CHAPTER 3: AERODYNAMICS

If you understand the aerodynamic principals of flight there is less chance that you will be unpleasantly surprised by the behavior of the glider. In this chapter, you will learn about the forces acting on a glider, how those forces are created, and how they affect the stability of the glider.

3.1 Nomenclature

There are some terms which are either unique to aerodynamics or which we use in unique ways when discussing it. In this section, you will learn some of these terms.

Airfoil Nomenclature

The shape of the cross-section of a wing is called an airfoil. The rounded end of the airfoil is known as the leading edge. The sharp end is known as the trailing edge. The line connecting the leading and trailing edges is called the chord line.

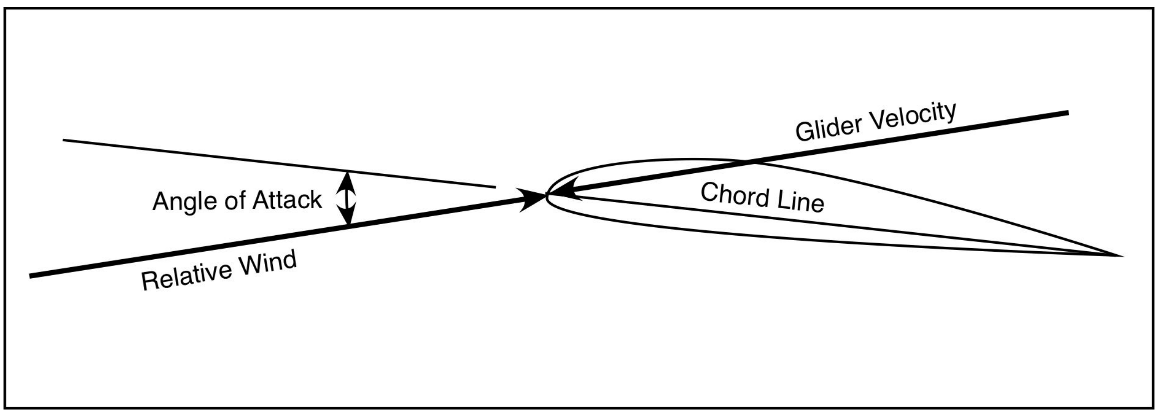

Figure 3.1 – The relative wind is a result of the glider's velocity. The angle of attack is the angle between the chord line and the relative wind.

As the airfoil moves through the air, it is said to experience a "relative wind". (Note that the relative wind is not related to what we normally mean by "wind".) Since the glider typically moves forward and downward, the relative wind typically comes from in front of and below the airfoil. The angle formed by the relative wind and the chord line is called the angle of attack.

Glider Axis

To discuss the glider's movements, we need to define its three axes of rotation. The axes intersect at the glider's center of gravity. The center of gravity is the "balance point" of the glider. The mass of the glider is equally distributed around the center of gravity.

The pitch axis is parallel to the wings, the roll axis is parallel to the fuselage, and the yaw axis is perpendicular to both the wings and the fuselage.

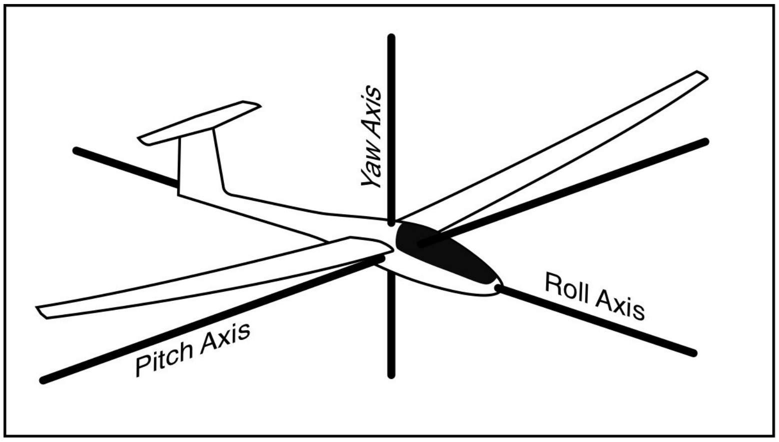

Figure 3.2 – The glider's axes

When the glider rotates about the pitch axis, the nose moves up or down. When it moves about the yaw axis, the nose moves from side to side. When the glider moves about the roll axis, one wing moves up, the other down.

3.2 Three Forces

Three forces act on the glider in flight; lift, drag, and weight.

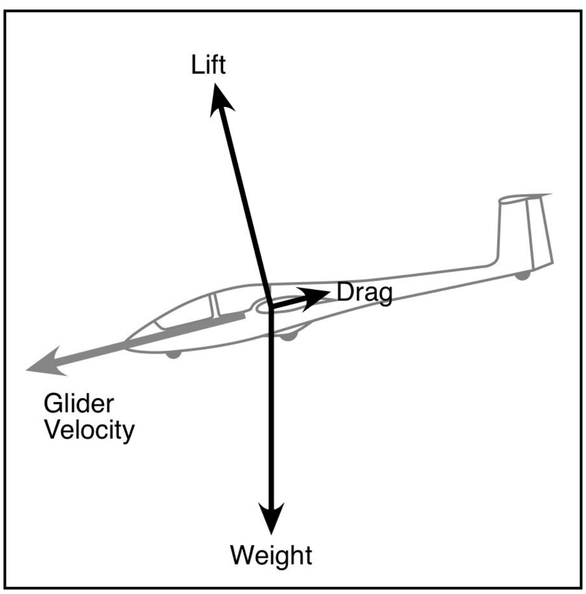

Figure 3.3 – The three forces acting on the glider in un-accelerated flight.

When the glider flies in a straight line at constant speed (i.e. when it is not accelerating), these three forces balance each other out.

Lift

Lift is produced as the airfoil deflects the airflow downward. The lift is always perpendicular to the relative wind.

For a given angle of attack, the airfoil produces more lift as the airspeed increases. The amount of lift created is proportional to the square of the airspeed. For example, if the airspeed doubles and the angle of attack is held constant, the lift increases by a factor of four.

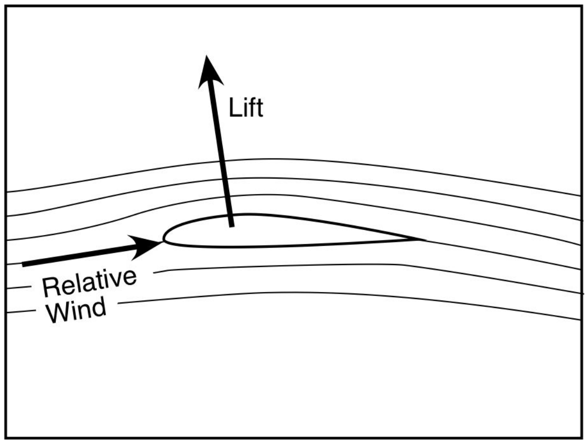

Figure 3.4 – Lift acts perpendicular to the relative wind and is a result of the deflection of airflow.

As the angle of attack increases, the incoming air is deflected more, resulting in increased lift. The amount of lift created at a constant airspeed is proportional to the angle of attack. For example, if you double the angle of attack while holding the airspeed constant, you double the amount of lift.

This relationship is expressed in the following equation. L stands for lift, V velocity, and α the angle of attack. ("$\propto$" means "is proportional to.")

$$L \propto V^2\alpha$$

Since most of the time the lift is equal to the weight of the glider (i.e. it is constant), we can rearrange this equation to get a relationship between the angle of attack and the velocity.

$$\alpha \propto 1/V^2$$

This equation tells us that the angle of attack is proportional to the inverse of the square of the airspeed. In other words, as the velocity increases, the angle of attack decreases. Conversely, as the airspeed decreases, the angle of attack must increase if the lift is to remain constant. The relationship between velocity, angle of attack, and lift is illustrated in Figure 3.5.

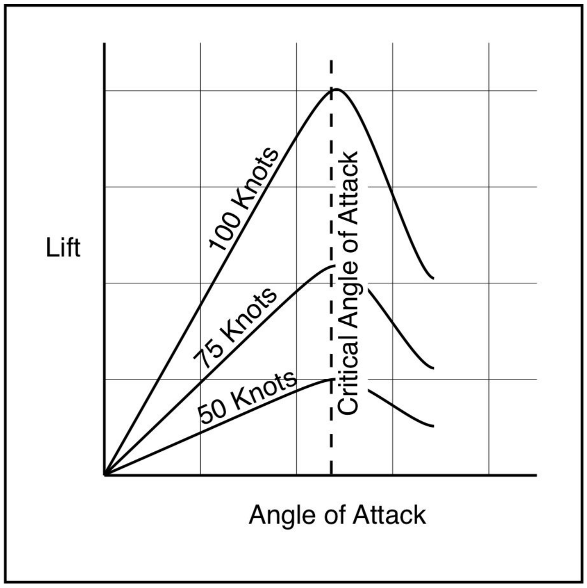

Figure 3.5 – As the angle of attack increases, lift increases until the critical angle of attack is exceeded.

Notice how lift increases as the angle of attack increases until the airfoil stalls at the critical angle of attack (see below) at which point, it drops off. Also, notice that for any angle of attack, the lift is four times greater at 100 knots than it is at 50 knots.

Stall

As illustrated in Figure 3.5, the relationship between lift and the angle of attack has a limit. Once a certain angle of attack is exceeded, the air can no longer “turn the corner” around the top of the airfoil and will separate from the airfoil. When this happens, the airfoil is said to have stalled. The angle of attack at which this happens is called the critical angle of attack.

When the airfoil stalls, airflow is no longer deflected, so the airfoil does not produce nearly as much lift. The drag also increases dramatically.

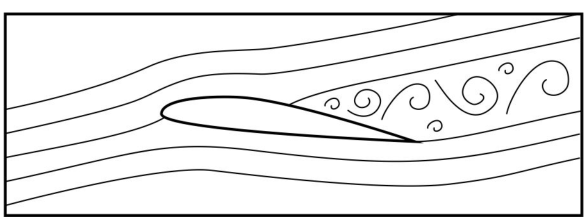

Figure 3.6 -A stalled airfoil produces less lift and much more drag.

An airfoil is more likely to stall at low airspeeds, because in order to create the required lift, the airfoil must operate at a high angle of attack. Nevertheless, at any airspeed, the airfoil will stall if the critical angle of attack is exceeded.

The critical angle of attack is determined primarily by the shape of the airfoil. However, it can also be affected by the surface condition of the airfoil. An airfoil that is coated with rain, frost, bugs, or dirt will typically stall at a lower angle (i.e. at a higher airspeed) than one that is clean.

Washout

Most aircraft wings are designed so that the root, or inboard, part of the wing stalls first, before the stall extends toward the tip. This allows the ailerons to remain effective even after part of the wing has stalled, and gives the pilot the opportunity to recognize that the entire wing is about to stall.

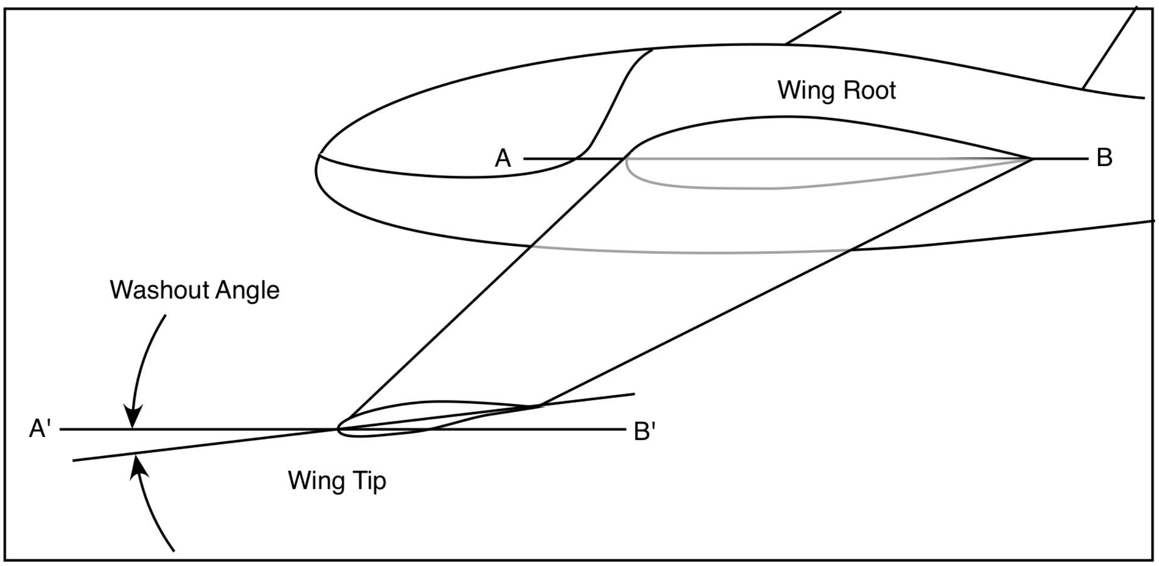

Figure 3.7 – Lines A-B and A′-B′ are parallel. The washout is the angle between the tip chord line and the root chord line. Washout causes the wing root to operate at a higher angle of attack and to stall before the tip does.

To make sure that the wingtip stalls last the wing is twisted so that the wing tip is at a lower angle of attack than the wing root. This twist, called washout, will always cause the root to be at a higher angle of attack and thus stall first. (An interesting side note: when the glider is flying upside down, washout becomes "wash-in", and the wing tip stalls first. It is quite clear why you do not want this to happen in normal flight: the tip will immediately drop—hard—and the glider will flip over very quickly.)

Spin

A spin can occur when both wings are stalled, but one wing stalls more than the other. The wing that stalls more lags behind and falls because it produces less lift and more drag. The other wing, being less stalled, will be creating more lift and less drag. The less stalled wing will in effect fly in circles around the inside wing.

In a spin the glider's nose drops well below the horizon and the glider rotates about the lower wing. The forces in a spin are mild, since the glider must be stalled for it to develop. To recover from a spin, you must pitch the nose down, thereby reducing the angle of attack on the wings, and apply the opposite rudder, which stops the rotation. Once the angle of attack is reduced, the glider should quickly recover. You will learn more about spins, their cause, and ways to avoid and recover from them in Lessons 4.22 and 4.23 in the *Flight Training Manual for Gliders.*

Drag

Drag is the glider pilot's enemy. Modern glider designers go to great lengths to ensure that their designs will experience minimum drag.

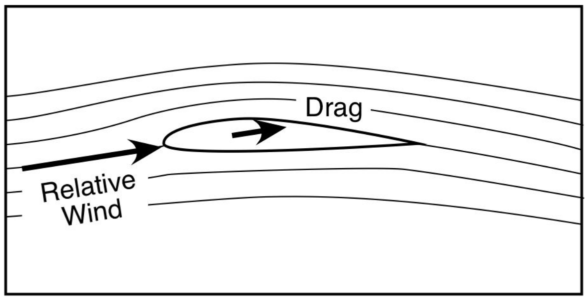

Figure 3.8 – Drag acts parallel to the relative wind.

Drag acts parallel to the relative wind. It has two components: parasite drag and induced drag.

Parasite Drag

Parasite drag is proportional to the square of the airspeed. If the airspeed is doubled, parasite drag increases by a factor of four. Parasite drag can in itself be divided into two categories: skin friction and profile drag.

Skin friction is a result of the viscosity of air. You can think of it as the friction between the surface of the glider and each "particle" of air that passes over it.

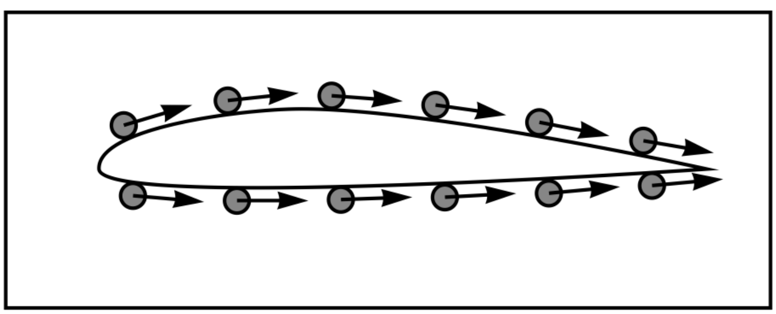

Figure 3.9 – Skin friction drag

Skin friction can be reduced by keeping the glider as clean and smooth as possible. A dirty or bug-covered glider will experience more skin friction drag than a clean, polished one.

Profile, or form drag is the result of the airflow separating from a surface as it is forced to flow around obstacles. These obstacles can be as large as the main