

# CHAPTER 2

## AERODYNAMICS OF FLIGHT

Chapters 2 and 3 of the *Pilot's Handbook of Aeronautical Knowledge* (FAA-H-8083-25) apply to powered parachutes and are a prerequisite to reading this book. This chapter will focus on the aerodynamic fundamentals unique to powered parachute (PPC) operations.

### Aerodynamic Terms

**Airfoil** is the term used for surfaces on a powered parachute that produce lift, typically the wing itself. Although many different airfoil designs exist, all airfoils produce lift in a similar manner.

**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. **Leading edge** describes 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. [Figure 2-1]

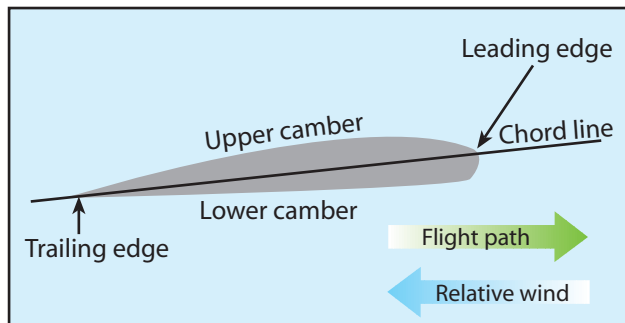


Figure 2-1. Aerodynamic terms of an airfoil.

**Relative wind** is the direction of the airflow with respect to the wing; it is usually parallel to and opposite the PPC **flight path**. Relative wind may be affected by movement of the PPC through the air, as well as by all forms of unstable, disturbed air such as wind shear, thermals, turbulence, and mountain rotors. When a PPC is flying through undisturbed air, the relative wind is parallel to and opposite the flight path.

**Angle of attack** is the angle between the relative wind and the wing chord line. [Figure 2-2]

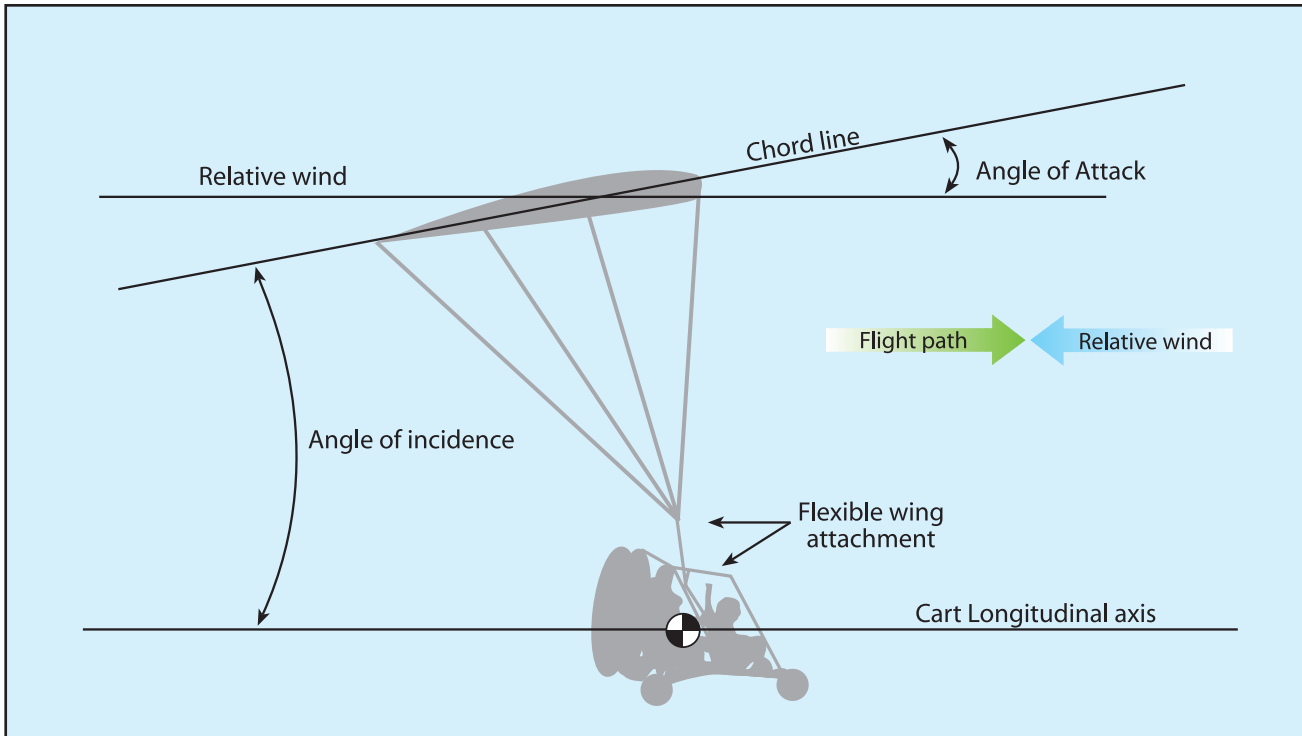
**Longitudinal axis** is an imaginary line about which the aircraft rolls; it is also called the roll axis. The longitudinal axis is not a fixed line through the cart because the angle of incidence changes in turbulence and with loading changes.

**Angle of incidence** is the angle formed by the chord line of the wing and the longitudinal axis of the PPC cart. The cart longitudinal axis is not the same as the aerodynamic longitudinal axis defined in the previous paragraph. [Figure 2-2] Unlike an airplane, the angle of incidence can change in flight because of the flexible line attachment between the wing and the cart. Angle of incidence can change for different types of flight configurations and PPC designs; this is covered in detail in the “Moments” section.

**Trim angle** is the angle between the chord line of the wing and the horizontal plane when the PPC is in non-powered gliding flight. [Figure 2-3] The PPC wing is designed at a slight angle, with the chord line inclined downward to the horizontal plane to maintain the manufacturer-designed angle of attack during gliding, level and climbing flight. This “trim angle” is built into the powered parachute by the manufacturer and cannot be adjusted by the pilot moving the controls.

**Pitch angle** is the angle the PPC wing chord makes with the horizontal plane. Pitch angle is what you can see. Many pilots confuse the pitch angle, which you can easily see and feel, with the angle of attack which may not be as perceptible. [Figure 2-4] For example, the pitch angle in an engine-out glide could be minus 8 degrees, in level flight 10 degrees above the horizon, and in a climb it could be 28 degrees above the horizon. These are significantly different angles you easily see. Pitch angles are covered in greater detail in Chapter 6.

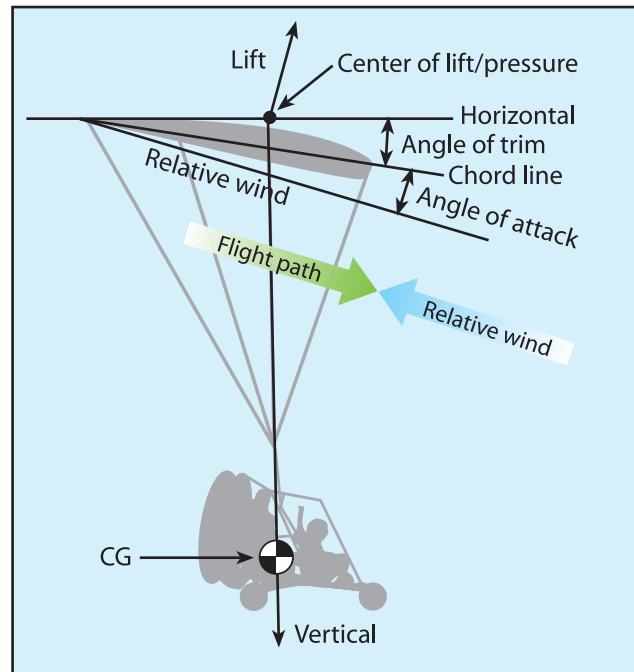
**Deck angle** is the angle of the cart's lower frame (from the front wheel to the rear wheels), to the landing surface. The deck on the lower part of the conventional cart frame can be used to visualize deck angle. An imaginary line between the front and back wheel axles can also be used on unconventional carts.



**Figure 2-2. Angle of incidence.**

**Planform** is the shape or form of a wing as viewed from above. The PPC wing comes in two wing planforms: rectangular, and elliptical. [Figure 2-5] The elliptical planform leading and trailing edges are curved to form an elliptical shape when viewed from the top or bottom. These two shapes have unique flying characteristics. Rectangular wings typically produce more drag, are lower-performance, and do not move fore and aft, relative to the cart, as quickly as elliptical wings. These characteristics are more obvious when the wing is inflating, during pitch changes, and when flying in turbulence. Rectangular wings are therefore more stable and require less effort to fly. Elliptical wings are higher-performance and more efficient due to less drag. Elliptical wings react more quickly with changing conditions and require greater pilot experience and skill during inflation, in turbulent air, and with abrupt throttle changes.

**Aspect ratio** is the wingspan divided by the average chord line. A PPC with a common 500-square foot rectangular wing (about a 38-foot wingspan) and with a typical mean chord line of 13 feet, would have an average aspect ratio of about 3. This relatively low aspect ratio is less efficient at producing lift. An elliptical wing with the same 500 square feet and a 45-foot wing span and an 11-foot average chord would have an aspect ratio of about 4. The PPC wing is similar to airplane wings in that the aspect ratio will differ with the specific design mission for the aircraft. Generally,

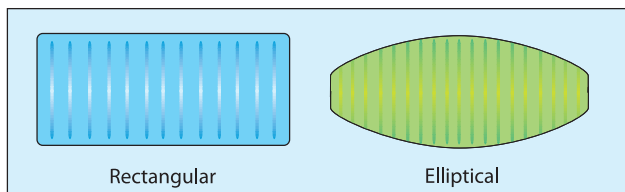


**Figure 2-3. Angle of trim and center of pressure in gliding flight.**

rectangular wings have lower aspect ratios and lower efficiency than the higher aspect ratio and higher efficiency elliptical wings. Generally, a high aspect ratio wing, compared to a low aspect ratio wing, produces higher lift at lower angles of attack with less induced drag. [Figure 2-6].



**Figure 2-4. Gliding and climbing pitch angles.**



**Figure 2-5. Planform view of a PPC inflated wing: rectangular and elliptical.**

**Wing loading** is a term associated with the total weight the ram-air wing must support. Wing loading is found by dividing the total weight of the aircraft, in pounds, by the total area of the wing, in square feet. Wing loading is found by dividing the weight of the aircraft, in pounds, by the total area of the wing, in square feet. For example, the wing loading would be 2.0 pounds per square foot when 1,000 pounds—a common weight for a two-seat PPC with two people—is under a 500-square foot wing. If flying with one person the aircraft weight might be 700 pounds and the wing loading would decrease to 1.4 pounds per square foot.

**Gliding flight** is flying in a descent with the engine at idle or shut off.

### Powered Parachute Wing Pressurization and Flexibility

The powered parachute has two distinctive modes: (1) inflated, it is a ram-air wing with a curved arc—a recognizable airfoil shape; and (2) deflated, it is a canopy that is either lying flat on the ground or packed into a bag.

Note: Chapter 7, Takeoffs and Departure Climbs, will detail the methods of getting the uninflated canopy laying on the ground turned into a flying wing. Since the aerodynamics of the PPC do not start until the wing is completely inflated, this chapter will assume each reference to the PPC wing is to an inflated ram-air wing already in the shape of an airfoil.

The powered parachute ram-air wing retains its airfoil shape due to the air pressurizing the inside cells via the relative wind airflow being rammed into the front openings of the canopy—thus the term “ram-air wing.” The pressure inside the wing is much higher than the outside top and bottom because the dynamic pressure from the relative wind is converted to static pressure to pressurize the wing. The greater the speed, the greater the pressure inside the wing and the more rigid the wing. The cell openings are designed to be perpendicular to the relative wind to achieve maximum pressure from the relative wind. This static internal pressure harnessed from the relative wind is called dynamic pressure ( $q$ ), and is determined by the velocity squared times the air density factor. [Figure 2-7] Note the dynamic air pressure converted to static pressure at point A is constant throughout the wing points B and C. This static pressure is always greater than the pressure outside the wing at points X and Z.

Cross-port openings are placed in the ribs of each cell, connecting the adjoining cells. These cross-ports are dispersed throughout the wing (with exception to the outboard side of the end cells) to maintain positive pressure throughout. The pressure is constant inside

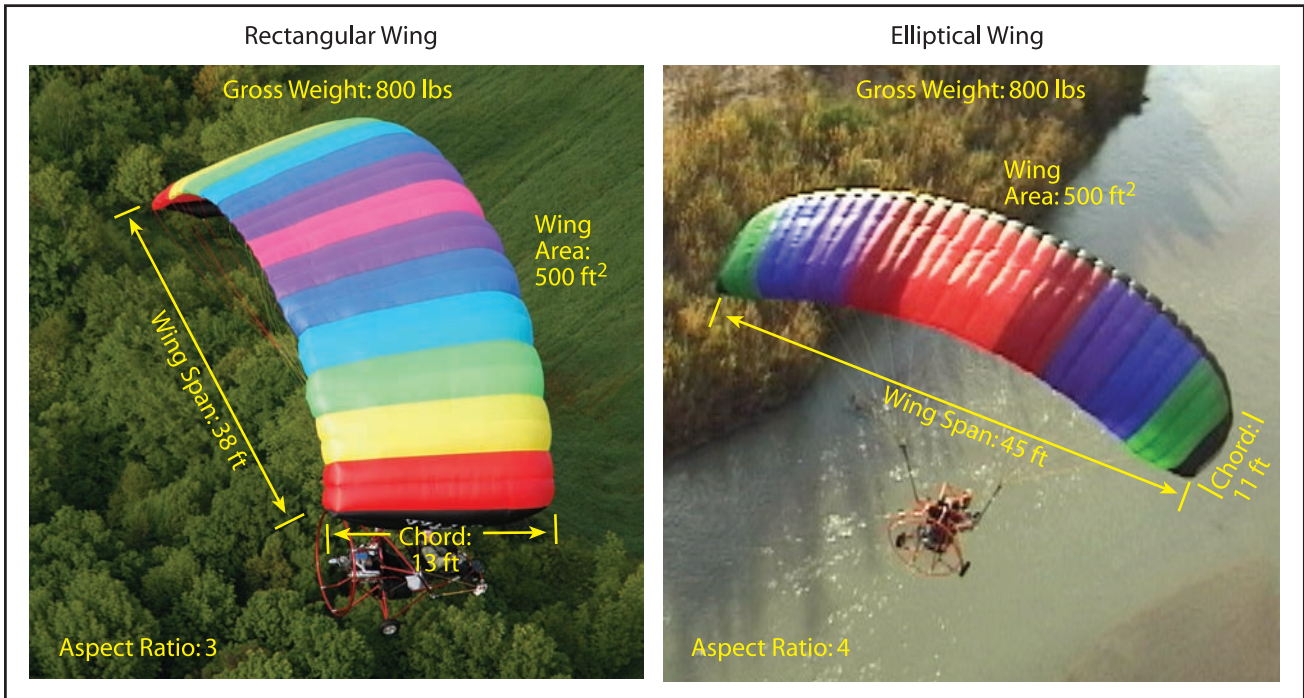


Figure 2-6. Aspect ratio comparisons for wings with similar areas.

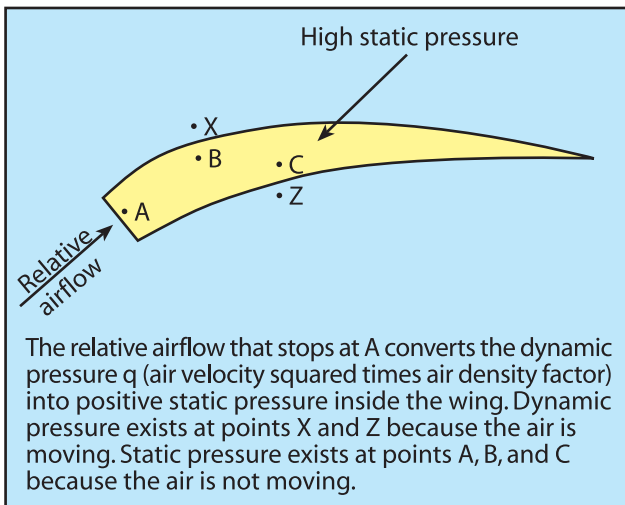


Figure 2-7. Dynamic pressure.

the wing because the dynamic pressure hitting the opening is the same for each cell and the speed is the same. The cross-ports aid the complete wing in becoming pressurized during inflation and maintaining the pressure throughout the wing in turbulence. [Figure 2-8]

The inflatable wing airfoil generally remains a consistent shape as designed by the manufacturer. However, pilot control of the wing to make a turn significantly changes the relative aerodynamic qualities of the PPC wing by pulling down the trailing edge similar to a flap on an airplane. [Figure 2-9]

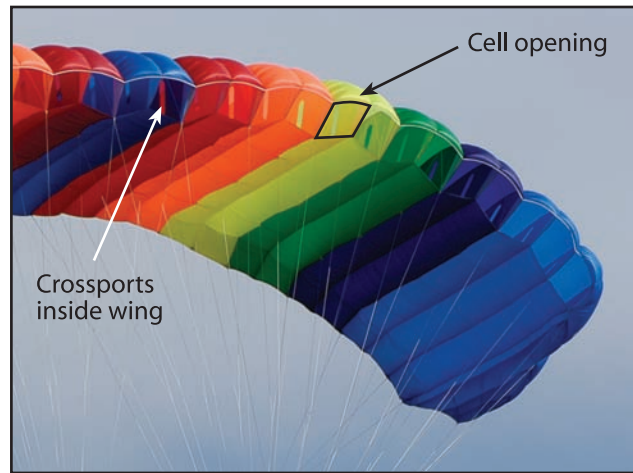


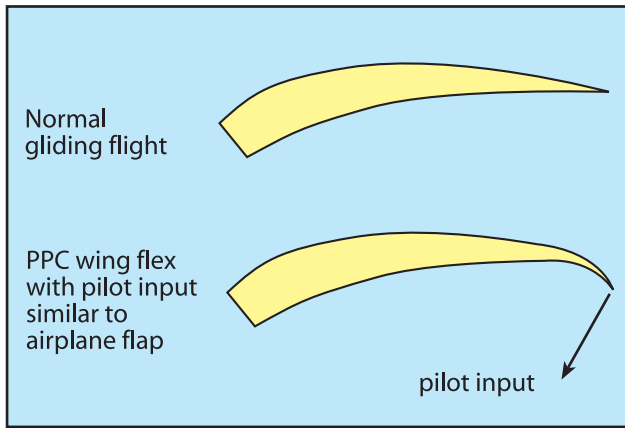
Figure 2-8. Cell openings and cross-port view.

Faster speeds from smaller wings or more weight create a higher pressure in the wing resulting in higher control forces because of the higher internal pressure.

## Forces in Flight

Like all aircraft, the four forces that affect PPC flight are thrust, drag, lift, and weight. [Figure 2-10] In steady PPC flight:

1. The sum of all upward forces equals the sum of all downward forces.
2. The sum of all forward forces equals the sum of all backward forces.



**Figure 2-9. PPC wing flexibility in flight.**

3. The sum of all moments equals zero.

**THRUST** – the forward force produced by a powerplant/propeller as it forces a mass of air to the rear (usually said to act parallel to the longitudinal axis).

**VS.**

**DRAG** – the aerodynamic force acting on the airfoil lines and cart in the same plane and in the same direction as the relative wind.

**LIFT** – the aerodynamic force caused by air flowing over the wing that is perpendicular to the relative wind.

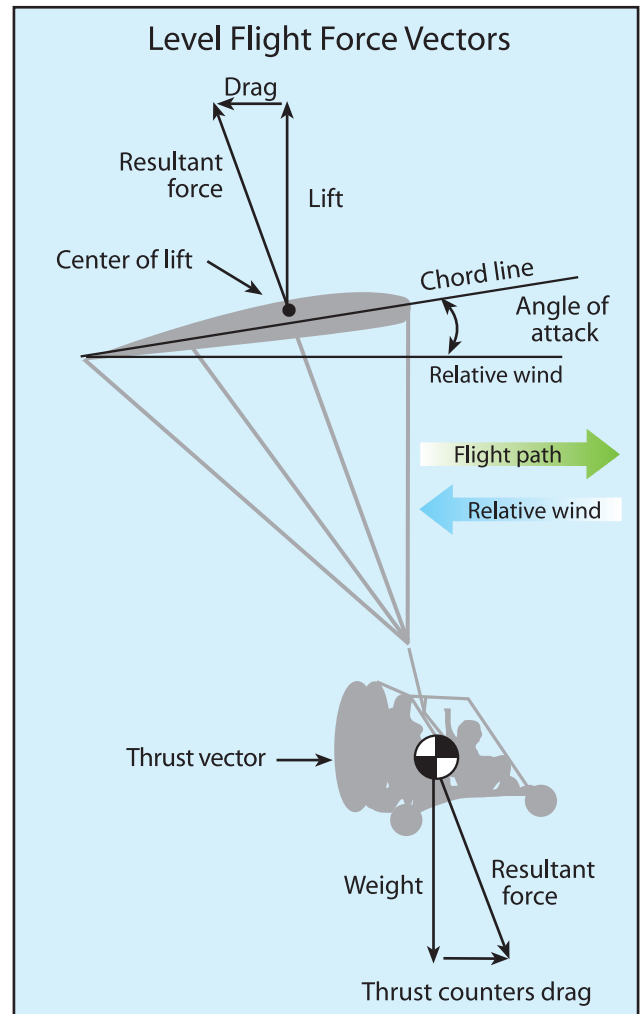
**VS.**

**WEIGHT** – the force of gravity acting upon a body.

### Lift

Lift opposes the downward force of weight and is produced by the dynamic effects of the surrounding air-stream 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 2-11.

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. Small changes in airspeed create larger changes in lift. 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



**Figure 2-10. Level flight forces.**

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

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)

$\rho$  = Air density (Slugs per cubic foot)

S = Wing surface area (Square feet)

**Figure 2-11. The lift equation.**