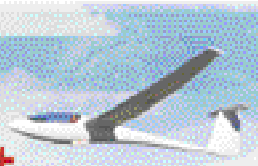
CHAPTER 3

Aerodynamics of Flight



To understand what makes a glider fly, you need to have an understanding of aerodynamics. This chapter discusses the fundamentals of the aerodynamics of flight.

AIRFOIL

Airfoil is the term used for surfaces on a glider that produce lift. Although many different airfoil designs exist, all airfoils produce lift in a similar manner.

Some airfoils are designed with an equal amount of curvature on the top and bottom surface. These are called symmetrical airfoils. Airfoils that have a different curvature on the bottom of the wing when compared to the top surface are asymmetrical.

The term **camber** refers to the curvature of a wing when looking at a cross section. A wing possesses upper camber on its top surface and lower camber on its bottom surface. The term leading edge is used to describe the forward edge of the airfoil. The rear edge of the airfoil is called the trailing edge. The **chord line** is an imaginary straight line drawn from the leading edge to the trailing edge.

Relative wind is created by the motion of an airfoil through the air. Relative wind may be affected by movement of the glider through the air, as well as wind sheer. When a glider is flying through undisturbed air, the relative wind is represented by its forward velocity and is parallel to and opposite of the direction of flight.

ANGLE OF ATTACK

The **angle of attack** is the angle formed between the relative wind and the chord line of the wing. You have direct control over angle of attack. By changing the **pitch attitude** of the glider in flight through the use of the elevator/stabilator, you are changing the angle of attack of the wings. [Figure 3-1]

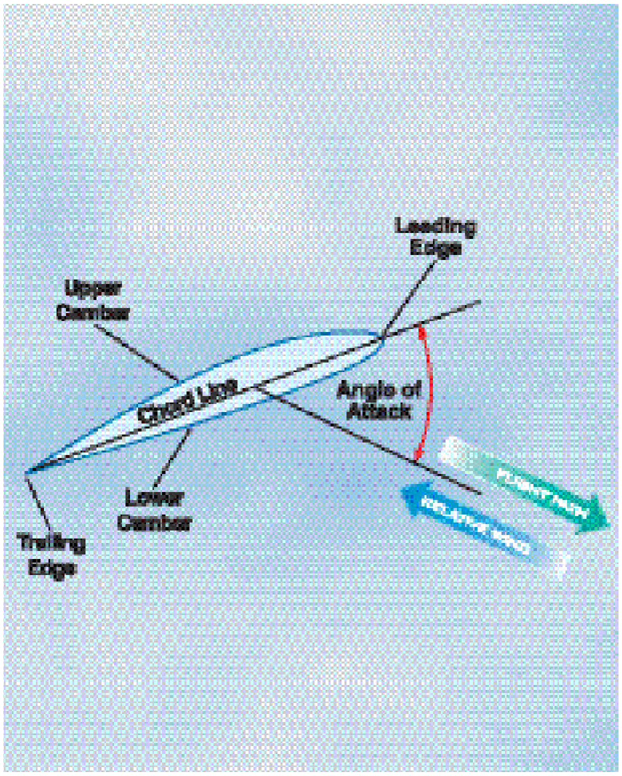


Figure 3-1. Aerodynamic terms of an airfoil.

ANGLE OF INCIDENCE

The wings are usually mounted to the fuselage with the chord line inclined upward at a slight angle. This angle, called the **angle of incidence**, is built into the glider by the manufacturer and cannot be adjusted by the pilot's movements of the controls. It is represented by the angle between the chord line of the wing and the longitudinal axis of the glider.

CENTER OF PRESSURE

The point along the wing chord line where lift is considered to be concentrated is called the **center of pressure**. For this reason, the center of pressure is sometimes referred to as the center of lift. On a typical **asymmetrical airfoil**, this point along the chord line changes position with different flight attitudes. It moves forward as the angle of attack increases and aft as the angle of attack decreases.

FORCES OF FLIGHT

Three forces act on an unpowered glider while in flight—lift, drag, and weight. Thrust is another force of flight that enables self-launch gliders to launch on their own and stay aloft when soaring conditions subside. The theories that explain how these forces work include

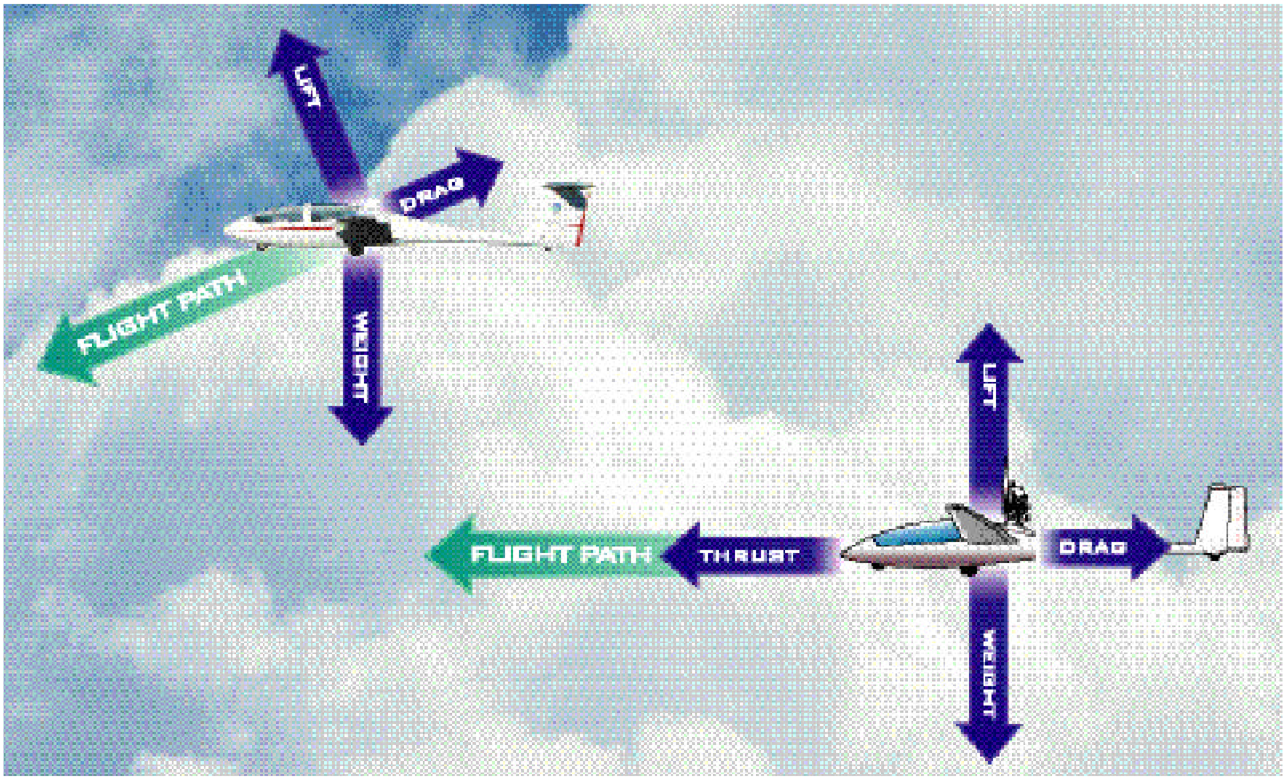
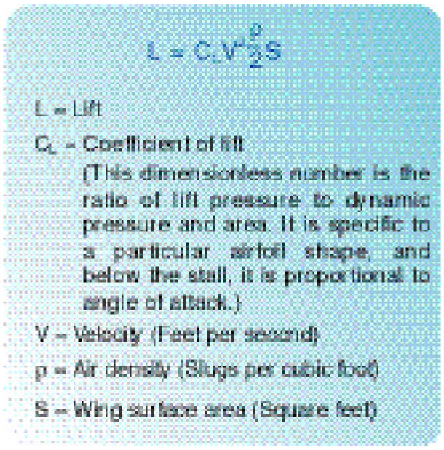


Figure 3-2. The forces that act on a glider in flight.

Magnus Effect, Bernoulli's Principle, and Newton's laws of motion. [Figure 3-2]

LIFT

Lift opposes the downward force of weight and is produced by the dynamic effects of the surrounding airstream acting on the wing. Lift acts perpendicular to the flight path through the wing's center of lift. There is a mathematical relationship between lift, angle of attack, airspeed, altitude, and the size of the wing. In the lift equation, these factors correspond to the terms coefficient of lift, velocity, air density, and wing surface area. The relationship is expressed in Figure 3-3.



$$L = C_L V^2 \frac{\rho}{2} S$$

L = Lift

C_L = Coefficient of lift
(This dimensionless number is the ratio of lift pressure to dynamic pressure and area. It is specific to a particular airfoil shape, and below the stall, it is proportional to angle of attack.)

V = Velocity (Feet per second)

ρ = Air density (Slugs per cubic foot)

S = Wing surface area (Square feet)

Figure 3-3. The lift equation is mathematically expressed by the above formula.

This shows that for lift to increase, one or more of the factors on the other side of the equation must increase. Lift is proportional to the square of the velocity, or airspeed, therefore, doubling airspeed quadruples the amount of lift if everything else remains the same. Likewise, if other factors remain the same while the coefficient of lift increases, lift also will increase. The coefficient of lift goes up as the angle of attack is increased. As **air density** increases, lift increases. However, you will usually be more concerned with how lift is diminished by reductions in air density on a hot day, or as you climb higher.

MAGNUS EFFECT

The explanation of lift can best be explained by looking at a cylinder rotating in an airstream. The local velocity near the cylinder is composed of the airstream velocity and the cylinder's rotational velocity, which decreases with distance from the cylinder. On a cylinder, which is rotating in such a way that the top surface area is rotating in the same direction as the airflow, the local velocity at the surface is high on top and low on the bottom.

As shown in Figure 3-4, at point "A," a stagnation point exists where the airstream line meets on the surface and then splits; some air goes over and some under. Another stagnation point exists at "B," where the two air streams rejoin and resume at identical velocities. We now have upwash ahead of the rotating cylinder and downwash at the rear.

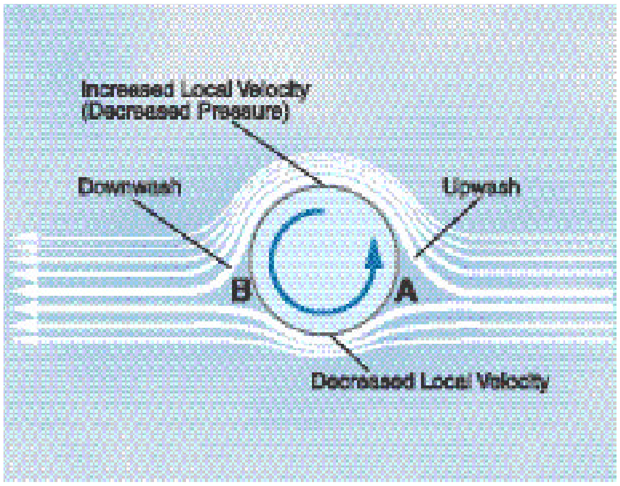


Figure 3-4. Magnus Effect.

The difference in surface velocity accounts for a difference in pressure, with the pressure being lower on the top than the bottom. This low pressure area produces an upward force known as the "Magnus Effect." This mechanically induced circulation illustrates the relationship between circulation and lift.

BERNOULLI'S PRINCIPLE

An airfoil with a positive angle of attack develops air circulation as its sharp trailing edge forces the rear stagnation point to be aft of the trailing edge, while the front stagnation point is below the leading edge. [Figure 3-5]

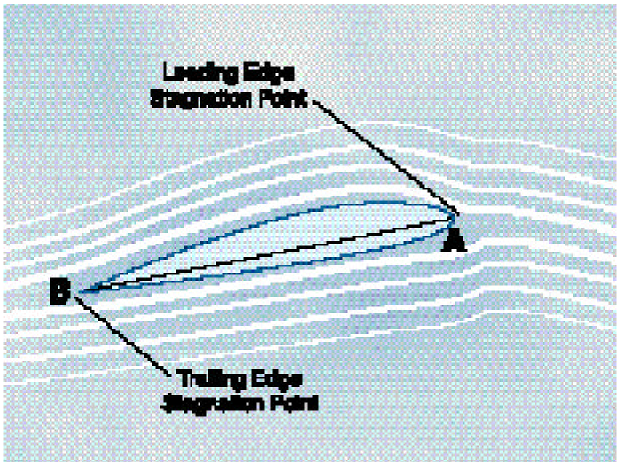


Figure 3-5. Stagnation points on an airfoil.

Air flowing over the top surface accelerates. The airfoil is now subjected to Bernoulli's Principle, or the "venturi effect." As air velocity increases through the constricted portion of a venturi tube, the pressure decreases. Compare the upper surface of an airfoil with the constriction in a venturi tube that is narrower in the middle than at the ends. [Figure 3-6]

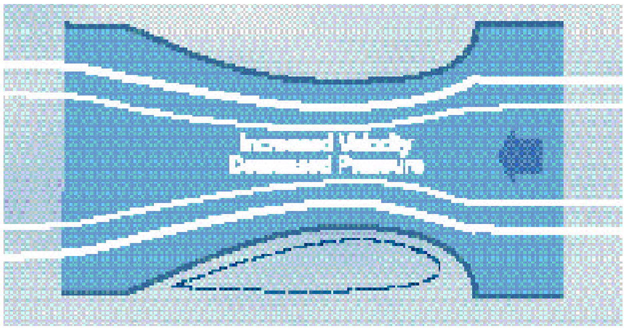
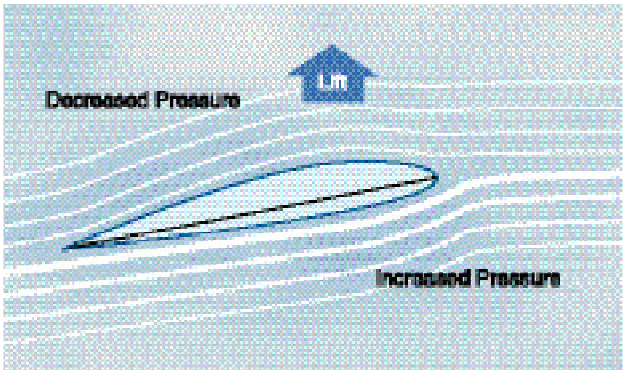


Figure 3-6. The upper surface of an airfoil is similar to the constriction in a venturi tube.

The upper half of the venturi tube can be replaced by layers of undisturbed air. Thus, as air flows over the upper surface of an airfoil, the camber of the airfoil causes an increase in the speed of the airflow. The increased speed of airflow results in a decrease in pressure on the upper surface of the airfoil. At the same time, air flows along the lower surface of the airfoil, building up pressure. The combination of decreased pressure on the upper surface and increased pressure on the lower surface results in an upward force. [Figure 3-7]



As angle of attack is increased, the production of lift is increased. More upwash is created ahead of the airfoil as the leading edge stagnation point moves under the leading edge, and more downwash is created aft of the trailing edge. Total lift now being produced is perpendicular to relative wind. In summary, the production of lift is based upon the airfoil creating circulation in the airstream (Magnus Effect) and creating differential pressure on the airfoil (Bernoulli's Principle).

NEWTON'S THIRD LAW OF MOTION

According to Newton's Third Law of Motion, "for every action there is an equal and opposite reaction." Thus, the air that is deflected downward also produces an upward (lifting) reaction. The wing's construction is designed to take advantage of certain physical laws that generate two actions from the airmass. One is a positive pressure lifting action from the airmass below the wing, and the other is a negative pressure lifting action from the lowered pressure above the wing.

As the airstream strikes the relatively flat lower surface of the wing when inclined at a small angle to its direction of motion, the air is forced to rebound downward, causing an upward reaction in positive lift. At the same time, airstream striking the upper curve section of the leading edge of the wing is deflected upward, over the top of the wing. The speed up of air on the top of the wing produces a sharp drop in pressure. Associated with the lowered pressure is downwash, a downward-backward flow. In other words, a wing shaped to cause an action on the air, and forcing it downward, will provide an equal reaction from the air, forcing the wing upward. If a wing is constructed in such form that it will cause a lift force greater than the weight of the glider, the glider will fly.

If all the required lift was obtained from the deflection of air by the lower surface of the wing, a glider would need only a flat wing like a kite. This, of course, is not the case at all. The balance of the lift needed to support the glider comes from the flow of air above the wing. Herein lies the key to flight. The fact that the most lift is the result of the airflow downwash from above the wing, forcing the wing upward, must be thoroughly understood in order to continue further in the study of flight.

It is neither accurate nor does it serve a useful purpose, however, to assign specific values to the percentage of lift generated by the upper surface of the airfoil versus that generated by the lower surface. These are not constant values, and will vary, not only with flight conditions, but also with different wing designs.

DRAG

The force that resists the movement of the glider through the air is called **drag**. Two different types of drag combine to form total drag—parasite and induced.

PARASITE DRAG

Parasite drag is caused by any aircraft surface, which deflects or interferes with the smooth airflow around the glider. Parasite drag is divided into three types—form drag, interference drag, and skin friction drag. [Figure 3-8]

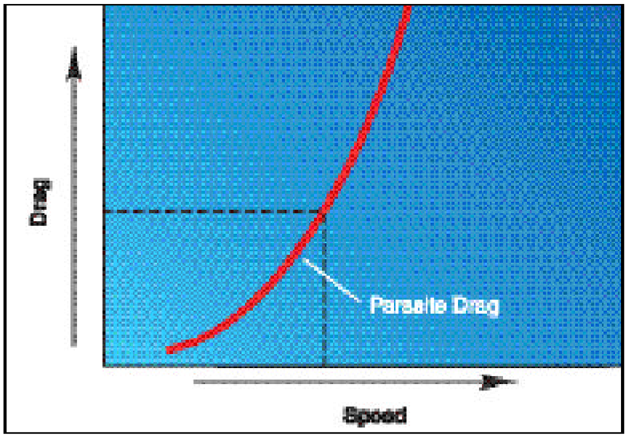


Figure 3-8. Parasite drag increases fourfold when airspeed is doubled.

FORM DRAG

Form drag results from the turbulent wake caused by the separation of airflow from the surface of a structure. The amount of drag is related to both the size and shape of the structure protruding into the relative wind. [Figure 3-9]

INTERFERENCE DRAG

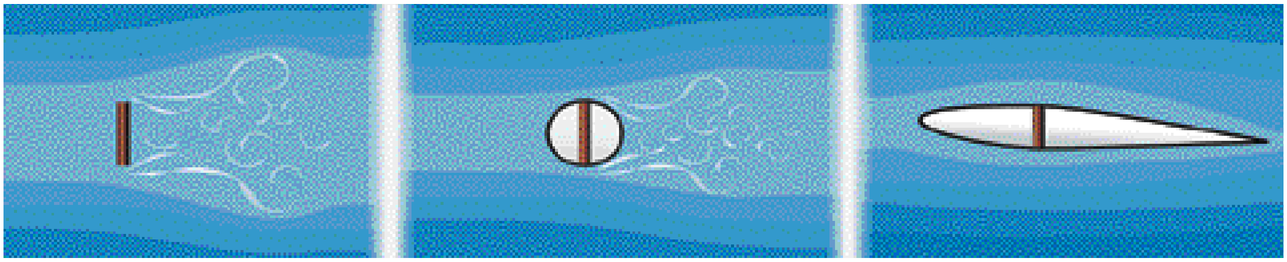
Interference drag occurs when varied currents of air over a glider meet and interact. Placing two objects adjacent to one another may produce turbulence 50 percent to 200 percent greater than the parts tested separately. An example of interference drag is the mixing of air over structures, such as the wing, tail surfaces, and wing struts.

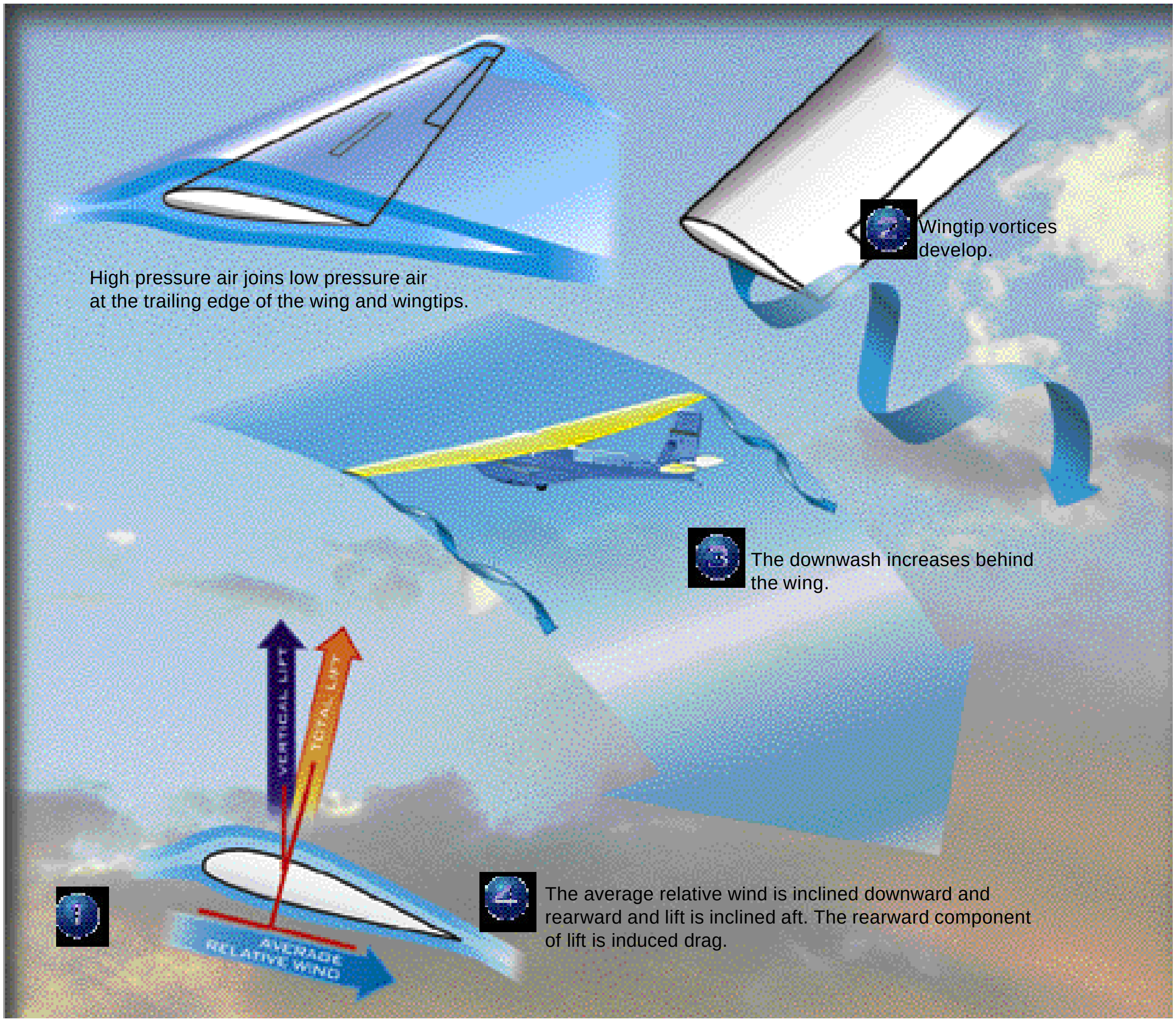
SKIN FRICTION DRAG

Skin friction drag is caused by the roughness of the glider's surfaces. Even though the surfaces may appear smooth, they may be quite rough when viewed under a microscope. This roughness allows a thin layer of air to cling to the surface and create small eddies, which contribute to drag.

INDUCED DRAG

The airflow circulation around the wing generates **induced drag** as it creates lift. The high-pressure air beneath the wing joins the low-pressure air above the wing at the trailing edge of the wingtips. This causes a spiral or vortex that trails behind each wingtip whenever lift is being produced. These





wingtip vortices have the effect of deflecting the airstream downward in the vicinity of the wing, creating an increase in downwash. Therefore, the wing operates in an average relative wind, which is deflected downward and rearward near the wing. Because the lift produced by the wing is perpendicular to the relative wind, the lift is inclined aft by the same amount. The component of lift acting in a rearward direction is induced drag. [Figure 3-10]

As the air pressure differential increases with an increase in the angle of attack, stronger vortices form and induced drag is increased. The wings of a glider are at a high angle of attack at low speed and at a low angle of attack at high speed.

TOTAL DRAG

Total drag on a glider is the sum of parasite and induced drag. The total drag curve represents these combined forces and is plotted against airspeed. [Figure 3-11]

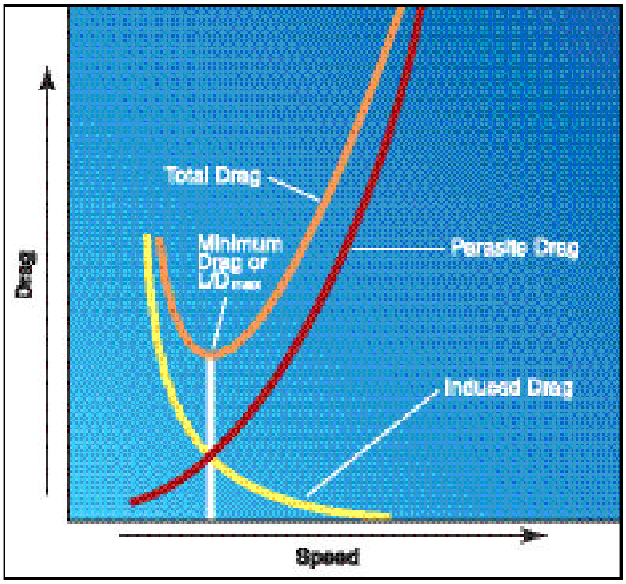


Figure 3-11. The low point on the total drag curve shows the airspeed at which drag is minimized.

L/D_{max} is the point, where lift-to-drag ratio is greatest. At this speed, the total lift capacity of the glider, when compared to the total drag of the glider, is most favorable. In calm air, this is the airspeed you can use to obtain maximum glide distance.

DRAG EQUATION

To help explain the force of drag, the mathematical equation $D=C_DqS$ is used. In this equation drag (D) is the product of drag coefficient (C_D), dynamic pressure (q), and surface area (S). The drag coefficient is the ratio of drag pressure to dynamic pressure. The drag coefficient is represented graphically by Figure 3-12. This graph shows that at higher angles of attack, the drag coefficient is greater than at low angles of attack. At high angles of attack, drag increases significantly with small increases in angle of attack. During a stall, the wing experiences a sizeable increase in drag. [Figure 3-12]

WING PLANFORM

The shape, or planform, of the wings also has an effect on the amount of lift and drag produced. The four most common wing planforms used on gliders are elliptical, rectangular, tapered, and swept-forward wing. [Figure 3-13]

Elliptical wings produce the least amount of induced drag for a given wing area. This design of wing is difficult to manufacture. The elliptical wing is more efficient in terms of L/D, but stall characteristics are not as good as the rectangular wing.

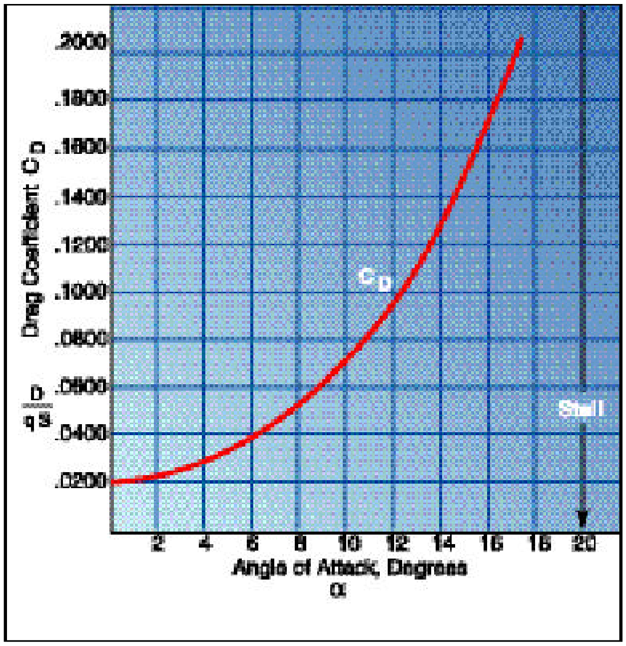


Figure 3-12. This graph shows drag characteristics in terms of angle of attack. As the angle of attack becomes greater, the amount of drag increases.

The rectangular wing is similar in efficiency to the elliptical wing but is much easier to build. Rectangular wings have very gentle stall characteristics with a warning buffet prior to stall and are easier to manufacture than elliptical wings. One drawback to this wing design is that rectangular wings create more induced drag than an elliptical wing of comparable size.

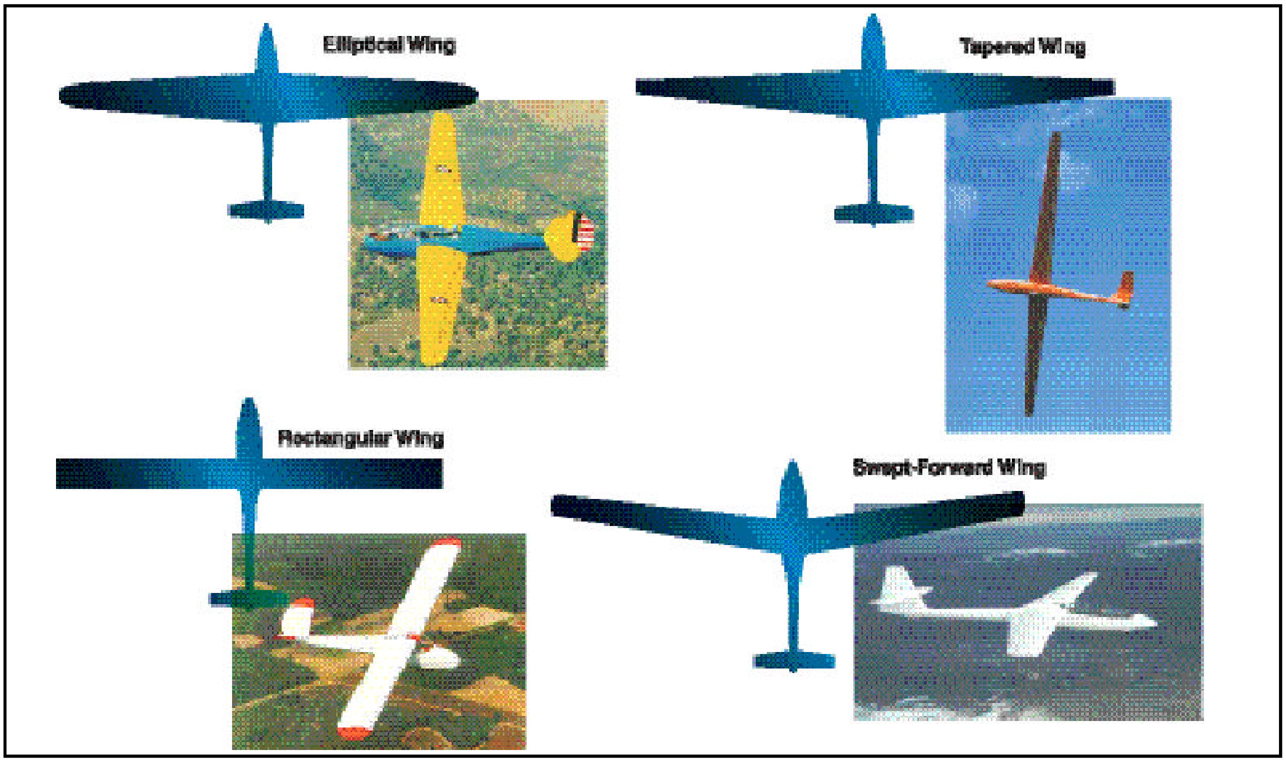


Figure 3-13. Planform refers to the shape of the glider's wing when viewed from above or below. There are advantages and disadvantages to each planform design.

The tapered wing is the planform found most frequently on gliders. Assuming equal wing area, the tapered wing produces less drag than the rectangular wing because there is less area at the tip of the tapered wing. If speed is the prime consideration, a tapered wing is more desirable than a rectangular wing, but a tapered wing with no twist has undesirable stall characteristics.

Swept-forward wings are used to allow for the lifting area of the wing to move forward while keeping the mounting point aft of the cockpit. This wing configuration is used on some tandem two-seat gliders to allow for a small change in center of gravity with the rear seat occupied or while flying solo.

Washout is built into wings by putting a slight twist between the wing root and wing tip. When washout is designed into the wing, the wing displays very good stall characteristics. As you move outward along the span of the wing, the trailing edge moves up in reference to the leading edge. This twist causes the wing root to have a greater angle of attack than the tip, and as a result stall first. This provides ample warning of the impending stall, and at the same time allows continued aileron control.

Dihedral is the angle at which the wings are slanted upward from the root to the tip. The stabilizing effect of dihedral occurs when the airplane sideslips slightly as one wing is forced down in turbulent air. This sideslip results in a difference in the angle of attack between the higher and lower wing with the greatest angle of attack on the lower wing. The increased angle of attack produces increased lift on the lower wing with a tendency to return the airplane to wings level flight.

ASPECT RATIO

The aspect ratio is another factor that affects the lift and drag created by a wing. **Aspect ratio** is determined by dividing the wingspan (from wingtip to wingtip), by the average wing chord. Glider wings have a high aspect ratio as shown in Figure 3-14. High-aspect ratio wings produce a comparably high amount of lift at low angles of attack with less induced drag.

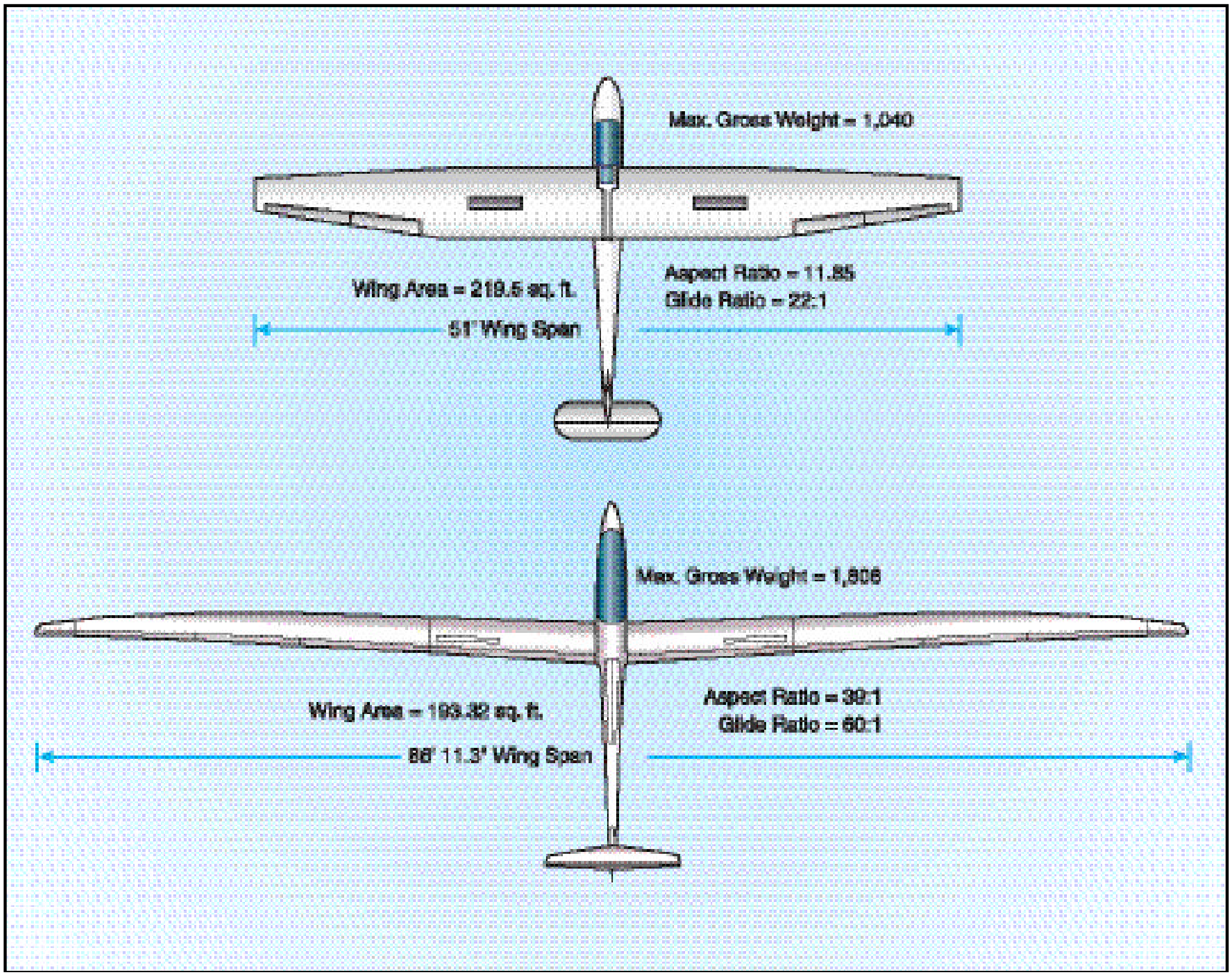


Figure 3-14. Aspect ratio is the relationship between the length and width of the wing and is one of the primary factors in determining lift/drag characteristics.

WEIGHT

Weight is the third force that acts on a glider in flight. **Weight** opposes lift and acts vertically through the center of gravity of the glider. Gravitational pull provides the force necessary to move a glider through the air since a portion of the weight vector of a glider is directed forward.

THRUST

Thrust is the forward force that propels a self-launch glider through the air. Self-launch gliders have engine-driven propellers that provide this thrust. Unpowered gliders have an outside force, such as a tow plane, winch, or automobile to launch the glider.

THREE AXES OF ROTATION

The glider is maneuvered around three axes of rotation. These axes of rotation are the **vertical axis**, the **lateral axis**, and the **longitudinal axis**. They rotate around one central point in the glider called the center of gravity (CG). This point is the center of the glider's total weight and varies with the loading of the glider.

When you move the rudder left or right, you cause the glider to yaw the nose to the left or right. Yaw is movement that takes place around the vertical axis, which can be represented by an imaginary straight line drawn vertically through the CG. When you move the ailerons left or right to bank, you are moving the glider around the longitudinal axis. This axis would appear if a line were drawn through the center of the fuselage from nose to tail. When you pull the stick back or push it forward, raising or lowering the nose, you are controlling the pitch of the glider or its movement around the lateral axis. The lateral axis could be seen if a line were drawn from one side of the fuselage to the other through the center of gravity. [Figure 3-15]

STABILITY

A glider is in equilibrium when all of its forces are in balance. **Stability** is defined as the glider's ability to maintain a uniform flight condition and return to that condition after being disturbed. Often during flight, gliders encounter equilibrium-changing pitch disturbances. These can occur in the form of vertical gusts, a sudden shift in CG, or deflection of the controls by the pilot. For example, a stable glider would display a tendency to return to equilibrium after encountering a force that causes the nose to pitch up.

Static and dynamic are two types of stability a glider displays in flight. **Static stability** is the initial tendency to return to a state of equilibrium when disturbed from that state. Three types of static stability are positive, negative, and neutral. When a glider demonstrates positive static stability it tends to return to equilibrium. A glider demonstrating negative static stability displays a tendency to increase its displacement. Gliders that demonstrate neutral static stability

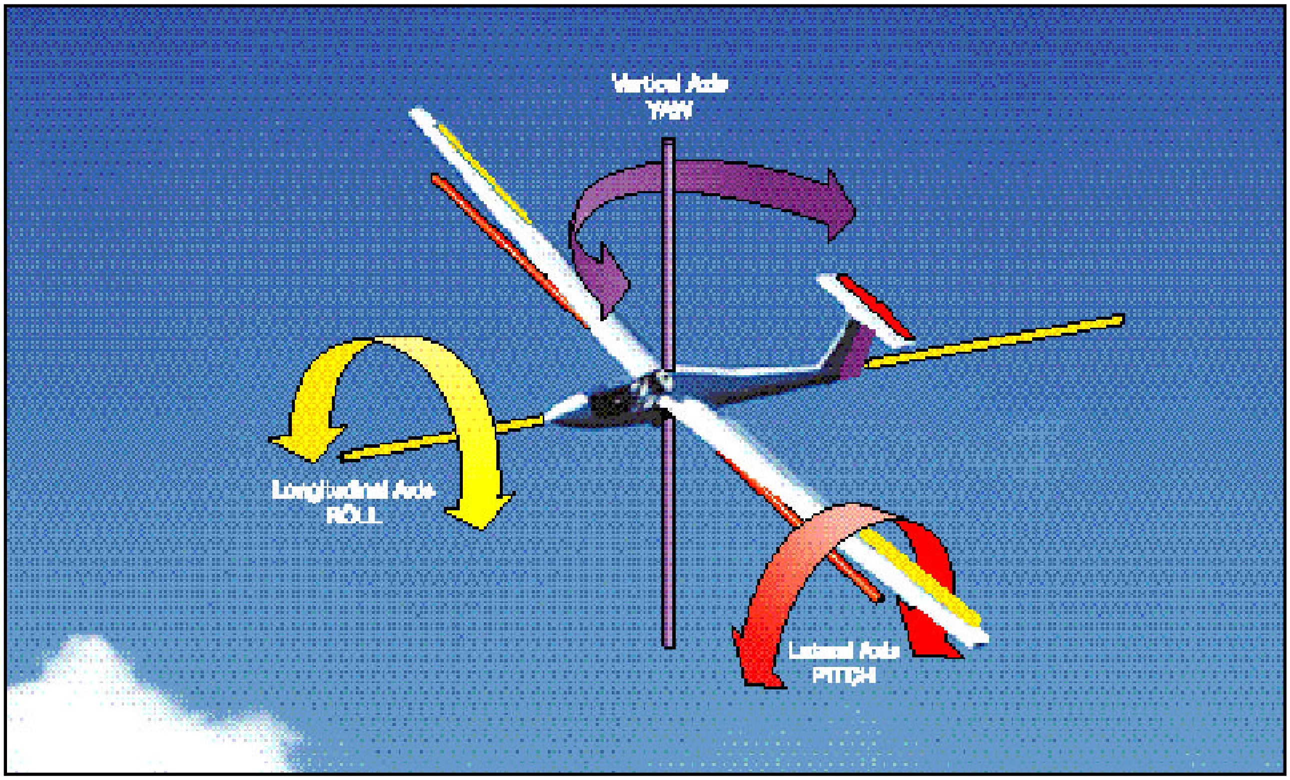


Figure 3-15. The elevator controls pitch movement about the lateral axis, the ailerons control roll movement about the longitudinal axis, and the rudder controls yaw movement about the vertical axis.

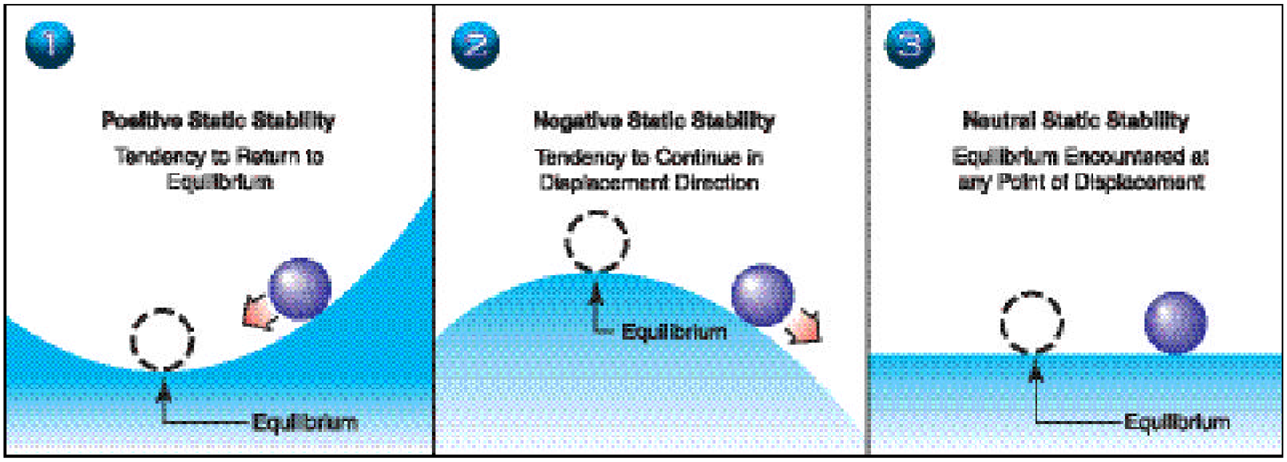


Figure 3-16. The three types of static stability are positive, negative, and neutral.

have neither the tendency to return to equilibrium nor the tendency to continue displacement. [Figure 3-16]

Dynamic stability describes a glider's motion and time required for a response to static stability. In other words, dynamic stability describes the manner in which a glider oscillates when responding to static stability. A glider that displays positive dynamic and static stability will reduce its oscillations with time. A glider demonstrating negative dynamic stability is the opposite situation where its oscillations increase in amplitude with time following a displacement. A glider displaying neutral dynamic stability experiences oscillations, which remain at the same amplitude without increasing or decreasing over time. Figure 3-17 illustrates the various types of dynamic stability.

Both static and dynamic stability are particularly important for pitch control about the lateral axis. Measurement of stability about this axis is known as longitudinal stability. Gliders are designed to be slightly nose-heavy in order to improve their longitudinal stability. This causes the glider to tend to nose down during normal flight. The horizontal stabilizer on the tail is mounted at a slightly negative angle of attack to offset this tendency. When a dynamically

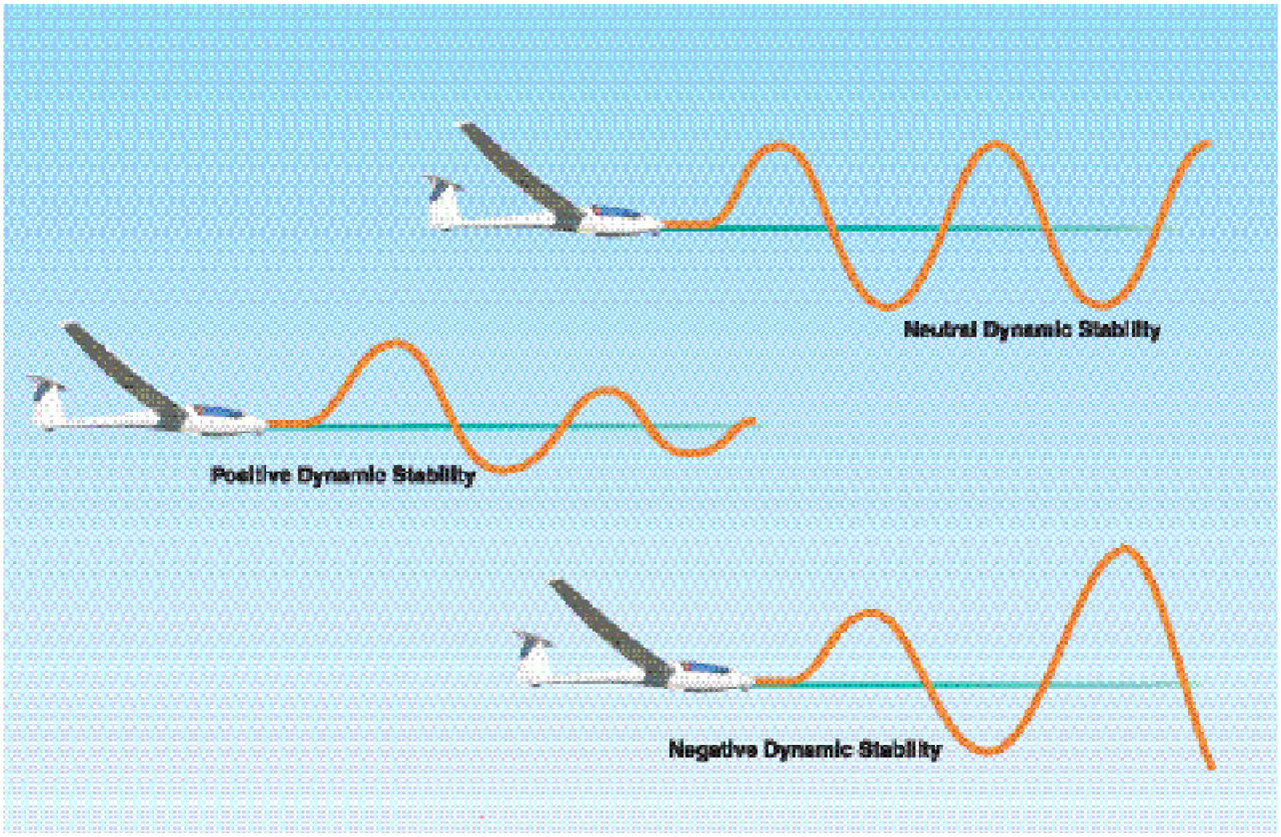


Figure 3-17. The three types of dynamic stability also are referred to as neutral, positive, and negative.

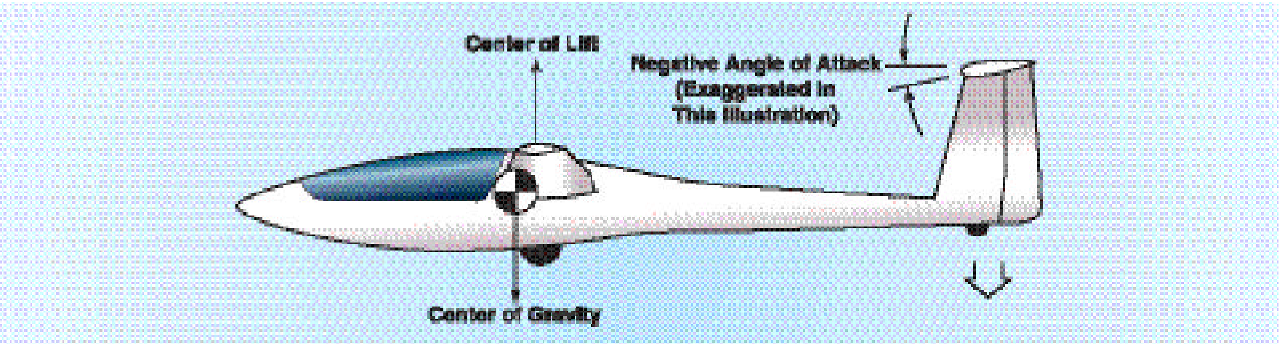


Figure 3-18. The horizontal stabilizer is mounted at a slightly negative angle of attack to offset the glider's natural tendency to enter a dive.

stable glider oscillates, the amplitude of the oscillations should reduce through each cycle and eventually settle down to a speed at which the downward force on the tail exactly offsets the tendency to dive. [Figure 3-18]

Adjusting the trim assists you in maintaining a desired pitch attitude. A glider with positive static and dynamic longitudinal stability tends to return to the trimmed pitch attitude when the force that displaced it is removed. If a glider displays negative stability, oscillations will increase over time. If uncorrected, negative stability can induce loads exceeding the design limitations of the glider.

Another factor that is critical to the longitudinal stability of a glider is its loading in relation to the center of gravity. The center of gravity of the glider is the point where the total force of gravity is considered to act. When the glider is improperly loaded so it exceeds the aft CG limit it loses longitudinal stability. As airspeed decreases, the nose of a glider rises. To recover, control inputs must be applied to force the nose down to return to a level flight attitude. It is possible that the glider could be loaded so far aft of the approved limits that control inputs are not sufficient to stop the nose from pitching up. If this were the case, the glider could enter a spin from which recovery would be impossible. Loading a glider with the CG too far forward also is hazardous. In extreme cases, the glider may not have enough pitch control to hold the nose up during an approach to a landing. For these reasons, it is important to ensure that your glider is within weight and balance limits prior to each flight. Proper loading of a glider and the importance of CG will be discussed further in Chapter 5–Performance Limitations.

FLUTTER

Another factor that can affect the ability to control the glider is flutter. **Flutter** occurs when rapid vibrations are induced through the control surfaces while the glider is traveling at high speeds. Looseness in the control surfaces can result in flutter while flying near maximum speed. Another factor that can reduce the airspeed at which flutter can occur is a disturbance to the balance of the control surfaces. If vibrations are felt in the control surfaces, reduce the airspeed.

LATERAL STABILITY

Another type of stability that describes the glider's tendency to return to wings-level flight following a displacement is lateral stability. When a glider is rolled into a bank, it has a tendency to sideslip in the direction of the bank. In order to obtain lateral stability, dihedral is designed into the wings. Dihedral increases the stabilizing effects of the wings by increasing the lift differential between the high and low wing during a sideslip. A roll to the left would tend to slip the glider to the left, but since the glider's wings are designed with dihedral, an opposite moment helps to level the wings and stop the slip. [Figure 3-19]

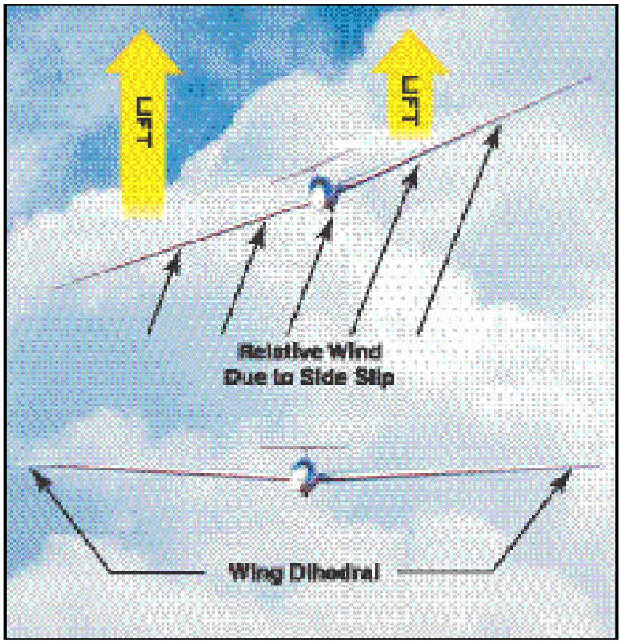


Figure 3-19. Dihedral is designed into the wings to increase the glider's lateral stability.

DIRECTIONAL STABILITY

Directional stability is the glider's tendency to remain stationary about the vertical or yaw axis. When the relative wind is parallel to the longitudinal axis, the glider is in equilibrium. If some force yaws the glider and produces a slip, a glider with directional stability develops a positive yawing moment and returns to equilibrium. In order to accomplish this stability, the vertical tail and the side surfaces of the rear fuselage must counterbalance the side surface area ahead of the center of gravity. The vertical stabilizer is the primary contributor to directional stability and causes a glider in flight to act much like a weather vane. The nose of the glider corresponds to a weather vane's arrowhead, while the vertical stabilizers on the glider act like the tail of the weathervane. When the glider enters a sideslip, the greater surface area behind the CG helps the glider realign with the relative wind. [Figure 3-20]

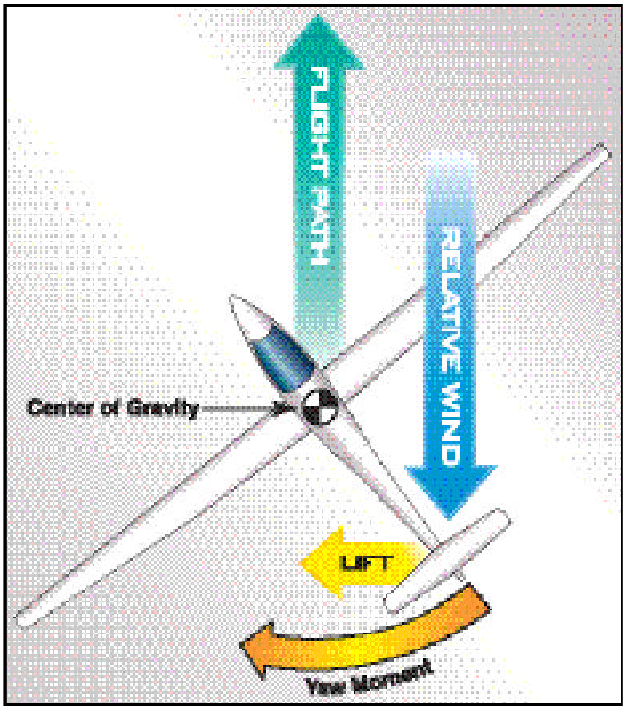


Figure 3-20. During a sideslip, the glider is helped to stay in alignment with the relative wind due to the added surface area behind the CG.

TURNING FLIGHT

Before a glider turns, it must first overcome inertia, or its tendency to continue in a straight line. You create the necessary turning force by using the ailerons to bank the glider so that the direction of total lift is inclined. This is accomplished by dividing the force of lift into two components; one component acts vertically to oppose weight, while the other acts horizontally to oppose centrifical force. The latter is the horizontal component of lift.

To maintain your attitude with the horizon during a turn, you need to increase backpressure on the control stick. The horizontal component of lift creates a force directed inward toward the center of rotation, which is known as centripetal force. This center-seeking force causes the glider to turn. Since centripetal force works against the tendency of the aircraft to continue in a straight line, **inertia** tends to oppose **centripetal force** toward the outside of the turn. This opposing force is known as **centrifugal force**. In reality, centrifugal force is not a true aerodynamic force; it is an apparent force that results from the effect of inertia during the turn.

If you attempt to improve turn performance by increasing angle of bank while maintaining airspeed, you must pay close attention to glider limitations due to the effects of increasing the load factor. **Load factor** is defined as the ratio of the load supported by the glider's wings to the actual weight of the aircraft and its contents. A glider in stabilized, wings level flight has a load factor of one. Load factor increases rapidly as the angle of bank increases. [Figure 3-21]

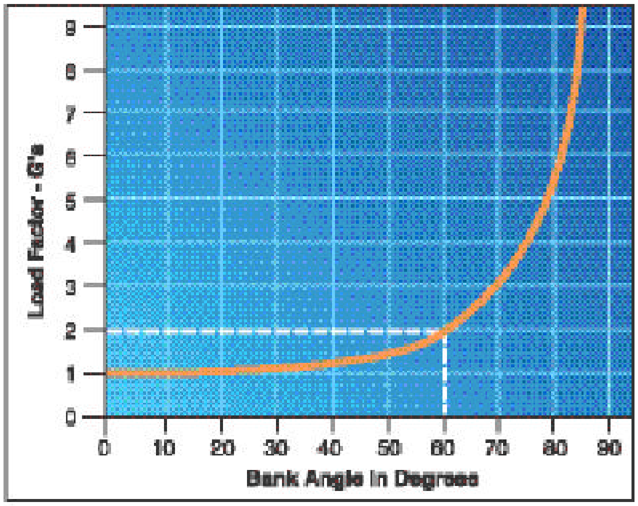
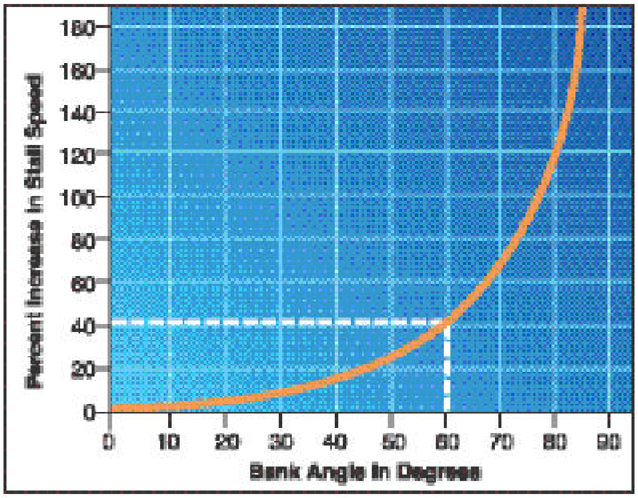


Figure 3-21. The loads placed on a glider increase as the angle of bank increases.

In a turn at constant speed, increasing the angle of attack must occur in order to increase lift. As the bank angle increases, angle of attack must also increase to provide the required lift. The result of increasing the angle of attack will be a stall when the critical angle of attack is exceeded in a turn. [Figure 3-22]



Induced drag also increases as a result of increased lift required to maintain airspeed in the turn. This increased induced drag results in a greater rate of sink during a turn compared to level flight.

RATE OF TURN

Rate of turn refers to the amount of time it takes for a glider to turn a specified number of degrees. If flown at the same airspeed and angle of bank, every glider will turn at the same rate. If airspeed increases and the angle of bank remains the same, the rate of turn will decrease. Conversely, a constant airspeed coupled with an angle of bank increase will result in a faster rate of turn.

RADIUS OF TURN

The amount of horizontal distance an aircraft uses to complete a turn is referred to as the **radius of turn**. The radius of turn at any given bank angle varies directly with the square of the airspeed. Therefore, if the airspeed of the glider were doubled, the radius of the turn would be four times greater. Although the radius of turn is also dependent of a glider's airspeed and angle of bank, the relationship is the opposite of rate of turn. As the glider's airspeed is increased with the angle of bank held constant, the radius of turn increases. On the other hand if the angle of bank increases and the airspeed remains the same, the radius of turn is decreased. [Figure 3-23]

TURN COORDINATION

It is important that rudder and aileron inputs are coordinated during a turn so maximum glider performance can be maintained. If too little rudder is applied or if rudder is applied too late, the result will be a slip. Too much rudder or rudder applied before aileron results in a skid. Both skids and slips swing the fuselage of the glider into the relative wind, creating additional parasite drag, which reduces lift and airspeed. Although this increased drag caused by a slip can be useful during approach to landing to steepen the approach path and counteract a crosswind, it decreases glider performance during other phases of flight.

When you roll into a turn, the aileron on the inside of the turn is raised and the aileron on the outside of the turn is lowered. The lowered aileron on the outside increases the angle of attack and produces more lift for that wing. Since induced drag is a by-product of lift, the outside wing also produces more drag than the inside wing. This causes a yawing tendency toward the outside of the turn called adverse yaw. Coordinated use of rudder and aileron corrects for adverse yaw and aileron drag.

SLIPS

A **slip** is a descent with one wing lowered and the glider's longitudinal axis at an angle to the flight path. It may be used for either two purposes, or both of them combined. A slip may be used to steepen the approach path without increasing the airspeed, as would be the case if a dive were used. It can also be used to make the glider move sideways through the air to counteract the drift, which results from a crosswind.

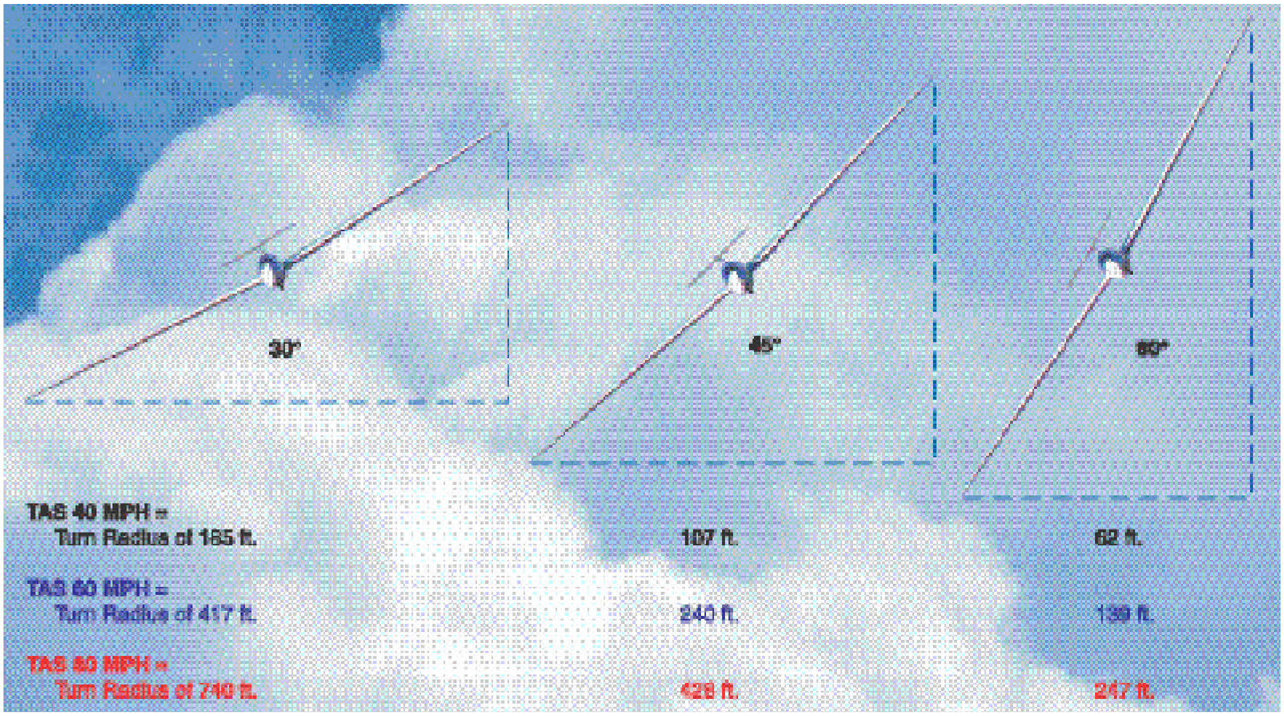


Figure 3-23. The radius of a turn is directly related to airspeed and bank angle.

Formerly, slips were used as a normal means of controlling landing descents to short or obstructed fields, but they are now primarily used in the performance of crosswind and short-field landings. With the installation of wing flaps and effective spoilers on modern gliders, the use of slips to steepen or control the angle of descent is no longer a common procedure. However, the pilot still needs skill in performance of forward slips to correct for possible errors in judgment of the landing approach.

The use of slips has definite limitations. Some pilots may try to lose altitude by violent slipping rather than by smoothly maneuvering and exercising good judgment and using only a slight or moderate slip. In short-field landings, this erratic practice invariably will lead to trouble since enough excess speed may result to prevent touching down anywhere near the proper point, and very often will result in overshooting the entire field.

If a slip is used during the last portion of a final approach, the longitudinal axis of the glider must be aligned with the runway just prior to touchdown so that the glider will touch down headed in the direction in which it is moving over the runway. This requires timely action to discontinue the slip and align the glider's longitudinal axis with its direction of travel over the ground at the instant of touchdown. Failure to accomplish this imposes severe sideloads on the landing gear and imparts violent groundlooping tendencies.

Discontinuing the slip is accomplished by leveling the wings and simultaneously releasing the rudder pressure while readjusting the pitch attitude to the normal glide attitude. If the pressure on the rudder is released abruptly the nose will swing too quickly into line and the glider will tend to acquire excess speed.

Because of the location of the pitot tube and static vents, airspeed indicators in some gliders may have considerable error when the glider is in a slip. The pilot must be aware of this possibility and recognize a properly performed slip by the attitude of the Glider, the sound of the airflow, and the feel of the flight controls.

FORWARD SLIP

The primary purpose of a **forward slip** is to dissipate altitude without increasing the glider's speed, particularly in gliders not equipped with flaps or if the spoilers are inoperative. There are many circumstances requiring the use of forward slips, such as in a landing approach over obstacles and in making short-field landings, when it is always wise to allow an extra margin of altitude for safety in the original estimate of the approach. In the latter case, if the inaccuracy of the approach is confirmed by excess altitude when nearing the boundary of the selected field, slipping can dissipate the excess altitude.

The "forward slip" is a slip in which the glider's direction of motion continues the same as before the slip was begun. [Figure 3-24] If there is any crosswind, the slip will be much more effective if made toward the wind.

Assuming the glider is originally in straight flight, the wing on the side toward which the slip is to be made should be lowered by use of the ailerons. Simultaneously, the airplane's nose must be yawed in the opposite direction by applying opposite rudder so that the glider's longitudinal axis is at an angle to its original flight path. The degree to which the nose is yawed in the opposite direction from the bank should be such that the original ground track is maintained. The nose should also be raised as necessary to prevent the airspeed from increasing.

Forward slips with wing flaps extended should not be done in gliders wherein the manufacturer's operating instructions prohibit such operation.

SIDE SLIP

A **side slip**, as distinguished from a forward slip [Figure 3-24], is one during which the glider's longitudinal axis remains parallel to the original flight path but in which the flight path changes direction according to the steepness of the bank. To perform a

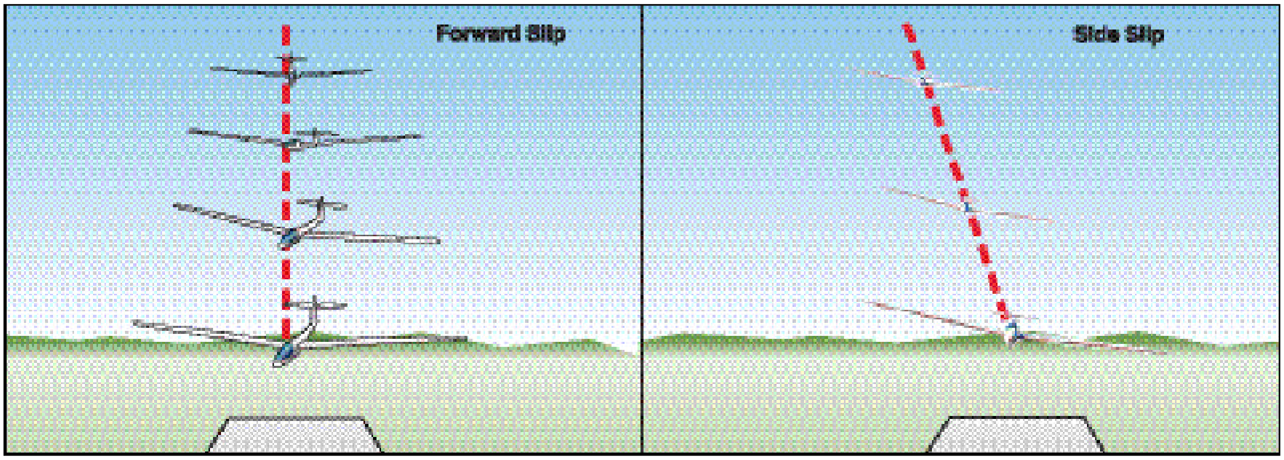
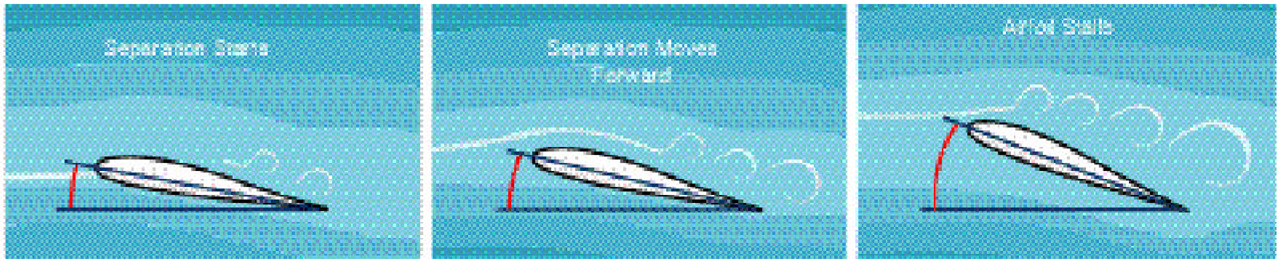


Figure 3-24. Two types of slips.



sideslip, the upwind wing is lowered and simultaneously the opposite rudder is applied to maintain the landing area alignment. The sideslip is important in counteracting wind drift during crosswind landings and is discussed in a later chapter.

STALLS

It is important to remember that a **stall** can occur at any airspeed and at any flight attitude. A stall will occur when the **critical angle of attack** is exceeded. [Figure 3-25] The stall speed of a glider can be affected by many factors including weight, load factor due to maneuvering, and environmental conditions. As the weight of the glider increases, a higher angle of attack is required to maintain the same airspeed since some of the lift is sacrificed to support the increase in weight. This is why a heavily loaded glider will stall at a higher airspeed than it will when lightly loaded. The manner in which this weight is distributed also affects stall speed. For example, a forward CG creates a situation that requires the tail to produce a greater downforce to balance the aircraft. The result of this configuration requires the wings to produce more lift than if the CG were located further aft. Therefore, a more forward CG also increases stall speed.

Environmental factors also can affect stall speed. Snow, ice, or frost accumulation on the wing's surface can increase the weight of the wing in addition to changing the shape and disrupting the airflow, all of which will increase stall speed. Turbulence is another environmental factor that can affect a glider's stall speed. The unpredictable nature of turbulence can cause a glider to stall suddenly and abruptly at a higher airspeed than it would in stable conditions. The reason turbulence has such a strong impact on the stall speed of a glider is that the vertical gusts change the direction of the relative wind and abruptly increase the angle of attack. During landing in gusty conditions, it is important that you increase your airspeed in order to maintain a wide margin above stall.

SPINS

A **spin** can be defined as an aggravated stall that results in the glider descending in a helical, or corkscrew, path. A spin is a complex, uncoordinated flight maneuver in which the wings are unequally stalled. Upon entering a spin, the wing that is more completely stalled will drop before the other, and the nose of the aircraft will yaw in the direction of the low wing.

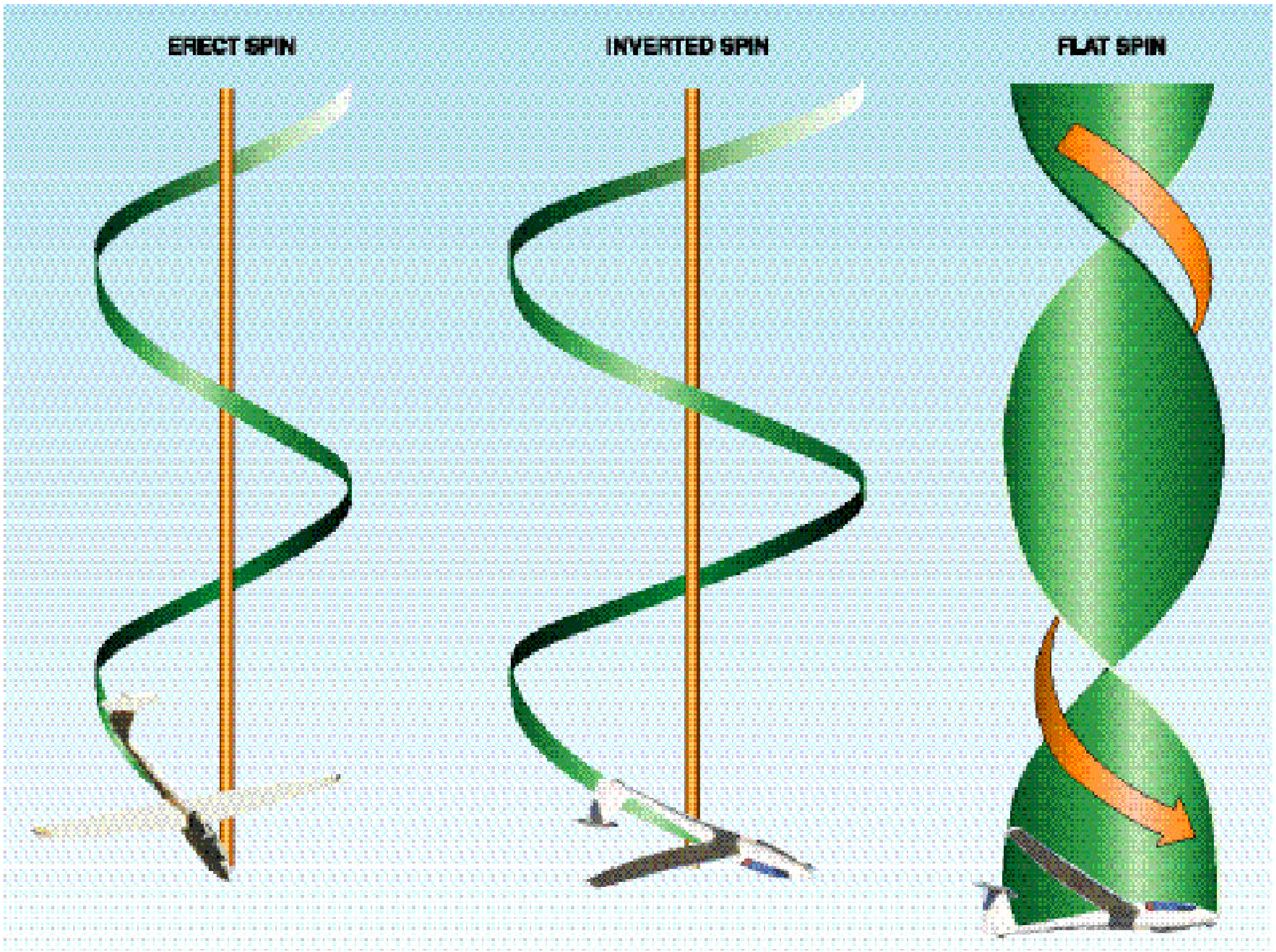
The cause of a spin is exceeding the critical angle of attack while performing an uncoordinated maneuver. The lack of coordination is normally caused by either too much or not enough rudder control for the amount of aileron being used. If the stall recovery is not promptly initiated, the glider is likely to enter a full stall that may develop into a spin. Spins that occur as the result of uncoordinated flight usually rotate in the direction of the rudder being applied, regardless of the raised wing. When you enter a slipping turn, holding opposite aileron and rudder, the resultant spin usually occurs in the opposite direction of the aileron already applied. In a skidding turn where both aileron and rudder are applied in the same direction, rotation will also be in the direction of rudder application.

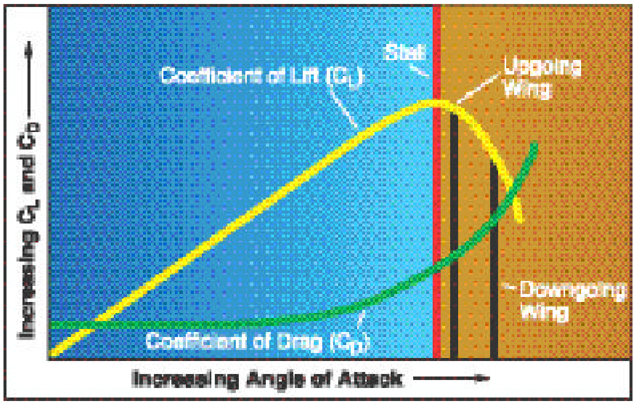
Spins are normally placed in three categories as shown in Figure 3-26. The most common is the upright, or erect, spin, which is characterized by a slightly nose down rolling and yawing motion in the same direction. An inverted spin involves the aircraft spinning upside down with the yaw and roll occurring in opposite directions. A third type of spin, the flat spin, is the most hazardous of all spins. In a flat spin, the glider yaws around the vertical axis at a pitch attitude nearly level with the horizon. A flat spin often has a very high rate of rotation; the recovery is difficult, and sometimes impossible. If your glider is properly loaded within its CG limits, entry into a flat spin should not occur.

Since spins normally occur when a glider is flown in an uncoordinated manner at lower airspeeds, coordinated use of the flight controls is important. It is critical that you learn to recognize and recover from the first sign of a stall or spin. Entering a spin near the ground, especially during the landing pattern, is most often fatal. [Figure 3-27]

GROUND EFFECT

Ground effect is a reduction in induced drag for the same amount of lift produced. Within one wingspan





above the ground, the decrease in induced drag enables the glider to fly at a slower airspeed. In ground effect, a lower angle of attack is required to produce the same amount of lift. Ground effect enables the glider to fly near the ground at a slower airspeed. It is ground effect that causes the glider to float as you approach the touchdown point.

During takeoff and landing, the ground alters the three-dimensional airflow pattern around the glider. The result is a decrease in upwash, downwash, and a reduction in wingtip vortices. Upwash and downwash refer to the effect an airfoil has on the free airstream. Upwash is the deflection of the oncoming airstream upward and over the wing. Downwash is the downward deflection of the airstream as it passes over the wing and past the trailing edge.

During flight, the downwash of the airstream causes the relative wind to be inclined downward in the vicinity of the wing. This is called the average relative wind. The angle between the free airstream relative wind and the average relative wind is the induced angle of attack. In effect, the greater the downward deflection of the airstream, the higher the induced angle of attack and the higher the induced drag. Ground effect restricts the downward deflection of the airstream, decreasing both induced angle of attack and induced drag.