Chapter 12

Transition to Multiengine Airplanes

MULTIENGINE FLIGHT

This chapter is devoted to the factors associated with the operation of small multiengine airplanes. For the purpose of this handbook, a “small” multiengine airplane is a reciprocating or turbopropeller-powered airplane with a maximum certificated takeoff weight of 12,500 pounds or less. This discussion assumes a conventional design with two engines—one mounted on each wing. Reciprocating engines are assumed unless otherwise noted. The term “light-twin,” although not formally defined in the regulations, is used herein as a small multiengine airplane with a maximum certificated takeoff weight of 6,000 pounds or less.

There are several unique characteristics of multiengine airplanes that make them worthy of a separate class rating. Knowledge of these factors and proficient flight skills are a key to safe flight in these airplanes. This chapter deals extensively with the numerous aspects of one engine inoperative (OEI) flight. However, pilots are strongly cautioned not to place undue emphasis on mastery of OEI flight as the sole key to flying multiengine airplanes safely. The inoperative engine information that follows is extensive only because this chapter emphasizes the differences between flying multiengine airplanes as contrasted to single-engine airplanes.

The modern, well-equipped multiengine airplane can be remarkably capable under many circumstances. But, as with single-engine airplanes, it must be flown prudently by a current and competent pilot to achieve the highest possible level of safety.

This chapter contains information and guidance on the performance of certain maneuvers and procedures in small multiengine airplanes for the purposes of flight training and pilot certification testing. The final authority on the operation of a particular make and model airplane, however, is the airplane manufacturer. Both the flight instructor and the student should be aware that if any of the guidance in this handbook conflicts with the airplane manufacturer’s recommended procedures and guidance as contained in the FAA-approved Airplane Flight Manual and/or Pilot’s Operating Handbook (AFM/POH), it is the airplane manufacturer’s guidance and procedures that take precedence.

GENERAL

The basic difference between operating a multiengine airplane and a single-engine airplane is the potential problem involving an engine failure. The penalties for loss of an engine are twofold: performance and control. The most obvious problem is the loss of 50 percent of power, which reduces climb performance 80 to 90 percent, sometimes even more. The other is the control problem caused by the remaining thrust, which is now asymmetrical. Attention to both these factors is crucial to safe OEI flight. The performance and systems redundancy of a multiengine airplane is a safety advantage only to a trained and proficient pilot.

TERMS AND DEFINITIONS

Pilots of single-engine airplanes are already familiar with many performance “V” speeds and their definitions. Twin-engine airplanes have several additional V speeds unique to OEI operation. These speeds are differentiated by the notation “$_{SE}$”, for single engine. A review of some key V speeds and several new V speeds unique to twin-engine airplanes follows.

- **V_R** – Rotation speed. The speed at which back pressure is applied to rotate the airplane to a takeoff attitude.
- **V_{LOF}** – Lift-off speed. The speed at which the airplane leaves the surface. (Note: some manufacturers reference takeoff performance data to V_R, others to V_{LOF}.)
- **V_X** – Best angle of climb speed. The speed at which the airplane will gain the greatest altitude for a given distance of forward travel.
- **V_{XSE}** – Best angle-of-climb speed with one engine inoperative.
- **V_Y** – Best rate of climb speed. The speed at which the airplane will gain the most altitude for a given unit of time.
- **V_{YSE}** – Best rate-of-climb speed with one engine inoperative. Marked with a blue radial line on most airspeed indicators. Above the single-engine absolute ceiling, V_{YSE} yields the minimum rate of sink.
- **V_{SSE}** – Safe, intentional one-engine-inoperative speed. Originally known as safe single-engine

speed. Now formally defined in Title 14 of the Code of Federal Regulations (14 CFR) part 23, Airworthiness Standards, and required to be established and published in the AFM/POH. It is the minimum speed to intentionally render the critical engine inoperative.

- **V_{MC}** – Minimum control speed with the critical engine inoperative. Marked with a red radial line on most airspeed indicators. The minimum speed at which directional control can be maintained under a very specific set of circumstances outlined in 14 CFR part 23, Airworthiness Standards. Under the small airplane certification regulations currently in effect, the flight test pilot must be able to (1) stop the turn that results when the critical engine is suddenly made inoperative within 20° of the original heading, using maximum rudder deflection and a maximum of 5° bank, and (2) thereafter, maintain straight flight with not more than a 5° bank. There is no requirement in this determination that the airplane be capable of climbing at this airspeed. V_{MC} only addresses directional control. Further discussion of V_{MC} as determined during airplane certification and demonstrated in pilot training follows in minimum control airspeed (V_{MC}) demonstration. [Figure 12-1]

Figure 12-1. Airspeed indicator markings for a multiengine airplane.

Unless otherwise noted, when V speeds are given in the AFM/POH, they apply to sea level, standard day conditions at maximum takeoff weight. Performance speeds vary with aircraft weight, configuration, and atmospheric conditions. The speeds may be stated in statute miles per hour (m.p.h.) or knots (kts), and they may be given as calibrated airspeeds (CAS) or indicated airspeeds (IAS). As a general rule, the newer AFM/POHs show V speeds in knots indicated airspeed (KIAS). Some V speeds are also stated in knots calibrated airspeed (KCAS) to meet certain regulatory requirements. Whenever available, pilots should operate the airplane from published indicated airspeeds.

With regard to climb performance, the multiengine airplane, particularly in the takeoff or landing configuration, may be considered to be a single-engine airplane with its powerplant divided into two units. There is nothing in 14 CFR part 23 that requires a multiengine airplane to maintain altitude while in the takeoff or landing configuration with one engine inoperative. In fact, many twins are not required to do this in any configuration, even at sea level.

The current 14 CFR part 23 single-engine climb performance requirements for reciprocating engine-powered multiengine airplanes are as follows.

- More than 6,000 pounds maximum weight and/or V_{SO} more than 61 knots: the single-engine rate of climb in feet per minute (f.p.m.) at 5,000 feet MSL must be equal to at least .027 V_{SO}^2. For airplanes type certificated February 4, 1991, or thereafter, the climb requirement is expressed in terms of a climb gradient, 1.5 percent. The climb gradient is not a direct equivalent of the .027 V_{SO}^2 formula. Do not confuse the date of type certification with the airplane's model year. The type certification basis of many multiengine airplanes dates back to CAR 3 (the Civil Aviation Regulations, forerunner of today's Code of Federal Regulations).

- 6,000 pounds or less maximum weight and V_{SO} 61 knots or less: the single-engine rate of climb at 5,000 feet MSL must simply be determined. The rate of climb could be a negative number. There is no requirement for a single-engine positive rate of climb at 5,000 feet or any other altitude. For light-twins type certificated February 4, 1991, or thereafter, the single-engine climb gradient (positive or negative) is simply determined.

Rate of climb is the altitude gain per unit of time, while climb gradient is the actual measure of altitude gained per 100 feet of horizontal travel, expressed as a percentage. An altitude gain of 1.5 feet per 100 feet of travel (or 15 feet per 1,000, or 150 feet per 10,000) is a climb gradient of 1.5 percent.

There is a dramatic performance loss associated with the loss of an engine, particularly just after takeoff. Any airplane's climb performance is a function of thrust horsepower which is in excess of that required for level flight. In a hypothetical twin with each engine producing 200 thrust horsepower, assume that the total level-flight thrust horsepower required is 175. In this situation, the airplane would ordinarily have a reserve of 225 thrust horsepower available for climb. Loss of one engine would leave only 25 (200 minus 175) thrust horsepower available for climb, a drastic reduction. Sea level rate-of-climb performance losses of at least 80 to 90 percent, even under ideal circumstances, are typical for multiengine airplanes in OEI flight.

OPERATION OF SYSTEMS

This section will deal with systems that are generally found on multiengine airplanes. Multiengine airplanes share many features with complex single-engine airplanes. There are certain systems and features covered here, however, that are generally unique to airplanes with two or more engines.

PROPELLERS

The propellers of the multiengine airplane may outwardly appear to be identical in operation to the constant-speed propellers of many single-engine airplanes, but this is not the case. The propellers of multiengine airplanes are featherable, to minimize drag in the event of an engine failure. Depending upon single-engine performance, this feature often permits continued flight to a suitable airport following an engine failure. To feather a propeller is to stop engine rotation with the propeller blades streamlined with the airplane's relative wind, thus to minimize drag. [Figure 12-2]

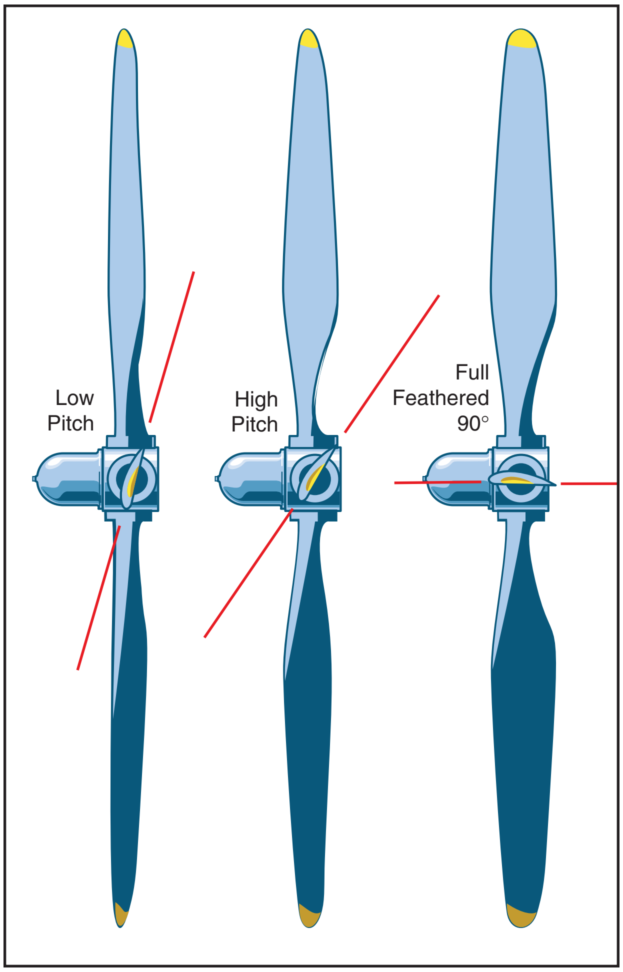


Figure 12-2. Feathered propeller.

Feathering is necessary because of the change in parasite drag with propeller blade angle. [Figure 12-3] When the propeller blade angle is in the feathered position, the change in parasite drag is at a minimum and, in the case of a typical multiengine airplane, the added parasite drag from a single feathered propeller is a relatively small contribution to the airplane total drag.

At the smaller blade angles near the flat pitch position, the drag added by the propeller is very large. At these small blade angles, the propeller windmilling at high r.p.m. can create such a tremendous amount of drag that the airplane may be uncontrollable. The propeller windmilling at high speed in the low range of blade angles can produce an increase in parasite drag which may be as great as the parasite drag of the basic airplane.

As a review, the constant-speed propellers on almost all single-engine airplanes are of the non-feathering, oil-pressure-to-increase-pitch design. In this design, increased oil pressure from the propeller governor drives the blade angle towards high pitch, low r.p.m.

In contrast, the constant-speed propellers installed on most multiengine airplanes are full feathering, counterweighted, oil-pressure-to-decrease-pitch designs. In this design, increased oil pressure from the propeller governor drives the blade angle towards low pitch, high r.p.m.—away from the feather blade angle. In effect, the only thing that keeps these propellers from feathering is a constant supply of high pressure engine oil. This is a necessity to enable propeller feathering in the event of a loss of oil pressure or a propeller governor failure.

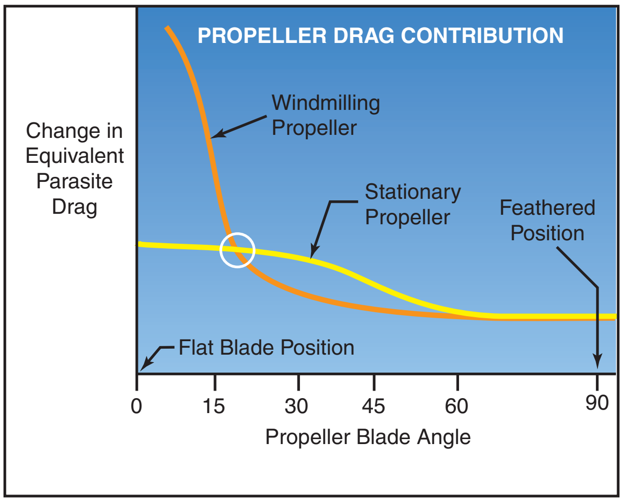


Figure 12-3. Propeller drag contribution.

The aerodynamic forces alone acting upon a windmilling propeller tend to drive the blades to low pitch, high r.p.m. Counterweights attached to the shank of each blade tend to drive the blades to high pitch, low r.p.m. Inertia, or apparent force called centrifugal force acting through the counterweights is generally slightly greater than the aerodynamic forces. Oil pressure from the propeller governor is used to counteract the counterweights and drives the blade angles to low pitch, high r.p.m. A reduction in oil pressure causes the r.p.m. to be reduced from the influence of the counterweights. [Figure 12-4]

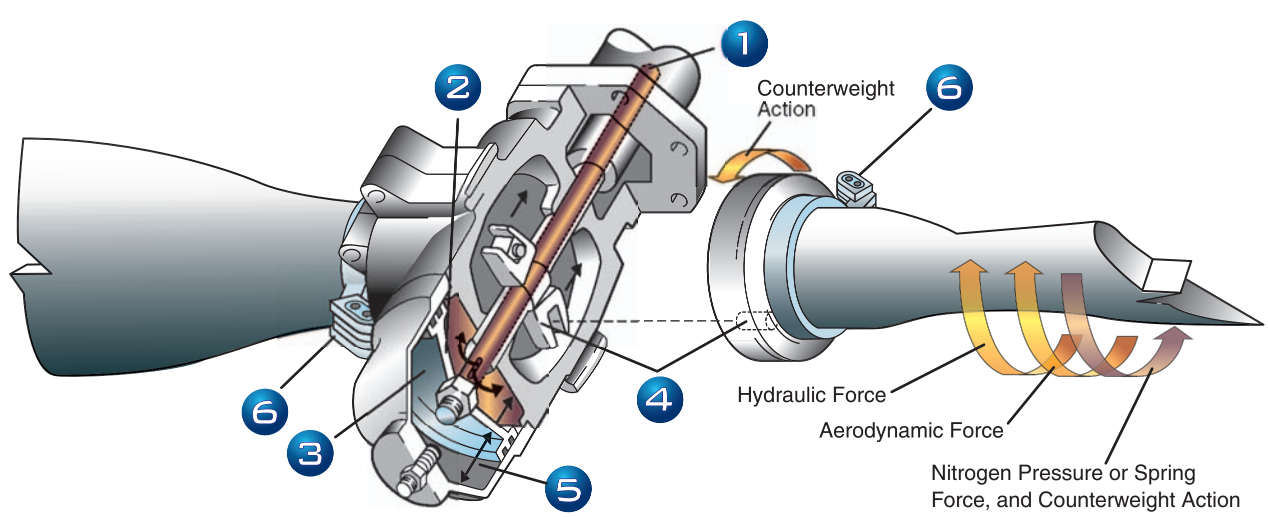
To feather the propeller, the propeller control is brought fully aft. All oil pressure is dumped from the governor, and the counterweights drive the propeller blades towards feather. As centrifugal force acting on the counterweights decays from decreasing r.p.m., additional forces are needed to completely feather the blades. This additional force comes from either a spring or high pressure air stored in the propeller dome, which forces the blades into the feathered position. The entire process may take up to 10 seconds.

Feathering a propeller only alters blade angle and stops engine rotation. To completely secure the engine, the pilot must still turn off the fuel (mixture, electric boost pump, and fuel selector), ignition, alternator/generator, and close the cowl flaps. If the airplane is pressurized, there may also be an air bleed to close for the failed engine. Some airplanes are equipped with firewall shutoff valves that secure several of these systems with a single switch.

Completely securing a failed engine may not be necessary or even desirable depending upon the failure mode, altitude, and time available. The position of the fuel controls, ignition, and alternator/generator switches of the failed engine has no effect on aircraft performance. There is always the distinct possibility of manipulating the incorrect switch under conditions of haste or pressure.

To unfeather a propeller, the engine must be rotated so that oil pressure can be generated to move the propeller blades from the feathered position. The ignition is turned on prior to engine rotation with the throttle at low idle and the mixture rich. With the propeller control in a high r.p.m. position, the starter is engaged. The engine will begin to windmill, start, and run as oil pressure moves the blades out of feather. As the engine starts, the propeller r.p.m. should be immediately reduced until the engine has had several minutes to warm up; the pilot should monitor cylinder head and oil temperatures.

Should the r.p.m. obtained with the starter be insufficient to unfeather the propeller, an increase in airspeed



1 High-pressure oil enters the cylinder through the center of the propeller shaft and piston rod. The propeller control regulates the flow of high-pressure oil from a governor.

2 A hydraulic piston in the hub of the propeller is connected to each blade by a piston rod. This rod is attached to forks that slide over the pitch-change pin mounted in the root of each blade.

3 The oil pressure moves the piston toward the front of the cylinder, moving the piston rod and forks forward.

4 The forks push the pitch-change pin of each blade toward the front of the hub, causing the blades to twist toward the low-pitch position.

5 A nitrogen pressure charge or mechanical spring in the front of the hub opposes the oil pressure, and causes the propeller to move toward high-pitch.

6 Counterweights also cause the blades to move toward the high-pitch and feather positions. The counterweights counteract the aerodynamic twisting force that tries to move the blades toward a low-pitch angle.

Figure 12-4. Pitch change forces.

from a shallow dive will usually help. In any event, the AFM/POH procedures should be followed for the exact unfeathering procedure. Both feathering and starting a feathered reciprocating engine on the ground are strongly discouraged by manufacturers due to the excessive stress and vibrations generated.

As just described, a loss of oil pressure from the propeller governor allows the counterweights, spring and/or dome charge to drive the blades to feather. Logically then, the propeller blades should feather every time an engine is shut down as oil pressure falls to zero. Yet, this does not occur. Preventing this is a small pin in the pitch changing mechanism of the propeller hub that will not allow the propeller blades to feather once r.p.m. drops below approximately 800. The pin senses a lack of centrifugal force from propeller rotation and falls into place, preventing the blades from feathering. Therefore, if a propeller is to be feathered, it must be done before engine r.p.m. decays below approximately 800. On one popular model of turboprop engine, the propeller blades do, in fact, feather with each shutdown. This propeller is not equipped with such centrifugally-operated pins, due to a unique engine design.

An unfeathering accumulator is an optional device that permits starting a feathered engine in flight without the use of the electric starter. An accumulator is any device that stores a reserve of high pressure. On multiengine airplanes, the unfeathering accumulator stores a small reserve of engine oil under pressure from compressed air or nitrogen. To start a feathered engine in flight, the pilot moves the propeller control out of the feather position to release the accumulator pressure. The oil flows under pressure to the propeller hub and drives the blades toward the high r.p.m., low pitch position, whereupon the propeller will usually begin to windmill. (On some airplanes, an assist from the electric starter may be necessary to initiate rotation and completely unfeather the propeller.) If fuel and ignition are present, the engine will start and run. For airplanes used in training, this saves much electric starter and battery wear. High oil pressure from the propeller governor recharges the accumulator just moments after engine rotation begins.

PROPELLER SYNCHRONIZATION

Many multiengine airplanes have a propeller synchronizer (prop sync) installed to eliminate the annoying "drumming" or "beat" of propellers whose r.p.m. are close, but not precisely the same. To use prop sync, the propeller r.p.m. are coarsely matched by the pilot and the system is engaged. The prop sync adjusts the r.p.m. of the "slave" engine to precisely match the r.p.m. of the "master" engine, and then maintains that relationship. The prop sync should be disengaged when the pilot selects a new propeller r.p.m., then re-engaged after the new r.p.m. is set. The prop sync should always be off for takeoff, landing, and single-engine operation. The AFM/POH should be consulted for system description and limitations.

A variation on the propeller synchronizer is the propeller synchrophaser. Prop sychrophase acts much like a synchronizer to precisely match r.p.m., but the synchrophaser goes one step further. It not only matches r.p.m. but actually compares and adjusts the positions of the individual blades of the propellers in their arcs. There can be significant propeller noise and vibration reductions with a propeller synchrophaser. From the pilot's perspective, operation of a propeller synchronizer and a propeller syncrophaser are very similar. A synchrophaser is also commonly referred to as prop sync, although that is not entirely correct nomenclature from a technical standpoint.

As a pilot aid to manually synchronizing the propellers, some twins have a small gauge mounted in or by the tachometer(s) with a propeller symbol on a disk that spins. The pilot manually fine tunes the engine r.p.m. so as to stop disk rotation, thereby synchronizing the propellers. This is a useful backup to synchronizing engine r.p.m. using the audible propeller beat. This gauge is also found installed with most propeller synchronizer and synchrophase systems. Some synchrophase systems use a knob for the pilot to control the phase angle.

FUEL CROSSFEED

Fuel crossfeed systems are also unique to multiengine airplanes. Using crossfeed, an engine can draw fuel from a fuel tank located in the opposite wing.

On most multiengine airplanes, operation in the crossfeed mode is an emergency procedure used to extend airplane range and endurance in OEI flight. There are a few models that permit crossfeed as a normal, fuel balancing technique in normal operation, but these are not common. The AFM/POH will describe crossfeed limitations and procedures, which vary significantly among multiengine airplanes.

Checking crossfeed operation on the ground with a quick repositioning of the fuel selectors does nothing more than ensure freedom of motion of the handle. To actually check crossfeed operation, a complete, functional crossfeed system check should be accomplished. To do this, each engine should be operated from its crossfeed position during the runup. The engines should be checked individually, and allowed to run at moderate power (1,500 r.p.m. minimum) for at least 1 minute to ensure that fuel flow can be established from the crossfeed source. Upon completion of the check, each engine should be operated for at least 1 minute at moderate power from the main (takeoff) fuel tanks to reconfirm fuel flow prior to takeoff.

This suggested check is not required prior to every flight. Infrequently used, however, crossfeed lines are ideal places for water and debris to accumulate unless they are used from time to time and drained using their external drains during preflight. Crossfeed is ordinarily not used for completing single-engine flights when an alternate airport is readily at hand, and it is never used during takeoff or landings.

COMBUSTION HEATER

Combustion heaters are common on multiengine airplanes. A combustion heater is best described as a small furnace that burns gasoline to produce heated air for occupant comfort and windshield defogging. Most are thermostatically operated, and have a separate hour meter to record time in service for maintenance purposes. Automatic overtemperature protection is provided by a thermal switch mounted on the unit, which cannot be accessed in flight. This requires the pilot or mechanic to actually visually inspect the unit for possible heat damage in order to reset the switch.

When finished with the combustion heater, a cool down period is required. Most heaters require that outside air be permitted to circulate through the unit for at least 15 seconds in flight, or that the ventilation fan be operated for at least 2 minutes on the ground. Failure to provide an adequate cool down will usually trip the thermal switch and render the heater inoperative until the switch is reset.

FLIGHT DIRECTOR/AUTOPILOT

Flight director/autopilot (FD/AP) systems are common on the better-equipped multiengine airplanes. The system integrates pitch, roll, heading, altitude, and radio navigation signals in a computer. The outputs, called computed commands, are displayed on a flight command indicator, or FCI. The FCI replaces the conventional attitude indicator on the instrument panel. The FCI is occasionally referred to as a flight director indicator (FDI), or as an attitude director indicator (ADI). The entire flight director/autopilot system is sometimes called an integrated flight control system (IFCS) by some manufacturers. Others may use the term "automatic flight control system (AFCS)."

The FD/AP system may be employed at three different levels.

- Off (raw data).
- Flight director (computed commands).
- Autopilot.

With the system off, the FCI operates as an ordinary attitude indicator. On most FCIs, the command bars are biased out of view when the flight director is off. The pilot maneuvers the airplane as though the system were not installed.

To maneuver the airplane using the flight director, the pilot enters the desired modes of operation (heading, altitude, nav intercept, and tracking) on the FD/AP mode controller. The computed flight commands are then displayed to the pilot through either a single-cue or dual-cue system in the FCI. On a single-cue system, the commands are indicated by "V" bars. On a dual-cue system, the commands are displayed on two separate command bars, one for pitch and one for roll. To maneuver the airplane using computed commands, the pilot "flies" the symbolic airplane of the FCI to match the steering cues presented.

On most systems, to engage the autopilot the flight director must first be operating. At any time thereafter, the pilot may engage the autopilot through the mode controller. The autopilot then maneuvers the airplane to satisfy the computed commands of the flight director.

Like any computer, the FD/AP system will only do what it is told. The pilot must ensure that it has been properly programmed for the particular phase of flight desired. The armed and/or engaged modes are usually displayed on the mode controller or separate annunciator lights. When the airplane is being hand-flown, if the flight director is not being used at any particular moment, it should be off so that the command bars are pulled from view.

Prior to system engagement, all FD/AP computer and trim checks should be accomplished. Many newer systems cannot be engaged without the completion of a self-test. The pilot must also be very familiar with various methods of disengagement, both normal and emergency. System details, including approvals and limitations, can be found in the supplements section of the AFM/POH. Additionally, many avionics manufacturers can provide informative pilot operating guides upon request.

YAW DAMPER

The yaw damper is a servo that moves the rudder in response to inputs from a gyroscope or accelerometer that detects yaw rate. The yaw damper minimizes motion about the vertical axis caused by turbulence. (Yaw dampers on sweptwing airplanes provide another, more vital function of damping dutch roll characteristics.) Occupants will feel a smoother ride, particularly if seated in the rear of the airplane, when the yaw damper is engaged. The yaw damper should be off for takeoff and landing. There may be additional restrictions against its use during single-engine operation. Most yaw dampers can be engaged independently of the autopilot.

ALTERNATOR/GENERATOR

Alternator or generator paralleling circuitry matches the output of each engine's alternator/generator so that the electrical system load is shared equally between them. In the event of an alternator/generator failure, the inoperative unit can be isolated and the entire electrical system powered from the remaining one. Depending upon the electrical capacity of the alternator/generator, the pilot may need to reduce the electrical load (referred to as load shedding) when operating on a single unit. The AFM/POH will contain system description and limitations.

NOSE BAGGAGE COMPARTMENT

Nose baggage compartments are common on multiengine airplanes (and are even found on a few single-engine airplanes). There is nothing strange or exotic about a nose baggage compartment, and the usual guidance concerning observation of load limits applies. They are mentioned here in that pilots occasionally neglect to secure the latches properly, and therein lies the danger. When improperly secured, the door will open and the contents may be drawn out, usually into the propeller arc, and usually just after takeoff. Even when the nose baggage compartment is empty, airplanes have been lost when the pilot became distracted by the open door. Security of the nose baggage compartment latches and locks is a vital preflight item.

Most airplanes will continue to fly with a nose baggage door open. There may be some buffeting from the disturbed airflow and there will be an increase in noise. Pilots should never become so preoccupied with an open door (of any kind) that they fail to fly the airplane.

Inspection of the compartment interior is also an important preflight item. More than one pilot has been surprised to find a supposedly empty compartment packed to capacity or loaded with ballast. The tow bars, engine inlet covers, windshield sun screens, oil containers, spare chocks, and miscellaneous small hand tools that find their way into baggage compartments should be secured to prevent damage from shifting in flight.

ANTI-ICING/DEICING

Anti-icing/deicing equipment is frequently installed on multiengine airplanes and consists of a combination of different systems. These may be classified as either anti-icing or deicing, depending upon function. The presence of anti-icing and deicing equipment, even though it may appear elaborate and complete, does not necessarily mean that the airplane is approved for flight in icing conditions. The AFM/POH, placards, and even the manufacturer should be consulted for specific determination of approvals and limitations.

Anti-icing equipment is provided to prevent ice from forming on certain protected surfaces. Anti-icing equipment includes heated pitot tubes, heated or non-icing static ports and fuel vents, propeller blades with electrothermal boots or alcohol slingers, windshields with alcohol spray or electrical resistance heating, windshield defoggers, and heated stall warning lift detectors. On many turboprop engines, the "lip" surrounding the air intake is heated either electrically or with bleed air. In the absence of AFM/POH guidance to the contrary, anti-icing equipment is actuated prior to flight into known or suspected icing conditions.

Deicing equipment is generally limited to pneumatic boots on wing and tail leading edges. Deicing equipment is installed to remove ice that has already formed on protected surfaces. Upon pilot actuation, the boots inflate with air from the pneumatic pumps to break off accumulated ice. After a few seconds of inflation, they are deflated back to their normal position with the assistance of a vacuum. The pilot monitors the buildup of ice and cycles the boots as directed in the AFM/POH. An ice light on the left engine nacelle allows the pilot to monitor wing ice accumulation at night.

Other airframe equipment necessary for flight in icing conditions includes an alternate induction air source and an alternate static system source. Ice tolerant antennas will also be installed.

In the event of impact ice accumulating over normal engine air induction sources, carburetor heat (carbureted engines) or alternate air (fuel injected engines) should be selected. Ice buildup on normal induction sources can be detected by a loss of engine r.p.m. with fixed-pitch propellers and a loss of manifold pressure with constant-speed propellers. On some fuel injected engines, an alternate air source is automatically activated with blockage of the normal air source.

An alternate static system provides an alternate source of static air for the pitot-static system in the unlikely event that the primary static source becomes blocked. In non-pressurized airplanes, most alternate static sources are plumbed to the cabin. On pressurized airplanes, they are usually plumbed to a non-pressurized baggage compartment. The pilot must activate the alternate static source by opening a valve or a fitting in the cockpit. Upon activation, the airspeed indicator, altimeter, and the vertical speed indicator (VSI) will be affected and will read somewhat in error. A correction table is frequently provided in the AFM/POH.

Anti-icing/deicing equipment only eliminates ice from the protected surfaces. Significant ice accumulations may form on unprotected areas, even with proper use of anti-ice and deice systems. Flight at high angles of attack or even normal climb speeds will permit significant ice accumulations on lower wing surfaces, which are unprotected. Many AFM/POHs mandate minimum speeds to be maintained in icing conditions. Degradation of all flight characteristics and large performance losses can be expected with ice accumulations. Pilots should not rely upon the stall warning devices for adequate stall warning with ice accumulations.

Ice will accumulate unevenly on the airplane. It will add weight and drag (primarily drag), and decrease thrust and lift. Even wing shape affects ice accumulation; thin airfoil sections are more prone to ice accumulation than thick, highly-cambered sections. For this reason certain surfaces, such as the horizontal stabilizer, are more prone to icing than the wing. With ice accumulations, landing approaches should be made with a minimum wing flap setting (flap extension increases the angle of attack of the horizontal stabilizer) and with an added margin of airspeed. Sudden and large configuration and airspeed changes should be avoided.

Unless otherwise recommended in the AFM/POH, the autopilot should not be used in icing conditions. Continuous use of the autopilot will mask trim and handling changes that will occur with ice accumulation. Without this control feedback, the pilot may not be aware of ice accumulation building to hazardous levels. The autopilot will suddenly disconnect when it reaches design limits and the pilot may find the airplane has assumed unsatisfactory handling characteristics.

The installation of anti-ice/deice equipment on airplanes without AFM/POH approval for flight into icing conditions is to facilitate escape when such conditions are inadvertently encountered. Even with AFM/POH approval, the prudent pilot will avoid icing conditions to the maximum extent practicable, and avoid extended flight in any icing conditions. No multiengine airplane is approved for flight into severe icing conditions, and none are intended for indefinite flight in continuous icing conditions.

PERFORMANCE AND LIMITATIONS

Discussion of performance and limitations requires the definition of several terms.

- **Accelerate-stop distance** is the runway length required to accelerate to a specified speed (either V_R or V_{LOF}, as specified by the manufacturer), experience an engine failure, and bring the airplane to a complete stop.

- **Accelerate-go distance** is the horizontal distance required to continue the takeoff and climb to 50 feet, assuming an engine failure at V_R or V_{LOF}, as specified by the manufacturer.

- **Climb gradient** is a slope most frequently expressed in terms of altitude gain per 100 feet of horizontal distance, whereupon it is stated as a percentage. A 1.5 percent climb gradient is an altitude gain of one and one-half feet per 100 feet of horizontal travel. Climb gradient may also be expressed as a function of altitude gain per nautical mile, or as a ratio of the horizontal distance to the vertical distance (50:1, for example). Unlike rate of climb, climb gradient is affected by wind. Climb gradient is improved with a headwind component, and reduced with a tailwind component. [Figure 12-5]

- The **all-engine service ceiling** of multiengine airplanes is the highest altitude at which the airplane can maintain a steady rate of climb of 100 f.p.m. with both engines operating. The airplane has reached its **absolute ceiling** when climb is no longer possible.

- The **single-engine service ceiling** is reached when the multiengine airplane can no longer maintain a 50 f.p.m. rate of climb with one engine inoperative, and its **single-engine absolute ceiling** when climb is no longer possible.

The takeoff in a multiengine airplane should be planned in sufficient detail so that the appropriate action is taken in the event of an engine failure. The pilot should be thoroughly familiar with the airplane's performance capabilities and limitations in order to make an informed takeoff decision as part of the preflight planning. That decision should be reviewed as the last item of the "before takeoff" checklist.

In the event of an engine failure shortly after takeoff, the decision is basically one of continuing flight or landing, even off-airport. If single-engine climb performance is adequate for continued flight, and the airplane has been promptly and correctly configured, the climb after takeoff may be continued. If single-engine climb performance is such that climb is unlikely or impossible, a landing will have to be made in the most suitable area. To be avoided above all is attempting to continue flight when it is not within the airplane's performance capability to do so. [Figure 12-6]

Takeoff planning factors include weight and balance, airplane performance (both single and multiengine), runway length, slope and contamination, terrain and obstacles in the area, weather conditions, and pilot proficiency. Most multiengine airplanes have AFM/POH performance charts and the pilot should be highly proficient in their use. Prior to takeoff, the multiengine pilot should ensure that the weight and balance limitations have been observed, the runway

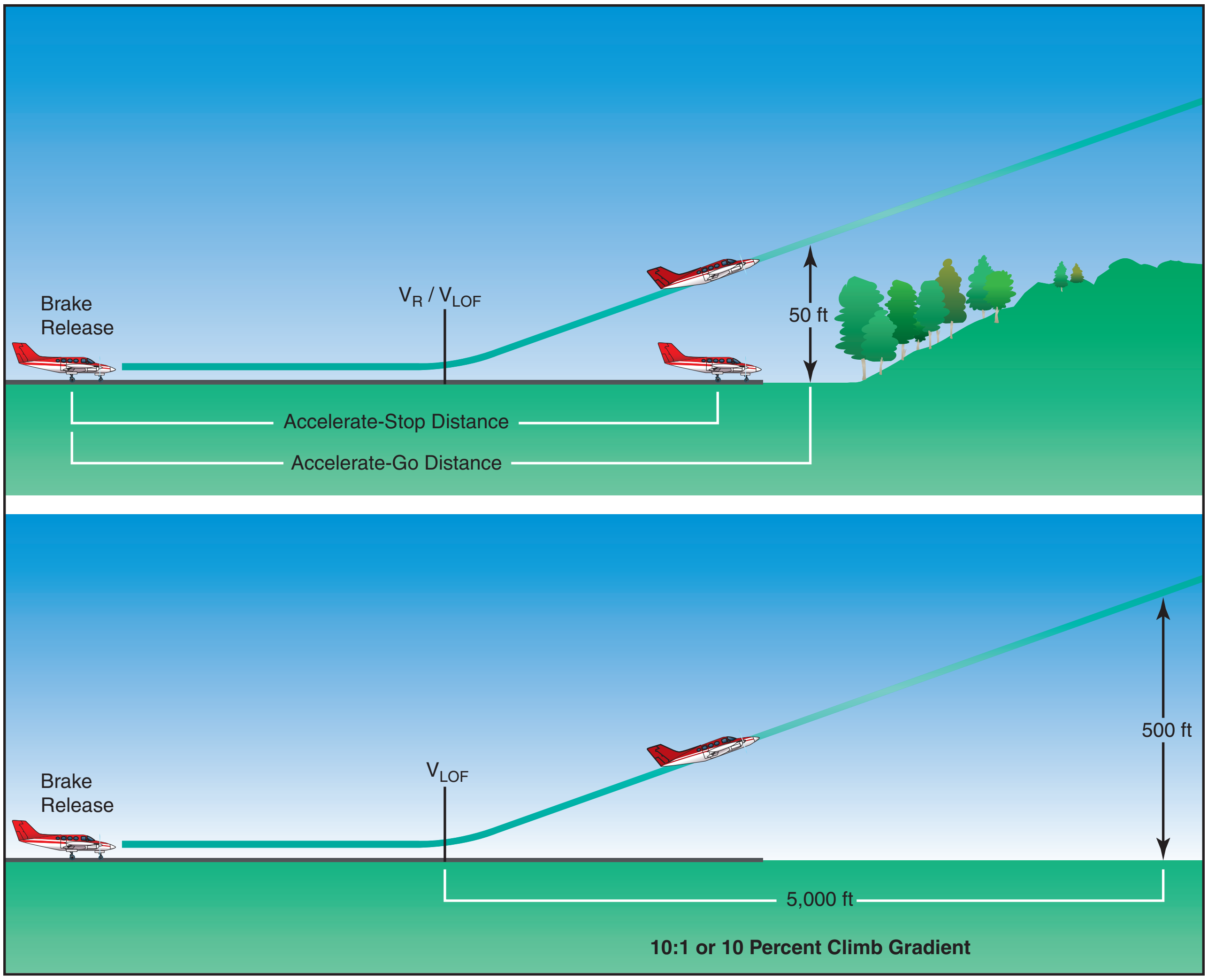


Figure 12-5. Accelerate-stop distance, accelerate-go distance, and climb gradient.

length is adequate, the normal flightpath will clear obstacles and terrain, and that a definitive course of action has been planned in the event of an engine failure.

The regulations do not specifically require that the runway length be equal to or greater than the accelerate-stop distance. Most AFM/POHs publish accelerate-stop distances only as an advisory. It becomes a limitation only when published in the limitations section of the AFM/POH. Experienced multiengine pilots, however, recognize the safety margin of runway lengths in excess of the bare minimum required for normal takeoff. They will insist on runway lengths of at least accelerate-stop distance as a matter of safety and good operating practice.

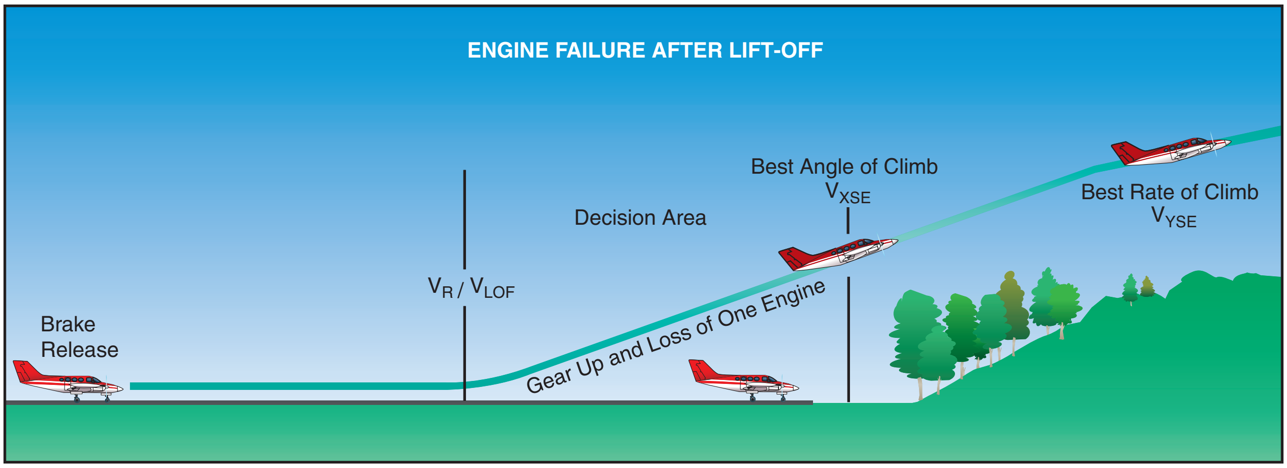


Figure 12-6. Area of decision.

The multiengine pilot must keep in mind that the accelerate-go distance, as long as it is, has only brought the airplane, under ideal circumstances, to a point a mere 50 feet above the takeoff elevation. To achieve even this meager climb, the pilot had to instantaneously recognize and react to an unanticipated engine failure, retract the landing gear, identify and feather the correct engine, all the while maintaining precise airspeed control and bank angle as the airspeed is nursed to V_{YSE}. Assuming flawless airmanship thus far, the airplane has now arrived at a point little more than one wingspan above the terrain, assuming it was absolutely level and without obstructions.

With (for the purpose of illustration) a net 150 f.p.m. rate of climb at a 90-knot V_{YSE}, it will take approximately 3 minutes to climb an additional 450 feet to reach 500 feet AGL. In doing so, the airplane will have traveled an additional 5 nautical miles beyond the original accelerate-go distance, with a climb gradient of about 1.6 percent. A turn of any consequence, such as to return to the airport, will seriously degrade the already marginal climb performance.

Not all multiengine airplanes have published accelerate-go distances in their AFM/POH, and fewer still publish climb gradients. When such information is published, the figures will have been determined under ideal flight testing conditions. It is unlikely that this performance will be duplicated in service conditions.

The point of the foregoing is to illustrate the marginal climb performance of a multiengine airplane that suffers an engine failure shortly after takeoff, even under ideal conditions. The prudent multiengine pilot should pick a point in the takeoff and climb sequence in advance. If an engine fails before this point, the takeoff should be rejected, even if airborne, for a landing on whatever runway or surface lies essentially ahead. If an engine fails after this point, the pilot should promptly execute the appropriate engine failure procedure and continue the climb, assuming the performance capability exists. As a general recommendation, if the landing gear has not been selected up, the takeoff should be rejected, even if airborne.

As a practical matter for planning purposes, the option of continuing the takeoff probably does not exist unless the published single-engine rate-of-climb performance is at least 100 to 200 f.p.m. Thermal turbulence, wind gusts, engine and propeller wear, or poor technique in airspeed, bank angle, and rudder control can easily negate even a 200 f.p.m. rate of climb.

WEIGHT AND BALANCE

The weight and balance concept is no different than that of a single-engine airplane. The actual execution, however, is almost invariably more complex due to a number of new loading areas, including nose and aft baggage compartments, nacelle lockers, main fuel tanks, aux fuel tanks, nacelle fuel tanks, and numerous seating options in a variety of interior configurations. The flexibility in loading offered by the multiengine airplane places a responsibility on the pilot to address weight and balance prior to each flight.

The terms "empty weight, licensed empty weight, standard empty weight, and basic empty weight" as they appear on the manufacturer's original weight and balance documents are sometimes confused by pilots.

In 1975, the General Aviation Manufacturers Association (GAMA) adopted a standardized format for AFM/POHs. It was implemented by most manufacturers in model year 1976. Airplanes whose manufacturers conform to the GAMA standards utilize the following terminology for weight and balance:

  Standard empty weight
\+ <u>Optional equipment</u>
= Basic empty weight

Standard empty weight is the weight of the standard airplane, full hydraulic fluid, unusable fuel, and full oil. Optional equipment includes the weight of all equipment installed beyond standard. Basic empty weight is the standard empty weight plus optional equipment. Note that basic empty weight includes no usable fuel, but full oil.

Airplanes manufactured prior to the GAMA format generally utilize the following terminology for weight and balance, although the exact terms may vary somewhat:

  Empty weight
\+ <u>Unusable fuel</u>
= Standard empty weight

  Standard empty weight
\+ <u>Optional equipment</u>
= Licensed empty weight

Empty weight is the weight of the standard airplane, full hydraulic fluid and undrainable oil. Unusable fuel is the fuel remaining in the airplane not available to the engines. Standard empty weight is the empty weight plus unusable fuel. When optional equipment is added to the standard empty weight, the result is licensed empty weight. Licensed empty weight, therefore, includes the standard airplane, optional equipment, full hydraulic fluid, unusable fuel, and undrainable oil.

The major difference between the two formats (GAMA and the old) is that basic empty weight includes full oil, and licensed empty weight does not.

Oil must always be added to any weight and balance utilizing a licensed empty weight.

When the airplane is placed in service, amended weight and balance documents are prepared by appropriately rated maintenance personnel to reflect changes in installed equipment. The old weight and balance documents are customarily marked "superseded" and retained in the AFM/POH. Maintenance personnel are under no regulatory obligation to utilize the GAMA terminology, so weight and balance documents subsequent to the original may use a variety of terms. Pilots should use care to determine whether or not oil has to be added to the weight and balance calculations or if it is already included in the figures provided.

The multiengine airplane is where most pilots encounter the term "zero fuel weight" for the first time. Not all multiengine airplanes have a zero fuel weight limitation published in their AFM/POH, but many do. Zero fuel weight is simply the maximum allowable weight of the airplane and payload, assuming there is no usable fuel on board. The actual airplane is not devoid of fuel at the time of loading, of course. This is merely a calculation that assumes it was. If a zero fuel weight limitation is published, then all weight in excess of that figure must consist of usable fuel. The purpose of a zero fuel weight is to limit load forces on the wing spars with heavy fuselage loads.

Assume a hypothetical multiengine airplane with the following weights and capacities:

Basic empty weight	3,200 lb.
Zero fuel weight	4,400 lb.
Maximum takeoff weight	5,200 lb.
Maximum usable fuel	180 gal.

1. Calculate the useful load:

Maximum takeoff weight	5,200 lb.
Basic empty weight	-3,200 lb.
Useful load	2,000 lb.

The useful load is the maximum combination of usable fuel, passengers, baggage, and cargo that the airplane is capable of carrying.

2. Calculate the payload:

Zero fuel weight	4,400 lb.
Basic empty weight	-3,200 lb.
Payload	1,200 lb.

The payload is the maximum combination of passengers, baggage, and cargo that the airplane is capable of carrying. A zero fuel weight, if published, is the limiting weight.

3. Calculate the fuel capacity at maximum payload (1,200 lb.):

Maximum takeoff weight	5,200 lb.
Zero fuel weight	-4,400 lb.
Fuel allowed	800 lb.

Assuming maximum payload, the only weight permitted in excess of the zero fuel weight must consist of usable fuel. In this case, 133.3 gallons.

4. Calculate the payload at maximum fuel capacity (180 gal.):

Basic empty weight	3,200 lb.
Maximum usable fuel	+1,080 lb.
Weight with max. fuel	4,280 lb.
Maximum takeoff weight	5,200 lb.
Weight with max. fuel	-4,280 lb.
Payload allowed	920 lb.

Assuming maximum fuel, the payload is the difference between the weight of the fueled airplane and the maximum takeoff weight.

Some multiengine airplanes have a ramp weight, which is in excess of the maximum takeoff weight. The ramp weight is an allowance for fuel that would be burned during taxi and runup, permitting a takeoff at full maximum takeoff weight. The airplane must weigh no more than maximum takeoff weight at the beginning of the takeoff roll.

A maximum landing weight is a limitation against landing at a weight in excess of the published value. This requires preflight planning of fuel burn to ensure that the airplane weight upon arrival at destination will be at or below the maximum landing weight. In the event of an emergency requiring an immediate landing, the pilot should recognize that the structural margins designed into the airplane are not fully available when over landing weight. An overweight landing inspection may be advisable—the service manual or manufacturer should be consulted.

Although the foregoing problems only dealt with weight, the balance portion of weight and balance is equally vital. The flight characteristics of the multiengine airplane will vary significantly with shifts of the center of gravity (CG) within the approved envelope.

At forward CGs, the airplane will be more stable, with a slightly higher stalling speed, a slightly slower cruising speed, and favorable stall characteristics. At aft CGs, the airplane will be less stable, with a slightly lower stalling speed, a slightly faster cruising speed, and less desirable stall characteristics. Forward CG limits are usually determined in certification by elevator/stabilator authority in the landing round-out. Aft CG limits are determined by the minimum acceptable longitudinal stability. It is contrary to the airplane's operating limitations and the Code of Federal Regulations (CFR) to exceed any weight and balance parameter.

Some multiengine airplanes may require ballast to remain within CG limits under certain loading conditions. Several models require ballast in the aft baggage compartment with only a student and instructor on board to avoid exceeding the forward CG limit. When passengers are seated in the aft-most seats of some models, ballast or baggage may be required in the nose baggage compartment to avoid exceeding the aft CG limit. The pilot must direct the seating of passengers and placement of baggage and cargo to achieve a center of gravity within the approved envelope. Most multiengine airplanes have general loading recommendations in the weight and balance section of the AFM/POH. When ballast is added, it must be securely tied down and it must not exceed the maximum allowable floor loading.

Some airplanes make use of a special weight and balance plotter. It consists of several movable parts that can be adjusted over a plotting board on which the CG envelope is printed. The reverse side of the typical plotter contains general loading recommendations for the particular airplane. A pencil line plot can be made directly on the CG envelope imprinted on the working side of the plotting board. This plot can easily be erased and recalculated anew for each flight. This plotter is to be used only for the make and model airplane for which it was designed.

GROUND OPERATION

Good habits learned with single-engine airplanes are directly applicable to multiengine airplanes for preflight and engine start. Upon placing the airplane in motion to taxi, the new multiengine pilot will notice several differences, however. The most obvious is the increased wingspan and the need for even greater vigilance while taxiing in close quarters. Ground handling may seem somewhat ponderous and the multiengine airplane will not be as nimble as the typical two- or four-place single-engine airplane. As always, use care not to ride the brakes by keeping engine power to a minimum. One ground handling advantage of the multiengine airplane over single-engine airplanes is the differential power capability. Turning with an assist from differential power minimizes both the need for brakes during turns and the turning radius.

The pilot should be aware, however, that making a sharp turn assisted by brakes and differential power can cause the airplane to pivot about a stationary inboard wheel and landing gear. This is abuse for which the airplane was not designed and should be guarded against.

Unless otherwise directed by the AFM/POH, all ground operations should be conducted with the cowl flaps fully open. The use of strobe lights is normally deferred until taxiing onto the active runway.

NORMAL AND CROSSWIND TAKEOFF AND CLIMB

With the "before takeoff" checklist complete and air traffic control (ATC) clearance received, the airplane should be taxied into position on the runway centerline. If departing from an airport without an operating control tower, a careful check for approaching aircraft should be made along with a radio advisory on the appropriate frequency. Sharp turns onto the runway combined with a rolling takeoff are not a good operating practice and may be prohibited by the AFM/POH due to the possibility of "unporting" a fuel tank pickup. (The takeoff itself may be prohibited by the AFM/POH under any circumstances below certain fuel levels.) The flight controls should be positioned for a crosswind, if present. Exterior lights such as landing and taxi lights, and wingtip strobes should be illuminated immediately prior to initiating the takeoff roll, day or night. If holding in takeoff position for any length of time, particularly at night, the pilot should activate all exterior lights upon taxiing into position.

Takeoff power should be set as recommended in the AFM/POH. With normally aspirated (non-turbocharged) engines, this will be full throttle. Full throttle is also used in most turbocharged engines. There are some turbocharged engines, however, that require the pilot to set a specific power setting, usually just below red line manifold pressure. This yields takeoff power with less than full throttle travel.

Turbocharged engines often require special consideration. Throttle motion with turbocharged engines should be exceptionally smooth and deliberate. It is acceptable, and may even be desirable, to hold the airplane in position with brakes as the throttles are advanced. Brake release customarily occurs after significant boost from the turbocharger is established. This prevents wasting runway with slow, partial throttle acceleration as the engine power is increased. If runway length or obstacle clearance is critical, full power should be set before brake release, as specified in the performance charts.

As takeoff power is established, initial attention should be divided between tracking the runway centerline and monitoring the engine gauges. Many novice multiengine pilots tend to fixate on the airspeed indicator just as soon as the airplane begins its takeoff roll. Instead, the pilot should confirm that both engines are developing full-rated manifold pressure and r.p.m., and that the fuel flows, fuel pressures, exhaust gas temperatures (EGTs), and oil pressures are matched in their normal ranges. A directed and purposeful scan of the engine gauges can be accomplished well before the airplane approaches rotation speed. If a crosswind is present, the aileron displacement in the direction of the crosswind may be reduced as the airplane accelerates. The elevator/stabilator control should be held neutral throughout.

Full rated takeoff power should be used for every takeoff. Partial power takeoffs are not recommended. There is no evidence to suggest that the life of modern reciprocating engines is prolonged by partial power takeoffs. Paradoxically, excessive heat and engine wear can occur with partial power as the fuel metering system will fail to deliver the slightly over-rich mixture vital for engine cooling during takeoff.

There are several key airspeeds to be noted during the takeoff and climb sequence in any twin. The first speed to consider is V_{MC}. If an engine fails below V_{MC} while the airplane is on the ground, the takeoff must be rejected. Directional control can only be maintained by promptly closing both throttles and using rudder and brakes as required. If an engine fails below V_{MC} while airborne, directional control is not possible with the remaining engine producing takeoff power. On takeoffs, therefore, the airplane should never be airborne before the airspeed reaches and exceeds V_{MC}. Pilots should use the manufacturer's recommended rotation speed (V_R) or lift-off speed (V_{LOF}). If no such speeds are published, a minimum of V_{MC} plus 5 knots should be used for V_R.

The rotation to a takeoff pitch attitude is done smoothly. With a crosswind, the pilot should ensure that the landing gear does not momentarily touch the runway after the airplane has lifted off, as a side drift will be present. The rotation may be accomplished more positively and/or at a higher speed under these conditions. However, the pilot should keep in mind that the AFM/POH performance figures for accelerate-stop distance, takeoff ground roll, and distance to clear an obstacle were calculated at the recommended V_R and/or V_{LOF} speed.

After lift-off, the next consideration is to gain altitude as rapidly as possible. After leaving the ground, altitude gain is more important than achieving an excess of airspeed. Experience has shown that excessive speed cannot be effectively converted into altitude in the event of an engine failure. Altitude gives the pilot time to think and react. Therefore, the airplane should be allowed to accelerate in a shallow climb to attain V_Y, the best all-engine rate-of-climb speed. V_Y should then be maintained until a safe single-engine maneuvering altitude, considering terrain and obstructions, is achieved.

To assist the pilot in takeoff and initial climb profile, some AFM/POHs give a "50-foot" or "50-foot barrier" speed to use as a target during rotation, lift-off, and acceleration to V_Y.

Landing gear retraction should normally occur after a positive rate of climb is established. Some AFM/POHs direct the pilot to apply the wheel brakes momentarily after lift-off to stop wheel rotation prior to landing gear retraction. If flaps were extended for takeoff, they should be retracted as recommended in the AFM/POH.

Once a safe single-engine maneuvering altitude has been reached, typically a minimum of 400-500 feet AGL, the transition to an enroute climb speed should be made. This speed is higher than V_Y and is usually maintained to cruising altitude. Enroute climb speed gives better visibility, increased engine cooling, and a higher groundspeed. Takeoff power can be reduced, if desired, as the transition to enroute climb speed is made.

Some airplanes have a climb power setting published in the AFM/POH as a recommendation (or sometimes as a limitation), which should then be set for enroute climb. If there is no climb power setting published, it is customary, but not a requirement, to reduce manifold pressure and r.p.m. somewhat for enroute climb. The propellers are usually synchronized after the first power reduction and the yaw damper, if installed, engaged. The AFM/POH may also recommend leaning

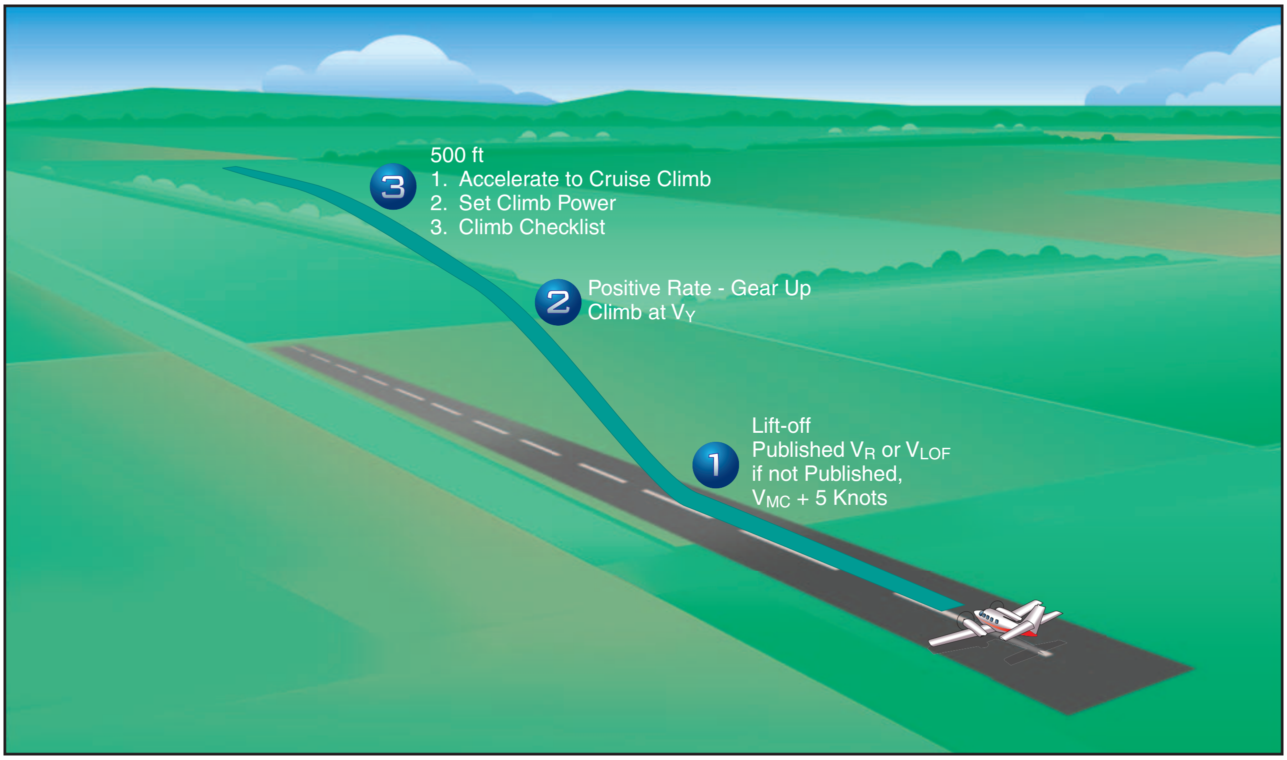


Figure 12-7. Takeoff and climb profile.

the mixtures during climb. The "climb" checklist should be accomplished as traffic and work load allow. [Figure 12-7]

LEVEL OFF AND CRUISE

Upon leveling off at cruising altitude, the pilot should allow the airplane to accelerate at climb power until cruising airspeed is achieved, then cruise power and r.p.m. should be set. To extract the maximum cruise performance from any airplane, the power setting tables provided by the manufacturer should be closely followed. If the cylinder head and oil temperatures are within their normal ranges, the cowl flaps may be closed. When the engine temperatures have stabilized, the mixtures may be leaned per AFM/POH recommendations. The remainder of the "cruise" checklist should be completed by this point.

Fuel management in multiengine airplanes is often more complex than in single-engine airplanes. Depending upon system design, the pilot may need to select between main tanks and auxiliary tanks, or even employ fuel transfer from one tank to another. In complex fuel systems, limitations are often found restricting the use of some tanks to level flight only, or requiring a reserve of fuel in the main tanks for descent and landing. Electric fuel pump operation can vary widely among different models also, particularly during tank switching or fuel transfer. Some fuel pumps are to be on for takeoff and landing; others are to be off. There is simply no substitute for thorough systems and AFM/POH knowledge when operating complex aircraft.

NORMAL APPROACH AND LANDING

Given the higher cruising speed (and frequently, altitude) of multiengine airplanes over most single-engine airplanes, the descent must be planned in advance. A hurried, last minute descent with power at or near idle is inefficient and can cause excessive engine cooling. It may also lead to passenger discomfort, particularly if the airplane is unpressurized. As a rule of thumb, if terrain and passenger conditions permit, a maximum of a 500 f.p.m. rate of descent should be planned. Pressurized airplanes can plan for higher descent rates, if desired.

In a descent, some airplanes require a minimum EGT, or may have a minimum power setting or cylinder head temperature to observe. In any case, combinations of very low manifold pressure and high r.p.m. settings are strongly discouraged by engine manufacturers. If higher descent rates are necessary, the pilot should consider extending partial flaps or lowering the landing gear before retarding the power excessively. The "descent" checklist should be initiated upon leaving cruising altitude and completed before arrival in the terminal area. Upon arrival in the terminal area, pilots are encouraged to turn on their landing and recognition lights when operating below 10,000 feet, day or night, and especially when operating within 10 miles of any airport or in conditions of reduced visibility.

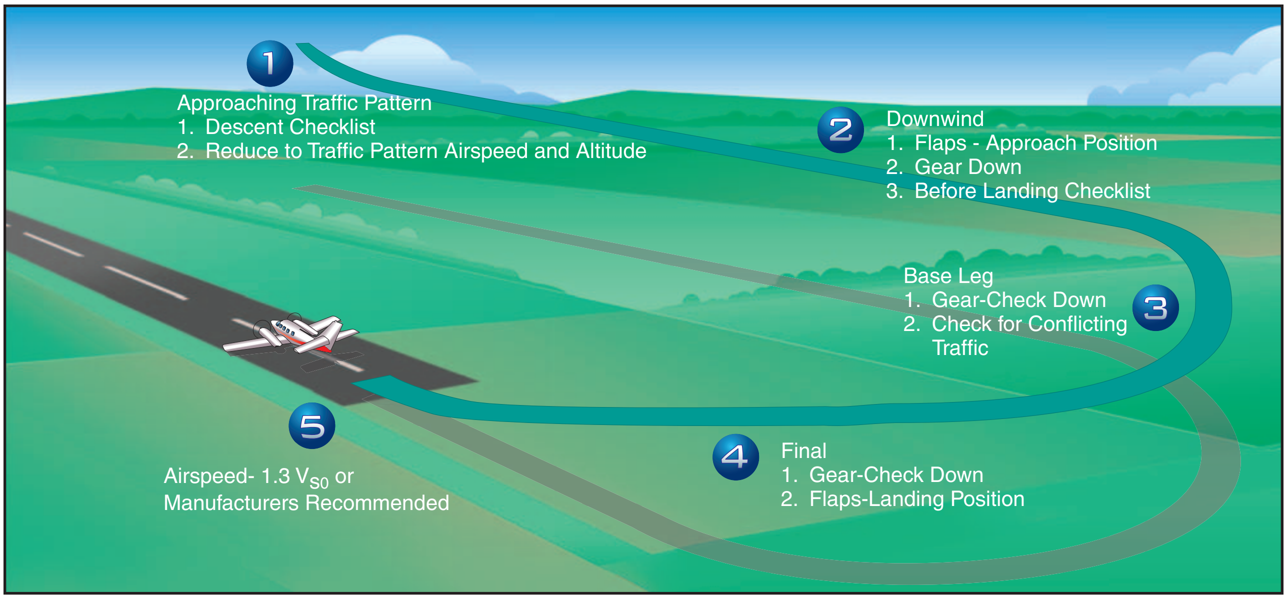


Figure 12-8. Normal two-engine approach and landing.

The traffic pattern and approach are typically flown at somewhat higher indicated airspeeds in a multiengine airplane contrasted to most single-engine airplanes. The pilot may allow for this through an early start on the "before landing" checklist. This provides time for proper planning, spacing, and thinking well ahead of the airplane. Many multiengine airplanes have partial flap extension speeds above V_{FE}, and partial flaps can be deployed prior to traffic pattern entry. Normally, the landing gear should be selected and confirmed down when abeam the intended point of landing as the downwind leg is flown. [Figure 12-8]

The Federal Aviation Administration (FAA) recommends a stabilized approach concept. To the greatest extent practical, on final approach and within 500 feet AGL, the airplane should be on speed, in trim, configured for landing, tracking the extended centerline of the runway, and established in a constant angle of descent towards an aim point in the touchdown zone. Absent unusual flight conditions, only minor corrections will be required to maintain this approach to the roundout and touchdown.

The final approach should be made with power and at a speed recommended by the manufacturer; if a recommended speed is not furnished, the speed should be no slower than the single-engine best rate-of-climb speed (V_{YSE}) until short final with the landing assured, but in no case less than critical engine-out minimum control speed (V_{MC}). Some multiengine pilots prefer to delay full flap extension to short final with the landing assured. This is an acceptable technique with appropriate experience and familiarity with the airplane.

In the roundout for landing, residual power is gradually reduced to idle. With the higher wing loading of multiengine airplanes and with the drag from two windmilling propellers, there will be minimal float. Full stall landings are generally undesirable in twins. The airplane should be held off as with a high performance single-engine model, allowing touchdown of the main wheels prior to a full stall.

Under favorable wind and runway conditions, the nosewheel can be held off for best aerodynamic braking. Even as the nosewheel is gently lowered to the runway centerline, continued elevator back pressure will greatly assist the wheel brakes in stopping the airplane.

If runway length is critical, or with a strong crosswind, or if the surface is contaminated with water, ice or snow, it is undesirable to rely solely on aerodynamic braking after touchdown. The full weight of the airplane should be placed on the wheels as soon as practicable. The wheel brakes will be more effective than aerodynamic braking alone in decelerating the airplane.

Once on the ground, elevator back pressure should be used to place additional weight on the main wheels and to add additional drag. When necessary, wing flap retraction will also add additional weight to the wheels and improve braking effectivity. Flap retraction during the landing rollout is discouraged, however, unless there is a clear, operational need. It should not be accomplished as routine with each landing.

Some multiengine airplanes, particularly those of the cabin class variety, can be flown through the roundout and touchdown with a small amount of power. This is an acceptable technique to prevent high sink rates and to cushion the touchdown. The pilot should keep in mind, however, that the primary purpose in landing is to get the airplane down and stopped. This technique should only be attempted when there is a generous margin of runway length. As propeller blast flows directly over the wings, lift as well as thrust is produced. The pilot should taxi clear of the runway as soon as speed and safety permit, and then accomplish the "after landing" checklist. Ordinarily, no attempt should be made to retract the wing flaps or perform other checklist duties until the airplane has been brought to a halt when clear of the active runway. Exceptions to this would be the rare operational needs discussed above, to relieve the weight from the wings and place it on the wheels. In these cases, AFM/POH guidance should be followed. The pilot should not indiscriminately reach out for any switch or control on landing rollout. An inadvertent landing gear retraction while meaning to retract the wing flaps may result.

CROSSWIND APPROACH AND LANDING

The multiengine airplane is often easier to land in a crosswind than a single-engine airplane due to its higher approach and landing speed. In any event, the principles are no different between singles and twins. Prior to touchdown, the longitudinal axis must be aligned with the runway centerline to avoid landing gear side loads.

The two primary methods, crab and wing-low, are typically used in conjunction with each other. As soon as the airplane rolls out onto final approach, the crab angle to track the extended runway centerline is established. This is coordinated flight with adjustments to heading to compensate for wind drift either left or right. Prior to touchdown, the transition to a sideslip is made with the upwind wing lowered and opposite rudder applied to prevent a turn. The airplane touches down on the landing gear of the upwind wing first, followed by that of the downwind wing, and then the nose gear. Follow-through with the flight controls involves an increasing application of aileron into the wind until full control deflection is reached.

The point at which the transition from the crab to the sideslip is made is dependent upon pilot familiarity with the airplane and experience. With high skill and experience levels, the transition can be made during the roundout just before touchdown. With lesser skill and experience levels, the transition is made at increasing distances from the runway. Some multiengine airplanes (as some single-engine airplanes) have AFM/POH limitations against slips in excess of a certain time period; 30 seconds, for example. This is to prevent engine power loss from fuel starvation as the fuel in the tank of the lowered wing flows towards the wingtip, away from the fuel pickup point. This time limit must be observed if the wing-low method is utilized.

Some multiengine pilots prefer to use differential power to assist in crosswind landings. The asymmetrical thrust produces a yawing moment little different from that produced by the rudder. When the upwind wing is lowered, power on the upwind engine is increased to prevent the airplane from turning. This alternate technique is completely acceptable, but most pilots feel they can react to changing wind conditions quicker with rudder and aileron than throttle movement. This is especially true with turbocharged engines where the throttle response may lag momentarily. The differential power technique should be practiced with an instructor familiar with it before being attempted alone.

SHORT-FIELD TAKEOFF AND CLIMB

The short-field takeoff and climb differs from the normal takeoff and climb in the airspeeds and initial climb profile. Some AFM/POHs give separate short-field takeoff procedures and performance charts that recommend specific flap settings and airspeeds. Other AFM/POHs do not provide separate short-field procedures. In the absence of such specific procedures, the airplane should be operated only as recommended in the AFM/POH. No operations should be conducted contrary to the recommendations in the AFM/POH.

On short-field takeoffs in general, just after rotation and lift-off, the airplane should be allowed to accelerate to V_X, making the initial climb over obstacles at V_X and transitioning to V_Y as obstacles are cleared. [Figure 12-9]

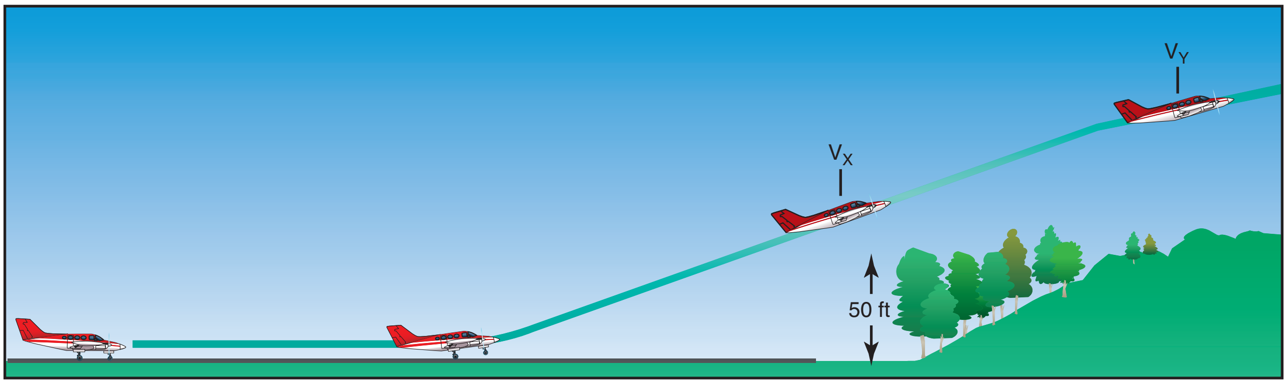


Figure 12-9. Short-field takeoff and climb.

When partial flaps are recommended for short-field takeoffs, many light-twins have a strong tendency to become airborne prior to V_{MC} plus 5 knots. Attempting to prevent premature lift-off with forward elevator pressure results in wheelbarrowing. To prevent this, allow the airplane to become airborne, but only a few inches above the runway. The pilot should be prepared to promptly abort the takeoff and land in the event of engine failure on takeoff with landing gear and flaps extended at airspeeds below V_X.

Engine failure on takeoff, particularly with obstructions, is compounded by the low airspeeds and steep climb attitudes utilized in short-field takeoffs. V_X and V_{XSE} are often perilously close to V_{MC}, leaving scant margin for error in the event of engine failure as V_{XSE} is assumed. If flaps were used for takeoff, the engine failure situation becomes even more critical due to the additional drag incurred. If V_X is less than 5 knots higher than V_{MC}, give strong consideration to reducing useful load or using another runway in order to increase the takeoff margins so that a short-field technique will not be required.

SHORT-FIELD APPROACH AND LANDING

The primary elements of a short-field approach and landing do not differ significantly from a normal approach and landing. Many manufacturers do not publish short-field landing techniques or performance charts in the AFM/POH. In the absence of specific short-field approach and landing procedures, the airplane should be operated as recommended in the AFM/POH. No operations should be conducted contrary to the AFM/POH recommendations.

The emphasis in a short-field approach is on configuration (full flaps), a stabilized approach with a constant angle of descent, and precise airspeed control. As part of a short-field approach and landing procedure, some AFM/POHs recommend a slightly slower than normal approach airspeed. If no such slower speed is published, use the AFM/POH-recommended normal approach speed.

Full flaps are used to provide the steepest approach angle. If obstacles are present, the approach should be planned so that no drastic power reductions are required after they are cleared. The power should be smoothly reduced to idle in the roundout prior to touchdown. Pilots should keep in mind that the propeller blast blows over the wings, providing some lift in addition to thrust. Significantly reducing power just after obstacle clearance usually results in a sudden, high sink rate that may lead to a hard landing.

After the short-field touchdown, maximum stopping effort is achieved by retracting the wing flaps, adding back pressure to the elevator/stabilator, and applying heavy braking. However, if the runway length permits, the wing flaps should be left in the extended position until the airplane has been stopped clear of the runway. There is always a significant risk of retracting the landing gear instead of the wing flaps when flap retraction is attempted on the landing rollout.

Landing conditions that involve either a short-field, high-winds or strong crosswinds are just about the only situations where flap retraction on the landing rollout should be considered. When there is an operational need to retract the flaps just after touchdown, it must be done deliberately, with the flap handle positively identified before it is moved.

GO-AROUND

When the decision to go around is made, the throttles should be advanced to takeoff power. With adequate airspeed, the airplane should be placed in a climb pitch attitude. These actions, which are accomplished simultaneously, will arrest the sink rate and place the airplane in the proper attitude for transition to a climb. The initial target airspeed will be V_Y, or V_X if obstructions are present. With sufficient airspeed, the flaps should be retracted from full to an intermediate position and the landing gear retracted when there is a positive rate of climb and no chance of runway contact. The remaining flaps should then be retracted. [Figure 12-10]

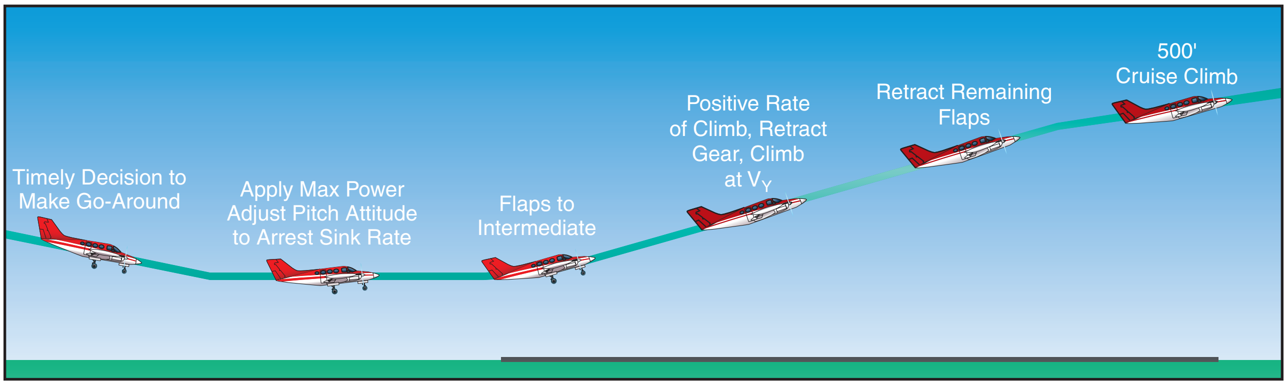


Figure 12-10. Go-around procedure.

If the go-around was initiated due to conflicting traffic on the ground or aloft, the pilot should maneuver to the side, so as to keep the conflicting traffic in sight. This may involve a shallow bank turn to offset and then parallel the runway/landing area.

If the airplane was in trim for the landing approach when the go-around was commenced, it will soon require a great deal of forward elevator/stabilator pressure as the airplane accelerates away in a climb. The pilot should apply appropriate forward pressure to maintain the desired pitch attitude. Trim should be commenced immediately. The "balked landing" checklist should be reviewed as work load permits.

Flaps should be retracted before the landing gear for two reasons. First, on most airplanes, full flaps produce more drag than the extended landing gear. Secondly, the airplane will tend to settle somewhat with flap retraction, and the landing gear should be down in the event of an inadvertent, momentary touchdown.

Many multiengine airplanes have a landing gear retraction speed significantly less than the extension speed. Care should be exercised during the go-around not to exceed the retraction speed. If the pilot desires to return for a landing, it is essential to re-accomplish the entire "before landing" checklist. An interruption to a pilot's habit patterns, such as a go-around, is a classic scenario for a subsequent gear up landing.

The preceding discussion of go-arounds assumes that the maneuver was initiated from normal approach speeds or faster. If the go-around was initiated from a low airspeed, the initial pitch up to a climb attitude must be tempered with the necessity of maintaining adequate flying speed throughout the maneuver. Examples of where this applies include go-arounds initiated from the landing roundout or recovery from a bad bounce as well as a go-around initiated due to an inadvertent approach to a stall. The first priority is always to maintain control and obtain adequate flying speed. A few moments of level or near level flight may be required as the airplane accelerates up to climb speed.

REJECTED TAKEOFF

A takeoff can be rejected for the same reasons a takeoff in a single-engine airplane would be rejected. Once the decision to reject a takeoff is made, the pilot should promptly close both throttles and maintain directional control with the rudder, nosewheel steering, and brakes. Aggressive use of rudder, nosewheel steering, and brakes may be required to keep the airplane on the runway. Particularly, if an engine failure is not immediately recognized and accompanied by prompt closure of both throttles. However, the primary objective is not necessarily to stop the airplane in the shortest distance, but to maintain control of the airplane as it decelerates. In some situations, it may be preferable to continue into the overrun area under control, rather than risk directional control loss, landing gear collapse, or tire/brake failure in an attempt to stop the airplane in the shortest possible distance.

ENGINE FAILURE AFTER LIFT-OFF

A takeoff or go-around is the most critical time to suffer an engine failure. The airplane will be slow, close to the ground, and may even have landing gear and flaps extended. Altitude and time will be minimal. Until feathered, the propeller of the failed engine will be windmilling, producing a great deal of drag and yawing tendency. Airplane climb performance will be marginal or even non-existent, and obstructions may lie ahead. Add the element of surprise and the need for a plan of action before every takeoff is obvious.

With loss of an engine, it is paramount to maintain airplane control and comply with the manufacturer's recommended emergency procedures. Complete failure of one engine shortly after takeoff can be broadly categorized into one of three following scenarios.

1. **Landing gear down**. [Figure 12-11] If the engine failure occurs prior to selecting the landing gear to the UP position, close both throttles and land on the remaining runway or overrun. Depending upon how quickly the pilot reacts to the sudden yaw, the airplane may run off the side of the runway by the time action is taken. There are really no other practical options. As discussed earlier, the chances of maintaining directional control while retracting the flaps (if extended), landing gear, feathering the propeller, and accelerating are minimal. On some airplanes with a single-engine-driven hydraulic pump, failure of that engine means the only way to raise the landing gear is to allow the engine to windmill or to use a hand pump. This is not a viable alternative during takeoff.

2. **Landing gear control selected up, single-engine climb performance inadequate**. [Figure 12-12] When operating near or above the single-engine ceiling and an engine failure is experienced shortly after lift-off, a landing must be accomplished on whatever essentially lies ahead. There is also the option of continuing ahead, in a descent at V_{YSE} with the remaining engine producing power, as long as the pilot is not tempted to remain airborne beyond the airplane's performance capability. Remaining airborne, bleeding off airspeed in a futile attempt to maintain altitude is almost invariably fatal. Landing under control is paramount. The greatest hazard in a single-engine takeoff is attempting to fly when it is not within the per-

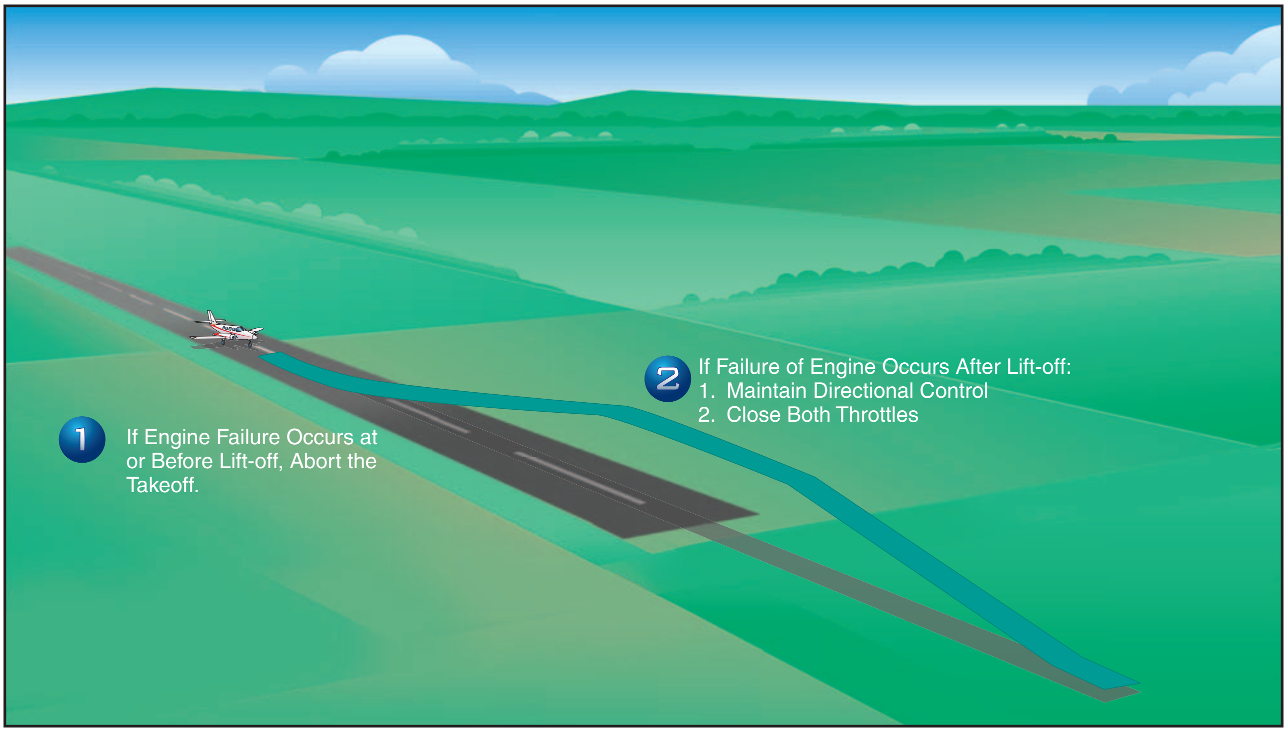


Figure 12-11. Engine failure on takeoff, landing gear down.

formance capability of the airplane to do so. An accident is inevitable.

Analysis of engine failures on takeoff reveals a very high success rate of off-airport engine inoperative landings when the airplane is landed under control. Analysis also reveals a very high fatality rate in stall-spin accidents when the pilot attempts flight beyond the performance capability of the airplane.

As mentioned previously, if the airplane's landing gear retraction mechanism is dependent upon hydraulic pressure from a certain engine-driven pump, failure of that engine can mean a loss of hundreds of feet of altitude as the pilot either windmills the engine to provide hydraulic pressure to raise the gear or raises it manually with a backup pump.

3. **Landing gear control selected up, single-engine climb performance adequate**. [Figure 12-13] If the single-engine rate of climb is adequate, the procedures for continued flight should be followed. There are four areas of concern: **control**, **configuration**, **climb**, and **checklist**.

- **CONTROL—** The first consideration following engine failure during takeoff is control of the airplane. Upon detecting an engine failure, aileron should be used to bank the airplane and rudder pressure applied, aggressively if necessary, to counteract the yaw and roll from asymmetrical thrust. The control forces, particularly on the rudder, may be high. The pitch attitude for V_{YSE} will have to be lowered from that of V_Y.

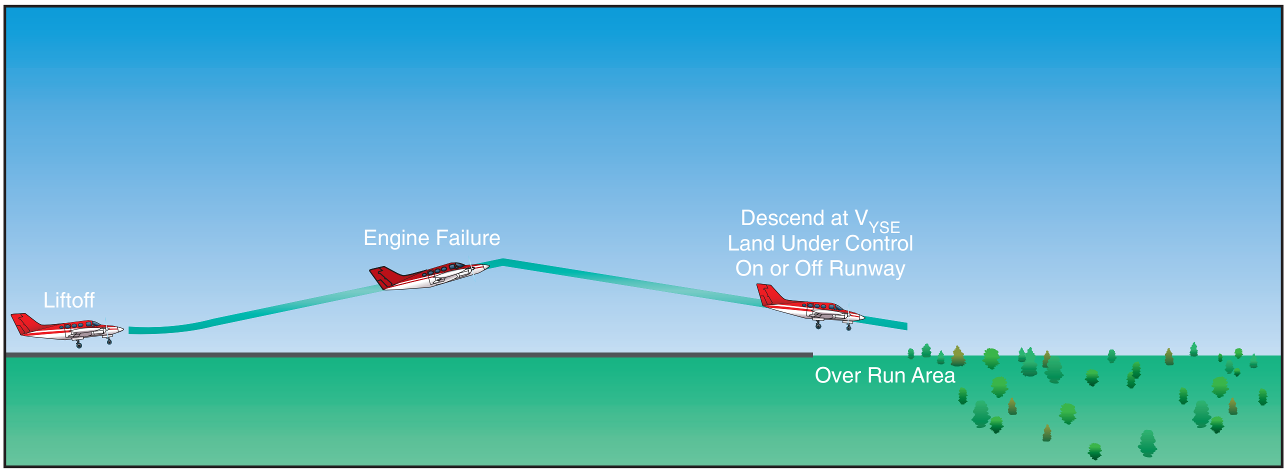


Figure 12-12. Engine failure on takeoff, inadequate climb performance.

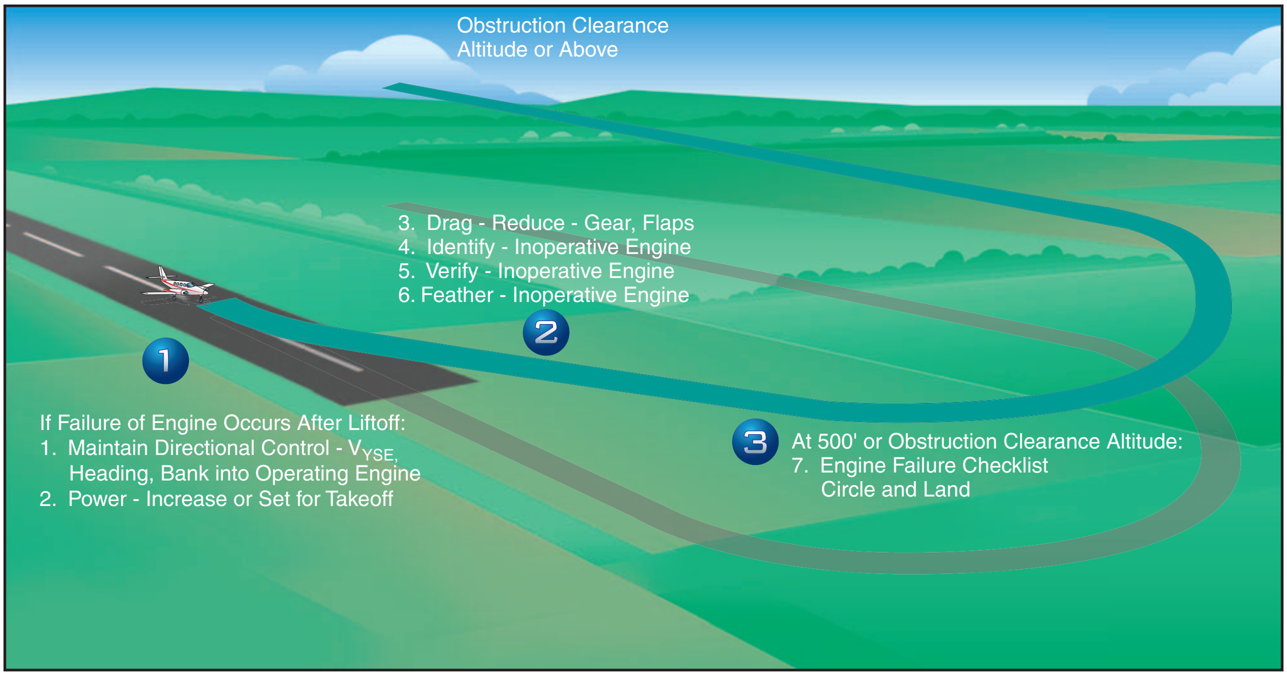


Figure 12-13. Landing gear up—adequate climb performance.

At least 5° of bank should be used, if necessary, to stop the yaw and maintain directional control. This initial bank input is held only momentarily, just long enough to establish or ensure directional control. Climb performance suffers when bank angles exceed approximately 2 or 3°, but obtaining and maintaining V_{YSE} and directional control are paramount. Trim should be adjusted to lower the control forces.

- **CONFIGURATION**—The memory items from the "engine failure after takeoff" checklist [Figure 12-14] should be promptly executed to configure the airplane for climb. The specific procedures to follow will be found in the AFM/POH and checklist for the particular airplane. Most will direct the pilot to assume V_{YSE}, set takeoff power, retract the flaps and landing gear, identify, verify, and feather the failed engine. (On some airplanes, the landing gear is to be retracted before the flaps.)

  The "identify" step is for the pilot to initially identify the failed engine. Confirmation on the engine gauges may or may not be possible, depending upon the failure mode. Identification should be primarily through the control inputs required to maintain straight flight, not the engine gauges. The "verify" step directs the pilot to retard the throttle of the engine thought to have failed. No change in performance when the suspected throttle is retarded is verification that the correct engine has been identified as failed. The corresponding propeller control should be brought fully aft to feather the engine.

ENGINE FAILURE AFTER TAKEOFF	
Airspeed	**Maintain V_{YSE}**
Mixtures	**RICH**
Propellers	**HIGH RPM**
Throttles	**FULL POWER**
Flaps	**UP**
Landing Gear	**UP**
Identify	**Determine failed engine**
Verify	**Close throttle of failed engine**
Propeller	**FEATHER**
Trim Tabs	ADJUST
Failed Engine	SECURE
As soon as practical	LAND

Bold - faced items require immediate action and are to be accomplished from memory.

Figure 12-14. Typical "engine failure after takeoff" emergency checklist.

- **CLIMB**—As soon as directional control is established and the airplane configured for climb, the bank angle should be reduced to that producing best climb performance. Without specific guidance for zero sideslip, a bank of 2° and one-third to one-half ball deflection on the slip/skid indicator is suggested. V_{YSE} is maintained with pitch control. As turning flight reduces climb performance, climb should be made straight ahead, or with shallow turns to avoid obstacles, to an altitude of at least 400 feet AGL before attempting a return to the airport.

- **CHECKLIST—**Having accomplished the memory items from the "engine failure after takeoff" checklist, the printed copy should be reviewed as time permits. The "securing failed engine" checklist [Figure 12-15] should then be accomplished. Unless the pilot suspects an engine fire, the remaining items should be accomplished deliberately and without undue haste. Airplane control should never be sacrificed to execute the remaining checklists. The priority items have already been accomplished from memory.

SECURING FAILED ENGINE	
Mixture	IDLE CUT OFF
Magnetos	OFF
Alternator	OFF
Cowl Flap	CLOSE
Boost Pump	OFF
Fuel Selector	OFF
Prop Sync	OFF
Electrical Load	Reduce
Crossfeed	Consider

Figure 12-15. Typical "securing failed engine" emergency checklist.

Other than closing the cowl flap of the failed engine, none of these items, if left undone, adversely affects airplane climb performance. There is a distinct possibility of actuating an incorrect switch or control if the procedure is rushed. The pilot should concentrate on flying the airplane and extracting maximum performance. If ATC facilities are available, an emergency should be declared.

The memory items in the "engine failure after takeoff" checklist may be redundant with the airplane's existing configuration. For example, in the third takeoff scenario, the gear and flaps were assumed to already be retracted, yet the memory items included gear and flaps. This is not an oversight. The purpose of the memory items is to either initiate the appropriate action or to confirm that a condition exists. Action on each item may not be required in all cases. The memory items also apply to more than one circumstance. In an engine failure from a go-around, for example, the landing gear and flaps would likely be extended when the failure occurred.

The three preceding takeoff scenarios all include the landing gear as a key element in the decision to land or continue. With the landing gear selector in the DOWN position, for example, continued takeoff and climb is not recommended. This situation, however, is not justification to retract the landing gear the moment the airplane lifts off the surface on takeoff as a normal procedure. The landing gear should remain selected down as long as there is usable runway or overrun available to land on. The use of wing flaps for takeoff virtually eliminates the likelihood of a single-engine climb until the flaps are retracted.

There are two time-tested memory aids the pilot may find useful in dealing with engine-out scenarios. The first, "Dead foot–dead engine" is used to assist in identifying the failed engine. Depending on the failure mode, the pilot won't be able to consistently identify the failed engine in a timely manner from the engine gauges. In maintaining directional control, however, rudder pressure will be exerted on the side (left or right) of the airplane with the operating engine. Thus, the "dead foot" is on the same side as the "dead engine." Variations on this saying include "Idle foot–idle engine" and "Working foot–working engine."

The second memory aid has to do with climb performance. The phrase "Raise the dead" is a reminder that the best climb performance is obtained with a very shallow bank, about 2° toward the operating engine. Therefore, the inoperative, or "dead" engine should be "raised" with a very slight bank.

Not all engine power losses are complete failures. Sometimes the failure mode is such that partial power may be available. If there is a performance loss when the throttle of the affected engine is retarded, the pilot should consider allowing it to run until altitude and airspeed permit safe single-engine flight, if this can be done without compromising safety. Attempts to save a malfunctioning engine can lead to a loss of the entire airplane.

ENGINE FAILURE DURING FLIGHT

Engine failures well above the ground are handled differently than those occurring at lower speeds and altitudes. Cruise airspeed allows better airplane control, and altitude may permit time for a possible diagnosis and remedy of the failure. Maintaining airplane control, however, is still paramount. Airplanes have been lost at altitude due to apparent fixation on the engine problem to the detriment of flying the airplane.

Not all engine failures or malfunctions are catastrophic in nature (catastrophic meaning a major mechanical failure that damages the engine and precludes further engine operation). Many cases of power loss are related to fuel starvation, where restoration of power may be made with the selection of another tank. An orderly inventory of gauges and switches may reveal the problem. Carburetor heat or alternate air can be selected. The affected engine may run smoothly on just one magneto or at a lower power setting. Altering the mixture may help. If fuel vapor formation is suspected, fuel boost pump operation may be used to eliminate flow and pressure fluctuations.

Although it is a natural desire among pilots to save an ailing engine with a precautionary shutdown, the engine should be left running if there is any doubt as to needing it for further safe flight. Catastrophic failure accompanied by heavy vibration, smoke, blistering paint, or large trails of oil, on the other hand, indicate a critical situation. The affected engine should be feathered and the "securing failed engine" checklist completed. The pilot should divert to the nearest suitable airport and declare an emergency with ATC for priority handling.

Fuel crossfeed is a method of getting fuel from a tank on one side of the airplane to an operating engine on the other. Crossfeed is used for extended single-engine operation. If a suitable airport is close at hand, there is no need to consider crossfeed. If prolonged flight on a single-engine is inevitable due to airport non-availability, then crossfeed allows use of fuel that would otherwise be unavailable to the operating engine. It also permits the pilot to balance the fuel consumption to avoid an out-of-balance wing heaviness.

AFM/POH procedures for crossfeed vary widely. Thorough fuel system knowledge is essential if crossfeed is to be conducted. Fuel selector positions and fuel boost pump usage for crossfeed differ greatly among multiengine airplanes. Prior to landing, crossfeed should be terminated and the operating engine returned to its main tank fuel supply.

If the airplane is above its single-engine absolute ceiling at the time of engine failure, it will slowly lose altitude. The pilot should maintain V_{YSE} to minimize the rate of altitude loss. This "drift down" rate will be greatest immediately following the failure and will decrease as the single-engine ceiling is approached. Due to performance variations caused by engine and propeller wear, turbulence, and pilot technique, the airplane may not maintain altitude even at its published single-engine ceiling. Any further rate of sink, however, would likely be modest.

An engine failure in a descent or other low power setting can be deceiving. The dramatic yaw and performance loss will be absent. At very low power settings, the pilot may not even be aware of a failure. If a failure is suspected, the pilot should advance both engine mixtures, propellers, and throttles significantly, to the takeoff settings if necessary, to correctly identify the failed engine. The power on the operative engine can always be reduced later.

ENGINE INOPERATIVE APPROACH AND LANDING

The approach and landing with one engine inoperative is essentially the same as a two-engine approach and landing. The traffic pattern should be flown at similar altitudes, airspeeds, and key positions as a two-engine approach. The differences will be the reduced power available and the fact that the remaining thrust is asymmetrical. A higher-than-normal power setting will be necessary on the operative engine.

With adequate airspeed and performance, the landing gear can still be extended on the downwind leg. In which case it should be confirmed DOWN no later than abeam the intended point of landing. Performance permitting, initial extension of wing flaps (10°, typically) and a descent from pattern altitude can also be initiated on the downwind leg. The airspeed should be no slower than V_{YSE}. The direction of the traffic pattern, and therefore the turns, is of no consequence as far as airplane controllability and performance are concerned. It is perfectly acceptable to make turns toward the failed engine.

On the base leg, if performance is adequate, the flaps may be extended to an intermediate setting (25°, typically). If the performance is inadequate, as measured by a decay in airspeed or high sink rate, delay further flap extension until closer to the runway. V_{YSE} is still the minimum airspeed to maintain.

On final approach, a normal, 3° glidepath to a landing is desirable. VASI or other vertical path lighting aids should be utilized if available. Slightly steeper approaches may be acceptable. However, a long, flat, low approach should be avoided. Large, sudden power applications or reductions should also be avoided. Maintain V_{YSE} until the landing is assured, then slow to 1.3 V_{SO} or the AFM/POH recommended speed. The final flap setting may be delayed until the landing is assured, or the airplane may be landed with partial flaps.

The airplane should remain in trim throughout. The pilot must be prepared, however, for a rudder trim change as the power of the operating engine is reduced to idle in the roundout just prior to touchdown. With drag from only one windmilling propeller, the airplane will tend to float more than on a two-engine approach. Precise airspeed control therefore is essential, especially when landing on a short, wet and/or slippery surface.

Some pilots favor resetting the rudder trim to neutral on final and compensating for yaw by holding rudder pressure for the remainder of the approach. This eliminates the rudder trim change close to the ground as the throttle is closed during the roundout for landing. This technique eliminates the need for groping for the rudder trim and manipulating it to neutral during final approach, which many pilots find to be highly distracting. AFM/POH recommendations or personal preference should be used.

Single-engine go-arounds must be avoided. As a practical matter in single-engine approaches, once the airplane is on final approach with landing gear and flaps extended, it is committed to land. If not on the intended runway, then on another runway, a taxiway, or grassy infield. The light-twin does not have the performance to climb on one engine with landing gear and flaps extended. Considerable altitude will be lost while maintaining V_{YSE} and retracting landing gear and flaps. Losses of 500 feet or more are not unusual. If the landing gear has been lowered with an alternate means of extension, retraction may not be possible, virtually negating any climb capability.

ENGINE INOPERATIVE FLIGHT PRINCIPLES

Best single-engine climb performance is obtained at V_{YSE} with maximum available power and minimum drag. After the flaps and landing gear have been retracted and the propeller of the failed engine feathered, a key element in best climb performance is minimizing sideslip.

With a single-engine airplane or a multiengine airplane with both engines operative, sideslip is eliminated when the ball of the turn and bank instrument is centered. This is a condition of **zero sideslip**, and the airplane is presenting its smallest possible profile to the relative wind. As a result, drag is at its minimum. Pilots know this as coordinated flight.

In a multiengine airplane with an inoperative engine, the centered ball is no longer the indicator of zero sideslip due to asymmetrical thrust. In fact, there is no instrument at all that will directly tell the pilot the flight conditions for zero sideslip. In the absence of a **yaw string**, minimizing sideslip is a matter of placing the airplane at a predetermined bank angle and ball position. The AFM/POH performance charts for single-engine flight were determined at zero sideslip. If this performance is even to be approximated, the zero sideslip technique **must** be utilized.

There are two different control inputs that can be used to counteract the asymmetrical thrust of a failed engine: (1) yaw from the rudder, and (2) the horizontal component of lift that results from bank with the ailerons. Used individually, neither is correct. Used together in the proper combination, zero sideslip and best climb performance are achieved.

Three different scenarios of airplane control inputs are presented below. **Neither of the first two is correct**. They are presented to illustrate the reasons for the zero sideslip approach to best climb performance.

1. Engine inoperative flight with wings level and ball centered requires large rudder input towards the operative engine. [Figure 12-16] The result is a moderate sideslip towards the inoperative engine. Climb performance will be reduced by the moderate sideslip. With wings level, V_{MC} will be significantly higher than published as there is no horizontal component of lift available to help the rudder combat asymmetrical thrust.

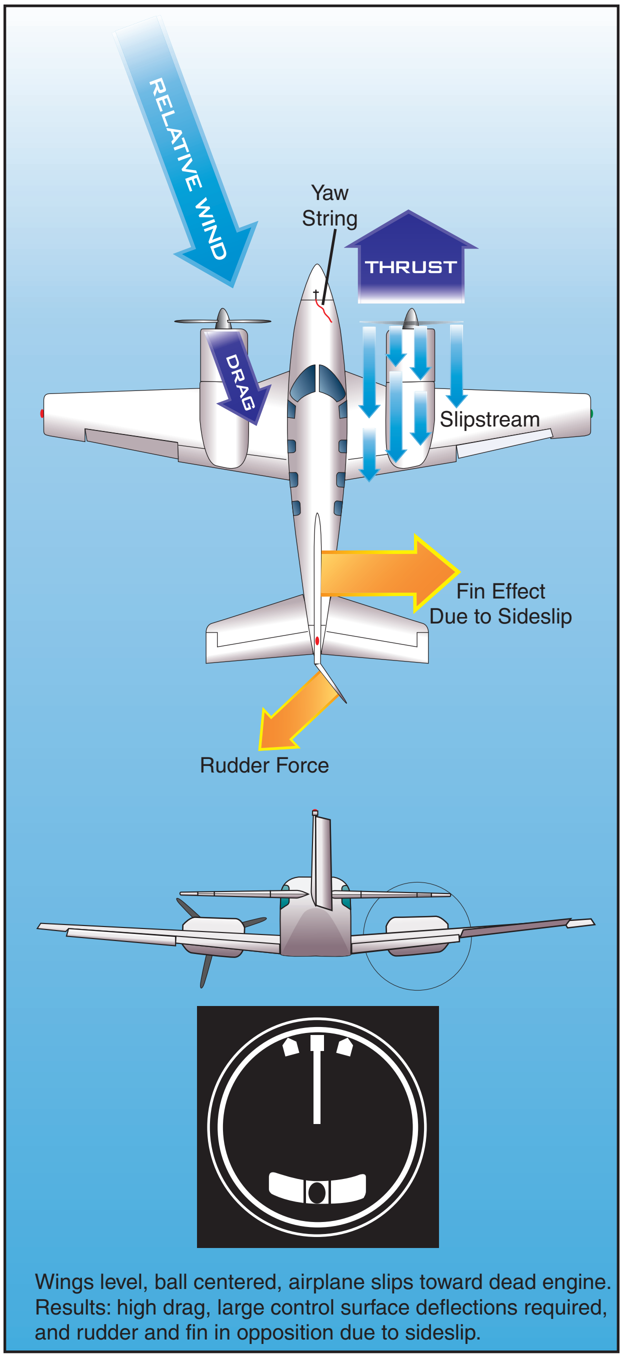


Figure 12-16. Wings level engine-out flight.

2. Engine inoperative flight using ailerons alone requires an 8 - 10° bank angle towards the operative engine. [Figure 12-17] This assumes no rudder input. The ball will be displaced well towards the operative engine. The result is a large sideslip towards the operative engine. Climb performance will be greatly reduced by the large sideslip.

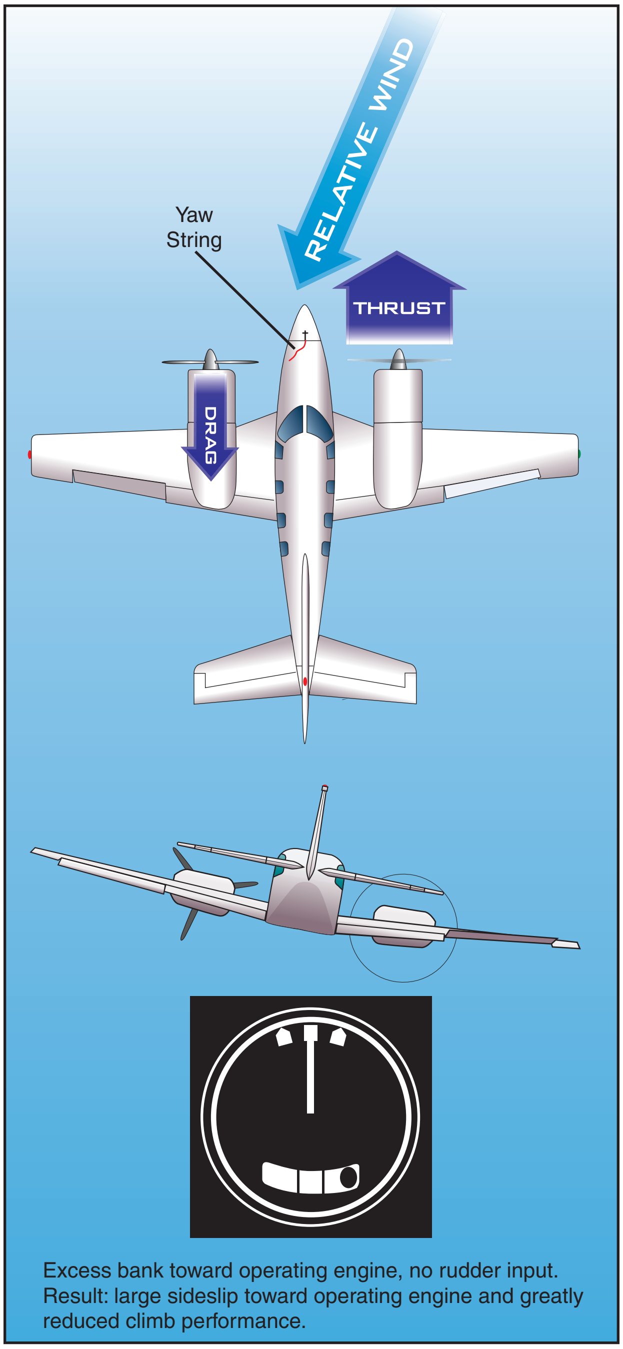


Figure 12-17. Excessive bank engine-out flight.

3. Rudder and ailerons used together in the proper combination will result in a bank of approximately 2° towards the operative engine. The ball will be displaced approximately one-third to one-half towards the operative engine. The result is zero sideslip and maximum climb performance. [Figure 12-18] Any attitude other than zero sideslip increases drag, decreasing performance. V_{MC} under these circumstances will be higher than published, as less than the 5° bank certification limit is employed.

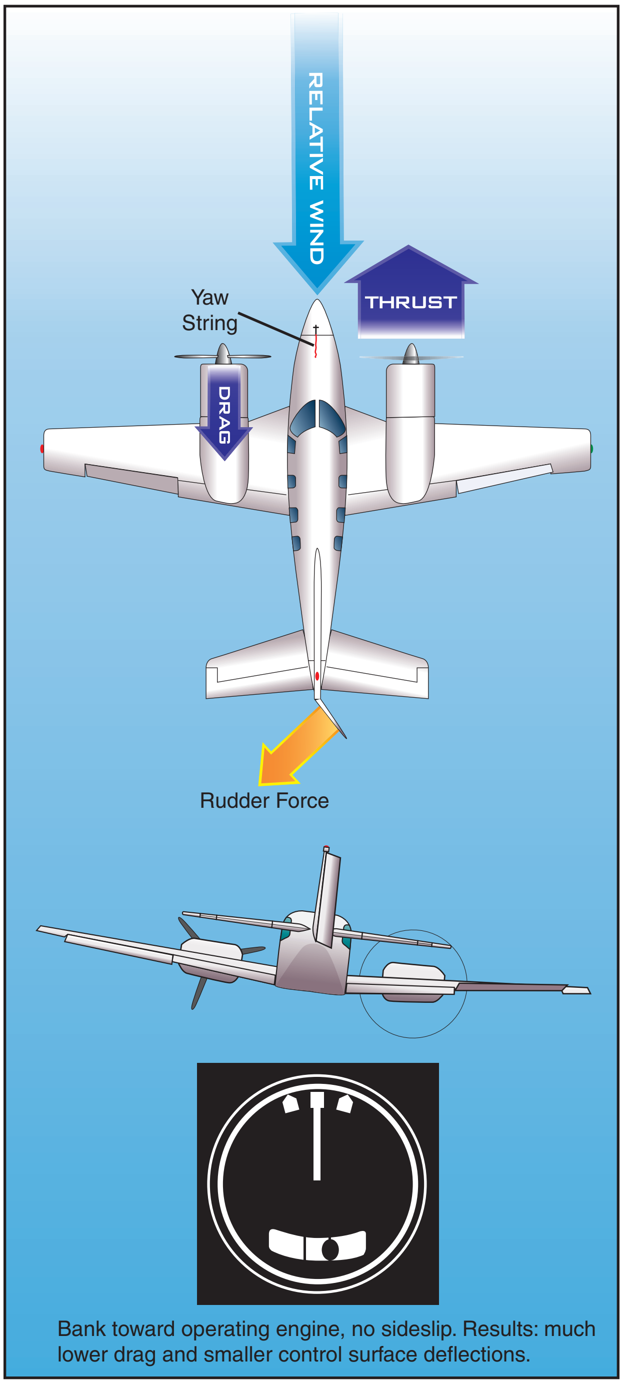


Figure 12-18. Zero sideslip engine-out flight.

The precise condition of zero sideslip (bank angle and ball position) varies slightly from model to model, and with available power and airspeed. If the airplane is not equipped with counter-rotating propellers, it will also vary slightly with the engine failed due to P-factor. The foregoing zero sideslip recommendations apply to reciprocating engine multiengine airplanes flown at V_{YSE} with the inoperative engine feathered. The zero sideslip ball position for straight flight is also the zero sideslip position for turning flight.

When bank angle is plotted against climb performance for a hypothetical twin, zero sideslip results in the best (however marginal) climb performance or the least rate of descent. Zero bank (all rudder to counteract yaw) degrades climb performance as a result of moderate sideslip. Using bank angle alone (no rudder) severely degrades climb performance as a result of a large sideslip.

The actual bank angle for zero sideslip varies among airplanes from one and one-half to two and one-half degrees. The position of the ball varies from one-third to one-half of a ball width from instrument center.

For any multiengine airplane, zero sideslip can be confirmed through the use of a yaw string. A yaw string is a piece of string or yarn approximately 18 to 36 inches in length, taped to the base of the windshield, or to the nose near the windshield, along the airplane centerline. In two-engine coordinated flight, the relative wind will cause the string to align itself with the longitudinal axis of the airplane, and it will position itself straight up the center of the windshield. This is zero sideslip. Experimentation with slips and skids will vividly display the location of the relative wind. Adequate altitude and flying speed must be maintained while accomplishing these maneuvers.

With an engine set to zero thrust (or feathered) and the airplane slowed to V_{YSE}, a climb with maximum power on the remaining engine will reveal the precise bank angle and ball deflection required for zero sideslip and best climb performance. Zero sideslip will again be indicated by the yaw string when it aligns itself vertically on the windshield. There will be very minor changes from this attitude depending upon the engine failed (with noncounter-rotating propellers), power available, airspeed and weight; but without more sensitive testing equipment, these changes are difficult to detect. The only significant difference would be the pitch attitude required to maintain V_{YSE} under different density altitude, power available, and weight conditions.

If a yaw string is attached to the airplane at the time of a V_{MC} demonstration, it will be noted that V_{MC} occurs under conditions of sideslip. V_{MC} was **not** determined under conditions of zero sideslip during aircraft certification and zero sideslip is **not** part of a V_{MC} demonstration for pilot certification.

To review, there are two different sets of bank angles used in one-engine-inoperative flight.

- To maintain directional control of a multiengine airplane suffering an engine failure at low speeds (such as climb), momentarily bank **at least** 5°, and a maximum of 10° towards the operative engine as the pitch attitude for V_{YSE} is set. This maneuver should be instinctive to the proficient multiengine pilot and take only 1 to 2 seconds to attain. It is held just long enough to assure directional control as the pitch attitude for V_{YSE} is assumed.

- To obtain the best climb performance, the airplane must be flown at V_{YSE} and zero sideslip, with the failed engine feathered and maximum available power from the operating engine. Zero sideslip is approximately **2**° of bank toward the operating engine and a one-third to one-half ball deflection, also toward the operating engine. The precise bank angle and ball position will vary somewhat with make and model and power available. If above the airplane's single-engine ceiling, this attitude and configuration will result in the minimum rate of sink.

In OEI flight at low altitudes and airspeeds such as the initial climb after takeoff, pilots must operate the airplane so as to guard against the three major accident factors: (1) loss of directional control, (2) loss of performance, and (3) loss of flying speed. All have equal potential to be lethal. Loss of flying speed will not be a factor, however, when the airplane is operated with due regard for directional control and performance.

SLOW FLIGHT

There is nothing unusual about maneuvering during slow flight in a multiengine airplane. Slow flight may be conducted in straight-and-level flight, turns, in the clean configuration, landing configuration, or at any other combination of landing gear and flaps. Pilots should closely monitor cylinder head and oil temperatures during slow flight. Some high performance multiengine airplanes tend to heat up fairly quickly under some conditions of slow flight, particularly in the landing configuration.

Simulated engine failures should not be conducted during slow flight. The airplane will be well below V_{SSE} and very close to V_{MC}. Stability, stall warning or stall avoidance devices should not be disabled while maneuvering during slow flight.

STALLS

Stall characteristics vary among multiengine airplanes just as they do with single-engine airplanes, and therefore, it is important to be familiar with them. The application of power upon stall recovery, however, has a significantly greater effect during stalls in a twin than a single-engine airplane. In the twin, an application of power blows large masses of air from the propellers directly over the wings, producing a significant amount of lift in addition to the expected thrust. The multiengine airplane, particularly at light operating weights, typically has a higher thrust-to-weight ratio, making it quicker to accelerate out of a stalled condition.

In general, stall recognition and recovery training in twins is performed similar to any high performance single-engine airplane. However, for twins, all stall maneuvers should be planned so as to be completed at least 3,000 feet AGL.

Single-engine stalls or stalls with significantly more power on one engine than the other should not be attempted due to the likelihood of a departure from controlled flight and possible spin entry. Similarly, simulated engine failures should not be performed during stall entry and recovery.

POWER-OFF STALLS (APPROACH AND LANDING)

Power-off stalls are practiced to simulate typical approach and landing scenarios. To initiate a power-off stall maneuver, the area surrounding the airplane should first be cleared for possible traffic. The airplane should then be slowed and configured for an approach and landing. A stabilized descent should be established (approximately 500 f.p.m.) and trim adjusted. The pilot should then transition smoothly from the stabilized descent attitude, to a pitch attitude that will induce a stall. Power is reduced further during this phase, and trimming should cease at speeds slower than takeoff.

When the airplane reaches a stalled condition, the recovery is accomplished by simultaneously reducing the angle of attack with coordinated use of the flight controls and smoothly applying takeoff or specified power. The flap setting should be reduced from full to approach, or as recommended by the manufacturer. Then with a positive rate of climb, the landing gear is selected up. The remaining flaps are then retracted as a climb has commenced. This recovery process should be completed with a minimum loss of altitude, appropriate to the aircraft characteristics.

The airplane should be accelerated to V_X (if simulated obstacles are present) or V_Y during recovery and climb. Considerable forward elevator/stabilator pressure will be required after the stall recovery as the airplane accelerates to V_X or V_Y. Appropriate trim input should be anticipated.

Power-off stalls may be performed with wings level, or from shallow and medium banked turns. When recovering from a stall performed from turning flight, the angle of attack should be reduced prior to leveling the wings. Flight control inputs should be coordinated.

It is usually not advisable to execute full stalls in multiengine airplanes because of their relatively high wing loading. Stall training should be limited to approaches to stalls and when a stall condition occurs. Recoveries should be initiated at the onset, or decay of control effectiveness, or when the first physical indication of the stall occurs.

POWER-ON STALLS (TAKEOFF AND DEPARTURE)

Power-on stalls are practiced to simulate typical takeoff scenarios. To initiate a power-on stall maneuver, the area surrounding the airplane should always be cleared to look for potential traffic. The airplane is slowed to the manufacturer's recommended lift-off speed. The airplane should be configured in the takeoff configuration. Trim should be adjusted for this speed. Engine power is then increased to that recommended in the AFM/POH for the practice of power-on stalls. In the absence of a recommended setting, use approximately 65 percent of maximum available power while placing the airplane in a pitch attitude that will induce a stall. Other specified (reduced) power settings may be used to simulate performance at higher gross weights and density altitudes.

When the airplane reaches a stalled condition, the recovery is made by simultaneously lowering the angle of attack with coordinated use of the flight controls and applying power as appropriate.

However, if simulating limited power available for high gross weight and density altitude situations, the power during the recovery should be limited to that specified. The recovery should be completed with a minimum loss of altitude, appropriate to aircraft characteristics.

The landing gear should be retracted when a positive rate of climb is attained, and flaps retracted, if flaps were set for takeoff. The target airspeed on recovery is V_X if (simulated) obstructions are present, or V_Y. The pilot should anticipate the need for nosedown trim as the airplane accelerates to V_X or V_Y after recovery.

Power-on stalls may be performed from straight flight or from shallow and medium banked turns. When recovering from a power-on stall performed from turning flight, the angle of attack should be reduced prior to leveling the wings, and the flight control inputs should be coordinated.

SPIN AWARENESS

No multiengine airplane is approved for spins, and their spin recovery characteristics are generally very poor. It is therefore necessary to practice spin avoidance and maintain a high awareness of situations that can result in an inadvertent spin.

In order to spin any airplane, it must first be stalled. At the stall, a yawing moment must be introduced. In a multiengine airplane, the yawing moment may be generated by rudder input or asymmetrical thrust. It follows, then, that spin awareness be at its greatest during V_{MC} demonstrations, stall practice, slow flight, or any condition of high asymmetrical thrust, particularly at low speed/high angle of attack. Single-engine stalls are **not** part of any multiengine training curriculum.

A situation that may inadvertently degrade into a spin entry is a simulated engine failure introduced at an inappropriately low speed. No engine failure should ever be introduced below safe, intentional one-engine-inoperative speed (V_{SSE}). If no V_{SSE} is published, use V_{YSE}. The "necessity" of simulating engine failures at low airspeeds is erroneous. Other than training situations, the multiengine airplane is only operated below V_{SSE} for mere seconds just after lift-off or during the last few dozen feet of altitude in preparation for landing.

For spin avoidance when practicing engine failures, the flight instructor should pay strict attention to the maintenance of proper airspeed and bank angle as the student executes the appropriate procedure. The instructor should also be particularly alert during stall and slow flight practice. Forward center-of-gravity positions result in favorable stall and spin avoidance characteristics, but do not eliminate the hazard.

When performing a V_{MC} demonstration, the instructor should also be alert for any sign of an impending stall. The student may be highly focused on the directional control aspect of the maneuver to the extent that impending stall indications go unnoticed. If a V_{MC} demonstration cannot be accomplished under existing conditions of density altitude, it may, for training purposes, be done utilizing the rudder blocking technique described in the following section.

As very few twins have ever been spin-tested (none are required to), the recommended spin recovery techniques are based only on the best information available. The departure from controlled flight may be quite abrupt and possibly disorienting. The direction of an upright spin can be confirmed from the turn needle or the symbolic airplane of the turn coordinator, if necessary. Do not rely on the ball position or other instruments.

If a spin is entered, most manufacturers recommend immediately retarding both throttles to idle, applying full rudder opposite the direction of rotation, and applying full forward elevator/stabilator pressure (with ailerons neutral). These actions should be taken as near simultaneously as possible. The controls should then be held in that position. Recovery, if possible, will take considerable altitude. The longer the delay from entry until taking corrective action, the less likely that recovery will be successful.

ENGINE INOPERATIVE—LOSS OF DIRECTIONAL CONTROL DEMONSTRATION

An engine inoperative—loss of directional control demonstration, often referred to as a "V_{MC} demonstration," is a required task on the practical test for a multiengine class rating. A thorough knowledge of the factors that affect V_{MC}, as well as its definition, is essential for multiengine pilots, and as such an essential part of that required task. V_{MC} is a speed established by the manufacturer, published in the AFM/POH, and marked on most airspeed indicators with a red radial line. The multiengine pilot must understand that V_{MC} is **not** a fixed airspeed under all conditions. V_{MC} is a fixed airspeed only for the very specific set of circumstances under which it was determined during aircraft certification. [Figure 12-19]

In reality, V_{MC} varies with a variety of factors as outlined below. The V_{MC} noted in practice and demonstration, or in actual single-engine operation, could be less or even greater than the published value, depending upon conditions and technique.

In aircraft certification, V_{MC} is the sea level calibrated airspeed at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the airplane with that engine still inoperative and then maintain straight flight at the same speed with an angle of bank of not more than 5°.

The foregoing refers to the determination of V_{MC} under "dynamic" conditions. This technique is only used by highly experienced flight test pilots during aircraft certification. It is never to be attempted outside of these circumstances.

In aircraft certification, there is also a determination of V_{MC} under "static," or steady-state conditions. If there is a difference between the dynamic and static speeds, the higher of the two is published as V_{MC}. The static determination is simply the ability to maintain straight flight at V_{MC} with a bank angle of not more than 5°. This more closely resembles the V_{MC} demonstration required in the practical test for a multiengine class rating.

The AFM/POH-published V_{MC} is determined with the "critical" engine inoperative. The critical engine is the

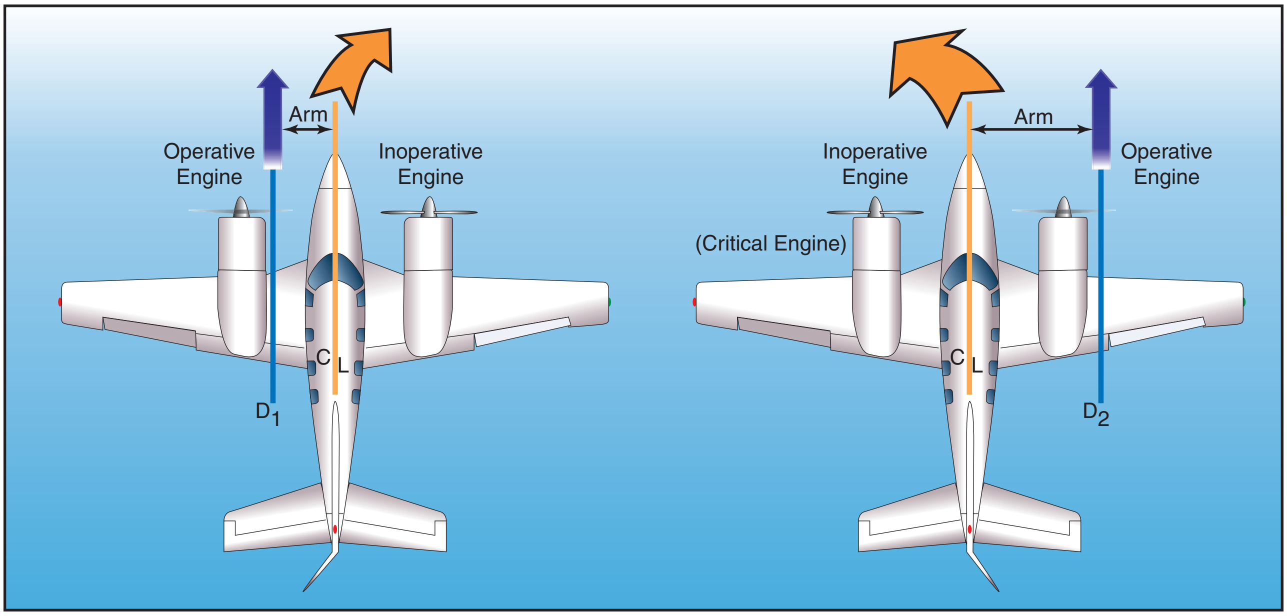


Figure 12-19. Forces created during single-engine operation.

engine whose failure has the most adverse effect on directional control. On twins with each engine rotating in conventional, clockwise rotation as viewed from the pilot's seat, the critical engine will be the left engine.

Multiengine airplanes are subject to P-factor just as single-engine airplanes are. The descending propeller blade of each engine will produce greater thrust than the ascending blade when the airplane is operated under power and at positive angles of attack. The descending propeller blade of the right engine is also a greater distance from the center of gravity, and therefore has a longer moment arm than the descending propeller blade of the left engine. As a result, failure of the left engine will result in the most asymmetrical thrust (adverse yaw) as the right engine will be providing the remaining thrust. [Figure 12-19]

Many twins are designed with a counter-rotating right engine. With this design, the degree of asymmetrical thrust is the same with either engine inoperative. No engine is more critical than the other, and a V_{MC} demonstration may be performed with either engine windmilling.

In aircraft certification, dynamic V_{MC} is determined under the following conditions.

- **Maximum available takeoff power.** V_{MC} increases as power is increased on the operating engine. With normally aspirated engines, V_{MC} is highest at takeoff power and sea level, and decreases with altitude. With turbocharged engines, takeoff power, and therefore V_{MC}, remains constant with increases in altitude up to the engine's critical altitude (the altitude where the engine can no longer maintain 100 percent power). Above the critical altitude, V_{MC} decreases just as it would with a normally aspirated engine, whose critical altitude is sea level. V_{MC} tests are conducted at a variety of altitudes. The results of those tests are then extrapolated to a single, sea level value.

- **Windmilling propeller.** V_{MC} increases with increased drag on the inoperative engine. V_{MC} is highest, therefore, when the critical engine propeller is windmilling at the low pitch, high r.p.m. blade angle. V_{MC} is determined with the critical engine propeller windmilling in the takeoff position, unless the engine is equipped with an autofeather system.

- **Most unfavorable weight and center-of-gravity position.** V_{MC} increases as the center of gravity is moved aft. The moment arm of the rudder is reduced, and therefore its effectivity is reduced, as the center of gravity is moved aft. At the same time, the moment arm of the propeller blade is increased, aggravating asymmetrical thrust. Invariably, the aft-most CG limit is the most unfavorable CG position. Currently, 14 CFR part 23 calls for V_{MC} to be determined at the most unfavorable weight. For twins certificated under CAR 3 or early 14 CFR part 23, the weight at which V_{MC} was determined was not specified. V_{MC} increases as weight is reduced. [Figure 12-20]

- **Landing gear retracted.** V_{MC} increases when the landing gear is retracted. Extended landing gear aids directional stability, which tends to decrease V_{MC}.

- **Wing flaps in the takeoff position.** For most twins, this will be 0° of flaps.

- **Cowl flaps in the takeoff position.**

- **Airplane trimmed for takeoff.**

- **Airplane airborne and the ground effect negligible.**

- **Maximum of 5° angle of bank.** V_{MC} is highly sensitive to bank angle. To prevent claims of an unrealistically low V_{MC} speed in aircraft certification, the manufacturer is permitted to use a maximum of a 5° bank angle toward the operative engine. The horizontal component of lift generated by the bank assists the rudder in counteracting the asymmetrical thrust of the operative engine. The bank angle works in the manufacturer's favor in lowering V_{MC}.

V_{MC} is reduced significantly with increases in bank angle. Conversely, V_{MC} increases significantly with decreases in bank angle. Tests have shown that V_{MC} may increase more than 3 knots for each degree of bank angle less than 5°. Loss of directional control may be experienced at speeds almost 20 knots above published V_{MC} when the wings are held level.

The 5° bank angle maximum is a regulatory limit imposed upon manufacturers in aircraft certification. The 5° bank does **not** inherently establish zero sideslip or best single-engine climb performance. Zero sideslip, and therefore best single-engine climb performance, occurs at bank angles significantly less than 5°. The determination of V_{MC} in certification is solely concerned with the minimum speed for directional control under a very specific set of circumstances, and has nothing to do with climb performance, nor is it the optimum airplane attitude or configuration for climb performance.

During dynamic V_{MC} determination in aircraft certification, cuts of the critical engine using the mixture control are performed by flight test pilots while gradually reducing the speed with each attempt. V_{MC} is the minimum speed at which directional control could be maintained within 20° of the original entry heading when a cut of the critical engine was made. During such tests, the climb angle with both engines operating was high, and the pitch attitude following the engine cut had to be quickly lowered to regain the initial speed. Pilots should never attempt to demonstrate V_{MC} with an engine cut from high power, and never intentionally fail an engine at speeds less than V_{SSE}.

The actual demonstration of V_{MC} and recovery in flight training more closely resembles static V_{MC} determination in aircraft certification. For a demonstration, the pilot should select an altitude that will allow completion of the maneuver at least 3,000 feet AGL. The following description assumes a twin with noncounter-rotating engines, where the left engine is critical.

With the landing gear retracted and the flaps set to the takeoff position, the airplane should be slowed to approximately 10 knots above V_{SSE} or V_{YSE} (whichever is higher) and trimmed for takeoff. For the remainder of the maneuver, the trim setting should not be altered. An entry heading should be selected and high r.p.m. set on both propeller controls. Power on the left engine should be throttled back to idle as the right engine power is advanced to the takeoff setting. The landing gear warning horn will sound as long as a

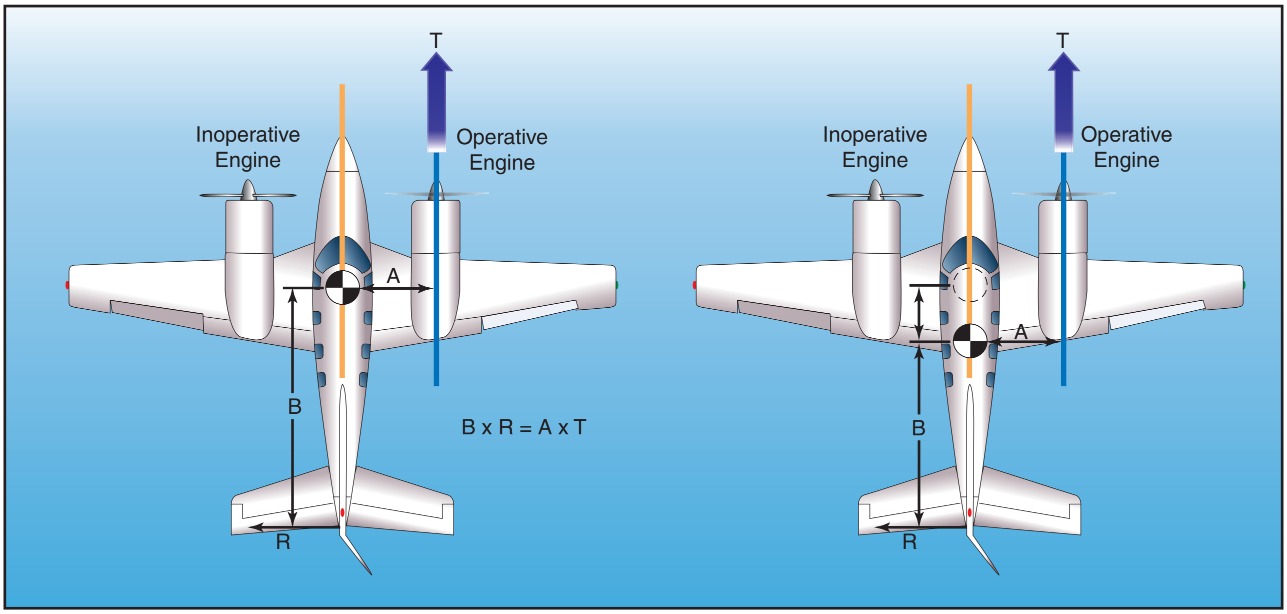


Figure 12-20. Effect of CG location on yaw.

throttle is retarded. The pilots should continue to carefully listen, however, for the stall warning horn, if so equipped, or watch for the stall warning light. The left yawing and rolling moment of the asymmetrical thrust is counteracted primarily with right rudder. A bank angle of 5° (a right bank, in this case) should also be established.

While maintaining entry heading, the pitch attitude is slowly increased to decelerate at a rate of 1 knot per second (no faster). As the airplane slows and control effectivity decays, the increasing yawing tendency should be counteracted with additional rudder pressure. Aileron displacement will also increase in order to maintain 5° of bank. An airspeed is soon reached where full right rudder travel and a 5° right bank can no longer counteract the asymmetrical thrust, and the airplane will begin to yaw uncontrollably to the left.

The moment the pilot first recognizes the uncontrollable yaw, or experiences **any** symptom associated with a stall, the operating engine throttle should be sufficiently retarded to stop the yaw as the pitch attitude is decreased. Recovery is made with a minimum loss of altitude to straight flight on the entry heading at V_{SSE} or V_{YSE}, before setting symmetrical power. The recovery should not be attempted by increasing power on the windmilling engine alone.

To keep the foregoing description simple, there were several important background details that were not covered. The rudder pressure during the demonstration can be quite high. In certification, 150 pounds of force is permitted before the limiting factor becomes rudder pressure, not rudder travel. Most twins will run out of rudder travel long before 150 pounds of pressure is required. Still, it will seem considerable.

Maintaining altitude is **not** a criterion in accomplishing this maneuver. This is a demonstration of controllability, not performance. Many airplanes will lose (or gain) altitude during the demonstration. Begin the maneuver at an altitude sufficient to allow completion by 3,000 feet AGL.

As discussed earlier, with normally aspirated engines, V_{MC} decreases with altitude. Stalling speed (V_S), however, remains the same. Except for a few models, published V_{MC} is almost always higher than V_S. At sea level, there is usually a margin of several knots between V_{MC} and V_S, but the margin decreases with altitude, and at some altitude, V_{MC} and V_S are the same. [Figure 12-21]

Should a stall occur while the airplane is under asymmetrical power, particularly high asymmetrical power, a spin entry is likely. The yawing moment induced from asymmetrical thrust is little different from that

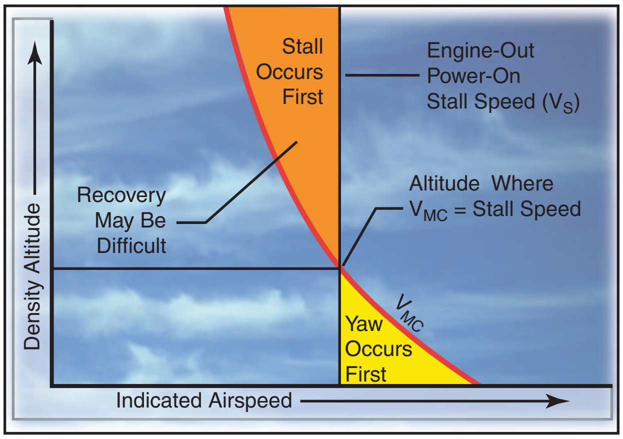


Figure 12-21. Graph depicting relationship of V_{MC} to V_S.

induced by full rudder in an intentional spin in the appropriate model of single-engine airplane. In this case, however, the airplane will depart controlled flight in the direction of the idle engine, not in the direction of the applied rudder. Twins are not required to demonstrate recoveries from spins, and their spin recovery characteristics are generally very poor.

Where V_S is encountered at or before V_{MC}, the departure from controlled flight may be quite sudden, with strong yawing and rolling tendencies to the inverted position, and a spin entry. Therefore, during a V_{MC} demonstration, if there are **any** symptoms of an impending stall such as a stall warning light or horn, airframe or elevator buffet, or rapid decay in control effectiveness, the maneuver should be terminated immediately, the angle of attack reduced as the throttle is retarded, and the airplane returned to the entry airspeed. It should be noted that if the pilots are wearing headsets, the sound of a stall warning horn will tend to be masked.

The V_{MC} demonstration only shows the earliest onset of a loss of directional control. It is not a loss of control of the airplane when performed in accordance with the foregoing procedures. A stalled condition should **never** be allowed to develop. Stalls should never be performed with asymmetrical thrust and the V_{MC} demonstration should never be allowed to degrade into a single-engine stall. A V_{MC} demonstration that is allowed to degrade into a single-engine stall with high asymmetrical thrust is very likely to result in a loss of control of the airplane.

An actual demonstration of V_{MC} may not be possible under certain conditions of density altitude, or with airplanes whose V_{MC} is equal to or less than V_S. Under those circumstances, as a training technique, a demonstration of V_{MC} may be safely conducted by artificially limiting rudder travel to simulate maximum available rudder. Limiting rudder travel should be accomplished at a speed well above V_S (approximately 20 knots).

The rudder limiting technique avoids the hazards of spinning as a result of stalling with high asymmetrical power, yet is effective in demonstrating the loss of directional control.

The V_{MC} demonstration should never be performed from a high pitch attitude with both engines operating and then reducing power on one engine. The preceding discussion should also give ample warning as to why engine failures are never to be performed at low airspeeds. An unfortunate number of airplanes and pilots have been lost from unwarranted simulated engine failures at low airspeeds that degenerated into loss of control of the airplane. V_{SSE} is the minimum airspeed at which any engine failure should be simulated.

MULTIENGINE TRAINING CONSIDERATIONS

Flight training in a multiengine airplane can be safely accomplished if both the instructor and the student are cognizant of the following factors.

- No flight should ever begin without a thorough preflight briefing of the objectives, maneuvers, expected student actions, and completion standards.
- A clear understanding must be reached as to how simulated emergencies will be introduced, and what action the student is expected to take.

The introduction, practice, and testing of emergency procedures has always been a sensitive subject. Surprising a multiengine student with an emergency without a thorough briefing beforehand has no place in flight training. Effective training must be carefully balanced with safety considerations. Simulated engine failures, for example, can very quickly become actual emergencies or lead to loss of the airplane when approached carelessly. Pulling circuit breakers can lead to a subsequent gear up landing. Stall-spin accidents in training for emergencies rival the number of stall-spin accidents from actual emergencies.

All normal, abnormal, and emergency procedures can and should be introduced and practiced in the airplane as it sits on the ground, power off. In this respect, the airplane is used as a cockpit procedures trainer (CPT), ground trainer, or simulator. The value of this training should never be underestimated. The engines do not have to be operating for real learning to occur. Upon completion of a training session, care should be taken to return items such as switches, valves, trim, fuel selectors, and circuit breakers to their normal positions.

Pilots who do not use a checklist effectively will be at a significant disadvantage in multiengine airplanes. Use of the checklist is essential to safe operation of airplanes and no flight should be conducted without one. The manufacturer's checklist or an aftermarket checklist for the specific make, model, and model year should be used. If there is a procedural discrepancy between the checklist and AFM/POH, then the AFM/POH always takes precedence.

Certain immediate action items (such as the response to an engine failure in a critical phase of flight) should be committed to memory. After they are accomplished, and as work load permits, the pilot should verify the action taken with a printed checklist.

Simulated engine failures during the takeoff ground roll should be accomplished with the mixture control. The simulated failure should be introduced at a speed no greater than 50 percent of V_{MC}. If the student does not react promptly by retarding both throttles, the instructor can always pull the other mixture.

The FAA recommends that all in-flight simulated engine failures below 3,000 feet AGL be introduced with a smooth reduction of the throttle. Thus, the engine is kept running and is available for instant use, if necessary. Throttle reduction should be smooth rather than abrupt to avoid abusing the engine and possibly causing damage. All inflight engine failures must be conducted at V_{SSE} or above.

If the engines are equipped with dynamic crankshaft counterweights, it is essential to make throttle reductions for simulated failures smoothly. Other areas leading to dynamic counterweight damage include high r.p.m. and low manifold pressure combinations, overboosting, and propeller feathering. Severe damage or repetitive abuse to counterweights will eventually lead to engine failure. Dynamic counterweights are found on larger, more complex engines—instructors should check with maintenance personnel or the engine manufacturer to determine if their engines are so equipped.

When an instructor simulates an engine failure, the student should respond with the appropriate memory items and retard the propeller control towards the FEATHER position. Assuming zero thrust will be set, the instructor should promptly move the propeller control forward and set the appropriate manifold pressure and r.p.m. It is vital that the student be kept informed of the instructor's intentions. At this point the instructor may state words to the effect, "I have the right engine; you have the left. I have set zero thrust and the right engine is simulated feathered." There should never be any ambiguity as to who is operating what systems or controls.

Following a simulated engine failure, the instructor should continue to care for the "failed" engine just as the student cares for the operative engine. If zero thrust is set to simulate a feathered propeller, the cowl flap should be closed and the mixture leaned. An occasional clearing of the engine is also desirable. If possible, avoid high power applications immediately following a prolonged cool-down at a zero-thrust power setting.

The flight instructor must impress on the student multiengine pilot the critical importance of feathering the propeller in a timely manner should an actual engine failure situation be encountered. A windmilling propeller, in many cases, has given the improperly trained multiengine pilot the mistaken perception that the failed engine is still developing useful thrust, resulting in a psychological reluctance to feather, as feathering results in the cessation of propeller rotation. The flight instructor should spend ample time demonstrating the difference in the performance capabilities of the airplane with a simulated feathered propeller (zero thrust) as opposed to a windmilling propeller.

All actual propeller feathering should be performed at altitudes and positions where safe landings on established airports could be readily accomplished. Feathering and restart should be planned so as to be completed no lower than 3,000 feet AGL. At certain elevations and with many popular multiengine training airplanes, this may be above the single-engine service ceiling, and level flight will not be possible.

Repeated feathering and unfeathering is hard on the engine and airframe, and should be done only as absolutely necessary to ensure adequate training. The FAA's practical test standards for a multiengine class rating requires the feathering and unfeathering of one propeller during flight in airplanes in which it is safe to do so.

While much of this chapter has been devoted to the unique flight characteristics of the multiengine airplane with one engine inoperative, the modern, well-maintained reciprocating engine is remarkably reliable. Simulated engine failures at extremely low altitudes (such as immediately after lift-off) and/or below V_{SSE} are undesirable in view of the non-existent safety margins involved. The high risk of simulating an engine failure below 200 feet AGL does not warrant practicing such maneuvers.

For training in maneuvers that would be hazardous in flight, or for initial and recurrent qualification in an advanced multiengine airplane, a simulator training center or manufacturer's training course should be given consideration. Comprehensive training manuals and classroom instruction are available along with system training aids, audio/visuals, and flight training devices and simulators. Training under a wide variety of environmental and aircraft conditions is available through simulation. Emergency procedures that would be either dangerous or impossible to accomplish in an airplane can be done safely and effectively in a flight training device or simulator. The flight training device or simulator need not necessarily duplicate the specific make and model of airplane to be useful. Highly effective instruction can be obtained in training devices for other makes and models as well as generic training devices.

The majority of multiengine training is conducted in four to six-place airplanes at weights significantly less than maximum. Single-engine performance, particularly at low density altitudes, may be deceptively good. To experience the performance expected at higher weights, altitudes, and temperatures, the instructor should occasionally artificially limit the amount of manifold pressure available on the operative engine. Airport operations above the single-engine ceiling can also be simulated in this manner. Loading the airplane with passengers to practice emergencies at maximum takeoff weight is not appropriate.

The use of the touch-and-go landing and takeoff in flight training has always been somewhat controversial. The value of the learning experience must be weighed against the hazards of reconfiguring the airplane for takeoff in an extremely limited time as well as the loss of the follow-through ordinarily experienced in a full stop landing. Touch and goes are not recommended during initial aircraft familiarization in multiengine airplanes.

If touch and goes are to be performed at all, the student and instructor responsibilities need to be carefully briefed prior to each flight. Following touchdown, the student will ordinarily maintain directional control while keeping the left hand on the yoke and the right hand on the throttles. The instructor resets the flaps and trim and announces when the airplane has been reconfigured. The multiengine airplane needs considerably more runway to perform a touch and go than a single-engine airplane. A full stop-taxi back landing is preferable during initial familiarization. Solo touch and goes in twins are strongly discouraged.