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Fuel injection nozzles

Critical importance with a simplistic design

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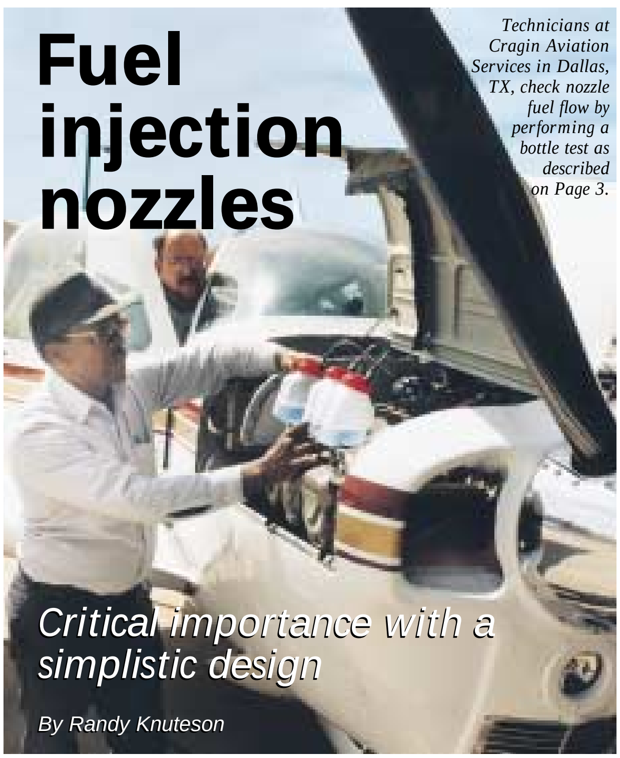


Technicians at Cragin Aviation Services in Dallas, TX, check nozzle fuel flow by performing a bottle test as described on Page 3.

Every fuel injection system made today requires that a calibrated device be used to accurately deliver a precise amount of fuel to each cylinder at the exact instant fuel is needed for combustion.

In high performance automobiles and industrial diesel engines, this is accomplished by combining an electrically operated sequence valve with a calibrated orifice in an effort to match precise flow with timed injection. It's a wonderfully complex series of events.

With the desire to maintain a simplistic design — one without need of moving parts — virtually all fuel injected engines made for general aviation utilize a continuous-flow fuel injection system. This means that fuel, under a given pressure, is sent to various components and finally delivered as metered pressure to the cylinder. Last in line for this delivery is the fuel nozzle.

Fuel nozzles are generally made of brass housings with either brass or stainless steel inserts. These inserts act as calibrated orifices and can vary in hole diameter to meet the flow requirement specified for the engine. Nozzles installed in normally aspirated engines are equipped with a stainless steel air bleed screen and shroud. This screen serves to filter the air as it enters the nozzle body. The resulting mixing of fuel with air helps atomize the fuel charge as it enters the intake port. Turbocharged engines do not incorporate this screen assembly but are equipped with a sealed "upper deck" shroud that allows the "Hiflow" nozzle to mix turbo deck air with the fuel for better fuel atomization.

Most nozzles are threaded into the cylinder at the intake port with a 1/8-inch pipe thread.

Some installations use a straight thread with a copper crush gasket (usually found with Continental GTSIO-520 engines). The other end provides a recessed cup to accept the injector line ball and a straight thread is used to secure the brass injector line "B" nut. Because fuel flows through the system in a continuous stream, regardless of piston position or stroke, the nozzle is placed upstream of the intake valve.

When the valve opens, fuel and air enter the cylinder. The size of the calibrated jet in the nozzle and the fuel pressure applied to this orifice will determine the amount of fuel delivered to the cylinder. Some installations, such as the Lycoming TIO-541 installed in the Beechcraft Duke, use a central plenum chamber in which all six fuel nozzles are affixed well upstream of the cylinders. Above the engine, air and fuel are mixed and the charge is routed to the cylinders via the intake pipes attached to the plenum.

Regardless of the design or style of nozzle, proper operation is critical to good engine performance.

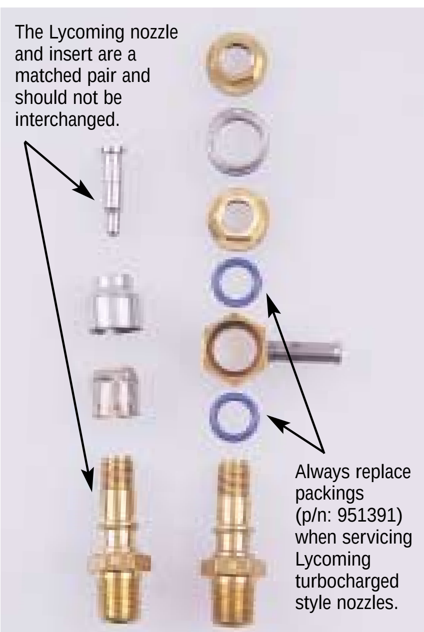
High output engines and nozzle function

Fuel injection is a necessary component for all high performance engines because the fuel to air ratio must be precisely controlled due to the extreme temperature and pressures found in high-compression turbo engines. Combine this with large displacement and multiple cylinder powerplants and the standard carburetor arrangement simply cannot deliver a precisely controlled fuel-air mix to all cylinders simultaneously.

For smaller engines, inlet-port fuel injection can increase the power output of an engine by merely reducing the temperature of the air charge, thereby increasing the density of the fuel and air mix. In most cases a 10 percent increase in power is achieved without any change to compression ratios or engine RPM; something a carburetor just can't do.

On engines where fuel is injected directly into the combustion chamber, the resulting spray pattern has a huge impact on the burn rate of the charge and the usefulness of the expanding flame-front. Fuel injected in this manner is better utilized if the entire combustion chamber is saturated with an atomized charge of fuel and air. For this reason, some large diesel engines use nozzles with two to 16 separate holes designed to provide a spray pattern that burns hotter and results in more complete combustion. Although efficient, the complexity of this system remains unsuitable for aviation use. However, the need for a consistent spray pattern — even from our single-point nozzle — remains vitally important.

Most fuel nozzles have an orifice pressed into the body of the nozzle. Some nozzles such as the two-piece Lycoming style have a stainless steel orifice that slides easily into the top of the nozzle body. These nozzles were introduced in 1981 for ease of cleaning the chambers within the injector body. Each nozzle and restrictor comes as a flow-matched pair from the factory. Because of this, special care should be taken to assure that the restrictor is installed in its original body. Failure to do so could result in a sloppy spray pattern and/or a diminished fuel flow.



Lycoming turbocharged and normally aspirated nozzles.

TCM nozzles have a press-fitted jet (orifice) that may be replaced at TBO. These jets may become partially restricted by contamination or possibly even oversized by fluid erosion. Some shops try to compensate for this change in fuel flow by increasing or reducing the spring tension against the pintle valve of the plunger assembly within the manifold valve. This action further masks the actual problem and should be discouraged. Such "corrective" measures tend to skew the flow and pressure curve established for the engine by the manufacturer. Instead, the jets should be replaced and the TCM maniflod valve reflowed in conjunction with the lines and nozzles.

Both the pressed-fit and the two-piece nozzle utilize the flow of fuel through the body and orifice to draw air through the air bleed hole(s) surrounding the nozzle circumference. The air-bleed assists in vaporizing the raw fuel charge and breaks the high vacuum created by the cylinder at idle. Chambers within the nozzle allow air to be pulled into the flow while preventing fuel from spilling out unless the nozzle becomes plugged with debris. This mix of air and fuel at the nozzle helps break up the solid flow of fuel and aids in better atomization in the intake port. This process of atomization is absolutely necessary, especially at lower power settings to ensure a smooth running engine.

The spray pattern at the nozzle is determined by the hole shape, size, fuel pressure, and the amount of ambient or deck-pressure air mixed at the nozzle. A good spray pattern will provide maximum atomization and smooth, consistent engine operation. Conversely, a nozzle with a dirty shroud or deteriorated upper deck shroud seals will not provide the same spray pattern as a clean unit. Likewise, if the calibrated orifice has become damaged due to rough handling or if the inside diameter of the orifice has been scratched or chipped by insertion of safety wire or some other equally offensive material, the spray pattern will never be right — despite the cleanliness of the screen or the condition of the shroud seals. The effects of such deficiencies are generally limited to rough and erratic operation; however, over time, a loss in cylinder efficiency could result. Symptoms often show up as severely staggered EGTs and CHTs. In the worst of cases, loss in flame-front propagation will result in combustion chamber "cold spots" and unwanted carbon deposits.

Routine maintenance

Unlike most aircraft components, fuel injection nozzles are not required by the engine manufacturers to be removed and cleaned at any particular time interval. Continental recommends removal and cleaning of the nozzles in the event a ground-run indicates some problem with the system. Precision Airmotive Corp. suggests in SB RS-77, Rev. 2, that cleaning occur every 100 hours or annually; whichever occurs first. In Lycomings SI# 1275B, cleaning the nozzles is accomplished on an "as required" basis. This situation leaves the cleaning of the nozzles up to the technician — some of whom only remove nozzles when they suspect one is partially plugged. In practice, there is no standard interval for nozzle cleaning, but there are several things to consider.

Engines that are flown on a regular basis and far exceed the nominal 80 to 100 hours of flight time per year, probably could accrue several hundred hours prior to the nozzles being removed for cleaning and seal replacement. On the other hand, engines that sit idle for prolonged periods or fly only a fraction of the average flight time per year should have the nozzles cleaned at each annual inspection. Obviously, any aircraft that is serviced with contaminated fuel, regardless of the extent of the contamination, should have its fuel injection system, including the nozzles, removed, cleaned, and possibly flow-tested.

Lycoming nozzle inserts are identified by notches around the circumference of the insert. All normally aspirated engines use the single-notch insert (also used by some turbo-charged nozzles). Two-notched inserts and stepped-tube inserts (not shown) are only used on turbo-charged nozzles.

The most common and naturally occurring form of contamination happens as fuel evaporates in the nozzles after hot engine shut-downs.

This evaporative process leaves minuscule deposits of varnish residue which build up over time. This residue in turn tends to inhibit the free flow of metered fuel to the cylinders. If left unattended, nozzles begin to clog, CHT readings begin to climb, and indicated fuel flow increases. This corresponding increase in indicated fuel flow (pressure) is an erroneous reading. In reality, back-pressure caused by partially obstructed nozzles diverts fuel to the gauge port of the flow divider.

The result is an increase in indicated fuel flow with the true metered fuel flow remaining unchanged. Pilots who excessively lean their mixture to compensate for this false indication risk damage to both their cylinders and their pocketbooks. Should an injector become obstructed or a nozzle become completely clogged, remove all nozzles for cleaning. The contamination typically does not limit itself to a single nozzle.

Removal of the nozzle is a straightforward procedure, but a few precautions are warranted. Remember, you are dealing with stainless steel injector lines. They will kink and crack if abused. The injectors themselves are brass and as such can be marred or distorted if over-torqued or removed using an ill-fitting socket. It should be noted that most injectors require the use of a 1/2- or 7/16-inch deep socket, hollowed out to allow an unrestricted fit over the nozzle shroud. Many socket brands are supported internally with a shoulder that won't allow a good fit on the injector. Try several brands of sockets until you find a six-point deep well type that fits easily over the wrenching

Lycoming nozzles: The nozzle on the left must be replaced due to wear caused by a loose fitting screen shroud. Always position Lycoming nozzles with the "A" facing down and the air-bleed hole up.

flats of the injector. Don't try to force the socket on the injector. To do so will require nozzle replacement.

When removing the injector, hold the socket and ratchet directly over the nozzle. If the injector is tight in the head, any side-load applied to the socket may break the nozzle off at the threaded portion. Your job will suddenly become much more difficult. Remember, the pipe threads are brass and the head is aluminum. When removing or installing the injectors, make sure all threads are clean and free of any burrs or rolled edges. Use a thread file or cleaning tap to restore damaged threads, and lightly oil the threads before torquing to the desired fit. Usually, not more than 60 inch-pounds. (Exact torque will depend upon engine model so refer to the engine manual for specifics.)

Ultrasonic cleaners

Many aircraft shops keep an old pint jar of gun cleaning solvent (usually Hoppes #9), and injection nozzles are generally thrown into this mixture and left overnight. In the morning the nozzles are removed, rinsed with MEK, and blown dry with compressed air. A quick look through the orifice is considered enough of an inspection. It's not.

All nozzles should be cleaned in some sort of ultrasonic cleaner. Ultrasonic cleaners are available in 110- and 220-volt configurations from a variety of sources. Ultrasonic cleaners tend to do a far better job than other less conventional methods. Some shops have large agitator tanks using 5 to 10 gallons of special-use cleaning fluid. While this method of cleaning is acceptable, the average maintenance facility wouldn't need the equipment or the added EPA expense for proper fluid disposal.

When using an ultrasonic cleaner, allow the injectors to remain in the solution for about one to three hours. Make certain they are supported on a screen that keeps the injectors off the bottom and away from any collected dirt and debris. Once cleaned, use clean compressed air to dry the nozzles and visually check for any orifice obstruction.

Testing procedures

Lycoming suggests a flow check of the nozzles, but this is difficult to accomplish without the aid of a flow bench. An alternate method that has proved successful in the field is the tried and true "bottle check." This procedure is accomplished by first collecting containers of equal volume capacities (baby food jars or soda bottles are suitable).

Next, reinstall the injectors on the injector lines. Do not screw the injectors into the cylinder heads. Place a container under each injection nozzle. Support the container by any creative means. With the mixture in the full-rich and the throttle in the wide-open positions, energize the boost pump pressure for a timed period. Thirty seconds to one minute should suffice. Be certain to visually inspect the discharge from each nozzle and look for a clear (nonatomized) column of fuel the size of pencil lead. Then place the containers on a flat surface and compare volumes while noting any discrepancies.

What this test amounts to is a contamination check, and it should not be construed as a calibration test. It's advisable to attempt this test more than once — switching the nozzles to ensure that the problem flow follows the suspect nozzle(s). Doing so will further isolate the restriction and reveal whether the problem is due to a kinked injector line or damaged flow divider port. Upon completing this task, reinstall the nozzles using all new seals and gaskets as required. When dealing with Lycoming nozzles be sure to position the flat of the wrenching hex with the letter "A" facing down. This positioning places the air-bleed hole upward and prevents any residual fuel from dripping out after engine shutdown.

Injector nozzles "tuned" for your engine

In an effort to mask some of the inefficiencies in the design of the average induction system, all air-cooled aircraft engines are provided with more fuel than would normally be required for operation. While it's true that these engines also need additional fuel for cooling purposes, especially at higher power settings, there is no doubt that air/fuel distribution is a compromise at best.

Many overhaulers and experimental engine builders have tried to alter the cylinder valve port and induction systems to allow a more equal flow of air and fuel to each cylinder. Though the benefits could be debated, the theory behind this effort is solid.

What this means for the injector nozzle is that fuel flow rates through a given nozzle in a given cylinder can be "tuned" to that cylinder's overall performance. This is what has been accomplished with General Aviation Modifications Inc. in Ada, OK, (GAMI) injectors.

GAMI offers engine sets of injection nozzles sized to meet the demand of each cylinder taking into consideration the propensity of one cylinder to run more or less lean than another on the same engine. The idea is to reduce your overall fuel consumption at a given power setting while maintaining adequate fuel/air ratios for all cylinders. Yes, it does work.

However, it should be noted that cooling plays a big role in the health and well-being of your air-cooled engine. A cylinder which peak EGT is first found in the climb might be the last to reach peak in cruise. In order to truly realize the full benefits of installing GAMI injectors (or the TCM brand of "Tuned Nozzles"), one must also purchase a graphic engine monitor to see the difference. The advantages of these tuned nozzle sets are most pronounced in updraft style induction systems (ie Bonanza engines). In these installations the tuned nozzles compensate for temperature changes and fuel migration through the induction system.

For information on GAMI fuel injectors, write 2800 Airport Rd., Hangar A, Ada Municipal Airport, Ada, OK, 74820; (405) 436-4833.

The two TCM nozzles (on the right) are identified by a number and a letter stamped on the wrenching flat. Each letter (A,B,C,D,E,J,K) denotes a +1/2 pounds/hour flow increase respectively. Example: At 12 1/2 psig, a 14B nozzle has a flow rate of 29 pounds/hour while a 14C is 29.5 pounds/hour. TCM manifolds reflect this increase/decrease in nozzle flow by a "P" or an "M" stamped on the divider data tag. Proper manifold and nozzle application may be found in TCM SIL 98-6B (The nozzle on the left is a Lycoming IO style.)

Final notes

Aircraft engine fuel nozzles lack much in the way of complexity. Their task is simple and their purpose is direct. Always use a torque wrench during installation, keep nozzles clean and any associated seals in like-new condition, use care in servicing the system, and avoid any internal or external contaminants. Practice these few considerations and your nozzles will perform as well at 10 hours in service as they will at 1,000 hours. AMT

Randy Knuteson is Director of Product Support for Kelly Aerospace Power Systems in Montgomery, AL.

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