Introduction

This chapter contains an overview of jet-powered airplane operations. The information contained in this chapter provides a useful preparation for, and a supplement to, structured jet airplane qualification training. This chapter provides information on major differences a pilot may encounter when transitioning to jet-powered airplanes. The major differences between jet-powered airplanes and piston-powered airplanes have been addressed in several distinct areas: differences in aerodynamics, systems, and pilot operating procedures. For airplane-specific information, a pilot should refer to the FAA-approved Airplane Flight Manual for that airplane.

Ground Safety

Stepping out on the ramp in the vicinity of jet airplanes requires special caution. There is no propeller to indicate visually whether a jet engine is running. It is easy to inadvertently stray into danger since, even at idle, jet engines are a threat. Enough air is being sucked into the intake to pull a nearby person into the fan. The air coming from the exhaust is hot and moving fast enough to blow a person down.

Pilots operating jet-powered airplanes should exercise caution during taxi and when adding power to start moving. Adding too much power can pull damaging debris up off the ground or cause damage well behind the aircraft. Jet blast when taxiing into parking areas may affect any loose ground equipment.

Jet Engine Basics

A jet engine is a gas turbine with basic cycle of operation; that is, induction, compression, combustion, expansion, and exhaust. Air passes through the intake and enters the compressor section, which is made up of a series of fan blades or "stages." The first stage, visible from the front of the engine, is the largest diameter and has the biggest blades. Each subsequent stage contains smaller diameter and thinner blades of increasing pitch. The compression in each stage raises the air temperature and pressure. The high-pressure hot air enters the combustion chamber where fuel is added. During engine start, igniters set the fuel air mixture on fire, after which the fire is self-sustaining. The rapidly expanding air flows to the turbine section, which like the compressor section, consists of a series of fan blade stages. The turbine section extracts a portion of the available energy from the airflow to turn a shaft, which drives the compressor. The remaining energy causes rapid air expansion in the nozzle of the tail pipe, accelerates the gas to a high velocity, and produces thrust. *[Figure 16-1]*
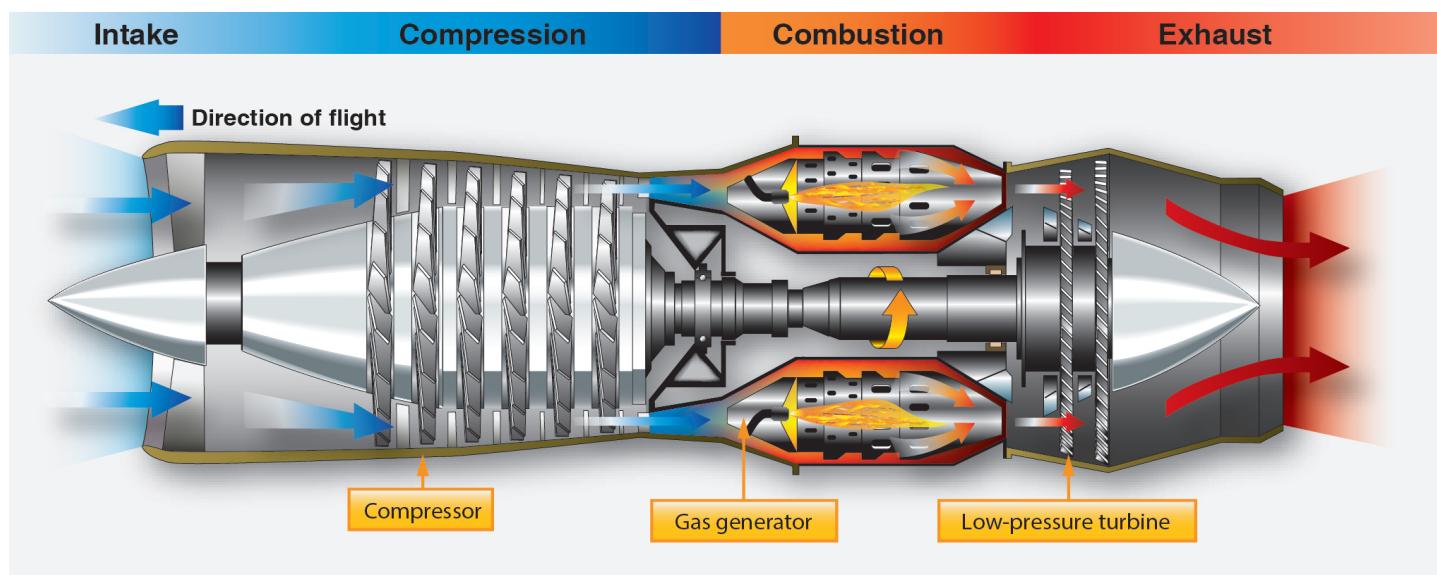

Figure 16-1. *Basic turbojet engine.*

The large first stage design of a turbofan engine, a ducted fan, diverts some of the air around the engine core. This cooler bypass air produces some of the thrust. The amount of air that bypasses the core compared to the amount compressed for combustion determines a turbofan's bypass ratio. In a turbofan engine, the compressor and turbine sections divide into sub-sections. Each sub-section in the turbine section connects to a specific sub-section of the compressor section via a split-spool shaft. *[Figure 16-2]*
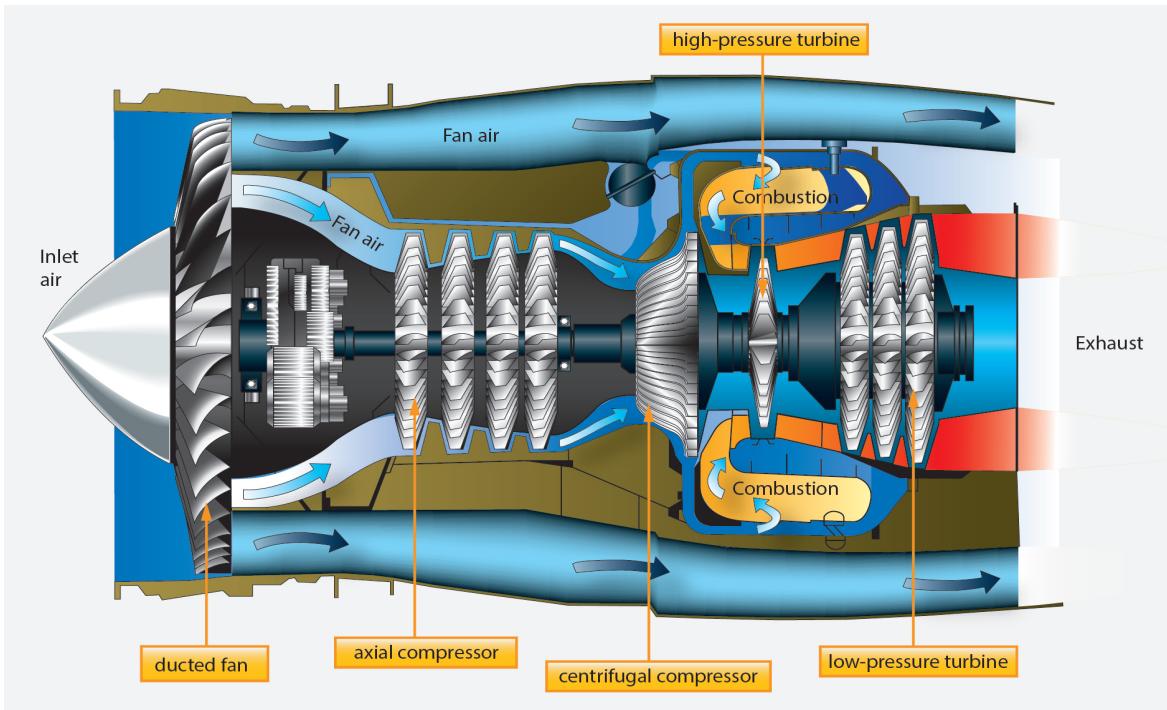
Figure 16-2. *Turbofan engine.*

Air drawn into the engine for the gas generator is further compressed and constitutes the core airflow. While a turbojet engine uses the entire gas generator's output to produce thrust in the form of a high-velocity exhaust gas jet, the lower velocity and cooler bypass air produces some of the thrust produced by a turbofan engine.

The turbofan engine design increases the thrust of the jet engine, particularly at lower speeds and altitudes. Although less efficient at higher altitudes, the turbofan engine increases acceleration, decreases the takeoff roll, improves initial climb performance, and often has the effect of decreasing fuel consumption.

Operating the Jet Engine

In a jet engine, the amount of fuel injected into the combustion chamber controls thrust. Because most engine control functions are automatic, the power controls on most turbojet-powered and turbofan-powered airplanes consist of just one thrust lever for each engine. The thrust lever links to a fuel control and/or electronic engine computer that meters fuel flow based on revolutions per minute (rpm), internal temperatures, ambient conditions, and other factors.

Typically in jet airplanes, there are flight deck indications for the rotation speed of each major engine section. Each engine section rotates at many thousands of rpm. For ease of interpretation, the indications read as percent of rpm rather than actual rpm. Depending on the make and model, there are usually indications for fuel flow, as well as for gas temperatures and pressures. The associated engine indications have different names according to their location.

As in any gas turbine engine, exceeding temperature or rpm limits, even for a few seconds, may result in serious damage to turbine blades and other components. The pilot should monitor the temperature of turbine gases and rotation speeds as needed. Modern aircraft are designed to prevent exceedances and alert the pilot of an impending or actual exceedance. Older designs rely more on the pilot to prevent any exceedances.

Setting Power

When setting power, the pilot normally uses pressure or rpm indications to set maximum allowable thrust. However, the forward movement of the thrust levers should be stopped for any limitation (e.g., pressure, rpm, or temperature).

Thrust to Thrust Lever Relationship

In a jet engine, thrust output changes much more per increment of throttle movement at high engine speeds. If the power setting is already high, it normally takes a small amount of movement to change the power output. This is a significant difference for the pilot transitioning to jet-powered airplanes. In a situation where significantly more thrust is needed and the jet engine is at low rpm, inching the thrust lever forward will have little effect. It this situation, the pilot needs to make a smooth and significant thrust lever position change to increase the power.

Variation of Thrust with RPM

Jets operate most efficiently in the 85 percent to 100 percent range. At idle rpm of approximately 55 percent to 60 percent, they produce a relatively small amount of thrust. An increase in rpm from 90 to 100 percent may increase thrust by as much as the total available at 70 percent. *[Figure 16-3]*
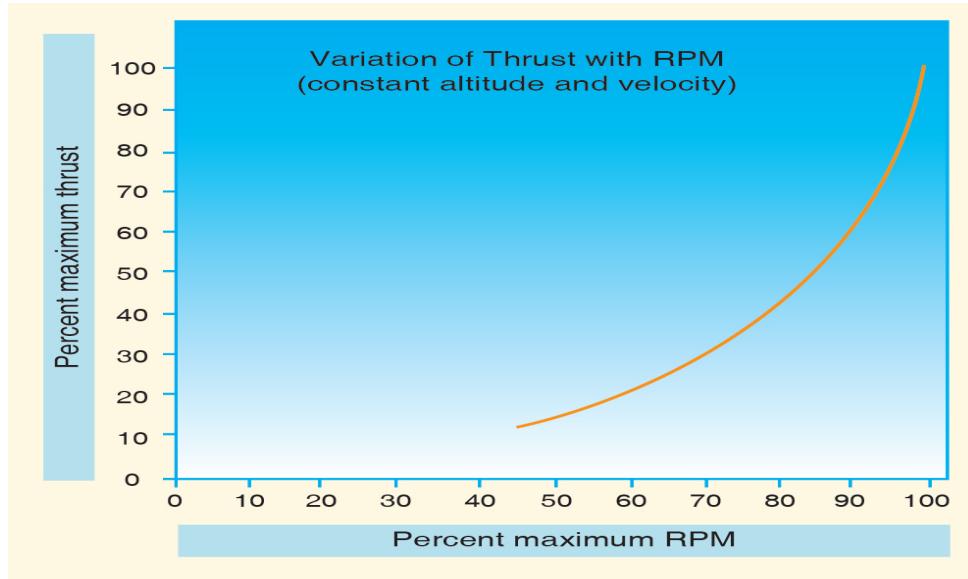
Figure 16-3. *Variation of thrust with rpm.*

Slow Acceleration of the Jet Engine

Acceleration of a piston engine from idle to full power is relatively rapid. The acceleration on different jet engines can vary considerably, but it is usually much slower. In some cases, the transition to full power could take up to 10 seconds. *[Figure 16-4]* Pilots should anticipate the need for adding power from low power settings.
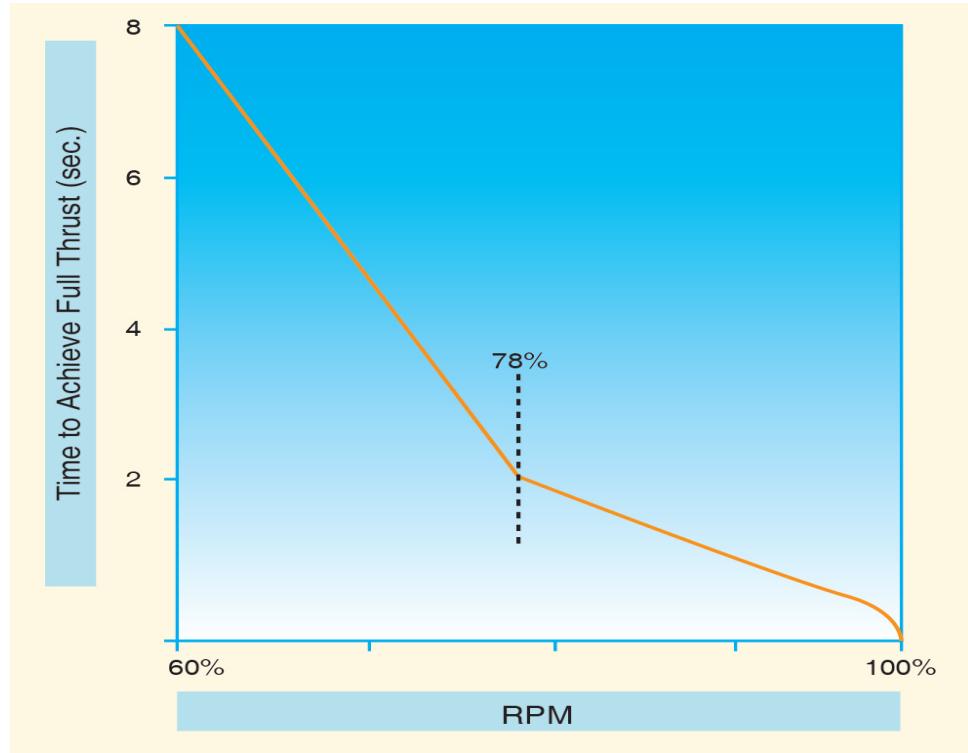
Figure 16-4. *Typical jet engine acceleration times.*

16-3

Jet Engine Efficiency

The efficiency of the jet engine increases in the cold temperatures found at high altitudes. The fuel consumption of jet engines decreases as the outside air temperature decreases for constant engine rpm and true airspeed (TAS). Thus, by flying at a high altitude, the airplane operates with improved fuel economy and speed. At high altitudes, engines may be operating close to rpm or temperature limits, and excess thrust may not be available. Therefore, pilots should accomplish all maneuvering within the limits of available thrust, stability, and controllability.

Absence of Propeller Effects

The absence of a propeller affects the operation of jet-powered airplanes. Specific effects include the absence of lift from the propeller slipstream and the absence of propeller drag.

Absence of Propeller Slipstream

A propeller produces thrust by accelerating a large mass of air rearward. With wing-mounted engines, this air passes over a comparatively large percentage of the wing area. The total lift equals the sum of the lift generated by the wing area not in the wake of the propeller (as a result of airplane speed) and the lift generated by the wing area influenced by the propeller slipstream. By increasing or decreasing the speed of the slipstream air, it is possible to increase or decrease the total lift on the wing without changing airspeed. Since the jet airplane has no propellers, the transitioning pilot should note the following:

1. Lift is not increased instantly by adding power.
2. The stall speed is not decreased by adding power.

The lack of ability to produce instant lift in the jet, along with the slow acceleration of jet engines, necessitates a stabilized approach where landing configuration, constant airspeed, controlled rate of descent, and stable power settings are maintained until over the threshold of the runway. This allows for better engine response when making minor changes in the approach speed or rate of descent and improves go-around performance.

Absence of Propeller Drag

When the throttles are closed on a piston-powered airplane, the propellers create significant drag. Airspeed or altitude is immediately decreased. The effect of reducing power to idle on the jet engine, however, produces no such drag effect. In fact, at an idle power setting, the jet engine still produces forward thrust. While this can be an advantage in certain descent profiles, it is a handicap when it is necessary to lose speed quickly. The lack of propeller drag, along with the aerodynamically clean airframe of the jet, are new to most pilots, and slowing the airplane down is one of the initial problems encountered by pilots transitioning into jets. In level flight at idle power, it takes about 1 mile to lose 10 knots of airspeed.

Speed Margins

Maximum speeds in jet airplanes are expressed differently and always define the maximum operating speed of the airplane, which is comparable to the VNE of the piston airplane. These maximum speeds in a jet airplane are referred to as:

- V_{MO}—maximum operating speed expressed in terms of knots.

- M_{MO}—maximum operating speed expressed as a Mach number (the decimal ratio of true airspeed to the speed of sound).

Mach number is the ratio of true airspeed to the speed of sound. The speed of sound varies with temperature. At low/warm altitudes, the speed of sound is so high that an aircraft is limited by indicated airspeed. At high/cold altitudes, the speed of sound is lower so the aircraft is limited by Mach. To observe both limits V_{MO} and M_{MO}, the pilot of a jet airplane needs both an airspeed indicator and a Mach indicator. In most jet airplanes, these are combined into a single display for airspeed and Mach number, as appropriate.

It looks much like a conventional airspeed display with the addition of a "barber pole" that automatically moves so as to indicate the applicable speed limit at all times. *[Figure 16-5]*

A jet airplane can easily exceed its speed limitations. The handling qualities of a jet may change significantly at speeds higher than the maximum allowed.

Figure 16-5. *Jet airspeed indicator.*

High-speed airplanes designed for subsonic flight are limited to some Mach number below the speed of sound. Shock waves (and the adverse effects associated with them) can occur when the airplane speed is substantially below Mach 1.0. The Mach number at which some portion of the airflow over the wing first equals Mach 1.0 is termed the critical Mach number (M_{CR}).

There is no particular problem associated with the acceleration of the airflow up to the critical Mach number, the point where Mach 1.0 airflow begins. However, a shock wave is formed at the point where the airflow suddenly returns to subsonic flow. This shock wave becomes more severe and moves aft on the wing as airflow velocity increases. Eventually, flow separation occurs behind the well-developed shock wave. *[Figure 16-6]*
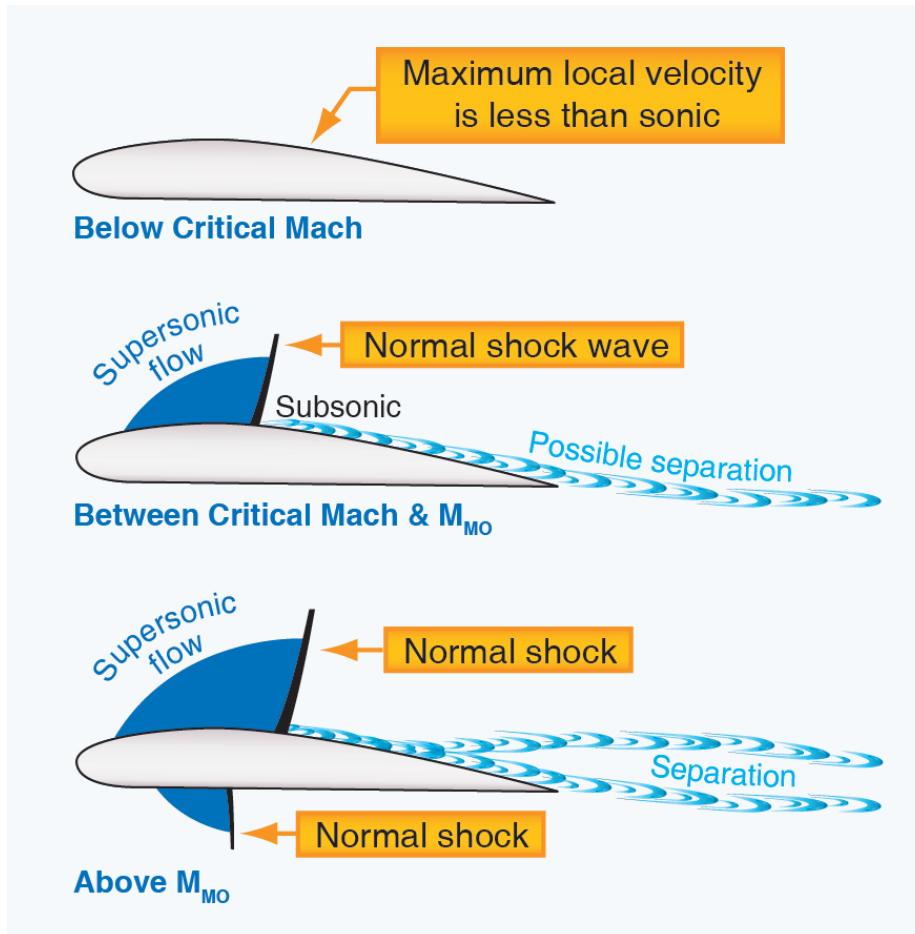

Figure 16-6. *Transonic flow patterns.*

If airplane speed progresses sufficiently beyond M_{MO}, the separation of air behind the shock wave may result in severe buffeting and possible loss of control or "upset." Because of the accompanying changes to the center of lift, the airplane may exhibit pitch change tendencies.

With increased speed and the aft movement of the shock wave, the wing's center of pressure moves aft causing the start of a nose-down tendency or "tuck." Mach tuck develops gradually, and the condition should not be allowed to progress to where there is no longer enough elevator authority to prevent entry into a steep, sometimes unrecoverable, dive. An alert pilot should respond to excessive airspeed, buffeting, or warning devices before the onset of extreme nose-down forces.

Due to the critical aspects of high-altitude/high-Mach flight, most jet airplanes capable of operating in the Mach ranges use some form of automated Mach tuck compensation. If the system becomes inoperative, the airplane is typically limited to a reduced maximum Mach number.

Mach Buffet

Mach buffet arises when airflow separates on the upper surface of a wing behind a shock wave. All other things being equal, shock wave strength increases as the local airflow speed ahead of the shock wave increases. Mach buffet is a function of the speed of the airflow over the wing—not necessarily the forward speed of the airplane, and the shock wave strength, rather than a stall, creates the airflow separation.

Mach buffet may result from two different conditions in cruise. At high-speed cruise, a shock wave that becomes too strong as the airflow speeds up over the upper surface causes a buffet. At low-speed cruise, the flow has a greater turn to make to follow the wing's upper surface. The air speeds up to do that and may exceed Mach 1 over the upper surface.

The shock wave position is different between the two situations. At high speed and a lower AOA, the shock wave tends to move aft. So when the flow separates behind the shock, that separated flow acts over a small range of the chord. In some cases, the separated flow acting on a small surface area may produce a little buzz. At low-speed cruise, the true airspeed is still high, but the shock wave does not move as far aft as it does in high-speed cruise. The separated flow behind the shock wave acts over a larger portion of the chord, which leads to a more significant effect on aircraft control.

The altitude at which an airplane flying at M_{MO} would experience buffeting with any increase in AOA determines the absolute or aerodynamic ceiling. This is the altitude where:

- If an airplane flew any faster, it would exceed M_{MO} leading to high-speed Mach buffet.
- If an airplane flew any slower, it would require an angle of attack leading to low-speed Mach buffet.

This region of the airplane's flight envelope is known as "coffin corner." Conceivably, a buffet could be the first indication of an issue at altitude, and pilots should understand the cause of any buffet in order to respond appropriately.

An increase in load factor (G factor) will raise the low-end buffet speed. For example, a jet airplane flying at 51,000 feet altitude at 1.0 G and a speed of 0.73 Mach that experiences a 1.4 G load, may encounter low-speed buffet. Consequently, a maximum cruising flight altitude and speed should be selected, which will allow sufficient margin for maneuvering and turbulence. The pilot should know the manufacturer's recommended turbulence penetration speed for the particular make and model airplane. This speed normally gives the greatest margin between the high-speed and low-speed buffets.

Low-Speed Flight

The jet airplane wing, designed primarily for high-speed flight, has relatively poor low-speed characteristics. As opposed to the normal piston-powered airplane, the jet wing has less area relative to the airplane's weight, a lower aspect ratio (long chord/short span), and thin airfoil shape—all of which amount to the need for speed to generate enough lift. The swept wing is additionally penalized at low speeds because its effective lift is proportional to airflow speed that is perpendicular to the leading edge.

In a typical piston-engine airplane, V_{MD} (minimum drag) in the clean configuration is normally at a speed of about 1.3 V_S. *[Figure 16-7]* Flight below V_{MD} in a piston-engine airplane is well identified and predictable. In contrast, in a jet airplane, flight in the area of V_{MD} (typically 1.5 – 1.6 V_S) does not normally produce any noticeable changes in flying qualities other than a lack of speed stability—a condition where a decrease in speed leads to an increase in drag, which leads to a further decrease in speed, which creates the potential for a speed divergence. A pilot who is not aware of a developing speed divergence may find a serious sink rate developing at a constant power setting, while pitch attitude appears to be normal. The fact that lack of speed stability may lead to a sinking flightpath, is one of the most important aspects of jet-airplane flying.
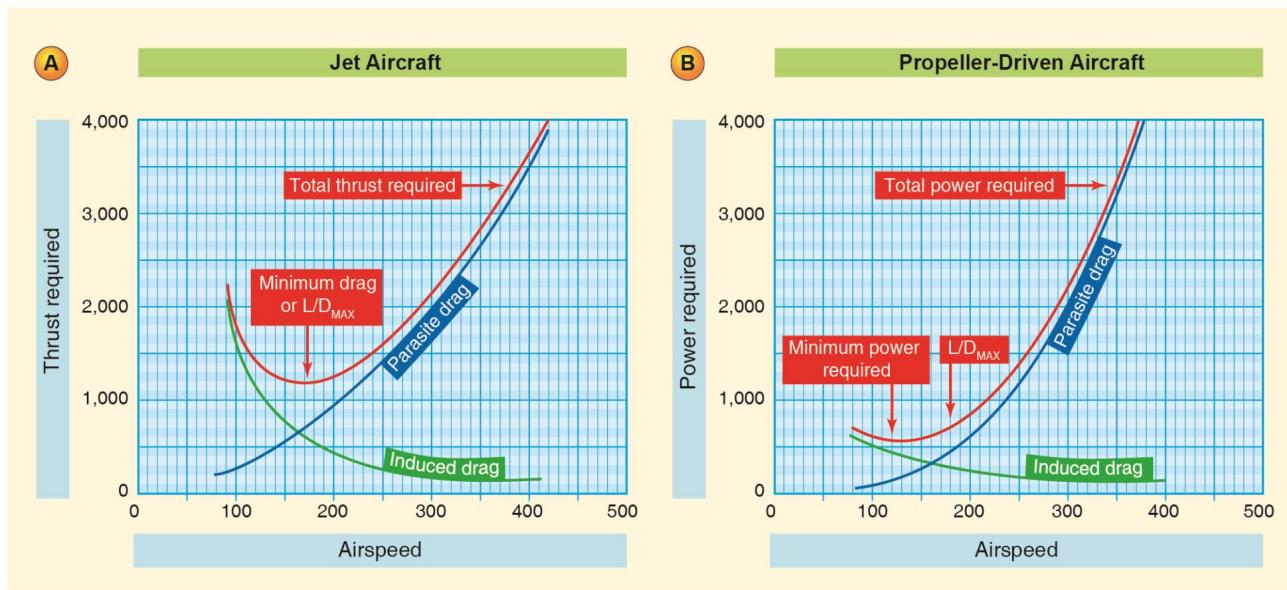
Figure 16-7. *Thrust and power required curves (jet aircraft vs. propeller-driven aircraft).*

Stalls

The stalling characteristics of the swept wing jet airplane can vary considerably from those of the normal straight wing airplane. The greatest difference noticeable to the pilot is the lift developed vs. angle of attack. An increase in angle of attack of the straight wing produces a substantial and constantly increasing lift vector up to its maximum coefficient of lift, and soon thereafter flow separation (stall) occurs with a rapid deterioration of lift.

By contrast, the swept wing produces a much more gradual buildup of lift with a less well-defined maximum coefficient. This less-defined peak also means that a swept wing may not have as dramatic a loss of lift at angles of attack beyond its maximum lift coefficient. However, these high-lift conditions are accompanied by high drag, which may result in a high rate of descent. *[Figure 16-8]*
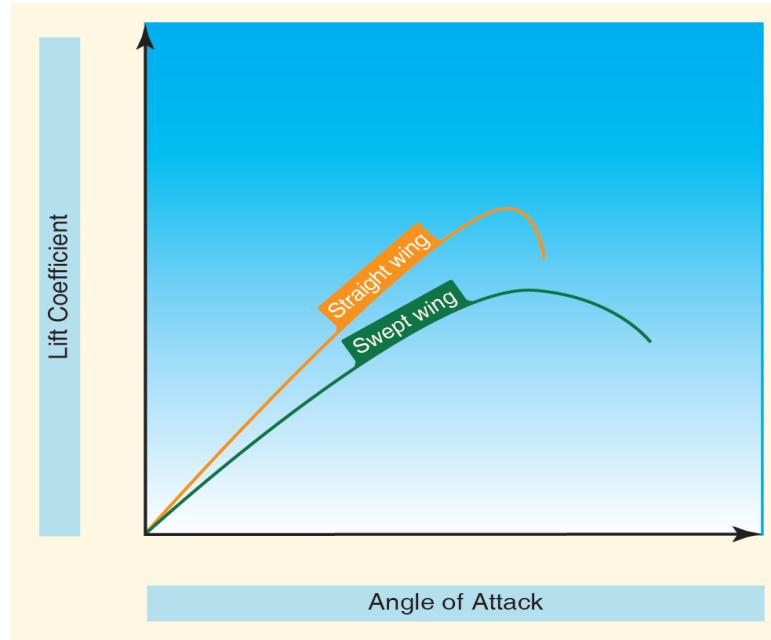

Figure 16-8. *Stall versus angle of attack—swept wing versus straight wing.*

If a simple, straight-wing airplane's airfoil is swept, a natural tendency arises that it will stall at the wing tips first. This is because the boundary layer tends to flow spanwise toward the tips. *[Figure 16-9]* The tendency for tip stall allowing the center of lift to move forward is greatest when wing sweep and taper are combined. To discourage a swept wing from stalling at the wingtips, manufacturers modify the wing spanwise with twist, changes in airfoil section, inclusion of vortex generators, or a combination of those modifications. This helps a pilot retain roll control initially if a stall is entered inadvertently.
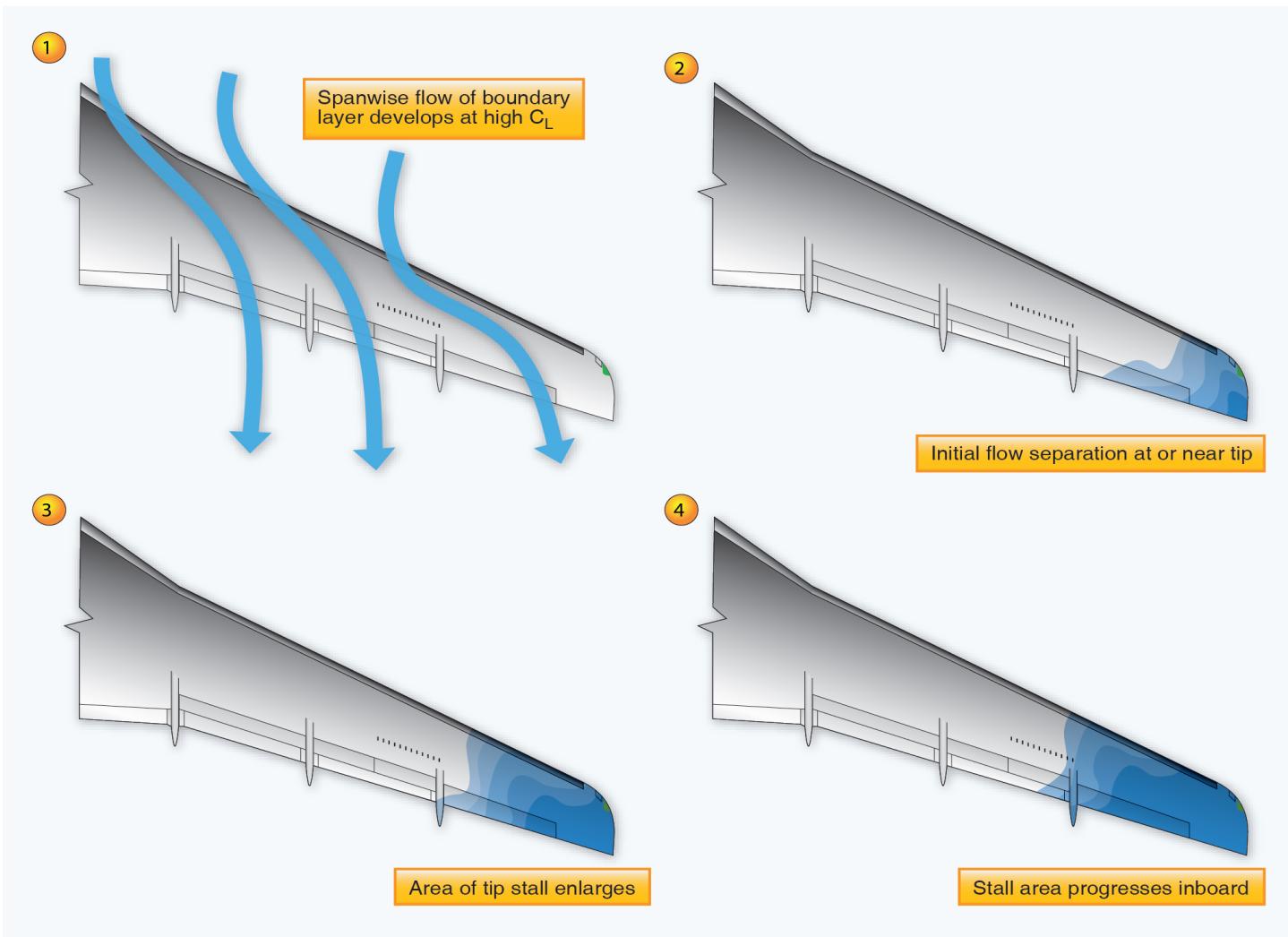
Figure 16-9. *Unmodified swept wing stall characteristics.*

Some T-tail configurations are prone to so-called deep stalls where the tail can become immersed in the wing wake at very high angles of attack and lose effectiveness. Such a situation can be accompanied by a high-rate of descent. Since high angles of attack can occur at any pitch attitude, even a pitch attitude with the nose below the horizon, it may seem counterintuitive in such a situation to take the appropriate recovery action, which is to push the nose down even further.

Deep stalls may be unrecoverable. Fortunately, they are easily avoided as long as published limitations are observed. On those airplanes susceptible to deep stalls (not all swept or tapered wing airplanes are), sophisticated stall warning systems such as stick shakers are standard equipment. A stick pusher (if installed), as its name implies, acts to automatically reduce the airplane's AOA before the airplane reaches a dangerous stall condition, or it may aid in recovering the airplane from a stall if an airplane's natural aerodynamic characteristics do so weakly. Pilots should avoid situations that would activate a stick pusher when close to the ground.

Pilots undergoing training in jet airplanes are taught to recover at the first indication of an impending stall instead of going beyond those initial cues and into a full stall. Normally, this is indicated by aural stall warning devices, annunciators, or activation of the airplane's stick shaker. Stick shakers normally activate around 107 percent of the actual stall speed. In response to a stall warning, the proper action is for the pilot to apply a nose-down input until the stall warning stops (pitch trim may be necessary). Then, the wings are rolled level, followed by adjusting thrust to return to normal flight. The elapsed time will be small between these actions, particularly at low altitude where significant available thrust exists. It is important to understand that reducing AOA eliminates the stall, but added thrust will allow the descent to be stopped once the wing is flying again. Note that airplanes without vortex generators may stall with little to no buffet.

At high altitudes the stall recovery technique is the same. A pilot will need to reduce the AOA by lowering the nose until the stall warning stops. However, after the AOA has been reduced to where the wing is again developing efficient lift, the airplane will still likely need to accelerate to a desired airspeed. At high altitudes where the available thrust is significantly less than at lower altitudes, recovery may require significant pitch down to regain airspeed. As such, several thousand feet or more of altitude loss may occur during the recovery. The above discussion covers most airplanes; however, the stall recovery procedures for a particular make and model airplane may differ, as recommended by the manufacturer, and are contained in the FAA-approved Airplane Flight Manual for that airplane.

Drag Devices

Jet airplanes have higher glide ratios than piston-powered airplanes. Due to their low drag design, jets take more time and distance to descend or reduce speed. Therefore, jet airplanes are often equipped with drag devices, such as spoilers and speed brakes.

The primary purpose of spoilers is to spoil lift. The most common type of spoiler consists of one or more rectangular plates that lie flush with the upper surface of each wing. They are installed approximately parallel to the lateral axis of the airplane and are hinged along the leading edges. When deployed, spoilers deflect up against the relative wind, which interferes with the flow of air about the wing. *[Figure 16-10]* This both spoils lift and increases drag. Spoilers are usually installed forward of the flaps but not in front of the ailerons so as not to interfere with roll control. Some aircraft use spoilers to augment roll control.

Figure 16-10. *Spoilers.*

When flight and ground spoilers are deployed after landing, most of the wing's lift is destroyed. This action transfers the airplane's weight to the landing gear so that the wheel brakes are more effective. A secondary beneficial effect of deploying spoilers on landing is that they create considerable drag, adding to the overall aerodynamic braking.

The primary purpose of speed brakes is to produce drag. Spoilers may also serve as speed brakes, or they may be panels attached to the fuselage. Deploying speed brakes results in a rapid decrease in airspeed and/or an increased rate of descent. Typically, speed brakes can be deployed at any time during flight. There is usually a certain amount of noise and buffeting associated with the use of speed brakes, along with an obvious penalty in fuel consumption. Pilots can minimize the use of speed brakes with proper descent and approach planning. Procedures for the use of spoilers and/or speed brakes in various situations are contained in the FAA-approved AFM for the particular airplane.

Thrust Reversers

Jet airplanes have high kinetic energy during the landing roll because of weight and speed. This energy is difficult to dissipate because a jet airplane has low drag with the nose-wheel on the ground, and the engines continue to produce forward thrust with the power levers at idle. While wheel brakes serve as the primary means to stop the airplane, reverse thrust, when available, assists in deceleration.

Certain thrust reverser designs effectively reverse the flow of the exhaust gases. The flow does not completely reverse. Typically, the final path of the exhaust gases is about 45° from straight ahead. This, together with the losses from the flow paths, reduces reverse thrust efficiency. If the pilot uses less than maximum rpm in reverse, the reverse thrust is further reduced.

Normally, a jet engine has one of two types of thrust reversers: a target reverser or a cascade reverser. *[Figure 16-11]* Target reversers are simple clamshell doors that swivel from the stowed position at the engine tailpipe to redirect thrust to a more forward direction.
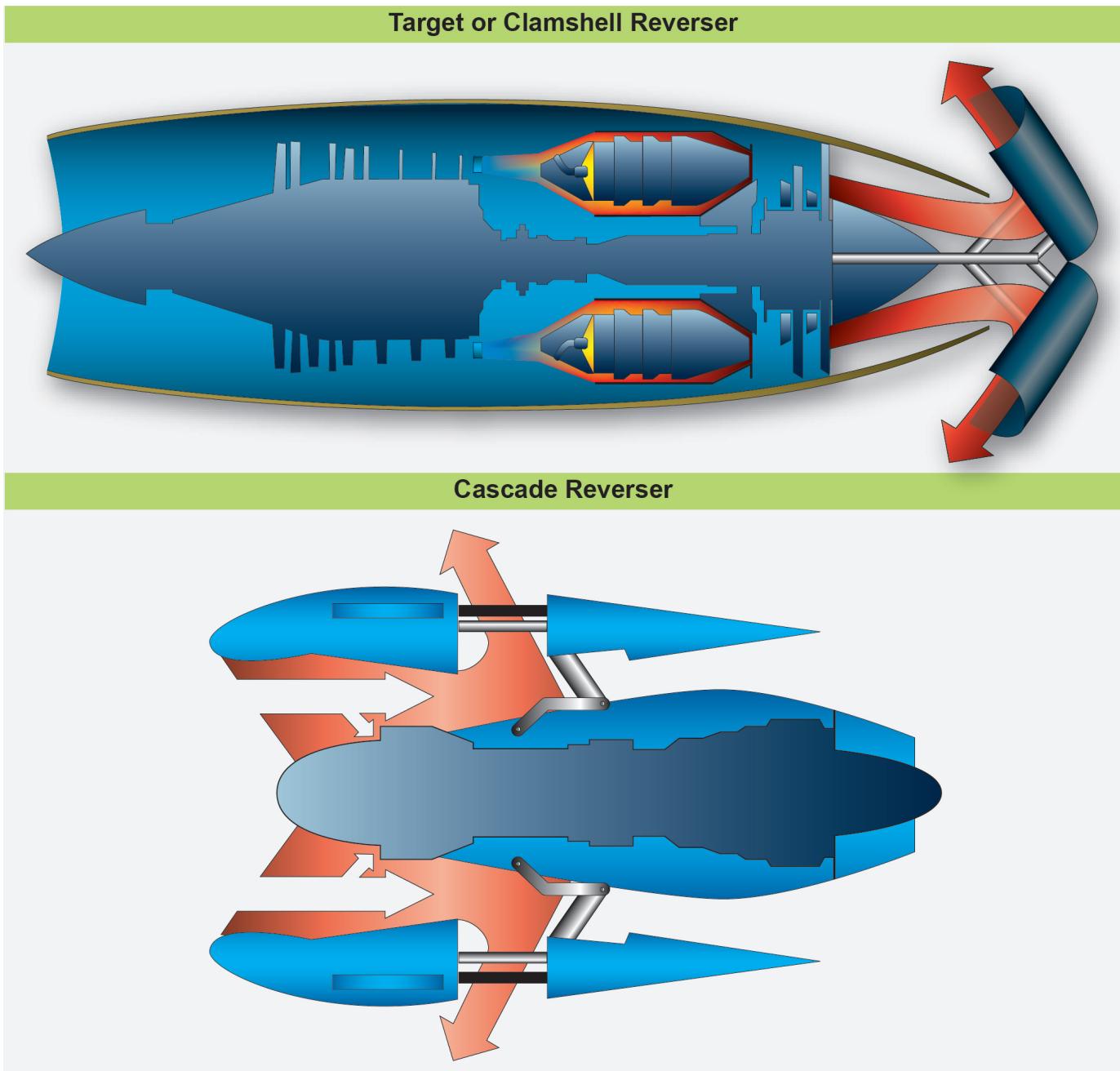
Figure 16-11. *Thrust reversers.*

Cascade reversers are normally found on turbofan engines and are often designed to reverse only the fan air portion. Blocking doors in the shroud obstruct forward fan thrust and redirect it through cascade vanes to generate reverse thrust.

On most installations, the pilot selects reverse thrust with the thrust levers at idle by pulling up the reverse levers to a detent. Doing so positions the reversing mechanisms for operation but leaves the engines at idle rpm. Further upward and backward movement of the reverse levers increases engine power. Reverse is canceled by closing the reverse levers to the idle reverse position, then dropping them fully back to the forward idle position. This last movement selects the stowed position, and the reversers return to the forward thrust position.

Reverse thrust is more effective at high speed than at low speed. For maximum reverse thrust efficiency, the pilot should use it as soon as is prudent after touchdown. The pilot should remember that some airplanes tend to pitch nose-up when reverse is selected on landing and this effect, particularly when combined with the nose-up pitch effect from the spoilers, can cause the airplane to leave the ground again momentarily. On these types, the airplane should be firmly on the ground with the nose-wheel down before reverse is selected. Other types of airplanes have no change in pitch, and reverse idle may be selected after the main gear is down and before the nose-wheel is down. Since reverse thrust may affect directional control, runway surface conditions (e.g., contamination), factor into the use of reverse thrust. Specific procedures for reverse thrust operation for a particular airplane/engine combination are contained in the FAA-approved AFM for that airplane.

There is a significant difference between reverse pitch on a propeller and reverse thrust from a jet engine. Idle reverse on a propeller produces a large amount of drag. On a jet engine, however, selecting idle reverse produces very little reverse thrust. In a jet airplane, the pilot should select reverse, apply reverse thrust as appropriate, and remain within any AFM limitations.

It is essential that pilots understand not only the normal procedures and limitations of thrust reverser use, but also the procedures for coping with uncommanded reverse. While thrust reverser systems are designed to prevent unintentional deployment, an uncommanded or inadvertent deployment of thrust reversers, while airborne, is an emergency. The systems normally contain several lock systems: one to keep reversers from operating in the air, another to prevent operation with the thrust levers out of the idle detent, and/or an "auto-stow" circuit to command reverser stowage any time thrust reverser deployment would be inappropriate, such as during takeoff and while airborne.

Pilot Sensations in Jet Flying

Pilots transitioning into jets may notice these general sensations:

1. response differences
2. increased control sensitivity
3. increased tempo of flight

In some flight conditions, airspeed changes may occur more slowly than in a propeller airplane. At high altitudes, the reduction in available thrust reduces the ability to accelerate. The long spool-up time required from low throttle settings also may affect acceleration. Finally, the clean aerodynamic design of a jet can result in more gradual deceleration when thrust is reduced.

The lack of propeller effects results in less drag at low power settings. Other changes the transitioning pilot should notice include the lack of effective slipstream over the lifting and control surfaces, and the lack of propeller torque effect.

Even though moving the power levers has less effect at low power settings, the pilot should change power settings smoothly. To slow the airplane, the transitioning pilot may also need to learn when to use available drag devices appropriately.

Transitioning pilots should learn power setting management for different situations. Power settings for desired performance vary because of significant changes in airplane weight as fuel is consumed. Therefore, the pilot needs to use a variety of cues to achieve desired performance. For example, airspeed trend information provides feedback for power required.

Power changes may result in a pitching tendency. These characteristics should be noticed and compensated for.

The jet airplane will differ regarding pitch tendencies with the lowering of flaps, landing gear, and drag devices. With experience, the jet airplane pilot will learn to anticipate the pitch change required for a particular operation. Most jet airplanes are equipped with a thumb operated pitch trim button on the control wheel. The usual method of operating the trim button is to apply several small, intermittent applications of trim in the direction desired rather than holding the trim button for longer periods of time, which can lead to overcontrolling.

The variation of pitch attitudes flown in a jet airplane also results from high thrust, flight characteristics of the low aspect ratio, and the swept wing. Flight at higher pitch attitudes requires greater reliance on the flight instruments for airplane control since outside references may be absent. Proficiency in attitude instrument flying, therefore, is essential to successful transition to jet airplane flying.

Control sensitivity will differ amongst various airplanes. Because of the higher speeds flown, the control surfaces are more effective and a variation of just a few degrees in pitch attitude in a jet can result in over twice the rate of altitude change that would be experienced in a slower airplane. The sensitive pitch control in jet airplanes is one of the first flight differences that the pilot may notice, and the transitioning pilot may have a tendency to overcontrol pitch during initial training flights. Accurate and smooth control is one of the first techniques the transitioning pilot should master. Rather than gripping the yoke with the hand at high speeds, just using fingertips will result in smoother control inputs.

The pilot flying a swept wing jet airplane should understand that it is normal to fly at higher angles of attack. Depending on weight, density altitude, and available thrust, the pitch angle on takeoff may seem high. It is also not unusual to have a noticeable nose-up pitch on an approach to a landing.

Jet Airplane Takeoff and Climb

The following information is generic in nature and, since most civilian jet airplanes require a minimum flight crew of two pilots, assumes a two-pilot crew. If any of the following information conflicts with FAA-approved AFM procedures for a particular airplane, the AFM procedures take precedence. Also, if any of the following procedures differ from the FAA-approved procedures developed for use by a specific air operator and/or for use in an FAA-approved training center or pilot school curriculum, the FAA-approved procedures for that operator and/or training center/pilot school take precedence.

V-Speeds

The following are speeds that affect the jet airplane's takeoff performance. The jet airplane pilot should understand how to use these speeds when planning for takeoff.

- V_S—stalling speed or minimum steady flight speed at which the airplane is controllable.

- V_1—critical engine failure speed or takeoff decision speed. It is the speed at which the pilot is to continue the takeoff in the event of an engine failure or other serious emergency. At speeds less than V_1, it is considered safer to stop the aircraft within the accelerate-stop distance. It is also the minimum speed in the takeoff, following a failure of the critical engine at VEF, at which the pilot can continue the takeoff and achieve the required height above the takeoff surface within the takeoff distance.

- V_{EF}—speed used during certification at which the critical engine is assumed to fail.

- V_R—rotation speed, or speed at which the rotation of the airplane is initiated to takeoff attitude. This speed cannot be less than V_1 or less than $1.05 \times V_{MCA}$ (minimum control speed in the air). On a single-engine takeoff, it also allows for the acceleration to V_2 at the 35-foot height at the end of the runway.

- V_{LOF}—lift-off speed, or speed at which the airplane first becomes airborne. This is an engineering term used when the airplane is certificated to meet certain requirements. The pilot takes this speed into consideration if the AFM lists it.

- V_2—takeoff safety speed, or a referenced airspeed obtained after lift-off at which the required one-engine-inoperative climb performance can be achieved.

Takeoff Roll

After confirming the runway and position match expectations, the airplane should be aligned in the center of the runway. When runway length is limited, the brakes should be held while the thrust levers are brought to a power setting specified in the AFM and the engines allowed to stabilize. The engine instruments should be checked for proper operation before the brakes are released or the power increased further. This procedure assures symmetrical thrust during the takeoff roll and aids in prevention of overshooting the desired takeoff thrust setting. After brake release, the power levers should be set to the pre-computed takeoff power setting and takeoff thrust adjustments made prior to reaching 60 knots. The final engine power adjustments are normally made by the pilot not flying. Retarding a thrust lever would only be necessary in case an engine exceeds any limitation.

Takeoff data, including V_1/V_R and V_2 speeds, takeoff power settings, and required field length should be computed prior to each takeoff. For any make and model without an FMS, the data should be recorded on a takeoff data card. This data is based on airplane weight, runway length available, runway gradient, field temperature, field barometric pressure, wind, icing conditions, and runway condition. Both pilots should review the takeoff data entered in an FMS or separately compute the takeoff data and cross-check with the takeoff data card. If takeoff plans change while taxiing, the pilot or crew should recalculate the takeoff data.

Captain's Briefing

I will advance the thrust levers.

Follow me through on the thrust levers.

Monitor all instruments and warning lights on the takeoff roll and call out any discrepancies or malfunctions observed prior to V_1, and I will abort the takeoff. Stand by to arm thrust reversers on my command.

Give me a visual and oral signal for the following:
- 80 knots, and I will disengage nosewheel steering.
- V_1, and I will move my hand from thrust to yoke.
- V_R, and I will rotate.

In the event of engine failure at or after V_1, I will continue the takeoff roll to V_R, rotate and establish V_2 climb speed. I will identify the inoperative engine, and we will both verify. I will accomplish the shutdown, or have you do it on my command.

I will expect you to stand by on the appropriate emergency checklist.

I will give you a visual and oral signal for gear retraction and for power settings after the takeoff.

Our VFR emergency procedure is to.............................
Our IFR emergency procedure is to.............................

Figure 16-12. *Sample captain's briefing.*

A captain's briefing is an essential part of crew resource management (CRM) procedures and should be accomplished prior to takeoff. *[Figure 16-12]*

If sufficient runway length is available, a "rolling" takeoff may be made without stopping at the end of the runway. Using this procedure, as the airplane rolls onto the runway, the thrust levers should be smoothly advanced to the recommended intermediate power setting and the engines allowed to stabilize, and then proceed as in the static takeoff outlined above. Rolling takeoffs can also be made from the end of the runway by advancing the thrust levers from idle as the brakes are released.

During the takeoff roll, the pilot flying should concentrate on directional control of the airplane. This is made somewhat easier because there is no torque-produced yawing in a jet as there is in a propeller-driven airplane. The airplane should be maintained exactly on centerline with the wings level. This automatically aids the pilot when contending with an engine failure. If a crosswind exists, the wings should be kept level by displacing the control wheel into the crosswind. During the takeoff roll, the primary responsibility of the pilot not flying is to closely monitor the aircraft systems and to call out the proper V speeds as directed in the captain's briefing.

Slight forward pressure should be held on the control column to keep the nose-wheel rolling firmly on the runway. If nose-wheel steering is being utilized, the pilot flying should monitor the nose-wheel steering to about 80 knots (or V_{MCG} for the particular airplane) while the pilot not flying applies the forward pressure. After reaching V_{MCG}, the pilot flying should bring his or her left hand up to the control wheel. The pilot's other hand should be on the thrust levers until at least V_1 speed is attained. Although the pilot not flying maintains a check on the engine instruments throughout the takeoff roll, the pilot flying (pilot-in-command) makes the decision to continue or reject a takeoff for any reason. A decision to reject a takeoff requires immediate retarding of thrust levers.

The takeoff and climb-out should be accomplished in accordance with a standard takeoff and departure profile developed for the particular make and model airplane. *[Figure 16-13]*
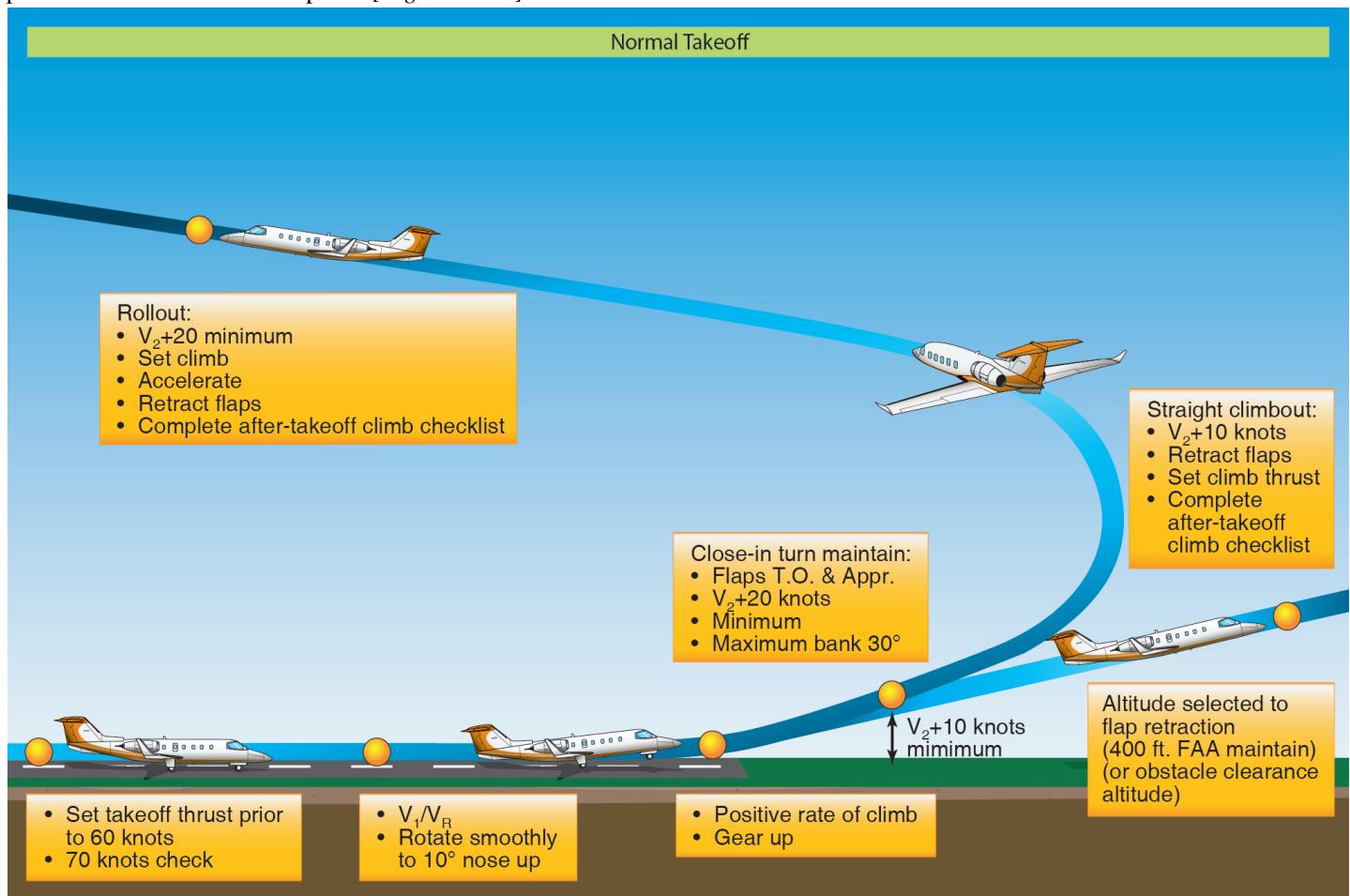

Figure 16-13. *Sample takeoff and departure profile.*

The pilot not flying should call out V_1. After passing V_1 speed on the takeoff roll, it is no longer mandatory for the pilot flying to keep a hand on the thrust levers. The point for abort has passed, and both hands may be placed on the control wheel. As the airspeed approaches V_R, the control column should be moved to a neutral position. As the pre-computed V_R speed is attained, the pilot not flying should make the appropriate call-out, and the pilot flying should smoothly rotate the airplane to the appropriate takeoff pitch attitude.

Rejected Takeoff

Every takeoff could potentially result in a rejected takeoff (RTO) for a variety of reasons: engine failure, fire or smoke, unsuspected equipment on the runway, bird strike, blown tires, direct instructions from the governing ATC authority, or recognition of a significant abnormality (split-airspeed indications, activation of a warning horn, etc.).

Ill-advised rejected takeoff decisions by flight crews and improper pilot technique during the execution of a rejected takeoff contribute to a majority of takeoff-related commercial aviation accidents worldwide. Statistically, although only 2 percent of rejected takeoffs are in this category, high-speed aborts above 120 knots account for the vast majority of RTO overrun accidents. A brief moment of indecision may mean the difference between running out of runway and coming to a safe halt after an aborted takeoff.

It is paramount to remember that FAA-approved takeoff data for any aircraft is based on aircraft performance demonstrated in ideal conditions, using a clean, dry runway, and maximum braking (reverse thrust is not used to compute stopping distance). In reality, stopping performance can be degraded by an array of factors as diversified as:

- Reduced runway friction (grooved/non-grooved)
- Mechanical runway contaminants (rubber, oily residue, debris)
- Natural contaminants (standing water, snow, slush, ice, dust)
- Wind direction and velocity
- Low air density
- Flap configuration
- Bleed air configuration
- Underinflated or failing tires
- Penalizing MEL or CDL items
- Deficient wheel brakes or RTO auto-brakes
- Inoperative anti-skid
- Pilot technique and individual proficiency

Taking pilot response times into account, the go/no-go decision should be made before V_1 so that deceleration can begin no later than V_1. If braking has not begun by V_1, the decision to continue the takeoff is made by default. Delaying the RTO maneuver by just one second beyond V_1 increases the speed 4 to 6 knots on average. Knowing that crews require 3 to 7 seconds to identify an impending RTO and execute the maneuver, it stands to reason that a decision should be made prior to V_1 in order to ensure a successful outcome of the rejected takeoff. This prompted the FAA to expand on the regulatory definition of V_1 and to introduce a couple of new terms through the publication of Advisory Circular (AC) 120-62, "Takeoff Safety Training Aid."

The expanded definition of V_1 is as follows:

a.) V_1—the speed selected for each takeoff, based upon approved performance data and specified conditions, which represents:

1.) The maximum speed by which a rejected takeoff assures that a safe stop can be completed within the remaining runway or runway and stopway;

2.) The minimum speed which assures that a takeoff can be safely completed within the remaining runway, or runway and clearway, after failure of the most critical engine at the designated speed; and

3.) The single speed which permits a successful stop or continued takeoff when operating at the minimum allowable field length for a particular weight.

b.) Minimum V_1—the minimum permissible V_1 speed for the reference conditions from which the takeoff can be safely completed from a given runway, or runway and clearway, after the critical engine had failed at the designated speed.

c.) Maximum V_1—the maximum possible V_1 speed for the reference conditions at which a rejected takeoff can be initiated and the airplane stopped within the remaining runway, or runway and stopway.

d.) Reduced V_1—a V_1 less than maximum V_1 or the normal V_1, but more than the minimum V_1, selected to reduce the RTO stopping distance required.

The main purpose for using a reduced V_1 is to properly adjust the RTO stopping distance in light of the degraded stopping capability associated with wet or contaminated runways, while adding approximately 2 seconds of recognition time for the crew.

Most aircraft manufacturers recommend that operators identify a "low-speed" regime (i.e., 80 knots and below) and a "high-speed" regime (i.e., 100 knots and above) of the takeoff run. In the "low-speed" regime, pilots should abort takeoff for any malfunction or abnormality (actual or suspected). In the "high-speed" regime, takeoff should only be rejected because of catastrophic malfunctions or life-threatening situations. Pilots should weigh the threat against the risk of overshooting the runway during an RTO maneuver. Standard operating procedures (SOPs) should be tailored to include a speed call-out during the transition from low-speed to high-speed regime, the timing of which serves to remind pilots of the impending critical window of decision-making, to provide them with a last opportunity to crosscheck their instruments, to verify their airspeed, and to confirm that adequate takeoff thrust is set, while at the same time performing a pilot incapacitation check through the "challenge and response" ritual.

Brakes provide the most effective stopping force, but experience has shown that the initial tendency of a flight crew is to use normal after-landing braking during a rejected takeoff. Delaying the intervention of the primary deceleration force during an RTO maneuver, when every second counts, increases stopping distance. Instead of braking after the throttles are retarded and the spoilers are deployed (normal landing), pilots should apply maximum braking immediately while simultaneously retarding the throttles, with spoiler extension and thrust reverser deployment following in short sequence. Differential braking applied to maintain directional control also diminishes the effectiveness of the brakes. A blown tire will eliminate any kind of braking action on that particular tire, and could also lead to the failure of adjacent tires.

In order to better assist flight crews in making a split-second go/no-go decision during a high-speed takeoff run, and avoid an unnecessary high-speed RTO, some commercial aircraft manufacturers have gone as far as inhibiting aural or visual malfunction warnings of non-critical equipment beyond a preset speed. The purpose is to prevent an overreaction by the crew and a tendency to select a risky high-speed RTO maneuver over a safer takeoff with a non-critical malfunction. Indeed, the successful outcome of a rejected takeoff, one that concludes without damage or injury, may be influenced by equipment characteristics.

In summary, a rejected takeoff should be perceived as an emergency. RTO safety could be vastly improved by:

- Developing SOPs aiming to advance the expanded FAA definitions of takeoff decision speed and their practical application, including the use of progressive callouts to identify transition from low-speed to high-speed regime.

- Promoting recognition of emergency versus abnormal situations through enhanced CRM training.

- Encouraging crews to carefully consider factors that may affect or even compromise available performance data.

- Expanding practical training in the proper use of brakes, throttles, spoilers, and reverse thrust during RTO demonstrations.

- Encouraging aircraft manufacturers to eliminate non-critical malfunction warnings during the takeoff roll at preset speeds.

Rotation and Lift-Off

Rotation and lift-off in a jet airplane requires planning, precision, and a fine control touch. The objective is to initiate the rotation to takeoff pitch attitude exactly at V_R so that the airplane accelerates through V_{LOF} and attains V_2 speed at 35 feet AGL. Rotation to the proper takeoff attitude too soon may extend the takeoff roll or cause an early lift-off, which results in a lower rate of climb and a divergence from the predicted flightpath. A late rotation, on the other hand, results in a longer takeoff roll, exceeding V_2 speed, and a takeoff and climb path below the predicted path.

Each airplane has its own specific takeoff pitch attitude that remains constant regardless of weight. The takeoff pitch attitude in a jet airplane is normally between 10° and 15° nose up. The rotation to takeoff pitch attitude should be made smoothly but deliberately and at a constant rate. Depending on the particular airplane, the pilot should plan on a rate of pitch attitude increase of approximately 2.5° to 3° per second.

In training, it is common for the pilot to overshoot V_R and then overshoot V_2 because the pilot not flying calls for rotation at or just past V_R. The pilot flying may visually verify V_R and then rotate late. If the airplane leaves the ground at or above V_2, the excess airspeed may be of little concern on a normal takeoff. However, a delayed rotation can be critical when runway length or obstacle clearance is limited. On some airplanes, the rapidly increasing airspeed may cause the achieved flightpath to fall below the engine-out scheduled flightpath unless flying correct speeds. Rotation at the right speed and rate to the right attitude gets the airplane off the ground at the right speed and within the right distance.

Initial Climb

Once the proper pitch attitude is attained, the pilot should maintain it. Takeoff power is also maintained and the airspeed allowed to accelerate. Landing gear retraction should be accomplished after a positive rate of climb has been established and confirmed. In some airplanes gear retraction may temporarily increase the airplane drag while landing gear doors open. Premature gear retraction may cause the airplane to settle back toward the runway surface. In addition, the vertical speed indicator and the altimeter may not show a positive climb until the airplane is 35 to 50 feet above the runway due to ground effect.

The pilot should hold the climb pitch attitude as the airplane accelerates to flap retraction speed. However, the flaps should not be retracted until obstruction clearance altitude or 400 feet AGL has been passed. Ground effect and landing gear drag reduction result in rapid acceleration during this phase of the takeoff and climb. Airspeed, altitude, climb rate, attitude, and heading should be monitored carefully. As the airplane develops a steady climb, longitudinal stick forces can be trimmed out. If making a power reduction, the pilot should reduce the pitch attitude simultaneously if needed and monitor the airplane airspeed and rate of climb so as to preclude an inadvertent reduction in desired performance or a descent.

Speed is limited to 250 KIAS below 10,000 feet MSL in the United States unless otherwise authorized by the Administrator (14 CFR part 91, section 91.117(a)). At or above that altitude, the best rate of climb speed is published in the AFM. If asked to increase rate of climb, increasing pitch slightly will have the desired effect as airspeed bleeds off. If the airplane slows to L/D_{MAX}, the airplane is at its best angle of climb speed, but the rate of climb is less than it was at best rate of climb speed. Trading airspeed for altitude and a temporary increased rate of climb is referred to as a "zoom climb." This type of climb provides an increased rate of climb for a few thousand feet, but it ultimately reduces overall climb performance.

Jet Airplane Descent and Approach

The smoothest and most fuel-efficient descent would be to reduce power to flight idle and slow to L/D_{MAX}. In this scenario, the pilot would descend, level off to decelerate, configure for landing, intercept the final approach, and continue a gradual deceleration until setting power for a stabilized descent on final. Traffic and time considerations almost always require deviation from this example, and the typical descent profile has three descent segments with two speed reductions in between.

Descent Planning

For a typical idle power descent, the top of descent (TOD), point A in *figure 16-14*, is determined by altitude, adjusted for wind. Jet descent profiles normally approximate a 3 degree path, with some time/distance required for deceleration in level flight. While exact distances will vary, having a descent plan will put the pilot well ahead of the jet and in a better position to monitor the automation.
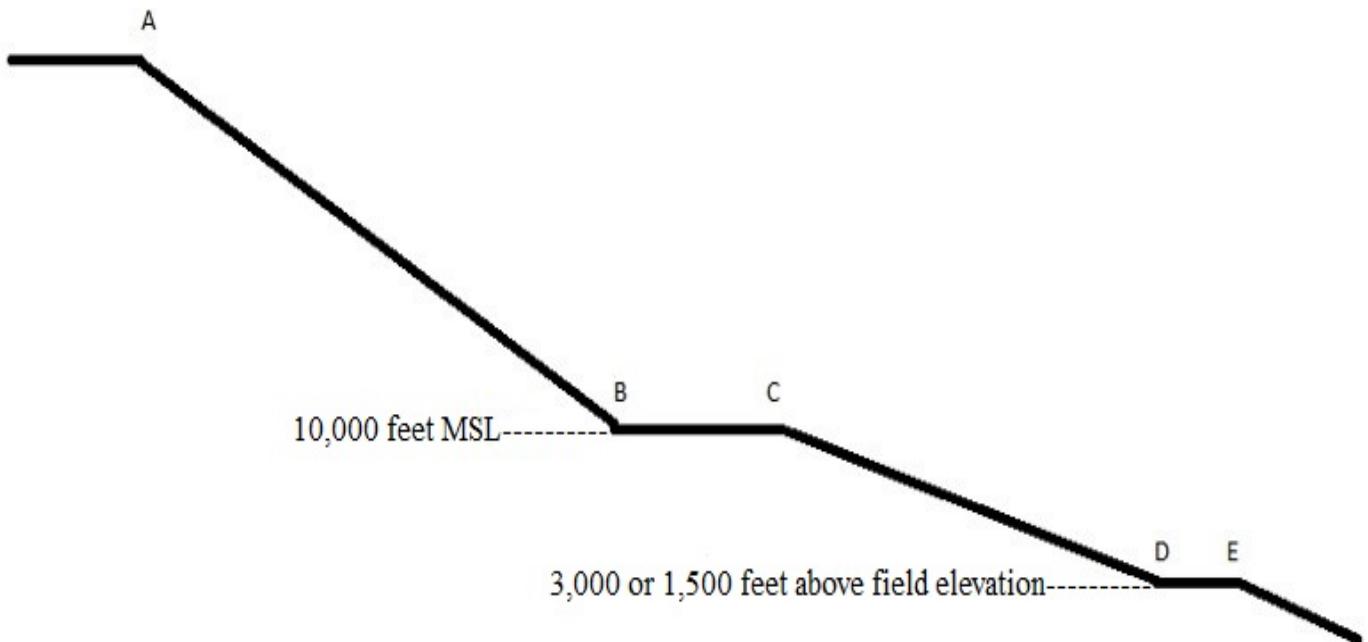

Figure 16-14. *Typical descent profile.*

For a straight-in VFR approach to an airport without factoring wind, an estimate for TOD may be calculated by multiplying the planned descent (in thousands of feet) by 3 and adding any distance needed for speed reductions in level flight (losing about 10 KIAS per mile when level). If flying at 35,000 feet above airport elevation, a cruise descent would start approximately 120 miles from the airport (35 times 3, plus about 15 miles for speed reduction, in stages, from cruise speed in this example). *[Figure 16-14]* Normally, cruise Mach is maintained until increasing air density causes indicated airspeed to increase to the desired descent speed, which usually occurs just below 30,000 feet. If arriving at point B at 10,000 feet MSL about 40 miles from the airport for deceleration to 250 knots, the pilot would resume a descent about 35 miles from the airport, continuing to 1,500 feet about 15 miles from the runway. The approach would continue with deceleration and flap extension so as to start the final descent 5 miles from the runway. There, the pilot extends the landing gear and selects landing flaps by 1,000 feet AGL, and brings the power up by 500 feet AGL to maintain the appropriate speed for a stabilized approach.

Variables that affect the TOD calculation include:

- Head/tail wind component (adjust distance 1 mile for each 10 knots of wind at cruise altitude),

- Field elevation,

- Terrain considerations,

- Runway alignment on arrival,

- ATC vectors and speed restrictions,

- Type of approach.

Descent Energy Management

While descending, the pilot can check the progress periodically. Estimating using round numbers keeps the calculation simple. Passing 25,000 feet should occur at 75 miles out plus or minus corrections; 20,000 feet should be at 60 miles, etc. If there is a deviation from the desired altitude/distance target, the energy state needs to be adjusted.

As discussed in Chapter 4, *Using Energy Management to Master Altitude and Airspeed Control*, there are two forms of energy in an airplane: potential energy in the form of altitude, and kinetic energy in the form of speed. In the normal operating regime at speeds above L/D_{MAX}, increasing speed increases total drag, while a decreasing speed will decrease total drag.

At idle power and at speeds above L/D_{MAX}, increasing speed increases the rate of descent. Sample data for a particular make and model might look like the following:

- 210 KIAS = 1,000 feet per minute

- 250 KIAS = 1,500 feet per minute

- 300 KIAS = 3,000 feet per minute

The exponential increase in parasite drag at higher speeds has a significant impact on both the rate of descent and the descent angle. Using the sample numbers, a 20% increase in airspeed from 210 to 250 knots, results in a 50% increase in the descent rate. However, a 20% increase in airspeed from 250 to 300 knots results in a 100% increase in the descent rate. Therefore, when at a higher altitude than desired in a descent, lowering the nose to increase speed will increase the descent angle and get the aircraft back to the desired path. Conversely, if lower than planned in descent, raising the nose to decrease speed will reduce descent angle until back on the desired path. Often, just a 10-knot change in speed allows for a smooth and gradual correction.

If speed adjustment is not an option, power can be added to correct a low-energy state, or the speed brakes used to correct a high-energy state. Numerous power fluctuations or repeated deployment and stowing of speed brakes is an indication of either pilot failure to adequately plan and/or manage the descent, or a poorly designed arrival procedure.

If a different descent speed from that planned is used during a descent, an adjustment should be made to the top of descent point. If ahead of schedule, leaving cruise altitude sooner, setting flight idle, and descending at a slower speed will burn less fuel. Conversely, if running late and willing to burn some extra fuel, the pilot can leave cruise later and descend at a higher speed. In all cases, the pilot should check progress during the descent and continue to adjust as necessary.

Planned descent speed will affect the position of the planned top of descent point. *[Figure 16-15]* In this example, both jets fly past point X at the same cruise speed and altitude with plans to arrive at point Y at 10,000 feet and 250 knots. In both cases, the aircraft would then be in a position to set up a continued descent. The 250-knot descent requires a few miles for deceleration and gives a shallower descent path. The 300-knot descent allows staying at altitude longer, descending at a steeper angle, and then leveling off to slow to 250 knots. The jet that descended at 300 knots arrives first at point Y but burns more fuel. While not depicted, an inefficient descent plan would start the descent at point X, maintain 300 knots, and require power to maintain that airspeed on a shallow descent path.
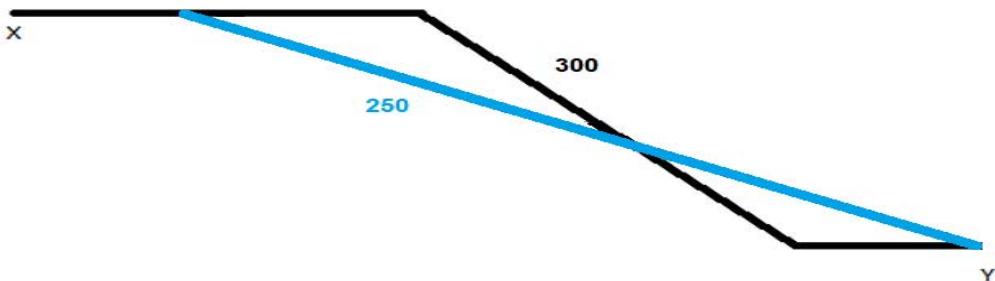

Figure 16-15. *Effect of speed on descent path.*

Descending prior to the planned TOD point will increase time to destination and fuel consumption. When given a descent clearance prior to the planned TOD, it is acceptable to ask ATC if the descent can be done at the pilot's discretion. If authorized to do so, this option allows for maintaining speed and altitude until reaching the calculated top of descent point. If an immediate descent is required, a descent at 1,000 feet per minute is usually acceptable until reaching the desired path. If a descent clearance has not been received by the planned TOD point, a speed reduction will reduce the airplane's kinetic and total energy while potential energy remains constant. When the clearance is received, a slightly steeper descent at the onset allows for a desired increase in kinetic energy at the expense of altitude and an appropriate descent rate such that the airplane follows the steeper desired path with acceptable energy distribution.

Jet Engine Landing

14 CFR part 25, section 25.125 defines the horizontal distance needed in order to land a jet airplane. The regulation describes the landing profile as the horizontal distance required to land and come to a complete stop from a point 50 feet above the landing surface. Manufacturers determine the landing distance on a dry, level runway at standard temperatures without using thrust reversers, auto brakes, or auto-land systems as a baseline. The pilot uses the landing weight and environmental conditions to determine the actual expected landing requirement based on the FAA-approved data in the AFM. As an accepted safety practice, pilots normally add a 40% cushion for landing on a dry runway. Dividing the usable runway length by 1.67 should give a number equal to or greater than the landing distance calculated from AFM data. For a wet runway, the distance should be increased by an additional 15%. *[Figure 16-16]*
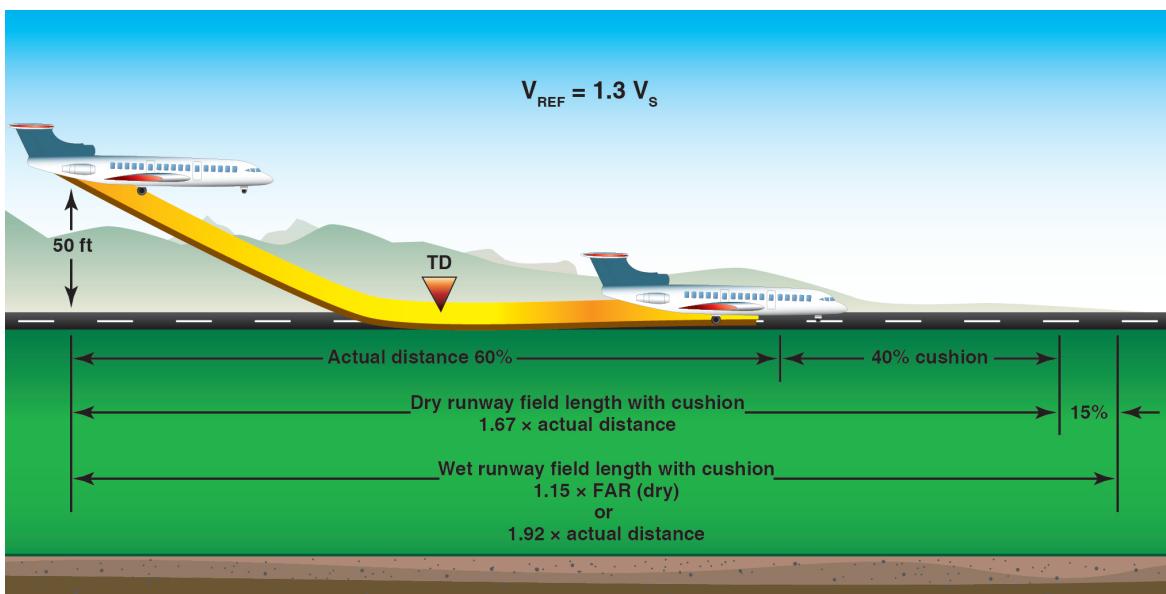

Figure 16-16. *FAR landing field length required.*

Simply put, the pilot divides the length of an intended runway by 1.67 or 1.92, as appropriate, to determine the minimum distance that should be available for landing. With this safety margin, it works out that the minimum dry runway field length should be at least 1.4 times the calculated air and ground distance needed, and the wet runway landing field length should be at least 1.61 times the calculated air and ground distance needed. Careful flight planning allows a pilot to determine how much load in terms of fuel, passengers, or cargo can be carried to a particular runway while still maintaining the desired safety margin. Depending on the destination, the load might need to be limited in order to protect the safety margin when landing. This is often complex, since fuel load has its own safety implications.

Certified landing field length requirements are computed for the stop made with speed brakes deployed and maximum wheel braking. Reverse thrust is not used in establishing the certified landing distances. However, reversers should definitely be used, if available.

Landing Speeds

As in the takeoff planning, there are certain speeds that should be taken into consideration when landing a jet airplane. The speeds are as follows:

- V_{SO}—stall speed in the landing configuration.

- V_{REF}—1.3 times the stall speed in the landing configuration.

- Approach climb—the speed that guarantees adequate performance in a go-around situation with an inoperative engine.

- Landing climb—the speed that guarantees adequate performance in arresting the descent and making a go-around from the final stages of landing with the airplane in the full landing configuration and maximum takeoff power available on all engines.

Pilots may need to perform traffic pattern takeoffs and landings. Pilots should use speeds recommended by the manufacturer while maneuvering in the traffic pattern prior to slowing to the final approach target speed in relation to V_{REF}. The speeds should be calculated for every landing and posted where they are visible to both pilots.

The approach and landing sequence in a jet airplane should be accomplished in accordance with an approach and landing profile developed for the particular airplane. *[Figure 16-17]*
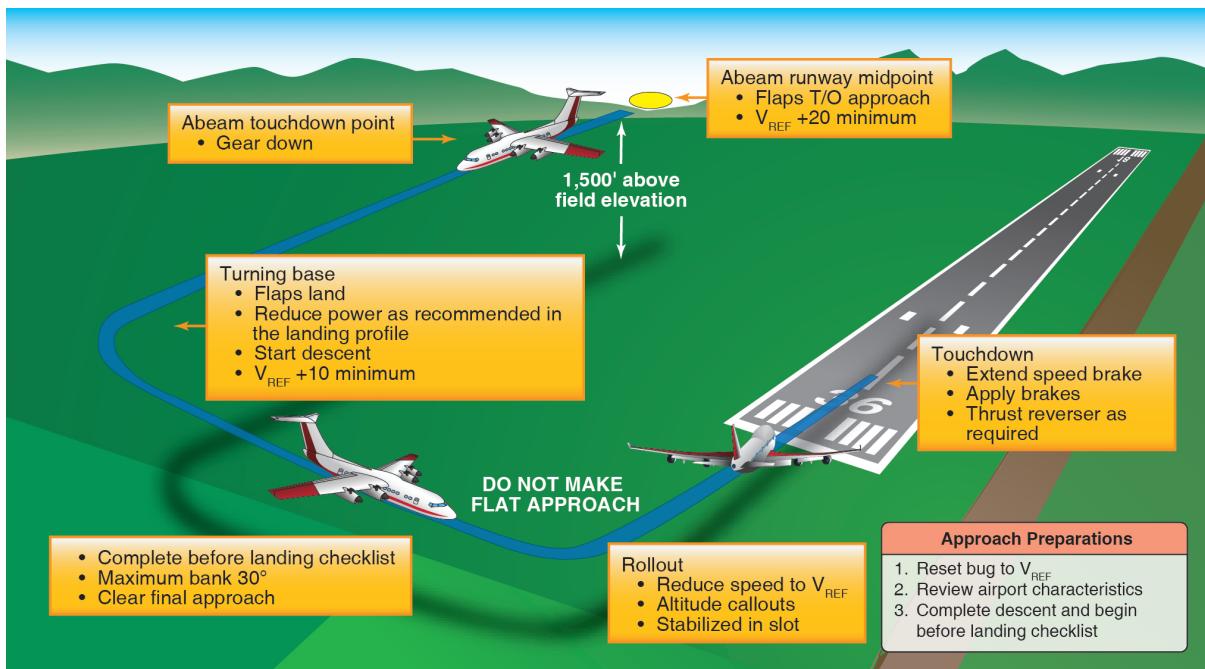

Figure 16-17. *Typical approach and landing profile.*

Significant Differences

A safe approach in any type of airplane culminates in a particular position, speed, and height over the runway threshold. That final flight condition is the target window at which the entire approach aims. Propeller-powered airplanes are able to approach that target from wider angles, greater speed differentials, and a larger variety of glidepath angles. Jet airplanes are not as responsive to power and course corrections, so the final approach should be more stable, more deliberate, and more constant in order to reach the window accurately.

The transitioning pilot should understand that in spite of their impressive performance capabilities, there are many reasons why jet airplanes are less forgiving than piston-engine airplanes during approaches and when correcting approach errors.

- There is no propeller slipstream to produce immediate extra lift at constant airspeed. There is no such thing as salvaging a misjudged glidepath with a sudden burst of power. Added lift can only be achieved by accelerating the airframe.

- Propeller slipstream is not available to lower the power-on stall speed. There is virtually no difference between power-on and power-off stall speed. It is not possible in a jet airplane to jam the thrust levers forward to avoid a stall.

- Jet engine response at low rpm is slower. This characteristic requires that the approach be flown at a stable speed and power setting on final so that sufficient power is available quickly if needed.

- Jet airplanes are consistently heavier and have faster approach speeds than a comparably sized propeller airplane. Since greater force is required to overcome momentum for speed changes or course corrections, the typical jet responds less quickly than the propeller airplane and requires careful planning and stable conditions throughout the approach.

- When the speed does increase or decrease, there is little tendency for the jet airplane to re-acquire the original speed. The pilot needs to make speed adjustments promptly in order to remain on speed.

- Drag increases faster than lift and produces a high sink rate at low speeds. Jet airplane wings typically have a large increase in drag in the approach configuration. When a sink rate does develop, the only immediate remedy is to increase pitch attitude (AOA). Because drag increases faster than lift, that pitch change rapidly contributes to an even greater sink rate unless a significant amount of power is promptly applied.

These flying characteristics of jet airplanes make a stabilized approach an absolute necessity.

Stabilized Approach

The performance charts and the limitations contained in the FAA-approved AFM are predicated on momentum values that result from programmed speeds and weights. Runway length limitations assume an exact 50-foot threshold height at an exact speed of 1.3 times V_{SO}. That "window" is critical and is a prime reason for the stabilized approach. Performance figures also assume that once through the target threshold window, the airplane touches down in a target touchdown zone approximately 1,000 feet down the runway, after which maximum stopping capability is used.

The basic elements to the stabilized approach are listed below as follows:

- The airplane should be in the landing configuration by 1,000 feet AGL in the approach. The landing gear should be down, landing flaps selected, trim set, and fuel balanced. Ensuring that these tasks are completed helps keep the number of variables to a minimum during the final approach.

- The airplane should be on profile before descending below 1,000 feet. Configuration, trim, speed, and glidepath should be at or near the optimum parameters early in the approach to avoid distractions and conflicts as the airplane nears the threshold window. An optimum glidepath angle of about 3° should be established and maintained.

- Indicated airspeed should be between zero and 10 knots above the target airspeed by 500 feet AGL. There are strong relationships between trim, speed, and power in most jet airplanes, and it is important to stabilize the speed in order to minimize those other variables.

- The optimum descent rate is dependent upon ground speed. A rule of thumb is to multiply half of ground speed by 10. For example, a 130-knot ground speed should result in a (65 times 10) 650 feet per minute descent rate. Typical descent rates fall between 500 and 700 feet per minute. An excessive vertical speed may indicate a problem with the approach.

Every approach should be evaluated at 500 feet. In a typical jet airplane, this is approximately 1 minute from touchdown. If the approach is not stabilized at that height, a go-around should be initiated. *[Figure 16-18]*
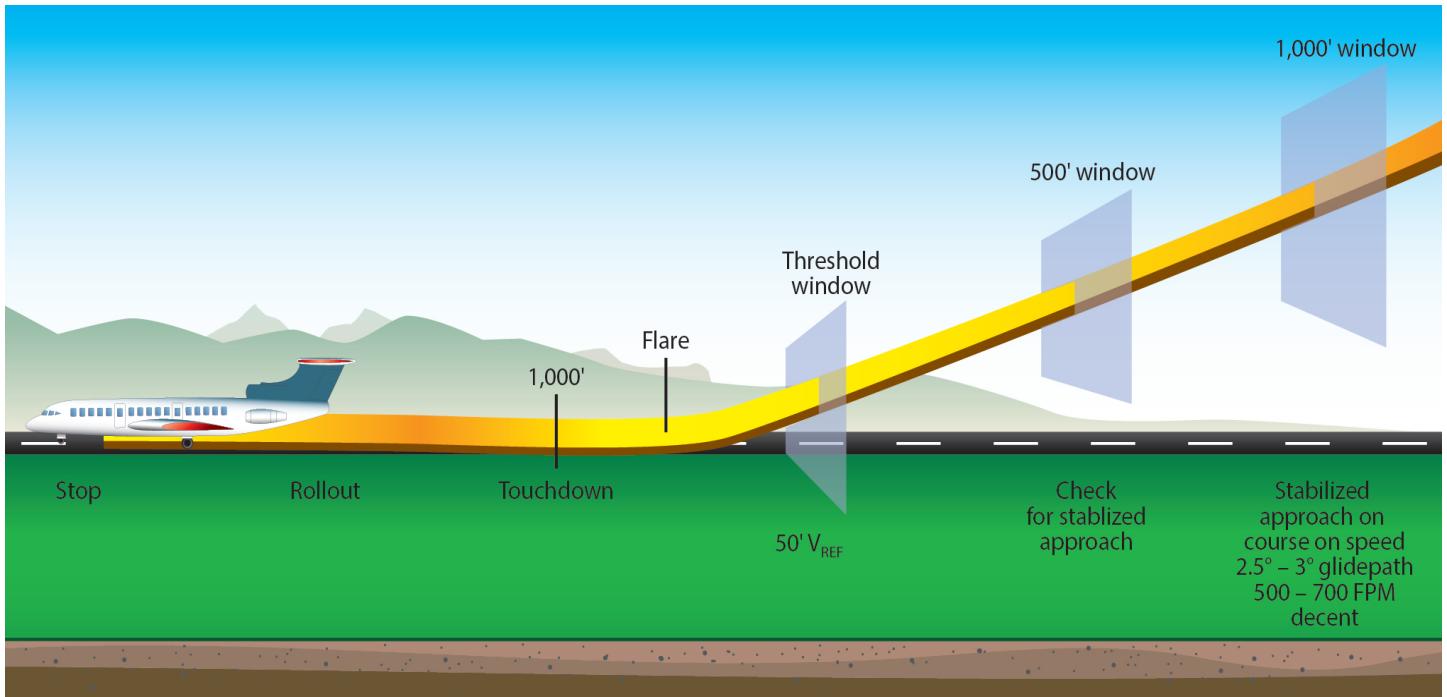

Figure 16-18. *Stabilized approach.*

Approach Speed

Any speed deviation on final approach should be detected immediately and corrected. With experience, the pilot is able to detect the onset of an increasing or decreasing airspeed trend, which normally can be corrected with a small adjustment. It is imperative the pilot does not allow the airspeed to decrease below V_{REF} or a high sink rate can develop. If an increasing sink rate is detected, it should be countered by increasing the AOA and simultaneously increasing thrust to counter the extra drag. The degree of correction depends on how much the sink rate needs to be reduced. For small amounts, smooth and gentle, almost anticipatory corrections are sufficient. For large sink rates, drastic corrective measures would be required that, even if successful, would destabilize the approach.

A common error in the performance of approaches in jet airplanes is excess approach speed. Excess approach speed carried through the threshold window and onto the runway increases the minimum stopping distance required by 20–30 feet per knot for a dry runway and 40–50 feet for a wet runway. Worse yet, the excess speed increases the chances of an extended flare, which increases the distance to touchdown by approximately 250 feet for each excess knot in speed.

Proper speed control on final approach is of primary importance. The pilot should anticipate the need for speed adjustment so that only small adjustments are required, and the airplane arrives at the approach threshold window exactly on speed.

Glidepath Control

The optimum glidepath angle is about 3°. On visual approaches, pilots may have a tendency to make flat approaches. A flat approach, however, increases landing distance and should be avoided. For example, an approach angle of 2° instead of a recommended 3° adds 500 feet to landing distance.

A more common error is excessive height over the threshold. This could be the result of an unstable approach or a stable but high approach. It also may occur during a nonprecision instrument approach where the missed approach point is close to or at the runway threshold. Regardless of the cause, excessive height over the threshold most likely results in a touchdown beyond the normal aiming point. An extra 50 feet of height over the threshold adds approximately 1,000 feet to the landing distance. The airplane should arrive at the approach threshold window exactly on altitude (50 feet above the runway).

The Flare

The flare reduces the approach rate of descent to a more acceptable rate for touchdown. Unlike light airplanes, a jet airplane should be flown onto the runway rather than "held off" the surface as speed dissipates. A jet airplane is aerodynamically clean even in the landing configuration, and its engines still produce residual thrust at idle rpm. Holding it off during the flare in an attempt to make a smooth landing greatly increases landing distance. A firm landing is normal and desirable. A firm landing does not mean a hard landing, but rather a deliberate or positive landing.

For most airports, the airplane passes over the end of the runway with the landing gear 30–45 feet above the surface, depending on the landing flap setting and the location of the touchdown zone. It takes 5–7 seconds from the time the airplane passes the end of the runway until touchdown. The flare is initiated by increasing the pitch attitude just enough to reduce the sink rate to 100–200 fpm when the landing gear is approximately 15 feet above the runway surface. In most jet airplanes, this requires a pitch attitude increase of only 1° to 3°. The thrust is smoothly reduced to idle as the flare progresses.

The normal speed bleed off during the time between passing the end of the runway and touchdown is just a few knots. Most of the decrease occurs during the flare when thrust is reduced. If the flare is extended (held off) while an additional speed is bled off, hundreds or even thousands of feet of runway may be used up. *[Figure 16-19]* The extended flare also results in additional pitch attitude, which may lead to a tail strike. It is, therefore, essential to fly the airplane onto the runway at the target touchdown point, even if the speed is excessive. A deliberate touchdown should be planned and practiced on every flight. A positive touchdown helps prevent an extended flare.
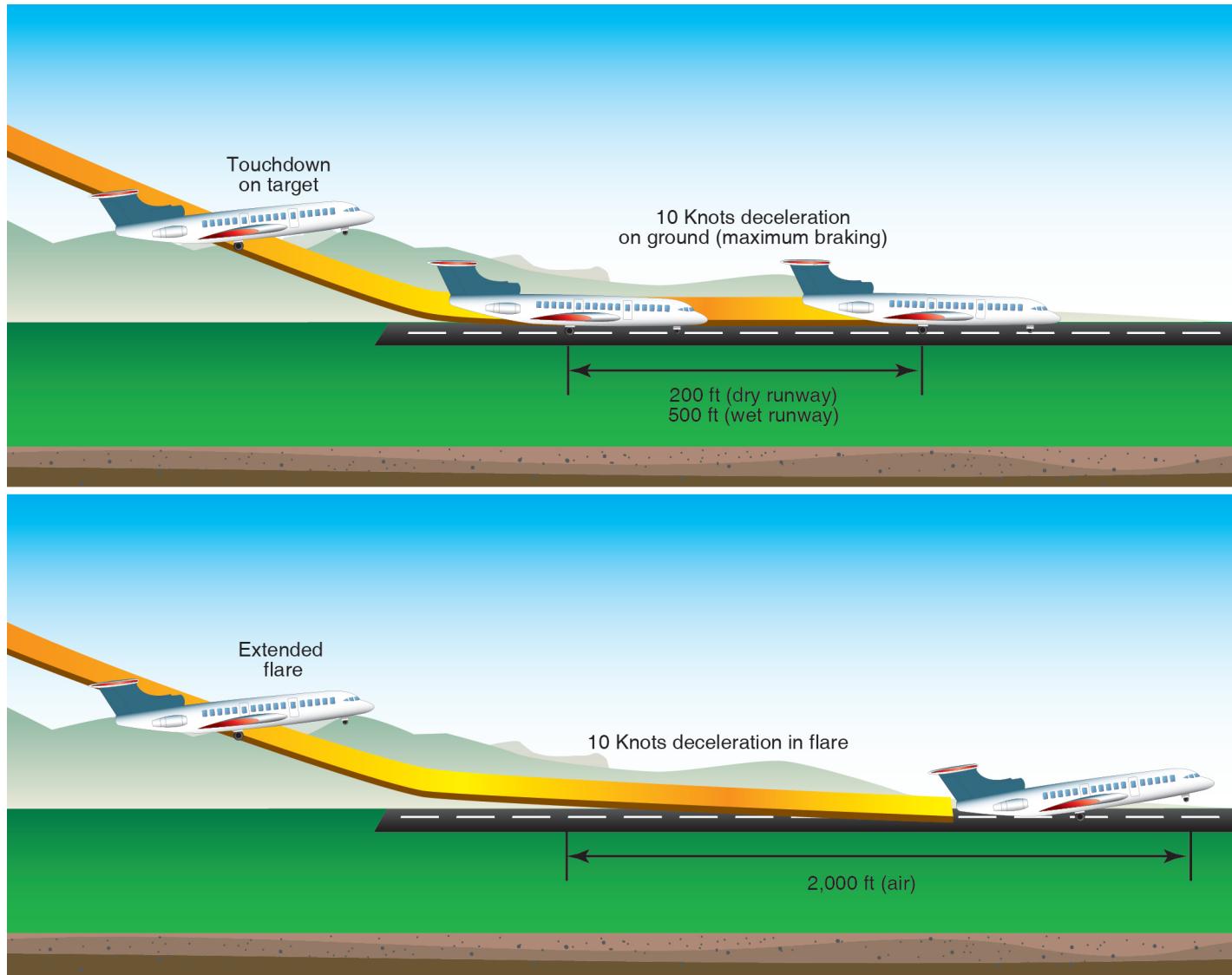

Figure 16-19. *Extended flare.*

16-23

Pilots should learn the flare characteristics of each model of airplane they fly. The visual reference cues observed from each airplane are different because window geometry and visibility are different. The geometric relationship between the pilot's eye and the landing gear is different for each make and model. It is essential that the flare maneuver be initiated at the proper height—not too high and not too low.

Beginning the flare too high or reducing the thrust too early may result in the airplane floating beyond the target touchdown point or may include a rapid pitch up as the pilot attempts to prevent a high sink rate touchdown. This can lead to a tail strike. The flare that is initiated too late may result in a hard touchdown.

Proper thrust management through the flare is also important. In many jet airplanes, the engines produce a noticeable effect on pitch trim when the thrust setting is changed. A rapid change in the thrust setting requires a quick elevator response. If the thrust levers are moved to idle too quickly during the flare, the pilot may need to make rapid changes in pitch control. If the thrust levers are moved more slowly, the elevator input can be more easily coordinated.

Touchdown and Rollout

A proper approach and flare positions the airplane to touch down in the touchdown target zone, which is usually about 1,000 feet beyond the runway threshold. Once the main wheels have contacted the runway, the pilot should maintain directional control and initiate the stopping process on the runway that remains in front of the airplane. The runway distance available to stop is longest if the touchdown was on target. The energy to be dissipated is least if there is no excess speed.

At the point of touchdown, the airplane represents a very large mass that is moving at a relatively high speed. The large total energy gets dissipated by the brakes, the aerodynamic drag, and the thrust reversers (if available). The nose-wheel should be lowered onto the ground immediately after touchdown because a jet airplane decelerates poorly when held in a nose-high attitude, and placing the nose-wheel tire(s) on the ground assists in maintaining directional control. Lowering the nose gear decreases the wing AOA, decreasing the lift, placing more load onto the tires, thereby increasing tire-to-ground friction. Landing distance charts for jet airplanes assume that the nose-wheel is lowered onto the runway within 4 seconds of touchdown.

There are only three forces available for stopping the airplane: wheel braking, reverse thrust, and aerodynamic braking. Of the three, the brakes are most effective and therefore the most important stopping force for most landings. When the runway is very slippery, reverse thrust and drag may be the dominant forces. Both reverse thrust and aerodynamic drag are most effective at high speeds. Neither is affected by runway surface conditions. Brakes, on the other hand, are most effective at low speed. The landing rollout distance depends on the touchdown speed, what forces are applied, and when they are applied. The pilot controls the what and when factors, but the maximum braking force may be limited by tire-to-ground friction.

The pilot should begin braking as soon after touchdown and wheel spin-up as possible, and smoothly continue the braking until stopped or a safe taxi speed is reached. However, caution should be used if the airplane is not equipped with a functioning anti-skid system. In such a case, heavy braking can cause the wheels to lock and the tires to skid.

Both directional control and braking utilize tire ground friction. They share the maximum friction force the tires can provide. Increasing either subtracts from the other. Understanding tire ground friction, how runway contamination affects it, and how to use the friction available to maximum advantage is important to a jet pilot.

Spoilers should be deployed immediately after touchdown because they are most effective at high speed. Timely deployment of spoilers increases drag significantly, but more importantly, they spoil much of the lift the wing is creating, thereby causing more of the weight of the airplane to be loaded onto the wheels. The spoilers increase wheel loading, which increases the tire ground friction force making the maximum tire braking forces available.

Like spoilers, thrust reversers are most effective at high speeds and should be deployed quickly after touchdown. However, the pilot should not command significant reverse thrust until the nose-wheel is on the ground. If the reversers deploy asymmetrically resulting in an uncontrollable yaw toward the side with more reverse thrust, the pilot needs whatever nose-wheel steering is available to maintain directional control. When runway length is not a factor, using idle reverse thrust may be adequate.

Jet Airplane Systems and Maintenance

All FAA-certificated jet airplanes are certificated under Title 14 of the Code of Federal Regulations (14 CFR) part 25, which contains the airworthiness standards for transport category airplanes. The FAA-certificated jet airplane is a highly sophisticated machine with proven levels of performance and guaranteed safety margins. The jet airplane's performance and safety margins can only be realized, however, if the airplane is operated in strict compliance with the procedures and limitations contained in the FAA-approved AFM for the particular airplane. Furthermore, in accordance with 14 CFR part 91, section 91.213(a), a turbine-powered airplane does not qualify to takeoff with inoperable instruments or equipment installed unless, among other requirements, an approved Minimum Equipment List (MEL) exists for that aircraft, and the aircraft is operated under all applicable conditions and limitations contained in the MEL (section 91.213(a)(5)).

Minimum Equipment List

The MEL serves as a reference guide for dispatchers and pilots to determine whether takeoff of an aircraft with inoperative instruments or equipment is authorized under the provisions of applicable regulatory requirements.

The operator models the MEL after the FAA's Master MEL (MMEL) for each type of aircraft and the Administrator approves the MEL before its implementation. The MEL includes a "General" section, comprised of definitions, general policies, as well as operational procedures for flight crews and maintenance personnel. Each aircraft component addressed in the MEL is listed in an alphabetical index for quick reference. A table of contents further divides the manual in different chapters, each numbered for its corresponding aircraft system designation (i.e., the electrical system, also designated as system number 24, would be found in chapter 24 of the MEL).

Pilots may defer repair of items on those aircraft systems and components allowed by the approved MEL. Per 14 CFR part 91, section 91.213(a)(3)(ii), an MEL must provide for the operation of the aircraft with the instruments and equipment in an inoperable condition. If particular items do not allow for safe operation, they do not appear on the MEL and takeoff is not authorized until the item is adequately repaired or replaced (section 91.213(a)). In cases where repairs may temporarily be deferred, operation or dispatch of an aircraft whose systems have been impaired is often subject to limitations or other conditional requirements explicitly stated in the MEL. Such conditional requirements may be of an operational nature, a mechanical nature, or both.

Mechanical conditions outlined in the MEL may require precautionary pre-flight checks, partial repairs prior to departure, or the isolation of selected elements of the deficient aircraft system (or related interacting systems), as well as the securing of other system components to avoid further degradation in flight. The MEL may contain either a step-by-step description of required partial maintenance actions or a list of numerical references to the Maintenance Procedures Manual (MPM) where each corrective procedure is explained in detail. Procedures performed to ensure the aircraft can be safely operated are categorized as either pperations procedures or maintenance procedures. The MEL will denote which by indicating an "O" or an "M" as appropriate.

If operational and mechanical conditions can be met, an authorized person makes an entry in the aircraft MEL Deferral Record and issues a temporary placard. This authorizes the operation for a limited time before permanent repairs take place. The placard is affixed by maintenance personnel or the flight crew onto or next to the instrument or control mechanism to remind the flight crew of any limitations.

The MEL only applies while the aircraft sits on the ground awaiting departure or takeoff. It is essentially a dispatching reference tool used in support of all applicable Federal Aviation Regulations. If dispatchers are not required by the operator's certificate, flight crews still need to refer to the MEL before dispatching themselves to ensure that the flight is planned and conducted within the operating limits set forth in the MEL. Once the aircraft leaves the ground, any mechanical failures should be addressed using the appropriate checklists and approved AFM, not the MEL. Although a pilot may refer to the MEL for background information and documentation, actions in flight should be based strictly on instructions provided by the AFM (i.e., Abnormal or Emergency sections).

Configuration Deviation List

A Configuration Deviation List (CDL) is used in the same manner as an MEL but it differs in that it addresses missing external parts of the aircraft rather than failing internal systems and their constituent parts. They typically include elements, such as service doors, power receptacle doors, slat track doors, landing gear doors, APU ram air doors, flaps fairings, nose-wheel spray deflectors, position light lens covers, slat segment seals, static dischargers, etc.

Chapter Summary

Some of the differences when transitioning from props to jets include:
- Engine intake suction and exhaust create a ground hazard.
- There is no propeller-induced lift when power increases.
- Engine spool up time from low power settings is longer.
- Swept wing stalls begin at the tips.
- Higher speeds require smaller and smoother flight control inputs.
- Descents require more planning and optimally occur at idle power.
- When descending at speeds above L/D_{MAX}, increasing speed increases rate of descent and descent angle.

There are many considerations for a pilot when transitioning to turbojet-powered airplanes. In addition to the information found in this chapter and type specific information that will be found in an FAA-approved Airplane Flight Manual, a pilot can find basic aerodynamic information for swept wing jets, considerations for operating at high altitudes, and airplane upset causes and general recovery procedures in the Airplane Upset Recovery Training Aid, Supplement, pages 1-14, and all of Section 2 found at www.faa.gov/other_visit/aviation_industry/airline_operators/training/media/ap_upsetrecovery_book.pdf.