INTRODUCTION TO A SINGLE-SHAFT TURBOPROP ENGINE

This section describes the components, component assemblies, systems and operation of a typical single shaft turbopropeller engine.

This engine is rated approximately 4900 E.S.H.P. at Standard Day conditions at 100% RPM and a maximum turbine inlet temperature of over 1050°C. The engine consists of a power section, a reduction gear, and a torquemeter assembly. The propeller is mounted on a single rotation propeller shaft. The following definitions apply to this engine.

FRONT: The propeller end.

REAR: The exhaust end.

TOP: Determined by the breather located at the forward end of the power section.

BOTTOM: Determined by the power section accessory drive housing, which is located at the forward end of the power section.

RIGHT AND LEFT: Determined by standing at the rear of the engine, facing forward.

ROTATION: The direction of rotation is determined when standing at the rear of the engine, facing forward. The power section rotors rotate in a counterclockwise direction. The propeller rotation is clockwise.

ACCESSORIES ROTATION: Determined by facing the mounting pad of each accessory.

COMBUSTION LINER NUMBERING: The combustion liners are numbered from one through six in a clockwise direction when viewing the engine from the rear.

COMPRESSOR AND TURBINE STAGES NUMBERING: Numbered beginning from the front of the power section toward the rear.

MAIN ROTOR BEARINGS: The main rotor bearings of the power section are the front compressor rotor bearing, the rear compressor rotor bearing, the front turbine rotor bearing, and the rear turbine rotor bearing. The bearings are numbered one through four. In addition to these main rotor bearings, there is a compressor extension shaft bearing.

SPARK IGNITER LOCATION: Two spark igniters are used. These are located in combustion liners numbers two and five.

MAJOR ENGINE ASSEMBLIES

The engine consists of a power section, torquemeter assembly, and a reduction gear assembly. The power section is attached to the reduction gear assembly by means of the torquemeter assembly and two tie struts.

The power section is divided into two subparts, the "cold section" and the "hot section."

The "cold section" consists of the compressor and accessory drive housing assemblies. It is so named because the temperatures that exist in this portion of the power section are lower than the temperatures that are present in the combustion and turbine assemblies.

The "hot section" is composed of the combustion and turbine sections. The temperatures of this portion of the power section are high because of combustion of the fuel/air mixture and exhausting gases.

The compressor assembly in this example engine is an axial flow type, incorporating a fourteen-stage compressor rotor and vane assembly encased in a casing. The air inlet housing, secured to the forward end of the compressor casing, receives air from the aircraft duct and directs this air to the compressor rotor. Provisions are made for the anti-icing of the air inlet housing struts and the inlet vanes that guide air into the rotor. A compressor air diffuser at the rear end of the compressor casing guides the air from the rotor into the combustor.

The accessory drive housing assembly, attached on the bottom of the air inlet housing, is driven from the compressor rotor assembly. Through a gear train, the power section RPM is reduced to that required to drive the accessories. There is a speed-sensitive valve, a speed-sensitive control, and an oil pump mounted on the front cover of the accessory drive housing. Mounted on the rear side of the accessory drive housing are the fuel control, fuel pump, and external scavenge oil pump.

The combustion assembly (also called the combustor), attached to the compressor diffuser, incorporates six cylindrical combustion liners positioned between the inner and outer combustion casings. The combustion liners mix the fuel and air, control combustion, and guide the exhausting gases into the turbine assembly.

The turbine assembly, mounted to the outer combustion casing, consists of a four-stage turbine rotor and vane assembly encased in the turbine inlet casing, turbine vane casing, and turbine rear bearing support. The rotor absorbs energy from the expanding exhaust gases to drive the compressor rotor, accessories, reduction gear assembly, gear trains, and propeller.

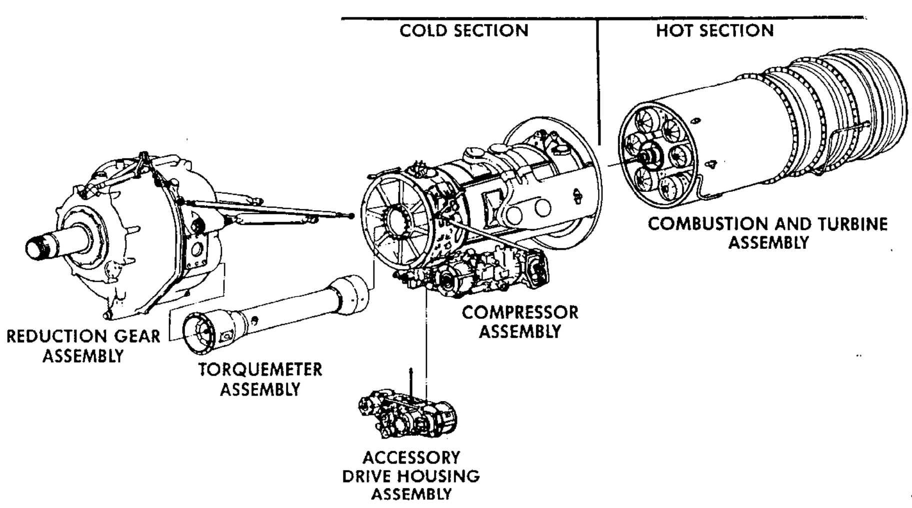
The turbine inlet casing supports the turbine front bearing and thermocouples, and encloses the first stage turbine vane assemblies. The turbine vane casing encloses the second, third, and fourth stage vane assemblies. The turbine rear bearing is supported and retained by the rear bearing support, which guides the exhausting gases into the aircraft tailpipe.

<u>The torquemeter assembly</u>, attached between the air inlet housing and the reduction gear assembly, consists of a housing and shaft assembly. The housing serves as the structural support that aligns the power section with the reduction gear assembly. Two tie struts provide the necessary rigidity to maintain alignment. The shaft assembly transmits torque from the power section to the reduction gear assembly. A pickup assembly, attached in the forward end of the housing, detects the torque transmitted through the shaft assembly. The pickup assembly signals are directed to the phase detection circuit of the torquemeter indicator. This circuit controls the torquemeter indicator, which registers the torque delivered into the reduction gear assembly.

<u>The reduction gear assembly</u> provides the required reduction of power section rotor RPM through two stages of reduction. This ensures that the propeller mounted on the propeller drive shaft rotates at the proper RPM. The reduction gear assembly also provides mounting pads and drives for necessary aircraft accessories and incorporates a propeller brake, a safety coupling, and a negative torque signal system.

MAJOR ENGINE ASSEMBLIES

Single-Shaft Turboprop Engine



ENGINE ACCESSORIES AND THEIR LOCATIONS

The engine accessories described below are shown on the chart at the end of this section.

Anti-Icing Solenoid (one per engine). This unit controls the position of the two anti-icing valves. The anti-icing solenoid is energized when no anti-icing airflow is required. If anti-icing airflow is required, the solenoid is de-energized. The anti-icing system is thus a "fail-safe" design; loss of 24-28V DC electrical power results in the flow of anti-icing air.

Anti-Icing Air Valves (two per engine). The position of these valves is controlled by the anti-icing solenoid. When the anti-icing air valves are open, anti-icing air flows to the torquemeter housing shroud, the inlet housing struts, the CIT sensor anti-icing probe, and the compressor inlet guide vane assembly.

Ignition Relay (one per engine). The ignition relay is energized at 16% (2200) RPM during an engine start, and de-energized at 65% (9000) RPM. When energized, the ignition relay completes the necessary electrical circuits to the ignition exciter, manifold drain valve solenoid, paralleling valve solenoid, and fuel enrichment valve solenoid

Ignition Exciter (one per engine). The ignition exciter receives 24-28V DC electrical power whenever the ignition relay is energized. It provides the necessary ignition current and voltage through two high-tension leads to the two spark igniters.

Manifold Drain Valve (one per engine). This valve drains fuel from the fuel manifold upon engine shutdown. The solenoid of the manifold drain valve is energized whenever the ignition relay is energized, thereby closing the valve. The manifold drain valve is held closed during engine operation by the fuel pressure in the fuel manifold, and is opened by a spring whenever the fuel manifold pressure is less than the spring force.

Burner Drain Valves (two per engine). These valves allow drainage of any liquids from the combustion section when the engine is not running. The burner drain valves close whenever the pressure within the combustion section is 2-4 psi greater than the pressure outside the combustion case. The valves open automatically by spring pressure whenever the pressure differential is less than spring force. Note that the burner drain valves may have been deactivated or eliminated on some engines.

Enrichment Valve (one per engine). This valve allows for a surge of fuel to bypass the metering section of the fuel control to provide a quick fill of the fuel manifold during engine starting. The solenoid of the enrichment valve is energized by the ignition relay at 16% RPM If selected by a flight deck switch. It is de-energized when the fuel manifold pressure switch senses 50 psi of fuel manifold pressure.

Fuel Manifold Pressure Switch (one per engine). This switch is electrically in series with the enrichment valve solenoid. The switch contacts are closed if fuel manifold pressure is less than 50 psi. The contacts open to turn off enrichment fuel flow when fuel manifold pressure exceeds 50 psi.

Fuel Pump (one per engine). The fuel pump actually contains three individual pumps: a centrifugal boost pump that augments aircraft boost pumps, a gear-type primary fuel pump that supplies fuel to the fuel control during normal operating conditions, and a gear-type secondary fuel pump that is normally a backup to the primary pump, but is used during engine start to supplement the primary pump.

Low Pressure Fuel Filter (one per engine). This unit filters the engine-driven boost pump output. Low pressure filtered fuel is delivered to the inlet of the high-pressure fuel pumps (secondary and primary).

High Pressure Fuel Filter Assembly (one per engine). The assembly is mounted to the fuel pump. In addition to filtering the high-pressure discharge of the fuel pump, it provides the passages and valves necessary to parallel the pump discharge during start and operate the pumps in series during other operation. A solenoid-actuated paralleling valve, controlled by the ignition relay, is mounted on the high-pressure fuel filter assembly. A pressure switch, to sense secondary fuel pump discharge pressure, is mounted on the assembly. This pressure switch actuates the flight deck secondary fuel pump pressure (primary pump fail) light.

Fuel Control (one per engine). The fuel control is a hydro-mechanical device that meters 120% of the fuel needed for starting and operation of the engine. Any fuel beyond 120% is bypassed back to the high-pressure fuel pump. Fuel volume is metered as a function of compressor inlet temperature (CIT), compressor inlet pressure (CIP), engine speed (RPM), and throttle position. The 20% excess fuel over 100% allows the temperature datum system to "trim" fuel flow to control the turbine inlet temperature. The fuel control also provides the means to initiate and shut off fuel flow for start and shut down of the engine.

Temperature Datum Valve (one per engine). This valve is the metering device of the fuel trimming system. Under direction of the temperature datum control, it varies the fuel flow to the fuel manifold by bypassing unneeded fuel back to the high-pressure fuel pump.

Fuel Nozzles (six per engine). The fuel nozzles atomize and inject fuel into the forward end of the six combustion liners.

Speed Sensitive Valve (one per engine). This valve is flyweight actuated, and controls the position of the eight (acceleration) bleed valves. The bleed valves (4 at the fifth and 4 at the tenth compressor stages) are open when engine RPM is less than 94% (13,000 RPM in this example engine). This increases the compressor flow velocity to avoid compressor surge. The bleed valves are closed above 94% RPM, which is above the potential surge range.

Speed Sensitive Control (one per engine). This control contains three flyweight-actuated switches set for 16% (2200) RPM, 65% (9000) RPM, and 94% (13,000) RPM. The 16% switch opens the fuel cut-off valve and turns on the ignition relay for automatic engine start sequencing. The 65% switch turns off the ignition relay, completing the start sequence. The 94% switch shifts the temperature datum system from start temperature limiting to normal limiting operation.

Coordinator Control (one per engine). The coordinator control is mounted to the rear of the fuel control. It coordinates power lever (throttle) input to the fuel control and the propeller linkage. Thus, the fuel control and propeller operations are coordinated at all times. The coordinator contains a "discriminator," which provides an override of the throttle to mechanically cut off fuel flow and feather the propeller regardless of the throttle position. This function is controlled by means of the condition lever input. The coordinator also contains a switch and potentiometer that are sensitive to throttle position. The switch and potentiometer provide the necessary signals to the temperature datum system for fuel trimming.

Temperature Datum Control (one per engine). The temperature datum control (TD control) compares the turbine inlet temperature (TIT) to one of three possible reference signals and directs the TD valve to trim the fuel flow to increase ("Put"), decrease ("Take"), or remain neutral ("Null"). The TD system thereby provides a closed-loop control to limit and schedule turbine inlet temperature.

Torquemeter Indicator (one per engine). The torquemeter indicator processes signals from the torquemeter pick-up assembly to display the torque being transmitted by the torquemeter torque shaft.

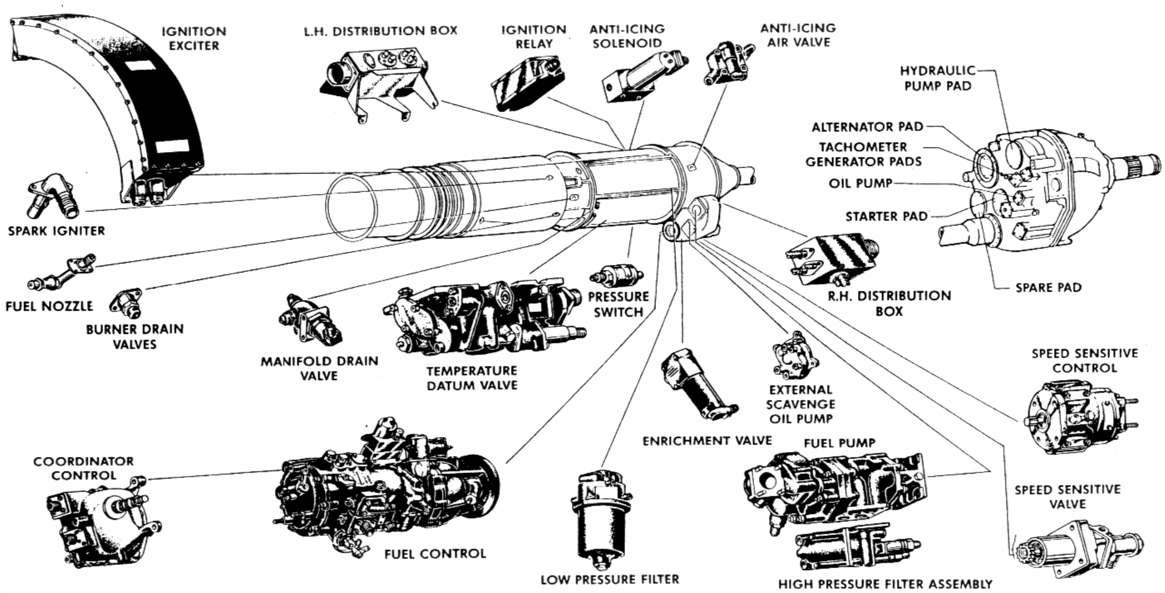
Engine Oil Pumps. Oil pumps are considered basic engine parts rather than accessories. The power section has three oil pump assemblies: a main oil pump with a pressure element and a scavenge element, an external scavenge pump with two scavenge elements, and a turbine rear scavenge oil pump in the turbine assembly. The reduction gear assembly has three oil pump assemblies: a pressure oil pump mounted on the rear case and two scavenge oil pumps mounted inside the reduction gear assembly.

Reduction Gear Assembly Accessory Drives. These drives, located on the rear case, provide mounting gearing for various airframe-furnished accessories. These airframe accessories vary depending upon aircraft type and mission. Typical accessories include a starter, alternator, generator, hydraulic pump(s), and tachometer generator. If needed, a spare pad can be activated for additional accessories.

Relay Box (one per engine). This box contains the necessary relays for the operation of the fuel trimming system.

Torquemeter Indicator (one per engine). The phase detection circuit of the torquemeter indicator receives electrical pulses from the two pickups in the torquemeter pickup assembly. These pickups detect the angular deflection (twist) that occurs when torque is transmitted through the torquemeter shaft assembly. The time spacing of electrical pulses from the two pickups varies directly with the torque transmission. The phase detection circuit electrically measures the time spacing of these pulses, and provides the necessary electrical signal to the torquemeter indicator. The torquemeter indicator indicates the positive torque being delivered by the power section to the reduction gear assembly. The torque on the propeller shaft will be somewhat less than the torque indicated by the torquemeter indicator due to motoring losses and accessory requirements. The torquemeter indicator will also indicate a negative torque being delivered to the power section from the propeller.

ACCESSORIES LOCATION



MAJOR ASSEMBLIES – POWER SECTION

1. Compressor
2. Combustor
3. Turbine
4. Accessory drive housing

Compressor

The compressor assembly consists of a compressor air inlet housing assembly, compressor casing assembly, compressor rotor assembly, and diffuser assembly.

The compressor air inlet housing is designed to direct and distribute air into the compressor rotor. It also provides the mounting location for the front compressor bearing, the engine breather, the accessory drive housing assembly, the anti-icing air valves, the torquemeter housing, and the inlet anti-icing vane assembly. The inlet anti-icing vane assembly, mounted on the aft side of the air inlet housing, imparts the proper direction and velocity to the airflow as the air enters the first stage of the compressor rotor. These vanes may accumulate ice under ideal icing conditions. Therefore, provisions are made to provide heat to each of the vanes. Engine core air may be extracted, if required, from the outlet of the compressor (diffuser) and directed through two tubes to the anti-icing valves mounted on the compressor air inlet housing. Since this air has been compressed in its path through the engine, its temperature is higher than the ambient air. The inlet anti-icing vanes, which are hollow, mate with an inner and outer annulus. The hot air is directed into these annuli, through the hollow vanes, and out to the first stage of the compressor through holes provided in the inboard and outboard ends of the vanes.

The compressor rotor, an axial flow type, consists of multiple stages. It is supported at the forward end by a roller bearing and at the rear by a ball bearing.

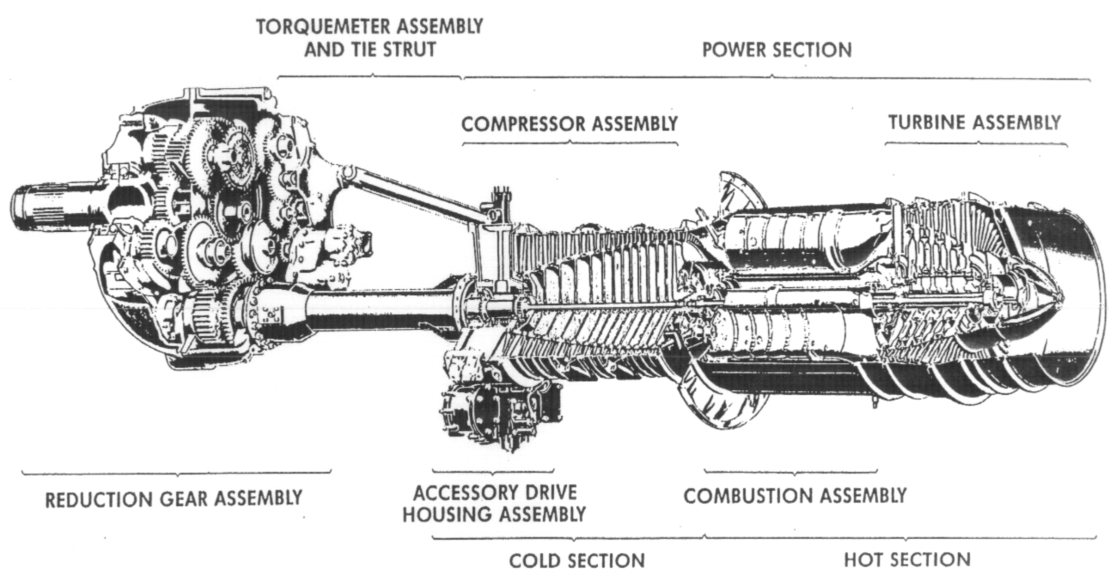
The compressor casing assembly consists of four quartercases permanently bolted together in halves. The compressor vane assemblies are bolted in channels in the compressor casing. The inner ring of the vane assemblies supports the interstage air seals, which form a labyrinth seal with the outer diameter of the compressor wheels. Thus, air is prevented from bleeding back from one stage to the previous one. Between each of the vane channels, the casing is coated with abradable aluminum to provide a minimum compressor rotor blade tip clearance, increasing compressor efficiency. The last stage and outlet vane assembly consists of an inner and an outer ring supporting two complete circles of vanes. Outlet guide vanes are used to straighten airflow prior to its entrance into the combustion section.

The compressor casing has ports around its circumference. Multiple bleed air valves are normally mounted on the outside of the compressor casing midway aft and at the latter stages. These valves are used to expel air from the compressor during engine start and acceleration or during operation at low speed ground idle. This activity improves compressor operability.

The compressor diffuser is a welded steel construction, and is bolted to a flange at the aft end of the compressor casing assembly. It is the structural member for the midsection of the engine. The power section-to-aircraft mounting is located at this point. Airfoil struts form passages that conduct compressed air from the outlet of the compressor to the forward end of the combustion liners. These struts also support the diffuser inner cone, which provides the mounting for the rear compressor ball bearing, the air and oil seals, the rear compressor bearing oil jet, and the forward end of the inner combustion casing.

Air is extracted from ports on the diffuser for anti-icing and operation of the compressor bleed air valves. Bleed air is also extracted for aircraft anti-icing and for cross-feeding from one engine to another for engine starter operation. The engine fuel nozzles are mounted here, and extend into the diffuser. At the rear splitline, a spray-shield baffle ring is provided to mate with the aircraft firewall.

MAJOR ENGINE ASSEMBLIES



Combustor

The combustor, or combustion section, assembly consists of an outer and an inner combustion casing that form an annular chamber in which multiple combustion liners are located. Nozzles spray fuel continuously into the forward end of each combustion liner.

During the start cycle, two spark igniters light the fuel-air mixture. The combustion liners are interconnected near their forward ends. Thus, after ignition takes place, the flame will propagate to the remaining liners. An outer combustion casing provides the supporting structure between the diffuser and the turbine section. Two burner drain valves, used to drain fuel after a false start, are mounted on the bottom of the outer combustion casing.

Turbine

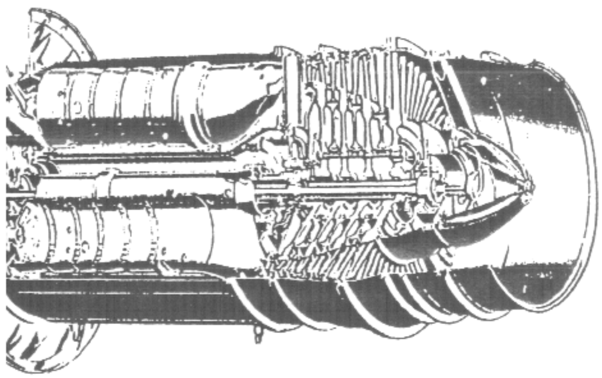
The turbine assembly includes six major items:

1. Turbine inlet casing
2. Turbine rear bearing support
3. Turbine rotor
4. Rear turbine scavenge oil pump
5. Turbine vane casing
6. Turbine vane assemblies

The turbine inlet casing is attached at its forward end to the outer and inner combustion casings. The casing is divided into six equal passages by six radial struts. The 1st stage turbine vane assemblies provide the means of locating and supporting the aft end of the combustion liners. There are holes for mounting the eighteen engine thermocouple assemblies around the outside of the casing. Thermocouple assemblies are normally dual junctions; so two complete and individual circuits are available in each thermocouple. One is used to provide a temperature indication (the turbine inlet temperature) to the flight deck, and the other is used to provide a signal to the fuel trimming system. The circuits measure the average of all of the engine-mounted thermocouples.

The turbine rotor assembly consists of multiple stages of turbine wheels. This engine uses four turbine stages that are splined together and secured by eight bolts. A roller bearing at the forward end and another at the aft end support the entire assembly. A turbine coupling shaft assembly connects the turbine rotor to the compressor rotor. Power extracted by the four stages of the turbine is transmitted to the compressor rotor, accessories, reduction gear assembly, gear trains, and the propeller. All four stages of blades are mounted to their wheel rims in a broached serration or "fir tree" design. The first stage turbine wheel has the smallest blade area, with each succeeding stage becoming larger and the disks becoming smaller. The first three stages of the turbine incorporate shrouded turbine blades. Cooling air is directed through hollow 1st stage vanes, hollow 1st stage blades, and over the front and rear faces of the turbine rotor 1st, 2nd, and 3rd stage wheels.

TURBINE UNIT ASSEMBLY



The turbine vane casing surrounds the turbine rotor assembly and provides retention for the three rear stages of turbine vane assemblies. The case is a structural member, supporting the turbine rear bearing support. The vanes are airfoils that serve two basic functions: to increase the gas velocity, and to direct the flow of gases to impinge upon the turbine blades at the most efficient angle.

The turbine rear bearing support attaches to the aft end of the turbine vane casing. It houses the turbine rear roller bearing, the turbine rear scavenge oil pump and support, and the inner exhaust cone and insulation. It also forms the exhaust (jet) nozzle for the engine.

Accessory drive housing

The accessory drive housing assembly is mounted on the bottom of the compressor air inlet housing. It includes the necessary gear trains for driving all power section driven accessories at their proper RPM in relation to engine RPM. Power for driving the gear trains is taken from the compressor extension shaft by a vertical shaft gear. The following are typical accessories:

1. Speed-sensitive control
2. Speed-sensitive valve
3. Oil pump
4. Fuel control
5. Fuel pump
6. External scavenge oil pump

A number of non-driven accessories and components are typically furnished with the engine. These may be broadly classified into fuel, air bleed, ignition, oil, and torquemeter systems.

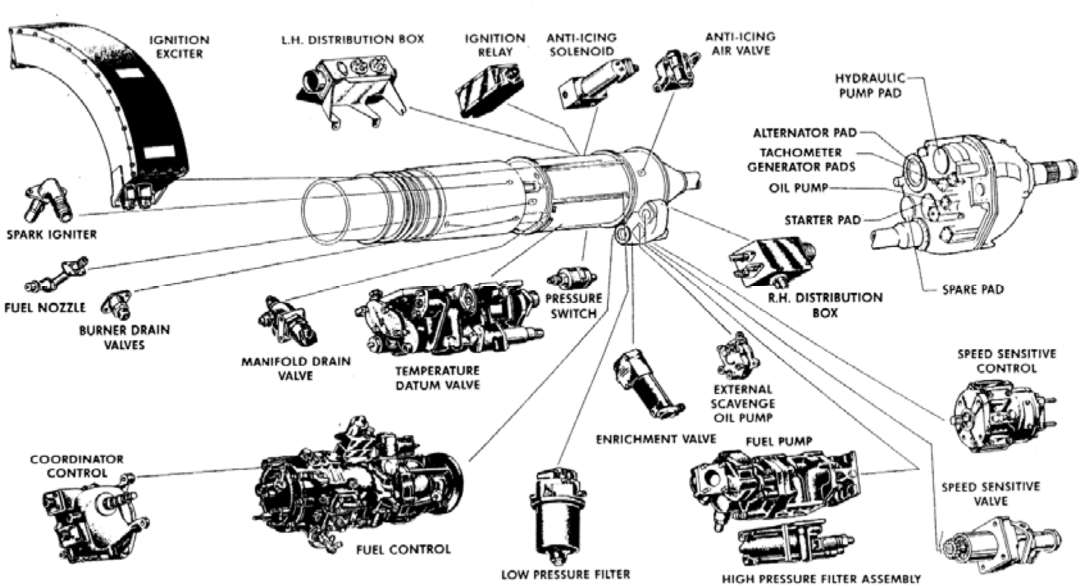
Fuel System:

1. High-pressure fuel filter
2. Low-pressure fuel filter
3. Enrichment valve
4. Fuel manifold pressure switch
5. Coordinator
6. Relay box (aircraft mounted)
7. Temperature datum control (aircraft mounted)
8. Temperature datum valve
9. Fuel nozzles (6)
10. Manifold drain valve
11. Burner drain valves (2)

Air Bleed System:

1. Anti-icing solenoid valve
2. Anti-icing air valves
3. Compressor bleed air valves

ACCESSORIES LOCATION



Ignition System:
1. Ignition exciter
2. Ignition relay
3. Spark igniters

Oil System:
1. Pressure oil filter
2. Scavenge oil filter

Torquemeter System
1. Indicator (flight deck mounted)

MAJOR ASSEMBLIES – REDUCTION GEAR

The primary function of the reduction gear assembly is to reduce the power section RPM to the range of efficient propeller RPM. It also provides pads on the rear case for mounting the following aircraft-furnished accessories:

1. Starter
2. Hydraulic pump
3. Alternator (115 V, 400 Hz)
4. Tachometer generator

The reduction gear has an independent lubrication system that includes pressure and scavenge pumps. Oil supply is furnished from a tank that also supplies the power section.

The reduction gear assembly, remotely located from the power section, is attached by a torquemeter housing and tie struts. The remote location offers a number of advantages:

1. Better air inlet ducting, which increases engine efficiency and performance.

2. The opportunity to offset the reduction gear assembly to accommodate high- or low-wing aircraft.

3. The ability to mount additional driven accessories without affecting frontal area.

4. Containing the engine in the minimum frontal area.

5. The ability to use an electronic torquemeter.

This reduction gear assembly has an overall reduction gear ratio of about 13.5:1, accomplished in two stages. A spur gear train allows the primary step-down, and a planetary gear train allows the secondary step-down. The propeller shaft rotates in a clockwise direction when viewed from the rear.

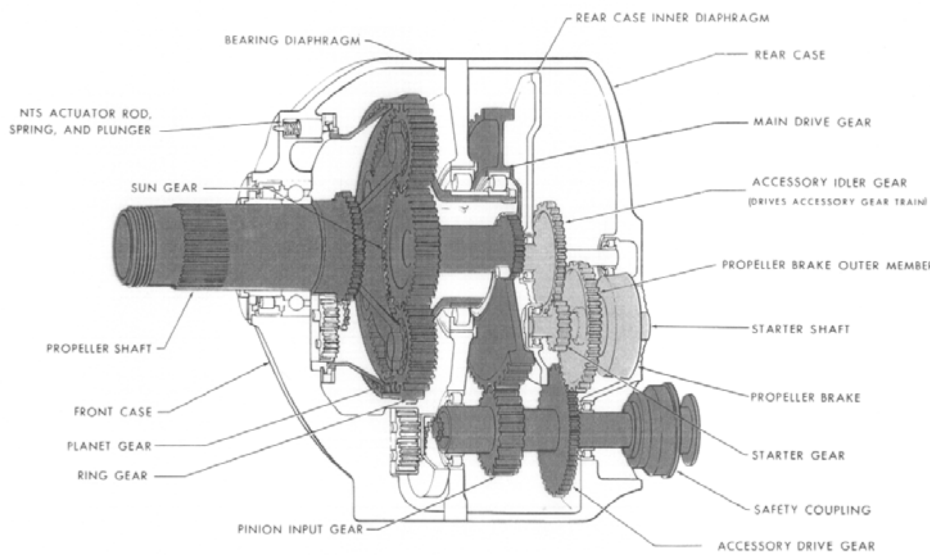
In addition to the reduction gears and accessory drives, the reduction gear assembly includes the following units:

1. Propeller brake - used to prevent windmilling of a feathered propeller.

2. Negative Torque System (NTS) - designed to prevent excessive propeller drag.

3. Safety coupling – disconnects the gearbox from the power section in extreme drag conditions.

BASIC REDUCTION GEAR DIAGRAM



Propeller brake

The propeller brake prevents the propeller from windmilling when it is feathered in flight. It is a friction type brake, consisting of a stationary inner cone and a rotating outer member. When applied, it acts upon the primary stage reduction gearing. During normal engine operation, reduction gear oil pressure holds the brake in the released position. This is accomplished by oil pressure (hydraulic force), which holds the outer member away from the inner cone. When the propeller is feathered, or at engine shutdown, reduction gear oil pressure and hydraulic force decrease. Spring force moves the outer member into contact with the inner cone.

Negative Torque System (NTS)

The negative torque system is designed to limit the amount of propeller drag the aircraft may encounter. This system, which is part of the planetary gear train, is completely mechanical in design and automatic in operation. A negative torque in the range of about 1000-1450 inch-pounds, transmitted from the propeller into the reduction gear, causes the ring gear to move forward, overcoming the force of the NTS springs. As the ring gear moves forward, it actuates a rod that moves forward through an opening in the reduction gear front case. When actuated, the propeller increases blade angle (toward feather) until the negative torque and the resultant propeller drag is relieved. The propeller will not go to the feather position when actuated by the NTS system, but will modulate through a small blade angle range such that it will not absorb more than approximately 1000-1450 inch-pounds of torque. The propeller returns to normal (RPM) governing when the negative torque is relieved.

Safety coupling

The safety coupling can be classified as a "backup" device for the negative torque system (NTS). It has a negative torque setting in the range of 4200-7200 inch-pounds. If the NTS system or propeller does not function properly, the safety coupling will prevent excessive propeller drag by uncoupling the power section from the reduction gear. By so doing, the drag effect is greatly reduced. The safety coupling is attached to the forward end of the torquemeter shaft that transmits power section torque to the reduction gear assembly.

During normal operation (when power is being produced by the power section), the safety coupling connects the torquemeter shaft to the reduction gear assembly through helical splines. Positive torque and a spring pack wind the splines toward engagement. Negative torque in excess of the spring pack value winds the splines in the other direction to disengage. This action decouples the drag of the power section from the reduction gear assembly.

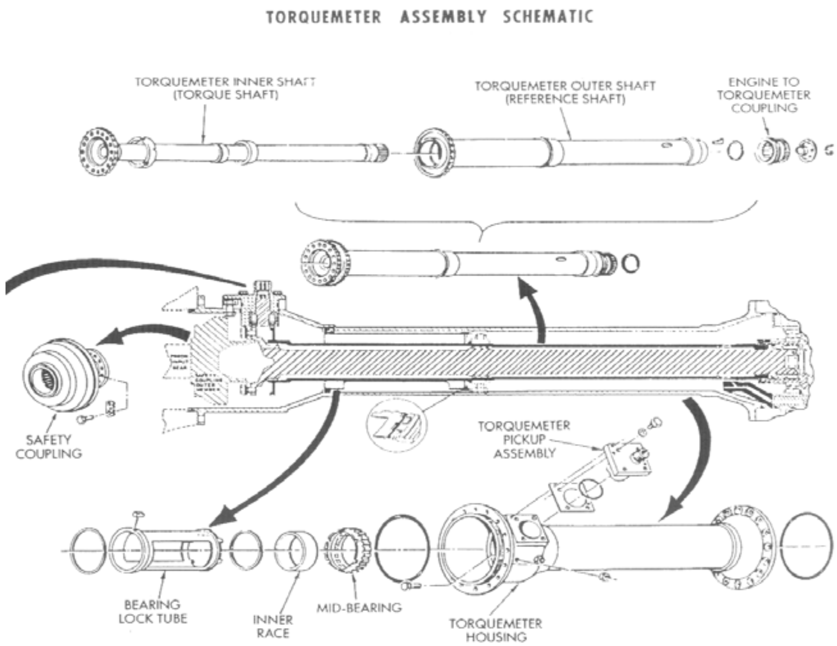
MAJOR ASSEMBLIES – TORQUEMETER AND TIE STRUTS

The torquemeter housing provides alignment and tie struts provide the necessary rigidity between the power section and the reduction gear assembly. The tie struts are adjustable. The torquemeter provides the means of accurately measuring torque input into the reduction gear assembly. It has an indicated accuracy of $\pm$2% at standard day static takeoff power. The torquemeter consists of the following major parts:

1. Torquemeter inner shaft (torque shaft)
2. Torquemeter outer shaft (reference shaft)
3. Torquemeter pickup assembly (magnetic pickup)
4. Torquemeter housing
5. Indicator (cockpit gage)

The principal operation of the torquemeter is that of electronically measuring the angular deflection (twist) that occurs in the torque shaft relative to the zero deflection of the reference shaft. The actual degree of angular deflection is measured by the pickup assembly and transmitted to the phase detection circuit of the torquemeter indicator in the cockpit.

TORQUEMETER ASSEMBLY



ENGINE SYSTEMS – LUBRICATION

The power section and reduction gear assemblies have separate and independent lubrication systems that use a common airframe-furnished oil supply system.

The engine manufacturer informs the airframe manufacturer of the amount of oil flow required by the reduction gear and the power section, and the heat rejection from the reduction gear and power section. With this information, the airframe manufacturer designs an aircraft oil supply system that will provide the required volume flow and the necessary oil cooling. In addition, the airframe manufacturer must provide the following flight deck indications for each engine:

1. Power section oil pressure
2. Reduction gear oil pressure
3. Oil inlet temperature (inlet to engine lubrication system)
4. Oil quantity

Power section lubrication system

The power section contains an independent lubrication system, with the exception of airframe-furnished parts that are common to power section and reduction gear.

Oil is supplied from the aircraft tank to the pressure pump. Before the oil is delivered to any parts requiring lubrication, it flows through the oil filter. System pressure (filter outlet pressure) is regulated to 50-60 psi by the pressure-regulating valve. A bypass valve is incorporated in the system to allow some oil to bypass the filter element in the event that the filter becomes contaminated. A one-way check valve prevents oil from seeping into the power section whenever the engine is not running.

The power section has multiple scavenge oil pump elements. The inlets of the scavenge oil pumps are located so that they will scavenge oil from the power section in any normal attitude of flight. The combined flows of scavenged oil from the power section and the reduction gear scavenge systems pass through the external scavenge oil filter before being cooled and returned to the supply tank. One magnetic plug is located on the bottom of the accessory drive housing, and another is positioned in the scavenge oil outlet on the forward side of the main oil pump housing.

Reduction gear lubrication system

Oil flows from the pressure pump through a filter to all parts within the reduction gear that require lubrication. In addition, oil pressure is used as hydraulic pressure in the propeller brake assembly. A filter bypass valve guarantees continued oil flow in the event that the filter becomes contaminated.

A check valve prevents oil from seeping into the reduction gear whenever the engine is not running. The pump pressure is limited to 320 psi by an externally-mounted pressure relief valve. The location of the scavenge pumps provide for scavenging in any normal attitude of flight. The output of the scavenge pumps returns the oil by a common outlet to the aircraft system. A magnetic plug, located on the bottom front of the reduction gear assembly in the main scavenge pump inlet, provides a means of draining the reduction gear assembly. A second magnetic plug is located near the bottom right of the front case in the nose scavenge pump outlet.

ENGINE SYSTEMS – BLEED AIR

The bleed air systems are:

1. Anti-icing system
2. Compressor bleed air system

Anti-icing system

The system includes an anti-icing solenoid valve located on the top of the compressor casing, anti-icing valve assemblies located on the compressor air inlet housing, and the necessary lines and passages from the compressor diffuser to the anti-icing valves. The system can operate in automatic or manual mode, as selected by the crew from the flight deck by switches. When automatic operation is selected, aircraft-furnished ice detectors will initiate system operation on all engines when icing conditions are encountered. For all manual operation, the propeller and engine anti-icing switch must be in "MANUAL", and each engine inlet air duct anti-icing switch must be placed in the "ON" position.

When system is ON, compressor discharge air heated by compression will flow to the anti-icing valves. From this point, the air flows to the compressor inlet anti-icing vane assembly, the compressor air inlet housing struts, the compressor air inlet temperature probe anti-icer (located in the air inlet housing below the left horizontal strut), and the lower half of the torquemeter housing shroud. The compressor air inlet pressure probe, located in the left horizontal strut of the air inlet housing, is anti-iced by heat conduction.

For each 1% of air bled from the compressor, there will be approximately a 3% decrease in torque. The engine anti-icing system requires approximately 1% of the airflow. However, when the engine anti-icing system is turned ON, air is also bled to anti-ice the inlet duct. This accounts for the additional decrease in torque.

Compressor bleed air system

The compressor bleed air system is entirely automatic, bleeding air from the compressor during engine start and acceleration and at low ground idle. It is used to unload the compressor between 0% and 94% RPM in order to prevent compressor stall and surge. The system includes pneumatically-operated bleed air valves, a mechanically-actuated speed-sensitive valve mounted on the forward side of the accessory drive housing assembly, and the necessary manifolding and plumbing. The bleed air valves empty compressor air into manifolds that are ducted to the aft side of the engine. The speed-sensitive valve is a flyweight type driven by the engine. When the engine is running at less than 94% RPM, the valve piston is vented to the atmosphere. This allows the compressor pressure to move the pistons to their OPEN position, bleeding air overboard. When the engine is running above 94% RPM, the speed-sensitive valve directs high-pressure air to the bleed air valve piston heads. The bleed air valve pistons move to the closed position, preventing air from bleeding from the forward stages of the compressor. During low ground idle operation, the bleed air valves will be in the OPEN position, bleeding air to help unload the compressor.

ENGINE SYSTEMS – CONTROL

The speed-sensitive control is an electrically-actuated unit mounted on the forward side of the accessory drive housing assembly. It is a flyweight-type unit that incorporates three snap action switches. At specific RPM, electrical circuits are "made" or "broken," which automates the engine starting procedure.

At about 16% RPM, the speed sensitive control does the following:

1. The fuel cutoff valve opens at the outlet of the fuel control.
2. Ignition system - ON.

3. A manifold drain valve is energized to the closed position.
4. The fuel pump goes into parallel to deliver increased starting fuel.
5. A fuel enrichment valve opens, if selected in the cockpit.

At about 65% RPM, the following occurs:

1. Ignition system – OFF.
2. The manifold drain valve is de-energized; but remains closed due to fuel pressure.
3. The fuel pump begins to operate in series.

At about 94% (13,000) RPM, the following occurs:

1. The fuel trimming system is changed from START LIMITING (with a maximum limiting temperature of 830°C) to NORMAL LIMITING (with a maximum limiting temperature of 1077°C).
2. A reset of the maximum possible TAKE of fuel by the temperature datum valve from 50% to 20%.

Control – temperature limiting

Temperature limiting eliminates the possibility of exceeding critical turbine inlet temperature limits during starting or acceleration. Whenever the engine is operating with the throttle in 0° to 66° position (coordinator angle), the engine is operating in temperature limiting.

Control – temperature controlling

Temperature controlling permits the use of the throttle to schedule a desired turbine inlet temperature when operating above 66° position (coordinator angle). Temperature control requires RPM to be excess of 94%.

ENGINE SYSTEMS – IGNITION

Ignition is only required during the engine start cycle. Once ignition occurs, the combustion process is continuous. This ignition system is a condenser discharge, high-energy type. The system includes an ignition exciter, an ignition relay, lead assemblies, and two spark igniters. It operates on 14 to 30 volts DC input. There are two independent systems, as the exciter is a dual unit with igniters. During the starting cycle, as RPM reaches 16%, the speed-sensitive control automatically completes an electrical circuit to the ignition relay. This closes the circuit to the ignition exciter, providing electrical energy to the spark igniters. When engine RPM reaches 65%, these circuits are de-energized through the action of the speed-sensitive control.

ENGINE SYSTEMS – FUEL

The engine operates on Grades JP-4, JP-5, and JP-8 fuel or approved alternatives.

The fuel system includes the following types of components and functions:

1. Fuel pump
2. Low-pressure and high-pressure fuel filters
3. Fuel control
4. Fuel enrichment valve and manifold pressure switch
5. Coordinator
6. Fuel trimming system
7. Thermocouples
8. Fuel nozzles
9. Manifold drain valve
10. Burner drain valves

The fuel system must deliver metered fuel to the fuel nozzles to meet all possible conditions of engine operation on the ground or in flight. This imposes a number of requirements on the fuel system, including:

1. The capability of starting under all ambient conditions.

2. The provision for rapid changes in power.

3. The provision for a means of limiting the maximum allowable turbine inlet temperature.

4. The need for a system to enable the operator to select a desired turbine inlet temperature and have it automatically maintained regardless of altitude, free air temperature, forward speed, and fuel BTU content.

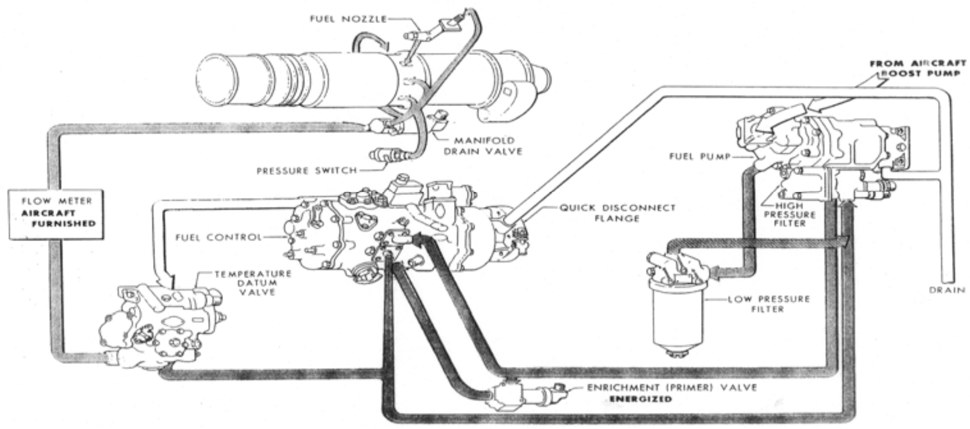
5. The need for a system that incorporates an RPM-limiting device in the event of propeller governor malfunction.

6. The need for a system to control fuel flow during the RPM range in which the engine compressor is susceptible to stall or surge.

7. The need for a system to coordinate propeller blade angle with fuel flow during ground operation (taxi range – start, taxi, and reverse).

8. The need for a system that is capable of operating only on the hydromechanical fuel control. However, if this is necessary, closer flight crew monitoring of throttle and engine instruments is required.

FUEL SYSTEM SCHEMATIC



Fuel pump and low-pressure fuel filter

Fuel is supplied to the engine fuel pump from the aircraft system. It enters a boost element and is directed to the low-pressure filter.

The low-pressure fuel filter is a paper-cartridge type that incorporates bypass valves that open in the event of unusual fuel contamination. The paper cartridge must be replaced rather than cleaned.

In addition to the boost element, the fuel pump assembly includes two spur gear high-pressure pumps. These are referred to as the primary and the secondary elements. During normal operation, these pumps are in series. However, during engine starting from 16% to 65% RPM, the pumps are placed in parallel by the action of the paralleling valve in the high-pressure filter. The paralleling of the pumps is used to increase fuel flow when the RPM is low. Failure of either primary or secondary pump will not affect normal operation, as either pump has sufficient fuel flow capacity for takeoff power.

High-pressure fuel filter

The high-pressure fuel filter assembly consists of check valves, a paralleling valve, a fuel filter, a pressure switch, and a bypass valve. The fuel filter assembly accomplishes the following:

1. Filters the output of primary and secondary pumps.

2. Connects the two pumps in parallel during the starting cycle from 16% to 65% RPM.

3. Connects the two pumps in series during normal operation, with the primary pump supplying high-pressure fuel flow to the power section.

4. Automatically enables the secondary pump to take over upon failure of the primary pump.

5. Provides a means of checking primary and secondary pump operation during the starting procedure.

6. Provides a means of indicating primary pump failure (via a pressure switch and flight deck fuel pump light).

Fuel control

The fuel control is a hydromechanical metering device that is designed to meet the following requirements:

1. Supply a controlled fuel flow to initiate engine start.

2. Supply fuel flow in relation to RPM during acceleration to idle to help the bleed valves protect against compressor surge.

3. Supply fuel flow in relation to throttle position during engine operation after starting.

4. Adjust RPM and throttle fuel flow schedules to correct for variations in air density resulting from changes in compressor inlet air pressure and temperature.

5. Provide for turning fuel flow ON for engine start and OFF for engine shutdown.

6. Limit the minimum and maximum possible fuel flow.

7. Provide overspeed protection for the engine.

8. Control the power available in maximum reverse.

9. Meter excess engine fuel requirements based upon compressor inlet air pressure, compressor inlet air temperature, RPM, and throttle setting.

10. Provide the means for selecting either low-speed ground idle or high speed ground idle operation. Low-speed ground idle operation is used for quieter operation and lower fuel consumption.

Enrichment valve and manifold pressure

The fuel enrichment system can only be used during the start cycle. If the enrichment system is used, it will provide an increased initial fuel flow during engine start. This is accomplished by permitting fuel to flow through the enrichment valve, bypassing the metering section of the fuel control and entering just before the fuel control cutoff valve.

This fuel flows through the cutoff valve and is directed to the manifold and fuel nozzles. The pressure switch, which senses manifold fuel pressure, breaks the electrical circuit to the enrichment valve solenoid when the fuel pressure reaches 50 psi. An electrical interlock in the control system prevents the energizing of the enrichment system after the engine is started.

Coordinator

This unit coordinates the operations of the fuel control, propeller, and the fuel trimming system. The operation of the coordinator is controlled by means of a mechanical linkage from the flight deck through the throttle and condition lever.

The cockpit throttle movement controls the main shaft of the coordinator, which in turn controls the following:

1. The amount of fuel flowing from the fuel control under any given set of conditions (by means of a mechanical linkage to the fuel control).

2. The propeller blade angle during all ground operation (by means of a mechanical linkage to the propeller).

3. The potentiometer output signal between 66° and 90° coordinator angle. This schedules a target turbine inlet temperature.

4. A switch set at 66° coordinator angle that changes the fuel trimming system from limiting to controlling.

5. The propeller blade angle follow-up mechanism.

Fuel trimming system

The fuel trimming system provides the following:

1. Overtemperature protection during starting and acceleration.

2. Engine operation closer to the maximum turbine inlet temperature because of accurate monitoring of fuel scheduling.

3. The ability to select any turbine inlet temperature in the controlling range (820°C to 1077°C) to be automatically maintained without throttle change.

4. Use of power-section bleed air for anti-icing purposes without the necessity of changing power settings.

5. Trim of the fuel flow to compensate for inaccurate compressor inlet air temperature or pressure sensing by the fuel control.

6 A more uniform throttle setting for all engines.

7. The locking in of a fuel correction prior to landing for more balanced power across all the engines.

The system trims a variable percent of fuel flow from the fuel control as required by any type of engine operation.

Thermocouples

There are eighteen dual thermocouples, which comprise two individual circuits. One circuit provides a turbine inlet temperature signal to the engine fuel trimming system; the other provides a turbine inlet temperature signal to the flight deck indicator. Since the circuitry is in parallel, the temperature indication is an average of the temperature sensed by the eighteen thermocouples.

Fuel nozzles

The fuel nozzles are duplex type, dual-orifice nozzles. The nozzles are mounted in the diffuser, and extend into the forward end of each of the combustion liners. The fuel nozzles must provide a controlled pattern of fuel flow and also a maximum amount of atomization. At the tip of each nozzle, an air shroud surrounds the dual orifices. The air shroud contains a number of air holes through which air is circulated at high velocity. This minimizes the formation of carbon around the orifices.

Manifold drain valve

The manifold drain valve is located at the lowest point in the fuel manifold. It is designed to drain the manifold when the engine is shut down. This prevents fuel from draining into the combustion liners after the fuel control cutoff valve is closed. The manifold drain valve is solenoid operated, and is closed by completion of the electrical circuit by the 16% RPM switch in the speed-sensitive control. At 65% RPM, the electrical circuit is broken and fuel manifold pressure, acting upon the valve, continues to hold the valve in the closed position. At engine shutdown, when manifold pressure drops to a value of 8 - 10 psi, the manifold drain valve opens due to spring force.

Burner drain valves

The two burner drain valves are located at the forward and aft ends on the bottom of the outer combustion casing. These valves, set at 2 to 4 psi air pressure, are held closed by the combustion chamber air pressure during all engine operations. At engine shutdown or after a false start, these valves open, draining the accumulated fuel from the outer combustion casing.

ENGINE SYSTEMS – POWER LEVER OR THROTTLE

The power lever or throttle provides the means of complete power control during all normal conditions of operation. Movement of the throttle actuates mechanical linkage to the coordinator. The coordinator has a total quadrant travel of 0° to 90°. Ground operation (propeller in Beta) is from 0° (maximum reverse) to 34° (flight idle). Flight operation (propeller in Alpha) is from 34° (flight idle) to 90° (maximum take-off). The temperature datum system controlling range is from 66° (crossover) to 90°.

Throttle positions

The throttle provides the means of selecting the following:

1. Ground idle – This schedules the minimum torque blade angle that is desired for best starting characteristics.

2. Maximum reverse – The throttle is in full aft position, which produces a blade angle and power setting for maximum aircraft braking after touchdown. Movement of the throttle forward and toward the start blade angle produces a lower amount of braking force

3. Taxi range – From the maximum reverse position to the flight idle detent. At this time, the propeller is a multi-position, selective blade angle propeller. For each position of the throttle, a specific blade angle is selected.

4. Flight range – From the flight idle detent to the full forward position. In this range, the propeller is a non-selective, automatic RPM governor. The throttle in this range serves primarily as the means of changing fuel flow.

The throttle is connected by aircraft linkage to the engine coordinator control, and any movement of the throttle will move this linkage. The coordinator control then has the function of coordinating the operation of the fuel system with that of the propeller.

The coordinator quadrant is marked from 0° to 90°, and has the following markings:

1. Maximum reverse	0°
2. Ground idle	15° - 20°
3. Flight idle	34°
4. Maximum power	90°