The Pilot's Manual

Ground School

Pass the FAA Knowledge Exam and operate as a private or commercial pilot

Seventh Edition

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Foreword by Barry Schiff

AVIATION SUPPLIES & ACADEMICS, INC.
NEWCASTLE, WASHINGTON

The Pilot's Manual: Ground School
Pass the FAA Knowledge Exam and operate as a private or commercial pilot
Seventh Edition

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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 also 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.

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Barry Schiff has over 27,000 hours in more than 320 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 has earned every FAA category and class rating (except airship) and every possible instructor's rating. He has 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 100 aviation periodicals, notably *AOPA Pilot*, of which he is a contributing editor, and ASA publishes several of his titles.

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Aerodynamics

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

1

Forces Acting on an Airplane

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.

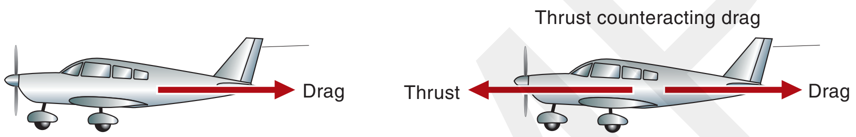

Figure 1-1. Drag counteracted by thrust.

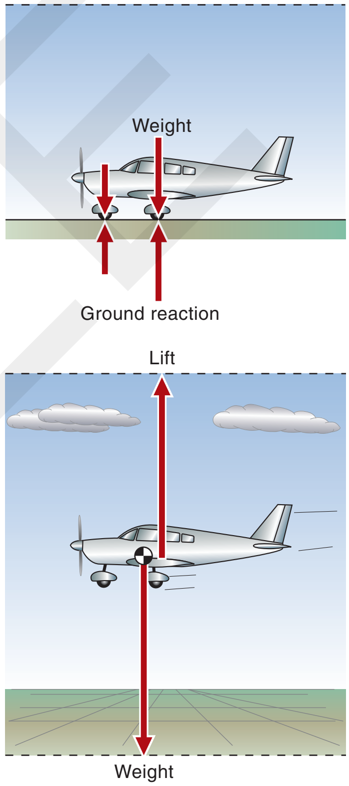

Figure 1-2. The airplane is supported by the ground, and in the air by lift.

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.

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.

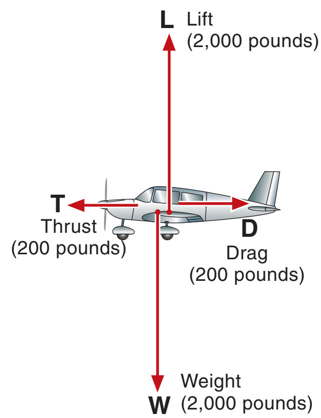

Figure 1-3. The four main forces are in equilibrium during unaccelerated flight.

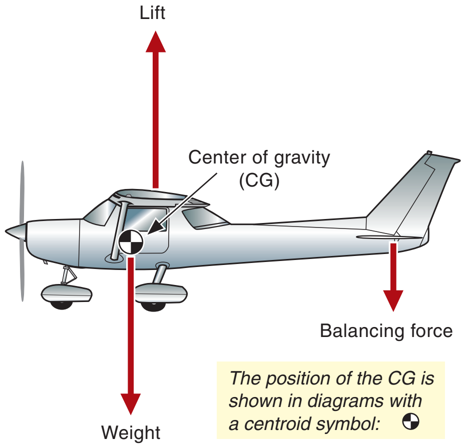

Figure 1-4. Weight acts downward through the center of gravity (CG).

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.

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?

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

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 streamlines, 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.

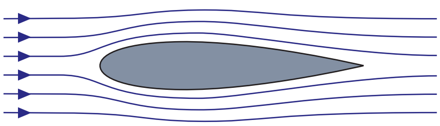

Figure 1-9. Laminar flow.

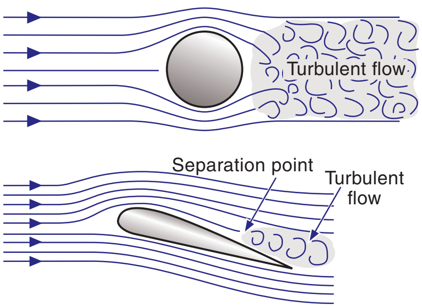

Figure 1-10. Turbulent flow.

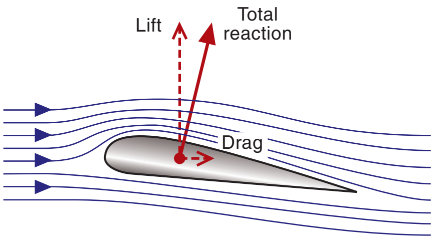

Figure 1-11. Total reaction.

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 mechanical 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).

Energy management is the process of controlling and monitoring aircraft altitude and airspeed.

The sum of potential energy and kinetic energy when combined is mechanical energy, which is a direct measure of the total energy available to the aircraft (for the purposes of this textbook).

Flight controls (specifically the throttle and elevator) play a significant role in the management of aircraft mechanical energy. You can think of the throttle as the total energy controller and the elevator as the total energy distribution controller. The throttle is used to set engine thrust to match the total energy demanded for a specific flight profile (vertical flight path and airspeed) and the elevator is used to set the vertical pitch to maintain the distribution of total energy for that profile.

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.

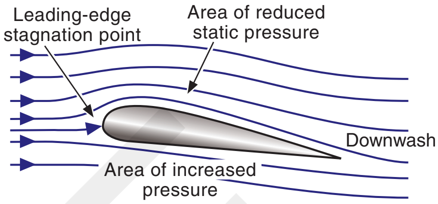

Figure 1-12.
Pressure around an airfoil.

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.

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

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.

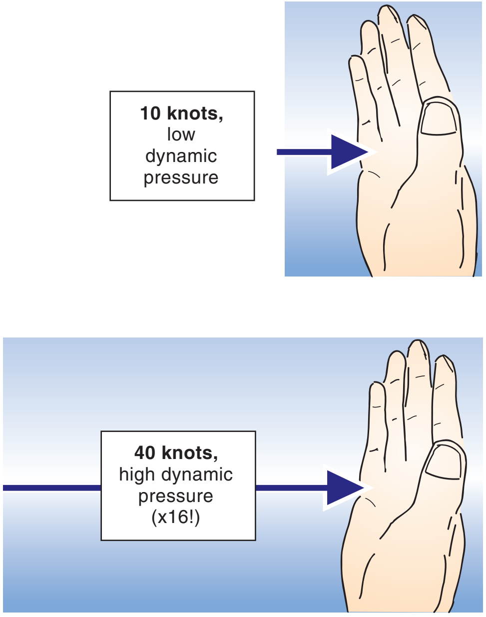

Figure 1-13.
Dynamic pressure increases with airspeed.

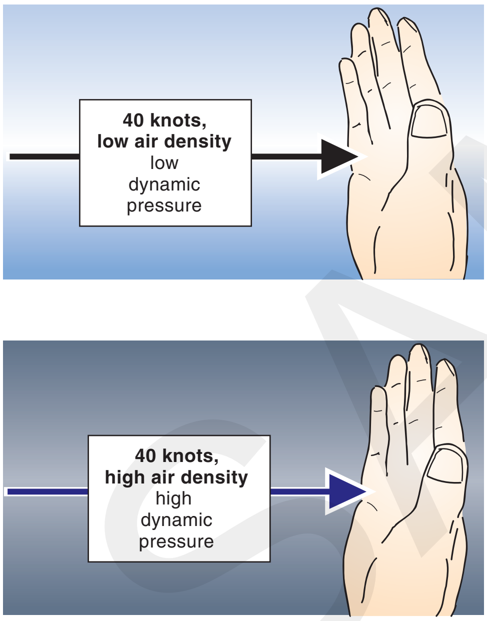

Figure 1-14.
Dynamic pressure is greater in dense air.

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.

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.

REVIEW 1

Forces Acting on an Airplane

Four Forces in Flight

1. Which force produced by the wings sup-ports the airplane in flight?
2. Which force is produced by the engine–propeller?
3. Which force resists the motion of the air-plane through the air?
4. Lift and weight are generally how much greater than thrust and drag in straight-and-level flight at a constant airspeed?
5. What relationships exist between lift and weight, and between thrust and drag, when the airplane is flying straight-and-level at a constant airspeed?

Airfoil Lift

6. Which surface is designed to create an aerodynamic lifting force as air flows over it?
7. What do you call a steady airflow around an airfoil in which succeeding parcels of air follow each other?
8. Where on an airfoil does the smooth boundary-layer flow separate from the airfoil surface and become turbulent?
9. Static pressure in the air is exerted in which direction(s)?
10. Which pressure is caused by motion?
11. What is total pressure energy the sum of?
12. In streamline flow, if dynamic pressure increases, what happens to the static pressure?
13. What does the expression "$\frac{1}{2}\rho V^2$" represent?
14. What line is drawn half-way between the upper and lower surfaces of the wing to give an indication of its curvature?
15. The wing shape and the angle of attack determine the profile that the airfoil presents to the airflow. What else do they determine?
16. True or false? The forces acting on an airfoil in flight, as a result of the changes in static pressure around it, may be considered to act through the center of pressure.
17. Describe how the relative airflow relates to the flight path of an airplane.
18. Define the term *angle of attack*.
19. If the angle of attack is gradually increased in normal cruise flight, what will happen to the lifting ability of the wing?
20. On a wing, the force of lift acts perpendicular to and the force of drag acts parallel to the:
    a. chord line.
    b. flight path.
    c. longitudinal axis.
21. What does the angle of attack of a wing control directly?
22. What happens to the center of pressure as the angle of attack is gradually increased in the normal flight range?
23. True or false? Beyond the stall angle of attack, the lifting ability of the wing decreases significantly and the center of pressure moves rearward on the wing.
24. How will frost on the wings of an airplane affect takeoff performance?

Drag

25. What is drag?
26. True or false? If drag can be kept low, thrust can be kept low.
27. Describe the two basic groups of total drag.
28. True or false? As airspeed increases, drag caused by skin friction decreases.
29. How can form drag be reduced?
30. True or false? The spanwise flow of air on the upper wing surface is toward the wing root.
31. When is the formation of wingtip vortices and induced drag greatest?
32. When is the total drag at a minimum?
33. Why is the thrust requirement greater at high speeds and low angles of attack?
34. True or false? Minimum drag means minimum thrust to maintain airspeed.
35. What does the lift/drag ratio describe?

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