Engines

Gas turbine engines are simply air pumps. Air is pulled into the intake of the engine and accelerated out the exhaust end. Let’s begin our engine discussion by comparing three general families of turbine engines in wide use today. Jet engines being built a few decades ago were what we refer to today as pure turbojets, or straight pipe jets. These engines pull air in, compress that air, mix it with fuel, ignite the mixture and then direct the exhaust gasses out the tailpipe. These engines accelerate a small column of air to a very high velocity. Just enough energy is extracted from the exhaust flow to turn the compressor. The volume of air displaced is small when compared to its velocity. These engines were by today’s standards simple to build but noisy due to the high velocity of the exhaust. Fuel efficiency is poor, especially at low altitudes. Though many of these engines are still in use, commercial production of these engines has all but ceased today.

The second family of gas turbine engines is the turboshaft/turboprop family. These engines incorporate additional turbine disks and blades, inserted into the exhaust path to extract as much energy as possible from the exhaust flow. Extracting energy from the exhaust gas path reduces exhaust gas velocity, therefore reduces noise and at the same time improves fuel efficiency. As much of this exhaust energy as possible is converted into torque to spin a shaft, hence the name turboshaft or turboprop. In many applications, this shaft is turning too fast and in some cases, in the wrong plane. A reduction gearbox is frequently employed to slow the shaft velocity down to a more useful speed. Typical applications for these engines are turboprop airplanes, helicopters and auxiliary power units installed on board some jet aircraft. These engines are among the most efficient of turbine engines and are being produced today in large numbers.

The class of turbine engines we are most interested in is the fanjet. The fanjet incorporates much of the turboprop technology, without the reduction gearbox or the propeller. Since the efficiency of a propeller begins to deteriorate as propeller speed increases above 2000 rpm or so, a reduction gearbox is always required on a turboprop. Though some do, most fanjets do not use reduction gearboxes. The fanjet solves the "propeller tip velocity" problem by allowing the propeller (fan) to turn at high velocity and place it in a tube or duct to improve efficiency. These engines are in wide use today and are still evolving. Fuel efficiency is continuing to improve while weight and number of moving parts declines. The following is a discussion of the Pratt & Whitney and Williams families of fanjet engines installed on the Citation.

The amount of thrust produced by a jet engine is the product of the weight or mass of the air being accelerated multiplied by the rate of acceleration. This thrust rating is described in pounds in the US and is usually defined as takeoff thrust. Takeoff thrust is available for a specified period of time, typically from 5 up to occasionally 10 minutes. This thrust rating is determined at standard sea level pressure and temperature, 29.92 inches of mercury and 59° F. Shortly after takeoff, power must be reduced to climb or maximum continuous thrust, typically around 95% of takeoff thrust, in order to keep internal engine temperatures below safe limits. As the aircraft climbs to cruise altitude, atmospheric pressure declines at the rate of roughly one inch every 1000 feet or so. This decline in pressure results in a further decay of thrust for numerous reasons. Since the air is thinner at altitude, there is less oxygen to support combustion, resulting in less fuel being burned and therefore less thrust being produced. This is proof of the law of conservation of mass and energy at work. Engine cooling also becomes a problem in this rarified air. In addition, the weight or mass of the air being accelerated by the fan diminishes with altitude. Since thrust is equal to mass multiplied by increase in velocity, when air mass declines, thrust declines. It is not uncommon for a light jet engine to produce only about a third or so of its sea level thrust at cruise altitude. While operating at high altitude in rarified air, aerodynamic drag diminishes significantly. This results in respectable cruise speeds at high altitude where thrust is reduced and fuel flow can be kept to a minimum.

As is true with any engine, some form of energy conversion must occur in order to accomplish its work. In our case the energy being converted is the chemical energy contained in jet fuel. The jet engine simply converts BTUs of heat into pounds of thrust.

The engines originally installed on 500, 550 & 560 Series Citations were built by Pratt and Whitney and are either members of the JT15D or PW-500 families. As of this writing, over 50 500/501 series Citations have undergone an engine conversion by Sierra Industries of Uvalde, Texas replacing the original JT15D powerplants with Williams FJ44-2A engines. In addition, Sierra is currently flying a Citation II and an SII with more powerful versions or the same engine platform, the FJ44-3A, with plans to market these conversions as well. It is encouraging to see these conversions taking place. The Citation family of aircraft have a lot of life left in them but the original engines on those aircraft were developed in the 60's and lots of advancement has taken place in metallurgy and thermodynamic engineering in the last 4 decades. Overhaul costs on these early Pratt powerplants, especially the -1A series installed on the original Citations, have increased to the point that a pair of new Williams engines with an electronic fuel controller should be considered as a reasonable alternative to overhaul. These FJ44-2A engines are rated at 2300 pounds of thrust, compared to 2200 pounds of thrust on the original JT15D engines. I have flown many of these converted Citations and the apparent difference in thrust is greater than the 100 pound difference in thrust these numbers imply. My guess is that engine thrust was calculated differently in the 60's than is the case today. Whether or not accessories such as hydraulic pumps and generators are installed also affects measured thrust output as well. Citation engines are medium to high bypass turbofans. Bybass ratios vary from a low of just over 2 to 1 to a high of 3.5 to 1 depending on model. This bypass ratio is the comparison of the volume of air forced around the engine and through the bypass duct compared to the air ingested into the core or hot section of the engine. With other factors equal, the higher the bypass ratio the more efficient and quieter the powerplant is.

Let's first analyze the gas path through an engine that we will assume to be running and producing steady state thrust. Air is first pulled in by the fan and split into two paths. The majority of this air is accelerated around the engine and pushed through the bypass duct by the fan. A lesser volume of air is ingested into the core of the engine. On all engine models except the JT15D-1A installed on 500 series Citation, this "core" air is then accelerated further by a booster compressor attached to the fan shaft. After the booster stage, injested air is then compressed by a centrifugal compressor. Only the original JT15D-1A engine does not utilize a booster axial compressor. The centrifugal compressor, also referred to as an impeller, functions as an air compressor and is located on the front of the N2 or turbine shaft.

JT15D Impeller

The impeller is a single piece of titanium milled into a shape that pulls air into the front of the engine when rotated, compresses it and discharges it centrifugally, hence its name. A small portion of this compressed air will become compressor discharge air, referred to as P3 bleed. Some of this P3 bleed we refer to as service air. Service air can consists of air used for ice protection, door seal inflation and air discharged through ejectors to create vacuum for various uses. In addition to service air, a larger portion of this compressor discharge air is environmental air, the air we will breathe. Compressor discharge air is very warm, typically over 500° F due to heat generated by compression. Some uses of bleed air such as environmental and windshield anti-ice require that this air be cooled. Compressor discharge air is also under high pressure and may need to be regulated to limit air pressure to a useable level. Environmental air, for example is regulated to a constant flow for cabin comfort regardless of power setting. There are also numerous 23 psi pressure regulators on the aircraft to limit bleed pressure for certain uses such as de-ice and to inflate the main cabin door seal. Another use for compressor discharge air is engine anti-ice. Bleed air used to anti-ice the engine is most often neither regulated nor cooled since its use requires high temperature and pressure to be effective. More detailed information on the handling of this compressor discharge air will be presented under the descriptions of systems that utilize that air such as Ice Protection and Environmental.

Compressed air that is not peeled off as P3 bleed is forced into a diffuser assembly. This diffuser assembly converts centrifugal flow into axial flow and forms an aerodynamically efficient path between the impeller and the combustion chamber. The combustion chamber is surrounded by a liner which is perforated with hundreds of holes allowing this compressed air to seep into the combustion region. A small percentage of the air that makes it into the combustion chamber will be mixed with fuel and burned.

However, the majority of that air will be used for cooling. Bleed air forms a cooling layer between the flame and the combustion chamber liner. It also cools the fuel nozzles, stators and high-pressure turbine. None of these surfaces could withstand temperatures this high for long without ventilation, so this cooling air is essential to engine longevity. Compressed air and atomized fuel are mixed in the combustion chamber and ignited. This combustion results in a rapid temperature rise and expansion of the fuel–air mixture. This hot and expanding air will seek a pressure and temperature equilibrium out the tailpipe. On its way out the tailpipe, this expanding air passes through three stages of stators and three turbine wheels. Stators are fixed vanes that direct this air onto the turbine blades at the optimum angle for efficient energy capture. Let’s discuss those stator/turbine pairs in more detail.

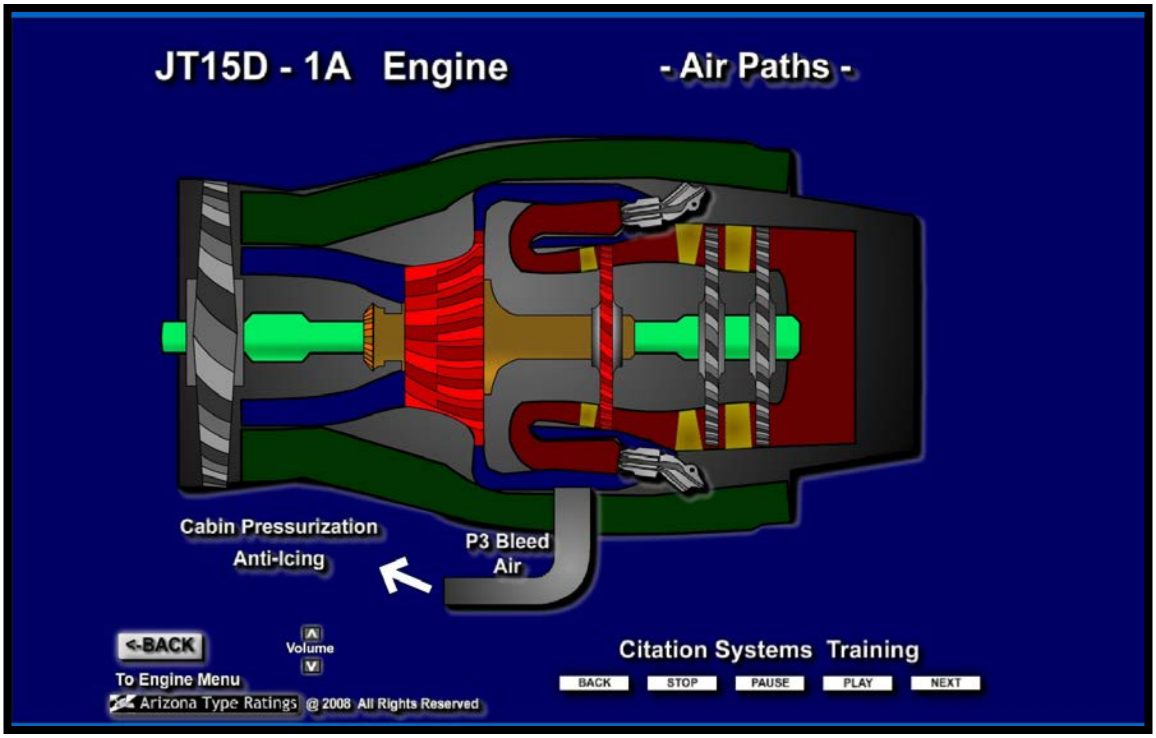
High pressure stators are located in front of the high pressure turbine wheel. These stators are frequently the first metallic engine component to be directly impacted by superheated gasses. These stator blades are hollow and compressor discharge air is forced through air passages in these stators for cooling. These stators will almost always need reconstructive welding work at the mid-life hot section inspection and at overhaul due to the thermal beating they take. Though the manufacturer refers to them as stators, a term I have heard that I like even better is “guide vanes”. Regardless of what name you prefer, the purpose of this hardware is to guide airflow onto the turbine blades at the proper angle for maximum energy transfer. If the angle of incidence onto the turbine blades is too shallow, little torque will be derived. If that angle is too steep, the blades will stall out and little or no torque will be derived. In both cases, there would be a deficit of torque to spin the centrifugal compressor and the engine will not perform properly.

Pratt High Pressure Stator

Immediately behind the high pressure stators is the high pressure turbine disk, sometimes referred to as the bladed disc assembly or HT (for high turbine) wheel. Turbine blades are inserted into fir tree slots milled into this turbine disk. These blades are actually very small airfoils which capture energy from the longitudinal flow of combustion gasses. Due to the way the blades are mounted on the turbine wheel, this flow of gasses is harnessed to create torque. That torque is applied to the N2 shaft, causing it to rotate.

High Turbine Disk with 2 blades inserted

The sole purpose of the high pressure turbine is to extract energy from the gas flow to drive the centrifugal compressor previously described. Energy extracted by the high pressure turbine results in the temperature drop that occurs immediately behind this turbine disk. Typical temperatures in the combustion chamber are in excess of 1000°C. Temperature in the region behind the high pressure turbine is measured and presented to the crew as ITT, or Inter Turbine Temperature. This temperature is typically in the low 600°C range. This temperature drop is the result of energy extracted by the turbine which is used to spin the centrifugal compressor.



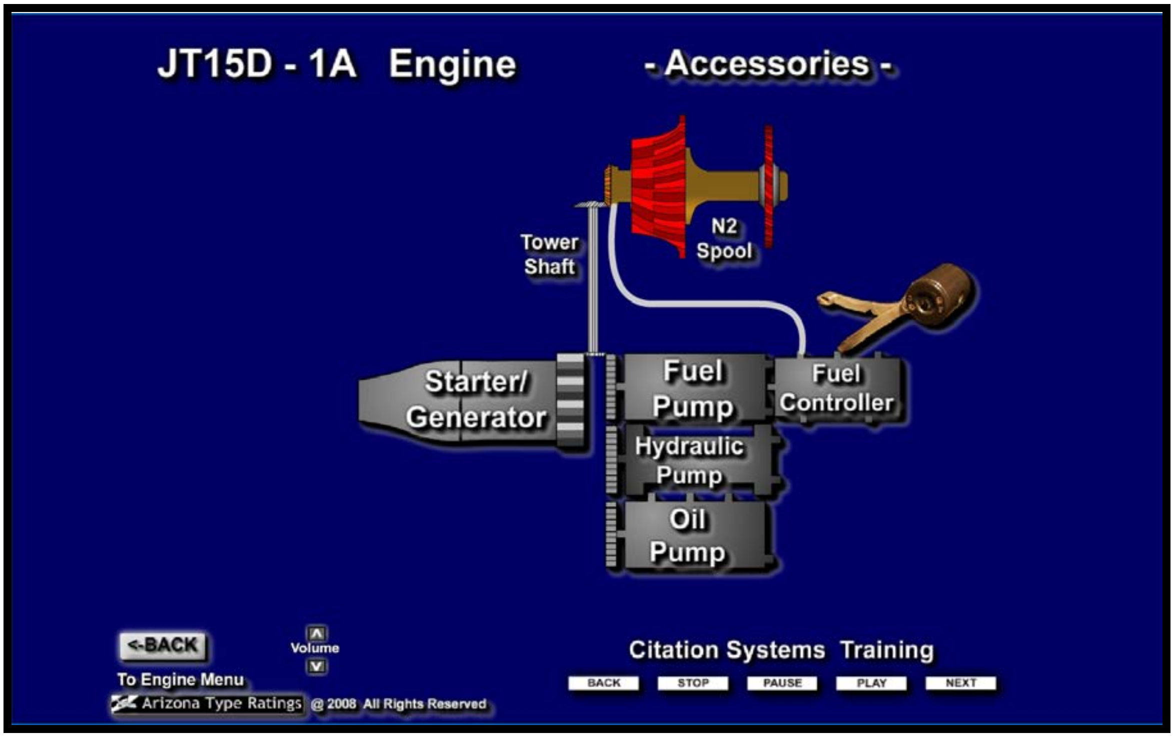
Basic Engine Assembly, Pratt

What has been described so far could actually be considered a jet engine itself. Exhaust gasses exiting the high pressure region of the engine could produce significant thrust if those gasses were ducted out the tailpipe unobstructed. However, those gasses would exit at very high velocity, make lots of noise and the process would be somewhat inefficient. What if additional energy could be extracted by placing one or more low pressure turbines and associated stators in the path of these exhaust gasses. Energy extracted by those turbines could then be used to turn a propeller, or in our case, a fan.

Downstream from the high pressure turbine reside two turbine wheels and associated stators in the exhaust gas path. These turbines are referred to as low pressure turbines and they extract additional energy from the exhaust flow. As a result, exhaust gasses exit the tailcone at a slower velocity, reducing exhaust noise and increasing efficiency. Energy extracted by the low turbines is converted to torque and this torque spins the N1 or fan shaft. The fan spins at a very high speed of about 16,000 RPM, too fast to operate efficiently in free space so the fan is housed in a tube known as the bypass duct. This fan accelerates air aft, some of which actually enters the engine core but most of which bypasses the engine completely. The fan shaft extends from the aft end of the engine where the low turbines are located to the front of the engine where the fan is located. The final low pressure turbine and blades are actually visible by looking into the tailpipe. The N1 shaft is threaded through the center of the larger diameter N2 shaft previously discussed. Whether being viewed from the front or the rear, the shaft you can see in most fanjets is the N1 shaft.

Thrust varies from 2200 lbs to just over 3000 lbs for the JT15D family of engines and up to 3400 lbs for the PW-535 engine. These thrust ratings are for takeoff thrust at sea level, ISA conditions and available for short time periods, usually 5 minutes. The engines installed on original Citations are of the JT15D series. PW-530 engines are installed on the Bravo and PW 535 and 535B Engines are installed on the Encore and Encore+. As of this writing, the only current production Citation is the "Encore+" which is powered by the PW535B engine. These later engines are of a more modern design with fewer parts and better specific fuel consumption figures but similar in basic design. Differences include a single piece fan instead of a fan composed of an assembly of the hub and individual blades. This hardware actually first appeared on the JT15D-5D engine installed on the Citation Ultra. PW500 series engines have only 11 dual orifice fuel nozzles instead of the 12 installed on the JD15D family of engines. In addition, the low pressure N1 shaft on the PW500 engines rotates in a counterclockwise direction, opposite of the N2 shaft. Spinning the fan shaft opposite to the turbine permits somewhat improved airflow. The primary advantages of the PW500 series of engines is that they contain fewer moving parts, are more maintenance free and thermodynamically more efficient.

The previous discussion describes the gas path through an engine that is up and running producing steady state thrust. So what happens and in what order when the captain presses the start button? The following explanation will follow the events and the gas path through an engine being started.

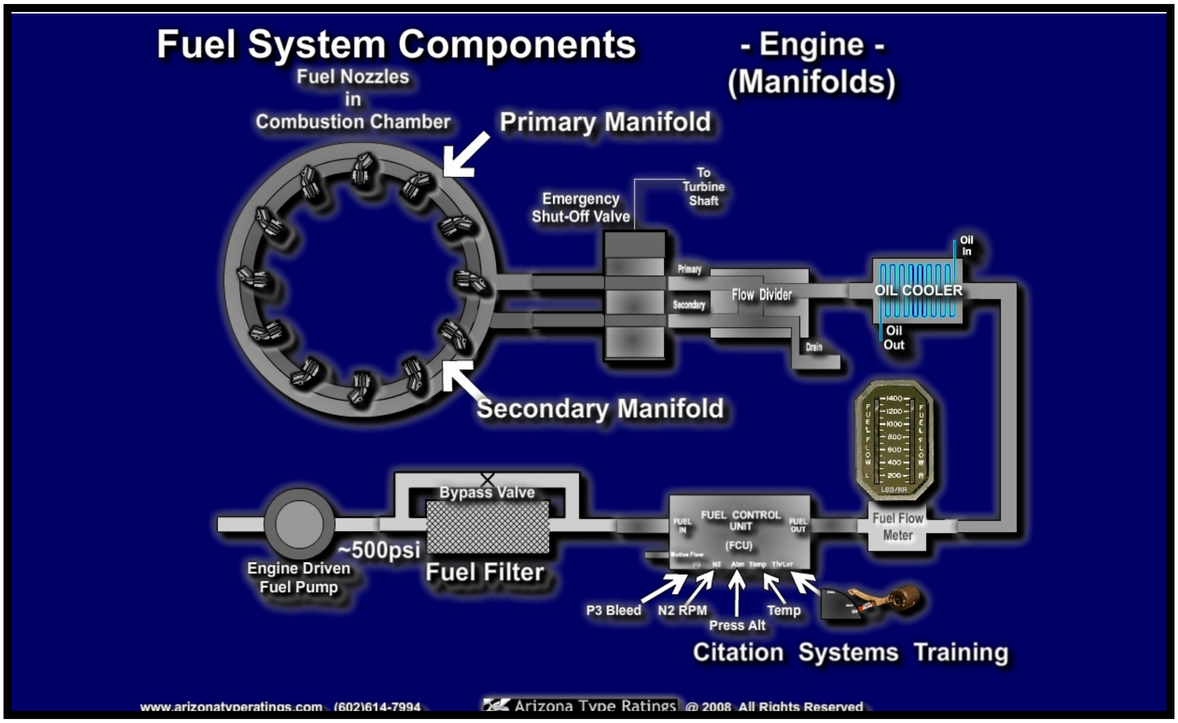


Accessory Drive Section, showing starter-generator

The starter used on the Citation engine is both a starter and a generator. This starter/generator is bolted onto and always turns with the accessory gearbox. It does not engage or disengage. This device either turns the engine by acting as a starter motor or if the engine is running, the starter/generator is being turned by the engine and is acting as a generator. Its function depends on whether the start relay or the generator relay is powered closed.

The start button is both a switch and a light and is located on the lower left captain's panel. Pressing the start button causes several events to take place. Most significantly, it completes a circuit resulting in the start contactor being powered closed, energizing the starter which rotates the turbine shaft through the accessory drive and tower shaft. In addition, the start button itself illuminates indicating start relay closure, the boost pump is energized as is evidenced by the associated “Fuel Boost On” annunciator and the engine instrument floodlights are illuminated. The ignitors are then powered as the thrust lever is advanced out of cut-off, courtesy of the ignition enable microswitch on the throttle quadrant. The start contactor delivers electrical power to the starter windings causing the armature to rotate. The armature is spline coupled to the accessory gearbox which in turn rotates the tower shaft and N2 shaft. The engine driven fuel pump is also mounted on the accessory drive and is therefore being rotated by the starter as well, providing pressurized fuel to the fuel control unit at constantly increasing pressure as a function of RPM. However, no fuel will flow to the engine until the thrust lever is moved out of cut-off. With the exception of the Encore+ and Williams FJ44 conversions, the fuel control unit is an all-mechanical unit with no electronic control and is bolted onto the aft end of the fuel pump. The throttle cable runs from the thrust lever in the cockpit to this fuel control unit. The “Engine Start Checklist” instructs the crew to move the thrust lever out of cut-off only after a specific N2 RPM, typically 10% or so is achieved. The purpose of this delay before introducing fuel is twofold. The first is to assure that adequate fuel pressure is available to atomize the fuel into a very fine mist which can be easily and completely burned. Since engines are designed to be reused and started several thousand times, it is important to minimize thermal stress in the hot portions of the engines during start. To that end, neither liquid fuel nor flame should ever contact the metal combustion chamber liner. Delaying the introduction of fuel until at least 10% N2 insures adequate fuel pressure to accomplish this. Secondly, as turbine RPM increases, the volume of air pushed through the engine increases. This increasing volume of airflow translates to an increasing cooling flow, keeping internal engine temperatures in the safe range.

Downstream from the fuel control unit, fuel now flows through a liquid-to-liquid heat exchanger used to cool engine oil and then through a flow transmitter which drives the “fuel flow” tape in the cockpit, indicating fuel consumption. Fuel then flows through a flow divider which splits fuel flow between primary and secondary flow as a function of engine RPM. Primary fuel flow is used for start and low power applications and both primary and secondary flows are utilized for high power operations. And finally, before entering the nozzles fuel flows through an automatic shut-off mechanization which will shut off fuel flow should the N1 shaft shift aft or stretch a mere .07 inches. This auto shutoff device will terminate fuel flow to the engine should the two halves of the N1 shaft separate or should a large bird hit the fan or bullet, displacing the N1 shaft aft.



Engine Fuel System

Fuel has finally made it into the nozzles, providing a fine mist of fuel that should completely burn as long as fuel pressure to the nozzles is adequate. Now that we have fuel to the nozzles, the other ingredients we need for combustion are a source of ignition and air, or more accurately oxygen. Ignition is initiated by a microswitch mounted on the thrust lever, introducing ignition automatically when the thrust lever is positioned out of cut-off during engine start. The source of ignition is either one or two capacitive discharge exciter boxes mounted on the engine case, firing 2 igniters in the combustor. Ignitors are basically glorified spark plugs.

The fuel delivery system to the combustion section is significantly different on the FJ44 family of engines. The fuel control unit itself operates electronically on the Sierra conversions and the Encore+, vs hydro-mechanically on the early Pratts. This relieves the crew of having to adjust power constantly during takeoff, climb and cruise. In addition, the FJ44 engine does not utilize fuel nozzles. It instead utilizes a unique and very effective fuel slinger, which harnesses centrifugal force and pressure from the engine driven fuel pump to atomize fuel into the combustion chamber. This slinger spins with the N2 shaft and slings fuel out centrifugally through tiny holes into the combustor.

We have delivered fuel and a source of ignition to our engine, leaving only air, our last ingredient to enable combustion. Compressed air is provided by the air compressor or impeller previously described, mounted on the front of the N2 shaft. Remember that the tower shaft runs from the accessory gearbox up to the front end of the N2 shaft, rotating that shaft during engine start. The impeller sucks air in through the fan, compresses it and forces that air aft and into the combustion chamber through holes in the combustion chamber liner.

We now have fuel, compressed air and ignition, the ingredients for a fire, all present in the combustion chamber. The fuel and air mixture in the combustion chamber ignites and the mixture expands due to the heat generated by this combustion. The exit path provided for these gases is through an assembly of stators and turbines designed to extract energy from the gases passing through them.

First, the high pressure turbine on the aft end of the N2 shaft extracts energy from the combustion gas path to spin the N2 shaft and thereby spins the compressor mounted on the front end. This process results in the N2 shaft increasing in RPM. At this point the starter and high pressure turbine are combining forces to accelerate the N2 shaft. Both starter and turbine torque are required for the first several seconds after fuel introduction to keep temperatures reasonably low by forcing cooling air through the combustion chamber. The start sequence terminates automatically when starter assistance is no longer necessary and the N2 shaft can continue accelerating as a results of torque generated by the high pressure turbine alone.

Shortly after the turbine section comes alive, exhaust gasses are expelled out the tailpipe through the last two stators (guide vanes) and low- pressure turbines. These low turbines are mounted on the rear of the N1 or fan shaft. When you look up the tailpipe, the blades you see are the final low pressure turbine blades. Those turbine blades are driven by exhaust gasses exiting the tailpipe and they in turn are now spinning the fan shaft and fan. Typically, several seconds will lapse between N2 rotation and N1 rotation during engine start. The force that spins the fan shaft is exhaust gas flow, and it takes a few seconds for the turbine section to spool up and create exhaust of adequate velocity to turn the fan. However, the fan will actually become the dominant source of thrust as fan RPM increases, especially at low altitudes. Now that the fan is spinning, it forces air aft, some of which is ingested into the core of the engine as previously described. The majority of the air pumped aft by the fan bypasses the engine core altogether and passes aft through the bypass duct. Think of the air pumped through the bypass duct as you would the air pushed by the propeller of a prop airplane. The fan is actually nothing more than a ducted propeller.

Unlike internal combustion engines, the operator does not terminate the start sequence by releasing a start button or key. The start sequence on turbine engines is automatically terminated, usually as a function of turbine or N2 RPM. On early Citations, a component in the fuel system known as the motive flow pressure switch terminates the start sequence as a function of fuel pressure. This pressure switch will be described in the fuel system chapter. The start sequence is terminated in later and modified Citations by a speed sensor in the generator control unit. By whatever means, the start process should be automatically terminated without crew action.

The N2 shaft should now be idling in the mid 40 to 50% RPM range and the fan in the 30% range, depending on altitude. As the engine lit off, the crew was hopefully monitoring ITT to assure it remained in the acceptable range, typically below 500°C on Pratt powerplants and significantly higher on FJ44 engines. Starting ITT can approach 1000°C on the tighter Williams engines. Oil pressure was hopefully also noted to assure that proper lubrication of the engine was taking place.

As mentioned earlier, the total thrust of these engines will diminish significantly on climb out. The fan produces the majority of the thrust down low while operating in heavy, dense air. Most of the erosion of thrust that occurs during climbout is the result of the diminishing of thrust contributed by the fan. As we climb into rarified air, the weight of the air being pumped by the fan is reduced due to lower air density, resulting in a constant decay of thrust being generated by the fan.

The load the fan experiences is the weight of the air it pushes through the engine. The weight of that air diminishes with altitude so the load the fan sees also diminishes, resulting in a steady increase in fan RPM on climbout. Unless the airplane is equipped with an electronic fuel controller, the crew will have to keep an eye on fan RPM during the climb to assure engine RPM limits are not exceeded. As previously mentioned, the only 500 series Citation equipped with electronic fuel controllers is the Encore+.

While fan thrust is diminishing significantly in the climb, turbine thrust is diminishing also, but by a much smaller percentage. The reason turbine thrust is reduced with altitude is a little more complex. Incorporated into the fuel controller is a governor with springs and flyweights much like a prop governor, only smaller. Instead of porting oil to twist propeller blades however, this governor ports fuel to keep N2 on speed. Just as is the case with the fan, the load the centrifugal compressor experiences is a function of air density. As air density diminishes with altitude, compressor load is reduced, resulting in a tendency of the N2 shaft to speed up. This increase in RPM causes the flyweights to spin faster and they are pulled out by centrifugal force, compressing a spring and driving a valve to a slightly more closed position. All of this results in less fuel being delivered to the engine, keeping N2 on speed. As a result of this governor action, N2 should not change in the climb as long as thrust levers are not moved. This governing action is electronic on the FJ44 family of engines.

Unlike the turbine, the fan is not governed and must be maintained at a safe RPM by the crew. As mentioned earlier, the load the fan sees is also a function of air density and like the turbine, its tendency is to accelerate in the climb. However, since air temperature declines with altitude, a higher fan setting is acceptable at high altitudes. The permitted increase in fan frequently tracks temperature drops that occur with altitude on some Citation models and others require constant attention to prevent the fan from overspeeding. With proper climb power set, the typical Citation will climb out in the low 600°C ITT range.

However, you still should confirm climb power with the climb charts by comparing actual temperature and altitude to those published values.

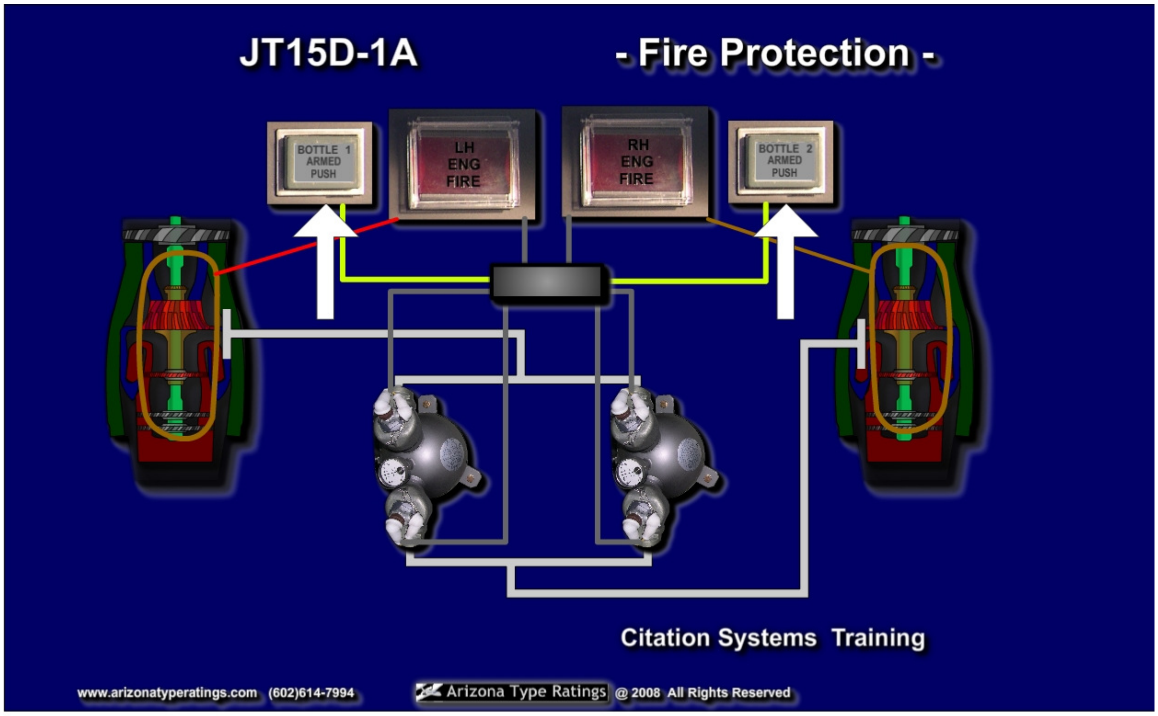
We actually have two engine limits to be aware of while setting takeoff power, climb power and cruise power. The absolute RPM limit on the fan is a centrifugal limit of 102.1% for example on a JT15D-1A engine, 104% on a -4 engine etc. These limits are not to be intentionally exceeded at any time regardless of conditions. In addition, there is a thermal limit which also may not be intentionally exceeded. Setting takeoff fan at the maximum allowed setting per the takeoff charts will frequently result in an ITT in the high acceptable or yellow range as the aircraft accelerates down the runway and into the air. ITT should not rise into the red range on takeoff. ITT is permitted in the yellow for up to 5 minutes, but most prudent operators prefer to keep ITT below the yellow band, even for takeoff. To this end, we frequently use a more conservative reduced takeoff power setting when we are not runway limited. There are actually "Simplified Criteria" charts provided in the AFM and checklist to document this procedure. Among the advantages of the electronically controlled engines, specifically the P&W 535A and FJ44 engines, an electronic fuel control unit will keep all engine parameters within acceptable range during all phases on flight, requiring minimal attention from the crew.

These takeoff and climb power settings vary with altitude to a degree but are primarily a function of temperature. Even though we are setting fan, we are actually always limited by engine temperature on takeoff. Cessna and Pratt have saved us the trouble of setting takeoff and climb power by watching ITT. They have given us a fan setting that will keep ITT within safe limits at a defined temperature and altitude. If you have flown any of the popular turboprops, you probably recall setting takeoff torque and then shifting to ITT to set power by as you climbed out. We are relieved from this complication by the “Takeoff Power” and “Climb Power” charts provided. Setting fan per the charts will always result in an acceptable ITT, assuming a healthy engine.

Hopefully one of these descriptions on turbine engine gas paths has enlightened you on just how the Citation engine works. Just think of a fanjet engine as an air pump using jet fuel as an energy source. The fanjet’s turbine section accelerates a small column of hot gasses to a high velocity. This air is pushed through the inner path through the engine’s core and constitutes the hot exhaust flow. Wrapped around this core air is a much larger volume of lower velocity bypass air. The fan contributes most in fuel efficiency at low altitudes during climb and descent. The fan also makes the airplane a good neighbor by holding noise level to a minimum. Next, let’s examine some support systems installed on the Citation’s engines.

Fire Detection and Extinguishing

Fire detection on the Citation family of airplanes is provided by thermally sensitive loops in the engine nacelles. These loops pass around the engine such that they sample temperatures at numerous areas deemed subject to fire or bleed leaks. These loops could employ numerous technologies to detect high temperatures in the nacelles. One technology consists of an inner and an outer conductor with a layer of semiconductor material with inverse temperature – resistance qualities layered between them. In most conductors, as temperature increases, resistance increases. The layer of semiconductor material in the sensing loop behaves in the opposite manner. As temperature increases in the loop, resistance decreases. At some temperature, typically around 500°F the resistance diminishes such that current flow between the inner and outer conductors is adequate to illuminate the red Fire Switchlight. This device I am calling a switchlight is exactly that, a switch and a light. The light illuminates to indicate an excessively high temperature in the engine nacelle. The switch shuts down the engine when depressed. The two operate independently. The light merely indicates an abnormally high temperature. The switch closes motor-driven firewall shut-off valves when pressed, shutting down the engine. The switchlights do not have to be illuminated to work as switches. The only use I have ever made of the fire switch is to shut down an engine when the throttle linkage has locked up. This can happen in the pylon or throttle cable itself. It is rare, but throttle cables and the pushrod that operates through the pylon are subject to locking up due to extremely cold temperatures, improper lubrication or simply mechanical events such as kinks, excessive pressure and tight bends. This problem is most likely when departing a warm moist environment where moisture is likely to condense on and in the throttle cables and eventually freeze as the aircraft climbs into the flight levels. Should this happen, you will notice the thrust lever meets resistance when moved by the crew and the fuel control unit may not respond at all to thrust lever movements made in the cockpit. If the throttle cable cannot be broken free, the engine will eventually have to be shut down with the fire switch.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Engine Fire Detection and Extinguishing Schematic

Should the crew observe an illuminated fire light, the memory response is to retard the associated thrust lever to idle. Statistically, this will nearly always extinguish the fire indication. If it does, simply land the airplane with that engine at idle thrust. If idle thrust does not extinguish the fire light, the memory items continue to include lifting the clear plastic cover on the illuminated switchlight and press it. This has the effect of powering the fuel and hydraulic firewall shutoff valves to their fully closed position, shutting down that engine and terminating the generator on that engine. When the red switchlight was pressed, both white “BOTTLE ARMED PUSH” switches should have illuminated. Both bottles are now armed towards and will fire into the effected engine. Pressing either illuminated white light will fire a pyrotechnic charge known as a squib, vacating either bottle “one” or bottle “two” into the engine nacelle of the effected engine. These bottles contain either a Freon gas historically used in the refrigeration business or Halon. This gas smothers the fire and then disperses into the atmosphere. This last step concludes the memory items on the “ENGINE FIRE” checklist. The crew should next consult that checklist and continue with the published steps, which essentially consist of an engine securing procedure. Some variation between models may exist but essentially those instructions include selecting the affected ignition switch to “NORM”, pulling the effected thrust lever to cut-off and selecting the effected fuel boost pump and perhaps generator switches to their “OFF” positions. As always, consult the checklist on the aircraft involved and follow it.

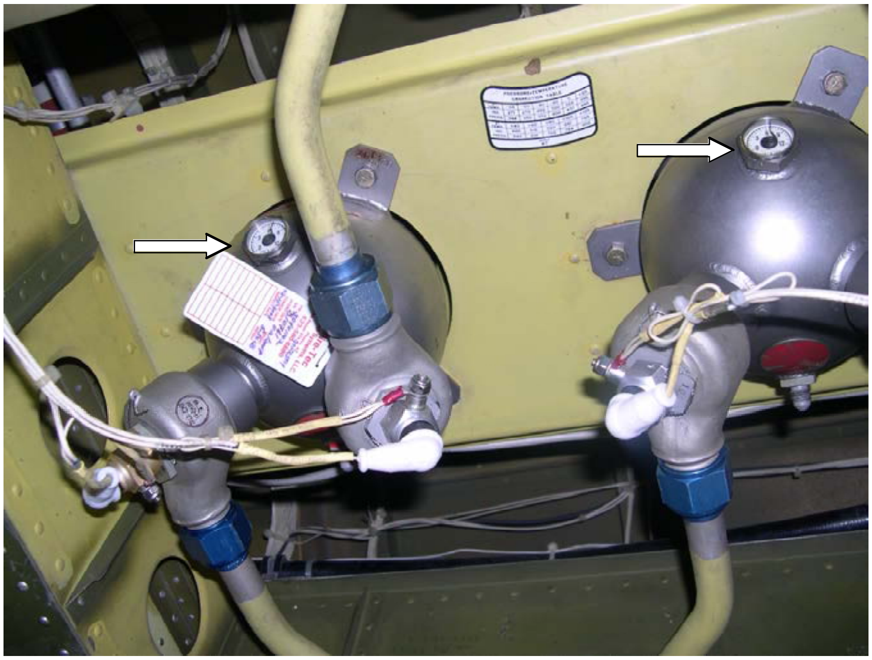
A word on securing engines in multiengine jets. If you are unlucky enough to experience an engine fire warning immediately after takeoff, I would suggest that you not pull the associated thrust lever to idle until the aircraft is at a safe altitude. Generally speaking, I would consider a safe altitude to be turbine pattern altitude or 1500 feet above the ground. Avoid creating an engine failure for yourself close to the ground by intentionally retarding a thrust lever, especially if no secondary fire indications are present. In other words, if the engine seems to be producing normal thrust, let it run at least until arriving at pattern altitude and then retard the thrust lever and perform the memory items on the checklist. The probability of the warning being due to an actual fire is low, statistically near zero probability. I know of no documented fires on Citations to this date.

Over the years of instructing in both Citations and Citation simulators, I have observed numerous times experienced crews pull the wrong thrust lever to idle and occasionally to cut-off. They just shut down the healthy operating engine. Following an engine abnormality on takeoff, NOTHING YOU DO TO THE THRUST LEVERS BETWEEN V1 AND PATTERN ALTITUDE IS NECESSARY. Unlike multiengine piston aircraft, there is no performance improvement gained by securing a jet engine. Securing jet engines simply reduces the probability of collateral damage to that engine. Do not let fiddling with a published

"Engine Securing Procedures" distract you from the most important chore at hand, that of flying the airplane. In addition to shutting down the wrong engine, I have also observed crews get so distracted with securing an engine that they do not properly set up and execute the instrument approach procedure. Should a fire indication or an engine failure occur in flight and time is available to properly secure the engine, then by all means do so. Just don't let securing an engine distract you to the point it compromises your ability to fly the airplane.

The fire detection and extinguishing system should be confirmed operational during the preflight and then during either the cockpit check or the before start check. It is apparent that many crew are not comfortable performing a complete check of this system. Many have never been introduced to a comprehensive fire system check so let's walk through one.

During the exterior preflight, the pressure gauges on the fire bottles in the tailcone should be visually observed to be in the 600 psi range, a little higher if it's hot outside and a little lower if it's cold. The system will check fine in the cockpit with an empty fire bottle. The only way to determine the bottles are charged is by visual inspection.



Fire Bottles showing pressure gauges

To some degree, part of the fire system check is performed when the battery switch is selected on. If the fire switchlight illuminates when the battery switch is selected on, a kinked, pinched or somehow shorted fire detection loop is likely the cause. This problem must be corrected before flight. A fire indication when the battery is switched on would most likely occur immediately after some form of maintenance has been performed.

There is a rotary test switch on the captain's left switch panel with a number of positions. The first clockwise position is usually labeled "FIRE WARN". Selecting that position should illuminate both red fire switchlights. This indicates that both fire loops are connected at both ends and are not open anywhere along the way. Frequently, the crew will simply observe this light and move on to the next position. However, there is more to check in the "FIRE WARN" position. If you lift the clear plastic guard over the left red switchlight and press it, you command the fuel and hydraulic shutoff valves to the left engine to close. Each of these valves is equipped with a position microswitch which indicates that shutoff valves is closed. These position microswitches are wired in series, so both valves must close in order to complete a loop through and to illuminate the “L F/W SHUTOFF” annunciator light, located roughly in the middle of most annunciator panels.

These shutoff valves are bi-directional DC motor driven valve bodies. They remain in their last position when electrical power is removed from or lost to these valves. Let’s explain the logic here. These valves could be manufactured to fail closed with power loss, fail open with power loss or remain in their last position with power loss. Failing closed is out of the question. This arrangement would shut down an engine if the valve lost electrical power and would shut down both engines if the entire aircraft lost electrical power. This would not be a good design feature. Another choice would be to fail open with power loss. This arrangement would certainly be superior to failing closed, but it does have one flaw. Let’s say you are destined to make history by suffering the first

Rotary Test Switch

actual engine fire on a Citation. You pull the throttle to idle, shut down the engine with the fire switch and proceed to fire a bottle into that engine. Then due to the fire, the electrical system is compromised and you suffer a complete electrical failure, which is certainly conceivable. The firewall shutoff valves you just closed would open, possibly delivering fuel to a burning engine. This is admittedly a bit of a long shot but possible and avoidable. The solution is to design the shutoff valves to remain in their current position with a loss of electrical power, whatever that position is.

Per this design, a given polarity of DC power closes the firewall shutoff valves and when that DC power is removed, the valves remain closed. You accomplished this by pressing the red fire switchlight once. In addition to closing the firewall shutoff valves, this position tests the squibs on the fire bottles themselves. As mentioned a few paragraphs back, these squibs are pyrotechnic charges that act as valves. There are four squibs in the tailcone, two on each bottle. One squib on each bottle is plumbed to each engine. When you pressed the left red fire switchlight you armed one squib on each bottle plumbed to the left engine. If the wires are tied down on the squibs and there is DC continuity through each squib, the white “BOTTLE 1 ARMED PUSH” and “BOTTLE 2 ARMED PUSH” lights will illuminate. You have just concluded with reasonable certainty that either squib will fire into the left engine if the associated white “Bottle Armed Push” switch is pushed. Pushing the guarded left fire switchlight again will re-open the fuel and hydraulic shutoff valves, extinguish the amber L FW SHUTOFF annunciator light and extinguish both white bottle armed lights.

This test may now be repeated in its entirety for the right engine, confirming that the right engine can be shut down with the fire switchlight and that the other two squibs can be fired into the right

Fire Switch-Lights and Bottle Armed Lights

engine. If engines were running and generators were on line, one additional event would occur when the fire switchlight is pressed. The field relay on the effected engine is also tripped by the fire switchlight. During our test, neither engines nor generators are operating, so tripping the field relay has no visible effect. This feature is designed to keep residual voltage produced by a windmilling generator out of the feeder cable which runs through the nacelle and pylon. If the feeder cable were damaged by fire, arcing could occur between the feeder and the airframe due to a windmilling generator, aggravating the fire hazard.

There is one precaution to performing this test completely. DON'T PUSH THE ILLUMINATED WHITE "BOTTLE ARMED PUSH" SWITCHLIGHT. These bottles will fire sitting on the ramp if this test is not done properly, which may explain why many crews forego this last step in the check. Unfortunately, I have witnessed first hand what happens when a student gets confused and presses the white "BOTTLE ARMED PUSH" light and it is very exciting and a little expensive. The fired squib is history, the bottle is empty and the airplane is unairworthy. Fortunately the extinguishing agent is a gas and it disperses leaving no residue to clean up. There is cost associated with replacing the squib and recharging the bottle. This mistake is at best a thousand dollar mistake and could be twice that, depending on transportation costs, urgency to get the airplane back in the air and status of the fire bottles themselves.

In all fairness, Cessna does not explain this test in detail in its checklist and many maintenance facilities unofficially suggest you might not want to perform this complete test before each flight due to wear and tear on the firewall shutoff valves. You have to go to the system description section in TAB II of the factory “OPERATING MANUAL” for a detailed description of this test.

We have now confirmed that both engines can be shut down with the fireswitches and that both bottles can be fired into both engines. This last statement assumes there is extinguishing agent in the bottles. As mentioned previously, this test will appear normal with an empty bottle, as long as the bottle was not emptied by firing a squib. The only way to assure the bottles are charged is to visually inspect pressure gauges on the bottles themselves during pre-flight of the tailcone. These pressure gauges will read roughly 600 psi on a standard day, a little less when cold and a little more when hot. A temperature – pressure correction chart near the bottles in the tailcone provides a reference for nonstandard temperatures.

In addition to the engine fire emergency discussed above, there are two other red annunciator lights associated with the engines, left and right “OIL PRES LO” annunciator lights. These lights are located on the annunciator panel. They indicate that oil pressure has dropped below the acceptable minimum pressure. Depending upon model, between 20 and 45psi will trigger the pressure switch which turns on this light. The problem is most often lack of oil, due to either a missing, improperly secured or defective oil filler cap/dipstick. If the filler cap is not properly replaced or is defective, pressure will frequently blow the dipstick out and oil will be pumped overboard in a matter of minutes. If you experience an “OIL PRES LO” annunciator just after takeoff, loss of oil is a likely cause. Low oil pressure can also be the result of a failure of any element in the oil pump.

The abnormal “LOW OIL PRESSURE” Checklist will spell out action to take depending on pressure indicated on the oil pressure tape. Depending on serial number, the oil pressure tape and light may be driven by a single pressure transducer. In other cases, the light is driven by a pressure switch and the tape is driven by a pressure transducer. To summarize, the checklist will essentially suggest you shut down the engine if the tape and light agree. The checklist may then suggest you operate the engine at reduced thrust if the tape is only in the yellow range and the red “OIL PRES LO” annunciator is illuminated. In any airplane I own or am responsible for, I would tend to err on the side of caution and shut down an engine with a low oil pressure light illuminated regardless of what the tape reads. The risk of continuing to operate an engine without oil or oil pressure is severe engine damage, an un-necessary financial risk for my wallet. We are not going to continue the flight with an oil pressure problem and you certainly do not need both engines to descend and land the airplane, so why take the risk? Secure the engine and land the airplane as soon as practical.