Chapter 2 **All About Stalls**

A Golden Rule of Flight is: “Maintain thy airspeed lest the earth shall arise and smite thee.”

This platitude has survived for a century of manned flight, and although it is certainly well intended, it can be grossly misleading. This is because airspeed is related only indirectly to the stall. Most pilots know that an airplane can be made to stall at any airspeed while being flown in any attitude.

A stall, we have been taught, results only from an excessive angle of attack. To relate a stall to airspeed can be as erroneous as the advice given by Daedalus to his impetuous son: “Don’t fly too high, Icarus, lest the heat of the sun shall melt your waxen wings and thee shall plummet from the skies.”

Figure 4 shows air flowing smoothly about a wing, caressing it fondly to produce lift. In the second case, the air (relative wind) strikes the wing at such a large angle of attack that it cannot negotiate a change in direction quickly enough to hug the wing’s upper surface. Instead, the air separates from above the wing and burbles; lift is destroyed.

Air, like every other mass, has inertia and resists making sharp turns.

Consider an athlete sprinting around a race track at maximum speed. As long as the track consists of straightaways and gentle curves, he has no difficulty following the oval course. But ask the runner to make a sharp, 90-degree turn without slowing down, and we ask the impossible. There is no way it can be done without either overshooting the corner or toppling in the attempt. Airflow about a wing behaves similarly; it can make only gradual changes in direction.

The elevator controls angle of attack. With it, a pilot determines the angle at which he would like the air to meet the wings. When the control wheel (or stick) is brought aft, the angle of attack increases. With sufficient back pressure on the wheel, the angle of attack reaches a critical value, an angle at which the air can no longer “make the turn.” The air is asked to perform the impossible. The result is a rebellious stall, irrespective of airspeed and attitude. (In an effort to make some aircraft “stall-proof,” designers simply limit up-elevator travel.)

The purpose here is not to belabor the significance of angle of attack. This drum is beaten loudly by every flight instructor and in every training manual. Unfortunately, these sources often drop the ball as soon as the pilot gets interested. The subject is presented like a striptease act; rarely do we get to see the whole picture.

A major problem arises when a stall is illustrated as in the second example in Figure 4. The pilot is given the impression that when a specific angle of attack is reached, the entire wing stalls. This is seemingly verified in flight when, during a practice stall, all lift seems to disappear suddenly. But this is not the way it works.

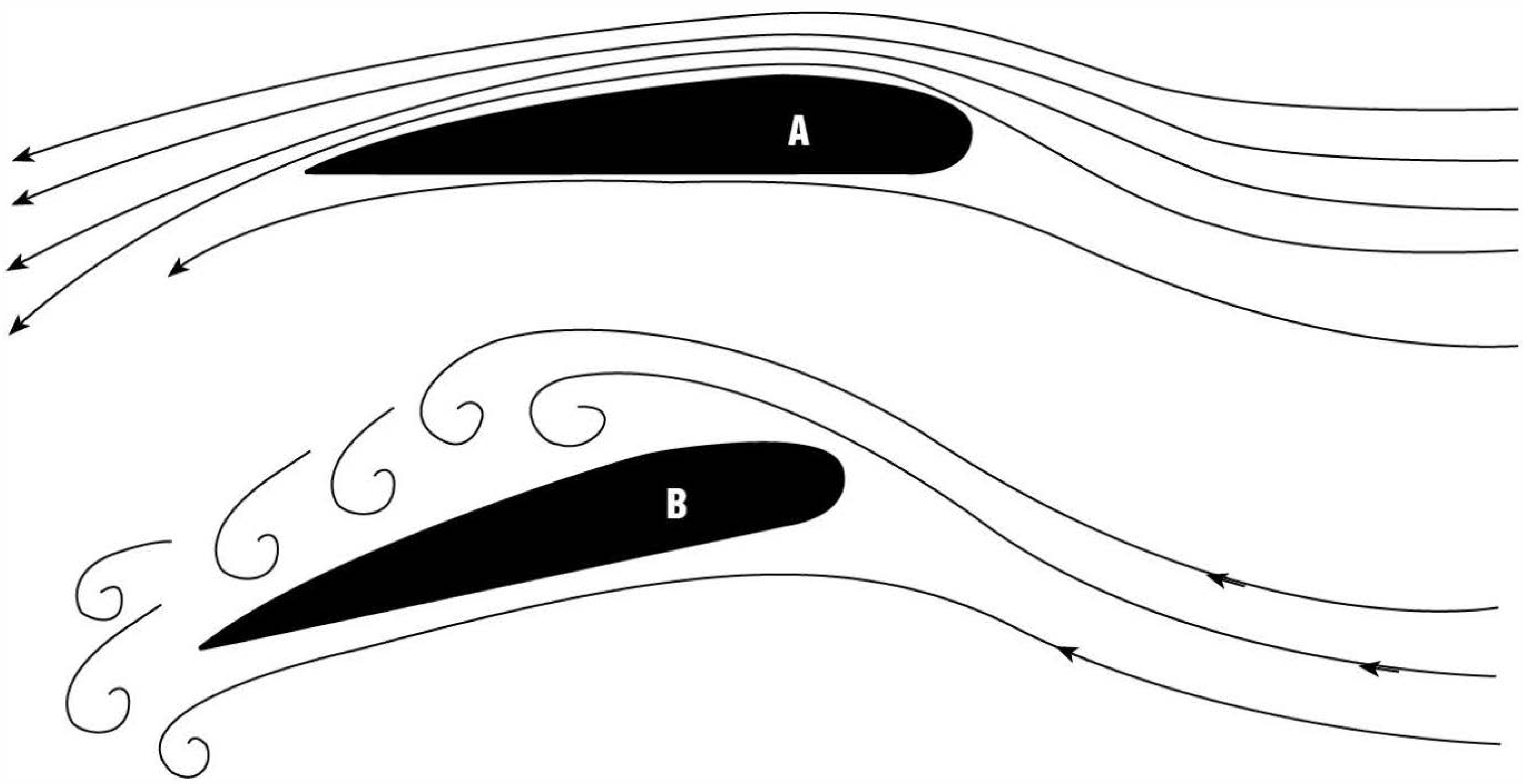

Figure 4. Lift production and lift destruction

The figure is misleading because it shows only an airfoil, a narrow, cross-sectional slice of wing. It represents what occurs at a specific point along the wing, but not what happens along the entire span. In other words, the pilot sees only one small, albeit important, piece of the puzzle. He is not shown the big picture.

One of the best ways to learn the stall characteristics of an entire wing is to actually observe airflow behavior. Since this is difficult without a wind tunnel, settle for second best: a tufted wing. By attaching small strands of yarn to a wing's upper surface, the development or erosion of lift can be seen at various angles of attack.

A low-wing airplane works best. Similar tests can be conducted with a high-wing airplane, but without mirrors the pilot would have difficulty observing the tuft patterns above the wing.

Although tufting a wing is not difficult, it is simplified with the help of a volunteer. My partner during one series of stall investigation tests was

NASA's Cal Pitts, who was particularly interested in observing the stall characteristics of the subject airplane, a Piper Cherokee 180.

Armed with two skeins of black yarn, a large roll of masking tape and a pair of scissors, we began the tufting process. After two hours of wrapping, taping and snipping, Cal and I stood back to admire the Cherokee's quaintly attired left wing. We couldn't help but wonder what it would be like to work for Boeing's flight test department and have to tuft the wing of a 747.

During the subsequent takeoff roll, neither of us paid much attention to the mechanics of flying; we were preoccupied watching the tufts line up with the relative wind, watching the fruits of our effort come to life.

Prior to takeoff, Pitts also attached a 10-foot strand of yarn to the right wingtip. During climbout, it whipped about like a small cyclone, describing a long cone in revolution. There it was, for all to see: a wingtip vortex. It makes a believer of you. It is one thing to read about vortices, but it is quite another to see one in action.

We began a stall series high above the smog oozing from the nearby Los Angeles basin. Throttle retarded and wings level, Pitts slowly raised the nose. With the wing flying at a relatively small angle of attack, we noticed a stall developing at the wingroot near the trailing edge. The tufts there were no longer lying flush with the wing. Instead, they had flipped forward, wriggling and writhing, reacting to the burbling, turbulent eddies of air. The airflow had separated from this area of the wing. We were witnessing the strangulation of lift.

Raising the nose farther, we could see the stall spread or propagate forward and spanwise, stealing larger and larger chunks of lift.

The stall warning came alive, and the familiar buffet was felt. With the control wheel fully aft, the Cherokee bucked lightly and the nose pitched downward.

When the wing had been flown at the maximum angle of attack, we noted that only the inboard half of the wing had stalled. During this and subsequent stalls, it was apparent that at no time did the entire wing stall.

Such a demonstration raises this question: If a stall develops progressively and the wing is always developing some lift, what causes the sudden "break" or "nose drop" associated with a stall?

The answer is only incidental to the loss of lift. In normal flight, downwash from the wing (Figure 5) strikes the upper surface of the horizontal tailplane. This action helps the elevator-stabilizer combination to produce a downward force that keeps the nose up in straight-and-level flight. Without "tailfeathers," a conventional aircraft would dive uncontrollably.

As a stall is approached, turbulent air from above the stalled portion of wing strikes the tail (and sometimes the aft fuselage). This is usually the cause of the familiar stall buffet. In other words, the wing doesn't buffet, the tail does. When enough of the wing stalls, insufficient downwash remains to keep the tail down. In a sense, the horizontal stabilizer stalls, too. This, in addition to the air striking the bottom of the stabilizer (at large angles of attack), causes the tail to rise.

As a result, the nose drops, a form of longitudinal stability that automatically assists stall recovery.

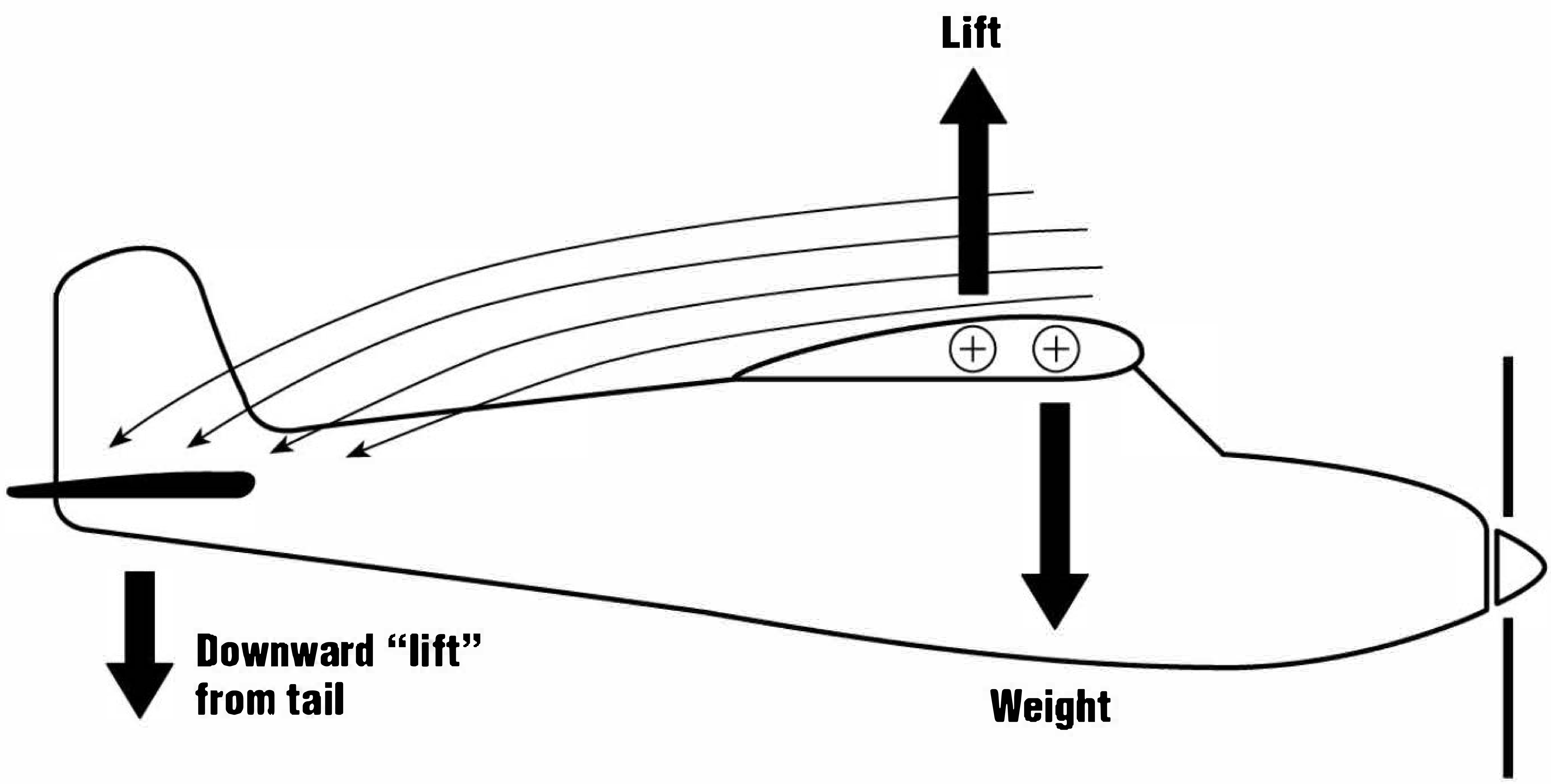

Figure 5. The effect of downwash

The stall pattern demonstrated by the Cherokee 180 wing is typical of a rectangular wing. Other wing shapes (Figure 6) exhibit different stall patterns. The stall of a swept wing, for example, begins at the outboard tip of the trailing edge and propagates inboard and forward.

The rectangular wing has the most ideal stall pattern (that is, an aft root stall). Such a stall provides a tail buffet to warn of an impending stall and allows the wingtips to remain flying as long as possible. This is, of course, where the ailerons are, and it is important for these controls to remain as effective as possible.

A tip stall, on the other hand, is bad news. The tailplanes are not behind the stalled portion of the wings and therefore may not provide the warning buffet. The ailerons become ineffective early in the stall and cannot be counted upon to provide roll control during flight at minimum airspeed. Also, the stabilizing effect of a nose-down pitching moment may not occur during a tip stall. A tip stall on a swept wing can be particularly hazardous because a loss of aft lift on the wing could produce a nose-up pitching moment and drive the airplane into a deeper stall.

For obvious reasons, aircraft designers go to great lengths to make certain that their aircraft exhibit optimum stall patterns that begin at or near the wingroot. Four methods are commonly used to achieve this.

Wing twist. The wings of high-wing Cessnas are twisted slightly so that the angle of attack of an inboard wing section is always larger than that of the outboard wing section. This is also called "washing out" a wing. For example, the wing twist of a Cessna 172 is 3 degrees. When the inboard section of a 172 wing is at an angle of attack of 14 degrees, the outer wing section has an angle of attack of only 11 degrees. Such a scheme forces the root to stall before the tip.

A stall strip is a narrow length of metal usually having a triangular cross section that is mounted spanwise on the leading edge of a wing. At large angles of attack, the strip interferes with airflow at the leading edge and induces a stall to form behind. In this manner, the initial stall pattern of a wing can be placed almost anywhere along the wing. A similar, but more expensive technique, is to sharpen the leading edge near the wingroot.

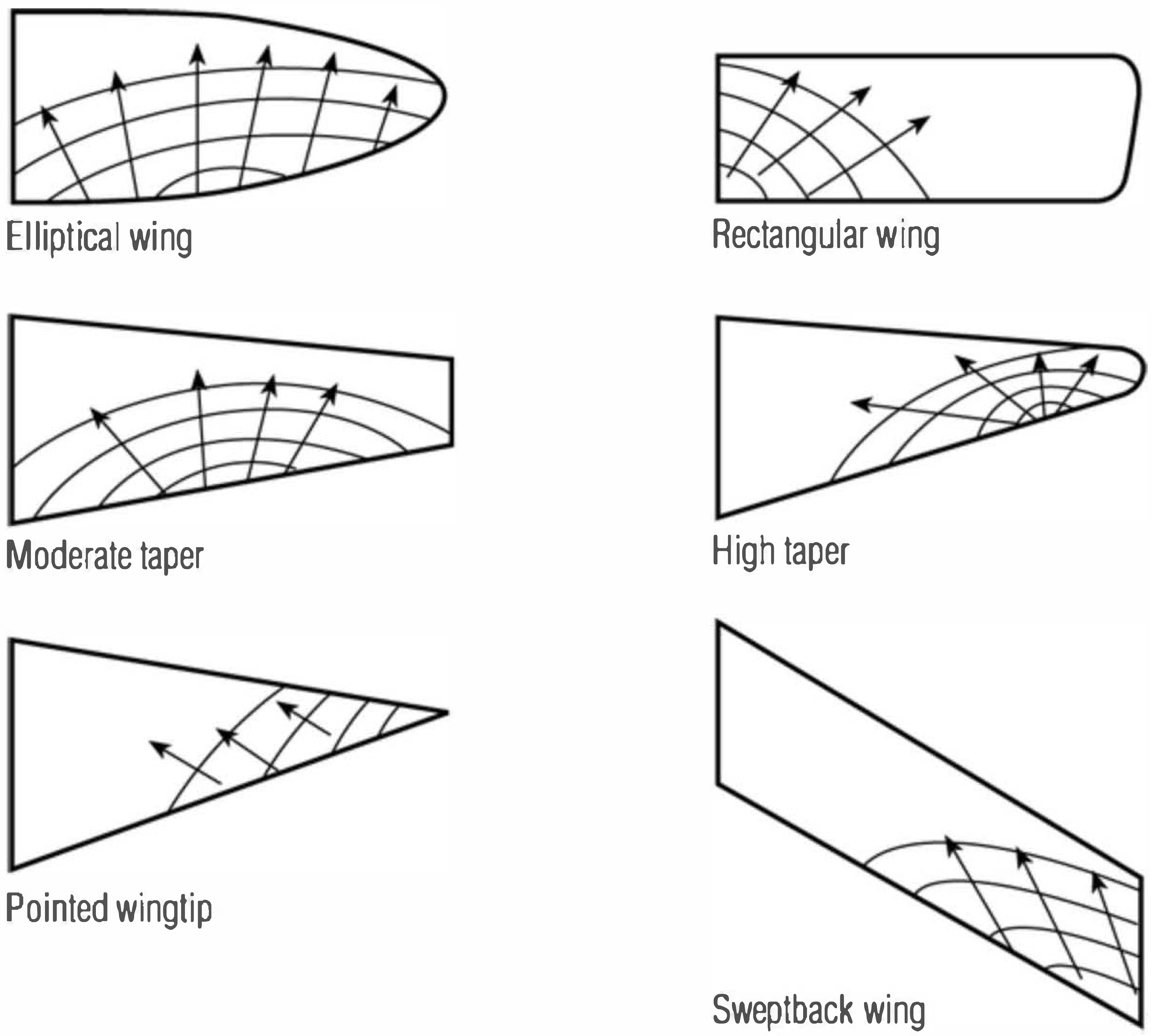

Figure 6. Wing shape affects stall pattern

Variable airfoil wings behave much like twisted wings. Such a wing incorporates two or more airfoils, an airfoil being a wing's cross-sectional shape at some given point. The airfoils are selected in such a way that those used near the wingroots have smaller stalling angles of attack than the airfoil(s) used near the tip. The result: a root stall. This sophisticated technique has been used in the design of many aircraft including the Ryan Navion and most jet transports.

Wingtip slots are expensive, which explains why they are uncommon. The Globe Swift, for example, has a moderately tapered wing that might create an unsatisfactory stall pattern were it not for the built-in wing slot on the outboard section of each wing. The slots tend to delay airflow separation behind them. Such slots delay stalling of the outboard wing sections and, as a fringe benefit, increase aileron effectiveness at low airspeed.

With the help of a tufted wing, it is possible also to observe the main difference between power-on and power-off stalls (Figure 7).

During an approach to a power-on stall, propwash flowing over the inboard wing section preserves lift in that area. Additionally, propwash helps to keep the tail flying longer.

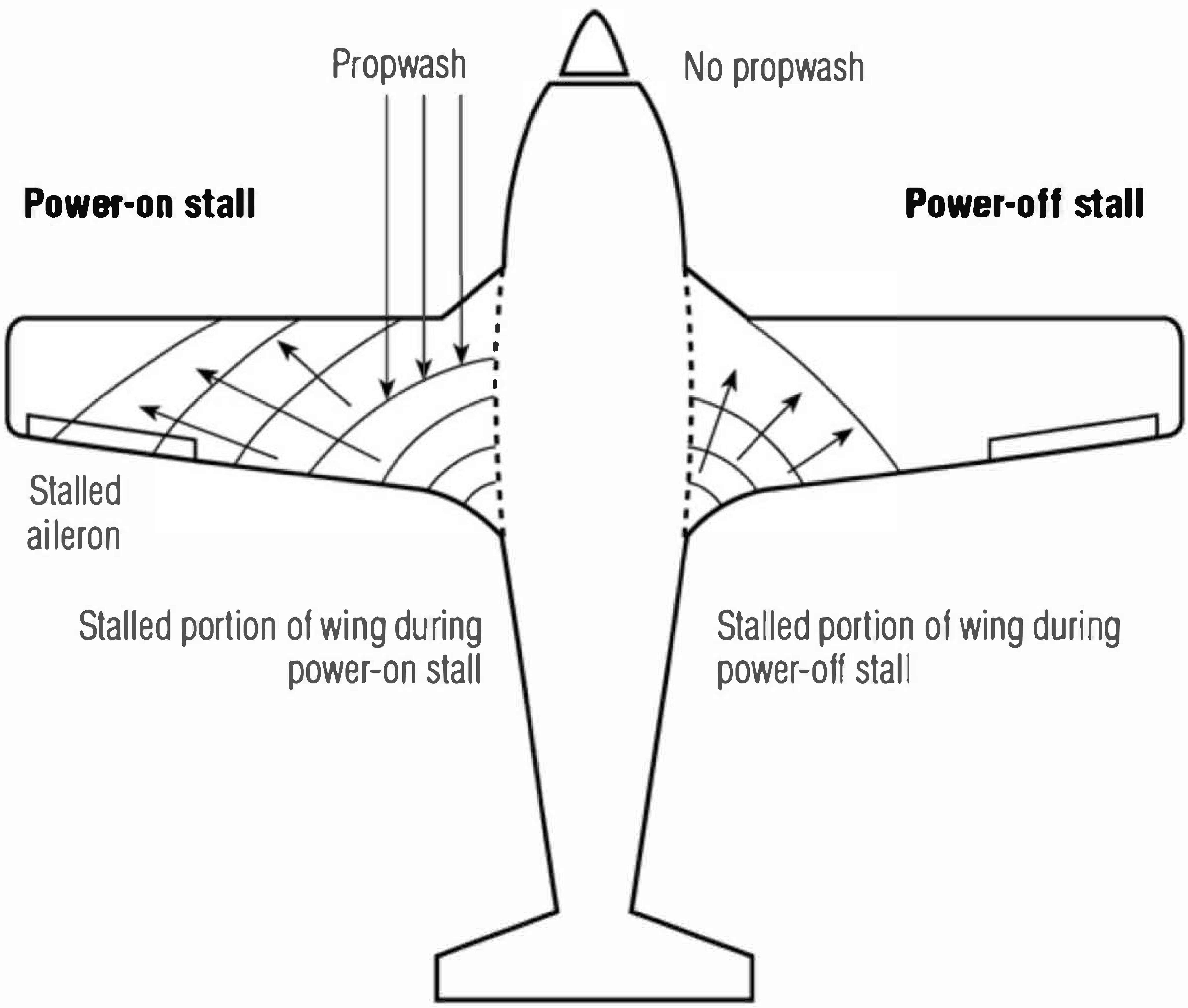

Figure 7. Effect of propwash on stall pattern

Consequently, the airplane can be forced into a deeper stall that involves considerably more wing area. So much of the wing is stalled that it is unable to provide much in the way of lateral stability. As a result, the aircraft often exhibits a surprisingly strong roll toward the wing most deeply involved in the stall, a problem that is compounded when flaps are extended.

A pilot's reaction to such an abrupt roll is to counter with opposite aileron. But since these controls may be located in the stalled portion of the wing, their deflection can have an adverse effect and actually contribute to an increased roll rate.

Without experience in a particular aircraft, it is difficult to predict which wing will drop during a full-power stall. This is because the factors causing one wing to stall before the other might consist of minute flaws on a leading edge such as a dent, a flat spot, or even a landing light.

Engine and propeller forces often cause the left wing to drop during a power-on stall, but only if both wings are identical, exactly identical—a condition rarely found on production airplanes.

Since the elevator usually is in the propwash, it is considerably more effective during an approach to a power-on stall. This, combined with the vertical component of thrust from the engine, results in the ability to force the aircraft into a deeper, more complete stall.

When the power-on stall pays off, the combined pitching and rolling moments are considerably more abrupt than during a power-off stall. The pilot must be prepared to use skillful recovery techniques and be particularly attentive to proper control usage.

Two other factors are noteworthy. During a climbing turn, the outside wing is at a slightly larger angle of attack than the inside wing. If the aircraft is stalled under these conditions, the outside (or high) wing usually stalls first, resulting in an abrupt reversal in the direction of bank. Such a maneuver is called an “over-the-top” stall. Failure to execute a timely recovery can lead to a full roll followed by a conventional spin.

During a descending turn, the converse occurs. The inside wing has the larger angle of attack. This means that if the aircraft stalls while turning and descending, the inside wing would tend to stall first, resulting in an increased bank angle. An attempt to recover using ailerons can aggravate the “under-the-bottom” stall and result in an increased bank angle and possible spin.

The difference between power-on and power-off stalls explains why stalling a conventional twin-engine airplane with a failed engine out can be so vicious. One wing is protected from an early stall by propwash from the operative engine; the wing with the inoperative engine has no such protection. When the angle of attack is increased under these conditions, only one wing stalls, and this can force the aircraft into something similar to a snap roll followed by a spin.

Quite obviously, airspeed—or the lack of it—is not the primary cause of a stall. This has been a rather involved discussion without mentioning knots or miles per hour because any airplane can be made to stall at any airspeed (as long as excessive load factors don’t break the machine first).

A stall occurs for only one reason: the pilot has tried to fly the wing at too large an angle of attack. Recovery is just as simple. Reduce the angle of attack.