SHA-SHIB GROUP OF INSTITUTIONS

Training Notes

Module 14- Propulsion

SHA-SHIB GROUP

EMPOWERING KNOWLEDGE THROUGH VISION

FOREWORD

- The information in this book is for study/ training purposes only and no revision service will be provided to the holder.

- While carrying out a procedure/ work on aircraft/ aircraft equipment you must always refer to the relevant Aircraft Maintenance Manual or Equipment Manufacturer's Handbook.

- For health and safety in the workplace you should follow the regulations/ Guidelines as specified by the Equipment Manufacturer, your company, National Safety Authorities and National Governments.

Knowledge Levels – Category A, B1, B2, B3 and C Aircraft Maintenance Licence

Basic knowledge for categories A, B1, B2 and B3 are indicated by the allocation of knowledge levels indicators (1, 2 or 3) against each application subject. Category C applicants must meet either the category B1 or the category B2 basic knowledge levels.

The knowledge level indicators are defined as follows:

LEVEL 1

- A familiarization with the principal elements of the subject.

Objectives: The applicant should be familiar with the basic elements of the subject.

- The applicant should be able to give a simple description of the whole subject, using common words and examples.
- The applicant should be able to use typical terms.

LEVEL 2

- A general knowledge of the theoretical and practical aspects of the subject.
- An ability to apply that knowledge.

Objectives: The applicant should be able to understand the theoretical fundamentals of the subject.

- The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
- The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject.
- The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
- The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

LEVEL 3

- A detailed knowledge of the theoretical and practical aspects of the subject.
- A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives: The applicant should know the theory of the subject and interrelationships with other subjects.

- The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
- The applicant should understand and be able to use mathematical formulae related to the subject.
- The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
- The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.
- The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

: DGCA MODULARISATION :-

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CAR – 66 ISSUE II R 2
(LICENSING OF AIRCRAFT MAINTENANCE ENGINEERS)
DIRECTORATE GENERAL OF CIVIL AVIATION
TECHNICAL CENTRE, OPP SAFDURJUNG AIRPORT, NEW DELHI

Modules	Subject	A or B1 Aero plane with		A or B1 Helicopter with		B2
		Turbine Engine (s)	Piston Engine (s)	Turbine Engine (s)	Piston Engine (s)	Avionics
1	Not Applicable					
2	Not Applicable					
3	ELECTRICAL FUNDAMENTALS	X	X	X	X	X
4	ELECTRONIC FUNDAMENTALS	X	X	X	X	X
5	DIGITAL TECHNIQUES ELECTRONIC INSTRUMENT SYSTEMS	X	X	X	X	X
6	MATERIALS AND HARDWARE	X	X	X	X	X
7A	MAINTENANCE PRACTICES	X	X	X	X	X
7B	MAINTENANCE PRACTICES					
8	BASIC AERODYNAMICS	X	X	X	X	X
9A	HUMAN FACTORS	X	X	X	X	X
9B	HUMAN FACTORS					
10	AVIATION LEGISLATION	X	X	X	X	X
11A	TURBINE AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS	X				
11B	PISTON AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS		X			
11C	PISTON AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS					
12	HELICOPTER AERODYNAMICS, STRUCTURES AND SYSTEMS			X	X	
13	AIRCRAFT AERODYNAMICS, STRUCTURES AND SYSTEMS					X
14	PROPULSION					X
15	GAS TURBINE ENGINE	X		X		
16	PISTON ENGINE		X		X	
17A	PROPELLER	X	X			
17B	PROPELLER					

MODULE 14. Propulsion		LEVEL	
		B1.1	B2
14.1	**14.1 Turbine Engines** (a) Constructional arrangement and operation of turbojet, turbofan, turbo shaft and turbo propeller engines; (b) Electronic Engine control and fuel metering systems (FADEC).	-	1
14.2	**14.2 Engine Indicating Systems** Exhaust gas temperature/Interstage turbine temperature systems; Engine speed; Engine Thrust Indication: Engine Pressure Ratio, engine turbine discharge pressure or jet pipe pressure systems; Oil pressure and temperature; Fuel pressure, temperature and flow; Manifold pressure; Engine torque; Propeller speed.	-	2
14.3	**14.3 Starting and Ignition Systems** Operation of engine start systems and components; Ignition systems and components; Maintenance safety requirements	-	2

Module 14: Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of DGCA, CAR – 66 (Appendix I) and the associated Knowledge Levels as specified.

REVISION LOG

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CHAPTER PAGE

14.1 Turbine Engines

(A)Introduction
To understand the working principle of the gas turbine engine,
the following facts about physics must be studied. These are.

- Newton's Laws of Motion
- Behavior of a gas as it flows through ducts of non-constant cross section.

Newton's Laws of Motion

First Law

A body at rest tends to stay at rest and a body in motion ends to stay in motion in a straight line unless caused to change its state by an external force.

Second Law

The acceleration of a body is directly proportional to the force causing it and inversely proportional to the mass of the body.

Third Law

For every action there is an equal and opposite reaction.
The first law is of little importance to the function of the gas turbine engine. The second law is the law which is used to determine exactly the amount of thrust achieved by the gas turbine engine. The second law can be written as a formula:

Force=Thrust =Mass x Acceleration

The third law is of most importance to us in understanding

The gas turbine engine. What it is saying is that if amas so fair is propelled backwards, the object which propelled it will be propelled forwards at an equal rate. It follows then that the more air that the gas turbine engine can propel backwards, the greater will be the forward thrust of the engine. The second law also tells us that the greater the mass propelled backwards (m), the greater is the forward force (F).

Convergent and Divergent Ducts

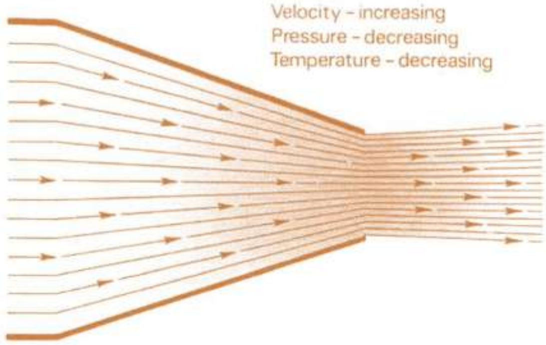


Figure1.1: Gas Flowing Through CONVERGENT DUCT- Subsonic Airflow

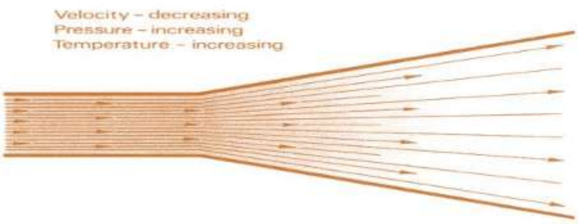


Figure1.2:GasflowingthroughaDIVERGENTDUCT- Subsonic airflow

The "Choked “Nozzle

An exception the above rules

There is one, and only one, exception to the above rule, and that is when the gas is at the speed of sound (Sonic Velocity) just before it enters the DIVERGENT part of the duct.
It is extremely difficult to accelerate a gas to supersonic speed-the only way to do it is to have a very high pressure to begin with and increase its speed in a CONVERGENT duct. Once it has reached sonic speed, it is impossible to increase its speed any further-the duct(or nozzle)is then said to be CHOKED
If this procedure is carried out in a CONVERGENT- DIVERGENT duct, an additional form of thrust (additional to Newton's Third Law) can be achieved.
This can be visualise more easily if you think of a beach- ball being forced and compressed through a convergent- divergent duct. As it expands through the divergent duct, it will cause a forward reaction on the wall of the duct.

The application of the CHOKEDCONVERGENT-

DIVERGENT nozzle can be seen in supersonic military aircraft and rockets.

The Rocket and the Ram Jet

The Rocket Engine

Although the rocket engine is a jet engine, it has one major difference in that it does not use atmospheric air as the propulsive fluid stream. Instead, it produces its own propelling fluid by the combustion of liquid or chemically decomposed fuel with oxygen ,which it carries, thus enabling it to operate outside the earth's atmosphere. It is, therefore, only suitable for operating over short periods. The fuel or propellant is carried in one tank and an oxidizer in another tank. These are typically pumped to and mixed in the combustion chamber where the fuel is burned. As the gases rush out of the nozzle at the back of the engine, thrust is produced. This nozzle as a definite shape and is known as a converging- diverging nozzle. This type of nozzle is required in rockets because of the desire for extremely high velocity(highly accelerated)exhaust gases.

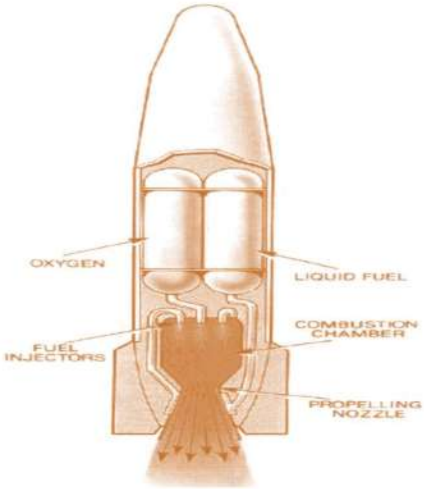


Figure1.4:Therocketengine

The Ram Jet

The Ram Jet requires initial forward motion to get it started. It's operation is then as follows

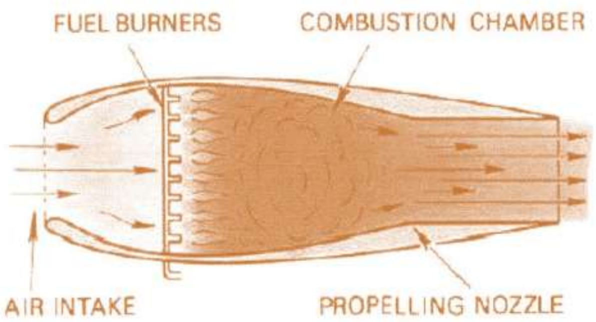


Figure1.5:Theramjet

Intake

The intake is convergent/divergent in shape and therefore the air flowing through its willed crease /increase in pressure.

Combustion
At a certain pressure, the air is mixed with fuel and ignited. Its temperature will increase, and it will expand. This expansion takes the form of an increase in velocity.
If the gas increases in velocity inside the jet, it will obey Newton's 2ndLaw,which is that:

Force=Mass x Change in Velocity through the duct

Exhaust
Before entering the exhaust nozzle, the gas may be of high enough pressure to be accelerated to supersonic speed. The exhaust nozzle would then be choked. The force produced as a result of the acceleration is known as momentum or kinetic thrust. A second type of thrust is produced in the divergent part of the exhaust nozzle and is called pressure thrust. The total force produced will, accordingtoNewton's3rdLaw,produceanequalandopposite reaction on the inner workings of the engine. This is known as Thrust.

The Turbojet Engine

Introduction
In 1931 Sir Frank Whittle patented the self-sustaining Gas Turbine Engine. It consists of a single rotating spool comprising of a compressor and turbine. The advantage of this Engine over the ram jet is that itis self-sustaining without the need for forward speed. In other words, it can be started whilst stationary on the ground.

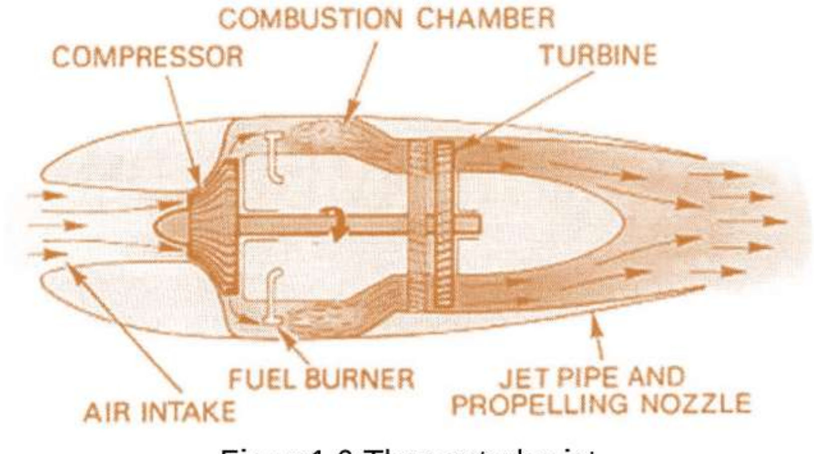


Figure1.6:Thepureturbo-jet

The engine is started by spinning the compressor. This establishes a rearward flow of air into the combustion zone where fuel is added and ignited. The gasses increase in temperature and therefore expand rearwards. Before the gasses reach the exhaust nozzle, some of its energy is extracted by rotating the turbine, which in turn drives the compressor.
To increase the thrust of the gas turbine engine, more fuel is added which raises the energy level of the gas stream. The turbine will therefore be turn data greater speed which will turn the compressor at a greater speed. The compressor will therefore deliver a greater mass of air, and the thrust force of the gas turbine engine is therefore increased according to

Newton's 2ndLaw.
The thrust produced by the turbojet is proportional to the

change in momentum of the gas stream. To increase the thrust, more fuel is introduced which raises the energy level of the gas stream and the turbine and compressor rotates at a higher speed. The compressor delivers a larger mass of air to the combustion zone and there is a corresponding increase in the thrust produced by the engine.

The gas turbine can also be compared with the piston engine where fuel and air are burned inside a cylinder to cause a
piston to move and turn a crankshaft. The working cycle of the gas turbine engine is indeed similar to that of the4-stroke piston engine as in each gas turbine engine there is induction, compression, combustion, and exhaust. In the piston engine cycle the combustion cycle is intermittent whereas in the gas turbine engine it is continuous. The gas turbine engine has a separate compressor, combustion chamber, turbine wheel, and exhaust system with each part concerned only with its function. Thus, the combustion in a gas turbine engine takes place as a continuous process at a constant pressure. This, combined with
the absence of reciprocating parts, provides a much smoother running engine that can be of a lighter structure, enabling more energy to be released for useful propulsive work.

The modern gas turbine engine is basically cylindrical in shape because it is essentially a duct in which amass airflow is the same from the intake to the exhaust nozzle. Into this duct the necessary parts are fitted. The parts from front to rear arena air compressor, a combustion chamber, a turbine wheel, and an exhaust duct. A shaft connects the turbine wheel to the compressor, so that turning the turbine will also turn the compressor. Inside the combustion chambers are fuel burners and the means of igniting the fuel.

Because the jet engine is basically an open-ended duct it is not satisfactory to ignite the fuel in static air, because this would allow the gas to expand equally forwards and backwards without doing any useful work; when the air was used up the flame would die out. Before lighting the fuel, it is, therefore, essential that the air is moving, and the moving columns of air must be moving through the engine from the front towards the rear. This movement is brought about by using a starter motor to spin the compressor and the turbine wheel in excess of
1500rpm;thisdrives a large volume of air through the combustion chamber. When the airflow is sufficient, fuel is injected into the chambers through spray nozzles, and is ignited by means of ignitor plugs.

(Note that the gas turbine engine is not an alternate firing engine. The spark ignitors are only used for the initial firing, and the fuel in all the combustion chambers burns continuously like a blowtorch). This burning will cause the airflow towards the rear to increase in velocity and drive the turbine wheel as it flows over the turbine blades in its head long rush through the exhaust system out to atmosphere. The spinning turbine wheel turns the compressor through the drive shaft, and the compressor feeds more air into the combustion chamber to complete a cycle of operations that continues as long as fuel is fed to the burners. The turbine wheel also originates drive to
A gear box that provides external drives for items such as:
Fuel pumps
Hydraulic pumps
Electrical generators
Other engine accessories

The Constant Pressure Cycle

The Constant Pressure Cycle or Brayton Cycle is so called because the heat is added within the combustion chamber where atheoretical constant pressure is maintained. (In fact, there is always a very slight-less than 3% - pressure drop due to friction between the gases and the combustion liner.

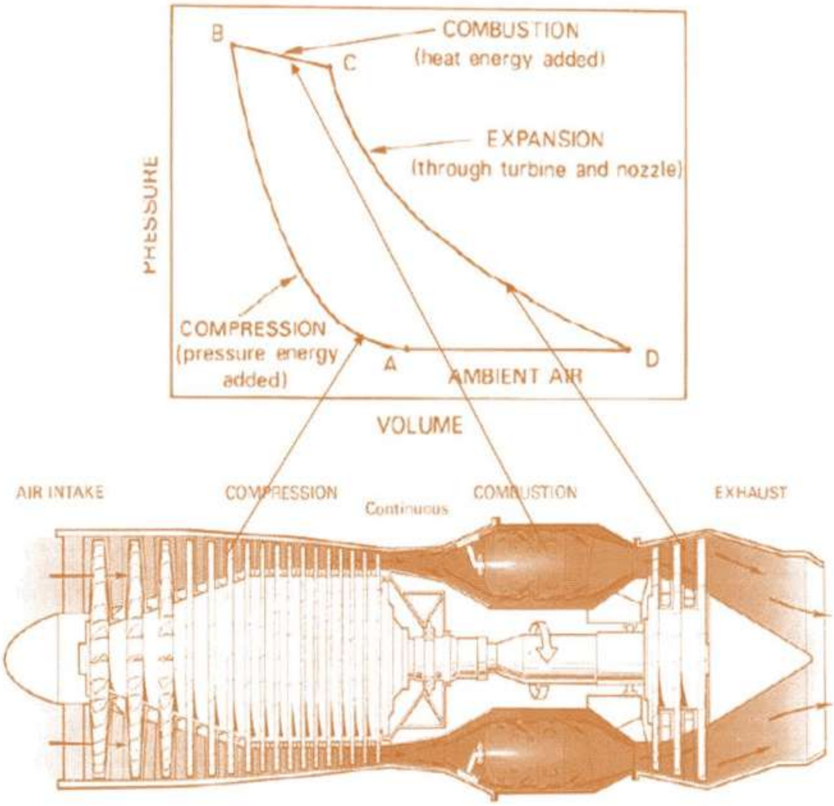


Figure1.7:Theconstant pressure cycle

Constructional Arrangements

The basic design of Whittles gas turbine engine exists in all

gas turbine engines. However various applications have been derived over the past 60years to suit the air frame and industrial requirements

Single Spool Axial Flow Engine

A modern single spool axial flow turbojet engine produces its thrust from the acceleration of the flow of the hot gases. Air enters the engine inlet and flows into the compressor where its pressure is increased. Fuel is added in the combustor where it is ignited and burns, expanding the gases as they leave the tail pipe produces the reaction we know as thrust.

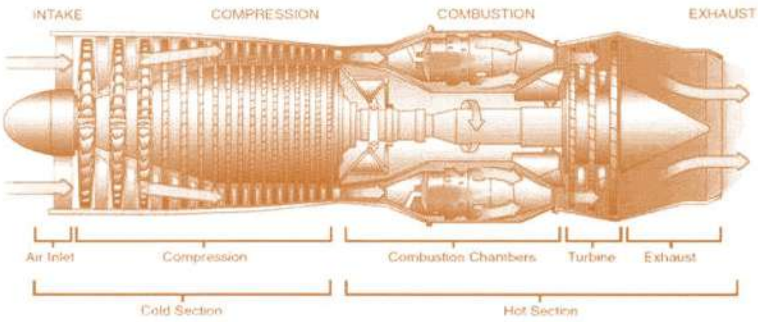


Figure1.8:Asinglespoolaxialflowengine

The use of a multistage axial flow compressor enabled higher compression ratios to be obtained and hence more thrust.
The single spool turbo jet has very low propulsive efficiency, high specific fuel consumption (SFC) and an undesirable noise level.

Multi-Spool Design

Dual and triple spool axial compressors were developed for the operational flexibility they provide to the engine in the form of high compression ratios, quick acceleration, and better control of stall characteristics. This operational flexibility is not possible with single spool axial flow engines.

For any given power lever setting, the high pressure(HP) compressor speed is held fairly constant by a fuel control governor. Assuming that a fairly constant energy level is available at the turbine, the low pressure(LP)compressor will speed up and slow down with changes in aircraft inlet conditions resulting in changes in atmospheric changes or man oeuvres in flight. The varying LP compressor output, therefore, provides the HP compressor with the best inlet condition within the limits of the design. That is, the LP compressor tries to supply the HP compressor with a fairly constant air pressure for a particular air pressure for a particular power setting.
To better understand when the low-pressure compressor speeds up and slowdown, consider that when ambient temperature increases, the air's molecular motion increases. In order to collect air molecules at the same rate as temperature increases, the compressor would have to change either its blade angles, which it cannot do, or its speed, which it in fact does.

Twin Spool Axial Flow Turbofan

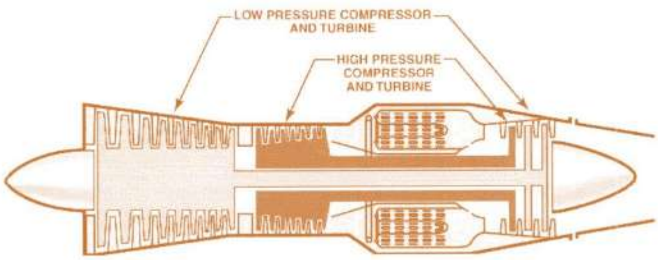


Figure1.9:Atwinspoolaxialflowengine

By-Pass Engines

Twin Spool Low By-Pass Turbo Fan

This type of engine has a twin spool layout with the addition that the L.P compressor is of larger diameter than before and thus handles a greater mass of air than is required by the HP. compressor. The air flow which is not required by the HP. Compressor is fed into the by-pass duct anditre joins the normal gas flow behind the turbines. The air flow is split approximately 50%eachway.Themixingofthe"hot"and "cold" gas streams promotes very rapid expansion of the gasses, which gives good power output with a low fuel consumption. Low bypass engines are defined as having a bypass ratio of 3:1 or less

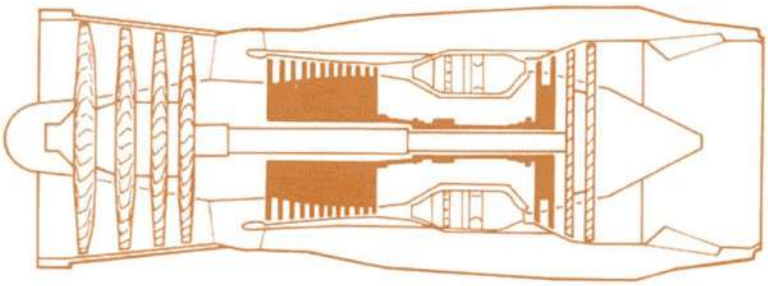


Figure1.10:Atwin-spoolby-passturbo-jet

High By-Pass Turbofan

The difference in operation between a propeller and a pure jet engine can be summarised as follows.
A propeller accelerates a large quantity of air rear wards at a low rate.

A pure jet engine accelerates a small quantity of air rearwards at a high rate.
The net result is the same, but the efficiency of each depends on the required speed of the aircraft. For medium speed aircraft, a combination of the two has been developed. On the following pages are two examples of high bypass multi-spool engines.HighBypassisdefinedasabypassratioof4:1upto 8:1.Ultra high bypass engines are being researched with a bypass ratio of 10:1andabove.

A high bypass engine is more efficient thana pure turbojet because its principle of operation is more akin to that of a propeller, in that it accelerates a relatively large mass of air at a low rate.

Twin Spool High Bypass

The amount of air going through the by-pass section(or “fan") is typically 5or6timesthatgoingthroughthecombustion section. Approximately 80%ofthethrustproducedisfromthe by-pass air ducting.

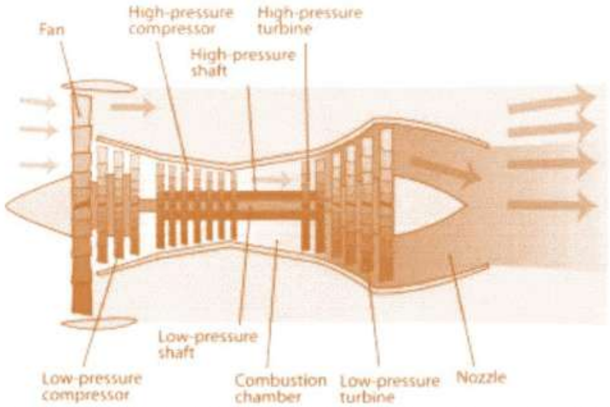


Figure1.11: A twin-spool high-bypass engine

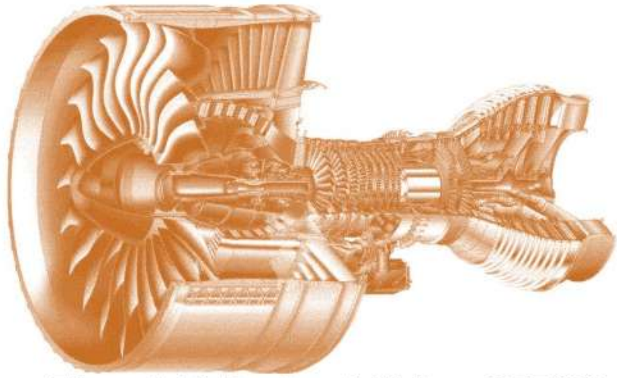
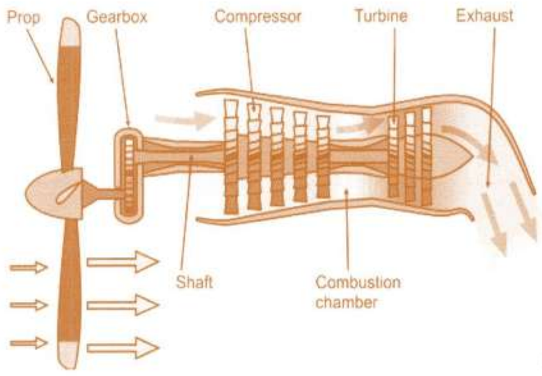


Figure1.12:PrattandWhitneyGP7000

Turbo Prop Engines

The advent of the twin spool engine enabled easier starting (only the small HP compressor needs to be rotated by the starter) and better surge resistance as the two spools run at their own optimum speeds This type was used as a pure thrust engine, but the example shown above drove a propeller on the end of the LP compressor shaft via a reduction gear



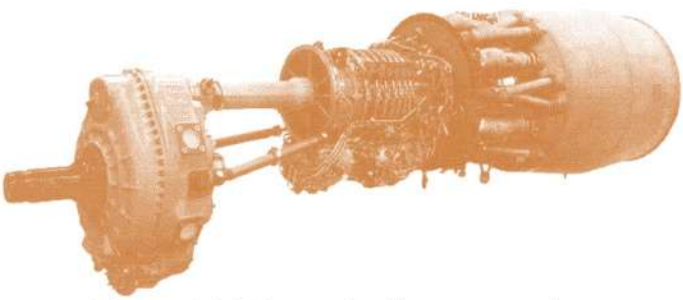


Figure1.13:Gearedturbo-propengines

All types invariably use a multi-stage turbine and an epicyclic reduction gear. Multi-stage turbines with small diameter discs can run at higher rev/min and thus absorb more energy from the gas stream than single large disc that must necessarily be restricted in rev/min because of high centrifugal loading. Epicyclic gearing is selected for the reduction gear because:

a. A high degree of speed reduction can be obtained.

b. The propeller shaft and thrust lines remain on the same centerline as the compressor and turbine shafts, thus causing little interference with the entry of air into the air intake. Streamlining of the whole unit is, therefore, an easier task.

This type of gas turbine engine is used wherever the direct thrust from the engine is not required, All the energy in the gasses is absorbed by the turbines and transformed into a rotational force -or TORQUE There is usually little, or no thrust produced in the exhaust.
The reduction gear box is required because the gas turbine engine is most efficient at high RPM, but the device which it drives(propeller, helicopter rotor etc.) becomes in efficient at such high speed.

This example of a turbo prop engine uses two centrifugal compressors in tandem. They are driven, along with the reduction gear by a three-stage turbine, all on one shaft. Compared to the axial flow twin spool turbo prop shown above this engine produces much less power and is very inefficient.

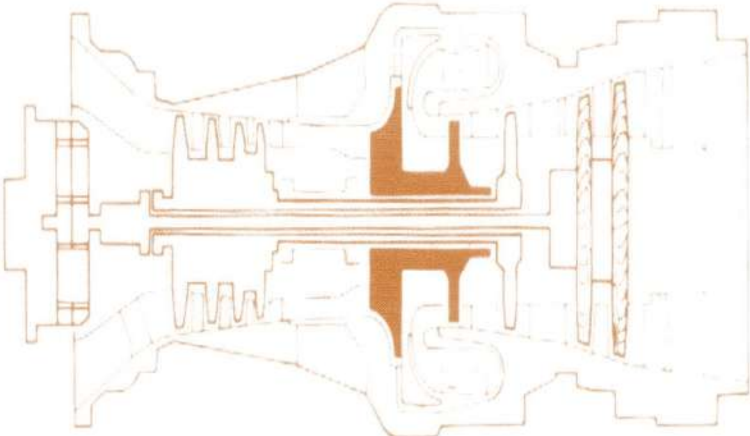


Figure1.15:TwinSpoolTurboShaftenginewithfree power turbine

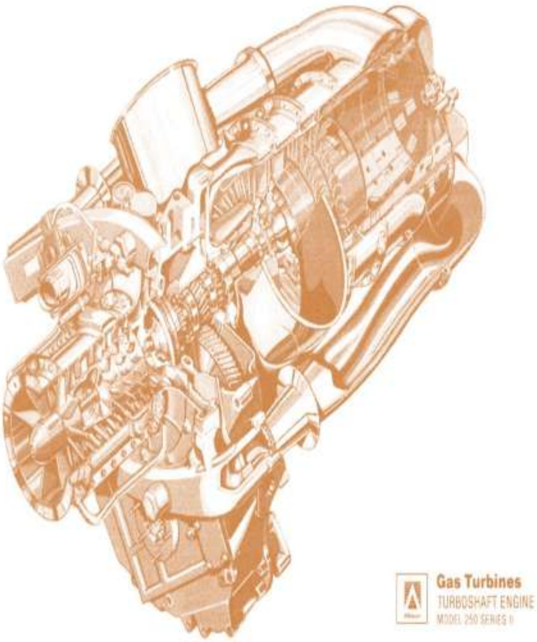


Figure1.16:TheAllison250 series turbo-shaft engine

A turbo-shaft engine used to drive any industrial application that requires high torque output.
For example:
Helicopter rotors
Ship Drive shafts
Hovercraft engines
Oil pumps
Generator sets
This example uses a free or power turbine. All the energy not required to drive the gas generator compressor is used to drive the free turbine which drives the output shaft. The output shaft is shown above coming out othe front of the engine, but it can be geared to come out at any angle, even through the exhaust directly connected to the rear of the turbine.

Summary of Engine Types

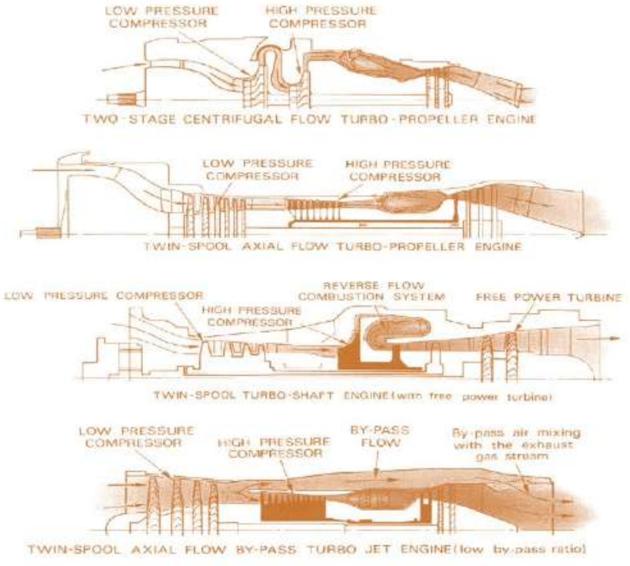


Figure1.17:

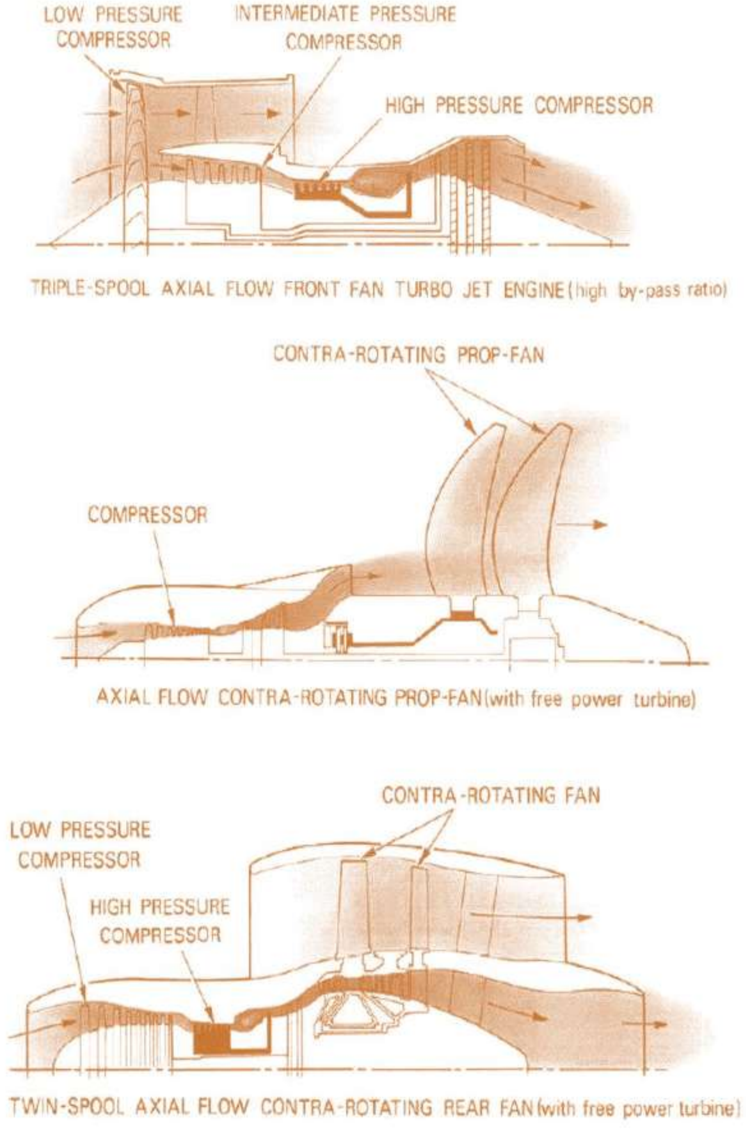


Figure1.18:Variousenginetypes

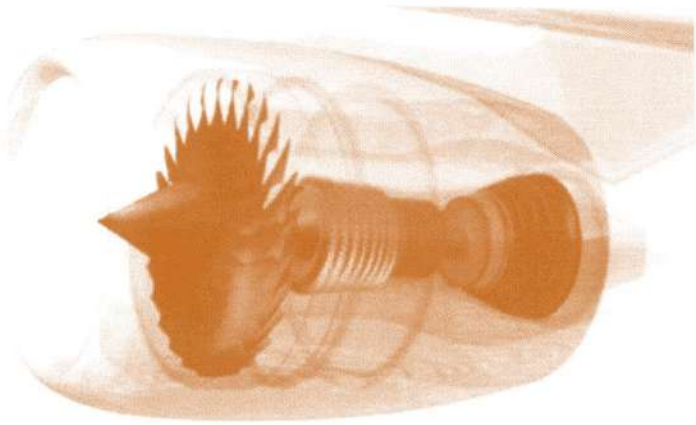


Figure1.19:Thetriplespoolhigh-bypassengine

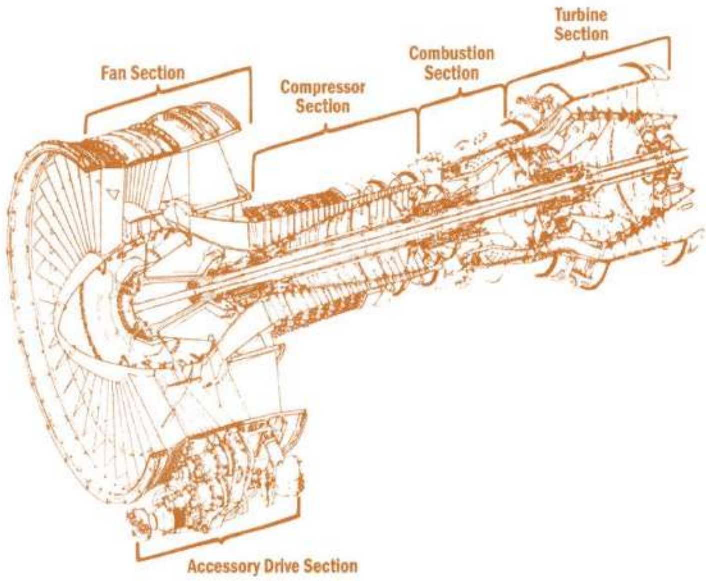


Figure1.20:Thesectionsofafanengine

Electronic Engine Control (EEC)

Advances ingas turbine technology has demanded more precise
Control of engine parameters than can be provided by hydromechanical fuel controls alone. These demands are met by electronic engine controls, or EEC, of which there are two types: supervisory and full authority.

Supervisory Electronic Engine Control

The first type of EEC is a supervisory control that works with a
proven hydromechanical fuel control.

The major components in the supervisory control system include the electronic control itself, the hydromechanical fuel control on the engine, and the bleed air and variable stator vane control.

The hydromechanical element controls the basic operation of the engine including starting, acceleration, deceleration, and shutdown. High-pressure rotor speed (N_2), compressor stator vane angles, and engine bleed system are also controlled hydro- mechanically. The EEC, acting in a supervisory capacity, modulates the engine fuel flow to maintain the designated thrust. The pilot simply moves the throttle lever to a desired thrust setting position such as full takeoff thrust, or maximum climb. The EEC adjusts the fuel flow as required to maintain the thrust compensating for changes in flight and environmental conditions. The EEC control also limits engine operating speed and temperature, ensuring safe operation throughout the flight envelope.

If problem develops, control automatically reverts to the hydromechanical system, with no discontinuity in thrust. A warning signal is displayed in the cockpit, but no immediate action is required by the pilot. The pilot can also revert to the hydro mechanical control at anytime

A Typical Electronic Engine Control System

A typical example of an EEC system is that used in many of the PrattandWhitney100seriesenginescurrentlyinservice.A brief explanation of how the system works, both in automatic and manual modes follows.

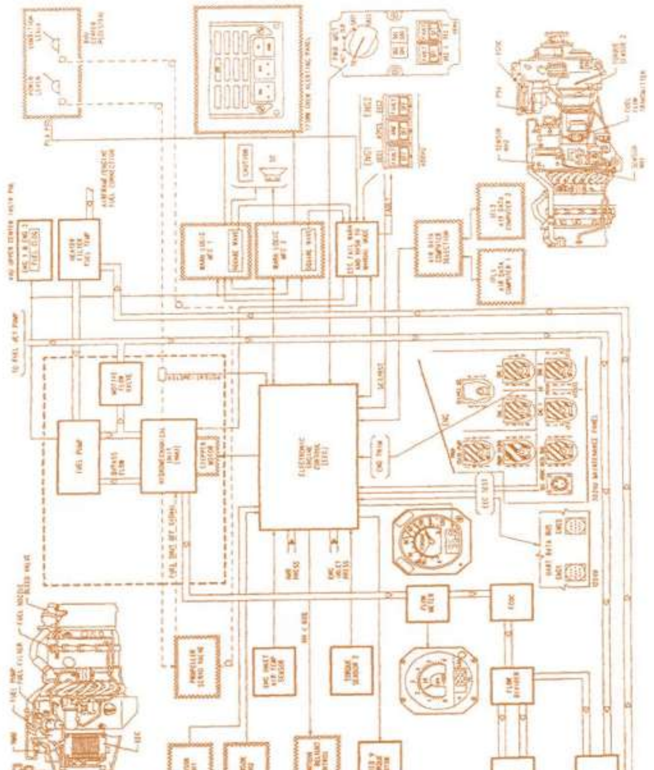


Figure1.21:Pratt&Whitney 100SeriesFuelControl System Schematic.

Automatic Operation(EEC mode)

The EEC receives signals from various sources:

Power Management Switch, enabling takeoff thrust, maximum continuous thrust, climb thrust, or cruise thrust settings to be selected

Engine inlet pressure and temperature

Ambient pressure

Air data computer inputs, (a computer that senses pitot pressure, static pressure, and total air temperature)\

Engine RPMs-Ni and N_2Power lever position, (via a potentiometer) Failure signals
Based on these input signals the EEC will output command signals to adjust and control:
The Hydromechanical Fuel Control Unit via a stepper motor which adjusts the throttle metering valve.
Ignition circuits.
Bleed valves
Torque gauge

Fuel Control

The fuel control is provided by the hydro-mechanical unit (HMU) The HMU is supplied by the HP fuel pump and provides the required fuel quantity to the nozzles.
In normal operation the fuel control is managed by the Electronic Engine Control (EEC). This enables accelerations and decelerations without engine surge or flame out whatever the displacement sequence of the power lever. The HMU is also mechanically connected to the power lever thus ensuring fuel control in case of failure of the EEC.

Hydro- mechanical Unit (HMU)

The HMU comprises:
A stepper motor controlled by the EEC
A lever which controls fuel shutoff
A lever which controls the fuel flow

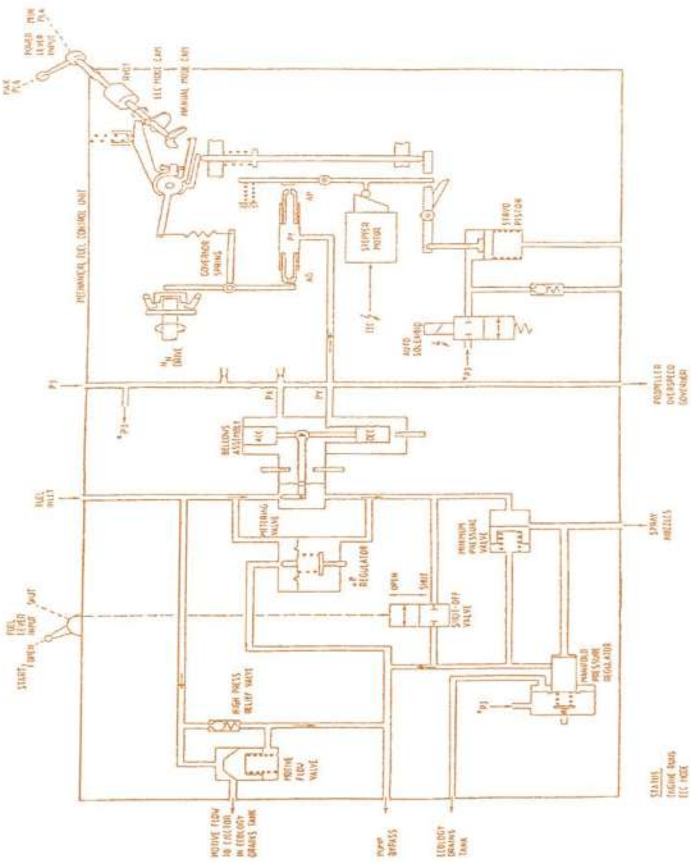


Figure1.22:PW100 Series Fuel System Auto/Normal Mode

Operation

The fuel flow supplied to the nozzles is mainly obtained through two valves:
■ a bypass valves
«a metering valves.
The fuel enters the HMU from pump outlet with a constant flow. This flow is split by the bypass valve in to two flows, one for the nozzles(via the metering valve)and one bypass return flow to the pump. The position of the bypass valve is a function of the loss of fuel pressure caused by the metering valve. The metering valve is pneumatically actuated. In the pneumatic servo block, the reference pressure is the HPcompressoroutletpressure,P3.A controlled reductionoftheP3pressureresultsinavariablePy pressure which when opposed to a bellows device, moves the piston of the metering valve.
The pneumatic servo block is managed:

- in normal operation by the EEC
- in manual operation, by the power input lever.

Normal Operation(EEC Mode)

According to the input data (pressures, temperatures, speeds)and to the commanded power(power lever), the EEC controls a stepper motor located in the HMU.
The stepper motor regulates Py pressure thus modulating the fuel flow as requested. A governor acts on the Py pressure, thus setting an NH speed limit function of the compression ofaspringbya cam (EEC cam) connected to the power lever.

Manual Operation(Manual Mode)

Py pressure is not regulated by the stepper motor but by the simultaneous actions of the NH speed governor and the spring, compressed by a second cam (manual cam)connected to the power lever.

Transfer from the EEC Mode to the Manual Mode.

In normal operation the EEC manages the fuel regulation. The manual operation is automatically connected when the operation in the EEC mode is switched off. A solenoid in the HMU selects
the manual cam instead of the EEC cam and cancels the regulation control through the stepper motor.

Operation of the HMU in the failure mode

In case of failure of the EEC, the position of the stepper motor is "frozen". Whatever the increase of power through the power lever, the last NH speed remains unchanged (the load applied by the spring on the NH speed governor increases).For any power reduction through the power lever, the NH speed decreases according to the curve of the EEC cam(decreasing spring load).

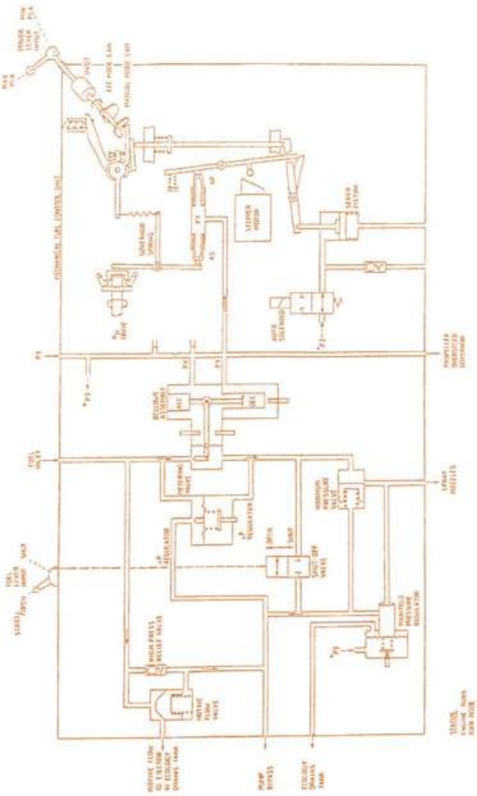


Figure1.23:PW100SeriesFuelSysteminManualMode

Full Authority Digital Engine Control

Overview

FADEC is the name given to the system that controls the engine on modern Gas Turbine Engines. This section discusses the common features of FADEC and also the different applications used by the large commercial passenger aircraft engine manufacturers, Rolls Royce and General Electric and their derivatives IAE and CFM. FADEC replaces the hydro- mechanical fuel control systems as exemplified by the Rolls Royce Spay or JT8D.

Benefits of FADEC:
- Substitution of Hydromechanical control system

Reduces weight and hence fuel consumption.
- Automation brings reduced pilot workload
- Optimized engine control reduces maintenance and optimizes fuel consumption.
- Optimized airflow control allows the engine to work nearer the surge line thus increasing thrust whilst reducing the chance of surge or flame out.

AFADEC system consists of
- Sensors
- A Central Process or Unit called an Electronic Engine

Control (EEC)or an Engine Control Unit(ECU)
- A Hydromechanical Unit(HMU).

The Central Processor Unit, for the purposes of this document will be referred to as the ECU.

A FADEC system has the following inputs:

1. Analogue signals from electrical sensors.

2. Digitalsignals,usuallyonanARINC429DataBus,from aircraft computers such as the Air Data Computer (ADC), Thrust Management Computer (TMC) and Flight Management Computer (FMC).

3. Thrust lever signals are transmitted by Rotational Variable Differential Transformers mechanically connected to a conventional thrust drum that is moved by the Manual Thrust Lever and the Auto Thrust Servo Motor.

4. Pressure inputs-apart from those received from the ADC.

Po and Ps3 (Compressor Delivery Pressure)signals are tapped directly into pressure transducers located within the

ECU.

5. Feedback signals from any moving mechanical device, such as Thrust Reverser, Variable Stator Vanes (VSVs) and Variable Bypass Valves, utilize Linear or Rotary Variable Differential Transducers (LVDTs or RVDTs).

Sections of a FADEC system

Engine Control Unit (ECU)

The ECU is a dual channel processor that computes all functions of the FADEC system based on its inputs and stored data and then commands the HMU to take appropriate
actions. The ECU also provides ARINC 429 data to the FMC TMC and EICAS (Boeing)or ECAM (Airbus) cockpit display computers.

Hydro Mechanical Unit (HMU)

The HMU provides an interface between the electrical analogue output from the ECU and the fuel. It is achieved by an Electrical Hydraulic Servo Valve(EHSV)actuating a Fuel Metering Valve (FMV),thus controlling fuel supply to the burners. In addition, the HMU will have EHSVs controlling fuel muscle pressure to VSV sand VBV sifted.

Figure1.25 shows simple schematic overview of the FADEC
System

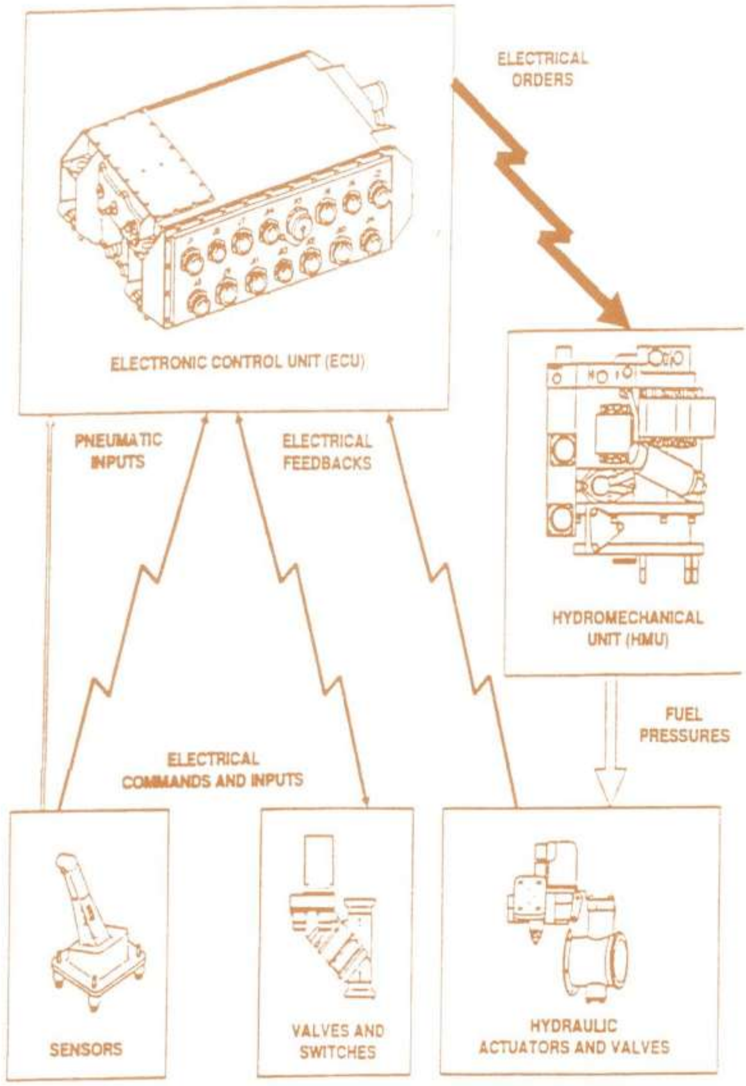


Figure1.25:FADECSchematic Overview

Figure1.25 shows the flow paths for a CFM 56-5Engine,which is a typical FADEC engine. Please note the following:

1 FADEC is a very useful tool for gathering information for a condition monitoring system. Customers can choose whether to have Condition Monitoring for their system, therefore the sensors required are customer options and are marked *.

2 TLA stands for Thrust Lever Angle. This signal is received from the RVDT fitted to the thrust lever drum. However, this angle is sometimes quoted as the TRA (Throttle or Thrust Resolver Angle)

3 The ECU is powered by its own alternator or by aircraft28VDCAircraft Bus for Starting Testing and Maintenance.115VACaircraftpower is required for the AC Ignitor circuit.

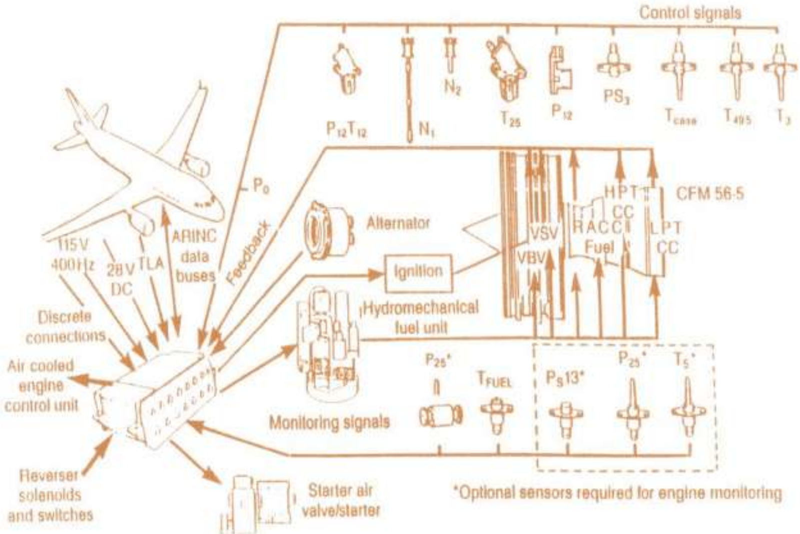


Figure1.26: CFM56-5Airframe-ECU- Engine Flow Paths

The Engine Control Unit(ECU)

The ECU is a dual channel processor housed within a single container, however all hardware within the container is partitioned into the two channels.
Normally mounted on the fan casing cooling is either by natural Fan Case Cooling Air or directly by a dedicated Fan Air Ducting.

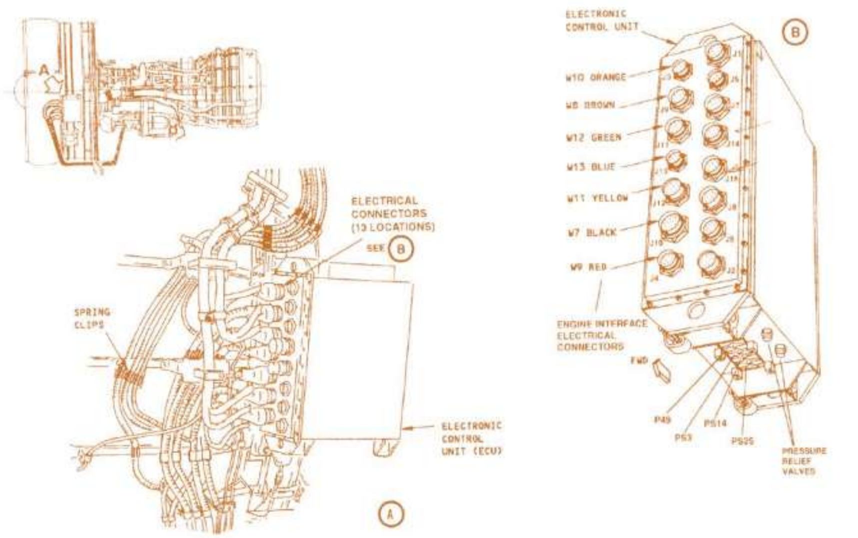


Figure1.27: ECU Location and Connectors (CF6-80C2 FADEC) -similar for all other High Bypass Gas Turbine

Engines

ECU Architecture
Dual Channel

The FADEC System is fully redundant built around two independent control channels. Dual Input, dual outputs, and automatic switching from one channel to the other eliminate any dormant failure.

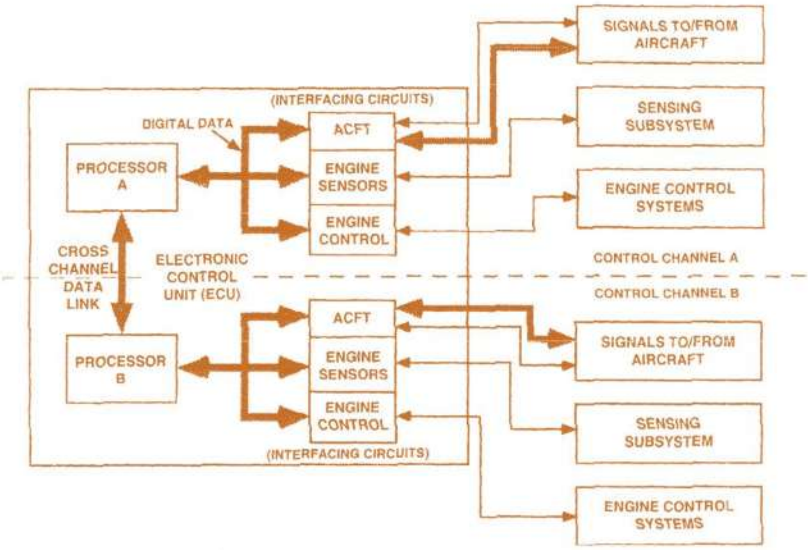


Figure1.27:ECUDualChannelPhilosophy

- Channel Selection

The ECU will always select the "healthiest" channel as the Active channel based on a fault priority list. The fault priority list contains critical faults such as processor, memory
Or power failures, and other failures that involve a channel's capability to control the FMV, VSV, or VBV torque motor(s). During engine run status, each channel within the
ECU will determine whether to be in the active state or standbystateevery30 milliseconds based on a comparison of its own health and the health of the cross-channel. Either channel can become active if its health is better than the cross- channels health; likewise, it will become standby fits health is not as good as the cross-channel. If the two channels have
equal health statuses, the channels will alternate tie/Standby status on each engine shutdown and the standby channel will become the active channel on the next start.

- Channel Transfer

Assuming the opposite channel is of equal or greater health, channel Active/Standby transfer will occur after the engine has been run above76%N2and subsequently shutdown (N2less than
35%).

- Dual Inputs

Electrical Inputs: All command inputs to the FADEC system are duplicated. Only some secondary parameters used for monitoring and indicating are single (e.g., the EGT input on the CF6engine).To increase the fault tolerant design, the parameters are exchanged between the two control channels
via the cross-channel datalink.

- Pressure inputs

Pressure tapping from the engine are plumbed directly into the ECU ,either discretely to each channel or a single tapping that is split within the ECU and then sent to discrete channel transducers.

- Hardwired Inputs

Information exchanged between aircraft computers and the ECU is transmitted over digital data buses. In addition, signals are hardwired directly from the aircraft where a computer is not used. (Thrust Reverser feedback via
RVDTs or TLA via an RVDT)

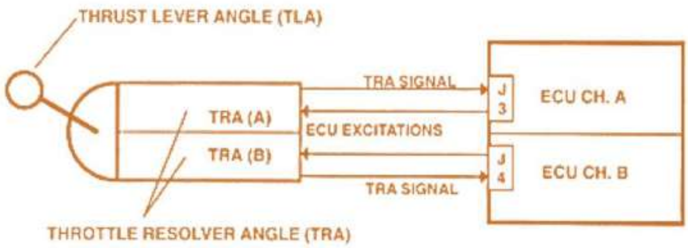


Figure1.29: Example Hardwired Dual Input Device-Thrust Lever Angle RVDTs

Dual Outputs

All the ECU outputs are double but only the channel in control supplies the engine control signals to the various receptors
such as torque motors, actuators, or solenoids. Further information on output signal receivers can be found below in the HMU section.

BITE Capability

The ECU is equipped with BITE, which provides maintenance information, and test capabilities via an aircraft mounted component called MCDU (Airbus) or PIMU (Boeing).
The ECU performs a self-test on power up, and self-monitors during operation. In addition, operation of a ground test switch powers up the ECU and hence a real time ground test is
carried out when this switch is operated. For Boeing airframes, the ECU stores faults in the ECU volatile memory until the aircraft lands. On landing the faults are streamed toa
Propulsion Interface Monitoring Unit (PIMU). There is a PIMU for each engine. The PIMU holds the fault until a BITE test is carried out. An EICAS message will advise
Maintenance staff to carry out this procedure even if the pilot has not noticed the problem.
AIR BUS faults will be stored in the MCDU in real time.
BITE interrogation is airframe specific and cannot be covered in a generic FADEC publication. Using the BITE system, the ECU can detect and isolate failures in real time and hence allows switching of engine control from the faulty channel to the healthy one.

Fail Safe Control

If a standby channel is faulty and the channel in control is unable to ensure one engine function, this control is moved to a fail-safe position.

Example

If the standby channel is faulty and the channel InControl is unable to control VBV position, the valves are operated to the open position.

Main Interfaces

To perform all its tasks the ECU interfaces with aircraft computers, either directly or via the Engine Interface Monitoring Unit (EIMU). Principle among these are the aircraft Left and Right Air Data Computers which supply data, notably Ambient Temperature(T_{amb});Total Air Temperature (TAT);Static Pressure(P_s0) and Total Pressure (P_T).All of these are required to determine that the thrust commanded remains constant for the ambient conditions and that thrust and EGT limits are not exceeded.

Limits Protection

The ECU has a dual channel limit protection section comprising max limits for N1 N2 and N3 (RR only) In addition various max limits are protected depending on the system, most commonly Compressor Delivery Pressure(P_s3)

Thrust Regulation

Thrust regulation on high bypass engine is calculated using ADC inputs to calculate the required fuel to provide the commanded thrust. The thrust is measured in terms of N-i speed or EPR (RR Trent). For the EPR engine in the event of EPR signal failure then it reverts to control by Ni.
As aback up there is a mechanical high-pressure compressor
(HP2 or HP3)governor located within the HM

Thrust Control Modes

Systems vary, therefore below are three typical systems:

CF6FADECControlModes

In the event that an ADC signal is lost then the ECU will use the opposite channel signal. In the event that the channels inputs do not agree as to which signal is accurate then the ECU will revert to an alternate mode using the last known ambient pressure signal. This is also known as the soft reversionary mode. The soft reversionary mode can cause throttle stagger as the other engine is still operating in the normal mode. To prevent this the ECU mode switches can be pushed for both engines, to select hard reversionary mode which means they are using the fixed corner point ambient temperature for that engine. Because T_{amb}may be higher than corner point there is now a danger of over boosting the engine. Consequently, the pilot will always throttle back before selecting hard reversionary and subsequently be aware ofhis maxN1indicationtopreventoverboostingorovertemping the engine.

R.R. Trent FADEC Control Modes

The primary thrust control loop uses EPR .In the event that EPR computation is impossible then the ECU reverts to theN1 mode where N1 is used to control thrust.IntheN1 mode Auto Throttle is no longer available.

CFM56 FADEC Control Modes

The engine operates in one of three thrust modes, AUTO- MEMO –MANUAL Entering/exiting these three modes is controlled by inputs to the Engine Interface Unit (EIU).

a. Auto Thrust Mode

The auto thrust mode is only available between idle and Max
Climb Thrust when the aircraft is in flight.
After take-off the throttle is pulled back to the max climb position, the auto thrust system will be active and the Automatic Flight system will provide an Ni target to provide either-

- Max Climb Thrust.
- An Optimum Thrust.
- A Minimum Thrust. An Aircraft Speed (Mach Number).
- In association with the autopilot.

b. Memo Mode

The Memo Mode is entered automatically, from Auto mode if the Ni target is in valid. One of the instinctive disconnect buttons on the throttle is activated. Auto thrust is disconnected by the EIU.
In the memo mode, the thrust is frozen to the last actual Ni value and will remain frozen until the throttle lever is moved manually,
or, auto thrust is reset

c. Manual Thrust Mode

This mode is entered any time the conditions for Auto or Memo
Are not present in this mode. Thrust is a function of throttle lever position.

Power Supplies

Permanent Magnet Alternator (PMA)

A dual coil Permanent Magnet Alternat or driven from
The External or Accessory Gear box powers the ECU. The dual output is fed independently to the two Channels. The PMA can provide all power requirements once the engine isrunningabove15%N2(N3for RR Engine).

28VDCAircraftBUS

For engine starting an aircraft 28VDC supply is used. In addition, a 28VDC Bus supplies power for ground testing the system and or back up in the case of theprimary28V DC Bus failing.
Aircraft 28 VDC is also always available in the event of PMA supply failing to both channels.28V DC is applied to the ECU when:
The start switch is activated
The Fuel switch is placed to on (for an in-flight windmilling start)
When ground test power is applied
115VAC400Hz

Theaircraftsuppliesa115VAC400HZpowersourceto eachchannelforignitionexcitor#1andignitionexcitor# 2.Theinputsareroutedtotheexcitersorterminatedwithin
the ECU by switching relays.
It should be noted that if the ECU has a double channel failure then the engine will not start as the exciters can only be powered via the ECU.

Hydro Mechanical Unit (HMU)

Primary outputs from the ECU are directed to the torque motors of the EHSV located on the HMU and to the torque motor controlling the primary fuel metering valve.
The fuel metering subsystem is completely contained in the HMU. The HMU is mounted on the front, right side of the accessory gearbox. It is driven by a mechanical connection to the gearbox. The HMU responds to electrical signals from the ECU to meter fuel flow for combustion and to modulate servo fuel flow to operate the engine air systems. The HMU also receives signals from the aircraft fuel control system to control an internal high pressure fuel shutoff valve (HPSOV).

There are four external electrical connectors for electrical interfaces with the aircraft and ECU. Four fuel ports connect the HMU with the fuel pump and fuel nozzles. There are five hydraulic connections for control interfaces with the engine fuel and air systems. Each hydraulic interface is controlled by an electro-hydraulic servo valve (EHSV) that varies servo fuel pressure in response to EEC signals. The fuel connections to the HMU are:
Fuel inlet from the fuel pump
Fuel discharge to the fuel nozzles
Fuel bypass discharge to the fuel pump
Servo fuel inlet from the servo fuel heater. The hydraulic connections from the HMU are :
Servo fuel pressure to the low-pressure turbine case cooling(LPTCC) valve
Servo fuel pressure to the high-pressure turbine case cooling(HPTCC) valve
Servo fuel reference pressure to the LPTCC and HPTCC
valves
Servo fuel pressure to the variable bypass valves (VBVs)
Servo fuel pressure to the variable stator vanes (VSVs). The electrical connections to the HMU are:
Fuel control signals from EEC channel A
Fuel control signals from EEC channel B
HPSOV solenoid inputs from the fuel control valves
HPSOV position indication outputs to the EEC.

The HMU has three hydraulic circuits:
A fuel metering circuit
A bypass circuits
A servo control circuit.
The fuel metering circuit controls fuel flow to the fuel nozzles in the engine combustor. It has a fuel metering valve and a high-pressure fuel shutoff valve(HPSOV).Unmetered fuel from the fuel pump goes to the FMV. Metered fuel from the FMV goes to the HPSOV. If the HPSOV is open, metered fuel is routed to the fuel nozzles.
The bypass circuit is composed of a bypass valve, a differential pressure(delta P)regulator, and an over speed governor. The fuel pump supplies more fuel than needed for the metered fuel flow. The bypass circuit returns excess fuel to the fuel pump. The servo control circuit divides the fuel supply from the servo fuel heater in to regulated and unregulated servo flows. These flows so perateactuators located both inside and outside of the HMU. The circuit has a servo regulating and distribution section and five electro-magnetic servo valves. One of these
servo valves supply servo pressure for FMV control and is discussed below. The other servo valves control pressure to engine air system actuators as listed previously.

Fuel Metering Valve

A fuel metering valve (FMV)inside the HMU controls fuel flow to the nozzles. The hydraulically driven metering valve is controlled by the fuel metering valve EHSV. The EHSV has two coils, one foreach EEC channel. The controlling EEC channel increases current through its EHSV coil to hydraulically open the FMV. If neither coil has power, the FMV closes. The FMV has two position-indicating resolvers. One resolver is excited by, and provides a position feedback signal to, EEC channel A. The other resolver goes to EEC channel B.

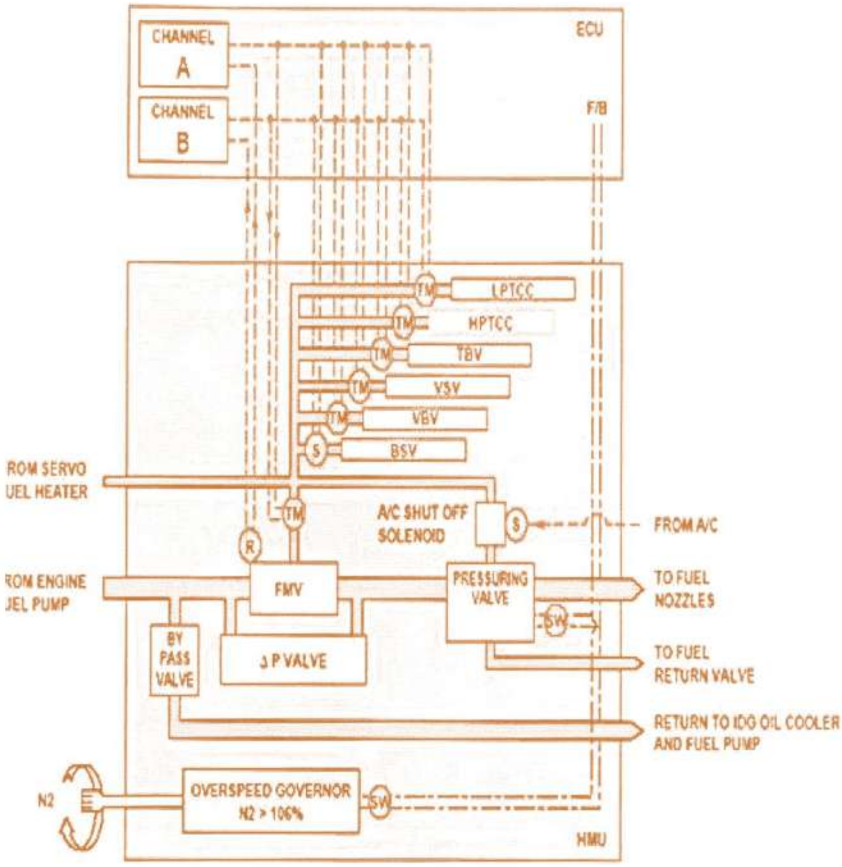


Figure1.30:TypicalHMUSystem

14.2: Engine Indicating Systems

EXHAUST GAS TEMPERATURE/ INTERSTAGE TURBINE TEMPERATURE SYSTEM

1. EXHAUST GAS TEMPERATURE SYSTEM

The measurement of Exhaust gas temperature based on the thermocouple Principal exhaust gas temperature(EGT) is based on the thermo e.m.f principle and requires the use of thermocouple probes immersed in the gas stream at the selected point appropriate to type of engine.

Thermocouple Materials and Combinations

The materials used for the thermocouple sensor fall into following two groups.

1. The base metal
2. The rare metal

Group Metals and Composition Temperature Application

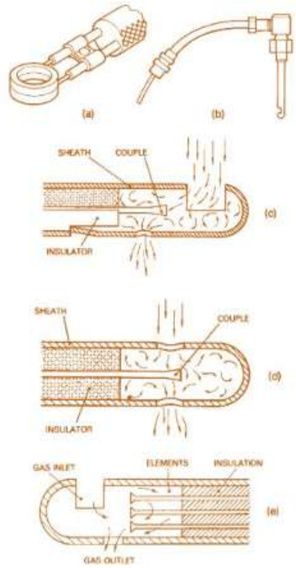


Fig. Thermocouple metals and composition Table

COLDJUNCTION(INDICATOR)

The temperatures measurement of hot junction is accomplished by connecting a moving coil millivoltmeter in series, calibrated indegrees Celsius, with the circuits so that it forms the cold junction.

HIGHLIGHT

- When fitting a new indicator, the pointer to be set to ambient temperature by zero adjustment.

- When indicator is removed from the system, short the terminal and during installation remove the shorting link.

 Ensure the correct polarity of the lead.

 The positive lead is flat end at the exposed end on the thermocouple and marked with red sleeve on compensating leads. And negative end marked with blue color.

Type of thermocouples

There are following two type of thermocouple are employed

1. Immersion type thermocouple.

Fig. Temperature Indicator (EGT)

a. Surface contact; Immersion;
b.
c. Stagnation;
d. Rapid response;
e. Triple-Element probe.

Fig. Types of thermocouple probes.

Material used for Immersion type of thermocouple

Nickel Chromel / Nickel Alumel

The sensing element is encased in ceramic insulation within a metal(typically, Inconel) protections heath, the complete assembly forming a probe which can be immersed in the gas stream at the points selected far measurement. The techniques for assembly of thermocouple elements include vacuum brazing; induction brazing and argon rewelding as well as the technique of electron-beam welding.

IDENTIFICATIONOFEGTTHERMOCOUPLE Nickel Chromel: the bare end of the conductor is flattened Nickel Alumel: suspected to magnetism CLASSIFICATION

The immersion-type thermocouples are classified as follows:

1. Stagnation type thermocouple
2. Rapid response type thermocouple

1. Stagnation type thermocouple

In which the exhaust gas passes through the sampling holes(entry and exit holes) are staggered duet unequal size of holes causing to delay respond to changes of gas temperature of hot junction.

APPLICATION Turbojet engine

2. Rapid response type thermocouple
In which the sampling holes are diametrically opposite each other and of equal size therefore the gases can flow directly over the hot junction enabling it to respond more rapidly.

Response times:
Stagnation type thermocouple: 1to2seconds
Rapid response typethermocouples:0.5to1second,

APPLICATION Turboprop engines

THERMOCOUPLEPROBES

It also designed to contain double, triple and in some cases, up to eight thermocouple elements within a single probe.

Example

An eight-probe arrangement of thermocouple

It comprising16 hot junctions and the cable pass through steel tubing and terminate at a main junction box which serves as a take point for the connection of indicators and other unit requires EGT data. The terminal studs of junction box remade of chrome land eumelanin order to ensure the correct polarity of cable connection nonidentified by the diameters of aluminum studs are larger than chrome studs.

A triple element arrangement of thermocouple
It is used to provide additional temperature signals for engine systems are as follows:

Exhaust-gas temperature control
Engine combustion analyzing.

Insulation of the thermocouple elements from each other is provided by compacted magnesium

Oxide (MgO) which also serves to maintain the elements in position. When the hot junction so immersion-type thermocouples are in contact with the gas stream.

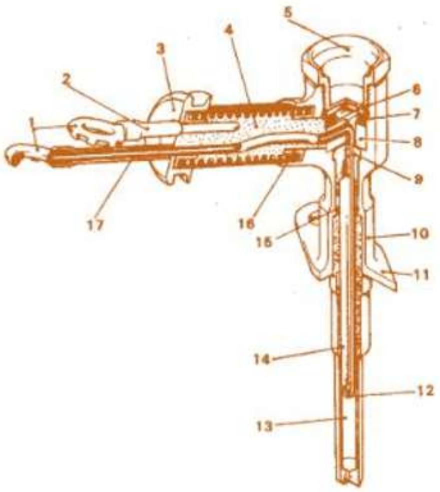


Fig. Nozzle guide vane thermocouple probe

1Terminals,2nickel-alumi-nium lead, 3end-cap, 4silicone filter,5 plug,6micawashers,7ceramictopclamp,8 ceramic bottom clamp, 9 glass seal,10 body, I mounting flange,12 couple junction, 13probe,14ceramic insulator, 15 washer,16ferrule,17nickel-chromiumlead.

CONSTRUCTION

It is designed to measure the gas temperatures between turbine stages. The hot junction is housed ins idea sheath which is shaped to form the leading edge of a stator guide vane and the assembly is called nozzle-guide-vane thermocouple. The sampling holes of nozzle-guide-vane thermocouples are much smaller in diameter and the thermocouple response is made slower-by them assofthe sheath and its proximity to the guide vane. The temperature sensor in this case is also a chrome/alumel thermocouple element are positioned over a vent hole between a mounting boss on the engine and an overheat detector switch.

PROBE LOCATION

Thermocouples probes are generally located at the exhaust, or jet pipe unit, and between the turbine stages atone of the stator positions. The temperatures at these locations are much lower, but they relate very close by to those at the turbine entry.

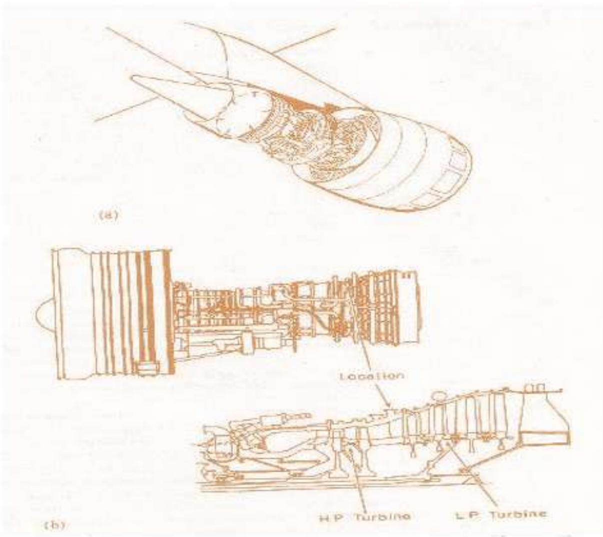


Fig Probe location

HIGHLIGHT

The accurate measurement it is necessary to sample temperatures from a number of points evenly distributed over a cross-section of the gas flow. This is because temperature differences can exist in various zone sorlayers of the flow through the turbine and exhaust unit.

Therefore, the measuring system always consists of a group of five or more thermocouple probes suitably disposed in the gas flow, and connected in parallel so as to measure a good average temperature condition The Nozzle guide-vane thermocouples are arranged in pairs of long-reach and short-reach probes, named according to the extent to which the hot junctions and gas sampling holes reach Into the gas stream.

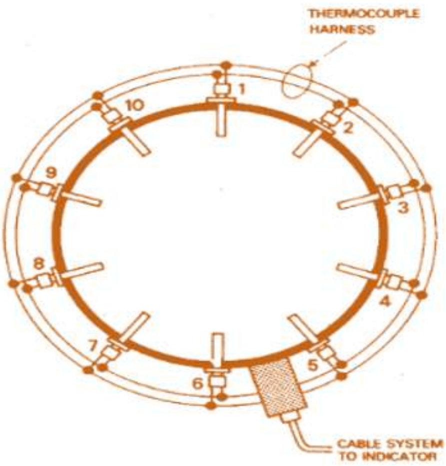


Fig. Disposition of EGT thermocouple probe

THERMOCOUPLE HARNESSASSEMBLIES

The thermocouple sensing elements and their leads are made up into harness assembly the design of which can vary dependent on the type of engine and the number of probes required

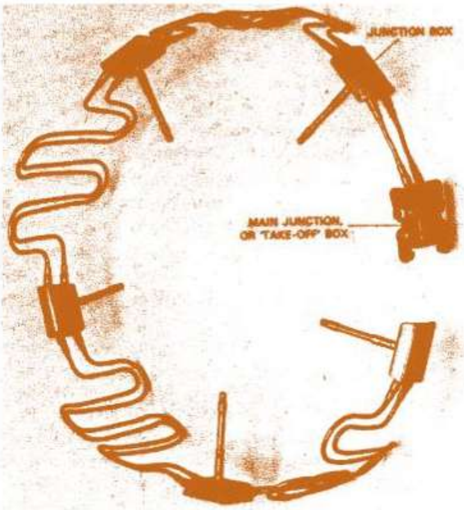


Fig. Thermocouple harness.

ARRANGEMENT OF THERMOCOUPLE (FIVE PROBES)

It contains two following thermocouple elements require for

1. Temperature indication,
2. Temperature control circuit.

The probes and thermocouple lead junction boxes for some engines maybe designed as separate items; the probes in the example considered are welded to stainless steel junction boxes thus forming single items. The parallel-connected thermocouple leads pass through Inconel conduits which are also welded to ferrules at the junction boxes. The leads terminate at a main junction, or 'take-off' box ,to which the leads of the remainder of the circuits are connected. The forming of the conduits in the manner shown provides sufficient flexibility to permit high number of harness removals and placements. Another type of harness designed for exhaust gas
temperature measurement known as a hub array. The thermocouple probes radiate from the hub, and since the bodies of each probe are high temperature brazed to the hub periphery.

The thermocouple leads are connected to rings of the same arterial as the thermocouples, i.e., chrome lead stoa chrome ring, and a lumelleadstoanalumelring. The rings are located within the hub and are insulated from each other, and the hub, by ceramic moldings.

The hub is also packed with magnesium oxide powder to provide support for the leads, and to provide further electrical insulation and connection of the harness to the remainder of the circuities done by means of mineral insulated and lead wires and a separately mounted 'take-off box.

COLD-JUNCTION TEMPERATURE COMPENSATION

If the ambient temperature of the indicator(cold junction) changes while the hot junction temperature remains constant, a change in e.m.f will result causing theindicatortoreadanerror.Thee.m.f.is obtained correspond to acold-junction temperature which is usually maintained at either0°Cor20°C.
A change in 'ambient and cold-junction' temperature decreases or increases the e.m.f. generated by the thermocouple cause an indicator to read low or high by an amount equal to the changes of ambient temperature.

EXAMPLE

The coldjunctionismaintainedat0°Candthehotjunction temperature hasreached500°C.andthee.m.f.generatedby a chrome /alumelcombinationis20.64mV.Ifnowthetemperature atthecoldjunctionincreasesto20°Cwhile the hot junction remainsat500" C,thetemperaturedifferencedecreasesto480°C and the e.m.f .equivalent to this difference is now 20.64 mV minusthee.m.f.at20°C,andasastandardvaluethiscorresponds to0.79mV.Themovingelementoftheindicatorwillrespondto an e.m.f. of19.85 mV and will indicate the reading of 480°C.

The effects on moving coil indicators is compensated by the bimetallic strip in which the strips of dissimilar metals are fastened together and coiled in the shape of a flat spiral spring. One end of the spring is anchored to a bracket which forms part of the moving-element support ,while the other end(free end)is connected by an anchor tag to the outer end of one of the controlling hairsprings.

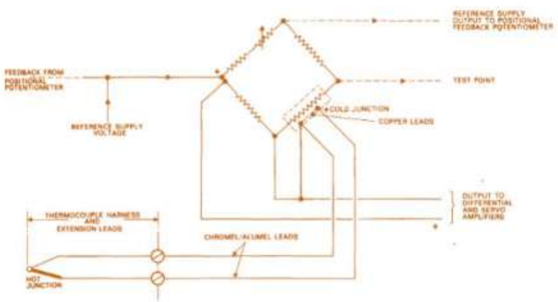


Fig. Cold-junction compensation circuit

When the indicator is on open circuit, i.e., disconnected from the thermocouple system, the spring responds to ambient temperature changes at the indicator, an increase in temperature causing the spring to unwind so that its free end carries the hairspring and moving element round to indicate the increase in temperature conversely, a temperature decrease will wind up the compensator spring so that the moving element will indicate the lower temperature.

SERVO-OPERATEDTEMPERATURE INDICATORS

The compensation for the effects of cold-junction temperature changes can also be accomplished by an electrical bridge circuit.

EXAMPLE

The output from the EGT thermocouple probe is supplied to reference bridge circuit to compensate for changes in ambient temperature of cold junction indicator.

The thermocouple harness leads(compensating leads)are connected to copper leads of the same metals of the thermocouple within the compensation circuit module which are embedded in close proximity to each other within the former which supports the copper coil resist or R, to form the effective cold junction of the system.

The bridge circuit is supplied with7V dc from a stabilized reference supply module within the indicator, and the output from the bridge circuit is supplied to the indicating element of the indicator through servo amplifier. The bridge circuit is adjusted by means of a variable resistor in series with that of the thermocouple.

The output is termed the demand exhaust as temperature(EGT) signal is compared with a dc output wiper of position feedback potentiometer which is geared to the main pointer and digital counter of the indicator.

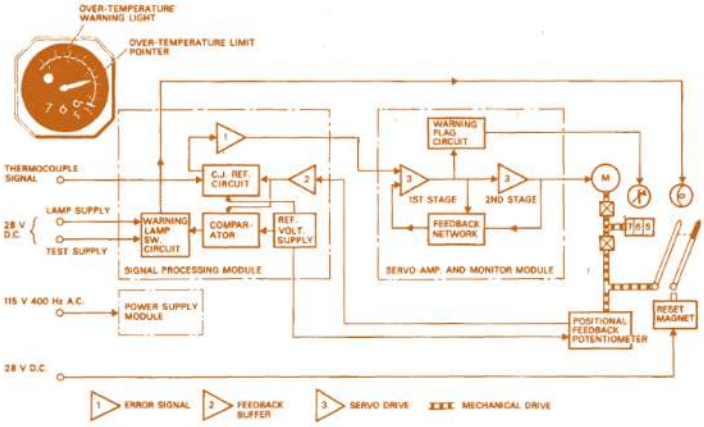


Fig. Servo operated EGT Indicator

The d. c. output which is fed to the cold junction(indicator) reference circuit represents the indicated exhaust gas temperature (EGT).

The difference between computed and indicated temperatures results in an error signal being produced by the cold-junction reference circuit supplied to a servo amplifier.

The servo amplifier output is fed to the armature winding of the d. c. servo motor which then drives the indicator pointer and digital counters causing them to display a coarse and fine indication respectively of the exhaust gas temperature (EGT).
The wiper of the positioned feedback potentiometer is also repositioned to provide a feedback voltage which backs-off the demanded temperature signal until the error signal is nullified (zero) and the indicator will display the demanded temperature.
The output voltage from one stage of the servo amplifier is also fed to a servo loop monitor to detect any failure of the servo loop to back-off the error signal voltage and the monitor functions as an 'on-off switch.

Note:

In the 'off' state condition:

- De-energized a solenoid-controlled warning flag which appears across the digital counter display.
- Theflagwillalsoappearingtheeventofthe115Va.c. supply to the indicator falling below 100 v.
- An over-temperature warning light is incorporated in the indicator which Is controlled by a relay, a comparator, and a solid-state switching circuit. The function of the comparator is to compare the feedback voltage from the positioned
- potentiometer with a preset voltage the level of which is equivalent to a predetermined over-temperature limit for the particular type of engine.
- In the event of this limit being exceeded, the feedback voltage will exceed the reference voltage level, and the switching circuit will cause the relay to energize, thereby closing its contacts to illuminate the warning light.

- A separate supply voltage may be connected to the light by means of an 'override 'facility as a mean so testing its filament at any point over the temperature range of the
- indicator.

- An over-temperature pointer is also fitted concentrically- with the main pointer,

COMPENSATION OF MOVING COIL RESISTANCE CHANGES

The compensation of moving coil resistance changes is compensated by the following two methods

i. Thermo resistor
ii. Thermomagnetic shunt

EXTERNAL CIRCUITAND RESISTANCE

The external circuit of a thermoelectric indicating system consists of

1. Thermocouple
2. Compensating leads.

The thermocouple, leads and harness are made up of low resistance and the extension or compensating leads must also be made up in lengths and of uniform resistance to suit the varying distances between the thermocouple hot junction and indicator installations.

The total external circuit resistance is adjusted by connecting a trimming resistance connected in series with compensating leads which is made of Eureka or Manganin,(negative temperature coefficients).

Note:

The resistance of compensating leads remains constant of specific valueof8Ωor25Ωwhich are made of same materials of the material of thermocouple.

QUESTION

1. Describe the construction of a typical thermocouple probe assembly used for turbine-engine exhaust-gas temperature measurement.
2. How is it ensured that a good average temperature condition of exhaust gases is measured by an indicating system?
3. What effects can change of cold-junction temperature have on the indications of thermoelectric indicators? Describe
4. The methods of compensation.
5. What is the difference between extension leads and compensating leads?
6. Briefly describe how the principle of servo control can be applied to the measurement of turbine engine exhaust gas temperature.

ENGINE SPEED

MEASUREMENT OF ENGINE SPEED

The measurement of engine speed with reciprocating engines the speed measure disses that of the crankshaft, while with turboprop and turbojet engines the rotational speed of the compressor shaft is measured, The indicating instruments are normally referred to as tachometers. The method most commonly used for measuring these speeds is an electrical one, although in several types of general aviation aircraft, mechanically operated tachometers are also employed.

ELECTRICAL TACHOMETER SYSTEMS

It consists of a magnet which is continually rotated by a flexible shaft coupled to a drive outlet at the engine. An alloy cup-shaped
element(known as a drag cup)fits around the magnet such that a small gap is left between the two.

The drag cup is supported on as haft to which is attached a pointer and a controlling spring. As the magnet rotate sit in duce eddy current sin the drag cup which tend to rotate the cup at the same speed as the magnet. This, however, is restrained by the controlling spring in such a manner that for any one speed, the eddy current drag, and spring tension are in equilibrium and the pointer then indicates the corresponding speed on the tachometer dial.

Systems of this type currently fall in to following two main categories:

(i) Generator and Indicator, (ii) Tach probe and Indicator.

GENERATOR AND 'INDICATOR SYSTEMS

A generator consists of a permanent-magnet rotor rotating within a slotted stator which carries a star-connected three-phase winding. The rotor maybe of either two-pole or four-pole

CONSTRUCTION

In some applications a twelve-pole rotor may be used. It will be noted that the poles of the four-pole rotor are angled so that when one end of a pole leaves one stator tooth the other end is entering the next tooth. This produces the best wave for mand permits an

even driving torque. With the two-pole rotor the same effect is achieved by skewing the stator teeth and the individual coils which make up a phase. The method most commonly used for driving a rotor is by mean sofa splined shaft coupling, the
generator as a whole being bolted directly to a mounting pad at the appropriate accessories drive gear outlet of the engine.

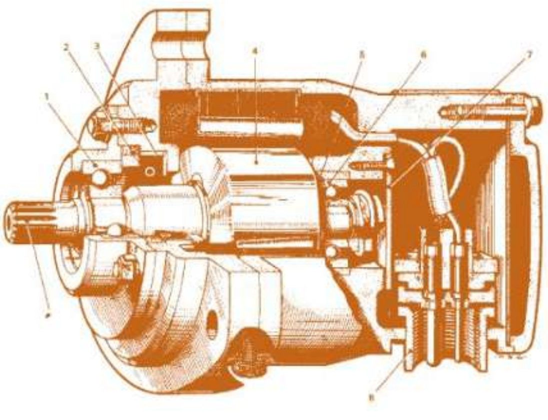


Fig.Sectionedviewofsplinedrivegenerator.1Ballbearings,2 oil-seal retaining ring, 3oil seal, 4 two-pole permanent-magnet rotor,5greaseretainer, 6ballbearings, 7 sealing cover, 8connector,
9 driving splines.

In order to limit the mechanical loads on generators, the operating speed of rotors is reduced by means of either our-to-one or two- to one ratio gears in the engine drive system.

EXAMPLE

As maller construction, the rotor being either two-pole or twelve- pole and driven via a square-ended shaft. The two-pole generator is utilized in conjunction with a three-phase synchronous motor type of indicator, while the twelve-pole generator, which produces a single-phase output at a much higher frequency and sensitivity,
is utilized in conjunction with servo operated counter pointer indicators, and also for supplying signals to engine control units.

Fig Light weight generator

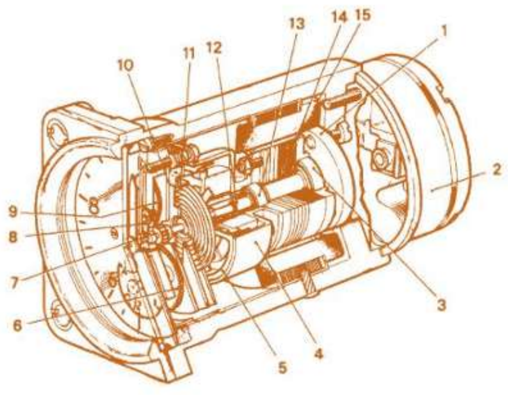


Figure: Sectioned view of a typical synchronous motor type tachometer indicator. 1 Cantilever shaft,2 terminal block assembly,3rear ball bearing, 4magneticcup assembly, 5drag element assembly,6 small pointer spindle andgear,7 outer spindle bearing,8 bearinglockingiag,9 intermediategear,10 bearing plate,
11 hairspring anchor tag,12 inner spindle bearing,
13 front ball bearing, 14rotors,15 stator.

It consists of two interconnected elements: a driving element and an eddy-current-drag speed-indicating element. The driving element. A synchronous motor having a star-connected three-phase stator winding and a rotor revolving on two ball bearings.
The rotor is of composite construction, embodying in one part soft-iron laminations ,and in the other part a laminated two-pole permanent magnet. An aluminum disc separates the two parts and a series of longitudinal copper bars passthrough the rotor forming a squirrel-cage. The purpose of constructing the rotor in this manner is to combine the self-starting and high torque properties of a squirrel-cage motor with the self-synchronous properties associated with a permanent-magnet type of motor.

The speed-indicating element consists of a cylindrical permanent magnet rotor inserted into a drum so that a small air gap is left between the periphery of the magnet and drum. A metal cup, called drag cup, is mounted on a shaft, and is supported in jeweled bearings so a store duce frictional forces, in such a way that it fits over the magnet rotor to reduce the airgap to a minimum.

A calibrated hair spring is attached at one end of the drag-cup shaft, and at the other end to the mechanism frame. At the front end of the drag cup shaft a gear train is coupled to two concentrically mounted pointers; a small one indicating hundreds and a large one indicating thousands of rev./min.

SYSTEMOPERATION

The generator rotor is driven round inside its stator, the poles sweep past each stator winding.
The magnitude of the e.m.f. induced by the magnet depends on the strength of the magnet and the number of turns on the phase
coils. Furthermore, as each coil is passed by a pair of rotor poles, the induced. e.m.f. completes one cycle at frequency determined by the rotational speed of the rotor, Therefore, rotor speed and frequency are directly proportional, and since the rotor is driven by the engine at some fixed ratio then the frequency of induced e.m.f. is a measure of the engine speed.

The generator e.m.f.'s are supplied to the corresponding phase coils of the indicator stator to produce current sofa magnitude and direction dependent on the e. m.f.'s. The distribution of stator currents produces a result antimagnetic field which rotates at a speed dependent on the generator frequency. As the field rotates it cuts through the copper bars of the squirrel-cage rotor, inducing a current which, in turn, sets up a magnetic field around each bar.

The reaction of the subfields with the main rotating field produces a torque on the rotor causing it to rotate in the same direction as the main field and at the same speed. As the rotor rotates it drives the permanent magnet of the speed indicating unit, and because of relative motion between the magnet and the drag-cup eddy currents are induced.

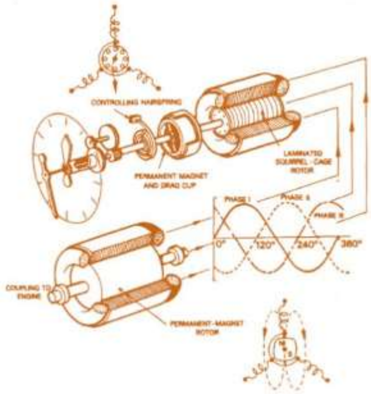


Figure generator and indicator system.

The subcurrents create a magnetic field which reacts with the permanent magnetic field, and since there is always a tendency to oppose the creation of induced currents (Lenz' slaw), the torque reaction of the fields causes the drag-cup to be continuously rotated in the same direction as the magnet.

The rotation of the drag-cup is restricted by the calibrated hairspring in such a manner that the cup will move to a position at which the eddy-current-drag torque is balanced by the tension of the spring. The resulting movement of the drag-cup shaft and gear train thus positions the pointers over the dial to indicate the engine speed prevailing at that instant.

Indicators are, compensated for the effects of temperature on the permanent magnet of the speed-indicating element by fitting a thermo-magnetics hunt device adjacent to the magnet.

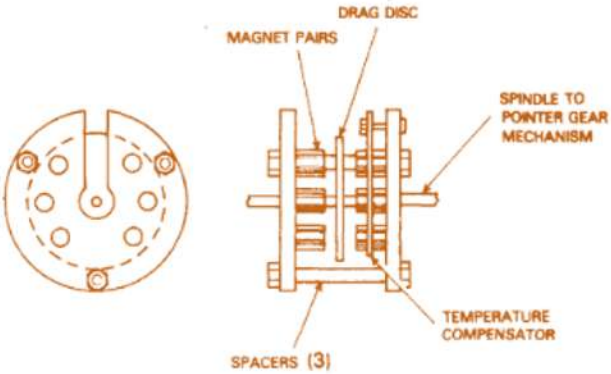


Figure Disc type drag element

Another version of speed-indicating element which is used in some types of indicator. In consists of six pairs of small permanent magnets mounted on plates bolted together in such a way that the magnets are directly opposite each other with a small air gap between pole faces to accommodate a drag disc. The Rotation of the disc is transmitted to pointers in a similar manner to the drag-cup method.

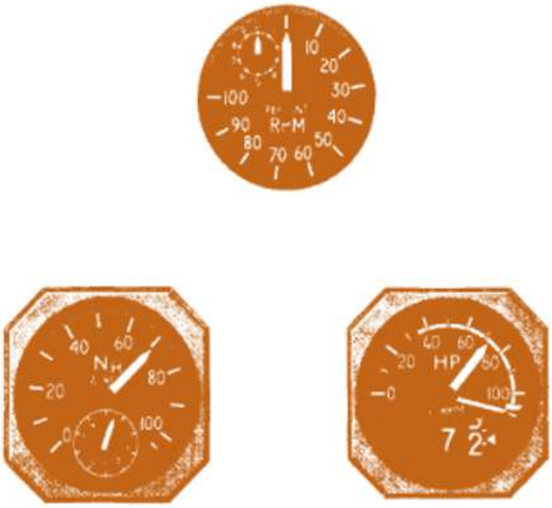


Figure: Dial presentations of percentage tachometers. (a) Synchronous motor type;

(b) d.c. torques motor indicator.
(c) served counter/pointer indicator.

PERCENTAGE REV. /MIN. TACHOMETERS

The measurement of engine speed in terms of a percentage is employed for turbojet engine operation. The main scales are calibratedfrom0to100%in10% increments,with100% corresponding to the optimum turbine speed.

In order to achieve this engine manufacturer chooses a ratio between the actual turbine speed and the generator drive so that the optimum speed produces 4,200 rev. /min. at the generator drive. A second pointer or digital counter displays speed in 1%increments.

SERVO-OPERATEDTACHOMETER

The generator signals are firstly converted to a square wave form by a squaring amplifier within the signal processing module, and in order to obtain suitable positive and negative triggering pulses for each half-cycle of the wave form, it is differentiated by a signal shaping circuit.

The pulses pass through a monostable which then produces a train of pulses of constant amplitude and width, Anda twice the frequency of the generator signal. In order to derive the voltage signal Torun, the d.c. motor to what is termed the demand speed condition, the monostable output is supplied to an integrator via a buffer amplifier.

Fig. Servo operated Tach Indicator

The demand signal from the integrator is then applied to a sensing network in a servo amplifier and monitor module, where itis compared with a d.c. output from the wiper of a positional feedback potentiometer. Since the wiper is geared to the main pointer indicator, its output therefore represents indicated speed. Any difference between the demand speed and indicated speed results in an error signal which is supplied to the input and output stages of the servo amplifier, and then to the armature winding of the motor; the indicator pointer and digital counter are then driven to the demanded speed position.

At the same time, the feedback potentiometer wiper is a lsore- positioned to provide a feedback voltage to back-off the demanded speed signal until the error signal is zero; at this point, the indicator will then display the demanded speed.

The output voltage from the servo amplifier input stage is also fed toa servo loop monitor, the purpose of which is to detect any failure of the servo circuit to back-off the error signal voltage.

In the event of such failure, the monitor functions as an' on-off switch, and in the 'off state it de-energizes a solenoid-controlled warning flag which appears across the digital counter display.

An over speed pointer is also fitted concentrically with the main pointer and is initially positioned at the appropriate scale graduation. If the main pointer exceeds this position, the limit pointer is carried with it.

When the speed has been reduced the main pointer will move correspondingly, but the limit pointer will remain at the maximum speed reached since it is under the control of a ratchet mechanism. It can be returned to its initial position by applying a
separatelyswitched28Vd.c.supply to are set solenoid within the indicator.

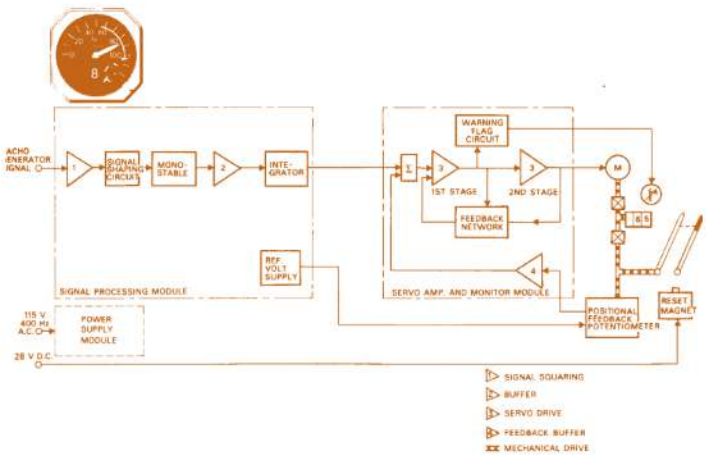


Fig. servo operated tachometer Indicator

TACHOPROBE ANDINDICATINGSYSTEM

This system is used in several types of large public transport aircraft and has the advantage of providing separate electrical outputs and probe has no moving parts additional to those required for speed indication, e.g., flight data recording and engine control.

The stainless steel, hermetically sealed probe comprises a permanent magnet, a pole piece, and a number of cupro-nickel or nickel/chromium coils around a ferromagnetic core. Separate windings(from five to seven depending on the type of probe) provide outputs to the indicator and other equipment requiring engine speed data.

The probe is flange- mounted on the engine at a station in the high-pressure compressor section of the engine so that it extends
Into this section. In some turbo fan engines, a probe may also be mounted at the fan section for measuring fan speed.

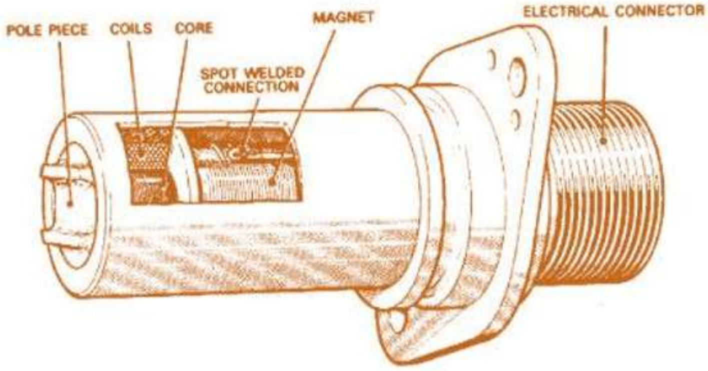
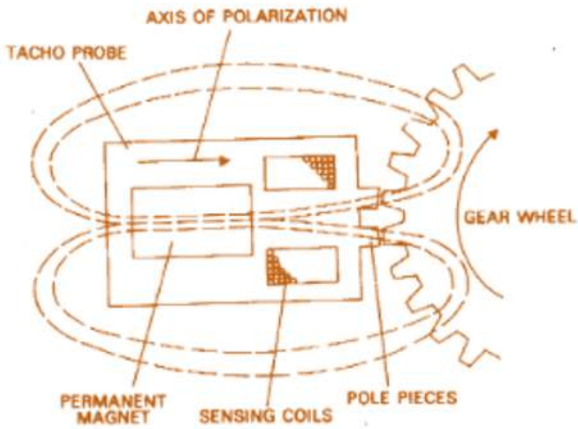


Figure: Tach probe.



When in position, the pole pieces are in close proximity to the teeth of a gear wheel (some times referred to as a phonic wheel)
Which is driven at the same speed as the compressor shaft or fan shaft as appropriate.

Note:
To ensure correct orientation of the probe, a locating plug is provided in the mounting flange.

The permanent magnet produces a magnetic field around the sensing coils, and as the gear wheel teeth pass the pole pieces, the intensity of flux through each pole varies in aversely with the width of the airgap between poles and the gear wheel teeth. As the flux density changes, an e.m.f. is induced in the sensing coils, the amplitude of the e.m.f. varying with the rate of flux density change.

The starting position, maximum intensity would occur, but the rate of density change would be zero, and so the induced. m.f. would beat zero amplitude. When the gear teeth move from this position, the flux density firstly begins to decrease reaching a maximum rate of change and there by inducing. m.f. of maximum amplitude.

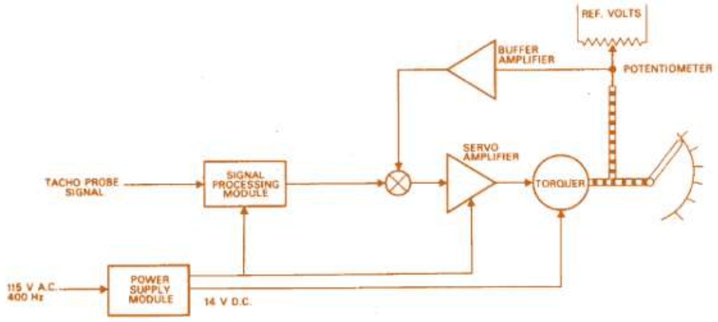


Fig. d. c torque motor tachometer

At the position in which the pole pieces align with the 'valleys' between gear teeth, the flux density will be at a maim urn, and because the rate of change is zero thee .m.f. is of zero amplitude. The flux density will again increase then ext gear teeth align with the pole pieces, the amplitude of the induced. m.f. reaching a maximum coincident with the greatest rate of flux density change.

The probe and gear teeth may therefore be considered as a magnetic flux switch that induces e.m.f.'s directly proportional to the gear wheel and compressor or fan shaft speed.

The output signals for speed indication purposes are supplied to an indicator of the d.c. torque type. The signals pass through signal processing of ad. c. module and are summed with an output from a motor tachometer. Servo potentiometer and a buffer amplifier and after summation the signal passes through a servo amplifier to the torque which then rotates the indicator pointers to indicate the changes in probe signals in terms of speed.

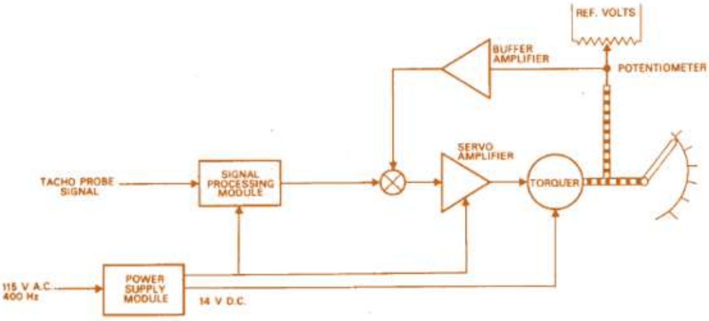
The servo potentiometer is supplied with a reference voltage, and since its wiper is also positioned by the torque, the potentiometer will control the summation of signals to the servo amplifier to ensure signal balancing at the various constant speed conditions. In the event of a power supply or signal failure, the main pointer of the indicator is returned to an 'off-scale' position under the action of a pre-loaded helical spring.

ENGINE THRUSTINDICATION

The power of piston engines, turbojet, and turboprop engines refers to the amount of thrust available for propulsion and is expressed as power ratings in units of brake or shaft horsepower (BHP or SHP)-at a propeller shaft or in pounds of thrust at the jet pipe.

The instruments associated with power indication for the various types of engine are listed in:

ENGINEPRESSURE RATIO (EPR)



The EPR system consists of

Engine inlet pressure sensing probe
Number of pressure sensing probes projected into the exhaust unit of an engine,
Pressure ratio transmitter,
Indicator.

CONSTRUCTION

The inlet pressure-sensing probe is similar to a pitot pressure probe and is mounted so that it faces into the airstream in the engine intake or, as in some powerplant installations, on the pylon and in the vicinity of the air intake.

The probe is protected against icing by a supply of warm air from the engine anti-ice system.
The exhaust pressure-sensing probes are interconnected by pipeline swhichterminateatamanifold, thus averaging the pressures.

A pipeline from the manifold, and another from the inlet pressure probe, is each connected to the pressure ratio transmitter which comprises bellows type of pressure-sensing transducer, linear voltage differential transformer (LVDT) a two-phase servomotor, amplifier, and a potentiometer.

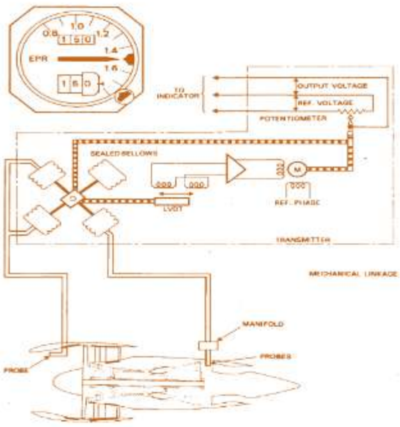


Fig: EPR system

The transducer bellows are arranged in two pairs at right angles and supported in a frame which, in turn, is supported in a gimbal and yoke assembly. The gimbal is mechanically coupled to the servo motor via a geartrain, while the yoke is coupled to the core of the LVDT.

The servo motor also drives the wiper of the potentiometer which adjusts the output voltage signals to the EPR indicator in terms of changes in pressure ratio.

The indicator is of the servo operated type, which is an adaptation of the indicator in some EPR systems, the indicator may be of the vertical scale/moving tape type.

Operation

The intake pressure is admitted to two of the bellow sin the transducer, exhaust gas pressure is admitted to the third bellows, while the fourth is evacuated and sealed. Thus, the system together with its frame, gimbal and yoke assembly forms a pressure balancing and torsional system.

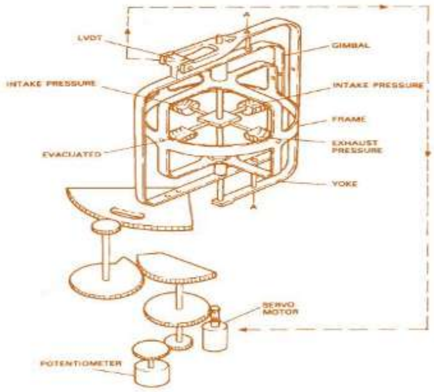


Fig: Pressure transducer

When a change in pressure occurs, it causes nun balance in the bellows system, and the resultant of the forces acting on the transducer frame acts on the yoke such that it is pivoted about the axis AA(Fig 14.6).The deflection displaces the core of the LVDT to induceana. c. signal which is amplified and applied to the control winding of the servo motor.

The motor, via the gear train, alters the potentiometer output signal to the indicator the pointer and digital counter of which are servo-driven to indicate the new pressure ratio. Simultaneously, the motor drives the transducer gimbal and LVDT coils in the same direction as the initially oke movement so that the relative movement now produced between the LVDT coil sand cure starts reducing the signal to the servo motor, utilities finally cancelled, and the system stabilized at the new pressure ratio.

ENGINE TURBINE DISCHARGE PRESSURE OR JET PIPEPRESSURE SYSTEM

PERCENTAGE THRUST INDICATOR

The power monitoring is done by mean sofa direct-reading type of pressure ratio indicator and indicates power in terms of percentage thrust over the range 50to100%.Inaddition,itincorporatesa manually controlled device permitting the thrust indications to be compensated for variation in ambient atmospheric conditions.

The compensation is accomplished by rotating a setting knob, which adjusts a digital counter(in some instruments a scale may be fitted)and at the same time rotates the complete mechanism and positions the pointer to anew datum value on the main dial.

With this compensation applied, the instrument normally indicates100%thrustasaminimumtake-offvalueunderengine

performance. Under this condition the engine performance may indicate a take-off value greater than 100%thrust.

The counter is of the three-digit display, and each number set on it corresponds to an appropriate ambient atmospheric condition obtained from performance curves plotted for specific aircraft engine combinations.

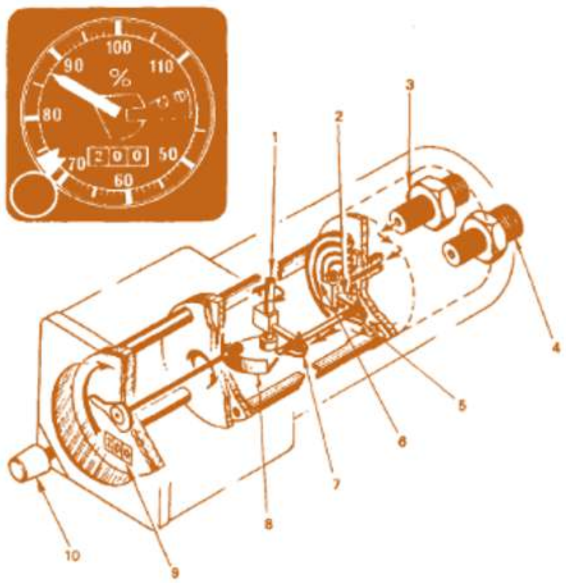


Fig.Percentage-thrustindicator.1Rockingshaft,2calibratingarm, 3exhaustunitpressureconnection,4static proweconnection,5 overload spring, 6 capsule,7 overload spring, 8 sector gear, 9 digital counters(atmospheric datum), 10counter setting knob.

Turbine Temperature Control

The power developed by a turbine engine is dependent on two main factors: the air mass flow through it and the temperature drop. The air mass flow varies with engine speed and also with air density, which in turn is determined by altitude, atmospheric temperature, and forward speed. Temperature drop is the difference between the temperatures immediately before and after the turbine and is therefore a measure of the energy extracted by the turbine.

The temperature drop will be a maximum and indicate the maximum energy extraction if the gas temperature eattheentry to the turbine is maintained at the highest level, there is, however, a practical limitation to this temperature brought about by the effects on the material of the turbine blades and consequently on their life,

Note:
The optimum temperatures are established at which the maximum
Power may be obtained without impairing the structural integrity of the turbine blading, and the operating conditions are carefully controlled to ensure that such limitations are not exceeded.

The control of the conditions can be instituted at ground level, but inflight a turbine must operate under changing conditions of atmospheric temperature, density, and forward speed, and as already mentioned, these variables determine the air mass flow through the turbine. For given atmospheric conditions, the air mass flow is controlled by the engine speed, and to maintain the maximum turbine entry temperature appropriate to these conditions, the flow of fuel to the engine must be controlled so as to match the air mass flow.

This process of fuel flow control is generally known as fuel trimming, depending on particular engine installations it may be affected by an electro-mechanical system under the direct

Control of the pilot, or by a temperature control system which automatically monitors the fuel flow in response to signals from the thermocouples of the standard exhaust-gas temperature measuring system.
FUELPRESSURE, TEMPERATURE ANDFLOW FUELTRIMINDICATINGSYSTEM
Example

The electro-mechanical method is the trimming of the fuel flow to the Rolls-Royce Dart turbo prop engine. The air mass and fuel flows are matched to the designed ratio, in the first instance, by mechanically interconnecting the fuel throttle valve with there.
/min. controls.

This results in an optimum gas temperature for any selected engine speed and to compensate for the changes in air mass flow, an electric actuator operates a differential compound lever mechanism incorporated as part of the inter connection between throttle valve and rev./min. controls. Electrical power to the actuator is controlled by a switch which is accessible to the pilot and is placarded INCREASE and DECREASE, indicating the trimming condition of fuel flow required and consequently the change of turbine temperature.

The pilot must, of course, have some mean so knowing by how much the fuel flow should be trimmed, and so a fuel-trim position indicating system is provided for his use in conjunction with datum position tables or a datum computer supplied by the engine manufacturer.
The indicating system consist sofa position transmitter and indicator operating on the basic Desync principle. The transmitter is mechanically connected to the trim actuator by a linkage suited to the engine installation and electrically connected to the indicator, which is usually mounted on the control pedestal in the cock pit. The scaleoftheindicatorisgraduatedfrom0(full decrease)to10(full increase),correspondingtotherange0to
100% fuel trim.

The percentage increase or decrease is related to the prevailing air temperature and the pressure altitude and is obtained from the datum position tables or computer. When the required value has been selected, the actuator is switched on so that its shaft will retractor extend, depending on whether an increase or decrease of the fuel flow is required.

The movement of the actuator shaft positions the throttle-valve lever, via control rods and the differential compound lever which permits trimming of the fuel without disturbing the setting of the rev./min. controls.

The actuator shaft also positions the brushes over the toroidal resistance of the transmitter, the voltage combinations so produced being supplied to the indicator stator windings. Since the indicator rotor is a permanent magnet, it aligns itself with the resultant magnetic field induced in the stator, and at the same time moves the pointer to indicate the change in fuel trim.

AUTOMATIC TEMPERATURE CONTROL SYSTEM

A logical development of the fuel trimming process, particularly since it is required to maintain turbine temperatures within specified limits, is to utilize the signals generated by the thermocouples of the standard temperature indicating system and so let these do the work of automatically changing the fuel flow.

A specially designed amplifier unit which, on being connected to the thermocouples, amplifies the signals produced above a preselected datum temperature and supplies them to a solenoid- operated servo valve which then progressively reduces the fuel flow to restore the datum temperature condition.

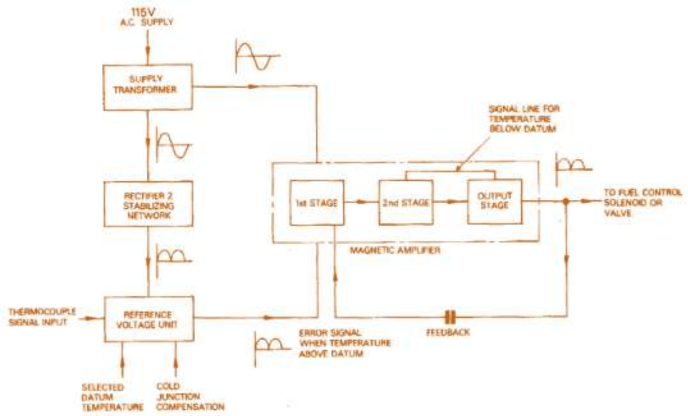


Fig. Automatic temperature control amplifier

The thermo-e.m.f. is fed as an input signal to a terminal block on the amplifier, the terminals forming the cold junction of the control and the compensation for temperature changes at this junction is affected by a bridge circuit, one arm of which changes its resistance with changes of temperature. In addition to the thermocouples, the bridge circuit is also connected to a reference- voltage unit which is to inject a voltage in opposition to that of the
Thermocouples and corresponding with the desired operating temperature range of the engine.

This voltage is stabilized against changes in supply voltage and frequency(I 1 5 V, 400 Hz) and ambient temperature and is selected by a temperature's elector. The amplifying section is in three main stages: amplifier stages1and2,andanoutputstage connected to the solenoid valve.

When the engine is running at the selected temperature, the e.m.f. from the thermocouple is opposed by an equal voltage from the reference-voltage unit, so that there is no input signal to stage

1 of the amplifiers.

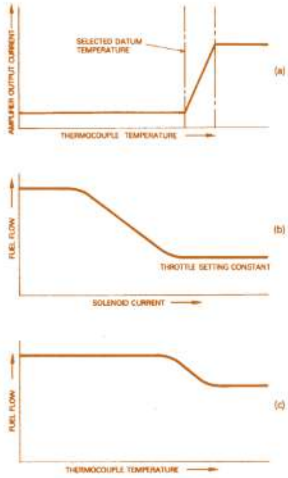


Fig. Characteristics of temperature control system.
(a) Amplifier; (b) fuel control system; (c)combined control characteristic

If the exhaust gas temperature is below the selected value, the reference voltage is greater than that of the thermocouples and this
Provides a reverse-polarity inputtostage1.Thisreversesignalis blocked by anetworkconnectedbetweenstage2andtheoutput stage so that no output current is obtained.

When the exhaust gas temperature rises above the selected value, and this is the more critical situation, the predominating voltage is that from the thermocouples. As this voltage is of the correct polarity theresultingsignalisfedtostagesland2and,after amplification, to the solenoid valve via the output stage.

The valve operates so a store strict the fuel supply to the engine, thus reducing the exhaust gas temperature and thermocouple e.m.f. until it balances the reference voltage once again. The solenoid valve is then released, and the normal fixed fuel flow is restored.

Fig: Temperature control unit

COMBINEDTEMPERATUREAND REV./MINCONTROL SYSTEM

The operating character is tics of a typical temperature control system are shown graphically in(a) that, when the temperature reaches the limiting value, the amplifier output continues to increase, reaching a constant maximum value after a small temperature increase of approximately 8OC.Thesolenoid-current/fuel-flow characteristic depends on the type of fuel system employed.

At(b), which clearly indicates the decrease in the fuel flow with the increase in solenoid current? A combination of(a)and(b) gives us the final control character is tic shown at (c).

Hunting' of the solenoid valve which would give rise to a fluctuation Temperature control unit. Fuel flow and engine thrust, is prevented by feeding back some of the output current into the amplifier stages, thus increasing the time lag.

This system is a further development in the field of automatic control of engine power and is one in which fuel flow is regulated by combining the signals from thermocouples with those supplied by a tachometer generator.

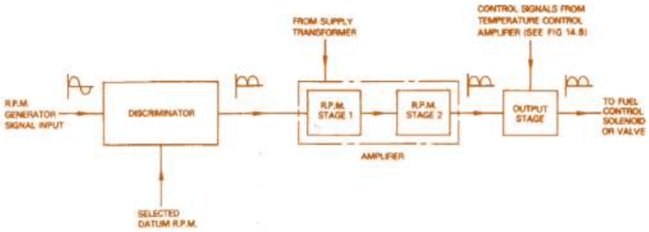


Figure. Temperature and rev./min control system

The three-phase output from the tachometer generator Is supplied to a rev./rnin. Discriminator section which is made up of two
elements, the purpose of which is to provide two independent voltages from the generator input.

One element is of the resistance type so that its voltage is largely independent of the generator frequency, and the other element is of the reactance type, i.e., it contains capacitors and so its voltage is proportional to frequency and therefore to engine speed. Both these voltages are then rectified and applied in opposition to the rev./min. control channel amplifier, which is of the two-stage type.

The voltages may be equalized at any desired engine speed by adjustment of the resistance-type element with the aid of a select or. The output of the ret./min. control channel amplifier is in turn fed to the output stage. At the selected datum speed, the current from the output stage is the standing current in the fuel- valve solenoid. When the engine speed is below the selected datum, the rev./min. control channel signal is suppressed by a discriminator network similar to that used for the temperature channel.

If the engine speed rises above datum, the voltage output from the reactive element of the rev./min. discriminator section will predominate and pass a signal on to the solenoid valve, which reduces the fuel flow to restore the datum speed condition.

The circuitry between both control channels is so arranged that the solenoid valve remains under the control of the rev/min. channel until such time as the exhaust gas temperature exceeds the datum limit, when the temperature control channel with its greater amplification overrides the speed signal and assumes control of the fuel flow to reduce turbine temperature.

EXAMPLE

Top limiting' relates to an aircraft climbing from ground level. Under these conditions, engine speed is the limiting factor and maximum take-off power is required. The solenoid valve modifies the fuel flow to maintain constant rev./min. until the exhaust gas temperature rises to its limiting value.

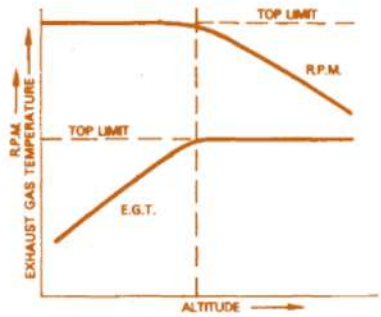


Fig. Top temperature limiting

When this limit is reached, the temperature channel takes full control and overrides the governing action of the rev/min. channel, thus reducing the fuel flow to avoid exceeding the datum temperature. The physical construction of a representative unit with its associated internal circuit boards.

FUELFLOW MEASUREMENT

The fuel-flow measuring systems come within two main groups:

i. Independent fuel flow
ii. Integrated fuel flow.

INDEPENDENTFUELFLOW SYSTEM

This system consists of a transmitter and indicator and requires 28Vdirect current for its operation.

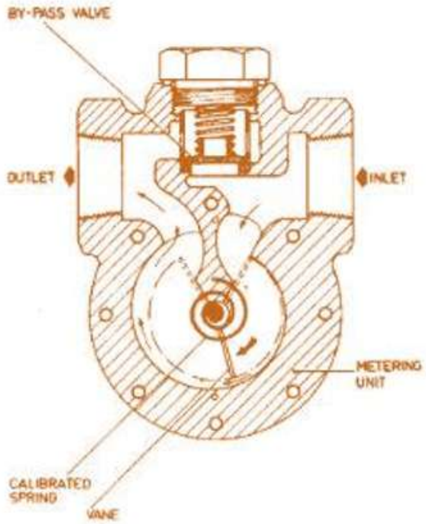


Figure13.a rotating-vane fuel-flow transmitter.

The transmitter has a cast body with inlet and outlet connections in communication with a spiral-shaped metering chamber containing the metering assembly. The latter consists of a metering vane pivoted so that it can be angularly displaced under the influence of fuel passing through the chamber.

A small gap is formed between the edge of the vane and the chamber wall, which on account of the volute form of the chamber, increases in area as the vane is displaced from its zero position. The variation in gap area controls the rate of vane displacement which is faster at the lower flow rates(gap narrower) than at the higher ones. Thus, its function may be likened to an

airspeed-indicator square-law compensator which it will be recalled is a device for opening pan indicator scale.

The vane is mounted a shaft carried in two bushed plain bearings, one in each cover plate enclosing the metering chamber. A tone end, the shaft protrudes through its bearing and carries a two-pole ring-type magnet which forms part of a magnetic coupling between the vane and the electrical transmitting unit. In this particular system the unit is a precision potentiometer, in some desistance. synchro maybe used.

The shaft of the potentiometer (or synchro) carries a two-pole bar- type magnet which is located inside the ring magnet. The interaction of the two fields provides a' magnetic lock' so that the potential meter wiper(or synchro rotor) can follow any angular displacement of the metering vane free of friction.

The other end of the metering vane shaft also protrudes through its bearing and carries the attachment for the inner end of a specially calibrated control spring. The outer end of the spring is anchored toa disc plate which can be rotated by a pinion meshing with teeth cut in the periphery of the plate. This provides for adjustment of the spring to requeuing transmitter calibration.

Any tendency for the metering assembly and transmission element to oscillate under static flow rate conditions is overcome by a liquid damping system, the liquid being the fuel itself. The system comprises a damping chamber containing a counterweight and circular vane which are secured to the same end of the metering vane shaft as the control spring. The damping chamber is secured at one side of the transmitter body, and except for a small bleed hole in a circular blanking plate, is separated from the metering chamber.

The purpose of the bleed hole is, of course, to permit fuel to fill the damping chamber and thus completely immerse the counterweight assembly. The effectiveness of the damping system is uninfluenced by the fuel flow. A threaded plugin the outer cover of the damping chamber provides for draining of fuel from the chamber.

The indicator is of simple construction, being made up of a moving coil milliammeter which carries a single pointer operating over a scale calibrated in gallons per hour, pounds per hour or kilograms per hour. The signals to the milliammeter are transmitted via a transistorized amplifier which is also contained within the indicator case. In systems employing synchronous transmission, the indicator pointer is operated by the rotor of a receiver synchro.

OPERATION

When fuel commences to flow through the main supply line it enters the body of the transmitter and passes through the metering chamber. In doing so it deflects the metering vane from its zero position and tends to carry it round the chamber.
Since the vane is coupled to the calibrated spring, the latter will oppose movement of the vane, permitting it only to take up an angular position at which the tension of the spring is in equilibrium with the rate of fuel flow at any instant. Through the medium of the magnetic lock coupling the vane will also cause the potentiometer wiper to be displaced, and with a steady direct voltage across the potentiometer the voltage at the wiper is directly proportional to the fuel flow.
The voltage is fed to the amplifier, whose output current drives the milliammeter pointer to indicate the fuel flow. In a system 'employing synchro's, the current flow due to differences in

angular position of the rotors will drive the indicator synchro rotor directly to the null position and thereby make the indicator pointer read the fuel flow.

The transmitter to provide a by-pass for the fuel in the event of jamming of the vane or some other obstruction causing a build-up of pressure on the inlet side and the valve is of the simple spring loaded type in corporate in the metering chamber.

The spring tension is adjusted so that the valve lifts from its seat and allows fuel to by-pass the metering chamber when the difference of pressure across the chamberexceeds2-5 lbfJin2.

INTEGRATEDFLOW METER

The system which the element indicating fuel consumed is combined with that required for fuel flow, thus permitting the display of both quantities in a single instrument. A device which will give directly the fuel consumed over a period of time from the flow rate during that period and a time integrator needed to work out fuel consumed in the ratio of fuel flow rate to time.

Such a device may be mechanical, for minganintegral part of an indicator mechanism, or a sin electronic flow meter system it may be a special dividing stage within the amplifier or even a completely separate integrator unit.

The system consists of three principal units: flow transmitter, electronic relay or computer, and indicator. Its operation depends on the principle that the torque required to accelerate fluid to a given angular velocity is a measure of the fluid's mass flow rate.
The angular velocity, which is imparted by means of rotating impeller and drum, sets up are action to establish relative angular

Displacements between the impeller and drum. Inductive-type pick offs sense the displacements in terms of signal pulses proportional to the flow rate and supply them via the amplifier computer, to the indicator.

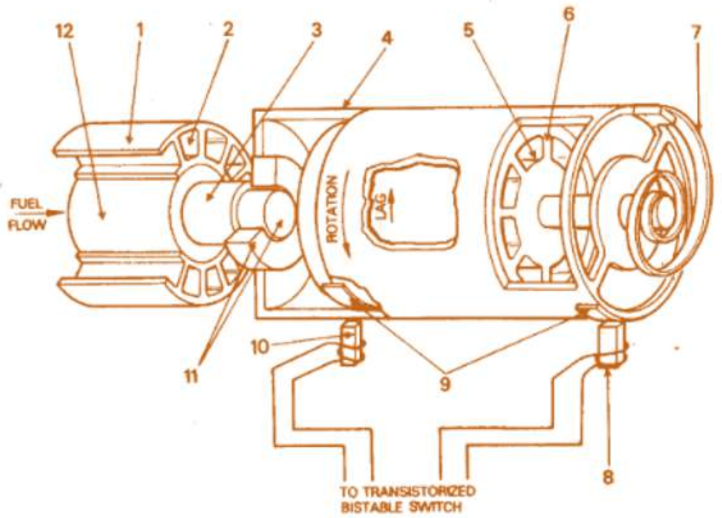


Fig. Fuel-flow transmitter of a typical integrated system.
1Turbine,2fluidpassage,3shaft,4light-alloy body, Fluid passage, 6 impeller, 7restrain-inspiring, 8 pick-off assembly, 9 magnets, 10 pick-offassembly11 magnetic coupling, 12rotors

The transmitter, shown schematically sectioned, consists of alight- alloy body containing a flow metering chamber, a motor driven impeller assembly, and an externally mounted inductor coil assembly.

The impeller assembly consists of an outer drum which is driven through a magnetic coupling and reduction gear, by asynchronous motor, and an impeller incorporating vanes to impart angular velocity to fuel flowing through the metering chamber. The drum

and impeller are coupled to each other by a calibrated linear spring.

The motor is contained within a fixed drum at the inlet end and rotates the impeller at a constant speed, straightening vanes are provided in the fixed drum to remove any angular velocity already present in the fuel before it passes through the impeller assembly.
A point to note about the use of a magnetic coupling between the motor and impeller assembly is that it overcomes the disadvantages which in this application would be associated with rotating seals.

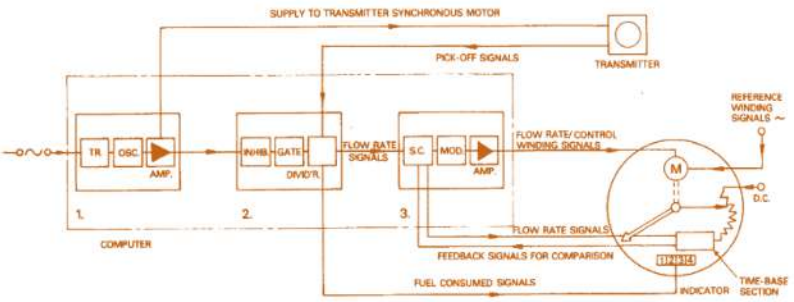


Fig. Fuel-flow transmitter integrated system.
1 Turbine,2fluid passage,3shaft,4light-alloy body,Sfluidpassage,6impeller,7 restraining spring, 8 pick-offassembly,9magnets,10 pick-off assembly11 magnetic coupling, 12 rotors.

The motor and its driving gear are isolated from fuel by enclosing the mina chamber which is evacuated and filled with an inert gas before sealing. Each of the two pick-off assemblies consists of a magnet and an iron-cored inductor. One magnet is fitted to the outer drum while the other is fitted to the impeller, thus providing the required angular reference points. The magnets are so

positioned that under zero flow conditions they are effectively in alignment with each other.

The coils are located in an electrical compartment on the outside of the transmitter body, together with transistorized units which amplify and switch the signals induced. The computer performs the overall function of providing. The integrated power for the various circuits of the system, detecting the number fuel flowmeter system of impulses produced at the transmitter, and computing and integrating the fuel flow rate and amount of fuel consumed.

It consists of a number of stages interconnected in three distinct sections. The stages of sections2and3consistof transistors and their associated coupling capacitors and resistors. The power supply section (1) controls the voltage and frequency of the supply to the transmitter synchronous motor, and consists of a transformer, transistorized crystal oscillator, output, and power amplifier units.

The section2ismadeupofthree stages: inhibitor, gate, and divider. The respective functions of these stages are: to suppress all transmitter signals below a certain flow rate; to control or gate the pulse signals from the power-supply oscillator; and to produce output signals proportional to true flow rate; to provide the time dividing factor and output pulses representing unit mass of fuel consumed.Section3isalsomade up of three stages: signal comparator, modulator and servo amplifier.

The respective functions of these stages are to compare the transmitter output signals with time-base signals fed back from the indicator; to combine the comparatoroutputwith400Hz alternating current and produce a new output; to provide an operating signal to the indicator servo motor control winding.

The indicator employs flow indicating section consisting of a 400Hzservomotorwhichdrivesapointer and potentiometer wiper through a reduction gear train. The reference winding of the motor is supplied with a constant alternating voltage, while the control winding receives its signals from the computer servo amplifier.

The potentiometer is supplied with direct current and its wiper is electrically connected to a transistorized time-base section, also with in the indicator. Transmitter output signals are also fed into the time-based section via a pre-set potentiometer which forms part of the computer signal comparator stage. The difference between the time base and the indicated fuel-flow signal voltages is fed to the servo motor which operates to reduce the error voltage to zero and so to correct the indicated fuel flow.

The fuel-consumed section of the indicator consists of a solenoid actuated 5dmm digital counter and a pulse amplifier. The amplifier receives a pulse from the divider stage of the computer for each unit mass of fuel consumed and feeds its output to the solenoid, which advances the counter drums appropriately. A mechanical reset button is provided for resetting the counter to zero.

OPERATION

When electrical power is switched on to the system, the synchronous motor in the transmitter is operated to drive the impeller assembly at a constant speed. Under zero fuel flow conditions the magnets of the pick- off assemblies are effectively in line with one another,

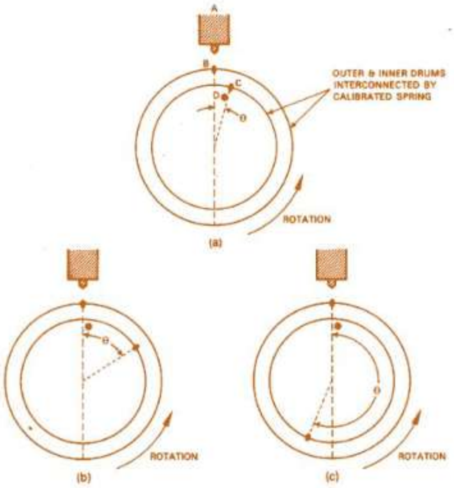


Fig. Operation of transmitter pick offs(a)Zero fuel flow A, Two Pick-off coils(one behind the other),p. C, vrgnets, D, stop(gives 3 to5 deflection), 8Lag angle at which both drum^ rotate together; (b) cruising fuel flow; (c)maxi-mum fuel flow.

A small angular difference established to maintain a deflection representing a specific minimum flow rate. This is indicated in Fig (a). As the fuel flows through the transmitter metering chamber, a constant angular velocity is imparted to the fuel by the rotating impeller and drum assembly, and since the two are interconnected by a calibrated spring, are action torque is created which alters the angular displacement between impeller and drum, and their corresponding magnets. Thus, angular displacement is proportional to flow rate. Figs(b)and(c) illustrate the displacement for typical cruising and maximum fuel flow rates.

The position of each magnet is sensed by its own pick-off coil, and the primary pulses induced as each magnet moves past its coil is fed to the dividing stage in the computer. The output from this stage is fed to the control winding of the indicator servo motor via section3ofthecomputer,andtheindicatorpointerisdrivento indicate the fuel flow.

At the same time, the motor drives the potentiometer wiper, producing a signal which is fed back to the signal comparator stage and compared with the output produced by the transmitter. Any resultant difference signal is amplified, modulated and power amplified to drive the indicator motor and pointer to a position indicating the actual fuel flow rate.

OILPRESSURE AND TEMPERATURE OILPRESSURE INDICATINGSYSTEM Remote indicating system

The system is consisting of two main components in which a transmitter unit located at the pressure source and an indicator located on instrument panel and the pressure is measured by transmitter and transmits the data through an electrical transmission circuit to the indicator.

The sensor unit is in the form of metal capsule, diaphragms, or bellow. The element(transmitter) are mechanically connected to electrical transmitters are of the moving core or synchro type induction device and are connected to indicator which incorporate either moving coil mechanism, synchro receiver, d. c. or a. c ratio meters or servo-operated d. c. synchronous System.

D. c. Synchronous system

The arrangement of a transmitter working on the principle of micro desync system.

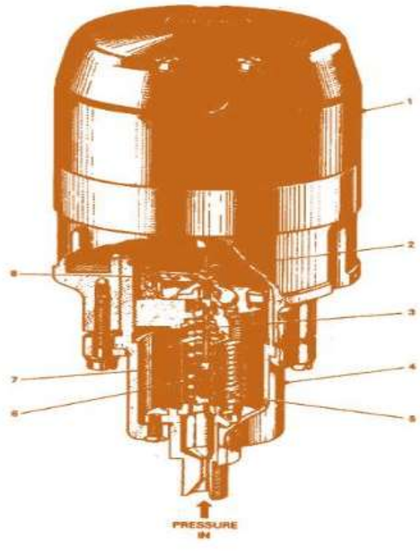


Figure. Micro Desync Transmitter

1 Micro- Desync transmitting element,
2 eccentric pin, 3 push rod, 4 pressure-sensing element, 5 bellows, 6 cup shaped pressing,
7 spring, 8 rocking levers

Construction

The pressure-sensing element consists of a bellows, which is open to the pressure source. A cup shaped pressing is fitted inside the bellows and forms a connection for a pushrod which bears against a rocking lever pivoted on a fixed part of the mechanism. A spring is provided inside the bellows.

The electrical element is positioned in the transmitter body in such a manner that the eccentric pin is also in contact with the pivoted rocking lever.

Operation

When pressure is admitted to the interior of the bellow sit expands and moves the pushrod up, thus rotating the rocking lever intern moves the eccentric pin and brushes coupled to it through a small angle over the coils. The resistance changes produced setup varying voltage and current combinations within the indicator, which is calibrated for the appropriate pressure range.

D.C. Ratiometer type pressure transmitter

The element has two brushes and resistance coils, but instead of the normal micro-Desync method of connection and are connected as a simple twin resistance parallel circuit. The two connections terminating at the coils are joined to the appropriate terminals of a ratio meter.

Operation

The movement of the bellow sand brushes results in a change of circuit resistance proportional to the pressure change, which is measured as a coil current ratio.

A.C. Inductor and ratiometer System

The operation of this system is dependent on the production of a current ratio by a variable inductor transmitter,

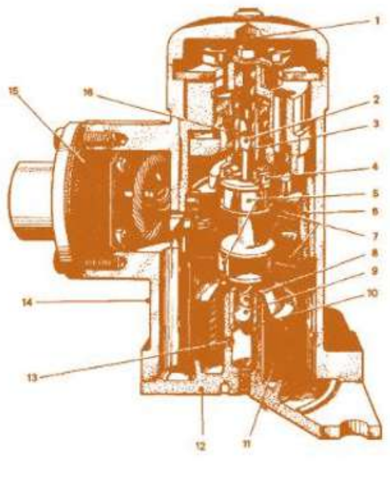


Figure inductor-type transmitter.

1 Overload stops crew, 2centre
spindlebearing,3guidebush,4aluminiumcup,5armaturecores,6 aluminum housing, 7 stators and windings, 8centre
spindle assembly, 9 Centre spindle bearing, 10guidebush,

11bellows,12baseplate,13radialducts,14body,15electrical connector,16main spring.

CONSTRUCTION:

It consists of a main body containing a bellows and two single- phase two-pole stators each surrounding a laminated salient-pole armature core which is on a common shaft. When the pressure increases, the lower core (A) moves further into its associated stator coil, while the upper core(B) moves outfits coil. The coilsaresuppliedwith26V,400Hzacvoltage.Aspringprovides a controlled loading on the bellows and armature cores to set the starting position of the cores during calibration.

The coils around the laminated cores are connected to the transmitter stator coils, and a gap is provided with in the limb of each core. To permit free rotation of two aluminum cam-shaped discs which form the moving element? When the element rotates in a clockwise direction, the effective radius of the front disc decreases in its air gap, while that of the rear disc increases.

The moving element is damped by a circular is cattherear end of the shaft, and free to rotate between the poles of a permanent magnet. A hairspring is provided to return the pointer to the off- scale position in the event of a power failure.

When the bellows expand under an increasing pressure, the armature cores move in their respective stators, and since the latter are supplied with alternating current, there is a change in the inductance of the coils. Thus, core a, moves further into its stator and increases the inductance and impedance, and core B, in moving out of its stator, decreases the inductance and impedance. The difference between the two may therefore be interpreted in terms of pressure.

As the stator coils are connected to the indicator coils in the form of a bridge network, then the changes in impedance will produce a change of current in the indicator coils at a predetermined ratio. The current is alternating, and so produces alternating fluxes in the laminated cores and across their gap sand that copper shading rings are provided at the air gaps.

The effect of the alternating flux is to induce eddy currents in the rings, these current sin turn setting up their own fluxes which react with the air gap fluxes to exert a torque on the cam shaped discs. The resulting movement of the cam discs is arranged to be in a direction determined by the coil carrying the greater current, and due to the disposition of the discs, this means there will be a
Difference between their torques, In the gap affected by the greater current and the effective radius of its disc (a) decreases, thereby increasing the impedance and decreasing the torque, while in the gap affected by the weaker current, the converse is true. We thus have two opposing to rques controlling the movement of the discs and pointer, the torques being dependent on the ratio of currents in the coils.

Note:

The variation of frequency of ratio meter indicator is compensated by connecting a capacitor in parallel with each coil. The temperature effects are compensated by connecting ahigh- temperature-coefficient resistor across the coils of the indicator.

INDICATINGSYSTEM

There are following pressure measuring indicating system:

1. Synchronous transmission pressure indicating systems.
2. Moving core inductive sensor and servo operated Indicating system.
3. AC inductor type pressure transmitter and moving coil indicating system

1. Synchronous transmission pressure indicating systems.

This arrangement is employed in turbine engine oil pressure indicting system in which the rotor of Transmitting(TX)synchro is connected in between the two bellows through a mechanical quad rant and pinion. One is sensitive to oil pressure and the other to prevailing ambient pressure in the cowled area of the engine.

The rotor is positioned to produce output signals proportional to the difference between the two(Gauge Pressure) pressure and in responds to these signals, the receiving transmitter (TR)rotor position the pointer over the indicator scale.

Note

In the event of failure of power supply to the system, the indicator pointer will remain at the pressure value that was being measured at time of failure

Fig integrated pallet page309

2. Moving core inductive sensor and servo operated
Indicating system.

ThissystemofarrangementsisemployedinBoeing747aircraft for the measurement of such parameter as engine oil and oil filter inlet pressures, fuel pump inlet and discharge pressure and engine breather pressure.

Construction

The indicator contains dual servomechanism connected to individualtransmitters.one of which the oil pressure and the other oil filter in let pressure. The only difference between the two is their operating pressuring which is respectively from 0 to100 psi and 0 to 200 psi.

Operation

When pressure is applied to the capsules cause ovary the position of the inductor core cause to change in reluctance between the two windings and output signals will be supplied to

amplifier of the indicator servo mechanisms to drives a double pointer , one part of which register against the fixed outer scale.

The mechanism which is connected to the oil filter inlet pressure transmitter drives an inner disc with an index marker that is also register against the outer scale. The inner disc is also has a scale which register against the second part of the double pointer so that a continuous indication of pressure difference is provided.

The servo motor of each mechanism drives a potentiometer which provides feedback signals to balance out the misalignment signal. A solenoid operated flag is provided in the indicator and comes in viewwheneverthereisafailureof26Vacpowersupply to the system.

Example

Theoilpressureindicates50psiandfilterinletpressureis100 psi, so that the differences indicate 50 psi.

3. AC inductor type pressure transmitter and moving coil indicating system

In which a capsule position an armature core relative to air gaps in the stator core. When pressure applied, the length of the air gap associatedwithstatorcoil1isdecreased,whilethatassociated with coil 2 is increased.

As the reluctance of the magnetic circuit across each coil is proportional to the effective length of the air gap, then the inductanceofcoil1willbeincreasedandthatofcoil2will be decreased, the current flowing in the coils will be decreased and increased. The output signals are supplied to a moving coil type indicator which operates on the dc ratio meter principle.

Fig. Pressure Transmitter

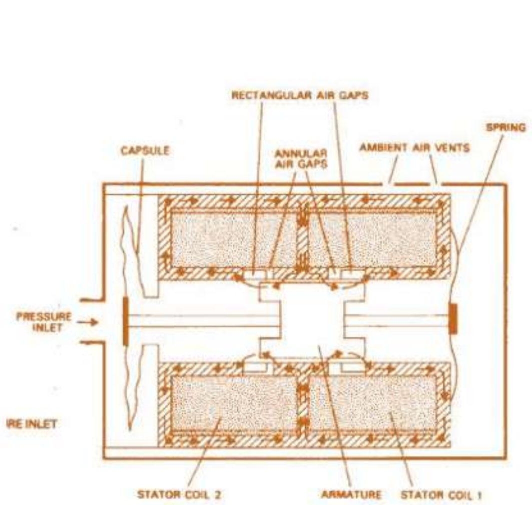


Fig Inductor type of Pressure Transmitter

OILTEMPERATURE INDICATINGSYSTEM

1. Variable-resistance system

It consists of sensor unit (referred to bulb) and indicators are connected in series.

Supply: dc power from relevant bus bar

Sensor Unit: It employed a resistance made of Nical/platinum wire. The sensor unit used for the measurement of liquid temperatures.

Indicator: Moving coil type based on the principle of Wheatstone bridge.

Sensor Unit: The resistance coil is wound on an insulated former and the ends of the coil are connected to a two-pin socket(ora plug) through contact strips. The 'bulb' casing is used to protect and seal the coil assembly and is made of stainless-steel tube in which closed at one end and secures to a union nut at the other end.

The resistance coil is wound at the bottom end of its former and not along the full length to ensure that the coil is well immersed in the hottest part of the liquid to minimizing the errors due to radiation and conduction losses.

A calibrating or balancing coil made of Manganin or Eureka wire, is connected in series with the sensor coil and pre-set in value during initial calibration by the manufacturer.

Note:
A calibrating or balancing coil is used to obtain a standard
constant temperature/ resistance characteristic.

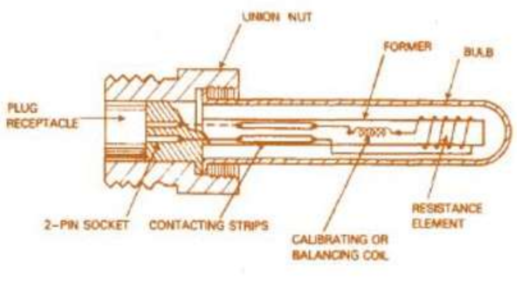


Fig. Temperature sensor

Wheatstone bridge system

The circuit is made up off our resistance's arms, RI, R2, R3 andR4. The variable resistance arm RX of the Wheatstone bridge forms the temperature sensor (bulb) and other three fixed resistance are connected to a moving-coil(galvanometer).

The moving-coil(galvanometer) is wounded on the former which is pivoted so that it can rotate within the field of permanent magnet by means of two calibrating spring and connected across points B and D of the bridge. The voltage is connected across the points A and C.
Operation

When the sensor R, is subjected to temperature variations, its resistance will also vary. This will unbalance of the bridge circuit, and the value of Rx at any particular temperature will govern the amount of current flowing through the moving coil.

The out-of-balance current is a measure of the prevailing temperature. The coil current produces a surrounding magnetic field which interacts with that of the permanent magnet causes a rotation of the coil and deflects the pointer over a scale to indicate the temperature of the liquid.

Note:

At which the circuit is balanced, and no current will flow through the moving coil referred to a null point and denoted by a datum mark, against which the pointer registers when the power supply is disconnected. A bridge circuit has the disadvantage of out-of- balance current depends on the voltage of the power supply cause an error in indicated readings.

Ratiometer System
A ratiometer-type temperature-indicating system consists of

1. Sensing element
2. Moving-coil indicator,

1. Sensing element

It has two coils moving together in permanent-magnet field of non- uniform strength. The coil arrangements and methods of obtaining the non-uniform field depend on the manufacturer's design.

There are three methods

In which the following two parallel resistance arms are connected to the temperature sensing element Rx

a. A coil and a fixed calibrating resistance R,
b. A coilin series with acalibratingresistanceR2

Note:

Both arms are supplied with direct current from the air craft's main power source, but the coils are so wound that current flows through them in opposite directions.

In any moving-coil indicator, rotation of the measuring element is produced by forces which are proportional to the product of the current and field strength, and the direction of rotation depends on the direction of current relative to the magnetic field.

In a ratio meter, the force produced by one coil will always tend to rotate the measuring element in the opposite direction to the force produced by the second coil. The coil carrying the greater current will always move towards the area of the weaker field, and vice versa.

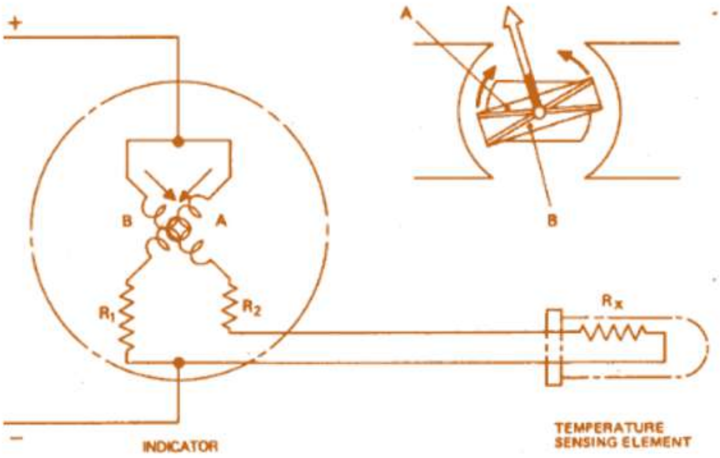


Fig. Temperature measurement ratiometer circuit

The basic circuit employs an indicator has the crossed-coil winding method and that winding B is connected with the variable-resistance arm(RX)and winding A is in the fixed- resistance arm.

The resistances of the arms are so chosen that at the zero position of the instrument the forces produced by the currents flowing in each winding are in balance. The balancing of the torques is always produced by the strength of the field in which the windings are positioned.

Operation

When the temperature at the sensing element R, increases, its resistance will increase cause a decrease in the current flowing in winding B and a corresponding decrease in the force created by it. The current ratio is altered and the force in winding A will rotate the measuring element.

Note:

When the temperature at the sensing element stabilizes at its new value, the forces produced by both windings will once again balance, at a new current ratio and the angular deflection of the measuring element will be proportional to the temperature change.

When the measuring element is at the mid- position of its rotation, the currents in both windings are equal.

A ratio meter system does not require hairsprings for exerting a controlling torque; this being provided by the appropriate coil winding and non-uniform field arrangements. But a spring is used to return the measuring element to off scale when the power supply is disconnected.

Example:
Ratio meter system of temperature measurement of Boeing737 aircraft

It consists of twin coil former system supplied with26V ac ,two potentiometers (one for range and other for centralizing i.e., midscale adjustment),a cabinet temperature compensator(ambient temperature)and swept off magnet and crank which mechanically moves the measuring element to an off-scale position.

FUELTEMPERATURE INDICATINGSYSTEM Effects of fuel temperature changes
With changes in temperature the volume, density and relative permittivity of fuels are affected. Since fuel quantity measuring system by volume, the indicator pointer movement is directly dependent on this. It varies in the same
Way as density, the percentage change is greater. Thus, a volumetric gauge system will be subject to a small error due to variations in fuel temperature. Furthermore, changes in K and density also occur indifferent types of fuel having the same temperature.

Example

A gauge system which is calibrated for a K-valueof2.1hasa calibrationfactorof2.1-1= 1.1.Ifthesame system is used for measuring a quantity offuelhavingaK-valueof2.3,thenthecalibrationfactorwillhave increasedto1.3andthe error in indication will be approximately1.3Errorin indication: x
100 =18% i.e., the gauge would over read by18%.

The computer divider stage also uses the transmitter signals to produce pulse 'time' signals for the operation of the fuel- consumed counter of the indicator. During each successive revolution of the transmitter impeller assembly the pulses are added and divided by as elected ratio, and then supplied to the counter as an impulse for each kilogram or pound of fuel consumed.

MANIFOLDPRESSURE

Manifold pressure gauges or 'boost' gauges as they are colloquially termed, are of the direct-reading type and are calibrated to measure absolute pressure in inches of mercury.

The power output of an internal combustion engine depends on the density of the combustible mixture of fuel and air introduced into its cylinder sat that part of the operating cycle known as the induction stroke.

On this stroke, the piston moves down the cylinder, an inlet valve opens, and the fuel air mixture, or charge prepared by the carburetor, enters the cylinder as a result of a pressure difference acting across it during the stroke.

If an engine is running in atmospheric conditions corresponding to the standard sea-level pressure of14.7lbf/in2,andthecylinder pressureisreducedtosay,2ibf/in2,thenthepressuredifference is12.7lbf/in2,anditisthispressuredifferencewhich'pushes' the charge into the cylinder.

SUPER CHARGINGOR BOOSTINGOFANAIRCRAFT

This limitation on the high-altitude performance of a normally aspirated engine can be overcome by artificially increasing the available pressure so as to maintain as far as possible a sea-level value in the induction system. The process of increasing pressure and charge density is known as super charging or boosting,

SUPER CHARGINGOR BOOSTINGPROCESS

A centrifugal air pump fitted between the carburetor and cylinders and driven from the engine cranks haft through step-up gearing. It pumps by giving the air a very high velocity, which is gradually reduced as it passes through diffuser vane sand a volute, the reduction in speed giving the required increase in pressure. In order to measure the boost pressure/absolute pressure delivered by the super charger is indicated by Manifold/ Booster pressure gauge.

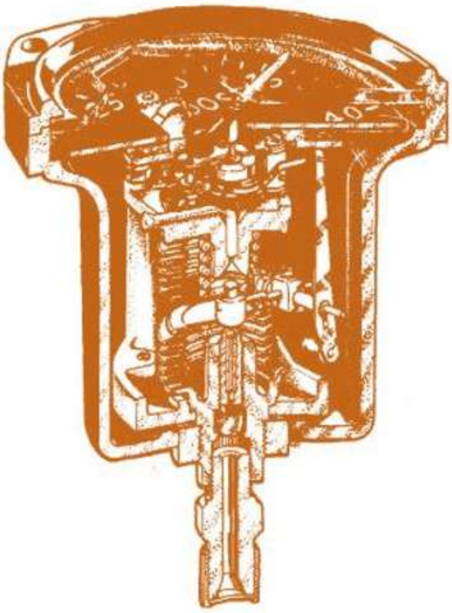


Fig. Manifold pressure gauge

The measuring element of Manifold/ Booster pressure gauge is made up of two bellows, one open to the induction manifold and the other evacuated and sealed. A controlling spring is fitted inside the sealed bellows and distension of both bellows is transmitted to the pointer via the usual lever, quadrant, and pinion mechanism. A filter is located at the inlet the open bellows, where the reis also a restriction to smooth out any pressure surges.

When pressure is admitted to the open bellows the latter expands causing the pointer to move over the scale (calibrated in inches of mercury)and so indicate a change in pressure. With increasing altitude, the reisatendency for the bellows to expand a little too far because the decrease in atmospheric pressure acting on the outside of the bellows offers less opposition.

However, this tendency is counteracted by the sealed bellows, which also senses the change in atmospheric pressure but expands in the opposite direction. Thus, a condition is reached at which the forces acting on each bellows are equal; cancelling out the effects of atmospheric pressures that manifold pressure is measured directly against the spring.

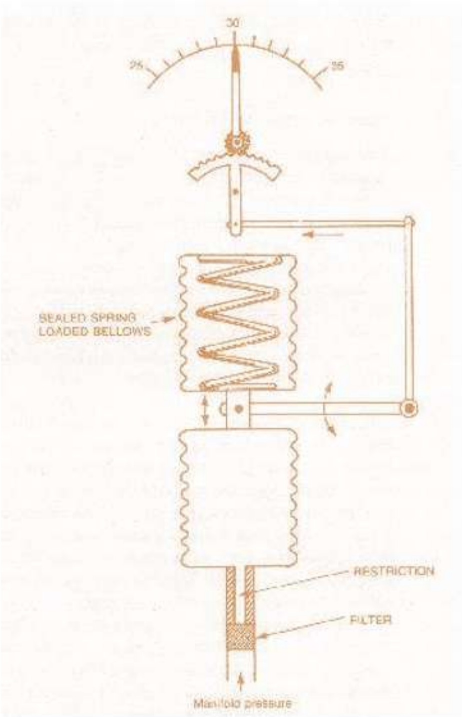


Fig. manifold pressure gauge

TORQUE PRESSURE

These indicators supplement the power indications obtainable from tachometers and manifold pressure gauges by measuring the pressures created by a torque meter system, such pressures being interpreted as power available at the propeller shaft, the torque meter system forms part of the engine itself and is usually built-in with the reduction-gear assembly between the crank shafts and propeller shaft.

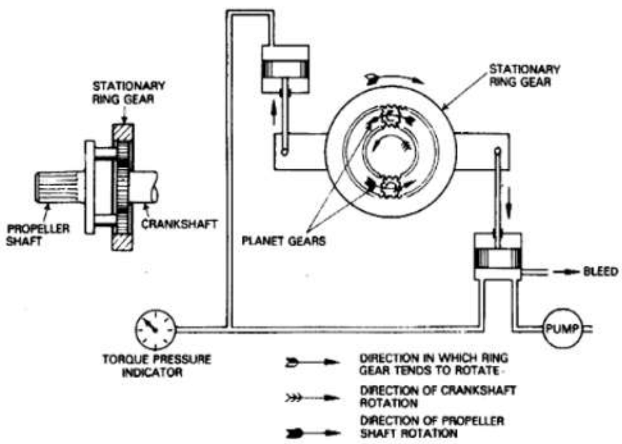


Fig. principle of torque meter

The construction of a system depends on the type of engine, but in most cases the operation is based on the same principles, i.e., the tendency for some part of the reduction gear to rotate is resisted by pistons working in hydraulic cylinders secured to the gear casing. The oil from the engine system is supplied to the cylinders via a special torque meter pump and absorbs the loads due to piston movement. The oil is thus subjected to pressures which are proportional to the applied loads or torques and are transmitted to the torque pressure-indicating system, which is normally of the remote indicating synchronous type.

The brake horsepower is calculated by the following formula:
BHP=p N/K where p is the oil pressure, N the speed (rev./min.) and K a torque meter constant derived from the reduction gear ratio, length of torque arm, and number and are a of pistons.

Turbo prop engines are, as far as power is concerned, similar to large, supercharged piston engines; most of the propulsive force is produced by the propeller, only a very small part being derived from the jet thrust. They are therefore fitted with a torque meter and pressure gauge system of which the oil pressure readings are an indication of the shaft horsepower. The torque meter pressure gauge is used in conjunction with the tachometer and turbine gas- temperature indicators.

The indicating system used is governed by the particular type of engine, but there are two main systems in current use and their operating principles are based on the Desync and alternating current synchro methods of transmission.

Desynn Torque Pressure Indicating System

The transmitter comprises both mechanical and electrical elements. The mechanical element consists of a Bourdon tube the open end of which is connected by a flexible hose to the supply line from the oil pump of the engine torque meter. The free end of the Bourdon tube is connected to the brushes of the electrical element via a sector gear and pinion. A union mounted adjacent to the main pressure connection is connected to a capillary tube accommodated with in the Bourdon tube and allows for the bleeding of the system.

The transmitter is mounted in a special anti-vibration mounting, the whole assembly being secured to the engine itself.

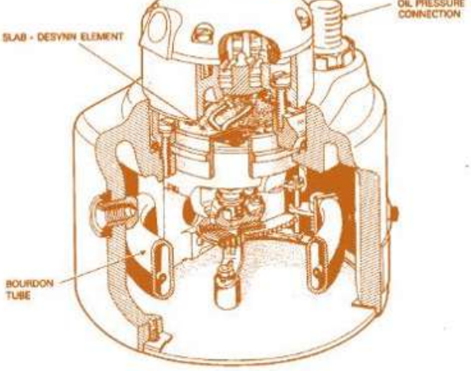


Fig Desynn Torque Pressure Transmitter

With the engine running the pressure produced at the pistons of the torque meter system is sensed by the transmitter Bourdon tube, the free end of which is distended so as to change the radius of the tube. The movement of the free end is magnified by the sector and pinion, which causes the brushes to be rotated over the slab-wound resistor. The resulting current sand magnetic field produced in the' indicator stator, position the rotor and pointer to indicate the torque pressure on a dialcalibratedfrom0to600 lbf/in2.Duringoperation,andduetopulsationsoftorque meter pressure, a certain amount of pointer fluctuation is possible, but this is limited to30 lbf/in2oneithersideofameantorquemeter pressure eading.

SYNCHRO TORQUE PRESSURE INDICATINGSYSTEM

This system is an application of the alternating-current control synchro principle in which the mechanical element of a synchro torque pressure transmitter is very similar to that of the slab-Desynn type. The Bourdon tube, sector gear and pinion are arranged to drive the rotor of a CX synchro. The transmitter is designed for mounting directly on to an engine an disconnected by flexible tubing to the torque meter system.

The indicator consists of a CT synchro connected to the transmitter synchro CX, a two-stage transits or amplifier, a two- phase servo motor, and two concentrically mounted pointers driven through a gear box.

The smaller pointer indicates hundreds of pounds and rotates in step with the synchro rotor, while the larger pointer rotates ten times as fast.

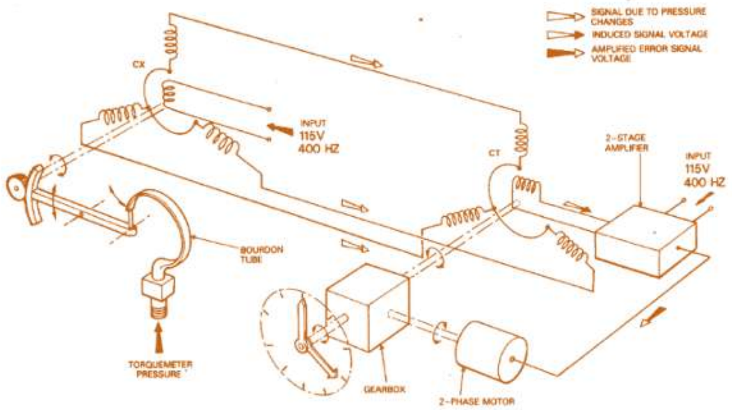


Figure: Synchro torque pressure indicating system

When the Bourdon tube sensesachangeintorquemetersystempressureitcausestheCXrotortoptateandtoinducea signal which is then transmitted to the stator of the CT sync Luo- type synchro in the indicator. This signal results in a change in direction indicating system.

The resultant magnetic field with respect to the CT rotor position, thus inducing an error voltage signal in the rotor. The error signal is fed to the amplifier, which determines its direction, i.e., whether it results from an increase or decrease in pressure, as well as amplifying it.

The amplified signal is then applied to the control phase of the servo motor, which, via the gear box, drives the pointers in the appropriate direction and also drives the CT rotor until it reaches a new null position at which no further error voltage signal is induced.

POWER INDICATORS FOR TURBOJET ENGINES

With turbo jet engines the number of instruments required for power monitoring depends upon whether the engine employs a centrifugal Oran axial type of compressor. The thrust of a centrifugal compressor engine is approximately proportional to the speed, so that the tachometer, together with the turbine gas- temperature indicator, may be used to indicate thrust at the specified throttle setting.

The thrust produced by an axial compressor engine does not vary indirect proportion to the speed, the thrust ratings being calculated in such a way that they must be corrected for variations in temperature and pressure prevailing at the compressor intake.

Since compressor in take pressure is related to the outlet or discharge pressure at the turbine, then thrust is more accurately determined by measuring the ratio between these two pressures. This is done by using an engine pressure ratio indicating system or, in some cases by a percentage thrust indicator in conjunction with the rev/min. turbine gas-temperature and fuel-flow indicators.

PROPELLER SPEED SYNCHROSCOPE

The aircraft powered by a multi-arrangement of either piston engines, or turbo propeller engines, the problem a rises of maintaining the engine speed sin synchronism at 'on-speed' conditions and so minimizing the effects of structural vibration and noise.

The simplest method of maintaining synchronism between' engines would be to manually adjust the throttle and speed control systems of the engines until the relevant tachometer indicators read the same.

Therefore, when made to read the same operating speeds, the engines would in fact be running at speeds differing by the indication errors. In addition, the synchronizing of engines by a direct comparison of tachometer indicator readings is made somewhat difficult by the sensitivity of the instruments causing a pilot or engineer to overshoot or under shoot an on-speed condition by having to' chase the pointers'.

In order to facilitate manual adjustment of speed an additional instrument known as a synchro scope was introduced. It provides a qualitative indication of the differences in speeds

between two or more engines, and by using the technique of setting up the required on-speed conditions on a selected master engine, the instrumental so provides a clear indication of whether a slave engine is running faster or slower than the master.

The operation is based on the principle of the induction motor, which, for this application, consists of a three-phase star- wound laminated stator and a three-phase star-wound laminated rotor pivoted in jewelled bearings within the stator.

The stator phases are connected to the tachometer generator of the slave engine while the rotor phases are connected to the master engine generator via sliprings and wire brushes.

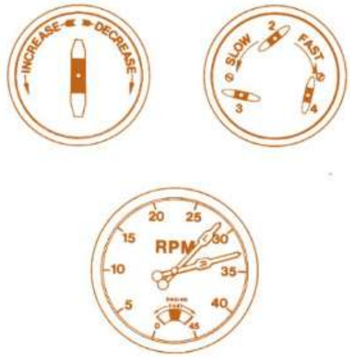


Figure: Dial presentations of synchroscopes.
(a) Twin-engine; (b) four engines;(c)combined dual

A disc at the front end of the rotor shaft provides for balancing of the rotor. The pointer, which is double ended to symbolize a propeller, is attached to the frontend of the rotor shaft and can be rotated over a dial marked INCREASE at its left-hand side and DECREASE at its right-hand side.

On some synchroscopes the left-hand and right-hand sides may be marked SLOW and FAST respectively. Synchro scopes designed for use in four-engine aircraft employ three separate induction motors, the rotor of each being connected to the master engine tach generator while each stator is connected to one of the three other generators.

OPERATION

The installation of a typical twin engine aircraft tachometer system, and the master engine, and this is usually the No l, has been adjusted to their quired 'on-speed' condition and that the slave engine has been brought into synchronism with it.

Now, both generators are producing a three-phase alternating current for the operation of their respective indicators, and this is also being fed to the synchro scope, generator No1 feeding the rotor synchro scope and No 2 the stator.

Thus, a magnetic field is setup in the rotor and stator, each field rotating at a frequency proportional to its corresponding generator frequency, and for the phase rotation of the system, rotating in the same direction. For the conditions assumed, and because generator frequencies are proportional to speed, it is clear that the frequency of the synchro scope stator field is the same as that of the rotor field.

This means that both fields reach their maximum strength at the same instant; the torques due to these fields is in balance, and the attraction between opposite poles keeps the rotor 'locked' in some stationary position, thus indicating synchronism between engine speeds.

The effect to the slave engine running slower than the master. The frequency of the slave engine generator will be lower than the master engine generator, and consequently the stator field will be lagging behind the rotor field.

The rotor, in being magnetized faster than the stator, tries to rotate the stator and brings the stator field into alignment, but the stator is a fixed unit; therefore, a reactive torque is setup by the interaction of the greater rotor torque with the stator.

This torque causes the rotor to turn in a direction opposite to that of its field so that it is forced to continually realign itself with the lagging stator field. The continuous rotation of the rotor drives the propeller-shaped pointer round to indicate that the slave engine is running SLOW and that an INCREASE of speed is required to bring it in to synchronism with the master engine,

If the slave engine should run faster than the master then the synchro scope stator field would lead the rotor field, reaching maximum strength at, say, point b. The stator field would then produce the greater torque, which would drive the rotor to realign itself with the leading stator field, the pointer indicating that the slave engine is running FAST and that a DECREASE of speed is required to synchronize it.

As the speed of the slave engine is brought into synchronism once again, the generator frequency is changed so that a balance

Between fields and torques is once more restored and the synchro scope rotor and pointer take up a stationary position.

The rotation Indicators In some aircraft using by-pass turbine engines, indicators are provided to indicate that the shaft of the low-pressure compressors commences to rotate during the starting cycle, and that it is safe to continue the cycle.

The basis of an indicator is a two-stage magnetic amplifier operating from a 1 15 V 400 Hz a.c. supply and connected to one phase of a normal tachometer generator. The signals from the generator are fed into the amplifiers are reference in put in revolutions per minute. An indicator lamp mounted on the main instrument panel, or flight engineer's panel, is connected to the amplifier ‘output stage. When the speed voltage input signal reaches acritical level, usually
6mVcorrespondingtoarotationspeedofa'fractionof1rev.
/min., sufficient output current is produced to light the indicator lamp.

The speed is reached in the first few degrees of rotation; therefore, the lamp provides an immediate indication that the low- pressure shaft has rotated. Signal sin excess of the critical cause the amplifier to saturate and the lamp to remain alight but without being overloaded.

The power supply is fed to the amplifier via an engine-starting circuit and is isolated once the starting cycle is satisfactorily concluded. In multi- engine, a single amplifier and lamp serve to indicate rotation of each engine being automatically selected during each starting cycle.

14.3 Starting and Ignition Systems

Start Sequence

Cranking the Engine

Two separate systems are required to start a gas turbine engine, a means to rotate the compressor/turbine assembly and a method of igniting the air/fuel mixture in the combustion chamber. Ideally the process is automatic after the fuel supply is turned on and the starting circuit brought into operation.

The starter motor is capable of cranking the engine to a speed slightly higher than that at which sufficient gas flow is generated to enable the engine to accelerate under its own power.

At nearly stage in the cranking operation, the igniter plugs in the engine combustion chamber are supplied with electrical power, followed by the injection of fuel when fuel pressure has built up sufficiently to produce anatomized spray.

Light-up normally occurs at this point and the engine assisted by the starter motor; accelerates to self-sustaining speed.

Self-Sustaining Speed

This is the speed at which the energy developed by the engine is sufficient to provide for continuous operation of the engine without the starting device.

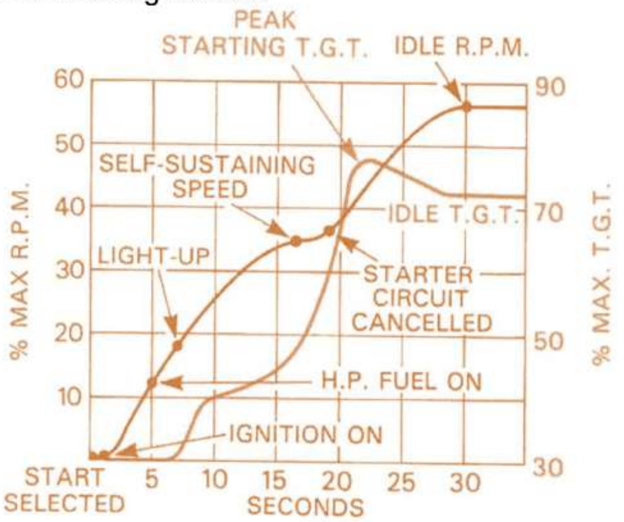


Figure3.1:TypicalenginestartsequenceIdleRPM

This speed is slightly above self-sustaining and is often referred to in the form of a percentage of compressor speed, and on the ground is about 60%of the high-pressure compressor, i.e.
60%N2 orN3. Note that on modern systems idle rpm is a throttle position (normally fully aft).Idle RPM varies with altitude and can be increased under certain flight conditions, for example on the approach or with anti-icing switched on.

Precautions

If engine acceleration is retarded, the possibility of alight-up occurring reduces at low engine speed and would result in over fueling and a high turbine gas temperature. The power supply to the starter should always be checked before starting, and must not be less than the minimum figure quoted in the aircraft Maintenance Manual. Facing the aircraft into wind will assist with engine acceleration, particularly in the case of turbo-prop aircraft, the propellers of which are normally provided with a special fine blade angle for starting and ground running.

There are many different methods used to crank the engine to self-sustaining speed, depending on the operational requirements of the particular aircraft.

Where speed of starting is of the utmost importance, on fighter aircraft for instance, a cartridge or mono-fuel turbine starter can be fitted. These devices are not used on civil aircraft however, due to the high cost and the handling difficulties involved.

Start Control

The start master switch does not just switch the starting system 'ON'. On some aircraft will prepare the aircraft electrical system for the start operation i.e., starter motors require a very high current for starting which is usually too much for a single Transformer rectifier (TRU),so it will parallel the DC systems. To ensure that a start is not carried out on a single TRU, it will place all the AC power systems onto one generator, so if it fails the start is aborted. It will also ensure that the engine gauging systems are all powered for the start in all conditions.

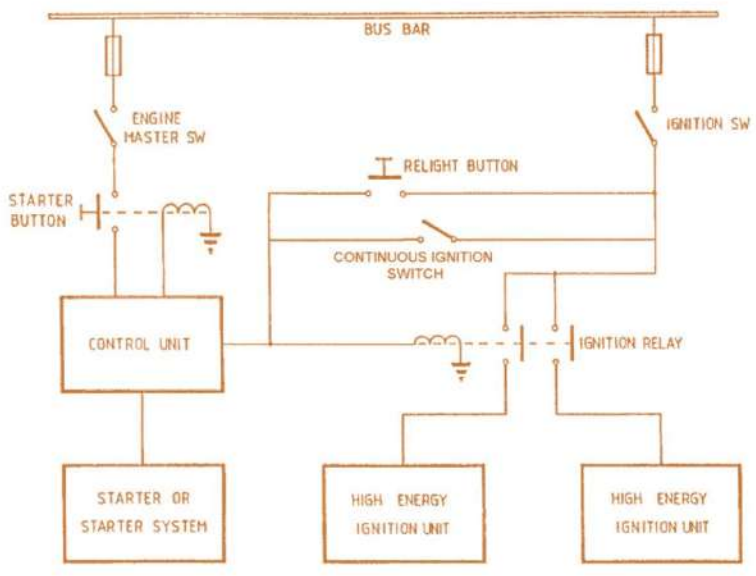


Figure3.2:Typicalstartingcontrolsystem

Starters

The two main methods used on transport aircraft are:

- Electric starters -fitted to Turboprop and small turbo jet engines

- Air starters -fitted to large turbo jet and turbo fan engines

Starter Motor Requirements

The starter motor must produce a high torque and transmits it to the engine rotating assembly in a manner that provides smooth acceleration from rest up to a speed at which the gas flowthrough the engine provides sufficient power for the engine turbine to takeover.

Cranking and Fuel Flow

As soon as the starter has accelerated the compressor sufficiently to establish airflow through the engine, the ignition is turned on, followed by the fuel. The exact sequence of the starting procedure is important since there must be sufficient airflow through the engine to support combustion before the fuel/air mixture is ignited. At low engine cranking speeds, the fuel flow rate is not sufficient to enable the engine to accelerate, and for this reason the starter continues to crank the engine until after self-accelerating speed has been attained.

Starter Cut- Off Before Self- Sustaining Speed

If assistance from the starter were cutoff below the self- accelerating speed, the engine would it her fail to accelerate to idle speed or might even decelerate because it could not produce sufficient energy to sustain rotation or to accelerate during the initial phase of the starting cycle.

Electric Starters

Direct Cranking Gas Turbine Starters

Direct cranking electric starting systems are similar to those used on reciprocating engines. Starter-generator starting systems are also similar to direct cranking electrical systems. Electrically, the two systems may be identical, but the starter generator is permanently engaged with the engine shaft through the necessary drive gears, while the direct cranking starter must employ some means of disengaging the starter from the shaft after the engine has started. On some direct cranking starters used on gas turbine engines no overload

release clutch or gear reduction mechanism is used. This is because of the low torque and high-speed requirement for starting gas turbine engines.

Starter Engagement

Starter Jaw -A common method of coupling the starter drive to the engine is by means of a jaw the starter, which moves axially into engagement with a similar jaw on the engine gearbox during initial starter rotation. Axial movement of this jaw is effected it herby helical splines on the starter driveshaft, as shown below, or by the pressure of a solenoid operated push rod in the starter motor.

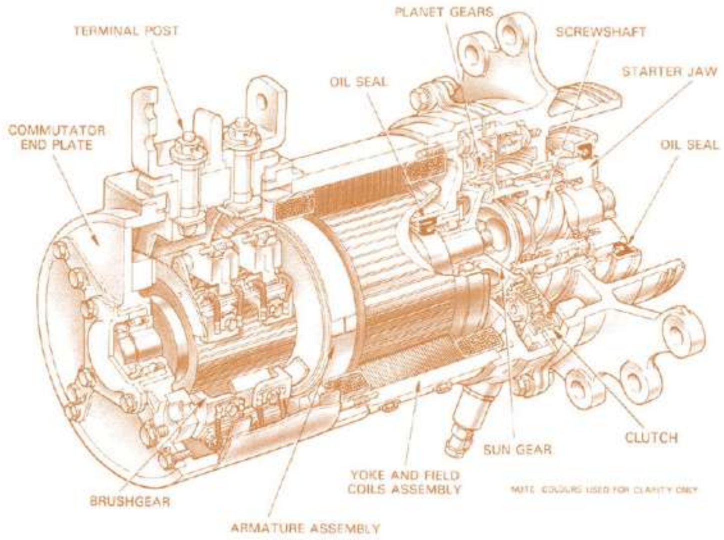


Figure3.3:ElectricalStarterMotor

Sprag Clutch-Alternative methods of engagement are the ratchet drive and sprag clutch, in which the ratchet pawls or sprags rotate with the engine. Engagement and disengagement are affected centrifugally, engagement by the engine taking place whenever its speed falls below idling.

Figure3.4:Typicalspragclutch

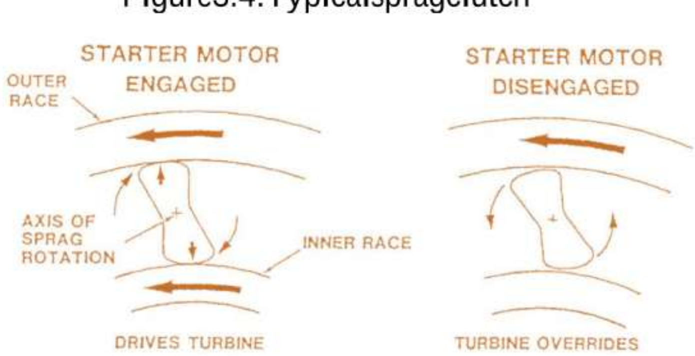


Figure3.5:Anothertypeofspragclutch

Low Voltage Starting System

Operation of the starting cycle is normally controlled by either of two methods. On some aircraft the high initial starter current is used to engage an over speed relay and hold-in solenoid; when the engine begins to accelerate under its own power, the starter current decreases and the hold-in solenoid breaks the circuit automatically.

In the low voltage system shown opposite, the hold-in solenoid is called the main relay.

The electrical supply maybe of a low or high voltage, and it is passed through a system of relays and resistances to allow the full voltage to be progressively built up as the starter gains speed. It also provides the power for operation of the ignition system. The electrical supply is automatically cancelled when the starter load is reduced after the engine has satisfactorily started, or when the time cycle is completed.

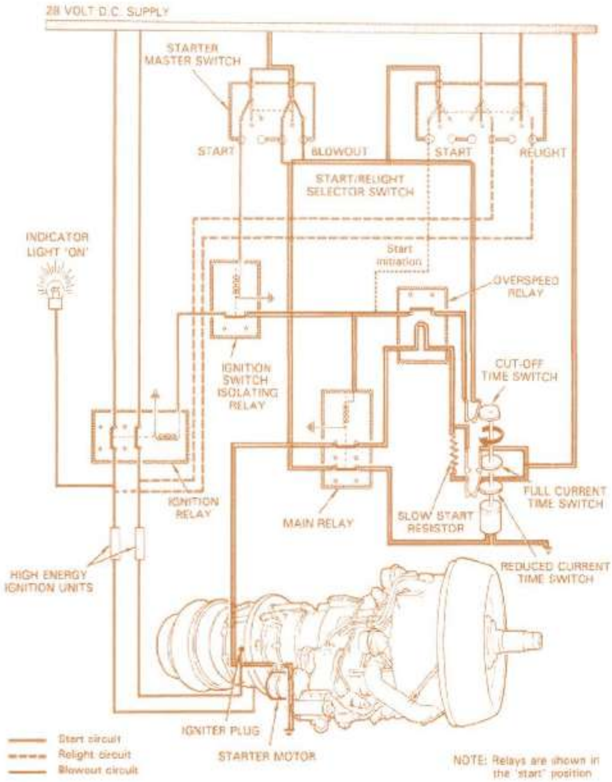


Figure3.6:LowVoltageStartingSystem

Starter Generator Systems

Many gas turbine aircraft are equipped with starter generator systems. These starting systems use a combination starter generator which operates as a starter motor to drive the engine during starting, and, after the engine has reached a self -sustaining speed, operates as a

generator to supply the electrical system power.

The starter generator unit, shown below, is basically a shunt generator with an additional heavy series winding. This series winding is electrically connected to produce a strong field and a resulting high torque for starting.

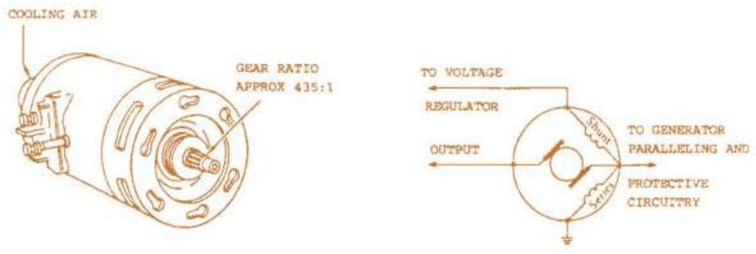


Figure3.7:StarterGenerator

Starter generator units are desirable from an economic standpoint, since one unit performs the functions of both starter and generator. Additionally, the total weight of starting system components is reduced, and fewer spare parts are required.

Operation

The unit is similar to a direct cranking starter since all of the windings used during starting are in series with the source. While acting as a starter, the unit makes no practicaluseofitsshuntfield.Asourceof24voltsand 1500 amperes are usually required for starting.

Installation

Ona typical aircraft installation, one starter generator is mounted on each engine gearbox. During starting, the starter generator unit functions as a DC starter motor until the engine has reached a predetermined self-sustaining speed. Aircraft equipped with two 24-volt batteries can supply the electrical load required for starting by operating the batteries in a series configuration.

Air Starters

Air Turbine Starter

For large gas turbine engines, starter motors are mainly Air Turbine types. The power from the turbine assembly is transmitted through are duction gear and sprag clutch engagement mechanism, to drive the engine rotating assembly. The engagement mechanism will allow the starter to 'run down' after an engine start.

Starting air is supplied via the aircraft ducting to a selected engine.

The distribution of air is normally achieved by electrically operated valves, switch controlled, from the flight deck. Air for starting may be obtained from various sources, as follows:-aground supply truck,

- an auxiliary power unit
- an engine compressor tapping, from an existing running engine

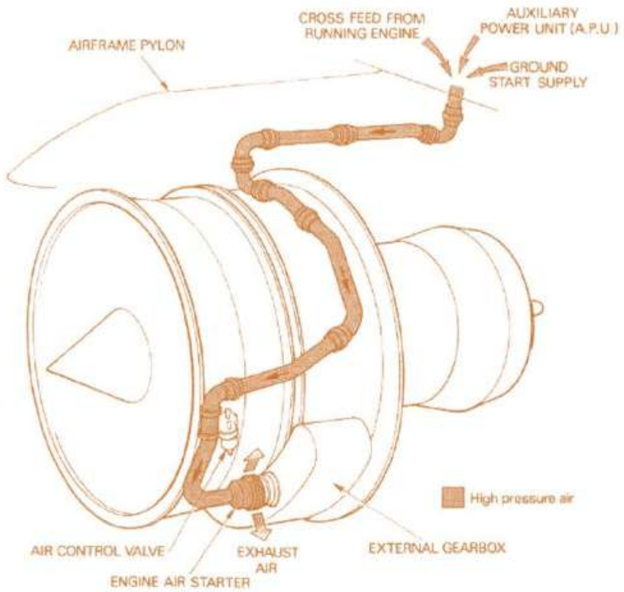


Figure3.8: Air Starter System Layout-Boeing

Air turbine starters are designed to provide a high starting torque from a small, lightweight source. A typical air turbine starter weighs from one quarter to one-half as much as an electric starter capable of starting the same engine. It is also capable of developing twice as much torque as the electric starter.

The typical air turbine starter illustrated over leaf consists of an axial flow turbine, which turns a drive coupling through a reduction gear train and a starter clutch mechanism.

Air Starter Operation

Introducing air of sufficient volume and pressure into the starter inlet operates the starter. The air passes into the starter turbine housing, where it is directed against the rotor blades by the nozzle vanes, causing the turbine rotor to turn. As the rotor turns, it drives the reduction gear train and clutch arrangement, which includes the rotor pinion, planet gears and carrier, sprag clutch assembly, output shaft assembly, and drive coupling.

Sprag Clutch Operation

The sprag clutch assembly engages automatically as soon as the rotor starts to turn, but' disengages as soon as the drive coupling turns more rapidly than the rotor side. When the starter reaches this over-run speed, the action of the sprag clutch allows the gear train to coast to a halt. The output shaft assembly and drive coupling continue to turn as long as the engine is running.

Starter Shut-Off

A rotor switch actuator, mounted in the turbine rotor hub, is set to open the turbine switch when the starter reaches cut-out speed. Opening the turbine switch interrupts an electrical signal to the pressure-regulating valve. This closes the valve and shuts off the air supply to the starter.

As the starter speeds up towards an over-speed, the ball weights centrifuge out forcing up the bell housing breaking the micro-switch.

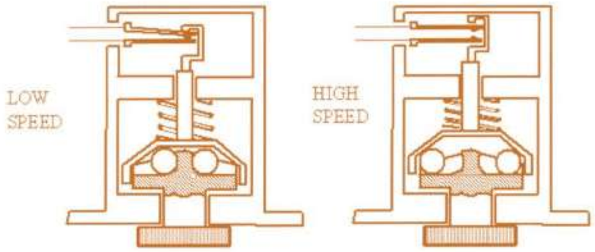


Figure3.9:Starterspeedswitchoperation

Starter Construction

The turbine housing contains the turbine rotor, the rotor switch actuator ,and the nozzle components, which direct the inlet air against the rotor blades. The turbine housing incorporates a turbine rotor containment ring designed to dissipate the energy of blade fragments and direct their discharge at low energy through the exhaust duct in the event of rotor failure due to excessive turbine overspeed.

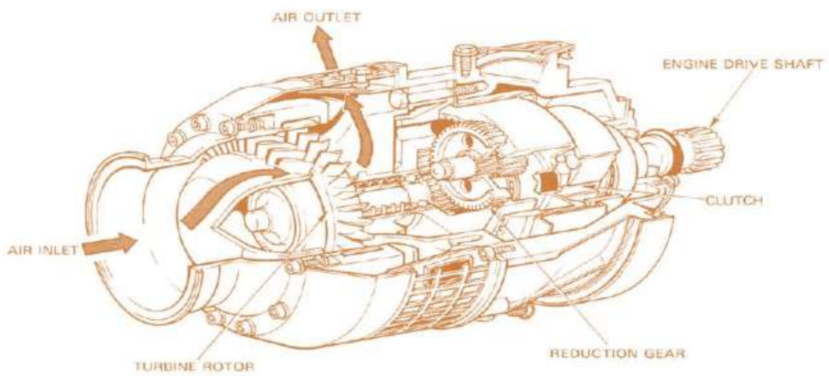


Figure3.10:Aturbineairstarter

The ring gear housing, which is internal, contains the rotor assembly. The switch housing contains the turbine switch and bracket assembly.

Also contained in the transmission housing are the reduction gears, the clutch components, the flyweight cut out switch and the drive couple in gas shown below.

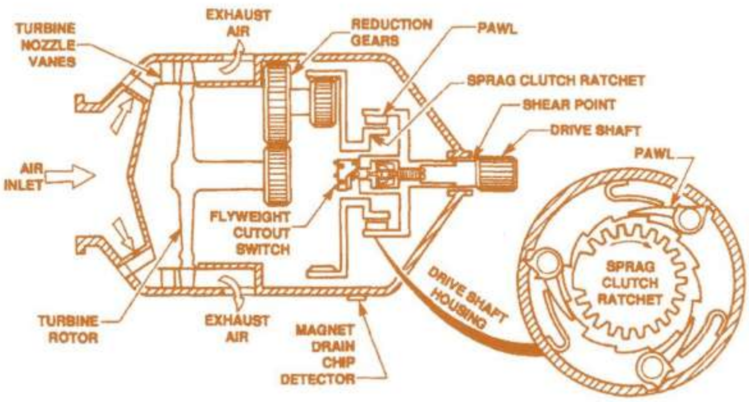


Figure3.11:Air Starter

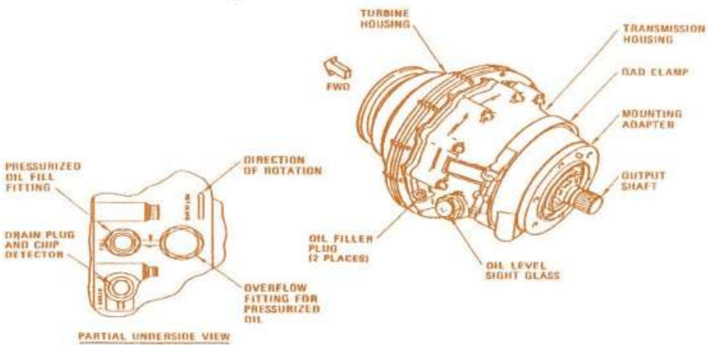


Figure3.12:Air Starter Installation

The transmission housing also provides a reservoir for the lubricating oil. Oil is added to the transmission housing sump through a port at the top of the starter. This port is closed by a vent plug containing a ball valve, which allows the sump to be vented to the atmosphere during normal flight but prevents loss of oil during inverted flight. The housing also incorporates two oil- level holes, which are used to check the oil quantity. A magnetic drainplug in the transmission drain opening attracts any ferrous particles, which maybe in the oil.

Starter Attachment

To facilitate starter installation and removal, amounting adapter is bolted to the mounting pad on the engine. Quick- detach clamps join the starter to the mounting adapter and inlet duct. Thus, the starter is easily removed for maintenance or overhaul by disconnecting the electrical line, loosening the clamps, and carefully disengaging the drive coupling from
the engine starter drive as the starter is withdrawn.

Air Starter Valve

The air for starting is directed through a combination pressure-regulating and shut-off valve in the starter inlet ducting. This valve regulates the pressure of the starter operating air and shuts off the air supply when the maximum allowable starter speed has been reached.

The pressure-regulating and shut-off valve consists of two sub- assemblies:-

- the pressure-regulating valve,
- the pressure-regulating valve control

Pressure Regulating and Shut-Off Valve Operation

The regulating valve assembly consists of a valve housing containing a butterfly-type valve. The shaft of the butterfly valve is connected through a cam arrangement to a servo piston. When the piston is actuated, its motion on the cam causes the rotation of the butterfly valve. The slope of the cam track is designed to provide a small initial travel and high initial torque when the starter is actuated. The cam track slope also provides a more stable action by increasing the time the valve is open.

System Control

The control assembly is mounted on the regulating valve housing and consists of a control housing in which a solenoid is used to stop the action of the control crank in the 'off' position. The control crank links a pilot valve, which meters pressure to the servo piston, with the bellows connected by an airline to the pressure sensing port on the starter.

Initiation

Turning on the starter switch energizes the regulating valve solenoid. The solenoid retracts and allows the control crank to rotate to the 'open' position. The control crank is then rotated by the control rod spring moving the control rod against the closed end of the bellows. Since the regulating valve is closed and downstream pressure is negligible, the bellows can be fully extended by the bellows spring.

As the control crank rotates to the open position, it causes the pilot valve rod to open the pilot valve allowing up stream air, which is supplied to the pilot valve through a suitable filter and restriction in the housing, to flow into the servo piston chamber. The drain side of the pilot valve, which bleeds the servo chamber to the atmosphere, is now closed by the pilot valve rod and the servo piston moves inboard.

This linear motion of the servo piston is translated to rotary motion of the valve shaft by the rotating cam, thus opening the regulating valve. As the valve opens, downstream pressure increases. This pressure is bled back to the bellows through the pressure-sensing line and compresses the bellows. This action moves the control rod, thereby turning the control crank and moving the pilot valve rod gradually away from the servo chamber to vent to the atmosphere.

When downstream (regulated) pressure reaches preset value, the amount of air flowing in to the servo through the restriction equals the amount of air being bled to the atmosphere through the servo bleed and the system is in a state of equilibrium.

Rotation

When the valve is open, the regulated air passing through the inlet housing of the starter impinges on the turbine, causing it to turn.

Starter Cut-Out

When starting speed is reached, a set of fly weights in a centrifugal cut-out switch actuates plunger which breaks the ground circuit of the solenoid.

Valve Closed

When the ground circuit is broken and the solenoid is de- energized, the pilot valve is forced back to the 'off position, opening the servo chamber to the atmosphere. This action allows the actuator spring to move the regulating valve to the
'closed' position.

When the air to the starter is terminated, the out-board clutch gear, driven by the engine, will begin to turn faster than the inboard clutch gear, and the inboard clutch gear, actuated by the return spring, will disengage the outboard clutch gear, allowing the rotor to coast to a halt. The outboard clutch shaft will continue to turn with the engine.

Manual Starting

Sometimes the solenoid on the start valve becomes unserviceable, so provision is made to enable the aircraft to be started manually. This can be by manually depressing the solenoid valve or turning the butterfly itself.

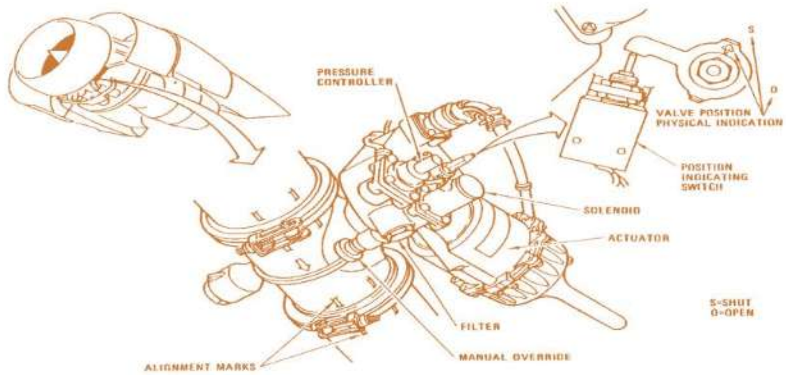


Figure3.13:Startercontrolvalve

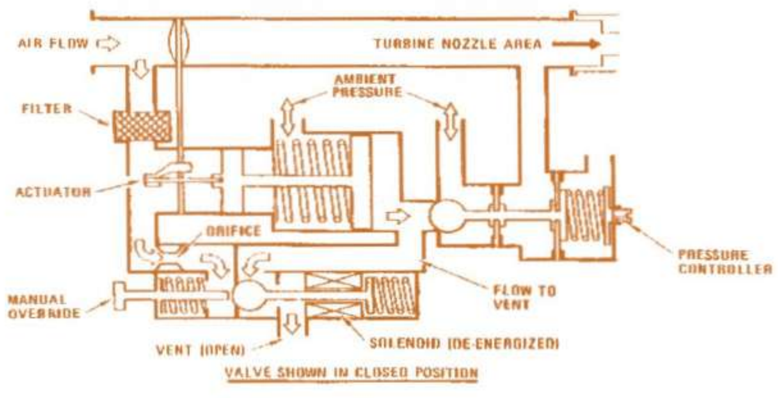


Figure3.14:StarterControlValveinstallationand schematic

Manual Start Procedure

The following procedure is typical of a manual start.

1. Gain access to the affected start valve.

2. Upon command from the flight deck, operate manual override handle to OPEN.

WARNING:WHENMANUALLYOPERATING THE START VALVE, HANDAND ARM COVERSMUST BE WORN. HOT AIR EXHAUSTING FROM STARTER COULD RESULT ININJURY TOPERSONNEL.

3. After engine has started and upon the command from the flight deck, operate the manual over ride handle to closed.

Starter Running Limitations

All air starters have run time limitations to prevent overheating. The limits are very generous for even considerable dry cranking operation. For example5 minutes on then10minutesoffisoneexample,butthey all vary and the AMM should be consulted fora particular type.

A Start System Example

A300StartingSystem
The following example of an engine start is taken from the training manuals for anA300-134 fitted with GE 6-50 engines.

Procedure

The engines are equipped with air starters. The air to start the engine is provided by:-
- The APU, the ground connectors, or the other engine if it is already running.

The starting system has provision for:-
- Engine start.
- Engine crank.
- Continuous ignition.

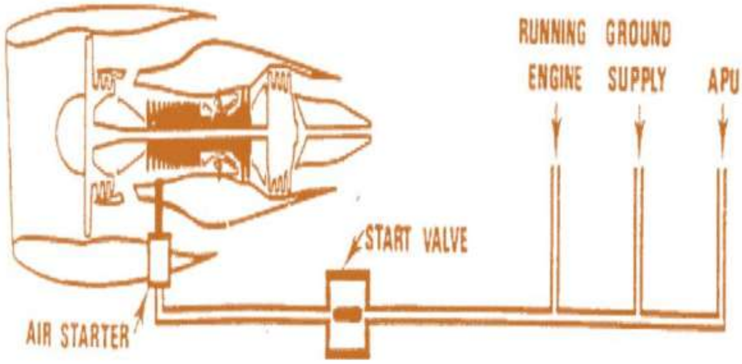


Figure3.15:A300startingsystem-overview

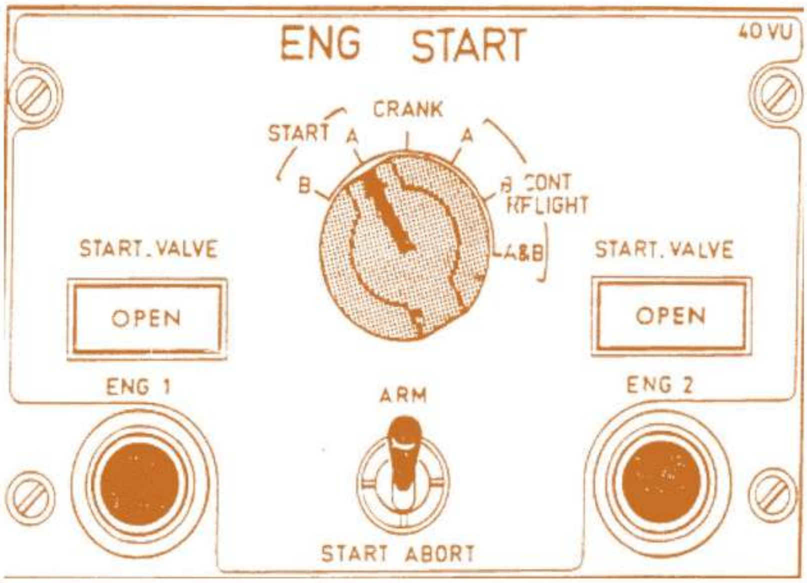


Figure3.16:Enginestartpanel

115VACisused to energize the exciter an decontrolled through the HP fuel shut off valve lever, the ignition selector, and the ignition relay. The ignition relay is energisedby28 VDC when the master switch is in the ARM position and the start button is pushed.

Starting is achieved in the following manner:-

Set the ignition selector to A or B. Set the master switch to "ARM". This arms the ignition circuit and closes the air conditioning system if it is open. The amber lights in the push-to start buttons will illuminate during this transit.

When the air-conditioning valves are closed, the lights in the push-to-start buttons extinguish and the operator can push the start button which will latch. This increases the APU rpm to
100%to provide sufficient air for starting.

It also arms the ignition circuit and finally, provided that pneumatic power is available, it opens the start valve and the blue OPEN light illuminates.

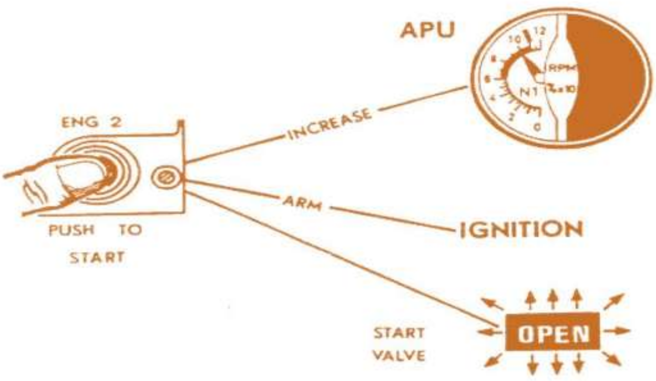


Figure3.17:WhentheStartButtonispressed,theAPU goesto100%

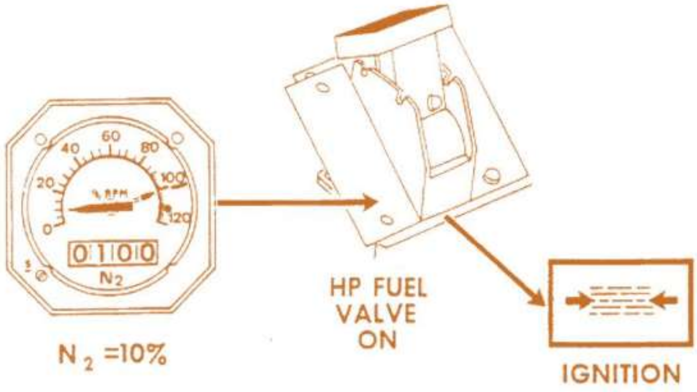


Figure3.18:At10%N2theHP fuel valve is opened

When engineN2reaches10%the HP Fuel Shut-off Valve must be opened. This supplies fuel to the engine and energizes the ignition exciters. The engine should light up and EGT should increase.
When N2reaches 45% the engine will be self-sustaining, so the ignition is switched off, the push-to-start button pops out and the APU demand goes back to normal. Engine rpm should now increase to Ground Idle, which is approximately65% N2and 24% N-,

TORCHING.

Hot Start Maximum start TGT exceeded-likely cause, low starter supplies electrical and/or air.

Abortive Start Engine does not light up within specified period. No increase in TGT. No increase in speed above motoring rpm-likely causes, no fuel or no ignition.
Ignition Systems Overview

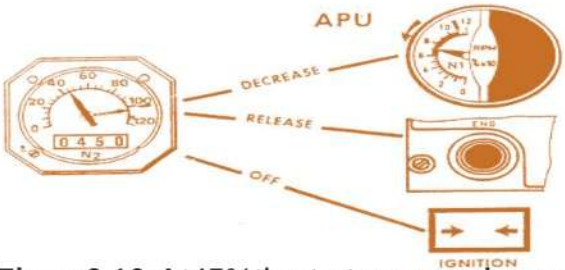


Figure3.19:At45%thestartsequenceiscancelled

Engine Start Fault Terminology

Here are some common phrases, often seen in technical log reports

Hung Start Engine lights up and reaches self-sustaining speed, but then the rpm is
slow or fails to reach IDLE rpm, TGT on or near limit.

Likely cause is the FCU.

Wet Start Excess fuel causing failure to light up. If start occurs, high TGT and

The purpose of the ignition system is to provide means of initiating or sustaining combustion within the engine, an identical system is fitted to each engine. The system requirements are

- Satisfactory engine starting
- Relight at altitude when necessary
- Continuous operation during critical flight conditions

High Energy(HE) ignition is used for starting all jet engines and a dual system is always fitted.
Each system has an igniter unit connected to its own igniter plug; the two plugs being situated indifferent positions in the
combustion chamber (usually at the4and 8 o'clock positions).

Ignition units are rated in "joules". A high value output(e.g., 12 joules) is necessary to ensure that the engine will "relight" at

high altitudes and is sometimes necessary for starting (especially with engines fitted with a vaporizing tube type nozzle). However, in certain flight conditions, such as icing or take-off in heavy rain or snow, it may be necessary to have the ignition system operating continuous to give an automatic relight should a "flame-out" occur. For this condition, a low output(e.g., 3 to 6 joules)would be used because it results in a longer life of both the igniter system and the plug. See diagram overleaf showing atypical large aircraft ignition system.

Use of Ignition

Many systems incorporate two circuits within the same casing- one a low energy continuous duty circuit, the other high energy intermittent duty circuit. Both plugs maybe fired from the intermittent duty circuits, but there is a second circuit which fires just one plug on a lower energy output.

Continuous duty-is used for periods of flying in icing conditions or during heavy rain or snow. The cockpit switches would be positioned to the left or right positions to protect against flame-out. The energy output of this system is not sufficient to cause "light-up" in the air or on the ground but will merely help to sustain ignition in bad flying conditions.

Intermittent duty-is used for initial "light-up" on the ground or to "re-light "should a flame-out occur at altitude. If the switch is placed in the "START" position, the intermittent duty circuit is activated, and the starter system is activated. In this position the "VALVE OPEN" light will illuminate to show that the starter motor is being fed with supply air. If the switch were placed in the "FLTSTART" position, the intermittent

Duty circuit is activated, but since the engine will be windmilling, it does not require starter motor, and hence this

system remains off.

With the older types of intermittent system, the intermittent duty circuits have a time limit on their operation. A typical time limit would be two minutes ON, with a three to twenty minutes OFF for cooling.

A Typical DC Ignition Unit

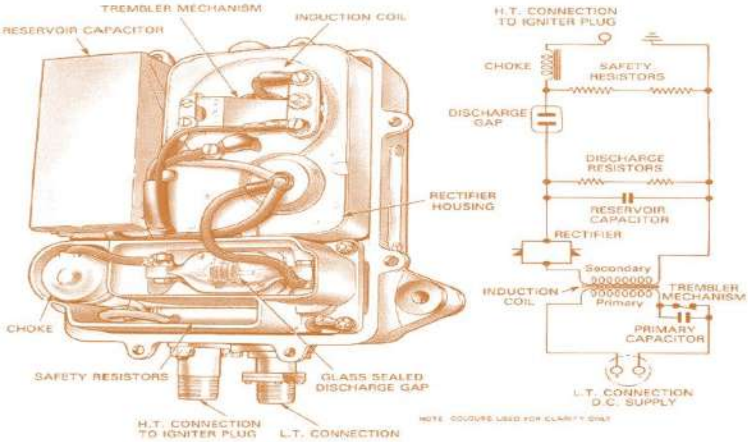


Figure3.20:TremblertypeDCIgnitionUnitandCircuit

Above is a typical DC trembler switch operated unit. Its operation is as follows.

The trembler mechanism is simply a switch which vibrates and hence opens and closes about 200 times a second, thereby pulsating DC current flows through the primary coil. This trembler sometimes works off the natural vibrations of the aircraft, but usually is a mechanism containing a" normally closed switch, which is opened as soon as current flows through it, by a solenoid(similar to an electric bell).

As the contacts open and close rapidly, there would be a tendency for a spark to ark across the points. This is reduced by the primary capacitor which provides a path of least resistance for the current to flow.

The secondary coil of the induction coil contains many more windings than the primary coil, so a large current is induced in the coil. The electrons flowing from the secondary coil begin
to build up on the left-hand side of the reservoir capacitor. The rectifier stops these electrons flowing the opposite way round the circuit to the right-hand side of the reservoir capacitor.

After about half a second of repeated cycles, there will be enough charge in the reservoir capacitor to jump the discharge gap. AH the charge in the reservoir capacitor will jump the gap at once and so the igniter plug receives large amount of current at once, which it conveys to the earth circuit. The choke is fitted to extend the duration of the discharges lightly, especially if there is more current than is required by the igniter plug at any one time. The cycle is repeated about twice a second. The discharge resistors are fitted to ensure that any stored energy in the capacitor is dissipated within one minute of the system being switched off. The safety resistor provides an alternative path for the discharge current if the igniter plug is disconnected but the system is still switched on.

More modern circuits have the trembler mechanism replaced by a transistorized" chopper circuit" which simply generates a pulsating DC supply.

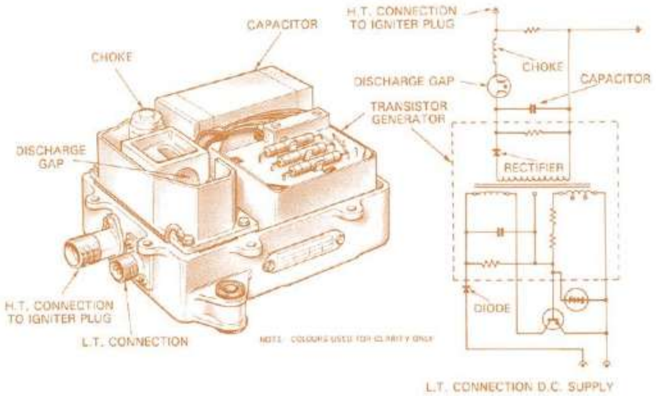


Figure3.21: A Typical DC Transistorized Unit

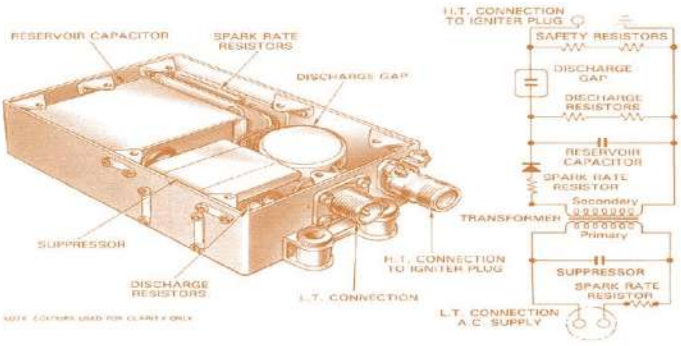


Figure3.22:ATypicalACIgnitionUnit

The operation of an AC circuit is identical to a DC
Circuit except that the trembler switch mechanism (or transistorized chopper circuit) is replaced with 115 V AC supply.

ACVersus DC Input Systems

The AC Input system has the following advantages over the DC systems-

The DC input system relies upon the aircraft battery for operation, whereas the AC input system relies upon some auxiliary power such as the APU or a Ground Power Unit. Therefore, an aircraft fitted with a DC input system is self-sufficient as far as starting is concerned.

The AC input system is said to have a better" extreme climate" reliability than the DC input system.

The operational cycle of a typical intermittent duty cycle, the AC system is 10 minutes on, 20minutes off (for cooling). A DC system heats up more rapidly, and a typical operational cycle of a system with the same Joule rating as the AC system mentioned above might be 2 minutes on,3 to 20 minutes off.

The DC system remains in popular use, especially when no auxiliary power unit is installed, and a battery input voltage is all that is available for starting.

Igniter Plugs

Spark Igniters

Constrained or Constricted Air Gap Type

Constrained Air Gap Igniter Plugs for Gas Turbine Engines differ considerably from sparkplugs for reciprocating engines. The gap at the igniter plug tip is much wide rand the electrode is designed towithst and a much higher intensity spark. The igniter plug is also less susceptibletofouling because the high

Energy spark removes carbon and other deposits every time the plug fires. The construction material is also different because the igniter plug is made of very high quality, nickel- chromium alloy for its corrosion resistance and low coefficient of heat expansion. The threads in many cases are also silver plated to prevent seizing. For this reason, it is many times more expensive than an auto mobile spark plug.

Many varieties of igniter plugs are available, but usually only one will suit the needs of a particular engine. The igniter
Plug tip must protrude properly into the combustion chamber and on some fully ducted fan engines, the plug must be long enough to mount on the outer case, pass through the fan duct, and penetrate the combustion chamber. Igniters for High and Low Energy systems are not inter changeable, and care should be taken to ensure that the manufacturers recommended plug is fitted.

Figure3.23:AirGapTypeigniter

Cooling-The shell at the hot end of the igniter is generally air cooled to keep it500°Fto600°F cooler than the surrounding gas temperature.

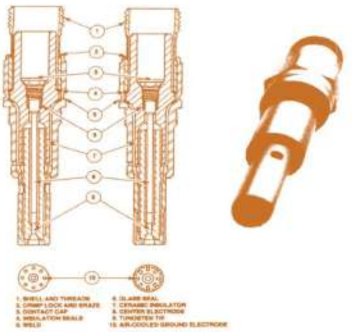


Figure3.24:HighEnergyConstrainedGapIgniter

Surface Discharge Igniter Plug

The surface discharge igniter plug has the end of the insulator formed by the semi-conductor pellet which permits an electrical leakage from the central high tension electrode to the body.
This ionises the surface of the pellet to provide a low resistance path for the energy stored in the capacitor. The discharge takes the form of ahigh energy flashover from the electrode to the body and only requires a potential difference of approximately
2000 volts for operation.

Glow Plugs

Some smaller engines are fitted with aglow plug type igniter rather than a spark igniter. This glow plug is a resistance coil of a very high heat value and is particularly effective for extremely low temperatures tarting.

The glow plug is supplied with 28VDC at approximately10 amps to heat the coil to a yellow hot condition. The coil is very similar in appearance to an automobile cigarette lighter. Air directed up through the coil mixes with fuel sprayed from the

main fuel nozzle. This is designed to occur
when the main nozzle is not completely atomizing its discharge at low flow conditions during start-up. The influence of the airflow on the fuel acts as to create a "hot streak" or blow torch type ignition.

Figure3.26:GlowPlug

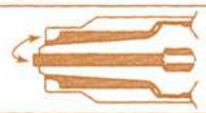
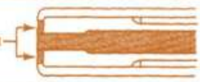
GAP DESCRIPTION	TYPICAL FIRING END CONFIGURATION	CLEAN FIRING END
HIGH VOLTAGE AIR SURFACE GAP		YES
HIGH VOLTAGE SURFACE GAP		YES
HIGH VOLTAGE RECESSED SURFACE GAP		YES
LOW VOLTAGE SHUNTED SURFACE GAP (SELF IONIZING)	SEMI-CONDUCTOR 	Only clean if manufacturer allows
LOW VOLTAGE GLOW COIL ELEMENT		YES

Figure3.27:IgnitionPlugFiringEndSummary

Cleaning, Inspection and Testing
Cleaning

High energy constrained gap type plugs are usually cleaned using a solvent and soft non-metallic brush. Never use abrasive grit blasting, as this will damage the ceramic insulator. Low energy surface discharge plugs are usually only cleaned on their outer surface, as the semi-conductor material in the tip is easily damaged, this is regardless of carbon build up.

Glow plugs can be cleaned if carbon build up is seen across the coil with a solvent to loosen the carbon deposit then a soft non-metallic brush can be used tore move particles Inspection

Inspection of igniter plugs consists of visual inspection and, for the high voltage type, a gap check using a gap wear gauge. The AMM willed fine the amount of permissible wear and carbon build up.

Testing

A Functional check of igniters is carried out in situ by isolating the fuel and starter circuit and selecting the igniters on. Standing outside the jet pipe distinct crack can be heard. The spark rate (normally60-100 sparks per minute) can also be checked. Glow plugs retested by connecting the plug to

the power lead and observing the plug end turn bright yellow within 15-20 seconds.

Fitment and Removal

The depth at which an igniter plug is fitted to a combustor is critical. Too deep and the plug will be burnt, not deep enough and the spark will not ignite the fuel. To ensure the correct depth the combustor is normally depth gauged from the boss on the engine outer casing into the combustor liner. Spacers or gaskets are then fitted to the igniter plug to reflect the depth gauge measurement. The depth gauge is a 'special to type' combustor tool. Refer to the applicable AMM for details.

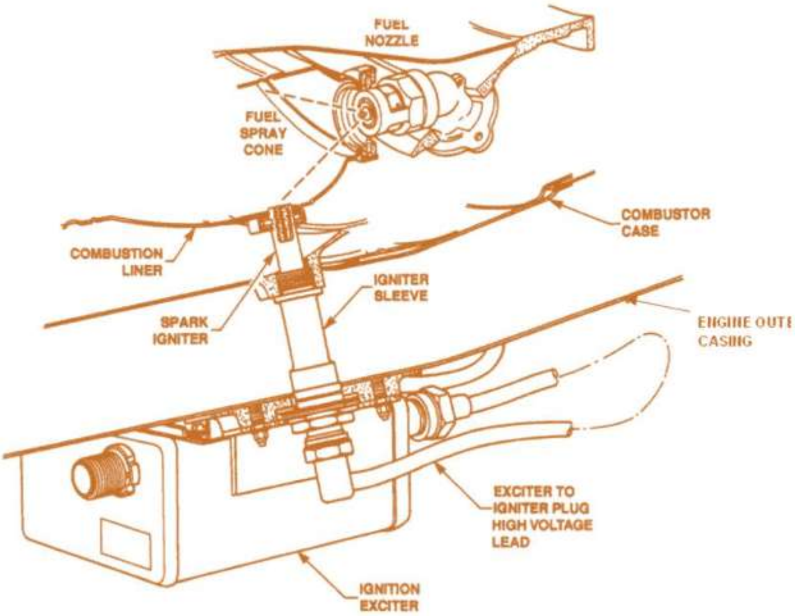


Figure3.28:Igniterpluginsitu

Handling of Ignition Units and Igniter Plugs

■ Ensure that the ignition switch is turned off before performing any maintenance on the system.

■ To remove an igniter plug, disconnect the HE ignition unit input lead and wait for the prescribed amount of time(usually1 minute)to allow any residual
Charge to dissipate through the safety resistors. Then disconnect the igniter lead and ground the center electrode to the engine to discharge any current stored in the plug, the igniter plug is now safe to remove.

■ Ensure proper disposal of unserviceable igniter plugs. If they are the type that contain aluminium oxide and beryllium oxide, a toxic
insulating material, the usual method is to place plugs in a sealed container and bury them at a designated disposal sight.

■ Exercise great caution in handling sealed ignition units.
Some contain radioactive material (cesium-barium
137)on the airgap points. This material is used to calibrate the discharge point to a pre-set voltage.

■ If an igniter plug is dropped it should be discarded since internal damage can occur that may not be detectable by testing or examination.

■ Always use anew gasket where the plug is reinstalled. The gasket is essential in providing a good conductive current path to ground.

An Ignition System Example

Boeing757StarterSystem

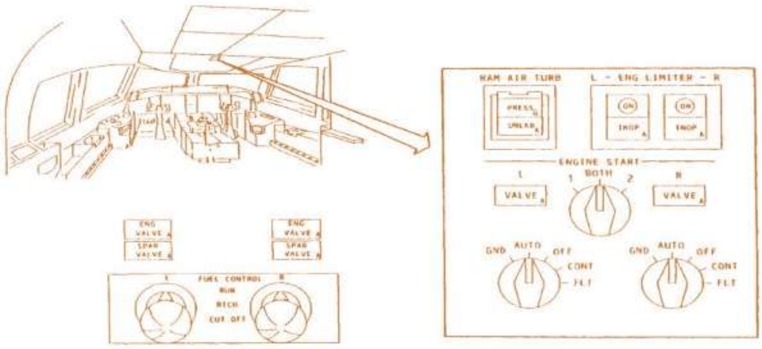


Figure3.29:Boeing757StartPanel

The ignition system initiates or sustains combustion of the fuel air mixture in the annular combustion chamber.

Ignition is available when the engine start switch in the overhead panel(P5) is placed in GND,AUTO,CONT, or FLT position and the fuel control switch in the center console (P10) is placed in RUN or RICH

Each engine has two independents high((10-joule) and low (4joule) energy ignition units, each feeding one igniter plug. High energy output is used for starting and relighting and low energy for continuous ignition.

A single rotary ignition select switch, with three positions1-BOTH-2 enables either or both ignition UNITS to be selected.

Control Sequence

115 volts AC is provided by the respective Left or Right AC buses to power igniters No. 1 on the left and right engines white the standby bus normally powers igniters No. 2. The power sense relay automatically selects stand by power for igniter No.
1 in case main bus power is not available.

The fire switch must be in normal and the fuel control switch
(P10) must be in the RUN or RICH position.

Normal Sequence The ignition select switch selects the ignition system to be used.
When the engine start switch is selected to the GND position it energizes the starter solenoid and a holding coil which maintainstheGNDpositionuntilN3reaches47%.Above
47%,N3 the engine start switches springs to AUTO.

With the switch in the AUTO position ignition is provided when the Flaps are not up, when the engine anti-ice is on or when a signal is received from the Transient Pressure Unit (TPU)FLT provides ignition for in-flight starts and CONT ignition is used during turbulent conditions or takeoffs and landings if AUTO is not selected.

High Energy Ignition Units Control

Whether the output of either 10-or4-joules is applied, is determined by the position of the engine start switch or whether or not a signal is received the transient pressure unit.

Normal power sources for the ignition units arethe115 voltac buses. Interruption of power from the normal bus sources causes automatic switching to the standby bus.

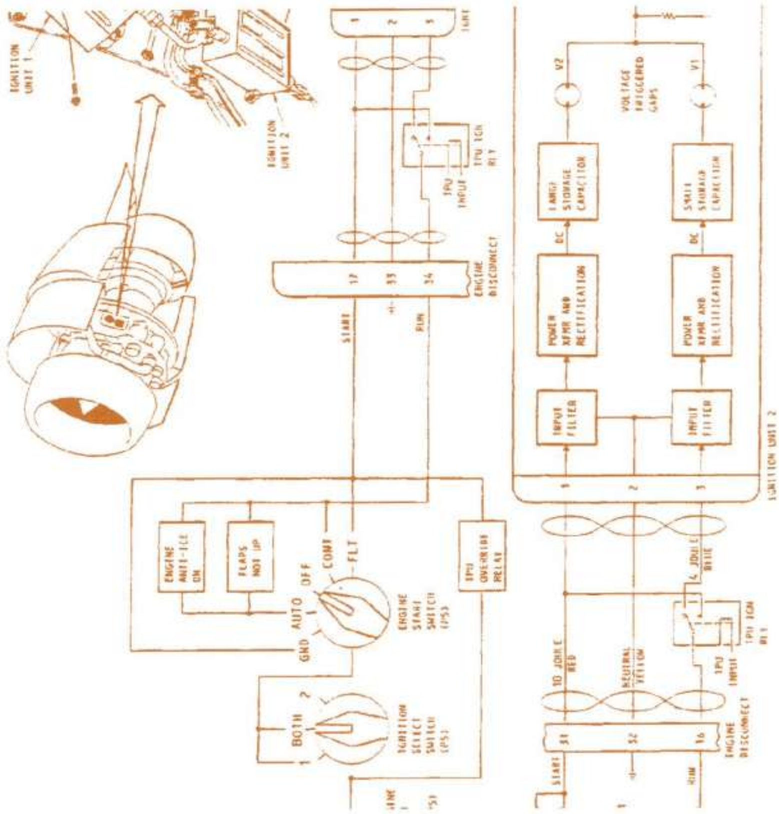


Figure3.30: HEIU Electrical Circuit