Chapter 11

Transition to Complex Airplanes

HIGH PERFORMANCE AND COMPLEX AIRPLANES

Transition to a complex airplane, or a high performance airplane, can be demanding for most pilots without previous experience. Increased performance and increased complexity both 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.

A complex airplane is defined as an airplane equipped with a retractable landing gear, wing flaps, and a controllable-pitch propeller. For a seaplane to be considered complex, it is required to have wing flaps and a controllable-pitch propeller. A high performance airplane is defined as an airplane with an engine of more than 200 horsepower.

WING FLAPS

Airplanes can be designed to fly fast or slow. High speed requires thin, moderately **cambered** airfoils with a small wing area, whereas the high lift needed for low speeds is obtained with thicker highly cambered airfoils with a larger wing area. [Figure 11-1] Many attempts have been made to compromise this conflicting requirement of high cruise and slow landing speeds.

Since an airfoil cannot have two different cambers at the same time, one of two things must be done. 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. 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 since deflection adds aft camber. Flap deflection does not increase the critical (stall) angle of attack, and in some cases flap deflection actually decreases the critical angle of attack.

Deflection of trailing edge control surfaces, such as the aileron, alters both lift and drag. With aileron deflection, there is asymmetrical lift (rolling moment) and drag (adverse yaw). Wing flaps differ in that deflection acts symmetrically on the airplane. There is no roll or yaw effect, and pitch changes depend on the airplane design.

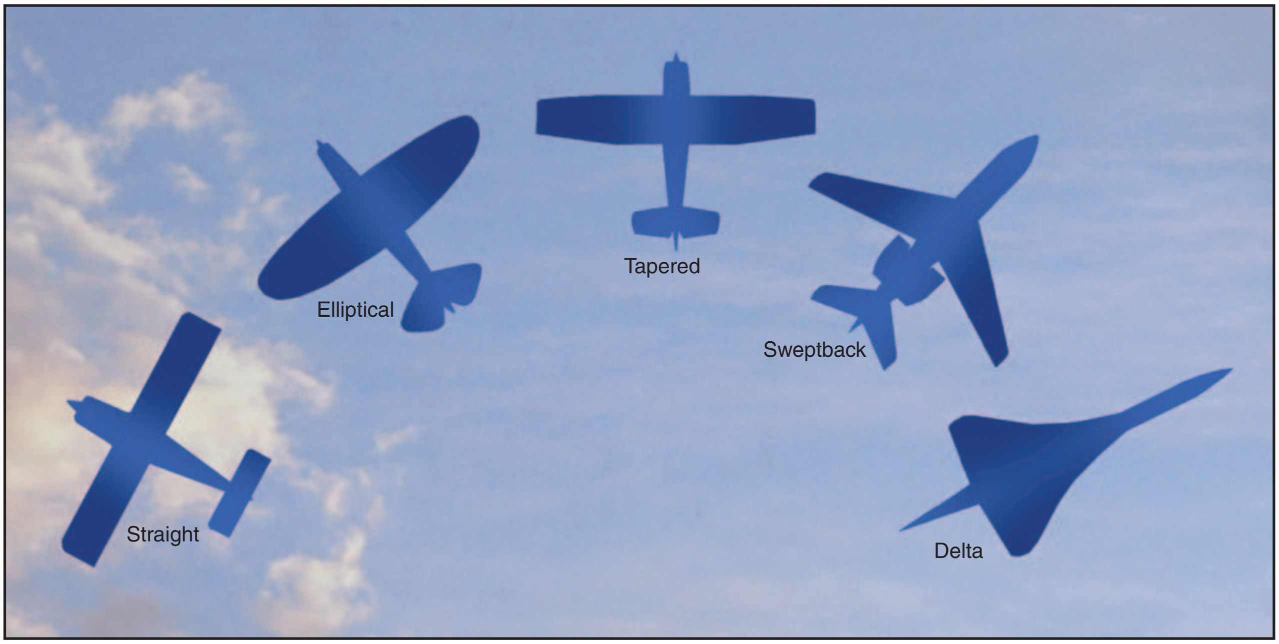


Figure 11-1. Airfoil types.

Pitch behavior depends on flap type, wing position, and horizontal tail location. The increased camber from flap deflection produces lift primarily on the rear portion of the wing. This produces a nosedown pitching moment; however, the change in tail load from the downwash deflected by the flaps over the horizontal tail has a significant influence on the pitching moment. Consequently, pitch behavior depends on the design features of the particular airplane.

Flap deflection of up to 15° primarily produces lift with minimal drag. The tendency to balloon up with initial flap deflection is because of lift increase, but the nosedown pitching moment tends to offset the balloon. Deflection beyond 15° 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° produces a significant noseup pitching moment in most high-wing airplanes because the resulting downwash increases 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 11-2]

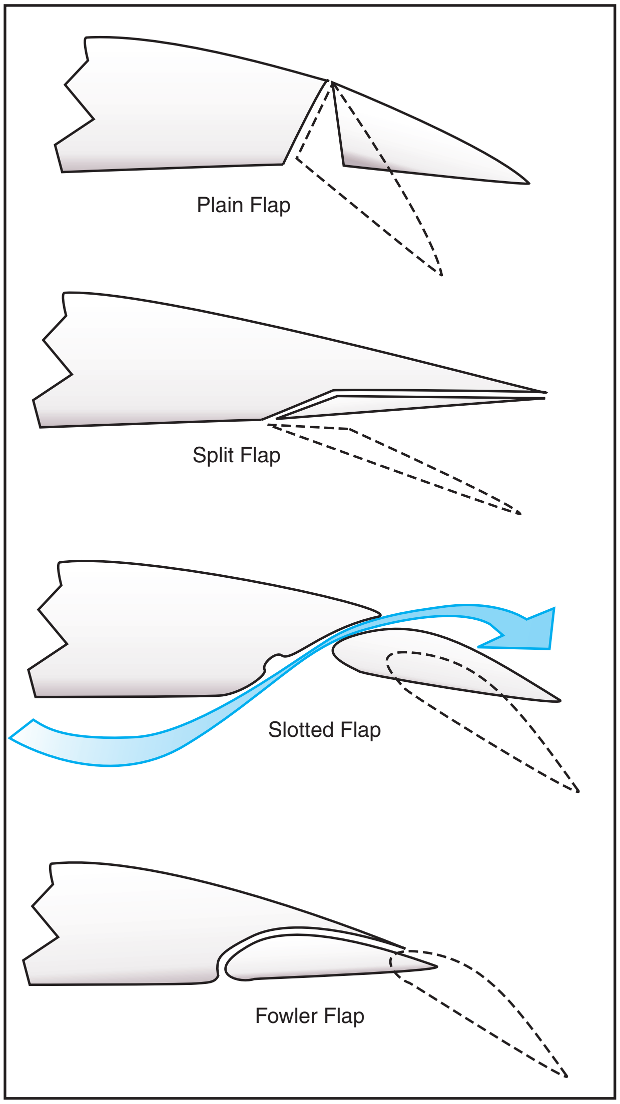


Figure 11-2. Four basic types of flaps.

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 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. Because of structural complexity and difficulty in sealing the slots, Fowler flaps are most commonly used on larger airplanes.

OPERATIONAL PROCEDURES

It would be impossible to discuss all the many airplane design and flap combinations. This emphasizes the importance of the 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, many are lacking. Hence, flap operation makes pilot judgment of critical importance. In addition, flap operation is used for landings and takeoffs, during which the airplane is in close proximity to the ground where the margin for error is small.

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

The time of flap extension and degree of deflection are related. Large flap deflections at one single point in the landing pattern produce large lift changes that require significant pitch and power changes in order to maintain airspeed and glide slope. Incremental deflection of flaps on downwind, base, and final approach allow smaller adjustment of pitch and power compared to extension of full flaps all at one time. This procedure facilitates a more stabilized approach.

A soft- or short-field landing requires minimal speed at touchdown. The flap deflection that results in minimal groundspeed, therefore, should be used. If obstacle clearance is a factor, the flap deflection that results in the steepest angle of approach should be used. It should be noted, however, that the flap setting that gives the minimal speed at touchdown does not necessarily give the steepest angle of approach; however, maximum flap extension gives the steepest angle of approach and minimum speed at touchdown. Maximum flap extension, particularly beyond 30 to 35°, results in a large amount of drag. This requires higher power settings than used with partial flaps. Because of the steep approach angle combined with power to offset drag, the flare with full flaps becomes critical. The drag produces a high sink rate that must be controlled with power, yet failure to reduce power at a rate so that the power is idle at touchdown allows the airplane to float down the runway. A reduction in power too early results in a hard landing.

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. In a crosswind, the "flapped" wing on the upwind side is more affected than the downwind wing. This is, however, eliminated to a slight extent in the crabbed approach since the airplane is more nearly aligned with the wind. When using a wing low approach, however, the lowered wing partially blankets the upwind flap, but 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.

Crosswind effects on the "flapped" wing become more pronounced as the airplane comes closer to the ground. The wing, flap, and ground form a "container" that is filled with air by the crosswind. With the wind striking the deflected flap and fuselage side and with the flap located behind the main gear, the upwind wing will tend to rise and the airplane will tend to turn into the wind. Proper control position, therefore, is essential for maintaining runway alignment. Also, it may be necessary to retract the flaps upon positive ground contact.

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 nosedown 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 "flapped" wing. This produces additional lift causing the nose to pitch up. 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, thereby allowing rapid increase in airspeed; however, flap retraction also decreases lift so that the airplane sinks rapidly.

The degree of flap deflection combined with design configuration of the horizontal tail relative to the wing requires that the pilot carefully monitor pitch and airspeed, carefully control flap retraction to minimize altitude loss, and properly use the rudder for coordination. Considering these factors, the pilot should extend the same degree of deflection at the same point in the landing pattern. This requires that a consistent traffic pattern be used. Therefore, the pilot can have a preplanned 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 will contain 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 speed of rotation and forward speed. This type of propeller will provide suitable performance in a narrow range of airspeeds; however, efficiency would suffer considerably outside this range. To provide high propeller efficiency through a wide range of operation, the **propeller blade angle** must be controllable. The most convenient way of controlling the propeller blade angle is by means of a constant-speed governing system.

CONSTANT-SPEED PROPELLER

The constant-speed propeller keeps the blade angle adjusted for maximum efficiency for most conditions of flight. When an engine is running at constant speed, the torque (power) exerted by the engine at the propeller shaft must equal the opposing load provided by the resistance of the air. The r.p.m. is controlled by regulating the torque absorbed by the propeller—in other words by increasing or decreasing the resistance offered by the air to the propeller. In the case of a fixed-pitch propeller, the torque absorbed by the propeller is a function of speed, or r.p.m. If the power output of the engine is changed, the engine will accelerate or decelerate until an r.p.m. is reached at which the power delivered is equal to the power absorbed. In the case of a constant-speed propeller, the power absorbed is independent of the r.p.m., for by varying the **pitch** of the blades, the air resistance and hence the torque or load, can be changed without reference to propeller speed. This is accomplished with a constant-speed propeller by means of a governor. The governor, in most cases, is geared to the engine crankshaft and thus is sensitive to changes in engine r.p.m.

The pilot controls the engine r.p.m. indirectly by means of a propeller control in the cockpit, which is connected to the governor. For maximum takeoff power, the propeller control is moved all the way forward to the low pitch/high r.p.m. position, and the throttle is moved forward to the maximum allowable manifold pressure position. To reduce power for climb or cruise, manifold pressure is reduced to the desired value with the throttle, and the engine r.p.m. is reduced by moving the propeller control back toward the high pitch/low r.p.m. position until the desired r.p.m. is observed on the tachometer. Pulling back on the propeller control causes the propeller blades to move to a higher angle. Increasing the propeller blade angle (of attack) results in an increase in the resistance of the air. This puts a load on the engine so it slows down. In other words, the resistance of the air at the higher blade angle is greater than the torque, or power, delivered to the propeller by the engine, so it slows down to a point where the two forces are in balance.

When an airplane is nosed up into a climb from level flight, the engine will tend to slow down. Since the governor is sensitive to small changes in engine r.p.m., it will decrease the blade angle just enough to keep the engine speed from falling off. If the airplane is nosed down into a dive, the governor will increase the blade angle enough to prevent the engine from overspeeding. This allows the engine to maintain a constant r.p.m., and thus maintain the power output. Changes in airspeed and power can be obtained by changing r.p.m. at a constant manifold pressure; by changing the manifold pressure at a constant r.p.m.; or by changing both r.p.m. and manifold pressure. Thus 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 low speeds and when maximum power and thrust are required, the constant-speed propeller sets up a low propeller blade angle (pitch). The low blade angle keeps the angle of attack, with respect to the relative wind, small and efficient at the low speed. [Figure 11-3]

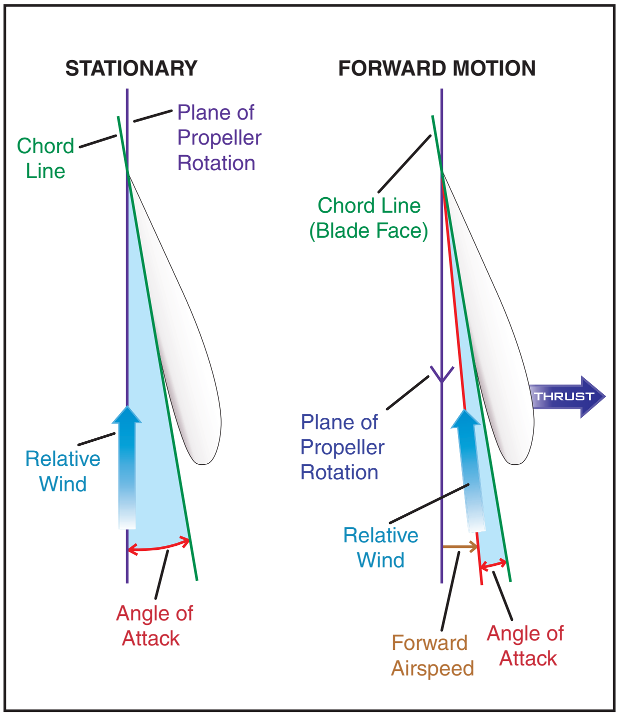


Figure 11-3. Propeller blade angle.

At the same time, it allows the propeller to "slice it thin" and handle a smaller mass of air per revolution. This light load allows the engine to turn at maximum r.p.m. and develop maximum power. Although the mass of air per revolution is small, the number of revolutions per minute is high. Thrust is maximum at the beginning of the takeoff and then decreases as the airplane gains speed and the airplane drag increases. Due to the high slipstream velocity during takeoff, the effective lift of the wing behind the propeller(s) is increased.

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 speeds, keeps the angle of attack 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 lowering r.p.m. by increasing the blade angle. 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 angle of attack 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, less power is required to produce a higher airspeed than is used in climb. Consequently, engine power is again reduced by lowering the manifold pressure and increasing the blade angle (to decrease r.p.m.). 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. Due to the increase in blade angle and airspeed, the angle of attack is still small and efficient.

BLADE ANGLE CONTROL

Once the pilot selects the r.p.m. settings for the propeller, the propeller governor automatically adjusts the blade angle to maintain the selected r.p.m. 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, which is integrated with the governor. The higher pressure provides a quicker blade angle change. The r.p.m. 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 cockpit 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, will affect each differently.

GOVERNING RANGE

The blade angle range for constant-speed propellers varies from about 11 1/2 to 40°. The higher the speed of the airplane, the greater the blade angle range. [Figure 11-4]

The range of possible blade angles is termed the propeller's governing range. The governing range is defined by the limits of the propeller blade's travel between high and low blade angle pitch stops. As long as the propeller blade angle is within the governing range and not against either pitch stop, a constant engine r.p.m. will be maintained. However, once the propeller blade reaches its pitch-stop limit, the engine r.p.m. will increase or decrease with changes in airspeed and propeller load similar to a fixed-pitch propeller. For example, once a specific r.p.m. is selected, if the airspeed decreases enough, the propeller blades will reduce pitch, in an attempt to maintain the selected r.p.m., until they contact their low pitch stops. From that point, any further reduction in airspeed will cause the engine r.p.m. to decrease. Conversely, if the airspeed increases, the propeller blade angle will increase until the high pitch stop is reached. The engine r.p.m. will then begin to increase.

CONSTANT-SPEED PROPELLER OPERATION

The engine is started with the propeller control in the low pitch/high r.p.m. 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 should be operated slowly and smoothly through a full cycle. This is done by moving the propeller control (with the

Aircraft Type	Design Speed (m.p.h.)	Blade Angle Range	Pitch	
			Low	High
Fixed Gear	160	$11^{1}/_{2}$°	$10^{1}/_{2}$°	22°
Retractable	180	15°	11°	26°
Turbo Retractable	225/240	20°	14°	34°
Turbine Retractable	250/300	30°	10°	40°
Transport Retractable	325	40°	10/15°	50/55°

Figure 11-4. Blade angle range (values are approximate).

manifold pressure set to produce about 1,600 r.p.m.) to the high pitch/low r.p.m. position, allowing the r.p.m. to stabilize, and then moving the propeller control back to the low pitch takeoff position. This should be done for two reasons: to determine whether the system is operating correctly, and to circulate fresh warm oil through the propeller governor system. It should be remembered that 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 isn't exercised before takeoff, there is a possibility that the engine may **overspeed** 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, must accelerate down the runway to increase airspeed and aerodynamically unload the propeller so that r.p.m. and horsepower can steadily build up to their maximum. With a constant-speed propeller, the tachometer reading should come up to within 40 r.p.m. of the red line as soon as full power is applied, and should remain there for the entire takeoff.

Excessive manifold pressure raises the cylinder compression pressure, resulting in high stresses within the engine. Excessive pressure also produces high engine temperatures. A combination of high manifold pressure and low r.p.m. 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 r.p.m. first, and then the manifold pressure.

- When decreasing power, decrease the manifold pressure first, and then decrease the r.p.m.

It is a fallacy that (in non-turbocharged engines) the manifold pressure in inches of mercury (inches Hg) should never exceed r.p.m. in hundreds for cruise power settings. The cruise power charts in the AFM/POH should be consulted when selecting cruise power settings. Whatever the combinations of r.p.m. and manifold pressure listed in these charts—they have been flight tested and approved by the airframe and powerplant engineers for the respective airframe and engine manufacturer. Therefore, if there are power settings such as 2,100 r.p.m. 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 overspeeding 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 r.p.m. constant. When this occurs, the r.p.m. is responsive to any change in throttle setting.

Some pilots consider it advisable to set the propeller control for maximum r.p.m. during the approach to have full horsepower available in case of emergency. If the governor is set for this higher r.p.m. early in the approach when the blades have not yet reached their minimum angle stops, the r.p.m. may increase to unsafe limits. However, if the propeller control is not readjusted for the takeoff r.p.m. until the approach is almost completed, the blades will be against, or very near their minimum angle stops and there will be little if any change in r.p.m. In case of emergency, both throttle and propeller controls should be moved to takeoff positions.

Many pilots prefer to feel the airplane respond immediately when they give short bursts of the throttle during approach. By making the approach under a little power and having the propeller control set at or near cruising r.p.m., this result can be obtained.

Although the governor responds quickly to any change in throttle setting, a sudden and large increase in the throttle setting will cause a momentary overspeeding 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 will cause momentary overspeeding of the engine beyond the r.p.m. for which the governor is adjusted. This temporary increase in engine speed acts as an emergency power reserve.

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

- The red line on the tachometer not only indicates maximum allowable r.p.m.; it also indicates the r.p.m. required to obtain the engine's rated horsepower.

- A momentary propeller overspeed may occur when the throttle is advanced rapidly for takeoff. This is usually not serious if the rated r.p.m. 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 r.p.m. This is normal in most cases. The pilot should consult the AFM/POH for limitations.
- All power changes should be made smoothly and slowly to avoid **overboosting** and/or overspeeding.

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 powerplant to operate; it is relatively simple mechanically, and some models can pressurize the cabin as well.

The turbocharger is an exhaust-driven device, which 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 11-5]

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 will be 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 pilot has set the desired manifold pressure, 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 maintains only the manifold pressure called for by the throttle setting.

GROUND BOOSTING VS. ALTITUDE TURBOCHARGING

Altitude turbocharging (sometimes called "normalizing") is accomplished by using a turbocharger that will maintain maximum allowable sea level manifold pressure (normally 29 – 30 inches 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,

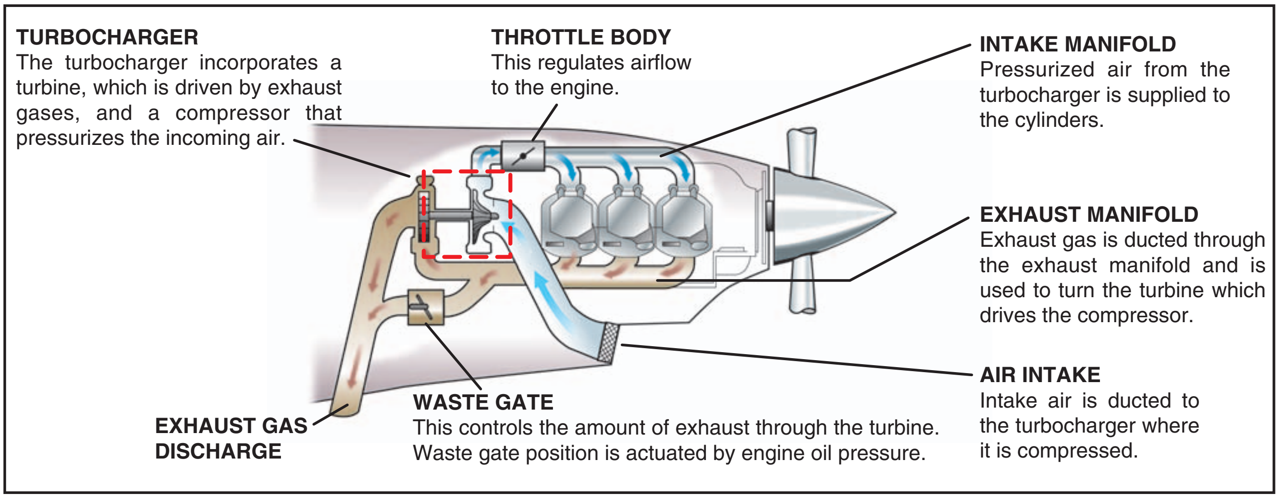


Figure 11-5. Turbocharging system.

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 inches of mercury.

Although a sea level power setting and maximum r.p.m. can be maintained up to the critical altitude, this does not mean that the engine is developing sea level power. Engine power is not determined just by manifold pressure and r.p.m. Induction air temperature is also a factor. Turbocharged induction air is heated by compression. This temperature rise decreases induction air density which causes a power loss. Maintaining the equivalent horsepower output will require a somewhat higher manifold pressure at a given altitude than if the induction air were not compressed by turbocharging. If, on the other hand, the system incorporates an automatic density controller which, instead of maintaining a constant manifold pressure, automatically positions the waste gate so as to maintain constant air density to the engine, a near constant horsepower output will result.

OPERATING CHARACTERISTICS

First and foremost, all movements of the power controls on turbocharged engines should be slow and gentle. Aggressive and/or abrupt throttle movements increase the possibility of **overboosting**. The pilot should carefully monitor engine indications when making power changes.

When the waste gate is open, the turbocharged engine will react the same as a normally aspirated engine when the r.p.m. is varied. That is, when the r.p.m. is increased, the manifold pressure will decrease slightly. When the engine r.p.m. is decreased, the manifold pressure will increase slightly. However, when the waste gate is closed, manifold pressure variation with engine r.p.m. is just the opposite of the normally aspirated engine. An increase in engine r.p.m. will result in an increase in manifold pressure, and a decrease in engine r.p.m. will result in a decrease in manifold pressure.

Above the critical altitude, where the waste gate is closed, any change in airspeed will result 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 may tend 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—pushes the fuel—reducing the tendency to vaporize.

HEAT MANAGEMENT

Turbocharged engines must 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 r.p.m., 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, therefore, is effective heat management.

The pilot monitors the condition of a turbocharged engine with manifold pressure gauge, tachometer, exhaust gas temperature/turbine inlet temperature gauge, and cylinder head temperature. The pilot manages the "heat system" with the throttle, propeller r.p.m., mixture, and cowl flaps. At any given cruise power, the mixture is the most influential control over the exhaust gas/turbine inlet temperature. 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, however, the pilot normally reduces power to 75 percent or less and simultaneously adjusts the mixture. Under cruise conditions, temperature limits should be monitored most closely because it's there that the temperatures are most likely to reach the maximum, even though the engine is producing less power. Overheating in an enroute climb, however, may require fully open cowl flaps and a higher airspeed.

Since turbocharged engines operate hotter at altitude than do 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. The pilot may find it helpful to lower the landing gear to give the engine something to work against while power is reduced and provide time for a slow cool down. 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 systems, any malfunction of the turbocharger must 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.

OVERBOOST 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 r.p.m. and mixture setting.
- Operate the engine in such a manner as to avoid a further overboost 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 the resulting decrease in drag. 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 cockpit 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. The complexity of the retractable landing gear system requires that specific operating procedures be adhered to and that certain operating limitations not be exceeded.

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 cockpit 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 will continue 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 cockpit 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 which 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 limit 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 in the cockpit. In most airplanes, the gear switch is shaped like a wheel in order to facilitate positive identification and to differentiate it from other cockpit controls. [Figure 11-6]

Landing gear position indicators vary with different make and model airplanes. The most common types of landing gear position indicators utilize a group of lights. One type consists of a group of three green lights, which illuminate when the landing gear is down and locked. [Figure 11-6] Another 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. Still other systems incorporate a red or amber light to indicate when the gear is in transit or unsafe for landing. [Figure 11-7] The lights are usually of the "press to test" type, and the bulbs are interchangeable. [Figure 11-6]

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 will sound 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 will sound.

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.

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 11-8] 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 cockpit is placed in the RETRACT position when weight is on the gear, the gear will remain 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 will release and the gear will retract.

Many airplanes are equipped with additional 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 extension system lowers the landing gear if the main power system fails. Some airplanes

Figure 11-6. Typical landing gear switches and position indicators.

Figure 11-7. Typical landing gear switches and position indicators.

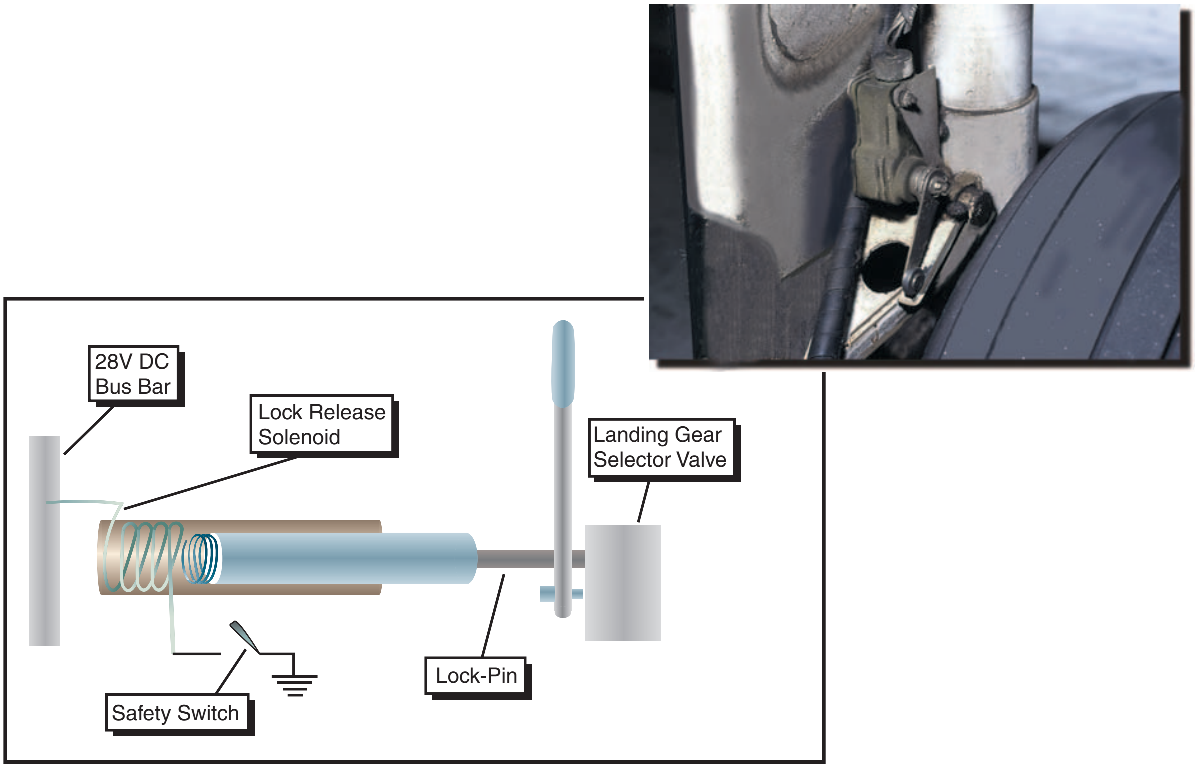
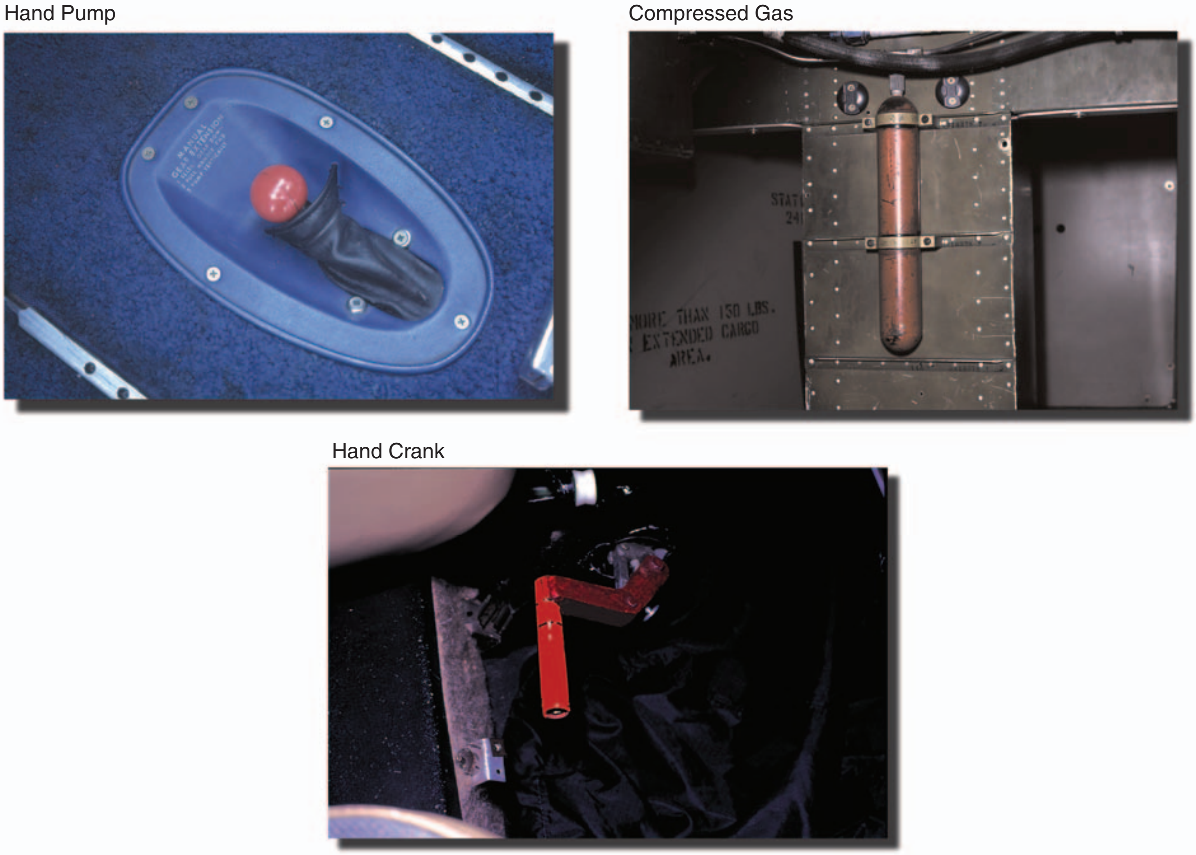


Figure 11-8. Landing gear safety switch.

have an emergency release handle in the cockpit, which is connected through a mechanical linkage to the gear uplocks. When the handle is operated, it releases the uplocks and allows the gears to free fall, or extend under their own weight. [Figure 11-9]


Hand Pump

Compressed Gas

Hand Crank

Figure 11-9. Typical emergency gear extension systems.

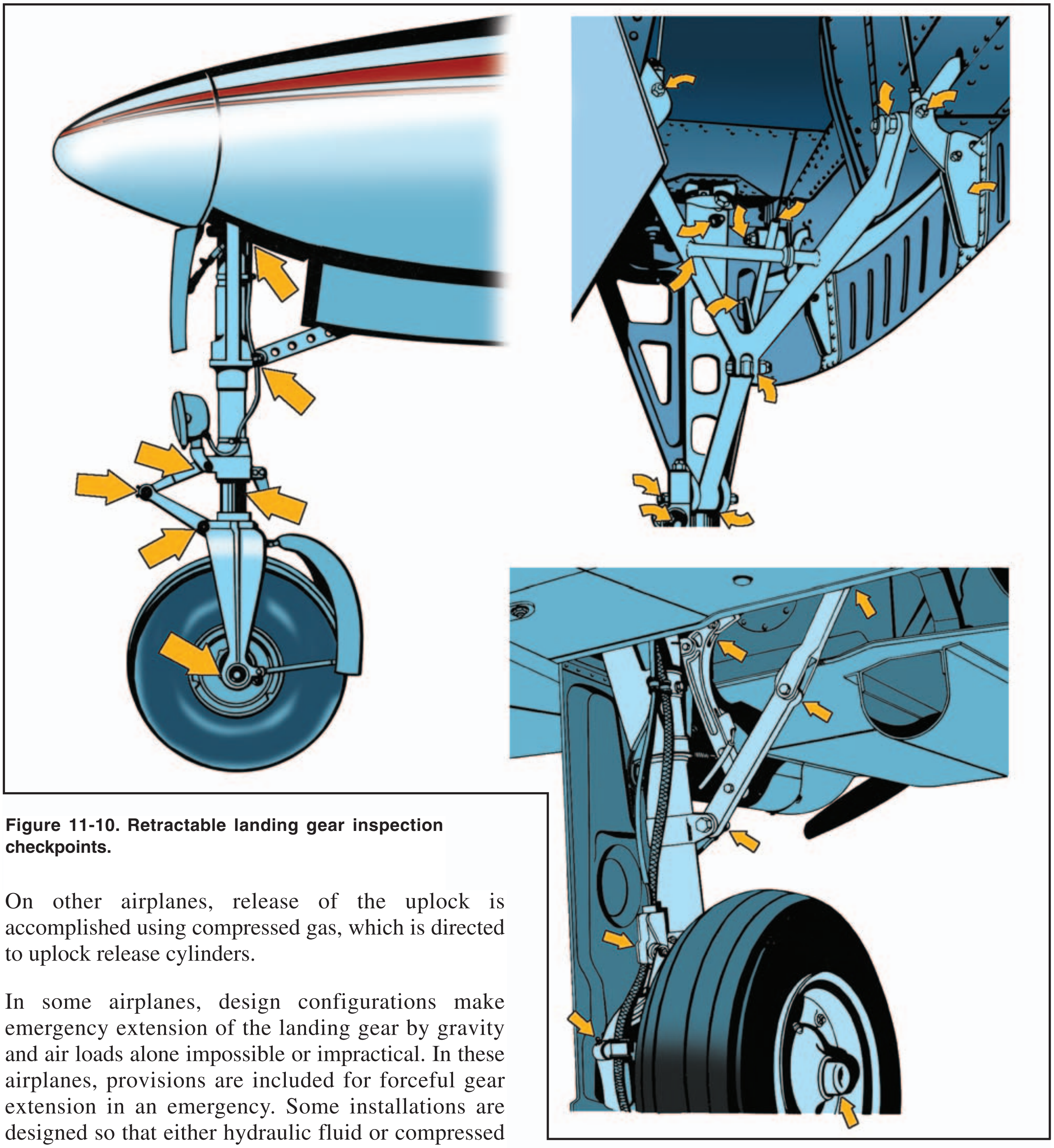


Figure 11-10. Retractable landing gear inspection checkpoints.

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 11-9] 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 gears demand a close inspection prior to every flight. The inspection should begin inside the cockpit. The pilot should first make certain that the landing gear selector switch is in the GEAR DOWN position. The pilot should then turn on the battery master switch and ensure that the landing gear position indicators show that the gear is down and locked.

External inspection of the landing gear should consist of checking individual system components. [Figure 11-10] 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.

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

TAKEOFF AND CLIMB

Normally**,** the landing gear should be 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. Landing gear retraction should be preplanned, taking into account the length of the runway, climb gradient, obstacle clearance requirements, the characteristics of the terrain beyond the departure end of the runway, and 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 terrain (see Chapter 16). 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.

Premature landing gear retraction should be avoided. The landing gear should not be retracted 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. The pilot should also remember that leaning forward to reach the landing gear selector may result in inadvertent forward pressure on the yoke, which will cause the airplane to descend.

As the landing gear retracts, airspeed will increase 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. The pilot should become familiar with the sounds and feel of normal gear retraction so that any abnormal gear operation can be readily discernable. 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 are not found on the airspeed indicator. They are published in the AFM/POH for the particular airplane and are usually listed on placards in the cockpit. [Figure 11-11] 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 11-11. Placarded gear speeds in the cockpit.

The landing gear is extended by placing the gear selector switch in the GEAR DOWN position. As the landing gear extends, the airspeed will decrease and the pitch attitude may increase. During the several seconds it takes for the gear to extend, the pilot should be attentive to any abnormal sounds or feel. The pilot should 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 cockpit. 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. The pilot should 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 will aid the pilot 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, the pilot should make it a habit to **complete** the landing gear checklist for that airplane. This accomplishes two purposes. It ensures that action has been taken to lower the gear, and it increases the pilot's 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 clear of the runway before any levers or switches are operated. This will accomplish the following: The landing gear strut safety switches will be actuated, deactivating the landing gear retract system. After rollout and clearing the runway, the pilot will be able to focus attention on the after landing checklist and to identify the proper controls.

Pilots transitioning to retractable gear airplanes should be aware that the most common pilot operational factors involved in retractable gear airplane accidents are:

- 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.

In order to minimize the chances of a landing gear related mishap, the pilot should:

- Use an appropriate checklist. (A condensed checklist mounted in view of the pilot as 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, so that you can properly replace a bulb to determine if the bulb(s) in the display is good. 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 11-12]

This sample syllabus for transition training is to be considered flexible. The arrangement of the subject matter may be changed and the emphasis may be shifted to fit the qualifications of the transitioning pilot, the airplane involved, and the circumstances of the training situation, provided the prescribed proficiency standards are achieved. These standards are contained in the practical test standards appropriate for the certificate that the transitioning pilot holds or is working towards.

The training times indicated in the syllabus are based on the capabilities of a pilot who is currently active and fully meets the present requirements for the issuance of at least a private pilot certificate. The time periods may be reduced for pilots with higher qualifications or increased for pilots who do not meet the current certification requirements or who have had little recent flight experience.

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

* The directed practice indicated may be conducted solo or with a safety pilot at the discretion of the instructor.

Figure 11-12. Transition training syllabus.