

## MODULE 14

FOR B2 LEVEL CERTIFICATION

# PROPULSION

## Aviation Maintenance Technician Certification Series



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Mike Stitt, Electronics Engineer, ADA, MI.

## PROPULSION

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## 14.1 - TURBINE ENGINES

### CONSTRUCTIONAL ARRANGEMENT

In a reciprocating engine, the functions of intake, compression, combustion, and exhaust all take place in the same combustion chamber. Consequently, each must have exclusive occupancy of the chamber during its respective part of the combustion cycle. A significant feature of the gas turbine engine is that separate sections are devoted to each function, and all functions are performed simultaneously without interruption. A typical gas turbine engine consists of:

1. An air inlet,
2. Compressor section,
3. Combustion section,
4. Turbine section,
5. Exhaust section,
6. Accessory section, and
7. The systems necessary for starting, lubrication, fuel supply, and auxiliary purposes, such as anti-icing, cooling, and pressurization.

Another common nomenclature describing the various sections of a turbine engine are known as the "cold section" and the "hot section". Cold section refers to the parts of the engine from the inlets up through the compressors and/or diffusers. Hot section refers to the areas past the compressors from the combustion chambers through the exhaust.

The major components of all gas turbine engines are basically the same; however, the nomenclature of the component parts of various engines currently in use varies slightly due to the difference in each manufacturer's terminology. These differences are reflected in the applicable maintenance manuals.

One of the greatest single factors influencing the construction features of any gas turbine engine is the type of compressor or compressors for which the engine is designed. Four types of gas turbine engines are used to propel and power aircraft. They are the turbo-jet, turbo-fan, turboshaft, and Turboprop. (*Figure 1-1*)

### TURBO-JET

The term "turbo-jet" was used to describe any gas turbine engine used in aircraft. As gas turbine technology evolved, these other engine types were developed to take the place of the pure turbo-jet engine. The turbo-jet

engine has problems with noise and fuel consumption in the speed range that airliners fly (0.8 Mach). Due to these problems, use of pure turbo-jet engines is very limited. So, almost all airliner type aircraft use a turbo-fan engine.

A Turbo-jet, turbine engine is one in which a turbine driven compressor draws in and compresses air, forcing it into a combustion chamber into which fuel is injected. Ignition causes the gases to expand and to rush first through the turbine and then through a nozzle at the rear. Forward thrust is generated as a reaction to the rearward momentum of the exhaust gases.

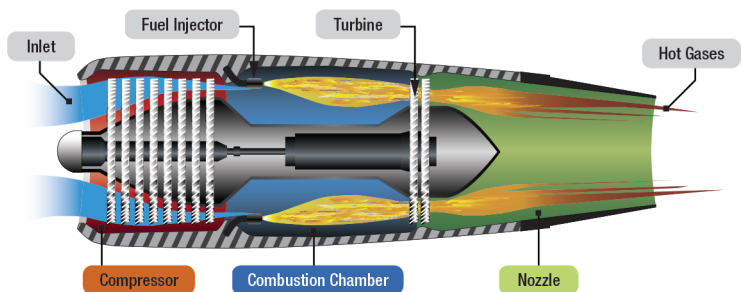
### TURBO-FAN ENGINES

Turbo-fan engines were developed to turn a large fan or set of fans at the front of the engine and produces about 80 percent of the thrust from the engine. This engine is quieter and has better fuel consumption in the high sub Mach speed range. Turbo-fan engines have more than one shaft in the engine; many are two shaft engines. This means that there are compressors and turbines that drive it. These two shafted engines use two spools (a spool is a compressor and a shaft and turbines that driven that compressor). In a two spool engine, there is a high pressure spool and a low pressure spool. The low pressure spool generally contains the fan(s) and the turbine stages it takes to drive them. The high pressure spool is the high pressure compressor, shaft, and turbines. This spool makes up the core of the engine, and this is where the combustion section is located. The high pressure spool is also referred to as the gas generator because it contains the combustion section.

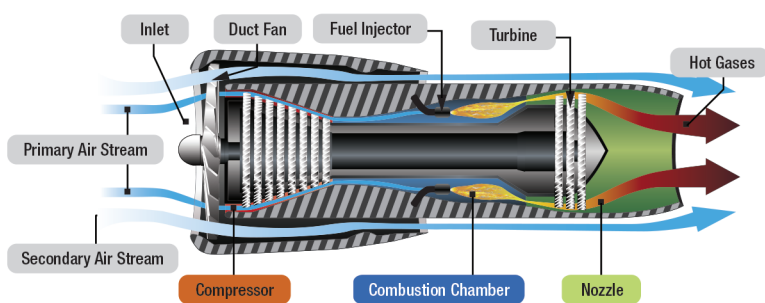
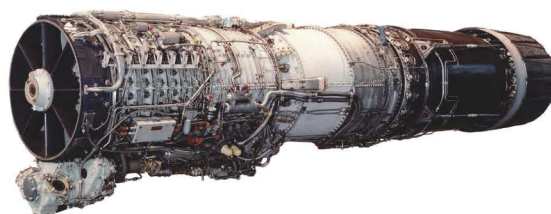
### TURBOSHAFT

A turboshaft engine is a variant of a jet engine that has been optimized to produce shaft power to drive machinery instead of producing thrust. Turboshaft engines are most commonly used in applications that require a small, but powerful, light weight engine, inclusive of helicopters and auxiliary power units (APU's).

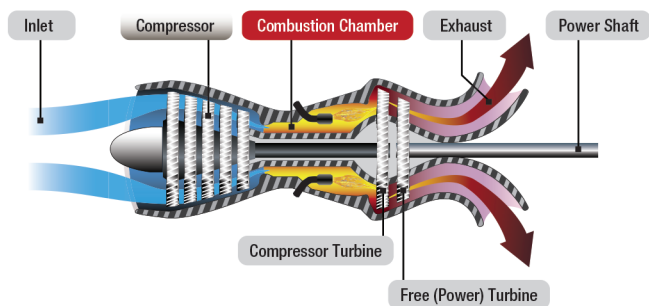
A turboshaft engine uses the same principles as a turbo-jet to produce energy, that is, it incorporates a compressor, combustor and turbine within the gas generator of the engine. The primary difference between



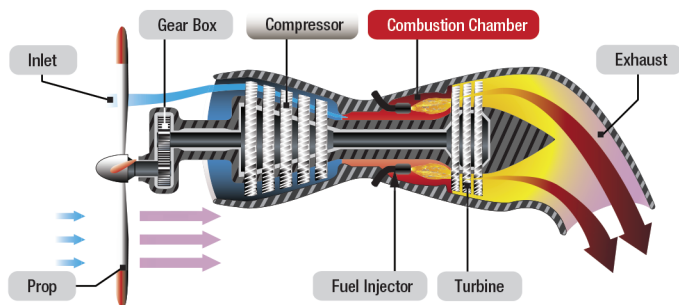
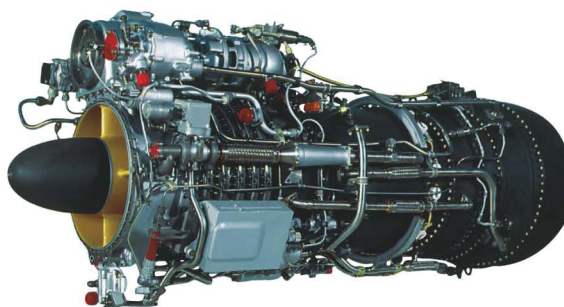
**TURBO-JET**



**TURBO-JET**



**TURBO-SHAFT**



**TURBO-PROP**

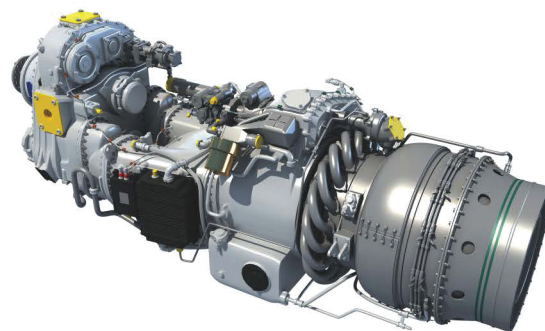


Figure 1-1. The four primary types of gas turbine engines.

the turboshaft and the turbo-jet is that an additional power section, consisting of turbines and an output shaft, has been incorporated into the design. In most cases, the power turbine is not mechanically linked to the gas generator. This design, which is referred to as a "free power turbine", allows the speed of the power turbine to be optimized for the machinery that it will energize without the need for an additional reduction gearbox within the engine. The power turbine extracts almost all of the energy from the exhaust stream and transmits it via the output shaft to the machinery it is intended to drive.

## **TURBOPROP**

A Turboprop engine uses the same principles as a turbo-jet to produce energy, that is, it incorporates a compressor, combustor and turbine within the gas generator of the engine. The primary difference between the Turboprop and the turbo-jet is that additional turbines, a power shaft and a reduction gearbox have been incorporated into the design to drive the propeller. The gearbox may be driven by the same turbines and shaft that drive the engine compressor, mechanically linking the propeller and the engine, or the turbines may be separate with the power turbine driving a concentric, mechanically isolated shaft to power the gearbox. The latter design is referred to as a free power turbine or, more simply, a "free turbine" engine. In either case, the turbines extract almost all of the energy from the exhaust stream using some of it to power the engine compressor and the rest to drive the propeller.

## **FUEL SYSTEMS**

### **GENERAL REQUIREMENTS**

The fuel system is one of the more complex aspects of the gas turbine engine. It must be possible to increase or decrease the power at will to obtain the thrust required for any operating condition. In turbine powered aircraft, this control is provided by varying the flow of fuel to the combustion chambers. However, some Turboprop aircraft also use variable pitch propellers; thus, the selection of thrust is shared by two controllable variables, fuel flow and propeller blade angle.

The quantity of fuel supplied must be adjusted automatically to correct for changes in ambient temperature or pressure. If the quantity of fuel becomes excessive in relation to mass airflow through the engine,

the limiting temperature of the turbine blades can be exceeded, or it will produce compressor stall and a condition referred to as rich blowout. This occurs when the amount of oxygen in the air supply is insufficient to support combustion and when the mixture is cooled below the combustion temperature by the excess fuel. The other extreme, lean flame out, occurs if the fuel quantity is reduced proportionally below the air quantity. The engine must operate through acceleration and deceleration without any fuel control related problems.

The fuel system must deliver fuel to the combustion chambers not only in the right quantity, but also in the right condition for satisfactory combustion. The fuel nozzles form part of the fuel system and atomize or vaporize the fuel so that it ignites and burns efficiently. The fuel system must also supply fuel so that the engine can be easily started on the ground and in the air. This means that the fuel must be injected into the combustion chambers in a combustible condition during engine starting, and that combustion must be sustained while the engine is accelerating to its normal idling speed.

Another critical condition to which the fuel system must respond occurs during a rapid acceleration. When the engine is accelerated, energy must be furnished to the turbine in excess of that necessary to maintain a constant rpm. However, if the fuel flow increases too rapidly, an over rich mixture can be produced, with the possibility of a rich blowout or compressor stall.

Turbofan, turbojet, turboshaft, and Turboprop engines are equipped with a fuel control unit which automatically satisfies the requirements of the engine. Although the basic requirements apply generally to all gas turbine engines, the way in which individual fuel controls meet these needs cannot be conveniently generalized.

### **TURBINE ENGINE FUEL METERING SYSTEMS**

Gas turbine engine fuel controls can be divided into three basic groups:

1. Hydromechanical.
2. Hydromechanical/Electronic.
3. Full Authority Digital Engine (or Electronics) Control (FADEC).

The hydromechanical/electronic fuel control is a hybrid of the two types of fuel control, but can function solely as a hydromechanical control. In the dual mode, inputs and outputs are electronic, and fuel flow is set by servo motors. The third type, FADEC, uses electronic sensors for its inputs and controls fuel flow with electronic outputs. The FADEC type control gives the electronic controller (computer) complete control. The computing section of the FADEC system depends completely on sensor inputs to the electronic engine control (EEC) to meter the fuel flow. The fuel metering device meters the fuel using only outputs from the EEC. Most turbine fuel controls are quickly going to the FADEC type of control. This electronically controlled fuel control is very accurate in scheduling fuel by sensing many of the engine parameters.

Regardless of the type, all fuel controls accomplish the same function. That function is to schedule the fuel flow to match the power required by the pilot. Some sense more engine variables than others. The fuel control can sense many different inputs, such as power lever position, engine rpm for each spool, compressor inlet pressure and temperature, burner pressure, compressor discharge pressure, and many more parameters as needed by the specific engine. These variables affect the amount of thrust that an engine produces for a given fuel flow. By sensing these parameters, the fuel control has a clear picture of what is happening in the engine and can adjust fuel flow as needed. Each type of turbine engine has its own specific needs for fuel delivery and control.

### HYDROMECHANICAL FUEL CONTROLS

Hydromechanical fuel controls were used and are still used on many engines, but their use is becoming limited, giving way to electronic based controls. Fuel controls have two sections, computing and metering, to provide the correct fuel flow for the engine. A pure hydromechanical fuel control has no electronic interface assisting in computing or metering the fuel flow. It also is generally driven by the gas generator gear train of the engine to sense engine speed. Other mechanical engine parameters that are sensed are compressor discharge pressure, burner pressure, exhaust temperature, and inlet air temperature and pressure. Once the computing section determines the correct amount of fuel flow, the metering section through cams and servo valves delivers the fuel to the engine fuel system.

Actual operating procedures for a hydromechanical fuel control is very complicated and still the fuel metering is not as accurate as with an electronic type of interface or control. Electronic controls can receive more inputs with greater accuracy than hydromechanical controls. Early electronic controls used a hydromechanical control with an electronic system added on the system to fine tune the metering of the fuel. This arrangement also used the hydromechanical system as a backup if the electronic system failed. (*Figure 1-2*)

### HYDROMECHANICAL/ELECTRONIC FUEL CONTROLS

The addition of the electronic control to the basic hydromechanical fuel control was the next step in the development of turbine engine fuel controls. Generally, this type of system used a remotely located EEC to adjust the fuel flow. A description of a typical system is explained in the following information.

The basic function of the engine fuel system is to pressurize the fuel, meter fuel flow, and deliver atomized fuel to the combustion section of the engine. Fuel flow is controlled by a hydromechanical fuel control assembly, which contains a fuel shutoff section and a fuel metering section.

This fuel control unit is sometimes mounted on the vane fuel pump assembly. It provides the power lever connection and the fuel shutoff function. The unit provides mechanical overspeed protection for the gas generator spool during normal (automatic mode) engine operation. In automatic mode, the EEC is in control of metering the fuel. In manual mode, the hydromechanical control takes over.

During normal engine operation, a remotely mounted electronic fuel control unit (EFCU) (same as an EEC) performs the functions of thrust setting, speed governing, acceleration, and deceleration; limited through EFCU outputs to the fuel control assembly in response to power lever inputs. In the event of electrical or EFCU failure, or at the option of the pilot, the fuel control assembly functions in manual mode to allow engine operation at reduced power under control of the hydromechanical portion of the controller only. The total engine fuel and control system consists of the following components and provides the functions as indicated.

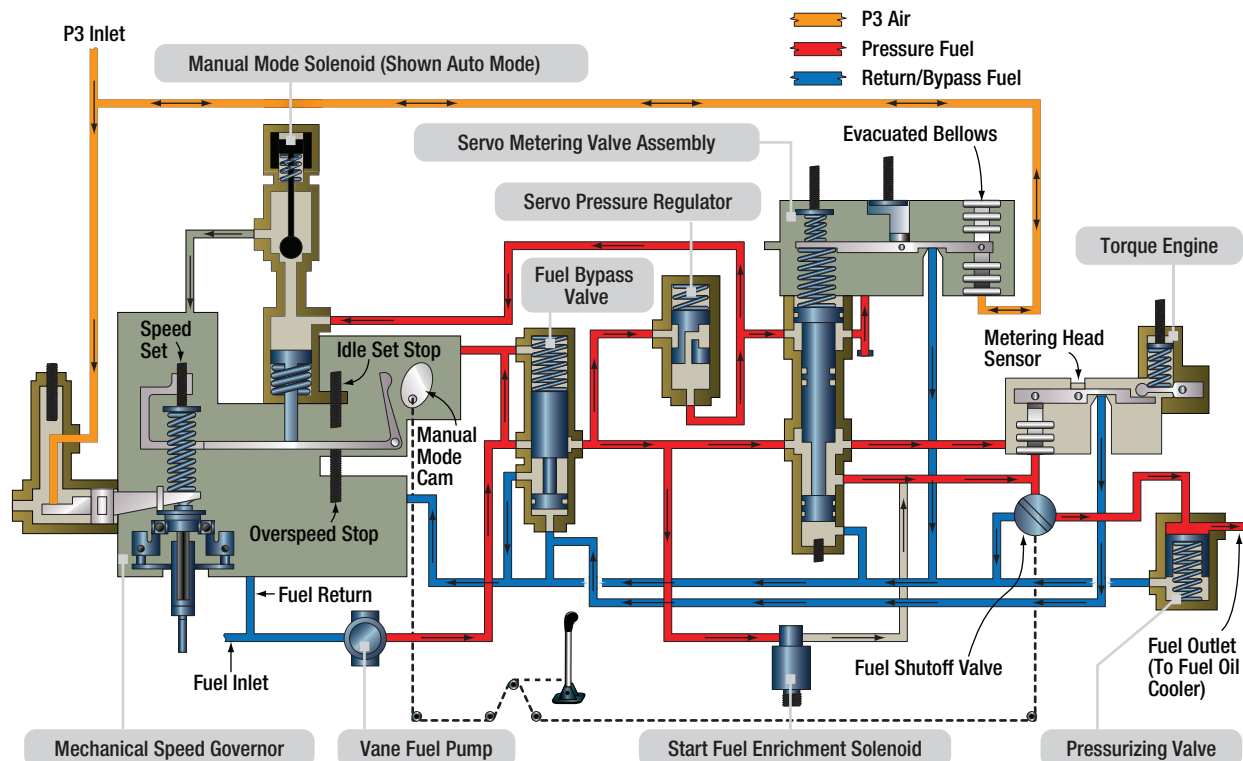


Figure 1-2. Fuel control assembly schematic hydromechanical/electronic.

1. The vane fuel pump assembly is a fixed displacement fuel pump that provides high pressure fuel to the engine fuel control system. (*Figure 1-3*)
2. The filter bypass valve in the fuel pump allows fuel to bypass the fuel filter when the pressure drop across the fuel filter is excessive. An integral differential pressure indicator visually flags an excessive differential pressure condition before bypassing occurs by extending a pin from the fuel filter bowl. Fuel pump discharge flow in excess of that required by the fuel control assembly is returned from the control to the pump interstage.
3. The hydromechanical fuel control assembly provides the fuel metering function of the EFCU.

Fuel is supplied to the fuel control through a 200 micron inlet filter screen and is metered to the engine by the servo operated metering valve. It is a fuel flow/compressor discharge pressure ( $Wf/P3$ ) ratio device that positions the metering valve in response to engine compressor discharge pressure ( $P3$ ). Fuel pressure differential across the servo valve is maintained by the servo operated bypass valve in response to commands from the EFCU. (*Figure 1-2*)



Figure 1-3. Fuel pump and filter.

The manual mode solenoid valve is energized in the automatic mode. The automatic mode restricts operation of the mechanical speed governor. It is restricted to a single overspeed governor setting above the speed range controlled electronically. Deenergizing the manual mode valve enables the mechanical speed governor to function as an all speed governor in response to power lever angle (PLA). The fuel control system includes a low power sensitive torque motor which may be activated to increase or decrease fuel flow in the automatic mode (EFCU)

mode). The torque motor provides an interface to an electronic control unit that senses various engine and ambient parameters and activates the torque motor to meter fuel flow accordingly. This torque motor provides electromechanical conversion of an electrical signal from the EFCU. The torque motor current is zero in the manual mode, which establishes a fixed Wf/P3 ratio.

This fixed Wf/P3 ratio is such that the engine operates surge free and is capable of producing a minimum of 90 percent thrust up to 30 000 feet for this example system. All speed governing of the high pressure spool (gas generator) is achieved by the flyweight governor. The flyweight governor modulates a pneumatic servo, consistent with the speed set point as determined by the power lever angle (PLA) setting. The pneumatic servo accomplishes Wf/P3 ratio modulation to govern the gas generator speed by bleeding down the P3 acting on the metering valve servo. The P3 limiter valve bleeds down the P3 pressure acting in the metering valve servo when engine structural limits are encountered in either control mode. The start fuel enrichment solenoid valve provides additional fuel flow in parallel with the metering valve when required for engine cold starting or altitude restarts. The valve is energized by the EFCU when enrichment is required. It is always deenergized in the manual mode to prevent high altitude sub idle operation.

Located downstream of the metering valve are the manual shutoff and pressurizing valves. The shutoff valve is a rotary unit connected to the power lever. It allows the pilot to direct fuel to the engine manually. The pressurizing valve acts as a discharge restrictor to the hydromechanical control. It functions to maintain minimum operating pressures throughout the control. The pressurizing valve also provides a positive leak tight fuel shutoff to the engine fuel nozzles when the manual valve is closed.

4. The flow divider and drain valve assembly proportions fuel to the engine primary and secondary fuel nozzles. It drains the nozzles and manifolds at engine shutdown. It also incorporates an integral solenoid for modifying the fuel flow for cold starting conditions.

During an engine start, the flow divider directs all flow through the primary nozzles. After start, as the engine fuel demand increases, the flow divider valve opens to allow the secondary nozzles to function. During all steady state engine operation, both primary and secondary nozzles are flowing fuel. A 74 micron, self bypassing screen is located under the fuel inlet fitting and provides last chance filtration of the fuel prior to the fuel nozzles.

5. The fuel manifold assembly is a matched set consisting of both primary and secondary manifolds and the fuel nozzle assemblies.

Twelve fuel nozzles direct primary and secondary fuel through the nozzles causing the fuel to swirl and form a finely atomized spray. The manifold assembly provides fuel routing and atomizing to ensure proper combustion.

The EEC system consists of the hydromechanical fuel control, EFCU, and aircraft mounted power lever angle potentiometer. Aircraft generated control signals include inlet pressure, airstream differential pressure, and inlet temperature plus pilot selection of either manual or auto mode for the EFCU operation. Engine generated control signals include fan spool speed, gas generator spool speed, inner turbine temperature, fan discharge temperature, and compressor discharge pressure. Aircraft and engine generated control signals are directed to the EFCU where these signals are interpreted.

The PLA potentiometer is aircraft mounted in the throttle quadrant. The PLA potentiometer transmits an electrical signal to the EFCU, which represents engine thrust demand in relation to throttle position. If the EFCU determines a power change is required, it commands the torque motor to modulate differential pressure at the head sensor. This change in differential pressure causes the metering valve to move, varying fuel flow to the engine as required. The EFCU also receives a pilot initiated signal (by power lever position) representing engine thrust demand. The EFCU is programmed to recognize predetermined engine operating limits and to compute output signals such that these operating limits are not exceeded.

The EFCU is remotely located and airframe mounted. An interface between the EFCU and aircraft/engine is provided through the branched wiring harness assembly. (Figure 1-4)

### FADEC FUEL CONTROL SYSTEMS

A full authority digital electronic control (FADEC) has been developed to control fuel flow on most new turbine engine models. A true FADEC system has no hydromechanical fuel control backup system. The system uses electronic sensors that feed engine

parameter information into the EEC. The EEC gathers the needed information to determine the amount of fuel flow and transmits it to a fuel metering valve. The fuel metering valve simply reacts to the commands from the EEC. The EEC is the computing section of the fuel delivery system and the metering valve meters the fuel flow. FADEC systems are used on many turbine engines from APUs to the largest propulsion engines.

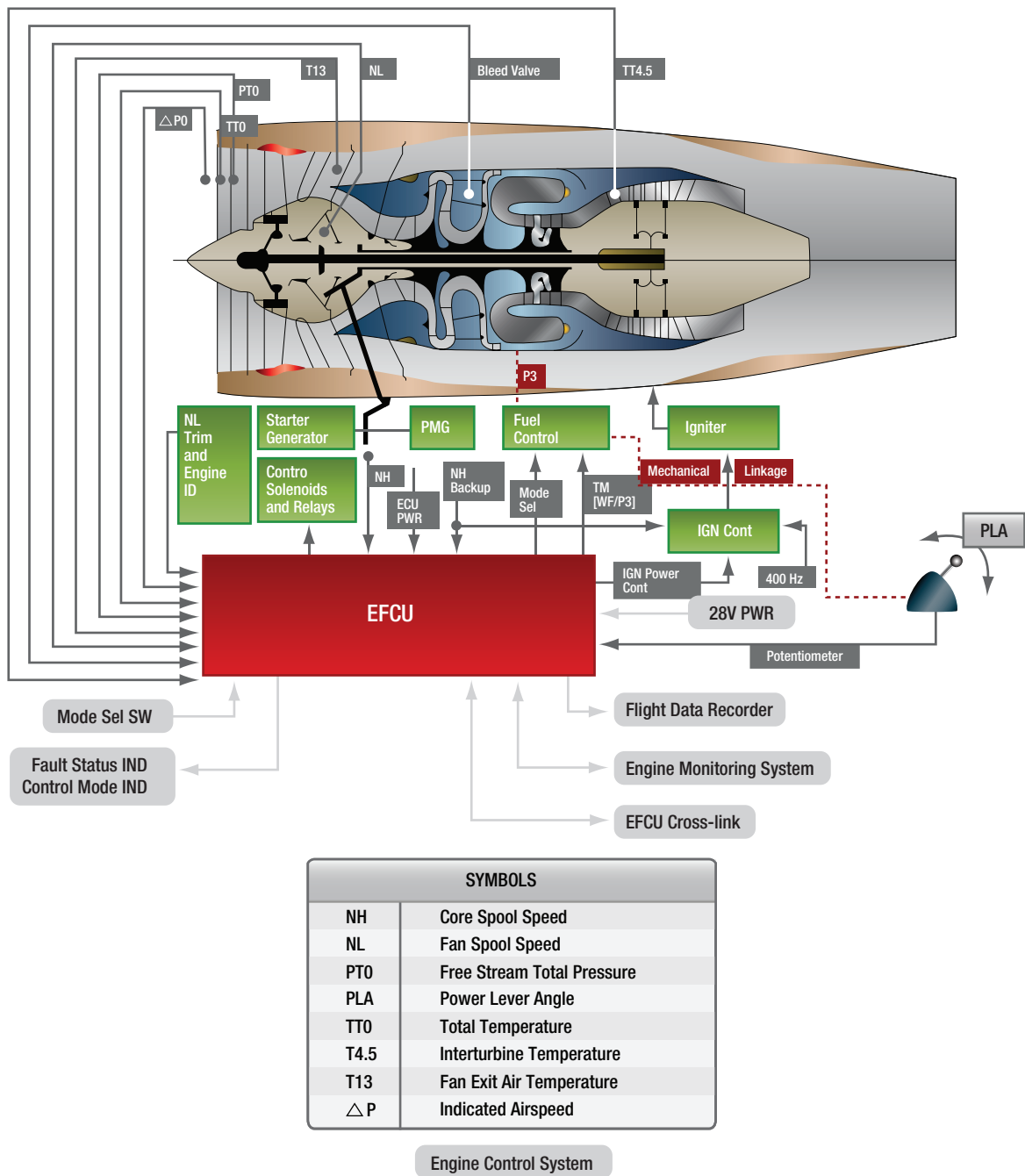


Figure 1-4. Engine control system.