



Engine Operations

The engine is
the beating
heart of
the airplane.

Do you know what to do if the engine burps and coughs during the runup, or runs rough during cruise? In-depth systems knowledge can give you the tools needed to assess the engine's actual condition.

Aircraft engines are extremely reliable when properly cared for, and can deliver years of safe flight. That being said, not all pilots know as much as they should about the proper care and maintenance of engines, or that mechanical failure accounts for 15 to 20 percent of all accidents. Knowing how to manage a powerplant helps you fly more safely and can minimize the cost of flying.

Whether the aircraft you fly is equipped with a sophisticated engine monitoring system or not, a basic understanding of how engines work is required to correctly diagnose potential engine problems. For all engines air is drawn into the engine, mixes with fuel, burns at a controlled rate and expands, pushing on a piston that turns the crankshaft and propeller.

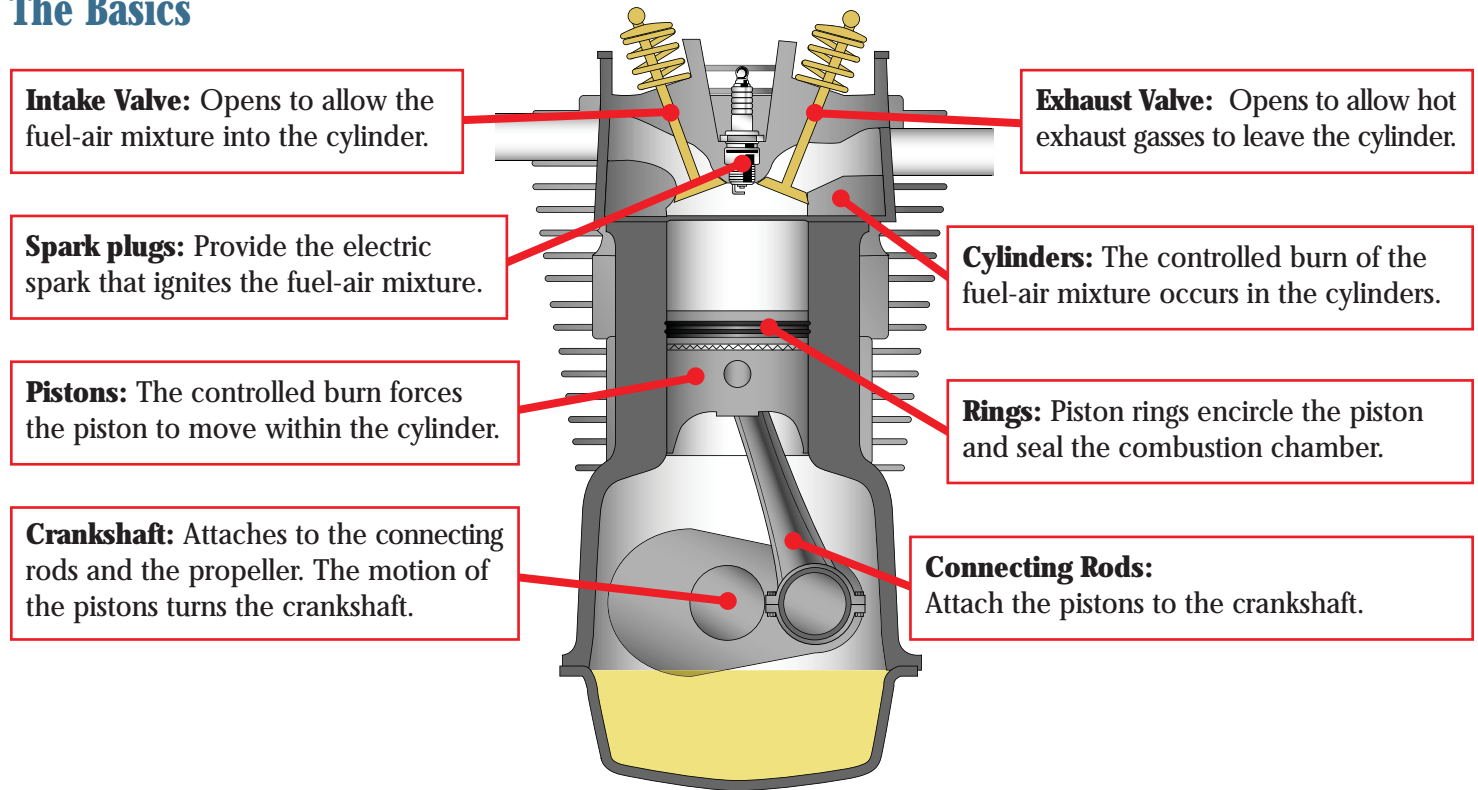
Most piston aircraft engines develop power with four cycles, or strokes, of each piston inside a cylinder. The four cycles are intake, compression, power, and exhaust.

Cockpit engine controls, usually the throttle, prop control and mixture, allow a pilot to extract the most efficient performance from the engine and ensure safe and reliable operation.

FADEC

Full authority digital engine control (FADEC) incorporates the throttle, mixture, and prop control into one pilot controlled lever. The FADEC system provides many benefits, including increased efficiency, lower fuel burn and troubleshooting tools for diagnosing engine problems.

The Basics



Throttle = Air and Fuel

The throttle is an air valve, opened all the way for full power and closed almost completely at idle. In a carbureted engine, as the throttle is opened further and further, more and more fuel is automatically drawn through the carburetor. The fuel and air combine in the carburetor throat and are sucked into the cylinder via intake tubes.

In a fuel-injected engine, the pilot still controls the volume of air entering the engine by moving the throttle, but the fuel is delivered separately into each cylinder, mixing with the air inside the cylinders. Fuel-injected engines are more efficient and develop more power than the same-size carbureted engine because of more precise fuel delivery.

With fuel-injected engines, there is no worry about carb ice, because there is no carburetor in which the fuel-air mixture can vaporize and cool. The main operational difference with fuel-injected engines is that they can be harder to start, especially when hot.

Magnetos = Spark

Aircraft engines have two spark plugs in each cylinder, to improve combustion efficiency and to provide a backup in case one ignition system fails. Feeding the spark plugs are two magnetos, each of which is self-contained and creates the spark, all without an external electrical

source. In your car, if the electrical charging system fails or the ignition is turned off, your engine stops running. In an airplane, the electrical system can be turned off with the master switch and the magneto-equipped engine will continue running.

Each magneto is independent, firing its own set of spark plugs. If one magneto fails, the aircraft will still fly safely on the other magneto and its set of spark plugs.

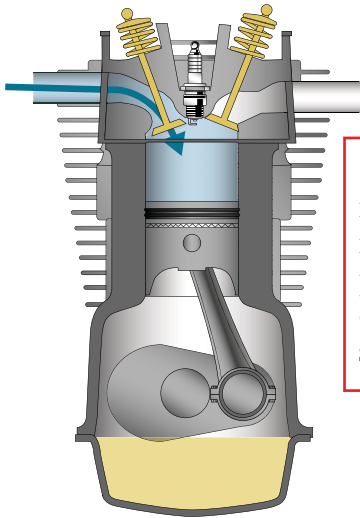
Getting Started

Most piston engines will start with the mixture rich, throttle advanced slightly, and fuel pump On. Still, starting an airplane engine isn't automatic, as it is in a car.

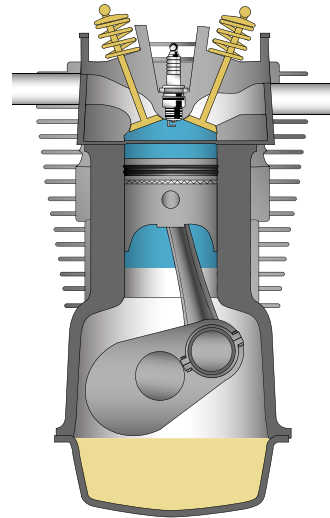
Carbureted Engine

On carbureted engines, cold starts are arguably the most difficult and provide a test of the pilot's understanding of aircraft systems.

To start a cold engine, add extra fuel by priming. This puts fuel directly into one or more cylinders (via the intake manifold). Refer to the aircraft's POH (pilots operating handbook) for the correct priming technique. Do not pump the throttle, as this will simply force raw fuel (which doesn't vaporize as easily in cold weather) into the intake system, possibly causing an engine fire.

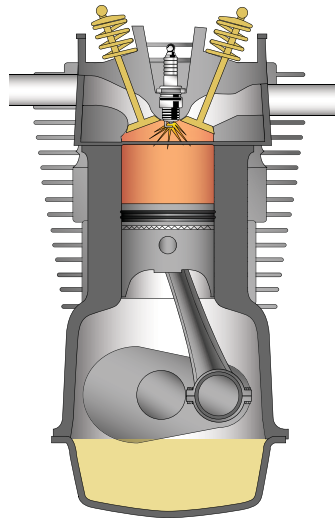


1. Intake: As the piston moves down, creating more space and lower pressure inside the cylinder, the fuel-air mixture is sucked into the cylinder.

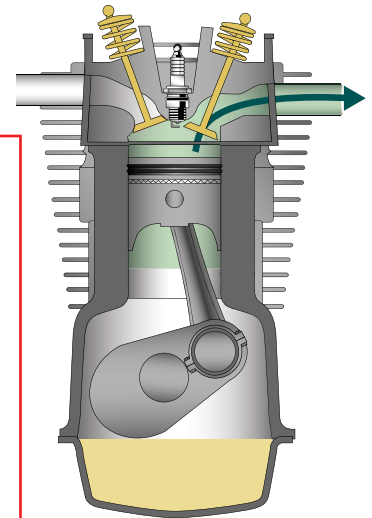


2. Compression: The piston moves up, compressing the fuel-air mixture into a small space at the top of the cylinder.

3. Power: The spark plug fires, igniting the compressed fuel-air mixture. Expanding hot gasses force the piston down, turning the crankshaft and propeller.



4. Exhaust: After the rapidly expanding hot gasses finish moving the piston, the exhaust valve opens, allowing the hot gasses to escape. Before the exhaust valve closes, the intake valve opens and the piston moves down, and a fresh fuel-air charge enters the cylinder. Part of the fresh charge's job is to help push out remaining exhaust gas. The cycle continues.



Signs of Trouble

Engine running a little rough? Notice a slight rpm drop? Whether in flight or on the ground, you may have carburetor ice.

The symptoms of carb ice are subtle. Pilots who have experienced it say it's much easier to recognize the symptoms of carb ice the second time around.

Some airplanes are more susceptible to carb ice than others; it depends on the design of the engine's air-intake systems. Carb ice is caused by the cooling of the fuel-air mixture as it passes through the carburetor throat or venturi. As the fuel-air mixture gains speed in the venturi, its temperature drops. If there is enough moisture in the air and the acceleration causes the

temperature of the mixture to drop below freezing, ice may form and block the venturi. The blockage can cause a reduction in rpm or even make the engine stop running.

To prevent or melt the ice, use the carburetor heat. Since warm air is less dense than cold air, effectively enriching the mixture, you will see an rpm drop when the carburetor heat is turned On. The rpm drop will continue until the carburetor heat is turned Off.

The first time you experience carb ice can be startling, since application of full carb heat – as recommended – will likely cause brief coughing and choking in the engine as the ice in the carburetor melts and is ingested by the engine.

If the outside temperature is below 20 degrees F, the engine may need a preheat, both to aid in starting and prevent engine damage. During a cold start try to avoid draining the battery unnecessarily. Leave avionics, electric flaps, and aircraft lighting, which all rely on and use battery power, off until the engine is running.

Engine Fires

Excess priming causes large amounts of fuel to pool in the carburetor intake. This fuel can ignite if the engine backfires. Most POHs recommend that you keep trying to start the engine after the fire is noticed. This puts the fire out by pulling the flames back into the engine. If you get the engine started let it run for a few minutes before shutting down and examining the damage. If the engine does not start turn off the master and ignition switches as well as the fuel selector and mixture, abandon the aircraft, and look for a fire extinguisher or call the fire department.

Fuel-Injected Engine

For some fuel-injected engines that are already hot, engage the starter and allow the engine to turn while keeping the mixture at idle cutoff. When the engine catches, advance the mixture. If the engine is over-primed because the mixture was advanced too soon, it may be flooded. The starting procedure for a flooded engine is similar to the hot-engine start, but the throttle may need to be opened (advanced or pushed in) in order to add air that will help purge the excess fuel.

Read the Pilot Operating Handbook (POH)

Different engine manufactures have different procedures for hot starts. Be sure to reference the POH for the aircraft you fly.

Fuel-injected engines use electric primers or the electric fuel pump to spray fuel into the cylinders for priming. In some airplanes, the amount of primer fuel is adjusted by advancing the mixture and the throttle. It's easy to flood the engine, and then the flooded-start procedure will be needed.

A typical flooded (or hot-start procedure) for a fuel-injected engine begins with the mixture at idle cutoff. Next, move the throttle to the open position (full power). Check the POH to see if the fuel pump needs to be On or Off. While cranking the engine, get ready to reverse the throttle and mixture controls as the engine starts (quickly retard the throttle and slowly richen the mixture). It takes some practice to gracefully hot-start a fuel-injected engine.

Preheats

Different metals in the engine will shrink at varying rates and parts clearances can become extremely small below 20 degrees F. Oil loses some ability to lubricate at extremely low temperatures. Starting an engine in these conditions can cause metal parts to rub together and cause extreme wear in a very short time. Preheating helps prevent this wear and also helps fuel vaporize easier for quick starting. There are many types of preheaters available. Hot-air preheaters pump hot air into the engine compartment. Electric preheaters provide electric heat directly to the oil pan. New systems that combine cylinder and oil pan electric preheaters are fast and help prevent damage by heating the cylinders as well as the oil.



When using a hot-air preheater, plug the air intakes on either side of the propeller, and place a blanket over the cowling to contain the heated air. Preheat for 15 to 20 minutes to ensure even heating for the entire engine.

How to Make Your Engine Live Longer

First and foremost – try to fly your engine at least an hour a week. Far more engines rust out than wear out. They rust because the oil drains off the cylinder walls and the moisture in the air then reacts with the iron in the engine. The rust creates roughness, which increases wear. Piston aircraft engines are made mostly of steel and aluminum, which expand and contract at different rates, depending on temperature. When flying at varying altitudes and from one climatic zone to another, temperature changes can be extreme. By keeping large engine temperature changes over a short period of time to a minimum, and within prescribed limits, the safety, reliability and longevity of the engine are significantly enhanced.

For example, avoiding rapid descents at idle power near your destination airport will help avoid “shock cooling,” which is the too-rapid cooling of hot engine metals. Shock cooling causes stress that can lead to cylinder head cracks. To avoid this, begin descent planning farther out

and descend at a slower rate with a low-cruise power setting. Good descent planning takes a little work, but your engine and passengers will thank you. This may take some negotiation with ATC, if IFR, or you may have to increase drag such as lowering the landing gear or flaps to keep airspeed and resultant engine cooling in check.

Pilots have two ways to control engine temperatures: fuel flow (throttle and mixture) and airflow (pitch attitude and cowl flaps, if your airplane is so equipped).

Fuel flow is a double-edged sword. As more fuel is provided to the engine (provided the mixture is set correctly), the more power is developed, which naturally means more heat. But extra fuel is also used as a cooling agent, which is one reason why mixtures are usually set full rich for takeoff and initial climb.



Good descent planning helps avoid shock cooling.

Cooling airflow and fuel-air mixture affect engine temperature, as well. The pilot's job is to keep engine temperatures at settings that maximize engine life. For example, an engine with a redline oil temperature of 250 degrees F will last much longer running at 180 degrees than 240 degrees. Keeping an engine too cool in flight can also be harmful; if oil cannot get hot enough to burn off water that has condensed in it, internal engine rust can occur. Engine experts suggest an oil temperature of around 180 degrees or a little higher as a happy medium for typical air-cooled GA engines.

Oil's primary function is to lubricate engine parts, but with the help of air flowing through the cowl and the oil cooler it also transfers heat out of the engine. There are two options for controlling oil cooling: Increase airflow through the engine and oil cooler by lowering the aircraft's pitch attitude or reducing power, if possible. If the airplane has cowl flaps, which increase



Oil temperature gauge

the amount of air flowing over the engine, leave them open even after leveling off until temperatures stabilize – then close them as appropriate. On a hot day, climb at higher airspeeds and lower pitch attitudes to keep engine temperatures in the green arc.

Using Gauges for More Precise Temperature Control

All airplanes have an oil temperature gauge, but, depending on the aircraft, two other sources of engine temperature information may be available:

A cylinder head temperature (CHT) gauge measures just that, the temperature at the cylinder head. CHT is a critical indicator of engine health, especially on high-power turbocharged engines.

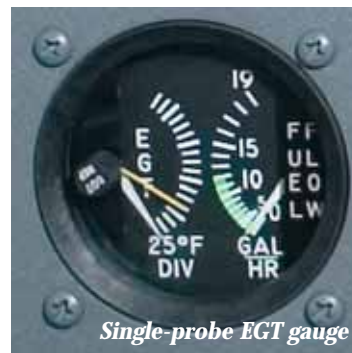
CHT can be adjusted with cowl flaps, if equipped, and by adjusting fuel and airflow. On hot days, you may need to enrich the mixture, open cowl flaps, lower the nose, or even reduce power to keep CHTs within limits. Always consult the POH to learn how to manage high engine temperatures.

Pilot control of engine temperatures

To control engine temperature adjust:

- **Cowl flaps (if equipped)**
- **Mixture**
- **Attitude**
- **Power setting**

An exhaust gas temperature (EGT) gauge measures the temperature as the exhaust leaves the cylinder. If the engine is turbocharged, the gases will be measured just before entering the turbocharger, by a turbine inlet temperature (TIT) gauge.



Single-probe EGT gauge

As the mixture is leaned by pulling the mixture control aft, the amount of fuel mixing with the air entering the engine is reduced. The fuel-air mixture thus becomes "leaner" because less fuel mixes with the same amount of air. When leaning the mixture, the EGT gauge shows the temperature climbing until the cylinder being measured reaches its peak temperature (peak EGT), indicating relatively efficient fuel-air combustion. Refer to the POH for correct mixture settings at various power settings.

When the mixture control is moved forward from peak EGT, the mixture is said to be rich of peak (ROP) because more fuel is being added to the fuel-air mixture. Moving the mixture control aft from the peak EGT position removes fuel from the mixture and thus the mixture is lean of peak (LOP). In both cases, actual EGT is lower than peak EGT.

Pilots should lean appropriately anytime they are below 75% power, regardless of altitude.

For most airplanes, correct mixture settings are detailed in the POH. As you gain experience with leaning, you'll find that it saves gallons of fuel and helps the engine run better. Follow the POH mixture settings carefully; this is not the time to experiment on your expensive engine.

Setting the Mixture

When you move the mixture control, you are adjusting the ratio of fuel to air delivered to the engine. Two typical mixture settings are "best power" and "best economy." Best power provides the most speed for a specific power setting. At a best economy mixture setting, you are trading a little speed for some fuel savings. Best economy results in the most miles per gallon at a specific power setting.



Major Surgery (Overhauls)

An annual or 100-hour inspection is done to the entire aircraft. The inspection must be signed off in the "aircraft" logbook, which means that the inspection applies to everything on the aircraft. However, it is often helpful to have the inspection signed off by the mechanic in the "engine" logbook as well, so that inspection status is easy to determine. No matter which logbook is used, there are specific requirements for the inspection of the engine. These requirements can be found in the federal aviation regulations (FARs) and in the manufacturers' maintenance manuals.

Typical items that a mechanic examines include: engine compression (for leakage inside the cylinders), oil system (leakage and metal in the oil filter), fuel system (clean filters and leaks, which could cause fires), and exhaust system (leaks could allow carbon monoxide into the cabin or cause fires).

Time between overhaul (TBO) is a recommendation by the engine manufacturers to indicate the expected engine overhaul interval. TBO is given in both hours on the engine and calendar time. Many Lycoming engines, for example, have an hourly TBO of 2,000 hours and a calendar TBO of 12 years. If an engine has only 300 hours but 20 years have passed since its last overhaul, it is likely in need of an overhaul.

These intervals are based on extensive engine testing and years of field experience. Remember that your airplane engine operates at much higher power settings for much longer than a typical car engine. Regular service and overhauls are essential to ensure that your engine delivers reliable, safe power every time you fly.

When you and your mechanic decide that it's time for major engine service, there are three possibilities:

1. Top Overhaul. Top overhaul refers to repair or replacement of an engine's "top end," the cylinders. The term "top overhaul" is not formally defined, however, and you may see it used to cover everything from minor cylinder repairs to complete replacement of all cylinders.

Typically a top overhaul includes the removal of one or more of the engine's cylinders, and a rebuild of cylinders with existing or replacement parts. It also can include the reconditioning of the cylinder walls, inspection of the pistons, valve operating mechanism, valve guides and seats, and replacing piston and piston rings.

A top overhauled engine carries forward all previous time in the engine logbook, whereas a factory rebuilt, or factory remanufactured engine, goes back to zero time.

Airplanes that seldom fly can develop engine problems due to corrosion, and these are frequently good candidates for some cylinder work between TBO intervals. A top overhaul does not extend or reset the TBO interval.

2. Engine Overhaul. An overhaul involves complete disassembly, cleaning, and renewal or replacement of all engine parts and components. Overhauls reset the TBO clock back to zero, although the engine continues to carry its previous total time.

Overhaul quality varies, depending on the standards of the mechanic or shop performing the overhaul. The minimum requirements for an overhaul are to ensure that parts meet overhaul limits (dimensions), which are not as

stringent as new part limits. Differences in overhaul pricing usually reflect the limits used during the overhaul.

3. Remanufacture. Engine manufacturers are authorized by the FAA to overhaul an engine to new part limits using many new parts and to call this engine a factory remanufactured engine. The advantage of this overhaul, in addition to all the new parts, is that it comes with a new, zero-time logbook. The engine's previous flight time is no longer relevant.

Common Engine Problems (and solutions)

What do I do if the engine runs rough during runup?

Engine roughness while checking the magnetos during runup could indicate a fouled spark plug or other ignition system problem. Accelerate the engine to runup rpm and lean the mixture until the engine runs rough. Let the engine run for about 30 seconds. Enrich the mixture then check the mags again. If this doesn't clear the roughness, have the ignition system checked by a mechanic before flying.

What if the mag drop is more than 200 rpm?

A larger than normal mag drop is not as critical as a rough mag. A smooth drop up to 200 rpm is fine. A drop greater than 200 rpm could indicate a mag-timing problem that should be checked. A mis-timed magneto can rob some power from the engine and also cause engine damage.

Can I fly if the carb heat drop is 300 rpm or more during runup?

No. A large carb heat drop during runup, more than the typical 50 to 100 rpm, is caused by an exhaust leak inside the shroud where hot air is diverted to the carburetor. All exhaust leaks are dangerous and must be fixed, because firewall air leaks can allow exhaust fumes and possibly carbon monoxide from the engine compartment into the cockpit. A leak can also direct hot exhaust onto vulnerable components such as fuel lines and possibly cause a fire in the engine compartment.



Is it possible for the carburetor to ice up during ground operations?

Yes. Under certain conditions carb icing can occur while taxiing. If you don't leave the carb heat on for at least 10 seconds during the runup check, the ice might not melt and could cause lower power output during takeoff and possibly engine failure. If the carburetor is iced up during runup, carb heat application will result in an initial small rpm drop, then a rise higher than the runup rpm.

How do I know if the engine is developing full power during takeoff?

The engine must reach the specified static rpm range (before releasing the brakes) at full rpm. Check the POH for these numbers. If the aircraft can't reach this rpm range on the ground there may be a problem with the tachometer indication or something wrong with the engine. Possible problems include a worn propeller (fixed-pitch), improperly set propeller governor (constant-speed), mis-timed magnetos, fouled spark plugs, clogged fuel injector nozzle, or a blocked muffler.

What is a hot magneto and how can I troubleshoot this?

A "hot" magneto is a magneto that can't be turned off. If someone manually turns the prop with a hot mag, it could begin turning even though the magneto switch is in the Off position. There are two times you can easily check for a hot mag: during runup and at engine shutdown. If an rpm drop is *not* noticed during the mag check on runup, you may have a hot mag. During engine shutdown, check for a hot mag by running the engine at idle and turning the ignition to Off. If the engine continues running with the ignition in the Off position, the mag is hot.

Can I take off if the oil temperature isn't in the green?

Yes, but check to make sure the engine picks up smoothly as the throttle is advanced. Throttle advancement should be smooth and take several seconds from idle to full power. Cold oil doesn't lubricate as well, and damage could occur if the oil isn't warm enough. While engines can be started at very low temperatures, it is generally safer to preheat below 20 degrees F. Preheating improves oil lubrication, the fuel vaporizes for easier starting, and engine parts expand uniformly.

Why is my engine so hard to start, especially when hot, and what can I do about it?

There are many causes of hard starting, including a weak battery, fouled spark plugs, worn magnetos, worn impulse couplings, fuel vapor lock, and improper technique. Fuel-injected engines can be difficult to start

when the engine is hot because fuel can turn into vapor in fuel lines near the hot engine. With air bubbles/vapor in the fuel lines the engine will not start or will not run after starting. One hot-start technique includes a method of purging the fuel lines to eliminate fuel vapor. Follow POH instructions for hot starting, but be sure that the mechanical items mentioned above aren't making the problem worse. If all else fails, ask your mechanic for his favorite hot start technique.

My engine runs very rough while it's starting then smooths out as it warms up. Is there something wrong?

Yes, there is a strong likelihood that you have a stuck valve. The valve sticks inside the cylinder head when the engine is cold and the metal parts are contracted. As the engine warms up, the valve eventually loosens and the engine runs smoother. A stuck valve is dangerous because the sticking can occur during normal operations and it can cause catastrophic engine failure. Have this symptom checked thoroughly before flying.

Can I hurt my engine by leaning too much?

Yes, at higher power settings you can hurt the engine by over leaning. Follow the POH leaning instructions to avoid damage. There is one time that over leaning isn't a problem and that is when running at just above idle power during ground operations. During a long taxi or a lengthy wait for takeoff clearance, you can lean the engine aggressively without the risk of damage. Leaning

on the ground helps prevent spark plug fouling. Just don't forget to enrich the mixture before takeoff.

Is it okay to lean below 3,000 feet?

Yes, you can lean the engine at any altitude. There is no reason not to lean during cruise; it saves gas and is better for the engine. While you will still see recommendations not to lean until reaching 3,000 or 5,000 feet, this advice is to keep pilots from forgetting to enrich the mixture before descending, and it is not related to any potential engine problems.

I learned what to do if the engine fails, but what do I do if there is just a partial power loss?

This is an important question. Instructors rarely teach partial power loss, but it is more likely to occur than a complete engine failure. Circumstances that can cause a partial power loss vary, but the key is to determine if there is enough power to remain aloft to troubleshoot the problem. If the engine is losing power steadily, you'll need to find a place to land quickly. An example might be a gradual loss of oil pressure; the end result is still total engine failure. A forced landing is in the very near future. A fuel line or muffler blockage could cause a partial power failure but leave enough power to stay level. In this case, you may be able to nurse the airplane to a nearby airport, but this will depend on terrain and weather. The bottom line for partial power is to treat it like a full engine failure. Troubleshoot as needed but plan to land at the nearest suitable airport.



Safe Pilots. Safe Skies.

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421 Aviation Way, Frederick, Maryland 21701 • Phone: 800/638-3101

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