’s landing gear to prepare for eventual contact with the runway.

When landing, the pilot continues to engage the flaps, slats, and spoilers to generate the high lift and high drag that landings require. The minimum safe speed is that which is above stall. The speed must also be enough to provide the pilot sufficient control and ability to abort a landing, climb, and circle around for another try.

The YAL-1A, a modified Boeing 747-400F known as the Airborne Laser, lands at Edwards Air Force Base, California. Courtesy of USAF.
Adequate runway length for a landing depends on wind, weight, and runway characteristics and slope, among other considerations. According to federal regulations, the landing distance is that length of runway needed to land and come to a complete stop from a point 50 feet above the threshold end of the runway (where the runway begins from the aircraft’s approach direction). The wheels generally won’t hit the runway until about 1,000 feet into the runway distance. The rules adjust depending on the aircraft, however.

Landings can be rough on brakes and tires, so an aircraft takes advantage of aerodynamic drag to slow down. Once the aircraft decelerates sufficiently, drag is no longer great enough to be of much use, so the pilot has to rely on the brakes for any continued deceleration. (Some aircraft also use their engines to slow down by using a device called a “thrust reverser,” which reverses an engine’s thrust.)

This lesson covered yaw, pitch, roll, primary and secondary control surfaces, and the different phases of flight. Engines usually provide the thrust to help make all these motions and controls possible. The next lesson will look at a number of different engine types and the scientific laws that explain how they operate.
Lesson 4 Review

Using complete sentences, answer the following questions on a sheet of paper.

1. During flight, an aircraft rotates about which point?
2. What must a pilot work with to direct an aircraft’s yaw, pitch, and roll?
3. How can an aircraft get the lift it needs in challenging speed conditions?
4. Who designed the split flap in 1920?
5. Sliding slats forward does what?
6. Rotating a slat’s leading edge down does what?
7. Once on the runway, why do pilots raise their spoilers?
8. What kind of motion will result by raising spoilers on only one wing?
9. What are some other factors that affect takeoff?
10. Adequate runway length for a landing depends on which considerations?

APPLYING YOUR LEARNING

11. Describe how a pilot would deploy the secondary control surfaces during a descent (which ones would he or she deflect up, down, aft, forward, or some combination) and what effect each deployment would achieve.