The last thing Karen remembered was looking straight up and seeing nothing but blue sky. She had started the pullup at 10,000 feet and a constant 3 Gs. About halfway through the loop, her vision started to tunnel and turn gray. By the time she had returned to what she thought was her starting position, she had lost all vision and was literally flying by the “seat of her pants.” After several seconds, her vision returned, and the cockpit instruments showed that she was at 10,300 feet and in a slight descent. It was an uncomfortable situation, and she was glad that she had put a lot of space between her aircraft and the ground.

ACCELERATION IS A PART OF FLYING that can uniquely affect the body in every axis. In most cases, other than for the high-performance fighter aircraft of the military, there is little chance for high-G maneuvers, except in acrobatic aircraft or extreme unusual attitudes. Because such extreme situations are uncommon, the pilot can usually tolerate these forces that are present without impairment; however, it is important that the pilot be familiar with acceleration forces because newer high-tech aircraft are capable of pulling Gs often in unexpected situations. Furthermore, the physical forces and physiological response to any accelerative situations are the same and will, sometime in your flying, affect your performance in an unpredictable way.

Before discussing the forces of acceleration, certain terms must be reviewed. Speed describes the rate of movement of an object and is expressed as distance covered in a unit of time (miles per hour). Velocity describes both the magnitude and direction of motion and is measured in distance per unit of time in a particular direction. The velocity of a body changes if it changes direction, speed, or both. Acceleration is a change of velocity in magnitude or direction and is generally expressed as distance traveled per second.

TYPES OF ACCELERATION

Acceleration is the rate of change in velocity and is measured in G units. As a point of reference, the pull of gravity is considered 1 G. Several forms of acceleration are distinguished by their impact on speed and direction:

- Linear acceleration is a change in speed without change in direction, such as an increase in thrust in straight-and-level flight.
- Radial (or centripetal) acceleration can occur in any change of direction without change in speed—for example, when executing a turn or when pulling out of a dive.
Angular acceleration occurs when both speed and direction are changed, as in a tight spin. For practical purposes, this type is not common, but it can play a role in disorientation.

$G$ force in aviation usually refers to the force exerted on the long (or vertical) axis of the body, but it can also affect the horizontal and transverse axis. How these $G$ forces impair the pilot is determined by the intensity and duration as well as the direction. For example, jumping off a table that is four feet high can result in a force of 12–15 $Gs$; however, a pilot in a 12-G turn would be unconscious in about two seconds.

In general, therefore, the body can usually tolerate about 5 $Gs$ for up to about five seconds if the pilot isn’t otherwise protected and adapted to tolerating higher $Gs$. Beyond that point, the pilot can experience a variety of symptoms, some incapacitating, most distracting or uncomfortable, and often disorienting.

Positive $G$ forces occur when the body is accelerated in the headward direction and the body is forced downward into the seat. Negative $G$ force is in the footward direction, and the body is lifted out of the seat. The body is less tolerant of negative $G$ forces than positive $G$ forces (Fig. 12-1).

**Figure 12-1** The three axes of $G$ forces that act on the body are horizontal, vertical, and transverse.
COMMON SITUATIONS IN CIVILIAN FLYING

The study of G forces is far more important in military aviation than in civilian flying. For civilian purposes, the discussion will be limited to predictable effects on the unprotected body and how the pilot can decrease his or her tolerance to unexpected G forces.

During any maneuver that produces positive Gs, the weight of the body is increased in direct proportion to the magnitude of the force. The 200-pound pilot on the ground will weigh 600 pounds under 3 Gs. More important is how the body organs are affected and how the physiology of the body is disrupted during this exposure.

The skeleton and soft tissues of the body can tolerate significant G forces without problems; however, the circulatory system, like any hydraulic system, is greatly affected by changes in G forces. This occurs because there is a direct effect on the hydraulic pressures of blood in the body, especially as the blood tries to get to the brain in a continuous flow (Fig. 12-2); therefore, in tight turns, rapid accelerations or deceleration during flight, and unexpected changes in flight resulting in accelerative forces, there will be physiological changes that can range from an awareness of pressure into the seat to various levels of consciousness and visual disturbances.

SYMPTOMS OF G FORCES

Most problems associated with G forces are related to the inability of the blood to reach crucial organs of body functions, specifically the heart and the brain. If G forces are significant, the heart is unable to get blood from various parts of the body (such as parts distant from the heart like the lower abdomen and the legs) returned through the lungs and to the brain. The brain must have an adequate blood supply at all times. A lapse of even a few seconds can compromise oxygen levels to brain cells, and make impairment imminent. Since the eyes are an extension of the brain, visual changes will be the first symptoms noticed (Fig. 12-3).

Closely following visual changes will be a change in consciousness, which is obviously much more incapacitating. This is important to keep in mind because after the vision begins to change, various levels of unconsciousness are quick to follow. Of course, the pilot is unaware that she is approaching unconsciousness, and her fate now is dependent on how soon and how much the G forces are reduced.

To complicate matters, even after the pilot regains consciousness, there is a period of amnesia where the pilot doesn’t know what happened. This whole sequence can take up to 20-30 seconds, which doesn’t sound very long, but it is plenty of time for a pilot to lose control of the aircraft and be unable to recover.

Some of the more specific symptoms include the feeling of pressure in the early stage of acceleration stress. The increased weight of the body’s organs tends to pull the diaphragm down and thus interferes with respiration.
Positive acceleration
(sustained)

As acceleration starts, blood begins to pool
Pooling increases, vision begins to fade (greyout)
Blackout occurs, no blood in brain about 5 Gs

Negative acceleration
(sustained)

Blood pools in the head, face feels flushed
Effect continues, vision begins to redden
"REDOUT" occurs, feeling of eyes "popping out"

Maximum G factor in negative acceleration for pilots is 3
Effect on pilot—5 seconds

Figure 12-2 Acceleration forces to the body (sustained).
Figure 12-3  Acceleration and time at maximum G required to produce visual symptoms and unconsciousness. Curves showing different rates of G development are given to show the importance of this parameter for the occurrence of peripheral vision and blackout.

As G forces increase or persist, there is a change in the hydrostatic pressure in the circulatory system. With a force of 5 Gs, this hydrostatic pressure is higher than the pressure produced by the heart pumping, and blood no longer gets to the brain. At this point, unconsciousness occurs rapidly.

Prior to this final event, there is a blackout period, at about 4 Gs. During this time, the pilot has a complete loss of vision but is still conscious. Tunnel vision might precede this stage and would be the first indication of impending impairment. Since hypoxia (lack of oxygen getting to the brain cells) is the symptom and decreased blood pressure is the cause, the combination results in a period of disorientation and loss of memory that can last a minute or more.

**TOLERANCE TO G FORCES**

Tolerance limits are usually fairly constant between individuals; however, various factors can increase or decrease one's tolerance to intensifying G forces. The most obvious is anything that interferes with the efficiency of the cardiovascular system.

The body, however, is able to increase its tolerance through a number of other factors. This includes being in excellent physical condition. Another is to use what the military calls the M-1 or L-1 maneuver, or "grunt," which
involves tightening all skeletal muscles and straining hard while holding your breath. (An L-1 maneuver included some exhalation during the straining.) It's somewhat related to straining when constipated or trying to lift a heavy weight. Then take a quick breath, and do it again about every 4–5 seconds until the G forces have diminished. This technique raises arterial blood pressure enough so as to endure an additional 1.5-G force or more.

NEGATIVE G FORCES

Experiencing negative G forces is a very uncomfortable feeling that is not often experienced except in aerobatic aircraft. It's similar to going over the top on a Ferris wheel ride. Here, hydrostatic blood pressure is the reverse of positive Gs, with the blood being forced to the head and into the brain tissues. The symptoms are commonly referred to as a “redout,” compared to “blackout” in positive Gs. A force of only 3 negative Gs is considered the limit for most humans.

Most G-force stresses are short lived in civilian aviation (except for aerobatics), and the body usually tolerates these forces well. As with most physiological events, it’s the recognition beforehand that such things can happen to the body in flight that keeps the pilot out of trouble. The susceptibility of the pilot to any G forces is related to the physical condition of the pilot as well as the level of hypoxia and fatigue.