The Pilot's Manual

PM 2

Ground School

All the aeronautical knowledge required to pass the FAA exams and operate as a Private and Commercial Pilot.

Fourth Edition

Foreword by Barry Schiff

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Aviation Supplies & Academics, Inc.
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The Pilot's Manual Volume 2: Ground School

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Foreword

When it was time to take my private pilot written examination in 1955, my flight instructor handed me a pocket-size booklet. It was published by the Civil Aeronautics Administration (FAA's predecessor) and contained 200 true/false questions (including answers).

"Study these well," he cautioned with a wink, "because the test consists of 50 of these." As I flipped through the dozen or so pages, my anxiety about the pending examination dissolved into relief. Nothing could be easier, I thought. One question, for example, stated "True or False: It is dangerous to fly through a thunderstorm." Really. (I passed the test with flying colors—but so did everyone else in those days.)

The modern pilot, however, must know a great deal more to hurdle today's more challenging examinations. This has resulted in a crop of books developed specifically to help pilots pass tests. Unfortunately, some do little else, and the student's education remains incomplete.

An exciting exception is *The Pilot's Manual* series. These voluminous manuals provide far in excess of that needed to pass examinations. They are chock-full of practical advice and techniques that are as useful to experienced pilots as they are to students.

The *Pilot's Manuals* are a refreshingly creative and clever approach that simplifies and adds spice to what often are regarded as academically dry subjects. Reading these books is like sitting with an experienced flight instructor who senses when you might be having difficulty with a subject and patiently continues teaching until confident that you understand.

Barry Schiff
Los Angeles

Barry Schiff has over 26,000 hours in more than 300 types of aircraft. He is retired from Trans World Airlines, where he flew everything from the Lockheed Constellation to the Boeing 747 and was a check captain on the Boeing 767. He earned every available FAA category and class rating (except airship) and every possible instructor's rating. He also received numerous honors for his contributions to aviation. An award-winning journalist and author, he is well known to flying audiences for his many articles published in some 90 aviation periodicals, notably *AOPA Pilot*, of which he is a contributing editor. ASA publishes several Barry Schiff titles.

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Richard Coffey is a commercial pilot and flight instructor with instrument, multi-engine, and sea plane privileges. He has also been an aviation writer and editor since 1976 and is the author of the Skylane Pilot's Companion (1996). He has written for Airports Services Management magazine, IFR, Aviation Consumer, Aviation Safety and IFR magazines. He regularly flies Cessna 210s and 182s, although he has a weakness for older Beech Bonanzas and has owned an M model.

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James Johnson has over 10 years experience in the aviation industry having first started his career as a flight and ground instructor in Southern California. He holds a B.S. in Aeronautics with minors in both Aviation Safety and Airport Management from Embry-Riddle Aeronautical University. James is a Product Specialist for ASA and regularly contributes to the ASA Learn to Fly blog.

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Barry Schiff has over 26,000 hours in more than 300 types of aircraft. He is retired from Trans World Airlines, where he flew everything from the Lockheed Constellation to the Boeing 747 and was a check captain on the Boeing 767. He earned every available FAA category and class rating (except airship) and every possible instructor's rating. He also received numerous honors for his contributions to aviation. An award-winning journalist and author, he is well known to flying audiences for his many articles published in some 90 aviation periodicals, notably AOPA Pilot, of which he is a contributing editor.

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Jackie earned a B.S. in Aviation Technology and Operations from Western Michigan University and earned a M.S. from Embry-Riddle Aeronautical University. As Curriculum Director for ASA, Jackie oversees new and existing product development, ranging from textbooks and flight computers to computer-based tutorials, and integration of these products into curricula. She also conducts aviation research as well as product development and project management. She holds Flight and Ground Instructor Certificates. Jackie is the author of *Guide to the Biennial Flight Review*, the technical editor for ASA's Test Prep series, and has written for numerous aviation publications.

Richard Taylor

Richard L. Taylor is an award-winning author of many articles and 14 aviation books. He retired from the Air Force Reserve as a major, having earned Command Pilot status. Now associate professor emeritus, Taylor was director of flight operations and training and taught at all levels of the flight curriculum at the Ohio State University. He is the founder and editor of The Pilot's Audio Update, a monthly audio tape cassette service published continuously since 1978. Taylor has accumulated nearly 13,000 hours of pilot time in a wide variety of aircraft including gliders, helicopters, amphibians, turboprops, jets, and most general aviation light airplanes. He remains active in accident investigation and as an aviation consultant in Dublin, Ohio.

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Introduction

You are about to become a flyer, and join the worldwide family of pilots. To do this safely, you need some knowledge, and the aim of *The Pilot's Manual* is to introduce you to this knowledge in an easy-to-follow manner that is both practical and thorough, so that you will fly the airplane confidently and pass the FAA Knowledge Exams with flying colors.

You will learn to be a safe pilot, to take off and fly in the vicinity of your home airport, and to navigate around the country without getting lost or tangled up with thunderstorms and airliners.

The Pilot's Manual has been written not only to help you to pass the FAA Knowledge Exams, but also for you to keep on your bookshelves as a ready reference containing items of practical importance to a pilot. The team involved in producing *The Pilot's Manual* includes many very experienced pilots from a wide range of backgrounds—flight instructors, ground instructors, mountain-flying experts, professors of aviation, meteorologists, FAA inspectors, examiners, air force pilots, naval aviators, airline pilots and others. The accumulated knowledge between these covers is yours for the taking!

Ground School is divided into five sections and introduces you to:

- *aerodynamics*—the basic principles of flight and airplane design;
- *the airplane*—the piston engine, airplane systems and flight instruments;
- *airplane and pilot peiformance*—the factors which affect takeoff and landing performance, climbing and the cruise, how to safely load your airplane and basic physiology so that you can maximize your personal performance;
- *weather*—the main processes of weather and how to interpret charts and forecasts; and
- *flight operations*—the Federal Aviation Regulations (to keep everyone safe), the basic principles of navigation, charts, airspace and airports, flight planning and radio navigation.

This manual is designed for both the Private and Commercial Pilot. The main body of each chapter contains the knowledge required for the Private Pilot Certificate, with review questions. The questions highlight important points and give you practice at typical Knowledge Exam questions.

Additional Commercial Pilot Certificate knowledge, with review questions is included. It is not necessary for the prospective Private Pilot to read these additions, but we hope, when you see how straightforward they are, you will be encouraged to further your aviation knowledge at some stage and take the Commercial Pilot Knowledge Exam. If you plan to go straight to Commercial, this book is ideal for you.

Note. Additions intended only for students studying for their CPL are indicated by a blue line across the top of the relevant text and the letters "CPL" on the outer margin. Subsequent pages are also indicated in this way when appropriate. The end of a CPL-only section is indicated with the text "End CPL" in the outer margin (and a blue line underneath the text should that text fall mid-page). No "End CPL" indication is given if the end of a chapter coincides with the end of a CPL-only section.

A Few Points on Studying

Keep your study periods short and intense. Quietness, good lighting, and a clear and fresh mind are important to efficient study. Leisure is important too. Occasional walks and breaks for relaxation are beneficial to study, as is a day a week away from it all.

Make your own notes and summaries as you read through our text. The summary that you prepare is a most important aid to your learning. We suggest you work your way through the manual chapter-by-chapter, making your own notes and completing each set of review questions as you go. The reviews are not difficult because the knowledge required is in the text. The review questions are designed to give you confidence in your own knowledge and ability while giving you practice for the Private or Commercial Knowledge Exams.

The FAA Knowledge Exams consist of multiple-choice questions which are quick and easy to process. However, multiple-choice questions are not a good learning aid as they present you with a choice of answers, some of which are wrong. To continually read incorrect statements is confusing, so in our reviews we question you in a more positive manner, while retaining some multiple-choice questions in the examination style for your practice.

Our advice when working multiple-choice questions is, prior to reading through the selection of possible answers, think in your own mind what the answer might be. Then read through the choices and quite often you will fmd the answer you already have in mind is among them. If not, then proceed to eliminate the incorrect statements.

Please note that if you are preparing for the Commercial Knowledge Exam you should complete both the private and commercial reviews.

Note. Italics are used throughout the text to highlight significant terms and concepts.

Conclusion

The Pilot's Manual: Ground School is designed to develop an in-depth understanding of the main facets of aviation. Not only will it help you pass the Knowledge Exams easily, it will also provide an excellent basis for becoming a competent and safe pilot, regardless of whether you plan to use your skills for personal recreation and travel, or in a full-fledged career as a flight instructor or with the airlines.

Best wishes for success in your Knowledge Exams and practical flying.

Aerodynamics

1. **Forces Acting on an Airplane**
2. **Stability and Control**
3. **Aerodynamics of Flight**

Forces Acting on an Airplane 1

Like all things, an airplane has *weight*, the force of gravity that acts through the center of the airplane in a vertical direction toward the center of the earth. While the airplane is on the ground, its *weight* is supported by the force of the ground on the airplane, which acts upward through the wheels.

During the takeoff roll, the task of supporting the weight of the airplane is transferred from the ground to the wings (and vice versa during the landing). While in level flight, the weight of the airplane is supported by the *lift* force, which is generated aerodynamically by the flow of air around the wings. In addition, as the airplane moves through the air it will experience a retarding force known as *drag*, which, unless counteracted, will cause the airplane to decelerate and lose speed.

In steady (unaccelerated) straight-and-level flight, the drag (or retarding force) is neutralized by the *thrust* (figure 1-2). In most smaller airplanes, thrust is produced by the engine–propeller combination; in pure-jet airplanes, the thrust is produced by the gas efflux, without the need for a propeller.

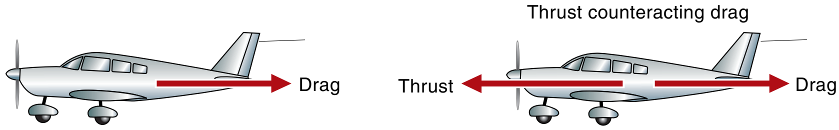

Figure 1-1 Drag counteracted by thrust.

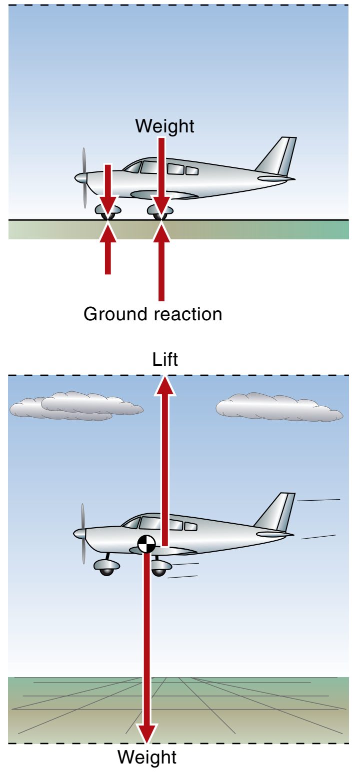

Figure 1-2
The airplane is supported by the ground, and in the air by lift.

In figure 1-3, the forces are equal and opposite, canceling each other out, so that the resultant force acting on the airplane is zero, and it will neither accelerate nor decelerate. In this situation the airplane is in a state of *equilibrium*:

- *weight* is equal to *lift*, and acts in the opposite direction; and
- *drag* is equal to *thrust*, and acts in the opposite direction.

During steady (unaccelerated) flight the four main forces are in equilibrium and the airplane will continue in level flight at the same speed.

For the type of airplane you are likely to be flying during your training, the amount of the lift (and therefore the weight) during cruise flight will be approximately 10 times greater than the drag (and thrust). This relationship of lift to drag is very important and is referred to as the *lift/drag ratio*. The L/D ratio in this case is 10 to 1.

If the airplane is to accelerate in level flight, the thrust must exceed the drag; if the airplane is to be slowed down in level flight, the thrust must be less than the drag. A state of equilibrium does not exist during acceleration or deceleration.

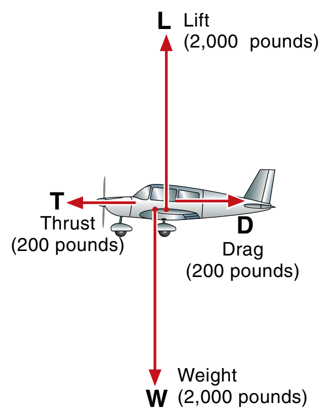

Figure 1-3 The four main forces are in equilibrium during unaccelerated flight.

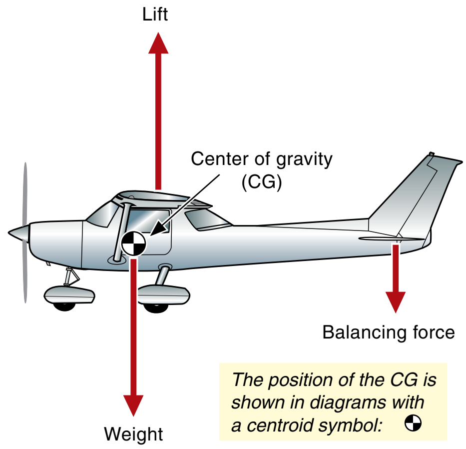

Figure 1-4
Weight acts downward through the center of gravity (CG).

Gravitational Force (Weight)

Gravity is the downward force attracting all bodies vertically toward the center of the earth. The name given to the gravitational force is *weight*, and for our purposes it is the total weight of the loaded airplane. This weight is called *gross weight*, and it may be considered to act as a single force through the *center of gravity* (CG).

The CG is the point of balance. Its position depends on the weight and position of the various parts of the airplane and the load that it is carrying. If the airplane were supported at its center of gravity, the airplane would be balanced.

The weight of an airplane varies depending on the load it has to carry (cargo, baggage, passengers) and the amount of fuel on board. Airplane gross weight will gradually decrease as the flight progresses and fuel is burned off. The magnitude of the weight is important and there are certain limitations placed on it—for instance, a maximum takeoff weight will be specified for the airplane. Weight limitations depend on the structural strength of the components making up the airplane and the operational requirements the airplane is designed to meet.

The balance point (center of gravity) is very important during flight because of its effect on the stability and performance of the airplane. It must remain within carefully defined limits at all stages of the flight.

The location of the CG depends on the weight and the location of the load placed in the airplane. The CG will move if the distribution of the load changes, for instance by transferring load from one position to another by passengers moving about or by transferring fuel from one tank to another. The CG may shift forward or aft as the aircraft weight reduces in flight, such as when fuel burns off or parachutists jump out.

CPL

Wing Loading

Both weight and balance must be considered by the pilot prior to flight. If any limitation is exceeded at any point in the flight, safety will be compromised. (A detailed study of weight and balance appears in chapter 11.) A useful means of describing the load that the wings carry in straight-and-level flight (when the lift from the wings supports the weight of the airplane) is *wing loading*, which is simply the weight supported per unit area of wing.

$$\text{Wing loading} = \frac{\text{weight of the airplane}}{\text{wing area}}$$

Example 1-1

An airplane has a maximum certificated weight of 2,600 pounds and a wing area of 200 square feet. What is its wing loading at maximum weight?

$$\text{Wing loading} = \frac{\text{weight}}{\text{wing area}} = \frac{2{,}600}{200} = 13 \text{ pounds/square foot}$$

End CPL

Airflow and Airfoils

An airfoil is a surface designed to lift, control, and propel an airplane. Some well-known airfoils are the wing, the horizontal stabilizer (or tailplane), the vertical stabilizer (or fin), and the propeller blades. A wing is shaped so that as the air flows over and under, a pressure difference is created—lower pressure above the wing and higher pressure below the wing—resulting in the upward aerodynamic force known as lift. The wing also bends the free stream of air, creating downwash. The total reaction has a vertical component to lift the aircraft or change its flight path, and it has a rearward component, drag, which resists the movement of the wing through the air.

The airplane's control surfaces—ailerons, elevator and rudder—form part of the various airfoils. You can move these to vary the shape of each airfoil and the forces generated by the airflow over it. This enables you to maneuver the airplane and control it in flight. These control surfaces also operate based on Newton's Third Law of Motion, which says that every action has an equal and opposite reaction. By deflecting the free stream of air that flows over them, control surfaces cause the airplane to roll, yaw or pitch as the reaction.

The wing shape can also be changed by extending the flaps to provide better low-speed airfoil characteristics for takeoff and landing.

Figure 1-5
Airfoil shape.

Figure 1-6
Left aileron.

Airflow Around an Airfoil

The pattern of the airflow around an airplane depends on the shape of the airplane and its attitude relative to the airflow. There are two airflow types: streamline flow and turbulent flow.

Laminar Flow

If successive molecules or particles of air follow the same steady path in a flow, then this path can be represented by a line called a *streamline*. There will be no flow across the streamlines, only along them. There is no turbulence or mixing, hence the name *laminar* (layered) flow. At any fixed point on the streamline, each particle of air will experience the same speed and pressure as the preceding particles of air when they passed that particular point. These values of speed and pressure may change from point to point along the streamline. A reduction in the speed of streamline flow is indicated by wider spacing on the stream-lines, while increased speed is indicated by decreased spacing of the streamlines. The existence of streamline flow is very desirable around an airplane because streamlined flow offers the least drag.

Figure 1-7
Vertical stabilizer and rudder.

Figure 1-8
Wing flaps.

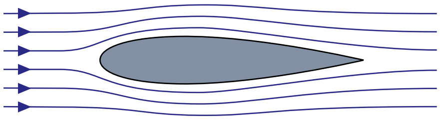

Figure 1-9 Laminar flow.

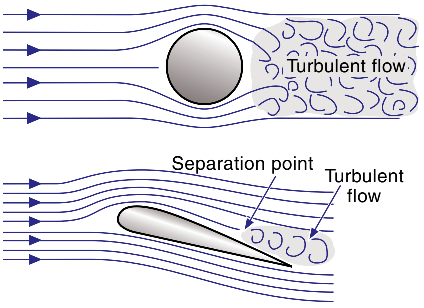

Figure 1-10 Turbulent flow.

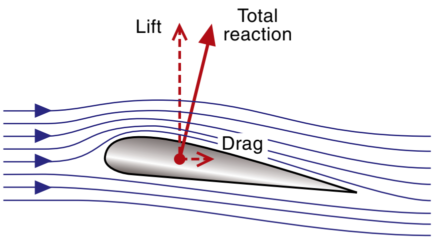

Figure 1-11 Total reaction.

Turbulent Flow

In turbulent flow, the airflow does not follow a streamlined pattern. Succeeding particles of air may travel a path quite different to the preceding parcels of air. This turbulent flow is also known as unsteady flow, vortices or eddying, and is an undesirable feature in most phases of flight. The point where the airflow around a surface becomes turbulent is called the *transition point*. The point where the turbulence is so severe that the airflow separates from the surface of an airfoil is known as the *separation point* (see figure 1-10).

The wing of an airplane pushes and induces the air downwards and forwards, because of its shape, angle of attack, and speed. The reaction is an upward/rearward force called the *total reaction*. The upward component of this reaction lifts the airplane (i.e. it overcomes gravity), and the rearward force (drag) is the force that must be overcome by the engine and propeller.

How the wing generates the action and total reaction has been a subject of theoretical debate for many years. You may hear theorems of lift due to:

- Bernoulli's principle (pressure inequalities);
- circulation theory (vortices); and
- Coanda effect (downwash).

The end result of these is that the passage of the wing causes downwash, and the reaction causes lift and drag (Newton's third law). The most common explanation of lift is given by Bernoulli's principle, but this theorem is by no means the whole story.

Energy and Pressure

There are two types of energy:

- potential energy (due to height—for example, the pressure in a faucet is a function of the relative height of the water tank); and
- kinetic energy (due to speed).

An airplane at 10,000 feet has the potential to dive and accelerate. An airplane at low altitude and high speed has the capacity to zoom up to a higher altitude. Thus any body has a total bank of energy that can be exchanged as speed or height (with some losses in the exchange process).

For a gas, mass equates to density and energy equates to pressure. The pressure forces exerted by air are caused by:

- static pressure (a function of height); and
- dynamic pressure (due to speed).

Static pressure is caused by gravity. The stack of air molecules in the earth's atmosphere causes the lower molecules to be squashed (less volume, greater density) and the upper molecules to be relaxed (more volume, less density). *Dynamic pressure* is caused by air moving against an object (wind and turbulence) or by an object trying to move through the air.

The forces experienced by an aircraft are a combination of static and dynamic pressure. If the aircraft is stationary, it experiences only static atmospheric pressure (and any dynamic pressure due to wind). Static pressure is equal in all directions—up, down and all around. As soon as the airplane moves through the air, the static and dynamic pressures change, while the total pressure remains constant. Thus for any place on the aircraft when the dynamic pressure increases, the static pressure drops. If the dynamic pressure reduces, the static pressure increases. This is reflected around an airfoil, as shown in figure 1-12.

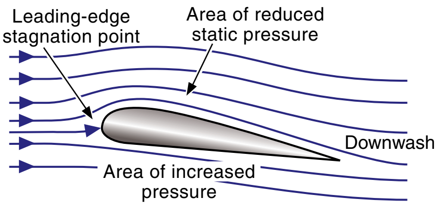

Figure 1-12
Pressure around an airfoil.

The dynamic pressure of a parcel of air moving relative to an object is a function of its density. This density (and velocity) generates a force on any object that tries to move through it. This force, when calculated per unit of surface area, is called *dynamic pressure*. If you hold your hand up in a strong wind or out of the window of a moving automobile, air pressure is felt because of the air striking your hand and flowing around it. This pressure is dynamic pressure—pressure caused by the relative movement between your hand and the air.

Dynamic pressure (represented by the symbol "q.") involves *air density* (mass per unit volume) which is denoted by the Greek letter *rho* (ρ). The more dense the air, the greater the dynamic pressure:

$$\text{Dynamic pressure (q)} = \tfrac{1}{2}\rho \times \text{velocity-squared} = \tfrac{1}{2}\rho V^2$$

The strength of dynamic pressure therefore depends on:

- the *velocity* (speed in a particular direction) of the body relative to the air; and
- the *density* of the air.

Bernoulli's Principle

The production of the lift force by an airfoil may be explained by *Bernoulli's principle*—also known as the *venturi effect*. Daniel Bernoulli (1700–82) was a Swiss scientist who discovered this effect. A fluid in steady motion has a total energy. Air is a fluid, and if we assume it to be incompressible, it behaves as a so-called "ideal" fluid. Bernoulli's principle states that for an ideal fluid the total energy in steady streamline flow remains constant. Therefore:

Bernoulli's principle is the easiest non-mathematical way to understand the production of lift (and drag) by an airfoil.

$$\text{Potential energy} + \text{kinetic energy} = \text{constant total energy}$$

Within any steady streamline flow the total energy content will always remain constant, but the relative proportions of pressure energy and kinetic energy can vary. If kinetic energy increases because of a greater speed of flow, then potential energy will decrease accordingly. This is explained by Bernoulli as fluid flowing through a tube. The mass flow (total energy) is constant. If the opening is restricted (like the nozzle in a garden hose), the velocity is increased.

Total energy in a steady streamline flow remains constant.

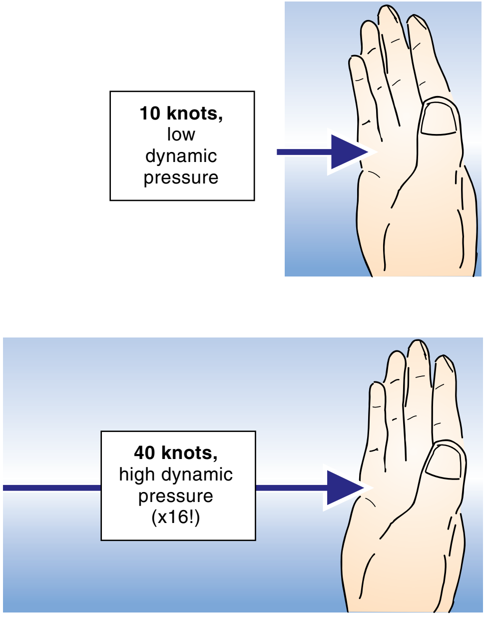

Figure 1-13
Dynamic pressure increases with airspeed.

The faster an automobile drives or the stronger the wind blows, the stronger the dynamic pressure that you feel on your hand. This is because of the greater number of air molecules that impact per second.

> **Note.** It is the *relative velocity* of the airplane and the airflow that matters. The force is the same whether it is the airplane moving through the air or the air is flowing over the airplane.

At the same speed, the denser the air, the more molecules per second that will strike your hand and so the greater the dynamic pressure. Density changes with altitude and temperature.

> **Note.** Bernoulli's principle may be used to explain many aspects of aerodynamics, but only if it is assumed that air is incompressible. At the private- and commercial-pilot level, such an assumption is valid because we are mainly concerned with airplanes that operate at relatively slow speeds and at altitudes below 10,000 feet. At higher speeds and altitudes, compressibility of air must be accounted for, but this is only applicable when you are studying at the Airline Transport Pilot (ATP) level.

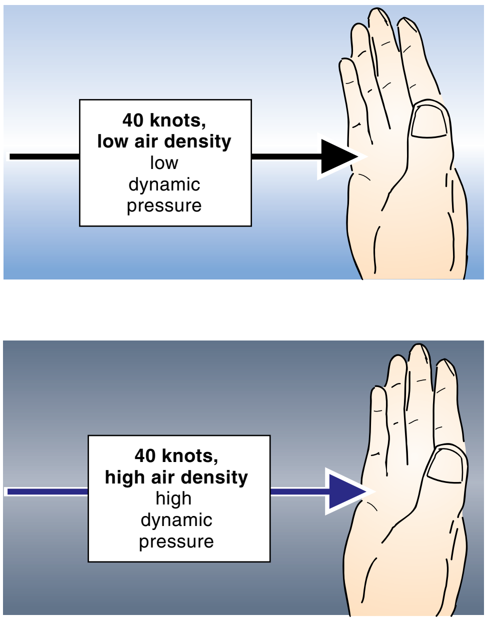

Figure 1-14
Dynamic pressure is greater in dense air.

Lift and Thrust

Pressure is force per unit area—pounds per square inch (psi). This force around an airplane is significant. Static pressure alone acts on all sides of the airplane and thus cancels itself, until we use dynamic pressure and the resultant differences in static pressure to our advantage. It is an imbalance of forces that allows the airplane to fly. The propeller causes reduced static pressure ahead and increased static pressure behind. The force is called *thrust* and drives the airplane forward. The airfoil section of the wing accelerates the air; this causes a downwash and a change in static pressure between the lower and upper surfaces. This is sufficient to carry the aircraft and to maneuver it (change its flight path). The control surfaces cause the change in flight path.

Airspeed

Dynamic pressure (q) and the term $\frac{1}{2}\rho V^2$ are very important in aviation. The airspeed indicator shows *indicated airspeed* (IAS), which is not a real speed but a measure of dynamic pressure. Since dynamic pressure is related to air density, the real speed of the airplane relative to the airflow can only be calculated if the change in density due to altitude or temperature is recognized. This corrected speed is known as *true airspeed* (TAS or V). Although indicated airspeed is of most concern to you when flying, you will need to calculate true airspeed for measuring time, fuel, and distance.