Chapter 10

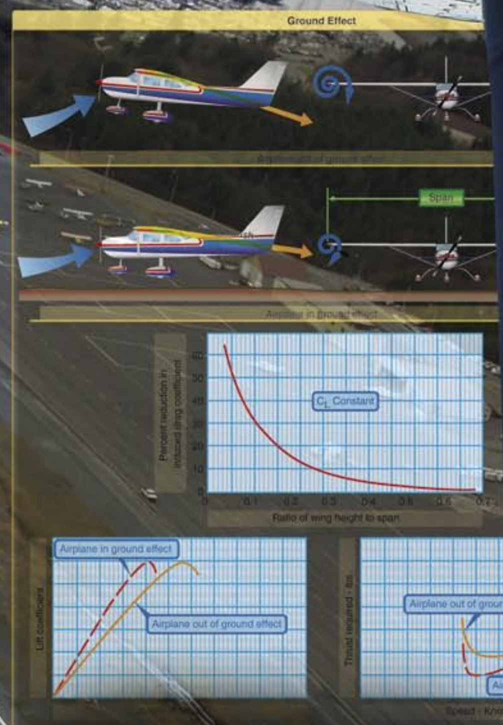
Aircraft Performance

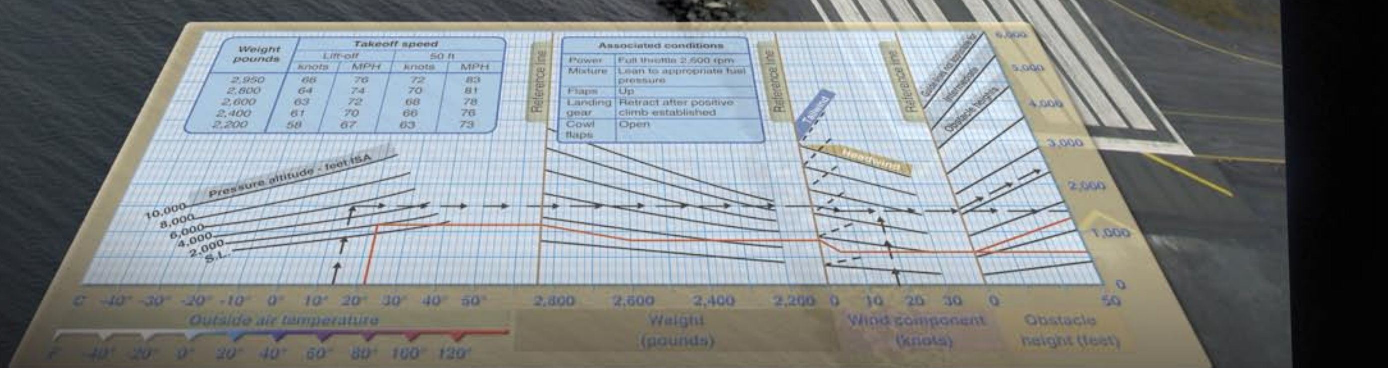
Introduction

This chapter discusses the factors that affect aircraft performance, which include the aircraft weight, atmospheric conditions, runway environment, and the fundamental physical laws governing the forces acting on an aircraft.

Importance of Performance Data

The performance or operational information section of the Aircraft Flight Manual/Pilot's Operating Handbook (AFM/POH) contains the operating data for the aircraft; that is, the data pertaining to takeoff, climb, range, endurance, descent, and landing. The use of this data in flying operations is mandatory for safe and efficient operation. Considerable knowledge and familiarity of the aircraft can be gained through study of this material.





It must be emphasized that the manufacturers' information and data furnished in the AFM/POH is not standardized. Some provide the data in tabular form, while others use graphs. In addition, the performance data may be presented on the basis of standard atmospheric conditions, pressure altitude, or density altitude. The performance information in the AFM/POH has little or no value unless the user recognizes those variations and makes the necessary adjustments.

To be able to make practical use of the aircraft's capabilities and limitations, it is essential to understand the significance of the operational data. The pilot must be cognizant of the basis for the performance data, as well as the meanings of the various terms used in expressing performance capabilities and limitations.

Since the characteristics of the atmosphere have a major effect on performance, it is necessary to review two dominant factors—pressure and temperature.

Structure of the Atmosphere

The atmosphere is an envelope of air that surrounds the Earth and rests upon its surface. It is as much a part of the Earth as its land and water. However, air differs from land and water inasmuch as it is a mixture of gases. It has mass, weight, and indefinite shape.

Air, like any other fluid, is able to flow and change its shape when subjected to even minute pressures because of the lack of strong molecular cohesion. For example, gas will completely fill any container into which it is placed, expanding or contracting to adjust its shape to the limits of the container.

The atmosphere is composed of 78 percent nitrogen, 21 percent oxygen, and 1 percent other gases, such as argon or helium. Most of the oxygen is contained below 35,000 feet altitude.

Atmospheric Pressure

Though there are various kinds of pressure, pilots are mainly concerned with atmospheric pressure. It is one of the basic factors in weather changes, helps to lift the aircraft, and actuates some of the most important flight instruments in the aircraft. These instruments often include the altimeter, the airspeed indicator (ASI), the vertical speed indicator, and the manifold pressure gauge.

Though air is very light, it has mass and is affected by the attraction of gravity. Therefore, like any other substance, it has weight; because it has weight, it has force. Since it is a fluid substance, this force is exerted equally in all directions, and its effect on bodies within the air is called pressure. Under standard conditions at sea level, the average pressure exerted by the weight of the atmosphere is approximately 14.7 pounds per square inch (psi). The density of air has significant effects on the aircraft's performance. As air becomes less dense, it reduces:

- Power, because the engine takes in less air.
- Thrust, because the propeller is less efficient in thin air.
- Lift, because the thin air exerts less force on the airfoils.

The pressure of the atmosphere varies with time and altitude. Due to the changing atmospheric pressure, a standard reference was developed. The standard atmosphere at sea level is a surface temperature of 59 degrees Fahrenheit (°F) or 15 degrees Celsius (°C) and a surface pressure of 29.92 inches of mercury ("Hg) or 1013.2 millibars (mb). *[Figure 10-1]*

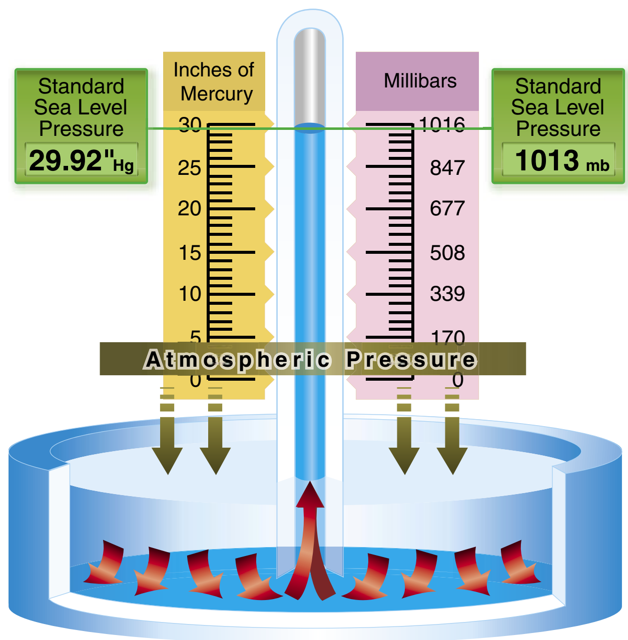


Figure 10-1. *Standard sea level pressure.*

A standard temperature lapse rate is one in which the temperature decreases at the rate of approximately 3.5 °F or 2 °C per thousand feet up to 36,000 feet. Above this point, the temperature is considered constant up to 80,000 feet. A standard pressure lapse rate is one in which pressure decreases at a rate of approximately 1 "Hg per 1,000 feet of altitude gain to 10,000 feet. *[Figure 10-2]* The International Civil Aviation Organization (ICAO) has established this as a worldwide standard, and it is often referred to as International Standard Atmosphere (ISA) or ICAO Standard Atmosphere. Any temperature or pressure that differs from the standard lapse rates is considered nonstandard temperature and pressure. Adjustments for nonstandard temperatures and pressures are provided on the manufacturer's performance charts.

Altitude (ft)	Pressure ("Hg)	Temperature	
		(°C)	(°F)
0	29.92	15.0	59.0
1,000	28.86	13.0	55.4
2,000	27.82	11.0	51.9
3,000	26.82	9.1	48.3
4,000	25.84	7.1	44.7
5,000	24.89	5.1	41.2
6,000	23.98	3.1	37.6
7,000	23.09	1.1	34.0
8,000	22.22	−0.9	30.5
9,000	21.38	−2.8	26.9
10,000	20.57	−4.8	23.3
11,000	19.79	−6.8	19.8
12,000	19.02	−8.8	16.2
13,000	18.29	−10.8	12.6
14,000	17.57	−12.7	9.1
15,000	16.88	−14.7	5.5
16,000	16.21	−16.7	1.9
17,000	15.56	−18.7	−1.6
18,000	14.94	−20.7	−5.2
19,000	14.33	−22.6	−8.8
20,000	13.74	−24.6	−12.3

Figure 10-2. *Properties of standard atmosphere.*

Since all aircraft performance is compared and evaluated with respect to the standard atmosphere, all aircraft instruments are calibrated for the standard atmosphere. Thus, certain corrections must apply to the instrumentation, as well as the aircraft performance, if the actual operating conditions do not fit the standard atmosphere. In order to account properly for the nonstandard atmosphere, certain related terms must be defined.

Pressure Altitude

Pressure altitude is the height above the standard datum plane (SDP). The aircraft altimeter is essentially a sensitive barometer calibrated to indicate altitude in the standard atmosphere. If the altimeter is set for 29.92 "Hg SDP, the altitude indicated is the pressure altitude—the altitude in the standard atmosphere corresponding to the sensed pressure.

The SDP is a theoretical level where the pressure of the atmosphere is 29.92 "Hg and the weight of air is 14.7 psi. As atmospheric pressure changes, the SDP may be below, at, or above sea level. Pressure altitude is important as a basis for determining aircraft performance, as well as for assigning flight levels to aircraft operating at above 18,000 feet.

The pressure altitude can be determined by either of two methods:

1. By setting the barometric scale of the altimeter to 29.92 "Hg and reading the indicated altitude, or
2. By applying a correction factor to the indicated altitude according to the reported "altimeter setting."

Density Altitude

The more appropriate term for correlating aerodynamic performance in the nonstandard atmosphere is density altitude—the altitude in the standard atmosphere corresponding to a particular value of air density.

Density altitude is pressure altitude corrected for nonstandard temperature. As the density of the air increases (lower density altitude), aircraft performance increases. Conversely, as air density decreases (higher density altitude), aircraft performance decreases. A decrease in air density means a high density altitude; an increase in air density means a lower density altitude. Density altitude is used in calculating aircraft performance. Under standard atmospheric condition, air at each level in the atmosphere has a specific density; under standard conditions, pressure altitude and density altitude identify the same level. Density altitude, then, is the vertical distance above sea level in the standard atmosphere at which a given density is to be found.

The computation of density altitude must involve consideration of pressure (pressure altitude) and temperature. Since aircraft performance data at any level is based upon air density under standard day conditions, such performance data apply to air density levels that may not be identical to altimeter indications. Under conditions higher or lower than standard, these levels cannot be determined directly from the altimeter.

Density altitude is determined by first finding pressure altitude, and then correcting this altitude for nonstandard temperature variations. Since density varies directly with pressure, and inversely with temperature, a given pressure altitude may exist for a wide range of temperature by allowing the density to vary. However, a known density occurs for any one temperature and pressure altitude. The density of the air, of course, has a pronounced effect on aircraft and engine performance. Regardless of the actual altitude at which the aircraft is operating, it will perform as though it were operating at an altitude equal to the existing density altitude.

For example, when set at 29.92 "Hg, the altimeter may indicate a pressure altitude of 5,000 feet. According to the AFM/POH, the ground run on takeoff may require a distance of 790 feet under standard temperature conditions.

However, if the temperature is 20 °C above standard, the expansion of air raises the density level. Using temperature correction data from tables or graphs, or by deriving the density altitude with a computer, it may be found that the density level is above 7,000 feet, and the ground run may be closer to 1,000 feet.

Air density is affected by changes in altitude, temperature, and humidity. High density altitude refers to thin air while low density altitude refers to dense air. The conditions that result in a high density altitude are high elevations, low atmospheric pressures, high temperatures, high humidity, or some combination of these factors. Lower elevations, high atmospheric pressure, low temperatures, and low humidity are more indicative of low density altitude.

Using a flight computer, density altitude can be computed by inputting the pressure altitude and outside air temperature at flight level. Density altitude can also be determined by referring to the table and chart in *Figures 10-3 and 10-4*.

Method for Determining Pressure Altitude		Alternate Method for Determining Pressure Altitude
Altimeter setting	Altitude correction	
28.0	1,825	
28.1	1,725	
28.2	1,630	
28.3	1,535	
28.4	1,435	
28.5	1,340	
28.6	1,245	
28.7	1,150	
28.8	1,050	
28.9	955	
29.0	865	To field elevation
29.1	770	
29.2	675	
29.3	580	
29.4	485	
29.5	390	
29.6	300	
29.7	205	
29.8	110	
29.9	20	
29.92	0	To get pressure altitude
30.0	–75	
30.1	–165	
30.2	–255	
30.3	–350	
30.4	–440	
30.5	–530	From field elevation
30.6	–620	
30.7	–710	
30.8	–805	
30.9	–895	
31.0	–965	

Add

Subtract

Field elevation is sea level

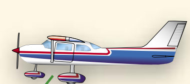


Figure 10-3. *Field elevation versus pressure. The aircraft is located on a field which happens to be at sea level. Set the altimeter to the current altimeter setting (29.7). The difference of 205 feet is added to the elevation or a PA of 205 feet.*

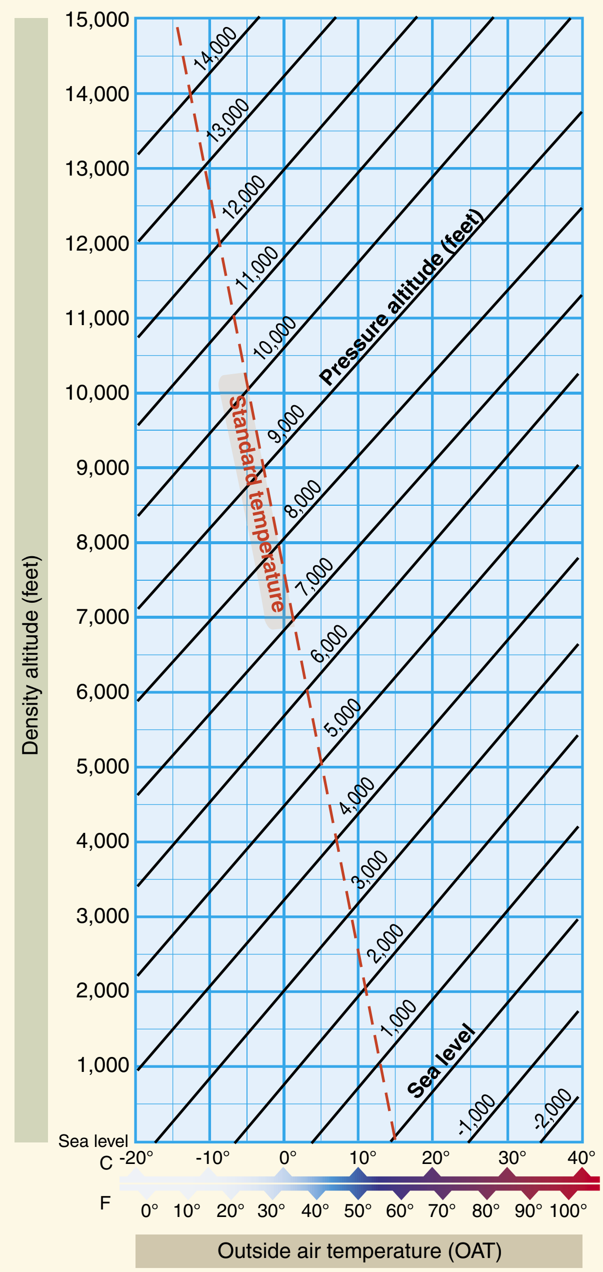


Figure 10-4. *Density altitude chart.*

Effects of Pressure on Density

Since air is a gas, it can be compressed or expanded. When air is compressed, a greater amount of air can occupy a given volume. Conversely, when pressure on a given volume of air is decreased, the air expands and occupies a greater space. That is, the original column of air at a lower pressure contains a smaller mass of air. In other words, the density is decreased. In fact, density is directly proportional to pressure. If the pressure is doubled, the density is doubled, and if the pressure is lowered, so is the density. This statement is true only at a constant temperature.

Effects of Temperature on Density

Increasing the temperature of a substance decreases its density. Conversely, decreasing the temperature increases the density. Thus, the density of air varies inversely with temperature. This statement is true only at a constant pressure.

In the atmosphere, both temperature and pressure decrease with altitude, and have conflicting effects upon density. However, the fairly rapid drop in pressure as altitude is increased usually has the dominant effect. Hence, pilots can expect the density to decrease with altitude.

Effects of Humidity (Moisture) on Density

The preceding paragraphs are based on the presupposition of perfectly dry air. In reality, it is never completely dry. The small amount of water vapor suspended in the atmosphere may be negligible under certain conditions, but in other conditions humidity may become an important factor in the performance of an aircraft. Water vapor is lighter than air; consequently, moist air is lighter than dry air. Therefore, as the water content of the air increases, the air becomes less dense, increasing density altitude and decreasing performance. It is lightest or least dense when, in a given set of conditions, it contains the maximum amount of water vapor.

Humidity, also called relative humidity, refers to the amount of water vapor contained in the atmosphere, and is expressed as a percentage of the maximum amount of water vapor the air can hold. This amount varies with the temperature; warm air can hold more water vapor, while colder air can hold less. Perfectly dry air that contains no water vapor has a relative humidity of zero percent, while saturated air that cannot hold any more water vapor has a relative humidity of 100 percent. Humidity alone is usually not considered an essential factor in calculating density altitude and aircraft performance; however, it does contribute.

The higher the temperature, the greater amount of water vapor that the air can hold. When comparing two separate air masses, the first warm and moist (both qualities making air lighter) and the second cold and dry (both qualities making it heavier), the first must be less dense than the second. Pressure, temperature, and humidity have a great influence on aircraft performance because of their effect upon density. There is no rule-of-thumb or chart used to compute the effects of humidity on density altitude, but it must be taken into consideration. Expect a decrease in overall performance in high humidity conditions.

Performance

Performance is a term used to describe the ability of an aircraft to accomplish certain things that make it useful for certain purposes. For example, the ability of an aircraft to land and take off in a very short distance is an important factor to the pilot who operates in and out of short, unimproved airfields. The ability to carry heavy loads, fly at high altitudes at fast speeds, or travel long distances is essential performance for operators of airline and executive type aircraft.

The primary factors most affected by performance are the takeoff and landing distance, rate of climb, ceiling, payload, range, speed, maneuverability, stability, and fuel economy. Some of these factors are often directly opposed: for example, high speed versus short landing distance, long range versus great payload, and high rate of climb versus fuel economy. It is the preeminence of one or more of these factors that dictates differences between aircraft and explains the high degree of specialization found in modern aircraft.

The various items of aircraft performance result from the combination of aircraft and powerplant characteristics. The aerodynamic characteristics of the aircraft generally define the power and thrust requirements at various conditions of flight, while powerplant characteristics generally define the power and thrust available at various conditions of flight. The matching of the aerodynamic configuration with the powerplant is accomplished by the manufacturer to provide maximum performance at the specific design condition (e.g., range, endurance, and climb).

Straight-and-Level Flight

All of the principal components of flight performance involve steady-state flight conditions and equilibrium of the aircraft. For the aircraft to remain in steady, level flight, equilibrium must be obtained by a lift equal to the aircraft weight and a powerplant thrust equal to the aircraft drag. Thus, the aircraft drag defines the thrust required to maintain steady, level flight. As presented in Chapter 4, Aerodynamics of Flight, all parts of an aircraft contribute to the drag, either induced (from lifting surfaces) or parasite drag.

While the parasite drag predominates at high speed, induced drag predominates at low speed. *[Figure 10-5]* For example,

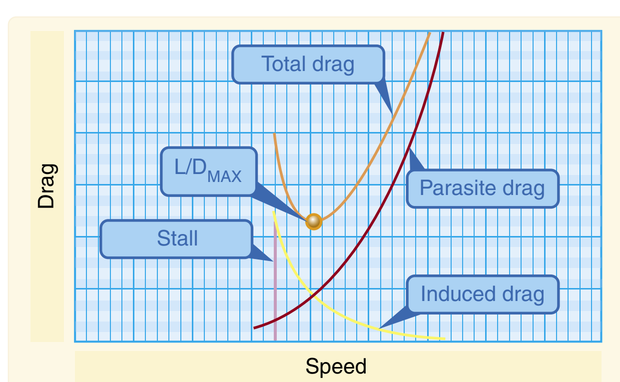


Figure 10-5. *Drag versus speed.*

if an aircraft in a steady flight condition at 100 knots is then accelerated to 200 knots, the parasite drag becomes four times as great, but the power required to overcome that drag is eight times the original value. Conversely, when the aircraft is operated in steady, level flight at twice as great a speed, the induced drag is one-fourth the original value, and the power required to overcome that drag is only one-half the original value.

When an aircraft is in steady, level flight, the condition of equilibrium must prevail. The unaccelerated condition of flight is achieved with the aircraft trimmed for lift equal to weight and the powerplant set for a thrust to equal the aircraft drag.

The maximum level flight speed for the aircraft will be obtained when the power or thrust required equals the maximum power or thrust available from the powerplant. *[Figure 10-6]* The minimum level flight airspeed is not usually defined by thrust or power requirement since conditions of stall or stability and control problems generally predominate.

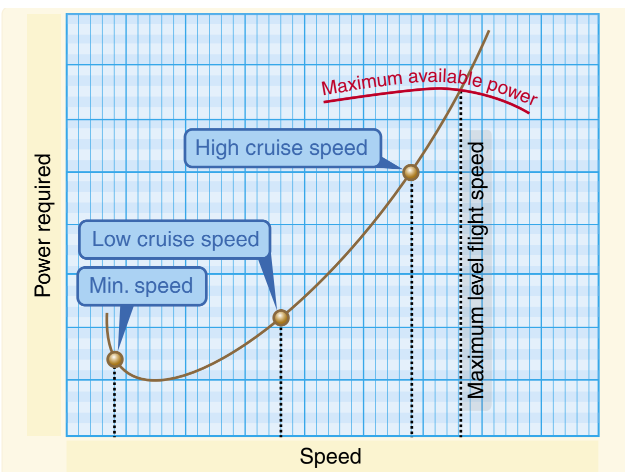


Figure 10-6. *Power versus speed.*

Climb Performance

Climb performance is a result of using the aircrafts potential energy provided by one, or a combination of two factors. The first is the use of excess power above that required for level flight. An aircraft equipped with an engine capable of 200 horsepower (at a given altitude) but using 130 horsepower to sustain level flight (at a given airspeed) has 70 excess horsepower available for climbing. A second factor is that the aircraft can tradeoff its kinetic energy and increase its potential energy by reducing its airspeed. The reduction in airspeed will increase the aircraft's potential energy thereby also making the aircraft climb. Both terms, power and thrust are often used in aircraft performance however, they should not be confused.

Although the terms "power" and "thrust" are sometimes used interchangeably, erroneously implying that they are synonymous, it is important to distinguish between the two when discussing climb performance. Work is the product of a force moving through a distance and is usually independent of time. Work is measured by several standards; the most common unit is called a foot-pound. If a one pound mass is raised one foot, a work unit of one foot-pound has been performed. The common unit of mechanical power is horsepower; one horsepower is work equivalent to lifting 33,000 pounds a vertical distance of one foot in one minute. The term power implies work rate or units of work per unit of time, and as such is a function of the speed at which the force is developed. Thrust, also a function of work, means the force that imparts a change in the velocity of a mass. This force is measured in pounds but has no element of time or rate. It can be said then, that during a steady climb, the rate of climb is a function of excess thrust.

This relationship means that, for a given weight of an aircraft, the angle of climb depends on the difference between thrust and drag, or the excess power. *[Figure 10-7]* Of course, when the excess thrust is zero, the inclination of the flightpath is zero, and the aircraft will be in steady, level flight. When the thrust is greater than the drag, the excess thrust will allow a climb angle depending on the value of excess thrust. On the other hand, when the thrust is less than the drag, the deficiency of thrust will allow an angle of descent.

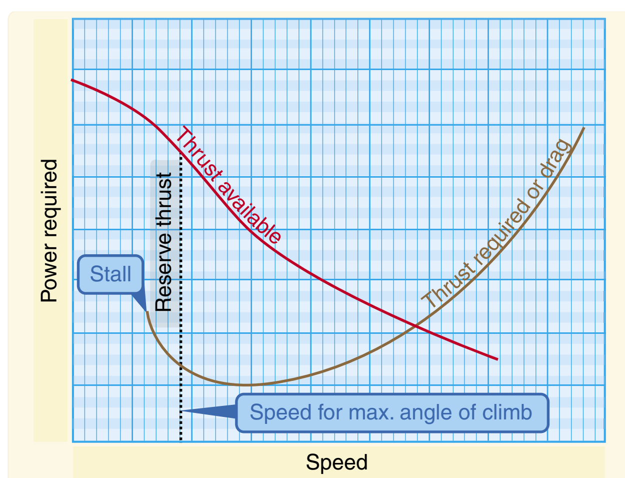


Figure 10-7. *Thrust versus climb angle.*

The most immediate interest in the climb angle performance involves obstacle clearance. The most obvious purpose for which it might be used is to clear obstacles when climbing out of short or confined airports.

The maximum angle of climb would occur where there exists the greatest difference between thrust available and thrust required; i.e., for the propeller-powered airplane, the maximum excess thrust and angle of climb will occur at some speed just above the stall speed. Thus, if it is necessary to clear an obstacle after takeoff, the propeller-powered airplane will attain maximum angle of climb at an airspeed close to—if not at—the takeoff speed.

Of greater interest in climb performance are the factors that affect the rate of climb. The vertical velocity of an aircraft depends on the flight speed and the inclination of the flightpath. In fact, the rate of climb is the vertical component of the flightpath velocity.

For rate of climb, the maximum rate would occur where there exists the greatest difference between power available and power required. *[Figure 10-8]* The above relationship means that, for a given weight of an aircraft, the rate of climb depends on the difference between the power available and the power required, or the excess power. Of course, when the excess power is zero, the rate of climb is zero and the aircraft is in steady, level flight. When power available is greater than the power required, the excess power will allow a rate of climb specific to the magnitude of excess power.

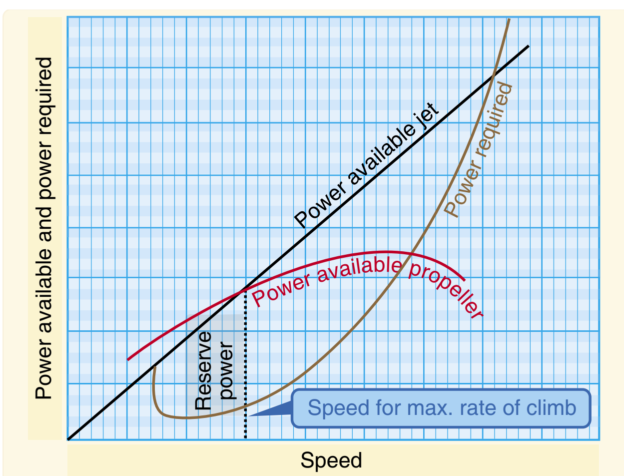


Figure 10-8. *Power versus climb rate.*

During a steady climb, the rate of climb will depend on excess power while the angle of climb is a function of excess thrust.

The climb performance of an aircraft is affected by certain variables. The conditions of the aircraft's maximum climb angle or maximum climb rate occur at specific speeds, and variations in speed will produce variations in climb performance. There is sufficient latitude in most aircraft that small variations in speed from the optimum do not produce large changes in climb performance, and certain operational considerations may require speeds slightly different from the optimum. Of course, climb performance would be most critical with high gross weight, at high altitude, in obstructed takeoff areas, or during malfunction of a powerplant. Then, optimum climb speeds are necessary.

Weight has a very pronounced effect on aircraft performance. If weight is added to an aircraft, it must fly at a higher angle of attack (AOA) to maintain a given altitude and speed. This increases the induced drag of the wings, as well as the parasite drag of the aircraft. Increased drag means that additional thrust is needed to overcome it, which in turn means that less reserve thrust is available for climbing. Aircraft designers go to great effort to minimize the weight since it has such a marked effect on the factors pertaining to performance.

A change in an aircraft's weight produces a twofold effect on climb performance. First, a change in weight will change the drag and the power required. This alters the reserve power available, which in turn, affects both the climb angle and the climb rate. Secondly, an increase in weight will reduce the maximum rate of climb, but the aircraft must be operated at a higher climb speed to achieve the smaller peak climb rate.

An increase in altitude also will increase the power required and decrease the power available. Therefore, the climb performance of an aircraft diminishes with altitude. The speeds for maximum rate of climb, maximum angle of climb, and maximum and minimum level flight airspeeds vary with altitude. As altitude is increased, these various speeds finally converge at the absolute ceiling of the aircraft. At the absolute ceiling, there is no excess of power and only one speed will allow steady, level flight. Consequently, the absolute ceiling of an aircraft produces zero rate of climb. The service ceiling is the altitude at which the aircraft is unable to climb at a rate greater than 100 feet per minute (fpm). Usually, these specific performance reference points are provided for the aircraft at a specific design configuration. *[Figure 10-9]*

In discussing performance, it frequently is convenient to use the terms power loading, wing loading, blade loading, and disk loading. Power loading is expressed in pounds per horsepower and is obtained by dividing the total weight of the aircraft by the rated horsepower of the engine. It is a significant factor in an aircraft's takeoff and climb capabilities. Wing loading is expressed in pounds per square foot and is obtained by dividing the total weight of an airplane in pounds by the wing area (including ailerons) in square feet. It is the airplane's wing loading that determines the landing speed. Blade loading is expressed in pounds per square foot and is obtained by dividing the total weight of a helicopter by the area of the rotor blades. Blade loading is not to be confused with disk loading, which is the total weight of a helicopter divided by the area of the disk swept by the rotor blades.

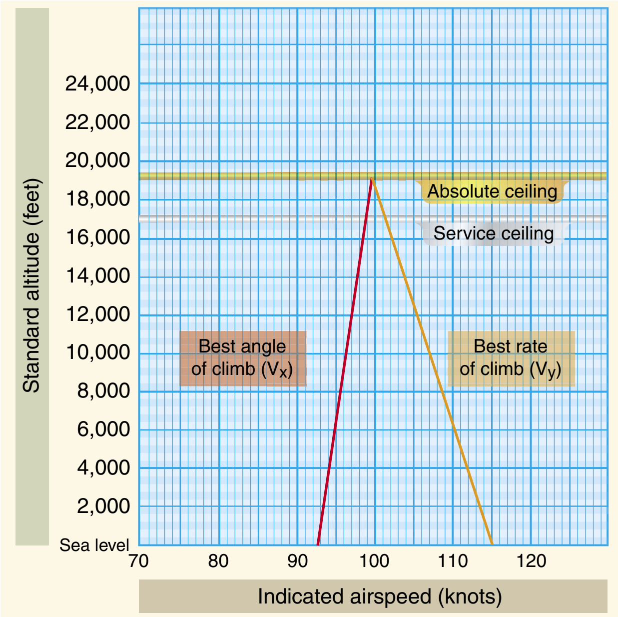


Figure 10-9. *Absolute and service ceiling.*

Range Performance

The ability of an aircraft to convert fuel energy into flying distance is one of the most important items of aircraft performance. In flying operations, the problem of efficient range operation of an aircraft appears in two general forms:

1. To extract the maximum flying distance from a given fuel load
2. To fly a specified distance with a minimum expenditure of fuel

A common element for each of these operating problems is the specific range; that is, nautical miles (NM) of flying distance versus the amount of fuel consumed. Range must be clearly distinguished from the item of endurance. Range involves consideration of flying distance, while endurance involves consideration of flying time. Thus, it is appropriate to define a separate term, specific endurance.

$$\text{specific endurance} = \frac{\text{flight hours}}{\text{pounds of fuel}}$$

or

$$\text{specific endurance} = \frac{\text{flight hours/hour}}{\text{pounds of fuel/hour}}$$

or

$$\text{specific endurance} = \frac{1}{\text{fuel flow}}$$

Fuel flow can be defined in either pounds or gallons. If maximum endurance is desired, the flight condition must provide a minimum fuel flow. In *Figure 10-10* at point A the airspeed is low and fuel flow is high. This would occur during ground operations or when taking off and climbing. As airspeed is increased, power requirements decrease due to aerodynamic factors and fuel flow decreases to point B. This is the point of maximum endurance. Beyond this point increases in airspeed come at a cost. Airspeed increases require additional power and fuel flow increases with additional power.

Cruise flight operations for maximum range should be conducted so that the aircraft obtains maximum specific range throughout the flight. The specific range can be defined by the following relationship.

$$\text{specific range} = \frac{\text{NM}}{\text{pounds of fuel}}$$

or

$$\text{specific range} = \frac{\text{NM/hour}}{\text{pounds of fuel/hour}}$$

or

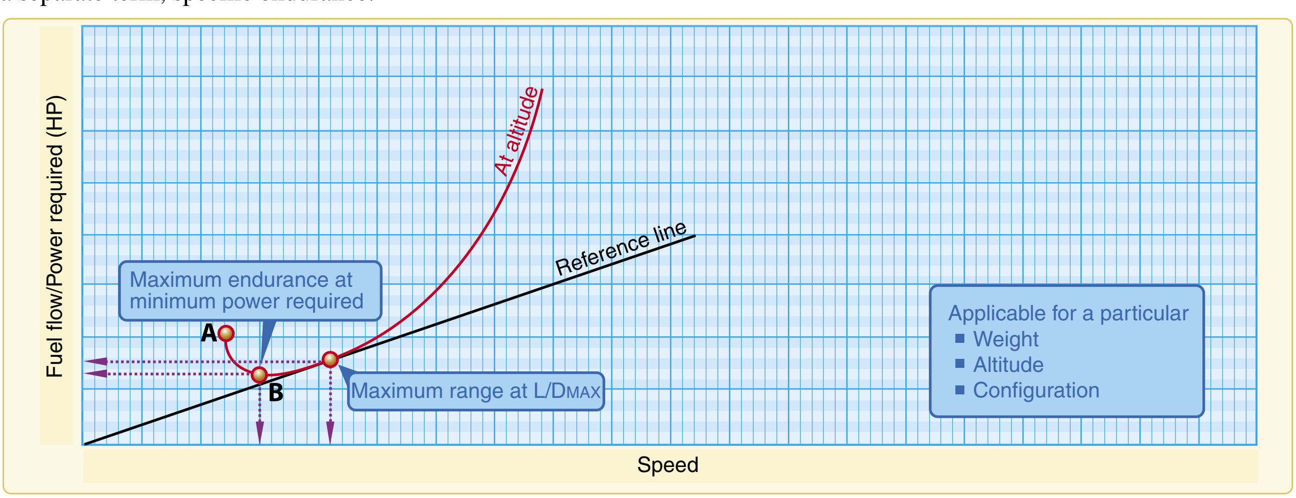


Figure 10-10. *Airspeed for maximum endurance.*

$$\text{specific range} = \frac{\text{knots}}{\text{fuel flow}}$$

If maximum specific range is desired, the flight condition must provide a maximum of speed per fuel flow. While the peak value of specific range would provide maximum range operation, long-range cruise operation is generally recommended at some slightly higher airspeed. Most long-range cruise operations are conducted at the flight condition that provides 99 percent of the absolute maximum specific range. The advantage of such operation is that one percent of range is traded for three to five percent higher cruise speed. Since the higher cruise speed has a great number of advantages, the small sacrifice of range is a fair bargain. The values of specific range versus speed are affected by three principal variables:

1. Aircraft gross weight
2. Altitude
3. The external aerodynamic configuration of the aircraft.

These are the source of range and endurance operating data included in the performance section of the AFM/POH.

Cruise control of an aircraft implies that the aircraft is operated to maintain the recommended long-range cruise condition throughout the flight. Since fuel is consumed during cruise, the gross weight of the aircraft will vary and optimum airspeed, altitude, and power setting can also vary. Cruise control means the control of the optimum airspeed, altitude, and power setting to maintain the 99 percent maximum specific range condition. At the beginning of cruise flight, the relatively high initial weight of the aircraft will require specific values of airspeed, altitude, and power setting to produce the recommended cruise condition. As fuel is consumed and the aircraft's gross weight decreases, the optimum airspeed and power setting may decrease, or, the optimum altitude may increase. In addition, the optimum specific range will increase. Therefore, the pilot must provide the proper cruise control procedure to ensure that optimum conditions are maintained.

Total range is dependent on both fuel available and specific range. When range and economy of operation are the principal goals, the pilot must ensure that the aircraft is operated at the recommended long-range cruise condition. By this procedure, the aircraft will be capable of its maximum design-operating radius, or can achieve flight distances less than the maximum with a maximum of fuel reserve at the destination.

A propeller-driven aircraft combines the propeller with the reciprocating engine for propulsive power. Fuel flow is determined mainly by the shaft power put into the propeller rather than thrust. Thus, the fuel flow can be related directly to the power required to maintain the aircraft in steady, level flight and on performance charts power can be substituted for fuel flow. This fact allows for the determination of range through analysis of power required versus speed.

The maximum endurance condition would be obtained at the point of minimum power required since this would require the lowest fuel flow to keep the airplane in steady, level flight. Maximum range condition would occur where the ratio of speed to power required is greatest. *[Figure 10-10]*

The maximum range condition is obtained at maximum lift/drag ratio (L/D_{MAX}), and it is important to note that for a given aircraft configuration, the L/D_{MAX} occurs at a particular AOA and lift coefficient, and is unaffected by weight or altitude. A variation in weight will alter the values of airspeed and power required to obtain the L/D_{MAX}. *[Figure 10-11]*

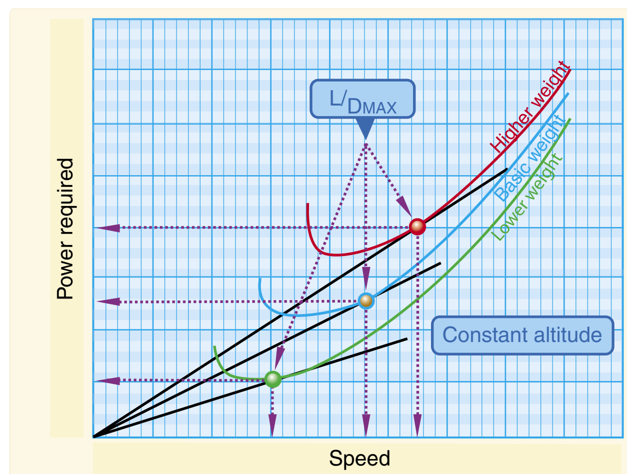


Figure 10-11. *Effect of weight.*

The variations of speed and power required must be monitored by the pilot as part of the cruise control procedure to maintain the L/D_{MAX}. When the aircraft's fuel weight is a small part of the gross weight and the aircraft's range is small, the cruise control procedure can be simplified to essentially maintaining a constant speed and power setting throughout the time of cruise flight. However, a long-range aircraft has a fuel weight that is a considerable part of the gross weight, and cruise control procedures must employ scheduled airspeed and power changes to maintain optimum range conditions.

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The effect of altitude on the range of a propeller-driven aircraft is illustrated in *Figure 10-12.* A flight conducted at high altitude has a greater true airspeed (TAS), and the power required is proportionately greater than when conducted at sea level. The drag of the aircraft at altitude is the same as the drag at sea level, but the higher TAS causes a proportionately greater power required. NOTE: The straight line that is tangent to the sea level power curve is also tangent to the altitude power curve.

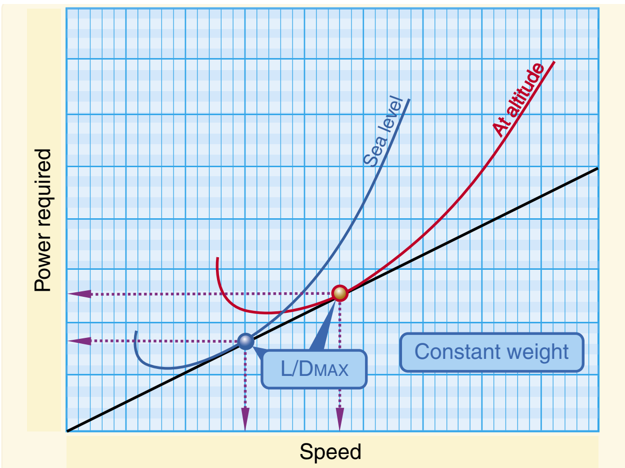


Figure 10-12. *Effect of altitude on range.*

The effect of altitude on specific range also can be appreciated from the previous relationships. If a change in altitude causes identical changes in speed and power required, the proportion of speed to power required would be unchanged. The fact implies that the specific range of a propeller-driven aircraft would be unaffected by altitude. Actually, this is true to the extent that specific fuel consumption and propeller efficiency are the principal factors that could cause a variation of specific range with altitude. If compressibility effects are negligible, any variation of specific range with altitude is strictly a function of engine/propeller performance.

An aircraft equipped with a reciprocating engine will experience very little, if any, variation of specific range up to its absolute altitude. There is negligible variation of brake specific fuel consumption for values of brake horsepower below the maximum cruise power rating of the engine that is the lean range of engine operation. Thus, an increase in altitude will produce a decrease in specific range only when the increased power requirement exceeds the maximum cruise power rating of the engine. One advantage of supercharging is that the cruise power may be maintained at high altitude, and the aircraft may achieve the range at high altitude with the corresponding increase in TAS. The principal differences in the high altitude cruise and low altitude cruise are the TAS and climb fuel requirements.

Region of Reversed Command

The aerodynamic properties of an aircraft generally determine the power requirements at various conditions of flight, while the powerplant capabilities generally determine the power available at various conditions of flight. When an aircraft is in steady, level flight, a condition of equilibrium must prevail. An unaccelerated condition of flight is achieved when lift equals weight, and the powerplant is set for thrust equal to drag. The power required to achieve equilibrium in constant-altitude flight at various airspeeds is depicted on a power required curve. The power required curve illustrates the fact that at low airspeeds near the stall or minimum controllable airspeed, the power setting required for steady, level flight is quite high.

Flight in the region of normal command means that while holding a constant altitude, a higher airspeed requires a higher power setting and a lower airspeed requires a lower power setting. The majority of aircraft flying (climb, cruise, and maneuvers) is conducted in the region of normal command.

Flight in the region of reversed command means flight in which a higher airspeed requires a lower power setting and a lower airspeed requires a higher power setting to hold altitude. It does not imply that a decrease in power will produce lower airspeed. The region of reversed command is encountered in the low speed phases of flight. Flight speeds below the speed for maximum endurance (lowest point on the power curve) require higher power settings with a decrease in airspeed. Since the need to increase the required power setting with decreased speed is contrary to the normal command of flight, the regime of flight speeds between the speed for minimum required power setting and the stall speed (or minimum control speed) is termed the region of reversed command. In the region of reversed command, a decrease in airspeed must be accompanied by an increased power setting in order to maintain steady flight.

Figure 10-13 shows the maximum power available as a curved line. Lower power settings, such as cruise power, would also appear in a similar curve. The lowest point on the power required curve represents the speed at which the lowest brake horsepower will sustain level flight. This is termed the best endurance airspeed.

An airplane performing a low airspeed, high pitch attitude power approach for a short-field landing is an example of operating in the region of reversed command. If an unacceptably high sink rate should develop, it may be possible for the pilot to reduce or stop the descent by applying power. But without further use of power, the airplane would probably stall or be incapable of flaring for the landing.

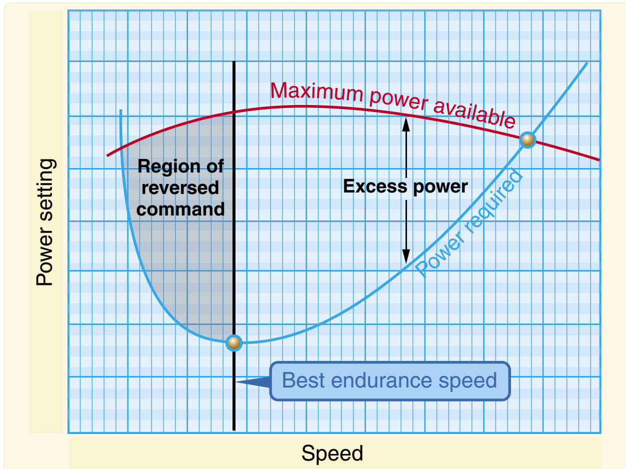


Figure 10-13. *Power required curve.*

Merely lowering the nose of the airplane to regain flying speed in this situation, without the use of power, would result in a rapid sink rate and corresponding loss of altitude.

If during a soft-field takeoff and climb, for example, the pilot attempts to climb out of ground effect without first attaining normal climb pitch attitude and airspeed, the airplane may inadvertently enter the region of reversed command at a dangerously low altitude. Even with full power, the airplane may be incapable of climbing or even maintaining altitude. The pilot's only recourse in this situation is to lower the pitch attitude in order to increase airspeed, which will inevitably result in a loss of altitude.

Airplane pilots must give particular attention to precise control of airspeed when operating in the low flight speeds of the region of reversed command.

Takeoff and Landing Performance

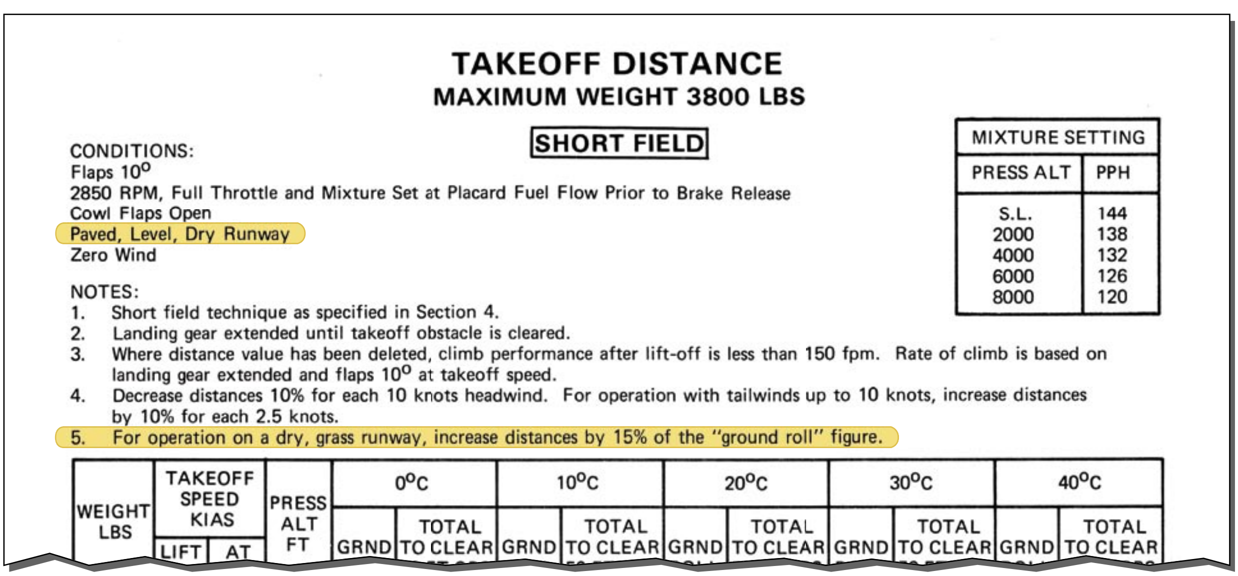
The majority of pilot-caused aircraft accidents occur during the takeoff and landing phase of flight. Because of this fact, the pilot must be familiar with all the variables that influence the takeoff and landing performance of an aircraft and must strive for exacting, professional procedures of operation during these phases of flight.

Takeoff and landing performance is a condition of accelerated and decelerated motion. For instance, during takeoff, an aircraft starts at zero speed and accelerates to the takeoff speed to become airborne. During landing, the aircraft touches down at the landing speed and decelerates to zero speed. The important factors of takeoff or landing performance are:

- The takeoff or landing speed is generally a function of the stall speed or minimum flying speed.
- The rate of acceleration/deceleration during the takeoff or landing roll. The speed (acceleration and deceleration) experienced by any object varies directly with the imbalance of force and inversely with the mass of the object. An airplane on the runway moving at 75 knots has four times the energy it has traveling at 37 knots. Thus, an airplane requires four times as much distance to stop as required at half the speed.
- The takeoff or landing roll distance is a function of both acceleration/deceleration and speed.

Runway Surface and Gradient

Runway conditions affect takeoff and landing performance. Typically, performance chart information assumes paved, level, smooth, and dry runway surfaces. Since no two runways are alike, the runway surface differs from one runway to another, as does the runway gradient or slope. *[Figure 10-14]*



TAKEOFF DISTANCE
MAXIMUM WEIGHT 3800 LBS
SHORT FIELD

CONDITIONS:
Flaps 10°
2850 RPM, Full Throttle and Mixture Set at Placard Fuel Flow Prior to Brake Release
Cowl Flaps Open
Paved, Level, Dry Runway
Zero Wind

MIXTURE SETTING	
PRESS ALT	PPH
S.L.	144
2000	138
4000	132
6000	126
8000	120

NOTES:
1. Short field technique as specified in Section 4.
2. Landing gear extended until takeoff obstacle is cleared.
3. Where distance value has been deleted, climb performance after lift-off is less than 150 fpm. Rate of climb is based on landing gear extended and flaps 10° at takeoff speed.
4. Decrease distances 10% for each 10 knots headwind. For operation with tailwinds up to 10 knots, increase distances by 10% for each 2.5 knots.
5. For operation on a dry, grass runway, increase distances by 15% of the "ground roll" figure.

WEIGHT LBS	TAKEOFF SPEED KIAS		PRESS ALT FT	0°C		10°C		20°C		30°C		40°C	
	LIFT	AT		GRND	TOTAL TO CLEAR	GRND	TOTAL TO CLEAR	GRND	TOTAL TO CLEAR	GRND	TOTAL TO CLEAR	GRND	TOTAL TO CLEAR

Figure 10-14. *Takeoff distance chart.*

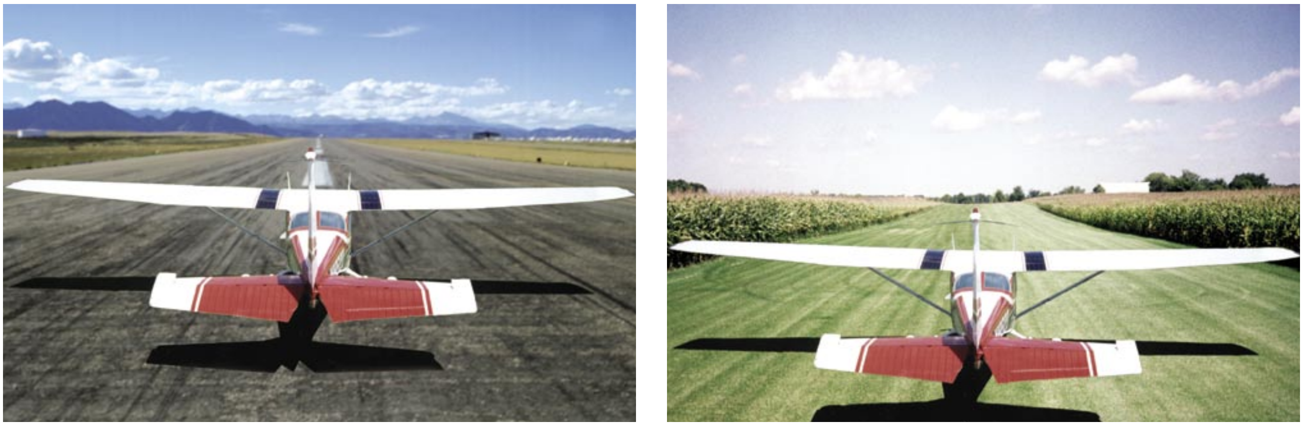


Figure 10-15. *An aircraft's performance depends greatly on the runway surface.*

Runway surfaces vary widely from one airport to another. The runway surface encountered may be concrete, asphalt, gravel, dirt, or grass. The runway surface for a specific airport is noted in the Airport/Facility Directory (A/FD). Any surface that is not hard and smooth will increase the ground roll during takeoff. This is due to the inability of the tires to roll smoothly along the runway. Tires can sink into soft, grassy, or muddy runways. Potholes or other ruts in the pavement can be the cause of poor tire movement along the runway. Obstructions such as mud, snow, or standing water reduce the airplane's acceleration down the runway. Although muddy and wet surface conditions can reduce friction between the runway and the tires, they can also act as obstructions and reduce the landing distance. *[Figure 10-15]* Braking effectiveness is another consideration when dealing with various runway types. The condition of the surface affects the braking ability of the airplane.

The amount of power that is applied to the brakes without skidding the tires is referred to as braking effectiveness. Ensure that runways are adequate in length for takeoff acceleration and landing deceleration when less than ideal surface conditions are being reported.

The gradient or slope of the runway is the amount of change in runway height over the length of the runway. The gradient is expressed as a percentage such as a 3 percent gradient. This means that for every 100 feet of runway length, the runway height changes by 3 feet. A positive gradient indicates the runway height increases, and a negative gradient indicates the runway decreases in height. An upsloping runway impedes acceleration and results in a longer ground run during takeoff. However, landing on an upsloping runway typically reduces the landing roll. A downsloping runway aids in acceleration on takeoff resulting in shorter takeoff distances. The opposite is true when landing, as landing on a downsloping runway increases landing distances. Runway slope information is contained in the A/FD. *[Figure 10-16]*

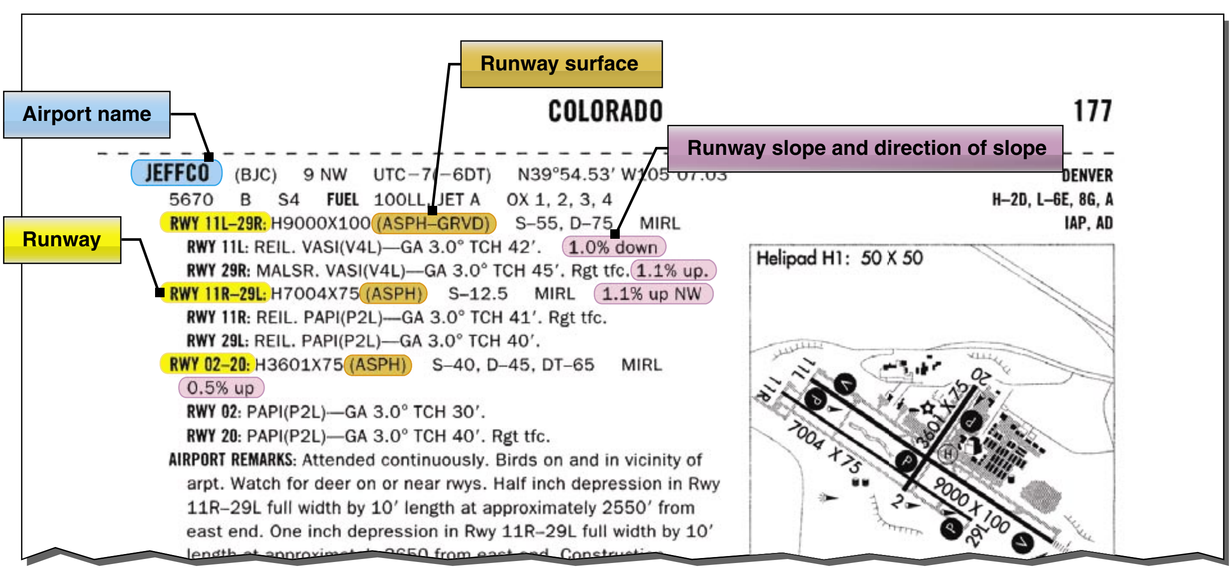


Figure 10-16. *Airport/facility directory (A/FD) information.*

Water on the Runway and Dynamic Hydroplaning

Water on the runways reduces the friction between the tires and the ground, and can reduce braking effectiveness. The ability to brake can be completely lost when the tires are hydroplaning because a layer of water separates the tires from the runway surface. This is also true of braking effectiveness when runways are covered in ice.

When the runway is wet, the pilot may be confronted with dynamic hydroplaning. Dynamic hydroplaning is a condition in which the aircraft tires ride on a thin sheet of water rather than on the runway's surface. Because hydroplaning wheels are not touching the runway, braking and directional control are almost nil. To help minimize dynamic hydroplaning, some runways are grooved to help drain off water; most runways are not.

Tire pressure is a factor in dynamic hydroplaning. Using the simple formula in *Figure 10-17,* a pilot can calculate the minimum speed, in knots, at which hydroplaning will begin. In plain language, the minimum hydroplaning speed is determined by multiplying the square root of the main gear tire pressure in psi by nine. For example, if the main gear tire pressure is at 36 psi, the aircraft would begin hydroplaning at 54 knots.

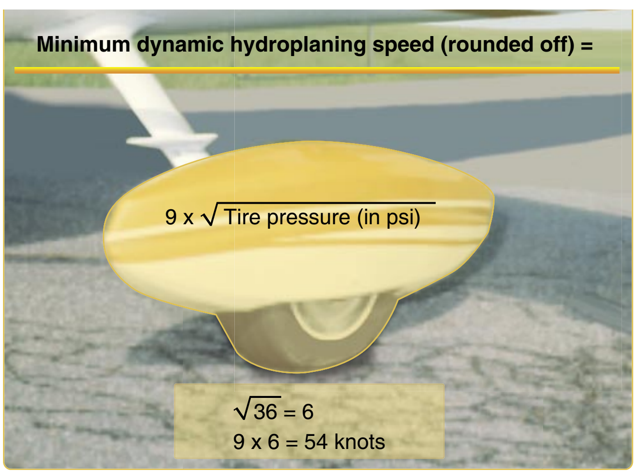


Figure 10-17. *Tire pressure.*

Landing at higher than recommended touchdown speeds will expose the aircraft to a greater potential for hydroplaning. And once hydroplaning starts, it can continue well below the minimum initial hydroplaning speed.

On wet runways, directional control can be maximized by landing into the wind. Abrupt control inputs should be avoided. When the runway is wet, anticipate braking problems well before landing and be prepared for hydroplaning. Opt for a suitable runway most aligned with the wind. Mechanical braking may be ineffective, so aerodynamic braking should be used to its fullest advantage.

Takeoff Performance

The minimum takeoff distance is of primary interest in the operation of any aircraft because it defines the runway requirements. The minimum takeoff distance is obtained by taking off at some minimum safe speed that allows sufficient margin above stall and provides satisfactory control and initial rate of climb. Generally, the lift-off speed is some fixed percentage of the stall speed or minimum control speed for the aircraft in the takeoff configuration. As such, the lift-off will be accomplished at some particular value of lift coefficient and AOA. Depending on the aircraft characteristics, the lift-off speed will be anywhere from 1.05 to 1.25 times the stall speed or minimum control speed.

To obtain minimum takeoff distance at the specific lift-off speed, the forces that act on the aircraft must provide the maximum acceleration during the takeoff roll. The various forces acting on the aircraft may or may not be under the control of the pilot, and various procedures may be necessary in certain aircraft to maintain takeoff acceleration at the highest value.

The powerplant thrust is the principal force to provide the acceleration and, for minimum takeoff distance, the output thrust should be at a maximum. Lift and drag are produced as soon as the aircraft has speed, and the values of lift and drag depend on the AOA and dynamic pressure.

In addition to the important factors of proper procedures, many other variables affect the takeoff performance of an aircraft. Any item that alters the takeoff speed or acceleration rate during the takeoff roll will affect the takeoff distance.

For example, the effect of gross weight on takeoff distance is significant and proper consideration of this item must be made in predicting the aircraft's takeoff distance. Increased gross weight can be considered to produce a threefold effect on takeoff performance:

1. Higher lift-off speed
2. Greater mass to accelerate
3. Increased retarding force (drag and ground friction)

If the gross weight increases, a greater speed is necessary to produce the greater lift necessary to get the aircraft airborne at the takeoff lift coefficient. As an example of the effect of a change in gross weight, a 21 percent increase in takeoff weight will require a 10 percent increase in lift-off speed to support the greater weight.

A change in gross weight will change the net accelerating force and change the mass that is being accelerated. If the aircraft has a relatively high thrust-to-weight ratio, the change in the net accelerating force is slight and the principal effect on acceleration is due to the change in mass.

For example, a 10 percent increase in takeoff gross weight would cause:

- A 5 percent increase in takeoff velocity.
- At least a 9 percent decrease in rate of acceleration.
- At least a 21 percent increase in takeoff distance.

With ISA conditions, increasing the takeoff weight of the average Cessna 182 from 2,400 pounds to 2,700 pounds (11 percent increase) results in an increased takeoff distance from 440 feet to 575 feet (23 percent increase).

For the aircraft with a high thrust-to-weight ratio, the increase in takeoff distance might be approximately 21 to 22 percent, but for the aircraft with a relatively low thrust-to-weight ratio, the increase in takeoff distance would be approximately 25 to 30 percent. Such a powerful effect requires proper consideration of gross weight in predicting takeoff distance.

The effect of wind on takeoff distance is large, and proper consideration also must be provided when predicting takeoff distance. The effect of a headwind is to allow the aircraft to reach the lift-off speed at a lower groundspeed while the effect of a tailwind is to require the aircraft to achieve a greater groundspeed to attain the lift-off speed.

A headwind that is 10 percent of the takeoff airspeed will reduce the takeoff distance approximately 19 percent. However, a tailwind that is 10 percent of the takeoff airspeed will increase the takeoff distance approximately 21 percent. In the case where the headwind speed is 50 percent of the takeoff speed, the takeoff distance would be approximately 25 percent of the zero wind takeoff distance (75 percent reduction).

The effect of wind on landing distance is identical to its effect on takeoff distance. *Figure 10-18* illustrates the general effect of wind by the percent change in takeoff or landing distance as a function of the ratio of wind velocity to takeoff or landing speed.

The effect of proper takeoff speed is especially important when runway lengths and takeoff distances are critical. The takeoff speeds specified in the AFM/POH are generally the minimum safe speeds at which the aircraft can become airborne. Any attempt to take off below the recommended speed means that the aircraft could stall, be difficult to

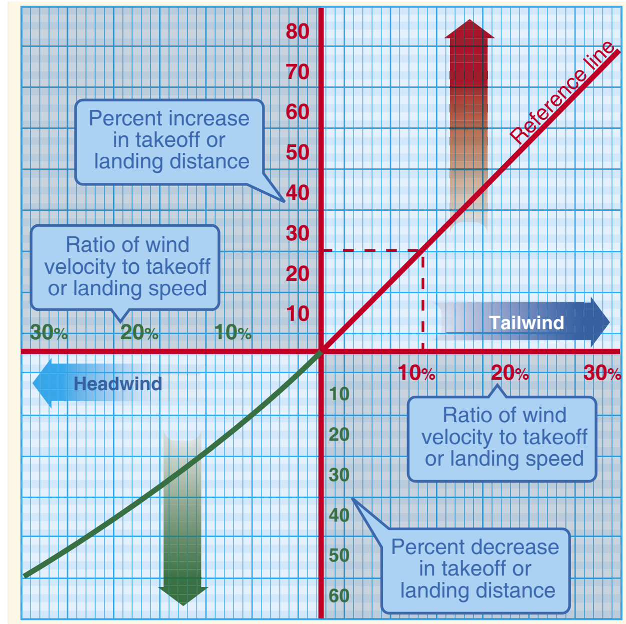


Figure 10-18. *Effect of wind on takeoff and landing.*

control, or have a very low initial rate of climb. In some cases, an excessive AOA may not allow the aircraft to climb out of ground effect. On the other hand, an excessive airspeed at takeoff may improve the initial rate of climb and "feel" of the aircraft, but will produce an undesirable increase in takeoff distance. Assuming that the acceleration is essentially unaffected, the takeoff distance varies with the square of the takeoff velocity.

Thus, ten percent excess airspeed would increase the takeoff distance 21 percent. In most critical takeoff conditions, such an increase in takeoff distance would be prohibitive, and the pilot must adhere to the recommended takeoff speeds.

The effect of pressure altitude and ambient temperature is to define the density altitude and its effect on takeoff performance. While subsequent corrections are appropriate for the effect of temperature on certain items of powerplant performance, density altitude defines specific effects on takeoff performance. An increase in density altitude can produce a twofold effect on takeoff performance:

1. Greater takeoff speed
2. Decreased thrust and reduced net accelerating force

If an aircraft of given weight and configuration is operated at greater heights above standard sea level, the aircraft requires the same dynamic pressure to become airborne at the takeoff lift coefficient. Thus, the aircraft at altitude will take off at the same indicated airspeed (IAS) as at sea level, but because of the reduced air density, the TAS will be greater.

The effect of density altitude on powerplant thrust depends much on the type of powerplant. An increase in altitude above standard sea level will bring an immediate decrease in power output for the unsupercharged reciprocating engine. However, an increase in altitude above standard sea level will not cause a decrease in power output for the supercharged reciprocating engine until the altitude exceeds the critical operating altitude. For those powerplants that experience a decay in thrust with an increase in altitude, the effect on the net accelerating force and acceleration rate can be approximated by assuming a direct variation with density. Actually, this assumed variation would closely approximate the effect on aircraft with high thrust-to-weight ratios.

Proper accounting of pressure altitude and temperature is mandatory for accurate prediction of takeoff roll distance. The most critical conditions of takeoff performance are the result of some combination of high gross weight, altitude, temperature, and unfavorable wind. In all cases, the pilot must make an accurate prediction of takeoff distance from the performance data of the AFM/POH, regardless of the runway available, and strive for a polished, professional takeoff procedure.

In the prediction of takeoff distance from the AFM/POH data, the following primary considerations must be given:

- Pressure altitude and temperature—to define the effect of density altitude on distance
- Gross weight—a large effect on distance
- Wind—a large effect due to the wind or wind component along the runway
- Runway slope and condition—the effect of an incline and retarding effect of factors such as snow or ice

Landing Performance

In many cases, the landing distance of an aircraft will define the runway requirements for flight operations. The minimum landing distance is obtained by landing at some minimum safe speed, which allows sufficient margin above stall and provides satisfactory control and capability for a go-around. Generally, the landing speed is some fixed percentage of the stall speed or minimum control speed for the aircraft in the landing configuration. As such, the landing will be accomplished at some particular value of lift coefficient and AOA. The exact values will depend on the aircraft characteristics but, once defined, the values are independent of weight, altitude, and wind.

To obtain minimum landing distance at the specified landing speed, the forces that act on the aircraft must provide maximum deceleration during the landing roll. The forces acting on the aircraft during the landing roll may require various procedures to maintain landing deceleration at the peak value.

A distinction should be made between the procedures for minimum landing distance and an ordinary landing roll with considerable excess runway available. Minimum landing distance will be obtained by creating a continuous peak deceleration of the aircraft; that is, extensive use of the brakes for maximum deceleration. On the other hand, an ordinary landing roll with considerable excess runway may allow extensive use of aerodynamic drag to minimize wear and tear on the tires and brakes. If aerodynamic drag is sufficient to cause deceleration, it can be used in deference to the brakes in the early stages of the landing roll; i.e., brakes and tires suffer from continuous hard use, but aircraft aerodynamic drag is free and does not wear out with use. The use of aerodynamic drag is applicable only for deceleration to 60 or 70 percent of the touchdown speed. At speeds less than 60 to 70 percent of the touchdown speed, aerodynamic drag is so slight as to be of little use, and braking must be utilized to produce continued deceleration. Since the objective during the landing roll is to decelerate, the powerplant thrust should be the smallest possible positive value (or largest possible negative value in the case of thrust reversers).

In addition to the important factors of proper procedures, many other variables affect the landing performance. Any item that alters the landing speed or deceleration rate during the landing roll will affect the landing distance.

The effect of gross weight on landing distance is one of the principal items determining the landing distance. One effect of an increased gross weight is that a greater speed will be required to support the aircraft at the landing AOA and lift coefficient. For an example of the effect of a change in gross weight, a 21 percent increase in landing weight will require a ten percent increase in landing speed to support the greater weight.

When minimum landing distances are considered, braking friction forces predominate during the landing roll and, for the majority of aircraft configurations, braking friction is the main source of deceleration.

The minimum landing distance will vary in direct proportion to the gross weight. For example, a ten percent increase in gross weight at landing would cause a:

- Five percent increase in landing velocity
- Ten percent increase in landing distance

A contingency of this is the relationship between weight and braking friction force.

The effect of wind on landing distance is large and deserves proper consideration when predicting landing distance. Since the aircraft will land at a particular airspeed independent of the wind, the principal effect of wind on landing distance is the change in the groundspeed at which the aircraft touches down. The effect of wind on deceleration during the landing is identical to the effect on acceleration during the takeoff.

The effect of pressure altitude and ambient temperature is to define density altitude and its effect on landing performance. An increase in density altitude increases the landing speed but does not alter the net retarding force. Thus, the aircraft at altitude lands at the same IAS as at sea level but, because of the reduced density, the TAS is greater. Since the aircraft lands at altitude with the same weight and dynamic pressure, the drag and braking friction throughout the landing roll have the same values as at sea level. As long as the condition is within the capability of the brakes, the net retarding force is unchanged, and the deceleration is the same as with the landing at sea level. Since an increase in altitude does not alter deceleration, the effect of density altitude on landing distance is due to the greater TAS.

The minimum landing distance at 5,000 feet is 16 percent greater than the minimum landing distance at sea level. The approximate increase in landing distance with altitude is approximately three and one-half percent for each 1,000 feet of altitude. Proper accounting of density altitude is necessary to accurately predict landing distance.

The effect of proper landing speed is important when runway lengths and landing distances are critical. The landing speeds specified in the AFM/POH are generally the minimum safe speeds at which the aircraft can be landed. Any attempt to land at below the specified speed may mean that the aircraft may stall, be difficult to control, or develop high rates of descent. On the other hand, an excessive speed at landing may improve the controllability slightly (especially in crosswinds), but causes an undesirable increase in landing distance.

A ten percent excess landing speed causes at least a 21 percent increase in landing distance. The excess speed places a greater working load on the brakes because of the additional kinetic energy to be dissipated. Also, the additional speed causes increased drag and lift in the normal ground attitude, and the increased lift reduces the normal force on the braking surfaces. The deceleration during this range of speed immediately after touchdown may suffer, and it is more probable for a tire to be blown out from braking at this point.

The most critical conditions of landing performance are combinations of high gross weight, high density altitude, and unfavorable wind. These conditions produce the greatest required landing distances and critical levels of energy dissipation required of the brakes. In all cases, it is necessary to make an accurate prediction of minimum landing distance to compare with the available runway. A polished, professional landing procedure is necessary because the landing phase of flight accounts for more pilot-caused aircraft accidents than any other single phase of flight.

In the prediction of minimum landing distance from the AFM/POH data, the following considerations must be given:

- Pressure altitude and temperature—to define the effect of density altitude
- Gross weight—which defines the CAS for landing.
- Wind—a large effect due to wind or wind component along the runway
- Runway slope and condition—relatively small correction for ordinary values of runway slope, but a significant effect of snow, ice, or soft ground

A tail wind of ten knots increases the landing distance by about 21 percent. An increase of landing speed by ten percent increases the landing distance by 20 percent. Hydroplaning makes braking ineffective until a decrease of speed to that determined using *Figure 10-17*.

For instance, a pilot is downwind for runway 18, and the tower asks if runway 27 could be accepted. There is a light rain and the winds are out of the east at ten knots. The pilot accepts because he or she is approaching the extended centerline of runway 27. The turn is tight and the pilot must descend (dive) to get to runway 27. After becoming aligned with the runway and at 50 feet AGL, the pilot is already 1,000 feet down the 3,500 feet runway. The airspeed is still high by about ten percent (should be at 70 knots and is at about 80 knots). The wind of ten knots is blowing from behind.

First, the airspeed being high by about ten percent (80 knots versus 70 knots), as presented in the performance chapter, results in a 20 percent increase in the landing distance. In performance planning, the pilot determined that at 70 knots the distance would be 1,600 feet. However, now it is increased by 20 percent and the required distance is now 1,920 feet.

The newly revised landing distance of 1,920 feet is also affected by the wind. In looking at *Figure 10-18*, the affect of the wind is an additional 20 percent for every ten miles per hour (mph) in wind. This is computed not on the original estimate but on the estimate based upon the increased airspeed. Now the landing distance is increased by another

320 feet for a total requirement of 2,240 feet to land the airplane after reaching 50 feet AGL.

That is the original estimate of 1,600 under planned conditions plus the additional 640 feet for excess speed and the tailwind. Given the pilot overshot the threshhold by 1,000 feet, the total length required is 3, 240 on a 3,500 foot runway; 260 feet to spare. But this is in a perfect environment. Most pilots become fearful as the end of the runway is facing them just ahead. A typical pilot reaction is to brake—and brake hard. Because the aircraft does not have antilock braking features like a car, the brakes lock, and the aircraft hydroplanes on the wet surface of the runway until decreasing to a speed of about 54 knots (the square root of the tire pressure ($\sqrt{36}$) x 9). Braking is ineffective when hydroplaning.

The 260 feet that a pilot might feel is left over has long since evaporated as the aircraft hydroplaned the first 300–500 feet when the brakes locked. This is an example of a true story, but one which only changes from year to year because of new participants and aircraft with different N-numbers.

In this example, the pilot actually made many bad decisions. Bad decisions, when combined, have a synergy greater than the individual errors. Therefore, the corrective actions become larger and larger until correction is almost impossible. Aeronautical decision-making will be discussed more fully in Chapter 17, Aeronautical Decision-Making (ADM).

Performance Speeds

True Airspeed (TAS)—the speed of the aircraft in relation to the air mass in which it is flying.

Indicated Airspeed (IAS)—the speed of the aircraft as observed on the ASI. It is the airspeed without correction for indicator, position (or installation), or compressibility errors.

Calibrated Airspeed (CAS)—the ASI reading corrected for position (or installation), and instrument errors. (CAS is equal to TAS at sea level in standard atmosphere.) The color coding for various design speeds marked on ASIs may be IAS or CAS.

Equivalent Airspeed (EAS)—the ASI reading corrected for position (or installation), or instrument error, and for adiabatic compressible flow for the particular altitude. (EAS is equal to CAS at sea level in standard atmosphere.)

V_{S0}—the calibrated power-off stalling speed or the minimum steady flight speed at which the aircraft is controllable in the landing configuration.

V_{S1}—the calibrated power-off stalling speed or the minimum steady flight speed at which the aircraft is controllable in a specified configuration.

V_Y—the speed at which the aircraft will obtain the maximum increase in altitude per unit of time. This best rate-of-climb speed normally decreases slightly with altitude.

V_X—the speed at which the aircraft will obtain the highest altitude in a given horizontal distance. This best angle-of-climb speed normally increases slightly with altitude.

V_{LE}—the maximum speed at which the aircraft can be safely flown with the landing gear extended. This is a problem involving stability and controllability.

V_{LO}—the maximum speed at which the landing gear can be safely extended or retracted. This is a problem involving the air loads imposed on the operating mechanism during extension or retraction of the gear.

V_{FE}—the highest speed permissible with the wing flaps in a prescribed extended position. This is because of the air loads imposed on the structure of the flaps.

V_A—the calibrated design maneuvering airspeed. This is the maximum speed at which the limit load can be imposed (either by gusts or full deflection of the control surfaces) without causing structural damage. Operating at or below manuevering speed does not provide structural protection against multiple full control inputs in one axis or full control inputs in more than one axis at the same time.

V_{NO}—the maximum speed for normal operation or the maximum structural cruising speed. This is the speed at which exceeding the limit load factor may cause permanent deformation of the aircraft structure.

V_{NE}—the speed which should *never* be exceeded. If flight is attempted above this speed, structural damage or structural failure may result.

Performance Charts

Performance charts allow a pilot to predict the takeoff, climb, cruise, and landing performance of an aircraft. These charts, provided by the manufacturer, are included in the AFM/POH. Information the manufacturer provides on these charts has been gathered from test flights conducted in a new aircraft, under normal operating conditions while using average piloting skills, and with the aircraft and engine in good working order. Engineers record the flight data and create performance charts based on the behavior of the aircraft during the test flights. By using these performance charts, a pilot can determine the runway length needed to take off and land, the amount of fuel to be used during flight, and the time required to arrive at the destination. It is important to remember that the data from the charts will not be accurate if the aircraft is not in good working order or when operating under adverse conditions. Always consider the necessity to compensate for the performance numbers if the aircraft is not in good working order or piloting skills are below average. Each aircraft performs differently and, therefore, has different performance numbers. Compute the performance of the aircraft prior to every flight, as every flight is different. (See appendix for examples of performance charts for a Cessna Model 172R and Challenger 605.)

Every chart is based on certain conditions and contains notes on how to adapt the information for flight conditions. It is important to read every chart and understand how to use it. Read the instructions provided by the manufacturer. For an explanation on how to use the charts, refer to the example provided by the manufacturer for that specific chart. *[Figure 10-19]*

The information manufacturers furnish is not standardized. Information may be contained in a table format, and other information may be contained in a graph format. Sometimes combined graphs incorporate two or more graphs into one chart to compensate for multiple conditions of flight. Combined graphs allow the pilot to predict aircraft performance for variations in density altitude, weight, and winds all on one chart. Because of the vast amount of information that can be extracted from this type of chart, it is important to be very accurate in reading the chart. A small error in the beginning can lead to a large error at the end.

The remainder of this section covers performance information for aircraft in general and discusses what information the charts contain and how to extract information from the charts by direct reading and interpolation methods. Every chart contains a wealth of information that should be used when flight planning. Examples of the table, graph, and combined graph formats for all aspects of flight will be discussed.

Interpolation

Not all of the information on the charts is easily extracted. Some charts require interpolation to find the information for specific flight conditions. Interpolating information means that by taking the known information, a pilot can compute intermediate information. However, pilots sometimes round off values from charts to a more conservative figure.

Using values that reflect slightly more adverse conditions provides a reasonable estimate of performance information and gives a slight margin of safety. The following illustration is an example of interpolating information from a takeoff distance chart. *[Figure 10-20]*

Density Altitude Charts

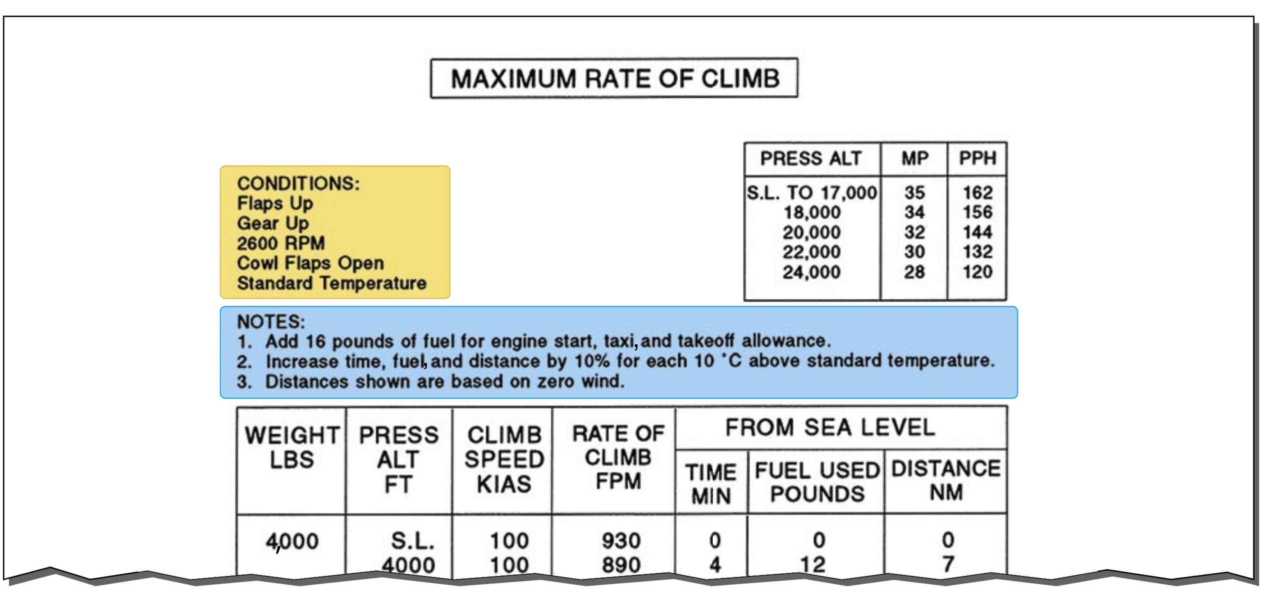
Use a density altitude chart to figure the density altitude at the departing airport. Using *Figure 10-21*, determine the density altitude based on the given information.

Sample Problem 1

Airport Elevation..5,883 feet

OAT..70 °F

Altimeter..30.10" Hg


MAXIMUM RATE OF CLIMB

CONDITIONS:
Flaps Up
Gear Up
2600 RPM
Cowl Flaps Open
Standard Temperature

PRESS ALT	MP	PPH
S.L. TO 17,000	35	162
18,000	34	156
20,000	32	144
22,000	30	132
24,000	28	120

NOTES:
1. Add 16 pounds of fuel for engine start, taxi, and takeoff allowance.
2. Increase time, fuel, and distance by 10% for each 10 °C above standard temperature.
3. Distances shown are based on zero wind.

WEIGHT LBS	PRESS ALT FT	CLIMB SPEED KIAS	RATE OF CLIMB FPM	FROM SEA LEVEL TIME MIN	FROM SEA LEVEL FUEL USED POUNDS	FROM SEA LEVEL DISTANCE NM
4,000	S.L.	100	930	0	0	0
	4000	100	890	4	12	7

Figure 10-19. *Conditions notes chart.*

Conditions	Flaps 10° Full throttle prior to brake release Paved level runway Zero wind			**TAKEOFF DISTANCE** MAXIMUM WEIGHT 2,400 LB									
Weight (lb)	Takeoff speed KIAS		Press ALT (feet)	0 °C		10 °C		20 °C		30 °C		40 °C	
	Lift off	AT 50 ft		Grnd Roll (feet)	Total feet to clear 50 ft OBS	Grnd Roll (feet)	Total feet to clear 50 ft OBS	Grnd Roll (feet)	Total feet to clear 50 ft OBS	Grnd Roll (feet)	Total feet to clear 50 ft OBS	Grnd Roll (feet)	Total feet to clear 50 ft OBS
2,400	51	56	S.L.	795	1,460	860	1,570	925	1,685	995	1,810	1,065	1,945
			1,000	875	1,605	940	1,725	1,015	1,860	1,090	2,000	1,170	2,155
			2,000	960	1,770	1,035	1,910	1,115	2,060	1,200	2,220	1,290	2,395
			3,000	1,055	1,960	1,140	2,120	1,230	2,295	1,325	2,480	1,425	2,685
			4,000	1,165	2,185	1,260	2,365	1,355	2,570	1,465	2,790	1,575	3,030
			5,000	1,285	2,445	1,390	2,660	1,500	2,895	1,620	3,160	1,745	3,455
			6,000	1,425	2,755	1,540	3,015	1,665	3,300	1,800	3,620	1,940	3,990
			7,000	1,580	3,140	1,710	3,450	1,850	3,805	2,000	4,220	- - -	- - -
			8,000	1,755	3,615	1,905	4,015	2,060	4,480	- - -	- - -	- - -	- - -

To find the takeoff distance for a pressure altitude of 2,500 feet at 20 °C, average the ground roll for 2,000 feet and 3,000 feet.

$$\frac{1{,}115 + 1{,}230}{2} = 1{,}173 \text{ feet}$$

Figure 10-20. *Interpolating charts.*

First, compute the pressure altitude conversion. Find 30.10 under the altimeter heading. Read across to the second column. It reads "–165." Therefore, it is necessary to subtract 165 from the airport elevation giving a pressure altitude of 5,718 feet. Next, locate the outside air temperature on the scale along the bottom of the graph. From 70°, draw a line up to the 5,718 feet pressure altitude line, which is about two-thirds of the way up between the 5,000 and 6,000 foot lines. Draw a line straight across to the far left side of the graph and read the approximate density altitude. The approximate density altitude in thousands of feet is 7,700 feet.

Takeoff Charts

Takeoff charts are typically provided in several forms and allow a pilot to compute the takeoff distance of the aircraft with no flaps or with a specific flap configuration. A pilot can also compute distances for a no flap takeoff over a 50 foot obstacle scenario, as well as with flaps over a 50 foot obstacle. The takeoff distance chart provides for various aircraft weights, altitudes, temperatures, winds, and obstacle heights.

Sample Problem 2

Pressure Altitude...2,000 feet

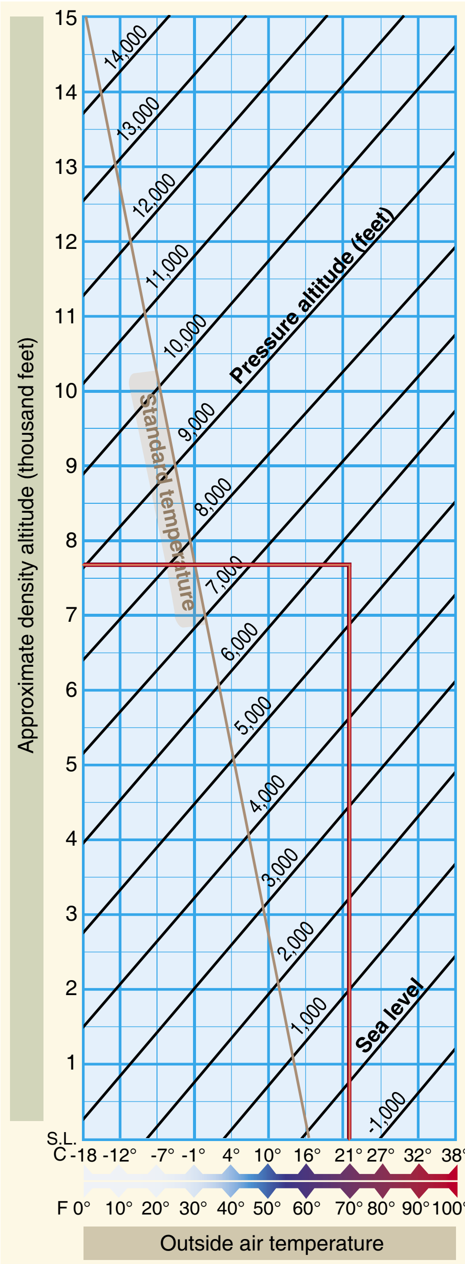
OAT..22 °C

Takeoff Weight...2,600 pounds

Headwind...6 knots

Obstacle Height.....................................50 foot obstacle

Refer to *Figure 10-22*. This chart is an example of a combined takeoff distance graph. It takes into consideration pressure altitude, temperature, weight, wind, and obstacles all on one chart. First, find the correct temperature on the bottom left-



Altimeter setting ("Hg)	Pressure altitude conversion factor
28.0	1,824
28.1	1,727
28.2	1,630
28.3	1,533
28.4	1,436
28.5	1,340
28.6	1,244
28.7	1,148
28.8	1,053
28.9	957
29.0	863
29.1	768
29.2	673
29.3	579
29.4	485
29.5	392
29.6	298
29.7	205
29.8	112
29.9	20
29.92	0
30.0	–73
30.1	–165
30.2	–257
30.3	–348
30.4	–440
30.5	–531
30.6	–622
30.7	–712
30.8	–803

Figure 10-21. *Density altitude chart.*

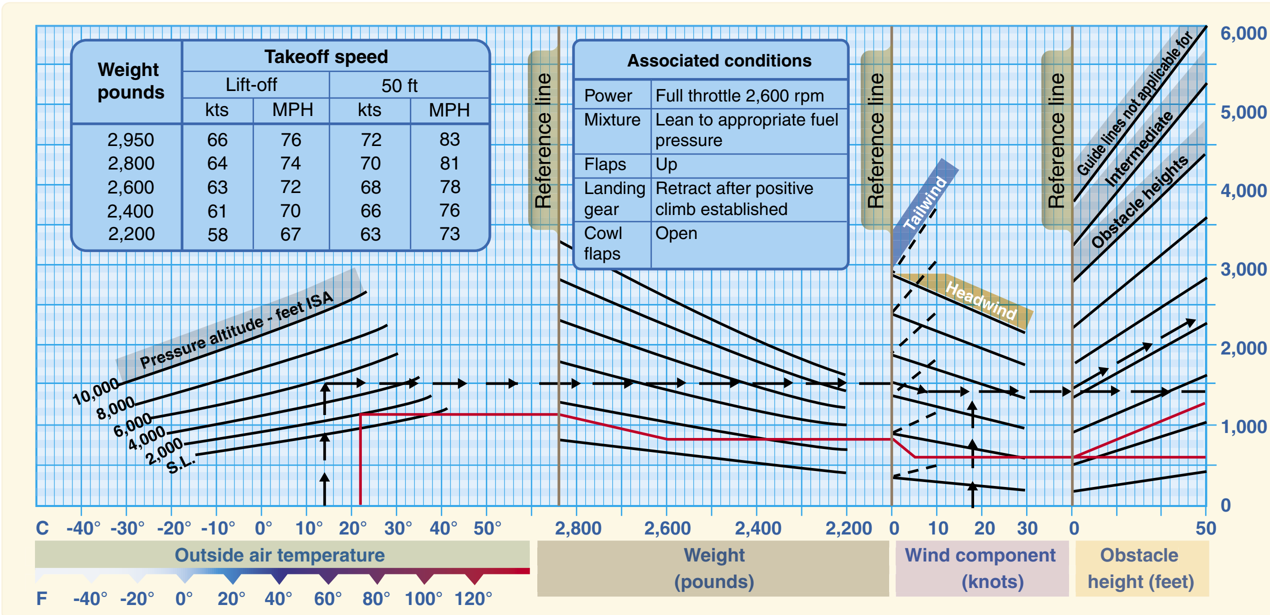


Figure 10-22. *Takeoff distance graph.*

hand side of the graph. Follow the line from 22° C straight up until it intersects the 2,000 foot altitude line. From that point, draw a line straight across to the first dark reference line. Continue to draw the line from the reference point in a diagonal direction following the surrounding lines until it intersects the corresponding weight line. From the intersection of 2,600 pounds, draw a line straight across until it reaches the second reference line. Once again, follow the lines in a diagonal manner until it reaches the six knot headwind mark. Follow straight across to the third reference line and from here, draw a line in two directions. First, draw a line straight across to figure the ground roll distance. Next, follow the diagonal lines again until it reaches the corresponding obstacle height. In this case, it is a 50 foot obstacle. Therefore, draw the diagonal line to the far edge of the chart. This results in a 600 foot ground roll distance and a total distance of 1,200 feet over a 50 foot obstacle. To find the corresponding takeoff speeds at lift-off and over the 50 foot obstacle, refer to the table on the top of the chart. In this case, the lift-off speed at 2,600 pounds would be 63 knots and over the 50 foot obstacle would be 68 knots.

Sample Problem 3

Pressure Altitude..3,000 feet

OAT..30 °C

Takeoff Weight...2,400 pounds

Headwind...18 knots

Refer to *Figure 10-23*. This chart is an example of a takeoff distance table for short-field takeoffs. For this table, first find the takeoff weight. Once at 2,400 pounds, begin reading from left to right across the table. The takeoff speed is in the second column and, in the third column under pressure altitude, find the pressure altitude of 3,000 feet. Carefully follow that line to the right until it is under the correct temperature column of 30 °C. The ground roll total reads 1,325 feet and the total required to clear a 50 foot obstacle is 2,480 feet. At this point, there is an 18 knot headwind. According to the notes section under point number two, decrease the distances by ten percent for each 9 knots of headwind. With an 18 knot headwind, it is necessary to decrease the distance by 20 percent. Multiply 1,325 feet by 20 percent (1,325 x .20 = 265), subtract the product from the total distance (1,325 – 265 = 1,060). Repeat this process for the total distance over a 50 foot obstacle. The ground roll distance is 1,060 feet and the total distance over a 50 foot obstacle is 1,984 feet.

Climb and Cruise Charts

Climb and cruise chart information is based on actual flight tests conducted in an aircraft of the same type. This information is extremely useful when planning a cross-country to predict the performance and fuel consumption of the aircraft. Manufacturers produce several different charts for climb and cruise performance. These charts include everything from fuel, time, and distance to climb, to best power setting during cruise, to cruise range performance.

The first chart to check for climb performance is a fuel, time, and distance-to-climb chart. This chart will give the fuel amount used during the climb, the time it will take to accomplish the climb, and the ground distance that will be covered during the climb. To use this chart, obtain the

Conditions
Flaps 10°
Full throttle prior to brake release
Paved level runway
Zero wind

TAKEOFF DISTANCE
MAXIMUM WEIGHT 2,400 LB

SHORT FIELD

Notes
1. Prior to takeoff from fields above 3,000 feet elevation, the mixture should be leaned to give maximum rpm in a full throttle, static runup.
2. Decrease distances 10% for each 9 knots headwind. For operation with tailwind up to 10 knots, increase distances by 10% for each 2 knots.
3. For operation on a dry, grass runway, increase distances by 15% of the "ground roll" figure.

Weight (lb)	Takeoff speed KIAS		Press ALT (FT)	0 °C		10 °C		20 °C		30 °C		40 °C	
	Lift off	AT 50 ft		Grnd Roll (FT)	Total feet to clear 50 ft OBS	Grnd Roll (FT)	Total feet to clear 50 ft OBS	Grnd Roll (FT)	Total feet to clear 50 ft OBS	Grnd Roll (FT)	Total feet to clear 50 ft OBS	Grnd Roll (FT)	Total feet to clear 50 ft OBS
2,400	51	56	S.L.	795	1,460	860	1,570	925	1,685	995	1,810	1,065	1,945
			1,000	875	1,605	940	1,725	1,015	1,860	1,090	2,000	1,170	2,155
			2,000	960	1,770	1,035	1,910	1,115	2,060	1,200	2,220	1,290	2,395
			3,000	1,055	1,960	1,140	2,120	1,230	2,295	1,325	2,480	1,425	2,685
			4,000	1,165	2,185	1,260	2,365	1,355	2,570	1,465	2,790	1,575	3,030
			5,000	1,285	2,445	1,390	2,660	1,500	2,895	1,620	3,160	1,745	3,455
			6,000	1,425	2,755	1,540	3,015	1,665	3,300	1,800	3,620	1,940	3,990
			7,000	1,580	3,140	1,710	3,450	1,850	3,805	2,000	4,220	- - -	- - -
			8,000	1,755	3,615	1,905	4,015	2,060	4,480		- - -	- - -	- - -
2,200	49	54	S.L.	650	1,195	700	1,280	750	1,375	805	1,470	865	1,575
			1,000	710	1,310	765	1,405	825	1,510	885	1,615	950	1,735
			2,000	780	1,440	840	1,545	905	1,660	975	1,785	1,045	1,915
			3,000	855	1,585	925	1,705	995	1,835	1,070	1,975	1,150	2,130
			4,000	945	1,750	1,020	1,890	1,100	2,040	1,180	2,200	1,270	2,375
			5,000	1,040	1,945	1,125	2,105	1,210	2,275	1,305	2,465	1,405	2,665
			6,000	1,150	2,170	1,240	2,355	1,340	2,555	1,445	2,775	1,555	3,020
			7,000	1,270	2,440	1,375	2,655	1,485	2,890	1,605	3,155	1,730	3,450
			8,000	1,410	2,760	1,525	3,015	1,650	3,305	1,785	3,630	1,925	4,005
2,000	46	51	S.L.	525	970	565	1,035	605	1,110	650	1,185	695	1,265
			1,000	570	1,060	615	1,135	665	1,215	710	1,295	765	1,385
			2,000	625	1,160	675	1,240	725	1,330	780	1,425	840	1,525
			3,000	690	1,270	740	1,365	800	1,465	860	1,570	920	1,685
			4,000	755	1,400	815	1,500	880	1,615	945	1,735	1,015	1,865
			5,000	830	1,545	900	1,660	970	1,790	2,145	1,925	1,120	2,070
			6,000	920	1,710	990	1,845	1,070	1,990	2,405	2,145	1,235	2,315
			7,000	1,015	1,900	1,095	2,055	1,180	2,225	2,715	2,405	1,370	2,605
			8,000	1,125	2,125	1,215	2,305	1,310	2,500	1,410	2,715	1,520	2,950

Figure 10-23. *Takeoff distance short field charts.*

information for the departing airport and for the cruise altitude. Using *Figure 10-24,* calculate the fuel, time, and distance to climb based on the information provided.

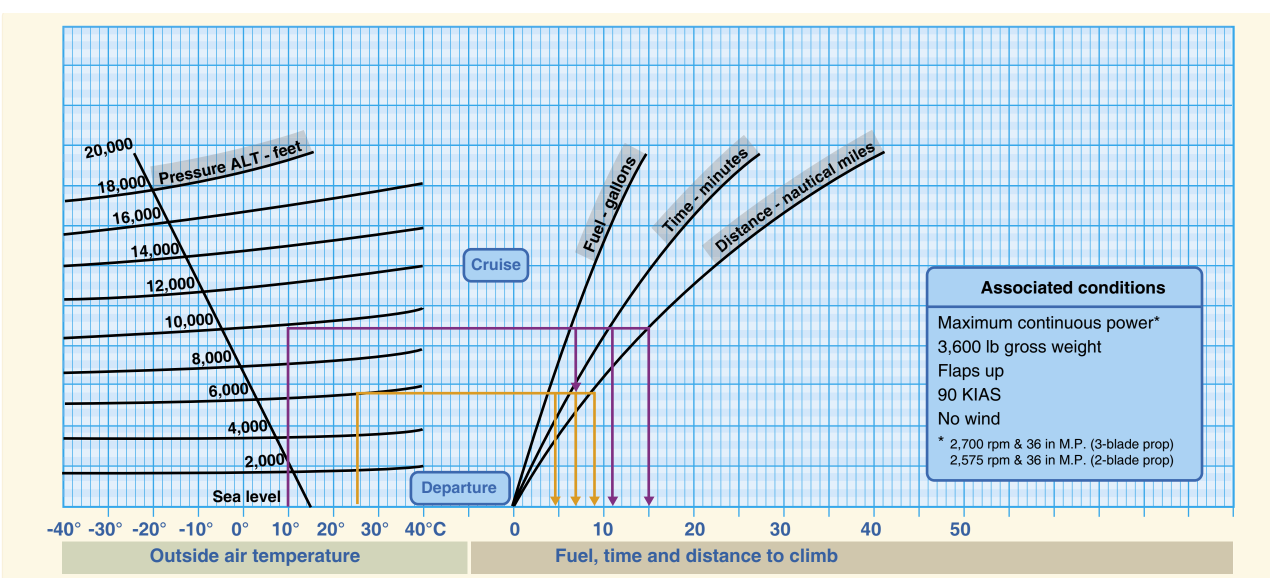


Figure 10-24. *Fuel time distance climb chart.*

Sample Problem 4

Departing Airport Pressure Altitude.................6,000 feet

Departing Airport OAT..25 °C

Cruise Pressure Altitude.................................10,000 feet

Cruise OAT..10 °C

First, find the information for the departing airport. Find the OAT for the departing airport along the bottom, left-hand side of the graph. Follow the line from 25 °C straight up until it intersects the line corresponding to the pressure altitude of 6,000 feet. Continue this line straight across until it intersects all three lines for fuel, time, and distance. Draw a line straight down from the intersection of altitude and fuel, altitude and time, and a third line at altitude and distance. It should read three and one-half gallons of fuel, 6.5 minutes of time, and nine NM. Next, repeat the steps to find the information for the cruise altitude. It should read six and one-half gallons of fuel, 11.5 minutes of time, and 15 NM. Take each set of numbers for fuel, time, and distance and subtract them from one another (6.5 – 3.5 = 3 gallons of fuel). It will take three gallons of fuel and 5 minutes of time to climb to 10,000 feet. During that climb, the distance covered is six NM. Remember, according to the notes at the top of the chart, these numbers do not take into account wind, and it is assumed maximum continuous power is being used.

The next example is a fuel, time, and distance-to-climb table. For this table, use the same basic criteria as for the previous chart. However, it is necessary to figure the information in a different manner. Refer to *Figure 10-25* to work the following sample problem.

Sample Problem 5

Departing Airport Pressure Altitude.................Sea level

Departing Airport OAT..22 °C

Cruise Pressure Altitude..................................8,000 feet

Takeoff Weight...3,400 pounds

To begin, find the given weight of 3,400 in the first column of the chart. Move across to the pressure altitude column to find the sea level altitude numbers. At sea level, the numbers read zero. Next, read the line that corresponds with the cruising altitude of 8,000 feet. Normally, a pilot would subtract these two sets of number from one another, but given the fact that the numbers read zero at sea level, it is known that the time to climb from sea level to 8,000 feet is 10 minutes. It is also known that 21 pounds of fuel will be used and 20 NM will be covered during the climb. However, the temperature is 22 °C, which is 7° above the standard temperature of 15 °C. The notes section of this chart indicate that the findings must be increased

NORMAL CLIMB
110 KIAS

Conditions:
Flaps up
Gear up
2,500 RPM
30" Hg
120 PPH fuel flow
Cowl flaps open
Standard temperature

Notes:
1. Add 16 pounds of fuel for engine start, taxi, and takeoff allowance.
2. Increase time, fuel, and distance by 10% for each 7°C above standard temperature.
3. Distances shown are based on zero wind.

Weight (pounds)	Press ALT (feet)	Rate of climb FPM	From sea level: Time (minutes)	Fuel used (pounds)	Distance (nautical miles)
4,000	S.L.	605	0	0	0
	4,000	570	7	14	13
	8,000	530	14	28	27
	12,000	485	22	44	43
	16,000	430	31	62	63
	20,000	365	41	82	87
3,700	S.L.	700	0	0	0
	4,000	665	6	12	11
	8,000	625	12	24	23
	12,000	580	19	37	37
	16,000	525	26	52	53
	20,000	460	34	68	72
3,400	S.L.	810	0	0	0
	4,000	775	5	10	9
	8,000	735	10	21	20
	12,000	690	16	32	31
	16,000	635	22	44	45
	20,000	565	29	57	61

Figure 10-25. *Fuel time distance climb.*

by ten percent for each 7° above standard. Multiply the findings by ten percent or .10 (10 x .10 = 1, 1 + 10 = 11 minutes). After accounting for the additional ten percent, the findings should read 11 minutes, 23.1 pounds of fuel, and 22 NM. Notice that the fuel is reported in pounds of fuel, not gallons. Aviation fuel weighs six pounds per gallon, so 23.1 pounds of fuel is equal to 3.85 gallons of fuel (23.1 ÷ 6 = 3.85).

The next example is a cruise and range performance chart. This type of table is designed to give TAS, fuel consumption, endurance in hours, and range in miles at specific cruise configurations. Use *Figure 10-26* to determine the cruise and range performance under the given conditions.

Sample Problem 6

Pressure Altitude...5,000 feet

RPM..2,400 rpm

Fuel Carrying Capacity.................38 gallons, no reserve

Find 5,000 feet pressure altitude in the first column on the left-hand side of the table. Next, find the correct rpm of 2,400 in the second column. Follow that line straight across and read the TAS of 116 mph, and a fuel burn rate of 6.9 gallons per hour. As per the example, the aircraft is equipped with a fuel carrying capacity of 38 gallons. Under this column,

Conditions	Gross weight—2,300 lb. Standard conditions Zero wind Lean mixture							
Notes	Maximum cruise is normally limited to 75% power.							
ALT	RPM	% BHP	TAS MPH	GAL/ Hour	38 gal (no reserve)		48 gal (no reserve)	
					Endr. hours	Range miles	Endr. hours	Range miles
2,500	2,700	86	134	9.7	3.9	525	4.9	660
	2,600	79	129	8.6	4.4	570	5.6	720
	2,500	72	123	7.8	4.9	600	6.2	760
	2,400	65	117	7.2	5.3	620	6.7	780
	2,300	58	111	6.7	5.7	630	7.2	795
	2,200	52	103	6.3	6.1	625	7.7	790
5,000	2,700	82	134	9.0	4.2	565	5.3	710
	2,600	75	128	8.1	4.7	600	5.9	760
	2,500	68	122	7.4	5.1	625	6.4	790
	2,400	61	116	6.9	5.5	635	6.9	805
	2,300	55	108	6.5	5.9	635	7.4	805
	2,200	49	100	6.0	6.3	630	7.9	795
7,500	2,700	78	133	8.4	4.5	600	5.7	755
	2,600	71	127	7.7	4.9	625	6.2	790
	2,500	64	121	7.1	5.3	645	6.7	810
	2,400	58	113	6.7	5.7	645	7.2	820
	2,300	52	105	6.2	6.1	640	7.7	810
10,000	2,650	70	129	7.6	5.0	640	6.3	810
	2,600	67	125	7.3	5.2	650	6.5	820
	2,500	61	118	6.9	5.5	655	7.0	830
	2,400	55	110	6.4	5.9	650	7.5	825
	2,300	49	100	6.0	6.3	635	8.0	800

Figure 10-26. *Cruise and range performance.*

read that the endurance in hours is 5.5 hours and the range in miles is 635 miles.

Cruise power setting tables are useful when planning cross-country flights. The table gives the correct cruise power settings, as well as the fuel flow and airspeed performance numbers at that altitude and airspeed.

Sample Problem 7

Pressure Altitude at Cruise...............................6,000 feet

OAT...36 °F above standard

Refer to *Figure 10-27* for this sample problem. First, locate the pressure altitude of 6,000 feet on the far left side of the table. Follow that line across to the far right side of the table under the 20 °C (or 36 °F) column. At 6,000 feet, the rpm setting of 2,450 will maintain 65 percent continuous power at 21.0 "Hg with a fuel flow rate of 11.5 gallons per hour and airspeed of 161 knots.

Another type of cruise chart is a best power mixture range graph. This graph gives the best range based on power setting and altitude. Using *Figure 10-28,* find the range at 65 percent power with and without a reserve based on the provided conditions.

Sample Problem 8

OAT...Standard

Pressure Altitude...5,000 feet

First, move up the left side of the graph to 5,000 feet and standard temperature. Follow the line straight across the graph until it intersects the 65 percent line under both the reserve and no reserve categories. Draw a line straight down from both intersections to the bottom of the graph. At 65 percent power with a reserve, the range is approximately 522 miles. At 65 percent power with no reserve, the range should be 581 miles.

The last cruise chart referenced is a cruise performance graph. This graph is designed to tell the TAS performance of the airplane depending on the altitude, temperature, and power

CRUISE POWER SETTING
65% MAXIMUM CONTINUOUS POWER (OR FULL THROTTLE)
2,800 POUNDS

Press ALT	ISA -20° (-36 °F)								Standard day (ISA)								ISA +20° (+36 °F)							
	IOAT		Engine speed	Man. press	Fuel flow per engine		TAS		IOAT		Engine speed	Man. press	Fuel flow per engine		TAS		IOAT		Engine speed	Man. press	Fuel flow per engine		TAS	
	°F	°C	RPM	" HG	PSI	GPH	kts	MPH	°F	°C	RPM	" HG	PSI	GPH	kts	MPH	°F	°C	RPM	" HG	PSI	GPH	kts	MPH
S.L.	27	-3	2,450	20.7	6.6	11.5	147	169	63	17	2,450	21.2	6.6	11.5	150	173	99	37	2,450	21.8	6.6	11.5	153	176
2,000	19	-7	2,450	20.4	6.6	11.5	149	171	55	13	2,450	21.0	6.6	11.5	153	176	91	33	2,450	21.5	6.6	11.5	156	180
4,000	12	-11	2,450	20.1	6.6	11.5	152	175	48	9	2,450	20.7	6.6	11.5	156	180	84	29	2,450	21.3	6.6	11.5	159	183
6,000	5	-15	2,450	19.8	6.6	11.5	155	178	41	5	2,450	20.4	6.6	11.5	158	182	79	26	2,450	21.0	6.6	11.5	161	185
8,000	-2	-19	2,450	19.5	6.6	11.5	157	181	36	2	2,450	20.2	6.6	11.5	161	185	72	22	2,450	20.8	6.6	11.5	164	189
10,000	-8	-22	2,450	19.2	6.6	11.5	160	184	28	-2	2,450	19.9	6.6	11.5	163	188	64	18	2,450	20.3	6.5	11.4	166	191
12,000	-15	-26	2,450	18.8	6.4	11.3	162	186	21	-6	2,450	18.8	6.1	10.9	163	188	57	14	2,450	18.8	5.9	10.6	163	188
14,000	-22	-30	2,450	17.4	5.8	10.5	159	183	14	-10	2,450	17.4	5.6	10.1	160	184	50	10	2,450	17.4	5.4	9.8	160	184
16,000	-29	-34	2,450	16.1	5.3	9.7	156	180	7	-14	2,450	16.1	5.1	9.4	156	180	43	6	2,450	16.1	4.9	9.1	155	178

Notes
1. Full throttle manifold pressure settings are approximate.
2. Shaded area represents operation with full throttle.

Figure 10-27. *Cruise power setting.*

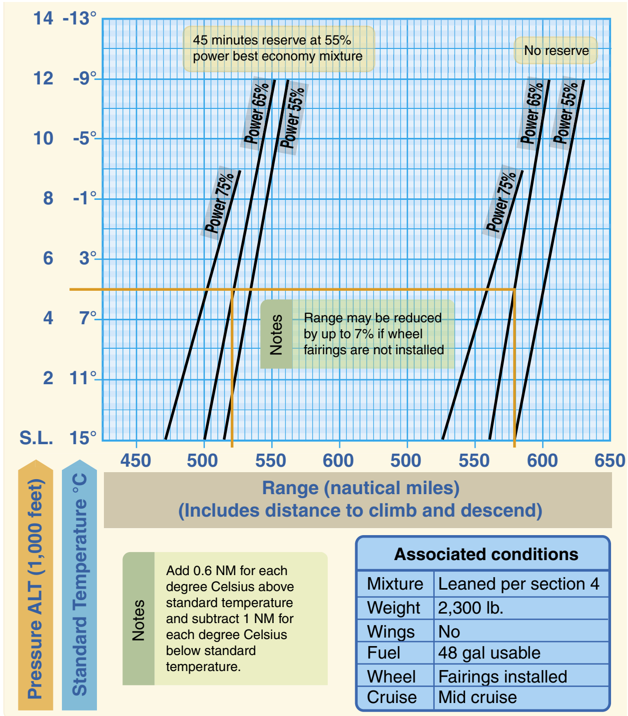


Figure 10-28. *Best power mixture range.*

setting. Using *Figure 10-29,* find the TAS performance based on the given information.

Sample Problem 9

OAT...16 °C

Pressure Altitude...6,000 feet

Power Setting...............................65 percent, best power

Wheel Fairings...Not installed

Begin by finding the correct OAT on the bottom, left side of the graph. Move up that line until it intersects the pressure altitude of 6,000 feet. Draw a line straight across to the 65 percent, best power line. This is the solid line, which represents best economy. Draw a line straight down from this intersection to the bottom of the graph. The TAS at 65 percent best power is 140 knots. However, it is necessary to subtract 8 knots from the speed since there are no wheel fairings. This note is listed under the title and conditions. The TAS will be 132 knots.

Crosswind and Headwind Component Chart

Every aircraft is tested according to Federal Aviation Administration (FAA) regulations prior to certification. The aircraft is tested by a pilot with average piloting skills in 90° crosswinds with a velocity up to 0.2 V_{SO} or two-tenths of the aircraft's stalling speed with power off, gear down, and flaps down. This means that if the stalling speed of the aircraft is 45 knots, it must be capable of landing in a 9-knot, 90° crosswind. The maximum demonstrated crosswind component is published in the AFM/POH. The crosswind and headwind component chart allows for figuring the headwind and crosswind component for any given wind direction and velocity.

Sample Problem 10

Runway...17

Wind..140° at 25 knots

Refer to *Figure 10-30* to solve this problem. First, determine how many degrees difference there is between the runway and the wind direction. It is known that runway 17 means a direction of 170°; from that subtract the wind direction of 140°. This gives a 30° angular difference, or wind angle. Next, locate the 30° mark and draw a line from there until it intersects

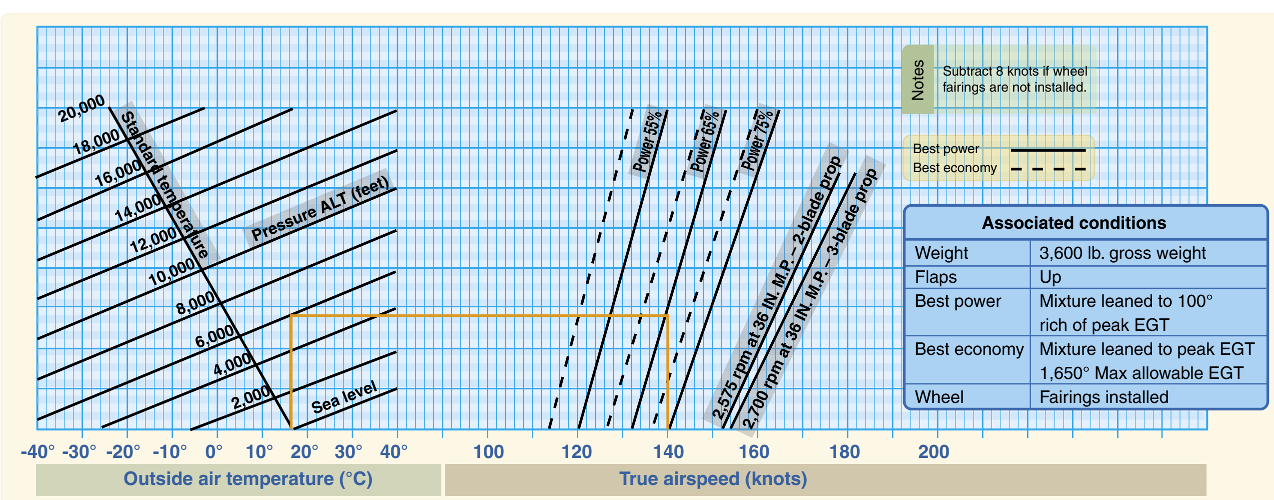


Figure 10-29. *Cruise performance graph.*

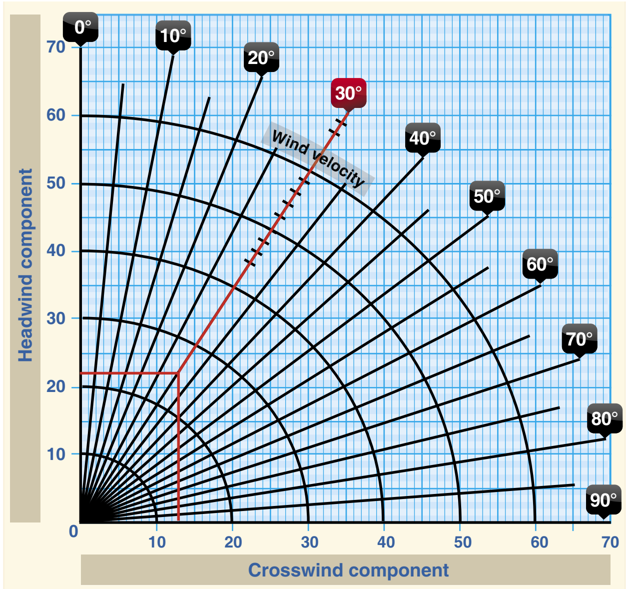


Figure 10-30. *Crosswind component chart.*

the correct wind velocity of 25 knots. From there, draw a line straight down and a line straight across. The headwind component is 22 knots and the crosswind component is 13 knots. This information is important when taking off and landing so that, first of all, the appropriate runway can be picked if more than one exists at a particular airport, but also so that the aircraft is not pushed beyond its tested limits.

Landing Charts

Landing performance is affected by variables similar to those affecting takeoff performance. It is necessary to compensate for differences in density altitude, weight of the airplane, and headwinds. Like takeoff performance charts, landing distance information is available as normal landing information, as well as landing distance over a 50 foot obstacle. As usual, read the associated conditions and notes in order to ascertain the basis of the chart information. Remember, when calculating landing distance that the landing weight will not be the same as the takeoff weight. The weight must be recalculated to compensate for the fuel that was used during the flight.

Sample Problem 11

Pressure Altitude...1,250 feet

Temperature..Standard

Refer to *Figure 10-31*. This example makes use of a landing distance table. Notice that the altitude of 1,250 feet is not on this table. It is, therefore, necessary to interpolate to find the correct landing distance. The pressure altitude of 1,250 is halfway between sea level and 2,500 feet. First, find the column for sea level and the column for 2,500 feet. Take the total distance of 1,075 for sea level and the total distance of 1,135 for 2,500 and add them together. Divide the total by two to obtain the distance for 1,250 feet. The distance is 1,105 feet total landing distance to clear a 50 foot obstacle. Repeat this process to obtain the ground roll distance for the pressure altitude. The ground roll should be 457.5 feet.

Sample Problem 12

OAT.. 57 °F

Pressure Altitude.. 4,000 feet

Landing Weight...2,400 pounds

Headwind.. 6 knots

Obstacle Height... 50 feet

Using the given conditions and *Figure 10-32,* determine the landing distance for the aircraft. This graph is an example of a combined landing distance graph and allows compensation for temperature, weight, headwinds, tailwinds, and varying obstacle height. Begin by finding the correct OAT on the scale on the left side of the chart. Move up in a straight line to the correct pressure altitude of 4,000 feet. From this intersection, move straight across to the first dark reference line. Follow the lines in the same diagonal fashion until the correct landing weight is reached. At 2,400 pounds, continue in a straight line across to the second dark reference line. Once again, draw a line in a diagonal manner to the correct wind component and then straight across to the third dark

Conditions	Flaps lowered to 40° Power off Hard surface runway Zero wind	LANDING DISTANCE							
Gross weight lb	Approach speed IAS, MPH	At sea level & 59 °F		At 2,500 ft & 59 °F		At 5,000 ft & 41 °F		At 7,500 ft & 32 °F	
		Ground roll	Total to clear 50 ft OBS	Ground roll	Total to clear 50 ft OBS	Ground roll	Total to clear 50 ft OBS	Ground roll	Total to clear 50 ft OBS
1,600	60	445	1,075	470	1,135	495	1,195	520	1,255

Note
1. Decrease the distances shown by 10% for each 4 knots of headwind.
2. Increase the distance by 10% for each 60 °F temperature increase above standard.
3. For operation on a dry, grass runway, increase distances (both “ground roll” and “total to clear 50 ft obstacle”) by 20% of the “total to clear 50 ft obstacle” figure.

Figure 10-31. *Landing distance table.*

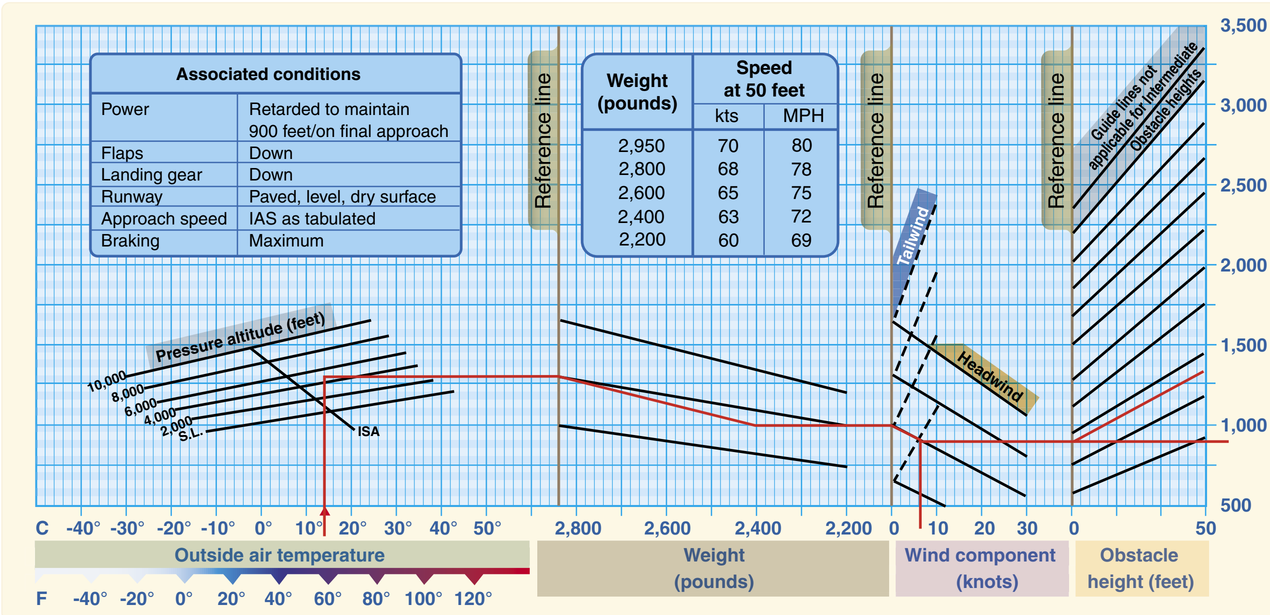


Figure 10-32. *Landing distance graph.*

reference line. From this point, draw a line in two separate directions: one straight across to figure the ground roll and one in a diagonal manner to the correct obstacle height. This should be 900 feet for the total ground roll and 1,300 feet for the total distance over a 50 foot obstacle.

Stall Speed Performance Charts

Stall speed performance charts are designed to give an understanding of the speed at which the aircraft will stall in a given configuration. This type of chart will typically take into account the angle of bank, the position of the gear and flaps, and the throttle position. Use *Figure 10-33* and the accompanying conditions to find the speed at which the airplane will stall.

Sample Problem 13

Power.. OFF

Flaps... Down

Gear.. Down

Angle of Bank.. 45°

First, locate the correct flap and gear configuration. The bottom half of the chart should be used since the gear and flaps are down. Next, choose the row corresponding to a power-off situation. Now, find the correct angle of bank column, which is 45°. The stall speed is 78 mph, and the stall speed in knots would be 68 knots.

Gross weight 2,750 lb			Angle of bank			
			Level	30°	45°	60°
			Gear and flaps up			
Power	On	MPH	62	67	74	88
		knots	54	58	64	76
	Off	MPH	75	81	89	106
		knots	65	70	77	92
			Gear and flaps down			
Power	On	MPH	54	58	64	76
		knots	47	50	56	66
	Off	MPH	66	71	78	93
		knots	57	62	68	81

Figure 10-33. *Stall speed table.*

Performance charts provide valuable information to the pilot. Take advantage of these charts. A pilot can predict the performance of the aircraft under most flying conditions, and this enables a better plan for every flight. The Code of Federal Regulations (CFR) requires that a pilot be familiar with all information available prior to any flight. Pilots should use the information to their advantage as it can only contribute to safety in flight.

Transport Category Airplane Performance

Transport category aircraft are certificated under Title 14 of the CFR (14 CFR) parts 25 and 29. The airworthiness certification standards of part 25 and 29 require proven levels of performance and guarantee safety margins for these aircraft, regardless of the specific operating regulations under which they are employed.

Major Differences in Transport Category Versus Non-Transport Category Performance Requirements

- Full temperature accountability—all of the performance charts for the transport category aircraft require that takeoff and climb performance be computed with the full effects of temperature considered.
- Climb performance expressed as percent gradient of climb—the transport category aircraft's climb performance is expressed as a percent gradient of climb rather than a figure calculated in fpm of climb. This percent gradient of climb is a much more practical expression of performance since it is the aircraft's angle of climb that is critical in an obstacle clearance situation.
- Change in lift-off technique—lift-off technique in transport category aircraft allows the reaching of V_2 (takeoff safety speed) after the aircraft is airborne. This is possible because of the excellent acceleration and reliability characteristics of the engines on these aircraft and due to the larger surplus of power.
- Performance requirements applicable to all segments of aviation—all aircraft certificated by the FAA in the transport category, whatever the size, must be operated in accordance with the same performance criteria. This applies to both commercial and non-commercial operations.

Performance Requirements

The performance requirements that the transport category aircraft must meet are:

Takeoff

- Takeoff speeds
- Takeoff runway required
- Takeoff climb required
- Obstacle clearance requirements

Landing

- Landing speeds
- Landing runway required
- Landing climb required

Takeoff Planning

Listed below are the speeds that affect the transport category aircraft's takeoff performance. The flight crew must be thoroughly familiar with each of these speeds and how they are used in takeoff planning.

- V_S—stalling speed or the minimum steady flight speed at which the aircraft is controllable.
- V_{MCG}—minimum control speed on the ground, with one engine inoperative, (critical engine on two-engine airplanes) takeoff power on other engine(s), using aerodynamic controls only for directional control (must be less than V_1).
- V_{MCA}—minimum control speed in the air, with one engine inoperative, (critical engine on two-engine aircraft) operating engine(s) at takeoff power, maximum of 5° bank into the good engine(s).
- V_1—critical engine failure speed or decision speed. Engine failure below this speed shall result in an aborted takeoff; above this speed the takeoff run should be continued.
- V_R—speed at which the rotation of the aircraft is initiated to takeoff attitude. The speed cannot be less than V_1 or less than 1.05 times V_{MC}. With an engine failure, it must also allow for the acceleration to V_2 at the 35-foot height at the end of the runway.
- V_{LOF}—lift-off speed. The speed at which the aircraft first becomes airborne.
- V_2—the takeoff safety speed which must be attained at the 35-foot height at the end of the required runway distance. This is essentially the best one-engine operative angle of climb speed for the aircraft and should be held until clearing obstacles after takeoff, or until at least 400 feet above the ground.
- V_{FS}—final segment climb speed, which is based upon one-engine inooerative climb, clean configuration, and mximum continuos power setting.

All of the V speeds should be considered during every takeoff. The V_1, V_R, V_2, and V_{FS} speeds should be visibly posted in the flightdeck for reference during the takeoff.

Takeoff speeds vary with aircraft weight. Before takeoff speeds can be computed, the pilot must first determine the maximum allowable takeoff weight. The three items that can limit takeoff weight are runway requirements, takeoff climb requirements, and obstacle clearance requirements.

Runway Requirements

The runway requirements for takeoff are affected by:

- Pressure altitude
- Temperature
- Headwind component
- Runway gradient or slope
- Aircraft weight

The runway required for takeoff must be based upon the possible loss of an engine at the most critical point, which is at V_1 (decision speed). By regulation, the aircraft's takeoff weight has to accommodate the longest of three distances:

1. Accelerate-go distance—the distance required to accelerate to V_1 with all engines at takeoff power, experience an engine failure at V_1 and continue the takeoff on the remaining engine(s). The runway required includes the distance required to climb to 35 feet by which time V_2 speed must be attained.
2. Accelerate-stop distance—the distance required to accelerate to V_1 with all engines at takeoff power, experience an engine failure at V_1, and abort the takeoff and bring the aircraft to a stop using braking action only (use of thrust reversing is not considered).
3. Takeoff distance—the distance required to complete an all-engines operative takeoff to the 35-foot height. It must be at least 15 percent less than the distance required for a one-engine inoperative engine takeoff. This distance is not normally a limiting factor as it is usually less than the one-engine inoperative takeoff distance.

These three required takeoff runway considerations are shown in *Figure 10-34*.

Balanced Field Length

In most cases, the pilot will be working with a performance chart for takeoff runway required, which will give "balanced field length" information. This means that the distance

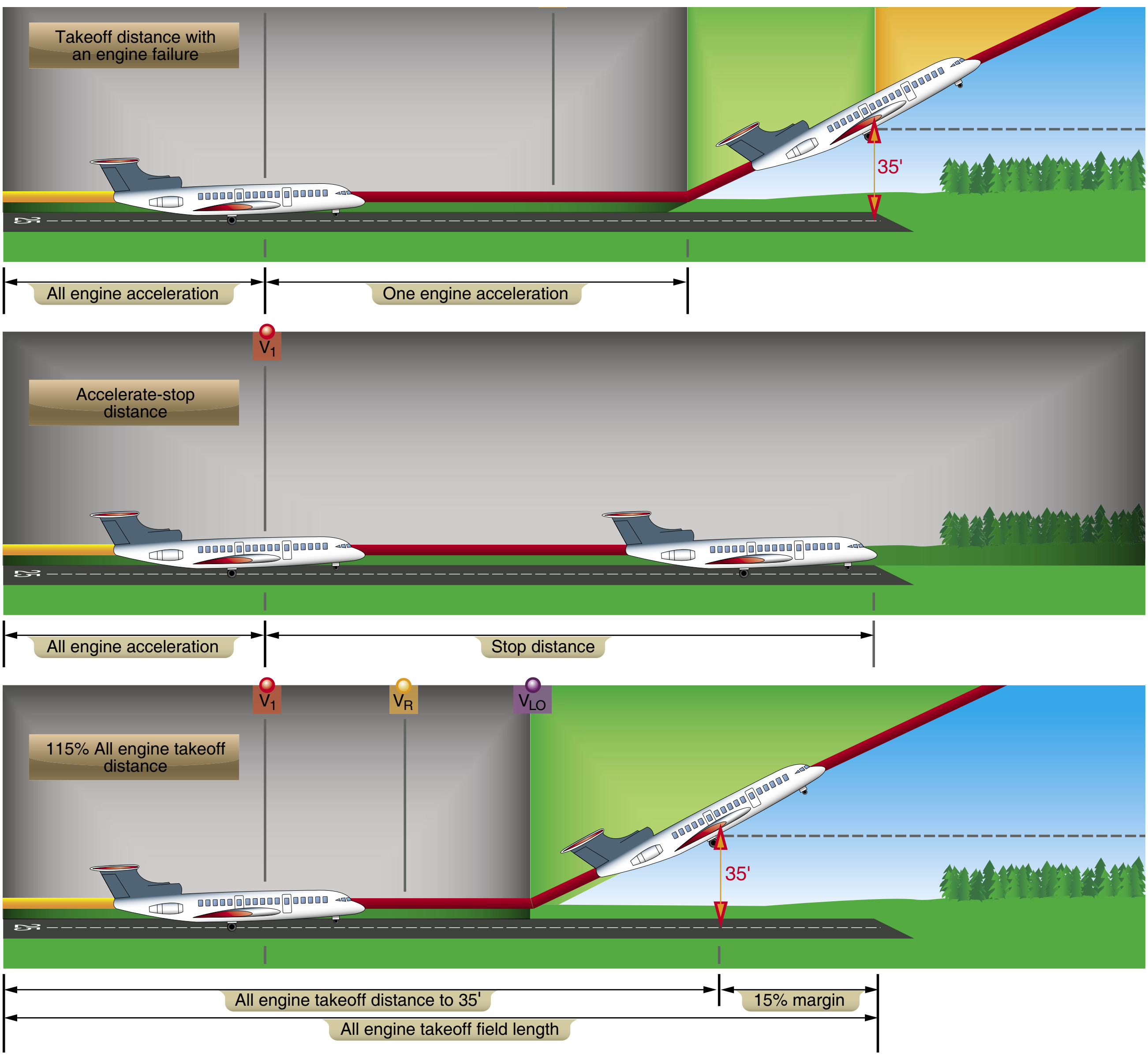


Figure 10-34. *Minimum required takeoff.*

shown for the takeoff will include both the accelerate-go and accelerate-stop distances. One effective means of presenting the normal takeoff data is shown in the tabulated chart in *Figure 10-35*.

The chart in *Figure 10-35* shows the runway distance required under normal conditions and is useful as a quick reference chart for the standard takeoff. The V speeds for the various weights and conditions are also shown.

For other than normal takeoff conditions, such as with engine anti-ice, anti-skid brakes inoperative, or extremes in temperature or runway slope, the pilot should consult the appropriate takeoff performance charts in the performance section of the AFM.

There are other occasions of very high weight and temperature where the runway requirement may be dictated by the maximum brake kinetic energy limits that affect

TAKEOFF RUNWAY REQUIREMENTS
Standard ISA conditions

Conditions:
Cabin pressurization On
Zero slope runway
No flaps—Anti-ice RAM air inlets Off
Anti-skid On
Distances—100 feet (V_1 – KIAS)

Notes:
Shaded area indicates conditions that do not meet second segment climb requirements.
Refer to F.M. for takeoff limitations.

Takeoff gross weight at brake release	Temp. °F	Temp. °C	Pressure altitude (feet): Sea level (V_1)	1,000 (V_1)	2,000 (V_1)	3,000 (V_1)	4,000 (V_1)	5,000 (V_1)	6,000 (V_1)	Headwind (knots)
19,612	30	-1.1	47 (121)	48 (121)	50 (120)	53 (121)	57 (122)	62 (123)	70 (123)	0
	50	10	48 (121)	51 (121)	55 (121)	60 (122)	63 (123)	69 (124)	77 (125)	
V_R = 126	70	21	53 (122)	56 (122)	60 (123)	65 (124)	70 (125)	77 (125)	85 (126)	
V_2 = 134	90	32	58 (123)	62 (124)	68 (124)	73 (125)	78 (126)	85 (127)	95 (129)	
	30	-1.1	43 (121)	43 (121)	45 (120)	48 (121)	52 (122)	56 (123)	64 (123)	20
	50	10	43 (121)	46 (121)	50 (122)	55 (122)	57 (123)	63 (124)	70 (125)	
	70	21	48 (122)	51 (122)	55 (123)	59 (124)	63 (125)	70 (125)	77 (126)	
	90	32	53 (123)	57 (124)	62 (124)	66 (125)	71 (126)	77 (127)	85 (129)	
19,000	30	-1.1	45 (118)	45 (118)	47 (117)	50 (118)	54 (119)	59 (120)	66 (120)	0
	50	10	46 (118)	48 (118)	51 (118)	56 (119)	59 (120)	65 (121)	73 (121)	
V_R = 124	70	21	50 (118)	53 (119)	57 (120)	66 (121)	66 (121)	72 (122)	80 (123)	
V_2 = 131	90	32	55 (120)	59 (121)	64 (121)	73 (122)	73 (123)	80 (124)	90 (124)	
	30	-1.1	40 (118)	41 (118)	43 (117)	45 (118)	49 (119)	54 (120)	60 (120)	20
	50	10	42 (118)	44 (118)	46 (118)	51 (119)	54 (120)	59 (121)	66 (121)	
	70	21	45 (118)	48 (119)	52 (120)	56 (121)	60 (121)	65 (122)	72 (123)	
	90	32	50 (120)	54 (121)	58 (121)	63 (122)	66 (123)	73 (124)	81 (124)	
18,000	30	-1.1	40 (114)	41 (114)	42 (113)	45 (113)	49 (114)	53 (115)	60 (115)	0
	50	10	41 (115)	43 (114)	46 (114)	50 (115)	53 (115)	59 (116)	66 (117)	
V_R = 119	70	21	45 (114)	48 (115)	51 (115)	56 (116)	59 (116)	65 (116)	72 (117)	
V_2 = 127	90	32	50 (115)	53 (116)	58 (116)	62 (117)	66 (118)	73 (118)	80 (119)	
	30	-1.1	36 (114)	37 (114)	38 (113)	41 (113)	45 (114)	48 (115)	54 (115)	20
	50	10	37 (115)	39 (114)	42 (114)	46 (115)	48 (115)	54 (116)	60 (117)	
	70	21	41 (114)	44 (115)	46 (115)	51 (116)	56 (116)	59 (116)	65 (117)	
	90	32	46 (115)	48 (116)	53 (116)	56 (117)	60 (118)	66 (118)	73 (119)	
17,000	30	-1.1	36 (108)	37 (108)	38 (107)	40 (108)	44 (109)	48 (110)	53 (111)	0
	50	10	37 (110)	39 (108)	41 (109)	45 (110)	48 (110)	53 (111)	59 (112)	
V_R = 115	70	21	40 (108)	43 (110)	46 (111)	50 (111)	53 (112)	58 (111)	65 (113)	
V_2 = 124	90	32	45 (111)	46 (112)	52 (112)	56 (113)	59 (114)	65 (114)	72 (114)	
	30	-1.1	32 (108)	33 (108)	34 (107)	36 (108)	40 (109)	44 (110)	48 (111)	20
	50	10	34 (110)	35 (108)	37 (109)	41 (110)	44 (110)	48 (111)	54 (112)	
	70	21	36 (108)	39 (110)	42 (111)	45 (111)	48 (112)	53 (111)	59 (113)	
	90	32	41 (111)	44 (112)	47 (112)	51 (113)	54 (114)	59 (114)	65 (114)	
16,000	30	-1.1	32 (104)	33 (103)	34 (103)	36 (103)	39 (105)	43 (106)	48 (106)	0
	50	10	34 (105)	35 (103)	37 (104)	41 (105)	43 (106)	47 (107)	53 (107)	
V_R = 111	70	21	36 (104)	38 (105)	41 (105)	45 (106)	48 (107)	52 (107)	58 (108)	
V_2 = 120	90	32	41 (106)	43 (107)	46 (107)	50 (108)	53 (108)	58 (109)	64 (110)	
	30	-1.1	29 (104)	30 (103)	31 (103)	32 (103)	35 (105)	39 (106)	44 (106)	20
	50	10	31 (105)	32 (103)	33 (104)	37 (105)	39 (106)	43 (107)	48 (107)	
	70	21	32 (104)	34 (105)	37 (105)	41 (106)	44 (107)	47 (107)	53 (108)	
	90	32	37 (106)	39 (107)	42 (107)	45 (108)	48 (108)	53 (109)	58 (110)	
15,000	30	-1.1	28 (98)	30 (98)	30 (98)	32 (98)	35 (99)	38 (101)	42 (101)	0
	50	10	30 (100)	31 (98)	33 (99)	36 (100)	38 (101)	42 (102)	46 (102)	
V_R = 106	70	21	32 (99)	34 (100)	37 (101)	40 (102)	42 (102)	46 (102)	51 (103)	
V_2 = 116	90	32	36 (101)	38 (102)	41 (102)	44 (103)	47 (104)	51 (104)	56 (105)	
	30	-1.1	25 (98)	27 (98)	27 (98)	29 (98)	32 (99)	34 (101)	38 (101)	20
	50	10	27 (100)	29 (98)	30 (99)	32 (100)	34 (101)	38 (102)	42 (102)	
	70	21	29 (99)	31 (100)	33 (101)	36 (102)	38 (102)	42 (102)	46 (103)	
	90	32	32 (101)	34 (102)	37 (102)	40 (103)	43 (104)	46 (104)	51 (105)	

Figure 10-35. *Normal takeoff runway required.*

the aircraft's ability to stop. Under these conditions, the accelerate-stop distance may be greater than the accelerate-go. The procedure to bring performance back to a balanced field takeoff condition is to limit the V_1 speed so that it does not exceed the maximum brake kinetic energy speed (sometimes called VBE). This procedure also results in a reduction in allowable takeoff weight.

Climb Requirements

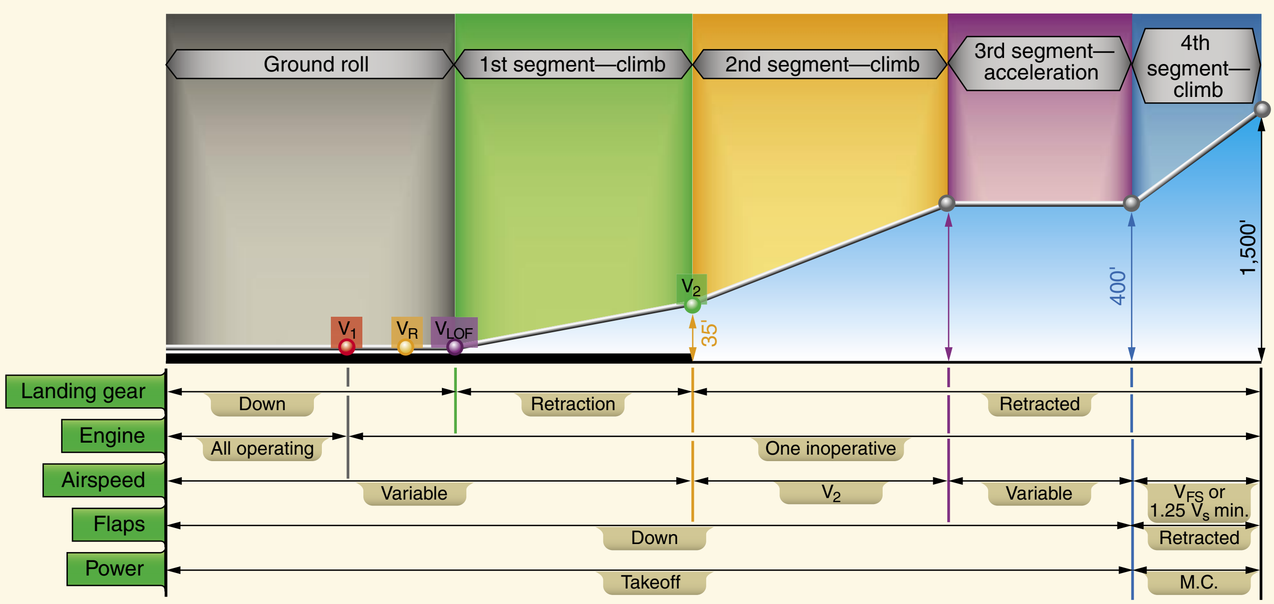
After the aircraft has reached the 35 foot height with one engine inoperative, there is a requirement that it be able to climb at a specified climb gradient. This is known as the takeoff flightpath requirement. The aircraft's performance must be considered based upon a one-engine inoperative climb up to 1,500 feet above the ground. The takeoff flightpath profile with required gradients of climb for the various segments and configurations is shown in *Figure 10-36.*

NOTE: Climb gradient can best be described as being a specific gain of vertical height for a given distance covered horizontally. For instance, a 2.4 percent gradient means that 24 feet of altitude would be gained for each 1,000 feet of distance covered horizontally across the ground.

The following brief explanation of the one-engine inoperative climb profile may be helpful in understanding the chart in *Figure 10-36.*

First Segment

This segment is included in the takeoff runway required charts, and is measured from the point at which the aircraft becomes airborne until it reaches the 35-foot height at the end of the runway distance required. Speed initially is V_{LO} and must be V_2 at the 35 foot height.



	Items	1st T/O segment	2nd T/O segment	Transition (acceleration)	Final T/O segment
*	2 Engine	Positive	2.4%	Positive	1.2%
*	3 Engine	3.0%	2.7%	Positive	1.5%
*	4 Engine	5.0%	3.0%	Positive	1.7%
	Wing flaps	T.O.	T.O.	T.O.	Up
	Landing gear	Down	Up	Up	Up
	Engines	1 Out	1 Out	1 Out	1 Out
	Power	T.O.	T.O.	T.O.	M.C.
	Air speed	$V_{LOF} \rightarrow V_2$	V_2	$V_2 \rightarrow 1.25\ V_S(\text{Min})$	$1.25\ V_S(\text{Min})$

* Required Absolute Minimum Gradient of Flightpath

M.C. = Maximum continuous
V_1 = Critical-engine-failure speed
V_2 = Takeoff safety speed
V_S = Calibrated stalling speed, or minimum steady flight speed at which the aircraft is controllable
V_R = Speed at which aircraft can start safely raising nose wheel off surface (Rotational Speed)
V_{LOF} = Speed at point where airplane lifts off

Figure 10-36. *One engine inoperative takeoff.*

Second Segment

This is the most critical segment of the profile. The second segment is the climb from the 35 foot height to 400 feet above the ground. The climb is done at full takeoff power on the operating engine(s), at V_2 speed, and with the flaps in the takeoff configuration. The required climb gradient in this segment is 2.4 percent for two-engine aircraft, 2.7 percent for three-engine aircraft, and 3.0 percent for four-engine aircraft.

Third or Acceleration Segment

During this segment, the airplane is considered to be maintaining the 400 feet above the ground and accelerating from the V_2 speed to the V_{FS} speed before the climb profile is continued. The flaps are raised at the beginning of the acceleration segment and power is maintained at the takeoff setting as long as possible (5 minutes maximum).

Fourth or Final Segment

This segment is from the 400 to 1,500 foot AGL altitude with power set at maximum continuous. The required climb in this segment is a gradient of 1.2 percent for two-engine airplanes, 1.55 for three-engine airplanes, and 1.7 percent for four-engine airplanes.

Second Segment Climb Limitations

The second segment climb requirements, from 35 to 400 feet, are the most restrictive (or hardest to meet) of the climb segments. The pilot must determine that the second segment climb is met for each takeoff. In order to achieve this performance at the higher density altitude conditions, it may be necessary to limit the takeoff weight of the aircraft.

It must be realized that, regardless of the actual available length of the takeoff runway, takeoff weight must be adjusted so that the second segment climb requirements can be met. The aircraft may well be capable of lifting off with one engine inoperative, but it must then be able to climb and clear obstacles. Although second segment climb may not present much of a problem at the lower altitudes, at the higher altitude airports and higher temperatures, the second segment climb chart should be consulted to determine the effects on maximum takeoff weights before figuring takeoff runway distance required.

Air Carrier Obstacle Clearance Requirements

Regulations require that large transport category turbine powered aircraft certificated after September 30, 1958, be taken off at a weight that allows a net takeoff flightpath (one engine inoperative) that clears all obstacles either by a height of at least 35 feet vertically, or by at least 200 feet horizontally within the airport boundaries and by at least 300 feet horizontally after passing the boundaries. The takeoff flightpath is considered to begin 35 feet above the takeoff surface at the end of the takeoff distance, and extends to a point in the takeoff at which the aircraft is 1,500 feet above the takeoff surface, or at which the transition from the takeoff to the en route configuration is completed. The net takeoff flightpath is the actual takeoff flightpath reduced at each point by 0.8 percent for two engine aircraft, 0.9 percent for three-engine aircraft, and 1.0 percent for four-engine aircraft.

Air carrier pilots therefore are responsible not only for determining that there is enough runway available for an engine inoperative takeoff (balanced field length), and the ability to meet required climb gradients; but they must also assure that the aircraft will safely be able to clear any obstacles that may be in the takeoff flightpath. The net takeoff flightpath and obstacle clearance required are shown in *Figure 10-37*.

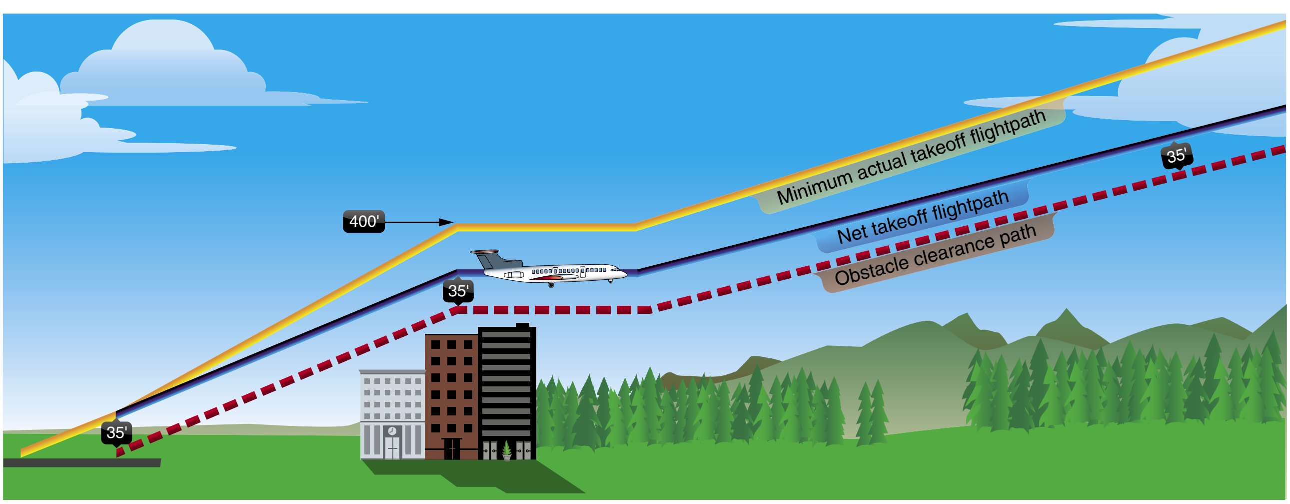


Figure 10-37. *Takeoff obstacle clearance.*

The usual method of computing net takeoff flightpath performance is to add up the total ground distances required for each of the climb segments and/or use obstacle clearance performance charts in the AFM. Although this obstacle clearance requirement is seldom a limitation at the normally used airports, it is quite often an important consideration under critical conditions such as high takeoff weight and/or high density altitude. Consider that at a 2.4 percent climb gradient (2.4 feet up for every 100 feet forward) a 1,500 foot altitude gain would take a horizontal distance of 10.4 NM to achieve.

Summary of Takeoff Requirements

In order to establish the allowable takeoff weight for a transport category aircraft, at any airfield, the following must be considered:

- Airfield pressure altitude
- Temperature
- Headwind component
- Runway length
- Runway gradient or slope
- Obstacles in the flightpath

Once the above details are known and applied to the appropriate performance charts, it is possible to determine the maximum allowable takeoff weight. This weight would be the lower of the maximum weights as allowed by:

- Balanced field length required
- Engine inoperative climb ability (second segment limited)
- Obstacle clearance requirement

In practice, restrictions to takeoff weight at low altitude airports are usually due to runway length limitations; engine inoperative climb limitations are most common at the higher altitude airports. All limitations to weight must be observed. Since the combined weight of fuel and payload in the aircraft may amount to nearly half the maximum takeoff weight, it is usually possible to reduce fuel weight to meet takeoff limitations. If this is done, however, flight planning must be recalculated in light of reduced fuel and range.

Landing Performance

As in the takeoff planning, certain speeds must be considered during landing. These speeds are shown below.

- V_{SO}—stalling speed or the minimum steady flight speed in the landing configuration.
- V_{REF}—1.3 times the stalling speed in the landing configuration. This is the required speed at the 50-foot height above the threshold end of the runway.
- Approach climb—the speed which gives the best climb performance in the approach confguration, with one engine inoperative, and with maximum takeoff power on the operating engine(s). The required gradient of climb in this configuration is 2.1 percent for two-engine aircraft, 2.4 percent for three-emgine aircraft, and 2.7 percent for four-engine aircraft.
- Landing climb—the speed giving the best performance in the full landing configuration with maximum takeoff power on all engines. The gradient of climb required in this configuration is 3.2 percent.

Planning the Landing

As in the takeoff, the landing speeds shown above should be precomputed and visible to both pilots prior to the landing. The V_{REF} speed, or threshold speed, is used as a reference speed throughout the traffic pattern or instrument approach as in the following example:

V_{REF} plus 30K	Downwind or procedure turn
V_{REF} plus 20K	Base leg or final course inbound to final fix
V_{REF} plus 10K	Final or final course inbound from fix (ILS final)
V_{REF}	Speed at the 50 foot height above the threshold

Landing Requirements

The maximum landing weight of an aircraft can be restricted by either the approach climb requirements or by the landing runway available.

Approach Climb Requirements

The approach climb is usually more limiting (or more difficult to meet) than the landing climb, primarily because it is based upon the ability to execute a missed approach with one engine inoperative. The required climb gradient can be affected by pressure altitude and temperature and, as in the second segment climb in the takeoff, aircraft weight must be limited as needed in order to comply with this climb requirement.

Landing Runway Required

The runway distance needed for landing can be affected by the following:

- Pressure altitude
- Temperature
- Headwind component
- Runway gradient or slope
- Aircraft weight

In computing the landing distance required, some manufacturers do not include all of the above items in their charts, since the regulations state that only pressure altitude, wind, and aircraft weight must be considered. Charts are provided for anti-skid on and anti-skid off conditions, but the use of reverse thrust is not used in computing required landing distances.

The landing distance, as required by the regulations, is that distance needed to land and come to a complete stop from a point 50 feet above the threshold end of the runway. It includes the air distance required to travel from the 50 foot height to touchdown (which can consume 1,000 feet of runway distance), plus the stopping distance, with no margin left over. This is all that is required for 14 CFR part 91 operators (non-air carrier), and all that is shown on some landing distance required charts.

For air carriers and other commercial operators subject to 14 CFR part 121, a different set of rules applies stating that the required landing distance from the 50 foot height cannot exceed 60 percent of the actual runway length available. In all cases, the minimum airspeed allowed at the 50 foot height must be no less than 1.3 times the aircraft's stalling speed in the landing configuration. This speed is commonly called the aircraft's V_{REF} speed and varies with landing weight. *Figure 10-38* is a diagram of these landing runway requirements.

Summary of Landing Requirements

In order to establish the allowable landing weight for a transport category aircraft, the following details must be considered:

- Airfield pressure altitude
- Temperature
- Headwind component
- Runway length
- Runway gradient or slope
- Runway surface condition

With these details, it is possible to establish the maximum allowable landing weight, which will be the lower of the weights as dictated by:

- Landing runway requirements
- Approach climb requirements

In practice, the approach climb limitations (ability to climb in approach configuration with one engine inoperative) are seldom encountered because the landing weights upon arrival at the destination airport are usually low. However, as in the second segment climb requirement for takeoff, this approach climb gradient must be met and landing weights must be restricted if necessary. The most likely conditions that would make the approach climb critical would be the landings at high weights and high pressure altitudes and temperatures, which might be encountered if a landing were required shortly after takeoff.

Landing field requirements can more frequently limit an aircraft's allowable landing weight than the approach climb limitations. Again, however, unless the runway is particularly short, this is seldom problematical as the average landing weight at the destination rarely approaches the maximum design landing weight due to fuel burn off.

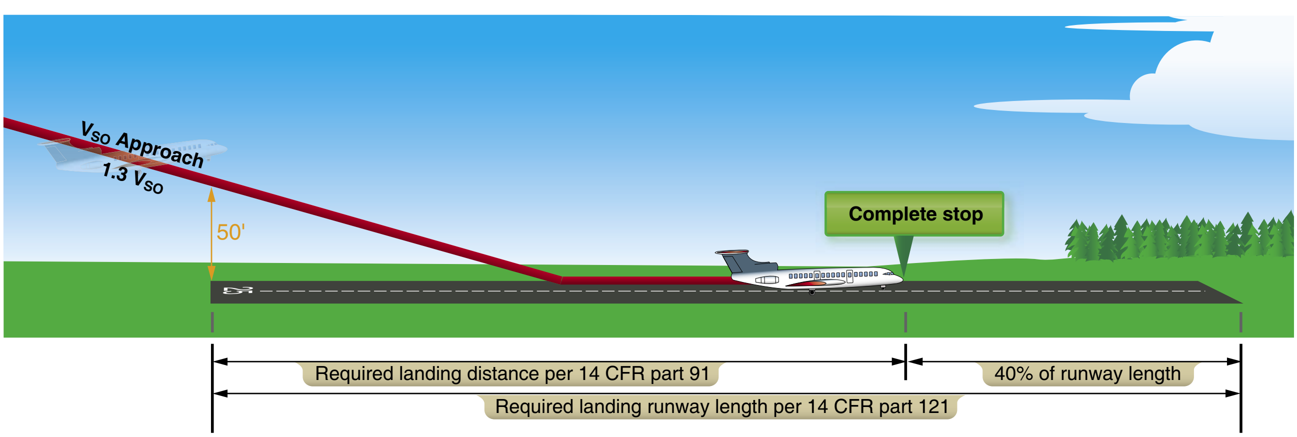


Figure 10-38. *Landing runway requirements.*

Chapter Summary

Performance characteristics and capabilities vary greatly among aircraft. Moreover, aircraft weight, atmospheric conditions, and external environmental factors can significantly affect aircraft performance. It is essential that a pilot become intimately familiar with the performance characteristics and capabilities of the aircraft being flown. The primary source of this information is the AFM/POH.

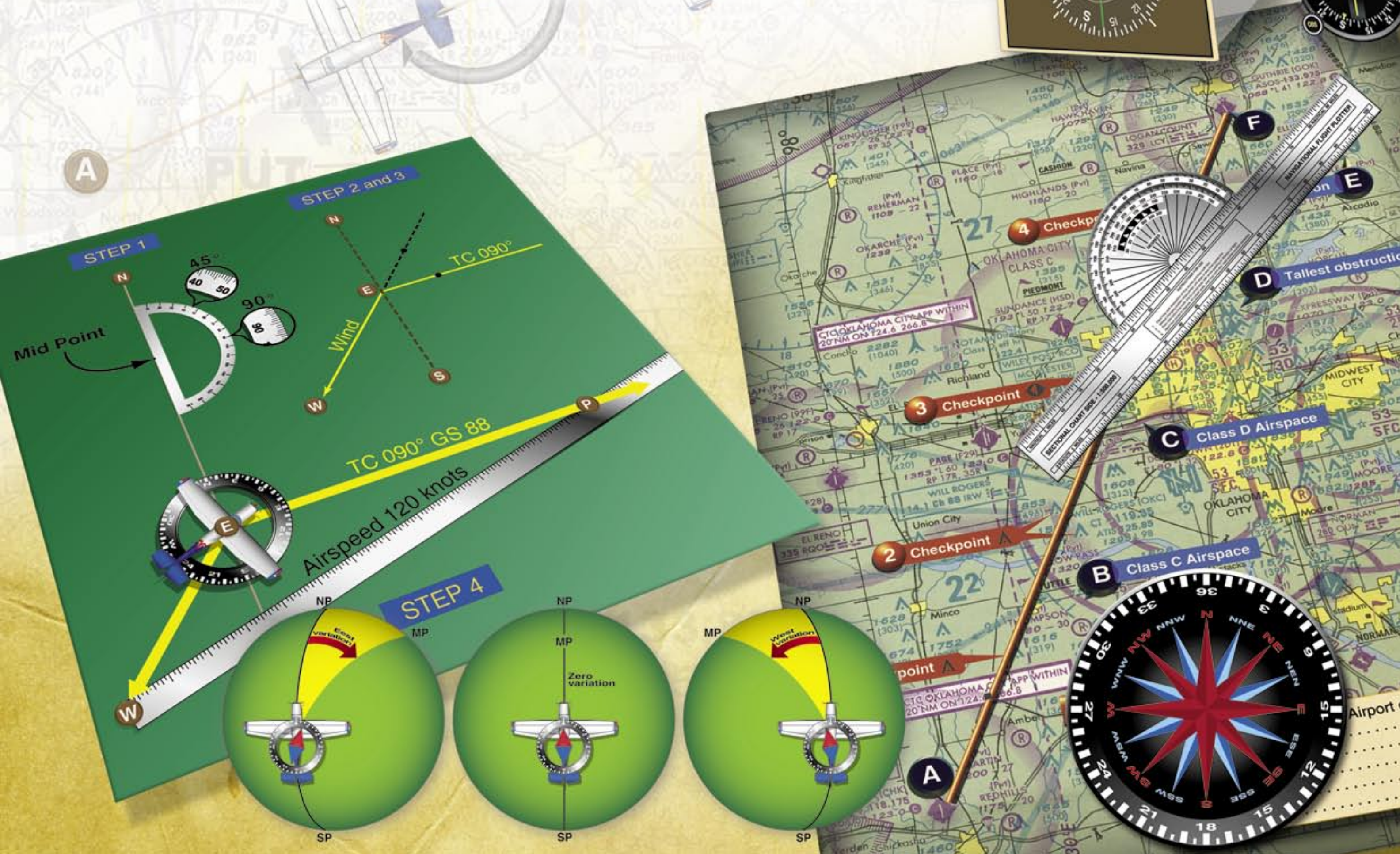
Chapter 15

Navigation

Introduction

This chapter provides an introduction to cross-country flying under visual flight rules (VFR). It contains practical information for planning and executing cross-country flights for the beginning pilot.

Air navigation is the process of piloting an aircraft from one geographic position to another while monitoring one's position as the flight progresses. It introduces the need for planning, which includes plotting the course on an aeronautical chart, selecting checkpoints, measuring distances, obtaining pertinent weather information, and computing flight time, headings, and fuel requirements. The methods used in this chapter include pilotage—navigating by reference to visible landmarks, dead reckoning—computations of direction and distance from a known position, and radio navigation—by use of radio aids.



Aeronautical Charts

An aeronautical chart is the road map for a pilot flying under VFR. The chart provides information which allows pilots to track their position and provides available information which enhances safety. The three aeronautical charts used by VFR pilots are:

- Sectional
- VFR Terminal Area
- World Aeronautical

A free catalog listing aeronautical charts and related publications including prices and instructions for ordering is available at the National Aeronautical Charting Group (NACG) web site: www.naco.faa.gov.

Sectional Charts

Sectional charts are the most common charts used by pilots today. The charts have a scale of 1:500,000 (1 inch = 6.86 nautical miles (NM) or approximately 8 statute miles (SM)) which allows for more detailed information to be included on the chart.

The charts provide an abundance of information, including airport data, navigational aids, airspace, and topography. *Figure 15-1* is an excerpt from the legend of a sectional chart. By referring to the chart legend, a pilot can interpret most of the information on the chart. A pilot should also check the chart for other legend information, which includes air traffic control (ATC) frequencies and information on airspace. These charts are revised semiannually except for some areas outside the conterminous United States where they are revised annually.

VFR Terminal Area Charts

VFR terminal area charts are helpful when flying in or near Class B airspace. They have a scale of 1:250,000 (1 inch = 3.43 NM or approximately 4 SM). These charts provide a more detailed display of topographical information and are revised semiannually, except for several Alaskan and Caribbean charts. *[Figure 15-2]*

World Aeronautical Charts

World aeronautical charts are designed to provide a standard series of aeronautical charts, covering land areas of the

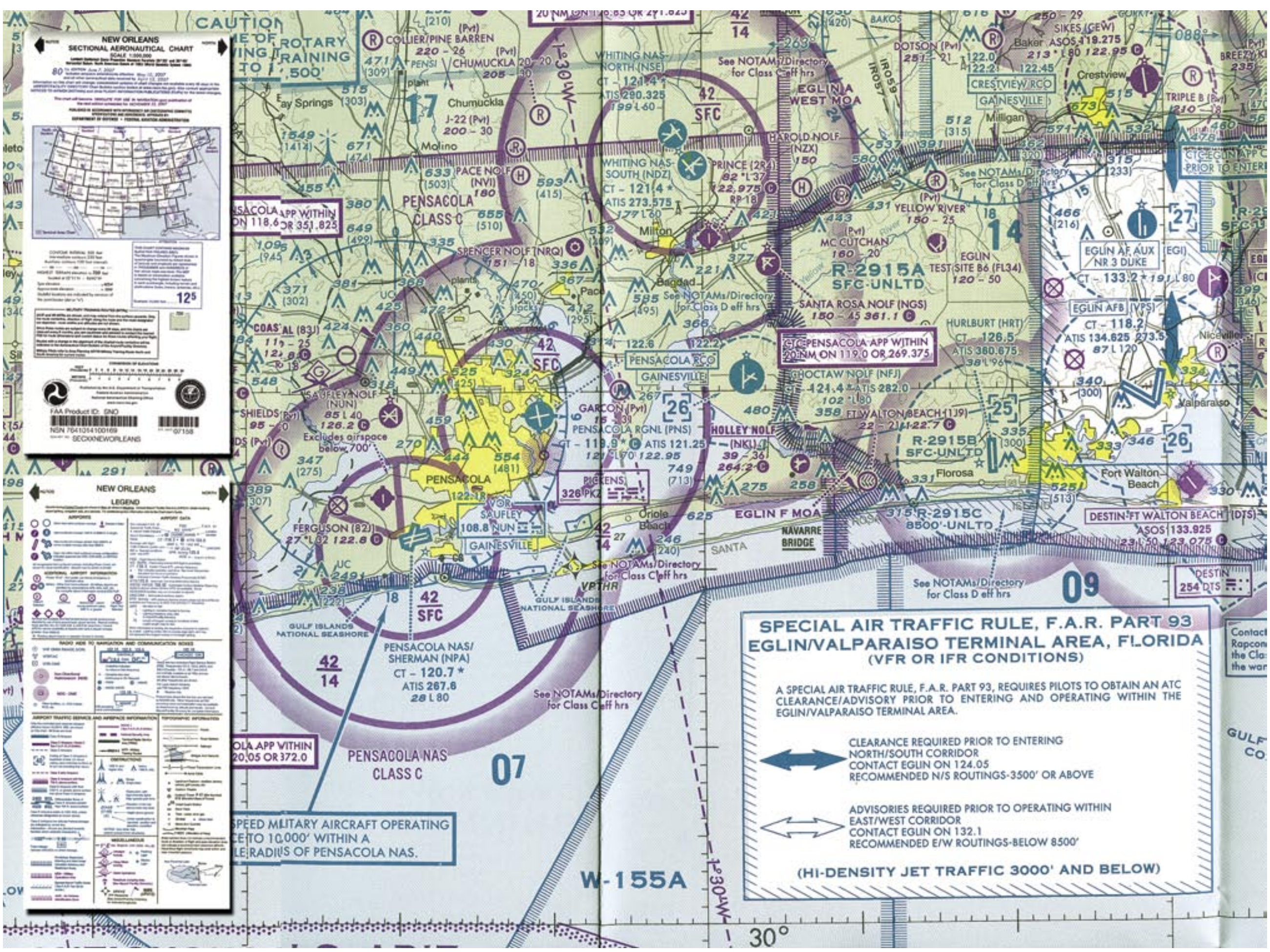


Figure 15-1. *Sectional chart and legend.*

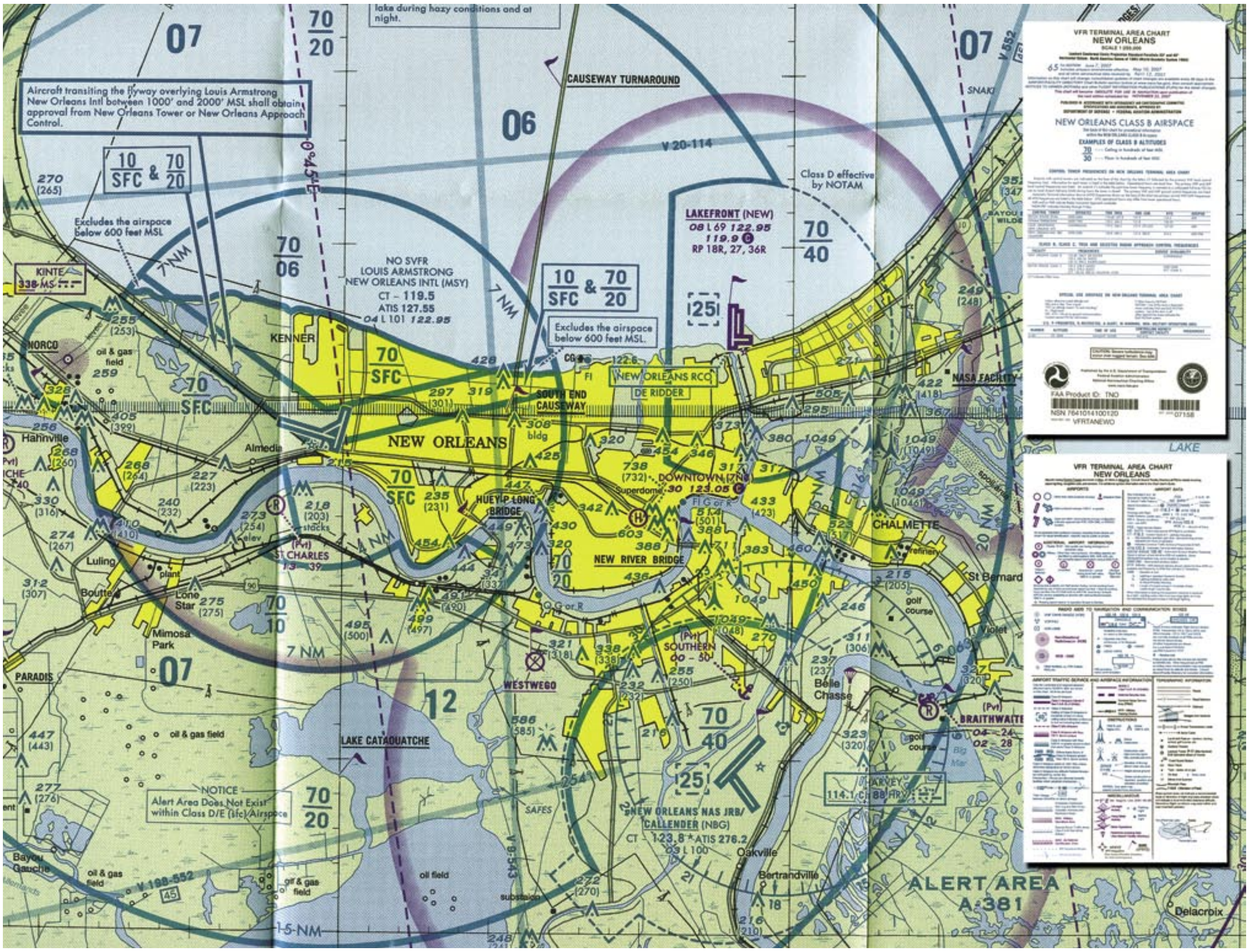


Figure 15-2. *VFR terminal area chart and legend.*

world, at a size and scale convenient for navigation by moderate speed aircraft. They are produced at a scale of 1:1,000,000 (1 inch = 13.7 NM or approximately 16 SM). These charts are similar to sectional charts and the symbols are the same except there is less detail due to the smaller scale. *[Figure 15-3]*

These charts are revised annually except several Alaskan charts and the Mexican/Caribbean charts which are revised every 2 years.

Lattitude and Longitude (Meridians and Parallels)

The equator is an imaginary circle equidistant from the poles of the Earth. Circles parallel to the equator (lines running east and west) are parallels of latitude. They are used to measure degrees of latitude north (N) or south (S) of the equator. The angular distance from the equator to the pole is one-fourth of a circle or 90°. The 48 conterminous states of the United States are located between 25° and 49° N latitude. The arrows in *Figure 15-4* labeled "Latitude" point to lines of latitude.

Meridians of longitude are drawn from the North Pole to the South Pole and are at right angles to the Equator. The "Prime Meridian" which passes through Greenwich, England, is used as the zero line from which measurements are made in degrees east (E) and west (W) to 180°. The 48 conterminous states of the United States are between 67° and 125° W longitude. The arrows in *Figure 15-4* labeled "Longitude" point to lines of longitude.

Any specific geographical point can be located by reference to its longitude and latitude. Washington, D.C., for example, is approximately 39° N latitude, 77° W longitude. Chicago is approximately 42° N latitude, 88° W longitude.

Time Zones

The meridians are also useful for designating time zones. A day is defined as the time required for the Earth to make one complete rotation of 360°. Since the day is divided into 24 hours, the Earth revolves at the rate of 15° an hour. Noon is the time when the sun is directly above a meridian; to the west of that meridian is morning, to the east is afternoon.

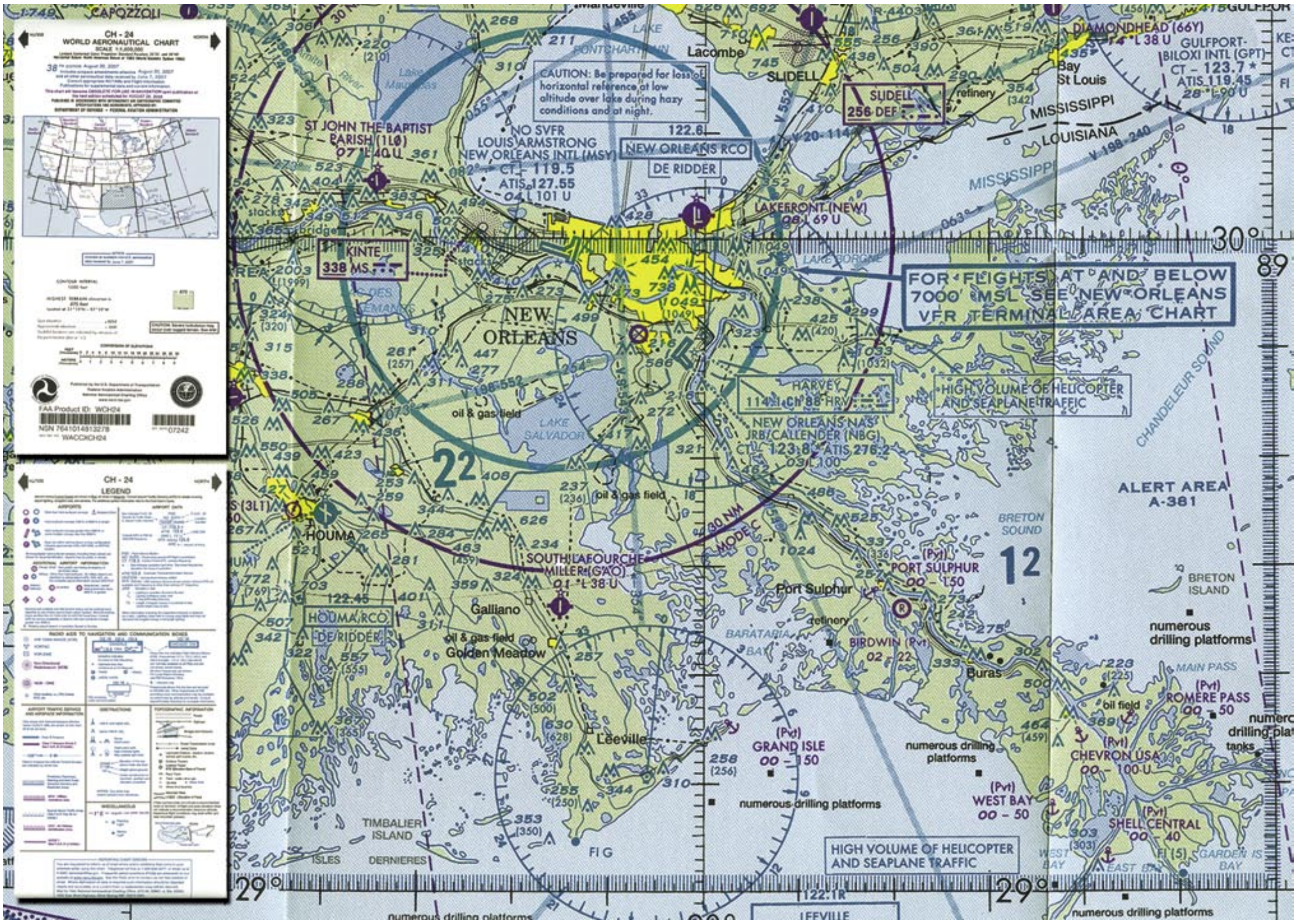


Figure 15-3. *World aeronautical chart.*

Figure 15-4. *Meridians and parallels—the basis of measuring time, distance, and direction.*

The standard practice is to establish a time zone for each 15° of longitude. This makes a difference of exactly 1 hour between each zone. In the United States, there are four time zones. The time zones are Eastern (75°), Central (90°), Mountain (105°), and Pacific (120°). The dividing lines are somewhat irregular because communities near the boundaries often find it more convenient to use time designations of neighboring communities or trade centers.

Figure 15-5 shows the time zones in the United States. When the sun is directly above the 90th meridian, it is noon Central Standard Time. At the same time, it is 1 p.m. Eastern Standard Time, 11 a.m. Mountain Standard Time, and 10 a.m. Pacific Standard Time. When Daylight Saving Time is in effect, generally between the second Sunday in March and the first Sunday in November, the sun is directly above the 75th meridian at noon, Central Daylight Time.

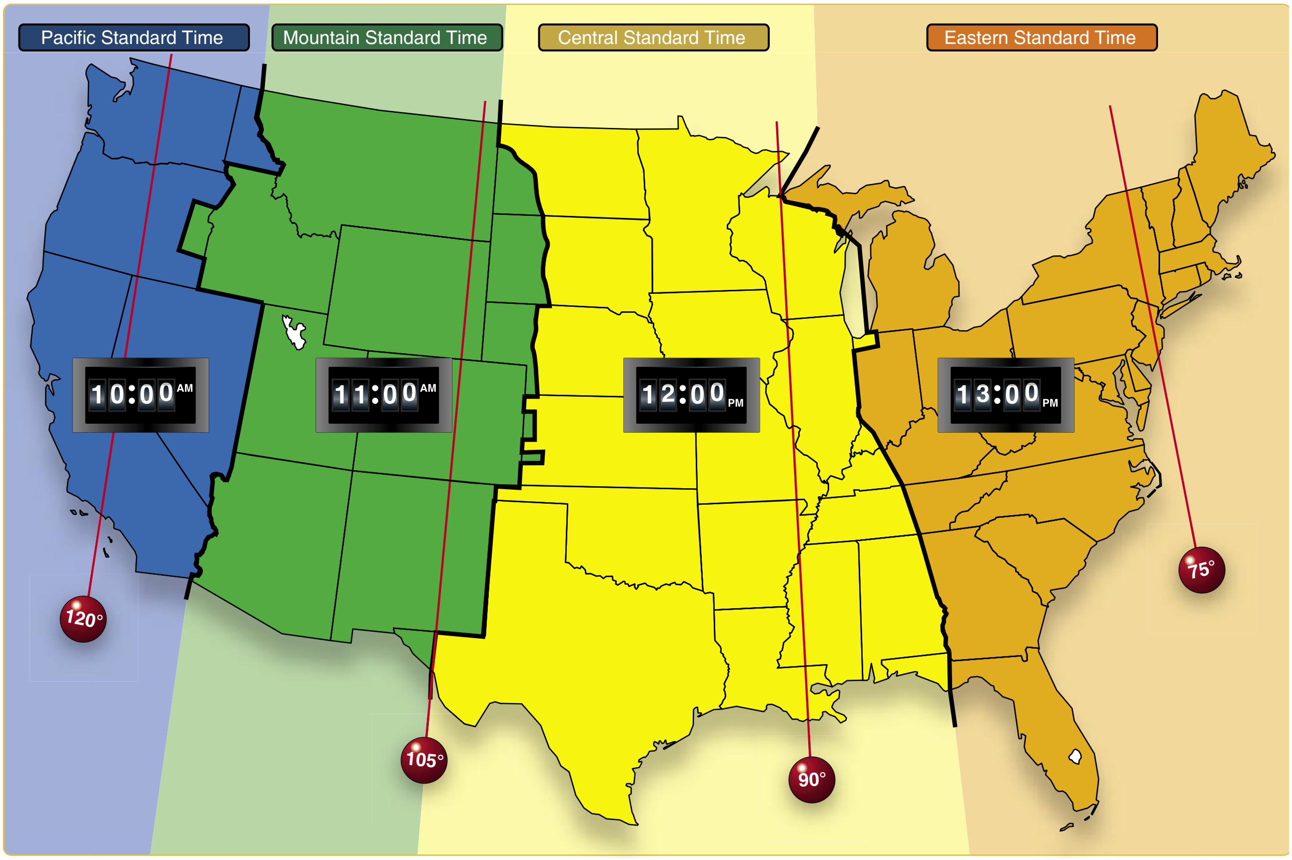


Figure 15-5. *Time zones.*

These time zone differences must be taken into account during long flights eastward—especially if the flight must be completed before dark. Remember, an hour is lost when flying eastward from one time zone to another, or perhaps even when flying from the western edge to the eastern edge of the same time zone. Determine the time of sunset at the destination by consulting the flight service stations (AFSS/FSS) or National Weather Service (NWS) and take this into account when planning an eastbound flight.

In most aviation operations, time is expressed in terms of the 24-hour clock. ATC instructions, weather reports and broadcasts, and estimated times of arrival are all based on this system. For example: 9 a.m. is expressed as 0900, 1 p.m. is 1300, and 10 p.m. is 2200.

Because a pilot may cross several time zones during a flight, a standard time system has been adopted. It is called Universal Coordinated Time (UTC) and is often referred to as Zulu time. UTC is the time at the 0° line of longitude which passes through Greenwich, England. All of the time zones around the world are based on this reference. To convert to this time, a pilot should do the following:

Eastern Standard Time..........Add 5 hours

Central Standard Time..........Add 6 hours

Mountain Standard Time...... Add 7 hours

Pacific Standard Time.......... Add 8 hours

For Daylight Saving Time, 1 hour should be subtracted from the calculated times.

Measurement of Direction

By using the meridians, direction from one point to another can be measured in degrees, in a clockwise direction from true north. To indicate a course to be followed in flight, draw a line on the chart from the point of departure to the destination and measure the angle which this line forms with a meridian. Direction is expressed in degrees, as shown by the compass rose in *Figure 15-6.*

Figure 15-6. *Compass rose.*

Because meridians converge toward the poles, course measurement should be taken at a meridian near the midpoint of the course rather than at the point of departure. The course measured on the chart is known as the true course (TC). This is the direction measured by reference to a meridian or true north. It is the direction of intended flight as measured in degrees clockwise from true north.

As shown in *Figure 15-7,* the direction from A to B would be a true course of 065°, whereas the return trip (called the reciprocal) would be a true course of 245°.

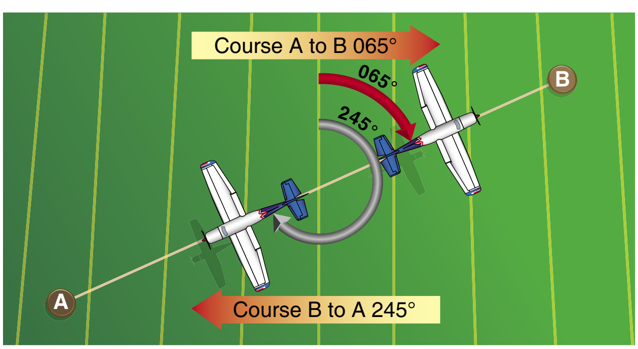


Figure 15-7. *Courses are determined by reference to meridians on aeronautical charts.*

The true heading (TH) is the direction in which the nose of the aircraft points during a flight when measured in degrees clockwise from true north. Usually, it is necessary to head the aircraft in a direction slightly different from the true course to offset the effect of wind. Consequently, numerical value of the true heading may not correspond with that of the true course. This is discussed more fully in subsequent sections in this chapter. For the purpose of this discussion, assume a no-wind condition exists under which heading and course would coincide. Thus, for a true course of 065°, the true heading would be 065°. To use the compass accurately, however, corrections must be made for magnetic variation and compass deviation.

Variation

Variation is the angle between true north and magnetic north. It is expressed as east variation or west variation depending upon whether magnetic north (MN) is to the east or west of true north (TN).

The north magnetic pole is located close to 71° N latitude, 96° W longitude and is about 1,300 miles from the geographic or true north pole, as indicated in *Figure 15-8.* If the Earth were uniformly magnetized, the compass needle would point toward the magnetic pole, in which case the variation between true north (as shown by the geographical meridians) and magnetic north (as shown by the magnetic meridians) could be measured at any intersection of the meridians.

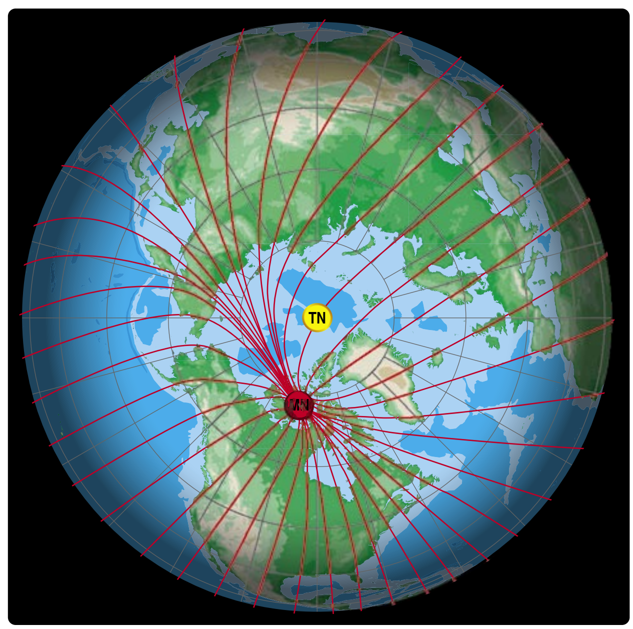


Figure 15-8. *Magnetic meridians are in red while the lines of longitude and latitude are in blue. From these lines of variation (magnetic meridians), one can determine the effect of local magnetic variations on a magnetic compass.*

Actually, the Earth is not uniformly magnetized. In the United States, the needle usually points in the general direction of the magnetic pole, but it may vary in certain geographical localities by many degrees. Consequently, the exact amount of variation at thousands of selected locations in the United States has been carefully determined. The amount and the direction of variation, which change slightly from time to time, are shown on most aeronautical charts as broken magenta lines, called isogonic lines, which connect points of equal magnetic variation. (The line connecting points at which there is no variation between true north and magnetic north is the agonic line.) An isogonic chart is shown in *Figure 15-9*. Minor bends and turns in the isogonic and agonic lines are caused by unusual geological conditions affecting magnetic forces in these areas.

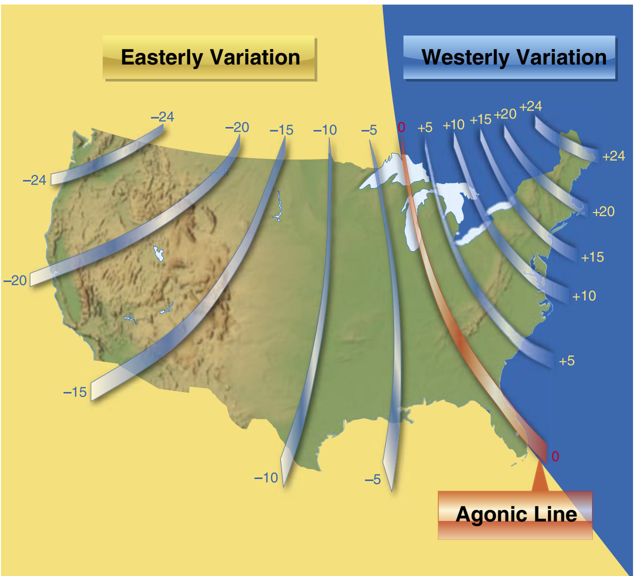


Figure 15-9. *Note the agonic line where magnetic variation is zero.*

On the west coast of the United States, the compass needle points to the east of true north; on the east coast, the compass needle points to the west of true north.

Zero degree variation exists on the agonic line, where magnetic north and true north coincide. This line runs roughly west of the Great Lakes, south through Wisconsin, Illinois, western Tennessee, and along the border of Mississippi and Alabama. *[Compare Figures 15-9* and *15-10.]*

Because courses are measured in reference to geographical meridians which point toward true north, and these courses are maintained by reference to the compass which points along a magnetic meridian in the general direction of magnetic north, the true direction must be converted into magnetic direction for the purpose of flight. This conversion is made by adding or subtracting the variation which is indicated by the nearest isogonic line on the chart.

For example, a line drawn between two points on a chart is called a true course as it is measured from true north. However, flying this course off the magnetic compass would not provide an accurate course between the two points due to three elements that must be considered. The first is magnetic variation, the second is compass deviation, and the third is wind correction. All three must be considered for accurate navigation.

Magnetic Variation

As mentioned in the paragraph discussing variation, the appropriate variation for the geographical location of the flight must be considered and added or subtracted as appropriate. If flying across an area where the variation changes, then the values must be applied along the route of flight appropriately. Once applied, this new course is called the magnetic course.

Magnetic Deviation

Because each aircraft has its own internal effect upon the onboard compass systems from its own localized magnetic influencers, the pilot must add or subtract these influencers based upon the direction he or she is flying. The application of

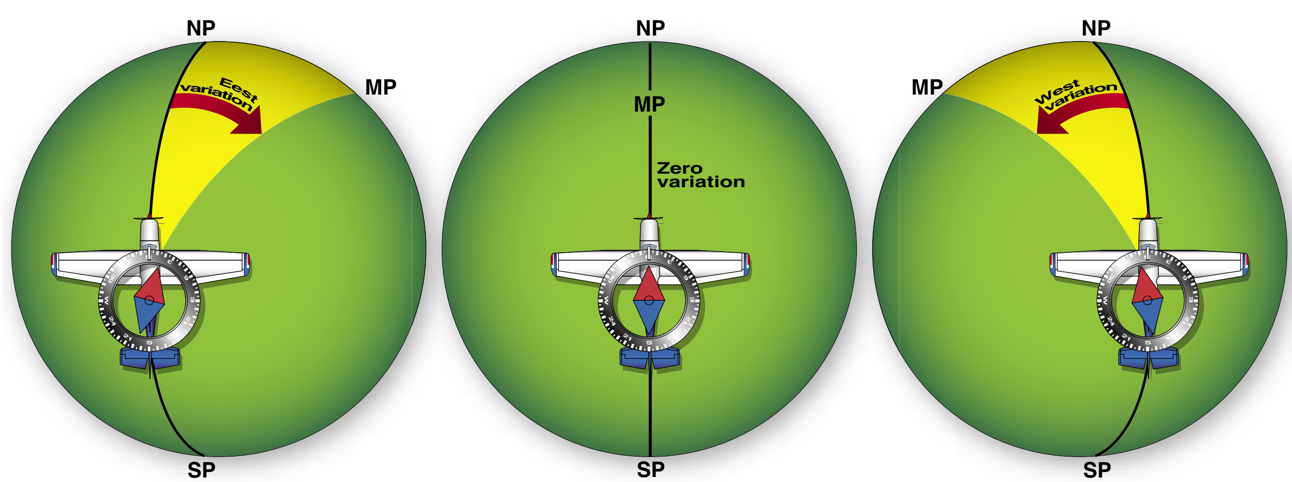


Figure 15-10. *Effect of variation on the compass.*

deviation (taken from a compass deviation card) compensates the magnetic course unique to that aircraft's compass system (as affected by localized magnetic influencers) and it now becomes the compass course. Therefore, the compass course when followed (in a no wind condition) takes the aircraft from point A to point B even though the aircraft heading may not match the original course line drawn on the chart.

If the variation is shown as "9° E," this means that magnetic north is 9° east of true north. If a true course of 360° is to be flown, 9° must be subtracted from 360°, which results in a magnetic heading of 351°. To fly east, a magnetic course of 081° (090° – 9°) would be flown. To fly south, the magnetic course would be 171° (180° – 9°). To fly west, it would be 261° (270° – 9°). To fly a true heading of 060°, a magnetic course of 051° (060° – 9°) would be flown.

Remember, if variation is west, add; if east, subtract. One method for remembering whether to add or subtract variation is the phrase "east is least (subtract) and west is best (add)."

Deviation

Determining the magnetic heading is an intermediate step necessary to obtain the correct compass heading for the flight. To determine compass heading, a correction for deviation must be made. Because of magnetic influences within an aircraft such as electrical circuits, radio, lights, tools, engine, and magnetized metal parts, the compass needle is frequently deflected from its normal reading. This deflection is deviation. The deviation is different for each aircraft, and it also may vary for different headings in the same aircraft. For instance, if magnetism in the engine attracts the north end of the compass, there would be no effect when the plane is on a heading of magnetic north. On easterly or westerly headings, however, the compass indications would be in error, as shown in *Figure 15-11*. Magnetic attraction can come from many other parts of the aircraft; the assumption of attraction in the engine is merely used for the purpose of illustration.

Some adjustment of the compass, referred to as compensation, can be made to reduce this error, but the remaining correction must be applied by the pilot.

Proper compensation of the compass is best performed by a competent technician. Since the magnetic forces within the aircraft change, because of landing shocks, vibration, mechanical work, or changes in equipment, the pilot should occasionally have the deviation of the compass checked. The procedure used to check the deviation (called "swinging the compass") is briefly outlined.

The aircraft is placed on a magnetic compass rose, the engine started, and electrical devices normally used (such as radio)

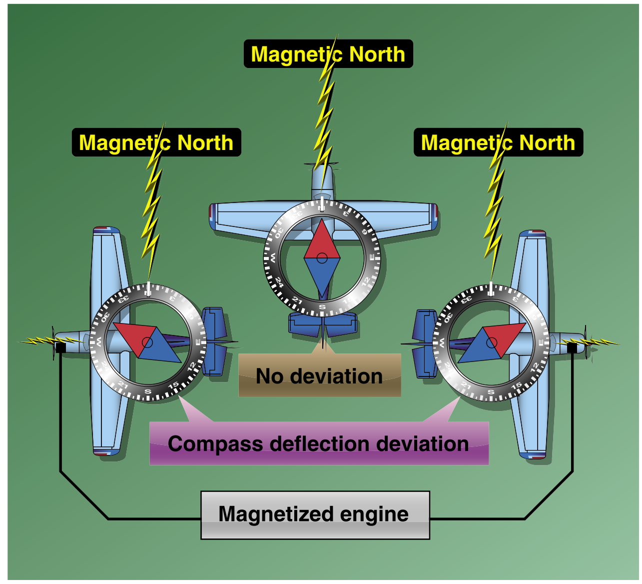


Figure 15-11. *Magnetized portions of the airplane cause the compass to deviate from its normal indications.*

are turned on. Tailwheel-type aircaft should be jacked up into flying position. The aircraft is aligned with magnetic north indicated on the compass rose and the reading shown on the compass is recorded on a deviation card. The aircraft is then aligned at 30° intervals and each reading is recorded. If the aircraft is to be flown at night, the lights are turned on and any significant changes in the readings are noted. If so, additional entries are made for use at night.

The accuracy of the compass can also be checked by comparing the compass reading with the known runway headings.

A deviation card, similar to *Figure 15-12,* is mounted near the compass, showing the addition or subtraction required to correct for deviation on various headings, usually at intervals of 30°. For intermediate readings, the pilot should be able to interpolate mentally with sufficient accuracy. For example, if the pilot needed the correction for 195° and noted the correction for 180° to be 0° and for 210° to be +2°, it could be assumed that the correction for 195° would be +1°. The magnetic heading, when corrected for deviation, is known as compass heading.

For (Magnetic)	N	30	60	E	120	150
Steer (Compass)	0	28	57	86	117	148
For (Magnetic	S	210	240	W	300	330
Steer (Compass)	180	212	243	274	303	332

Figure 15-12. *Compass deviation card.*

Effect of Wind

The preceding discussion explained how to measure a true course on the aeronautical chart and how to make corrections for variation and deviation, but one important factor has not been considered—wind. As discussed in the study of the atmosphere, wind is a mass of air moving over the surface of the Earth in a definite direction. When the wind is blowing from the north at 25 knots, it simply means that air is moving southward over the Earth's surface at the rate of 25 NM in 1 hour.

Under these conditions, any inert object free from contact with the Earth is carried 25 NM southward in 1 hour. This effect becomes apparent when such things as clouds, dust, and toy balloons are observed being blown along by the wind. Obviously, an aircraft flying within the moving mass of air is similarly affected. Even though the aircraft does not float freely with the wind, it moves through the air at the same time the air is moving over the ground, thus is affected by wind. Consequently, at the end of 1 hour of flight, the aircraft is in a position which results from a combination of the following two motions:

- Movement of the air mass in reference to the ground
- Forward movement of the aircraft through the air mass

Actually, these two motions are independent. It makes no difference whether the mass of air through which the aircraft is flying is moving or is stationary. A pilot flying in a 70-knot gale would be totally unaware of any wind (except for possible turbulence) unless the ground were observed. In reference to the ground, however, the aircraft would appear to fly faster with a tailwind or slower with a headwind, or to drift right or left with a crosswind.

As shown in *Figure 15-13,* an aircraft flying eastward at an airspeed of 120 knots in still air has a groundspeed (GS) exactly the same—120 knots. If the mass of air is moving eastward at 20 knots, the airspeed of the aircraft is not affected, but the progress of the aircraft over the ground is 120 plus 20, or a GS of 140 knots. On the other hand, if the mass of air is moving westward at 20 knots, the airspeed of the aircraft remains the same, but GS becomes 120 minus 20, or 100 knots.

Assuming no correction is made for wind effect, if an aircraft is heading eastward at 120 knots, and the air mass moving southward at 20 knots, the aircraft at the end of 1 hour is almost 120 miles east of its point of departure because of its progress through the air. It is 20 miles south because of the motion of the air. Under these circumstances, the airspeed remains 120 knots, but the GS is determined by combining

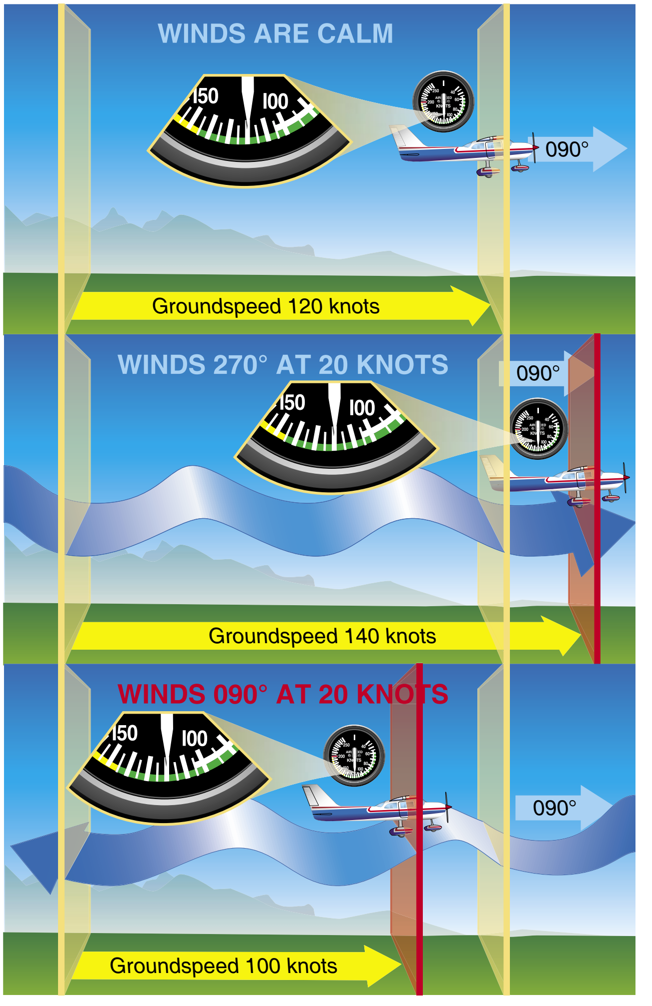


Figure 15-13. *Motion of the air affects the speed with which aircraft move over the Earth's surface. Airspeed, the rate at which an aircraft moves through the air, is not affected by air motion.*

the movement of the aircraft with that of the air mass. GS can be measured as the distance from the point of departure to the position of the aircraft at the end of 1 hour. The GS can be computed by the time required to fly between two points a known distance apart. It also can be determined before flight by constructing a wind triangle, which is explained later in this chapter. *[Figure 15-14]*

The direction in which the aircraft is pointing as it flies is heading. Its actual path over the ground, which is a combination of the motion of the aircraft and the motion of the air, is its track. The angle between the heading and the track is drift angle. If the aircraft heading coincides with the true course and the wind is blowing from the left, the track does not coincide with the true course. The wind causes the aircraft to drift to the right, so the track falls to the right of the desired course or true course. *[Figure 15-15]*

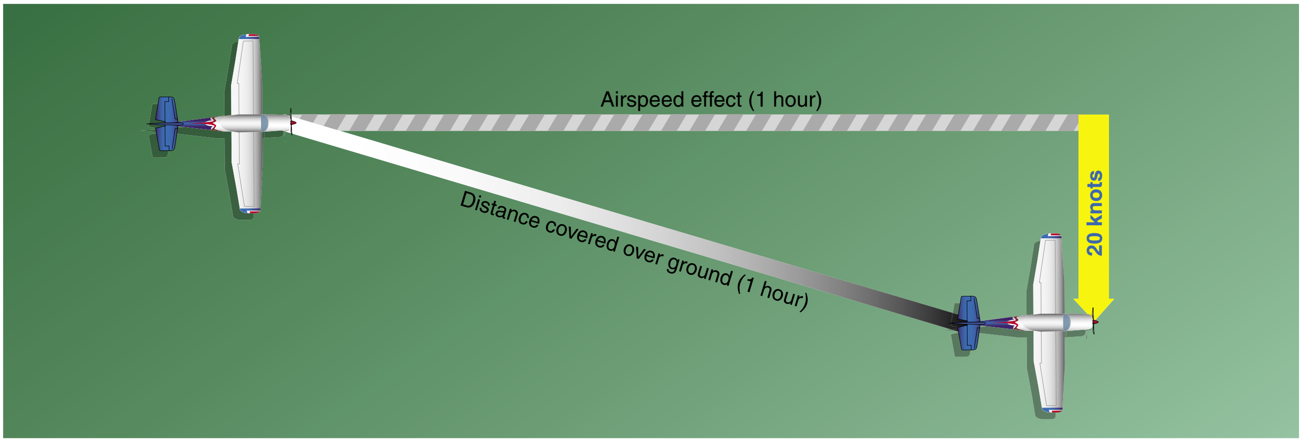


Figure 15-14. *Aircraft flightpath resulting from its airspeed and direction, and the wind speed and direction.*

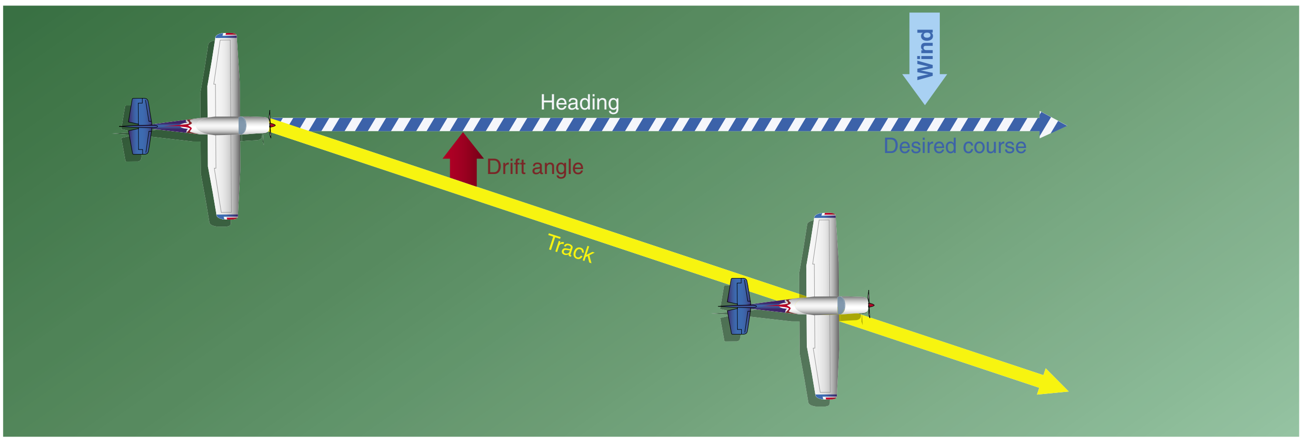


Figure 15-15. *Effects of wind drift on maintaining desired course.*

The following method is used by many pilots to determine compass heading: after the TC is measured, and wind correction applied resulting in a TH, the sequence TH ± variation (V) = magnetic heading (MH) ± deviation (D) = compass heading (CH) is followed to arrive at compass heading. *[Figure 15-16]*

By determining the amount of drift, the pilot can counteract the effect of the wind and make the track of the aircraft coincide with the desired course. If the mass of air is moving across the course from the left, the aircraft drifts to the right, and a correction must be made by heading the aircraft sufficiently to the left to offset this drift. To state in another way, if the wind is from the left, the correction is made by pointing the aircraft to the left a certain number of degrees, therefore correcting for wind drift. This is the wind correction angle (WCA) and is expressed in terms of degrees right or left of the true course. *[Figure 15-17]*

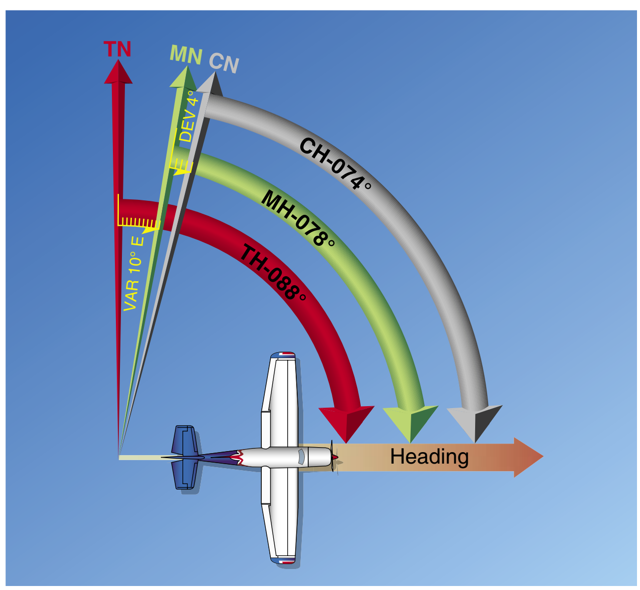


Figure 15-16. *Relationship between true, magnetic, and compass headings for a particular instance.*

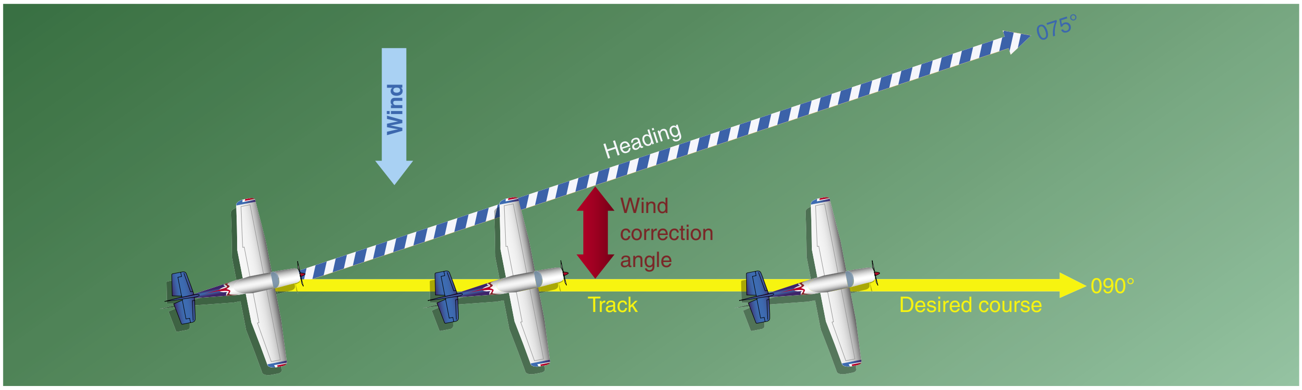


Figure 15-17. *Establishing a wind correction angle that will counteract wind drift and maintain the desired course.*

To summarize:

- Course—intended path of an aircraft over the ground or the direction of a line drawn on a chart representing the intended aircraft path, expressed as the angle measured from a specific reference datum clockwise from 0° through 360° to the line.
- Heading—direction in which the nose of the aircraft points during flight.
- Track—actual path made over the ground in flight. (If proper correction has been made for the wind, track and course are identical.)
- Drift angle—angle between heading and track.
- WCA—correction applied to the course to establish a heading so that track coincides with course.
- Airspeed—rate of the aircraft's progress through the air.
- GS—rate of the aircraft's inflight progress over the ground.

Basic Calculations

Before a cross-country flight, a pilot should make common calculations for time, speed, and distance, and the amount of fuel required.

Converting Minutes to Equivalent Hours

Frequently, it is necessary to convert minutes into equivalent hours when solving speed, time, and distance problems. To convert minutes to hours, divide by 60 (60 minutes = 1 hour). Thus, 30 minutes is 30/60 = 0.5 hour. To convert hours to minutes, multiply by 60. Thus, 0.75 hour equals 0.75 x 60 = 45 minutes.

Time T = D/GS

To find the time (T) in flight, divide the distance (D) by the GS. The time to fly 210 NM at a GS of 140 knots is 210 ÷ 140, or 1.5 hours. (The 0.5 hour multiplied by 60 minutes equals 30 minutes.) Answer: 1:30.

Distance D = GS X T

To find the distance flown in a given time, multiply GS by time. The distance flown in 1 hour 45 minutes at a GS of 120 knots is 120 x 1.75, or 210 NM.

GS GS = D/T

To find the GS, divide the distance flown by the time required. If an aircraft flies 270 NM in 3 hours, the GS is 270 ÷ 3 = 90 knots.

Converting Knots to Miles Per Hour

Another conversion is that of changing knots to miles per hour (mph). The aviation industry is using knots more frequently than mph, but it might be well to discuss the conversion for those that use mph when working with speed problems. The NWS reports both surface winds and winds aloft in knots. However, airspeed indicators in some aircraft are calibrated in mph (although many are now calibrated in both miles per hour and knots). Pilots, therefore, should learn to convert wind speeds that are reported in knots to mph.

A knot is 1 nautical mile per hour (NMPH). Because there are 6,076.1 feet in 1 NM and 5,280 feet in 1 SM, the conversion factor is 1.15. To convert knots to miles per hour, multiply speed in knots by 1.15. For example: a wind speed of 20 knots is equivalent to 23 mph.

Most flight computers or electronic calculators have a means of making this conversion. Another quick method of conversion is to use the scales of NM and SM at the bottom of aeronautical charts.

Fuel Consumption

Aircraft fuel consumption is computed in gallons per hour. Consequently, to determine the fuel required for a given flight, the time required for the flight must be known. Time in flight multiplied by rate of consumption gives the quantity of fuel required. For example, a flight of 400 NM at a GS of 100 knots requires 4 hours. If an aircraft consumes 5 gallons an hour, the total consumption is 4 x 5, or 20 gallons.

The rate of fuel consumption depends on many factors: condition of the engine, propeller/rotor pitch, propeller/rotor revolutions per minute (rpm), richness of the mixture, and particularly the percentage of horsepower used for flight at cruising speed. The pilot should know the approximate consumption rate from cruise performance charts, or from experience. In addition to the amount of fuel required for the flight, there should be sufficient fuel for reserve.

Flight Computers

Up to this point, only mathematical formulas have been used to determine such items as time, distance, speed, and fuel consumption. In reality, most pilots use a mechanical or electronic flight computer. These devices can compute numerous problems associated with flight planning and navigation. The mechanical or electronic computer has an instruction book that probably includes sample problems so the pilot can become familiar with its functions and operation. *[Figure 15-18]*

Plotter

Another aid in flight planning is a plotter, which is a protractor and ruler. The pilot can use this when determining true course and measuring distance. Most plotters have a ruler which measures in both NM and SM and has a scale for a sectional chart on one side and a world aeronautical chart on the other. *[Figure 15-18]*

Pilotage

Pilotage is navigation by reference to landmarks or checkpoints. It is a method of navigation that can be used on any course that has adequate checkpoints, but it is more commonly used in conjunction with dead reckoning and VFR radio navigation.

The checkpoints selected should be prominent features common to the area of the flight. Choose checkpoints that can be readily identified by other features such as roads, rivers, railroad tracks, lakes, and power lines. If possible, select features that make useful boundaries or brackets on each side of the course, such as highways, rivers, railroads, and mountains. A pilot can keep from drifting too far off course by referring to and not crossing the selected brackets. Never place complete reliance on any single checkpoint. Choose ample checkpoints. If one is missed, look for the next one while maintaining the heading. When determining position from checkpoints, remember that the scale of a sectional chart is 1 inch = 8 SM or 6.86 NM. For example, if a checkpoint selected was approximately one-half inch from the course line on the chart, it is 4 SM or 3.43 NM from the course on the ground. In the more congested areas, some of the smaller features are not included on the chart. If confused, hold the heading. If a turn is made away from the heading, it is easy to become lost.

Roads shown on the chart are primarily the well-traveled roads or those most apparent when viewed from the air. New roads and structures are constantly being built, and may not be shown on the chart until the next chart is issued. Some structures, such as antennas may be difficult to see. Sometimes TV antennas are grouped together in an area near a town. They are supported by almost invisible guy wires. Never approach an area of antennas less than 500 feet above the tallest one. Most of the taller structures are marked with strobe lights to make them more visible to a pilot. However, some weather conditions or background lighting may make them difficult to see. Aeronautical charts display the best information available at the time of printing, but a pilot should be cautious for new structures or changes that have occurred since the chart was printed.

Dead Reckoning

Dead reckoning is navigation solely by means of computations based on time, airspeed, distance, and direction. The products derived from these variables, when adjusted by wind speed and velocity, are heading and GS. The predicted heading takes the aircraft along the intended path and the GS establishes the time to arrive at each checkpoint and the destination. Except for flights over water, dead reckoning is usually used with pilotage for cross-country flying. The heading and GS as calculated is constantly monitored and corrected by pilotage as observed from checkpoints.

The Wind Triangle or Vector Analysis

If there is no wind, the aircraft's ground track is the same as the heading and the GS is the same as the true airspeed. This condition rarely exists. A wind triangle, the pilot's version of vector analysis, is the basis of dead reckoning.

The wind triangle is a graphic explanation of the effect of wind upon flight. GS, heading, and time for any flight can be determined by using the wind triangle. It can be applied to the simplest kind of cross-country flight as well as the most complicated instrument flight. The experienced pilot becomes so familiar with the fundamental principles that estimates can be made which are adequate for visual flight without actually drawing the diagrams. The beginning student, however, needs

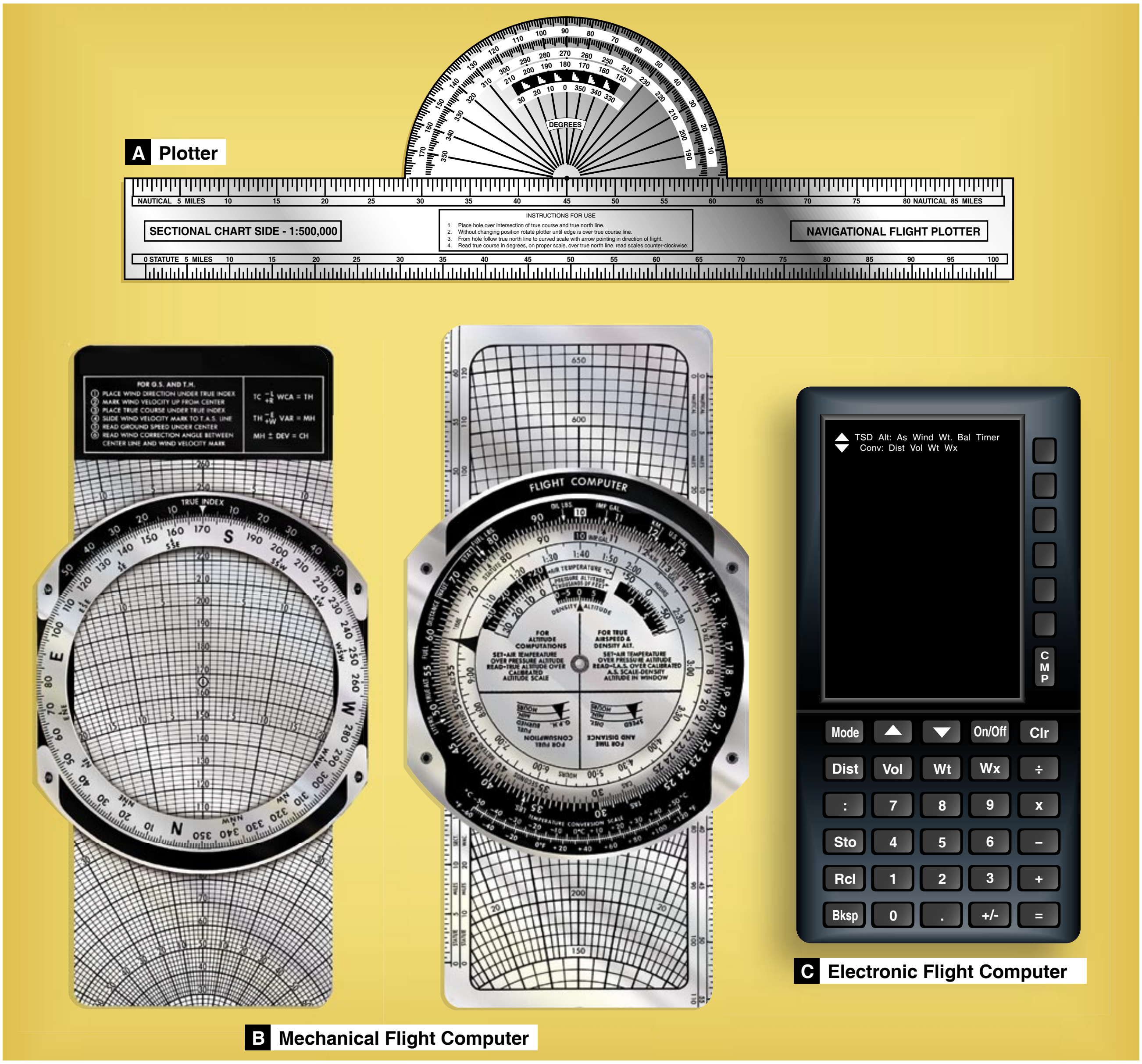


Figure 15-18. *A plotter (A), the computational and wind side of a mechanical flight computer (B), and an electronic flight computer (C).*

to develop skill in constructing these diagrams as an aid to the complete understanding of wind effect. Either consciously or unconsciously, every good pilot thinks of the flight in terms of wind triangle.

If flight is to be made on a course to the east, with a wind blowing from the northeast, the aircraft must be headed somewhat to the north of east to counteract drift. This can be represented by a diagram as shown in *Figure 15-19.* Each line represents direction and speed. The long blue and white hashed line shows the direction the aircraft is heading, and its length represents the distance the airspeed for 1 hour. The short blue arrow at the right shows the wind direction, and its length represents the wind velocity for 1 hour. The solid yellow line shows the direction of the track or the path of the aircraft as measured over the earth, and its length represents the distance traveled in 1 hour, or the GS.

In actual practice, the triangle illustrated in *Figure 15-19* is not drawn; instead, construct a similar triangle as shown by the blue, yellow, and black lines in *Figure 15-20,* which is explained in the following example.

Suppose a flight is to be flown from E to P. Draw a line on the aeronautical chart connecting these two points; measure its direction with a protractor, or plotter, in reference to a meridian. This is the true course, which in this example is assumed to be 090° (east). From the NWS, it is learned that

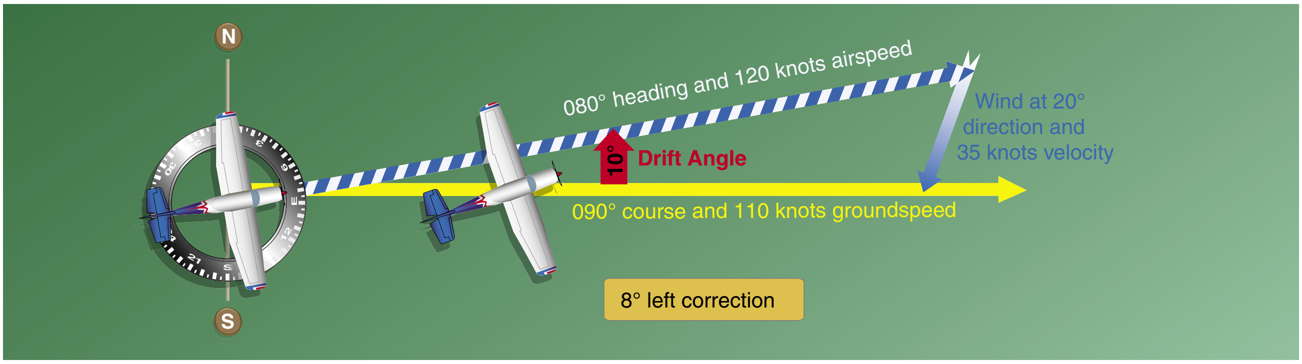


Figure 15-19. *Principle of the wind triangle.*

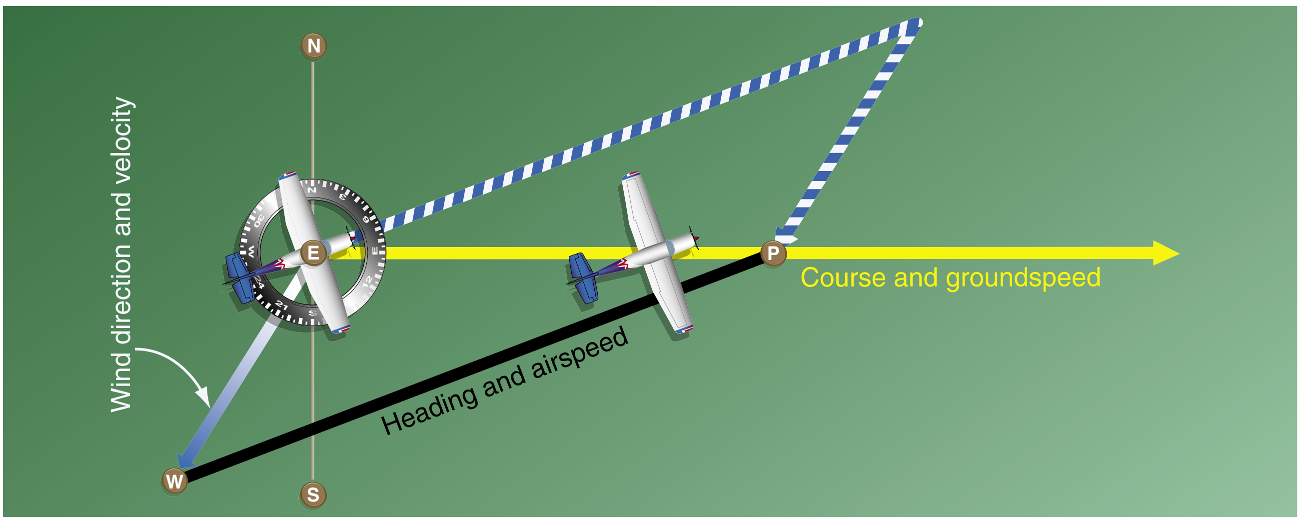


Figure 15-20. *The wind triangle as is drawn in navigation practice.*

the wind at the altitude of the intended flight is 40 knots from the northeast (045°). Since the NWS reports the wind speed in knots, if the true airspeed of the aircraft is 120 knots, there is no need to convert speeds from knots to mph or vice versa.

Now, on a plain sheet of paper draw a vertical line representing north to south. (The various steps are shown in *Figure 15-21*.)

Step 1

Place the protractor with the base resting on the vertical line and the curved edge facing east. At the center point of the base, make a dot labeled "E" (point of departure), and at the curved edge, make a dot at 90° (indicating the direction of the true course) and another at 45° (indicating wind direction).

Step 2

With the ruler, draw the true course line from E, extending it somewhat beyond the dot by 90°, and labeling it "TC 090°."

Step 3

Next, align the ruler with E and the dot at 45°, and draw the wind arrow from E, not toward 045°, but downwind in the direction the wind is blowing, making it 40 units long, to correspond with the wind velocity of 40 knots. Identify this line as the wind line by placing the letter "W" at the end to show the wind direction.

Step 4

Finally, measure 120 units on the ruler to represent the airspeed, making a dot on the ruler at this point. The units used may be of any convenient scale or value (such as ¼ inch = 10 knots), but once selected, the same scale must be used for each of the linear movements involved. Then place the ruler so that the end is on the arrowhead (W) and the 120-knot dot intercepts the true course line. Draw the line and label it "AS 120." The point "P" placed at the intersection represents the position of the aircraft at the end of 1 hour. The diagram is now complete.

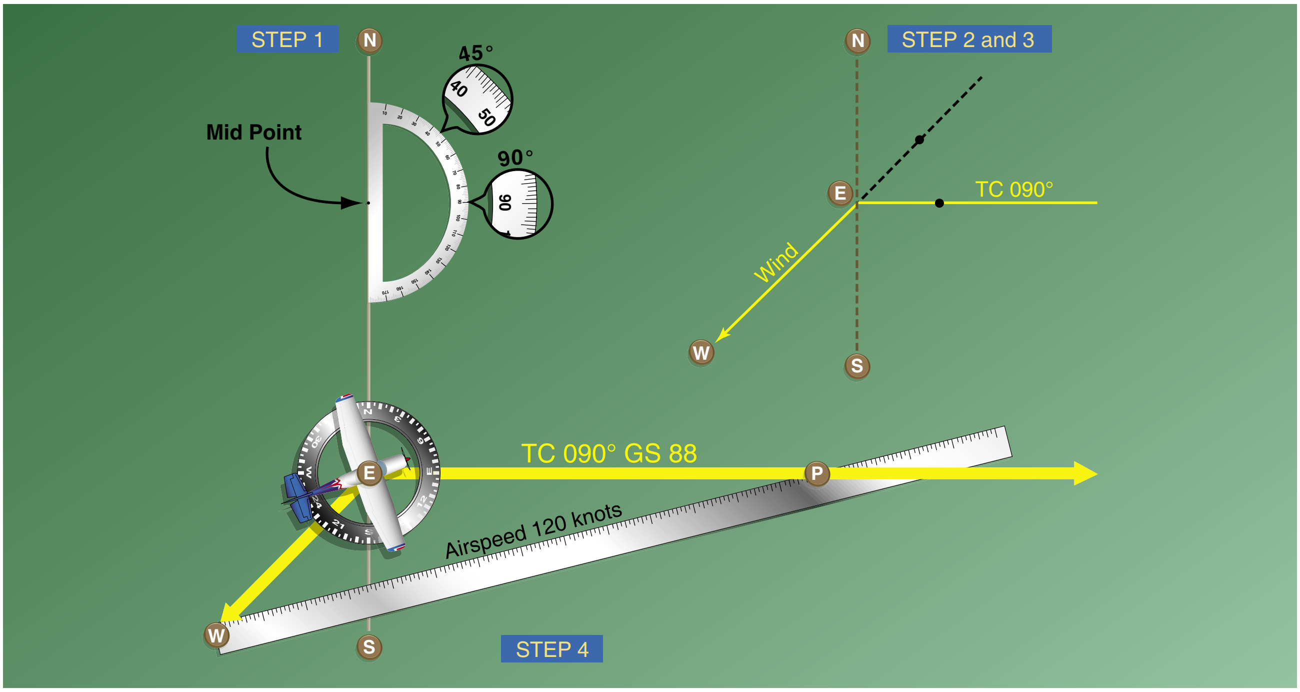


Figure 15-21. *Steps in drawing the wind triangle.*

The distance flown in 1 hour (GS) is measured as the numbers of units on the true course line (88 NMPH, or 88 knots). The true heading necessary to offset drift is indicated by the direction of the airspeed line, which can be determined in one of two ways:

- By placing the straight side of the protractor along the north-south line, with its center point at the intersection of the airspeed line and north-south line, read the true heading directly in degrees (076°). *[Figure 15-22]*
- By placing the straight side of the protractor along the true course line, with its center at P, read the angle between the true course and the airspeed line. This is the WCA, which must be applied to the true course to obtain the true heading. If the wind blows from the right of true course, the angle is added; if from the left, it is subtracted. In the example given, the WCA is 14° and the wind is from the left; therefore, subtract 14° from true course of 090°, making the true heading 076°. *[Figure 15-23]*

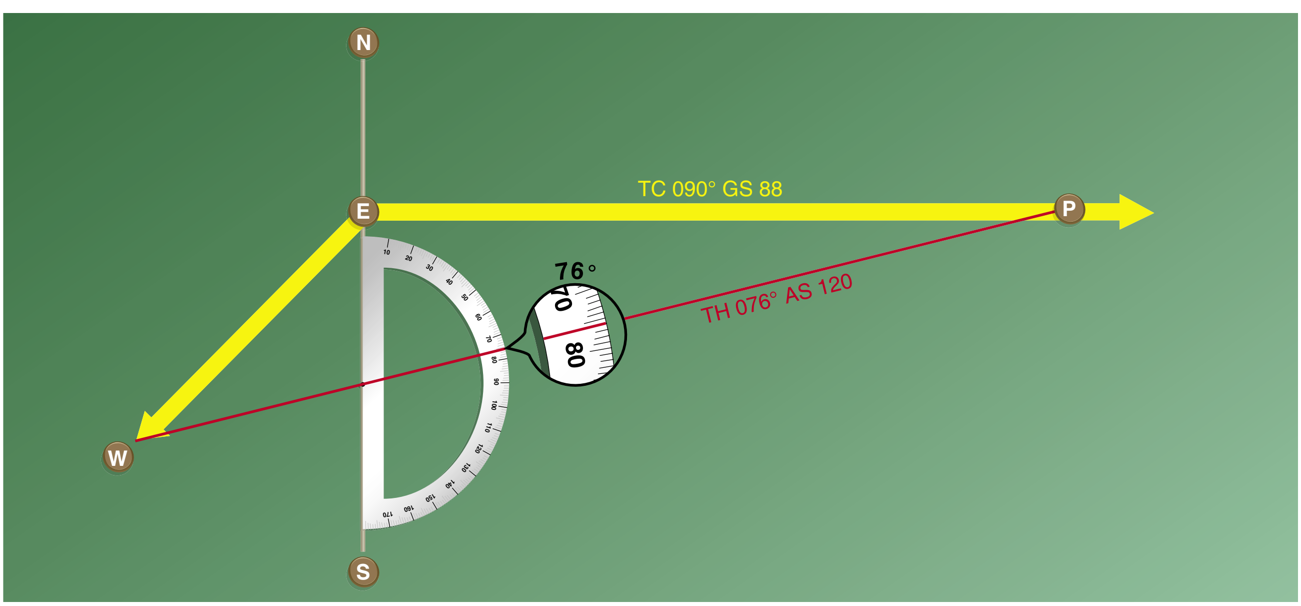


Figure 15-22. *Finding true heading by the wind correction angle.*

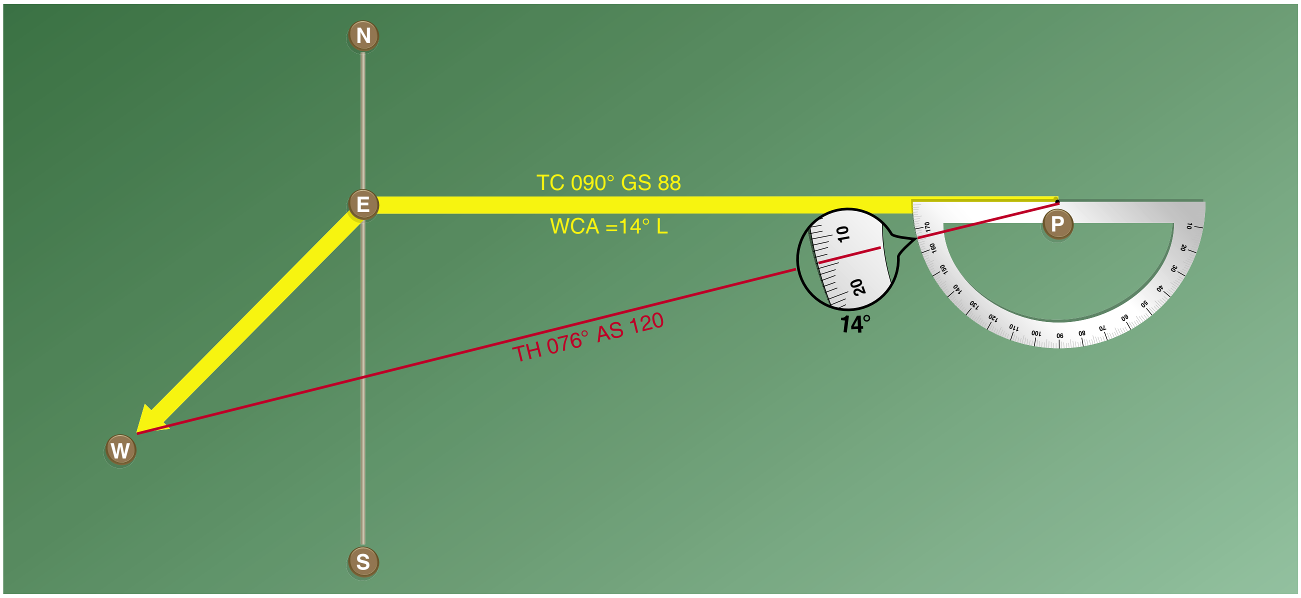


Figure 15-23. *Finding true heading by direct measurement.*

After obtaining the true heading, apply the correction for magnetic variation to obtain magnetic heading, and the correction for compass deviation to obtain a compass heading. The compass heading can be used to fly to the destination by dead reckoning.

To determine the time and fuel required for the flight, first find the distance to destination by measuring the length of the course line drawn on the aeronautical chart (using the appropriate scale at the bottom of the chart). If the distance measures 220 NM, divide by the GS of 88 knots, which gives 2.5 hours, or 2:30, as the time required. If fuel consumption is 8 gallons an hour, 8 x 2.5 or about 20 gallons is used. Briefly summarized, the steps in obtaining flight information are as follows:

- TC—direction of the line connecting two desired points, drawn on the chart and measured clockwise in degrees from true north on the mid-meridian.
- WCA—determined from the wind triangle. (Added to TC if the wind is from the right; subtracted if wind is from the left).
- TH—direction measured in degrees clockwise from true north, in which the nose of the plane should point to make good the desired course.
- Variation—obtained from the isogonic line on the chart (added to TH if west; subtracted if east).
- MH—an intermediate step in the conversion (obtained by applying variation to true heading).
- Deviation—obtained from the deviation card on the aircraft (added to MH or subtracted from, as indicated).
- Compass heading—reading on the compass (found by applying deviation to MH) which is followed to make good the desired course.
- Total distance—obtained by measuring the length of the TC line on the chart (using the scale at the bottom of the chart).
- GS—obtained by measuring the length of the TC line on the wind triangle (using the scale employed for drawing the diagram).
- Estimated time en route (ETE)—total distance divided by GS.
- Fuel rate—predetermined gallons per hour used at cruising speed.

NOTE: Additional fuel for adequate reserve should be added as a safety measure.

Flight Planning

Title 14 of the Code of Federal Regulations (14 CFR) part 91 states, in part, that before beginning a flight, the pilot in command (PIC) of an aircraft shall become familiar with all available information concerning that flight. For flights not in the vicinity of an airport, this must include information on available current weather reports and forecasts, fuel requirements, alternatives available if the planned flight cannot be completed, and any known traffic delays of which the pilot in command has been advised by ATC.

Assembling Necessary Material

The pilot should collect the necessary material well before the flight. An appropriate current sectional chart and charts for areas adjoining the flight route should be among this material if the route of flight is near the border of a chart.

Additional equipment should include a flight computer or electronic calculator, plotter, and any other item appropriate to the particular flight. For example, if a night flight is to be undertaken, carry a flashlight; if a flight is over desert country, carry a supply of water and other necessities.

Weather Check

It is wise to check the weather before continuing with other aspects of flight planning to see, first of all, if the flight is feasible and, if it is, which route is best. Chapter 12, Aviation Weather Services, discusses obtaining a weather briefing.

Use of Airport/Facility Directory (A/FD)

Study available information about each airport at which a landing is intended. This should include a study of the Notices to Airmen (NOTAMs) and the A/FD. *[Figure 15-24]* This includes location, elevation, runway and lighting facilities, available services, availability of aeronautical advisory station frequency (UNICOM), types of fuel available (use to decide on refueling stops), AFSS/FSS located on the airport, control tower and ground control frequencies, traffic information, remarks, and other pertinent information. The NOTAMs, issued every 28 days, should be checked for additional information on hazardous conditions or changes that have been made since issuance of the A/FD.

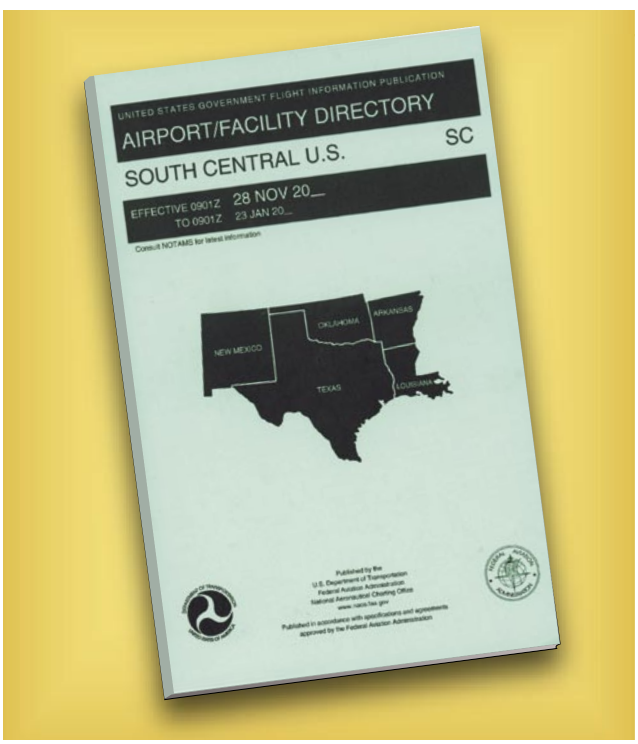


Figure 15-24. *Airport/Facility Directory.*

The sectional chart bulletin subsection should be checked for major changes that have occurred since the last publication date of each sectional chart being used. Remember, the chart may be up to 6 months old. The effective date of the chart appears at the top of the front of the chart. The A/FD generally has the latest information pertaining to such matters and should be used in preference to the information on the back of the chart, if there are differences.

Airplane Flight Manual or Pilot's Operating Handbook (AFM/POH)

The Aircraft Flight Manual or Pilot's Operating Handbook (AFM/POH) should be checked to determine the proper loading of the aircraft (weight and balance data). The weight of the usable fuel and drainable oil aboard must be known. Also, check the weight of the passengers, the weight of all baggage to be carried, and the empty weight of the aircraft to be sure that the total weight does not exceed the maximum allowable. The distribution of the load must be known to tell if the resulting center of gravity (CG) is within limits. Be sure to use the latest weight and balance information in the FAA-approved AFM or other permanent aircraft records, as appropriate, to obtain empty weight and empty weight CG information.

Determine the takeoff and landing distances from the appropriate charts, based on the calculated load, elevation of the airport, and temperature; then compare these distances with the amount of runway available. Remember, the heavier the load and the higher the elevation, temperature, or humidity, the longer the takeoff roll and landing roll and the lower the rate of climb.

Check the fuel consumption charts to determine the rate of fuel consumption at the estimated flight altitude and power settings. Calculate the rate of fuel consumption, and then compare it with the estimated time for the flight so that refueling points along the route can be included in the plan.

Charting the Course

Once the weather has been checked and some preliminary planning done, it is time to chart the course and determine the data needed to accomplish the flight. The following sections provide a logical sequence to follow in charting the course, filling out a flight log, and filing a flight plan. In the following example, a trip is planned based on the following data and the sectional chart excerpt in *Figure 15-25.*

Figure 15-25. *Sectional chart excerpt.*

Route of flight: Chickasha Airport direct to Guthrie Airport

True airspeed (TAS)..115 knots

Winds aloft..360° at 10 knots

Usable fuel..38 gallons

Fuel rate...8 GPH

Deviation...+2°

Steps in Charting the Course

The following is a suggested sequence for arriving at the pertinent information for the trip. As information is determined, it may be noted as illustrated in the example of a flight log in *Figure 15-26.* Where calculations are required, the pilot may use a mathematical formula or a manual or electronic flight computer. If unfamiliar with the use of a manual or electronic computer, it would be advantageous to read the operation manual and work several practice problems at this point.

First draw a line from Chickasha Airport (point A) directly to Guthrie Airport (point F). The course line should begin at the center of the airport of departure and end at the center of the destination airport. If the route is direct, the course line consists of a single straight line. If the route is not direct, it consists of two or more straight line segments. For example, a VOR station which is off the direct route, but which makes navigating easier, may be chosen (radio navigation is discussed later in this chapter).

Appropriate checkpoints should be selected along the route and noted in some way. These should be easy-to-locate points such as large towns, large lakes and rivers, or combinations of recognizable points such as towns with an airport, towns with a network of highways, and railroads entering and departing. Normally, choose only towns indicated by splashes of yellow on the chart. Do not choose towns represented by a small circle—these may turn out to be only a half-dozen houses. (In isolated areas, however, towns represented by a small circle can be prominent checkpoints.) For this trip, four checkpoints have been selected. Checkpoint 1 consists of a tower located east of the course and can be further identified by the highway and railroad track, which almost parallels the course at this point. Checkpoint 2 is the obstruction just to the west of the course and can be further identified by Will Rogers World

PILOT'S PLANNING SHEET

PLANE IDENTIFICATION N123DB **DATE**

COURSE	TC	Wind Knots	Wind From	WCA R+ L-	TH	WCA R+ L-	MH	DEV	CH	TOTAL MILES	GS	TOTAL TIME	FUEL RATE	TOTAL FUEL
From Chickasha To Guthrie	031°	10	360°	3° L	28	7° E	21°	+2°	23	53	106 kts	35 min	8 GPH	38 gal
From To														

VISUAL FLIGHT LOG

TIME OF DEPARTURE	NAVIGATION AIDS	COURSE	DISTANCE	ELAPSED TIME	GS	CH	REMARKS
POINT OF DEPARTURE Chickasha Airport	NAVAID IDENT. FREQ.	TO FROM	POINT TO POINT CUMULATIVE	ESTIMATED ACTUAL	ESTIMATED ACTUAL	ESTIMATED ACTUAL	WEATHER AIRSPACE ETC.
CHECKPOINT #1			11 NM	6 min +5	106 kts	023°	
CHECKPOINT #2			10 NM 21 NM	6 min	106 kts	023°	
CHECKPOINT #3			10.5 NM 31.5 NM	6 min	106 kts	023°	
CHECKPOINT #4			13 NM 44.5 NM	7 min	106 kts	023°	
DESTINATION Guthrie Airport			8.5 NM 53 NM	5 min			

Figure 15-26. *Pilot's planning sheet and visual flight log.*

Airport which is directly to the east. Checkpoint 3 is Wiley Post Airport, which the aircraft should fly directly over. Checkpoint 4 is a private, non-surfaced airport to the west of the course and can be further identified by the railroad track and highway to the east of the course.

The course and areas on either side of the planned route should be checked to determine if there is any type of airspace with which the pilot should be concerned or which has special operational requirements. For this trip, it should be noted that the course passes through a segment of the Class C airspace surrounding Will Rogers World Airport where the floor of the airspace is 2,500 feet mean sea level (MSL) and the ceiling is 5,300 feet MSL (point B). Also, there is Class D airspace from the surface to 3,800 feet MSL surrounding Wiley Post Airport (point C) during the time the control tower is in operation.

Study the terrain and obstructions along the route. This is necessary to determine the highest and lowest elevations as well as the highest obstruction to be encountered so that an appropriate altitude which conforms to 14 CFR part 91 regulations can be selected. If the flight is to be flown at an altitude more than 3,000 feet above the terrain, conformance to the cruising altitude appropriate to the direction of flight is required. Check the route for particularly rugged terrain so it can be avoided. Areas where a takeoff or landing is made should be carefully checked for tall obstructions. Television transmitting towers may extend to altitudes over 1,500 feet above the surrounding terrain. It is essential that pilots be aware of their presence and location. For this trip, it should be noted that the tallest obstruction is part of a series of antennas with a height of 2,749 feet MSL (point D). The highest elevation should be located in the northeast quadrant and is 2,900 feet MSL (point E).

Since the wind is no factor and it is desirable and within the aircraft's capability to fly above the Class C and D airspace to be encountered, an altitude of 5,500 feet MSL is chosen. This altitude also gives adequate clearance of all obstructions as well as conforms to the 14 CFR part 91 requirement to fly at an altitude of odd thousand plus 500 feet when on a magnetic course between 0 and 179°.

Next, the pilot should measure the total distance of the course as well as the distance between checkpoints. The total distance is 53 NM and the distance between checkpoints is as noted on the flight log in *Figure 15-26.*

After determining the distance, the true course should be measured. If using a plotter, follow the directions on the plotter. The true course is 031°. Once the true heading is established, the pilot can determine the compass heading. This is done by following the formula given earlier in this chapter. The formula is:

TC ± WCA = TH ± V = MH ± D = CH

The WCA can be determined by using a manual or electronic flight computer. Using a wind of 360° at 10 knots, it is determined the WCA is 3° left. This is subtracted from the TC making the TH 28°. Next, the pilot should locate the isogonic line closest to the route of the flight to determine variation. *Figure 15-25* shows the variation to be 6.30° E (rounded to 7° E), which means it should be subtracted from the TH, giving an MH of 21°. Next, add 2° to the MH for the deviation correction. This gives the pilot the compass heading which is 23°.

Now, the GS can be determined. This is done using a manual or electronic calculator. The GS is determined to be 106 knots. Based on this information, the total trip time, as well as time between checkpoints, and the fuel burned can be determined. These calculations can be done mathematically or by using a manual or electronic calculator.

For this trip, the GS is 106 knots and the total time is 35 minutes (30 minutes plus 5 minutes for climb) with a fuel burn of 4.7 gallons. Refer to the flight log in *Figure 15-26* for the time between checkpoints.

As the trip progresses, the pilot can note headings and time and make adjustments in heading, GS, and time.

Filing a VFR Flight Plan

Filing a flight plan is not required by regulations; however, it is a good operating practice, since the information contained in the flight plan can be used in search and rescue in the event of an emergency.

Flight plans can be filed in the air by radio, but it is best to file a flight plan by phone just before departing. After takeoff, contact the AFSS by radio and give them the takeoff time so the flight plan can be activated.

When a VFR flight plan is filed, it is held by the AFSS until 1 hour after the proposed departure time and then canceled unless: the actual departure time is received; a revised proposed departure time is received; or at the time of filing, the AFSS is informed that the proposed departure time is met, but actual time cannot be given because of inadequate communication. The FSS specialist who accepts the flight plan does not inform the pilot of this procedure, however.

Figure 15-27 shows the flight plan form a pilot files with the AFSS. When filing a flight plan by telephone or radio, give the information in the order of the numbered spaces. This enables the AFSS specialist to copy the information more efficiently. Most of the fields are either self-explanatory or non-applicable to the VFR flight plan (such as item 13). However, some fields may need explanation.

- Item 3 is the aircraft type and special equipment. An example would be C-150/X, which means the aircraft has no transponder. A listing of special equipment codes is found in the Aeronautical Information Manual (AIM).
- Item 6 is the proposed departure time in UTC (indicated by the "Z").
- Item 7 is the cruising altitude. Normally, "VFR" can be entered in this block, since the pilot chooses a cruising altitude to conform to FAA regulations.
- Item 8 is the route of flight. If the flight is to be direct, enter the word "direct;" if not, enter the actual route to be followed such as via certain towns or navigation aids.
- Item 10 is the estimated time en route. In the sample flight plan, 5 minutes was added to the total time to allow for the climb.
- Item 12 is the fuel on board in hours and minutes. This is determined by dividing the total usable fuel aboard in gallons by the estimated rate of fuel consumption in gallons.

Remember, there is every advantage in filing a flight plan; but do not forget to close the flight plan on arrival. Do this by telephone to avoid radio congestion.

Radio Navigation

Advances in navigational radio receivers installed in aircraft, the development of aeronautical charts which show the exact location of ground transmitting stations and their frequencies, along with refined flight deck instrumentation make it possible for pilots to navigate with precision to almost any point desired. Although precision in navigation is obtainable through the proper use of this equipment, beginning pilots should use this equipment to supplement navigation by visual reference to the ground (pilotage). This method provides the

Form Approved OMB No. 2120-0026

U.S. DEPARTMENT OF TRANSPORTATION FEDERAL AVIATION ADMINISTRATION **FLIGHT PLAN**	(FAA USE ONLY) ☐ PILOT BRIEFING ☐ VNR ☐ STOPOVER				TIME STARTED	SPECIALIST INITIALS
1. TYPE: **X** VFR / IFR / DVFR	2. AIRCRAFT IDENTIFICATION **N123DB**	3. AIRCRAFT TYPE/ SPECIAL EQUIPMENT **C150/X**	4. TRUE AIRSPEED **115** KTS	5. DEPARTURE POINT **CHK, CHICKASHA AIRPORT**	6. DEPARTURE TIME PROPOSED (Z) **1400** ACTUAL (Z)	7. CRUISING ALTITUDE **5500**

8. ROUTE OF FLIGHT **Chickasha direct Guthrie**

9. DESTINATION (Name of airport and city)	10. EST. TIME ENROUTE HOURS	MINUTES	11. REMARKS
GOK, Guthrie Airport Guthrie, OK		**35**	

12. FUEL ON BOARD HOURS	MINUTES	13. ALTERNATE AIRPORT(S)	14. PILOT'S NAME, ADDRESS & TELEPHONE NUMBER & AIRCRAFT HOME BASE	15. NUMBER ABOARD
4	**45**		**Jane Smith** **Aero Air, Oklahoma City, OK (405) 555-4149** 17. DESTINATION CONTACT/TELEPHONE (OPTIONAL)	**1**

16. COLOR OF AIRCRAFT **Red/White**

CIVIL AIRCRAFT PILOTS. 14 CFR Part 91 requires you file an IFR flight plan to operate under instrument flight rules in controlled airspace. Failure to file could result in a civil penalty not to exceed $1,000 for each violation (Section 901 of the Federal Aviation Act of 1958, as amended). Filing of a VFR flight plan is recommended as a good operating practice. See also Part 99 for requirements concerning DVFR flight plans.

FAA Form 7233-1 (8-82) CLOSE VFR FLIGHT PLAN WITH **McAlester** FSS ON ARRIVAL

Figure 15-27. *Flight plan form.*

pilot with an effective safeguard against disorientation in the event of radio malfunction.

There are four radio navigation systems available for use for VFR navigation. These are:

- VHF Omnidirectional Range (VOR)
- Nondirectional Radio Beacon (NDB)
- Long Range Navigation (LORAN-C)
- Global Positioning System (GPS)

Very High Frequency (VHF) Omnidirectional Range (VOR)

The VOR system is present in three slightly different navigation aids (NAVAIDs): VOR, VOR/DME, and VORTAC. By itself it is known as a VOR, and it provides magnetic bearing information to and from the station. When DME is also installed with a VOR, the NAVAID is referred to as a VOR/DME. When military tactical air navigation (TACAN) equipment is installed with a VOR, the NAVAID is known as a VORTAC. DME is always an integral part of a VORTAC. Regardless of the type of NAVAID utilized (VOR, VOR/DME or VORTAC), the VOR indicator behaves the same. Unless otherwise noted, in this section, VOR, VOR/DME and VORTAC NAVAIDs are all referred to hereafter as VORs.

The prefix "omni-" means all, and an omnidirectional range is a VHF radio transmitting ground station that projects straight line courses (radials) from the station in all directions. From a top view, it can be visualized as being similar to the spokes from the hub of a wheel. The distance VOR radials are projected depends upon the power output of the transmitter.

The course or radials projected from the station are referenced to magnetic north. Therefore, a radial is defined as a line of magnetic bearing extending outward from the VOR station. Radials are identified by numbers beginning with 001, which is 1° east of magnetic north, and progress in sequence through all the degrees of a circle until reaching 360. To aid in orientation, a compass rose reference to magnetic north is superimposed on aeronautical charts at the station location.

VOR ground stations transmit within a VHF frequency band of 108.0–117.95 MHz. Because the equipment is VHF, the signals transmitted are subject to line-of-sight restrictions. Therefore, its range varies in direct proportion to the altitude of receiving equipment. Generally, the reception range of the signals at an altitude of 1,000 feet above ground level (AGL) is about 40 to 45 miles. This distance increases with altitude. *[Figure 15-28]*

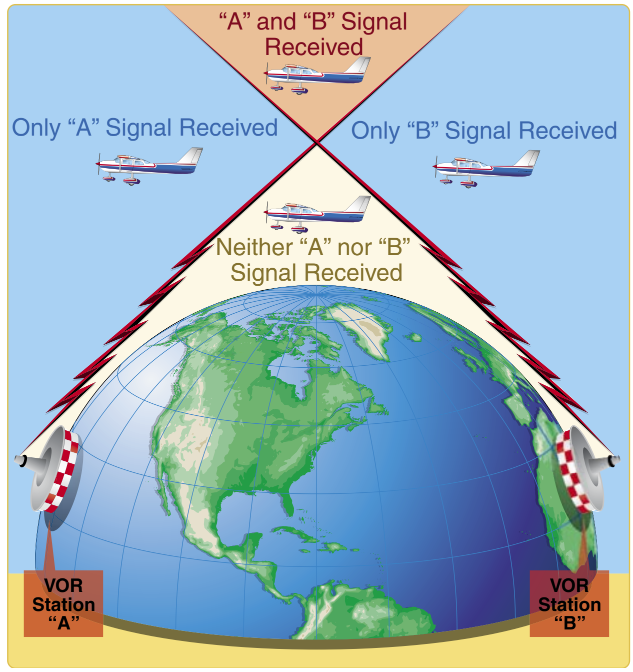


Figure 15-28. *VHF transmissions follow a line-of-sight course.*

VORs and VORTACs are classed according to operational use. There are three classes:

- T (Terminal)
- L (Low altitude)
- H (High altitude)

The normal useful range for the various classes is shown in the following table:

VOR/VORTAC NAVAIDS
Normal Usable Altitudes and Radius Distances

Class	*Altitudes*	*Distance (Miles)*
T	12,000' and below	25
L	Below 18,000'	40
H	Below 14,500'	40
H	Within the conterminous 48 states only, between 14,500 and 17,999'	100
H	18,000'—FL 450	130
H	60,000'—FL 450	100

The useful range of certain facilities may be less than 50 miles. For further information concerning these restrictions, refer to the Communication/NAVAID Remarks in the A/FD.

The accuracy of course alignment of VOR radials is considered to be excellent. It is generally within plus or minus 1°. However, certain parts of the VOR receiver equipment deteriorate, and this affects its accuracy. This is particularly true at great distances from the VOR station. The best assurance of maintaining an accurate VOR receiver is periodic checks and calibrations. VOR accuracy checks are not a regulatory requirement for VFR flight. However, to assure accuracy of the equipment, these checks should be accomplished quite frequently and a complete calibration each year. The following means are provided for pilots to check VOR accuracy:

- FAA VOR test facility (VOT)
- Certified airborne checkpoints
- Certified ground checkpoints located on airport surfaces

If an aircraft has two VOR receivers installed, a dual VOR receiver check can be made. To accomplish the dual receiver check, a pilot tunes both VOR receivers to the same VOR ground facility. The maximum permissible variation between the two indicated bearings is 4 degrees. A list of the airborne and ground checkpoints is published in the A/FD.

Basically, these checks consist of verifying that the VOR radials the aircraft equipment receives are aligned with the radials the station transmits. There are not specific tolerances in VOR checks required for VFR flight. But as a guide to assure acceptable accuracy, the required IFR tolerances can be used—±4° for ground checks and ±6° for airborne checks. These checks can be performed by the pilot.

The VOR transmitting station can be positively identified by its Morse code identification or by a recorded voice identification which states the name of the station followed by "VOR." Many FSS transmit voice messages on the same frequency that the VOR operates. Voice transmissions should not be relied upon to identify stations, because many FSS remotely transmit over several omniranges, which have names different from that of the transmitting FSS. If the VOR is out of service for maintenance, the coded identification is removed and not transmitted. This serves to alert pilots that this station should not be used for navigation. VOR receivers are designed with an alarm flag to indicate when signal strength is inadequate to operate the navigational equipment. This happens if the aircraft is too far from the VOR or the aircraft is too low and, therefore, is out of the line of sight of the transmitting signals.

Using the VOR

In review, for VOR radio navigation, there are two components required: ground transmitter and aircraft receiving equipment. The ground transmitter is located at a specific position on the ground and transmits on an assigned frequency. The aircraft equipment includes a receiver with a tuning device and a VOR or omninavigation instrument. The navigation instrument could be a course deviation indicator (CDI), horizontal situation indicator (HSI), or a radio magnetic indicator (RMI). Each of these instruments indicates the course to the tuned VOR.

Course Deviation Indicator (CDI)

The CDI is found in most training aircraft. It consists of (1) omnibearing selector (OBS) sometimes referred to as the course selector, (2) a CDI needle (Left-Right Needle), and (3) a TO/FROM indicator.

The course selector is an azimuth dial that can be rotated to select a desired radial or to determine the radial over which the aircraft is flying. In addition, the magnetic course "TO" or "FROM" the station can be determined.

When the course selector is rotated, it moves the CDI or needle to indicate the position of the radial relative to the aircraft. If the course selector is rotated until the deviation needle is centered, the radial (magnetic course "FROM" the station) or its reciprocal (magnetic course "TO" the station) can be determined. The course deviation needle also moves to the right or left if the aircraft is flown or drifting away from the radial which is set in the course selector.

By centering the needle, the course selector indicates either the course "FROM" the station or the course "TO" the station. If the flag displays a "TO," the course shown on the course selector must be flown to the station. *[Figure 15-29]* If

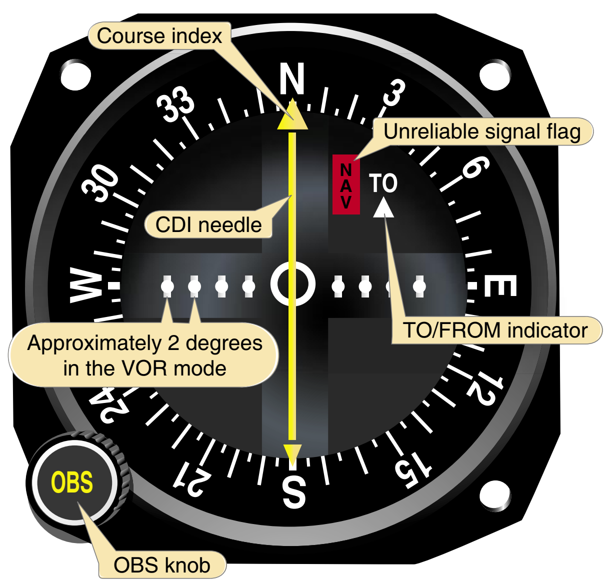


Figure 15-29. *VOR indicator.*

"FROM" is displayed and the course shown is followed, the aircraft is flown away from the station.

Horizontal Situation Indicator

The HSI is a direction indicator that uses the output from a flux valve to drive the compass card. The HSI *[Figure 15-30]* combines the magnetic compass with navigation signals and a glideslope. The HSI gives the pilot an indication of the location of the aircraft with relationship to the chosen course or radial.

In *Figure 15-30,* the aircraft magnetic heading displayed on the compass card under the lubber line is 184°. The course select pointer shown is set to 295°; the tail of the pointer indicates the reciprocal, 115°. The course deviation bar operates with a VOR/Localizer (VOR/LOC) or GPS navigation receiver to indicate left or right deviations from the course selected with the course select pointer; operating in the same manner, the angular movement of a conventional VOR/LOC needle indicates deviation from course.

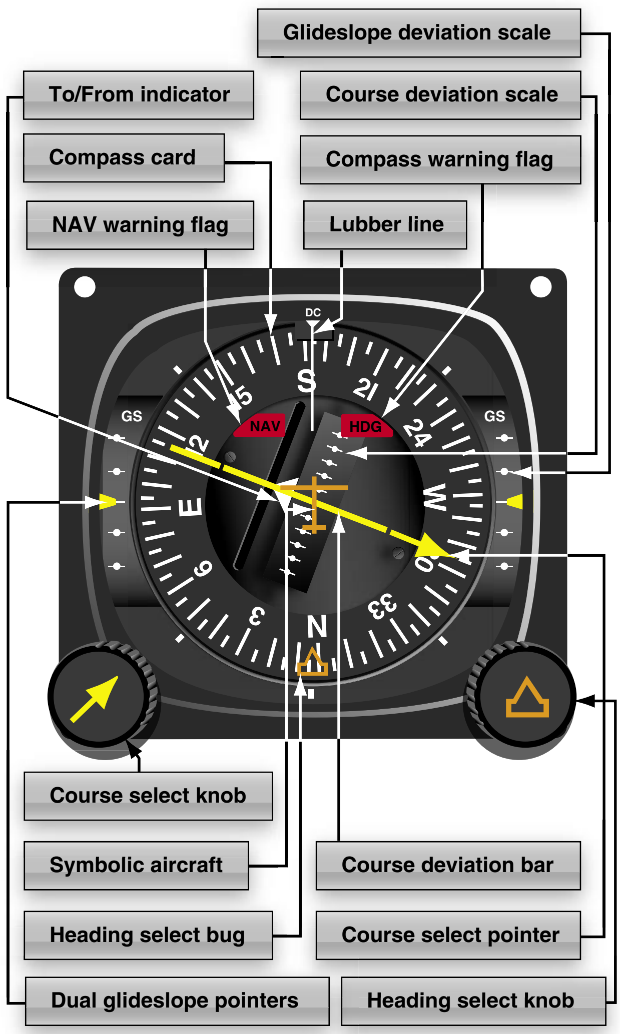


Figure 15-30. *Horizontal situation indicator.*

The desired course is selected by rotating the course select pointer, in relation to the compass card, by means of the course select knob. The HSI has a fixed aircraft symbol and the course deviation bar displays the aircraft's position relative to the selected course. The TO/FROM indicator is a triangular pointer. When the indicator points to the head of the course select pointer, the arrow shows the course selected. If properly intercepted and flown, the course will take the aircraft to the chosen facility. When the indicator points to the tail of the course, the arrow shows that the course selected, if properly intercepted and flown, will take the aircraft directly away from the chosen facility.

When the NAV warning flag appears it indicates no reliable signal is being received. The appearance of the HDG flag indicates the compass card is not functioning properly.

The glideslope pointer indicates the relation of the aircraft to the glideslope. When the pointer is below the center position, the aircraft is above the glideslope and an increased rate of descent is required. In some installations, the azimuth card is a remote indicating compass; however, in others the heading must be checked occasionally against the magnetic compass and reset.

Radio Magnetic Indicator (RMI)

The RMI *[Figure 15-31]* is a navigational aid providing aircraft magnetic or directional gyro heading and very high frequency omnidirectional range (VOR), GPS, and automatic direction finder (ADF) bearing information. Remote indicating

Figure 15-31. *Radio magnetic indicator.*

compasses were developed to compensate for errors in and limitations of older types of heading indicators.

The remote compass transmitter is a separate unit usually mounted in a wingtip to eliminate the possibility of magnetic interference. The RMI consists of a compass card, a heading index, two bearing pointers, and pointer function switches. The two pointers are driven by any two combinations of a GPS, an ADF, and/or a VOR. The pilot has the ability to select the navigation aid to be indicated. The pointer indicates course to selected NAVAID or waypoint. In *Figure 15-31* the green pointer is indicating the station tuned on the ADF. The yellow pointer is indicating the course to a VOR of GPS waypoint. Note that there is no requirement for a pilot to select course with the RMI, but only the NAVAID is to be indicated.

Tracking With VOR

The following describes a step-by-step procedure to use when tracking to and from a VOR station using a CDI. *Figure 15-32* illustrates the procedure.

First, tune the VOR receiver to the frequency of the selected VOR station. For example, 115.0 to receive Bravo VOR. Next, check the identifiers to verify that the desired VOR is being received. As soon as the VOR is properly tuned, the course deviation needle deflects either left or right. Then, rotate the azimuth dial to the course selector until the course deviation needle centers and the TO-FROM indicator indicates "TO." If the needle centers with a "FROM" indication, the azimuth should be rotated 180° because, in this case, it is desired to fly "TO" the station. Now, turn the aircraft to the heading indicated on the VOR azimuth dial or course selector, 350° in this example.

If a heading of 350° is maintained with a wind from the right as shown, the aircraft drifts to the left of the intended track. As the aircraft drifts off course, the VOR course deviation needle gradually moves to the right of center or indicates the direction of the desired radial or track.

To return to the desired radial, the aircraft heading must be altered to the right. As the aircraft returns to the desired track, the deviation needle slowly returns to center. When centered, the aircraft is on the desired radial and a left turn must be made toward, but not to the original heading of 350° because a wind drift correction must be established. The amount of correction depends upon the strength of the wind. If the wind velocity is unknown, a trial-and-error method can be used to find the correct heading. Assume, for this example, a 10° correction for a heading of 360° is maintained.

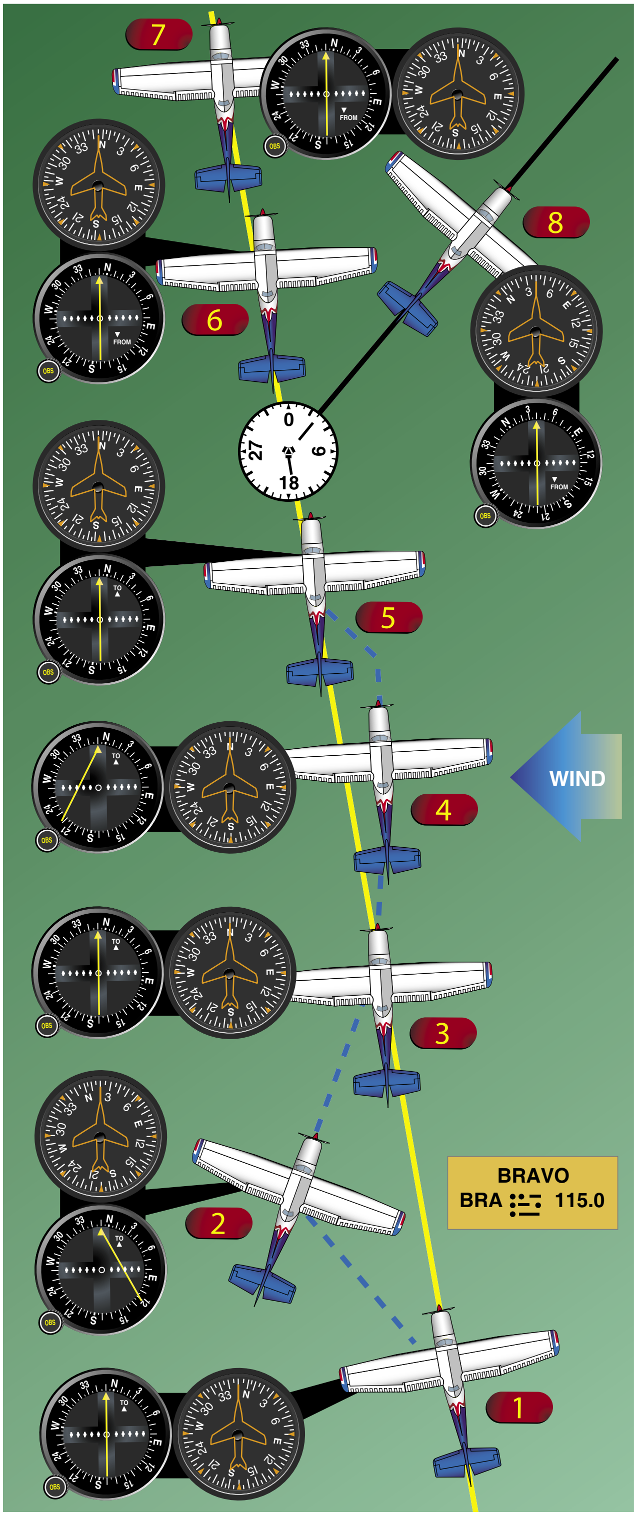


Figure 15-32. *Tracking a radial in a crosswind.*

While maintaining a heading of 360°, assume that the course deviation begins to move to the left. This means that the wind correction of 10° is too great and the aircraft is flying to the right of course. A slight turn to the left should be made to permit the aircraft to return to the desired radial.

When the deviation needle centers, a small wind drift correction of 5° or a heading correction of 355° should be flown. If this correction is adequate, the aircraft remains on the radial. If not, small variations in heading should be made to keep the needle centered, and consequently keep the aircraft on the radial.

As the VOR station is passed, the course deviation needle fluctuates, then settles down, and the "TO" indication changes to "FROM." If the aircraft passes to one side of the station, the needle deflects in the direction of the station as the indicator changes to "FROM."

Generally, the same techniques apply when tracking outbound as those used for tracking inbound. If the intent is to fly over the station and track outbound on the reciprocal of the inbound radial, the course selector should not be changed. Corrections are made in the same manner to keep the needle centered. The only difference is that the omnidirectional range indicator indicates "FROM."

If tracking outbound on a course other than the reciprocal of the inbound radial, this new course or radial must be set in the course selector and a turn made to intercept this course. After this course is reached, tracking procedures are the same as previously discussed.

Tips on Using the VOR

- Positively identify the station by its code or voice identification.
- Keep in mind that VOR signals are "line-of-sight." A weak signal or no signal at all is received if the aircraft is too low or too far from the station.
- When navigating to a station, determine the inbound radial and use this radial. Fly a heading that will maintain the course. If the aircraft drifts, fly a heading to re-intercept the course then apply a correction to compensate for wind drift.
- If minor needle fluctuations occur, avoid changing headings immediately. Wait momentarily to see if the needle recenters; if it does not, then correct.
- When flying "TO" a station, always fly the selected course with a "TO" indication. When flying "FROM" a station, always fly the selected course with a "FROM" indication. If this is not done, the action of the course deviation needle is reversed. To further explain this reverse action, if the aircraft is flown toward a station with a "FROM" indication or away from a station with a "TO" indication, the course deviation needle indicates in an direction opposite to that which it should indicate. For example, if the aircraft drifts to the right of a radial being flown, the needle moves to the right or points away from the radial. If the aircraft drifts to the left of the radial being flown, the needle moves left or in the direction opposite to the radial.
- When navigating using the VOR it is important to fly headings that maintain or re-intercept the course. Just turning toward the needle will cause overshooting the radial and flying an S turn to the left and right of course.

Time and Distance Check From a Station

To compute time and distance from a station, first turn the aircraft to place the bearing pointer on the nearest 90° index. Note time and maintain heading. When the bearing pointer has moved 10°, note the elapsed time in seconds and apply the formulas in the following example to determine time and distance. *[Figure 15-33]*

Time-Distance Check Example

$$\frac{\textbf{Time in seconds between bearings}}{\textbf{Degrees of bearing change}} = \textbf{Minutes to station}$$

For example, if 2 minutes (120 seconds) is required to fly a bearing change of 10 degrees, the aircraft is—

$$\frac{120}{10} = \textbf{12 minutes to the station}$$

Figure 15-33. *Time-distance check example.*

The time from station may also be calculated by using a short method based on the above formula, if a 10° bearing change is flown. If the elapsed time for the bearing change is noted in seconds and a 10° bearing change is made, the time from the station in minutes is determined by counting off one decimal point. Thus, if 75 seconds are required to fly a 10° bearing change, the aircraft is 7.5 minutes from the station. When the bearing pointer is moving rapidly or when several corrections are required to place the pointer on the wingtip position, the aircraft is at station passage.

The distance from the station is computed by multiplying TAS or GS (in miles per minute) by the previously determined time in minutes. For example, if the aircraft is 7.5 minutes from station, flying at a TAS of 120 knots or 2 NM per minute, the distance from station is 15 NM (7.5 x 2 = 15).

The preceding are methods of computing approximate time and distance. The accuracy of time and distance checks is governed by existing wind, degree of bearing change, and accuracy of timing. The number of variables involved causes the result to be only an approximation. However, by flying an accurate heading and checking the time and bearing closely, the pilot can make a reasonable estimate of time and distance from the station.

Course Intercept

Course interceptions are performed in most phases of instrument navigation. The equipment used varies, but an intercept heading must be flown that results in an angle or rate of intercept sufficient to solve a particular problem.

Rate of Intercept

Rate of intercept, seen by the aviator as bearing pointer or HSI movement, is a result of the following factors:

- The angle at which the aircraft is flown toward a desired course (angle of intercept)
- True airspeed and wind (GS)
- Distance from the station

Angle of Intercept

The angle of intercept is the angle between the heading of the aircraft (intercept heading) and desired course. Controlling this angle by selection/adjustment of the intercept heading is the easiest and most effective way to control course interceptions. Angle of intercept must be greater than the degrees from course, but should not exceed 90°. Within this limit, adjust to achieve the most desirable rate of intercept.

When selecting an intercept heading, the key factor is the relationship between distance from the station and degrees from the course. Each degree, or radial, is 1 NM wide at a distance of 60 NM from the station. Width increases or decreases in proportion to the 60 NM distance. For example, 1 degree is 2 NM wide at 120 NM—and ½ NM wide at 30 NM. For a given GS and angle of intercept, the resultant rate of intercept varies according to the distance from the station. When selecting an intercept heading to form an angle of intercept, consider the following factors:

- Degrees from course
- Distance from the station
- True airspeed and wind (GS)

Distance Measuring Equipment (DME)

Distance measuring equipment (DME) consists of an ultra high frequency (UHF) navigational aid with VOR/DMEs and VORTACs. It measures, in NM, the slant range distance of an aircraft from a VOR/DME or VORTAC (both hereafter referred to as a VORTAC). Although DME equipment is very popular, not all aircraft are DME equipped.

To utilize DME, the pilot should select, tune, and identify a VORTAC, as previously described. The DME receiver, utilizing what is called a "paired frequency" concept, automatically selects and tunes the UHF DME frequency associated with the VHF VORTAC frequency selected by the pilot. This process is entirely transparent to the pilot. After a brief pause, the DME display shows the slant range distance to or from the VORTAC. Slant range distance is the direct distance between the aircraft and the VORTAC, and is therefore affected by aircraft altitude. (Station passage directly over a VORTAC from an altitude of 6,076 feet above ground level (AGL) would show approximately 1.0 NM on the DME.) DME is a very useful adjunct to VOR navigation. A VOR radial alone merely gives line of position information. With DME, a pilot may precisely locate the aircraft on that line (radial).

Most DME receivers also provide GS and time-to-station modes of operation. The GS is displayed in knots (NMPH). The time-to-station mode displays the minutes remaining to VORTAC station passage, predicated upon the present GS. GS and time-to-station information is only accurate when tracking directly to or from a VORTAC. DME receivers typically need a minute or two of stabilized flight directly to or from a VORTAC before displaying accurate GS or time-to-station information.

Some DME installations have a hold feature that permits a DME signal to be retained from one VORTAC while the course indicator displays course deviation information from an ILS or another VORTAC.

VOR/DME RNAV

Area navigation (RNAV) permits electronic course guidance on any direct route between points established by the pilot. While RNAV is a generic term that applies to a variety of navigational aids, such as LORAN-C, GPS, and others, this section deals with VOR/DME-based RNAV. VOR/DME RNAV is not a separate ground-based NAVAID, but a method of navigation using VOR/DME and VORTAC signals specially processed by the aircraft's RNAV computer. *[Figure 15-34]*

NOTE: In this section, the term "VORTAC" also includes VOR/DME NAVAIDs.

In its simplest form, VOR/DME RNAV allows the pilot to electronically move VORTACs around to more convenient locations. Once electronically relocated, they are referred to as waypoints. These waypoints are described as a

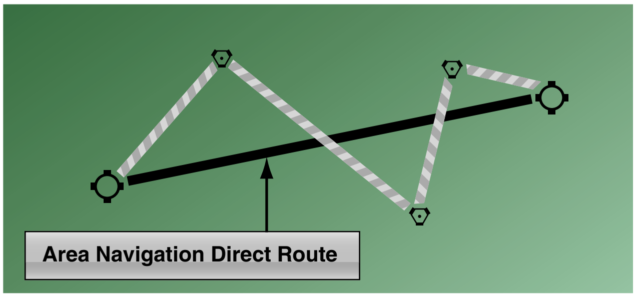


Figure 15-34. *Flying an RNAV course.*

combination of a selected radial and distance within the service volume of the VORTAC to be used. These waypoints allow a straight course to be flown between almost any origin and destination, without regard to the orientation of VORTACs or the existence of airways.

While the capabilities and methods of operation of VOR/DME RNAV units differ, there are basic principles of operation that are common to all. Pilots are urged to study the manufacturer's operating guide and receive instruction prior to the use of VOR/DME RNAV or any unfamiliar navigational system. Operational information and limitations should also be sought from placards and the supplement section of the AFM/POH.

VOR/DME-based RNAV units operate in at least three modes: VOR, en route, and approach. A fourth mode, VOR Parallel, may also be found on some models. The units need both VOR and DME signals to operate in any RNAV mode. If the NAVAID selected is a VOR without DME, RNAV mode will not function.

In the VOR (or non-RNAV) mode, the unit simply functions as a VOR receiver with DME capability. *[Figure 15-35]* The unit's display on the VOR indicator is conventional in all respects. For operation on established airways or any other ordinary VOR navigation, the VOR mode is used.

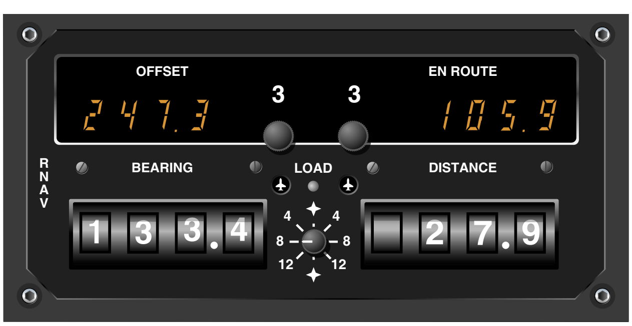


Figure 15-35. *RNAV controls.*

To utilize the unit's RNAV capability, the pilot selects and establishes a waypoint or a series of waypoints to define a course. To operate in any RNAV mode, the unit needs both radial and distance signals; therefore, a VORTAC (or VOR/DME) needs to be selected as a NAVAID. To establish a waypoint, a point somewhere within the service range of a VORTAC is defined on the basis of radial and distance. Once the waypoint is entered into the unit and the RNAV en route mode is selected, the CDI displays course guidance to the waypoint, not the original VORTAC. DME also displays distance to the waypoint. Many units have the capability to store several waypoints, allowing them to be programmed prior to flight, if desired, and called up in flight.

RNAV waypoints are entered into the unit in magnetic bearings (radials) of degrees and tenths (i.e., 275.5°) and distances in NM and tenths (i.e., 25.2 NM). When plotting RNAV waypoints on an aeronautical chart, pilots find it difficult to measure to that level of accuracy, and in practical application, it is rarely necessary. A number of flight planning publications publish airport coordinates and waypoints with this precision and the unit accepts those figures. There is a subtle, but important difference in CDI operation and display in the RNAV modes.

In the RNAV modes, course deviation is displayed in terms of linear deviation. In the RNAV en route mode, maximum deflection of the CDI typically represents 5 NM on either side of the selected course, without regard to distance from the waypoint. In the RNAV approach mode, maximum deflection of the CDI typically represents 1¼ NM on either side of the selected course. There is no increase in CDI sensitivity as the aircraft approaches a waypoint in RNAV mode.

The RNAV approach mode is used for instrument approaches. Its narrow scale width (¼ of the en route mode) permits very precise tracking to or from the selected waypoint. In visual flight rules (VFR) cross-country navigation, tracking a course in the approach mode is not desirable because it requires a great deal of attention and soon becomes tedious.

A fourth, lesser-used mode on some units is the VOR Parallel mode. This permits the CDI to display linear (not angular) deviation as the aircraft tracks to and from VORTACs. It derives its name from permitting the pilot to offset (or parallel) a selected course or airway at a fixed distance of the pilot's choosing, if desired. The VOR parallel mode has the same effect as placing a waypoint directly over an existing VORTAC. Some pilots select the VOR parallel mode when utilizing the navigation (NAV) tracking function of their autopilot for smoother course following near the VORTAC.

Confusion is possible when navigating an aircraft with VOR/DME-based RNAV, and it is essential that the pilot become familiar with the equipment installed. It is not unknown for pilots to operate inadvertently in one of the RNAV modes when the operation was not intended by overlooking switch positions or annunciators. The reverse has also occurred with a pilot neglecting to place the unit into one of the RNAV modes by overlooking switch positions or annunciators. As always, the prudent pilot is not only familiar with the equipment used, but never places complete reliance in just one method of navigation when others are available for cross-check.

Automatic Direction Finder (ADF)

Many general aviation-type aircraft are equipped with ADF radio receiving equipment. To navigate using the ADF, the pilot tunes the receiving equipment to a ground station known as a nondirectional radio beacon (NDB). The NDB stations normally operate in a low or medium frequency band of 200 to 415 kHz. The frequencies are readily available on aeronautical charts or in the A/FD.

All radio beacons except compass locators transmit a continuous three-letter identification in code except during voice transmissions. A compass locator, which is associated with an instrument landing system, transmits a two-letter identification.

Standard broadcast stations can also be used in conjunction with ADF. Positive identification of all radio stations is extremely important and this is particularly true when using standard broadcast stations for navigation.

NDBs have one advantage over the VOR. This advantage is that low or medium frequencies are not affected by line-of-sight. The signals follow the curvature of the Earth; therefore, if the aircraft is within the range of the station, the signals can be received regardless of altitude.

The following table gives the class of NDB stations, their power, and usable range:

NONDIRECTIONAL RADIOBEACON (NDB)
(Usable Radius Distances for All Altitudes)

Class	Power (Watts)	Distance (Miles)
Compass Locator	Under 25	15
MH	Under 50	25
H	50–1999	*50
HH	2000 or more	75

*Service range of individual facilities may be less than 50 miles.

One of the disadvantages that should be considered when using low frequency (LF) for navigation is that low frequency signals are very susceptible to electrical disturbances, such as lightning. These disturbances create excessive static, needle deviations, and signal fades. There may be interference from distant stations. Pilots should know the conditions under which these disturbances can occur so they can be more alert to possible interference when using the ADF.

Basically, the ADF aircraft equipment consists of a tuner, which is used to set the desired station frequency, and the navigational display.

The navigational display consists of a dial upon which the azimuth is printed, and a needle which rotates around the dial and points to the station to which the receiver is tuned.

Some of the ADF dials can be rotated to align the azimuth with the aircraft heading; others are fixed with 0° representing the nose of the aircraft, and 180° representing the tail. Only the fixed azimuth dial is discussed in this handbook. *[Figure 15-36]*

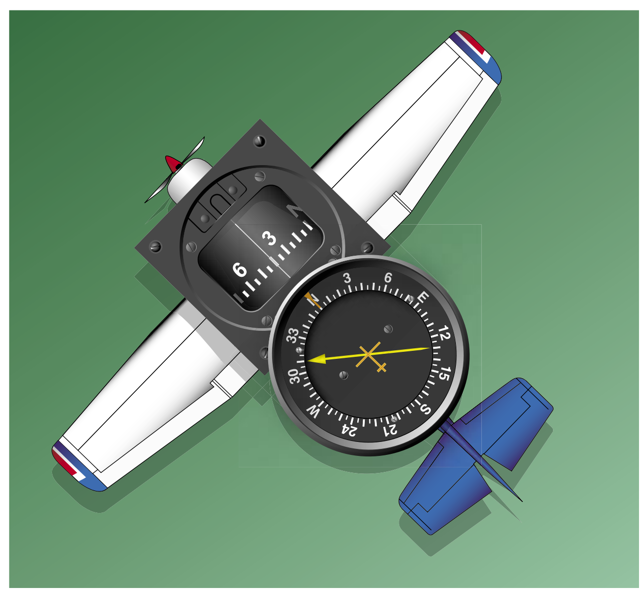


Figure 15-36. *ADF with fixed azimuth and magnetic compass.*

Figure 15-37 illustrates terms that are used with the ADF and should be understood by the pilot.

To determine the magnetic bearing "FROM" the station, 180° is added to or subtracted from the magnetic bearing to the station. This is the reciprocal bearing and is used when plotting position fixes.

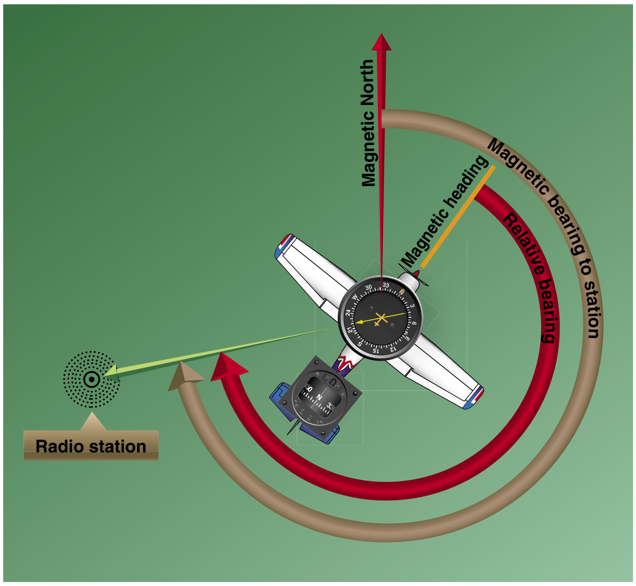


Figure 15-37. *ADF terms.*

Keep in mind that the needle of fixed azimuth points to the station in relation to the nose of the aircraft. If the needle is deflected 30° to the left for a relative bearing of 330°, this means that the station is located 30° left. If the aircraft is turned left 30°, the needle moves to the right 30° and indicates a relative bearing of 0°, or the aircraft is pointing toward the station. If the pilot continues flight toward the station keeping the needle on 0°, the procedure is called homing to the station. If a crosswind exists, the ADF needle continues to drift away from zero. To keep the needle on zero, the aircraft must be turned slightly resulting in a curved flightpath to the station. Homing to the station is a common procedure, but results in drifting downwind, thus lengthening the distance to the station.

Tracking to the station requires correcting for wind drift and results in maintaining flight along a straight track or bearing to the station. When the wind drift correction is established, the ADF needle indicates the amount of correction to the right or left. For instance, if the magnetic bearing to the station is 340°, a correction for a left crosswind would result in a magnetic heading of 330°, and the ADF needle would indicate 10° to the right or a relative bearing of 010°. *[Figure 15-38]*

When tracking away from the station, wind corrections are made similar to tracking to the station, but the ADF needle points toward the tail of the aircraft or the 180° position on the azimuth dial. Attempting to keep the ADF needle on the 180° position during winds results in the aircraft flying a curved flight leading further and further from the desired track. To correct for wind when tracking outbound, correction should be made in the direction opposite of that in which the needle is pointing.

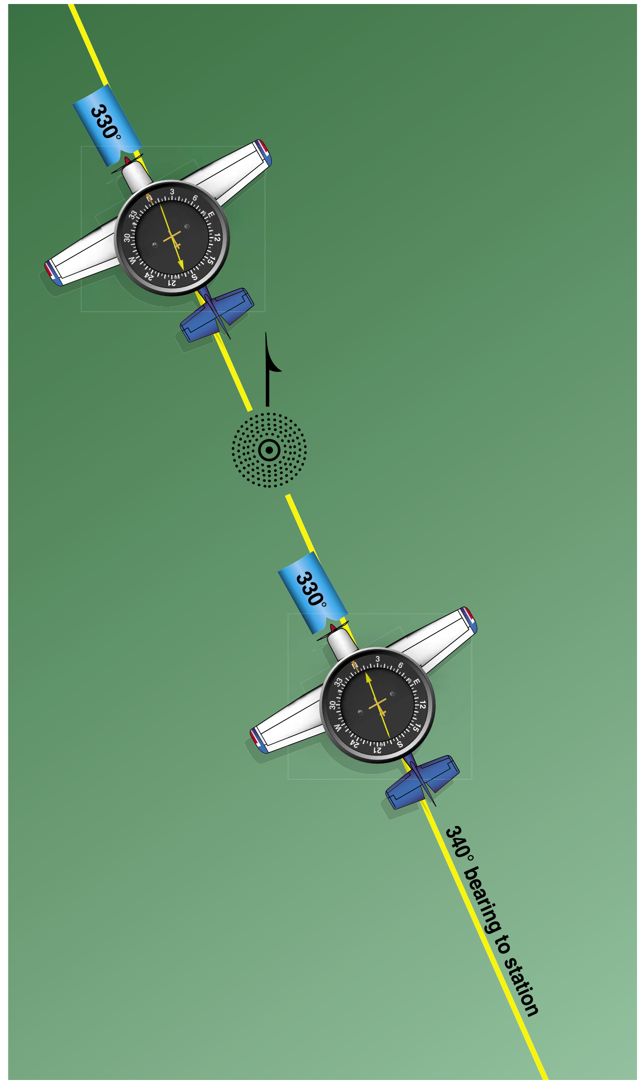


Figure 15-38. *ADF tracking.*

Although the ADF is not as popular as the VOR for radio navigation, with proper precautions and intelligent use, the ADF can be a valuable aid to navigation.

Loran-C Navigation

Long range navigation, version C (LORAN-C) is another form of RNAV, but one that operates from chains of transmitters broadcasting signals in the LF spectrum. World Aeronautical Chart (WAC), sectional charts, and VFR terminal area charts do not show the presence of LORAN-C transmitters. Selection of a transmitter chain is either made automatically by the unit, or manually by the pilot using guidance information provided by the manufacturer. LORAN-C is a highly accurate, supplemental form of navigation typically installed as an adjunct to VOR and ADF equipment. Databases of airports, NAVAIDs, and ATC facilities are frequently features of LORAN-C receivers.

LORAN-C is an outgrowth of the original LORAN-A developed for navigation during World War II. The LORAN-C system is used extensively in maritime applications. It experienced a dramatic growth in popularity with pilots with the advent of the small, panel-mounted LORAN-C receivers available at relatively low cost. These units are frequently very sophisticated and capable, with a wide variety of navigational functions.

With high levels of LORAN-C sophistication and capability, a certain complexity in operation is an unfortunate necessity. Pilots are urged to read the operating handbooks and to consult the supplements section of the AFM/POH prior to utilizing LORAN-C for navigation. Many units offer so many features that the manufacturers often publish two different sets of instructions: (1) a brief operating guide and (2) in-depth operating manual.

While coverage is not global, LORAN-C signals are suitable for navigation in all of the conterminous United States, and parts of Canada and Alaska. Several foreign countries also operate their own LORAN-C systems. In the United States, the U.S. Coast Guard operates the LORAN-C system. LORAN-C system status is available from: USCG Navigation Center, Alexandria, Virginia at (703) 313-5900.

LORAN-C absolute accuracy is excellent—position errors are typically less than .25 NM. Repeatable accuracy, or the ability to return to a waypoint previously visited, is even better. While LORAN-C is a form of RNAV, it differs significantly from VOR/DME-based RNAV. It operates in a 90–110 kHz frequency range and is based upon measurement of the difference in arrival times of pulses of radio frequency (RF) energy emitted by a chain of transmitters hundreds of miles apart.

Within any given chain of transmitters, there is a master station, and from three to five secondary stations. LORAN-C units must be able to receive at least a master and two secondary stations to provide navigational information. Unlike VOR/DME-based RNAV, where the pilot must select the appropriate VOR/DME or VORTAC frequency, there is not a frequency selection in LORAN-C. The most advanced units automatically select the optimum chain for navigation. Other units rely upon the pilot to select the appropriate chain with a manual entry.

After the LORAN-C receiver has been turned on, the unit must be initialized before it can be used for navigation. While this can be accomplished in flight, it is preferable to perform this task, which can take several minutes, on the ground. The methods for initialization are as varied as the number of different models of receivers. Some require pilot input during the process, such as verification or acknowledgment of the information displayed.

Most units contain databases of navigational information. Frequently, such databases contain not only airport and NAVAID locations, but also extensive airport, airspace, and ATC information. While the unit can operate with an expired database, the information should be current or verified to be correct prior to use. The pilot can update some databases, while others require removal from the aircraft and the services of an avionics technician.

VFR navigation with LORAN-C can be as simple as telling the unit where the pilot wishes to go. The course guidance provided is a great circle (shortest distance) route to the destination. Older units may need a destination entered in terms of latitude and longitude, but recent designs need only the identifier of the airport or NAVAID. The unit also permits database storage and retrieval of pilot defined waypoints. LORAN-C signals follow the curvature of the Earth and are generally usable hundreds of miles from their transmitters.

The LORAN-C signal is subject to degradation from a variety of atmospheric disturbances. It is also susceptible to interference from static electricity buildup on the airframe and electrically "noisy" airframe equipment. Flight in precipitation or even dust clouds can cause occasional interference with navigational guidance from LORAN-C signals. To minimize these effects, static wicks and bonding straps should be installed and properly maintained.

LORAN-C navigation information is presented to the pilot in a variety of ways. All units have self-contained displays, and some elaborate units feature built-in moving map displays. Some installations can also drive an external moving map display, a conventional VOR indicator, or a horizontal situation indicator (HSI). Course deviation information is presented as a linear deviation from course—there is no increase in tracking sensitivity as the aircraft approaches the waypoint or destination. Pilots must carefully observe placards, selector switch positions, and annunciator indications when utilizing LORAN-C because aircraft installations can vary widely. The pilot's familiarity with unit operation through AFM/POH supplements and operating guides cannot be overemphasized.

LORAN-C Notices to Airmen (NOTAMs) should be reviewed prior to relying on LORAN-C for navigation. LORAN-C NOTAMs are issued to announce outages for specific chains and transmitters. Pilots may obtain LORAN-C NOTAMs from FSS briefers only upon request.

The prudent pilot never relies solely on one means of navigation when others are available for backup and cross-check. Pilots should never become so dependent upon the extensive capabilities of LORAN-C that other methods of navigation are neglected.

Global Positioning System

The GPS is a satellite-based radio navigation system. Its RNAV guidance is worldwide in scope. There are no symbols for GPS on aeronautical charts as it is a space-based system with global coverage. Development of the system is underway so that GPS is capable of providing the primary means of electronic navigation. Portable and yoke mounted units are proving to be very popular in addition to those permanently installed in the aircraft. Extensive navigation databases are common features in aircraft GPS receivers.

The GPS is a satellite radio navigation and time dissemination system developed and operated by the U.S. Department of Defense (DOD). Civilian interface and GPS system status is available from the U.S. Coast Guard.

It is not necessary to understand the technical aspects of GPS operation to use it in VFR/instrument flight rules (IFR) navigation. It does differ significantly from conventional, ground-based electronic navigation, and awareness of those differences is important. Awareness of equipment approvals and limitations is critical to the safety of flight.

The GPS navigation system broadcasts a signal that is used by receivers to determine precise position anywhere in the world. The receiver tracks multiple satellites and determines a pseudorange measurement to determine the user location. A minimum of four satellites is necessary to establish an accurate three-dimensional position. The Department of Defense (DOD) is responsible for operating the GPS satellite constellation and monitors the GPS satellites to ensure proper operation.

The status of a GPS satellite is broadcast as part of the data message transmitted by the satellite. GPS status information is also available by means of the U.S. Coast Guard navigation information service at (703) 313-5907 or online at http://www.navcen.uscg.gov/. Additionally, satellite status is available through the Notice to Airmen (NOTAM) system.

The GPS receiver verifies the integrity (usability) of the signals received from the GPS constellation through receiver autonomous integrity monitoring (RAIM) to determine if a satellite is providing corrupted information. At least one satellite, in addition to those required for navigation, must be in view for the receiver to perform the RAIM function; thus, RAIM needs a minimum of five satellites in view, or four satellites and a barometric altimeter (baro-aiding) to detect an integrity anomaly. For receivers capable of doing so, RAIM needs six satellites in view (or five satellites with baro-aiding) to isolate the corrupt satellite signal and remove it from the navigation solution. Baro-aiding is a method of augmenting the GPS integrity solution by using a nonsatellite input source. GPS derived altitude should not be relied upon to determine aircraft altitude since the vertical error can be quite large and no integrity is provided. To ensure that baro-aiding is available, the current altimeter setting must be entered into the receiver as described in the operating manual.

RAIM messages vary somewhat between receivers; however, generally there are two types. One type indicates that there are not enough satellites available to provide RAIM integrity monitoring and another type indicates that the RAIM integrity monitor has detected a potential error that exceeds the limit for the current phase of flight. Without RAIM capability, the pilot has no assurance of the accuracy of the GPS position.

Selective Availability

Selective Availability (SA) is a method by which the accuracy of GPS is intentionally degraded. This feature is designed to deny hostile use of precise GPS positioning data. SA was discontinued on May 1, 2000, but many GPS receivers are designed to assume that SA is still active.

The GPS constellation of 24 satellites is designed so that a minimum of five satellites are always observable by a user anywhere on earth. The receiver uses data from a minimum of four satellites above the mask angle (the lowest angle above the horizon at which a receiver can use a satellite).

VFR Use of GPS

GPS navigation has become a great asset to VFR pilots, providing increased navigation capability and enhanced situational awareness, while reducing operating costs due to greater ease in flying direct routes. While GPS has many benefits to the VFR pilot, care must be exercised to ensure that system capabilities are not exceeded.

Types of receivers used for GPS navigation under VFR are varied, from a full IFR installation being used to support a VFR flight, to a VFR only installation (in either a VFR or IFR capable aircraft) to a hand-held receiver. The limitations of each type of receiver installation or use must be understood by the pilot to avoid misusing navigation information. In all cases, VFR pilots should never rely solely on one system of navigation. GPS navigation must be integrated with other forms of electronic navigation as well as pilotage and dead reckoning. Only through the integration of these techniques can the VFR pilot ensure accuracy in navigation.

Some critical concerns in VFR use of GPS include RAIM capability, database currency and antenna location.

RAIM Capability

Many VFR GPS receivers and all hand-held units have no RAIM alerting capability. Loss of the required number of satellites in view, or the detection of a position error, cannot be displayed to the pilot by such receivers. In receivers with no RAIM capability, no alert would be provided to the pilot that the navigation solution had deteriorated, and an undetected navigation error could occur. A systematic cross-check with other navigation techniques would identify this failure, and prevent a serious deviation.

In many receivers, an up-datable database is used for navigation fixes, airports, and instrument procedures. These databases must be maintained to the current update for IFR operation, but no such requirement exists for VFR use. However, in many cases, the database drives a moving map display which indicates Special Use Airspace and the various classes of airspace, in addition to other operational information. Without a current database the moving map display may be outdated and offer erroneous information to VFR pilots wishing to fly around critical airspace areas, such as a Restricted Area or a Class B airspace segment. Numerous pilots have ventured into airspace they were trying to avoid by using an outdated database. If there is not a current data base in the receiver, disregard the moving map display when making critical navigation decisions.

In addition, waypoints are added, removed, relocated, or re-named as required to meet operational needs. When using GPS to navigate relative to a named fix, a current database must be used to properly locate a named waypoint. Without the update, it is the pilot's responsibility to verify the waypoint location referencing to an official current source, such as the A/FD, sectional chart, or en route chart.

In many VFR installations of GPS receivers, antenna location is more a matter of convenience than performance. In IFR installations, care is exercised to ensure that an adequate clear view is provided for the antenna to see satellites. If an alternate location is used, some portion of the aircraft may block the view of the antenna, causing a greater opportunity to lose navigation signal.

This is especially true in the case of hand-helds. The use of hand-held receivers for VFR operations is a growing trend, especially among rental pilots. Typically, suction cups are used to place the GPS antennas on the inside of aircraft windows. While this method has great utility, the antenna location is limited by aircraft structure for optimal reception of available satellites. Consequently, signal losses may occur in certain situations of aircraft-satellite geometry, causing a loss of navigation signal. These losses, coupled with a lack of RAIM capability, could present erroneous position and navigation information with no warning to the pilot.

While the use of a hand-held GPS for VFR operations is not limited by regulation, modification of the aircraft, such as installing a panel- or yoke-mounted holder, is governed by 14 CFR part 43. Pilots should consult with a mechanic to ensure compliance with the regulation and a safe installation.

Tips for Using GPS for VFR Operations

Always check to see if the unit has RAIM capability. If no RAIM capability exists, be suspicious of a GPS displayed position when any disagreement exists with the position derived from other radio navigation systems, pilotage, or dead reckoning.

Check the currency of the database, if any. If expired, update the database using the current revision. If an update of an expired database is not possible, disregard any moving map display of airspace for critical navigation decisions. Be aware that named waypoints may no longer exist or may have been relocated since the database expired. At a minimum, the waypoints planned to be used should be checked against a current official source, such as the A/FD, or a Sectional Aeronautical Chart.

While a hand-held GPS receiver can provide excellent navigation capability to VFR pilots, be prepared for intermittent loss of navigation signal, possibly with no RAIM warning to the pilot. If mounting the receiver in the aircraft, be sure to comply with 14 CFR part 43.

Plan flights carefully before taking off. If navigating to user-defined waypoints, enter them before flight, not on the fly. Verify the planned flight against a current source, such as a current sectional chart. There have been cases in which one pilot used waypoints created by another pilot that were not where the pilot flying was expecting. This generally resulted in a navigation error. Minimize head-down time in the aircraft and keep a sharp lookout for traffic, terrain, and obstacles. Just a few minutes of preparation and planning on the ground makes a great difference in the air.

Another way to minimize head-down time is to become very familiar with the receiver's operation. Most receivers are not intuitive. The pilot must take the time to learn the various keystrokes, knob functions, and displays that are used in the operation of the receiver. Some manufacturers provide computer-based tutorials or simulations of their receivers. Take the time to learn about the particular unit before using it in flight.

In summary, be careful not to rely on GPS to solve all VFR navigational problems. Unless an IFR receiver is installed in accordance with IFR requirements, no standard of accuracy or integrity has been assured. While the practicality of GPS is compelling, the fact remains that only the pilot can navigate the aircraft, and GPS is just one of the pilot's tools to do the job.

VFR Waypoints

VFR waypoints provide VFR pilots with a supplementary tool to assist with position awareness while navigating visually in aircraft equipped with area navigation receivers. VFR waypoints should be used as a tool to supplement current navigation procedures. The uses of VFR waypoints include providing navigational aids for pilots unfamiliar with an area, waypoint definition of existing reporting points, enhanced navigation in and around Class B and Class C airspace, and enhanced navigation around Special Use Airspace. VFR pilots should rely on appropriate and current aeronautical charts published specifically for visual navigation. If operating in a terminal area, pilots should take advantage of the Terminal Area Chart available for that area, if published. The use of VFR waypoints does not relieve the pilot of any responsibility to comply with the operational requirements of 14 CFR part 91.

VFR waypoint names (for computer entry and flight plans) consist of five letters beginning with the letters "VP" and are retrievable from navigation databases. The VFR waypoint names are not intended to be pronounceable, and they are not for use in ATC communications. On VFR charts, a stand-alone VFR waypoint is portrayed using the same four-point star symbol used for IFR waypoints. VFR waypoint collocated with a visual checkpoint on the chart is identified by a small magenta flag symbol. A VFR waypoint collocated with a visual checkpoint is pronounceable based on the name of the visual checkpoint and may be used for ATC communications. Each VFR waypoint name appears in parentheses adjacent to the geographic location on the chart. Latitude/longitude data for all established VFR waypoints may be found in the appropriate regional A/FD.

When filing VFR flight plans, use the five-letter identifier as a waypoint in the route of flight section if there is an intended course change at that point or if used to describe the planned route of flight. This VFR filing would be similar to VOR use in a route of flight. Pilots must use the VFR waypoints only when operating under VFR conditions.

Any VFR waypoints intended for use during a flight should be loaded into the receiver while on the ground and prior to departure. Once airborne, pilots should avoid programming routes or VFR waypoint chains into their receivers.

Pilots should be especially vigilant for other traffic while operating near VFR waypoints. The same effort to see and avoid other aircraft near VFR waypoints is necessary, as is the case when operating near VORs and NDBs. In fact, the increased accuracy of navigation through the use of GPS demands even greater vigilance, as off-course deviations among different pilots and receivers is less. When operating near a VFR waypoint, use whatever ATC services are available, even if outside a class of airspace where communications are required. Regardless of the class of airspace, monitor the available ATC frequency closely for information on other aircraft operating in the vicinity. It is also a good idea to turn on landing light(s) when operating near a VFR waypoint to make the aircraft more conspicuous to other pilots, especially when visibility is reduced.

Lost Procedures

Getting lost in an aircraft is a potentially dangerous situation especially when low on fuel. If a pilot becomes lost, there are some good common sense procedures to follow. If a town or city cannot be seen, the first thing to do is climb, being mindful of traffic and weather conditions. An increase in altitude increases radio and navigation reception range, and also increases radar coverage. If flying near a town or city, it might be possible to read the name of the town on a water tower.

If the aircraft has a navigational radio, such as a VOR or ADF receiver, it can be possible to determine position by plotting an azimuth from two or more navigational facilities. If GPS is installed, or a pilot has a portable aviation GPS on board, it can be used to determine the position and the location of the nearest airport.

Communicate with any available facility using frequencies shown on the sectional chart. If contact is made with a controller, radar vectors may be offered. Other facilities may offer direction finding (DF) assistance. To use this procedure, the controller requests the pilot to hold down the transmit button for a few seconds and then release it. The controller may ask the pilot to change directions a few times and repeat the transmit procedure. This gives the controller enough information to plot the aircraft position and then give vectors to a suitable landing site. If the situation becomes threatening, transmit the situation on the emergency frequency 121.5 MHz and set the transponder to 7700. Most facilities, and even airliners, monitor the emergency frequency.

Flight Diversion

There probably comes a time when a pilot is not able to make it to the planned destination. This can be the result of unpredicted weather conditions, a system malfunction, or poor preflight planning. In any case, the pilot needs to be able to safely and efficiently divert to an alternate destination. Before any cross-country flight, check the charts for airports or suitable landing areas along or near the route of flight. Also, check for navigational aids that can be used during a diversion.

Computing course, time, speed, and distance information in flight requires the same computations used during preflight planning. However, because of the limited flight deck space, and because attention must be divided between flying the aircraft, making calculations, and scanning for other aircraft, take advantage of all possible shortcuts and rule-of-thumb computations.

When in flight, it is rarely practical to actually plot a course on a sectional chart and mark checkpoints and distances. Furthermore, because an alternate airport is usually not very far from your original course, actual plotting is seldom necessary.

A course to an alternate can be measured accurately with a protractor or plotter, but can also be measured with reasonable accuracy using a straightedge and the compass rose depicted around VOR stations. This approximation can be made on the basis of a radial from a nearby VOR or an airway that closely parallels the course to your alternate. However, remember that the magnetic heading associated with a VOR radial or printed airway is outbound from the station. To find the course TO the station, it may be necessary to determine the reciprocal of that heading. It is typically easier to navigate to an alternate airport that has a VOR or NDB facility on the field.

After selecting the most appropriate alternate, approximate the magnetic course to the alternate using a compass rose or airway on the sectional chart. If time permits, try to start the diversion over a prominent ground feature. However, in an emergency, divert promptly toward your alternate. Attempting to complete all plotting, measuring, and computations involved before diverting to the alternate may only aggravate an actual emergency.

Once established on course, note the time, and then use the winds aloft nearest to your diversion point to calculate a heading and GS. Once a GS has been calculated, determine a new arrival time and fuel consumption. Give priority to flying the aircraft while dividing attention between navigation and planning. When determining an altitude to use while diverting, consider cloud heights, winds, terrain, and radio reception.

Chapter Summary

This chapter has discussed the fundamentals of VFR navigation. Beginning with an introduction to the charts that can be used for navigation to the more technically advanced concept of GPS, there is one aspect of navigation that remains the same. The pilot is responsible for proper planning and the execution of that planning to ensure a safe flight.