

# Airplane Flying Handbook (FAA-H-8083-3C)

## Chapter 12: Transition to Complex Airplanes

### Introduction

A high-performance airplane is defined as an airplane with an engine capable of developing more than 200 horsepower (see 14 CFR part 61, section 61.31(f)(1)). A complex airplane (see 14 CFR part 61, section 61.1) means an airplane that has a retractable landing gear, flaps, and a controllable pitch propeller, including airplanes equipped with an engine control system consisting of a digital computer and associated accessories for controlling the engine and propeller, such as a full authority digital engine control; or, in the case of a seaplane, flaps and a controllable pitch propeller, including seaplanes equipped with an engine control system consisting of a digital computer and associated accessories for controlling the engine and propeller, such as a full authority digital engine control.

Transition to a complex airplane, or a high-performance airplane, can be demanding for many pilots. Both increased performance and complexity require additional planning, judgment, and piloting skills. Transition to these types of airplanes, therefore, should be accomplished in a systematic manner through a structured course of training administered by a qualified flight instructor.

Airplanes can be designed to fly through a wide range of airspeeds. High speed flight requires smaller wing areas and moderately cambered airfoils whereas low speed flight is obtained with airfoils with a greater camber and larger wing area. [Figure 12-1] Many compromises are often made by designers to provide for higher speed cruise flight and low speeds for landing. Flaps are a common design effort to increase an airfoil's camber and surface area for lower-speed flight. [Figure 12-2]

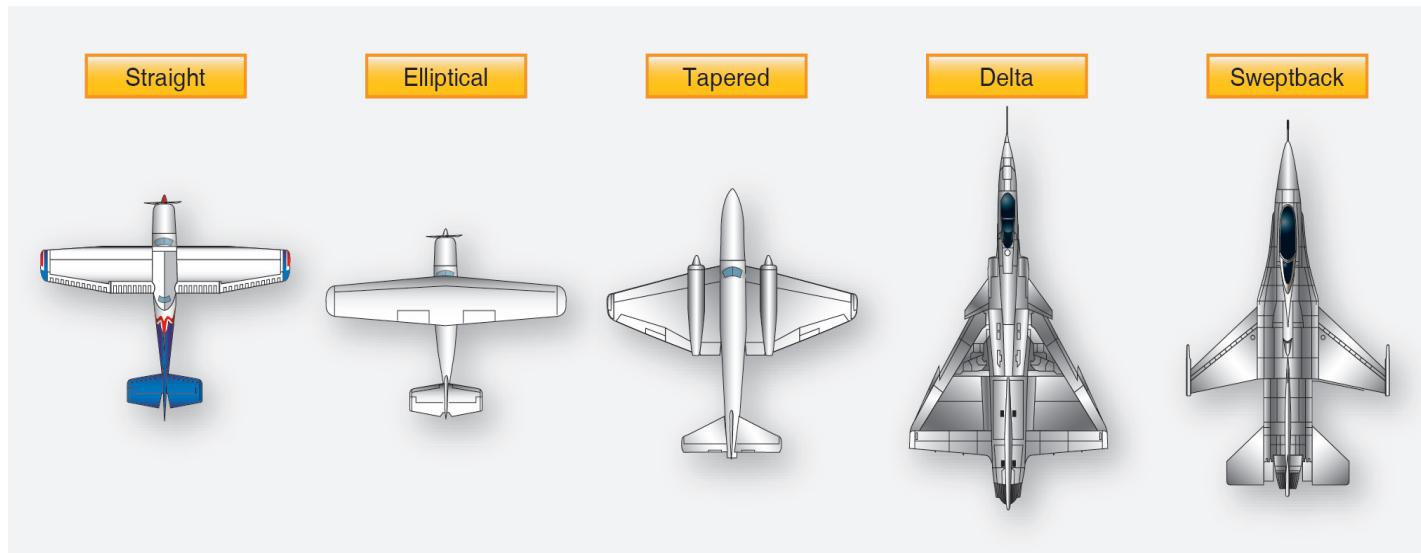
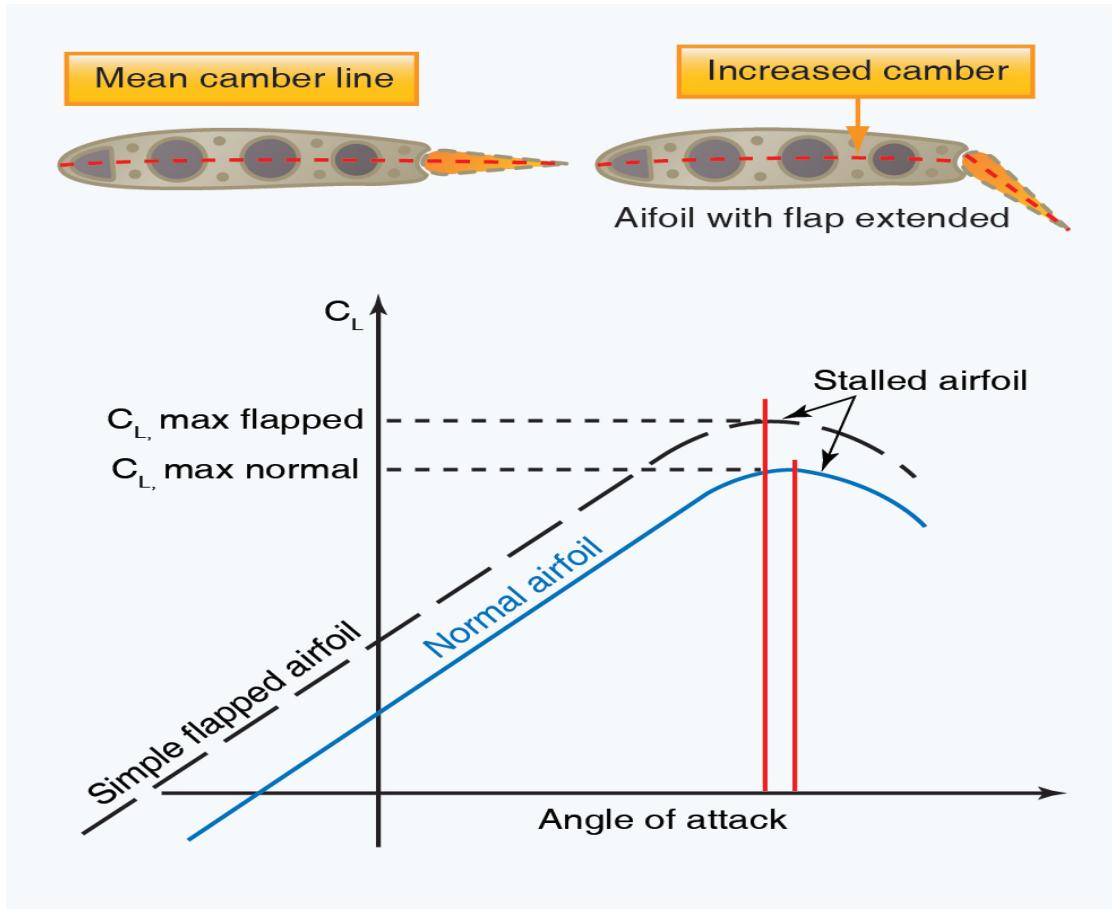


Figure 12-1. Airfoil types.

Since an airfoil cannot have two different cambers at the same time, designers and engineers deliver the desired performance characteristics using two different methods. Either the airfoil can be a compromise, or a cruise airfoil can be combined with a device for increasing the camber of the airfoil for low-speed flight. Camber is the asymmetry between the top and the bottom surfaces of an airfoil. One method for varying an airfoil's camber is the addition of trailing-edge flaps. Engineers call these devices a high-lift system.

### Function of Flaps

Flaps work primarily by changing the camber of the airfoil, which increases the wing's lift coefficient. With some flap designs, the surface area of the wing is also increased. Flap deflection does not increase the critical (stall) angle of attack (AOA). In some cases, flap deflection actually decreases the critical AOA. Deflection of a wing's control surfaces, such as ailerons and flaps, alters both lift and drag. With aileron deflection, there is asymmetrical lift which imparts a rolling moment about the airplane's longitudinal axis. Wing flaps act symmetrically about the longitudinal axis producing no rolling moment; however, both lift and drag increase as well as a pitching moment about the lateral axis. Lift is a function of several variables including air density, velocity, surface area, and lift coefficient. Since flaps increase an airfoil's lift coefficient, lift is increased. [Figure 12-3]



**Figure 12-2.** Coefficient of lift comparison for flap extended and retracted positions.

$$L = \frac{1}{2} p V^2 S C_L$$

L = Lift produced

P = Air density

V = Velocity relative to the air

S = Surface area of the wing

$C_L$  = lift coefficient which is determined by the camber of the airfoil used, the chord of the wing and AOA

**Figure 12-3.** Lift equation.

As flaps are deflected, the aircraft may pitch nose-up, nose-down, or have minimal changes in pitch attitude. Pitching moment is caused by the rearward movement of the wing's center of pressure; however, that pitching behavior depends on several variables including flap type, wing position, downwash behavior, and horizontal tail location. Consequently, pitch behavior depends on the design features of the particular airplane.

Flap deflection of up to  $15^\circ$  primarily produces lift with minimal increases in drag. Deflection beyond  $15^\circ$  produces a large increase in drag. Drag from flap deflection is parasite drag and, as such, is proportional to the square of the speed. Also, deflection beyond  $15^\circ$  produces a significant nose-up pitching moment in most high-wing airplanes because the resulting downwash changes the airflow over the horizontal tail.

## Flap Effectiveness

Flap effectiveness depends on a number of factors, but the most noticeable are size and type. For the purpose of this chapter, trailing edge flaps are classified as four basic types: plain (hinge), split, slotted, and Fowler. [Figure 12-4]

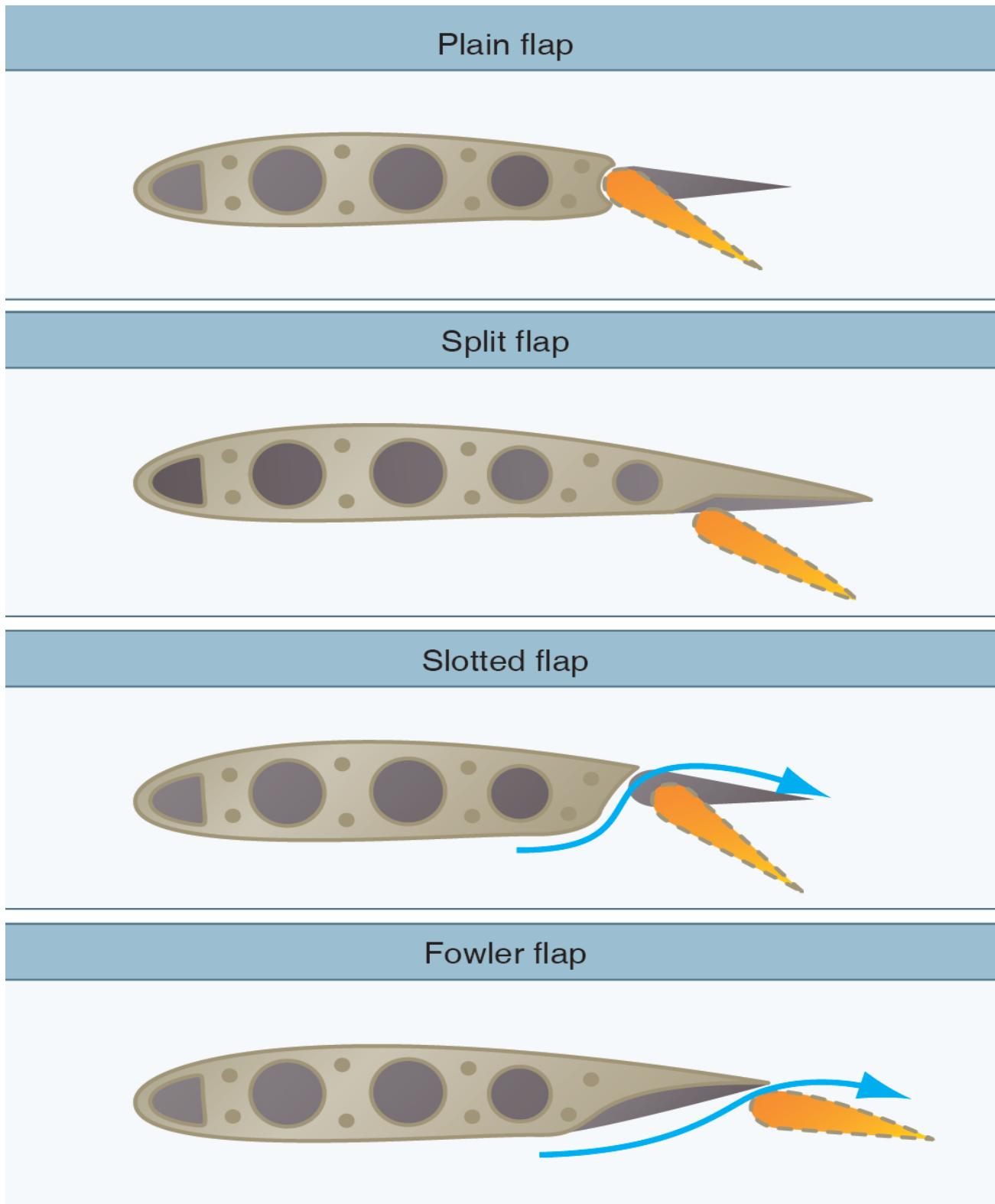


Figure 12-4. Four basic types of flaps.

The plain or hinge flap is a hinged section of the wing. The structure and function are comparable to the other control surfaces—ailerons, rudder, and elevator. The split flap is more complex. It is the lower or underside portion of the wing; deflection of the flap leaves the upper trailing edge of the wing undisturbed. It is, however, more effective than the hinge flap because of greater lift and less pitching moment, but there is more drag. Split flaps are more useful for landing, but the partially deflected hinge flaps have the advantage in takeoff. The split flap has significant drag at small deflections, whereas the hinge flap does not because airflow remains “attached” to the flap.

The slotted flap has a gap between the wing and the leading edge of the flap. The slot allows high-pressure airflow on the wing undersurface to energize the lower pressure over the top, thereby delaying flow separation. The slotted flap has greater lift than the hinge flap but less than the split flap; but, because of a higher lift-drag ratio, it gives better takeoff and climb performance. Small deflections of the slotted flap give a higher drag than the hinge flap but less than the split. This allows the slotted flap to be used for takeoff.

The Fowler flap deflects down and aft to increase the wing area. This flap can be multi-slotted making it the most complex of the trailing-edge systems. This system does, however, give the maximum lift coefficient. Drag characteristics at small deflections are much like the slotted flap. Fowler flaps are most commonly used on larger airplanes because of their structural complexity and difficulty in sealing the slots.

## Operational Procedures

It would be impossible to discuss all the many airplane design and flap combinations. Pilots should refer to the Federal Aviation Administration (FAA) approved Airplane Flight Manual and/or Pilot’s Operating Handbook (AFM/POH) for a given airplane. However, while some AFM/POHs are specific as to operational use of flaps, others leave the use of flaps to pilot discretion. Since flaps are often used for landings and takeoffs, when the airplane is close to the ground, pilot judgment and error avoidance are of critical importance.

Since the recommendations given in the AFM/POH are based on the airplane and the flap design, the pilot should relate the manufacturer’s recommendation to aerodynamic effects of flaps. This requires basic background knowledge of flap aerodynamics and geometry. With this information, a decision as to the degree of flap deflection and time of deflection based on runway and approach conditions relative to the wind conditions can be made.

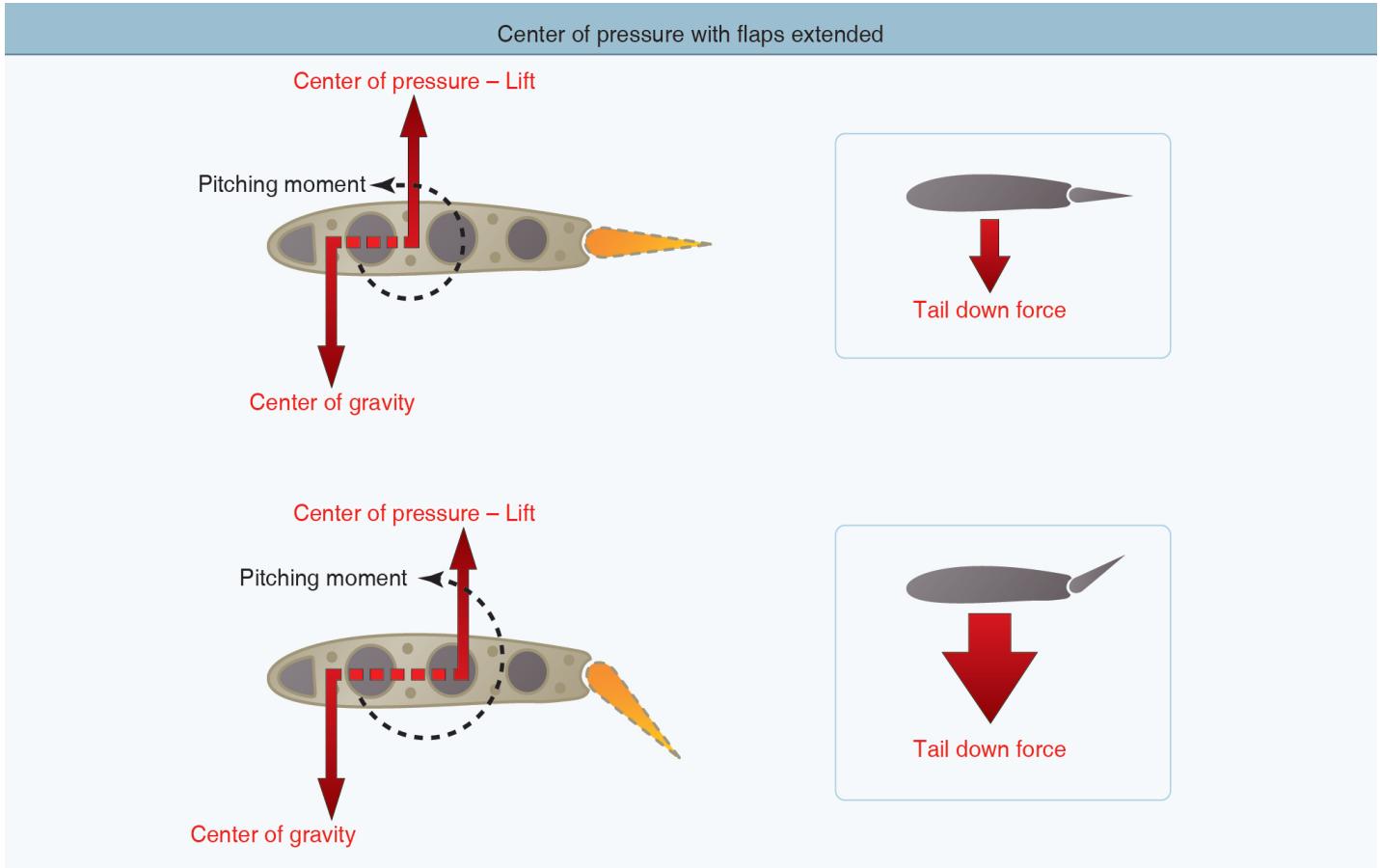
The time of flap extension and the degree of deflection are related. Large changes in flap deflection at one single point in the landing pattern can produce large lift changes that require significant pitch and power changes in order to maintain airspeed and descent angle. Consequently, there is an advantage to extending flaps in increments while in the landing pattern. Incremental deflection of flaps on downwind, base leg, and final approach allow smaller adjustments of pitch and power and support a stabilized approach.

While normal, soft-field, or short-field landings require minimal speed at touchdown, a short-field obstacle approach requires minimum speed and a steep approach angle. Flap extension, particularly beyond 30°, results in significant levels of drag. The drag can produce a high sink rate that the pilot needs to control with power. When a pilot uses power during a steep approach or short-field approach to offset the drag produced by the flaps, the landing flare becomes critical. A reduction in power too early can result in a hard landing, airplane damage, or loss of control. A reduction in power too late causes the airplane to float down the runway.

Crosswind component is another factor to be considered in the degree of flap extension. The deflected flap presents a surface area for the wind to act on. With flaps extended in a crosswind, the wing on the upwind side is more affected than the downwind wing. The effect is reduced to a slight extent in the crabbed approach since the airplane is more nearly aligned with the wind. When using a wing-low approach, the lowered wing partially blocks the upwind flap. The dihedral of the wing combined with the flap and wind make lateral control more difficult. Lateral control becomes more difficult as flap extension reaches maximum and the crosswind becomes perpendicular to the runway.

With flaps extended, the crosswind effects on the wing become more pronounced as the airplane reaches the ground. The wing, flap, and ground on the upwind side of the airplane form a “container” that is filled with air by the crosswind. Since the flap is located behind the main landing gear, wind striking the deflected flap tends to yaw the airplane into the wind and raise the upwind wing. The raised wing reduces the tire forces and further increases the tendency to turn into the wind. Proper control position (ailerons into the wind) is essential for maintaining runway alignment. Depending on the amount of crosswind, it may be necessary to retract the flaps soon after touchdown in order to maintain control of the airplane.

The go-around is another factor to consider when making a decision about degree of flap deflection and about where in the landing pattern to extend flaps. Because of the nose-down pitching moment produced with flap extension, trim is used to offset this pitching moment. Application of full power in the go-around increases the airflow over the wing. This produces additional lift causing significant changes in pitch. The pitch-up tendency does not diminish completely with flap retraction because of the trim setting. Expedient retraction of flaps is desirable to eliminate drag; however, the pilot should be prepared for rapid changes in pitch forces as the result of trim and the increase in airflow over the control surfaces. [Figure 12-5]



**Figure 12-5. Flaps extended pitching moment.**

During a go-around, the pilot should carefully monitor pitch and airspeed and expect that the degree of flap deflection and the design configuration of the horizontal tail relative to the wing will affect go-around characteristics. The pilot should carefully monitor pitch and airspeed, control flap retraction to minimize altitude loss, and use rudder for coordination. Considering these factors, it is good practice to extend the same degree of flaps at the same point in the landing pattern for each landing. Consistent use of flaps in the traffic pattern allows for a preplanned and familiar go-around sequence based on the airplane's position in the landing pattern.

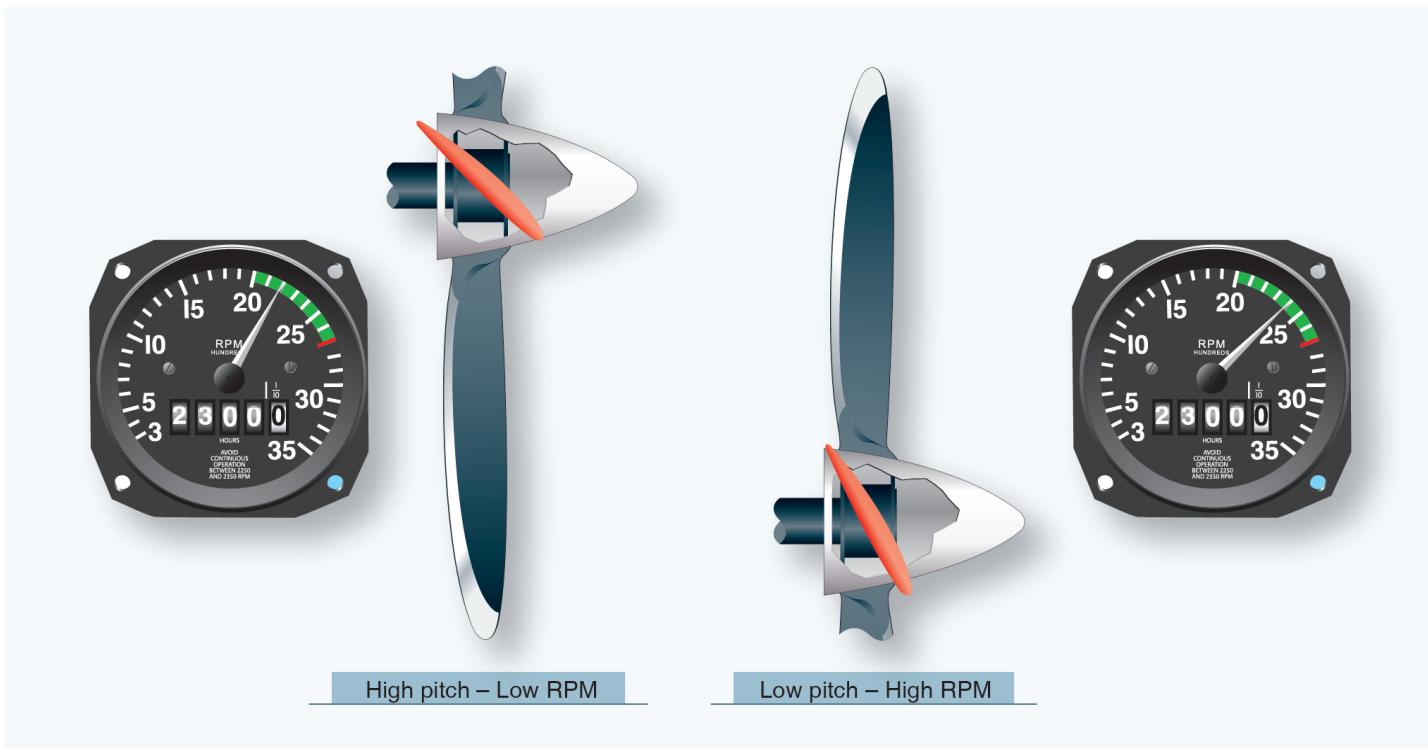
There is no single formula to determine the degree of flap deflection to be used on landing because a landing involves variables that are dependent on each other. The AFM/POH for the particular airplane contains the manufacturer's recommendations for some landing situations. On the other hand, AFM/POH information on flap usage for takeoff is more precise. The manufacturer's requirements are based on the climb performance produced by a given flap design. Under no circumstances should a flap setting given in the AFM/POH be exceeded for takeoff.

## Controllable-Pitch Propeller

Fixed-pitch propellers are designed for best efficiency at one particular revolutions per minute (rpm) setting and one airspeed. A fixed-pitch propeller provides suitable performance in a narrow range of airspeeds. However, fixed-pitch efficiency suffers considerably when operating outside of this range. To provide improved propeller efficiency through a wide range of operation, the propeller blade angle needs to be controllable.

## Constant-Speed Propeller

A constant-speed propeller keeps the blade angle adjusted for maximum efficiency during most flight conditions. The pilot controls the engine rpm indirectly by means of a propeller control, which is connected to the propeller governor. For maximum takeoff power, the propeller control is moved all the way forward to the low pitch/high rpm position, and the throttle is moved forward to the maximum allowable manifold pressure position. [Figure 12- 6] To reduce power for climb or cruise, the pilot reduces manifold pressure to the desired value with the throttle, and then reduces engine rpm by moving the propeller control back toward the high pitch/low rpm position. The pilot sets the rpm accurately using the tachometer.



**Figure 12-6.** Controllable-pitch propeller pitch angles.

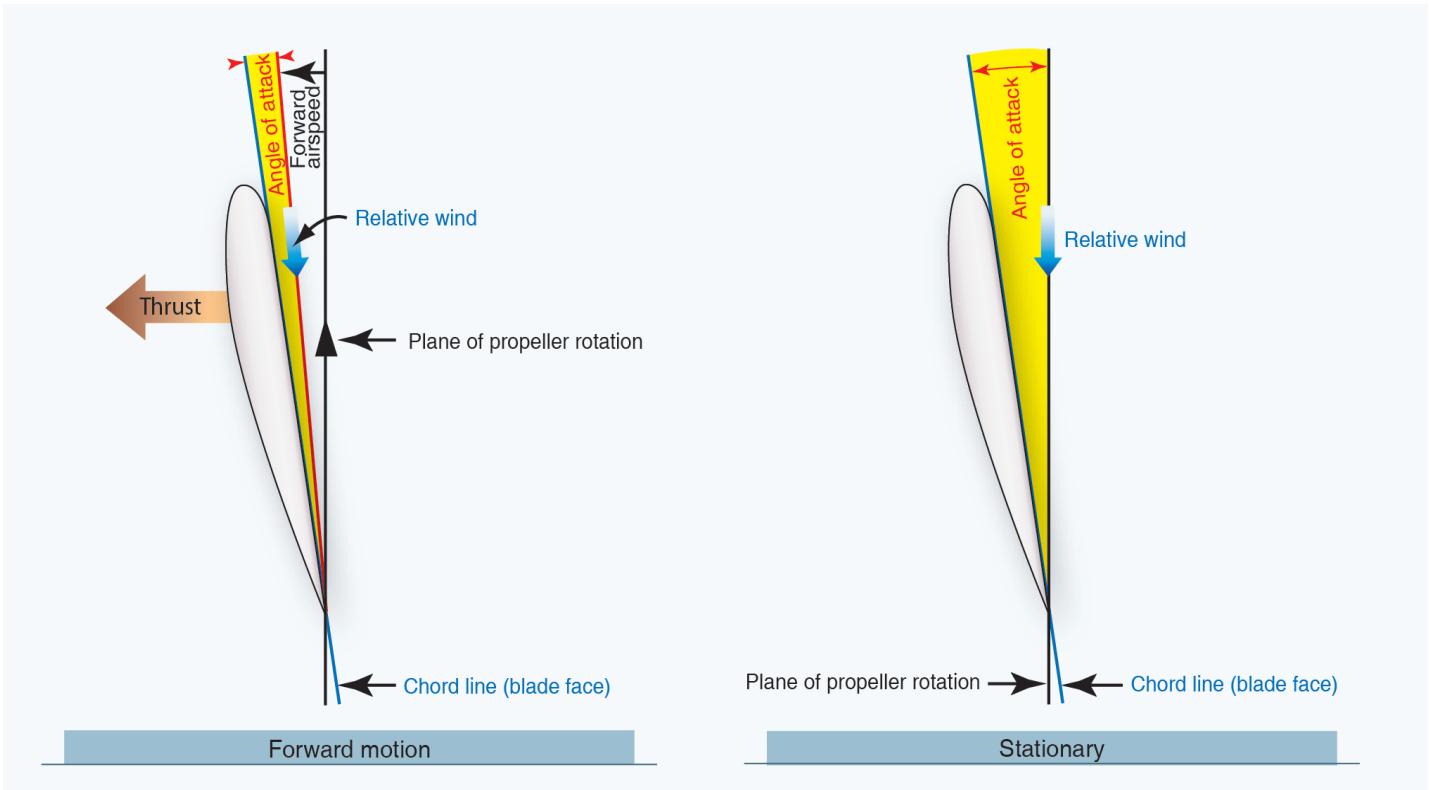
When an airplane engine runs at a constant governed speed, the torque (force) exerted by the engine at the propeller shaft equals the force resisting the moving blades. The pilot uses the propeller control to change engine rpm by adjusting the propeller blade pitch, which increases or decreases the air resistance on the rotating propeller. For example, pulling back on the propeller control moves the propeller blades to a higher pitch. This increases the air resistance exerted on the spinning propeller and puts an additional load on the engine, which causes it to slow down until the forces reach equilibrium. Advancing the propeller control reduces the propeller blade pitch. This reduces the resistance of the air against the propeller. In response, the engine rpm increases until the opposing forces balance. In order for this system to function, a constant-speed propeller governor needs the means to sense engine rpm and a means to control the propeller AOA. In most cases, the governor is geared to the engine crankshaft giving it a means to sense engine rpm. The "Blade Angle Control" section of this chapter discusses the ways a propeller governor adjusts propeller blade angle.

Other factors affect constant-speed propeller blade pitch. When an airplane is nosed up into a climb from level flight, the engine tends to slow down. Since the governor is sensitive to small changes in engine rpm, it decreases the blade angle just enough to keep the engine speed constant. If the airplane is nosed down into a dive, the governor increases the blade angle just enough to keep the engine speed constant. This allows the engine to maintain a constant rpm and power output. The pilot can also set engine power output by changing rpm at a constant manifold pressure; by changing the manifold pressure at a constant rpm; or by changing both rpm and manifold pressure. The constant-speed propeller makes it possible to obtain an infinite number of power settings.

### Takeoff, Climb, and Cruise

During takeoff, when the forward motion of the airplane is at a low speed and when maximum power and thrust are required, the constant-speed propeller sets up a low propeller blade pitch. The low blade angle keeps the blade angle of attack, with respect to the relative wind, small and efficient at the low speed. [Figure 12-7]

At the same time, low blade pitch allows the propeller to handle a smaller mass of air per revolution. This light propeller load allows the engine to turn at maximum rpm and develop maximum engine power. Although the mass of air per revolution is small, the number of rpm is high, and propeller thrust is maximized until brake release. Thrust is maximum at the beginning of the takeoff roll and then decreases as the airplane gains speed.



**Figure 12-7. Propeller blade angle.**

As the airspeed increases after lift-off, the load on the engine is lightened because of the small blade angle. The governor senses this and increases the blade angle slightly. Again, the higher blade angle, with the higher speed, keeps the blade AOA with respect to the relative wind small and efficient.

For climb after takeoff, the power output of the engine is reduced to climb power by decreasing the manifold pressure and increasing the blade angle to lower engine rpm. At the higher (climb) airspeed and the higher blade angle, the propeller is handling a greater mass of air per second at a lower slipstream velocity. This reduction in power is offset by the increase in propeller efficiency. The blade AOA is again kept small by the increase in the blade angle with an increase in airspeed.

At cruising altitude, when the airplane is in level flight, airspeed increases, and less power is required. Consequently, the pilot uses the throttle to reduce manifold pressure and uses the propeller control to reduce engine rpm. The higher airspeed and higher blade angle enable the propeller to handle a still greater mass of air per second at still smaller slipstream velocity. At normal cruising speeds, propeller efficiency is at or near maximum efficiency.

### Blade Angle Control

Once the rpm settings for the propeller are selected, the propeller governor automatically adjusts the blade angle to maintain the selected rpm. It does this by using oil pressure. Generally, the oil pressure used for pitch change comes directly from the engine lubricating system. When a governor is employed, engine oil is used and the oil pressure is usually boosted by a pump that is integrated with the governor. The higher pressure provides a quicker blade angle change. The rpm at which the propeller is to operate is adjusted in the governor head. The pilot changes this setting by changing the position of the governor rack through the flight deck propeller control.

On some constant-speed propellers, changes in pitch are obtained by the use of an inherent centrifugal twisting moment of the blades that tends to flatten the blades toward low pitch and oil pressure applied to a hydraulic piston connected to the propeller blades which moves them toward high pitch. Another type of constant-speed propeller uses counterweights attached to the blade shanks in the hub. Governor oil pressure and the blade twisting moment move the blades toward the low pitch position, and centrifugal force acting on the counterweights moves them (and the blades) toward the high pitch position. In the first case above, governor oil pressure moves the blades towards high pitch and in the second case, governor oil pressure and the blade twisting moment move the blades toward low pitch. A loss of governor oil pressure, therefore, affects each differently.

## Governing Range

The blade angle range for constant-speed propellers varies from about  $11.5^\circ$  to  $40^\circ$ . The higher the speed of the airplane, the greater the blade angle range. [Figure 12-8]

Aircraft Type	Design Speed (mph)	Blade Angle Range	Pitch	
			Low	High
Fixed gear	160	$11\frac{1}{2}^\circ$	$10\frac{1}{2}^\circ$	$22^\circ$
Retractable	180	$15^\circ$	$11^\circ$	$26^\circ$
Turbo retractable	225/240	$20^\circ$	$14^\circ$	$34^\circ$
Turbine retractable	250/300	$30^\circ$	$10^\circ$	$40^\circ$
Transport retractable	325	$40^\circ$	$10/15^\circ$	$50/55^\circ$

Figure 12-8. Blade angle range (values are approximate).

The range of possible blade angles between high and low blade angle pitch stops define the propeller's governing range. As long as the propeller's blades operate within the governing range and not against either pitch stop, a constant engine rpm is maintained. However, once the propeller blades reach their pitch-stop limit, the engine rpm increases or decreases with changes in airspeed and propeller load similar to a fixed-pitch propeller. For example, once a specific rpm is selected, if the airspeed decreases enough, the propeller blades reduce pitch in an attempt to maintain the selected rpm until they contact their low pitch stops. From that point, any further reduction in airspeed causes the engine rpm to decrease. Conversely, if the airspeed increases, the pitch angle of the propeller blades increase until the high pitch stop is reached. The engine rpm then begins to increase.

## Constant-Speed Propeller Operation

The engine is started with the propeller control in the low pitch/high rpm position. This position reduces the load or drag of the propeller and the result is easier starting and warm-up of the engine. During warm-up, the propeller blade changing mechanism is operated slowly and smoothly through a full cycle. This is done by moving the propeller control (with the manifold pressure set to produce about 1,600 rpm) to the high pitch/low rpm position, allowing the rpm to stabilize, and then moving the propeller control back to the low pitch takeoff position. This is done for two reasons: to determine whether the system is operating correctly and to circulate fresh warm oil through the propeller governor system. Remember the oil has been trapped in the propeller cylinder since the last time the engine was shut down. There is a certain amount of leakage from the propeller cylinder, and the oil tends to congeal, especially if the outside air temperature is low. Consequently, if the propeller is not exercised before takeoff, there is a possibility that the engine may over-speed on takeoff.

An airplane equipped with a constant-speed propeller has better takeoff performance than a similarly powered airplane equipped with a fixed-pitch propeller. This is because with a constant-speed propeller, an airplane can develop its maximum rated horsepower (red line on the tachometer) while motionless. An airplane with a fixed-pitch propeller, on the other hand, needs to accelerate down the runway to increase airspeed and aerodynamically unload the propeller so that rpm and horsepower can steadily build up to their maximum. With a constant-speed propeller, the tachometer reading should come up to within 40 rpm of the red line as soon as full power is applied and remain there for the entire takeoff. Excessive manifold pressure raises the cylinder combustion pressures, resulting in high stresses within the engine. Excessive pressure also produces high-engine temperatures. A combination of high manifold pressure and low rpm can induce damaging detonation. In order to avoid these situations, the following sequence should be followed when making power changes.

- When increasing power, increase the rpm first and then the manifold pressure
- When decreasing power, decrease the manifold pressure first and then decrease the rpm

The cruise power charts in the AFM/POH should be consulted when selecting cruise power settings. Whatever the combinations of rpm and manifold pressure listed in these charts—they have been flight tested and approved by engineers for the respective airframe and engine manufacturer. Therefore, if there are power settings, such as 2,100 rpm and 24 inches manifold pressure in the power chart, they are approved for use. With a constant-speed propeller, a power descent can be made without over-speeding the engine. The system compensates for the increased airspeed of the descent by increasing the propeller blade angles. If the descent is too rapid or is being made from a high altitude, the maximum blade angle limit of the blades is not sufficient to hold the rpm constant. When this occurs, the rpm is responsive to any change in throttle setting.

Although the governor responds quickly to any change in throttle setting, a sudden and large increase in the throttle setting causes a momentary over-speeding of the engine until the blades become adjusted to absorb the increased power. If an emergency demanding full power should arise during approach, the sudden advancing of the throttle causes momentary over-speeding of the engine beyond the rpm for which the governor is adjusted.

Some important points to remember concerning constant speed propeller operation are:

- The red line on the tachometer not only indicates maximum allowable rpm; it also indicates the rpm required to obtain the engine's rated horsepower.
- A momentary propeller overs-speed may occur when the throttle is advanced rapidly for takeoff. This is usually not serious if the rated rpm is not exceeded by 10 percent for more than 3 seconds.
- The green arc on the tachometer indicates the normal operating range. When developing power in this range, the engine drives the propeller. Below the green arc, however, it is usually the windmilling propeller that powers the engine. Prolonged operation below the green arc can be detrimental to the engine. On takeoffs from low elevation airports, the manifold pressure in inches of mercury may exceed the rpm. This is normal in most cases, but the pilot should always consult the AFM/POH for limitations.
- All power changes should be made smoothly and slowly to avoid over-boosting and/or over-speeding.

## Turbocharging

The turbocharged engine allows the pilot to maintain sufficient cruise power at high altitudes where there is less drag, which means faster true airspeeds and increased range with fuel economy. At the same time, the powerplant has flexibility and can be flown at a low altitude without the increased fuel consumption of a turbine engine. When attached to the standard powerplant, the turbocharger does not take any horsepower from the engine to operate; it is relatively simple mechanically, and some models can pressurize the cabin as well.

The turbocharger is an exhaust-driven device that raises the pressure and density of the induction air delivered to the engine. It consists of two separate components: a compressor and a turbine connected by a common shaft. The compressor supplies pressurized air to the engine for high-altitude operation. The compressor and its housing are between the ambient air intake and the induction air manifold. The turbine and its housing are part of the exhaust system and utilize the flow of exhaust gases to drive the compressor. [Figure 12-9]

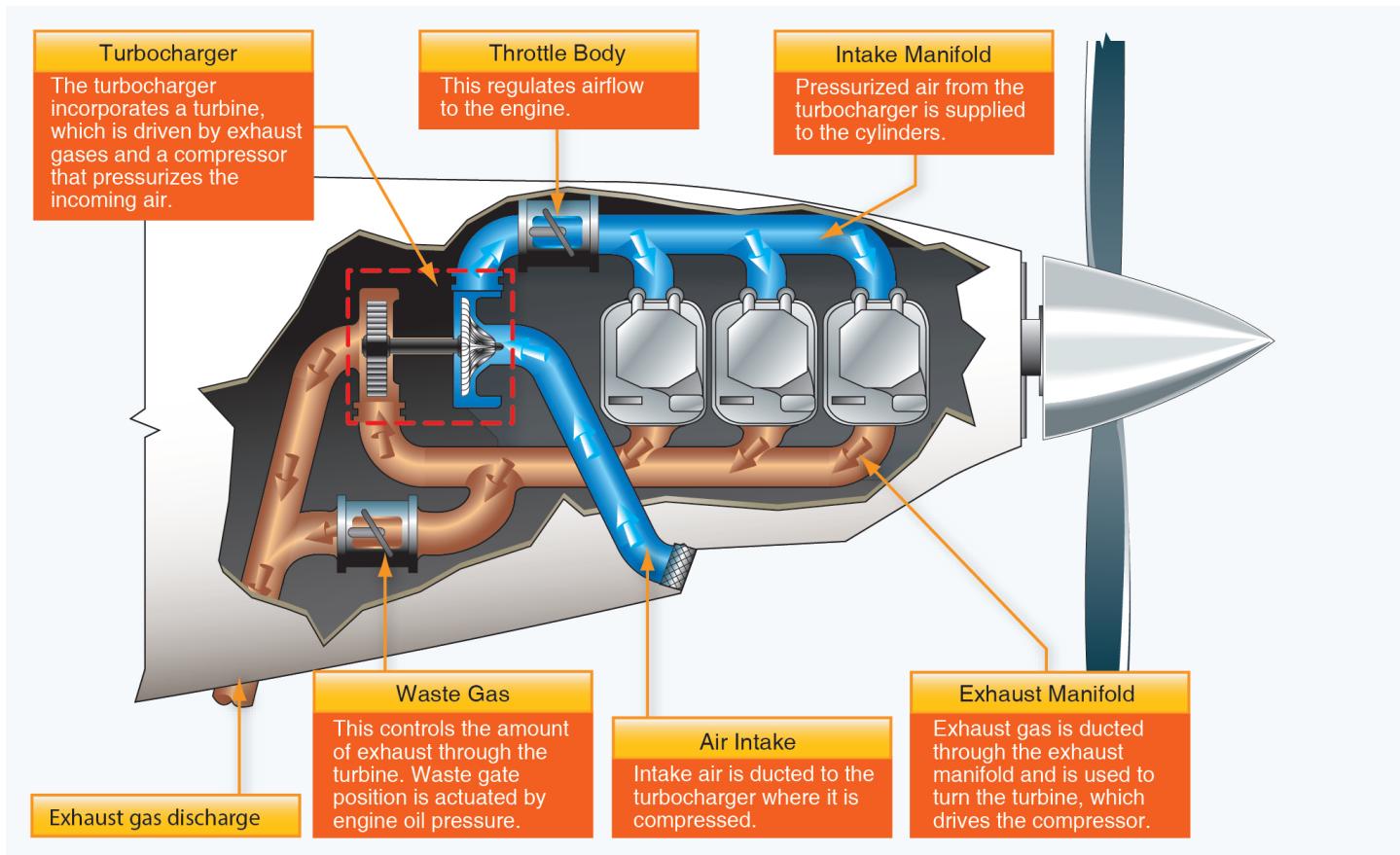


Figure 12-9. Turbocharging system.

The turbine has the capability of producing manifold pressure in excess of the maximum allowable for the particular engine. In order not to exceed the maximum allowable manifold pressure, a bypass or waste gate is used so that some of the exhaust is diverted overboard before it passes through the turbine.

The position of the waste gate regulates the output of the turbine and therefore, the compressed air available to the engine. When the waste gate is closed, all of the exhaust gases pass through and drive the turbine. As the waste gate opens, some of the exhaust gases are routed around the turbine through the exhaust bypass and overboard through the exhaust pipe.

The waste gate actuator is a spring-loaded piston operated by engine oil pressure. The actuator, which adjusts the waste gate position, is connected to the waste gate by a mechanical linkage.

The control center of the turbocharger system is the pressure controller. This device simplifies turbocharging to one control: the throttle. Once the desired manifold pressure is set, virtually no throttle adjustment is required with changes in altitude. The controller senses compressor discharge requirements for various altitudes and controls the oil pressure to the waste gate actuator, which adjusts the waste gate accordingly. Thus the turbocharger will maintain the manifold pressure called for by the throttle setting.

### **Ground Boosting Versus Altitude Turbocharging**

Altitude turbocharging (sometimes called “normalizing”) is accomplished by using a turbocharger that maintains maximum allowable sea level manifold pressure (normally 29–30 "Hg) up to a certain altitude. This altitude is specified by the airplane manufacturer and is referred to as the airplane’s critical altitude. Above the critical altitude, the manifold pressure decreases as additional altitude is gained. Ground boosting, on the other hand, is an application of turbocharging where more than the standard 29 inches of manifold pressure is used in flight. In various airplanes using ground boosting, takeoff manifold pressures may go as high as 45 "Hg.

Although a sea-level manifold pressure setting and maximum rpm can be maintained up to the critical altitude, the engine may not be developing sea-level power. Because the turbocharged induction air is heated by compression, lower induction air density causes a loss of engine power. Maintaining the equivalent horsepower output requires a somewhat higher manifold pressure at a given altitude than if the induction air were not compressed and heated by turbocharging. If, on the other hand, the system incorporates an automatic density controller, which automatically positions the waste gate so as to maintain constant air density to the engine, a near equivalent to sea-level horsepower output results.

### **Operating Characteristics**

First and foremost, all movements of the power controls on turbocharged engines should be slow and smooth. Aggressive or abrupt throttle movements increase the possibility of over-boosting. Carefully monitor engine indications when making power changes.

When the waste gate is open, the turbocharged engine reacts the same as a normally aspirated engine when the rpm is varied. That is, when the rpm is increased, the manifold pressure decreases slightly. When the engine rpm is decreased, the manifold pressure increases slightly. However, when the waste gate is closed, manifold pressure variation with engine rpm is just the opposite of the normally aspirated engine. An increase in engine rpm results in an increase in manifold pressure, and a decrease in engine rpm results in a decrease in manifold pressure.

Above the critical altitude, where the waste gate is closed, any change in airspeed results in a corresponding change in manifold pressure. This is true because the increase in ram air pressure with an increase in airspeed is magnified by the compressor resulting in an increase in manifold pressure. The increase in manifold pressure creates a higher mass flow through the engine, causing higher turbine speeds and thus further increasing manifold pressure.

When running at high altitudes, aviation gasoline tends to vaporize prior to reaching the cylinder. If this occurs in the portion of the fuel system between the fuel tank and the engine-driven fuel pump, an auxiliary positive pressure pump may be needed in the tank. Since engine-driven pumps pull fuel, they are easily vapor locked. A boost pump provides positive pressure, which pushes the fuel and reduces the tendency to vaporize.

### **Heat Management**

Turbocharged engines should be thoughtfully and carefully operated with continuous monitoring of pressures and temperatures. There are two temperatures that are especially important—turbine inlet temperature (TIT) or, in some installations, exhaust gas temperature (EGT) and cylinder head temperature. TIT or EGT limits are set to protect the elements in the hot section of the turbocharger, while cylinder head temperature limits protect the engine’s internal parts.

Due to the heat of compression of the induction air, a turbocharged engine runs at higher operating temperatures than a non-turbocharged engine. Because turbocharged engines operate at high altitudes, their environment is less efficient for cooling. At altitude, the air is less dense and, therefore, cools less efficiently. Also, the less dense air causes the compressor to work harder. Compressor turbine speeds can reach 80,000–100,000 rpm, adding to the overall engine operating temperatures. Turbocharged engines are also operated at higher power settings a greater portion of the time.

High heat is detrimental to piston engine operation. Its cumulative effects can lead to piston, ring, and cylinder head failure and place thermal stress on other operating components. Excessive cylinder head temperature can lead to detonation, which in turn can cause catastrophic engine failure. Turbocharged engines are especially heat sensitive. The key to turbocharger operation is effective heat management.

Monitor the condition of a turbocharged engine with manifold pressure gauge, tachometer, exhaust gas temperature/turbine inlet temperature gauge, and cylinder head temperature gauge. Manage the “heat system” with the throttle, propeller rpm, mixture, and cowl flaps. At any given cruise power, the mixture is the most influential control over the exhaust gas/TIT. The throttle regulates total fuel flow, but the mixture governs the fuel-to-air ratio. The mixture, therefore, controls temperature.

Exceeding temperature limits in an after-takeoff climb is usually not a problem since a full rich mixture cools with excess fuel. At cruise, power is normally reduced and mixture adjusted accordingly. Under cruise conditions, monitor temperature limits closely because that is when the temperatures are most likely to reach the maximum, even though the engine is producing less power. Overheating in an en route climb, however, may require fully open cowl flaps and a higher airspeed.

Since turbocharged engines operate hotter at altitude than normally aspirated engines, they are more prone to damage from cooling stress. Gradual reductions in power and careful monitoring of temperatures are essential in the descent phase. Extending the landing gear during the descent may help control the airspeed while maintaining a higher engine power setting. This allows the pilot to reduce power in small increments which allows the engine to cool slowly. It may also be necessary to lean the mixture slightly to eliminate roughness at the lower power settings.

## **Turbocharger Failure**

Because of the high temperatures and pressures produced in the turbine exhaust system, any malfunction of the turbocharger should be treated with extreme caution. In all cases of turbocharger operation, the manufacturer’s recommended procedures should be followed. This is especially so in the case of turbocharger malfunction. However, in those instances where the manufacturer’s procedures do not adequately describe the actions to be taken in the event of a turbocharger failure, the following procedures should be used.

### ***Over-Boost Condition***

If an excessive rise in manifold pressure occurs during normal advancement of the throttle (possibly owing to faulty operation of the waste gate):

- Immediately retard the throttle smoothly to limit the manifold pressure below the maximum for the rpm and mixture setting.
- Operate the engine in such a manner as to avoid a further over-boost condition.

### ***Low Manifold Pressure***

Although this condition may be caused by a minor fault, it is quite possible that a serious exhaust leak has occurred creating a potentially hazardous situation:

- Shut down the engine in accordance with the recommended engine failure procedures, unless a greater emergency exists that warrants continued engine operation.
- If continuing to operate the engine, use the lowest power setting demanded by the situation and land as soon as practicable.

It is very important to ensure that corrective maintenance is undertaken following any turbocharger malfunction.

## **Retractable Landing Gear**

The primary benefits of being able to retract the landing gear are increased climb performance and higher cruise airspeeds due to a decrease in drag after gear retraction. Retractable landing gear systems may be operated either hydraulically or electrically or may employ a combination of the two systems. Warning indicators are provided in the flight deck to show the pilot when the wheels are down and locked and when they are up and locked or if they are in intermediate positions. Systems for emergency operation are also provided. Due to the complexity of a retractable landing gear system, the pilot should adhere to specific operating procedures and should not exceed any operating limitations.

### **Landing Gear Systems**

An electrical landing gear retraction system utilizes an electrically-driven motor for gear operation. The system is basically an electrically-driven jack for raising and lowering the gear. When a switch in the flight deck is moved to the UP position, the electric motor operates. Through a system of shafts, gears, adapters, an actuator screw, and a torque tube, a force is transmitted to the drag strut linkages. Thus, the gear retracts and locks. Struts are also activated that open and close the gear doors. If the switch is moved to the DOWN position, the motor reverses and the gear moves down and locks. Once activated, the gear motor continues to operate until an up or down limit switch on the motor's gearbox is tripped.

A hydraulic landing gear retraction system utilizes pressurized hydraulic fluid to actuate linkages to raise and lower the gear. When a switch in the flight deck is moved to the UP position, hydraulic fluid is directed into the gear up line. The fluid flows through sequenced valves and downlocks to the gear actuating cylinders. A similar process occurs during gear extension. The pump that pressurizes the fluid in the system can be either engine-driven or electrically-powered. If an electrically-powered pump is used to pressurize the fluid, the system is referred to as an electrohydraulic system. The system also incorporates a hydraulic reservoir to contain excess fluid and to provide a means of determining system fluid level.

Regardless of its power source, the hydraulic pump is designed to operate within a specific range. When a sensor detects excessive pressure, a relief valve within the pump opens, and hydraulic pressure is routed back to the reservoir. Another type of relief valve prevents excessive pressure that may result from thermal expansion. Hydraulic pressure is also regulated by limit switches. Each gear has two limits switches—one dedicated to extension and one dedicated to retraction. These switches de-energize the hydraulic pump after the landing gear has completed its gear cycle. In the event of limit switch failure, a backup pressure relief valve activates to relieve excess system pressure.

### **Controls and Position Indicators**

Landing gear position is controlled by a switch on the flight deck panel. In most airplanes, the gear switch is shaped like a wheel in order to facilitate positive identification and to differentiate it from other flight deck controls.

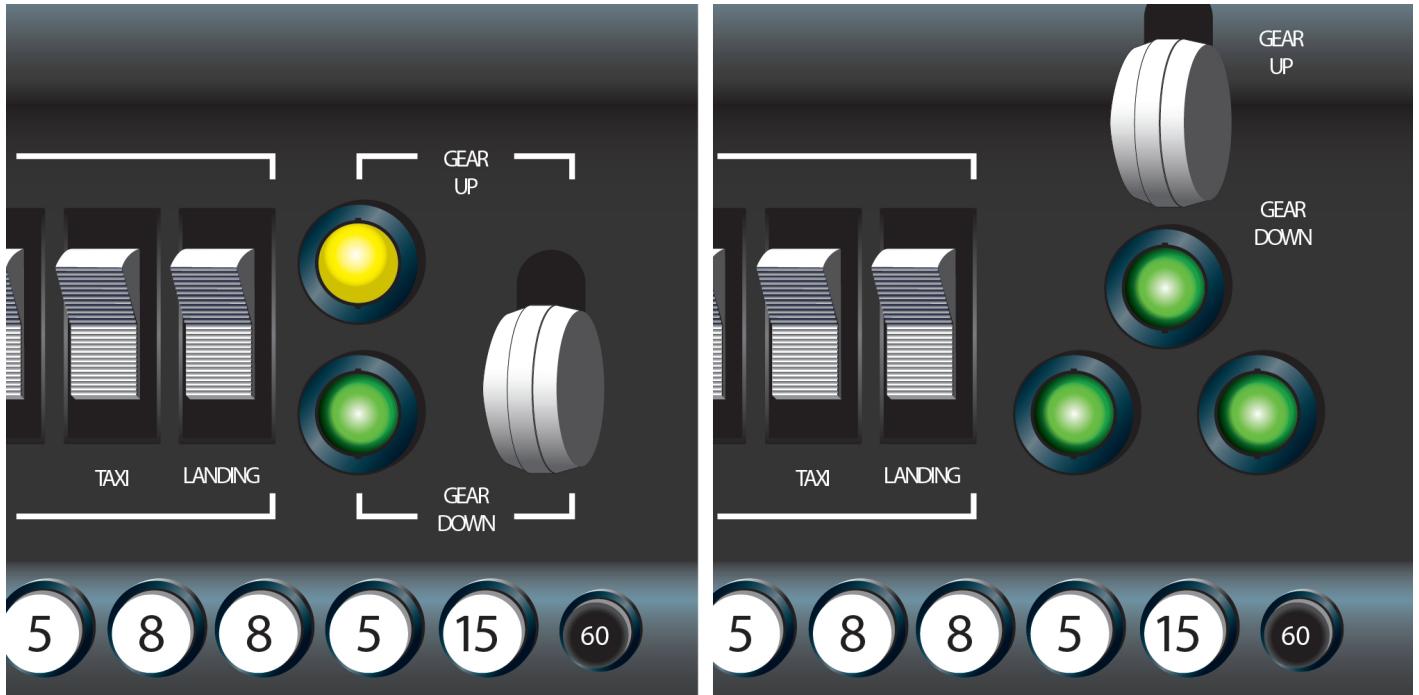
Landing gear position indicators vary with different make and model airplanes. Some types of landing gear position indicators utilize a group of lights. One type consists of one green light to indicate when the landing gear is down and an amber light to indicate when the gear is up. [Figure 12-10] Another type consists of a group of three green lights, which illuminate when the landing gear is down and locked. [Figure 12-10] Still other systems incorporate a red or amber light to indicate when the gear is in transit or unsafe for landing. [Figure 12-11] When the lights use a “press to test” feature, the bulbs are often interchangeable. Integrated electronic displays may also indicate gear position on a portion of the screen without any dedicated lights.

Other types of landing gear position indicators consist of tab-type indicators with markings “UP” to indicate the gear is up and locked, a display of red and white diagonal stripes to show when the gear is unlocked, or a silhouette of each gear to indicate when it locks in the DOWN position.

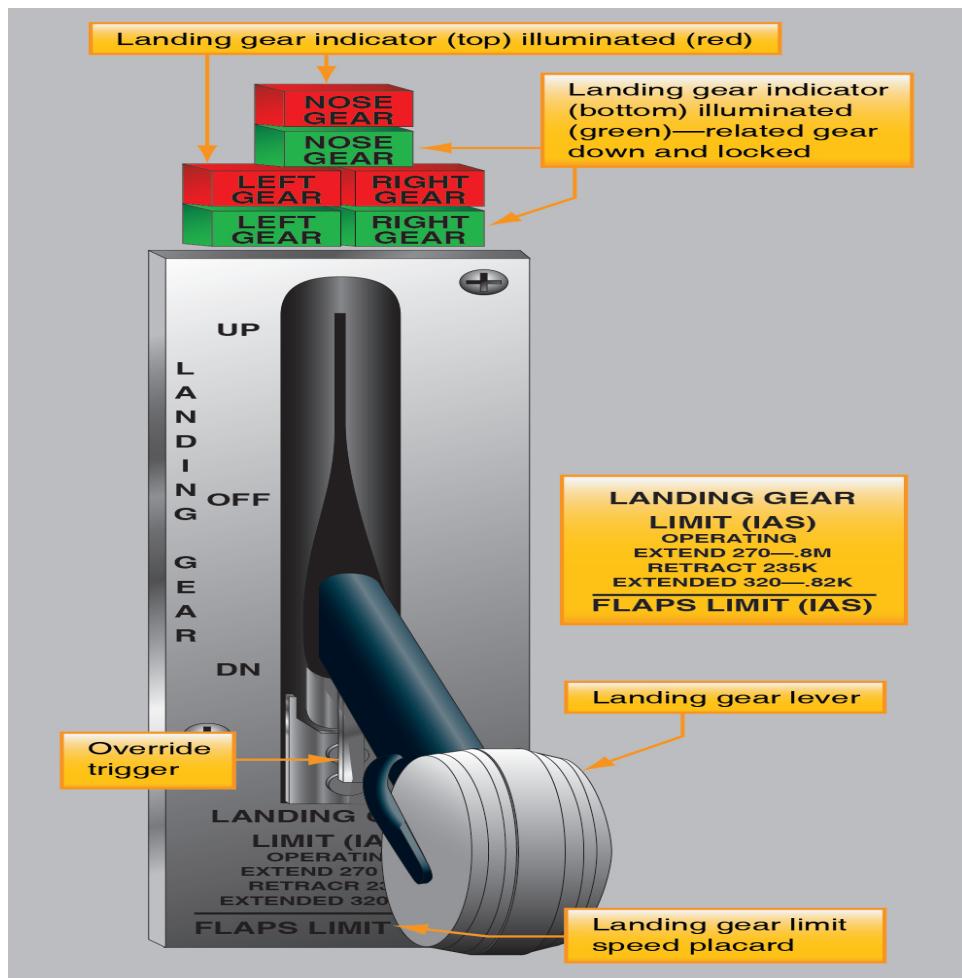
### **Landing Gear Safety Devices**

Most airplanes with a retractable landing gear have a gear warning horn that sounds when the airplane is configured for landing and the landing gear is not down and locked. Normally, the horn is linked to the throttle or flap position and/or the airspeed indicator so that when the airplane is below a certain airspeed, configuration, or power setting with the gear retracted, the warning horn sounds.

Accidental retraction of a landing gear may be prevented by such devices as mechanical downlocks, safety switches, and ground locks. Mechanical downlocks are built-in components of a gear retraction system and are operated automatically by the gear retraction system. To prevent accidental operation of the downlocks and inadvertent landing gear retraction while the airplane is on the ground, electrically-operated safety switches are installed.

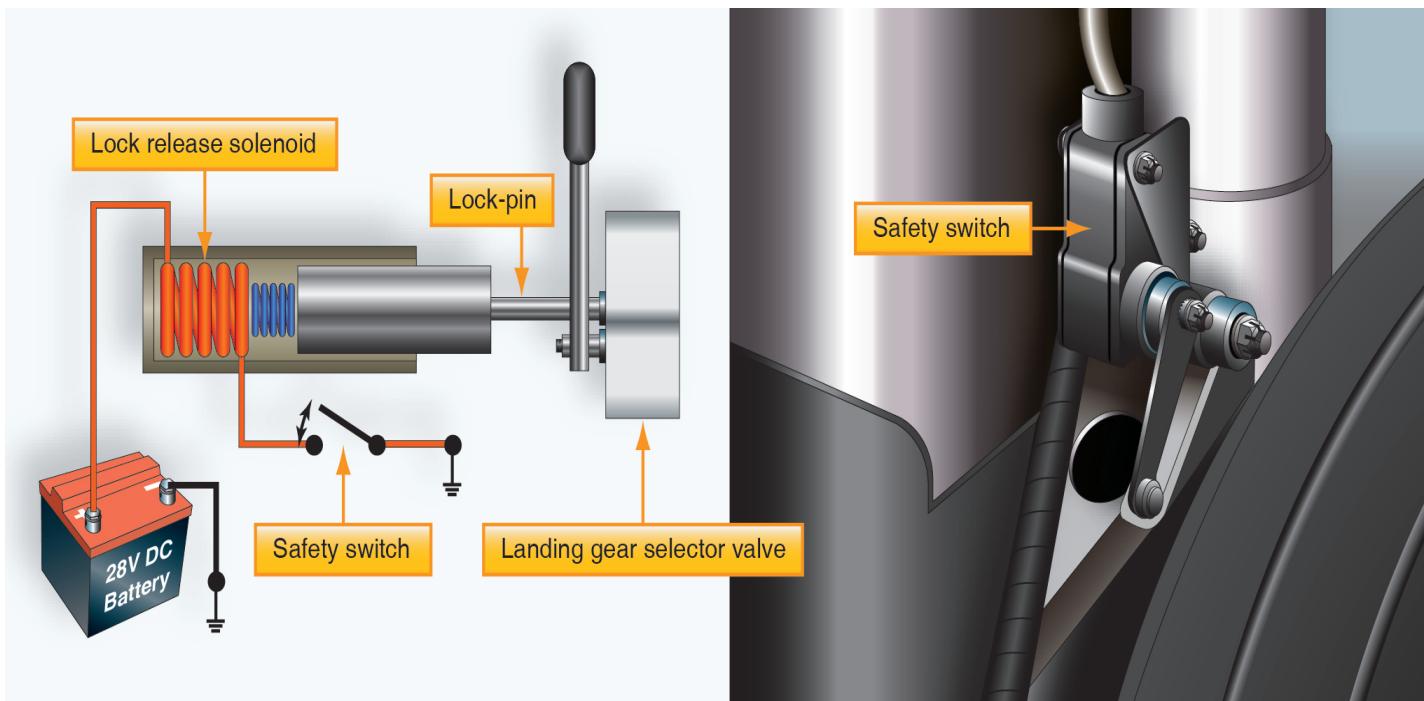


**Figure 12-10.** Typical landing gear switch with combination amber and green. Another combination has a three light indicator.



**Figure 12-11.** Landing gear handles and single and multiple light indicator.

A landing gear safety switch, sometimes referred to as a squat switch, is usually mounted in a bracket on one of the main gear shock struts. [Figure 12-12] When the strut is compressed by the weight of the airplane, the switch opens the electrical circuit to the motor or mechanism that powers retraction. In this way, if the landing gear switch in the flight deck is placed in the RETRACT position when weight is on the gear, the gear remains extended, and the warning horn may sound as an alert to the unsafe condition. Once the weight is off the gear, however, such as on takeoff, the safety switch releases and the gear retracts.



**Figure 12-12. Landing gear safety switch.**

Many airplanes are equipped with removable safety devices to prevent collapse of the gear when the airplane is on the ground. These devices are called ground locks. One common type is a pin installed in aligned holes drilled in two or more units of the landing gear support structure. Another type is a spring-loaded clip designed to fit around and hold two or more units of the support structure together. All types of ground locks usually have red streamers permanently attached to them to readily indicate whether or not they are installed.

### **Emergency Gear Extension Systems**

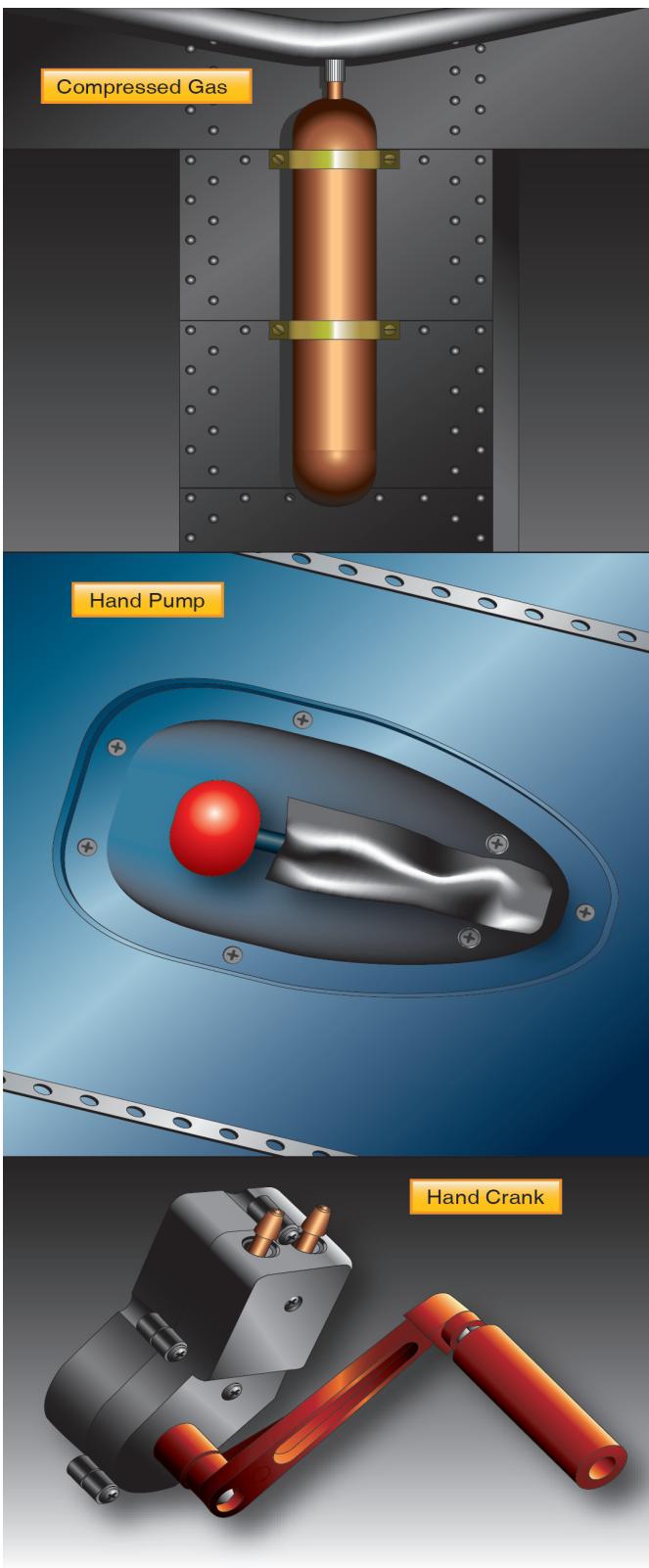
The emergency gear extension system lowers the landing gear if the main power system fails. Some airplanes have an emergency release handle in the flight deck, which is connected through a mechanical linkage to the gear uplocks. When the handle is operated, it releases the uplocks and allows the gear to free fall or extend under their own weight. [Figure 12-13]

On other airplanes, release of the uplock is accomplished using compressed gas, which is directed to uplock release cylinders. In some airplanes, design configurations make emergency extension of the landing gear by gravity and air loads alone impossible or impractical. In these airplanes, provisions are included for forceful gear extension in an emergency. Some installations are designed so that either hydraulic fluid or compressed gas provides the necessary pressure, while others use a manual system, such as a hand crank for emergency gear extension. [Figure 12-14] Hydraulic pressure for emergency operation of the landing gear may be provided by an auxiliary hand pump, an accumulator, or an electrically-powered hydraulic pump depending on the design of the airplane.

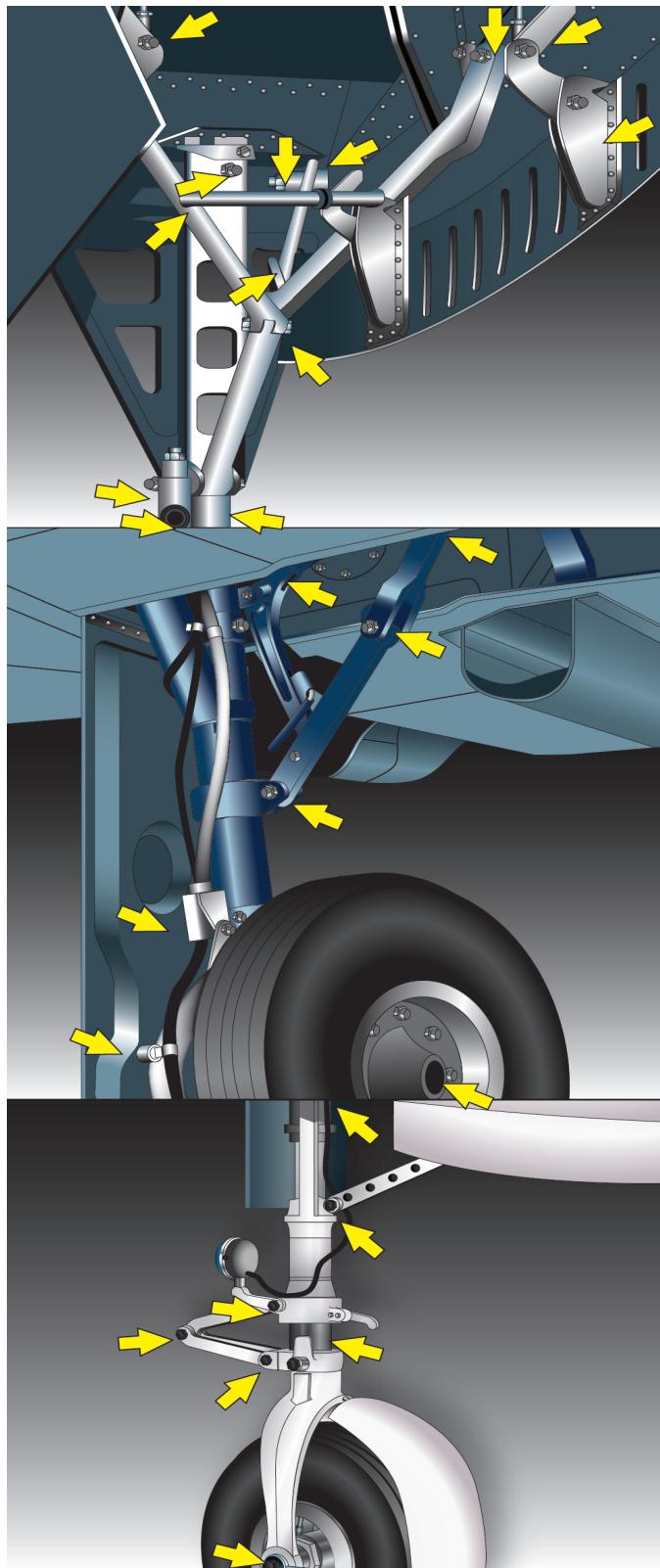
### **Operational Procedures**

#### **Preflight**

Because of their complexity, retractable landing gear demands a close inspection prior to every flight. The inspection should begin inside the flight deck. First, make certain that the landing gear selector switch is in the GEAR DOWN position. Then, turn on the battery master switch and ensure that the landing gear position indicators show that the gear is down and locked.



**Figure 12-13.** Typical emergency gear extension systems.



**Figure 12-14.** Retractable landing gear inspection checkpoints.

External inspection of the landing gear consists of checking individual system components. [Figure 12-14] The landing gear, wheel well, and adjacent areas should be clean and free of mud and debris. Dirty switches and valves may cause false safe light indications or interrupt the extension cycle before the landing gear is completely down and locked. The wheel wells should be clear of any obstructions, as foreign objects may damage the gear or interfere with its operation. Bent gear doors may be an indication of possible problems with normal gear operation.

Ensure shock struts are properly inflated and that the pistons are clean. Check main gear and nose gear uplock and downlock mechanisms for general condition. Power sources and retracting mechanisms are checked for general condition, obvious defects, and security of attachment. Check hydraulic lines for signs of chafing and leakage at attach points. Warning system micro switches (squat switches) are checked for cleanliness and security of attachment. Actuating cylinders, sprockets, universal joints, drive gears, linkages, and any other accessible components are checked for condition and obvious defects. The airplane structure to which the landing gear is attached is checked for distortion, cracks, and general condition. All bolts and rivets should be intact and secure.

### **Takeoff and Climb**

Normally, the landing gear is retracted after lift-off when the airplane has reached an altitude where, in the event of an engine failure or other emergency requiring an aborted takeoff, the airplane could no longer be landed on the runway. This procedure, however, may not apply to all situations. Preplan landing gear retraction taking into account the following:

- Length of the runway
- Climb gradient
- Obstacle clearance requirements
- The characteristics of the terrain beyond the departure end of the runway
- The climb characteristics of the particular airplane

For example, in some situations it may be preferable, in the event of an engine failure, to make an off airport forced landing with the gear extended in order to take advantage of the energy absorbing qualities of the terrain (see Chapter 18, "Emergency Procedures"). In which case, a delay in retracting the landing gear after takeoff from a short runway may be warranted. In other situations, obstacles in the climb path may warrant a timely gear retraction after takeoff. Also, in some airplanes the initial climb pitch attitude is such that any view of the runway remaining is blocked, making an assessment of the feasibility of touching down on the remaining runway difficult.

Avoid premature landing gear retraction and do not retract the landing gear until a positive rate of climb is indicated on the flight instruments. If the airplane has not attained a positive rate of climb, there is always the chance it may settle back onto the runway with the gear retracted. This is especially so in cases of premature lift-off. Remember that leaning forward to reach the landing gear selector may result in inadvertent forward pressure on the yoke, which causes the airplane to descend.

As the landing gear retracts, airspeed increases and the airplane's pitch attitude may change. The gear may take several seconds to retract. Gear retraction and locking (and gear extension and locking) is accompanied by sound and feel that are unique to the specific make and model airplane. Become familiar with the sound and feel of normal gear retraction so that any abnormal gear operation can be readily recognized. Abnormal landing gear retraction is most often a clear sign that the gear extension cycle will also be abnormal.

### **Approach and Landing**

The operating loads placed on the landing gear at higher airspeeds may cause structural damage due to the forces of the airstream. Limiting speeds, therefore, are established for gear operation to protect the gear components from becoming overstressed during flight. These speeds may not be found on the airspeed indicator. They are published in the AFM/POH for the particular airplane and are usually listed on placards in the flight deck. [Figure 12-15] The maximum landing extended speed ( $V_{LE}$ ) is the maximum speed at which the airplane can be flown with the landing gear extended. The maximum landing gear operating speed ( $V_{LO}$ ) is the maximum speed at which the landing gear may be operated through its cycle.



**Figure 12-15.** Placarded gear speeds in the flight deck.

The landing gear is extended by placing the gear selector switch in the GEAR DOWN position. As the landing gear extends, the airspeed decreases and the pitch attitude may change. During the several seconds it takes for the gear to extend, be attentive to any abnormal sounds or feel. Confirm that the landing gear has extended and locked by the normal sound and feel of the system operation, as well as by the gear position indicators in the flight deck. Unless the landing gear has been previously extended to aid in a descent to traffic pattern altitude, the landing gear should be extended by the time the airplane reaches a point on the downwind leg that is opposite the point of intended landing. Establish a standard procedure consisting of a specific position on the downwind leg at which to lower the landing gear. Strict adherence to this procedure aids in avoiding unintentional gear up landings.

Operation of an airplane equipped with a retractable landing gear requires the deliberate, careful, and continued use of an appropriate checklist. When on the downwind leg, make it a habit to complete the before-landing checklist for that airplane. This accomplishes two purposes—it ensures that action has been taken to lower the gear and establishes awareness so that the gear down indicators can be rechecked prior to landing.

Unless good operating practices dictate otherwise, the landing roll should be completed and the airplane should be clear of the runway before any levers or switches are operated. This technique greatly reduces the chance of inadvertently retracting the landing gear while on the ground. Wait until after rollout and clearing the runway to focus attention on the after-landing checklist. This practice allows for positive identification of the proper controls.

When transitioning to retractable gear airplanes, it is important to consider some frequent pilot errors. These include pilots that have:

- Neglected to extend landing gear
- Inadvertently retracted landing gear
- Activated gear but failed to check gear position
- Misused emergency gear system
- Retracted gear prematurely on takeoff
- Extended gear too late

These mistakes are not only committed by pilots who have just transitioned to complex aircraft, but also by pilots who have developed a sense of complacency over time. In order to minimize the chances of a landing gear-related mishap:

- Use an appropriate checklist. (A condensed checklist mounted in view is a reminder for its use and easy reference can be especially helpful.)
- Be familiar with, and periodically review, the landing gear emergency extension procedures for the particular airplane.
- Be familiar with the landing gear warning horn and warning light systems for the particular airplane. Use the horn system to cross-check the warning light system when an unsafe condition is noted.
- Review the procedure for replacing light bulbs in the landing gear warning light displays for the particular airplane, if applicable, so that you can properly replace a bulb to determine if the bulb(s) in the display is good. If bulbs are replaceable, check to see if spare bulbs are available in the airplane spare bulb supply as part of the preflight inspection.
- Be familiar with and aware of the sounds and feel of a properly operating landing gear system.

## Transition Training

Transition to a complex airplane or a high-performance airplane should be accomplished through a structured course of training administered by a competent and qualified flight instructor. The training should be accomplished in accordance with a ground and flight training syllabus. [Figure 12-16]

This sample syllabus for transition training is an example. The arrangement of the subject matter may be changed and the emphasis shifted to fit the qualifications of the transitioning pilot, the airplane involved, and the circumstances of the training situation. The goal is to ensure proficiency standards are achieved. These standards are contained in the Airman Certification Standards for the certificate that the transitioning pilot holds or is working toward.

Ground Instruction	Flight Instruction
One hour	One hour
1. Operations sections of flight manual	1. Flight training maneuvers
2. Line inspection	2. Takeoffs, landings and go-arounds
3. Flight deck familiarization	
One hour	One hour
1. Aircraft loading, limitations and servicing	1. Emergency operations
2. Instruments, radio and special equipment	2. Control by reference to instruments
3. Aircraft systems	3. Use of radio and autopilot
One hour	One hour
1. Performance section of flight manual	1. Short and soft-field takeoffs and landings
2. Cruise control	2. Maximum performance operations
3. Review	

**Figure 12-16.** Sample transition training syllabus.

The training times indicated in the syllabus are for illustration purposes. Actual times should be based on the capabilities of the pilot. The time periods may be minimal for pilots with higher qualifications or increased for pilots who do not meet certification requirements or have had little recent flight experience.

## Chapter Summary

Flying a complex or high-performance airplane requires a pilot to further divide his or her attention during the most critical phases of flight: takeoff and landing. The knowledge, judgment, and piloting skills required to fly these airplanes needs to be developed. It is essential that adequate training is received to ensure a complete understanding of the systems, their operation (both normal and emergency), and operating limitations.