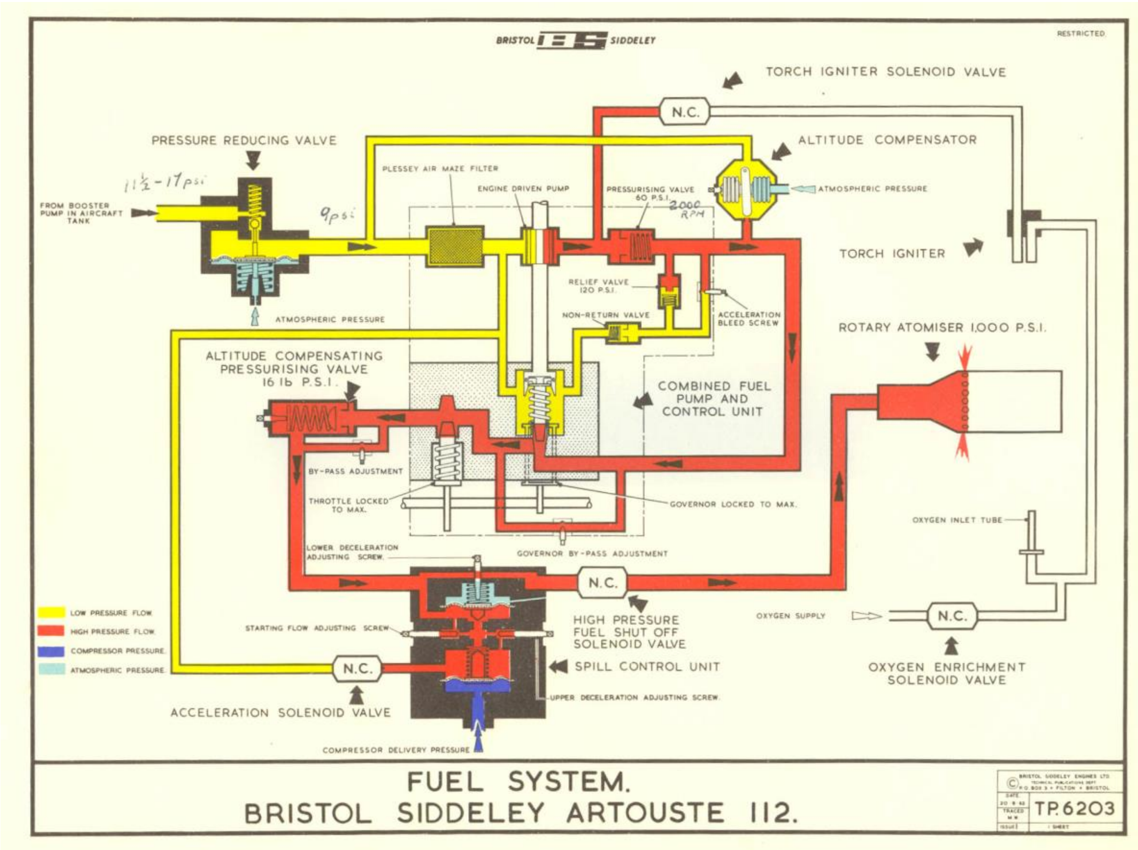
Chapter 2

Fuel Systems



A complex part of a typical small gas turbine is the fuel system. Small gas turbines in a similar way too much larger units make high demands on the fuel systems. A typical fuel system is required to start and accelerate the engine, govern or control the engine at one or more running speeds, maintain a given speed under load conditions and in many designs, the engine must be protected against excessive exhaust gas temperatures and compressor surging.

All small gas turbines are designed to operate on Jet fuel such as Jet A, Jet A1 and JP4, these fuels are similar to Kerosene. Paraffin is a type of kerosene, as is 28 second heating oil and gas oil. Small engines will run satisfactorily on any of these fuels, tolerance of differing fuels is one of the advantages of the gas turbine engine. As the combustion process is continuous and takes place at constant pressure, there are no problems with detonation or pinking. Detonation or pinking which is associated with piston engines significantly limits their performance. Certain designs of gas turbine intended for specialist stationary applications may be operated on natural gas.

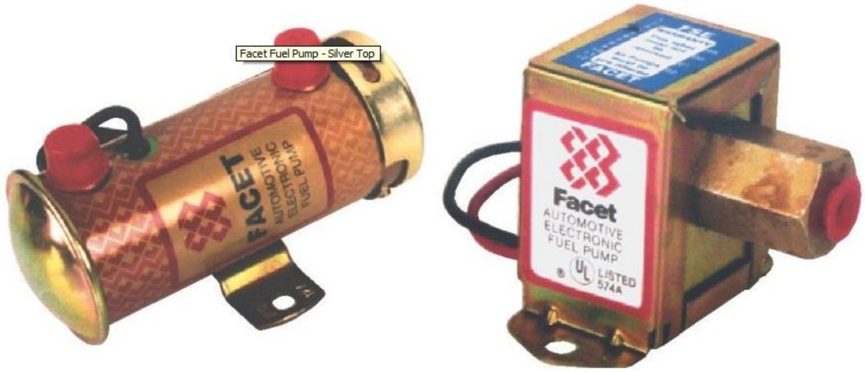
Many small engines may be operated on Diesel fuel or Petrol (Gasoline), the basic performance of the engine will be unaffected but prolonged use is not recommended for several reasons.

Some diesel fuels contains sulfur that may deposit itself on components in the fuel system. Certain fuel pump components are often silver-plated which will be damaged by the sulfur content in the fuel.

Petrol or Gasoline even when cold gives off vapors that may make the operation of the engine hazardous, accumulated fuel vapors will become explosive and will ignite if the ignition system is operated with the engine is stationary, this could lead to a fire. Kerosene type fuel when at low temperatures is more difficult to ignite than petrol; testimony to this is the ferocity of high-energy igniters required too reliably light it! The fuel in a gas turbine also serves as a lubricant for the fuel pump, petrol is not as an effective lubricant as kerosene.

A typical aviation type gas turbine engine originating from an aircraft installation will require the fuel to be supplied to it under slight pressure. Aircraft installations normally feed engines from what is known as a low-pressure (LP) system. Centrifugal impellor-type booster pumps submerged in the aircraft tanks pressurize the LP system to about 10 PSI. The pumps draw fuel through mesh screens so that no large foreign matter enters the LP system. Fuel to a small engine should be further filtered to prevent any small particles from entering the system. Automotive fuel injection filters and diesel injection filters are suitable for this purpose. The flow rate is higher than for automotive applications so depending on the cleanliness of the fuel, they will need replacing more often. Larger high -capacity filters intended for trucks or marine diesel applications are suitable for this purpose.

A stationary ground-based gas turbine engine will often benefit from a booster pump placed in the fuel system to draw fuel from a tank. It is possible to use an electric automotive pump such as solenoid interrupter types made by Facet or SU. During installation or commissioning slight fuel pressure will assist in bleeding the system and removing any trapped air. Certain small gas turbine engines are sensitive to air bubbles or pockets which may be trapped in the fuel, the bubbles or trapped air result in a brief loss in fuel pressure which may cause an engine to "flame out". Larger engines of 250HP rating or more may require two pumps in order to ensure sufficient flow is available. Fuel consumption figures should be checked to ensure a given fuel pump meets the requirements of the engine when on load etc.



Automotive low pressure fuel pumps

When constructing a low-pressure fuel system to feed a gas turbine, a shut off cock should be included to stop the engine in an emergency. The stop-cock may consist of a manual "Gate" type ball valve, or an electrically operated solenoid valve which closes when de-energized. This arrangement will ensure that if electrical power is lost to the engine, it will shut down safely.

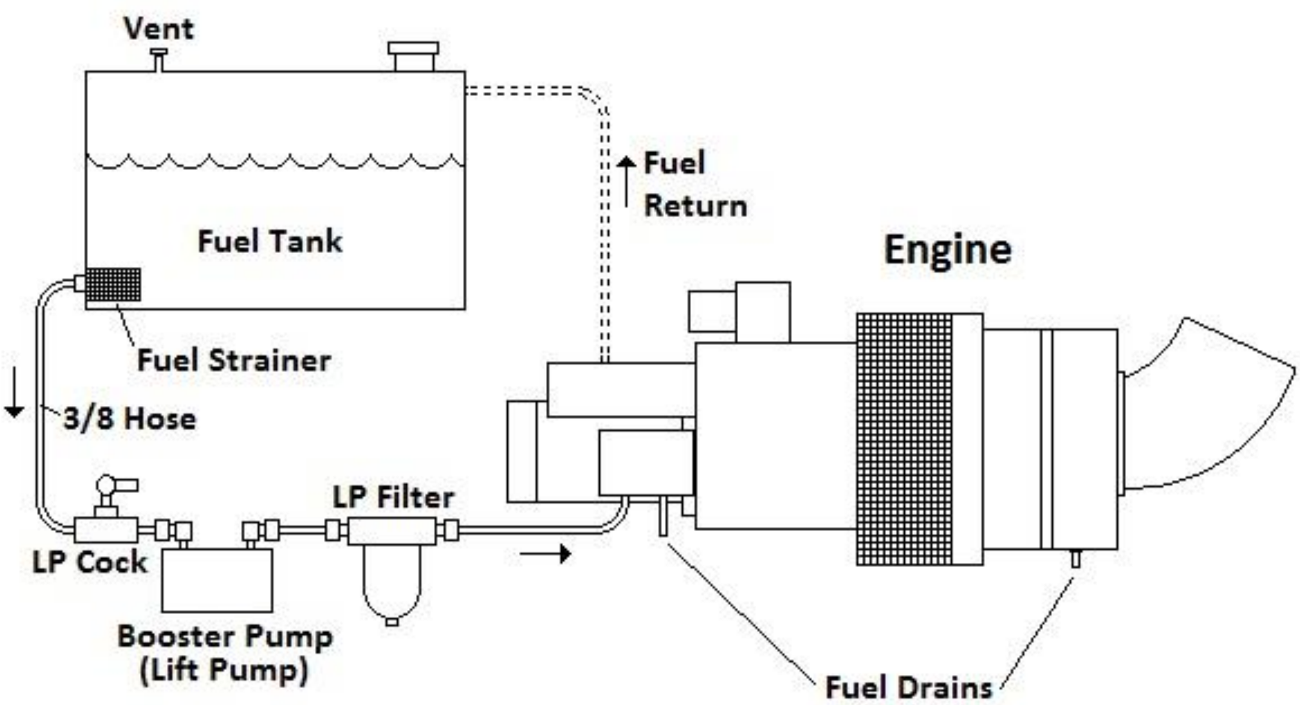
Warning:
Caution should be exercised when choosing a suitable booster pump, fuel injection pumps for cars should be avoided as they are capable of high pressure (>100 PSI). The pump itself will operate satisfactorily but if no pressure relief valve is fitted, the high fuel pressure will affect the governing system of the engine. High fuel pressure at the inlet will cause it to run at excessive speed. Any positive displacement pump to be used for this purpose should be checked and fitted with a pressure relief valve to ensure that the output pressure does not exceed 20 PSI. Certain models of car fuel pump exceed 100 PSI. An SU solenoid type pump features a built-in pressure-limiting device as it was originally designed to feed a needle valve inside a carburetor.

Many gas turbine engines will work satisfactorily from a gravity fuel feed, small gas turbines are very thirsty compared to similarly sized piston engines, if prolonged operation is required a large fuel tank will be needed. To ensure satisfactory starting and running the tank will have to be placed above the level of the engine. A gravity head of fuel may be gained at the rate of approximately 1 PSI per raised meter of fuel tank height. If the required pressure cannot be met by fuel head, then a booster pump is required.

Fuel consumption may be between 5 and 10 gallons per hour so the tank should be vented to prevent it becoming partially evacuated as the fuel is consumed. A fuel tank of Jeri-can size with a capacity around 5 gallons is usually sufficient for testing and operating small APU size engines for moderate periods.

Typical fuel consumption figures-

GTP30 (40HP)	7.5 Gal/hr at Full Load	3.75 Gal/hr at no load
Rover 1S60 (60HP)	11 Gal/hr under Load	
Palouste (300HP)	37 Gal/hr under Load	

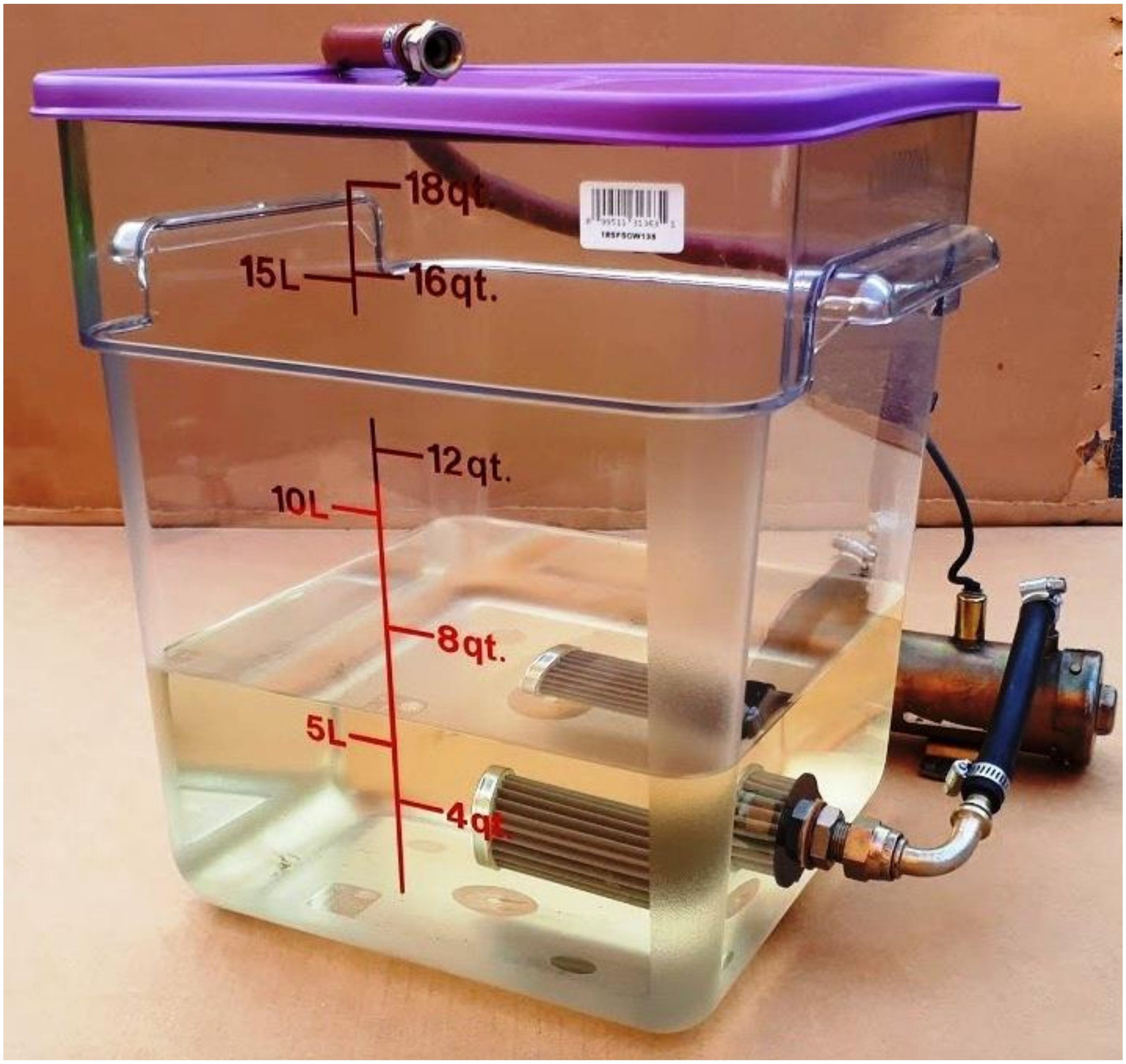


Typical small gas turbine LP fuel supply system

Gas Turbine Fuel systems adopt several different system architectures that fall into three distinct categories as follows-

1. **Hydro-mechanical Fuel Control System** - All system components are mechanically driven, fuel flow scheduling to the engine is performed by a number of hydraulic or pneumatic valves, calibrated orifices and the engine speed is governed mechanically.
2. **Electronic Fuel Control System** - The fuel scheduling to the engine is carried out under electronic control via a special electrically operated metering valve. In addition, the fuel pump may be driven by an electric motor and not from the engine itself.
3. **Hybrid Fuel Control system**. – The fuel scheduling to the engine is partially controlled by an electronic control unit and partially by hydro-mechanical or pneumatic devices. e.g., The fuel flow and engine acceleration are controlled by a pneumatic valve and the engine speed is governed by an electronic control unit.

Fuel Tank



Polycarbonate transparent fuel tank

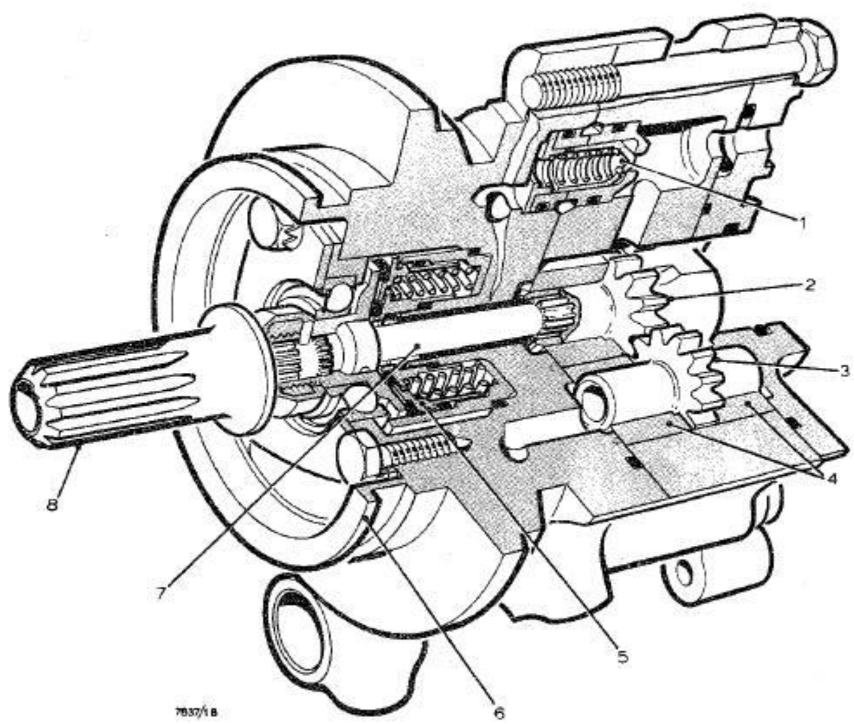
For the laboratory testing and bench running of small engines up to 100HP an 18 liter fuel tank may be suitable if limited running time is required. Shown above is a polycarbonate tank fitted with a fine mesh strainer and a booster pump is also connected to the outlet. Polycarbonate is an excellent material and compatible with jet fuels. This food container was successfully modified for this purpose and may be carefully drilled without fractures and cracks forming. The fuel consumption may be easily monitored with this arrangement. It should be remembered the lid will have to sit partially open in order to ventilate the tank during operation.

The facet type fuel pump shown also allows the fuel to flow when not operating and so can be used to aid priming and turned off for running if sufficient flow is available.

Hydro-mechanical fuel system components

Fuel pump

A fuel pump is required to provide a source of high-pressure fuel to be fed to the engine combustion system. The pump is driven by the engine accessory gearbox; this reduces the rotational speed to that which can be accepted by the pump. Typical pump speeds range from 4000-10,000 rpm. The pump is sometimes referred to a high pressure (HP) pump and is usually one of two types. -



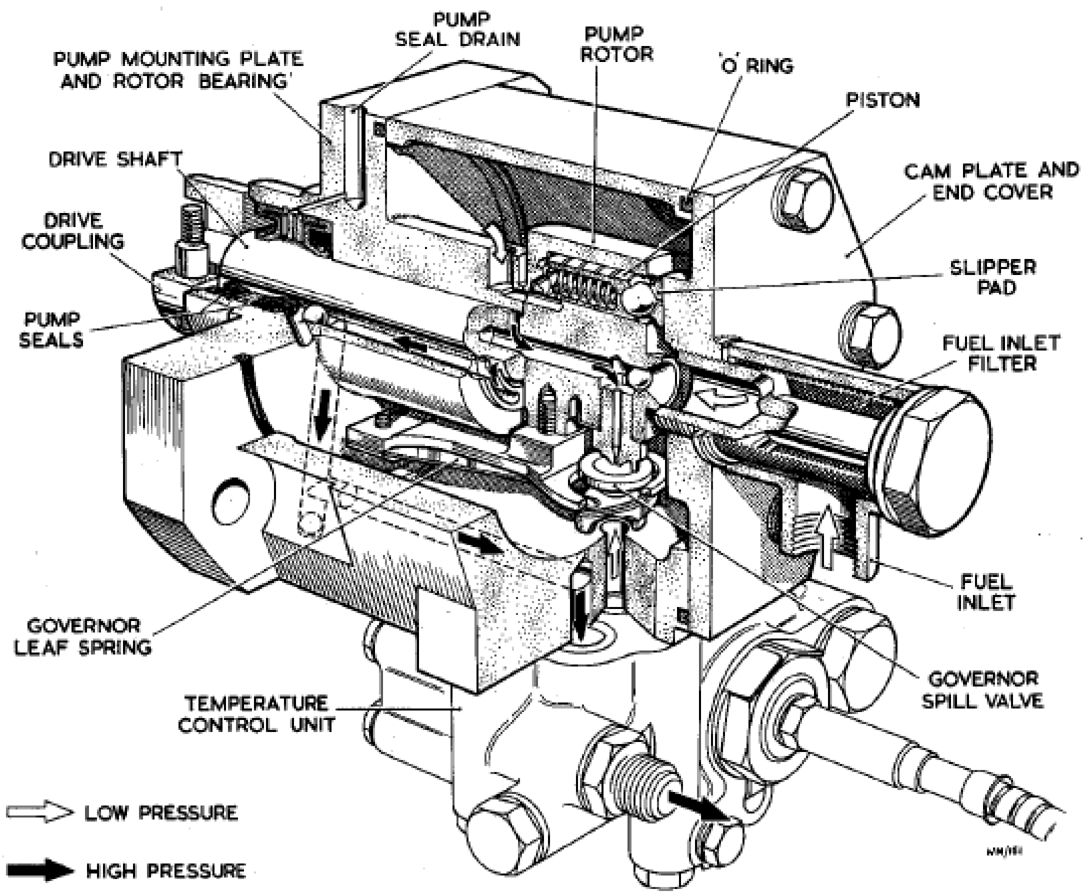
1 PRESSURE RELIEF VALVE
2 DRIVER GEAR
3 DRIVEN GEAR
4 GEAR BEARINGS
5 CO-AXIAL SEALS
6 MOUNTING SPIGOT
7 QUILLSHAFT
8 DRIVESHAFT

Cutaway view of a gear type fuel pump

Gear pump- Gear type pumps may be found fitted to small gas turbines, two meshed gears turn inside a machined metal housing, a fuel supply enters the housing and travels around the outer circumference of the two gears between the teeth. The rotation of the gears produces a positive displacement as the fuel cannot return to the inlet due to the meshed portion of the gears between them. The pump gears have to run in a close-fitting housing built to tight tolerances to ensure sufficient fuel pressure is built up and to prevent the fuel from leaking back to the inlet. The end faces of the gears are sometimes mated to carbon or bronze seals to further reduce leakage. A carbon seal consists of a spring-loaded carbon bush which mates up with a rotating component; the mating surfaces are highly polished to prevent friction. Carbon seals are common in small gas turbines, it they are disturbed during disassembly, care should be taken with them not to scratch the mating surfaces, carbon seals may also be brittle. Naturally only one gear in a gear pump needs to be driven around by the engine. Many small engines use gear pumps, Garrett engines, Lucas Aerospace GTSs (Gas Turbine Starter) and Man-Turbo units all make use of this type, as do a number of larger Helicopter engines.

Disassembled gear type pump taken from small gas turbine engine

Piston pump- A second type of fuel pump uses a series of small pistons to pump the fuel, this arrangement is common in larger aircraft engines. A rotating disc or swash plate is shaped in such a way that it varies in distance from a fixed point along its axis. As it rotates the disc impinges on one or more pistons and pushes them against a spring to provide a pumping action. Many larger engines are fitted with a lever mechanism to vary the pump stroke that in turn controls the fuel flow rate. This arrangement is more complicated than a gear pump but is capable of higher pressure.



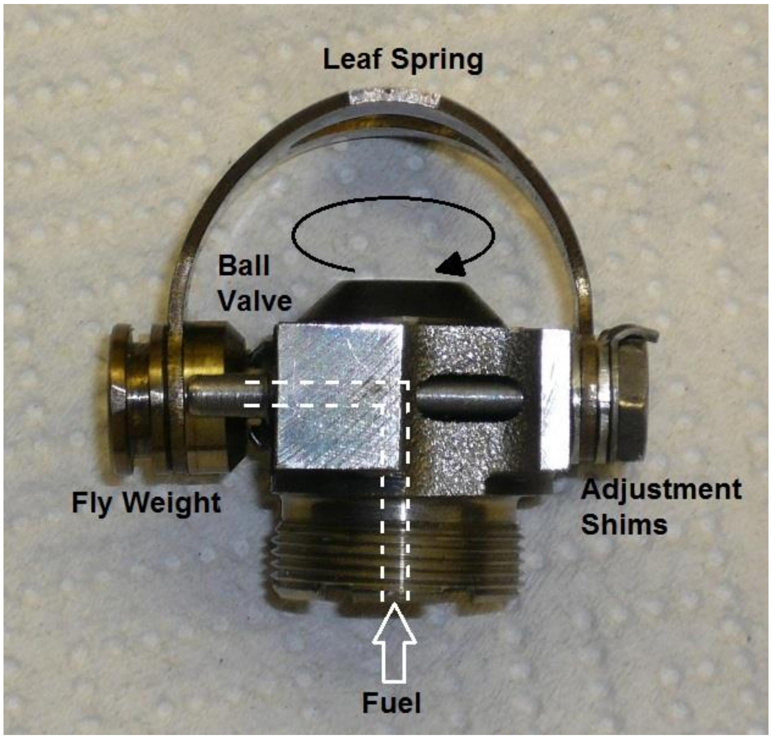
Piston type fuel pump also incorporating a governor valve

The fuel pump is lubricated and partly cooled by the incoming fuel, any foreign matter in the fuel will cause the pump components to wear and pick up, hence the need for good filtering. Fuel pumps should not be rotated when dry due to the lack of lubrication, if an engine needs to be turned over, the pump should be kept "wet" with a fuel supply or by squirting oil such as WD40 into the pump inlet at regular intervals.

Fuel pumps fitted to small engines usually form part of an integrated fuel control unit. The control unit will also incorporate various other devices all placed inside one casing. Fuel pumps normally incorporate a pressure relief valve, when an engine is shut down the fuel flow downstream of the pump is closed off with a shut-off valve or cock, the relief valve will open to limit the resulting pressure build up. The fuel pump flow and capacity will normally be in excess of engine running requirements, this is so that the governor can function properly by spilling excess fuel back to the pump low pressure inlet side under all load conditions.

Governor

Gas turbine engines employ a governor system to maintain the engine at constant speed. Mechanical governors employ the action of centrifugal force to normally open a fuel spill valve when a pre-determined rpm is reached. The fuel flowing at high pressure from the pump feeds into a rotating spill valve (often a ball valve) assembly held closed by a calibrated spring force. As the rotational speed increases the centrifugal force eventually overcomes the spring force at a predetermined speed and opens the spill valve, this limits the flow of fuel to the engine and the speed is held constant. The engine speed becomes stabilized at this point with sufficient fuel flow to maintain a constant rpm even under load. Some models of governor also use a second ball valve that opens at a slightly higher speed to act as a backup governor in case the first one fails. Simple governor types will malfunction if an excessive inlet fuel pressure is present, it will act against the governor valve and hold it closed until a greater speed and hence centrifugal force is reached, causing the engine to over-speed, obviously this dangerous condition should be avoided. More sophisticated fuel control systems may incorporate a pressure regulating system to ensure the pressure drop presented across the governor valve remains constant over a range of inlet fuel pressures and operating conditions.



Simple leaf spring governor with ball spill valve

Certain models of gas turbine engine also employ various over-speed safety devices, such as centrifugal switches and trip mechanisms.

The Garrett GTP30 engine uses a rotating bob weight type governor to control speed. The two bob weights rotate around a shaft and under the action centrifugal force move outwards, at the same time elbow levers attached to the weights act upon a sleeve placed around the shaft that is hollow. HP fuel from a gear pump travel through the hollow shaft and is prevented from escaping through openings placed in the shaft by the sleeve. The sleeve is spring loaded axially along the shaft against the bob weight force, eventually as the rotational speed rises the bob weight force overcomes the spring force and the sleeve moves, as the sleeve moves it uncovers the openings. The uncovered openings in the shaft allow fuel to escape reducing the delivery flow to the engine resulting in a steady speed being maintained. The spring force acting along the shaft may be varied by axially moving the end of the spring via a ball race that couples this stationary piece to the rotating governor. The ball race arrangement allows for adjustment of the engine speed whilst the engine is operating as the main governor components will be rotating.

The Artouste engine uses a small portion of bleed (P2) air from the compressor to balance the forces from various spring-loaded fuel valves. The air feeding the valves is vented to atmosphere by a centrifugal valve that prevents the pressure from exceeding a certain limit and the engine exceeding a predetermined speed.

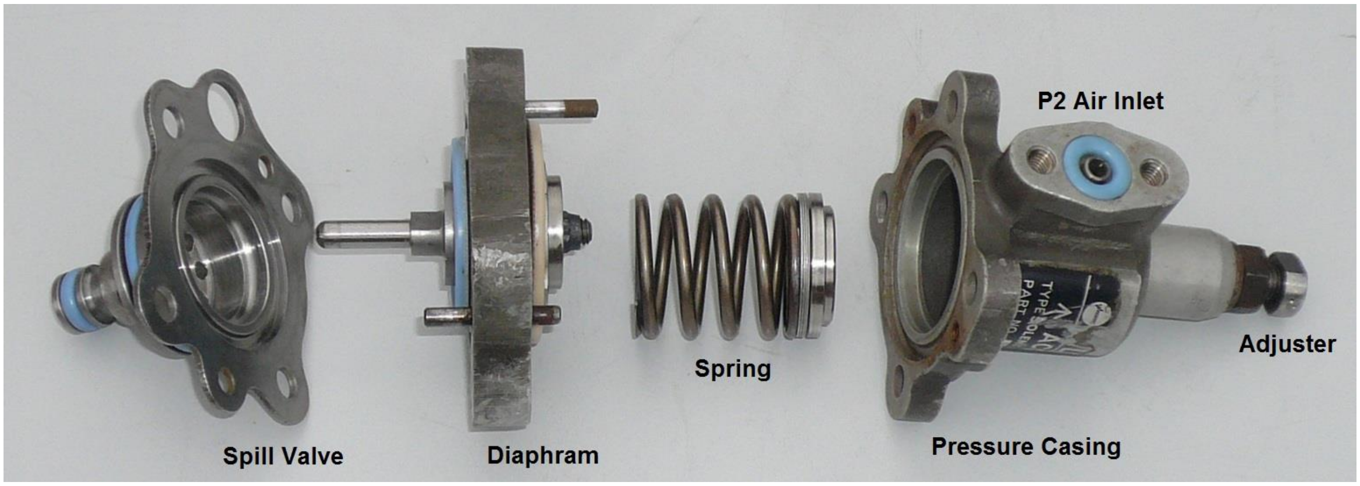
Acceleration limiter valve

The purpose of this valve is to control the acceleration of the engine during starting and a transition from idle to full speed. If a gas turbine accelerates too quickly two possible problems can exist. Firstly, the operation of the compressor can suffer, if excessive fuel is supplied to the combustion chamber, the resulting combustion and expansion of the gases in it will present an excessive load on the compressor. The aerodynamics in the compressor are finally balanced, if the engine tries to accelerate too quickly these aerodynamics break down and the compressor suffers what is referred to as a "Surge" condition. Surging in small engines should not normally occur, unless the fuel control system has been tampered with and the settings disturbed. If it does occur, the engine may be heard to “cough” and “splutter” or emit a low frequency humming noise. Compressor surge usually results in higher-than-normal exhaust temperatures, also smoke and flames may briefly appear at the air intakes.

A second problem associated with acceleration is exhaust temperature. As an engine accelerates there is always a greater quantity of fuel than air compared to a steady state running condition. The faster the engine accelerates the more fuel is burnt and the hotter the exhaust temperature will be. By limiting the maximum possible acceleration of the engine, the temperature can be kept to within a safe limit.

Small gas turbines, particularly gas turbine starter units start and accelerate very quickly. The fuel system is set up so that they achieve maximum acceleration before surging or overheating occurs. The Plessey "Solent" gas turbine starter will reach full speed in under 10 seconds.

The acceleration limiter valve works by balancing compressor air (P2) and fuel pressure with the assistance of a calibrated spring force. As the engine gathers speed, the P2 pressure gradually rises, this pressure compresses a spring which progressively opens a needle valve to allow more fuel to the burner system. A small portion of fuel is always needed to reach the burner so that it is available for startup, this is because the P2 pressure at the relatively low starting rpm will be almost zero and not enough to move the valve. The spring force on the acceleration control valve can normally be adjusted and is set up during manufacture and testing. The acceleration limiter valve should not normally need adjusting, care must be exercised if the settings are to be adjusted, for stationary applications certain engines may benefit from a reduction in acceleration to reduce temperatures.



Disassembled view of simple acceleration control valve components

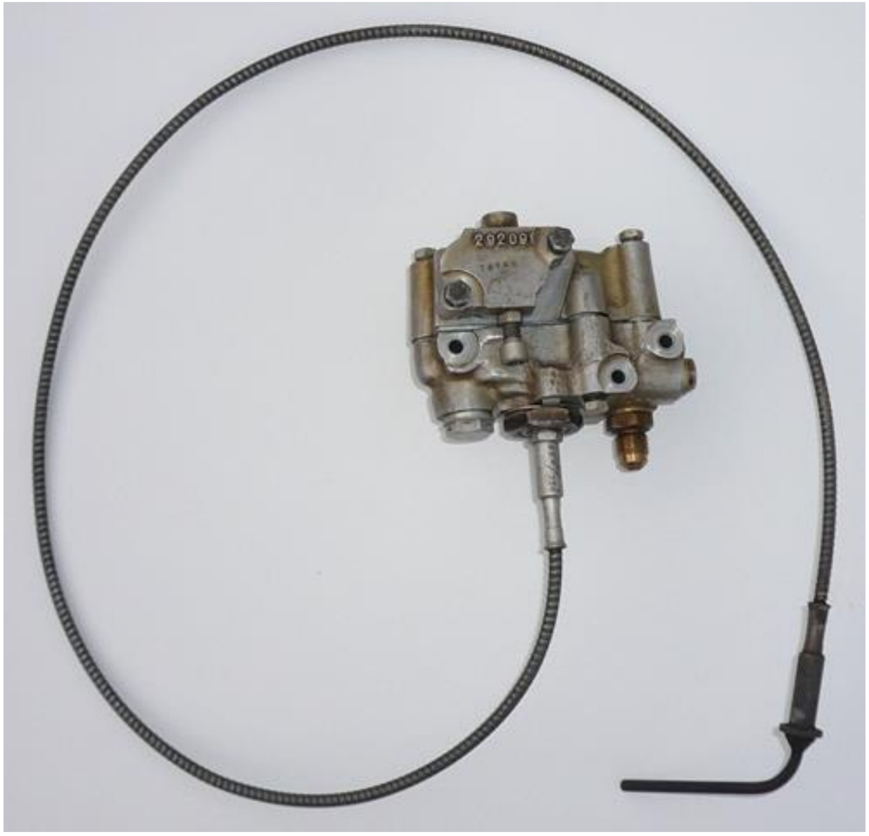
The “Solent” gas turbine starter unit built by Plessey Dynamics adopts a novel fuel control system. The unit is fitted with a conventional gear fuel pump incorporating a simple leaf spring spill type governor. The unit is also fitted with an acceleration control unit (ACU) which senses the rise in air pressure delivered by the compressor as the unit starts and accelerates. The Solent features a reverse flow annular combustion chamber fitted with eight spray burners. The burners incorporate special pressurizing valves which are set to open at different pressures in groups of two. When the engine is started it initially lights up on two burners, as the compressor rpm increases under action of the ACU the fuel pressure increases, and more burners open until all eight are functioning and the engine reaches governed speed. This process results in asymmetric combustion during the acceleration phase which is not a problem as the unit starts and runs up to speed very quickly, it also is only rated for a 1-minute operating duration, this is because its duty is only that of a aircraft main engine starter.

Temperature limiter (protection) valve

Many small gas turbine engines feature temperature limiting devices, these are able to detect excessive exhaust temperature and reduce fuel flow.

It is important during the starting and heavy load operation of a gas turbine that it does not exceed a safe exhaust temperature limit (And hence turbine inlet temperature). Many fuel systems employ a temperature regulating device to keep the exhaust temperature below a predetermined limit, this usually consists of a thermal sensing device which is placed in the exhaust jet pipe. As the exhaust temperature increases, the sensor operates a valve in the fuel system and reduces the fuel supply to the burner (s).

The Rover and Man-Turbo 6012 engines use a small mercury filled capsule which is mounted in the exhaust, the capsule is connected to a bellows inside the fuel control unit via a thin tube. The bellows are spring loaded and mechanically connected to a valve, when the exhaust temperature rises above a certain value, the mercury expands and expands the bellows. As the bellows expand the valve spills fuel from the HP pump outlet to reduce the fuel delivery and the temperature.



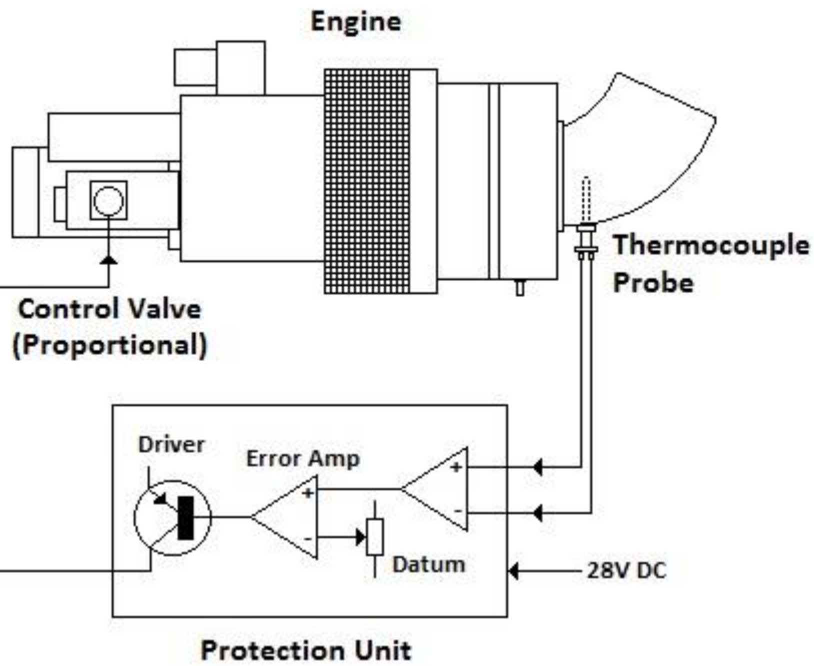
Temp limiter probe and fuel spill valve (Rover)

Garrett engines use a pneumatic thermostat that is mounted in the exhaust. P2 air is supplied to the fuel control unit for acceleration limiting, this air also passes to a thermostatically operated valve. As the temperature rises the valve opens and starves the fuel control unit of P2 air causing it to reduce the fuel supply and thus bring the temperature down.

Picture Garrett temp limiter sensing valve

Electronic protection devices

It is possible to use an electronic device to protect a gas turbine engine from excessive exhaust gas temperature and other running parameters such as rpm. A thermocouple is placed in the exhaust or turbine inlet stream and is connected to an amplifier. The amplifier may in turn be connected to a protection circuit consisting of an error amplifier and temperature datum. The small electrical current generated by the thermocouple is amplified and compared with the temperature datum. When the temperature exceeds a pre-determined limit (The datum) an error signal is produced that is used to drive a regulating valve placed in the engine fuel system. The regulating valve lowers the fuel flow to the engine and consequently the temperature is reduced. A gas turbine fitted with a hydro-mechanical fuel control system may also be fitted with an electrically driven regulating or spill valve that acts as in additional fuel scheduling device to control flow.



Simplified representation of an electronic engine protection system

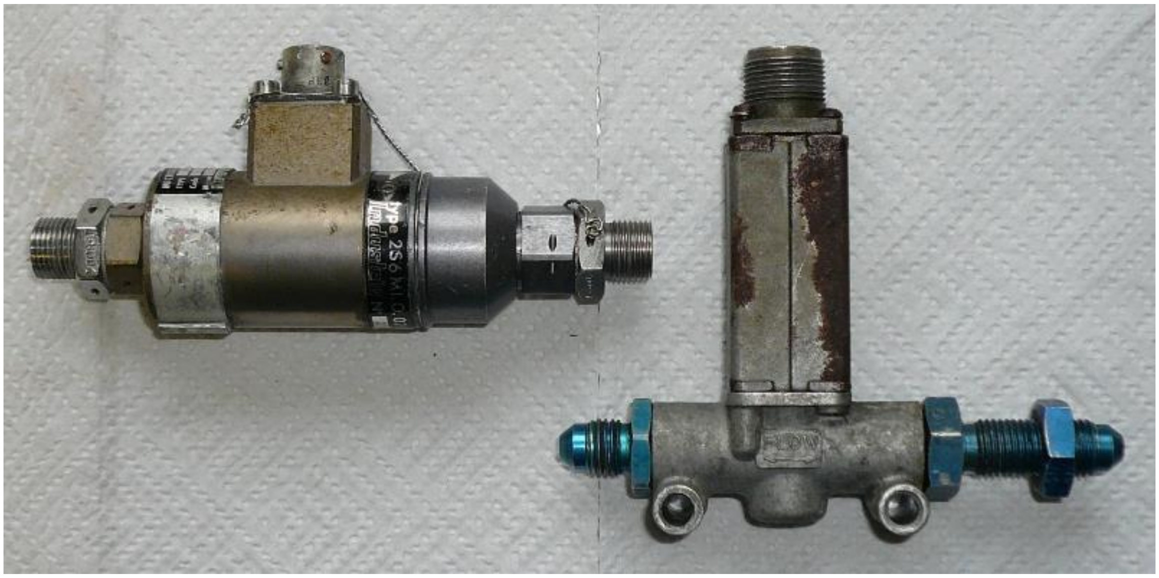
The RR Gem MK510 helicopter engine features a hydro-mechanical fuel control unit that is also fitted with an electronic protection device known as a protection control unit (PCU). A DC powered module accepts a signal from the thermocouple turbine inlet temperature harness. When the turbine inlet temperature exceeds a predetermined limit (For instance during start up) the fuel flow is reduced by means of a special proportional rotary solenoid valve that is driven by the module. In addition to over-temperature protection, the unit also monitors the low pressure (LP) compressor shaft and protects it from an over-speed condition.

Electronic protection unit (RR Gem MK510)

Inside engine protection unit showing circuit boards

Shut-off valve

To start and stop a gas turbine engine a valve is normally placed in the fuel feed to the combustion process, this valve is sometimes referred to as an HP (High Pressure) cock. During the start cycle the valve may be opened as soon as the engine begins rotating or may be delayed until the engine has gathered speed and sufficient air is flowing through it to support stable combustion. Solenoid valves are often used as HP cocks, normally 24V DC supply is required to hold them open while the engine operates, to shut down the engine the current in the valve solenoid is cut off. Solenoid valves are useful for stationary applications, complete failure of a 24V supply to the engine will result in it shutting down, a fail-safe condition.



Solenoid operated fuel supply valves

Certain Rover 1S models use a gate valve that is operated by a motor driven mechanical actuator unit, this is used to control the fuel supply. The actuator consists of an electric motor and gearbox, the motor runs briefly to open or shut the valve and is then cut off by limit switches mounted inside the actuator. Electrical power is required to open and shut the valve, this arrangement does not "Fail Safe" in the same way that solenoid valves do. Failure of the DC supply during operation of the engine will leave it running, in this case an emergency LP cock may be used to stop the engine by starving it of fuel. Due to the thirst of gas turbines, stopping the fuel supply to them will almost instantly stop them, unlike petrol engines that will continue to run off fuel stored in a carburetor.

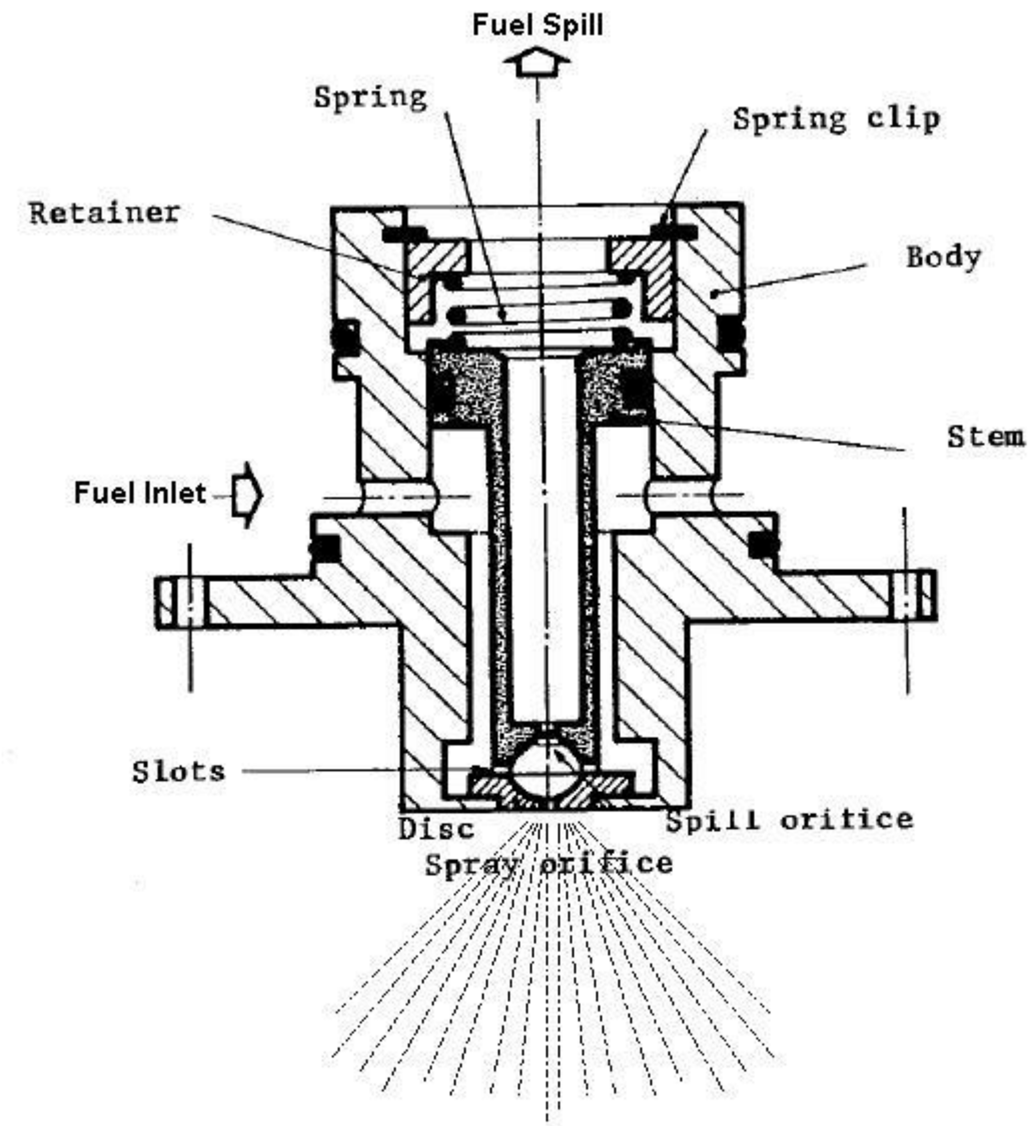
When a Lucas GTS shuts down, a valve shuts off the fuel supply to the burners and opens the burner fuel line to the outside atmosphere. The instantaneous pressure in the combustion chamber back purges all the fuel from the burners and associated pipe work, the fuel is then dumped to atmosphere. This process prevents deterioration of static fuel in the hot burners that will lead to carbon buildup and other deposits.

Several stationary engines including the Rover fire-pump use a simple hand operated shut off cock to supply fuel to the engine.

Burners

Spray (atomizing) burner nozzles

As mentioned in the previous chapter, fuel is admitted to the combustion chamber through one or more nozzles called burners, sprayers or atomizers.



Spray type burner nozzle

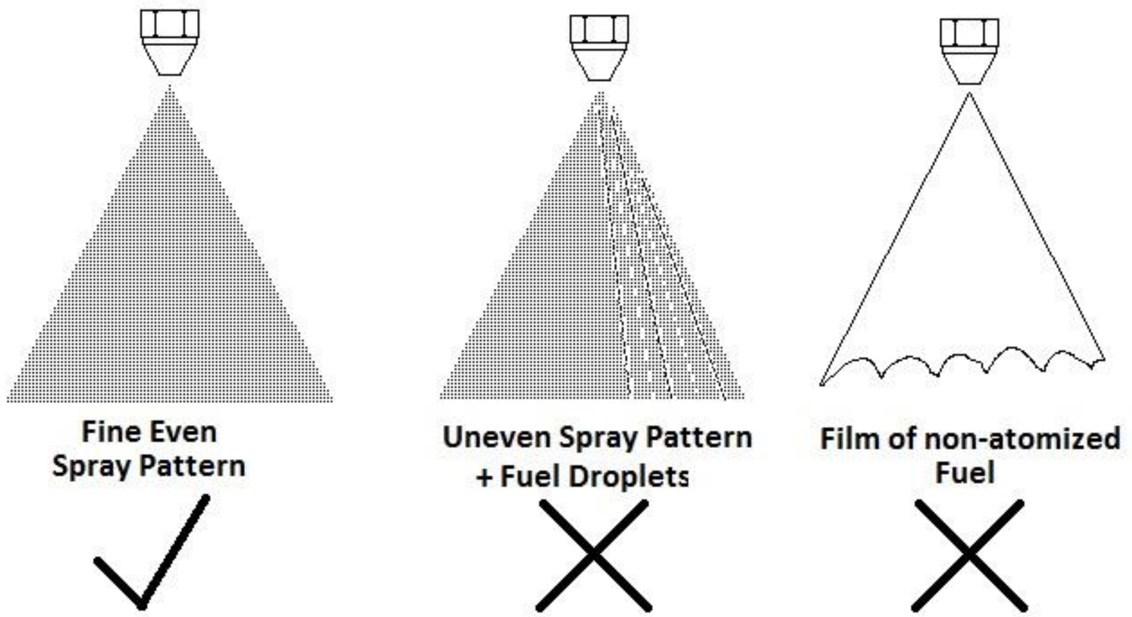
Burners are required to spray fuel into the combustion chamber in the form of a very fine atomized mist. Fuel under pressure (100-250 PSI) is forced through a very small orifice that causes it to break up into tiny droplets. Compressed air from the compressor or a separate pump is sometimes mixed with the fuel inside the burner to assist the process of atomization. Certain designs of burner incorporate a valve (Check valve or pressurizing valve) that shuts off at low pressure to prevent dribbles and leakage and opens when sufficient pressure is present to maintain satisfactory atomization. The Rover gas turbine uses compressed air from a small motor driven pump to assist atomization, the pump improves ignition and starting performance. The burner air supply pump is known as an emulsion pump as it creates a fuel/air emulsion.

A cone shape spray pattern from a burner is normally required to fill the combustion zone within the combustion chamber, as the engine ages this pattern may deteriorate due to carbon deposits and abrasion from the fuel. The engine fuel supply is filtered to ensure that no foreign matter enters the burner and clogs it up. Burner units are often fitted with small internal filters to further prevent damage due to foreign matter contaminating the fuel supply.

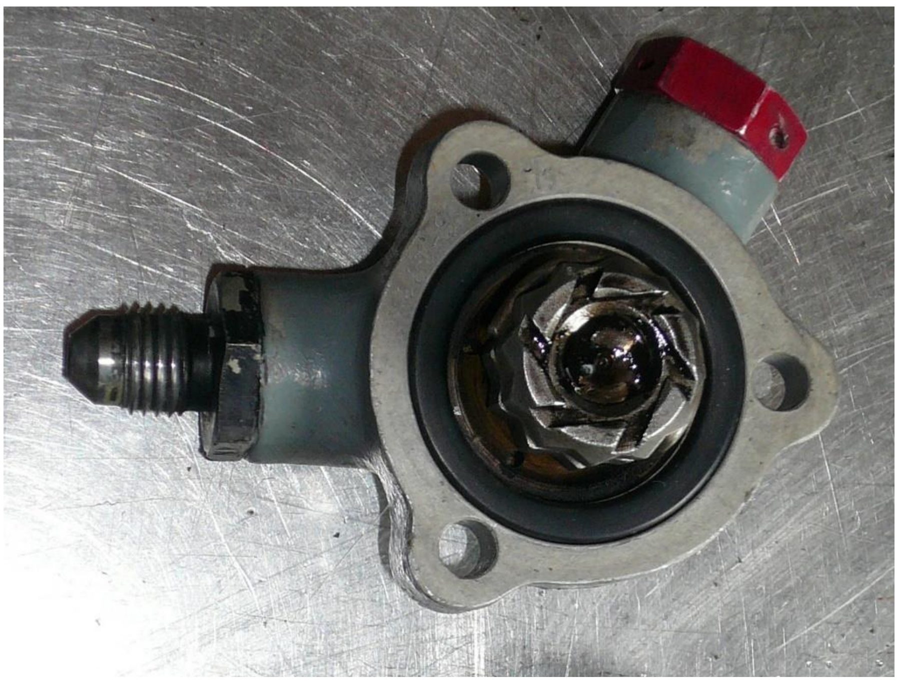
Good even atomization is important in gas turbine combustion systems. Poor or irregular atomization may lead to hot spots in the combustion chamber which will lead to damage. During engine overhaul and maintenance, the burners will be tested on a special rig to ensure they maintain prescribed performance over a range of fuel flow rates and pressures. Engines fitted with reverse flow annular combustion chambers and consequently multiple burners will have then checked and matched.

Testing burner nozzles can be a messy business. A correctly functioning nozzle will admit an extremely fine mist type spray, special tanks with compartments are used to simultaneously allow the fuel spray to be collected (For flow rate measurements) and observed with the naked eye. Care should be exercised when testing nozzles, the fine mist vapors admitted should not be breathed in.

Spray pattern emitted by a single atomizing burner (Lucas)



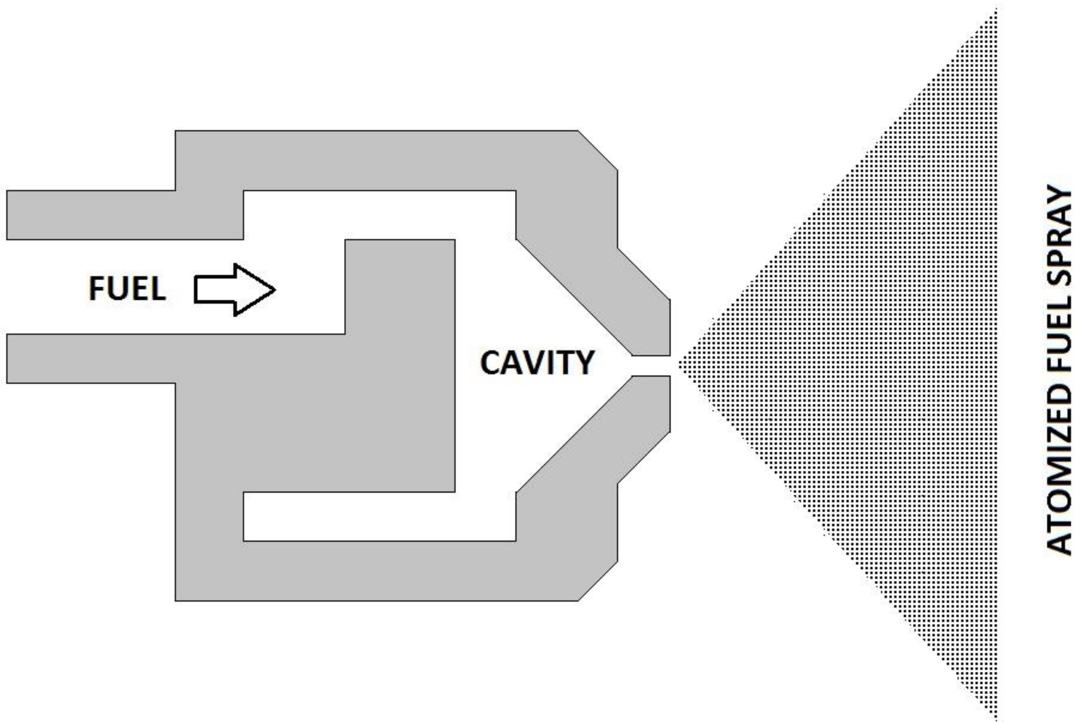
Correct and faulty burner spray patterns



Small gas turbine burner nozzle viewed from "wet" end (Garrett GTP30)

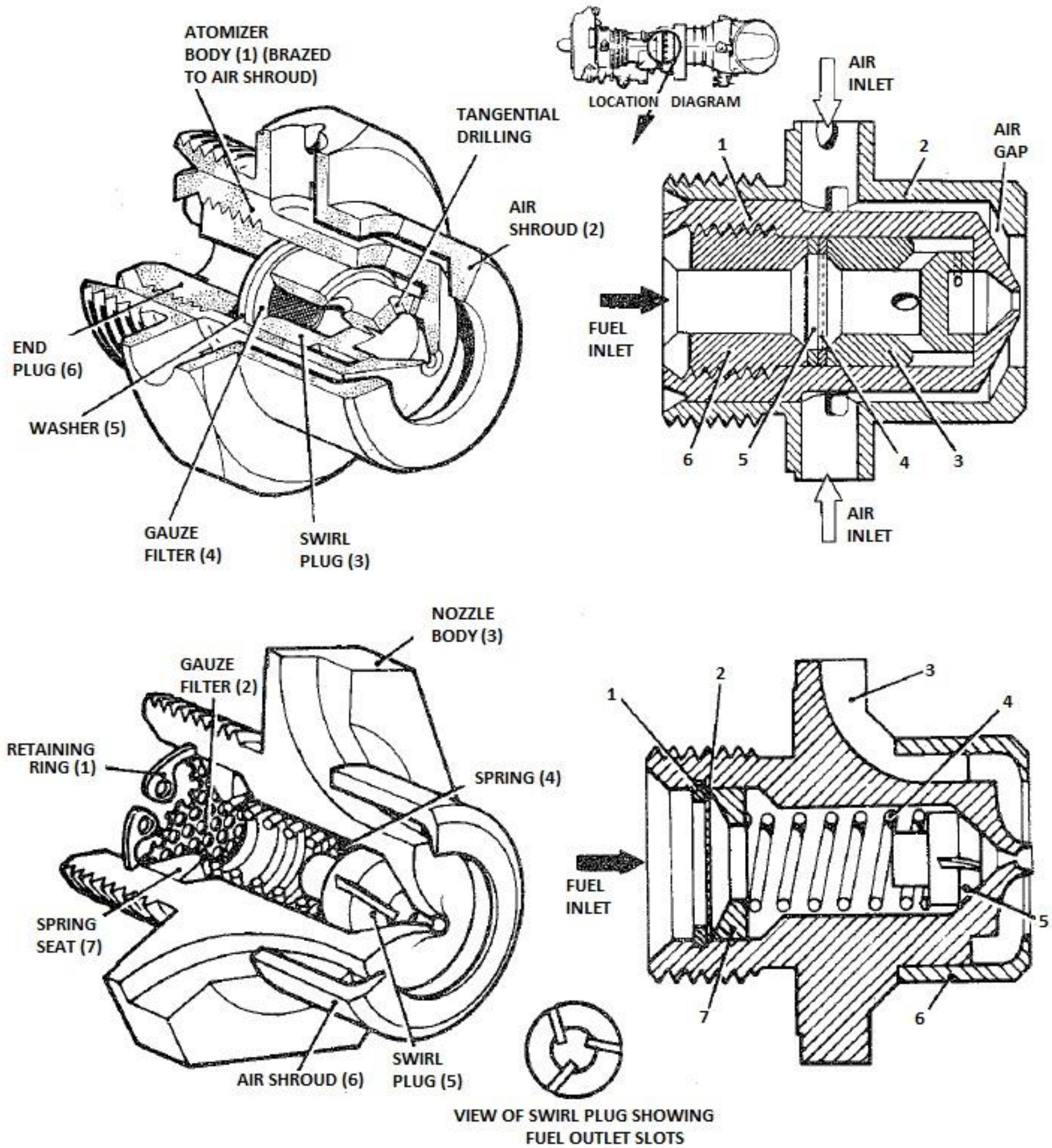
Simplex burner nozzle

A common design of simplex burner incorporates a cone shaped internal cavity that is supplied with fuel from one side at a tangent. At the center of the cone is a small exit orifice that forms the spray nozzle and discharges the fuel into the combustion zone. As the fuel passes through the cavity under pressure it swirls around and then exits as a fine cone shaped spray pattern. The requirement of any burner is always to achieve the best possible atomization of the fuel and produce the smallest fuel droplet size. Once combustion is established in the combustion chamber, the heat generated vaporizes the fuel droplets in to a gas and it is this that actually burns.



Simplex pressure-swirl burner nozzle cross-section view

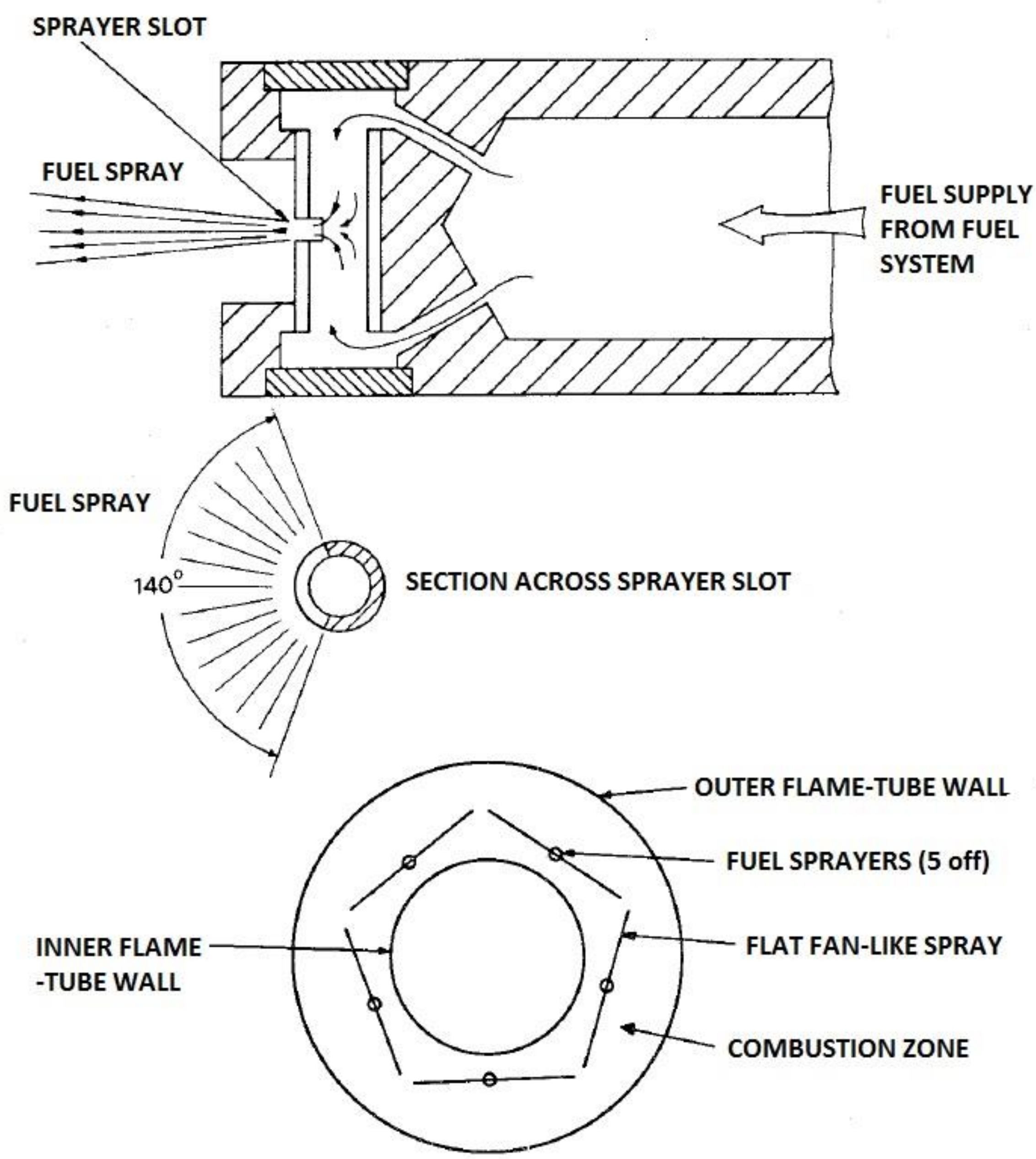
A supply of air is often guided over the front face of the burner nozzle to further aid in atomization process and help reduce carbon formation and other deposits.



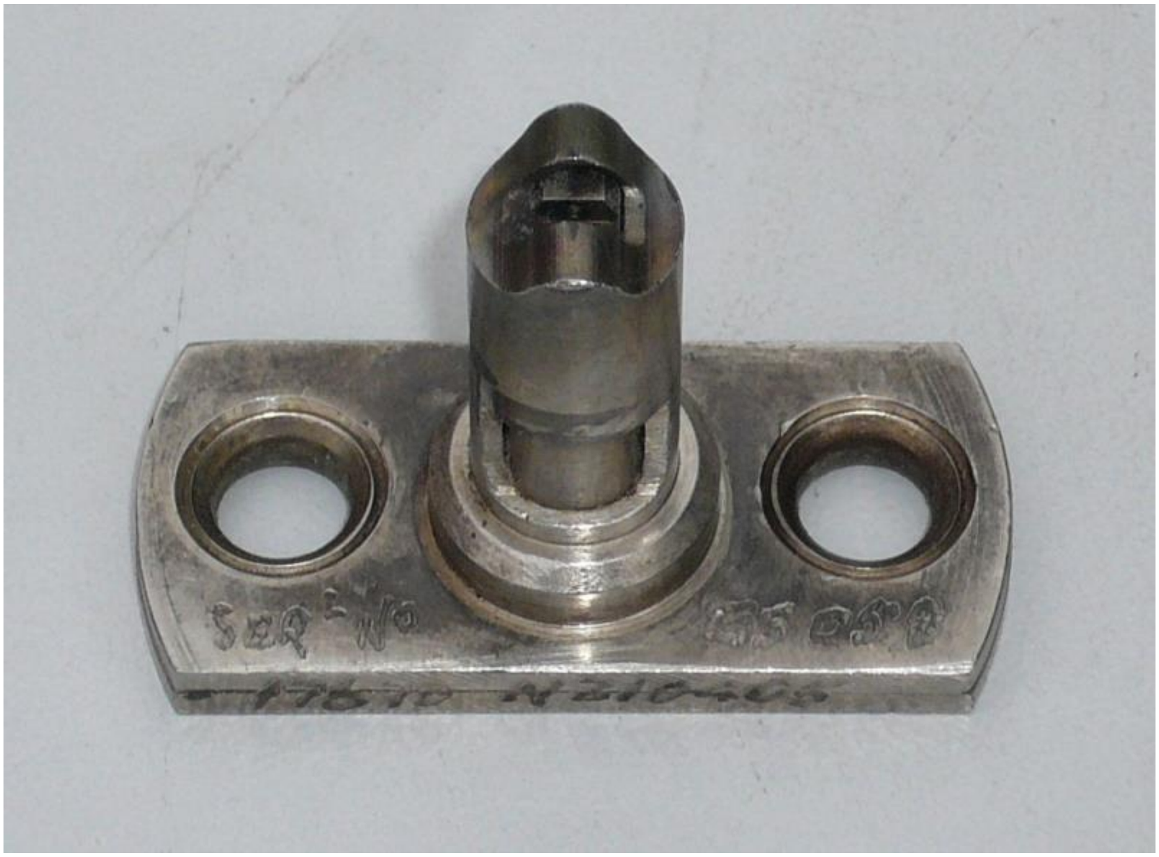
Examples of simplex pressure-swirl type burner nozzles. (RR Gnome)

Simplex burner nozzle unit mounted in tubular distribution manifold (RR Gnome)

A variation on the swirl nozzle design developed by Rover gas turbines features a slotted orifice that produces a flat fan – type fuel spray. Five miniature sprayers are placed in an annular combustion chamber, the net result is a compact combustor design.



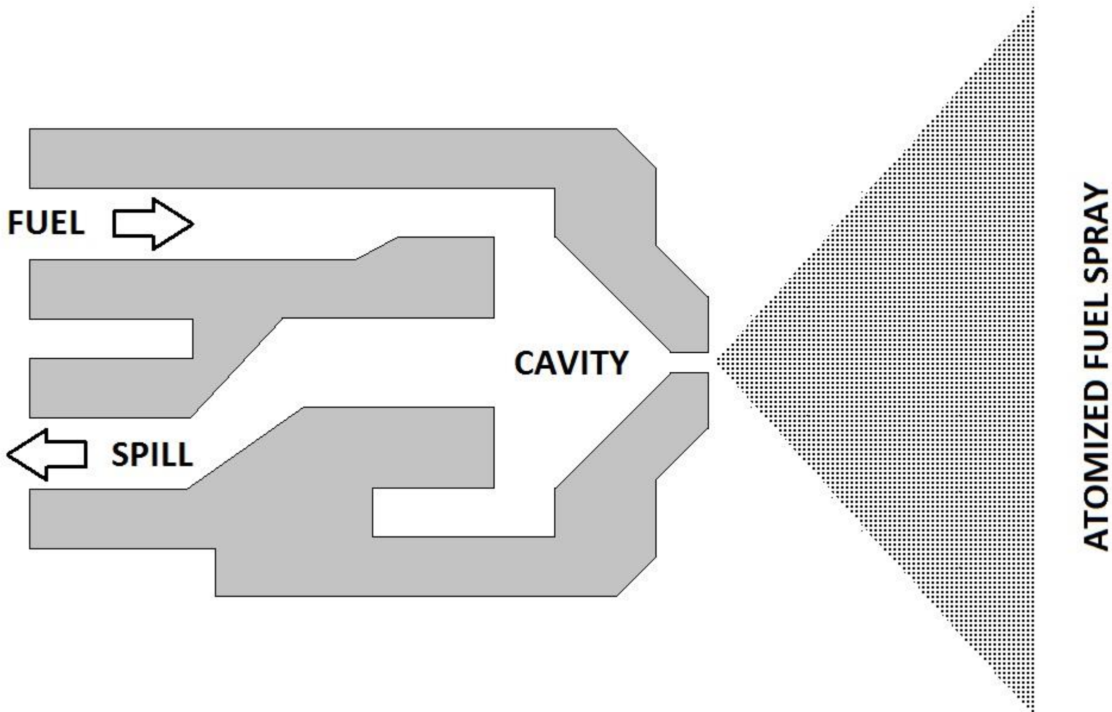
Small, slotted atomizer to produce flat-fan shape spray pattern



Miniature flat-fan atomizer taken from a small gas turbine engine (Rotax CT2023)

Spill type burner

A type of burner nozzle fitted to small gas turbines consists of a fuel feed line and a return line. Fuel flow in excess of engine requirements is delivered to the nozzle swirl chamber, a portion of the fuel is discharged through the nozzle and is atomized for combustion and the remaining portion is allowed to flow back from the burner and does not enter the combustion chamber. A proportional valve is placed in the fuel spill line and operates to restrict the fuel flow thus controlling the ratio between delivered fuel and spilled fuel. An advantage of this system is that the burner nozzle is sized for relatively high flow rates, the unused spilled excess being returned to the fuel tank or supply. This spill arrangement is a common feature of many Microturbo small gas turbine engines. A servo-type Moog valve is often used to control the fuel spill via an electronic control box.

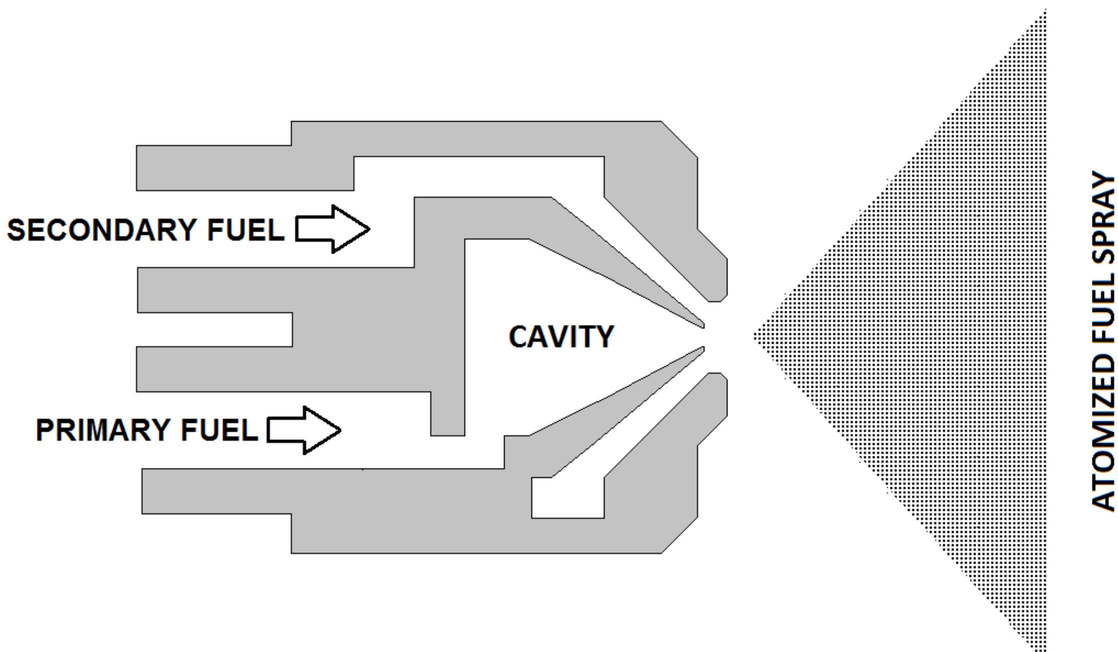


Spill-return type burner nozzle.

Duplex fuel nozzle

A type of burner nozzle found in larger jet engines and gas turbines is known as the Duplex nozzle. The duplex nozzle may be considered as two atomizing nozzles mounted coaxially as one unit. Two swirl chambers exist that are separately pressurized with individually fed fuel supplies. For the initial starting and running at low power settings the burner is fed with only a primary feed of fuel and satisfactory atomization occurs over this range of fuel flows with the one nozzle activated. For greater engine power settings that consequently require greater fuel flows the second swirl chamber and nozzle are activated providing additional atomized fuel. A flow divider device with pressure and flow controls is used to supply one or more burners via two fuel manifolds. The advantage of using this type of burner design is that it provides a wider overall operating range compared to that of a simplex burner.

The duplex burner is not in common use on small gas turbine engines but is found fitted to certain model helicopter engines. The Lycoming LTS101 and H&S STAD250 are examples where Duplex burners are in operation.

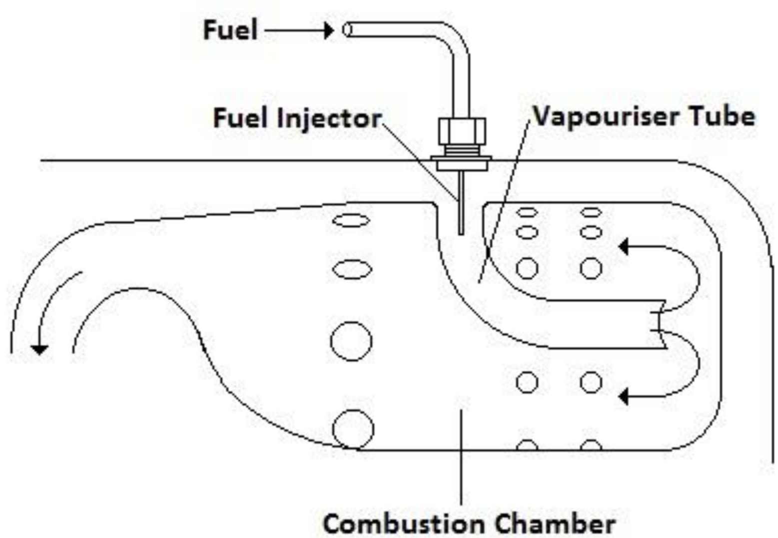


Duplex fuel burner section view

Duplex fuel burner nozzle (RR Spey)

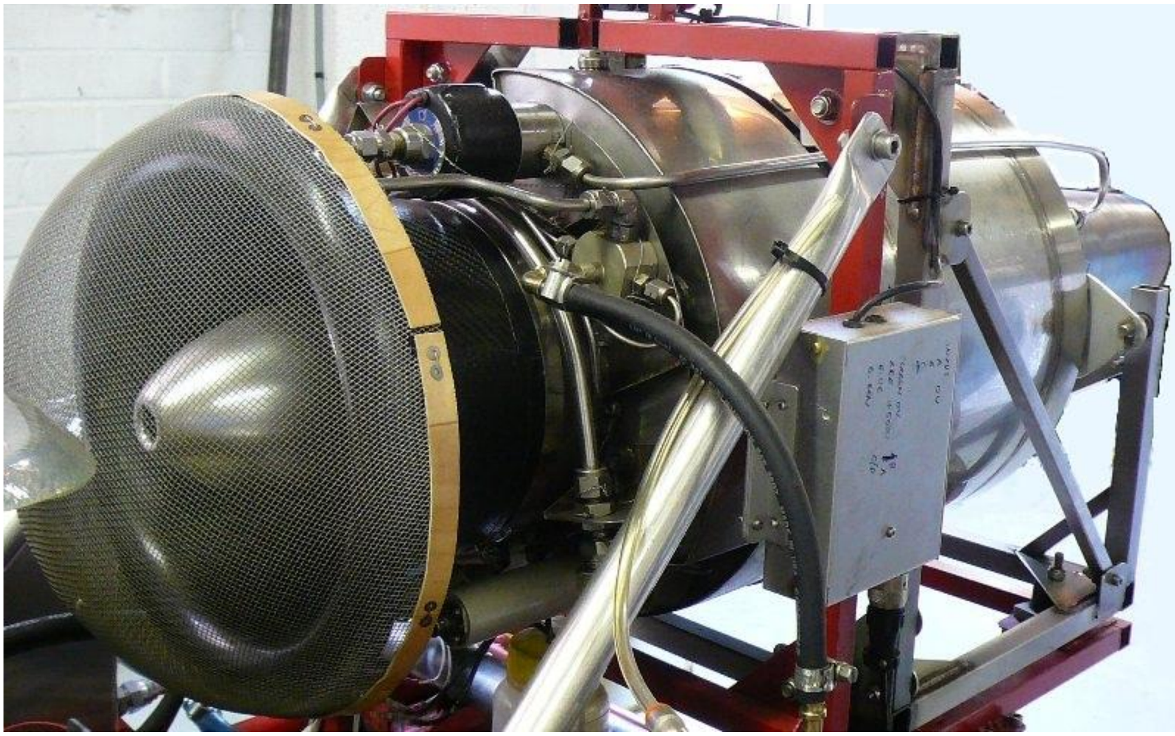
Vaporizing burners

A special type of burner utilizes the heat of combustion to vaporize the fuel before it is burnt. Fuel for combustion is supplied through a small capillary injector tube that is placed inside a larger vaporizer tube where it is mixed with a portion of incoming air. The vaporizer tube becomes heated by the combustion process around it, this creates a fuel vapor which burns cleanly without the need for a fine atomizer nozzle. For starting, this process is initiated by a special "Pilot" or "Torch" burner that supplies an initial flame and heat in the combustion chamber to start the vaporization process.



Section through annular combustor featuring vaporizing burners

When starting an engine fitted with vaporizing burners some delay after the initial light up of the torch igniter may be experienced as the vaporizing process establishes and the combustion chamber heats up. With some systems care is needed to ensure the combustion chamber is not flooded as the initial throttle response will be leading to unwanted flames in the exhaust system.

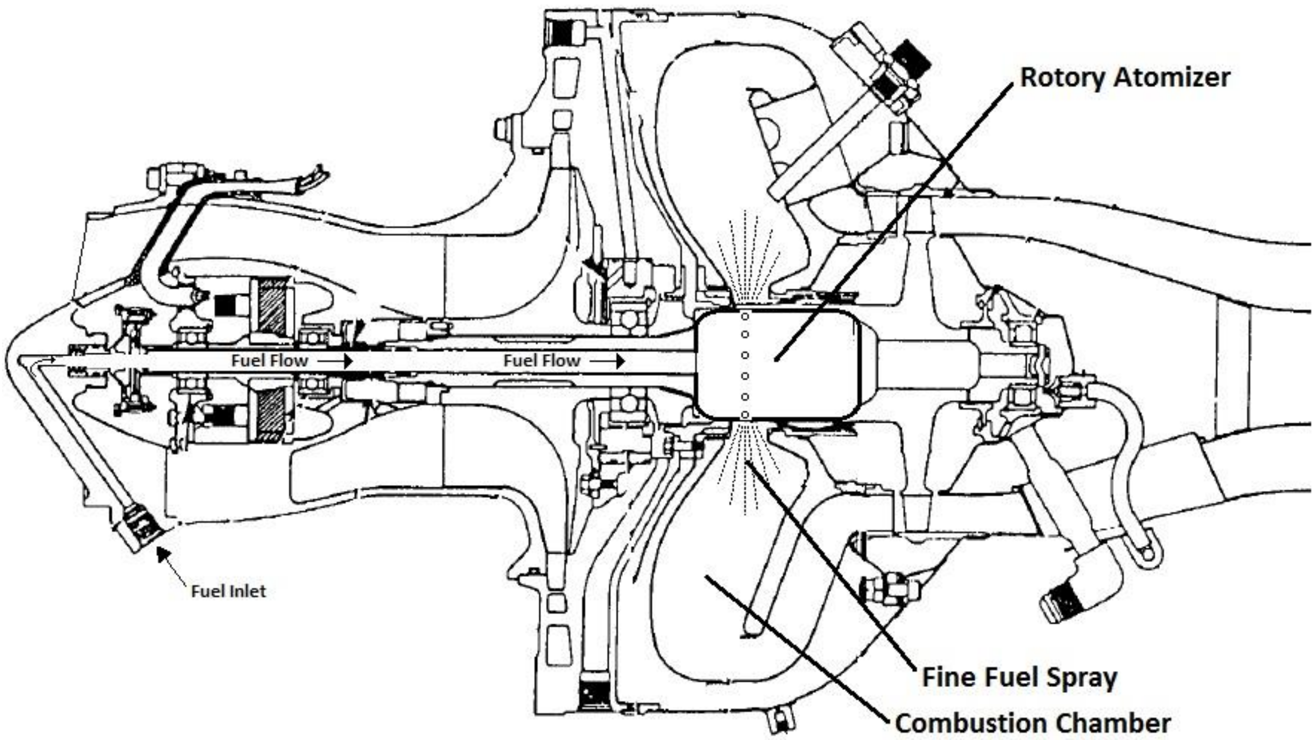


300Lb thrust turbojet featuring vaporizing burners (NPT301)

A small turbojet engine built in the late 1980s by Noel Penny Turbines was fitted with vaporizing burners. The simple design saves weight and manufacturing complexity. A variable speed electric motor was used to supply fuel to a ring of burners with a variable flow rate. A second electric motor was used to supply fuel to a small atomizing nozzle placed close to an igniter plug for engine starting.

Rotary atomizer

Chapter 1 detailed a special type of combustion chamber that utilizes the rotating shaft of the engine itself to create an atomized supply of fuel for combustion. Fuel is passed into and along the shaft connecting the compressor to the turbine. Special seals at the cold compressor end of the shaft admit the fuel into it and maintain separation between the fuel and oil lubrication systems. A series of small holes or orifices positioned around the circumference of the shaft form rotating nozzles that admit fuel into the combustion system that surrounds the shaft. As the shaft turns at high speed a disc shaped spray pattern results that is contained within a toroidal or doughnut shaped combustion chamber liner. The flame pattern resulting from this arrangement burns outward from the center and so the hot gases emerge at the outer diameter where they are guided into a radial or axial turbine.



Section view of an engine showing rotating fuel atomizer nozzles

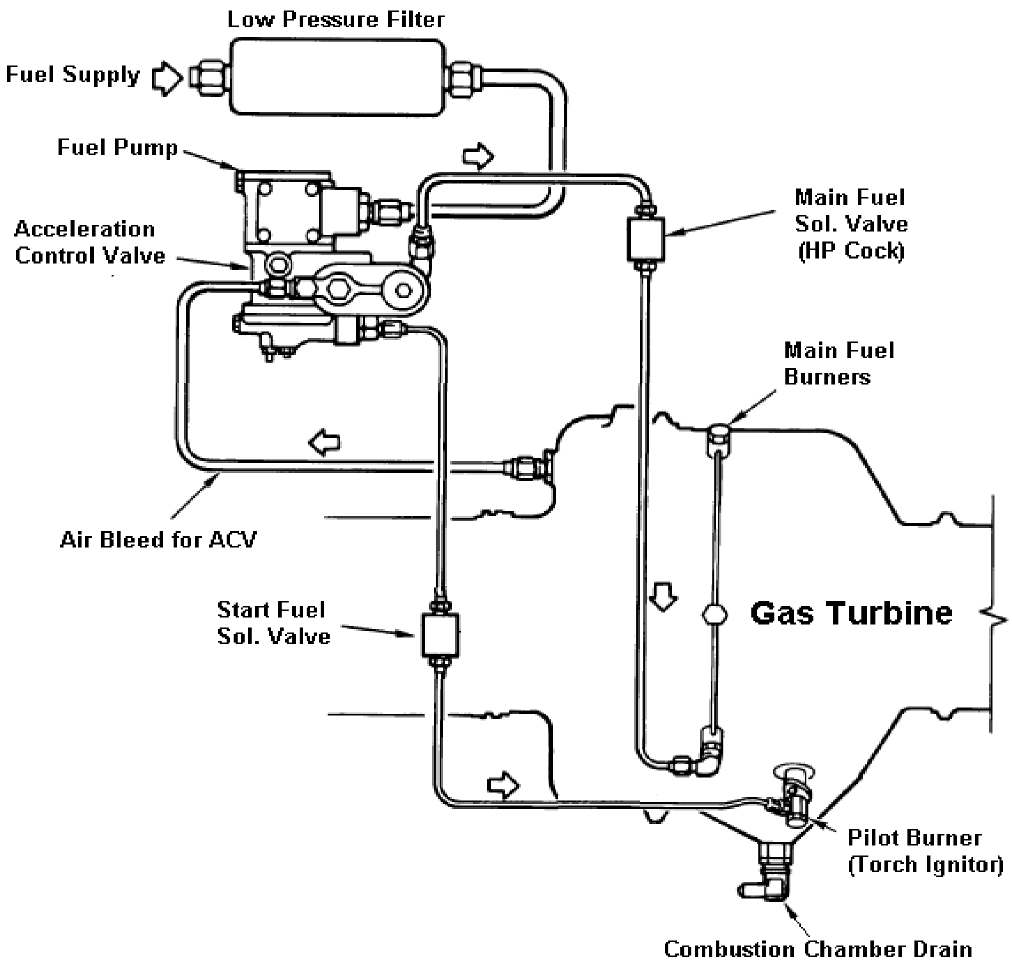


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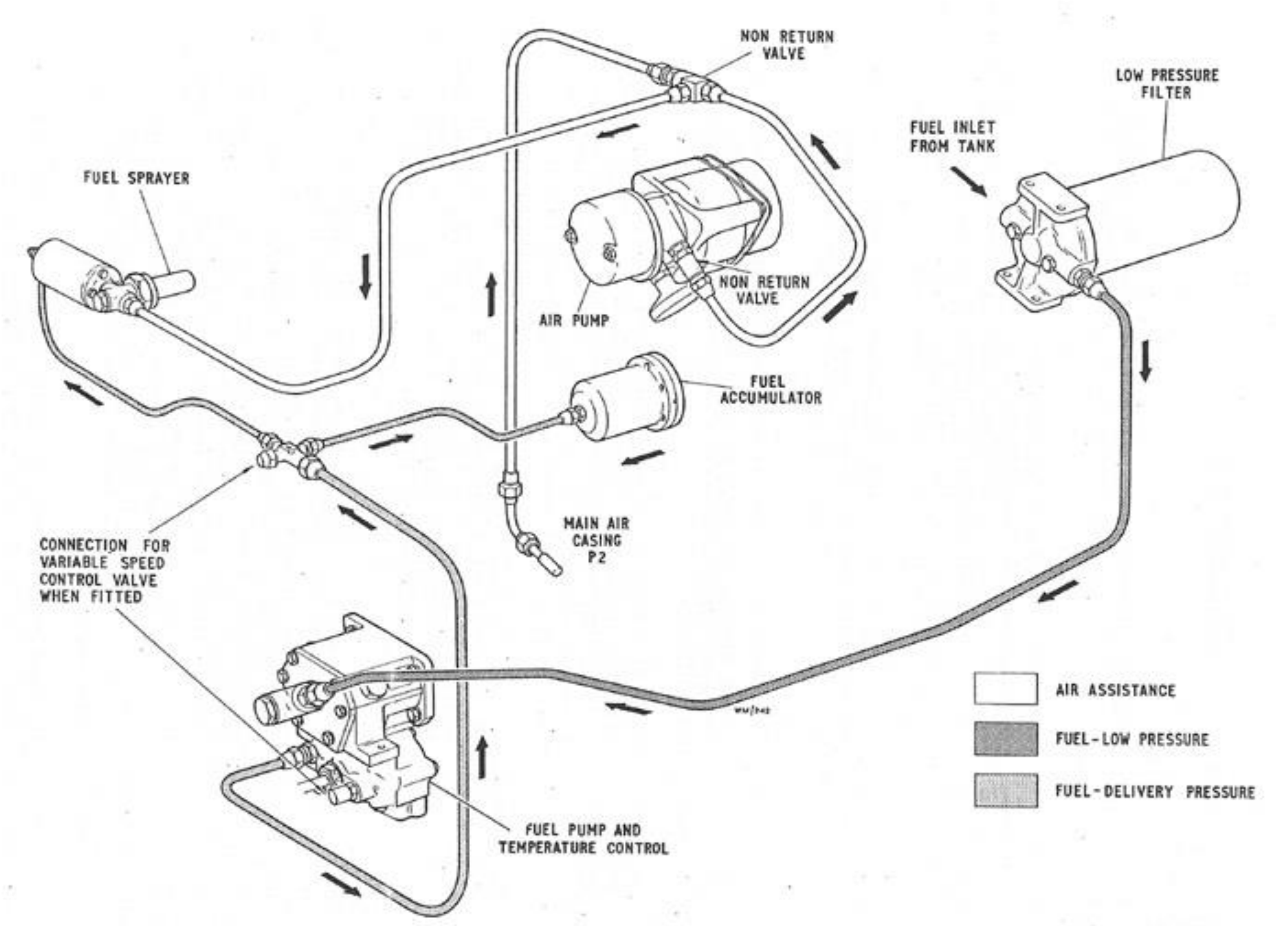
Diagram showing basic small gas turbine fuel system



Rover 1S60 fuel system

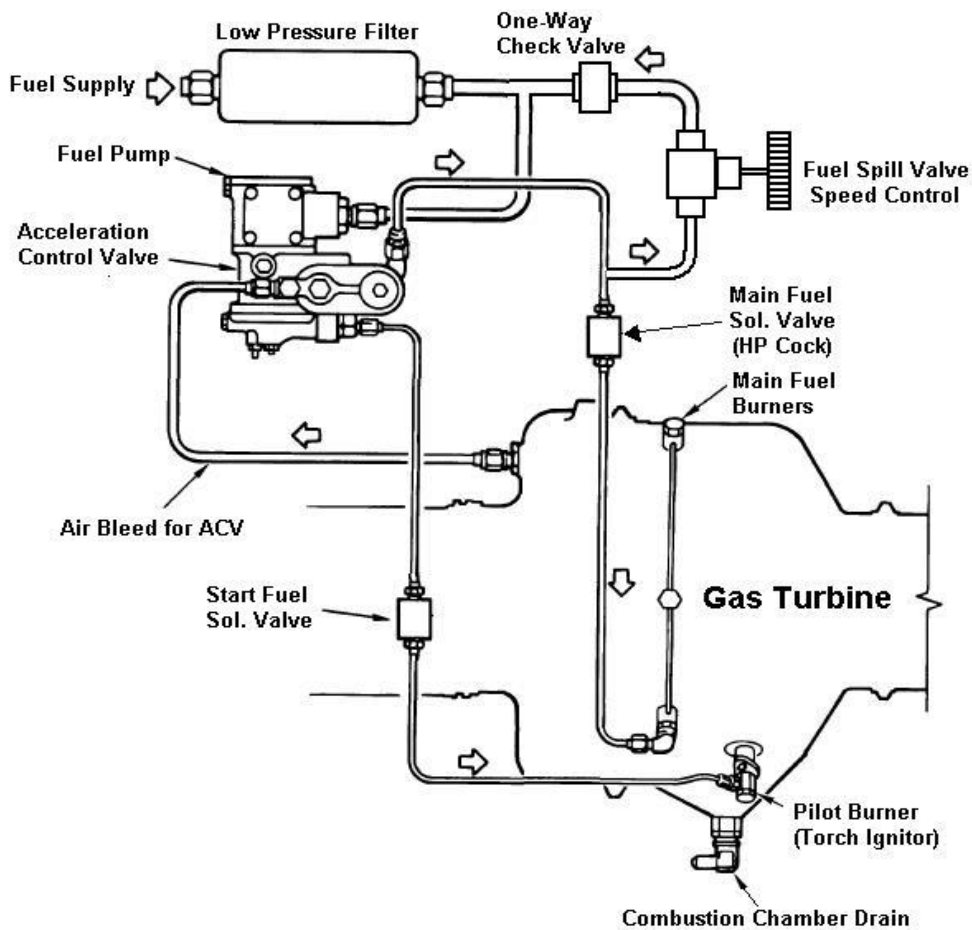
Rover 1S60 fuel system

The illustration above depicts the fuel system belonging to a Rover 1S60 engine installation. A small piston type fuel pump with built in centrifugal governor supplies fuel to a single burner nozzle. A temperature limiting fuel spill valve is included in the fuel pump housing assembly. This system is also fitted with an air pump to improve starting atomization and a small fuel reservoir also to aid starting. The reservoir holds a small amount of pressure against a spring to provide adequate fuel pressure during the initial rotation of the engine.

Idle and speed controls

Many small gas turbines do not run at an idle speed, they simply start and accelerate to governed maximum speed. Single shaft engines driving generators or hydraulic pumps are only loaded when full speed has been reached; there is often no need for an intermediate idle speed.

Certain engines are fitted with idle controls for various reasons. An idle speed is normally achieved by restricting the fuel flow to the burner in some way. A restricting orifice is placed in the fuel supply to the burner, and a solenoid valve bypasses the orifice for normal full speed operation. Fuel flow may also be reduced by bleeding or spilling fuel from the burner back to the fuel pump low-pressure inlet, this then lowers the engine speed by starving the combustion process off a portion of fuel flow. When fitting spill valves care must be exercised to ensure when the engine is stationary a fuel flow path is established which will enter the combustion system for example fuel should not be allowed to “Siphon” from a low-pressure system into the combustion chamber or other parts of the fuel system.



Gas turbine fuel system fitted with a simple spill-valve speed control

To aid the test-running of an engine the speed may often be varied, and the engine "throttled" manually by using a needle valve to spill fuel from the burners. It should be noted that the valve will operate in the opposite sense to that what might be expected, as the valve is opened more fuel is bypassed from the engine and it consequently slows down.

Whitey valves (Swagelock) often suitable for use as spill valves

Small industrial needle and ball valves are potentially suitable for use as spill valves in gas turbine speed control systems. A range of valves are manufactured by Whitey or Swagelock, some experimentation is required establish the suitability of a valve for use with a particular engine. It should be noted that these valves function as a spill valve and not a restriction so to reduce spill and hence increase engine speed the valve is turned clockwise.

The suitability of a particular valve for use with Jet and Kerosene type fuels should be checked with the valve manufacturer before use. Certain types of valves may be fitted with seal materials which are not compatible with Jet fuel.

The Rover system is fitted with a T-junction in the high-pressure fuel line where a suitable spill valve may be inserted to control the engine speed. It should be noted when using this valve, the engine speed is not governed against a datum and so some “wondering” and rpm instability may result.

A more sophisticated way of varying the engine speed and to establish an idle speed is to adjust the governor. The datum point around which the governor works is dependent on centrifugal force balancing a spring force. On certain types of governors, the spring force can be varied which will cause the engine speed to change. Once set, the engine speed will remain constant and governed at that value.

Caution should be exercised if adjustments or modifications are to be made to a governor system. The malfunction of a governor could lead to over-speeding and consequently catastrophic failure.

Gas turbines as compared to piston engines generally have a small range over which their speed can be varied. A typical APU may run at 45,000 rpm and idle at 25,000 rpm, this is a speed range of less than 2:1. The fuel efficiency of a gas turbine is related to the amount of compression that takes place in the compressor. As the speed drops the pressure ratio falls off quickly and so does the fuel efficiency, there are limited advantages in operating an engine at an idle speed.

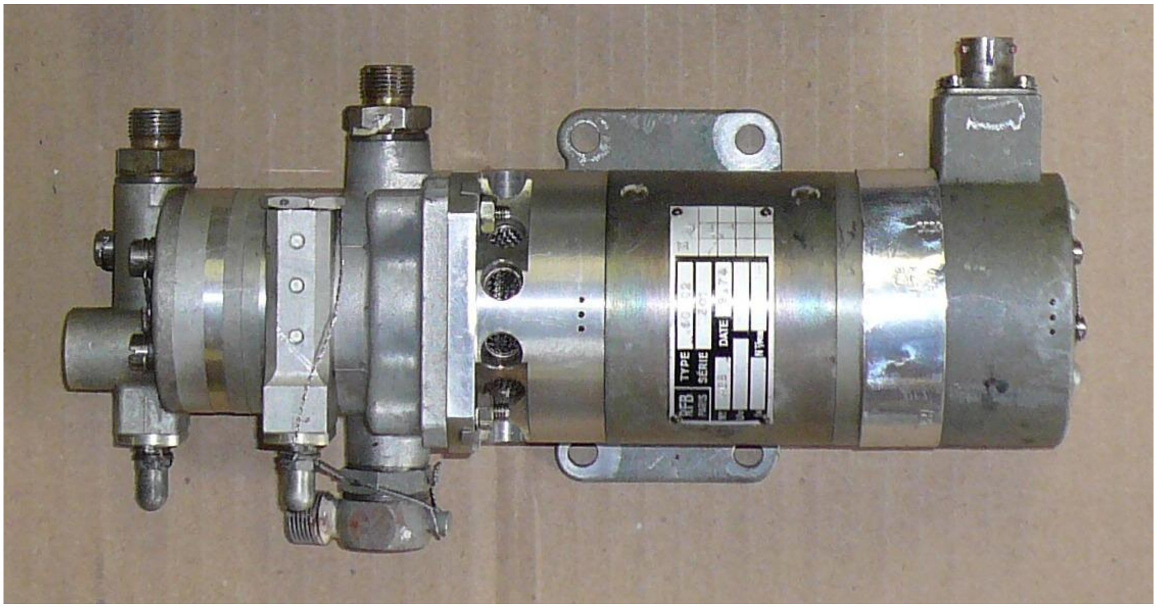
Electronic fuel control systems

It is possible to control a gas turbine engine by the use of electronics. Most of the engines referred to in this document were built in the 1960s and 1970s, during this period transistorized electronics and micro-electronics were still relatively new. Several gas turbine manufacturers during this period fitted an electronic control system to their engine designs.

Electronic fuel control system components

The basic electronic control system consists of a fuel pump, an electronic control unit or box, an electrical fuel metering valve and an electronic engine speed sensor.

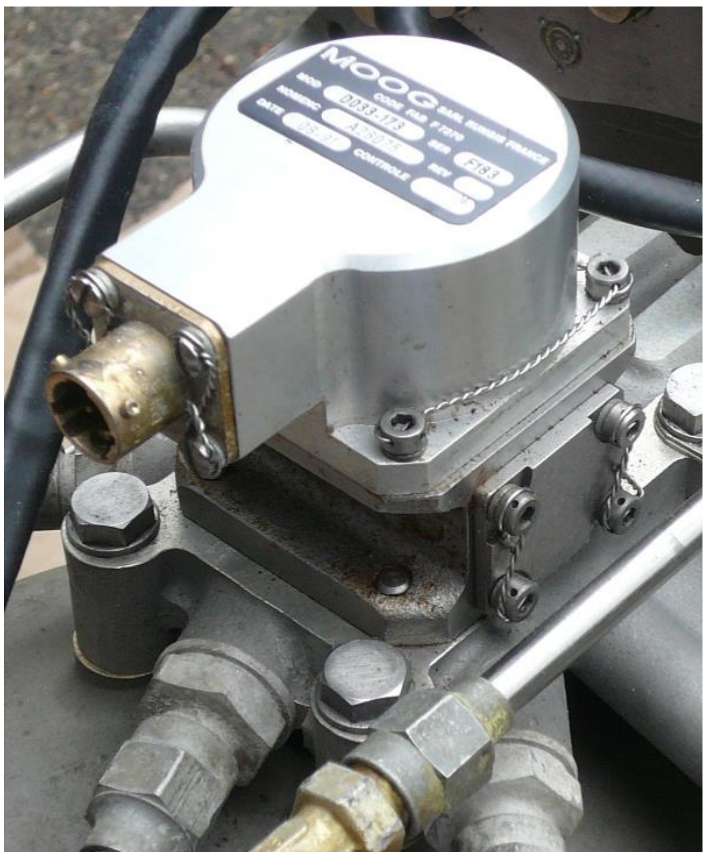
Fuel pump A fuel pump is required to provide a source of pressure so that it may be admitted to the combustion chamber through burner nozzles. In many cases the fuel pump is driven by the gas turbine engine via a train of gears (to reduce the rotational speed) but it is also possible to use a separate electric motor to drive this pump. The use of an electric motor simplifies the design of the engine accessory gearbox that is required, it may also reduce manufacturing costs and aid servicing and replacement procedures.



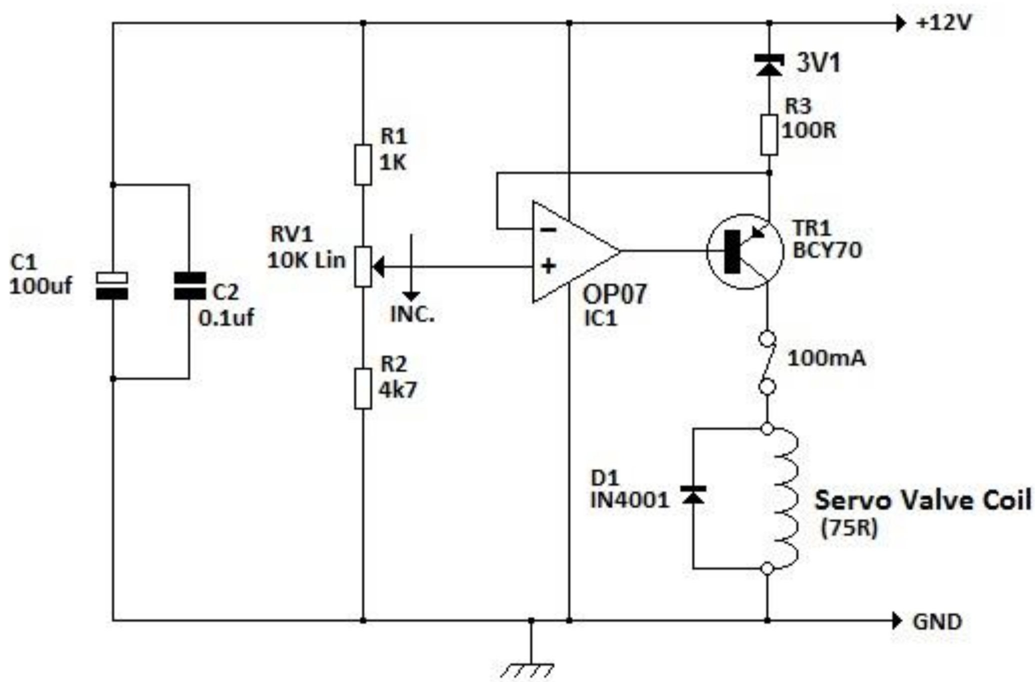
Electric motor driven gear type fuel pump (Microturbo)

Fuel metering valve In order to control the flow of fuel into the gas turbine engine, a special electrically operated valve is required. A valve with a proportional characteristic is required to convert a changing electric current into a variable fuel flow rate. Usually, an orifice within the valve through which the fuel flows varies in size under the action of an electromagnet, the orifice size thus varies according to the electric current applied to the valve.

Metering valves are specialized devices often specially manufactured for controlling gas turbines. A special type of valve called a "Servo" valve may be used to control fuel flow. The pressure of the fuel itself is used as a hydraulic force to move components inside the valve. This pressure force is augmented by components moved by an electromagnet. The company "Moog" manufactures such valves, they are commonplace in the aerospace industry, the engine manufacturer Microturbo uses a form of these valves to interface electronic controls with their fuel systems.



Servo valve used as a fuel metering control



Simple servo-valve driver circuit (Constant I 0-30mA)

The diagram shows a simple constant current source driver circuit intended to supply a Moog type servo valve unit for bench engine testing. An op-amp feedback circuit maintains a potential across R3 that is set by RV1. The op-amp will drive the transistor sufficiently to achieve a potential at the emitter equal to the potential at RV1. The transistor draws the necessary current to achieve this through the collector circuit thus creating a constant current action independent of the resistance in the collector circuit (Within limits).

RV1 is able to vary the potential at R3 and thus controls the current drawn through the collector circuit. The zener diode is present to ensure the circuit controls down to zero current and enables the OP-Amp to operate away from the supply rails. The circuit is essentially upside down and uses a PNP transistor so that one side of the Moog valve load circuit may be at ground potential. Some small adjustments of R1 and R2 may be necessary to achieve the required adjustment range of RV1.

The advantage of a constant current variable test circuit is it maintains a constant setting in the Moog valve and doesn't drift due to changes in the temperature of the Moog valve coil. ECU engine circuits operate as a feedback loop and so this drift is automatically compensated for in an ECU circuit configuration.

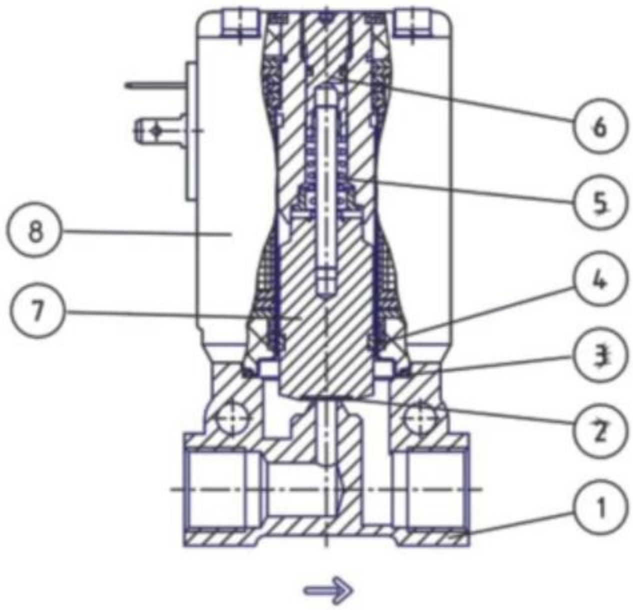
Moog valves or servo valves may be operated with small DC currents, it is possible to augment the operation of these valves by applying an additional AC current to the valve operating coil at a frequency of a few hundred hertz. This current acts as a "Dither" signal that agitates the valve components slightly and helps overcome "stiction".

Proportional Solenoid Valve

Solenoid operated proportional valve (Burkert)

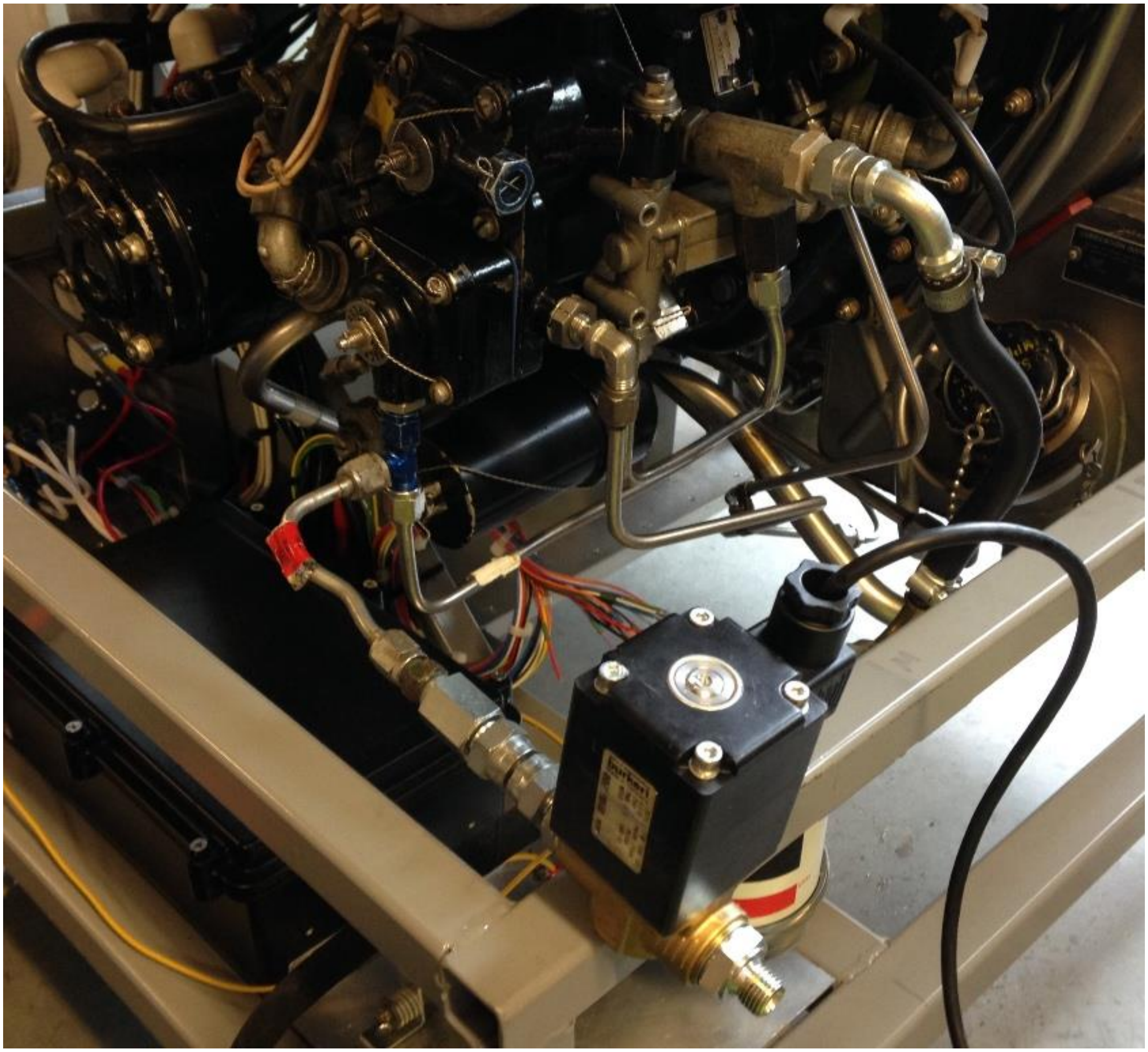
Proportional solenoid valves are available that may be suitable for the control of gas turbine engines. A typical valve features a solenoid operated plunger that fits in to an orifice inside the valve. A variable current through the solenoid coil will affect proportional control of the aperture created by the plunger and the orifice. The valve may be used to spill fuel from the burner system or spill air form an acceleration control circuit that will alter the metering of fuel to the burner system. Care is needed to select the correct valve so that the orifice size will create an appropriate pressure drop in order to meter the fuel through a sensible control range. Also, compatibility of the valve with jet fuel and kerosene is necessary. Proportional control valves operate over limited differential pressure ranges (e.g., 10 bar) and so may not be suitable for a larger engine with higher fuel pressures.

A variable power supply is necessary to control the valve position and may be a DC type or pulse-width-modulated (PWM signal). An advantage of the latter type is that it produces a small vibration or "dither" of the valve plunger and so may aid in smooth operation and reducing stiction.



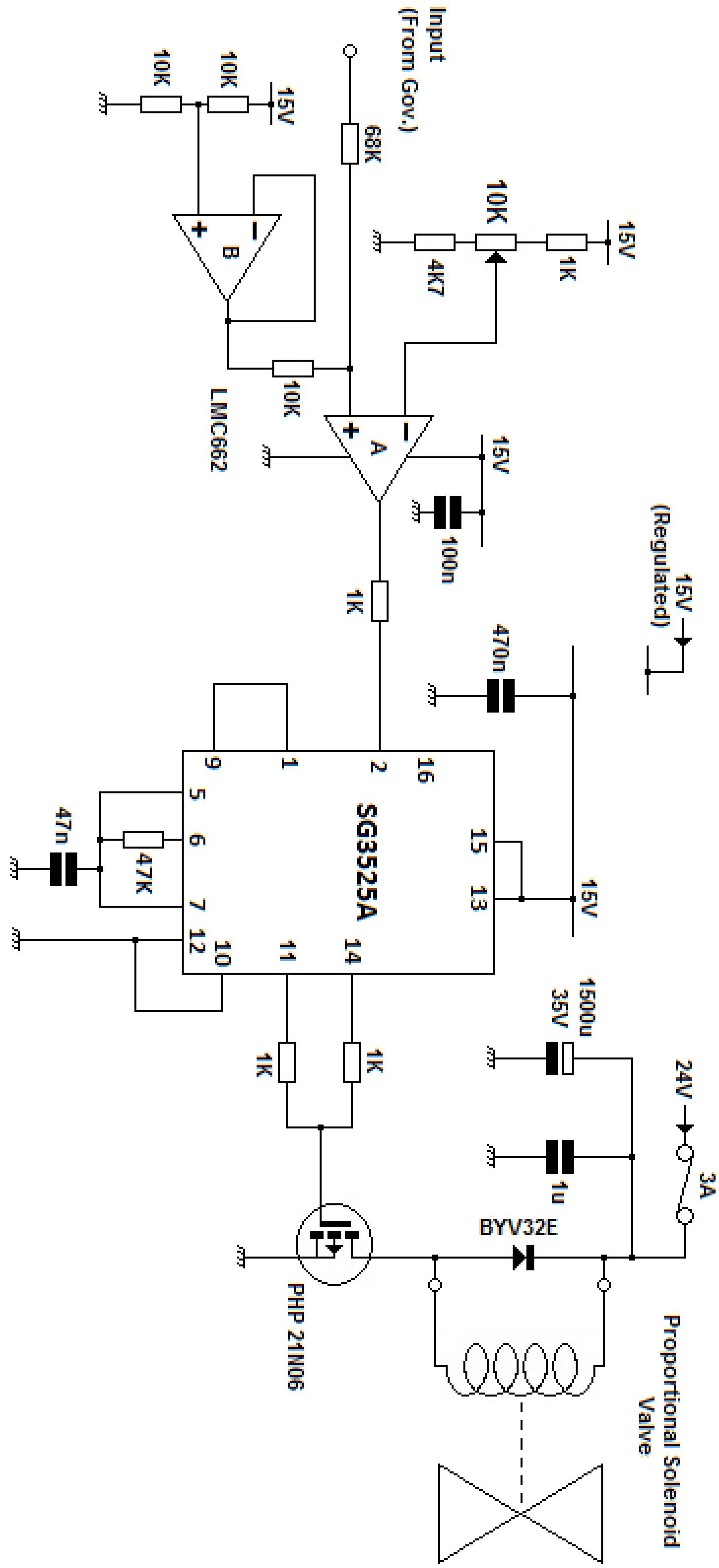
1 Valve body, brass or stainless steel
2 Plunger, FKM (standard)
3 O-ring, FKM (standard)
4 Glide ring, PTFE compound
5 Return spring, stainless steel
6 Stopper with integrated adjusting screw, stainless steel
7 Plunger, stainless steel
8 Coil, Epoxy-encapsulated

Burkert proportional valve internal layout



Proportional valve installed in P2 air control circuit

With a proportional valve installed the engine may be "throttled" at a distance and or a governor circuit added to hold the engine speed constant below the normal (mechanically) governed figure. Caution should be exercised here, it is advantageous for testing to run engines at intermediate speeds, but some designs may be damaged if operated in rpm regions where shaft dynamics are not settled or the oil system flow, sealing or scavenging is reduced.

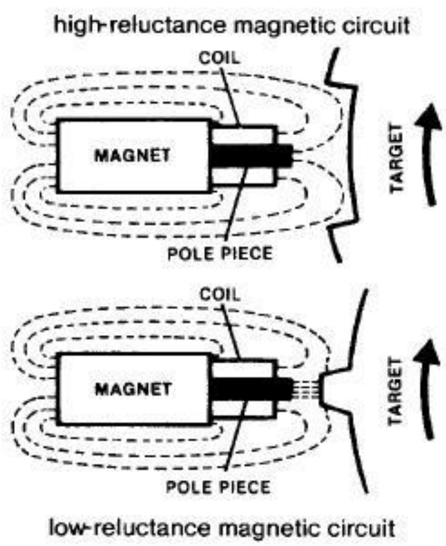


PWM Driver circuit for proportional valve

Speed sensors An electronic speed sensor is required to provide an electronic control unit with a speed signal. The sensor generates a signal that is directly proportional to the rotational speed of the engine.

A common speed sensor arrangement consists of a special electromagnetic probe that is placed near a rotating toothed wheel or cog. This type of probe is referred to as a “Magnetic Reluctance probe”. The probe consists of a small coil and a magnet that is placed close to the moving teeth of the cog or wheel. The wheel is sometimes referred to as a “Phonic” wheel and may be placed specially inside the engine or an existing gearwheel is used instead. As the wheel rotates the passing teeth vary the magnetic coupling between the teeth and the probe that varies the magnetic flux through the probe. The changing magnetic flux in the probe intern generates electrical pulses in the probe coil as the individual teeth pass by. The probe output appears as a train of electrical pulses the repetition rate or frequency of which is proportional to engine speed. This speed signal is then processed by electronic control unit or box.

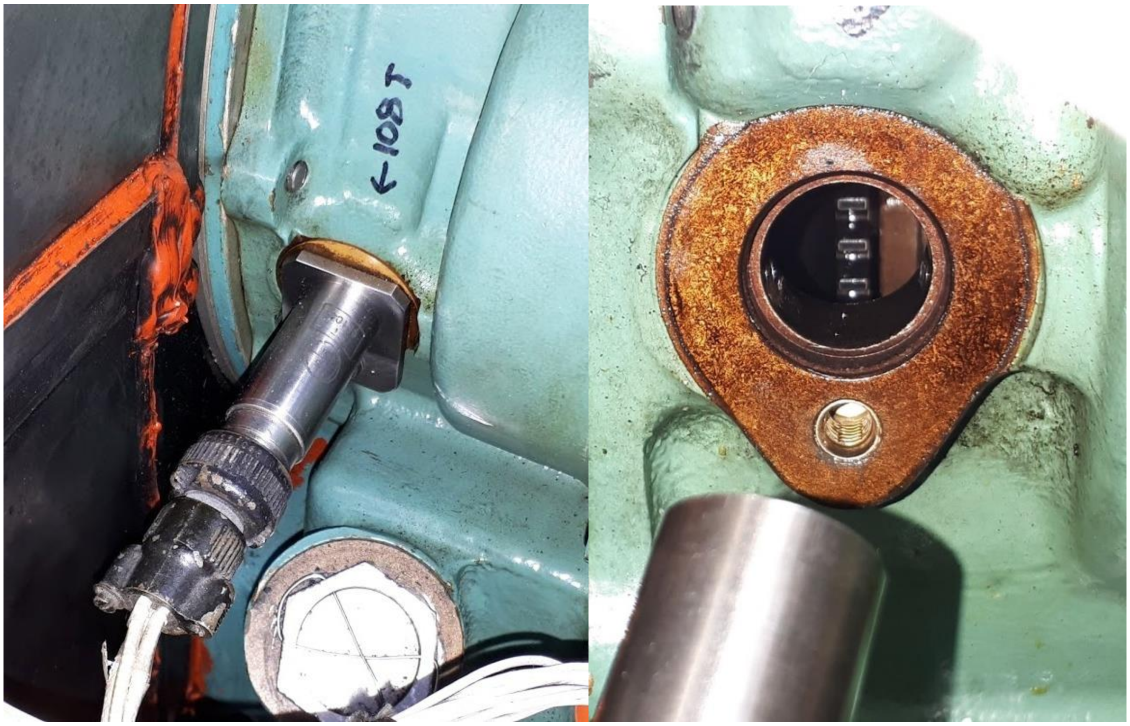
FIGURE 2



Reluctance RPM Sensors

Magnetic reluctance speed sensor probes

Other types of electrical speed sensors are also used in gas turbine engine. Many engines are equipped with small electrical generators intended as part of an electrical instrumentation system. The generator unit is often referred to as a “Tachometer Generator” and may be mounted on the engine gearbox or accessory gearbox. In addition to a speed indicating system, these generators can supply a signal proportional to engine speed that may be fed to the electronic control system.



Reluctance speed sensor probe fitted to an APU accessory gearbox

The above picture shows a reluctance speed probe fitted to an APU accessory gearbox. With the probe removed the gear wheel teeth may be clearly seen which forms the "Phonic" wheel. In this case the wheel has 108 teeth, spinning at 10,000 rpm it creates an electrical signal of 18KHz in frequency. The distance between the probe and the gear teeth must be accurately set (often with shims), too close and the probe could rub and contact the gear and too far away the probe will not produce sufficient electrical impulses to operate the control unit and instrumentation.

Electronic control unit (ECU)

An electronic control system is designed to control all the stages of engine operation and may also protect the engine against overheating, over-speeding and compensate against changes in ambient temperature, pressure and power supply voltage.

A typical gas turbine APU electronic control unit (ECU)

The electronic control system is normally housed in a protective enclosure and mounted close to the engine. The electronic control unit may be powered from a 24V supply. The electronics are often sophisticated, a control unit may be an analogue computer, many signals such as temperatures, engine speed and pressures are all processed simultaneously.

The basic function of an ECU is to schedule the fuel supply to the engine so that it maintains a constant rpm and so governed and ready to accept a load. In addition to this, the ECU may be required to control the starting and acceleration sequence of the engine, prevent compressor surge and prevent excessive exhaust gas temperature.

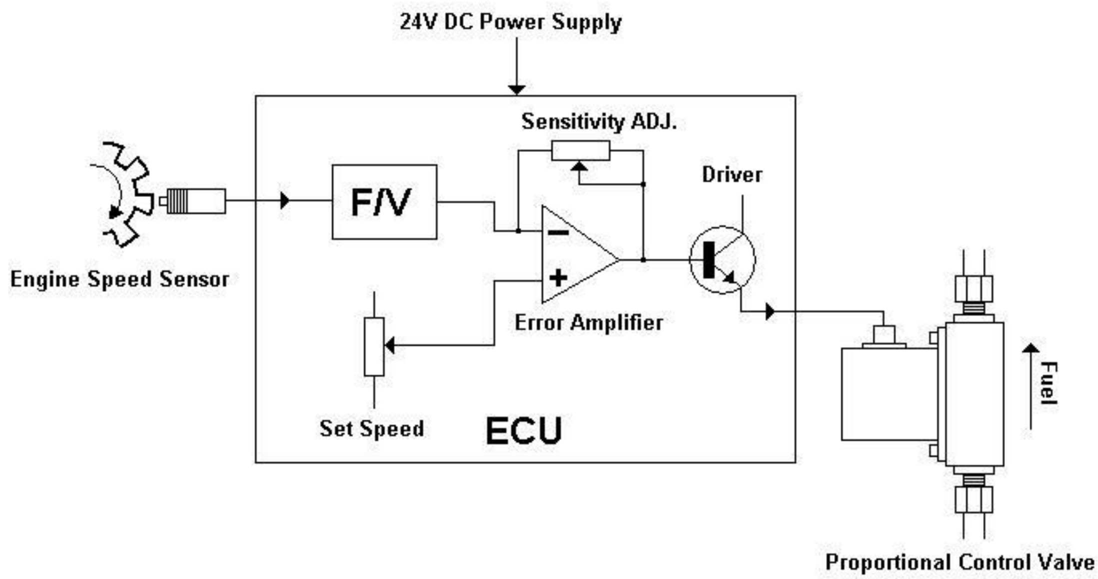


Fig 1 Simple ECU

Figure 1 shows a diagram of a basic electronic control system. It consists of a speed sensor that feeds an AC signal into a device known as a frequency to voltage converter. This accepts the speed signal and converts it to a DC voltage that varies in magnitude according to the speed of the engine. The speed sensor provides an AC signal or series of pulses of which the frequency can be measured. A typical frequency might be 2 KHz at an engine speed of 60,000 rpm. The exact relationship between the engine speed and the frequency of the speed signal will be determined by the number of teeth on the “Phonic Wheel” and the gear ratio between the sensor wheel and the engine main shaft.

A common speed signal frequency developed by engine a mounted tachometer generator is 70Hz. This will interface with many percent reading engine speed indicators. A 70Hz signal is relatively low for many electronic controls so it is normal to feed control units from a probe arrangement that develops a higher frequency signal in the region of several KHz.

An electrical amplifier is used to compare the voltage generated by the frequency to voltage converter and a fixed voltage reference. The amplifier effectively amplifies the difference between these two signals; it is referred to as a differential amplifier. The output signal from the amplifier is used to drive a proportional control valve placed in the fuel feed to the engine.

As the engine runs the amplifier sends a signal to the control valve increasing fuel flow to the engine and as a result the engine speed increases. An increase in engine speed increases the F/V speed-signal voltage; this then reduces voltage signal difference at the amplifier input. The amplifier output now reduces and so the fuel supply to the engine also reduces. A point is reached where the system stabilizes with a given amount of fuel to maintain a constant engine speed. The amplifier detects the difference or error between the speed reference and the speed signal. The error or fuel signal does not stabilize at a zero difference; instead, an offset is created giving the engine the fuel needed to run otherwise a zero error would mean a zero-fuel supply!

The control system has formed a simple control loop whereby it can respond to changes in reference voltage (increasing or decreasing the controlled speed of the engine) or changes in the load placed upon the engine. The reference voltage that sets the engine speed is known to as the speed datum. The control loop may be considered as a governor system running at a speed set by the datum. In electronics an "Amplitude Locked Loop" has been created as a feedback loop seeks to maintain a constant difference between the amplitude of the datum and the amplitude resulting from the speed signal.

This simple electronic control circuit can be made to work as a practical system, but it suffers a number of disadvantages-

1. The simple error amplifier system only functions for near steady state conditions, it doesn't allow for engine starting as at starting speeds the difference between the rpm signal and speed datum is very large supplying excessive amounts of fuel to the engine! Additional electronics are needed to allow an initial starting fuel flow to be set and the fuel flow and acceleration to be controlled as the engine runs up to speed.
2. The engine response to fuel supply changes is not instantaneous; if the amplifier is made too sensitive it will overshoot the fuel before the sluggish engine catches up leading to system oscillation and hunting. Violent oscillation and hunting can lead to compressor surge and or flameouts if the fuel supply is cut back too quickly.
3. If the amplifier is not sensitive enough, a load applied to the engine will not create a very large error signal, this will lead to an inadequate increase in fuel flow. An inadequate supply of fuel under load will result in the engine slowing down, this is often referred to rpm droop in governor systems.
4. The simple system does not take into account other engine parameters such as exhaust temperature, inlet temperature and even atmospheric pressure. Monitoring and protection circuits can be built into a sophisticated ECU thus preserving the engine under fault or excessive load conditions.

In addition to the fuel supply function a gas turbine ECU may also provide electrical outputs to sequence automatic starting, fault detection, instrumentation and load application.

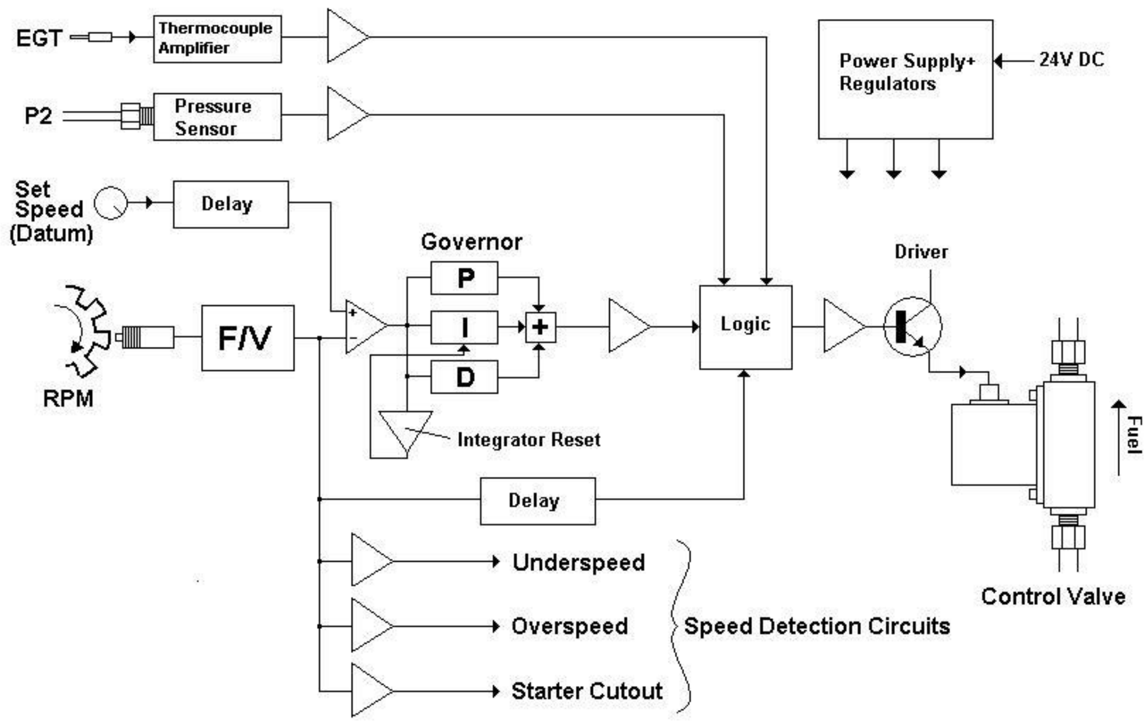


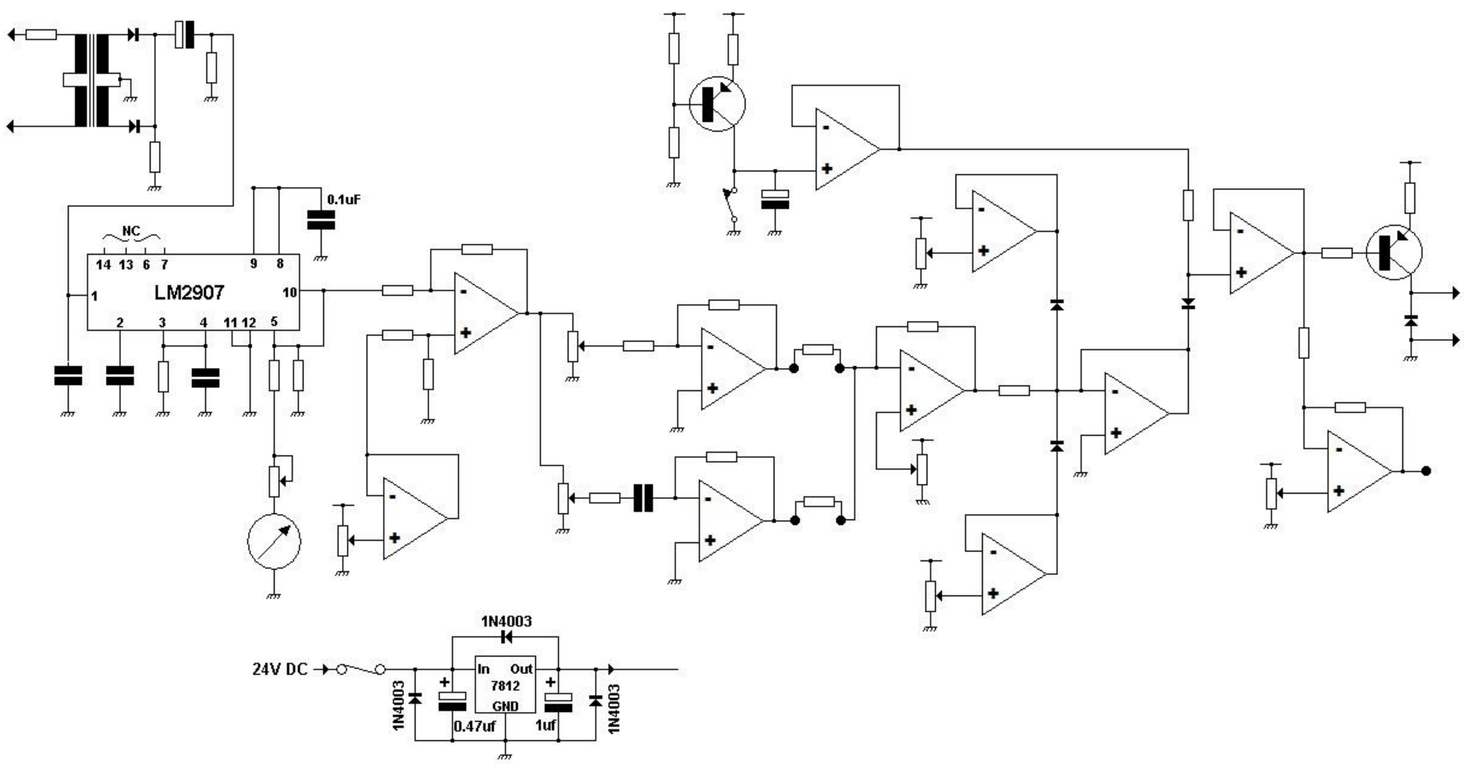
Figure 2 Complex ECU

Figure 2 shows an advanced engine control unit schematic. Practical designs vary enormously between engine types and will depend on the exact function of the engine and how it is required to behave. This design incorporates a special type of electronic governor circuit called a PID controller. PID stands for proportional integrated differential, PID circuits are commonplace in electronic controls. A PID controller consists of three special circuit functions that are combined and used to process the error signal developed in a control loop. PID controllers are used in many electronic control systems, almost anything where there is a feedback loop and a varying system is held constant against a reference, examples include, engine speed controls (Governors), temperature control, vehicle cruise controls and frequency synthesizers.

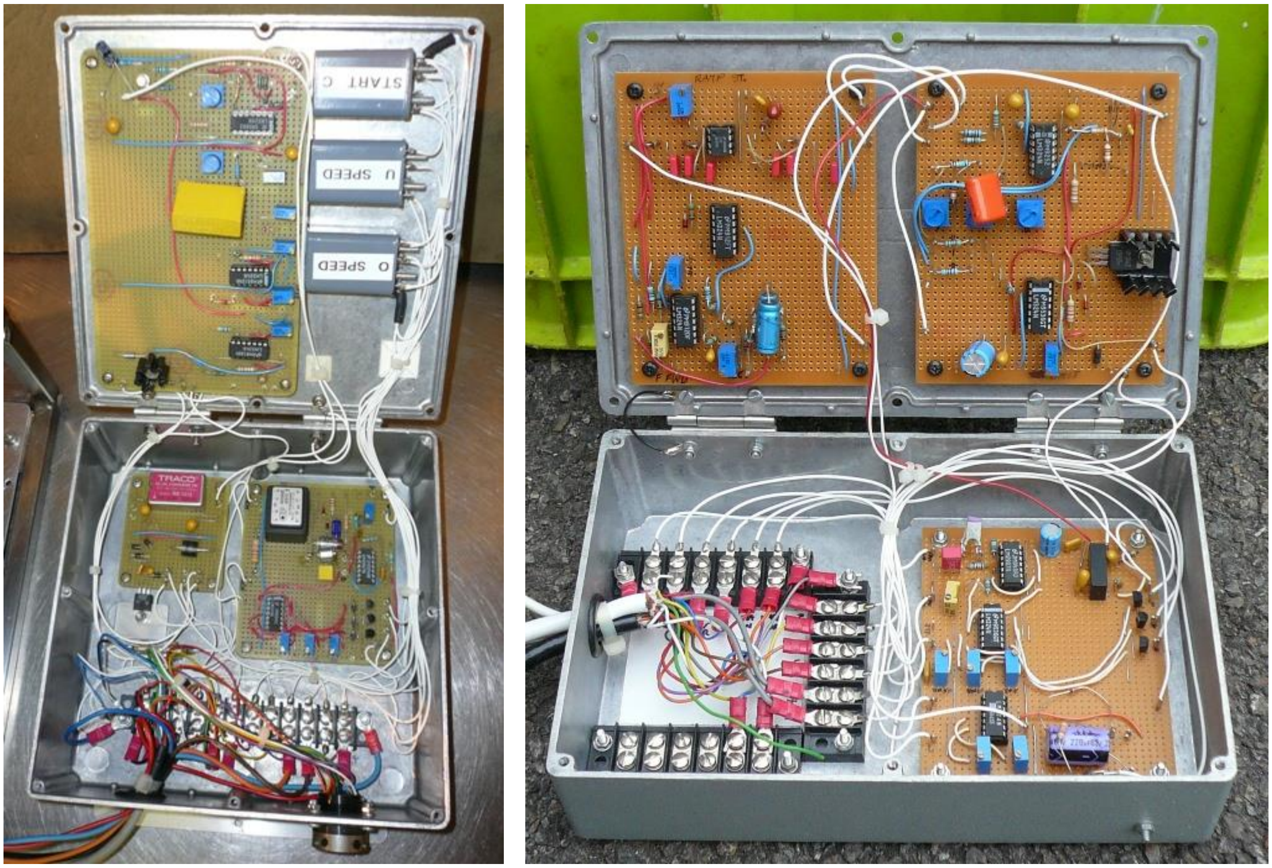
The circuit features sensor circuits to monitor and detect engine parameters such as pressure, temperature and speed selection. These functions are applied to logic circuits to ensure the engine does not exceed maximum permitted limits. The electronics are designed to fail-safe i.e., failure of external signals will cause the fuel supply to be cut back or the engine shut down. The circuits may also incorporate timed response changes or delays so that the engine is not subjected to sudden transients which could induce compressor stall or flame out.

A particular hazard exists with electronic speed controls. Failure of the speed signal is essentially the same condition as a low engine speed signal so there is a tendency to increase the fuel supply and speed up the engine. An electronic circuit should be incorporated in to the system so that when a speed signal fails or is cut off the engine fuel supply "trips" off preventing the engine from running away.

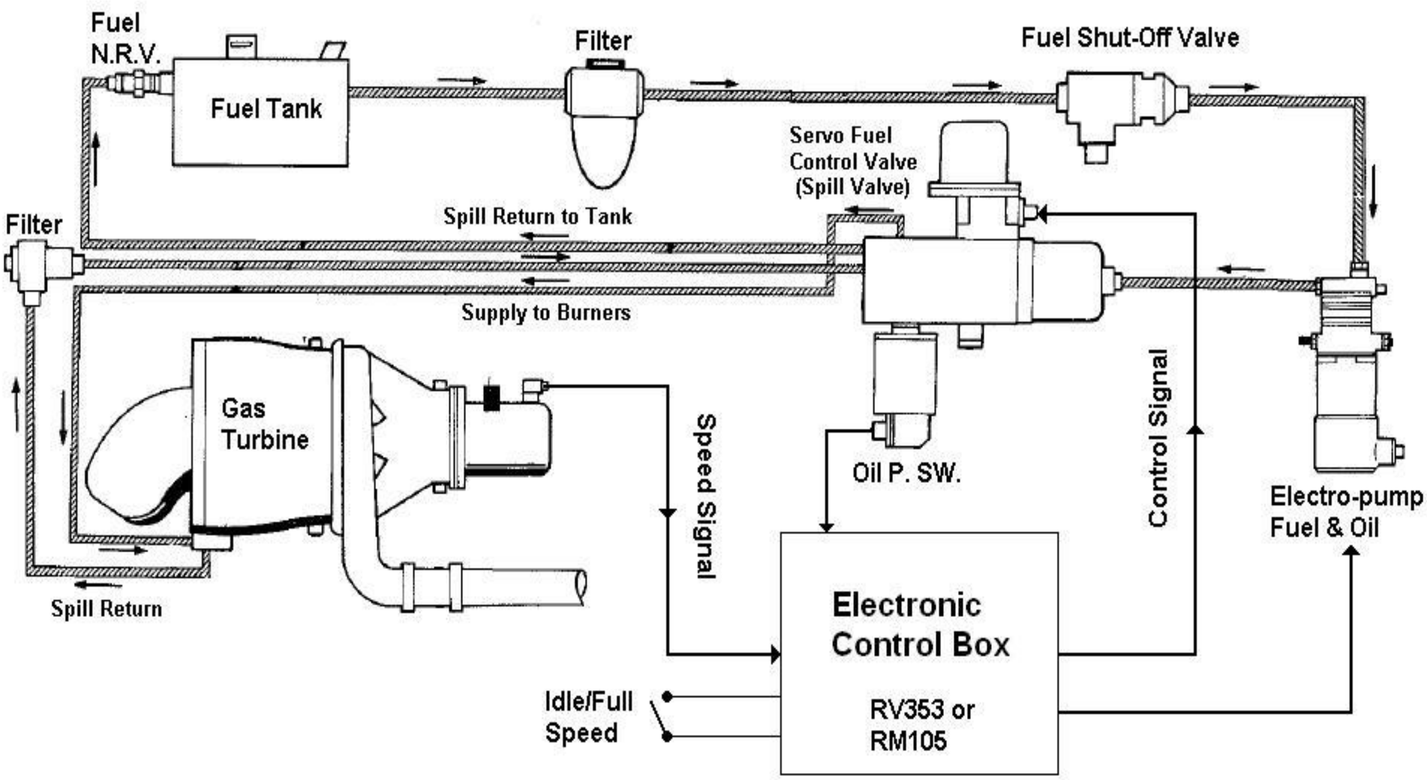
An electronic control unit will often feature speed detection circuits to augment the starting sequence of the engine. Circuits will be used to operate the starter and ignition and cut them off when a detected speed value is reached. Additional protection circuits will be armed to guard the engine from low or absent lubricating oil pressure and an over-speed condition.



Home constructed ECU circuit



Home constructed experimental ECUs (left GT15 right T62)



Microturbo fuel system featuring an electronic engine control unit

The company Microturbo produced a small gas turbine intended as an APU and as a starter for military aircraft called the Saphir series. The Saphir engine is rated at 50HP (depending on application) and produces an air supply of 0.4 kg/sec air bleed at approximately 40 PSI pressure. This unit is sometimes referred to as an “Air Generator”. The aircraft installation is designed to be fully automated, and it employs an electronic control unit to fully manage the starting and running process of the APU. In addition, this system is interfaced with the main propulsion engine starting system so that the APU starts up, runs and shuts down at the right time during the aircraft engine starting cycle.

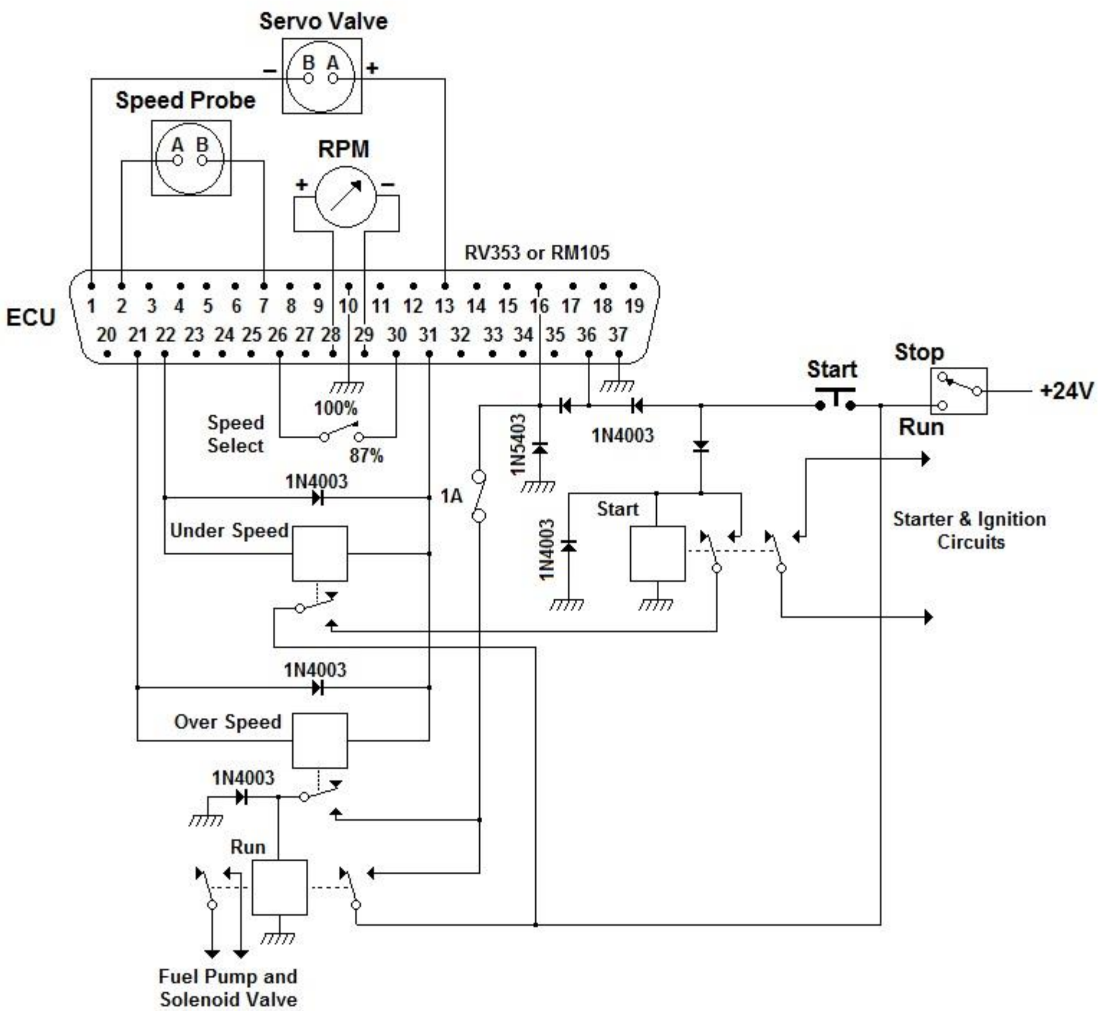
This Microturbo system uses an electric motor driven pump to provide both oil and fuel circulation through the engine. The engine itself is only fitted with a mechanically coupled starter motor and no other driven accessories.

At the heart of the control system is a control box module known as an RV353; later units with increased functionality are known as RM105. The primary function of the module is to govern the engine speed at two settings, an idle speed of 87% and a full running speed of 100% (100%=51,000 compressor rpm). A magnetic speed probe is installed inside the engine electric starter motor, the starter remains engaged (but not powered) at all times and so a continuous speed-signal is available to the control box. The probe detects the rotation of a phonic wheel mounted on the outboard end of the motor shaft inside the casing. The probe and wheel arrangement produce a signal of 4.290 KHz at 100% rpm.

The RM105 module is a sophisticated analogue control unit, it performs the following functions. -

1. Provides a relay hold-in signal for the engine electric starter motor so that it initiates the start cycle and cancels automatically when the engine achieves self-sustaining speed.
2. Provides a hold-in fuel signal that operates the engine fuel pump and low pressure shut off valve. If the engine speed exceeds 110% rpm, the hold in opens and the unit shuts down.
3. The hold-in cancels if the speed signal fails to the unit, providing a fail-safe shut down condition.
4. Provides a metered signal to the engine fuel control valve which ensures it lights up and accelerates smoothly to 87% idle condition and the unit is then governed at this speed.
5. An external contact closure sets the speed datum at 100% and the unit accelerates the engine smoothly to 100%.
6. Times out and cancels the start cycle if no rpm signal develops or the engine fails to light up and or accelerate beyond 70%.
7. Shuts the engine down if a pressure switch detects a lack of oil pressure.
8. The unit also provides an output voltage signal to directly drive a moving coil meter to indicate compressor rpm.
9. The unit also provides regulated positive and negative supply rails for operating other external electronic modules.

As the control module functions it sends voltage signal to the fuel spill control valve that is of the "Servo Valve" type. When the gas turbine initially starts this signal is at zero, the system is arranged so that some fuel is admitted to the combustion chamber even at maximum spill so that an initial light-up occurs. As the engine lights and accelerates, the module senses the rise in rpm and slowly increases the voltage signal to increase the fuel supply and further accelerate the engine until idle speed is reached. At idle a typical voltage of 7V is supplied to the Servo Valve (Which is now partially closed off decreasing fuel spill), when full speed is selected this voltage increases to 8V (With still lower fuel spill).



Basic Microturbo (007 series) engine control circuit

An advantage of an electronic control system is that it can be "fooled" into operating by generating artificial signals for test purposes. A signal generator may be used to produce a speed signal voltage that exercises the module, and its behavior may be monitored with various meters and test instruments. Microturbo like many manufactures also produce a test-set unit which may be plugged into the engine system and simulate an engine run to check out all the system components. Microturbo control boxes consist of complex wiring and many electrical relays, a test set is a valuable tool used to pursue and identify faults.

Test-set for gas turbine testing electronic control circuits.

The Saurer GT15 gas turbine engine employs a metering valve that is mounted axially at the end of the main compressor shaft. Fuel is supplied to the combustion chamber along the shaft that is hollow, the electronically controlled metering valve supplies fuel into the shaft by moving a small tube in and out. The position of the tube is controlled by the current flowing in an adjacent electro-magnet. Interestingly this design functions backwards, a decrease in electrical current corresponds to an increase in engine rpm.

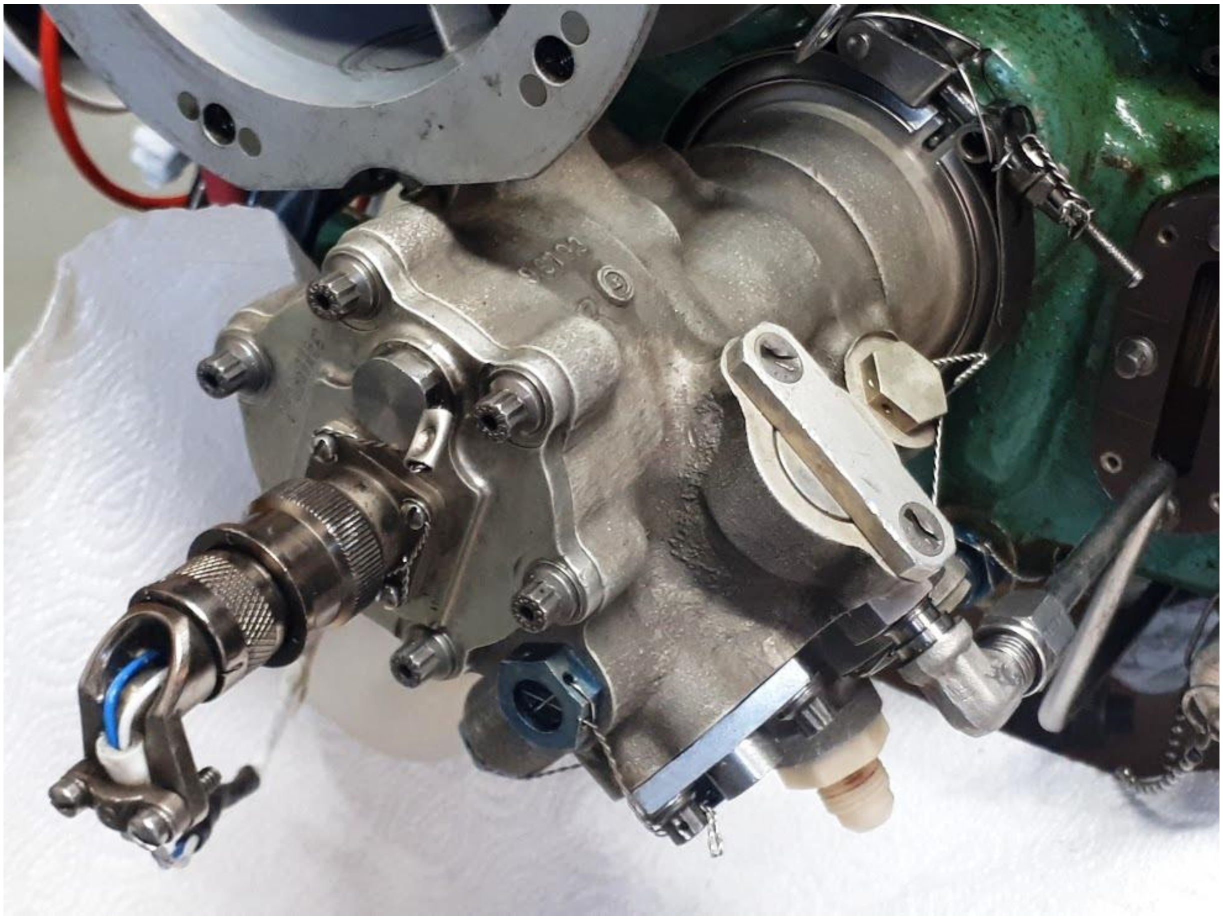
During the operation of an electronically controlled engine, the signal supplied to the metering valve is available to be measured. The results obtained may be compared to that which is specified in the manufacturers operating manual. For example, a current of 70mA might be required to hold the engine at idle speed and 40mA at full operating speed.

GT15 electronic control box and indicator panel

Honeywell ECU

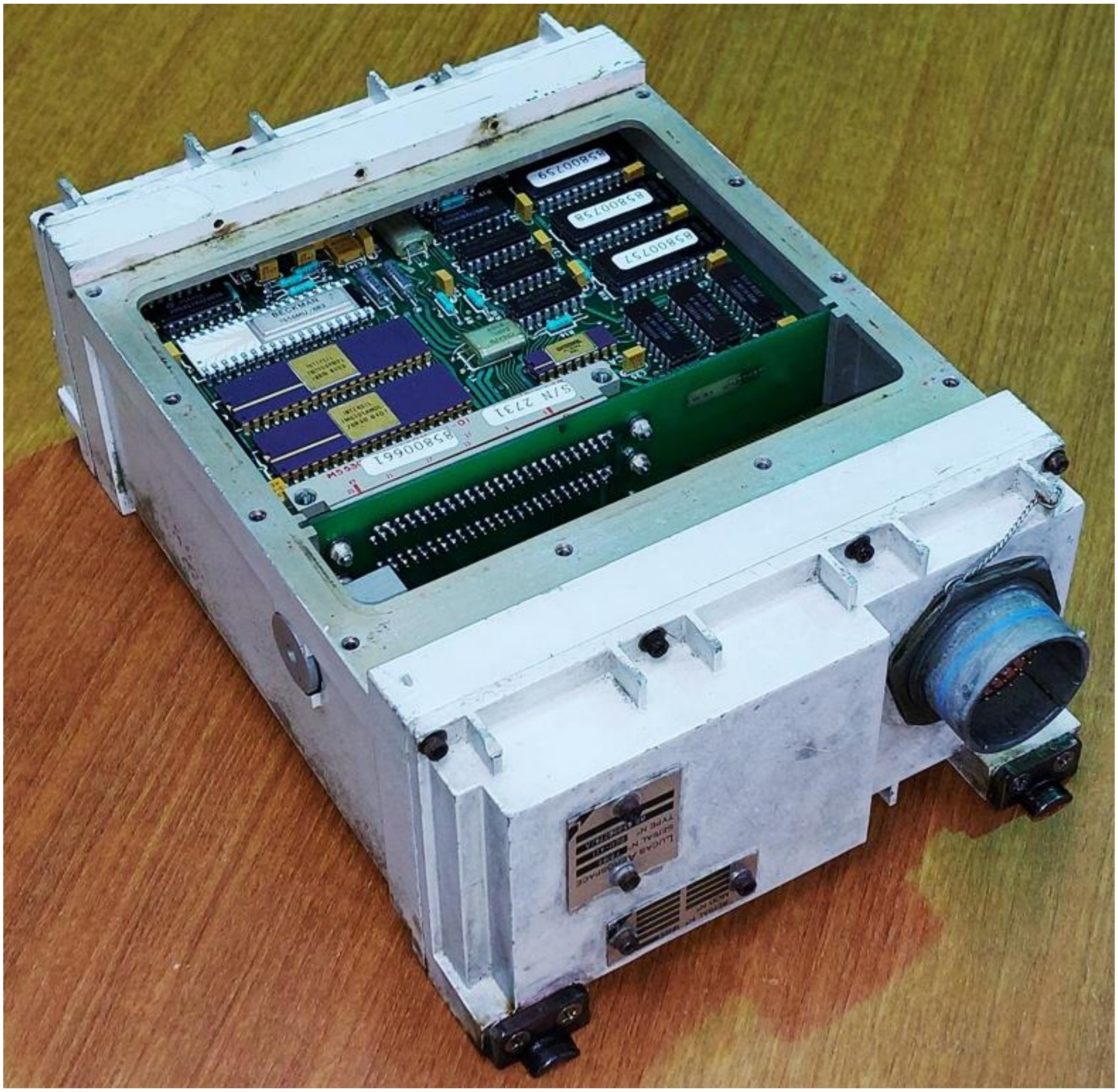
A Honeywell model 36 analogue engine control unit (ECU)

The Honeywell GTCP36-150 series of auxiliary power units feature full electronic control. An analogue control unit monitors rpm, and exhaust gas temperature and schedules fuel flow to the engine by means of a special "torque motor" fitted to a valve integrated in the fuel pump housing. The control unit limits acceleration and exhaust temperature during start up and governs the engine at 100% rpm. A reluctance probe is fitted to the engine accessory gearbox and generates and rpm signal from the main reduction gear. 108 teeth gear turns at 1/6 engine speed producing a signal of 18 KHz in frequency at 100% rpm corresponding to 60,000 rpm engine speed. In addition, logic circuits control the engine start sequence, over speed protection and load requirements. The ECU also provides instrumentation feeds to cockpit indicators.



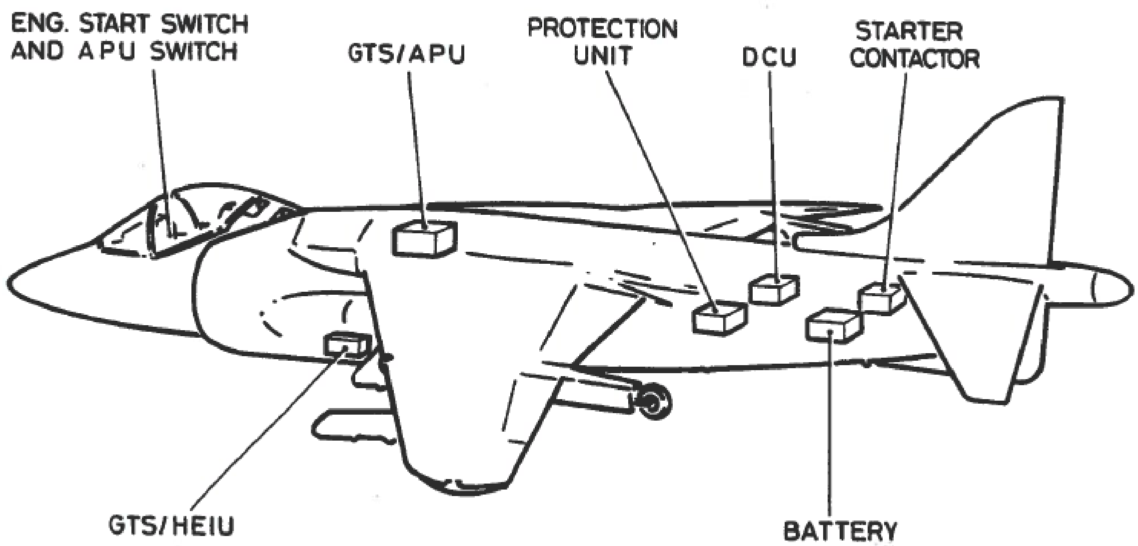
Integrated fuel pump and torque motor

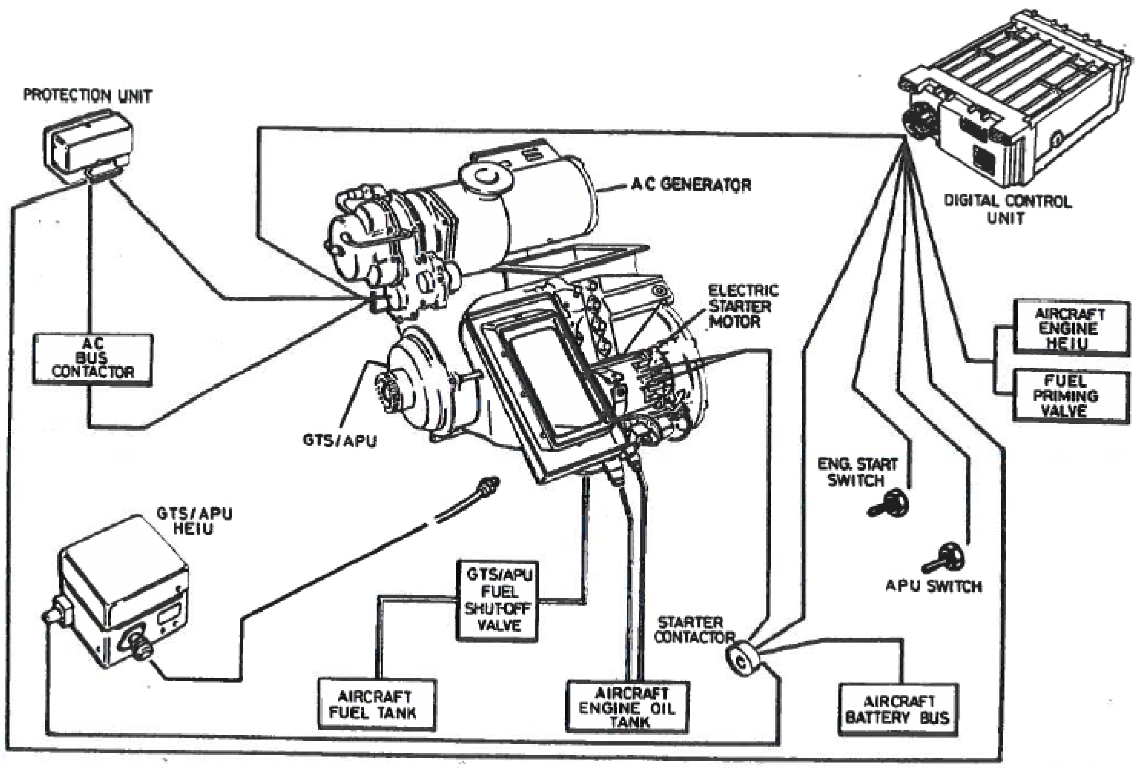
An electronically controlled engine may be identified by the presence of an electrical connection to the fuel pump assembly. The pump also has no external user adjustments unlike a hydro-mechanical type of fuel control.

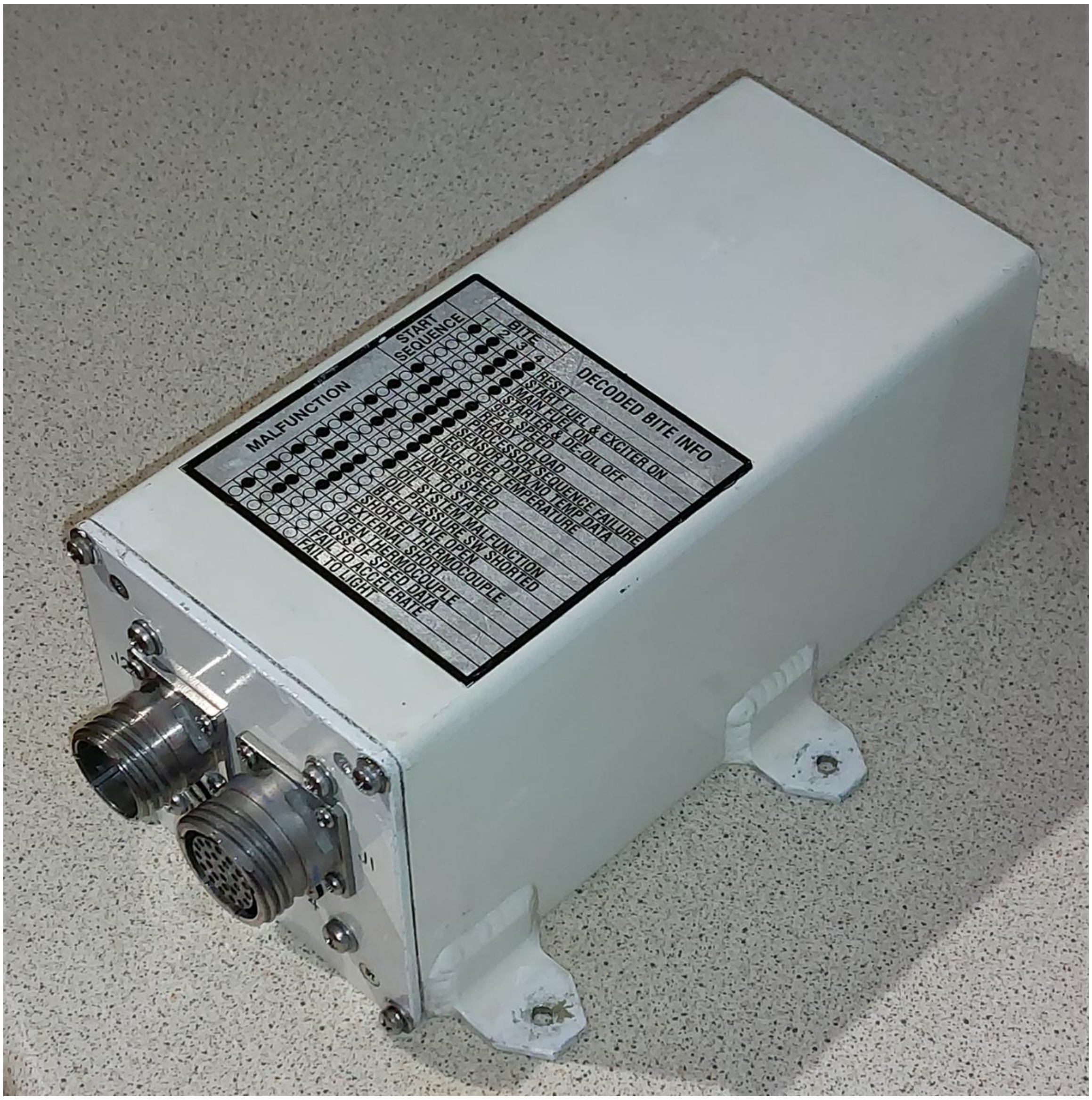


Lucas digital engine control unit (DCU)

The Harrier aircraft is fitted with a combined gas turbine starter and auxiliary power unit GTS/APU. Early versions were fitted with a simple gear pump and hydro-mechanical fuel control and governing system. Later aircraft were fitted with a revised version of the GTS/APU which employed a digital electronic control unit. The engine was fitted with a speed sensor and fuel metering valve which under microprocessor control the small gas turbine and main engine starting sequences were carried out.

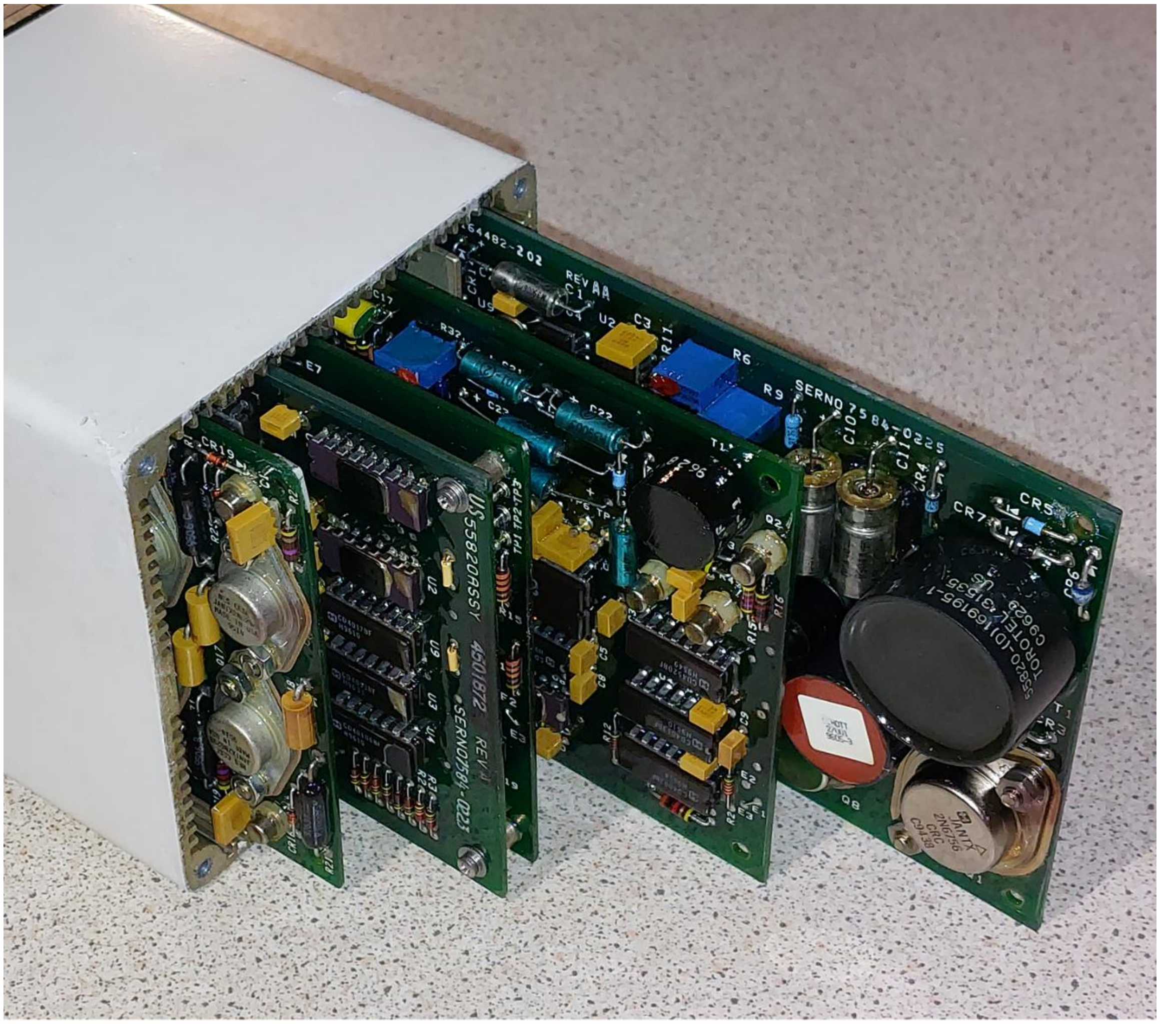

ENG. START SWITCH AND APU SWITCH
GTS/APU
PROTECTION UNIT
DCU
STARTER CONTACTOR
GTS/HEIU
BATTERY


PROTECTION UNIT
AC GENERATOR
DIGITAL CONTROL UNIT
ELECTRIC STARTER MOTOR
AC BUS CONTACTOR
AIRCRAFT ENGINE HEIU
FUEL PRIMING VALVE
GTS/APU
ENG. START SWITCH
GTS/APU HEIU
APU SWITCH
GTS/APU FUEL SHUT-OFF VALVE
STARTER CONTACTOR
AIRCRAFT FUEL TANK
AIRCRAFT ENGINE OIL TANK
AIRCRAFT BATTERY BUS



Hamilton Sundstrand T62 digital APU control unit from the 1990s

Some BA146 aircraft are fitted with an auxiliary power unit (APU) made by Hamilton Sundstrand. The APU is controlled by a digital control unit featuring a micro-processor based logic system and running in machine code language. The unit will be built from high grade military spec components and sealed in a moisture and EMC proof enclosure. The unit may be mounted in the airframe close to the APU installation although not necessarily adjacent to it. When obtaining this type of APU, for re-commissioning and ground running it will be necessary to obtain the correct ECU that may unfortunately get separated from it’s companion engine! Detailed interconnection wiring information will also be required obtained from the engine manual.



Digital T62 ECU Internal circuit cards partially withdrawn

Open loop electronic operation

It may become necessary to operate a gas turbine engine without a complete fuel control system for test purposes. This may be the case with electronic systems that are missing, faulty or not fully understood (Due to a lack of published information necessitating some reverse engineering). Mechanical systems may also be found to malfunction or suffer from missing components as may be the case with engines obtained as surplus units.

The amount of fuel delivered to the combustion system may be controlled manually by hand provided sufficient instrumentation is available so that engine parameters may be closely monitored during a running cycle. In the case of an electronically controlled engine a variable electrical signal may be provided to a fuel-metering valve (electrical/fuel interface), the current is supplied from a variable power supply and the current controlled by hand whilst carefully observing rpm and temperature. During engine operation the current is carefully controlled so that the engine rpm and temperature remain inside acceptable limits.

Simple test-set built to bench run a turbo-jet engine

The current supplied to a fuel-metering valve should be carefully controlled so that the valve is not damaged. Certain types of valves are fragile and excessive current will burn them out. Ideally a variable constant current supply should be used with a maximum setting that prevents damage to the valve coil and remains within the manufacturer’s limits.

To start the engine, the engine is first spooled up by means of the starter with the ignition system operating during which no fuel is supplied to it. The fuel supply is then enabled by either opening an HP Cock type valve or by the combination of opening a HP cock and supplying current to a fuel metering valve or spill valve. The current to the valve is increased (May be decreased depending on the action of the valve) so that the engine will light up (Establish combustion) and then the current carefully increased further to accelerate the engine to the required speed. At the appropriate time the engine will be deemed self-sustaining, and the starting/ignition processes terminated. During this process recorded measurements may be made of the engine speed and the current supplied to the valve. A basic current/rpm characteristic is built up which is useful for further starts and tests.

This type of "Open Loop" control system is very useful when testing engines and attempting to re-develop replacement fuel systems. Small gas turbine engines may rapidly accelerate and so it is recommended that an over-speed cut out system is employed. An electronic tachometer circuit is used to detect an over-speed condition and cut the current supplied to any fuel control valves and may also close off the engine HP cock. Fail-safe solenoid valves are useful here and should be used with a re-settable trip-type relay circuit. A useful technique is to test and validate the over-speed trip before operating the engine. A variable oscillator is used to supply the tachometer circuitry with a signal to simulate the running engine. The calibration and operation of the tachometer and trip system may be then checked safely. The trip speed is initially set to an estimated self-sustaining speed and as experience and confidence grows the trip speed may be increased.

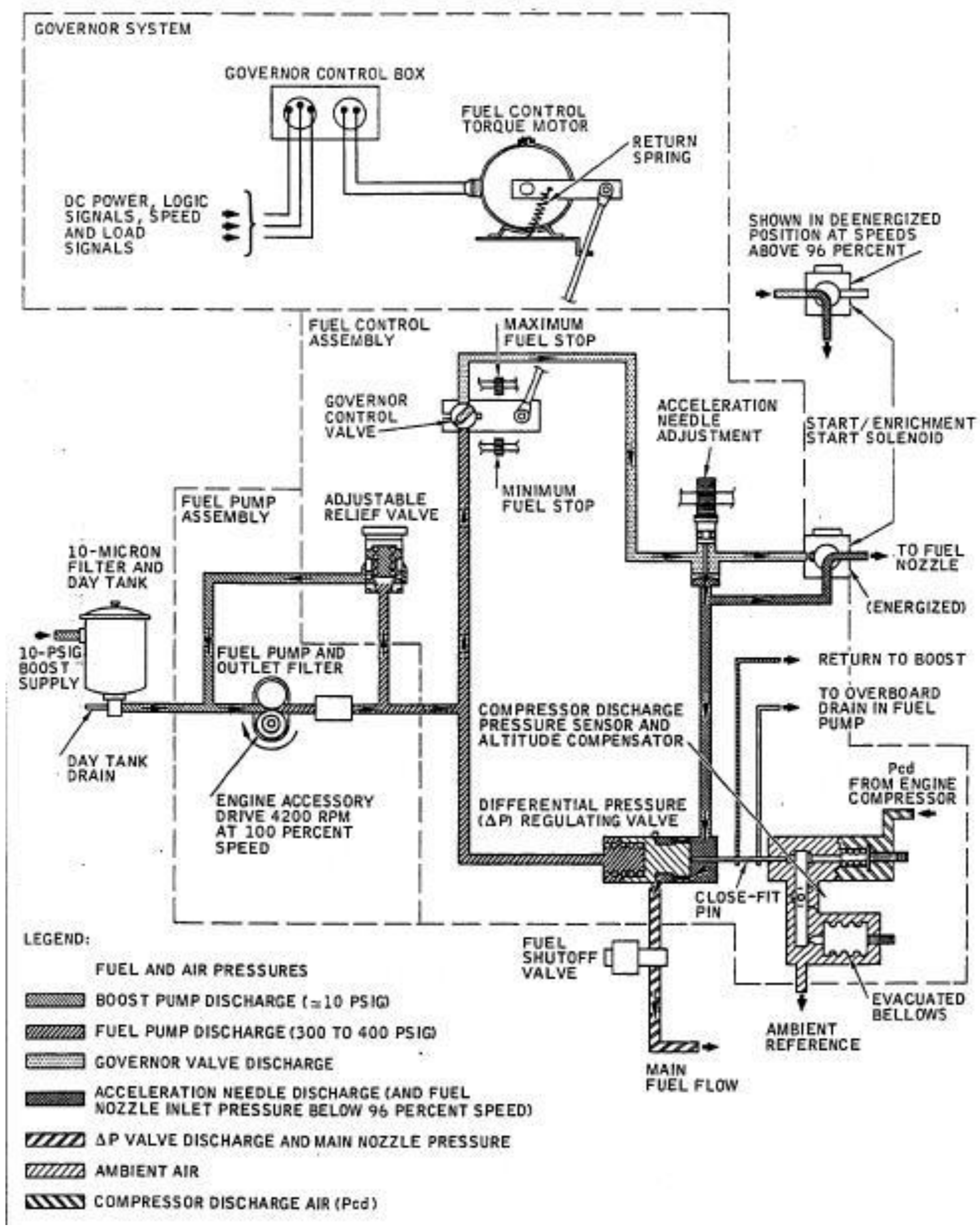
Over-temperature circuits are useful when testing small gas turbines. An electronic circuit may be constructed which monitors the exhaust temperature and at a predetermined point operates a relay circuit to cut off the fuel in a similar way to the over-speed protection.

A mechanical open loop control may be used to supply fuel to a gas turbine. An electric high pressure fuel pump (As opposed to a low-pressure booster pump) supplies fuel to the burner (S) and a hand operated needle valve is used to bleed fuel from the burner supply reducing the delivery to the engine. Solenoid valves and the use of an over-speed cut-out is recommended to protect the operator.

In all cases of open loop control, wet cycling (Operation with no ignition) and inspection of the burners may be necessary to obtain a "feel" for the fuel system characteristics. Various metering valves exhibit different and even reverse current/voltage/fuel characteristics. Over-fueling or operation with insufficient atomization in the combustion chamber may damage the engine and create a fire hazard.

During open loop control gas turbine engines generally exhibit a tendency for unstable rpm also with a tendency to wander, particularly during the warmup phase just after starting. As the rpm varies the fuel pump delivery and compressor delivery may also vary and so a mildly unstable condition exists. The oil temperature may also affect rpm as the temperature rise and the oil drag placed upon the bearings may reduce. The operator may find himself having to continually watch the engine rpm and adjust the fuel flow accordingly.

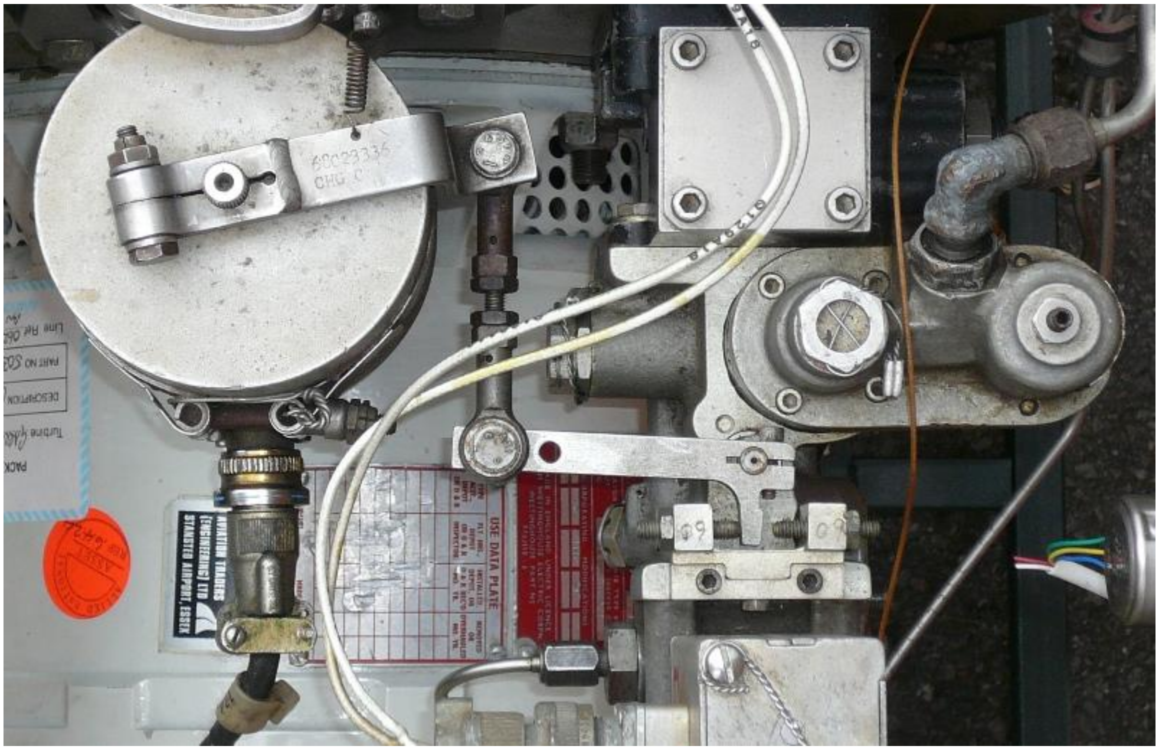
Hybrid fuel control system



Solar T62T32 fuel system featuring hybrid control

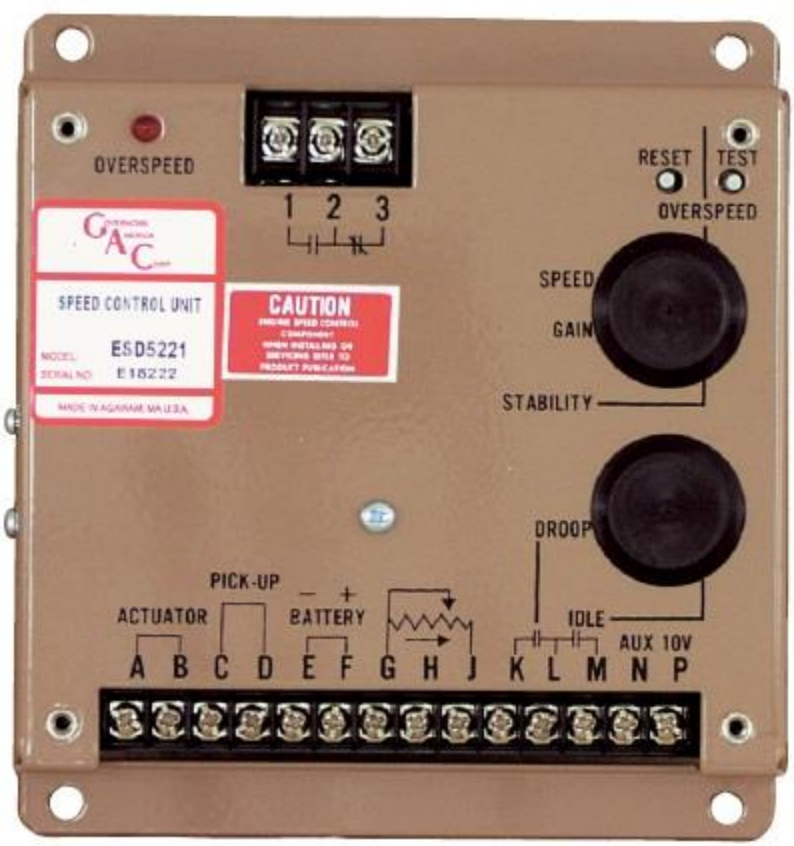
The Solar T62T32 series engine employs a hybrid fuel control system. The fuel delivery to the engine during the starting and acceleration phase is controlled by a pneumatic valve that senses the compressor delivery pressure. As the engine rpm rises the compressor outlet air pressure rises also, this operates the valve that further admits fuel into the engine increasing speed. A throttle valve is included in the fuel system that is operated by an electrical actuator (Torque Motor). The actuator is driven with an electrical signal derived from a control box that functions as a governor. A speed signal is sent to the governor from a reluctance probe mounted in the engine. During acceleration the throttle is held wide open until governing speed is approached the throttle is then closed off until the engine speed stabilizes at the required rpm. The T62T32 engine operates at 60,000 rpm generating an electrical speed signal of 2KHz.

The actuator system fitted to this engine is not dissimilar to many automotive diesel applications. A piston engine governor module may be employed to hold the speed constant and has adjustments for gain, stability, and droop.

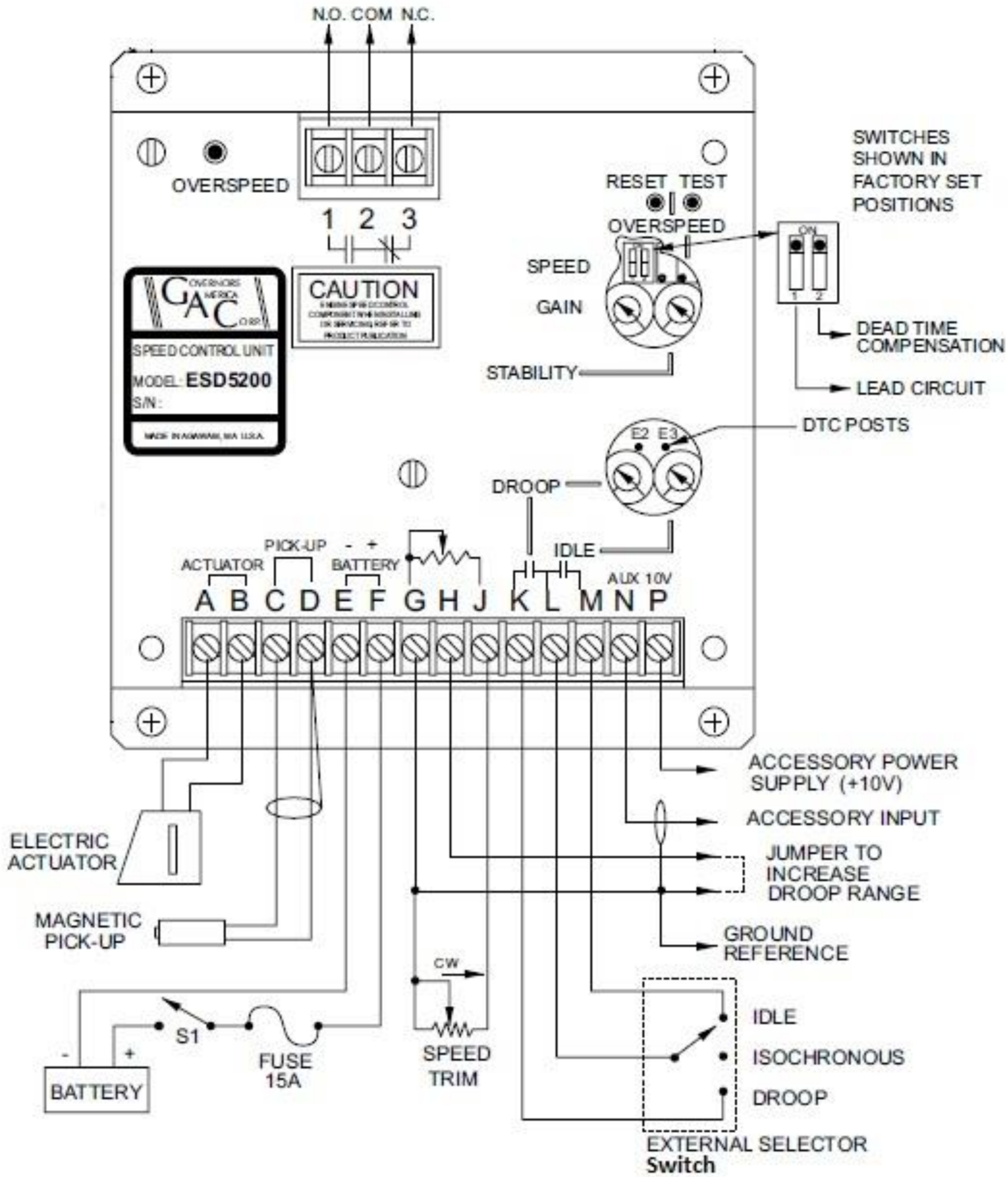


Fuel system featuring hydro-mechanical and electronic control (T62)

GAC type governor



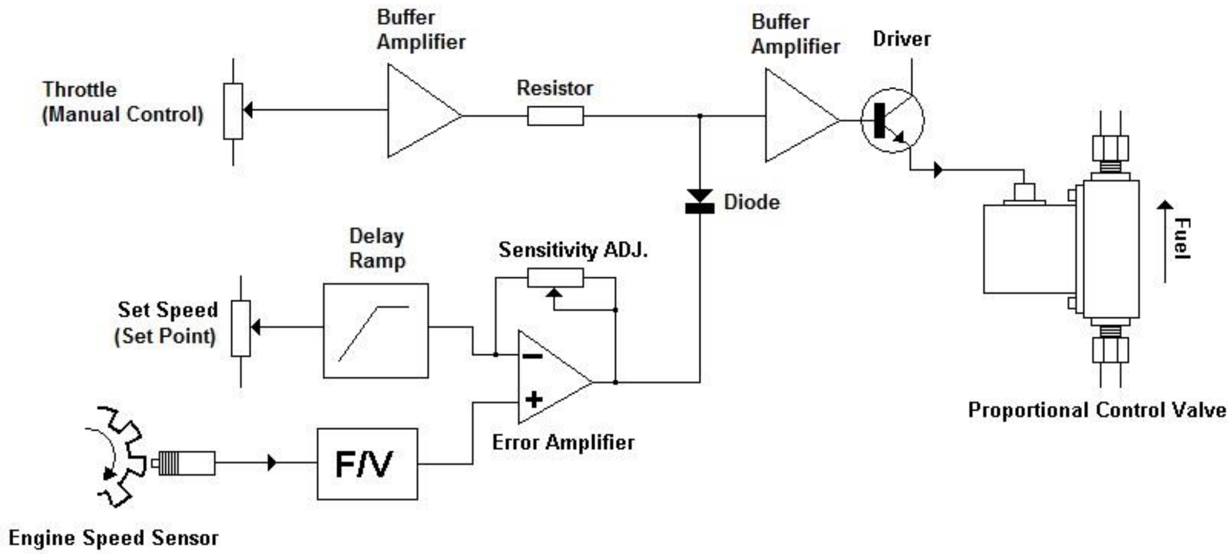
Diesel engine type gen-set governors may sometimes be adapted to run with gas turbines. The GAC (Governors of America) manufacture a range of governor units, a similar companies are also Woodward and Heinzman.



GAC engine governor unit

Diesel engine type governors incorporate gain and stability adjustments so that the unit may be "Tuned" to match the characteristics of the engine. The units may also provide over-speed protection and will shut down if speed signals are lost etc. Diesel engine governors are normally designed to drive torque motor type mechanical actuators that are mechanically linked to a throttle valve. Many types of gas turbine metering valves may need extra circuitry to interface them to a diesel engine type governor unit such as the GAC unit.

Semi-automatic engine speed control (Governor)



Simplified semi-automatic engine speed control

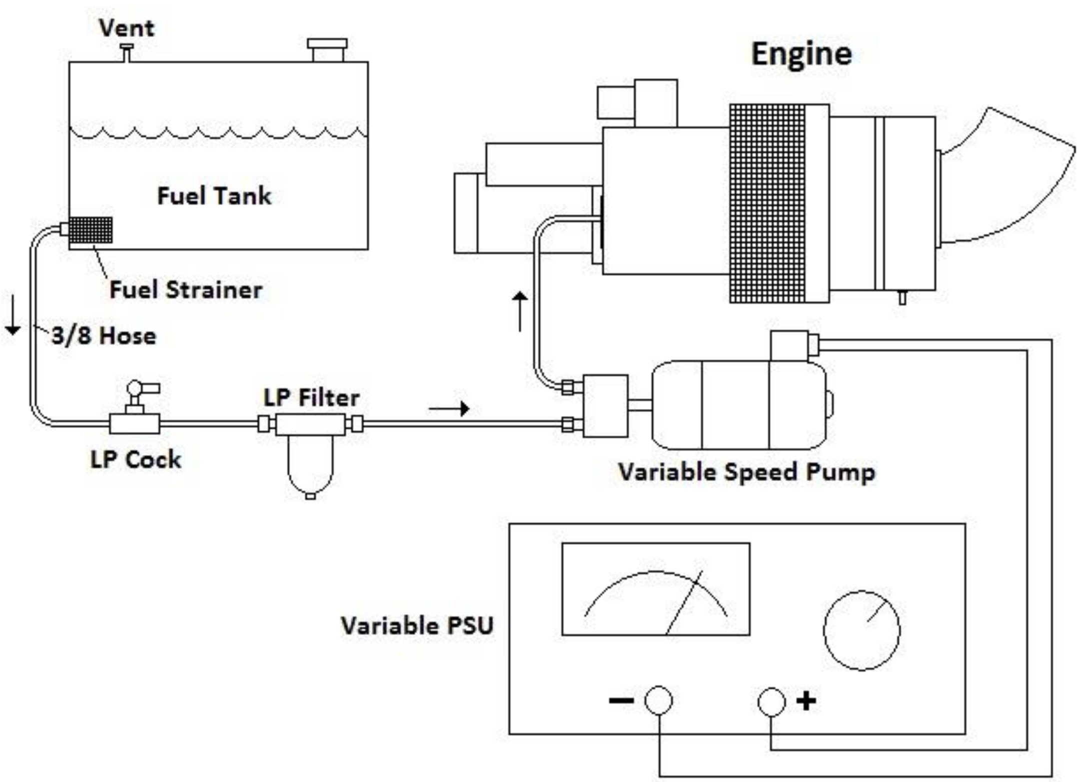
The diagram shows a semi-automatic engine fuel control system. A manual throttle control is used to start, light up and accelerate the engine. The control is gently advanced whilst monitoring engine parameters until the desired running speed is reach beyond that of the self-sustaining speed. The throttle control may be advanced further so that the engine speed reaches that speed set by the set-point control in an automatic feedback control circuit. By means of a diode combining circuit an error amplifier is able to reduce the engine speed in order to match the set point speed. As the throttle control passes this point the error amplifier takes over and becomes an automatic control of the engine speed. The throttle is advanced further beyond the set point, the engine speed remains constant but some “fuel supply headroom” is provided so that the circuit is able to hold the engine speed under changing conditions such as load. The engine is now in a governed condition (Closed loop condition), manual control may be “Taken back” by reducing the throttle so that the engine slows below the set point speed and operates in an “open loop” condition.

This circuit is useful for bench testing engines where a simple governed speed condition is required with no drift. Developing fully automatic starting and acceleration controls is a much more complex task.

The gain of the error amplifier should be carefully adjusted so that no control loop instability is present, also the throttle should be adjusted slowly so that the governing point is intercepted gently so as not to induce any oscillation or instability.

Electric motor speed-based fuel system

An electric motor driven fuel pump may in itself form a complete fuel control system. An electric motor coupled to a positive displacement pump may be used to directly meter fuel into a gas turbine engine. An electronic motor speed control unit is used to vary the motor speed that in turn varies the fuel flow as it is delivered to the engine. This arrangement is useful for bench running and testing development engines where the complete fuel system is either missing or faulty.



Motor-driven variable speed fuel pump

Typical industrial electronic DC motor controllers

The Noel Penny Turbines 301 series engine adopted this novel arrangement for supply fuel under pressure to the combustion chamber.

Caution: Care should be exercised when bench running gas turbine engines with this fuel supply arrangement. There is no inherent over-speed protection, excessive fuel flow may cause the engine to "Run Away". It is recommended that an over-speed protection system is used to automatically shut down the engine if the maximum rated RPM is exceeded.

Radio Control (RC) Turbine controls

electronic control unit for radio control aircraft applications

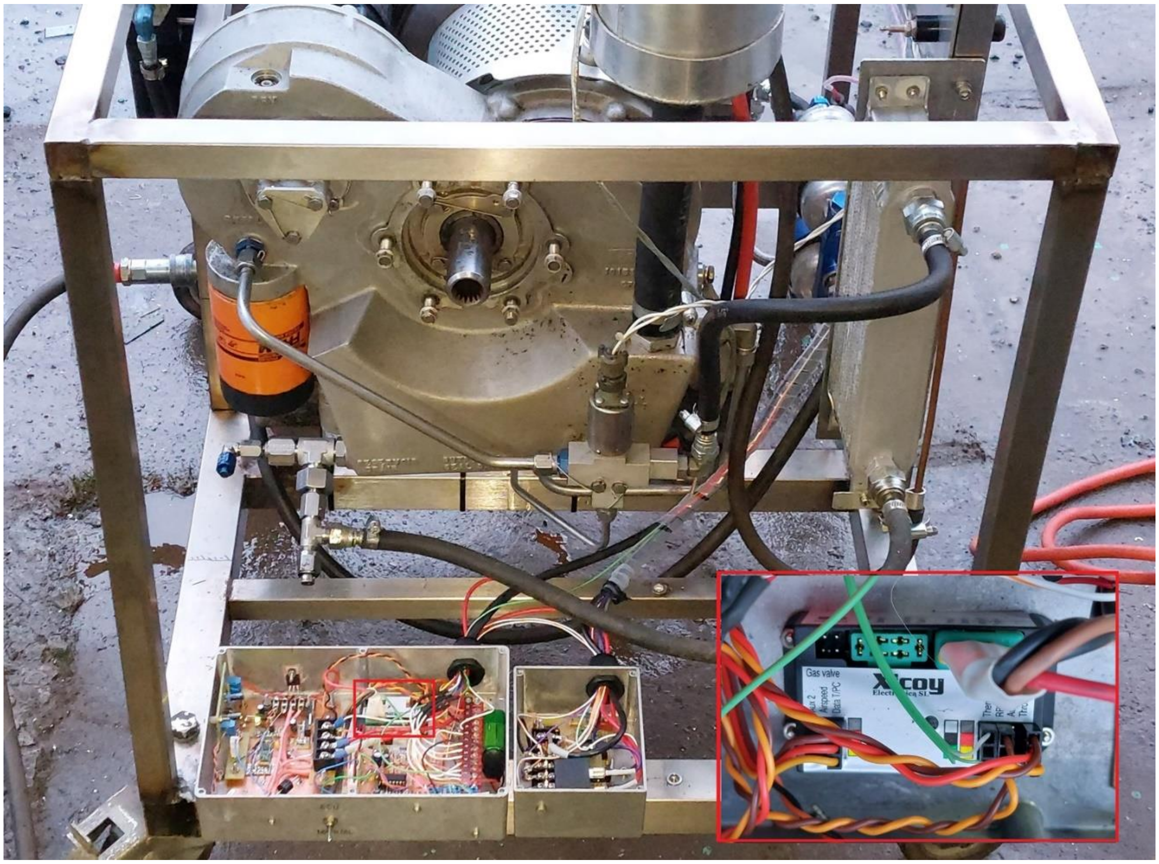
Gas turbines built for radio control (RC) model aircraft applications incorporate electronic control units to interface throttle demands with the engine fuel control system. Typically, the system uses a miniature motor driven gear pump to meter fuel flow into the engine. In addition, starting may sometimes be achieved by using a gas start system which pre-heats the combustion chamber to aid in the initiation of fuel vaporization. All RC turbines make use of vaporizing burners. It's not practical or feasible to use high pressure atomizing burner nozzles in what is already a compact and challenging combustion environment.

A company, Xicoy electronics have produced an ECU for use with their own brand of gas turbine but also alternative third-party turbines may be used by configuring and calibrating the ECU via a simple data entry terminal. The ECU accepts a throttle signal (usually from the radio control receiver) and will schedule fuel flow to the turbine according to some pre-set parameters such as idle speed and full throttle speed. At full throttle the engine rpm will be governed and held constant – a very useful feature applicable to other types of gas turbine.

ECU data entry terminal

A data entry terminal is connected to the ECU, this would normally be done to program the ECU for the engine parameters in use with the model aircraft on the ground. Once the ECU is programmed the data terminal is disconnected but it is also possible to use it to monitor the engine as it is started and run before a flight.

For operation with non-RC type gas turbines the ECU may need some extra external electronic circuitry to condition sensor signals (such as RPM and EGT) and interface the ECU with a larger duty fuel pump motor.

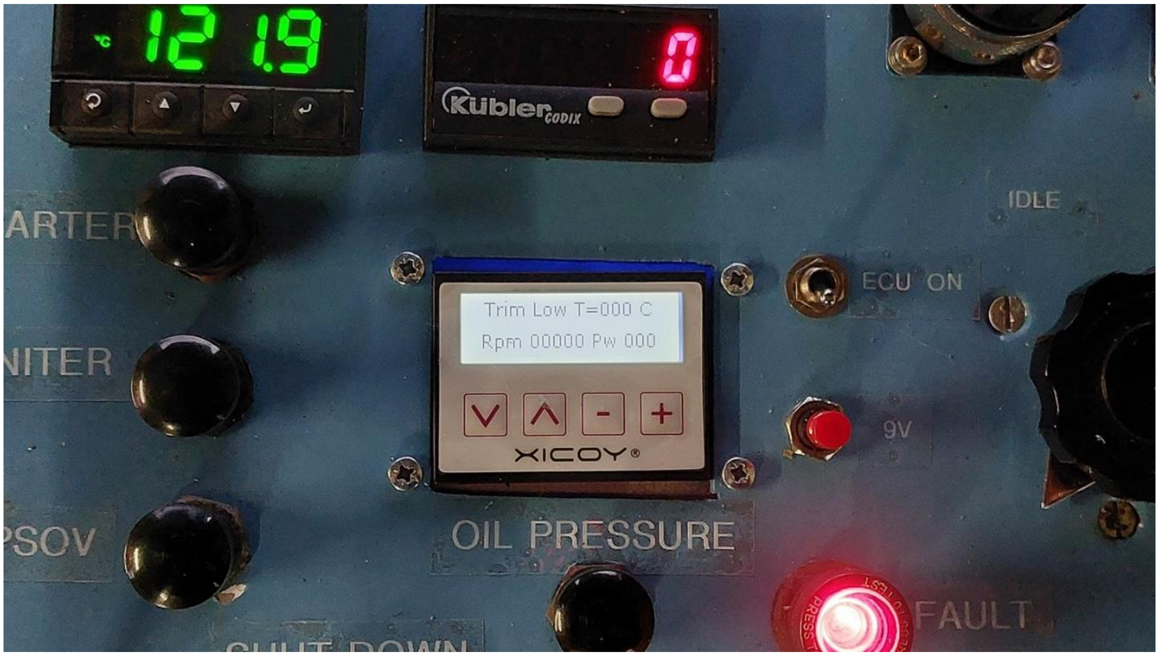


Xicoy RC type FADEC ECU installed with an APU type gas turbine (credit the WTF)

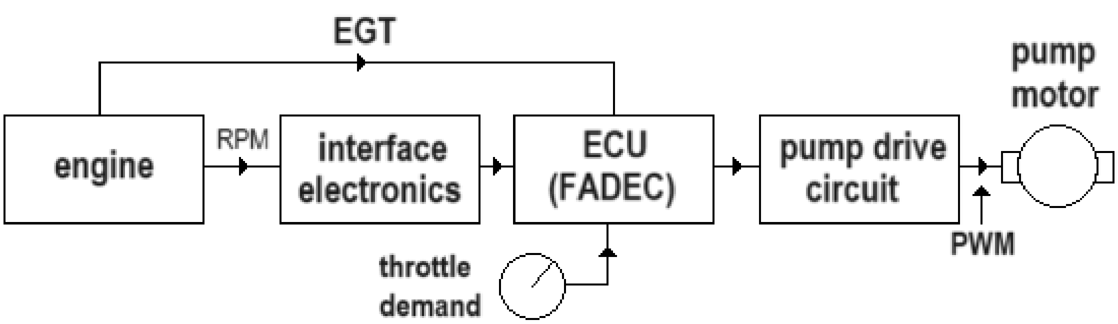
A frequency divider circuit may be used to re-calibrate the rpm signal (reluctance probe) before passing it to the ECU. Similarly, a thermocouple signal may need to be altered so that the ECU behaves in the correct way during start up. The signal may need to feed several devices simultaneously e.g. a gauge indicator and the ECU EGT input signal.

The variable speed motor driven fuel pump is often driven directly from the ECU. This is designed for a small radio control size turbine, for bigger turbines this drive should be up rated. The pump motor drive is a pulse-width type DC signal current; a buffer amplifier stage may be constructed typically with suitably rated MOS FET transistors.

As with all electronic ECUs care is needed to ensure it will fail safe in the event of a fault and engine over-speed protection is strongly advised.



Xicoy data terminal installed with gas turbine control panel (credit the WTF)



basic RC turbine style system adapted for a small APU type engine

Gas fired gas turbine engines

A gas turbine engine may be operated on gaseous fuels as well as liquid fuels. Gas holds the advantage that atomization or evaporation is not required prior to entry into the combustion zone and often a cleaner burn results. It is one of the advantages that a gas turbine holds over piston engines is fuel flexibility. It is possible to run piston engines from differing gas types, typically natural gas or propane (LPG). When using gases of low calorific value modifications two the reciprocating engine are required to prevent pre-ignition and slow burning times. This may necessitate a reduction in compression ratio for example that will reduce power output. Larger industrial size gas turbines may be operated in liquid and gaseous fuels and in some cases may even switch over fuel types whilst in operation.

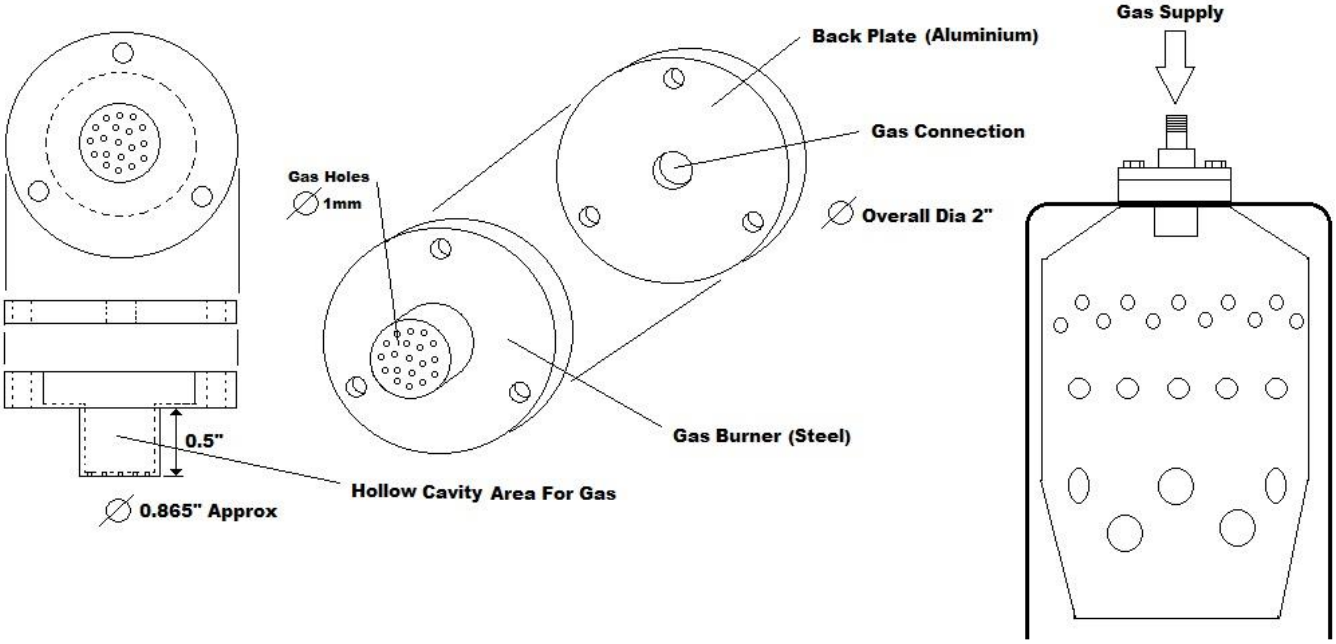
A typical engine designed to run on a gas will incorporate a combustion system similar to an engine designed to run on liquid fuel. Instead of an atomizing fuel nozzle, the engine will be fitted with a gas burner head. The burner head consists of several small orifices that admit the gas into the combustion zone and promote mixing of the gas with the primary air flow. From then on, the combustion process is the same as with liquid fuel, i.e. cooling air is mixed with the combustion gases to cool it to a level acceptable to the turbine inlet assembly. When burning gases of low colorific value, less heat is release per given volume and so it is necessary to increase the size of the combustion chamber.

It is required to feed gas to the combustion system under pressure in order to overcome the pressure loss in the burner head and the static pressure in the combustion chamber. Mains gas (Natural gas) is supplied under very low pressure, so a special external electrically driven gas compressor unit is required to raise the pressure to the required level. A typical pressure when working with a small gas turbine (Low PR) is in the region of 5-10 bar.

A control and governing system are required to manage the gas flow into the engine, this may often be achieved by using an electronic system.

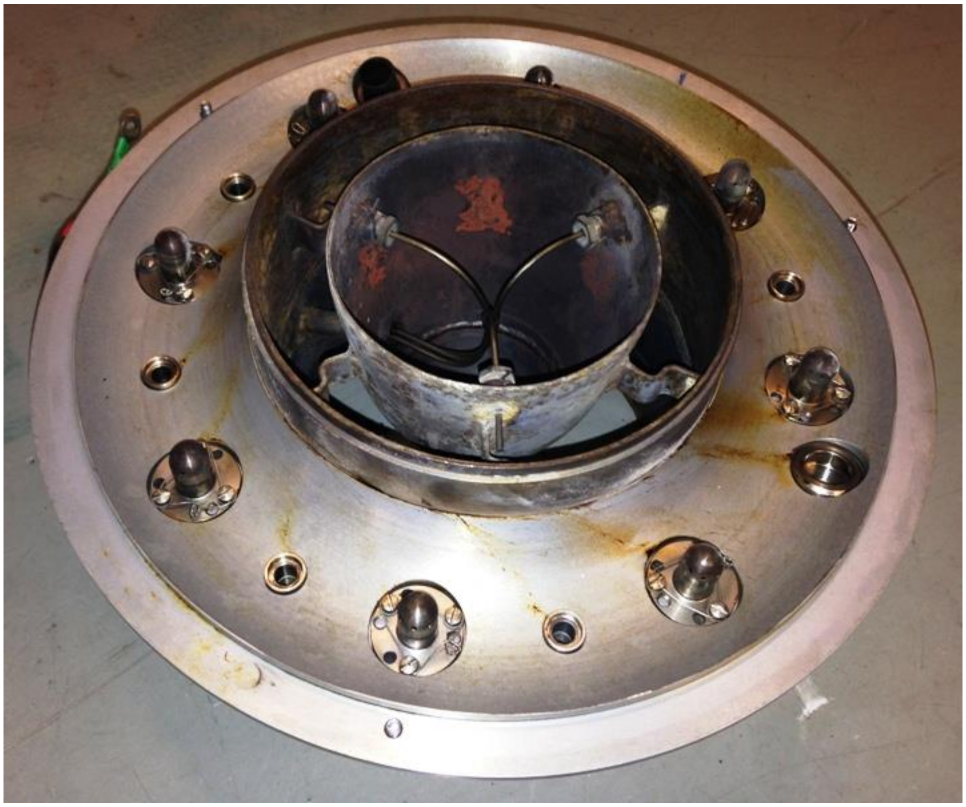
Burner unit intended for operation with natural gas (can type combustor)

Test running a 250HP gas turbine fired by propane gas



Simple experimental gas burner head for use with propane gas supply

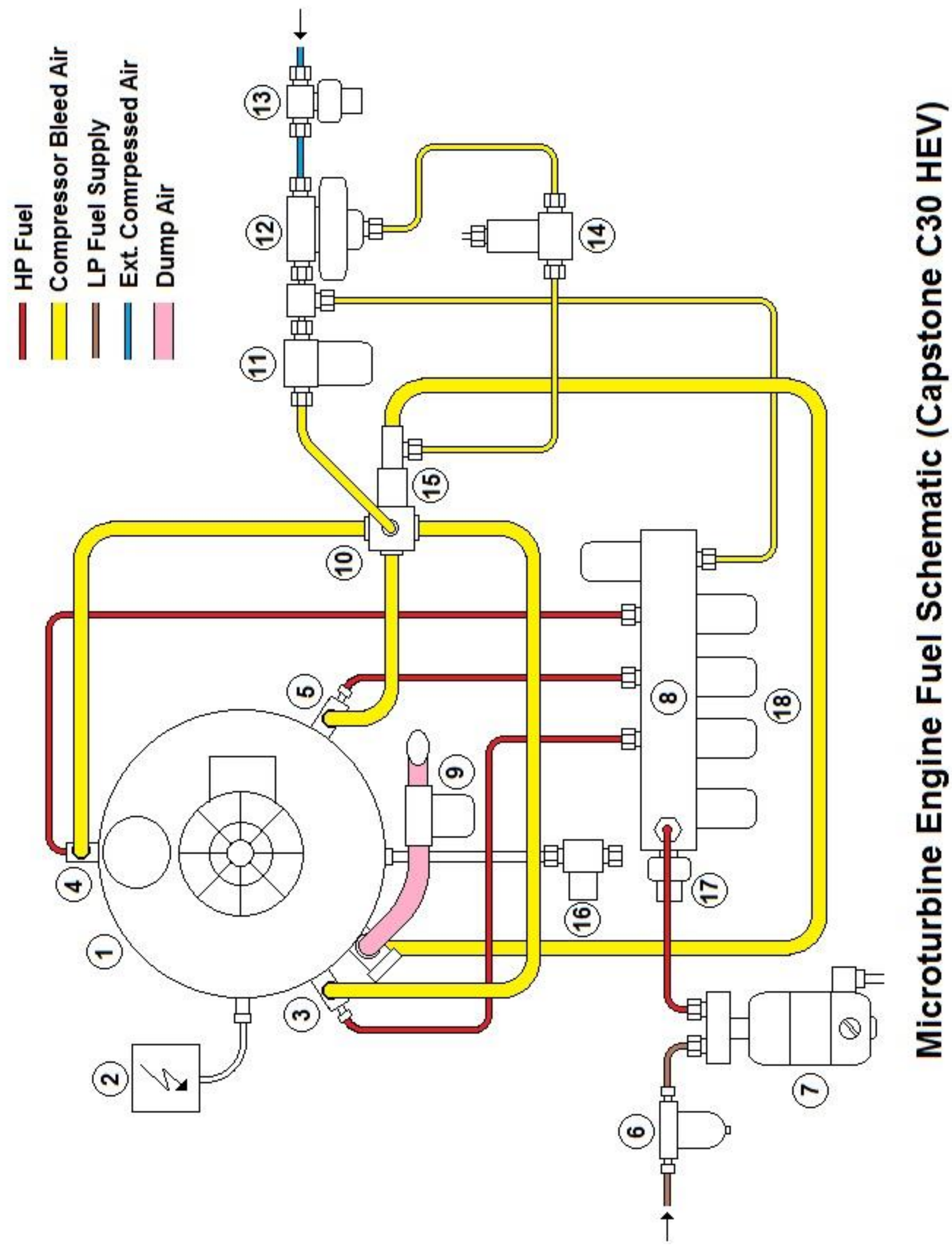
Manufactured experimental gas burner head unit (replaces liquid atomizer)



PBS (Saphir derived) natural gas fired burner ring

Burner head and igniter plug

Microturbine fuel system



1. Microturbine engine

2. Igniter

3. Injector #1

4. Injector #2

5. Injector #3

6. LP fuel filter

7. HP fuel pump

8. Fuel distribution manifold

9. Compressor dump valve

10. Air distribution manifold

11. Air assist solenoid valve

12. Differential pressure regulator

13. Pressure switch

14. 3-way solenoid valve

15. Check valve

16. Drain valve

17. Fuel pressure switch

18. Injector solenoids

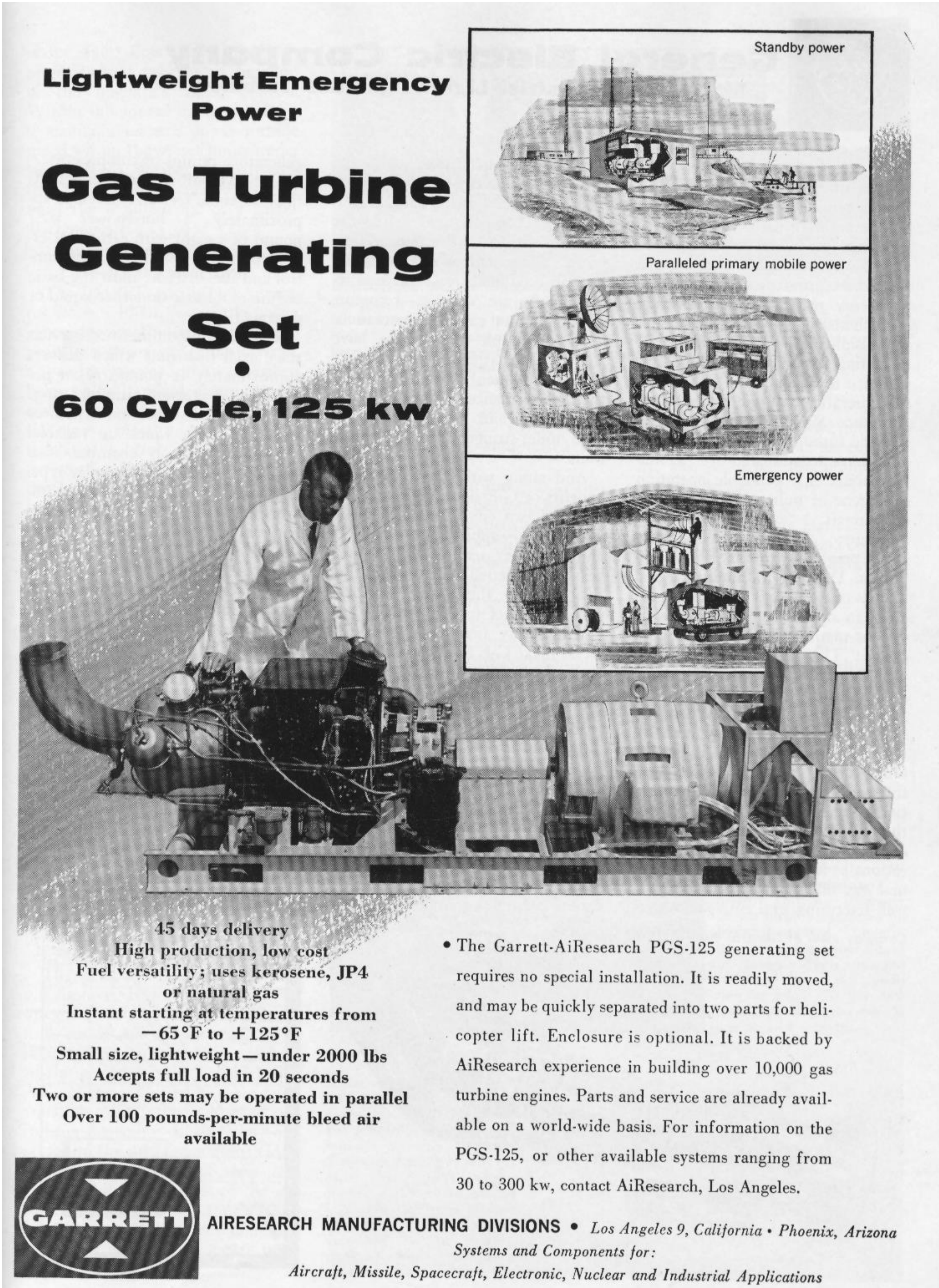
The illustration shows the sophisticated fuel system belonging to a Capstone 30Kw micro turbine engine. The engine consists of a centrifugal compressor driven by a radial inflow turbine wheel. The turbine shaft directly drives a permanent magnet alternator that also serves as a starter motor. The turbine shaft is supported by foil type air bearings and has no oil lubrication. The combustion system consists of a reverse flow annular chamber fed by three simplex burner nozzles. The micro turbine engine is fitted with a heat exchanger unit (recuperator) that re-cycles heat from the turbine exhaust into the compressor outlet stream this improves the fuel efficiency of the engine.

The engine fuel system is essentially an electronic system that employs a variable speed electric pump to meter the fuel into the engine. A micro-controller monitors multiple engine parameters and adjusts the fuel supply according to load and ambient conditions.
Signals are sent to the micro-controller from a number of pressure switches, sensors and it sends commands back to operate solenoid valves. In addition, an air system is used to aid atomization of the burners and purge the system of unwanted fuel (to prevent harmful deposits) during shut down and cool down cycles. The air system is fed from a small engine compressor bleed and an external air supply (40 PSI) is required to start and operate the engine.

During high-speed operation and when a rapid decrease in load is experienced, an air dump valve discharges a portion of the compressor outlet air to atmosphere to slow the turbine down and prevent an over speed condition.

During start up and light load operation, the engine functions on the single number one burner nozzle that is placed adjacent to the igniter plug. As engine load increases the second and third nozzles are brought into operation. The fuel supply to the burners is interrupted as necessary by solenoid valves mounted in a manifold block. During shut down and cool down air is supplied into the fuel manifold via a one-way check valve.

During running at differing compressor rpm, a pressure regulator referenced from compressor delivery pressure ensures air is fed at the correct pressure to the atomizers.


Lightweight Emergency Power
Gas Turbine Generating Set
60 Cycle, 125 kw
Standby power
Paralleled primary mobile power
Emergency power
45 days delivery
High production, low cost
Fuel versatility; uses kerosene, JP4 or natural gas
Instant starting at temperatures from −65°F to +125°F
Small size, lightweight—under 2000 lbs
Accepts full load in 20 seconds
Two or more sets may be operated in parallel
Over 100 pounds-per-minute bleed air available
• The Garrett-AiResearch PGS-125 generating set requires no special installation. It is readily moved, and may be quickly separated into two parts for helicopter lift. Enclosure is optional. It is backed by AiResearch experience in building over 10,000 gas turbine engines. Parts and service are already available on a world-wide basis. For information on the PGS-125, or other available systems ranging from 30 to 300 kw, contact AiResearch, Los Angeles.
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