THE COMPLETE
PRIVATE PILOT

THIRTEENTH EDITION

Bob Gardner

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The Complete Private Pilot
Thirteenth Edition
By Bob Gardner

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FOREWORD

A new aviation book — one that plows new ground, one that develops material never before considered — is pretty hard to come by. And until there are some radical changes in the types of aircraft we fly and the techniques necessary to fly them, the situation is quite likely to stay that way.

But there are always better, if not "new," ways to communicate aviation information…that's what Bob Gardner has accomplished with *The Complete Private Pilot*.

A writer embarking on the task of creating a fundamental aviation text is faced with a formidable challenge; if prospective pilots are to reap the benefits of his work, the writing must be at once very readable and very comprehensive.

The Complete Private Pilot does both of those in spades, as Bob Gardner reaches into his own aeronautical experience and brings to the reader a clear exposition of the knowledge required by the budding private pilot.

It's not all here — you'll continue learning (we hope!) long after your initial study of regulations, weather, navigation, and so on — but this book is a great way to get started.

Your author has met the challenge well. *The Complete Private Pilot* is indeed readable, comprehensive, and perhaps more important than those, it's a book which will lead you to a greater understanding of flying's fundamentals.

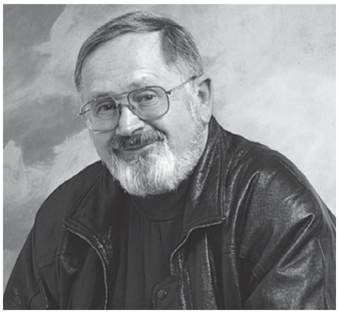
I've always contended that a smart pilot is a safe pilot…you are to be commended for your choice of *The Complete Private Pilot* as a bedrock book in your aviation library.

Richard Taylor

About the Author

Robert Gardner has long been an admired member of the aviation community. He began his flying career in Alaska in 1960 while in the U.S. Coast Guard. By 1966, Bob accomplished his Private land and sea, Commercial, instrument, Instructor, CFII and MEL. Over the next 16 years he was an instructor, charter pilot, designated examiner, freight dog and Director of ASA Ground Schools.

Currently, Bob holds an Airline Transport Pilot Certificate with single- and multi-engine land ratings; a CFI certificate with instrument and multi-engine ratings, and a Ground Instructor's Certificate with advanced and instrument ratings. In addition, Bob is a Gold Seal Flight Instructor and has been instructing since 1968; he has been recognized as a Flight Instructor of the Year in Washington State. To top off this impressive list of accomplishments, Bob is also a well-known author, journalist and airshow lecturer.



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The Complete Private Pilot

The Complete Advanced Pilot

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Say Again, Please—
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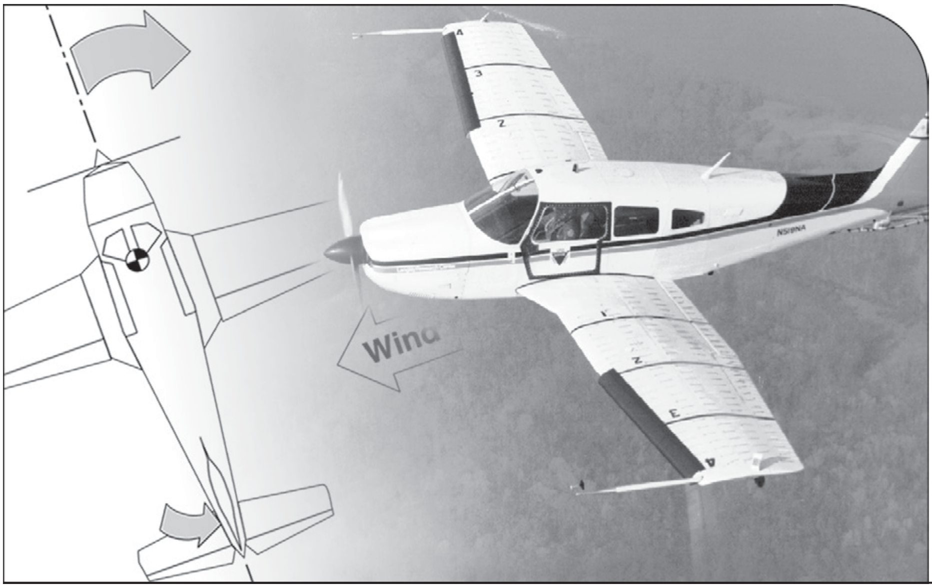


LESSON 1

Basic Aerodynamics

In this book we are going to assume that your training airplane is all-metal (although airplanes that are partially or completely made of composites are increasingly available), has one engine, a fixed-pitch propeller, and a non-retractable landing gear. A stroll along the ramp of your hometown airport will show you there are many variables, however, and you may want to compare features on other airplanes with the one you fly. Here are some things to look for:

Fuselage Construction

The fuselage (or cabin, in most modern airplanes) is the basic structure to which the wings and empennage (*see* Figure 1-1 on the next page) are attached. Most of the small airplanes you will see during your flight training are unpressurized (Lesson 2)—you can tell by the square windows and non-airtight doors. Airplanes that are pressurized for passenger comfort at high altitudes have round or oval windows and tight-fitting doors.

The fuselage of almost every airplane you see will be of aluminum construction with internal strengthening members. A close look will show that on some models more attention has been paid to reducing drag caused by rivet heads and other protrusions. Looking at non-metal airplanes will take you to both the past and the future. Fabric-covered airplanes with tubing structures (wood-framed airplanes are really classics!) are lovingly restored and flown by proud owners. No less proud are the pilots of modern composite aircraft, formed of plastic reinforced with glass fibers, carbon fibers, or similar materials which offer great strength and minimal drag. Most light sport aircraft (LSA) and technically advanced aircraft (TAA) are made of composites. Technically advanced aircraft, by definition, have an IFR-approved Global Positioning System navigator with a moving-map display, and an integrated autopilot. Most go beyond this to replace the traditional "six-pack" of analog instruments (*see* Lesson 3) with digital instruments, leading to the term "glass cockpit."

It is altogether possible that you might take your initial training in a composite airplane, but right now they are outnumbered by aluminum planes and that is what I will emphasize.

Wings

The "main spar" within the wing is the structural member that supports the load. Airfoil-shaped ribs are attached to the main spar and the metal or fabric skin is attached to the ribs to give the wing its shape, and it is that airfoil shape that makes the wing capable of developing enough lift to support the airplane in flight. The wings of composite aircraft are

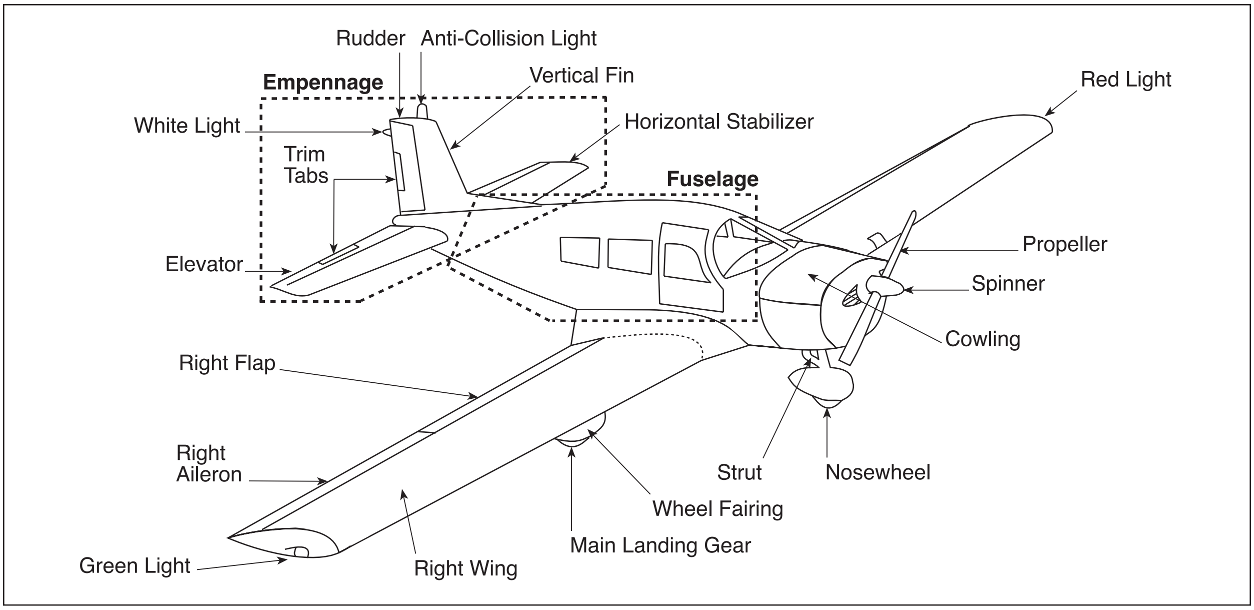


Figure 1-1

formed with molds and have no internal ribs. They do have a main spar, of course.

Almost all modern airplanes have a single wing, mounted either above or below the fuselage. Most, but not all, high wing airplanes have supporting struts. Low wing and strutless high wing airplanes are cantilevered: the internal structure is designed to support the load so there are no struts.

You may see vortex generators (little metal tabs adhering to the upper surface of the wing). They act to keep the airflow over the wing surface attached at high angles of attack and reduce stall speed (*see* pages 1–6 and 1–7).

Wing fuel tanks are either “wet wings” with the wing structure serving as the fuel container, or there are rubber bladders contained within the wing.

Empennage

The horizontal stabilizer, the rudder, the vertical fin, the elevator, or any combination thereof is called the airplane’s empennage or “tail feathers.” These surfaces allow the pilot to change the airplane’s attitude in relation to the horizon by moving the nose up and down (using the yoke or control stick) or left and right (using the rudder pedals) as seen by the pilot. There may be a fixed horizontal stabilizer with a movable elevator, or the whole horizontal assembly may be movable (called a stabilator).

Flight Controls

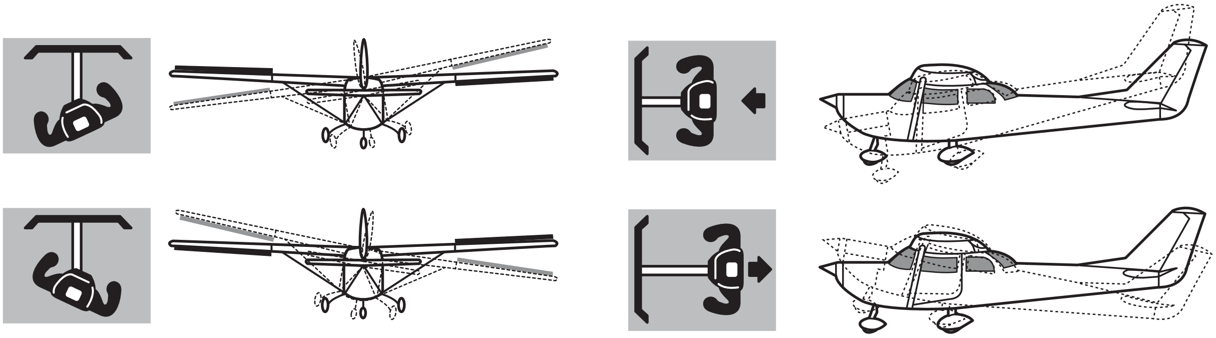
See Figure 1-2: Fore-and-aft movement of the control wheel or stick is transmitted by pushrods or cables and pulleys to these control surfaces, and left-right movement is controlled by the rudder, which is mounted at the rear of the vertical fin. The pilot depresses the rudder pedal in the desired direction of nose movement and a cable system moves the control surface. You will see V-tails, T-tails, and straight tails, and maybe a home-built airplane with no horizontal surfaces mounted on the tail.

Ailerons

You won’t find many airplanes that do not have ailerons, which are movable control surfaces at the outer trailing edge of the wings. Ailerons are used to bank the airplane. A control wheel or stick at the pilot station is moved in the direction of bank desired (left or right). The ailerons are deflected through a system of cables, pulleys, and bellcranks or pushrods. When no control force is exerted, the ailerons are held flush with the wing surface by the airstream.

Flaps

The hinged portions of the trailing edges of the wings near the fuselage are called flaps, and are normally used to steepen the glide angle without increasing airspeed. As you walk along the ramp you will see many different types of flaps, some that simply hinge

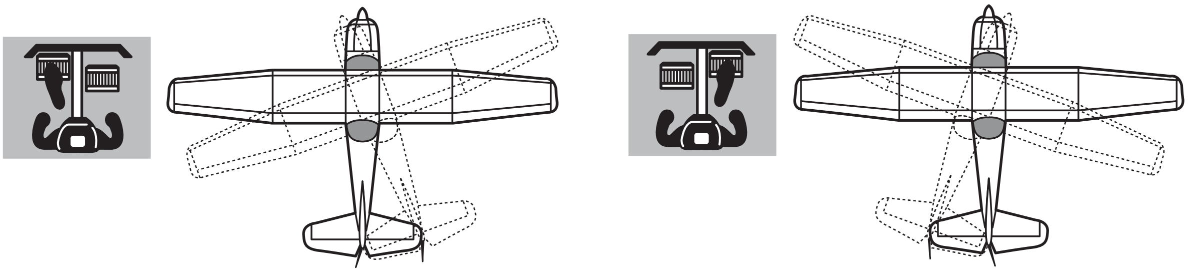


Ailerons

Turning the control wheel (yoke) left or right causes the airplane to bank.

Elevators

Pushing the control wheel forward or pulling it back causes the nose of the airplane to pitch down or up.



Rudder

Pressing on a rudder pedal causes the nose of the airplane to move left or right.

Figure 1-2. Flight controls

down and others that extend down and backward. Older airplanes may not have any flaps at all.

Landing Gear

The two main landing wheels and their supporting structure are designed to withstand landing loads and support the airplane on the ground. A third, smaller wheel mounted either forward (tricycle) or aft (conventional) is for ground steering control only. Nosewheels are usually close to or a part of the engine mount and are definitely not designed to absorb landing loads. (Your instructor will devote a lot of training time to making sure that you do not land on the nose wheel!)

The shiny cylinders on nose wheels and some main landing gear are called struts (the Katana's nosewheel uses replaceable rubber "doughnuts"). They absorb the bumpiness of runways and taxiways. The shiny kind are filled with air and oil, just like your car's shock absorbers. When a strut is "flat" there is no cushioning effect and vibrations are transmitted to the entire airframe. You will see some airplanes which use a spring steel assembly on the main landing gear instead of a strut.

Wheel pants, or fairings, may or may not be present. They reduce aerodynamic drag and add a knot or two to airspeed. Your airplane may have either nonretractable (straight leg) or retractable landing gear. Landing gear that retract into the wing or fuselage add considerably to cruise speed.

Almost all airplanes use disc brakes on the main landing gear, and you can see the discs if there are no wheel pants. Checking brake condition is considerably easier to do on airplanes than it is on cars. The nose wheel is usually not steerable with the rudder pedals and swivels freely, so steering is accomplished by tapping the brake lightly on the side toward the turn.

Propeller

The propellers you see may be either fixed or variable in pitch, or blade angle. You will probably see some amphibians (airplanes that can land on either land or water) with pusher-type propellers, but most are mounted up front and pull the airplane through the air. The conical spinner is not only decorative but serves to direct air into the cooling air intakes.

Engine

Modern airplanes have four- or six-cylinder flat opposed engines: when you open the cowling you will see that the cylinders are on opposite sides of the engine, and that the flat profile allows maximum aerodynamic streamlining of the cowling. As you walk along the ramp you may see an older airplane with a radial engine, its cylinders arranged in a "star" pattern. Most light sport aircraft use water-cooled Rotax engines.

Lights

The lighting system on a modern airplane consists of position lights on the wing tips (red on the left, green on the right) and a white light on the tail, an anticollision light system which may be either red or white (or both) and one or more landing lights. Many airplanes also have bright flashing strobe lights to increases the chances of being seen during both day and night flights.

Light Sport Aircraft

When your pilot certificate says "PRIVATE PILOT Airplane—Single Engine—Land" you are free to fly any single-engine airplane, subject to the endorsement requirement for tailwheel, high performance, and complex airplanes. When it says SPORT PILOT, however, you are limited to those weighing less than 1,320 pounds with no more than two seats, fixed landing gear, and a cruise speed of no more than 120 knots.

Introduction to the Cockpit

This is a typical non-glass cockpit instrument panel layout. Airplane manufacturers have their own ideas about where engine instruments should be located, but the locations of the six flight instruments on the left side of the panel are standardized among manufacturers. (*See* Figure 1-3.)

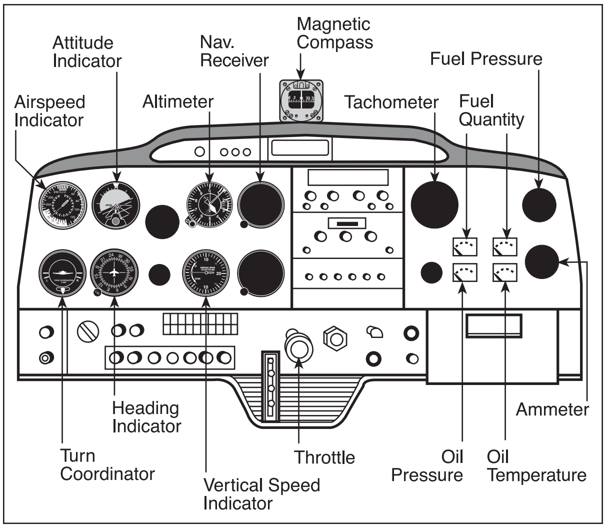


Figure 1-3. Typical "six-pack" of traditional non-digital instruments

If you are training in a Technically Advanced Aircraft ("TAA" in FAA-speak), all of these "steam gauges" will exist on a flat-screen digital display, similar to the G1000 illustrated on Page D-1 in the color section (Appendix D).

Aerodynamics

The subject of aerodynamics deals with forces acting on bodies in motion through the air; in fact "aerodyne" means an aircraft deriving lift from its motion through the air. To oversimplify, an airplane flies because the pilot causes it to accelerate down the runway until its wings develop a lifting force greater than its weight, and it lands because the pilot causes the lifting force to be less than its weight. In flight, the pilot controls the magnitude and direction of lift through use of the flight controls.

To make the airplane go where you want it to go and do what you want it to do, you must use the flight controls as tools and, like any artisan, you have to know what your tools are capable of and how they are used to accomplish the four fundamentals of flight... straight-and-level, turns, climbs, and descents.

As a pilot you will be working with the forces of lift, drag, thrust, and weight. Of these, lift is the force that allows you to move in three dimensions. While it is true that *anything* can be made to "fly" if enough power is applied, an airplane features **airfoils**—shapes specifically designed to develop lift. The amount of lift generated by an airfoil is a function of the area of the lifting surface, the density of the air, the velocity of the airflow over the lifting surface, and the coefficient of lift. This is how these elements are related:

$$\text{Lift} = \text{Coefficient of Lift} \times \text{Area} \times \text{Velocity}^2 \times \text{Density}/2$$

Coefficient of Lift

Don't be intimidated by the words "coefficient of lift"—they apply to physical relationships that are easy to visualize. Before investigating just what coefficient of lift means, or how the other factors affect lift development, you should understand how an airfoil develops lift. Figure 1-4 shows a fluid (illustrated as ping-pong balls) moving through a tube with a restriction in it. If 1,000 units of fluid enter one end of the tube each second, and 1,000 units leave the tube each second, and there is not enough room at the restriction for 1,000 units of fluid to pass, something clearly has to change at the restriction. That "something" is velocity—fewer units must travel at a higher velocity if 1,000 units per second are going to pass the restriction.

As the fluid moves through the tube, its total energy consists of forward movement (**kinetic energy**) and the static force it exerts against the walls of the tube. At the restriction, the energy of forward movement increases, and since total energy can neither increase nor decrease within the system, the static pressure has to decrease. A scientist named Daniel Bernoulli discovered this effect: when a fluid is accelerated the pressure it exerts is reduced. Bernoulli's Theorem accounts for most of the lift developed by an airfoil. You might think of an airfoil as a device designed to accelerate airflow and change its direction.

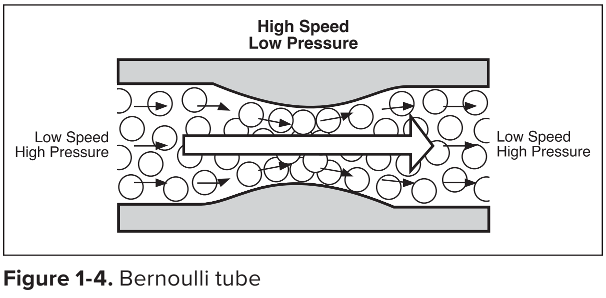


Figure 1-4. Bernoulli tube

If you are having difficulty relating tubes and fluids to airplane wings, the airfoil in Figure 1-5 represents the bottom half of Bernoulli's restricted tube, and the length of the arrows indicates the energy imparted to air molecules as they travel over it. They move most rapidly over the curved surface, which is the area of least pressure.

A second contributor to total lift is Newton's Third Law: for every action there is an equal and opposite reaction. As the airfoil moves through the air it pushes the air downward and, in accordance with Newton's Law, the air exerts an equal upward force. Because of differences in wing design and operating conditions, it is impossible to say what percentage of total lift can be attributed to Bernoulli or to Newton at any time. In Figure 1-6, the dashed lines represent lift due to pressure difference and the solid lines indicate lift due to Newton's Law.

Don't get into any arguments about what creates lift—Bernoulli and Newton share the credit, with Newton holding a slight edge. The bottom line is that there must be a net positive pressure difference between the top and bottom of the lifting surface.

Part of the explanation of coefficient of lift has to do with the curvature, or **camber**, of the upper surface of the wing and angle of incidence. A large curve, or camber, means greater acceleration of the air over the upper surface. Oncoming free air is drawn upward toward the low pressure area on top of the

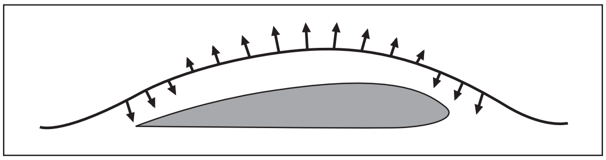


Figure 1-5. Bernoulli airfoil

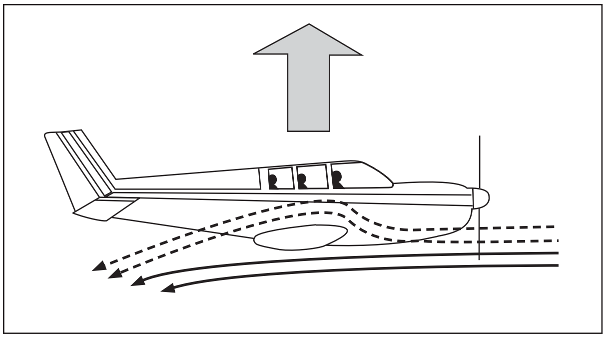


Figure 1-6. Sources of lift

wing, accelerates over the curvature, and flows off the trailing edge creating **downwash**. Most general aviation airplanes change camber and increase lift by moving the trailing edge up or down with control surfaces called ailerons and flaps. Changing lift development by changing wing camber is largely the province of the designer, and is only partially under the control of the pilot. **Angle of incidence**, *which is defined as the angle at which the wing is fastened to the fuselage*, is set by the designer at 1° to 3° in relation to the longitudinal axis and is beyond the control of the pilot.

Wing design is one element of the coefficient of lift, and the other is **angle of attack**—over which the pilot has direct control. An imaginary line drawn from the leading edge of the wing to the trailing edge is called the chord line, and *the angle between the chord line and the relative wind is called the angle of attack* (Figure 1-7). If relative wind is an unfamiliar term, consider this: you are sitting in a convertible at a stop light with the wind blowing on the left side of your face; the wind that you feel is the true wind. When the light changes, and the car accelerates, the wind strikes you directly in the face—that is the relative wind, caused by motion.

In flight, *the relative wind is parallel and opposite to the flight path*. Figure 1-8 shows this relationship in level flight, climbing, and descending. To the wing of a military jet climbing almost vertically, the relative wind is coming straight down, while to the wing of an aerobatic airplane completing a loop, the relative wind is coming straight up. More importantly, when a pilot attempts to maintain altitude by using angle of attack alone, without adding power, the relative wind strikes the bottom of the wing as shown in Figure 1-9. The angle between where the airplane is pointed and where it is going is the angle of attack, and as it approaches about 17 degrees a stall is imminent; the illustration exaggerates the angle to make a point. This is called mushing flight; back pressure must be released and power added to avoid a hard landing.

Lift developed by pressure difference (Bernoulli lift) depends on a smooth flow of air over the upper surface of the wing. As angle of attack is increased (Figure 1-10), the air being drawn over the top surface of the wing begins to tear away from the wing surface at the trailing edge, causing loss of lift. This “burbling” effect can be felt as the disturbed air flows over the horizontal stabilizer and is a better indication of an impending stall than all of the warning lights and horns; it must be announced to the instruc-

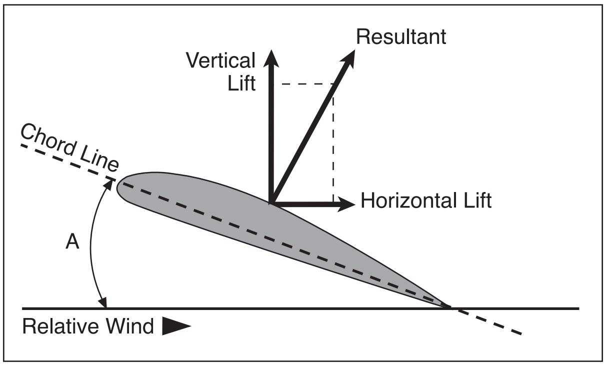


Figure 1-7. Angle of attack

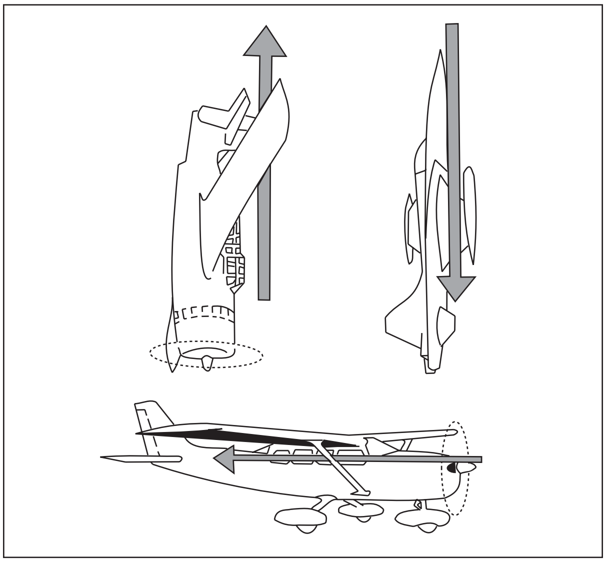


Figure 1-8. Relative wind is opposite to flight path

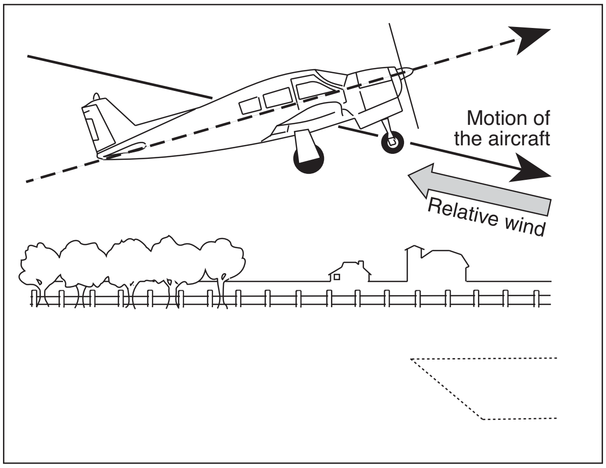


Figure 1-9. Mushing flight

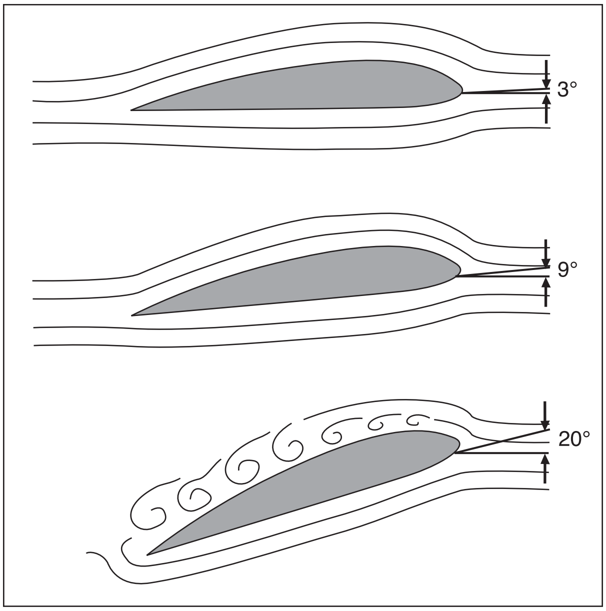


Figure 1-10. Increasing angle of attack to the stall point

tor/examiner. At high angles of attack, the airflow near the trailing edge of the wing even reverses and begins to flow forward!

Aerodynamicists devote considerable time and effort to designing wings that maintain a layer of smoothly flowing air over the maximum area of wing surface; after-market vortex generators aid in keeping the boundary layer attached at high angles of attack. The stalling angle of attack does not change with aircraft weight; if you add thrust in level flight without adding control pressure or trim, the aircraft will climb at a constant airspeed. The indicated airspeed at which the wing will stall is not affected by altitude.

A simple explanation of the aerodynamic stall is that the angle of attack can be increased until the oncoming air is unable to make the sharp turn necessary to follow the wing's surface, and begins to separate from it at the trailing edge. The separation point moves forward on the wing as the angle of attack is increased. The designer controls the progression of this process by twisting the wing slightly from the wing roots to the tips so that the inner sections of the wing lose lift first, and the outer sections (where the ailerons are located), continue to develop lift until the wing is fully stalled.

The NASA photographs (Figures 1-11 and 1-12) show how increasing the angle of attack causes the area of disturbed airflow to expand until total loss

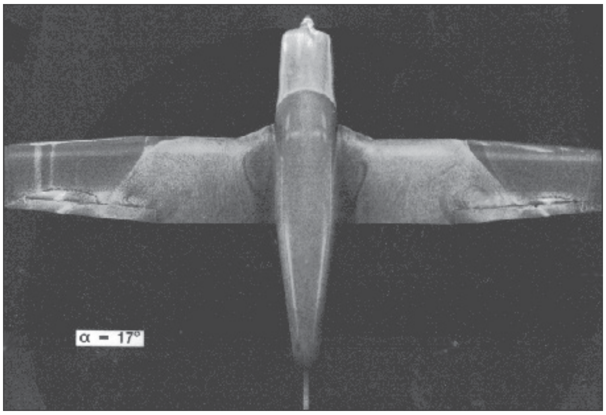


Figure 1-11. NASA photo: 17° angle of attack

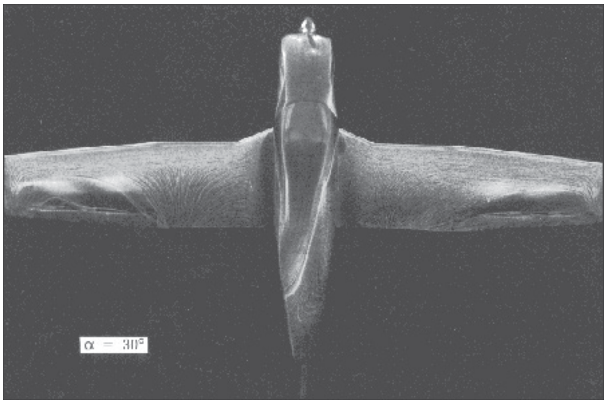


Figure 1-12. NASA photo: 30° angle of attack

of lift occurs. With an angle of attack of 17°, there is still smooth airflow at the outer ends of the wings, while the inner sections are covered with disturbed airflow.

The airflow in the vicinity of the ailerons on this experimental airfoil remains attached to the wing surface and the "pilot" of this wind-tunnel model would retain some roll control. The same wing at an angle of attack of 30° is fully stalled, with no smooth airflow remaining on the wing surface. Notice that air flowing through the gap between the aileron and the wing provides a small area of smooth airflow over the aileron itself. A normal (unmodified) wing stalls at an angle of attack of 18°–20°.

Note: A video of stall progression is available at www.asa2fly.com/reader/ppt

To ensure that the wing root stalls first, some manufacturers install "stall strips" on the leading edge of the wing near the root. Some airplanes have slots in the leading edge near the wing tip which direct high pressure air from beneath the wing to the upper

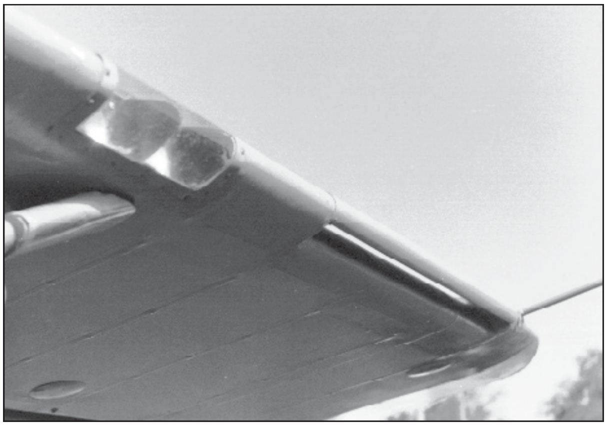


Figure 1-13. Leading edge slots

surface and ailerons, and thus retain controllability at high angles of attack (Figure 1-13). Short takeoff and landing (STOL) airplanes usually have some type of device on the leading edge of the wing which extends only at high angles of attack and which channels airflow in the same manner as the fixed slot in the illustration. Large jet aircraft also use leading edge lift devices.

Figure 1-10 also shows that the lift developed by the wing increases as angle of attack increases, until the angle of attack reaches a critical value (usually 18°–20°) beyond which the air no longer flows smoothly over the wing surface and the wing stalls. The *only* way to stall the wing is to exceed the critical angle of attack. In training, most of your stall practice will be at slow speeds, with the nose of the airplane above the horizon, but you must realize that *the wing can be stalled at any airspeed and in any attitude*. The lift developed by the wing must support the weight of the airplane, and the pilot controls lift by varying the angle of attack. If the weight being supported by the wing is increased, either by overloading the airplane or by adding "G" (gravity) forces while maneuvering, the angle of attack must be increased to provide the necessary lift. There is always the danger of exceeding the critical angle of attack and stalling the wing.

Velocity

Velocity of airflow over the lifting surface plays a major role in lift development. The effect of airspeed is dramatically evident because lift varies as the square of the airspeed: double the airspeed and the lift quadruples; cut the airspeed in half and the lift drops to 25% of the former value. Your control of lift through airspeed will play a major role in your ability to fly efficiently—flying "by the numbers" ensures that you always have the proper angle of attack for the condition of flight (Figure 1-14).

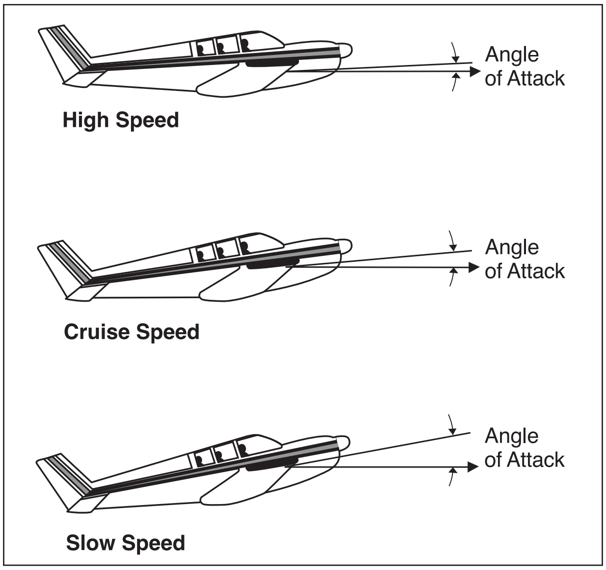


Figure 1-14. Angle of attack vs. attitude and speed

Area

The pilot has very little control over the area of the lifting surface except when the flaps are designed to add area. The wing area of a jet airliner increases considerably as it approaches the runway, as its flaps are extended downward and backward. A wing with a large surface area is desirable at low speeds but would add unacceptable amounts of drag due to skin friction at high speeds.

Air Density

Changes in air density affect the creation of lift because it takes molecules of air flowing over the lifting surface to create lift, and as you encounter higher density altitudes there are fewer air molecules. High altitude means less lift, unless angle of attack or airspeed or both are increased. Water vapor in the air (high relative humidity) means that fewer air molecules are available for lift generation (it takes air, not water, to create lift), so high moisture content also means less lift. Air density decreased by either high altitude or high moisture content will also decrease propeller efficiency (the propeller is an airfoil), and will decrease the power output of the engine which needs air, not moisture, to burn fuel efficiently. It isn't necessary to climb to high altitudes to encounter reductions in air density because air (a gas) expands when heated. At sea level on a hot day in July there will be fewer air molecules available to develop lift.

Drag

Lift is the first tool you will learn to control and use. The second tool you must understand is drag. There are two types of drag for you to be concerned about: **parasite drag** and **induced drag**. Parasite drag is largely beyond the control of the pilot because it comes from such things as struts, fixed landing gear, rivet heads, antennas, and the friction of air passing along the skin of the airplane. Engine cooling drag is 20% of total parasite drag—those air inlets behind the propeller channel a tremendous volume of air over and around the engine. Parasite drag increases as the square of the speed: double the airspeed and the drag quadruples. That is what limits top speed—when all of the available horsepower is being used to overcome drag, you can't go any faster. Figure 1-15 shows how parasite and induced drag vary with airspeed and how each contributes to total drag.

Induced drag is the inevitable result of lift development. Remember how Bernoulli's and Newton's effects in combination provide high pressure on the bottom of the wing and low pressure on the top? These forces are resolved at the wing tip as the high pressure air corkscrews up and around the wing tip toward the low pressure area. This meeting of high and low pressure air, with the rotational velocity imparted to the air, creates induced drag (Figure 1-16).

At large angles of attack with great pressure differences, induced drag is a considerable force; however, as airspeed increases and angle of attack is reduced, induced drag becomes less of a factor. Every time you change the angle of attack, you change the induced drag. Induced drag varies inversely as the square of the airspeed. You will see many modern airplanes with winglets, devices which reduce induced drag by controlling the mixing of high and low pressure air at the tip of a lifting surface. Anything that reduces total drag adds to efficiency. Most recent design advances have been accomplished through drag reduction programs, because increasing performance through the addition of sheer horsepower has reached a practical limit.

Some airplanes can be equipped with spoilers, pilot-controlled flat plates that extend perpendicular to the top of the wing and destroy a large portion of the wing's lift. These after-market modifications allow the pilot to lose altitude rapidly without changing airspeed or thrust.

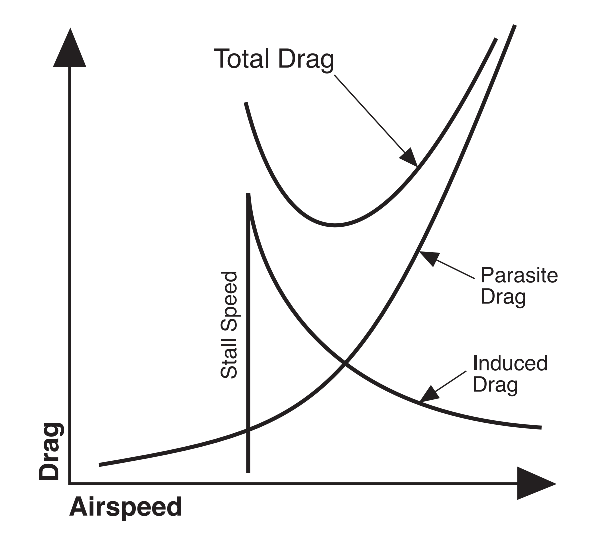


Figure 1-15. Drag and speed graph

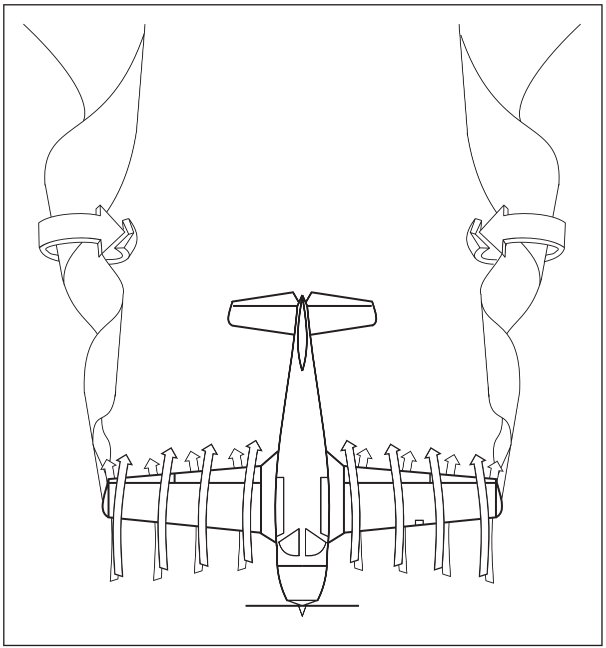


Figure 1-16. Wing-tip vortices create induced drag

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