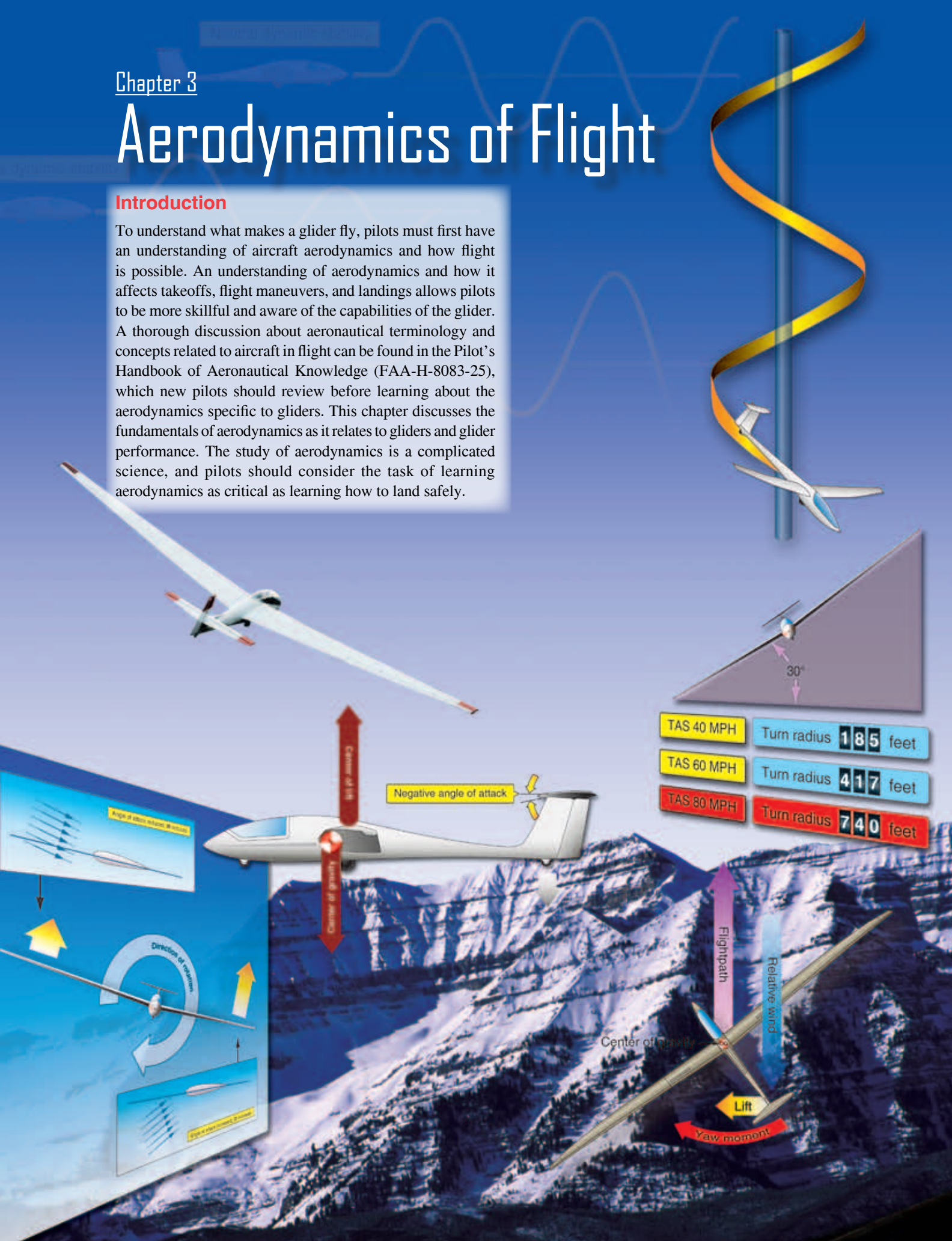


Chapter 3

Aerodynamics of Flight

Introduction

To understand what makes a glider fly, pilots must first have an understanding of aircraft aerodynamics and how flight is possible. An understanding of aerodynamics and how it affects takeoffs, flight maneuvers, and landings allows pilots to be more skillful and aware of the capabilities of the glider. A thorough discussion about aeronautical terminology and concepts related to aircraft in flight can be found in the Pilot's Handbook of Aeronautical Knowledge (FAA-H-8083-25), which new pilots should review before learning about the aerodynamics specific to gliders. This chapter discusses the fundamentals of aerodynamics as it relates to gliders and glider performance. The study of aerodynamics is a complicated science, and pilots should consider the task of learning aerodynamics as critical as learning how to land safely.



Forces of Flight

There are four forces that act upon an aircraft during straight-and-level flight. They are lift, gravity, thrust, and drag. Lift counters gravity, and drag counters thrust. When all four forces are in balance, straight-and-level flight is sustained. Engine-powered gliders obtain thrust from the engine. Once in flight and the engine has been shut off, or the glider has been launched, towed, or winched, the need to obtain thrust is still there. The glider does this by converting the potential energy that it has accumulated into kinetic energy as it glides downward, trading height for distance. In essence, the gravity vector becomes the horizontal forward thrust vector component. We measure the force of gravity as the weight in pounds or kilograms. This explains why the faster the glider flies, the faster it also descends.

Figure 3-1 shows a basic vector diagram for an unpowered glider with all forces in equilibrium. The lift vector is effectively split into two components: one part is opposing the weight force (gravity in straight-and-level flight), and the other component of the lift vector opposes drag by supplying thrust by the conversion of potential energy of the elevated weight of the glider into kinetic energy. This conversion continues until the airframe comes to rest on the surface. A glider is always descending in the air. This allows development of thrust by the energy conversion process. The objective of a glider pilot is to remain in air rising faster than the glider must descend to maintain flying speed. The same is true for a powered aircraft with its engine turned off. These forces are explained in greater detail in the Pilot's Handbook of Aeronautical Knowledge (FAA-H-8083-25) and by examining Newton's laws of motion.

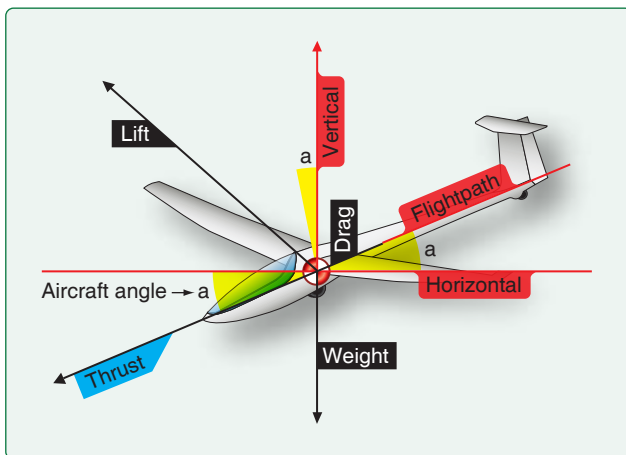


Figure 3-1. Vector components of lift, drag, and weight (gravity).

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 air mass. One is a positive pressure lifting action from the air mass 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 increase in airspeed 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, provides an equal reaction from the air, forcing the wing upward. If a wing is constructed in such form that it causes a lift force greater than the weight of the glider, the glider flies.

If all the required lift were 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. Lift is the result of the airflow above and over the wing lowering the air pressure above the wing, which pull the wing upwards and the downwash from below the wing pushing the wing upward. This fact must be thoroughly understood to continue in the study of flight.

Lift

Lift opposes the downward force of weight (gravity) and is produced by the dynamic effects of the surrounding airstream acting on the wing. Lift acts perpendicular to the flightpath through the wing's center of lift. There is a mathematical relationship between lift, angle of attack (AOA), airspeed, altitude, and the size of the wing. In the lift equation, these factors correspond to the coefficient of lift, velocity, air density, and wing surface area. These relationships are expressed in Figure 3-2. For a complete explanation of the lift formula and terms refer to the Pilots Handbook of Aeronautical Knowledge.

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 or lift increases, lift also increases. The coefficient of lift goes up as the AOA is increased. As air density increases, lift increases. However,

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

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 3-2. Equation of the factors of lift.

glider pilots are usually more concerned with how lift is diminished by reductions in air density on a hot day, or as they climb higher.

The Effects of Drag on a Glider

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. The various types of drag are explained in greater detail in the Pilot's Handbook of Aeronautical Knowledge (FAA-H-8083-25).

Parasite Drag

Parasite drag is the resistance offered by the air to anything moving through it. The aircraft surface deflects or interferes with the smooth airflow around the glider. The wing of the sailplane alone has very low parasite drag, but when the total drag of the glider is added to it, the amount of drag becomes significant. This is apparent particularly at high speeds since parasite drag increases with the square of speed. Simply put, if the speed of the glider is doubled, parasite drag increases four times. [Figure 3-3] Parasite drag is divided into three types: form drag, skin friction, and interference drag.

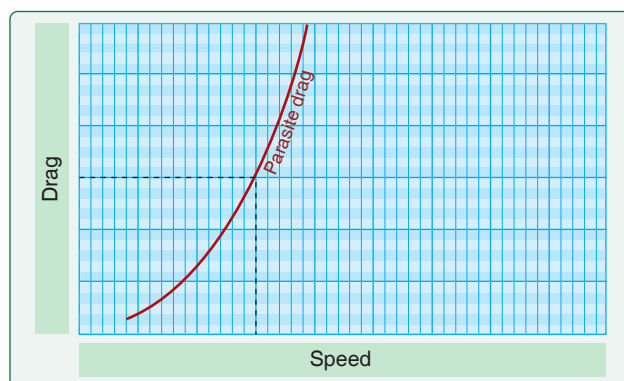


Figure 3-3. Drag versus speed.

Form Drag

Form drag results from the turbulent wake caused by the separation of airflow from the surface of a structure. [Figure 3-4] Any object moving through the air has to push

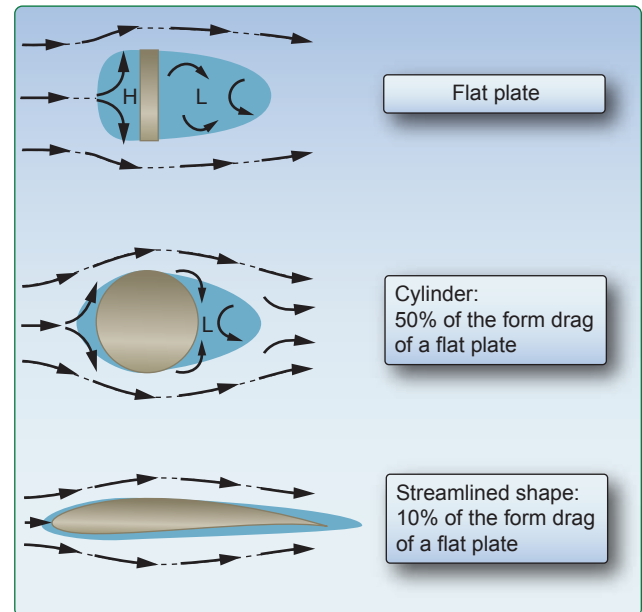


Figure 3-4. Streamlined airfoil designs greatly reduce form drag by reducing the amount of airflow separation.

the air in front of it out of the way. This causes a buildup of pressure in front of the object. Similarly, the object leaves a low-pressure void in its wake. This difference in pressure between the front and back surfaces of the object results in the force called form drag. Form drag can be reduced by reducing the object's cross-sectional area or by streamlining it.

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 or areas of lower pressure that contribute to drag. As air flows across a wing, friction brings the layer of air molecules directly in contact with the surface to a standstill. Air is a viscous fluid, hence the stationary layer of air on the wing's surface slows the layer above it, but not as much as the layer above. This layer then slows the layer above it, but again not as much, and so on. Therefore, the velocity of the flow increases with distance from the surface until the full speed of the flow is reached. This layer of decelerated air is called the boundary layer. The frictional forces that create the boundary layer [Figure 3-5] create an equal and opposite skin friction force on the glider. When the surface area is reduced, the amount of skin friction is reduced.

The boundary layer can take on two distinct forms: the laminar boundary layer and the turbulent boundary layer.

- Laminar boundary layer—each layer of air molecules slides smoothly over its neighbors. [Figure 3-6]

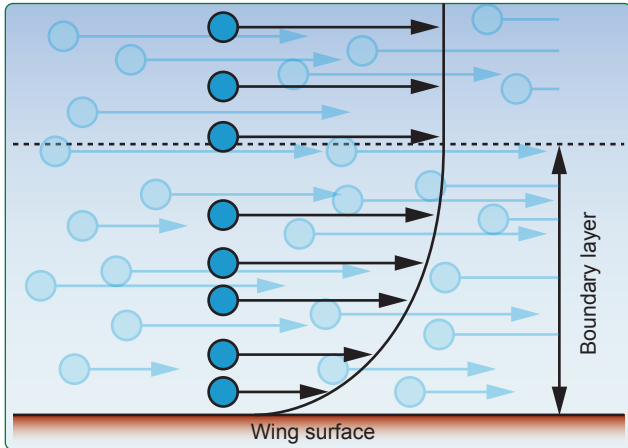


Figure 3-5. Layer of decelerated air called the boundary layer.

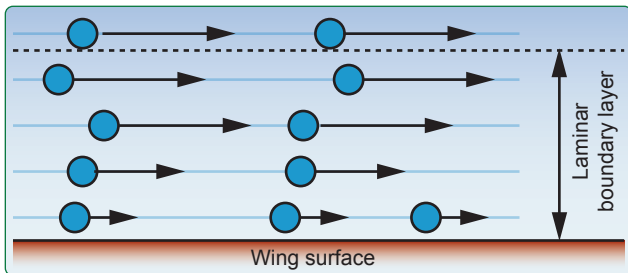


Figure 3-6. Laminar boundary layer.

- Turbulent boundary layer—dominated by eddies and irregular turbulent flow. [Figure 3-7]

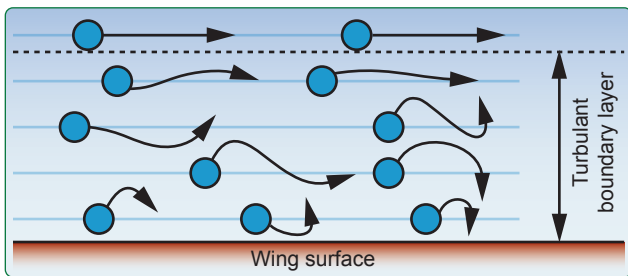


Figure 3-7. Turbulent boundary layer.

Turbulent boundary layers generate 5 to 10 times more skin friction drag than the equivalent laminar boundary layer. [Figure 3-8] Therefore, glider designers try to maintain laminar flow across as much of the aircraft as possible. Figure 3-9 shows why this turbulent transition occurs.

There is a point that is referred to as the separation point, in which the boundary layer breaks away from the surface of the wing due to the magnitude of the positive pressure gradient. Beneath the separated layer, bubbles of stagnant air form, creating additional drag because of the lower pressure in the wake behind the separation point.

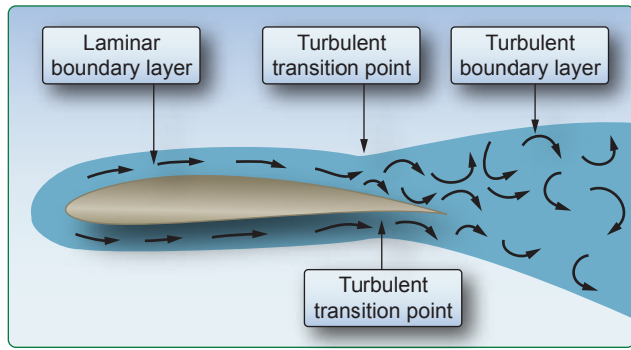


Figure 3-8. Skin friction increases due to the turbulent boundary layer.

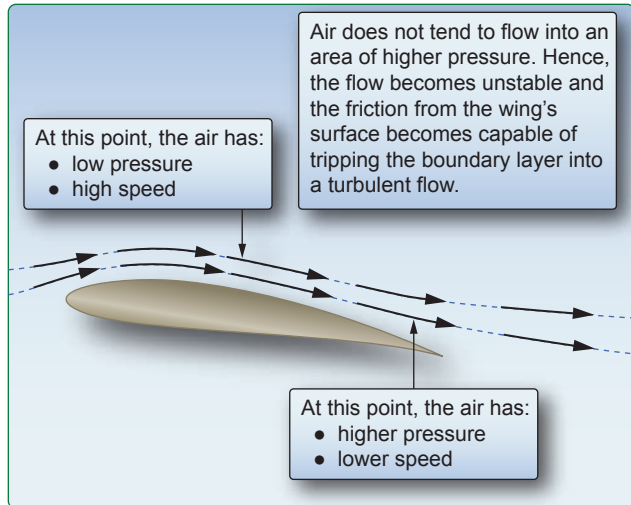


Figure 3-9. Combinations of low and high pressure on the airfoil causing a turbulent flow of air.

These bubbles can be reduced or even eliminated by shaping the airfoil to move the separation point downstream or by adding a turbulator. Turbulators are aerodynamically positioned in a spanwise line along the wing and are used to trip laminar flow air into turbulent flow air at a desired location on the wing. This is beneficial because the turbulent boundary layer contains more energy, which will delay separation until a greater magnitude of negative pressure gradient is reached, effectively moving the separation point further aft on the airfoil and possibly eliminating separation completely. A consequence of the turbulent boundary layer is increased skin friction relative to a laminar boundary layer, but this is very small compared to the increase in drag associated with separation.

In gliders, the turbulator is often a thin zig-zag strip that is placed on the underside of the wing and sometimes on the fin. [Figure 3-10] For a glider with low Reynolds numbers (i.e., where minimizing turbulence and drag is a major concern), the small increase in drag from the turbulator at higher speeds is minor compared with the larger improvements at best glide speed, at which the glider can fly the farthest for a given height.



Figure 3-10. Glider wing on the left shows the airflow with a turbulator installed and the glider wing on the right shows how the airflow is disturbed without the turbulator installed.

The boundary layer can also be tripped into a turbulent flow at any point by discontinuities on the wing's surface. It is important to keep wings clean and avoid rain and icing to prevent premature transition, and the increase in drag that it causes. As the boundary layer is only 1.0 millimeter thick at the leading edge, objects, such as rivets, splattered insects, rain drops, ice crystals, and dust, are all large enough to cause localized turbulent transition to occur. [Figure 3-11]

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 50–200 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. Interference drag can be reduced on gliders with fairings to streamline the intersection of air.

Induced Drag

Induced drag is generated as the wing is driven through the air to develop the difference in air pressures that we call lift. As the higher pressure air on the lower surface of the airfoil curves around the end of the wing and fills in the lower pressure area on the upper surface, the lift is lost, yet the energy to produce the different pressures is still expended. The result is drag because it is wasted energy. The more energy the glider requires to fly, the greater the required rate of descent is to supply sufficient energy to convert into thrust

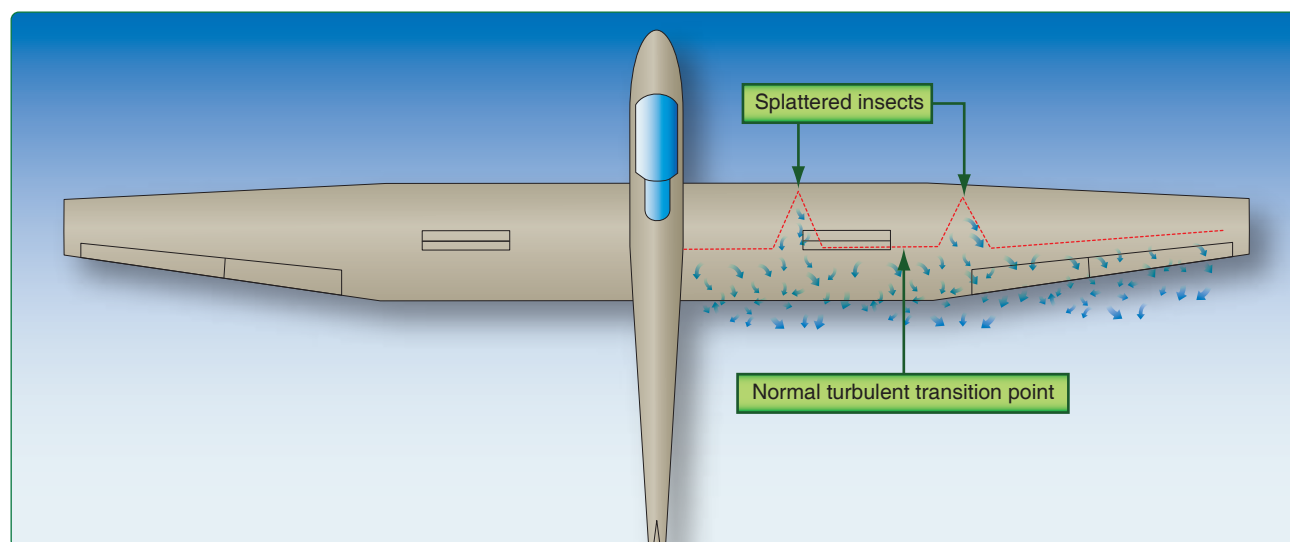


Figure 3-11. Turbulence due to insects, ice crystals, and dust.

to overcome that unnecessary drag. The energy that produces the vortices is wasted energy. The object of glider design is to convert all of the energy into useful lift and the necessary thrust. Any wasted energy translates into poorer performance. [Figure 3-12] Glider designers attempt to reduce drag by increasing the aspect ratio of the glider. The greater the aspect ratio of the wing is, the lower the induced drag is. Wingtip devices, or winglets, are also used to improve the efficiency of the glider. There are several types of wingtip devices and, though they function in different manners, the intended effect is always to reduce the aircraft's drag by altering the airflow near the wingtips. Such devices increase the effective aspect ratio of a wing, without materially increasing the wingspan.

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 3-13]

L/D_{MAX} is the point at which the 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 used to obtain maximum glide distance.

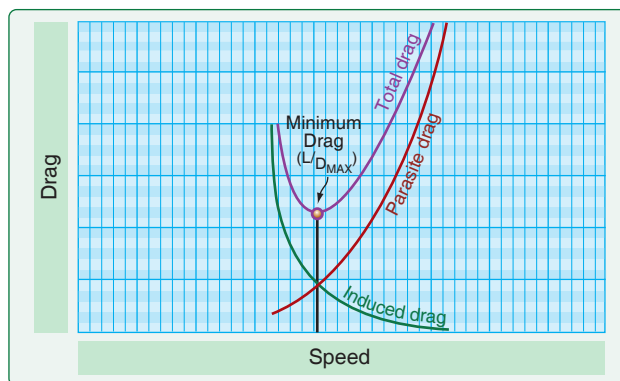


Figure 3-13. Total drag from the sum of parasite and induced drag.

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. [Figure 3-14]

Elliptical Wing

An elliptical wing is a wing planform shape that minimizes induced drag. Elliptical taper shortens the chord near the wingtips in such a way that all parts of the wing experience equivalent downwash, and lift at the wing tips is essentially

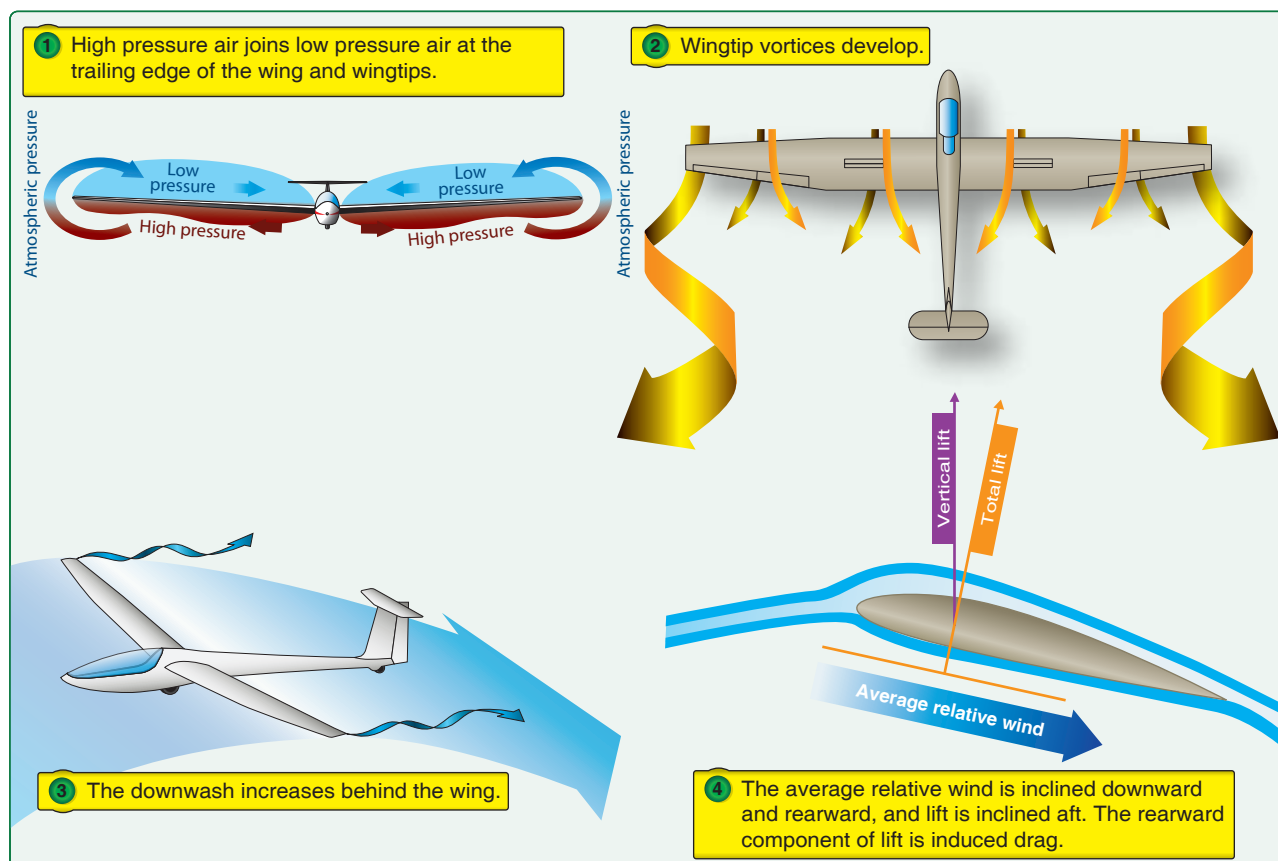


Figure 3-12. Induced drag is that part of total drag created by the production of lift, occurring only when lift is being developed.

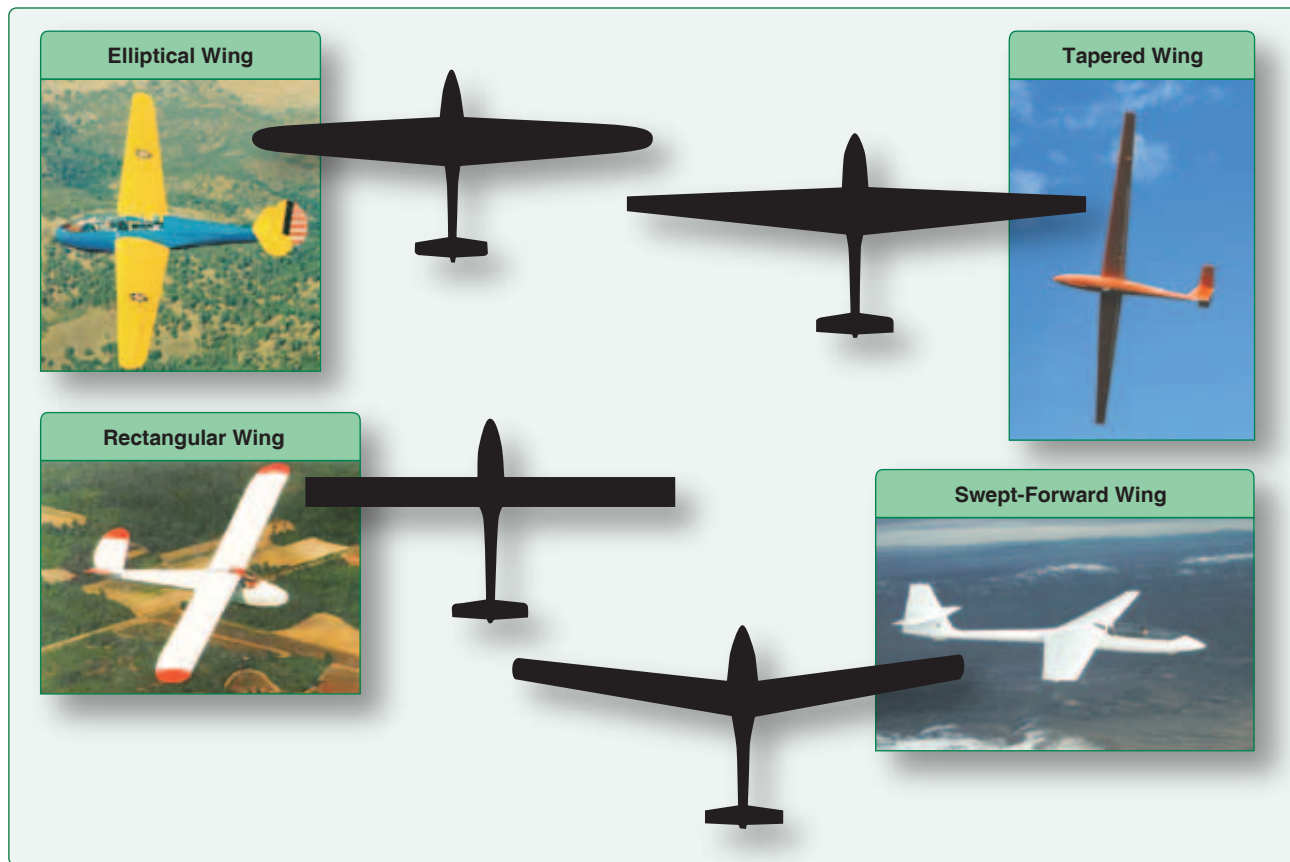


Figure 3-14. *Planforms of glider wings.*

zero, improving aerodynamic efficiency. This wing design is difficult and costly to manufacture because of the compound curves in its design. The elliptical wing is more efficient in terms of L_D , but the wing's uniform lift distribution causes the entire span of the wing to stall simultaneously, potentially causing loss of control with little warning.

Rectangular Wing

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.

Tapered Wing

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 primary consideration, a tapered wing is more desirable than a rectangular wing, but a tapered wing with no twist (also called washout) has undesirable stall characteristics.

Swept-Forward Wing

A swept-forward planform is a wing configuration in which the quarter-chord line of the wing has a forward sweep. Swept-forward wings are used to allow 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 (CG) with the rear seat occupied, or while flying solo. This type of planform design gives the glider increased maneuverability due to airflow from wing tip to wing root, preventing a stall of the wing tips and ailerons at high angles of attack. Instead, the stall occurs in the region of the wing root.

Washout

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. Moving 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 AOA 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.

Glide Ratio

Glide ratio is the number of feet a glider travels horizontally in still air for every foot of altitude lost. If a glider has a 50:1 glide ratio, then it travels 50 feet for every foot of altitude lost.

$$\text{Glide ratio} = \frac{\text{Lift}}{\text{Drag}} : 1$$

This explains why minimizing drag is so critically important. Because drag varies with airspeed, the glide ratio must also vary with airspeed. A glide polar shown in *Figure 3-15* is a graph, normally provided in a glider's flight manual, that details the glider's still air sink rate at airspeeds within its flight envelope. The glide ratio at a particular airspeed can be estimated from the glide polar using:

$$\text{Glide ratio} = \frac{\text{Airspeed}}{\text{Sink rate}} : 1$$

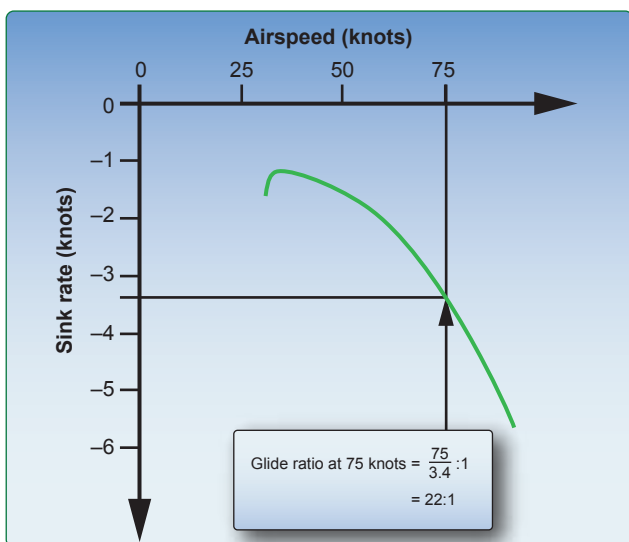


Figure 3-15. *Glide polar graph.*

Airspeed and sink rate must both be in the same units. The example in *Figure 3-14* uses knots. The minimum sink speed is the airspeed at which the glider loses altitude at the lowest rate. It can be determined from the polar by locating the point on the graph with the lowest sink rate and reading off the corresponding airspeed. [*Figure 3-16*]

The best glide speed is the airspeed at which, in still air, the glider achieves its best glide ratio. It is also known as the best lift/drag (L/D) speed. This can be determined from the polar by drawing a line from the origin that is tangential to the curve (e.g., just touching). [*Figure 3-17*] The point of contact is the best glide speed; the glide ratio at this speed can be calculated as previously described. In still air, the glider should be flown at this speed to get from A to B with minimum height loss.

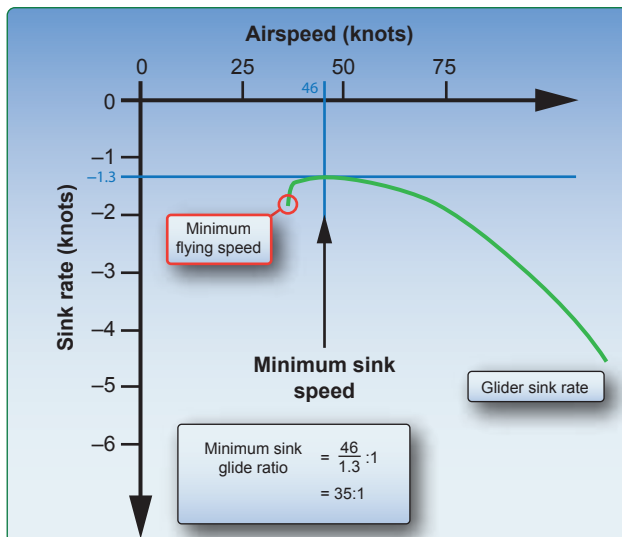


Figure 3-16. *Minimum sink speed can be found using the glide polar graph.*

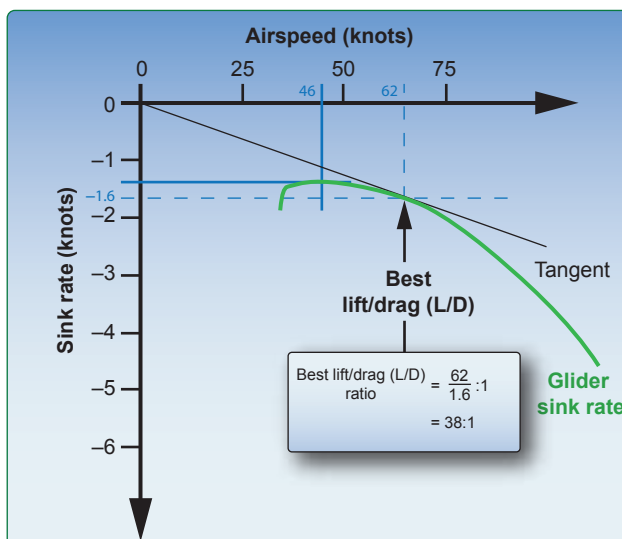


Figure 3-17. *The glider polar graph helps determine the glider's best glide speed.*

Increasing the mass of a glider by adding water ballast, for example, shifts the glide polar down and to the right. [*Figure 3-18*] The minimum sink rate is therefore increased, so as expected, the extra weight makes it harder to climb in thermals. However, the best glide ratio remains approximately the same, but now occurs at a higher airspeed. Therefore, if the thermals are strong enough to compensate for the poor climb performance, then water ballast allows a faster inter-thermal cruise. This results in greater distances being traveled per time interval.

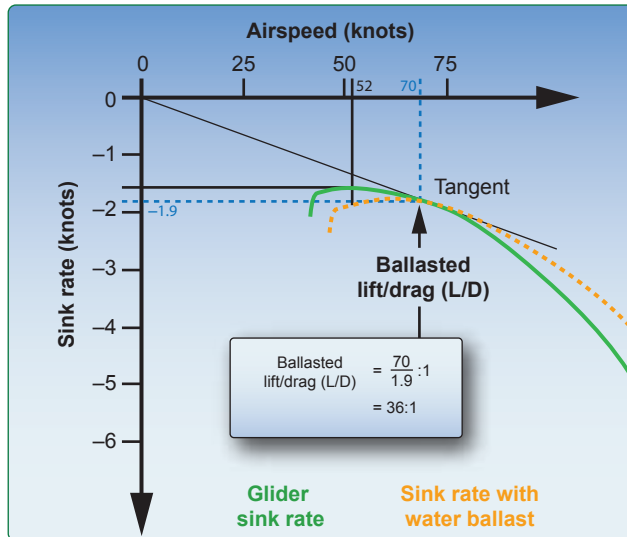


Figure 3-18. Calculating glide speed with water ballast.

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 3-19*. High aspect ratio wings produce a comparably high amount of lift at low angles of attack with less induced drag.

Weight

Weight is the third force that acts on a glider in flight. Weight opposes lift and acts vertically through the CG 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-launching glider through the air. Self-launching gliders have engine-driven propellers that provide this thrust. Unpowered gliders have an outside force, such as a towplane, winch, or automobile, to launch the glider. Airborne gliders obtain thrust from conversion of potential energy to kinetic energy.

Three Axes of Rotation

The glider is maneuvered around three axes of rotation: yaw (vertical), lateral, and longitudinal. They rotate around one

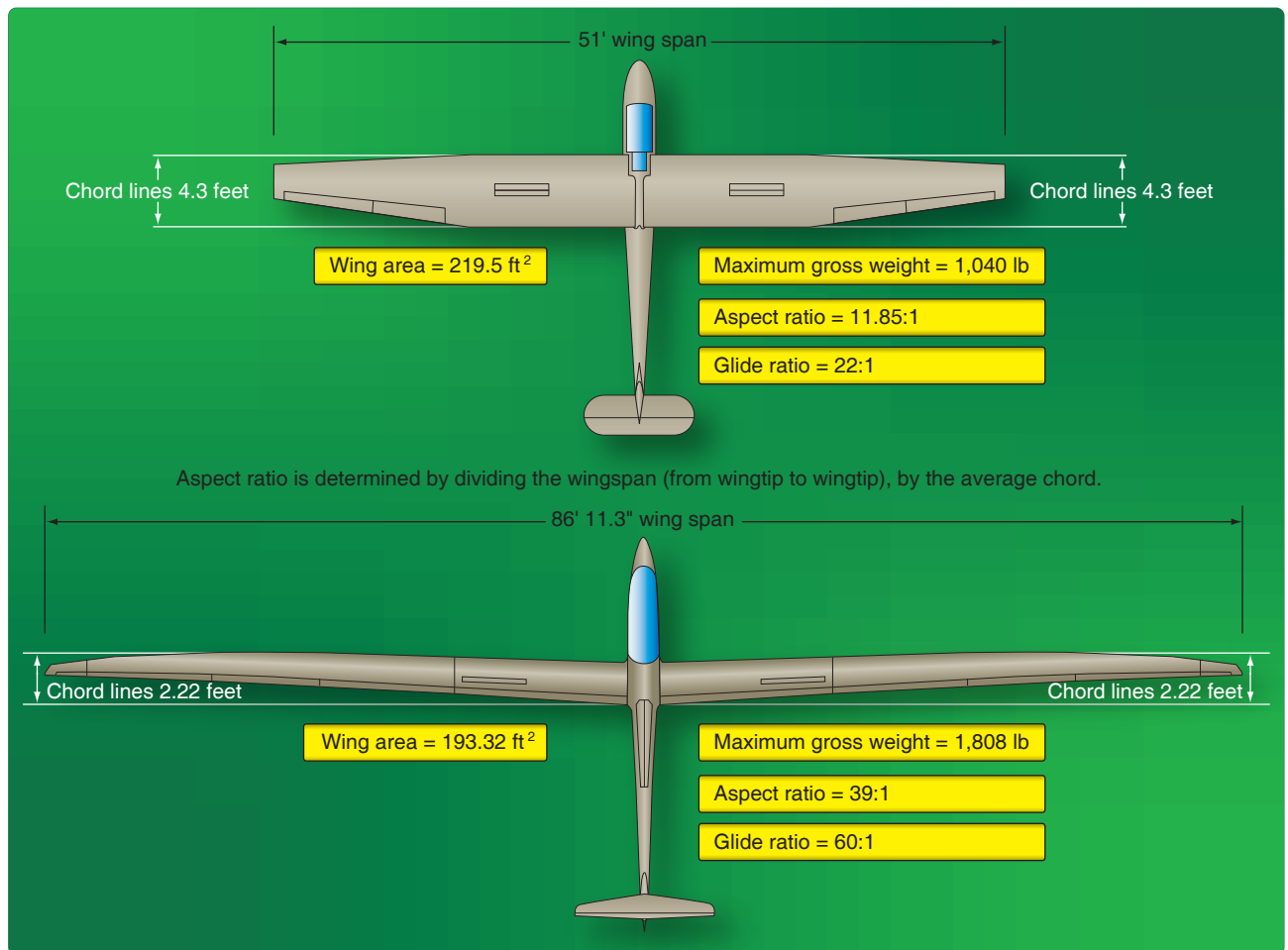


Figure 3-19. Aspect ratio.

central point in the glider called the CG. This point is the center of the glider's total weight and varies with the loading of the glider.

Yaw is movement around the vertical axis, which can be represented by an imaginary straight line drawn vertically through the CG. Moving the rudder left or right causes the glider to yaw the nose to the left or right. Moving the ailerons left or right to bank moves 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. Pulling the stick back or pushing it forward, raising or lowering the nose, controls 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 CG. [Figure 3-20]

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 stability and dynamic stability 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. The 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 have neither the tendency to return to equilibrium nor the tendency to continue displacement.

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 reduces its oscillations with time. A glider demonstrating negative dynamic stability is the opposite situation; 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 3-21* 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 AOA to offset this tendency. When a dynamically 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 3-22]

Adjusting the trim assists 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 increase over time. If uncorrected, negative stability can induce loads exceeding the design limitations of the glider.

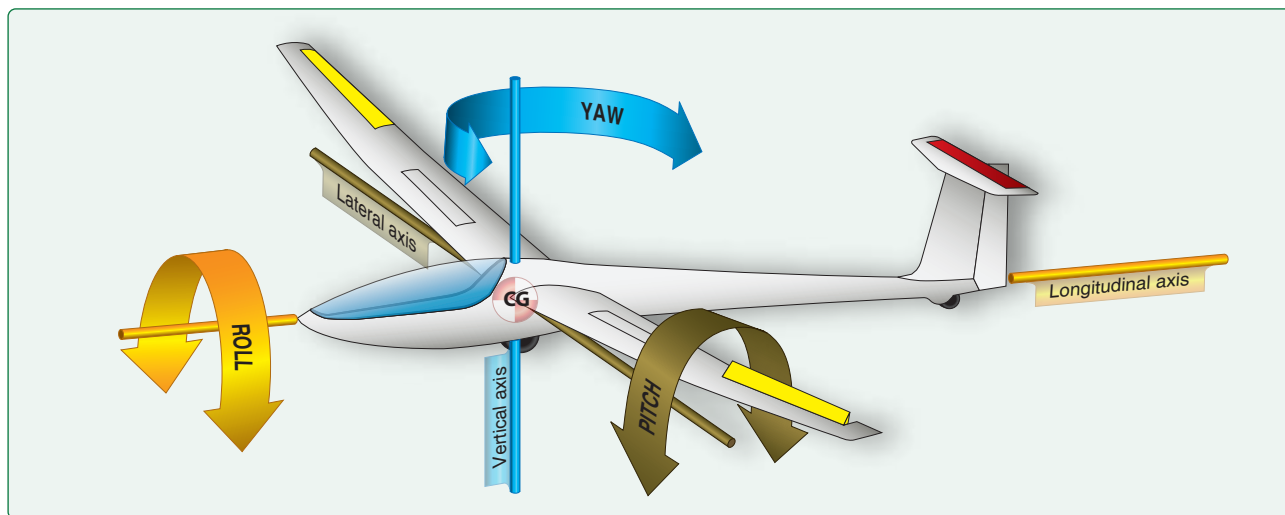


Figure 3-20. *Three axes of rotation.*

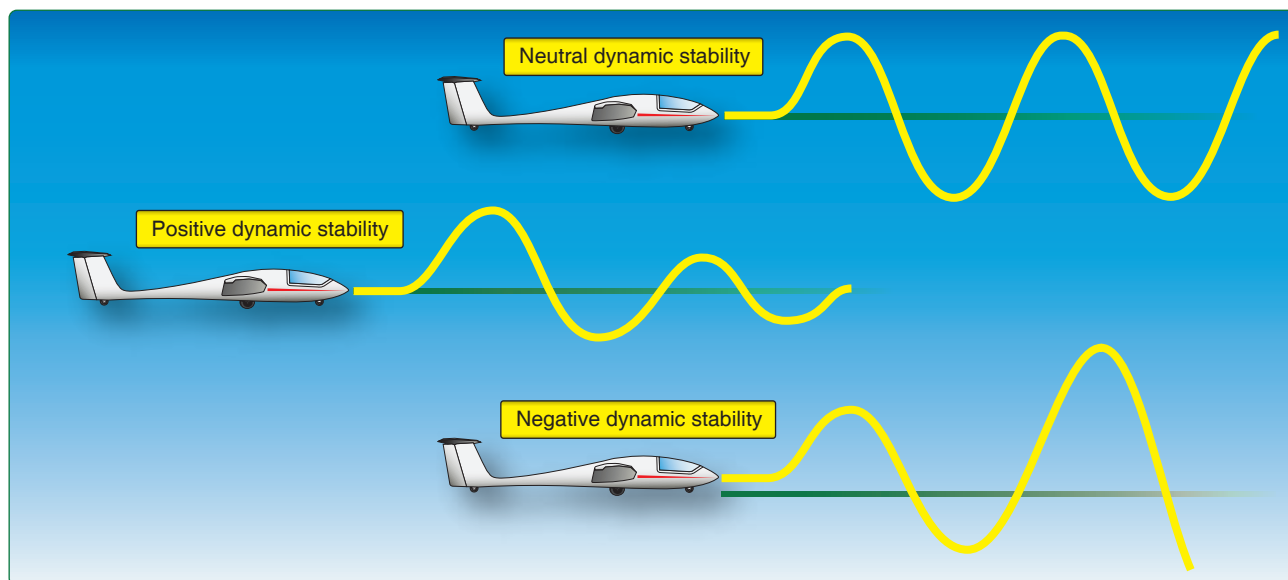


Figure 3-21. *Three types of dynamic stability.*

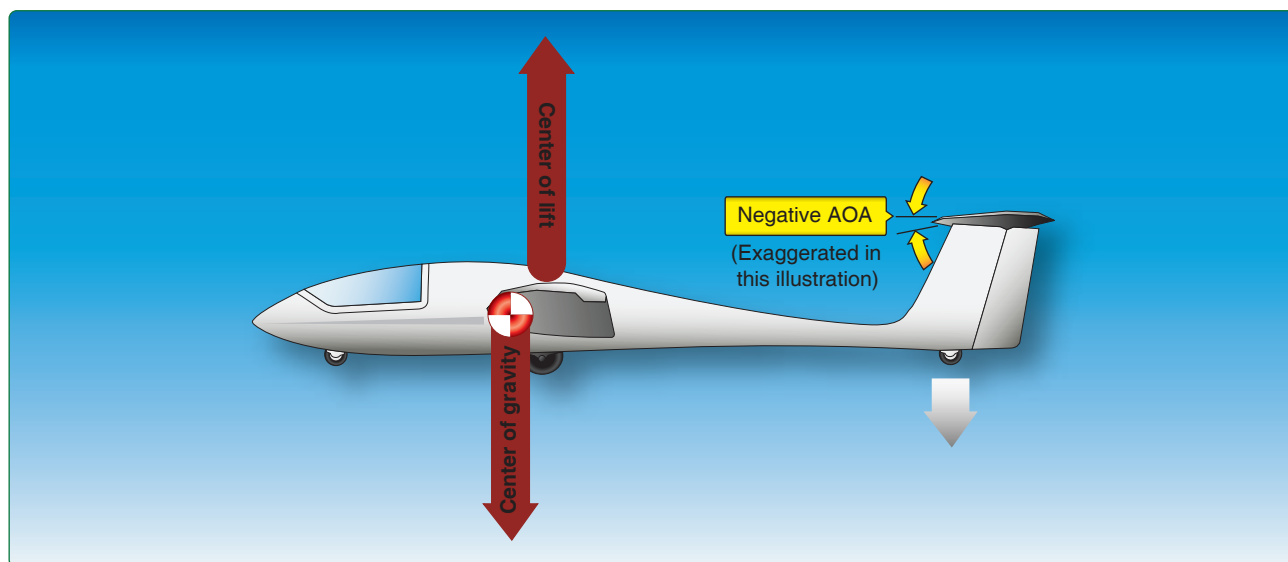


Figure 3-22. *Use of the horizontal stabilizer angle to offset the natural tendency of a glider to nose down.*

Another factor that is critical to the longitudinal stability of a glider is its loading in relation to the CG. The CG of the glider is the point at which 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 is also 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 the glider is within weight and balance limits prior to each flight. Proper loading of a glider and the importance of CG is 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. For example, due to a gust of wind, the glider wing is lifted and the glider starts to roll. The angle of attack on the downward going wing is increased because the wing is moving down and now the air is moving up past it. This causes the lift on this wing to increase. On the upward going wing, the opposite is

occurring. The angle of attack is reduced because the wing is moving up and the air is moving down past it. Lift on this wing is therefore reduced. This does produce a counter torque that damps out the rolling motion, but does not roll the glider back to wings level as the effect stops when the glider stops. [Figure 3-23] To obtain lateral stability, dihedral is designed into the wings.

Dihedral is the upward angle of the wings from a horizontal (front/rear view) axis of the plane. As a glider flies along

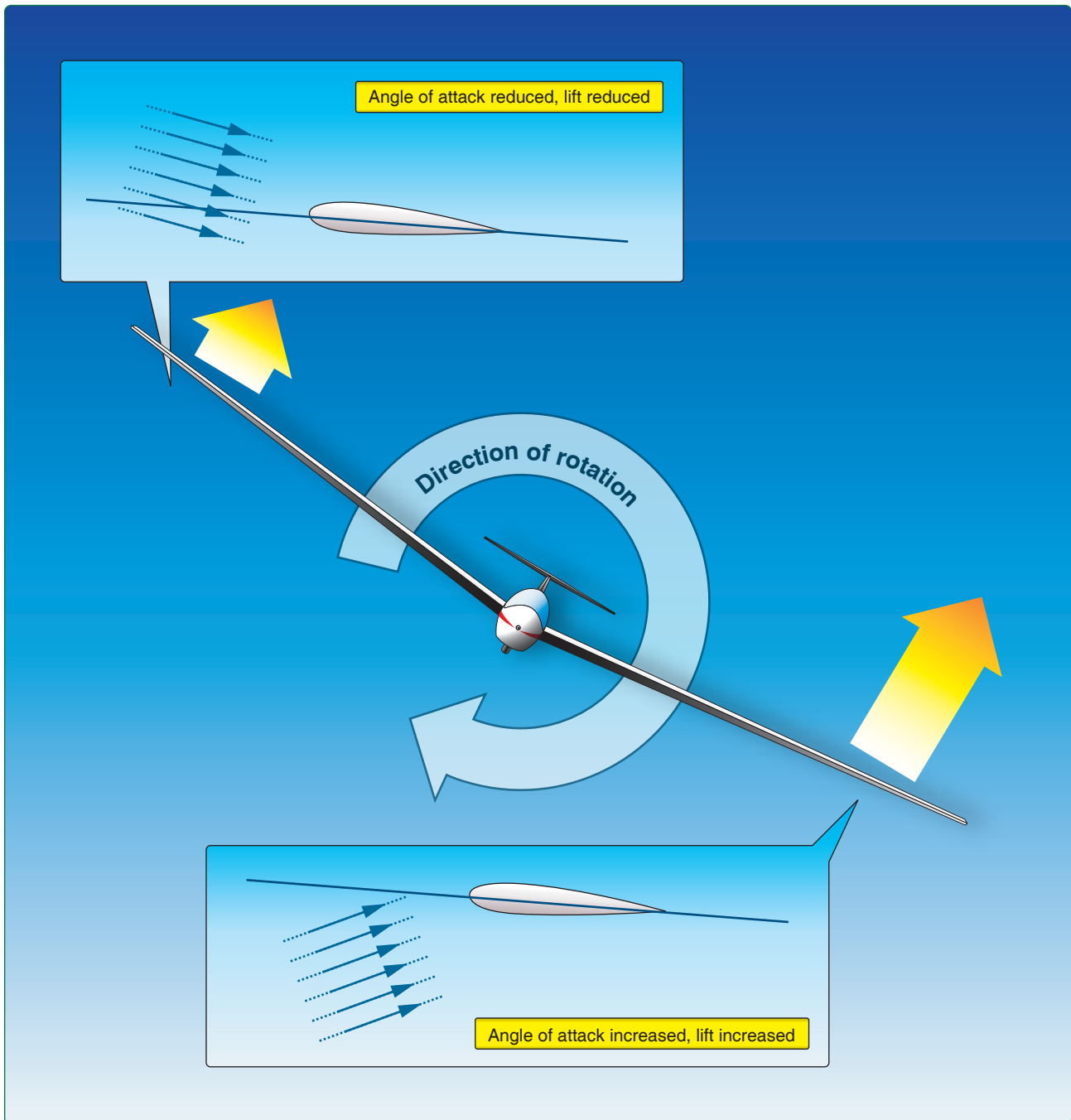


Figure 3-23. Lateral stability.

and encounters turbulence, the dihedral provides positive lateral stability by providing more lift for the lower wing and reducing the lift on the raised wing. As one wing lowers, it becomes closer to perpendicular to the surface and level. Because it is closer to level and perpendicular to the weight force, the lift produced directly opposes the force of weight. This must be instantly compared to the higher and now more canted wing referenced to the force of weight. The higher wing's lift relative to the force of weight is now less because of the vector angle. This imbalance of lift causes the lower wing to rise as the higher descends until lift equalizes, resulting in level flight. [Figure 3-24]

Turning Flight

Before a glider turns, it must first overcome inertia, or its tendency to continue in a straight line. A pilot creates the necessary turning force by using the ailerons to bank the glider so that the direction of total lift is inclined. This divides the force of lift into two components; one component acts vertically to oppose weight, while the other acts horizontally to oppose centrifugal force. The latter is the horizontal component of lift. [Figure 3-25]

To maintain attitude with the horizon during a turn, glider pilots need to increase back pressure 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. [Figure 3-26] 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.

Load Factors

The preceding sections only briefly considered some of the practical points of the principles of turning flight. However, with the responsibilities of the pilot and the safety of passengers, the competent pilot must have a well-founded concept of the forces that act on the glider during turning flight and the advantageous use of these forces, as well as the operating limitations of the particular glider. Any force applied to a glider to deflect its flight from a straight line produces a stress on its structure; the amount of this force is called load factor.

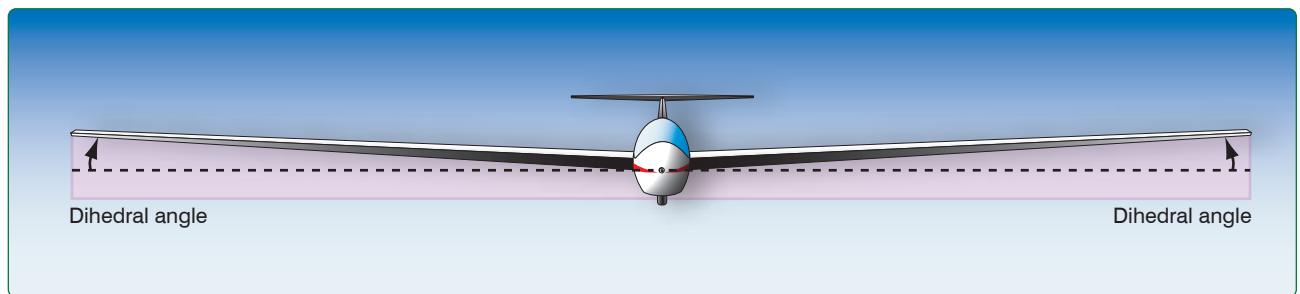


Figure 3-24. Dihedral angle.

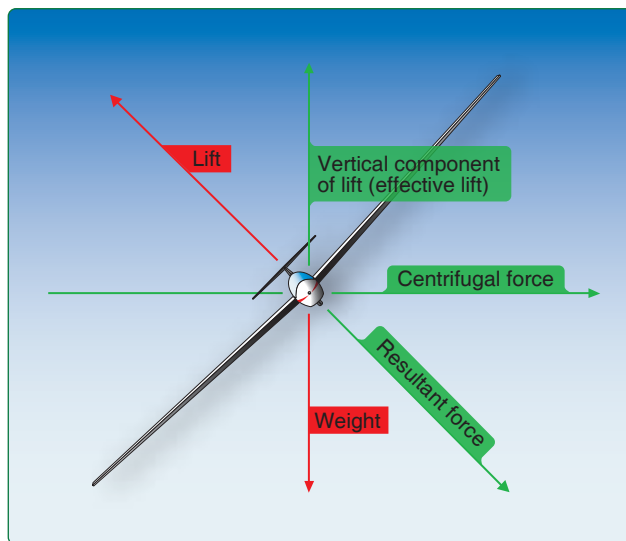


Figure 3-25. Forces in a banked turn.

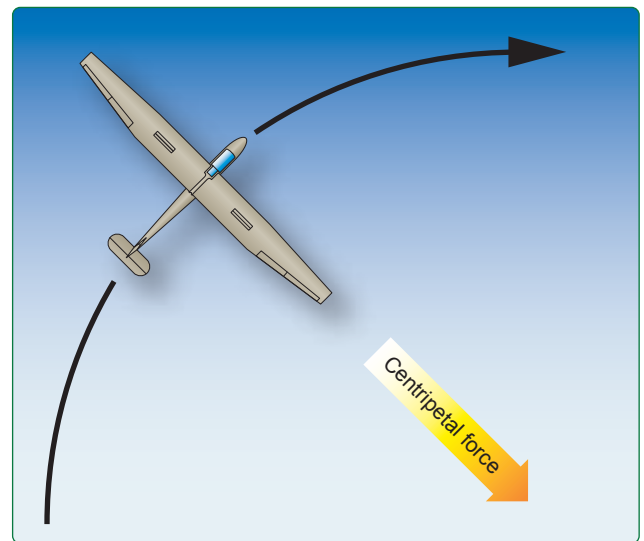


Figure 3-26. Centripetal force is a force that makes a body follow a curved path.

A load factor is the ratio of the total air load acting on the glider to the gross weight of the glider. A glider in flight with a load factor of one does not mean the glider is accelerating; it means the lift on the aircraft is the same as in straight-and-level flight. Load factor may be positive or negative, dependent on the current flightpath.

A load factor of three means that the total load on a glider's structure is three times its gross weight. Gravity load factors are usually expressed in terms of "G"—that is, a load factor of three may be spoken of as three Gs, or a load factor of four as four Gs. A load factor of one, or 1 G, represents conditions in straight-and-level flight, in which the lift is equal to the weight. Therefore, two Gs would be two times the normal weight. Gliders may be designed to withstand stress of up to nine Gs.

It is interesting to note that in subjecting a glider to three Gs in a pullup from a dive, the pilot is pressed down into the seat with a force equal to three times the person's weight. Thus, an idea of the magnitude of the load factor obtained in any maneuver can be determined by considering the degree to which the pilot is pressed down into the seat. Since the operating speed of modern gliders has increased significantly, this effect has become so pronounced that it is a primary consideration in the design of the structure for all gliders.

If attempting to improve turn performance by increasing angle of bank while maintaining airspeed, 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 due to increase wing loading. [Figure 3-27] With the structural design of gliders planned to withstand only a certain amount of overload, knowledge of load factors has become essential for all pilots. Load factors are important to the pilot for two distinct reasons:

1. It is possible for a pilot to impose an obviously dangerous overload on the glider structures.
2. Increased load factor increases the stalling speed, making stalls possible at seemingly safe flight speeds due to increased wing loading.

In a turn at constant speed, the AOA must be increased to furnish the extra lift necessary to overcome the centrifugal force and inertia opposing the turn. As the bank angle increases, AOA must also increase to provide the required lift. The result of increasing the AOA is a stall when the critical AOA is exceeded in a turn. [Figure 3-28]

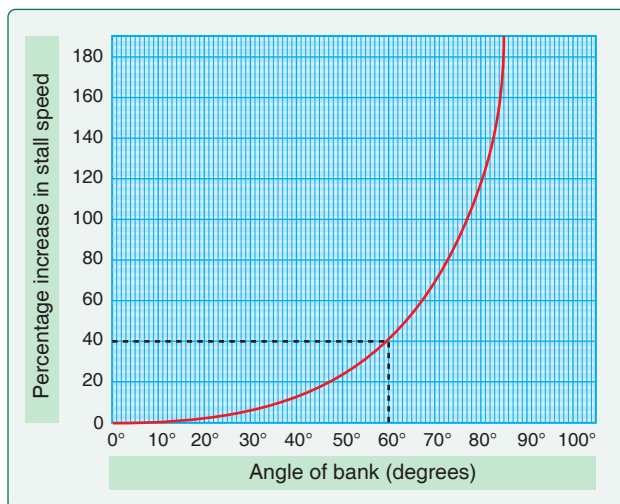


Figure 3-27. A glider's stall speed increases as the bank angle increases. For example, a 60° angle of bank causes a 40 percent increase in the glider's stall speed.

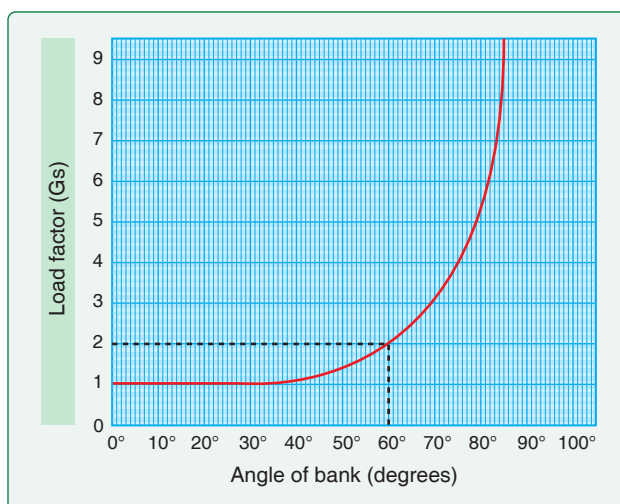


Figure 3-28. The loads placed on a glider increase as the angle of bank increases.

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 turns at the same rate. If airspeed increases and the angle of bank remains the same, the rate of turn decreases. Conversely, a constant airspeed coupled with an angle of bank increase results in a higher 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 on 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 3-29] When flying in thermals, the radius of turn is an important factor as it helps to gain the maximum altitude. A smaller turn radius enables a glider to fly closer to the fastest rising core of the thermal and gain altitude more quickly.

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 is 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 rolling 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 wing increases lift by increasing wing camber and produces more lift for that wing. Since induced drag is a byproduct of lift, the outside wing also produces more drag than the inside wing. This causes adverse yaw, a yawing tendency toward the outside of the turn. Coordinated use of rudder and aileron corrects

for adverse yaw and aileron drag. Adverse yaw in gliders can be more pronounced due to the much longer wings as compared to an airplane of equal weight. The longer wings constitute longer lever arms for the adverse yaw forces to act on the glider. Therefore, more rudder movement is necessary to counteract the adverse yaw and have a coordinated turn.

Slips

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

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 the only procedure available. However, pilots still need skill in the performance of forward slips to correct for possible errors in judgment of the landing approach.

The shape of the glider's wing planform can greatly affect the slip. If the glider has a rectangular wing planform, the slip has little effect on the lift production of the wing other than the wing area being obscured by the fuselage vortices. The direction of the relative wind to the wing has the same effect on both wings so no inequalities of lift form. However, if the wing is tapered or has leading edge aft sweep, then the relative wind has a large effect on the production of lift.

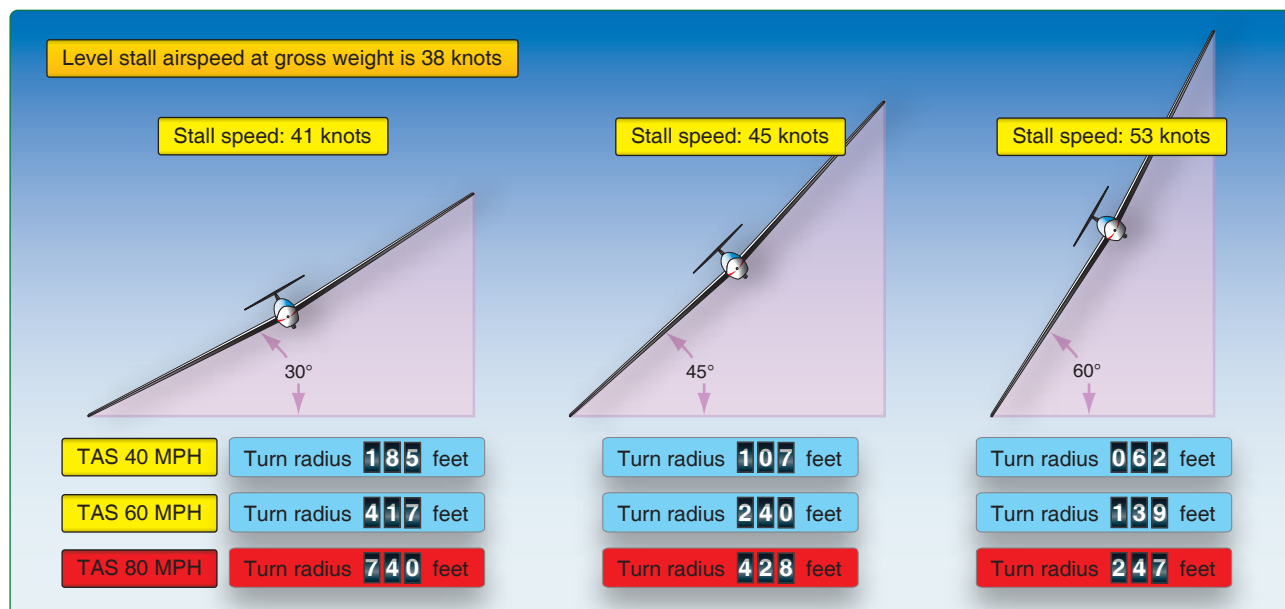


Figure 3-29. A glider's radius of turn as compared to angle of bank.

If a glider with tapered wings, as shown in *Figure 3-14*, were to begin a slip to the left with the left wing lower, the left wing will have a relative wind more aligned with its chord line and effectively higher airflow (airspeed) that generates more lift as compared to the higher right wing with angled relative wind, resulting in lower effective airflow (airspeed) over that wing. This differential in airflow or relative airspeed of the wings when taken to the extremes of the flight envelope results in the higher wing stalling and often an inverted spin.

Depending on the exact wing shape, an elliptical wing can have characteristics more like a tapered wing. [Figure 3-14] Pilots should always consult the GFM and know what the gliders limitations are concerning slips.

The use of slips has limitations. Some pilots may try to lose altitude by violent slipping, rather than by smoothly maneuvering, exercising good judgment, and using only a slight or moderate slip. In short-field landings, this erratic practice invariably leads to trouble since enough excess speed may prevent touching down anywhere near the proper point, and very often results 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 touches down headed in the direction in which it is moving over the runway. This requires timely action to modify 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 ground looping 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 swings too quickly into line and the glider tends 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 forward slip is a slip in which the glider's direction of motion is the same as before the slip was begun. [Figure 3-30] 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 a landing approach over obstacles and short-field landings, in which 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. If there is any crosswind, the slip is 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 flightpath. 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.

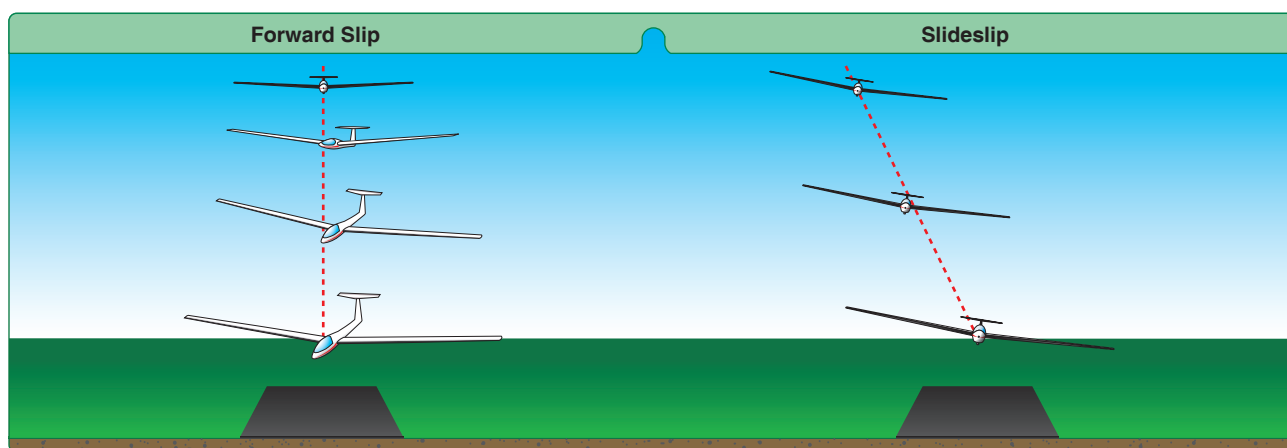


Figure 3-30. A comparison of a forward slip to a sideslip.

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

Sideslip

A sideslip, as distinguished from a forward slip, is one during which the glider's longitudinal axis remains parallel to the original flightpath, but in which the flightpath changes direction according to the steepness of the bank. To perform a 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.

The dihedral angle of the wings works to add lateral stability to the airframe and ease the pilot's tasking to correct for upsets. As the glider flies along, turbulence may upset the balance and raise one wing and roll the glider about the longitudinal axis. As the wing rises, the vertical lift vector decreases while the horizontal component of the wing's lifting force increases. As the other wing descends, the lifting force vertical component increases while the horizontal component decreases. This imbalance is designed so the airframe returns to level without pilot input. Depending on the airflows, the AOA on the wings may or may not be a factor. If the air on one wing is descending (sink) and the air on the other wing is ascending (lift) both wings will have different relative winds, thus different AOA's and developed lift.

Stalls

It is important to remember that a stall can occur at any airspeed and at any flight attitude. A stall occurs when the critical AOA is exceeded. [Figure 3-31] During a stall, the wings still support some of the aircraft's weight. If the wings did not, it would accelerate according to Newton's Second Law. 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 AOA

is required to maintain flight at the same airspeed since more lift is required to support the increase in weight. This is why a heavily loaded glider stalls at a higher airspeed than 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 wing shape and disrupting the airflow, all of which 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. Turbulence has a strong impact on the stall speed of a glider because the vertical gusts change the direction of the relative wind and abruptly increase the AOA. During landing in gusty conditions, it is important to increase the approach airspeed by half of the gust spread value in order to maintain a wide margin above stall. For example, if the winds were 10 knots gusting to 15 knots, it would be prudent to add 2.5 knots ($(15 - 10) \div 2 = 2.5$) to the approach speed. This practice usually ensures a safe margin to guard against stalls at very low altitudes.

Spins

If the aircraft is not stalled, it cannot spin. 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 drops before the other, and the nose of the aircraft yaws in the direction of the low wing. [Figure 3-32]

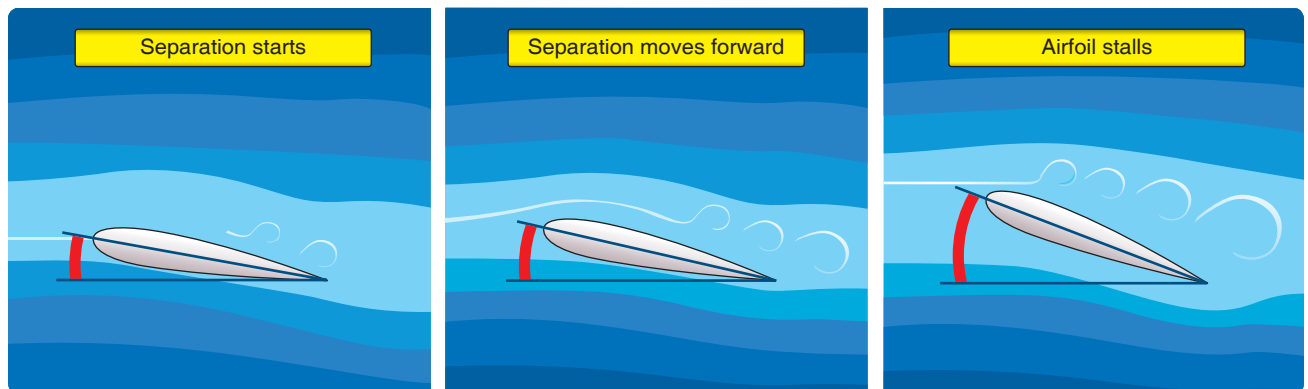


Figure 3-31. A stall occurs when the critical angle of attack is exceeded.

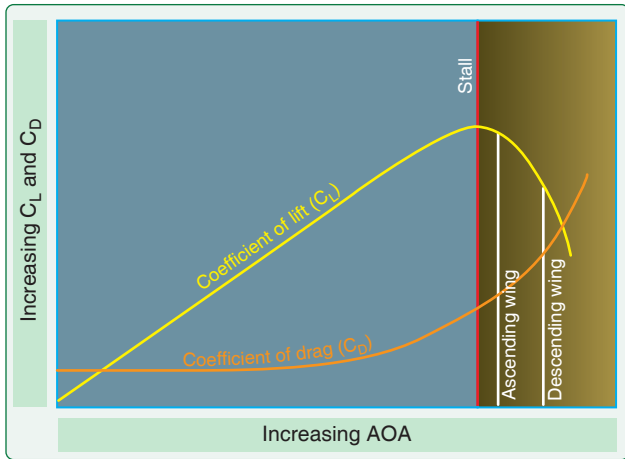


Figure 3-32. The relative coefficients of lift and drag for each wing during a spin. Note that the ascending wing experiences more lift and less drag. The opposite wing is forced down and back due to less lift and increased drag.

The cause of a spin is stalled airflow over one wing before airflow stalling over the other wing. This is a result of uncoordinated flight with unequal airflows over the wings.

Spins occur in uncoordinated slow flight and high rate turns (overbanking for airspeed). The lack of coordination is normally caused by 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 entering a slipping turn, holding opposite aileron and rudder, the resultant spin usually occurs in the direction opposite of the aileron already applied. In a skidding turn in which both aileron and rudder are applied in the same direction, rotation is also in the direction of rudder application. Glider pilots should always be aware of the type of wing forms on their aircraft and the stall characteristics of that wing in various maneuvers.

Spins are normally placed in three categories, as shown in Figure 3-33. 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

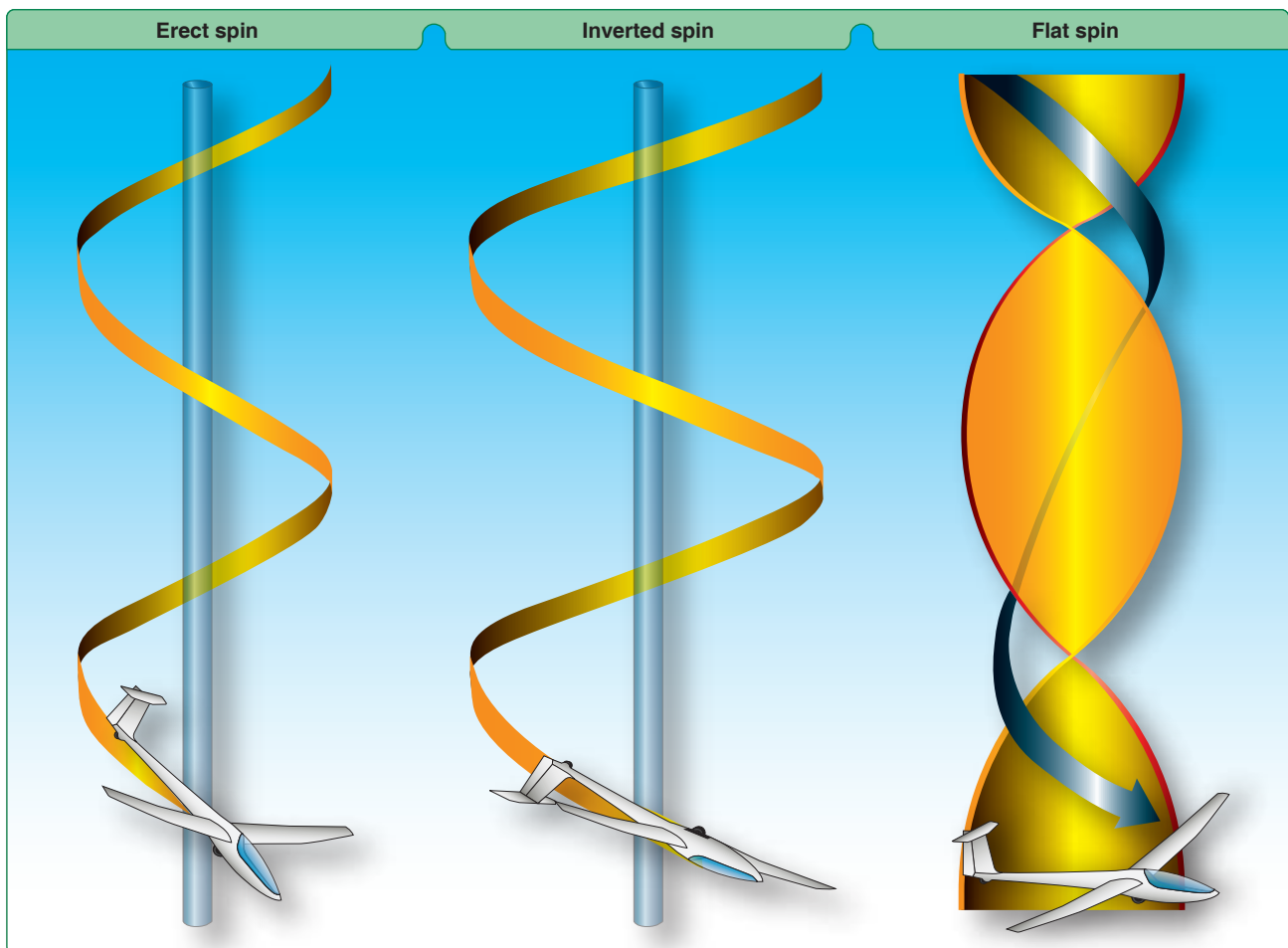


Figure 3-33. A glider's stall speed increases as the bank angle increases. In a spin, one wing is more deeply stalled than the other.

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 a glider is properly loaded within its CG limits, entry into a flat spin should not occur. Erect spins and flat spins can also be inverted. The entry, wing form, and CG usually determine the type of spin resulting from an uncoordinated wing stall.

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 pilots 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 usually fatal. *[Figure 3-33]* A pilot must learn to recognize the warning signs, especially during the approach and landing phase in a crosswind. A crosswind resulting in a tailwind on the base leg may lead the pilot to tighten the turn using rudder, or too steep a turn for the airspeed. An uncoordinated turn could lead to the upper wing exceeding its critical AOA before the lower wing, which could result in a very high rate of roll towards the upper wing as the upper wing stalls. If an excessive steep turn is attempted, the glider may roll towards the inside wing or the outside wing depending on the exact trim state at the instant of the stall. Situational awareness of position to final approach should be part of a before-landing routine.

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 lower airspeed. In ground effect, a lower AOA is required to produce the same amount of lift. Ground effect enables the glider to fly near the ground at a lower airspeed and causes the glider to float as it approaches the touchdown point.

During takeoff and landing, the ground alters the three-dimensional airflow pattern around the glider. The result is a decrease in 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 AOA. In effect, the greater the downward deflection of the airstream, the higher the induced AOA and the higher the induced drag. Ground effect restricts the downward deflection of the airstream, decreasing both induced AOA and induced drag.

Ground effect, in addition to the decrease in wind due to surface friction and other terrain features upwind of the landing area, can greatly increase the landing distance of a glider. A glider pilot, especially a visiting pilot, should inquire about local effects from local pilots to enhance flight planning and safe landings.

