Chapter 10

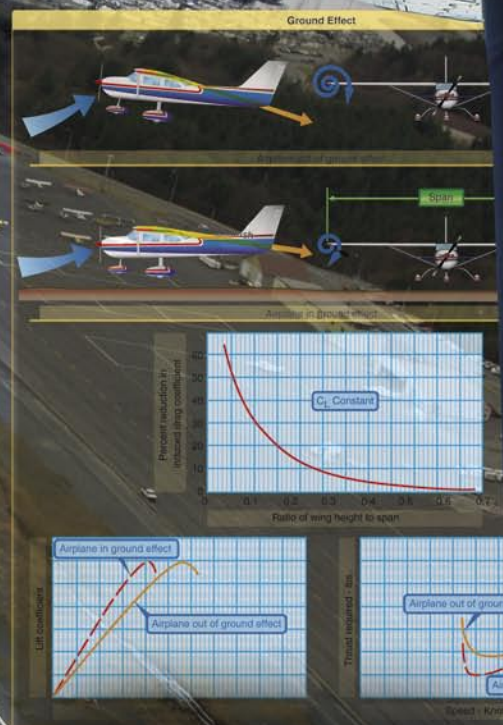
Aircraft Performance

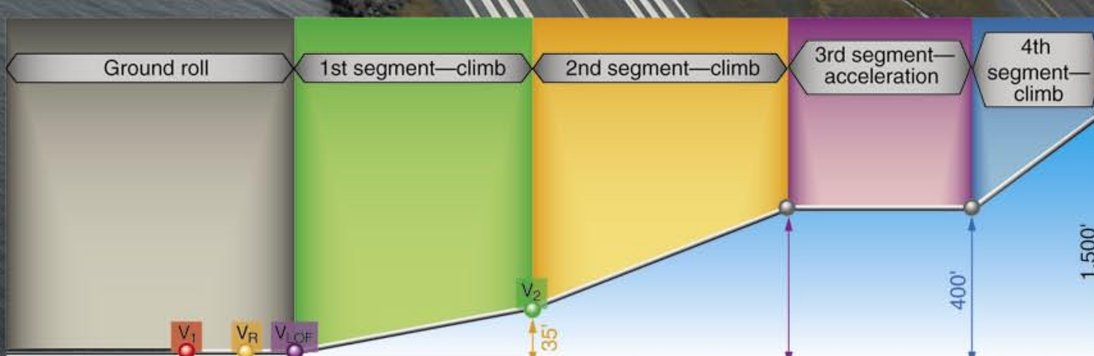
Introduction

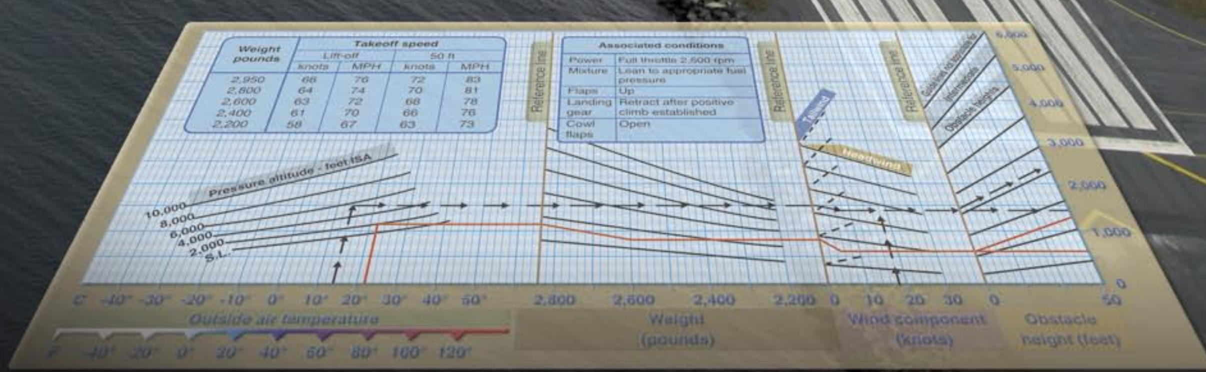
This chapter discusses the factors that affect aircraft performance, which include the aircraft weight, atmospheric conditions, runway environment, and the fundamental physical laws governing the forces acting on an aircraft.

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]*

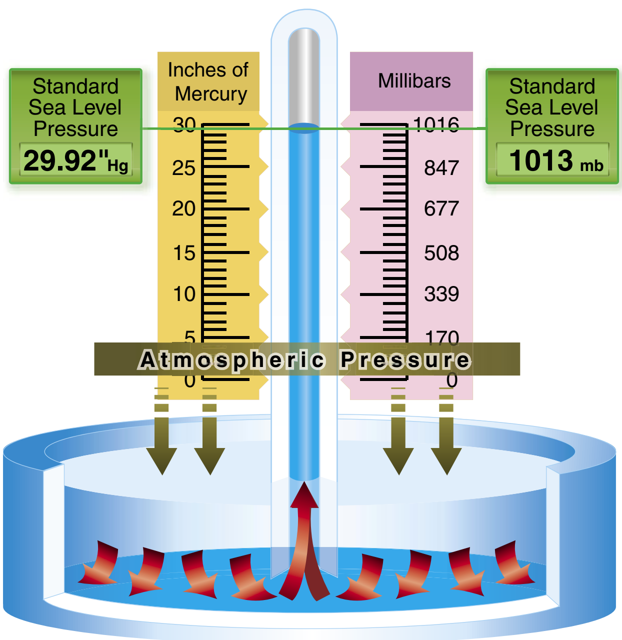


Figure 10-1. *Standard sea level pressure.*

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 (28.0–29.92); Subtract (30.0–31.0); 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.*

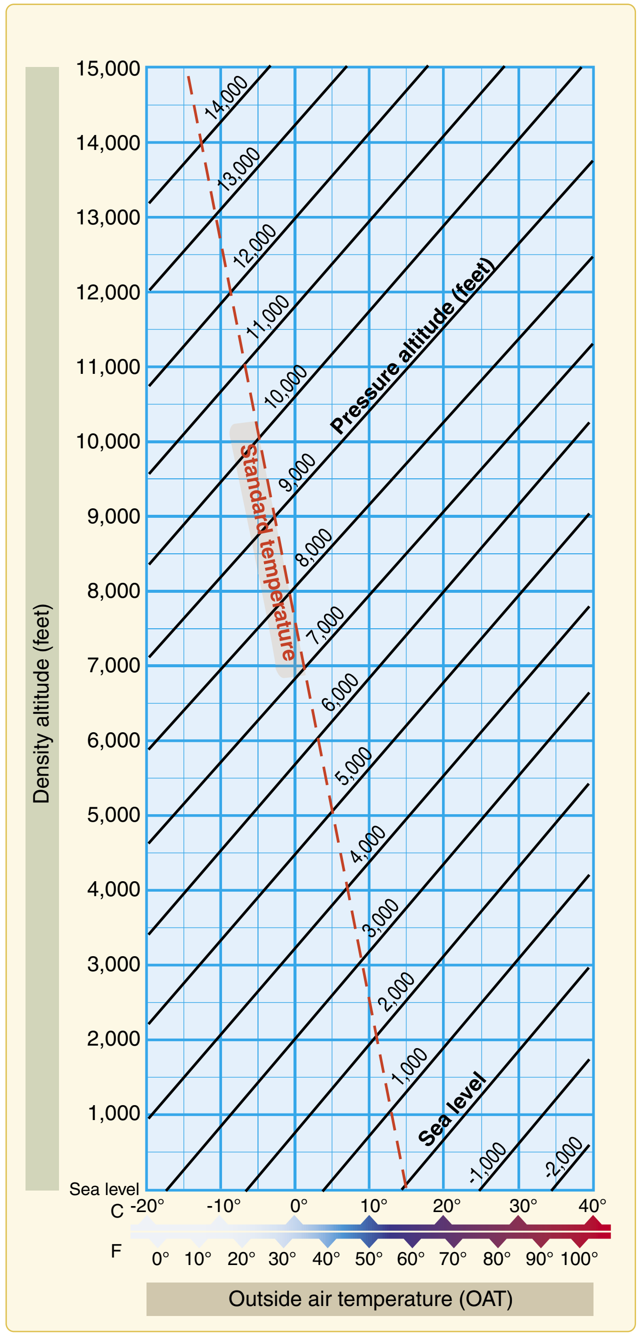


Figure 10-4. *Density altitude chart.*

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,

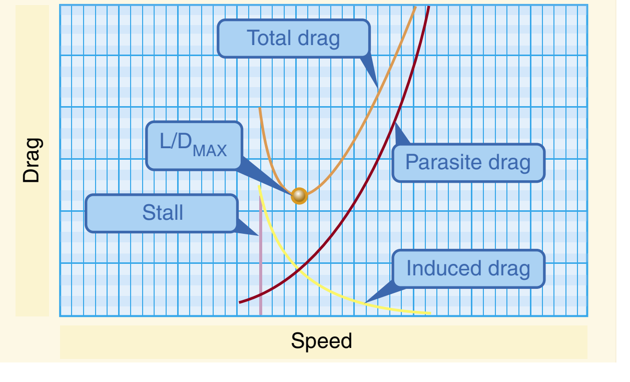


Figure 10-5. *Drag versus speed.*

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.

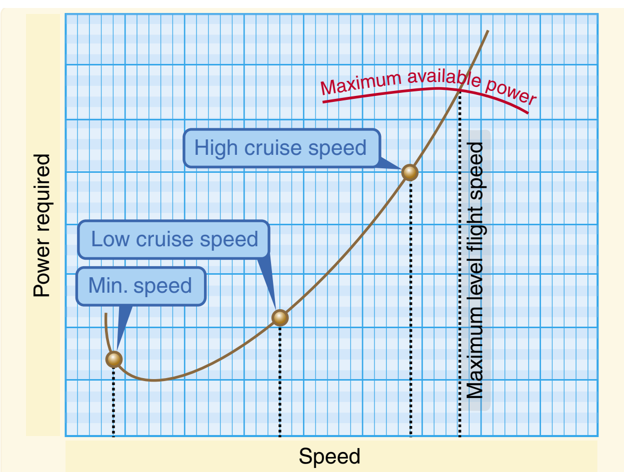


Figure 10-6. *Power versus speed.*

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.

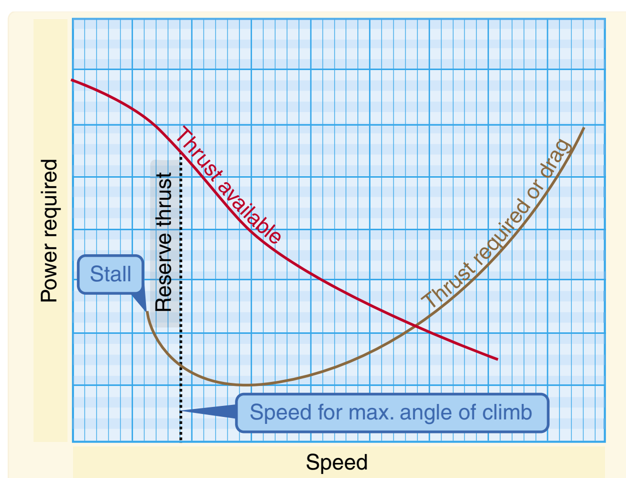


Figure 10-7. *Thrust versus climb angle.*

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.

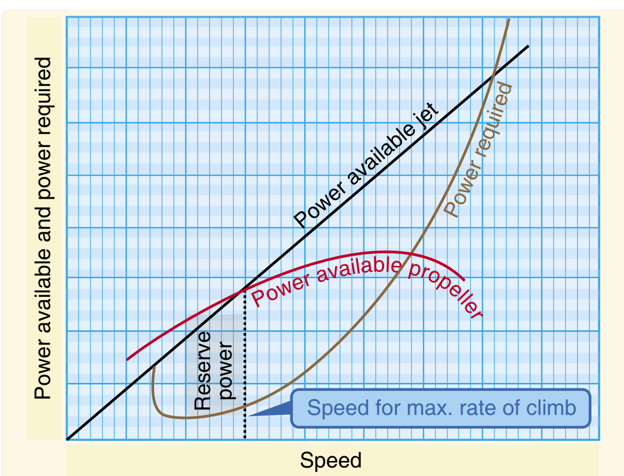


Figure 10-8. *Power versus climb rate.*

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.

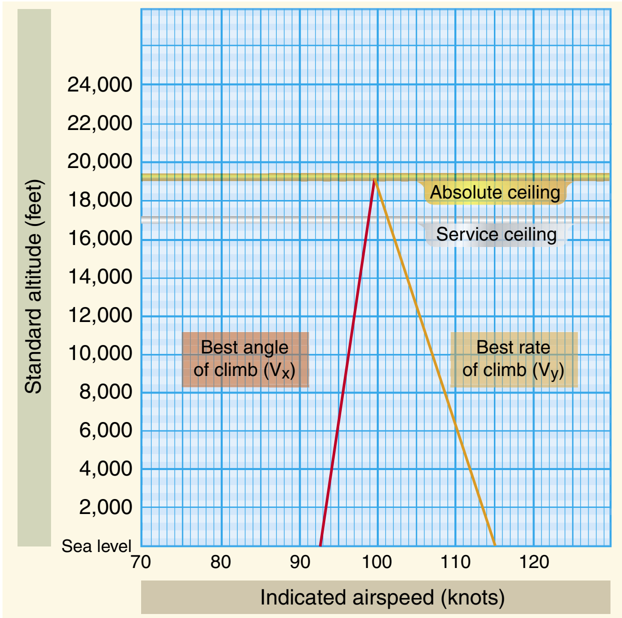


Figure 10-9. *Absolute and service ceiling.*

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

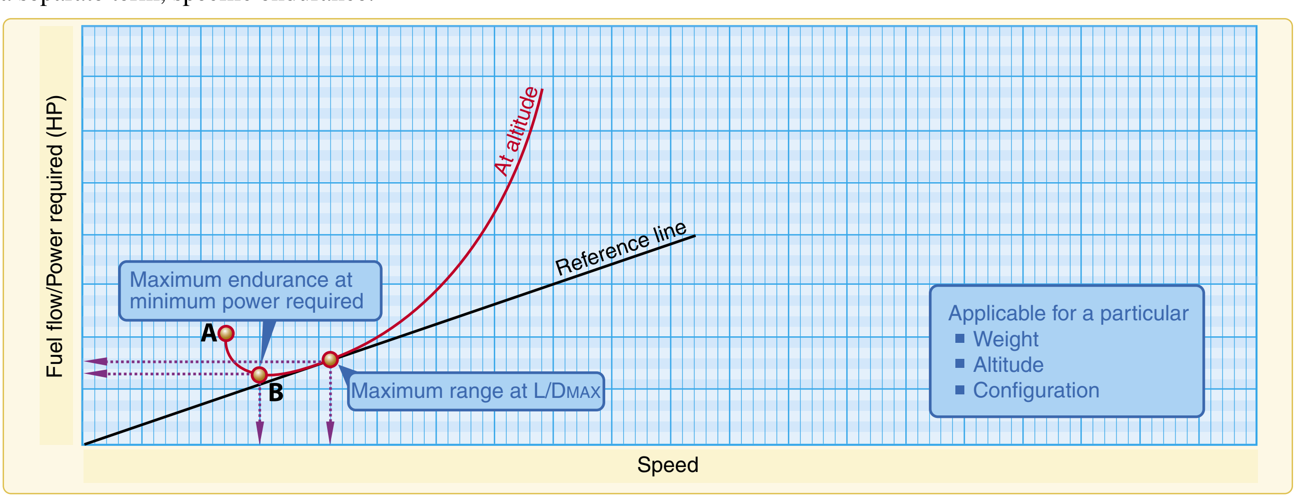


Figure 10-10. *Airspeed for maximum endurance.*

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]*

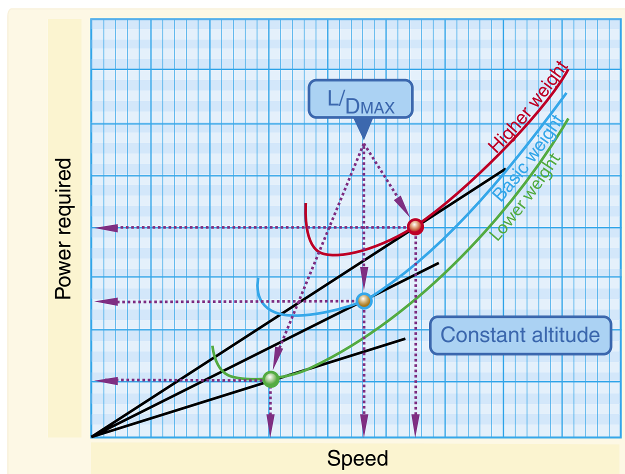


Figure 10-11. *Effect of weight.*

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.

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.

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.

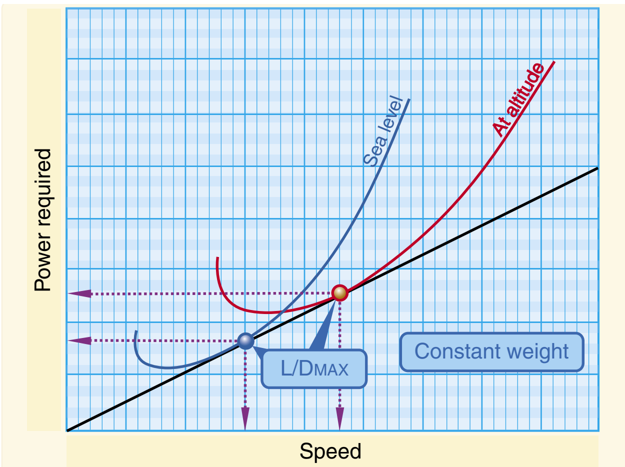


Figure 10-12. *Effect of altitude on range.*

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.

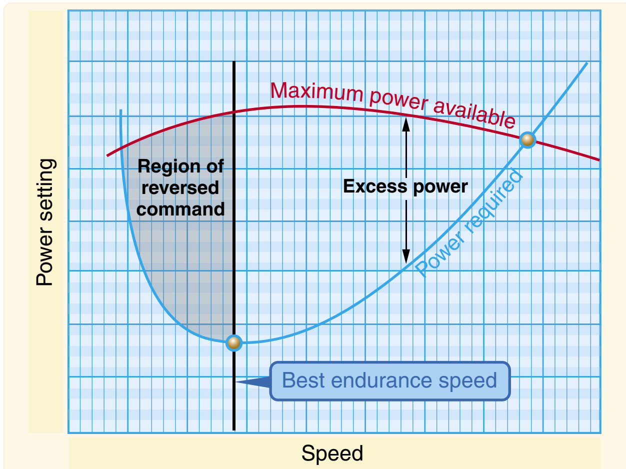


Figure 10-13. *Power required curve.*

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

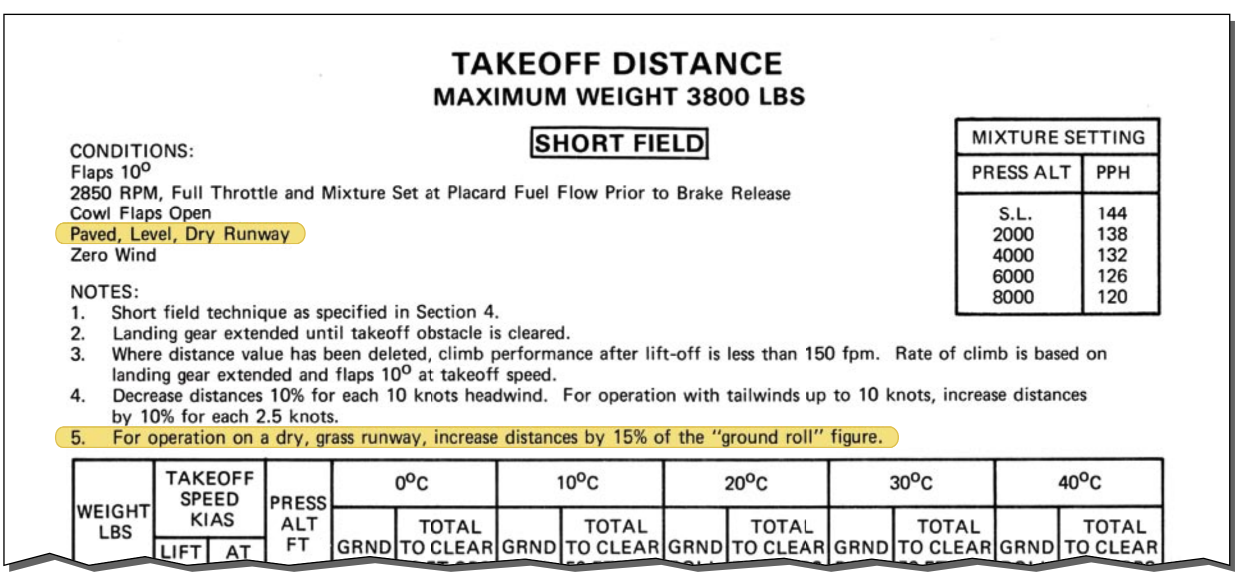
The majority of pilot-caused aircraft accidents occur during the takeoff and landing phase of flight. Because of this fact, the pilot must be familiar with all the variables that influence the takeoff and landing performance of an aircraft and must strive for exacting, professional procedures of operation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

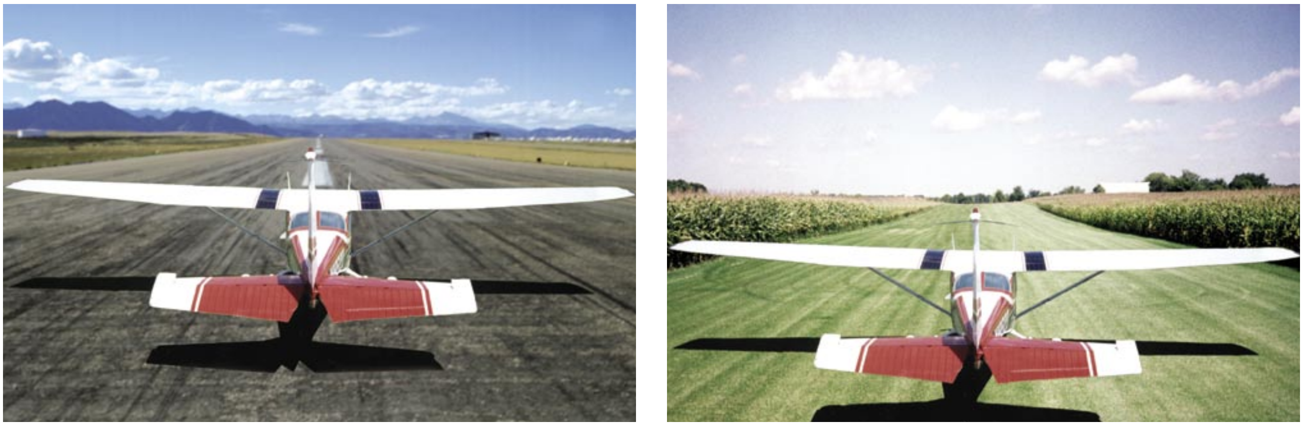


Figure 10-15. *An aircraft's performance depends greatly on the runway surface.*

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]*

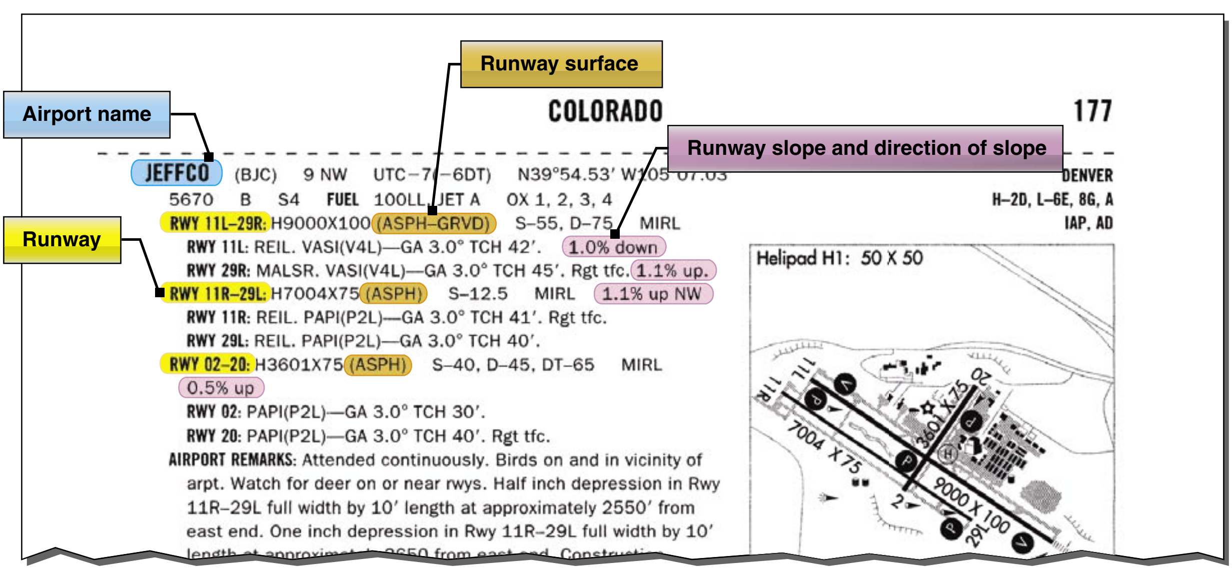


Figure 10-16. *Airport/facility directory (A/FD) information.*

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.

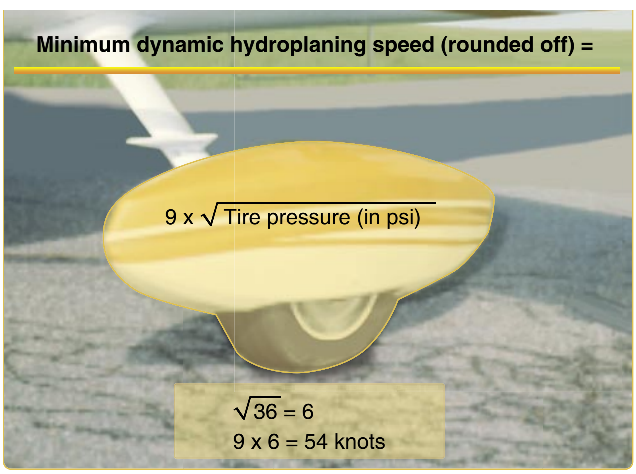


Figure 10-17. *Tire pressure.*

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

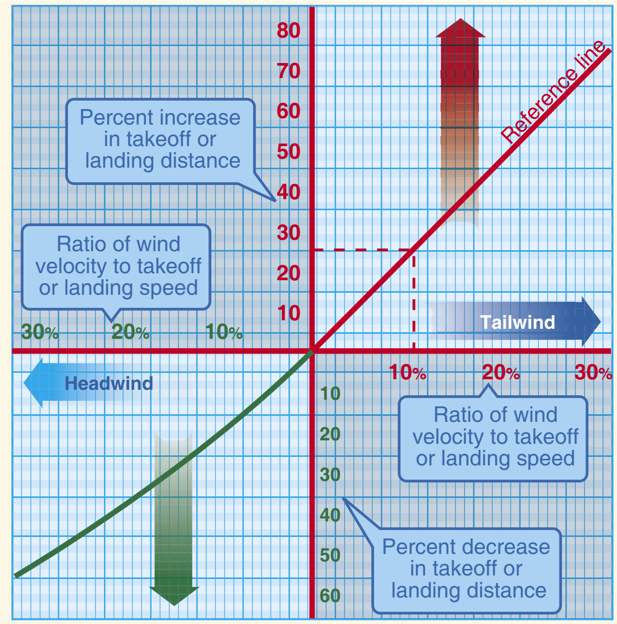


Figure 10-18. *Effect of wind on takeoff and landing.*

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

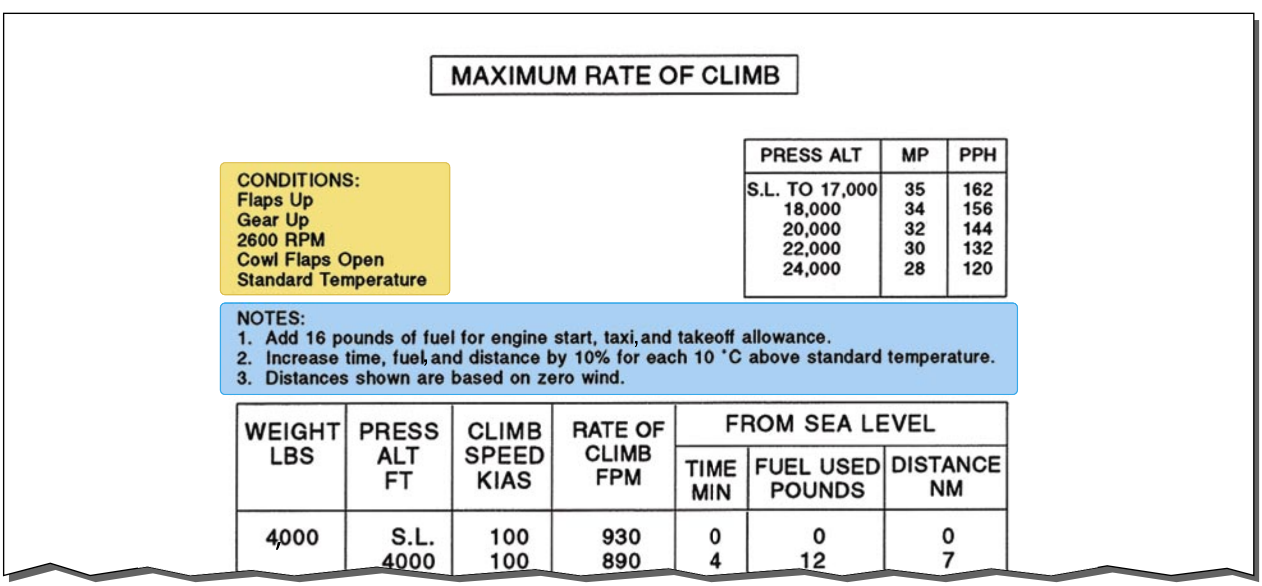


Figure 10-19. *Conditions notes chart.*

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-

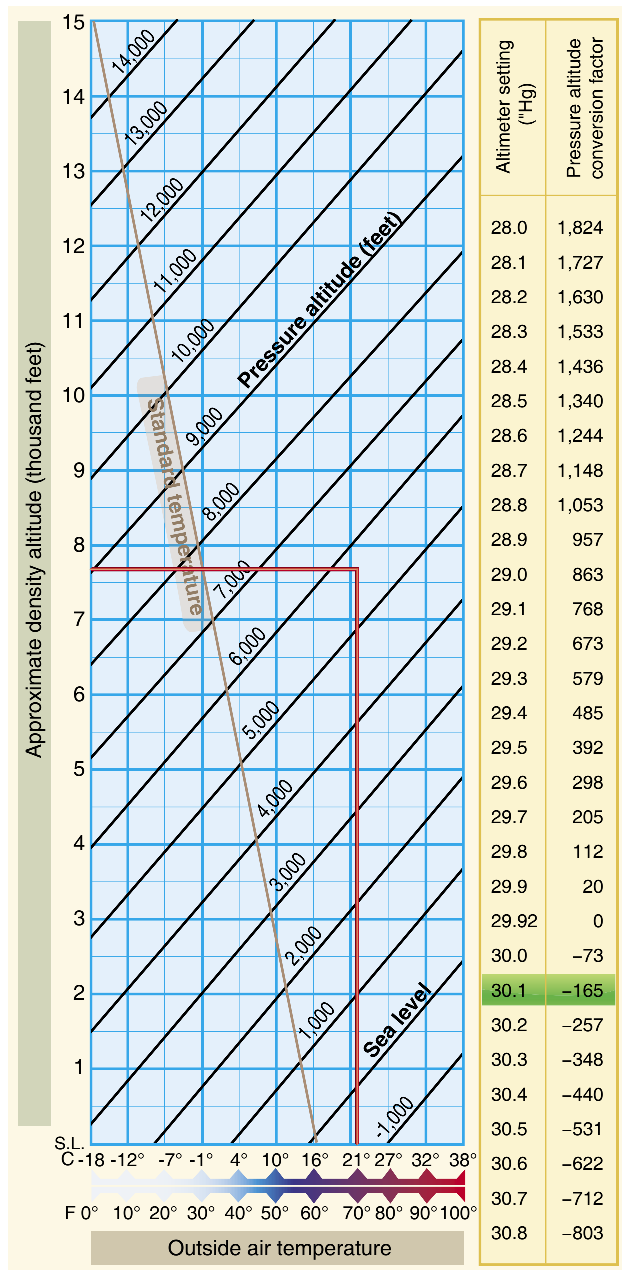


Figure 10-21. *Density altitude chart.*

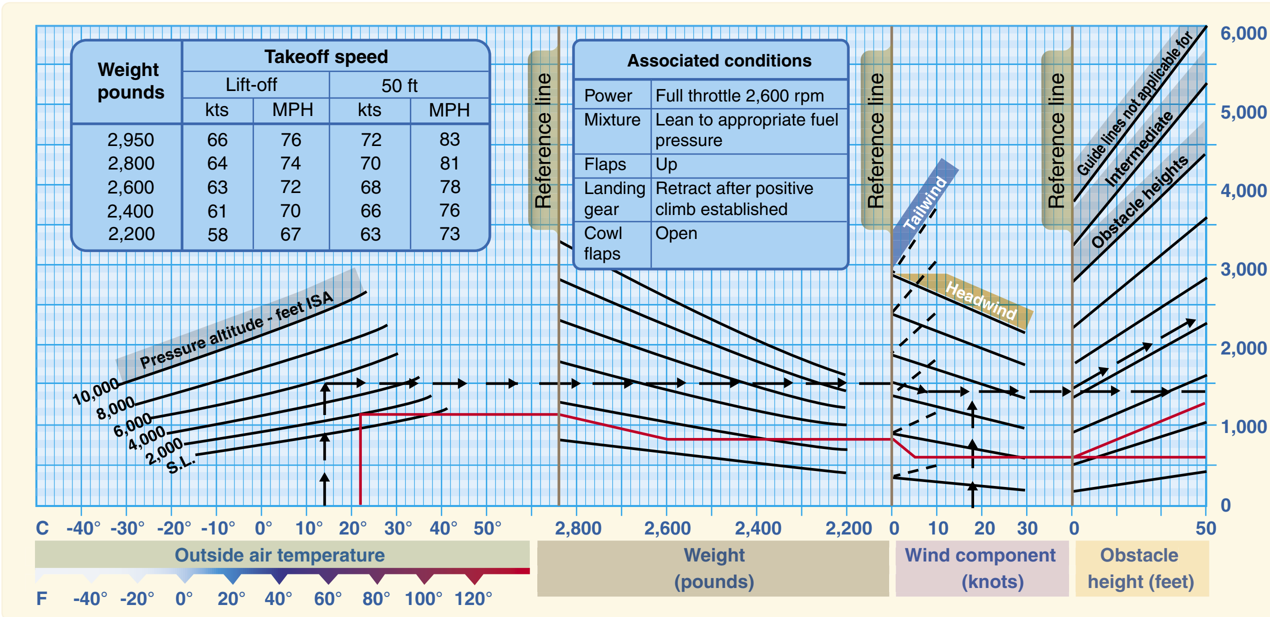


Figure 10-22. *Takeoff distance graph.*

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.

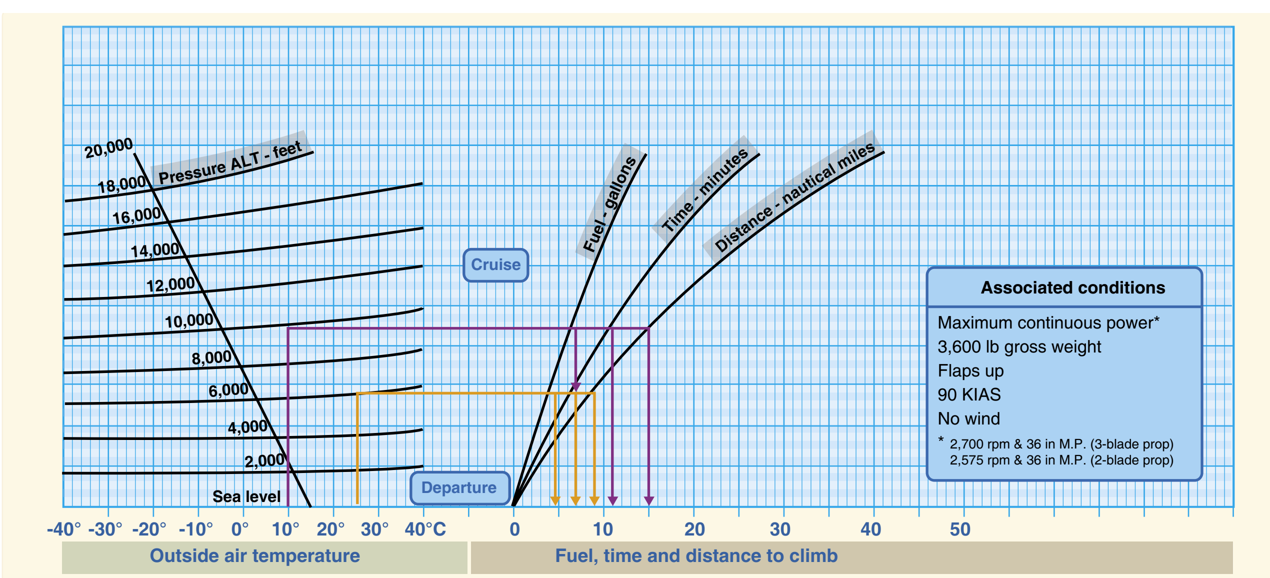


Figure 10-24. *Fuel time distance climb chart.*

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

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

NORMAL CLIMB
110 KIAS

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
	S.L.	810	0	0	0
	4,000	775	5	10	9
3,400	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.*

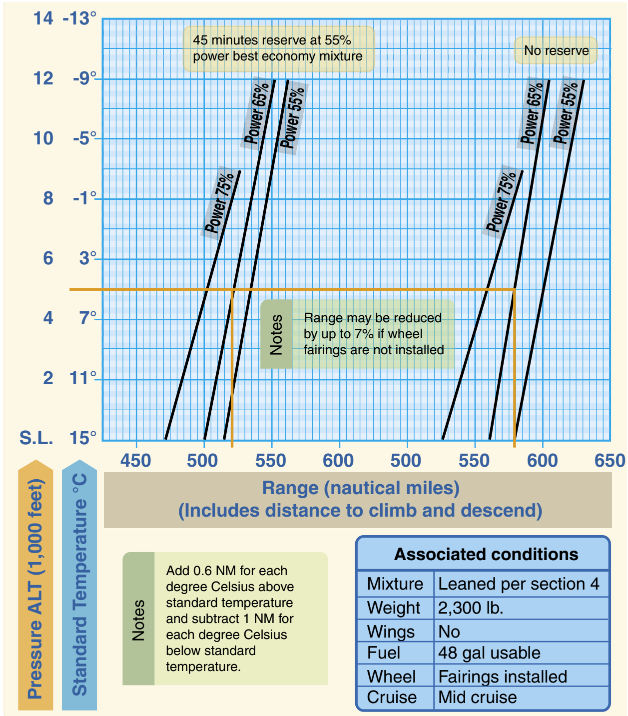


Figure 10-28. *Best power mixture range.*

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

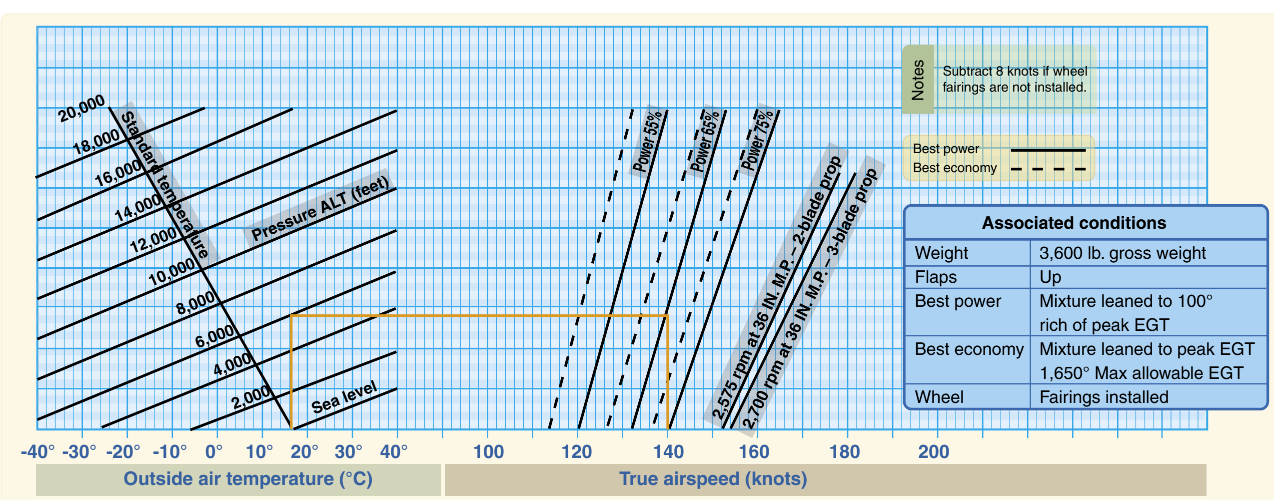


Figure 10-29. *Cruise performance graph.*

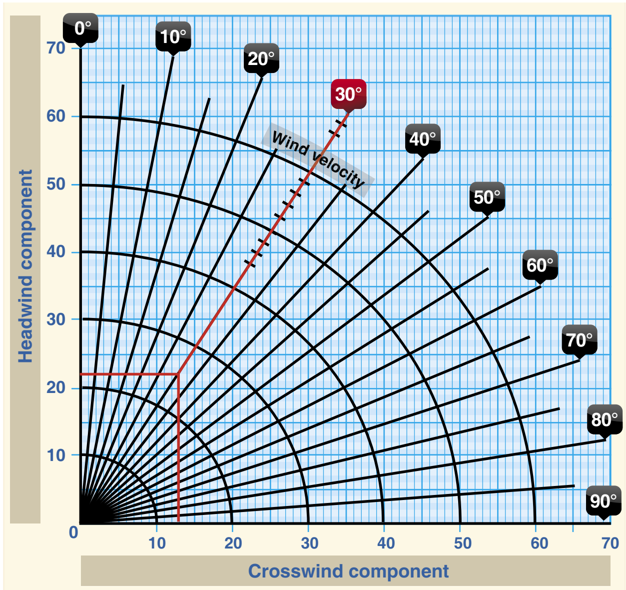


Figure 10-30. *Crosswind component chart.*

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.*

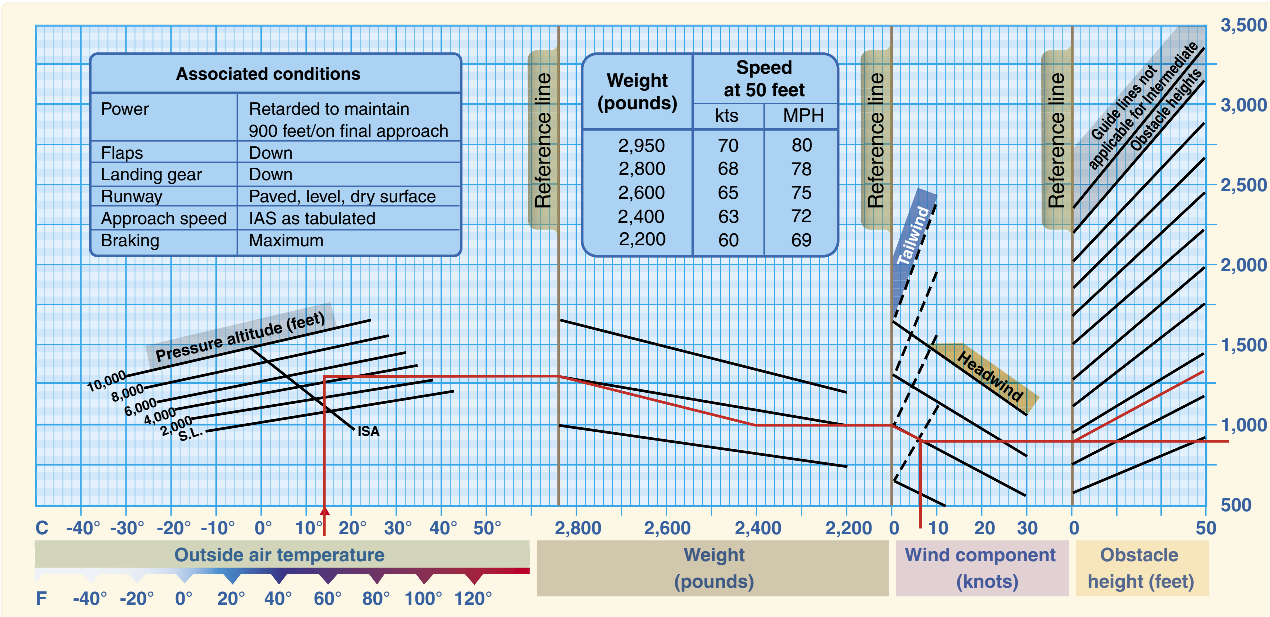


Figure 10-32. *Landing distance graph.*

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

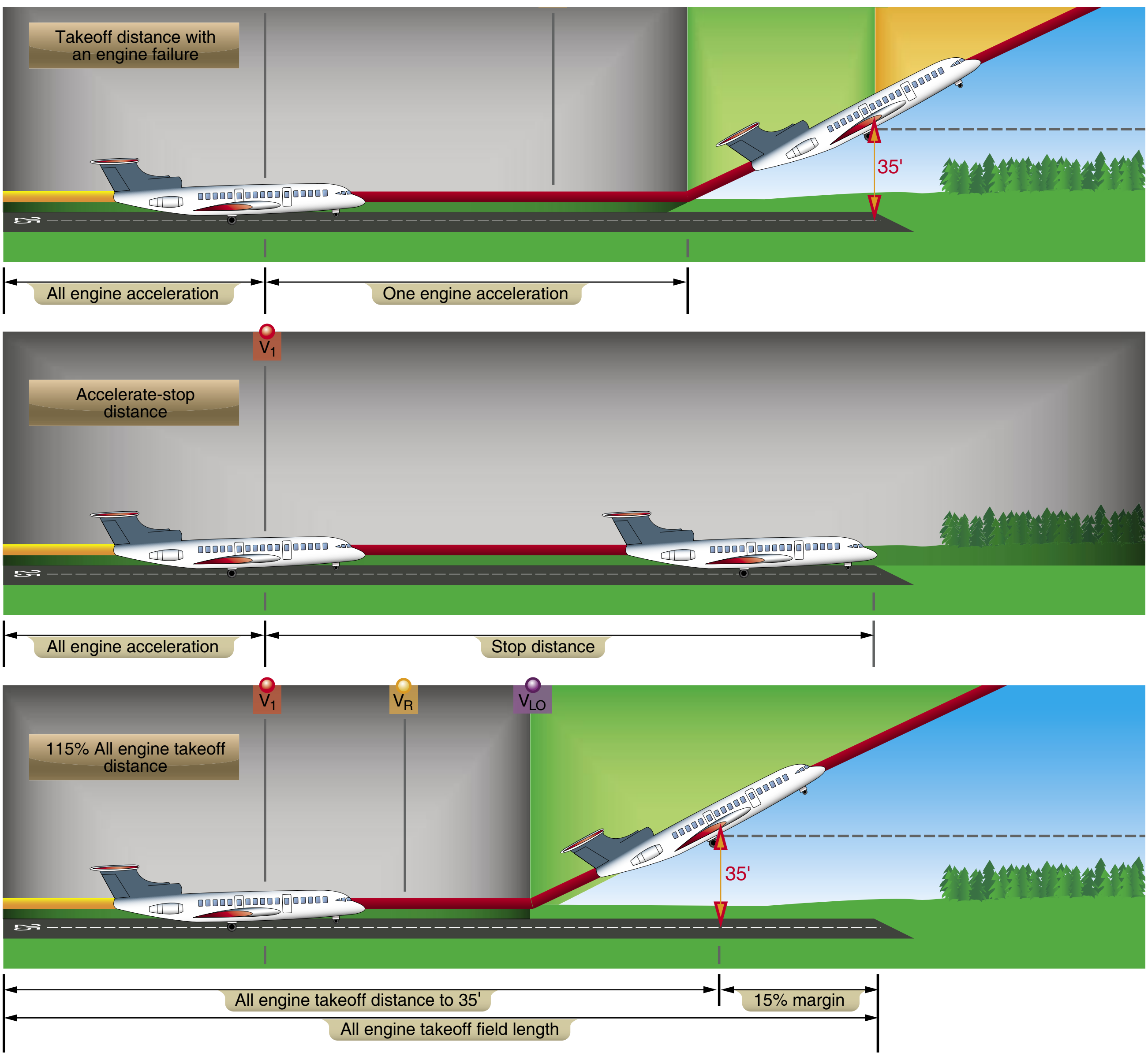


Figure 10-34. *Minimum required takeoff.*

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.		Pressure altitude (feet)							Headwind (knots)
	°F	°C	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)	
19,612	30	-1.1	47 (121)	48 (121)	50 (120)	53 (121)	57 (122)	62 (123)	70 (123)	0
V_R = 126	50	10	48 (121)	51 (121)	55 (121)	60 (122)	63 (123)	69 (124)	77 (125)	
V_2 = 134	70	21	53 (122)	56 (122)	60 (123)	65 (124)	70 (125)	77 (125)	85 (126)	
	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
V_R = 124	50	10	46 (118)	48 (118)	51 (118)	56 (119)	59 (120)	65 (121)	73 (121)	
V_2 = 131	70	21	50 (118)	53 (119)	57 (120)	66 (121)	66 (121)	72 (122)	80 (123)	
	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
V_R = 119	50	10	41 (115)	43 (114)	46 (114)	50 (115)	53 (115)	59 (116)	66 (117)	
V_2 = 127	70	21	45 (114)	48 (115)	51 (115)	56 (116)	59 (116)	65 (116)	72 (117)	
	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
V_R = 115	50	10	37 (110)	39 (108)	41 (109)	45 (110)	48 (110)	53 (111)	59 (112)	
V_2 = 124	70	21	40 (108)	43 (110)	46 (111)	50 (111)	53 (112)	58 (113)	65 (113)	
	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
V_R = 111	50	10	34 (105)	35 (103)	37 (104)	41 (105)	43 (106)	47 (107)	53 (107)	
V_2 = 120	70	21	36 (104)	38 (105)	41 (105)	45 (106)	48 (107)	52 (107)	58 (108)	
	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
V_R = 106	50	10	30 (100)	31 (98)	33 (99)	36 (100)	38 (101)	42 (102)	46 (102)	
V_2 = 116	70	21	32 (99)	34 (100)	37 (101)	40 (102)	42 (102)	46 (102)	51 (103)	
	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

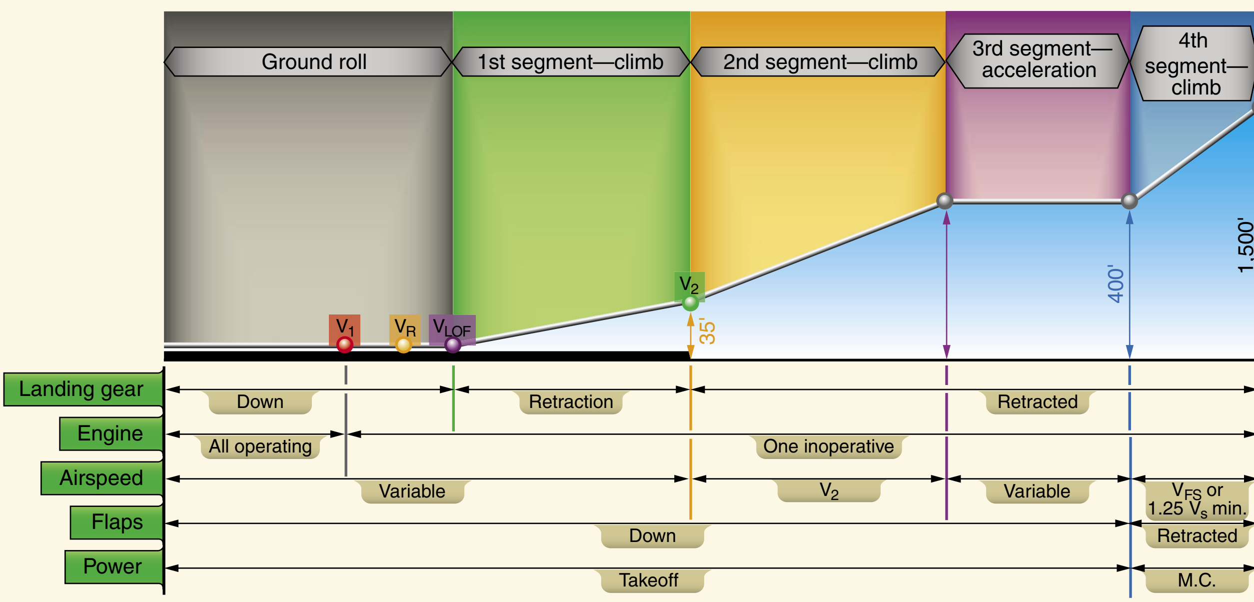
After the aircraft has reached the 35 foot height with one engine inoperative, there is a requirement that it be able to climb at a specified climb gradient. This is known as the takeoff flightpath requirement. The aircraft's performance must be considered based upon a one-engine inoperative climb up 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*.

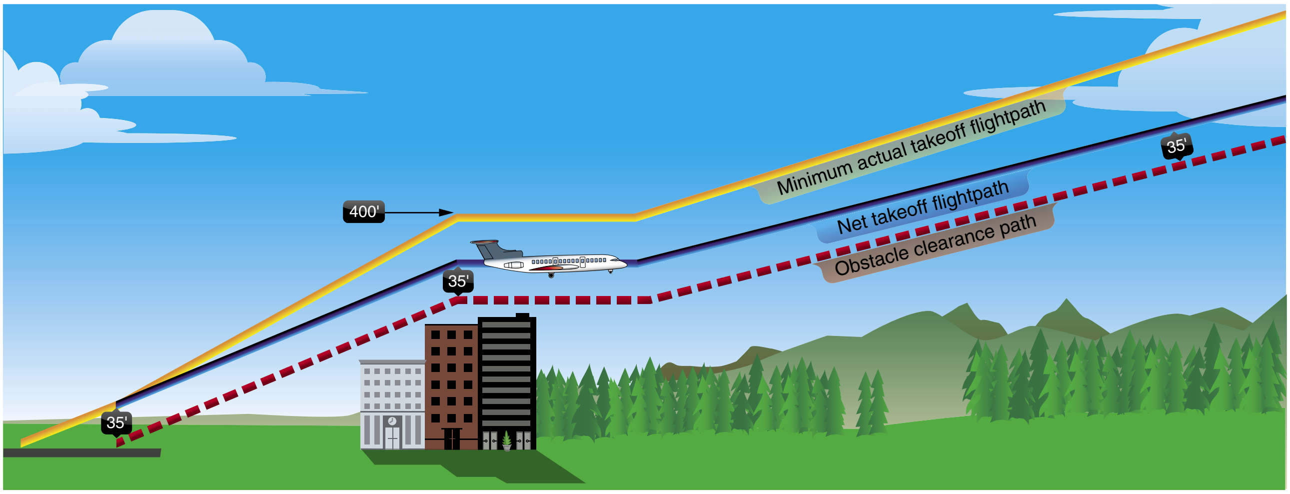


Figure 10-37. *Takeoff obstacle clearance.*

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.

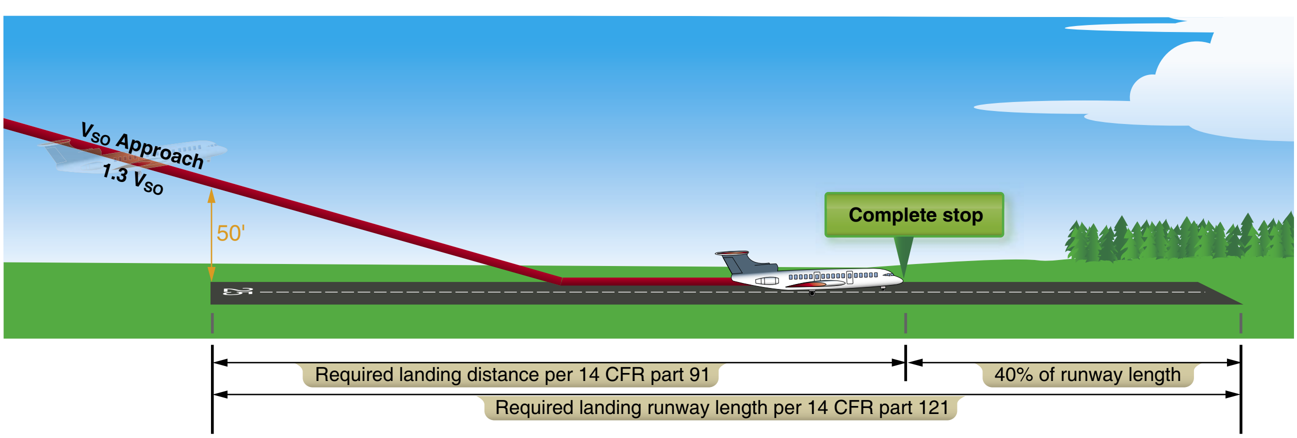


Figure 10-38. *Landing runway requirements.*

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.